PLANET EARTH

GOD'S DOMINION

JOHN S POTTER, D.Litt.

PLANET EARTH – GOD'S DOMINION

JOHN S POTTER
B.Ag.Sc., Dip.Ed., B.Ed., M.Ed., D.Litt., CMC

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CONTENTS

John Potter began his professional career in 1957 as a Soil Conservation Officer in the South Australian Department of Agriculture. After ten years located in rural areas he was promoted to the position of Principal Soils Office, in charge Of Soil Conservation Research and Extension, Land Mapping and Arid Zone Ecology. He served in that position for a further ten years.

In 1977 John took up a position with the Malawi Government Land Husbandry Training Centre in Zomba, training Malawi nationals in land management techniques. This began a period of involvement in education, firstly in Australia and later in South Africa. The material in this book was first published in the period 1989-1991 as modules in a curriculum for middle school students in private schools in South Africa.

Dr Potter's biography and his other publications can be viewed on his webpage: www.johnpotterpublish.com

CHAPTER ONE

INTRODUCING PLANT EARTH

PART ONE: GENERAL DESCRIPTION

The earth, as seen from space, is a truly beautiful sight. It is a gracious and delightful planet that God has created to work out man's eternal destiny.

The book of Genesis tells us that the Earth has been cursed for the sake of man’s redemption, so we may assume that the original earth was at least as beautiful as it is now and probably more so.

SHAPE

For many years some people thought the Earth was flat. In the late 15th

Century the Polish astronomer Kopernik (1473-1543), usually known by his Latinised name Copernicus, was reaching conclusions which led to the acceptance of the idea that the earth was a sphere. These days we not only have the testimony of the astronauts/cosmonauts, but wonderful pictures taken by space exploration satellites to confirm this (see above).

But, even for those of us on the earth, there are many signs to support the idea that the earth is a sphere. Here are a few ideas:

- If the earth were flat the sun would rise at the same time in all places.
- During an eclipse of the moon the earth's shadow is curved.
- If we get in a plane and fly in a straight line in one direction we will eventually arrive back at our starting point.
- Ships sailing around the world have never found an edge or end to the world‘s surface.
- As the sun moves across the sky it eventually drops out of sight below the horizon. But, if we are at the sea and run quickly up a cliff we will see it again for a moment or two (Fig.1).

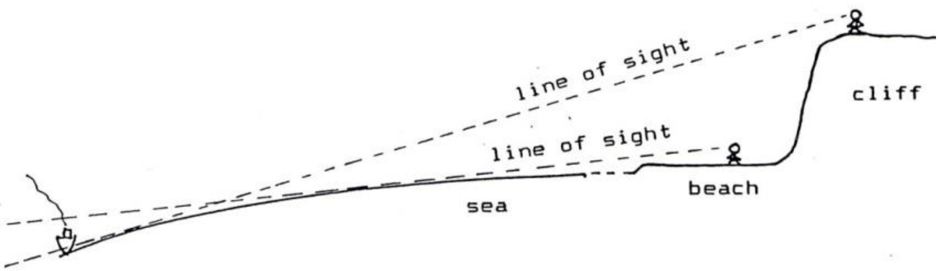


Figure 1

In fact, the earth is not a true sphere. It is slightly flattened on the 'top‘ and ‘bottom‘. More strictly its shape is **oblate spheroid.**

MOVEMENT OF THE EARTH

The Earth is moving in three ways.

The Earth Spins on its Own Axis

There is no actual axle through the earth but the earth spins on an axis, nevertheless. The axis is positioned through the slightly flattened parts of the earth. The exact position of the axis is called the **North and South Poles**, (Fig.2). The fixed nature of these poles is very helpful and important in helping us locate other things on the earth's surface.

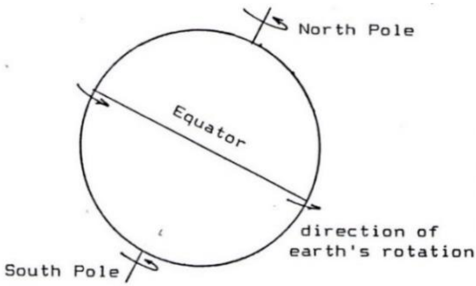


Figure 2

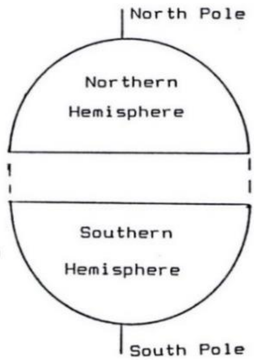


Figure 3

Equidistant from the two poles is a line running around the earth's surface which we call the **Equator**. The Equator is the maximum circumference of the Earth. The hemisphere of the Earth between the equator and the North Pole is called the **Northern Hemisphere**. The hemisphere south of the equator is called being the **Southern Hemisphere**, (see Fig.3).

The rotation of the earth is towards the East. When viewed at the poles:

- In the Northern Hemisphere - rotation is anti-clockwise.
- In the Southern Hemisphere - rotation is clockwise.

An interesting effect of this is that water in the Northern Hemisphere runs down the plug hole clockwise, while in the Southern Hemisphere it runs down anti-clockwise. This is the opposite of the rotational direction due to friction. It is an interesting way of knowing in which hemisphere you are!

The time taken for the earth to rotate once we have called 1 day. This can be measured two ways:

Solar Day: This is measured from the time when the sun is directly overhead until it is overhead again. We call this time noon. The mean solar day was used as the standard of time for many years. It was divided into 24 hours, each hour having 60 minutes and each minute 60 seconds.

Sidereal Day: When the Earth's rotation is measured against the apparent motion of stars around the Polar Star we find that 1 Day = 23hours 56 minutes and 4 seconds on the Solar day clock. We call this the Sidereal Day. The reason that the Sidereal Day is different from the Solar Day is that the Earth has moved 1/356 of the distance along its orbit around the sun (see below) while we are measuring the Earth's rotation. This makes no difference when the Sun is the reference, but it is important in relation to distant stars.

1/356th of 24 hours = 0.06742 hours = about 4 minutes.

The speed of movement of objects on the Earth's surface due to the Earth's rotation on its axis varies with their distance from the poles. (Observe this by slowly rotating a Desk Globe or some spots marked on a ball).

At the poles themselves the movement is Nil. At the equator the speed is approximately 1 660km/h. (This is calculated from the information that the circumference at the equator is 40 075 km. Dividing this by 24 hours we get 1660 km/h). All other points on the earth move at speeds somewhere between 0 and 1660km/h - increasing from each pole towards the equator.

LOCAL TIME

Because time is measured from noon to noon and the earth is rotating on its axis, local time varies from place to place.

The Earth's rotation is 360° every 24 hours or 4 minutes for every degree of rotation or 1 hour for every 15° of rotation. This means that for a point on the earth's surface 15° of rotation away from another point, the local time difference between the two points will be 1 hour (Fig. 5). On this basis, the world is divided in time zones. These are often modified so that small countries do not have two time zones. Countries which cover large distances East-West are more affected by time zones than countries tending North-South.

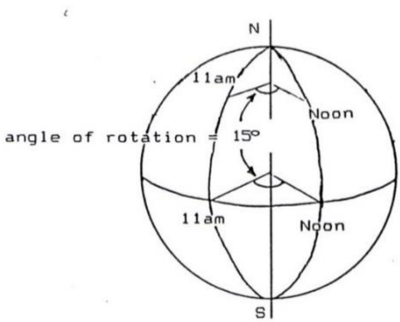


Figure 5

Countries nearer the poles are also more affected than countries on the equator, (Fig. 5).

Country	**Degrees**	**Time Zones**
Russia	160	11
USA	45	4
Australia	40	3
Southern Africa	20	1

For dating purposes, time zones are determined as beginning along a line joining the poles and running through the Pacific Ocean. This is called the **International Dateline.**

The International Dateline is fixed by being 180° rotation from a circumference line from pole to pole through the Greenwich Observatory in England - see longitude below.

If we pass through the International Dateline strange things happen.

Traveling towards the East - we repeat a calendar day
Traveling towards the West - we lose a calendar day

Of course, we do not actually lose or gain actual time. It is just that when we travel eastwards we are shortening our day (travelling towards the sun); when we travel westwards we make our day longer (travelling away from the sun) . When we cross the dateline we actually put ourselves back into local time. Sometimes our bodies take a lot of convincing about this as they keep note of actual time, not the date on the calendar - we call this jetlag.

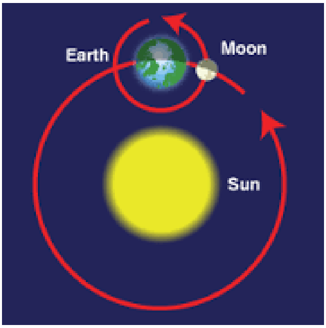
When embarking on international travel we need to take note of our departure and arrival times: e.g. The flight between Perth, Australia and Harare, Zimbabwe takes 10hrs flying time give or take an hour depending on the wind direction and strength. The difference in time zone between Harare and Perth is 5 hours. So, flying from Perth to Harare - if we leave Perth at 1pm on the 6th Dec. our arrival time will be 1pm plus 10 hours (flying time) less 5 hours zone change = 6 pm. 6th December.

Flying from Harare to Perth - if we leave Harare at l pm on the 6th December our arrival time will be 1pm plus 10 hours (flying time) plus 5 hours zone change = 4 am, 7th December.

Another way of thinking about it is this: when we leave from Perth at l pm it is only 8am in Harare. Plus 10 hrs flying gives arrival 6pm. If we leave Harare at 1 pm it is already 6 pm in Perth. Plus 10 hours flying gives arrival 4am.

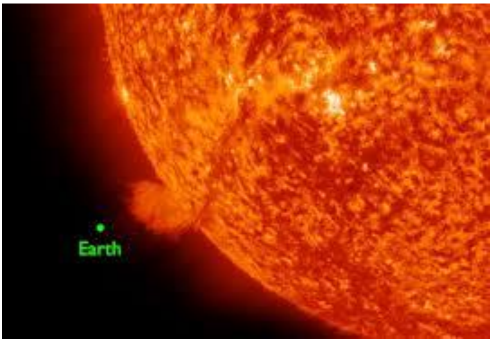
THE EARTH AND THE SUN

The Earth is a Planet of the Sun and moves in an orbit around the Sun. One complete orbit takes 365 days, 5 hour, 48 minutes and 46 seconds based on Solar Day time. We call this time a **Solar Year**



The Earth orbits the sun

The Earth, moon, sun in the distance



The real size of the Earth and Sun

Our calendar year operates on complete days, so the Calendar Year has:

365 days for 3 years out of 4 and 366 days every fourth (leap) year.

By making this adjustment every 4 years, we keep the Solar Year and the Calendar Year coordinated.

The radius of the Earth's orbit (distance from Sun) averages **150 million km**, and the orbit is 942.5 million km. To complete this in 365 1/4 days the Earth must travel at **110 230 km/h**.

DAY AND NIGHT

As we have noted, the earth is rotating on its axis; this causes each part of the earth to be in sunlight (daylight) or in darkness (night) in turn (Fig.6).

Figure 6

GREAT CIRCLES AND FLIGHT PATHS

Exactly half of the Earth is in shadow at all times. The plane defined by the edge of the shadow passes through the Earths Centre and cuts the Earth exactly into two hemispheres. The circumference defined by the edge of the shadow is called a **great circle**. The circumference of any plane passing through the Earth's geometric centre is a great circle. Planes which cut through the earth but do not pass through the centre are called **small circles** (see Fig.7).

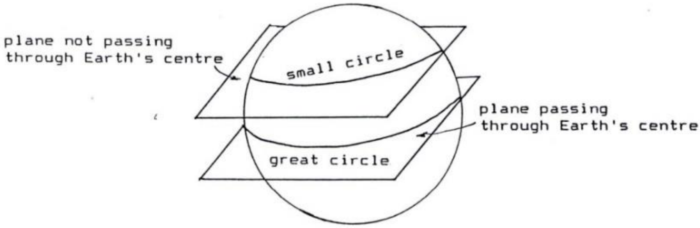


Figure 7

The shortest distance between any two points on the earth's surface is along the great circle line which includes the two points. This is well known to pilots who fly as close as possible to a great circle route wherever possible (Fig.8).

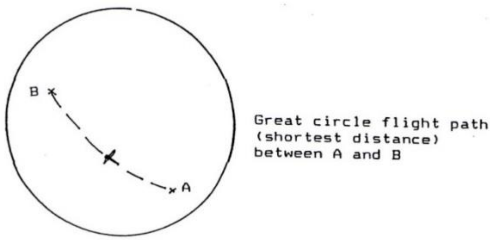


Figure 8

SEASONS

Another phenomenon associated with the earth's movement around the sun is the seasons. Seasons are due to the apparent movement of the sun, not only from east to west, but also from north to south and back to north again during any one year.

This effect is due to two things:

- The tilt of the Earth's axis in relation to its plane of orbit.
- The earth moves in its orbit in such a way that its axis is always parallel to its position at any other point in its orbit.

The continued effect of these two things is shown in Fig. 9.

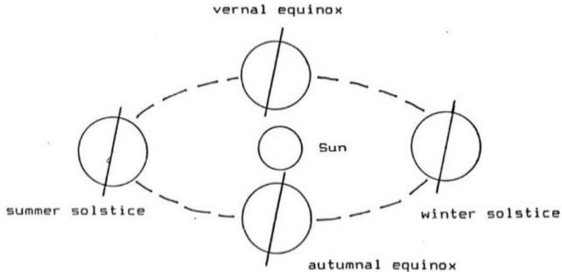
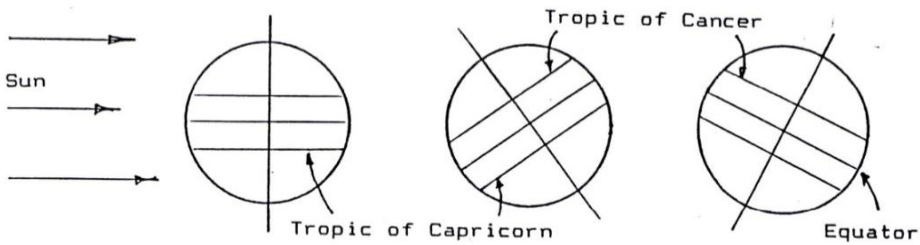


Figure 9

The tilt of the earth in relation to the plane of orbit is always $66^1/_2°$ (or $23^1/_2°$ from the vertical), but the tilt of the earth in relation to the Sun varies due to the principle of parallelism. The result is that the place on the earth where the sun is directly overhead varies as shown in Fig.10.



Axis vertical to sun's rays

$23^1/_2$ ° from vertical <u>towards</u> sun

$23^1/_2$ ° from vertical away from sun

Figure 10

A summary of the variations in the sun's relative position to points on the earth is given below.

Tilt Relative to Sun's rays	**Date Julian Calendar**	**Sun Directly Overhead**	**Name***
Vertical	March 21st	Equator	Vernal Equinox
$23^1/_2$° towards sun	June 21st	Tropic of Cancer	Summer Solstice
Vertical	September 21st	Equator	Autumnal Equinox
$23^1/_2$° away from sun	December 21st	Tropic of Capricorn	Winter Solstice

*NB This is from northern hemisphere perspective. For the southern hemisphere the name of the equinox must be reversed.

We have introduced two new names: The **Tropic of Cancer** and the **Tropic of Capricorn.** These are small circle lines marking the overhead position of the sun at the solstices. They are at latitude $23^1/_2°$ North and $23^1/_2°$ South, see Fig.11.

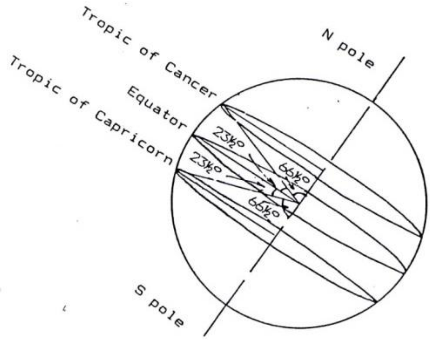


Figure 11

The whole Solar System of Planets relating to our Sun is moving in orbit in Galactic Space, (in the Milky Way) at a speed calculated at 68 200km/h.

The Milky Way – Our Galaxy

Our Sun is one of billions of stars in the Galaxy

SUMMARY OF THE EARTH'S MOVEMENT

Any point on planet Earth at any one time is:

- Rotating around the Earth's axis at a speed somewhere between 0 km/h (at either pole) and 1 660km/h (at the equator).

- Orbiting the sun at a speed approaching 110 000 km/h.
- Moving with the Solar System through The Milky Way at 68 200 km/h.

All of this would be bewildering and perhaps a little frightening if we did not know that God created it this way and therefore must have a definite reason for it. We can relax and trust Him in the midst of all of our circumstances.

THE SIZE OF THE EARTH

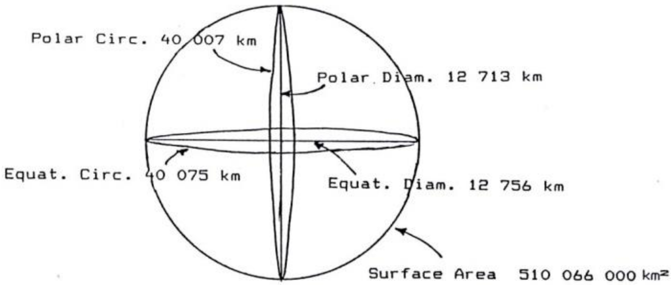


Figure 12

The Polar Circumference is 40 007km (Diameter 12 713k.m).

The Equatorial Circumference is 40 075km (Diameter 12 756km) (See Fig.l2).

The Earth's Surface Area = 510 066 000 km^2

NB: The difference between the polar and equatorial circumference is 68km. This may not seem much but it has a big effect. Consider the following:

> If we tie a string tightly around the equator of the Earth and then cut the string and lengthen it by one metre; how loose will the new string be around the earth? **Answer**: It will average 16cm from the earth's surface at every point on the Circumference!

This is why a slight slip in a knot in a string around a parcel makes the string very loose. We also notice this problem when roping down a load on a truck or trailer unless of course we learn to tie a 'truckies knot'!

LOCATION

Make a mark on a ball. Try to describe exactly where it is. NB: Unless we have some other fixed position to relate to we cannot say where the mark is. It is the same with the Earth. Fortunately, the Poles give us the fixed positions that we need to set up a system of location on the Earth.

Latitude: Position North-South

Because the Poles are fixed, we can fix the line equidistant between them, i.e. the Equator. **Latitude is the distance North or South of the equator measured as the angle with its apex at the centre of the earth**. In Fig.13 we have shown one Latitude North of the Equator: 40° North. Note that many places on the Earth's surface are at Latitude 40°N. All of these places can be joined by running a line around the Earth. We call this Line of latitude 40°N.

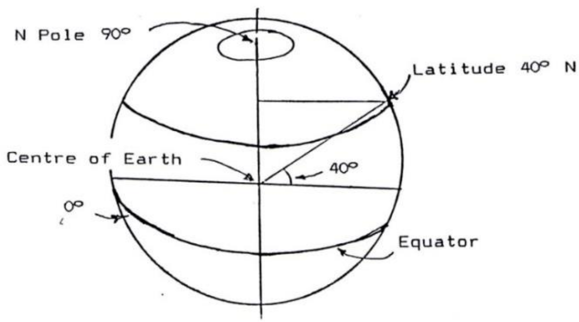


Figure 13

Note also: The North Pole = Latitude 9O°N
The Equator (of course) is Latitude O^0.
The South Pole is Latitude 9O°S.
Note also there is a Latitude 40°S.

Now, all lines of latitude lie in planes which are parallel to the plane at the equator. For this reason, lines of latitude are often called Parallels: e.g. The

49th Parallel North = Latitude 49°N, etc.

Special Parallels include some we have seen before:

Parallel $23^1/_2$°N = the Tropic of cancer
Parallel $23^1/_2$°S = the Tropic of Capricorn

But note also Parallel $66^1/_2$°N = the Arctic Circle
Parallel $66^1/_2$°S = the Antarctic Circle

Longitude Position East - West

To fix the position of an object properly we must have another location apart from latitude. This has been done by making a reference line stretching from the North Pole to the South Pole through a point in the Greenwich Observatory near London in England.

Any line from pole to pole is called a Meridian. The meridian through Greenwich is called the Prime or Greenwich Meridian, see Fig.14. The position of any meridian can be located by reference to the angle formed with its axis at the centre of the Earth between the meridian and the Prime Meridian.

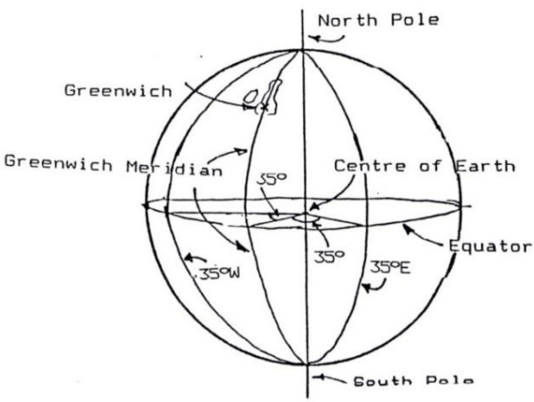


Figure 14

Note that this angle can be to the east or the west of the Prime Meridian. We speak therefore of Longitude East and Longitude West. These meet at Longitude 180°, which is the meridian of the **International Date Line**. (We mentioned this before)

NB: The International Date Line actually bends a bit to miss all land, to make sure there are not two dates in any one country.

Location of a Point

By reference to Latitude and Longitude, any point on the Earth can be accurately located. Remember, location requires **two references**: Longitude (Meridian) and Latitude (Parallel).

RULE: It is usual to give the Longitude first, Latitude second; e.g. The position 26°E.40°N means Meridian 26E and Parallel 40N.

We can always tell which reference is longitude and which is latitude because:

- Longitude bearings are always East or West.
- Latitude bearings are always North or South.

Accuracy

By using fractions of degrees (minutes, seconds) with Latitude and Longitude we can very accurately locate a position. When we discuss Mapping (Chapter Three) we shall see how it is possible to locate a point in an exact way with an accuracy of a fraction of a metre.

Antipodes

The Antipodes is defined as the point on the Earth's surface which is diametrically opposite to another point. That is, if we dig in a straight line from one side of the Earth to the other, through the centre of the Earth, the point we reach on the other side of the Earth will be the antipodes of the place at which we started. Fortunately, to find the Antipodes we do not have to dig!

We find the Antipodes as follows:

> Longitude - subtract 180° from the longitude of the starting point.
> Latitude - take same latitude but in the opposite hemisphere.

- The Antipodes of a point 18°E, 26°N is 162°W (18°E minus 180°) and 26°S (opposite hemisphere).
- The Antipodes of a point 150°W, 42°S is 30°E, 42°N.

NB: Globes and Maps may not have marked meridians and parallels for every degree. It is permissible to **guess fractions** between any two meridians or parallels given.

For instance, if meridians and parallels are only marked every 10°, we can guess to the nearest degree fairly accurately. Use a ruler if you wish but note that the distance travelled for one degree of longitude will be less as you approach the poles. Make sure you align your ruler E-W for calculating fractions of longitude and N-S for latitude.

SECTION TWO: THE NATURE OF THE EARTH

The earth is called a **terrestrial planet** from the Latin 'terra‘, which means ‘earth' as in soil; the name refers to the firm nature of the surface of the Earth.

Mercury, Venus, Mars and probably Pluto are also terrestrial. By contrast the surface of the planets Jupiter, Saturn, Uranus and Neptune are known to be gaseous, although they may possibly have small inner terrestrial cores.

The scripture says the Lord formed the Earth to be inhabited (= lived in), Is.45:18. One part of this was to provide an ‘earthy’ Earth, i.e. with firm land for standing and walking and good soil for growing things.

There are lots of theories about the formation of the Earth, but the Bible tells us that it came into being ready to be inhabited with trees, animals and humans brought forth over a period of six days. This seems to have included not only good soil but also an automatic watering system, see Genesis 2:5-6.

The original Earth's surface has been destroyed by the flood, but we can still find things that may have been part of it.

An interesting thing occurred in 1979: The great lakes of Africa (Victoria, Tanzania and Malawi) suddenly rose 3m. Infra-red photos showed this to be due to a release of water from beneath the lakes. Was this a release of water from the ‘fountains of the deep’ referred to in Gen. 7:11?

The whole of the earth's surface shows unmistakable evidence of the flood. As we come to examine the Earth at close quarters in later Chapters we will see this even more. In this Chapter we are concerned with getting a clear general knowledge of the Earth's structure. We will deal with:

The Earth's Inner Structure
The Surface Plates
Oceans and Land Masses

THE EARTH‘S STRUCTURE

Many holes have been drilled into the earth over time. These have usually been for mining purposes (gold, oil and coal) water (artesian bores) or simply for exploration purposes.

Of course, even the deepest drilling has not gone anywhere near reaching the inner core of the Earth. We can only guess at what might be in there.

Volcanism, the release of molten material through the Earth's crust, is quite common and the analysis of lava gives us a good idea of what some of the deeper materials are like.

A current idea as to the inner structure of the Earth is given in Fig. 15.

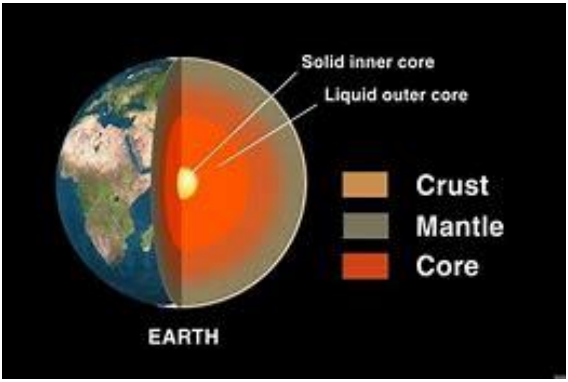


Figure 15

The Crust

The hard surface crust of the Earth is believed to average 32-40km thick where there are land plates and the sea bed 6-8km thick. The diameter of the earth through its centre is 12 000km, so the crust is only 0.1% to 0.5% of the total thickness of the Earth.

The ocean crust is called **SIMA** because it contains mainly silicon and magnesium. Its specific gravity is about 3 grams/cm^3.

The continental crust is called **SIAL** because it is rich in silicon and aluminium. Its specific gravity is lower at 2.7grams/cm^3.

The Mantle

The mantle is believed to be about 2 900km thick. The top of the mantle is hard (specific gravity 3.4 grams/cm^3) but becomes softer (semi-molten) at depths of 70-100km. Its specific gravity is 4.5 grams/cm^3.

The Core

The specific gravity of the core ranges from 19 to 13 grams/cm^3. It is thought to consist mainly of iron and nickel.

THE PLATES

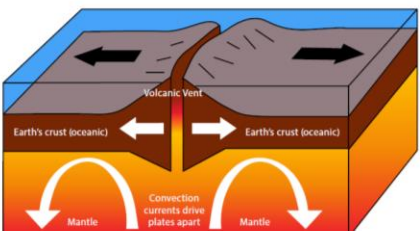
Since 1960, the theory of plate tectonics has been in vogue. This theory suggests that the Earth's crust and the top of the mantle are split into rigid, moving blocks called plates. These plates move because heat in the mantle sets up convection currents in the semi-fluid part of the mantle.

The study of the ocean floor supports this theory. Under the sea there are long ridges like mountain ranges. The centre of these ridges is believed to be plate edges as molten material is continually coming up through them, spreading sideways as it cools in the water. Because new rock material is feeding up through the ocean ridges they are called **construction plate margins,** (Fig. 16).

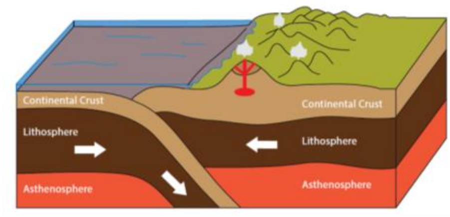
Sometimes the volcanic material released is sufficient to build up right to the surface of the ocean. New land masses are formed; e.g. Iceland, Hawaii, New Zealand, all of which have active volcanoes.

Another feature on the ocean floors are the ocean trenches. These can be very deep (the deepest known is the Marianas Trench in the Pacific Ocean which is 11 km deep.

In the trenches, the edges of the plates turn down and rock material is being pushed down into the molten mantle. For this reason, they are called **destructive plate margins** (see Fig. 16).



Constructive Plate



Destructive Plate

Figure 16

The jerky movement that occurs between the destructive plate margins causes earthquakes.

A third kind of plate edge is the **transform fault** such as along the California Coast - called the San Andreas fault. Here plate margins run against each other in jerky movements. Earthquakes occur quite frequently, some serious.

It is clear from scripture that the original Earth did not have these features. Most people agree that the flood was cause by seismic conditions (widespread and massive earthquake activity). This can be tied to the supernatural action of God (Gen.7:11) who "broke up the fountains of the deep" and "opened the windows of heaven", causing the canopy to fall.

The earth today displays these features of ridges and trenches; not only under the ocean but also on the land; the Great African Rift Valley is an obvious case. The main zones where plate edges and earthquakes occur are shown in Fig.l7. Active volcanoes are also shown to be closely related to these zones.

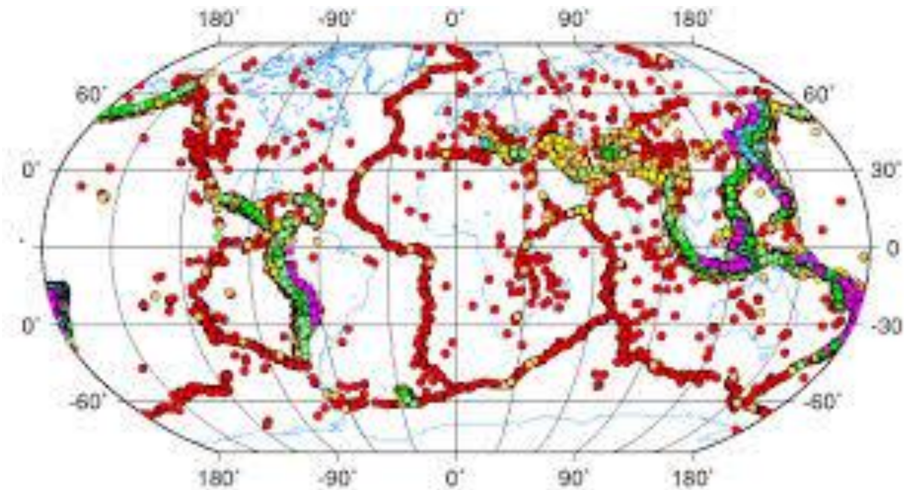


Fig. 17: Earthquake Zones

OCEANS AND LAND MASSES

Oceans

Water covers 71% of the Earth's surface (= 362 million km^2).

The average depth below sea level is 3 554 km

- In the Northern hemisphere - oceans cover 60% of surface.
- In the Southern hemisphere - oceans cover 80% of surface.

The ocean waters are divided geographically as follows:

Name	**Area (million km^2)**
Pacific Ocean	166
Atlantic Ocean	83
Indian Ocean	73
Arctic Ocean	14
Antarctic Ocean	13

Land

Land covers 29% of the Earth's surface (= 148 million km^2).

The average height above sea level is 747m (compare average depth of oceans).

The land mass is divided for convenience into continents

Continent Name	**Area (millions km^2)**
North America	24
South America	18
Eurasia	52
Africa	29
Australia	8

The rest of the land is made of numerous islands, the main ones being the West Indies, the East Indies and Oceania (New Zealand, Polynesia, Melanesia, Micronesia). Spend some time looking at the Globe and world maps so that you become familiar with the continents and oceans.

Landform

A cross-section of the continental land masses and ocean floors is shown in Fig. 18.

NB: The continental shelf is really a continuation of the land mass. It ends with a steep slope (the continental slope) which is the true edge of the continent.

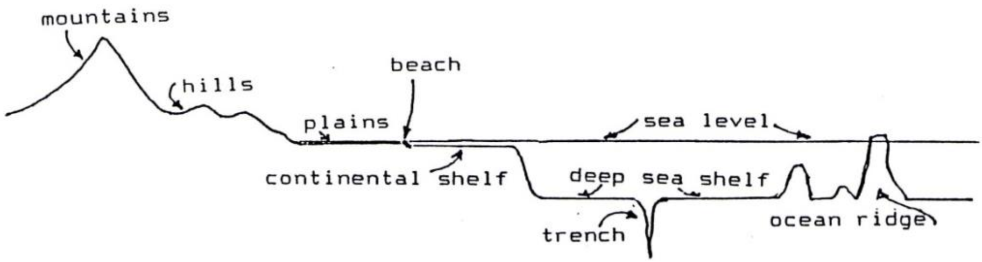


Figure 18

As we have seen, islands may be the result of volcanic action (Iceland, Hawaii, New Zealand etc.).

CHAPTER TWO

MAP READING

INTRODUCTION

The Earth is an oblate spheroid body and the best way to study it is by using a globe. A globe is a scale model of the Earth.

But globes have several limitations. For instance:

- Globes are only practical in small scale. It is not possible to carry around globes or even use them in a library, if they are bigger than l metre or so in diameter.

- The amount of detail that can be recorded on a small globe is limited.

- It is hard to measure distances on a curved surface.

Most of these difficulties are resolved by using **planar maps**, i.e. recording geographical information on a flat piece of paper.

We need to remember, though, that the Earth is not flat, and therefore cannot be strictly and accurately represented on a flat surface. However, the advantages of a flat map outweigh the problems for many purposes, particularly when we are studying small areas of the Earth's surface; the errors are light in this case, a lot less than when we try to project the whole Earth‘s surface on to a flat map. However, even this can and is done.

The technology of preparing and printing maps is called Cartography. While the main purpose of this Chapter is to help you read and use maps intelligently, we will also spend a little time looking behind the scene at the cartographer's methods and skills.

MATERIALS

You will find it useful to have the following materials available:

- An Atlas of the World containing a variety of projections of the whole Earth, or several Atlases.
- A Regional Atlas, appropriate to your own area.
- Survey and Ordinance Maps at scales of 1:1 000 000, 1:250 000, 1:50 O00 1:10 000, 1:2 500. These are available from most National Survey Departments.

SECTION ONE: THE CONCEPT OF SCALE

A desk globe is obviously much smaller than the real Earth. It is a model. Its aim is to represent to us a visual impression of how the Earth looks in real life when viewed from outer space. This is normally impossible except for those fortunate enough to be chosen to be space travellers. Besides, we cannot take a space trip every time we need to look at the Earth. The globe records the major features of the Earth in an accessible form. But we must remember that the globe is only a model.

Models may be:

- Life size Models i.e. equal in size to the real thing.

- Scale Models i.e. not the same size as the real thing but all dimensions of the model are in **a set ratio** with the corresponding measurements in real life. Scale models may be smaller or larger than the real thing.

Choosing the Scale Ratio

Scale ratios relate to measurements of a single dimension: the **length of lines**. The diameter of the Earth averages out at just over 12 700km. If we want to make a scale model of the Earth (a globe) we must choose a diameter for the model which is:

- Convenient for storage and use
- A simple ratio of 12 700k.m

Suppose we decide that, for convenience, the globe should be l metre in diameter. At a diameter of 1m the scale ratio of dimension: on the model compared to the real thing would be 1m :12 700km = 1m:12 700 x 1000m (both sides must have the same units) = 1:12 700 000

Choosing a scale:	**Scale**	**Globe Size**
	1: 20 000 000	63.5 cm
	1: 25 000 000	50.8 cm
	1: 40 000 000	31.8 cm

There is a definite limit to the size of real-life measurements that can be accurately recorded on the globe; 1mm will represent 25km in real life on a globe of 1:25 000 000 scale. Any feature less than 25km in length or breadth cannot be shown adequately on a model globe of this size.

Converting this to area: the smallest area that can be represented by an area on the globe of l mm^2 is $625km^2$, i.e. 6.25 million hectares!

Flat Maps

The peculiarity of Scale of Area applies to flat maps in the same way. We can see this by looking at a simple case. Consider the case where the linear scale is 1:2, i.e. all map linear dimensions are **half actual size**.

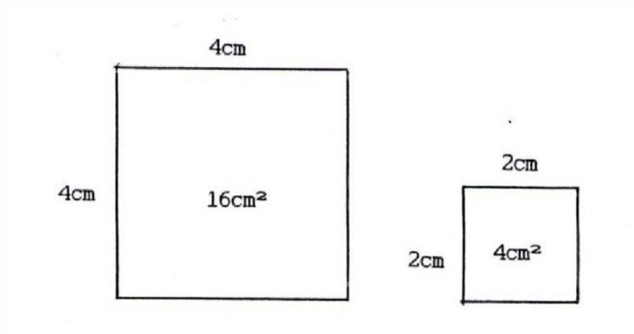


Figure 1: Comparison of Linear Scale with Scale of Area

In Fig.1 the 'real life' area is 4 x 4 = 16cm^2. The map area representing this area is 2 x 2 = 4cm^2. Thus, the **area scale ratio** is 4 = 16 or 1:4.

Another way of checking this is to do some copy reductions on a photo copier that has a reduction facility. You will find out that if you wish to reduce the area by half, e.g. A3 to A4, you will have to use the 71% linear reduction. This is because the square root of (0.5) = 0.707 or 70.7%

Representation of Scale

Have a look at any map or a page in an Atlas. See if you can find the Scale indicator. You should find something like that shown in Fig.2.

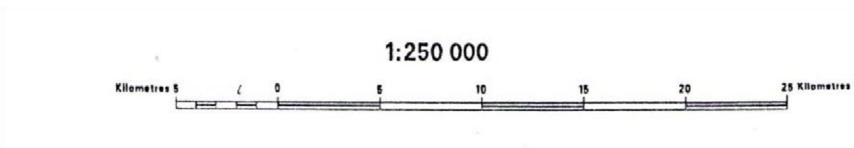


Figure 2: Example of a Scale Indicator

In the example (Fig.2) the scale is shown in two ways:

- The ratio is given – 1:250 000.
- A scale like that on any ruler is given showing the actual distance on the map that represents some convenient real-life distances e.g. in this case 2cm (20mm) = 5km in real life.

The ratio figure gives us the figure to use in any calculation; e.g. suppose we are using a map of Southern Africa and wish to know the distance from Johannesburg to Cape Town:

- First measure the distance on the map with a ruler as accurately as you can. (To the nearest half mm is as close as you can get with an ordinary ruler; even if we have a more accurate rule the accuracy of the map detail will be probably not greater than half a mm).
- Multiply the measurement (cm) by the scale ratio (x 250 000); this gives the distance from Johannesburg to Cape Town in cm which can be converted to km by dividing by 100 000. NB: This figure will be accurate only to half a mm representing about 12km. So, your answer may be out this amount.

The published rule scale enables us to calculate the distance on a map in another way. Taking our measurement of the distance from Johannesburg to Cape Town (cm) we divide by 2.0, multiply by 5 and the answer is in km!

Another way this published scale rule can be used, when you do not have a ruler with you, is to mark the graduations on a piece of paper. You now have a rough ruler to make measurement comparisons in any part of the map. Try this method of measuring distances on a map for yourself. Write down your conclusions.

Check several maps to see if you can find the Scale Indicator on each. If they are not there, the map is very little use. But before discarding it, look in the introduction pages - they may quote a general scale figure there.

SECTION TWO: MAP PROJECTIONS

We have already mentioned the difficulties of transferring information from a curved surface of a globe (which is an accurate representation of the real Earth) to the flat surface of a map. However carefully we do this we are bound to get some distortion. But this distortion can be minimized by using one or other of the **standard projections** We call the process of transferring information from a curved surface to a flat surface a projection because it is much the same as projecting a slide on to a screen with a slide projector (see Fig.3).

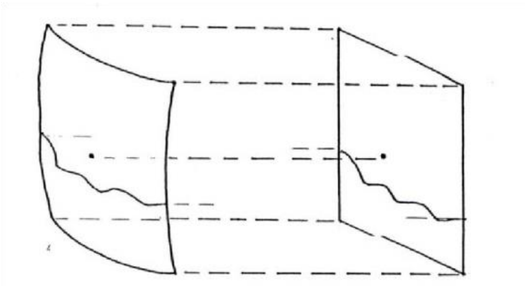


Figure 3: Diagrammatic representation of the process of projecting information from a curved surface to a flat surface

With a slide projector we not only project but enlarge. We can vary the enlargement by moving the projector closer or further away from the screen. In the same way we can enlarge or reduce the size of a map and hence the scale, when we are projecting it. This is the way that modern cartographers work much of the time.

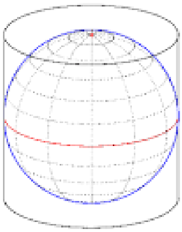
There are three main ways that the surface of a sphere can be projected on to a flat surface. These are:

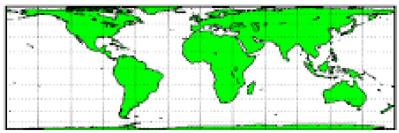
- The cylindrical projection
- The azimuthal projection

- The conic projection (see Fig. 4)

The choice of which projection to use depends on which part of the globe we are projecting and the type of projection we use depends on the relative convergence of the lines of Longitude.

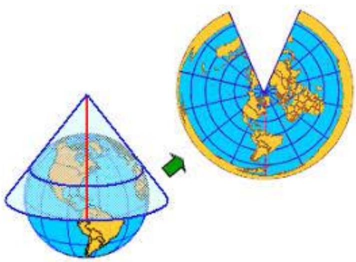
A cylindrical projection is better for areas near the equator.





An azimuthal projection is best for polar regions.

A conic projection is better for areas between Latitudes 30° and 60°.

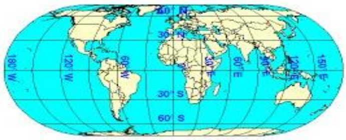


When we come to the problem of putting the whole world on a flat piece of paper, we use one of the Standard Map Projections. There are many different standard projections but the most common are:

- Sinusoidal
- Mollweide's (named after the inventor)

- Eckert's (named after the inventor)
- Flat Polar Quartic

Sinusoidal



Eckert's IV

Mollweide's

Flat Polar

Figure 5: Four commonly used Standard Projections

SECTION THREE: MAP NOTATION

Refer to a **Topographical Map**, like to one shown below

A cartographer uses a topographical map to represent what a piece of land looks like in real life. The four main types of notation are:

- Notation showing the extent, shape and outline of areas; e.g. the political boundaries of various countries can be highlighted using lines and colour.

- Notation showing patterns of arrangement, e.g. location of rivers, streets, roads, towns and cities.

- Notation showing the relative elevation of land, i.e. the relief and form of the land. This is usually done in two ways: by contour lines and colour.

Definitions

- **Landform** The outward shape of land.
- **Contour Line** A line joining points of equal elevation.
- **Relief** Relative height of points in the landscape

Relief can be measured from any reference point that is suitable but usually heights are related to **sea level**; sea level is recorded as 0 000m of relief. Of course, tidal movement affects sea level every day at any point along the coast, so an average level is taken as the standard. To make sure that it is easily found a permanent mark is made at beach sites on some relatively immovable object such as a large concrete block.

Notation representing numerical values and distribution, i.e. the relative quantity of things like population densities of people, animals, trees. etc., can be shown with various sized dots or different density of uniform dots. The location of minerals can be shown by symbols or words. Climatic factors such as annual average rainfall, temperatures and pressure readings can be represented by lines joining areas of equal value. We cannot put all this information on one map. it would be very confusing. Maps tend to include only certain categories of information.

Map Orientation

Normally a map is oriented with **north towards the top**. If there is no indication otherwise this can be assumed to be so. One way of checking is to examine the degrees and direction noted alongside the lines which run from the top to the bottom of the map. If the directions given are East or West, then these are lines of longitude

Another clue is whether the lines are converging or diverging. If the map is oriented with north at the top, the lines of Longitude will converge towards the top for land in the Northern Hemisphere and converge towards the bottom for land in the Southern Hemisphere If for some reason the map is not oriented with north towards the top there will be a largish compass symbol in a conspicuous place on the map. This is particularly so for small, local, large scale maps.

Some people find it difficult to read a map unless they have north towards the top. Other people don't mind which way they are reading it. Whatever the case, it is important to know which way north is pointing.

STANDARD MAP TYPES

The four main types of maps you will encounter are:

Political and Communication Maps
Directory Maps
Topographical Maps
Distribution Maps

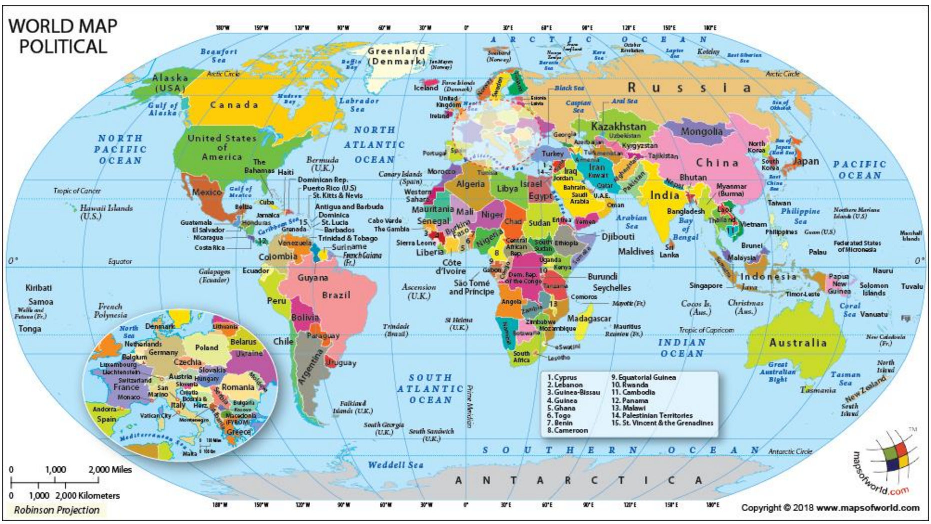
Political and Communication Maps

Find a map in your Atlas with this type of heading. Features that you will probably find include:

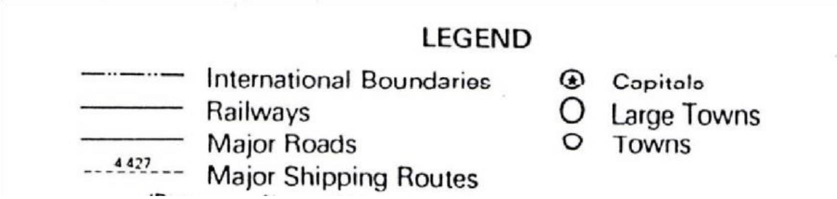
- A heading describing the region covered

- A sub-heading describing the type of map; e.g. "Political and Communication"
- A Scale - ratio and printed rule
- Lines of Latitude and Longitude - usually subdued lines with directional notation
- Boundaries of continents with oceans - lines and colour, names within the boundaries
- Location of rivers (lines, names); wet areas, lakes, swamps, large dams and reservoirs (boundaries marked and often coloured blue plus names)
- National political boundaries - lines, colour and name
- Principal Roads - lines of distinctive colour and pattern
- Railways -lines of distinctive colour and pattern
- Major cities and towns - symbols and names
- Sea Ports - symbols and names
- Airports - symbols and names

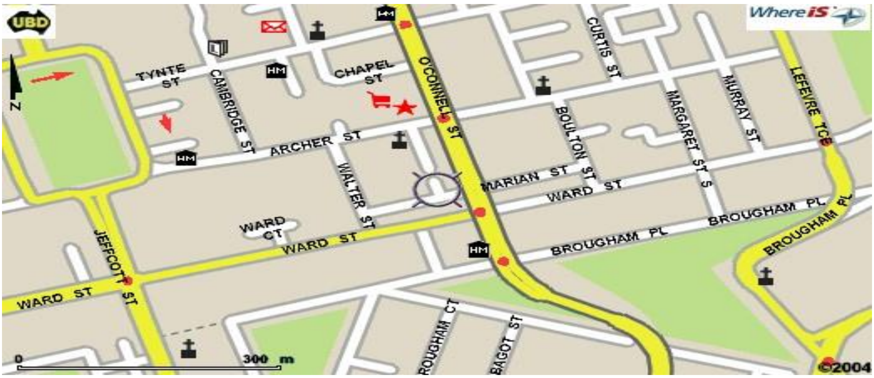
All this information fits easily on one map without being confusing.



NB You can check what a map contains by examining the KEY. NB In an Atlas the key may be in the introductory pages and not on each map. On single maps a Key is always present - it will look something like this:



Directory Maps



Look in your Atlas for a map (usually a large-scale map, l:250 000 or less) which shows roads and towns or even streets in a town. Alternatively, look at a street directory .

Things commonly shown in a directory map are:

- Heading - Name of Region or Town
- Scale
- Key
- Lines of Latitude and Longitude
- Freeways, other main roads, streets, lanes, footpaths – usually indicated by lines of distinctive colour and thickness

- Railway Lines
- Water or Gas Pipelines
- Power lines
- Major features in the landscape which are useful for location when you are traveling through the area - monuments, major bridges, rivers, recreational areas, schools, hospitals, etc.
- General land-use information, e.g. urban areas, rural areas, recreational, etc., usually shown by background colour charges.

Topographical Maps

Many maps in your Atlas will be coloured/shaded to give a three-dimensional effect. This will probably be a Topographical Map. Topography is defined as a detailed description represented on a map, of natural and artificial features on the surface of a piece of land: "topos" = place. "graphe" = writing.

There is some variation in the amount and type of material included in a topographical map, depending on the scale. Much more information can be included on a large-scale map (i.e. 1:250 000 or bigger) than on a small-scale map (l: l 000 000 or smaller scale).

Look at your Atlas for a small-scale topographical map. This should show:

- A heading – Region
- A Scale indicator
- Lines of Lat. and Log
- Continental/Ocean lines and national boundary lines/names
- Key - in some Atlases the key may be in the general introductory pages
- Relief - in a small-scale map relief is usually represented by colour and shading with a few spot heights of high points.
- General Features are rivers, roads, railway lines, towns, etc.

Exercise: Examine a 1:250 000 topographical map and note any additional information you can find that is not on a small-scale map in your Atlas.

Example of a 1:250000 Map

Contour Lines: Of interest in the l:250 000map are the contour lines. As mentioned, these lines join points of equal elevation above sea level. We can illustrate this by drawing contour lines on a model hill. Fig. 6 is an attempt to show a hill 3-dimenaional1y. Note the gullies running up the sides of the

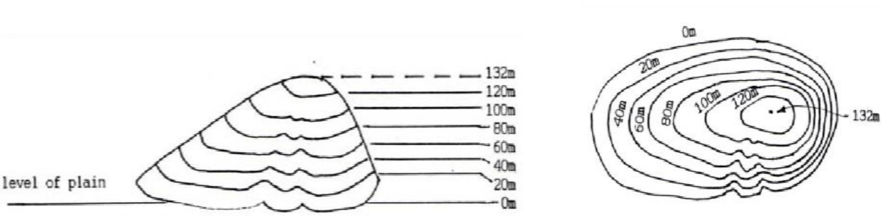


Figure 6: Showing contours around a model hill and plan view of the same hill

hill and how the contour lines bend at these points. On a hill of this type many of the contours will completely circle the hill.

In a Topographical Map the contours are not drawn haphazardly but at set vertical intervals. In the diagram we have chosen a vertical interval of 20m; the height of the hill is 130m above the general level of the surrounding plain, so the highest contour line is at 120m. Note that the base level in this case is the plain and not sea level. It is a common practice to take some local standard point when the map covers a small area (large scale). In smaller scale Topographical Maps, the heights of contours given will be a.s.l. (above sea level standard) . When the hill is projected on to a map it will appear as shown in the PLAN VIEW. It is as if we were directly above the hill in a helicopter.

The information in Fig.6 is much the same as you will find on any 1:250 000 Topographical Map except that;

Contour heights given will be above sea level.
Contour vertical intervals given will be 100m.

Distribution Maps (Thematic Maps)

- **Natural Region Maps**

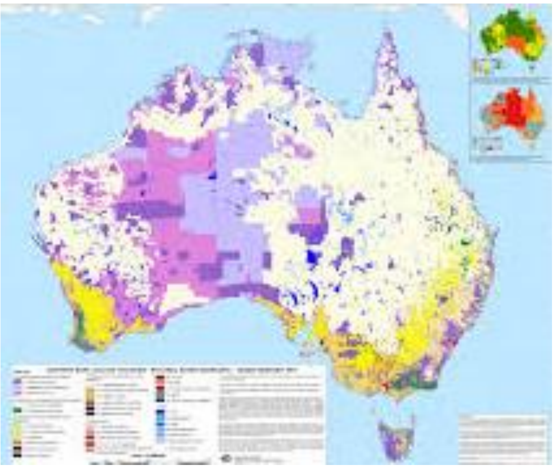
Rainfall Map of Australia

Examples of Natural Region Maps are maps showing:

Annual Average Temperature
Annual Average Rainfall
Soil Types
Vegetation Type

- **Land Use Maps** — Showing one or more of the following:

Mining activity
Types of Agriculture being practiced
Irrigation Schemes
Game Parks
Population distribution and density
Location of Industry

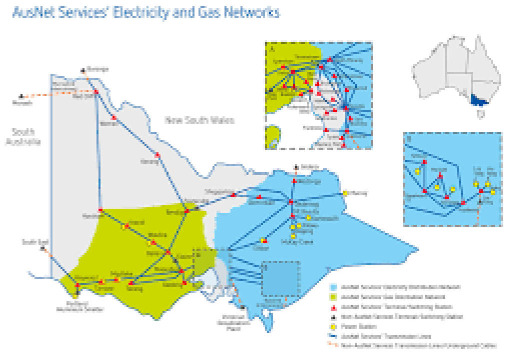


Land Use Map of Australia

- **Historical Maps** — Showing one of the following:

Migration paths of nations over time
Religious or political affiliation at a certain time

Historical Map



Service Map of electricity lines

- **Service Maps** ~ Showing one or more of the following:

  Location of Water Supplies
  Location of Electricity Supplies
  Location of Communication Services, e.g. telegraph lines
  Road Transport Routes
  Air Flight Paths
  Shipping Routes

As you can see, maps are used for many purposes. Being able to read them intelligently is vital as we all must refer to a map at some time or other. In certain instances, it can be lifesaving to be able to read a map properly, e.g. when you are in remote areas.

SECTION FOUR: MAP PREPARATION

Men have been drawing maps since the beginning of time/ Examples of old maps are shown in Fig. 9.

Figure 9: Old Maps of the World and Africa

In order to draw a map, we need to:

1. Find a way of accurately defining the boundaries and location of the area concerned.

   NB: Lines of Latitude and Longitude are not found drawn on the ground. The Survey Department in most countries can provide you with base maps of various scales with the location lines already on them; i.e. continental, national and provincial (state) boundaries and lines of Latitude and Longitude, plus a key, a scale and other essential information. Apart from these essential things the map is blank. The user has plenty of space to put on their own information, colours, etc.

   Base Maps can be found not only for regions but for cities and towns. A visit to your local Survey Dept. will be useful.

2. Choose a base map of suitable projection.

3. Gather information in the field about the features to be represented on the map - their precise location. This requires the skills of a Land Surveyor. Land Surveyors include people who are expert at locating objects with surveying instruments (e.g. levels. theodolites, chains, etc. - see if you can find someone who is a surveyor and get him to show you his instruments and what they do - Local Government offices usually

have such people and might be willing to help. Construction firms are another place where surveyors are employed).

Figure 10: Survey Equipment: A Compass, A measuring tape, A Theodolite

To collect information on soil, climate and rock type, we need the services of other experts like Soil Surveyors, Meteorologists and Geologists. To collect population details, we need people skilled in Census taking. The information normally found on maps represents much work by a variety of skilled people.

4. Record the information on the map

   We do this by using appropriate symbols, lines, shading, etc. in a neat way. The final form must be suitable for printing. Here we need the skills of a Cartographer and a Printer. The skills of cartographers include those of interpretation of aerial photography, draughting (plan drawing) skills, colour choice and separation.

Looking at this list of skills required we can see that map preparation can be quite complicated. Land Surveyors, Cartographers and Printers all spend many years in training. However, over a small area we can all do a reasonable job of map preparation given the time and some basic tools.

SECTION FIVE: USING MAPS

The main uses of maps fall into one or other of two categories:

Locating ourselves and objects of interest when travelling

This use simply requires map reading skills, i.e. being able to orient in the field and relate the symbols to the actual land features. In fact, this is not as easy as it sounds, particularly for some people who do not have a natural perception for map reading. (This is not evidence that they are dumb, it is just that they are different. If you are one of these people you will have other compensating skills but in map reading you will have to work a little harder than people who do it easily)

Road Map

Gathering information about a piece of land without having to visit it

For this we need instruments like rulers (NB you can get scale rulers which when used with the appropriate map enable you to read distances directly); planimeters which can measure area on a map; dividers are also useful for comparing distances. Using these tools, you can assess distances between places of interest, define locations by referencing the lines of latitude and longitude; and get much general information about landform (steepness, shape, etc.) from the contour lines, colour and shading, rivers, etc.

From contour lines we can estimate land slope from a Topographical Map. See Fig.l1.

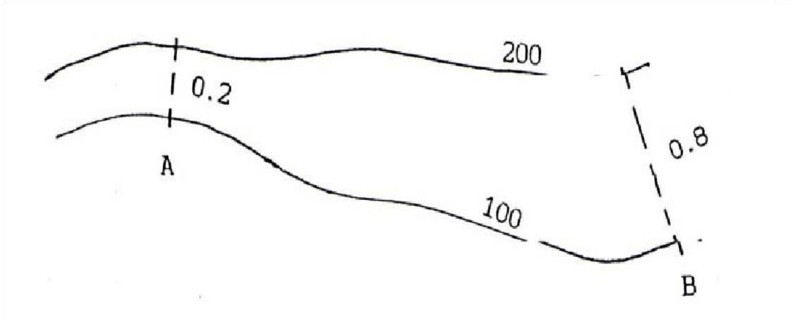


Figure 11: Portion of a map showing two adjacent contour lines (at levels l00m and 200m) and distances measured between them at two points of interest (A and B) on the 100m contour

If we wish to measure the slope at points A and B in Fig.l1, we simply measure at right angles to the 100m contour the distance to the next contour up hill, i.e. the 200m contour. NB Make sure that you are correct about the vertical interval (in this case 100m) as the height measurement is critical in the calculation.

To way to calculate slope is shown in Fig.12.

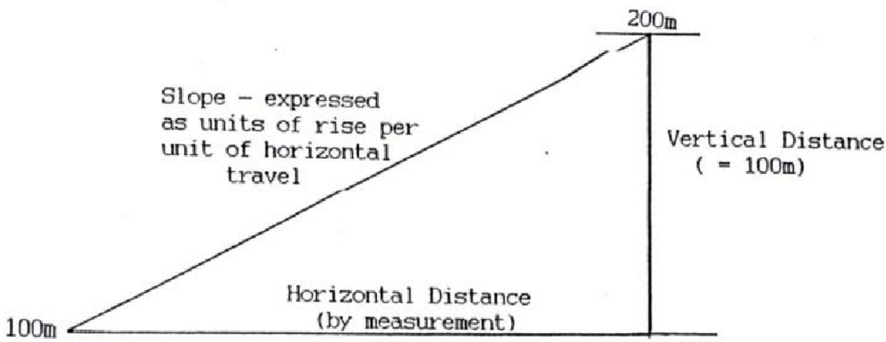


Figure 12: Calculating slope from measurements made on a Topographical Map

Point A (Fig.11)

Horizontal Distance measured is 0.20 m representing 0.2 x 250 000cm in the field.

i.e. $\frac{0.2 \text{ X } 250\ 000}{100\ 000}$ km in the field = 0.5km

The vertical distance is 100m or 0.1km

The slope is expressed as the amount of rise in a standard distance.

i.e. slope = $\frac{\text{vertical distance}}{\text{horizontal distance}} = \frac{0.1}{0.5}$ = 1:5 or **20% slope**

Point B (Fig.11)

Horizontal Distance is 0.8cm; i.e. 0.8 x 250 000cm in the field = 2 km

The vertical Distance is 100m = 0.1km and the slope is 1:20 **or 5%**

NB: The wider the contours on the map the less the slope, i.e. the flatter the land. The closer the contour, the steeper the land.

CHAPTER THREE

THE WEATHER

DEFINITIONS

Weather

The word 'weather' (noun and adjective) refers to **atmospheric conditions prevailing at a place and time**. In particular:

- relative heat and cold
- clearness or cloudiness
- dryness or wetness (rain, dew, snow, hail, etc.)
- calmness or windiness
- high or low air pressure
- electrical state of the atmosphere

Climate

The word 'climate' is more embracing (e.g. ‘climate of opinion‘) but is often used to refer to weather conditions especially as they apply to a region as opposed to local conditions.

Climate is not ‘average weather’ but a picture of the **patterns** of weather charges as they affect man, animal behaviour and the growth of plants, especially crops, over time.

SECTION 1: THE EARTH'S ATMOSPHERE

Around the Earth there is a blanket of gases which we call the AIR. This blanket is 500km thick and consists of several distinct layers - see Fig.1.

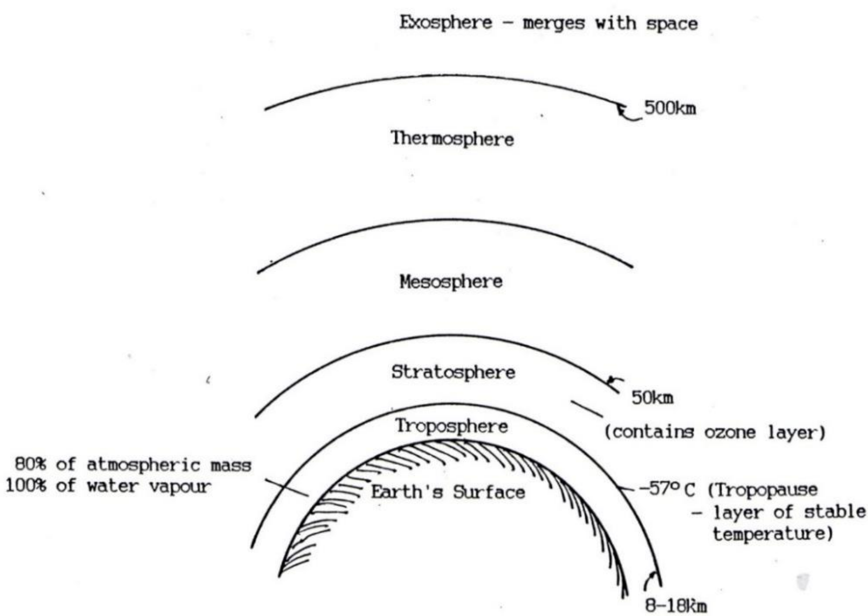


Figure 1: The atmosphere

COMPOSITION OF AIR

Gases: The main constituents of air are the gases NITROGEN and OXYGEN; other gases make up around 1% of the air.

Nitrogen	78.09%
Oxygen	20.95%
Argon	0.93%

There are traces of Neon, Helium, Hydrogen, Ozone, Krypton, Methane, Xenon, and other gases. Close to the Earth, carbon dioxide, a product of respiration of plants and animals, constitutes 0.04% of the air mass.

Water Vapour: Is found only in the Troposphere (see Fig.1). It can be as much as 4% of air by volume.

Pollutants: Dust, smoke and salt can be present in the Troposphere. We call these substances pollutants because they render the air undesirable for normal use. Most evidence of pollutants is found near cities and certain types of factory.

Motor vehicles are a great source of pollutants; in the USA it has been calculated that 90 million cars release 350 000 tonnes of pollutants per day.

SECTION 2: AIR TEMPERATURE

Solar Energy

The Sun is 100 times the diameter of the earth with a surface temperature of around 5 500°C; it is the only significant source of energy reaching the Earth's atmosphere. We call this energy SOLAR ENERGY (Latin: ‘solaris'. the sun).

The Earth is about 150 000 000 km from the Sun. It intercepts 1 two thousand millionth of the solar output. However, this amount has a powerful influence on the temperature conditions of the Earth's atmosphere. Of the solar radiation:

- One sixth (1/6) is visible to the human eye; i.e. is in the LIGHT SPECTRUM.
- Five Sixths (5/6) is either INFRA-RED, i.e. beyond the red band of the light spectrum, or, ULTRA-VIOLET i.e. beyond the violet band of the light spectrum.

Infra-red energy is discernible as HEAT. An obvious effect of ultra-violet energy is SUNBURN.

The relative amount of solar energy reaching the atmosphere and the Earth‘s surface is the single most important factor affecting weather conditions. It not only affects temperatures but also air pressure which affects windiness and moisture conditions. It has a major influence on animal and plant life, including human behaviour.

Losses of Incoming Energy in the Upper Atmosphere

A beam of sunlight reaching the upper atmosphere loses ONE THIRD of its energy to outer space. The loss depends on the angle of incidence which controls the depth of atmosphere that the energy must pass through, see Fig.2.

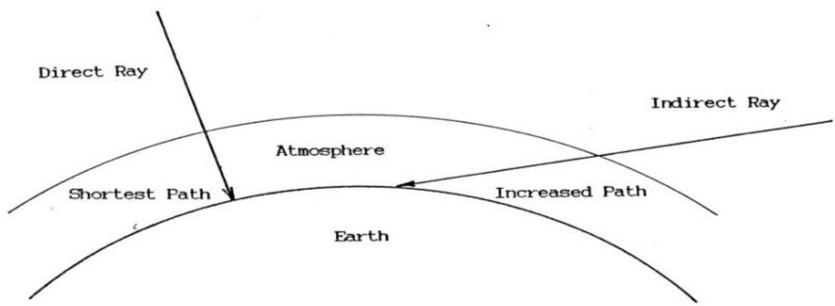


Figure 2: The Effect of Angle of Incidence on Energy Loss in the Atmosphere

Fate of Energy in the Troposphere

Of the energy reaching the Troposphere (66% of the original energy reaching the outer atmosphere layers):

> 30% (19% of the original) is absorbed by atmospheric water vapour.
> 70% (47% of the original) reaches the Earth's surface.

The effectiveness of the energy reaching the surface also depends on the angle of incidence. This is due to the fact that when the sun is lower in the sky (small angle of incidence from the horizontal) the area of ground which it affects is greater than when the sun in nearer to overhead; see Fig.3. This effect can be demonstrated by using a torch at various angles to a wall, or on a globe of the Earth.

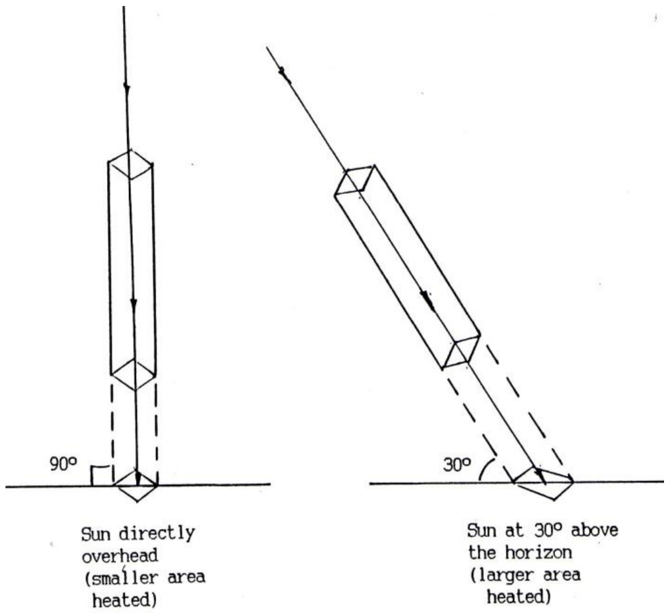


Figure 3: The increase in area of the Earth affected by lowering the angle of incidence of the sun's rays

Various effects flow from this fact.

- Outside of the Tropics, winter sunlight is weaker than that in summer due to changes in the incidence angle.
- The noon sun is stronger than early morning or late afternoon sun.
- The amount and strength of sunlight decreases towards the poles.
- In the mid-latitude regions, there is a marked temperature change between seasons. This is due to the combined effect of angle of incidence and variation in the hours of sunlight between seasons.

The marked difference between energy received at different latitudes is shown in Fig.4. This shows the situation in the Northern Hemisphere; the situation in the Southern Hemisphere is the same except that the timing is displaced by six months.

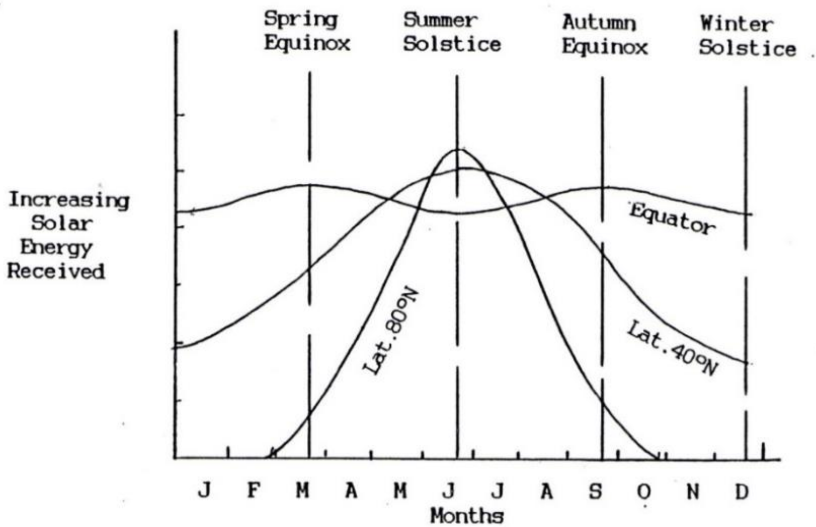


Figure 4: Showing Average Energy received at Three Different latitudes in the Northern Hemisphere over the Period of One Year

The area under each curve represents the total energy received over one year. This amount is modified to some extent by whether the energy reaches land or ocean. This is partly due to varying amounts of cloud cover over land compared with oceans.

The amount is obviously different for the three latitudes shown. One expression of this is that the Tropical Oceans receive twice as much energy as those at Lat.80°N. The mid- Latitudes lie somewhere in between.

Some tropical desert regions, where cloud is rare, receive almost three times the energy of Lat.80°N land due to absence of cloud cover over desert places.

Effects of Solar Energy on Air Temperature

The important processes affecting air temperature are shown in Fig.5.

- About 19% of the solar energy reaching the atmosphere is absorbed by water in the Troposphere. About half of this is absorbed above 1 800m elevation above the Earth so its effect on the lower layers is modifying but not influential in daily or seasonal changes in the temperature of the air close to the Earth's surface.

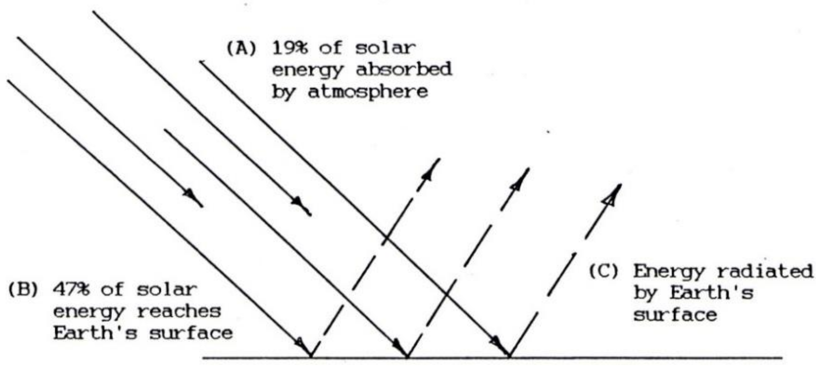


Figure 5: Processes leading to changes in Air Temperatures

- About 47% of all energy reaching the atmosphere is absorbed by the Earth's surface.

- The heated surfaces radiate energy back into the atmosphere. It is this radiation which mainly accounts for the daily and seasonal charges experienced in the lower layers of the atmosphere. NB Energy which has been absorbed and radiated is energy with a longer wavelength than that which reaches the surface from the sun. This is more readily absorbed by the air mass.

Radiation varies with the type of surface. Land surfaces tend to radiate much more heat than water surfaces. One of the reasons for this is that energy reaching the surface of water tends to be moved into deeper water layers due to water movement, waves etc. Energy reaching land surfaces does not penetrate very far so land surfaces tend to radiate more of it back into the lower atmosphere.

Thus, changes in temperature in air over water masses tend to be slower and smaller than those over land. The charges over land are greater, not only in heating up but also in chilling. In deserts, day temperatures may rise to over 40°C and fall to 0^0C over night. This can never happen over a water surface. A water surface will freeze (ice caps at the poles; winter freezing of lakes and rivers, etc.) but this change only occurs over an extended time.

Solar energy reflected, rather than absorbed and radiated, is not as effective as that absorbed and radiated. This is due to the fact that the longer the wave of the energy the more easily it is absorbed. Reflected energy has the same wavelength as the incident energy. Energy that is absorbed is radiated with a much longer wavelength.

The Glass House Effect

A glass house maintains an air temperature much higher than air outside of the glass house. This is because a glass house (or car) heats up on the principle that absorbed and radiated energy, having a longer wavelength cannot pass readily through glass. This is further helped by white washing the under surface of the glass, see Fig.6.

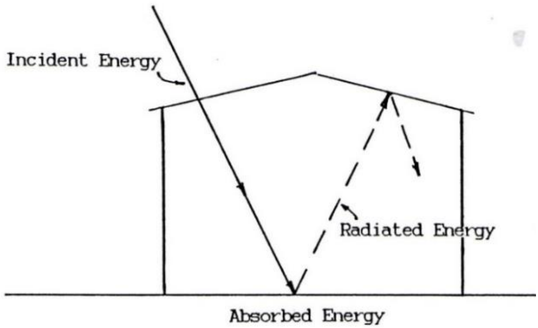


Figure 6: Explanation of the Green House Effect.

Heat of Condensation and other Factors Affecting Air Temperature

Latent heat is the heat required for a change of state. When water vapour condenses to liquid form in the atmosphere, latent heat is released and heats the air around. This can have a considerable effect on air temperatures.

There are a number of other minor factors such as conduction which modify air temperatures, but we will leave these for this time. The processes described above are by far the most important.

Effect of Altitude on Air Temperature

Generally speaking, the higher we go the lower the air temperature. Fig.7 gives some indication of the type of thing you find.

Air temperature falls at a uniform rate of about **6ºC per 1 000m** at altitudes above 270 to 300m. At lower altitudes, rates can rapidly increase (summer daytime temperatures) or rapidly decrease (winter night inversion).

Inversions are an interesting phenomenon. Some inversions develop as a result of sinking cold air. These are called **above-surface inversions**. The main side effect of this is to reduce the amount of precipitation of water vapour.

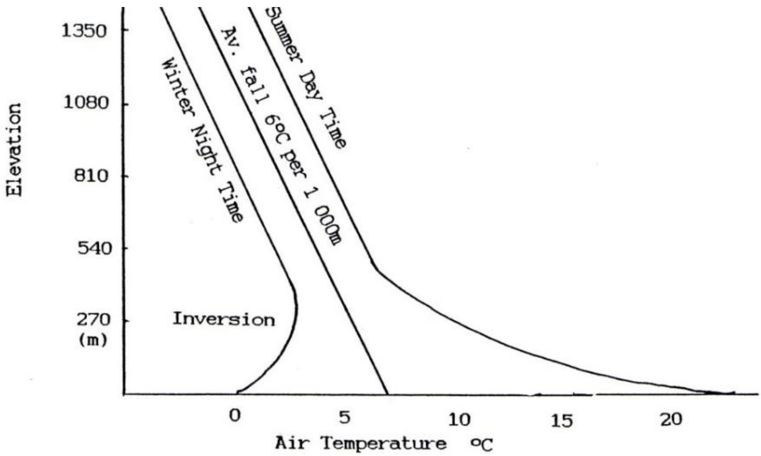


Figure 7: Temperatures at Different Elevations Above the Earth

Some inversions develop due to chilling of the lower air by the land surface. These are called **surface inversions**. Such inversions have a close relationship with fogs, frost and increased air pollution due to their effect in preventing upward movement of air.

Frost

Frost is produced when temperatures fall low enough that surface water freezes. The first water to freeze will be droplets on the surface of plants. Later the water inside of plants may freeze. Still later general freezing of free water surfaces will occur.

Frosts confined to a dew-droplets is usually referred to as a light frost. Frosts which affect water in the internal structures of plants are called Black Frosts because the plant tissues die and turn black. The reason for this is that the volume of ice is greater than the volume of the water from which it forms, and this expansion tears the tissue cells apart.


Frost

Conditions favouring a frost are those which induce rapid cooling of the land surface. Clear, calm, cloudless nights are the most likely to produce frost, especially if the air temperature is low at the end of the day. Thus, frost is most likely in winter and at mid latitudes. In areas nearer the poles, cold air can flow from the poles and precipitate a frost.

Cold air, being denser than warmer air, tends to gravitate to the lowest part of the landscape. Depressions and land locked valleys are the first places to show frost because the coldest air is found there.

Frost prevention techniques include:

- Planting crops in less prone areas.
- Removing barriers to air movement when this is possible
- Creating wind through wind machines to mix the cold air close to the ground with warmer air at higher elevations.
- Burning oil pots to increase the air temperature.

These techniques are important where frost susceptible crops are being grown.

Measuring Surface Air Temperature

We measure temperature with a thermo-meter. The traditional thermometer consists of a glass tube with a supply of mercury in a bulb at the bottom; as the temperature rises, the mercury expands up a thin glass tube and the temperature is read from a scale printed on the backing board. These days there are at least eleven different types of thermometer; here are a few of them:

Traditional

Resistance

Thermocouple

Dual Sensor

K-type

The positioning of the thermometer will greatly influence the reading .For instance: temperatures in open sun will be much higher than shade temperatures; temperatures close to the Earth's surface will be higher than even a few feet in the air.

Exercise: Take daytime temperatures at different heights and in different degrees of shade, etc.

When we want to compare temperatures at one place from day to day, or between different places, we need to always take the temperature in the same way, at the same place and at the same time of day because, as we have seen above, temperature varies a lot over a small area. It is not useful to compare temperatures measured at noon with those at 9am or the day after at 5pm. Similarly, we need to select standard shade conditions and a standard height above the ground, etc.

The Stevenson Screen

The Stevenson Screen is widely accepted as the standard place for recording temperatures. This white louvered box is set so that the thermometers are exactly 1.2m above the ground surface. The box must be placed in an open place; not shaded by a tree, bushes or buildings. The louvered sides allow free movement of air, but direct sunlight is excluded. The white colour ensures that the thermometer is not influenced by energy absorbed by the box.

Temperature recorded in a Stevenson Screen is referred to as STANDARD SHADE TEMPERATURE.

The Stevenson Screen set at a standard height above the ground; instruments in the screen box

For further standardization, temperatures are usually read at a standard time or times; 9am is a common time for readings to be made. Not that this prevents us reading the temperature at other times, it depends what we need the information for.

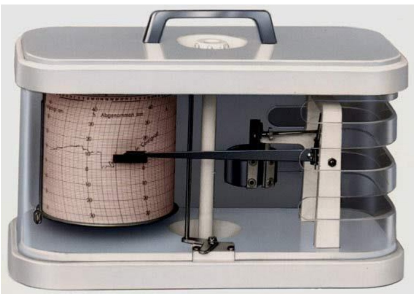
In other cases, people measure direct sun temperatures and temperatures close to the ground, over water, etc. However, such readings cannot be compared with standard shade readings.

Maximum and Minimum Temperatures

Another standard procedure is to use a set of special thermometers; one which records the maximum reached in a period and the other the minimum. The temperatures given on TV, radio and Newspaper Weather Reports usually include both the Maximum and Minimum. Watch the weather report on TV. They quote the day recently past and the predict temperatures for the next day.

Exercise: Examine a set of Maximum and Minimum thermometers. Note the metal pointers in the mercury tubes and see how they are left behind when the mercury moves away from the maximum/minimum positions.

Thermographs



A Thermograph

Sometimes we need to know the temperatures at many different times over the time span of a day. In this case we use a machine called a thermograph. This translates movements in temperature through an arm to a pen which rises and falls on a piece of paper, leaving a trail which records the temperature continuously throughout the day. The paper is fixed to a drum which moves under the influence of a clockwork motor. The paper is a piece of graph paper with the hours of the day marked on it.

From temperature records derived from these procedures the weather authorities prepare daily weather reports and books of tables which summarize the records over long periods of time. These are available to interested people.

Ways of Summarising and Presenting Temperature Data

From air temperature records we can prepare the following useful summaries.

- Graphs of daily changes in Temperature (requires a thermograph)
- Tables of Daily Maximum and Minimums
- Average daily max/min temperatures for days, weeks, months, years, etc. These are calculated by adding the daily figures for the period concerned and dividing by the number of days in the period. From this information we can produce graphs of trends over a month, a year or even longer periods. Fig. 8 was prepared by plotting on a graph monthly average temperatures against months.
- Annual Averages - averages of months over many years, all averaged as an expression of overall temperature for a locality.

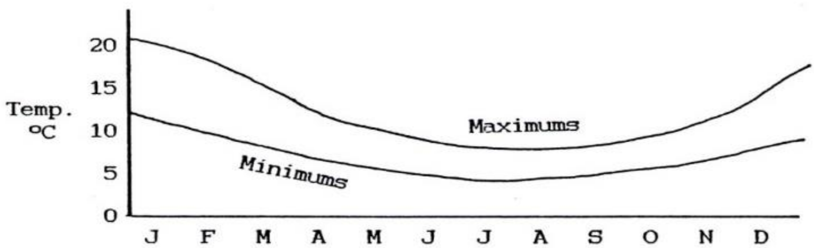
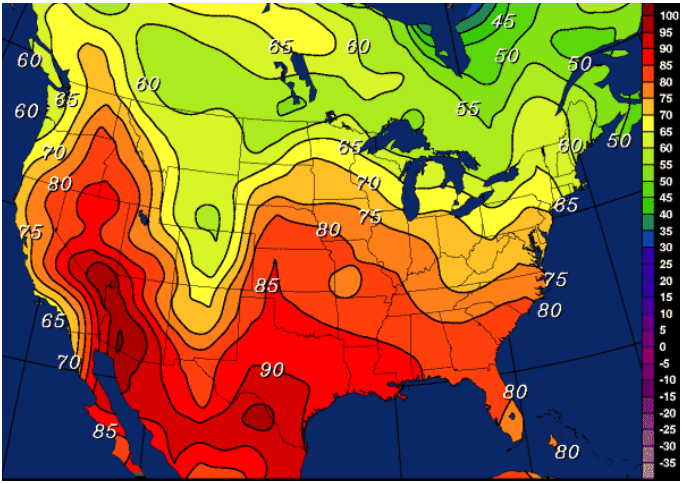


Figure 8: Average Daily Maximum and Minimum Temperatures by Months

- Isotherm Maps - these are like contours in a Topographical Map. By joining localities of the same average temperature, we produce lines which form a pattern which helps us think about the climate of a region, see example below



Isotherms for the USA, June 3rd, 2003

Measuring Atmospheric Temperature

The usual way we measure temperature above the earth is to send instruments up in a balloon. The instrument package contains a radio which sends message back to the earth station. But these days we can also measure atmospheric temperature by using weather satellites; these carry equipment that measures **radiance**, i.e. heat being reflected from oxygen molecules in the atmosphere.

SECTION 3: AIR PRESSURE AND WIND

A blanket of air 500 km high must have some weight. In fact, the pressure exerted by the air on the Earth's surface averages 1kg per cm^2.

This varies a bit for reasons we shall examine in this section. It is variations in pressure which cause air movement (wind, breezes). This in turn has an effect on air temperature and the movement and precipitation of water vapour in the atmosphere.

Effects of Temperature on Air Pressure

The higher the temperature, the less dense the air. At the Equator the Sun's heat is more constantly direct and this causes the air to expand and rise almost continually. This has several effects"

- The Troposphere (the layer of air in which air temperatures are not constant - see back) is thicker at the equator (18km) than at the middle latitudes (10-11km) and the Poles (8km). See Fig.9.

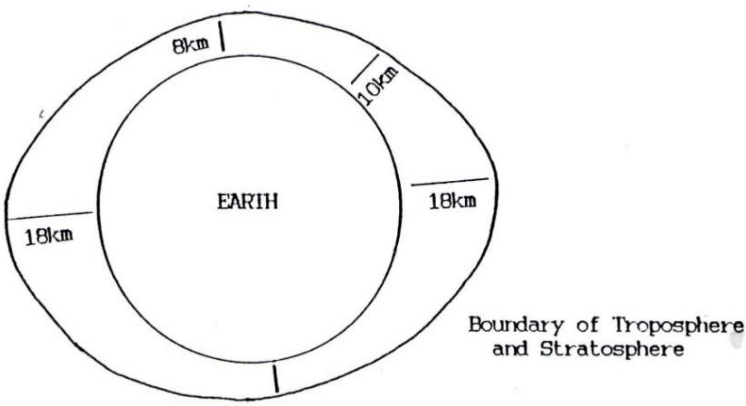


Figure 9: Showing the extent of the Troposphere

- The air pressure at the Equator is constantly low and there is practically no wind, especially over the ocean at this latitude; ships crews call this area the Doldrums.

- The rising air eventually spreads out towards the Poles, cooling and becoming denser. After a time, it begins to sink back towards the surface at about Latitudes 30°N & S. This creates a high-pressure zone at these latitudes called the Horse latitudes

- At the surface, some air from the Horse Latitudes flows towards the Equator producing the winds known as the Trade Winds.

- There is also some flow from the Horse Latitudes towards the Poles. This produces the Westerly Wind Belt (Westerlies) in the 40°'s Latitudes N & S

- The Westerlies eventually meet the Polar Easterlies at the Polar Fronts. The Easterlies are cold dense currents of air from the Polar Regions

All these effects are summarized in Figs.10 and 11.

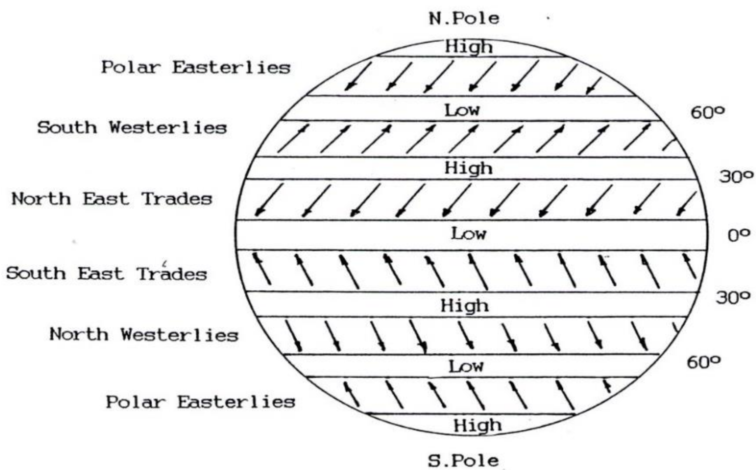


Figure 10: Simplified Diagram showing Air Pressure and Wind Zones

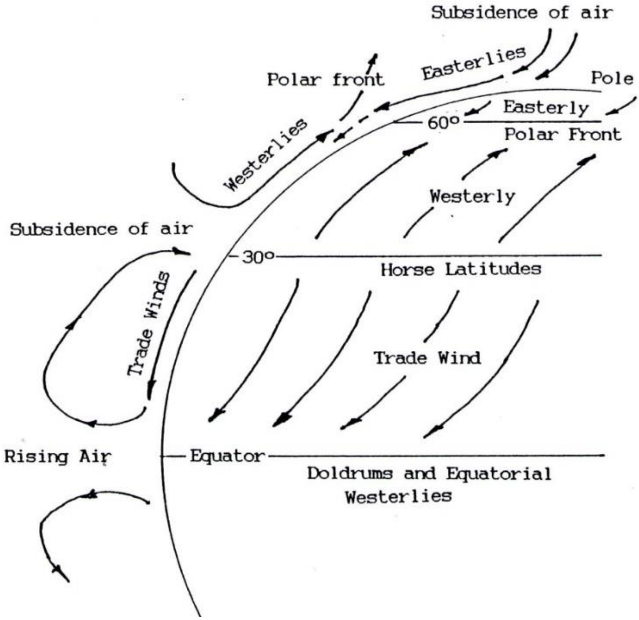


Figure 11: General Circulation of the Earth's Atmosphere

Types of Pressure Systems and Their Origins

Apart from the immense semi-permanent centres of high and low pressure described above, many smaller and more rapidly moving pressure systems show up on the daily surface pressure maps. These are important because they are associated with local weather changes.

Two types of pressure system are observed:

- Centres of High Pressure — called Highs or Anticyclones.
- Centres of Low Pressure — called Lows, Depressions or Cyclones.

The causes of the appearance and behaviour of these systems cannot always be explained. Temperature in this case is a minor influence. Friction produced by air movement itself, centrifugal forces and the blocking action of hills and mountains all have some influence.

Measurement of Air Pressure

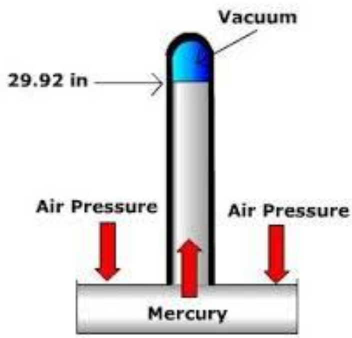
Numerous units have been used to express pressure over time, but the current Standard International Unit of pressure is the PASCAL = l gm/cm^2.

The pressure of the atmosphere at the Earth's surface is approximately 1 000 Pascals or 1 kilo Pascal written l kPa. Normal Air Pressure lies between the two extremes 940 and 1050 Pa = 0.94 kPa and l.05 kPa. All measuring instruments are calibrated to these extremes.

The main types of instruments used to measure air pressure are:

- The Mercury Barometer

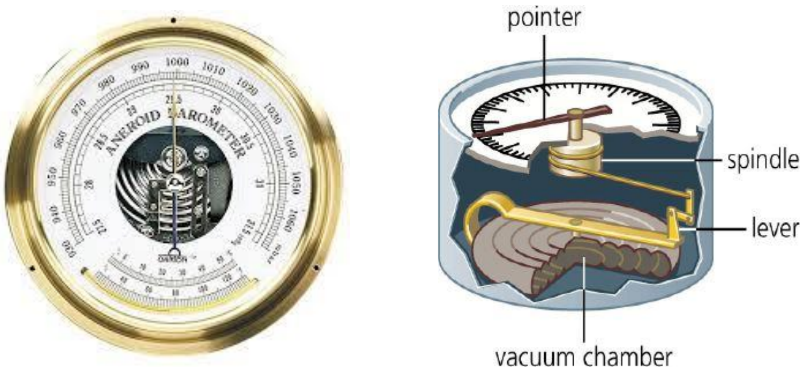
Mercury Barometer



How it works

- The Aneroid Barometer or Barograph

  The Aneroid Barometer consists of a sealed and evacuated thin walled drum. Air pressure tends to push the sides of this drum inwards - any change in pressure is detected and transferred to either a dial or a pen arm which writes on a graph fixed to a clockwork drum (as for a Thermograph). The dialled instrument is called an Aneroid Barometer; this is a common household weather prediction aid. Aneroid Barographs are more commonly found in meteorological stations and where people are doing weather research.



Aneroid Barometer

Barograph

As with temperature, standard atmospheric pressure is measured in the Stevenson Screen, i.e. 1.2m from the ground surface. The time of reading is again important. If the reading is once per day - the 9am reading is often used for daily comparisons. The barograph gives a continuous reading throughout the day.

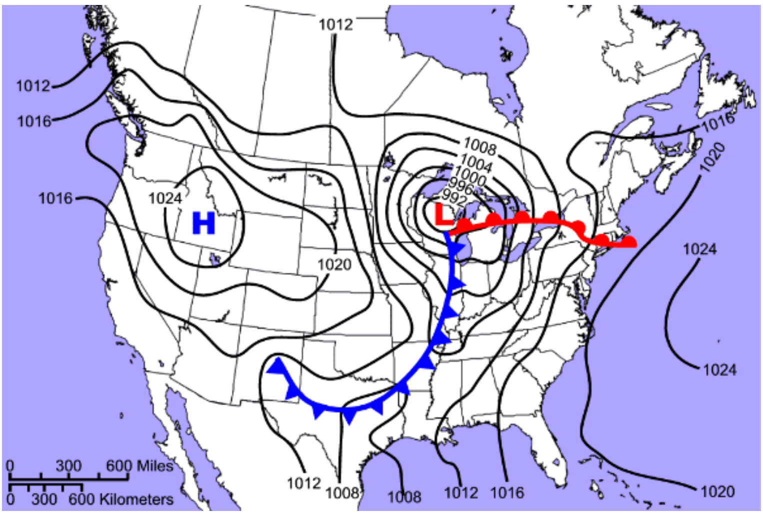
Distribution of Atmospheric Pressure

Vertical Distribution: Since air is very compressible, air weight and pressure decrease rapidly with altitude. The lower layers are densest because of the weight above them. The loss of pressure in the first few thousand metres is about 11 Pa per 1 000m. With high altitudes the air becomes rapidly ‘thinner’; despite the fact that the atmosphere is 500km thick, half the weight of air lies below altitude 5 500 m.

Horizontal Distribution: Because there are areas of rising and sinking air, air pressure in the horizontal plane varies with elevation. The study of changes in the surface horizontal distribution of air pressure is important in weather prediction.

Presentation of Atmospheric Pressure Data

Isobars (lines joining points of the same pressure) are commonly drawn for daily weather assessment. The drawing of isobars is the way in which the surface highs and lows are detected.



Weather map showing Isobars

Relationships of Wind to Air Pressure

Air which moves parallel to the Earth's surface is called wind. The strength of wind depends on the pressure gradient. This is determined by the difference in pressure between the point of higher pressure and the point of lower pressure and the distance between the two points.

When the isobars are far apart we know that the pressure gradient is weak (cf. slope and contour lines on the Topographical Map). When they are close together we know that there is a strong pressure gradient.

Translating this to the ground, pressure gradients have both direction and magnitude. Direction is indicated by a line drawn at right angles to the isobar.

The Earth's Rotation and Wind

Another force that effects the direction of wind is the Earth's rotation. This is known as the Coriolis Force. If the Earth was stationary, air would continue to move at right angles to the isobars, But the rotation of the Earth causes a steady deflection

- To the right of the gradient in the Northern Hemisphere
- To the left of the gradient in the Southern Hemisphere.

The net result of this is that winds move **diagonally** to the direction of the gradient. Fig.15 shows this effect on the Westerlies and Trade Winds.

Friction and Wind

A third force affecting the direction and speed of wind is friction between the moving air and the land or sea surface. This operates in the lower 600m of the atmosphere. Its result is to slow the wind down.

Wind Direction Terminology

Winds are always named by the direction from which they come. Similarly, 'windward' refers to the direction from which the wind blows. A **windward coast** is one in which the prevailing wind moves onshore. A **leeward coast** is one in which the prevailing winds move offshore.

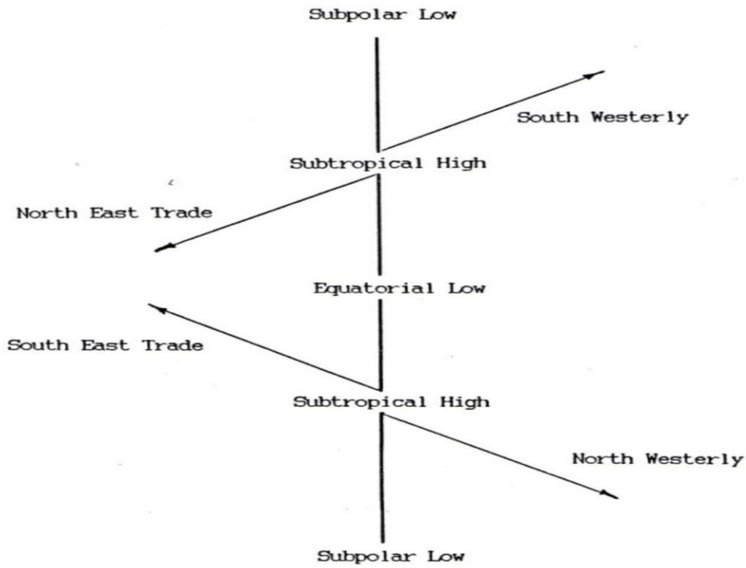


Figure 15: Showing Deflections of Wind due to Earth's Rotation

Measurement of Wind

Wind Direction is measure with a weathervane - a free moving arrow with a broad tail. Under windy conditions the tail settles directly away from the wind direction leaving the arrowhead pointing windward.

Wind direction is related to compass points. Thirty-two different compass points are used to describe wind direction. As with bearings this can be quoted:

- In degrees e.g. 45° East of North.
- In points e.g. Nor-West, Nor-Nor-West etc.

Exercise: Construct a wind vane and note the wind direction each day for one week. You can inspect it a one time (e.g. 9am) or several fixed times during the day if you wish.

Wind speed is measured by an Anemometer. This is a cupped instrument which is caused to rotate when the wind blows. The instrument is calibrated to convert revolutions into km/hour. A counter records the total daily reading which is mostly read at 9am (0900hrs) each day.

Wind speed is normally measured 2m from the ground. But for some scientific purposes, anemometers are placed at various heights, depending on the need.

It is very important that an anemometer be placed in an open area, well away from walls, bushes and trees or any other obstruction.

Anemometer Weathervane

Winds and Their Behaviours

- **Tropical Easterlies - the Trade Winds**

These are usually uniform in speed and direction and therefore were greatly used by sailing ships. Storms and spells of bad weather are rare.

- **Winds of the Equatorial Conveyance Zone**

Very often light to calm (Doldrums) but in some parts develop strong westerly character and are often called the Equatorial Westerlies.

- **Winds of the Sub-Tropics** (Lat. 25° to 35°N 8- S)

These areas lie between the Westerlies moving towards the poles and the Trades moving to the Equator.

- **Mid Latitude Westerlies** (Lat. 35°/40° to 60°/65°N & S)

These are highly variable winds; often gale force and stormy; at other times mild breezes.

- **Monsoon Winds**

These are due largely to pressure differences between air over land and that over sea.

> The **summer monsoons** originate over the oceans in the lower latitudes, i.e. near the equator. They are warm and humid and thus conducive to rain.
>
> The **winter monsoons** are an off-land wind thus low in moisture and associated with dry conditions.

- **Land and Sea Breezes**

These are due to daily alteration of air temperature over land compared with that over the adjacent sea. Normally blow on shore (sea breeze) by day and off- shore (land breeze) by night.

- **Valley or Mountain Breezes**

These minor winds are common in many areas and can have local importance. They are caused by air next to a slope receiving nearly vertical solar energy (South facing in the Northern Hemisphere and north facing in the Southern Hemisphere). The air over these slopes gets hotter than air on the nearby plain. This causes an up draught (useful to balloonists and hang gliders) or valley winds moving up from the plain. Because the air is warm clouds may form around the mountain as the day progresses (Orographic Cloud). This may lead to rain in the afternoons. After sundown, the chilly heavier air tends to slip down the mountains to the valleys and plains below. These are called mountain breezes.

- **Tropical Cyclones**

These form over the oceans just North and South of the Equator. They are produced by lows with very strong pressure gradients. Winds up to 200kph can develop. About eleven cyclones hit the North American coastline each year. They are also common in South East Asia and the Pacific Island groups. Darwin, Australia was levelled by a cyclone in 1974.

Tropical Cyclone

Cyclone destruction

Tornadoes

These are the most intense storms known. They usually operate in a path about 400m wide at ground level. They are caused by a disturbance when two airflows of distinctly different temperature meet. The tornado belt in the USA is typical; here warm air from the Gulf of Mexico flowing north flows under cooler and denser air from the polar region flowing south.

Tornado

Effect of Tornado

SECTION FOUR: ATMOSPHERIC MOISTURE AND PRECIPITATION

All air in the Troposphere contains some water vapour. Water vapour is a gas like other gases; it is dry and invisible.

Warm air has more water vapour than cold air

When warm air rises it gradually cools. This causes some of the water vapour to condense (gas to liquid) around specks of dust and salt. This process leads to the formation of water droplets or ice crystals. Masses of these become visible as cloud. Mist, fog and frost form in a similar way.

Eventually, droplets and ice crystals may coalesce become heavier enough to fall as rain or snow, sleet or hail. We call this **precipitation**.

Rainstorms are associated with electrical energy in the atmosphere. About 45000 thunderstorms occur every day around the world, so they are an important feature of global rainfall.

The Importance of Water Vapour

Water vapour is important because:

- It is the source of all condensation and precipitation.
- It is the atmospheres chief absorber of solar energy and radiant Earth energy and. therefore, the chief regulator of air temperature.
- Latent heat from condensation is an important source of energy for storms.
- Latent heat causes air to ascend, giving rise to cloud formation and precipitation.
- The presence or absence of water vapour controls evaporation from free water surfaces, plants and animals, affecting comfort and life processes.
- Water vapour is the only gas in the atmosphere which can change state in the normal range of atmospheric temperatures.

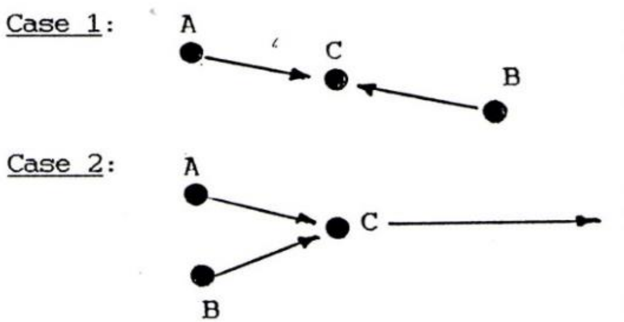
Evaporation

Water vapour gets into the atmosphere by evaporation. Evaporation is the process whereby water molecules escape from a free water surface into the atmosphere at normal temperatures, as opposed to being heated to 100°C.

This comes about because water molecules consist of two hydrogen atoms combined with one oxygen atom, and, in the liquid and gas state, these atoms are highly mobile, i.e. they have energy and move about. This energy derives from solar energy; activity increases as the temperature of water is increased.

The process of evaporation is brought about because of collisions between molecules. If it were not for these collisions all the molecules would have the same amount of energy. But collision results in some molecules having more energy than others and therefore more speed. It is much like the situation in a Dodgem Car Side-show.

The two extreme cases are shown in the two diagrams below. In case 1 we see that collisions may cause one molecule to be stationary at any one time. In case 2 we see that some molecules may be given extra momentum by the combined effects of collision with two or more molecules at one time. Case 2 molecules near the surface of water may have sufficient energy to jump out into the atmosphere and stay there. This is evaporation.



In any closed system where there is a water/air interface (see Fig.16), after a time the air above the water will become saturated with water vapour. By saturated we mean holding the maximum amount of water vapour which it is able to carry. Under atmospheric conditions this is about 4% by volume.

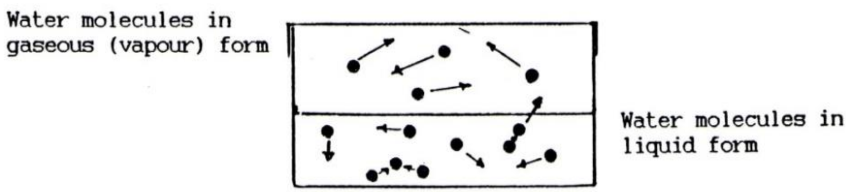


Figure 16: A Closed System Showing the Process of Evaporation

Factors affecting the rate of evaporation

- The difference in temperature between the liquid water and the air above it; the warmer the air the greater the evaporation.

- The aridity (dryness) or degree of saturation of the air: the dryer the air the greater the potential for evaporation.

- Wind speed; the more wind the more evaporation because wind takes the moister air away from the site of the evaporation.

Hot, arid and windy conditions give the greatest evaporation.

Looking at the Earth's surface:

- Evaporation is greater over the oceans because of the water supply.

- Evaporation shows zonal pattern due to differences in air temperature.

Fig.17 graphs the amount of evaporation within different latitude zones. Note that evaporation is high at the Equator and low at the poles, mainly due to temperature effects. Sixty percent (60%) of all evaporation occurs in the Latitude belt 25°N to 25°S. Eighty percent (80%) occurs between Latitudes 35°N and 35°S.

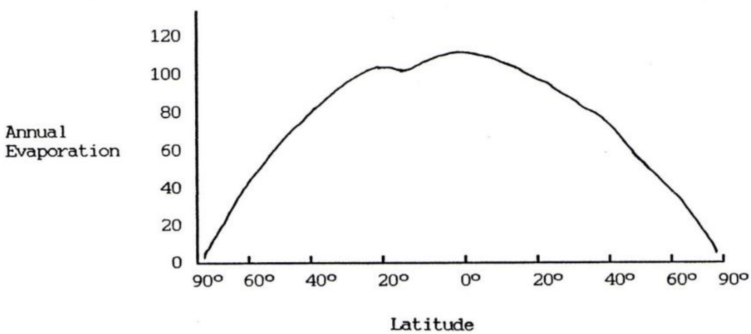
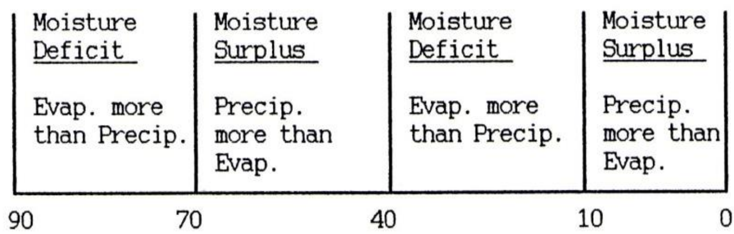


Figure 17: Evaporation against Latitude

The Hydrological Cycle

Moisture in the atmosphere operates in a never-ending cycle, which we call the hydro-logical cycle. There are actually two different hydrological cycles operating. These are called:

The Meridional Moisture Exchange This operates between zones of latitude in which evaporation exceeds precipitation and adjacent zones in which precipitation exceeds evaporation. These zones are indicated in Fig. l8.



Latitude

Figure 18: Regions of Surplus Precipitation and Surplus Evaporation

The Land-Sea Moisture Exchange; see Fig.19.

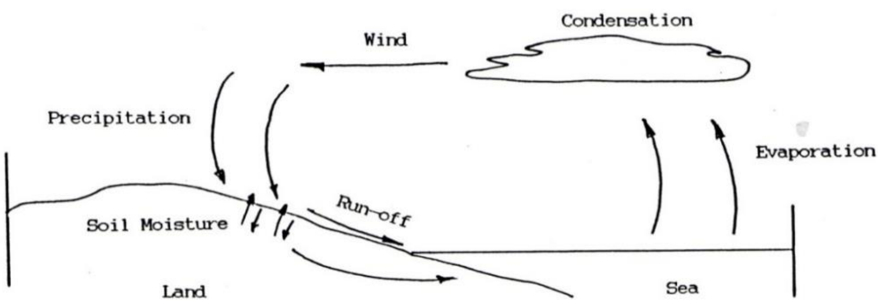


Figure 19: The Land/Sea Hydrological Cycle

To complete the picture for the Land/Sea cycle we need to look at the fate of soil moisture Fig.20.

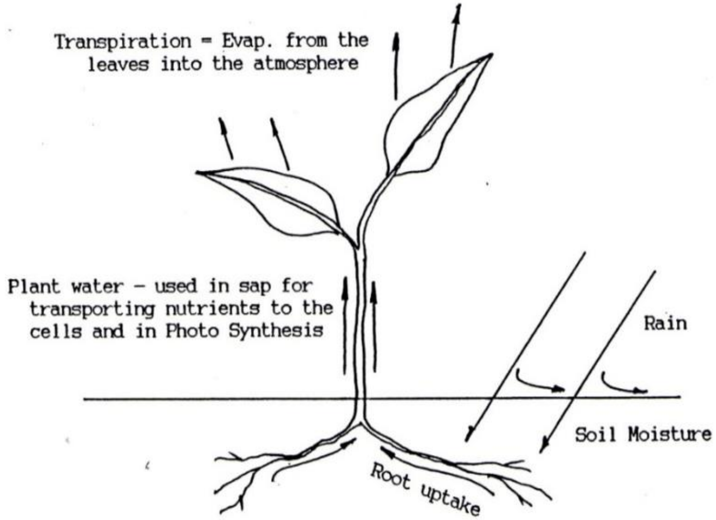


Figure 20: The Fate of Soil Moisture

Humidity and the Measurement of Atmospheric Water Vapour

Humidity is a term referring to the relative presence or absence of water vapour in the air. As we have seen, humidity varies depending on:

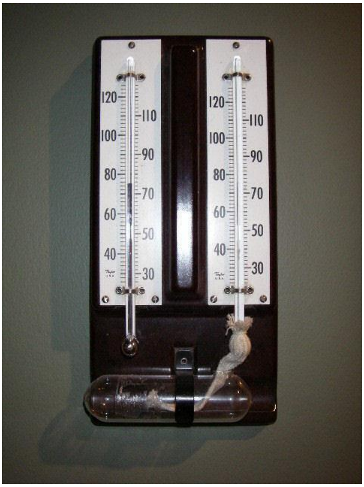
- The air temperature; the higher the temperature the more water can be absorbed.
- The availability of water for evaporation and atmospheric conditions which favour evaporation.

The common way of measuring humidity is by the combination of **Wet and Dry Bulb Thermometers**.

The Dry Bulb Thermometer is a normal mercury thermometer with a range appropriate to the area.

- In Equatorial and mid latitude areas the range needs to be 10° to 50°C.

- At Polar latitudes the minimum figure might have to be as low as minus 50°C.



Wet and Dry Bulb Thermometers

The Wet Bulb Thermometer is a normal thermometer except that the bulb is wrapped in a wick which is kept permanently wet by being connected to a sealed waster container, see Figure above. Water from the wick evaporates resulting in a loss of latent heat. This in turn cools the bulb resulting in a lower temperature being recorded on the wet bulb thermometer than on the dry bulb thermometer.

The degree of cooling of the wet bulb will depend on the amount of evaporation. This will be affected by whether the conditions favour evaporation and by the amount of water vapour already in the air. As Wet and Dry Bulb readings are taken under standard conditions in the Stevenson Screen, variations in the external conditions favouring evaporation are eliminated to a large degree. The result is that the difference in the readings can be taken to reflect the amount of water vapour in the air at the time of the reading.

If the atmosphere is very dry, then the wet bulb reading will be much lower than the dry bulb. If the atmosphere is already full of water vapour then evaporation will be low and the difference in readings will be low. The humidity on a cold day will be less than that on a warm day, due to the capacity of warm air to absorb more water vapour than cold air. The Wet and Dry Bulb Thermometers are a means of measuring this variation in humidity due to temperature

Given wet and dry bulb readings, there are tables from which we can read directly the degree of saturation of the atmosphere. This is called the **Relative Humidity**, i.e. the percentage of the maximum possible water vapour. This is important in reporting the weather because it is noticeable that 90% humidity on a cold day is quite comfortable but 90% on a hot day can be very trying because there is no evaporation of sweat from the human body. A hot day with low humidity is still hot but evaporation of sweat cools us considerably.

Condensation

Condensation is the reversion of water vapour into the liquid form. The occurrence of this in the atmosphere is of the greatest importance in the hydrological cycles especially in the precipitation process.

- **Dew Point**

If air that is not saturated with water vapour is cooled, it will reach a point where it is saturated even though the amount of water vapour has not increased. The critical temperature at which this occurs we call the **Dew Point**. As cooling continues below the dew point water vapour condenses, i.e. reverts to a liquid form, because the air can no longer hold it.


Dew

Dew point is affected by the relative humidity, i.e. how much water vapour is in the air initially. If the air is near saturation before cooling, then the dew point will be reached quickly. If the air is relatively dry before cooling, the temperature will have to drop a long way before the dew point is reached. The actual temperature at which dew point is reached will depend on both the initial temperature of the air and the relative humidity.

If the dew point occurs above freezing point the result is liquid water in the form of clouds, fogs or dew (on grass, etc.).

If the dew point is not reached until cooling has gone beyond freezing the resulting condensation mainly remains in the liquid form but some ice crystals may form also. Ice crystals are found in clouds, white frost and snow.

- **Types of Condensation**

Fog, Dew, White Frost and Rime

These are common forms of condensation. They are all produced by cooling of the layers of air close to the Earth‘s surface. In fact, apart from a little discomfort they have little effect on weather conditions.

Clouds

All precipitation occurs from clouds, so these are very important. The process of cloud formation is as follows:

When air rises it expands due to decreasing pressure from the air column above. If air rises 6 000m, the pressure is only half that at the surface and the air volume is doubled. But to expand, the air has to displace other air, and this requires the use of energy in the form of solar heat. The result is that there is a general cooling effect. Conversely, when air descends it is compressed and its temperature is raised.

Rising air cools . . . . ..Descending air is warmed

This process is called ADIABATIC TEMPERATURE CHANGE. The rate of adiabatic cooling is about **10°C per 1 000m**. This is much higher than the normal drop in temperature due to elevation (called the LAPSE RATE) which is 6°C per 1 000m.

The process of cooling by expansion is the only way that thick layers of air can be cooled below the dew point. Normally all precipitation occurs through condensation relating to the expansion and cooling of rising air currents.

The direct effect of cooling is CLOUD FORMATION. Not all clouds give rise to precipitation, but all precipitation comes from clouds.

NB: Buoyant air will rise until it reaches an air layer of its own temperature and density. This is why clouds develop at different heights on different days under different conditions.

Cloud Types

The weather people identify a number of different types of cloud formation. Cloudiness is usually expressed in terms of cloud type and degree of cover

Of the various cloud types there are two main types that produce precipitation. These are:

- **Cumulus Cloud**

These are identified by having great vertical thickness, a dome shaped top and a dark (shaded) level base. Cumulus clouds occur as distinct clouds with clear sky breaks between. Cumulus cloud is the result of rapidly rising air. When it rises very high we call it cumulonimbus cloud. Cumulus cloud is noted for producing short term heavy rain, squall winds, lightning and thunder.

- **Stratus Cloud**

Stratus cloud is a solid complete cloud cover with no obvious shape and no breaks. If rain occurs it is usually steady and continuing.

Cumulus Cloud

Stratus Cloud

Precipitation

Condensation particles in clouds are very small; far too small to fall as rain. One good sized raindrop may contain as much as 8 million cloud particles!

The combining of cloud particles is due to two processes:

- The ascent of cloudy air above freezing point. When this happens, some droplets form ice, and this acts as a nucleus for the formation of larger rain drops.

- Cloud particles collide and join together until they are heavy enough to fall.

Forms of Precipitation

- **Rain**

Rain is the most common form of precipitation. Rain results when condensation occurs at temperatures above freezing or when snow or hail melts on the way down.

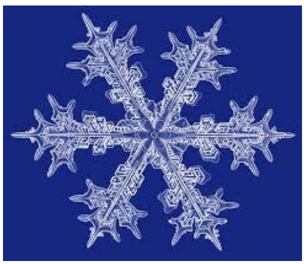
- **Snow**

Snow is the most common form of solid precipitation. The fundamental shape of a snow crystal is an intricately branched six-sided flat crystal of infinite variety of patterns. There is a strong suggestion that no two snow crystals are the same despite their being untold millions of them.

Snow only develops from condensation that occurs below freezing. A snowflake consists of numerous crystals matted together. Snow is not very dense: 30cm of snow = about 3cm of rain.

Over the oceans snow only falls at Latitudes greater than 30°N or 30°S. Over land snow is known to fall at low latitudes especially on land at high elevation; e.g. Mt. Kilimanjaro (6 000m) is near the Equator but has snow for long periods of the year.

Snow fall



Snow crystal

- **Sleet and Hail**

Sleet is frozen raindrops. Hail, which is almost exclusively associated with thunderstorms are ice lumps larger than sleet.


Hailstorm


Hail

Types of Precipitation

As we have seen, precipitation is the result of adiabatic cooling in rising air. There are three main causes of air rising - each with a characteristic type of precipitation. In most situations, when precipitation occurs, more than one type of uplift is operating. However, it is useful to look at them separately.

Convective precipitation

This comes from adiabatic cooling of air currents which are rapid and truly vertical. Usually when this happens, there are a number of distinct cells or ‘thermals', i.e. separate columns of air in which cumulus cloud develops. Convection (cumulus cloud) precipitation is characterized by brief (sharp) heavy local showers.

Orographic Precipitation

This is precipitation caused by uplift which results from rising air being uplifted more quickly than normal by mountain ranges or escarpments. As a result of this process, the windward side of a mountain chain, running near to right angles to the prevailing winds, tends to be a wet region. On the other hand, the leeward side of such a range tends to be dry because by the time the air gets there it has dropped most of its water vapour. We call this leeward effect a **Rain Shadow**. These are prevalent in the 10° to 40° Latitudes.

Orographic Cloud

Atmospheric Disturbance

Whenever surface winds converge, lifting and cooling of the opposing air masses results. In the middle latitudes, converging air masses are usually at different temperatures and density. The result is that warmer less dense air is pushed upwards by the colder air stream. The cold air usually has a sloping surface on which the warm air glides, see Fig.21.

Such a surface is called a front. Frontal precipitation is very common in middle latitudes - mostly associated with lows (cyclones). Note that where the warm air is forced under the colder air, much disturbance results due to density differences. The cold air forces its way down through the warm air resulting in Tornadoes in some instances

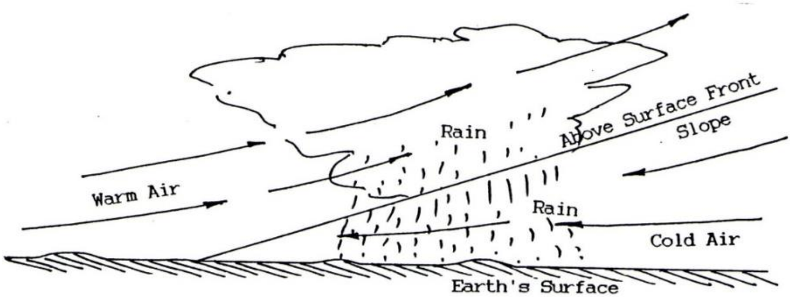


Figure 21: Precipitation Produced by Air Disturbance along a front.

Measurement of Precipitation

- **Instruments**

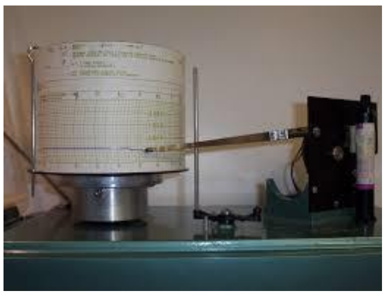
The simplest way of measuring rainfall is with a rain gauge. There are standard rain gauges made of metal. They have a circular opening at the top of definite size and shape (sharp edged). It is important in using a rain gauge that it be properly placed at ground level in a clear open place; i.e. away from trees which might drip into it, and walls of buildings. .

Official Rain Gauges are normally read once per day at 9am. However, if more information is needed there is nothing to stop them being read several times through the day. Cheaper plastic rain gauges are available for home use. They are quite suitable for this situation.

Automatic, continuous recording Pluviographs are available for research projects, but these are expensive and only used when absolutely necessary. As with the Thermograph and Barograph, the Pluviograph records rainfall on a graph paper fixed to a clockwork drum by means of a pen connected to the filling container. When the container is full it automatically siphons empty and starts filling again.


Metal Rain Guage


Plastic Rain Guage


Pluviograph Recorder

Presentation of Rainfall Data

Daily Totals; Weekly/Monthly/Annual Totals and Averages; the Number of

Wet Days per Month/Year, are all ways in which rainfall data can be summarized, depending on the need. If you need daily records these can always be obtained from the Weather Authorities.

SECTION FIVE: READING THE WEATHER MAP

So far we have been looking at the causes of various conditions found in the atmosphere. Understanding these things and having a good picture of the broad climatic zones is the foundation of weather understanding. We must add to this basic information some understanding of features which develop in the atmosphere within the broad zones as these greatly affect the day to day local weather conditions. In fact, as far as weather forecasting is concerned, within a region these features are of great importance.

Surface Fronts

Fronts are caused by moving air masses. An air mass is a body of air which shows uniform characteristics of temperature and humidity. Air masses form when air stays over a uniform temperature/humidity area long enough for the air to pick up the characteristics of the surface over which it is lying. Areas where air masses form are called SOURCE AREAS. The main source regions are the poles and the tropics. Each produces two types of air mass: continental (land) and maritime (ocean) air masses - see table.

Air masses do not stay still for too long. Pressure differences cause them to move to other areas. Because of their size and stability their movement can be traced for a number of days. This is very important in weather forecasting.

When air masses of different temperatures meet the warmer, less dense mass of air is usually forced upwards by the colder air mass. The two masses do not mix but develop a sloping boundary. This sloping surface is called a FRONT.

Where a front intersects the ground, we call it a SURFACE FRONT. NB: Fronts are not lines but zones ranging in width from 5 to 80k.

Region	Type of Source area	Locations	Properties of Air Mass
Polar	Polar Continental	Arctic Basin, Nth. Eurasia, Nth Amer. Antarctica	Cold, dry, very stable
	Polar Maritime	Oceans in Lats. 50-80°.	Cold, moist, unstable
Equator	Tropical Continental	Low Lats., espec. Australian and the Sahara Deserts	Hot, very dry, stable
	Tropical Maritime	Tropical and Sub-Tropical Oceans	Hot, moist, instability increases towards west side of oceans

When a front passes over us, we notice a distinct temperature and humidity change. There are actually two types of front, depending on which air mass is the most active.

- When a warm air mass moves into a zone of cold air we have a WARM FRONT.
- When a cold air mass moves into a zone of warm air we have a COLD FRONT.

Both types of fronts are shown in Fig.22.

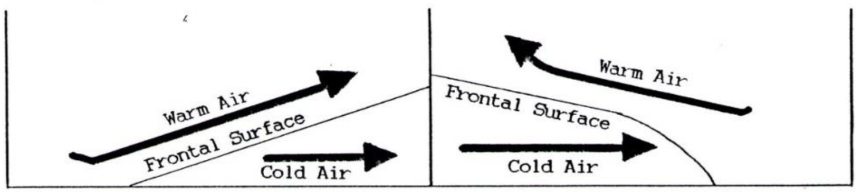


Figure 22: Two Types of Fronts

Cold fronts are represented on a weather map by a line with pointed symbols on the leading edge; warm fronts have rounded symbols (see Fig.23).

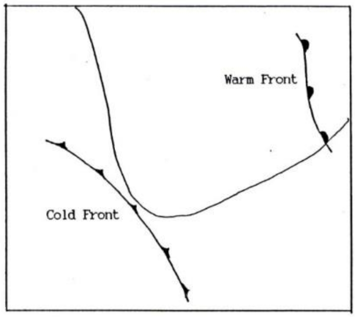


Figure 23: Two Types of Fronts on a Weather Map

Atmospheric Disturbance

- **Mid Latitude Disturbances**

By mid-Latitudes we mean 35° to 60°. At these latitudes the obvious features on the surface weather map are the 'highs' and ‘lows’ - cyclones and anticyclones.

As we have seen, cyclones are areas of low pressure; anti-cyclones are regions of high pressure. To be more exact, cyclones are a region where the isobars tend to be circular with the inner circle having the lowest pressure. Anticyclones are also distinguished by circular isobars but in this case the inner circle has the highest pressure.

The closeness of the lines indicates the steepness of the pressure gradient; the closer the lines the greater the pressure gradient and the greater the likelihood of strong winds. Highs and Lows continually move across the land surface at mid-latitudes. They have a big influence on day to day weather charges.

Highs and lows tend to be less intense, i.e. weaker in pressure gradient, in summer than in winter. They vary in size from a few hectares to large features covering areas as large as Australia or the USA.

Cyclones often bring rain, particularly in winter, as they are usually associated with cold fronts, see Fig.24.

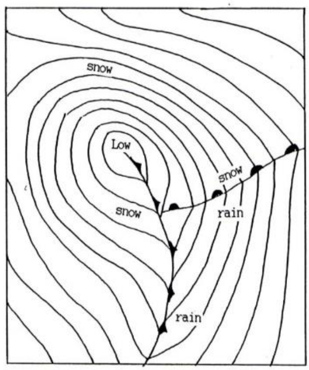


Figure 24: A Mid Latitude Cyclone Showing Associated Fronts

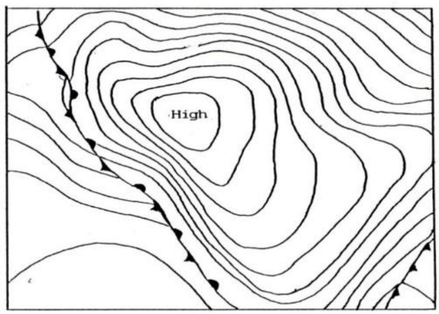


Figure 25: Anti-Cyclone - a Tongue of Polar Air moving into a Warmer Zone

Tropical Disturbances

Severe tropical disturbances, including hurricanes, are produced by tropical cyclones which tend to be vertically deep and very violent. Cyclones at these latitudes tend to have isobars which are very concentric. They are easy to recognize on a weather map (see Fig.26).

Tropical Cyclones develop over water, but no one is sure why. Unlike the mid latitudes, cyclones do not have anti cyclone companions. They are maintained by heat of condensation not by temperature controls. They are more plentiful in summer than in winter. There are no fronts associated with them because temperatures are relatively even.

The gradient of a tropical cyclone is usually high and winds of at least 130 km/h develop with a spiral tendency and strong vertical movement around the vortex or cone. The diameter of a cyclone is about 160-600 km. Rain produced is torrential. They do a lot of damage.

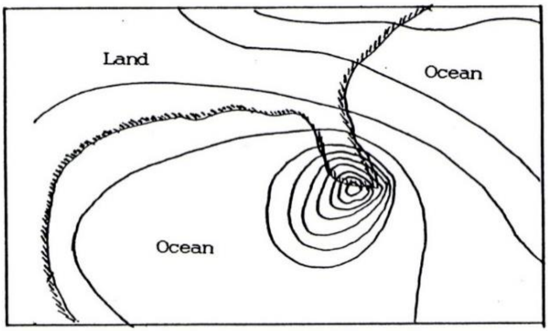


Figure 26: A Tropical Cyclone

SUMMARY

These features are just a few of the main things you will see on a weather map. Interpreting them and making forecasts of weather is a very skilled job and we cannot expect to become experts in this field without a lot more experience and study.

The weather is important to all of us. It is a useful skill to be able to understand the atmosphere around us.

CHAPTER FOUR

LANDFORM

INTRODUCTION

By Landform we mean the OUTWARD SHAPE of the Land Surface. When we stand on the Earth and look around us, the most obvious thing is landform. Of course, we see surface features such as trees, houses, telephone poles, people and cars, animals and roads - but underneath all of these is the land surface and that has a certain shape.

Landform is a good indicator of many things we want to know about land. Being able to describe and identify differences in landform helps us in assessing the value and usefulness of the land we live in.

Exercise: Go outside and look around you. Describe what you see; particularly the shape of the land in front of you. Do you see mountains? hills? plains? river valleys? These are all features which we include under the term landform.

SECTION ONE: ROCKS AND SOIL

When we walk on the Earth's surface, ignoring the vegetation and the man-made things that we have placed there, we are either standing on ROCK or SOIL.

- Rock is solid material which does not break up readily.
- Soil is solid material which breaks up readily into finer particles when disturbed.

Soil particles are actually small pieces of rock. Soil is important. Most plants need soil to grow in; very few can survive in rocky areas and most that do, do not produce anything useful as food.

Soil is relatively shallow. If we dig deep enough we can always find some kind of rock material underlying the soil. The soil in valleys tends to be deeper than the soil on hills. In fact, on many hills there may be no soil.

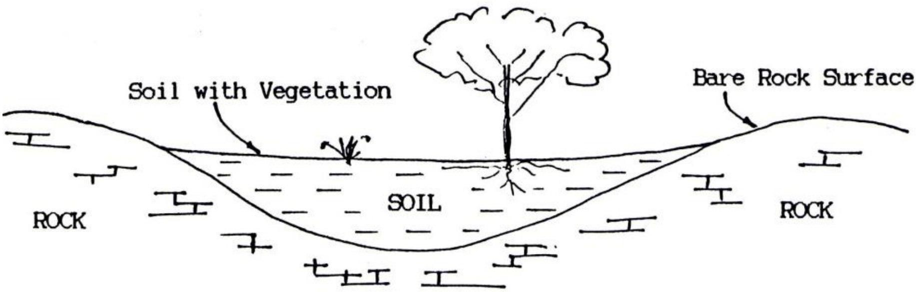


Figure 1: The Earth's Surface Showing Rock and Soil

The Earth's crust is presumed to have arisen from the cooling of the molten mantle. All rock material derived in this way, including larval flows from volcanoes, is called **IGNEOUS ROCK.** The most common rock in the land plates we call **Granite**. Granite is a grey to pinkish rock made up of three **minerals**: quartz, mica and feldspar.


Two samples of granite rock

A mineral is a component of rocks which has a definite chemical composition. Quartz is silicon dioxide. In rocks it is found in a crystalline form.



Minerals in granite : Quartz crystals Mica Feldspar

In many places around the world the seabed has been pushed by tectonic forces up on to land. Seabed rocks consist mainly of silicon and magnesium. These rocks are basic (alkaline); the rock type most commonly found is called **Basalt**.


Two samples of Basalt

Outcrops of both granite and basalt are common in Africa and Australia in parricular.

Outcrops of Basalt (left) and Granite (right)

SECTION TWO: TECTONIC PROCESSES

Definition: Tectonic processes are associated with deformation, **the changing of form, i.e. outward shape.**

Crust Warping and Folding

Folding is commonly found in rock strata. Keep your eyes open and you are bound to see some evidence of this. Various types of folding are found. These are shown in Fig.3. Note the various names of the different folds as these are commonly used to describe landform which is the subject under review.

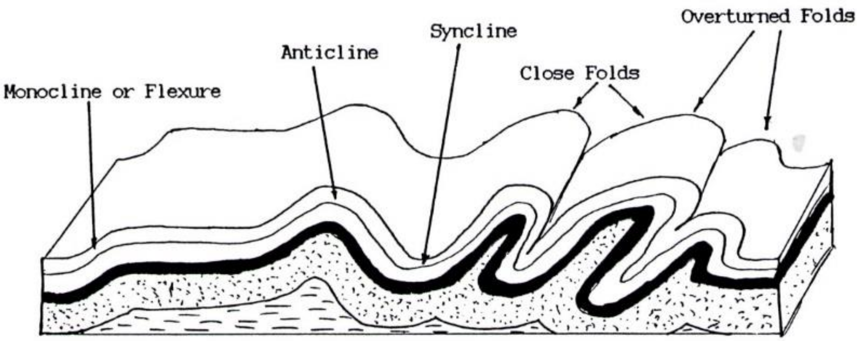


Figure 3: Types of Folding Commonly Found in Rock Strata

Examples of rock folding

Fracture and Faulting

In some places the crust has broken along a line called a **fault line**. Movement is common at such places causing faulting of the rock layers.

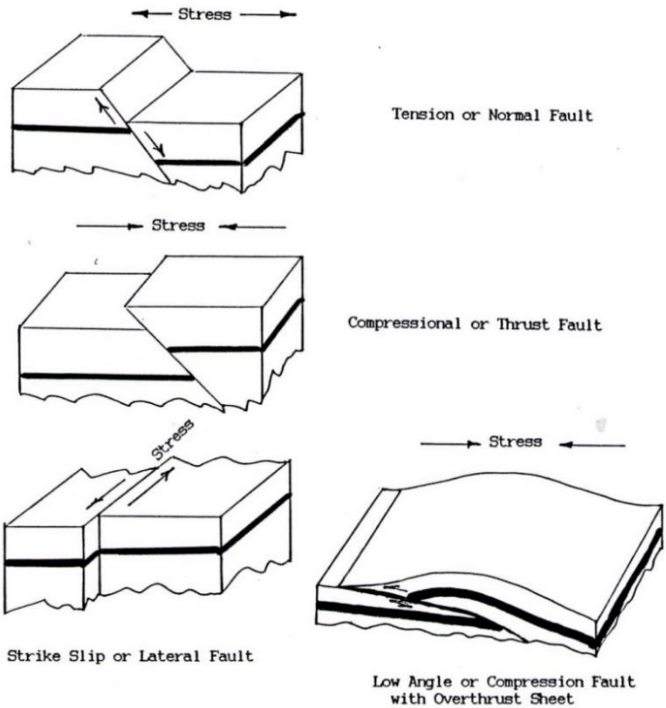


Figure 4: Types of Faulting

Fig.4 shows several types of faulting that are found in the field. Earthquakes are associated with fault movement. These can be quite devastating to people living on or close to the fault line; e.g. Japan and the West Coast of the USA. Strangely, people choose to live in such places, despite their record of catastrophe!


Examples of faulting in rocks

Volcanism

Volcanism has to do with molten material from the liquid mantle forcing its way up through fractures in the crust. Sometimes the molten material breaks through the land surface: this is called EXTRUSIVE volcanism. In other cases, the crust prevents the molten material breaking through: INTRUSIVE volcanism. Fig.5 shows these two types of volcanism.

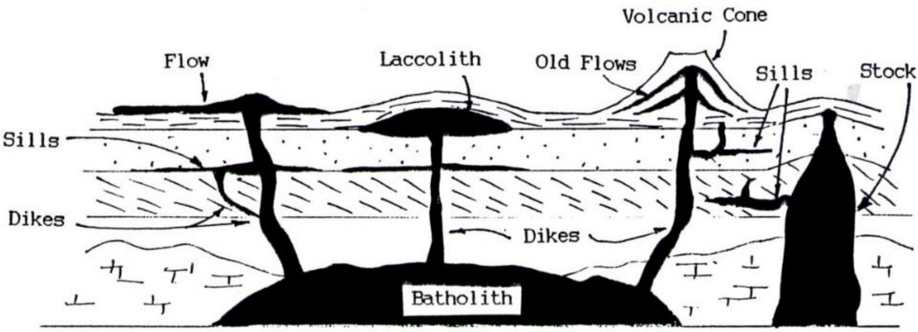


Figure 5: Types of Volcanism

The eventual shape that the cooled lava takes influences landform. Various results are shown in Fig.5.

Examples of Intrusions: Batholiths, laccoliths, stocks, dikes and sills. While these are formed underground, land movement and erosion of the surface layers can expose such features.


Exposed dikes

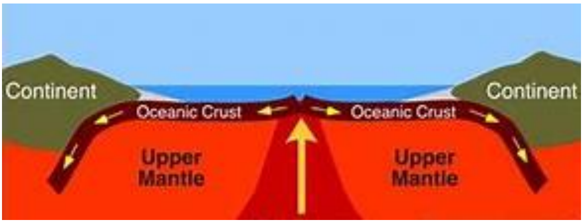

Exposed laccolith

Examples of Extrusions: Laval flows and ash are the main effects. Lava flows around a volcano overlay previous flows; this can dramatically affect the landform in places. Extrusive volcanism is confined to volcanoes: it is very spectacular for those lucky enough to see it.


Volcano erupting

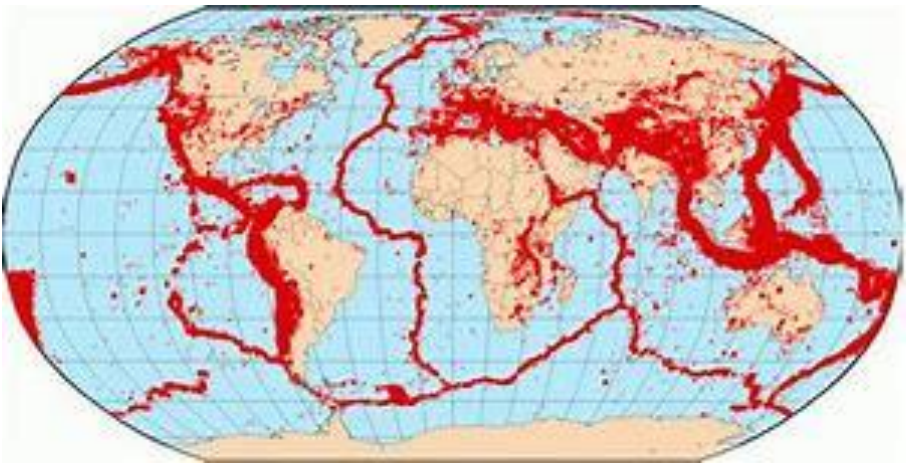

Laval flows

There are over million volcanoes under the oceans. These occur along splits in the seabed crust; we call these seismic zones:



Seismic Zone Diagram

Ocean volcano erupting



World Map of Seismic Zones

SECTION THREE: WEATHERING AND TRANSPORT OF ROCK MATERIAL

Some people believe that soil has taken many millions of years to develop. They assume this from several assumptions;

- Weathering is a slow process and it has always been so.
- The pristine Earth was formed as bare rock.

Neither of these conclusions agrees with the Biblical account. It is clear from Genesis 1:9-13 that the newly exposed land immediately brought forth vegetation - and not just small plants but trees and shrubs with their seed pods on them! It is clear from this that the newly formed land had excellent soil already formed upon it.

The second omission in the alternative theories of the development of soil is the ignoring of the Deluge or Flood at the time of Noah. Clearly this has been the most important influence on the appearance of the Earth in its short history since creation time. If we look closely at the Earth's surface with the Flood of Noah in mind we will quickly see that such an event as the Bible describes in Genesis 7 and 8 easily and wonderfully explains the things we see around us.

The Bible says that the Flood was associated with massive tectonic movement (‘the fountains of the great deep were broken up, Gen.7:1l) and enormous amounts of rainfall (‘forty days and forty nights‘, Gen.7:12) . The combined effects of these would have created a seismic wave of massive proportions. Halle, the great astronomer estimated a wave 1km high moving at 1 600kph! Such a wave would certainly have had a dramatic effect on the weathering of exposed rock surfaces! Having seen the effects of small seismic waves produced by extremely small amounts of movement in small pieces of the ocean floor we can well imagine that the effect of the tectonic processes at the time of flood would leave the world in a devastated state. There is no question, most of what we see around us can be explained in terms of the Flood.

Sumatran tsunami 2004 and devastation

Whatever we believe to be the cause, there is around us today, much exposed rock showing signs of weathering and much material that appears to be derived from weathering of rocks which has been moved and accumulated in various places.

ROCK WEATHERING PROCESSES

While the effects of the flood have been the dominant influence on the rock weathering process, on-going weathering is observed wherever rocks are observed today. Several different causes of weathering are found:

Pressure Effects

- Formation of tiny fault lines called **joint planes** due to external pressure or contraction due to cooling.
- Water in crevices expands as it freezes causing the rock to crack.
- Plant roots exert enormous power when they get into crevices.

Rocks showing joint planes

Decomposition (Chemical Weathering)

Rock minerals can be decomposed by two distinct processes:

- Dilute Acid: Water often contains small amounts of dissolved carbon dioxide. This forms a weak acid (Carbonic Acid) which can dissolve some rock minerals.

- Oxidation: Minerals exposed to air continually oxidize, forming different substances, some of which are soft and flake away from the hard rock.

Rock weathering occurs when rocks are exposed to the atmosphere. Generally, it is a very slow process and does not influence land shape or soil accumulation to any marked degree. There are some exceptions. In the South Island of New Zealand for instance, the mountains show massive disintegration. Pieces of rock literally flow down the mountains. As they move their rough edges are rounded and they take on the form of shingles. On the Canterbury Plain there are layers of these stones 300m deep overlain with a thin layer of soil. Engineers have calculated that these layers of stones would have accumulated in about 3 000 years. In the North Island of New Zealand there are interesting examples of soil forming from recent volcanic ash. These soils are often less than 100 years old.


Shingles stones in rivers and their final resting place on the beach in New Zealand

While there is on-going tectonic movement and weathering, it is quite clear that the Flood explains the bulk of the things we see around us. Weathering since the time of the Flood has contributed very little to rock weathering or soil formation by comparison.

The one exception may be the separation of the Land Masses at the time of the Patriarch Peleg (Genesis 10:25). Just what happened at this time to make it worthy of mention in scripture is not clear, but it may have had to do with movement of the land masses to their present position: a process recognised by Geologists as Continental Drift.

Transport

***Exercise**:* Put a handful of soil from the garden into a tall glass jar. Fill the jar two thirds full of water and seal it with a lid. Shake the jar vigorously, turning the jar end over end a number of times. After a final slow turn, stand the jar upright and leave it to settle. After a time examine the soil in the water to see what has happened to it. Most of the soil will settle out on the bottom of the jar. Soil particles vary considerably in size; some are quite coarse, others are very fine. The coarse particles will settle out quickly on the bottom of the jar. If you have dispersed the soil well you may find that the material on the bottom is layered: coarsest particles on the bottom, grading to less coarse particles on top.

Coarse particles on the bottom

No suspended particles

If there are very small particles present they may not settle out at all. This explains why in some cases the water will stay milky, not clearing even after many days. We have a special word for particles which remain in suspension. We call them **colloidal particles**.

NB: Colloidal particles are not dissolved like sugar or salt in the water, they are suspended because their weight is insufficient for them to settle out. By contrast, the coarser non-colloidal particles quickly settle out on the bottom. The results of this exercise are important in understanding how rock fragments, especially soil particles, are transported.

Water is by far the main soil transporting agent. Enormous quantities of soil can be shifted in a short time by moving water. The process starts with raindrops. These have a lot of energy: when they strike bare soil, particles are quickly detached and splashed about.

Exercise: Spray a garden hose pipe on to bare soil and see what happens. Place pieces of paper at various distances from the area being sprayed; see how far soil particles are splashed.

The Water Erosion Process

During a rainstorm, if the land is bare for any reason, raindrops smash away at the soil surface and soil particles are separated from the soil mass and splashed around. On sloping ground, some of the rain soaks into the ground but much of it runs off. The amount of run off will depend on the length and intensity of the rainfall.

When the soil cannot take all the rain that is falling, the drops quickly form into little trickles. These pick up the splashed particles and start to transport them. Trickles become streamlets, streamlets become mountain streams, mountain streams flow into small rivers and these eventually flow into larger rivers which make their way to the sea. All of this water may be carrying soil particles. Colloidal particles will become suspended and will be are carried as far as the water goes. Coarser particles will be bounced along by the force of the water. Very coarse particles are rolled along; the size of particles that can be shifted depending on the force and quantity of the water moving past.



Erosion Process: First raindrop action, then soil washed off the slope and carried to the sea by rivers

This is a simplified picture of the water erosion process, but it helps us understand the main process affecting the picking up and transportation of soil material.

Deposition

When a river crosses a flat plain, it tends to slow down and spread out. When this happens, the 'silt' load is dropped. (The term 'silt' is often applied to soil material being carried by a river, but it is also a name for soil particles of a particular size and character – see Chapter Five).

It is worth looking at a few river channels running through flat land. You will find that they have a lot of sand in them, especially on bends.

Mud dropped in a village after a flood

Sand banks in rivers

After the Flood

The Bible says that it rained for forty days after the fountains of the great deep were broken up. And the waters prevailed upon the Earth for 150 days (Gen.7:24 and following). And God made a wind to go over the Earth and the waters subsided... and the waters returned (drained) from off the Earth continually. This all happened after the fountains and the rain were stopped (after forty days). After 150 days the waters were abated enough for the ark to settle on the top of the Ararat Range. After this the drainage continued to the tenth month, the first day of that month, when the tops of the mountains were seen for the first time. Forty days after that Noah released a raven and a dove but the dove returned having found no-where to rest other than on the ark. Seven days later the dove returned with an olive leaf in her mouth and seven days after that it did not return at all. On the twenty seventh day of the second month of Noah's six hundredth and first year the Earth was finally dried!

We can imagine that after the terrible destruction wrought by the deluge that a considerable amount of material would have broken from the rocks and have been swept around the earth's surface by the massive seismic waves.

As the Earth drained, enormous amounts of silt would have been carried by the receding waters. Eventually, as the water reached flattened places, the silt load would have been dropped on to developing plains. The more silt was dropped, the flatter the land would have become, and the slower the rivers. As the rivers slowed even more silt would be dropped. So, the plains would have come deeply overlaid with soil material.

It is interesting to fly over various landscapes and see how obviously this process is revealed in the landscape. Southern Africa and Australia show these processes particularly clearly. Raindrops continue to splash soil particles from exposed soil and moving water continues to transport particles to distant places. Flood water, moving across plains still cuts deeply into soil deposits, carving out gullies, and run off water is still moving soil afresh into lakes and seas. The process of erosion is still with us!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Hillside erosion An erosion gully on the plain

We need to note that such occurrences are **dramatic events**; not slow processes; 99% of all modern water erosion occurs in a short space of time following an unusual rainfall event. But even the most extreme case of modern erosion is a small event in comparison to the results of the deluge.

The general picture we have today is that mountains tend to have only thin layers of soil whereas plains have deep layers - due to the related processes of weathering, transportation and deposition, Fig.7:

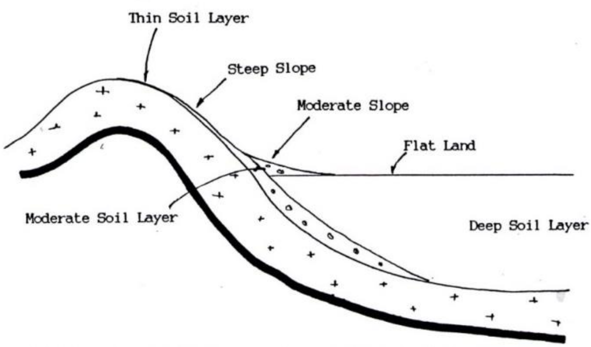

Figure 7: Diagram of Soil Depth in relation to Slope

Glaciation

Another rock and soil transporting agent is the Ice Glacier. Glaciers are not common, so their overall contribution to transportation of rock and soil material is minor compared with water but they can have a big influence in particular localities.

Glaciers move slowly; usually only a few centimetres per day although rates of movement of 30m per day have been measured. Glaciers can be 50m thick. As they move they carry rock fragments in the body of the ice, roll other fragments along underneath them and also push a considerable amount of rock in front of them (Fig.8). Rock material moved by a glacier is called **Glacial Till**. It is identified by its size (water cannot move rock fragments greater than soil particle size) and location: a piece of rock which is regularly found in an area where no parent rock is known has probably been moved in times past by glacial action.

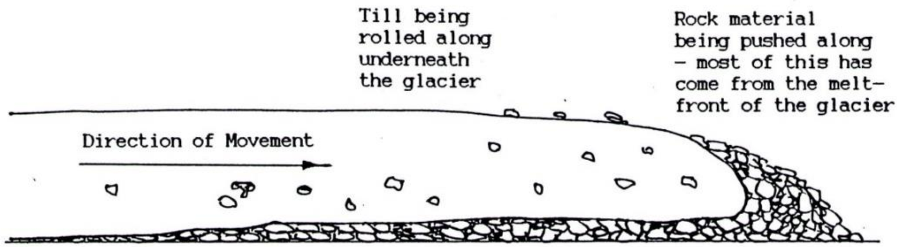

Figure 8: Showing how a glacier moves rock material

A Glacier

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Wind Erosion

In dry sandy areas, wind erosion can have a big influence, especially if the soil surface has been allowed to become bare. As with water transportation, wind carries fine particles much further than coarser particles. Coarse particles tend to skip or 'saltate' along the ground surface. They can do a lot of damage to any plants growing in the area.

Wind will continue to move the coarser ‘sand’ particles along the soil surface until a barrier is met. This might be a fence or a belt of trees. Here the sand will start to pile up until eventually a sand dune may result. The dunes will continue to shift about with the prevailing winds. Unless considerable effort is put into rehabilitating such areas they will revert to total desert. This is seen in many places: e.g. North Africa (Sahara, Namib, Kalahari), Asia (Gobi)

Wind erosion

Drifting sand engulfing a house

The rehabilitation of sandy areas is difficult because sand is very infertile. It is quite hard to get plants to grow in it, particularly as even small amounts of wind will stir up the sand, causing fatal damage to developing seedlings. Consequently, left to themselves, deserts and wind scalded areas will continue to blow about

There is an interesting desert in Peru, the ‘Desierto de Atacama‘ (the Atacama Desert), where it never rains, and the wind never blows. In this desert nothing grows except an occasional rare type of plant which has no roots. Because of the lack of wind, the expected dunes are not present.

Livestock grazing in the Atacama

Plants with no roots in the Atacama

Fine materials caught up by wind can be blown many hundreds of miles. They will only be deposited when the wind drops completely. Large deposits of this type are called **Loessal Deposits.** A remarkable example of this is the Palouse, Wheat Lands of NW USA. These soils are magnificently deep and fertile; some of the highest wheat yields in the world are found there.

The Palouse, Washington State USA

Deep Loessal soil in the Palouse

SUMMARY

In this section we have looked at the processes of weathering and transport of rock and soil materials. The purpose of this has been to explain why land has the shape it has and to give us some understanding of what we can expect to find under lard surfaces showing different landform.

As a general rule, steep mountain slopes are likely to have much bare exposed rock; soil, if present, will be only a thin layer.

Lower slopes of mountains will generally have moderately deep soil layers due to material being washed or gravitating down the mountain slopes. Plains will tend to have deep soil layers and be the best areas for growing crops. It is not by chance that the first people after the Flood migrated from the Ararat Range to the Plain of Shinar, i.e. the Mesopotamian Basin. The next big settlement was on the plains of the Nile, in the rich delta area where the most fertile soil is to be found. In fact, looking around the world, it is obvious that the great plains, developed as a result of the drainage after the flood, are the food ‘bowls‘ that feed the bulk of earth's population.

Interestingly, the growth of food stuffs on the ancient plains is still dependent to a large extent on the annual deposit of silt from higher regions; e.g. the Nile (Egypt) and the Yellow River (China). This silt carries the plant food necessary to grow good crops. If the floods do not come crops tend to be poor.

SECTION FOUR: PRODUCTS OF ROCK AND SOIL

In the field we find a large number of rocks which are obviously different from the basic igneous rocks like granite and basalt. Get into the habit of looking at rocks as you travel about. You will soon see that rocks vary considerably. Things to look for include:

- **Texture**: some are crystalline, some powdery, some have coarse grains, others are fine grained.
- **Structure**: some show distinct bedding lines. others are masses of grains cemented together.
- **Hardness**: rocks with quartz crystals are hard, others may be soft.
- **Composition**: from the different colours and crystal shapes we can see that different rocks contain different minerals - you may need a magnifying glass to see these things.

Some rocks are the result of chemical changes in rock and soil transported sediments. Others are the product of unusual pressure and heat.

SEDIMENTARY ROCKS

Rocks formed in sediments are called **SEDIMENTARY ROCKS**. We can often distinguish these by the obvious layering of particles in the rock. The hardening of transported sediments comes about through two main agents:

- Pressure
- Cementing Agents like lime and silica

Some common sedimentary rocks are:

Conglomerate - very coarse particles cemented together.
Sandstone - gritty, medium particles cemented together.
Shale - very fine particles pressed together, smooth, platy.
Limestone - soft, often grey to white; may be dense or crystalline.


Conglomerate


Sandstone


Shale


Limestone

Metamorphic Rocks

Apart from igneous and sedimentary rocks there is a great range of other rocks which fit into neither category. We call these **metamorphic rocks**. By metamorphic we mean *changed* in some way. The main causes of change are pressure and heat - sometimes these forces cause actual mineral changes and therefore a different rock than previously. Some common metamorphic rocks include:

Gneiss - derived from granite.
Schist - derived from shale or basalt. etc.
Slate - derived from shale.
Marble - derived from limestone.
Quartzite - derived from sandstone

Gneiss

Schist

Slate

Marble

Quartzite

When we dig into the soil we often find quite different layering of soil materials in different places. The reasons for this will be discussed at length in Chapter Five.

SECTION FIVE: CLASSIFICATION OF LANDFORM

Macro Landform

The standard way of describing and classifying landform is shown in Fig.9.

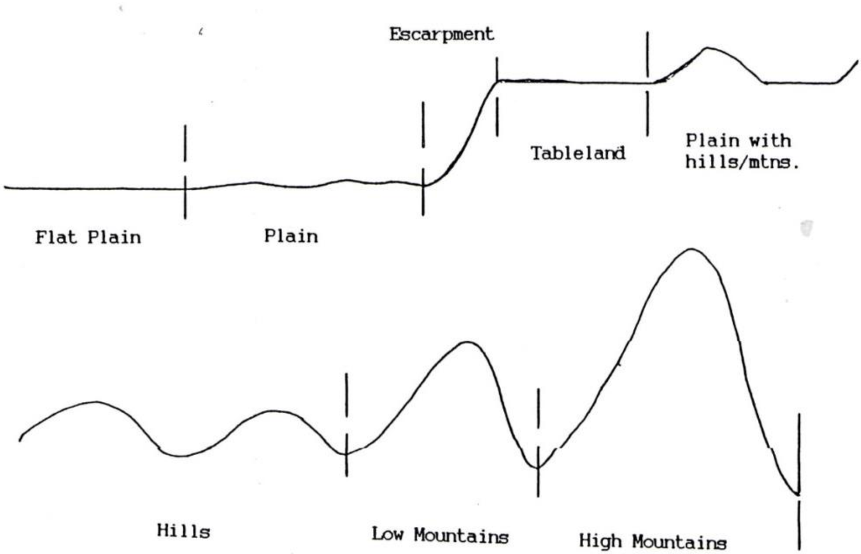


Figure 9: Macro Landform Units

The Macro Units are:

Flat Plain
Plain
Tableland (above the escarpment)
Plain with Hills or Mountains
Hills
Low mountains
High Mountains

Table 1 gives the relative proportions of these macro units found in the different continents.

	Nth Amer.	Sth Amer.	Eurasia	Africa	Oceania	Antarct.	Total
Flat Plain	7	18	2	1	4	0	5
Plain	30	29	30	44	51	0	31
Tableland	6	14	3	5	1	0	5
Pla/Hill/Mtns	9	7	10	22	19	0	11
Hills	15	8	11	11	12	0	10
Low Mtns	9	13	21	13	12	1	14
High Mtns	16	11	23	4	1	1	13
Ice Caps	8	0	0	0	0	98	11

Table 1: Percentages of Macro Land Units in each Continent

These figures give us an idea as to the usefulness of land for agriculture and settlement in different continents. Climate plays a big part as well, but good climate is useless without good land. Study the figures in the Table closely. Which continents do you think might be the best for agricultural purposes? Where might we find the greatest populations of people?

Local Landform

Facets: In classifying land at a local level we try to divide the landscape into units which show a high degree of uniformity on the basis of their landform. A good term for these units is **facets**.

Example 1: Classification of a Flat Plain

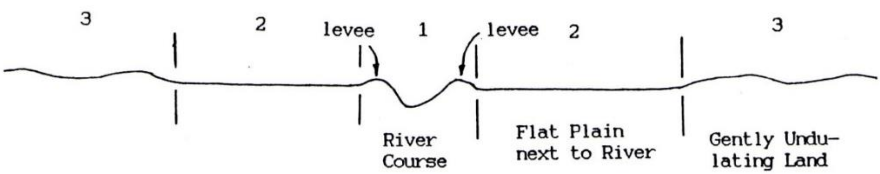


Figure 10: Cross Section of a Flat Plain showing Facets

Some facets we might find in a flat plain area are shown in Fig.10. Some reasons for identifying these facets might be that:

- Facet 1: River courses are unsuitable for agriculture but could be a good water supply.
- Facet 2: Flat Land near the River is a good area for flood irrigation
- Facet 3: Gently Undulating Land is good for agriculture but will need sprinklers for irrigation.

Example 2: Classifying Hilly Land

In an area of hilly land, we might have facets as shown in Fig.11.

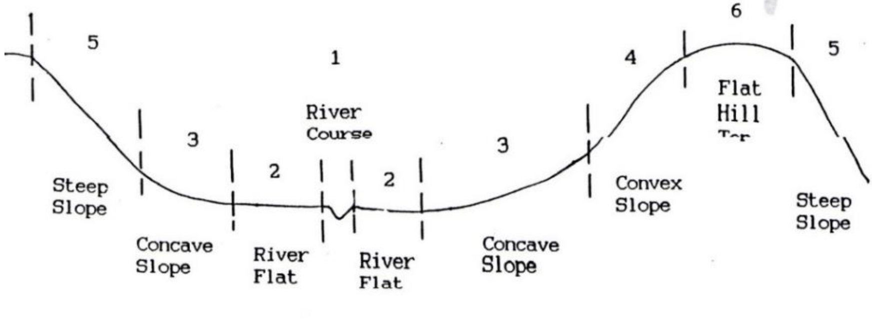


Figure 11: Facets in Hilly Land

The potential land use for these facets might be as follows:

1	Water Supply
2	Irrigation Land
3	Cropping Land/Spray Irrigation
4	Pasture/Grazing Land (too steep for cultivation)
5	Forest Land
6	Pasture/Forest/Housing

Exercise: Identify the facets in three local landscapes. Draw a cross sectional diagram to represent them, lable the facets. Discuss possible uses of each land facet.

Land Units

In the examples above we can see that the facets are arranged in a certain pattern. A facet pattern, the type and position of certain facets, may extend beyond a particular piece of land that we are interested in. Where two areas of land show exactly the **same pattern** of land facets we say that they belong to the same **Land Unit**.

Definition: A land Unit is an area or areas of land showing a distinctive pattern of land facets (type and position); as opposed to other areas which show a different pattern of arrangement and type of facets.

Land Mapping

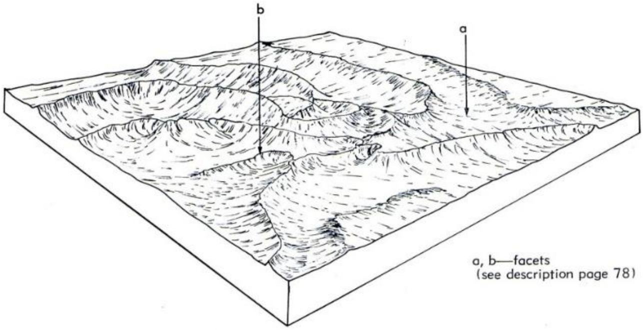
The mapping of Landform Units is a useful way of telling land users what type of land is present in various areas.

The amount of detail we can present on a map depends on the scale of the map (see Chapter Two).

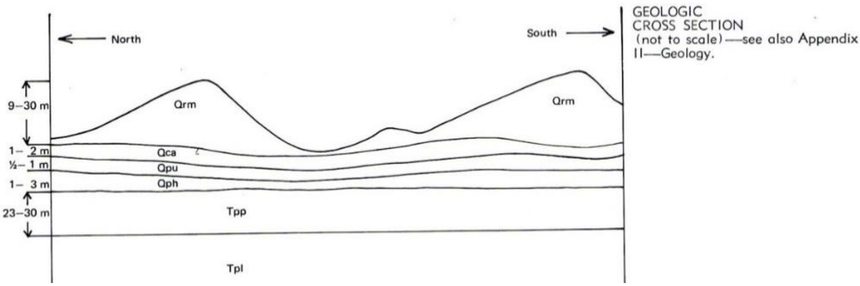
In the following list we can see the most appropriate mapping units for various map scales.

Scale	Land Mapping Units
1:2 500/10 000	Land Facets
1:50 000/100 000	Land Units
1:250 000/1 000 000	Contour lines, Colour Code for Relief

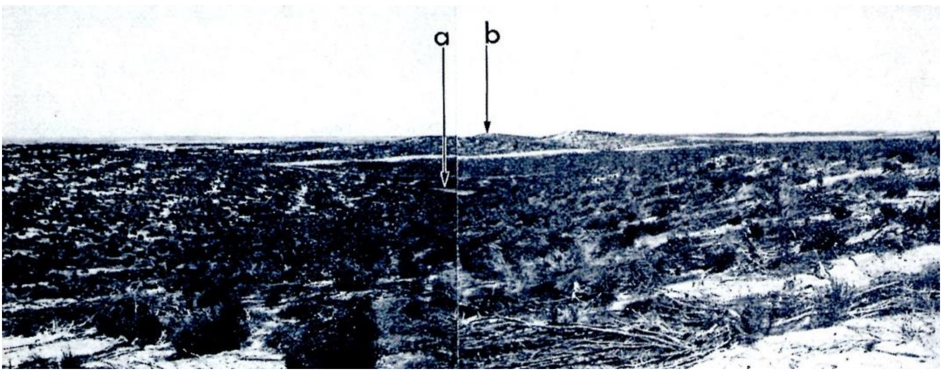
When we map Land Units we need to supply a description of the facets in each Land Unit. This can be done in various ways: Block Diagrams, Cross Sections, etc., together with word descriptions of each facet.



A Block Diagram



A Cross Section



A Photograph

CHAPTER FIVE

SOIL

INTRODUCTION

Soil is one of Planet Earth‘s most valuable assets. Most plants need soil to grow in and all animals and man are dependents on plants in one way or another.

Soil is not ‘dirt' as some people call it. It is a complex living thing. The main components of soil are:

- Soil Particles (small fragments of rock)
- Organic Matter (the remains of dead plants and animals)
- Living organisms (bacteria, fungi, worms, insects, and even small mammals).

- Soil Water (water stored in the soil)

All of these things interact to make soil a valuable medium for plants to grow in. In this Chapter we will look at how these components of soil interact. We will also see how soil can be described and classified.

Further, we will see that soil is a LIMITED RESOURCE; if it is allowed to wash or blow away it cannot be replaced. Soil Conservation is vital if we are going to continue to meet the needs of the Earth's growing population.

SECTION 1: SOIL PROFILES

In Chapter Four we saw that soil is the friable material that overlays the landscape. We believe that it is there through the action of weathering agents and the transportation of materials by water, wind and glacial action; in particular, by the action of the Flood.

As a rule, soil on the tops and higher slopes of mountains tends to be shallow; that on the lower slopes moderately deep and that in valleys deep to very deep.

In order to inspect the depth and type of soil at any particular place we need to dig a hole or find a road cutting where the soil layer is exposed. When we look at soil this way we say that we are examining the SOIL PROFILE.

Soil Profiles vary a lot. Things to look for include:

- Depth of soil (i.e. depth to underlying rock or free water)
- Different kinds of layers
- Colour
- Texture
- Structure
- Acidity
- The presence or absence of lime

To describe soil, we need a SOIL DESCRIPTION KIT containing:

- A Measuring Tape
- A Pocket Knife
- Sample Bags and labels
- Water Bottle for texturing
- A pH kit for measuring acidity
- Dilute hydrochloric acid for detecting lime

Soil Description

If possible, the profile should be dug until rock or free (ground) water is found. With rock, the boundary may not always be sharp; there may be a layer of rock fragments just above the rock body.

Before attempting to describe the profile, it is important to locate the profile (preferably on a map) and to describe the SITE in some detail.

Things to note here are: Land Unit and Facet
Position of profile in facet
Vegetative cover/presence of rock
Land Use being practiced

Horizons

When describing a profile, the first thing to do is to identify the different layers or HORIZONS present. Sometimes the horizon boundaries are abrupt and clear; at other times the boundaries are vague - the horizons grading into one another.

Defining horizons requires experience but it is very much up to the person to make the decisions about horizon boundaries that they think best.

Profiles have various numbers of **horizons**. These are defined by letters as follows:

A Horizon: This is the TOPSOIL (the top layer). It is a very valuable part of the soil as it contains most of the PLANT FOOD. It is often darker in colour than the underlying material due to the presence or organic matter, but this is not always the case. Sometimes the topsoil has two distinct layers; one with a dark staining due to organic matter and the other having the same sort of soil particles without the staining. In that case we describe them separately as A1 and A2 horizons.

B Horizon: This is the SUBSOIL. If present, it is usually darker in colour and more clayey (see below) than the topsoil. Sometimes it has lime in it - fine lime or fragments of limestone. Sometimes the B horizon has distinct layers: Bl. B2 and even B3 horizons.

C Horizon: This term usually refers to the underlying rocky material.

Three Soil Profiles showing horizons

Parent Material

Some soil material is formed directly from the rock beneath it. In this case we call the C Horizon PARENT MATERIAL.

Such soils are normally only found on mountain slopes and hill tops; the soil on lower slopes and valleys are mainly formed from transported material.

Buried Soil

Sometimes a profile shows that one or more well developed soil profiles have been buried under transported material, brought down either by landslide, flood or perhaps volcanic ash.

The soil on river plains often shows many layers of silt dropped by the river over many years.

We need to think about transportation processes quite a lot when we are thinking about the possible origin of soil material.

Exercise: Examine three (3) soil profiles in the field. Identify and describe each horizon and take some samples from each horizon. If possible, examine profiles in varied situations; e.g. a hilltop profile, one on a slope and another in a valley.

Make models of each profile that you have examined, as follows:

- Sieve the soil taken from the horizons observed in the field; remove all litter and stones. NB Do not discard the stones.
- Cut some strips of cardboard 300mm x 75mm.
- The depth of soil on the strip should be related to the actual depth of soil in the field; use a scale of about 1:5.
- From your field information and using the same scale, calculate the depths required for the various horizons on the strip to be in the same proportions as in the field, i.e. make a scale model of the soil profile at scale 1:5. Mark the various depths on the strip in pencil.

- Paint the strips with wood glue and sprinkle soil on to the wet glue, making sure that the sieved soil from each horizon is in the same order as found in the field.

- If an horizon contains a lot of gravel in the field, stick a few small stones from the sieved material on to the strip.

Models of soil profiles

SECTION TWO: SOIL DESCRIPTION

Soil Texture

By texture we mean the relative fineness or coarseness of the soil particles.

There are five standard classes of soil particles found in soil:

- Gravel — > 2mm diameter
- Coarse Sand — 0.2mm – 2.0mm diameter
- Fine Sand — 0.02mm-0.2mm diameter
- Silt — 0.002mm-0.02mm diameter
- Clay — < than 0.002mm diameter

Coarse Sand and Fine Sand tend to be mainly quartz (silica) crystals. Silt particles are mainly derived from slates and shales.

Clay particles are COLLOIDAL PARTICLES - those which are too light to settle out in water. When we examine them under a microscope we find that clay particles are actually very special minerals (CLAY MINERAIS). They are important in binding the soil together and in storing water in the soil.

These particle size classes are found in many varied proportions. We can find the exact proportions by MECHANICAL ANALYSIS in the laboratory, but a good idea can be obtained by HAND TEXTURING.

Hand Texturing is done by moistening some soil in your hand and, after moulding it for a while, rubbing it between your thumb and fore finger.

- A soil which feels coarse to touch and falls apart when moulded will have a lot of sand in it. We call this a SANDY SOIL.

- A soil which feels smooth and can be moulded when moist, but which will not ribbon out between the fingers probably has a fairly even mixture of particle sizes - we call this type of soil LOAM or LOAMY SOIL.

- A soil which is sticky and plastic and which ribbons out between the fingers will contain a lot of clay and we call it a CLAY SOIL.

Hand Texturing

There are various categories between these three main groups. Some groups, together with their clay content are given below:

Soil Type	Clay Content
Sandy Soil	0 to 9%
Sandy Loam Soil	8 to 21%
Loamy Soil	10 to 26%
Clay Loam Soil	21 to 40$
Clay	> 31%

We can add other groups, e.g. Loamy Sands, Silty Loams, Silty Clay Loans, etc. Identifying these mixtures of soil particles comes with experience.

Exercise: Practice texturing on some samples collected in Section 1.

Soil Structure

We seldom find soil particles in the field existing as single grains – except on beaches and on sand dunes. Usually they are found bound together into small aggregates, clods or crumbs.

The type of aggregates we find is referred to as the SOIL STRUCI‘URE. The structure varies from place to place and from horizon to horizon.

Surface (A) Horizon Structure

There are four types of structure commonly found in surface horizons:

- Single Grain Structure: beach sand, etc.
- Granular or Crumb Structure: when the soil dries out the soil crumbles into aggregates about 5 to 10mm diameter.
- Platy Structure: becomes flaky as it dries.
- Massive: this is really ‘structureless’; when the soil dries it sets hard. The surface may be so sealed that rainwater cannot get into the soil.

Single Grain

Crumb


Platy Massive

Subsoil (B) Horizons

Clay loam and clay subsoils tends to show three distinct types of structure which are quite different from the surface horizons.

- Columnar Structure: when the soil dries it shrinks forming vertical pillars. These columns may have hard caps or domes.

- Prismatic Structure: cracks into elongated prisms with straight sides and edges.

- Blocky Structure has prisms of equal length and breadth.



Columnar Prismatic Blocky

Soil Colour

Soil colour comes from two main sources:

- Soil Organic Matter: This tends to produce brown to black colouration in the soil. It is mostly found in the A1 Horizon. The exception is peat soil which is found in bogs in Europe and other places. Peat is 100% organic material; it may be half a metre thick or more.

- Mineral Colourations: All rock materials have some colour due to the minerals in them. The particles formed from the various rocks give their colour to the soil. Colouration due to IRON and LIME tend to dominate. Particle coated with iron tend to be RED in dry conditions, YELLOW in average moisture conditions and GREY to BLUE GREY in waterlogged conditions.

  Lime and Gypsum (Calcium Sulphate) tends to make soil pale in colour, even white in some cases.

Two profiles showing different soil colour

Soil Colour is usually measured against a standard colour chart called the Munsell Soil Colour Chart. This is necessary as a standard as everybody has their own ideas about colour. If you can obtain a Munsell Chart, try matching a few soil samples against the chips in the book.

Checking the colour of soil using a Munsell Colour Chart

Leaching

As water moves through the profile it collects soluble salts and even some clay particles. The movement of soil components in this way is called LEACHING.

Under very wet conditions leaching can produce different horizons. The movement of water down the soil profile may have an influence on soil colour also. Many sandy soils have a blackish A1 horizon (organic layer) but a pale washed out A2 horizon (leached layer). The products of leaching may be found in the B Horizon or may have been completely washed out of the profile in some cases.

Soil Acidity

Soil varies considerably in its acidity. This is important because various plants have different acidity preferences and tolerances.

The standard measure of acidity and alkalinity is the pH scale. This refers to the Negative Logarithm of the Hydrogen Ion Concentration in a solution. In the case of soil, we normally measure the pH of the solution formed by shaking one part by volume of soil with five parts by volume of water for a set time.

A pH Kit

The pH scale starts at 1 and finishes at 14.

- pH 1 is strongly acid
- pH 7 is neutral
- pH 14 is strongly alkaline.

Most soil is in the range pH 5.0 top 8.4. Soil with a pH of less than pH 5 is far too acid for most plants. Soil with a pH greater than 9 tends to be 'salty', too salty for most plants.

The reason for measuring pH is to see which plants might grow in it. There are plants which prefer slightly acid soil (pH 5.0-6.5). Other plants prefer slightly alkaline conditions (pH 7.0 to 8.4).

Soluble Salts

Most soil contains some soluble salts. The main salt found in soil by far is common salt (sodium chloride), the same salt that we use in cooking and on our food at the table.

Salt gets into the soil in different ways. Some rocks are naturally high in salts so the soil derived from these rocks may also have salt in it. Transported soil formed from salty rocks is unlikely to be salty because the water that transports the soil particles will dissolve the salt and carry it away in the rivers.

Ocean spray is a major source of salt in the soil. When salt spray over the ocean is picked up by an offshore wind it can be blow some miles inland. As the wind meets vegetation it drops its load of salt and this finds its way into the soil. All coastal soil tends to be high in salt for this reason.

Another important way in which salt gets into the soil is through irrigation water. River water and underground water used for irrigation always has some soluble salt in it. When this is added to the soil the salt in the water tends to accumulate over time. Saltiness in irrigation areas is a major problem worldwide.


Salt affected irrigation area

The presence of soluble salt in soil is not helpful to plant growth. It has a bad effect on plant water uptake.

Lime is a salt (calcium carbonate) and this can occur in the soil in large quantities. However, lime is only very slightly soluble and does not effect, the plant water uptake in the same way as sodium chloride. The presence of lime has another effect; it affects the soil pH and the uptake of some plant foods (nutrients).

Measurement of Soil Salt Concentration

Soluble Salts are measured by shaking the soil in distilled water and then measuring the amount of electrical resistance when a current is passed through a sample of the solution.

The presence of lime is detected by adding a drop of hydrochloric acid to the soil.

Soil Density

The weight per unit volume of soil in its natural state we call the BULK DENSITY. We calculate it by weighing a known volume of soil taken from the field with a core sampler. The sample will contain air and organic material (roots etc.) as well as soil particles

NB: We always dry the soil sample in an oven before weighing as soil moisture content can vary a lot - depending on when we take the sample. Water has a high specific gravity and can affect the result quite a lot.

Contrary to what you would think, the bulk density of sandy soil is usually higher than clay soil. This is because clay soil tends to be well structured and have a lot of space and air between the soil aggregates.

Common values of density for soil are:

Sandy Soil:	1.6g/cc
Clay Soil	1.1g/cc

SECTION 3: SOIL ORGANIC MATTER

It is important to have some understanding of the interaction of plant roots, living soil animals and their remains and soil particles if we are aiming to grow crops and garden plants. For now, we shall just try to get some idea of what we can expect to find in the soil by way of organic material - dead or alive.

Organic matter in soil can be divided into two main categories

- Living Material: plant roots, plant microorganisms (bacteria, fungi, etc.), soil animals (microbes. insects. earth worm and mammals)

- Dead Material: the remains of plants and animals in varying stages of decomposition.

Humus

As soon as living plants or animals in the soil die, a process of decomposition begins. The end result of this decomposition is a dark brown to black substance called HUMUS. This is an important component of soil. It is important in helping the soil to hold water for plant use and in storing some plant foods.

Soils vary a great deal in the amount of humus they contain:

- Peat Soil: the soil in bogs or marshes may contain almost 100% humus – i.e. no soil particles at all. Peat can be dug up and used for fuel in fires!

- Organic Soil: Soil which is black or dark brown will often contain high amounts of organic matter and humus in particular.

- Sandy Soil: Sandy soil usually has a low level of humus.

Peat soil

The amount of organic matter (humus) is also affected by land use. Forest soil has a higher level of humus than the same soil under cultivation. Cultivation opens up the soil to the air and increases the breakdown of organic matter.

Land under pasture will have higher humus levels than the same soil cultivated for crops. Even the type of crop grown will affect the amount of organic matter - see table below.

Organic matter contains high amounts of the elements carbon and nitrogen. Because of this, the amount of organic matter in a soil sample can be estimated in the laboratory by measuring its carbon and nitrogen content by chemical analysis.

In England, samples have been taken for over 100 years from a field in which some of the soil has been kept under permanent pasture and other parts have been cropped in various ways. The amount of organic matter in the soil varies a lot, depending on the land usage:

Land Use	Carbon*	Nitrogen*
Continuous pasture since1894	22.9	2.4
30 years continuous cropping with maize	8.3	0.9
30 years continuous cropping with wheat	14.3	1.5
Five course rotation (maize, oats, wheat, clover, grass)	17.4	1.7
Three course rotation (maize, wheat, clover)	19.2	2.0

*tonnes per hectare17cm deep

The volume of soil 1 hectare by 17cm deep is: 1 700m^3.

The weight of 1 700m^3 of soil is:

Sand (specific gravity 1.6g/cm^3)	2720 tonnes
Clay (specific gravity 1.1g/cm^3)	1870 tomes

The initial carbon and nitrogen in the soil in the table above was 22.9 tonnes and 2.4 tonnes respectively, or:

0.8% and 0.08% if the soil was sand.
1.2% and 0.13% if the soil was clay.

Note that the ratio of Carbon to Nitrogen (the C:N ratio) in the various samples in the table above are:

Sample	C/N Ratio
Original Soil	9.5
Continuous Maize	8.8
Continuous Wheat	9.5
5-year rotation	10.0
3-year rotation	9.6

The bacteria which break down organic matter to humus prefer carbon and nitrogen in a maximum ratio of 10:1. Soil which has a ratio less than 10:1 tends to be 'fertile' because the bacteria can quickly break down the organic matter to release nitrogen, one of the essential elements for plant growth. Organic matter which has a ratio of more than 10:1 tends to be only slowly decomposed by bacteria and consequently, nitrogen supply can be limited and plant growth slow in such soil.

Organic matter and the Soil Profile

Most of the organic matter in a soil is found in the top 10cm. This is a strong reason why soil erosion should be avoided if at all possible. If we lose the top few centimetres of soil we are losing the most valuable part of the soil as far as plants are concerned.

The Importance of Organic Matter

Organic Matter is the main source of the essential plant food NITROGEN. If the soil organic matter is low then the supply of this element to plants may restrict growth, sometimes badly. Plants look yellow and stunted when nitrogen is low.


Nitrogen deficiency

Humus acts like clay in helping water storage in the soil. It also has a wonderful effect on soil structure, helping to keep it friable well aerated and permeable to water leading to good root development. This effect is a direct one in that humus binds together the soil particles into aggregates. There is also an indirect effect in that high organic matter leads to the presence and activity of helpful animal life, e.g. earth worms. These in turn help to keep the soil open and fertile. Thus, the presence of organic matter is very advantageous to plant growth in that it influences several of the most important factors affecting plant growth - root development, nitrogen supply and water availability.

A further factor to consider is that the bacteria and fungi which thrive in the soil when there is a good supply of organic matter with a low ratio of C:N are not harmful to plants. When organic matter is low the numbers of these helpful microorganisms tends to be low, and other, harmful disease-causing bacteria, fungi and microscopic worms (nematodes) tend to increase. A high level of organic matter not only has a direct effect on the plant; it also ensures that the soil is kept free of disease-causing organisms.

Adding Organic Matter to the Soil

Making sure that the amount of organic matter is kept at a high level is a main job in keeping soil fertile. If the soil organic matter is low we can add organic manures such as:

- Compost: Compost is organic matter which has been decomposed before it is added to the soil. Good compost is dark brown because it is mainly humus. It is an excellent material to add to the soil but, because the quantities produced are small, it is a technique which is mainly applicable to home gardens and nurseries.

- Farmyard Manure: Animal manure is an excellent material to add to the soil, but there are problems with using this material. Firstly, if it is too fresh it may burn growing plants; make sure you do not add too much, too quickly or put it close to plant stems. Secondly, there is not enough of it for broad acre farming. Grazing animals add considerable quantities of manure to the soil and are a useful addition to the farm program in many situations.

- Green Manuring: Clover and peas are high in nitrogen and ploughing them into the soil just prior to planting a crop like maize or wheat is helpful This technique is especially suited to land which is under horticultural crops like fruit trees and vines

- Pasture: The level of organic matter in a soil under pasture tends to increase until equilibrium is reached between addition and break down. Growing pasture in a rotation is a main way in which farmers maintain organic matter levels.

- Cereal Stubble: The stubble from maize or wheat crops is often ploughed into the soil. We need to be careful doing this as the ratio of C:N in stubble is usually higher than 10:1. If we plough stubble into the soil just before we plant next crop the bacteria will tie up the soil nitrogen until such time that they have broken down the stubble. This can severely stunt the new crop. On the other hand, stubble turned into the soil well before the next crop can add large amounts of useful organic matter to the soil.

- Fertilizer: In some soil the amount of some plant foods is naturally in short supply. The addition of fertiliser which adds the required quantities of these elements not only improves the growth of the current crop but can also add appreciable quantities of organic matter to the soil.

Soil Animals

Our discussion on organic matter in soil would not be complete without a few words on soil animal life.

In addition to one-celled-animals (like protozoa) there are many other forms of life found frequently in soil; some in large numbers. These all play a part in the organic matter breakdown process. As a general rule: the greater the organic matter content, the greater the numbers of useful animals in the soil and the greater the general health and fertility of the soil. To give you an idea of the numbers of animals existing in a normal field see the following table:

Numbers of small animals found in a soil in the United Kingdom - showing a comparison of the same soil cultivated (with and without farmyard manure) and under pasture [Figures given in **millions/hectare in the top 20cm of soil**].

Animal	Cultivated Soil	Pasture-Land	Manure	No Manure
Insects	Springtails	100.3	69.9	133.7
	Beetle larvae	14.6	2.2	5.7
	Fly larvae	47.9	9.4	27.4
	Others	8.4	1.2	27.2

Animal	Cultivated Soil	Pasture-Land	Manure	No Manure
Millipedes		11.1	4.4	4.4
Arachnids	Mites	16.1	4.7	7.2
	Spiders	0.4	0.2	3.0
	Wood lice	0.1	0.1	-
Slugs and Snails		0.1	-	0.1
Oligochaetes		8.4	1.5	20.0
Nematodes		3.7	0.5	18.7

spring tail

beetle larvae

soil spider

These numbers are surprising. Imagine nearly 50 million fly maggots per hectare and nearly 15 million beetle larvae; also 400 000 spiders and 16 million mites. Not forgetting the 100 million springtails.

Soil is a living thing! And if we wish to use it to advantage we need to keep it that way. The main way of keeping the soil fauna active is to maintain the organic matter supply, as discussed above.

Summary

From the brief introduction to soil organic matter above, we can see that the management of soil organic matter is a matter of major concern in the growing of all agricultural and related crops.

SECTION 4: WATER AND AIR IN THE SOIL

In Chapter Three, we looked briefly at the Hydrological Cycle. Looking back to Fig. 19 in that module we see that part of the precipitation falls on the land. This water either runs off on the surface into streams or sinks into the soil. In this section we want to look at this part of the hydro- logical cycle more closely.

Infiltration and Run Off

While the surface of the land looks solid and feels solid to walk on in fact there is a lot of air space in soil due to the fact that the particles do not fit exactly together. These inter-particle spaces tend to inter-connect, forming channels or PORES through the soil mass.

The number and size of soil pores varies depending on the texture and structure. Soil made up mainly of sand particles has a lot of spaces and rather large pores. Clay and silt soils have finer pores but when well-structured can have a lot of large pores as well.

The amount of water that can INFILTRATE into the soil depends on three things:

- The number and size of pores in the surface of the soil: water goes easily into sand, more slowly into dense, poorly structured clay We say that sandy soil and well-structured clay soil is PERMEABLE while poorly structured clay soil often exhibits Low PERMEABILITY or even become IMPERMEABLE.

- The pores in the lower layers: while the surface layer is the most important when it first starts to rain, as the rain continues water must be able to move into lower layers if more water is to enter the surface. If there is a restricting layer of rock or dense clay, water may be unable to enter the surface because the soil mass is saturated.

- The capacity of the soil to store water is also important in infiltration. The more water that can be stored, the more can enter. Storage capacity is especially important if the soil is shallow.

As soon as water is unable to enter the soil it begins to run-off. If the soil is bare this can cause transportation of soil particles - especially once the raindrops have done their work of disturbing the soil particles.

Further down the slope, run off water can do further damage - both through flooding and through gully erosion. The Grand Canyon was formed through the erosive action of concentrated run-off water – run-off is a powerful force and takes a lot of stopping.

While some run-off is inevitable, as far as possible we need to ensure that the soil surface is not left in a condition which will aid run-off. Keeping some cover of grass, trees or other vegetation is the best way to keep run-off water to a minimum. Another way is to construct banks on the contour. These have the duel effect of stopping run-off and leading it to a safe disposal area and causing all cultivation to be on the contour rather than down the slopes. This practice is part of SOIL CONSERVATION, i.e. practices which keep run-off to a minimum and prevent loss of valuable topsoil.

Contour banks: The bank in the foreground shows the structure of a bank; the banks in the background show how the banks are placed at regular intervals down the slops

There is another reason why we wish to prevent run-off. Less run-off means more water in the soil for use by plants. The more water stored in the soil the better – providing the soil does not become waterlogged; plant roots need air as well as water. Temporary water logging, such as occurs during a rainstorm will not do any permanent harm to plants. Prolonged and sustained water-logged conditions in the soil will severely restrict root growth and this is likely to affect plant health.

We have mentioned a lot of ideas in a few sentences. Let's draw a diagram to summarize the processes in the soil section of the hydrological cycle. In Fig 1 (next page) we see that some of the precipitation infiltrates into the soil while some may run-off, especially if rain is heavy for some time. Water which enters the soil PERCOLATES through the soil where some is stored, and some continues to percolate until it reaches an impermeable layer.

If the impermeable layer is sloping and the soil above it is porous, the water may continue to drain until it reaches a river basin. Sometimes the drainage water finds its way down to an impermeable layer and forms a pool of GROUND WATER.

Ground water may be shallow or very deep. Shallow ground wafer may be a nuisance, causing the soil above it to be permanently wet or even waterlogged. This will be deleterious to plants. Deep ground water can be very useful, especially as a supply of clean water for human and irrigation use. Bore holes and wells are examples of ways in which we humans tap into ground water supplies for various uses.

Some ground water is ARTESIAN, i.e. when a bore hole is drilled, the water rises to the surface and flows out without pumping. This is because it is under pressure. An example of how this may occur is shown in Fig. 2.

Soil Moisture

Now we have a picture of the way water moves into and through the soil the

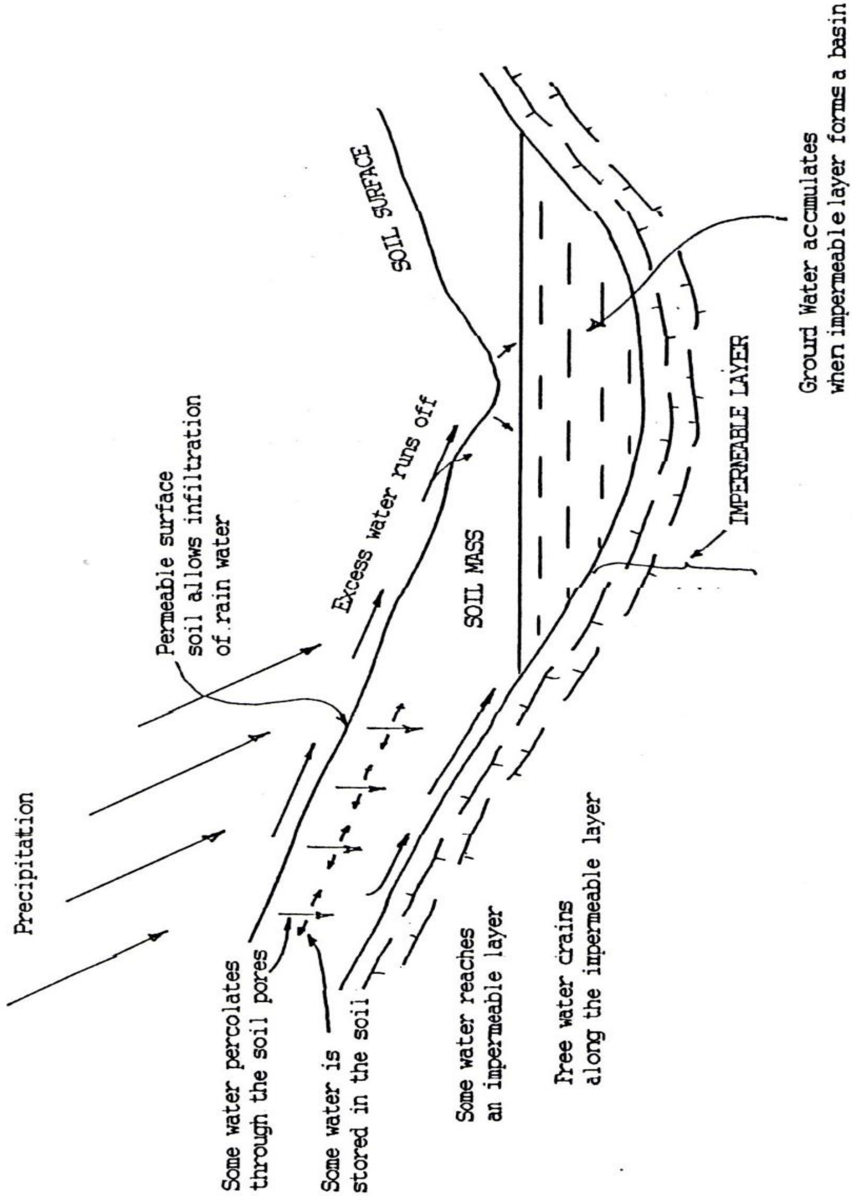


Figure 1: Soil Moisture Processes

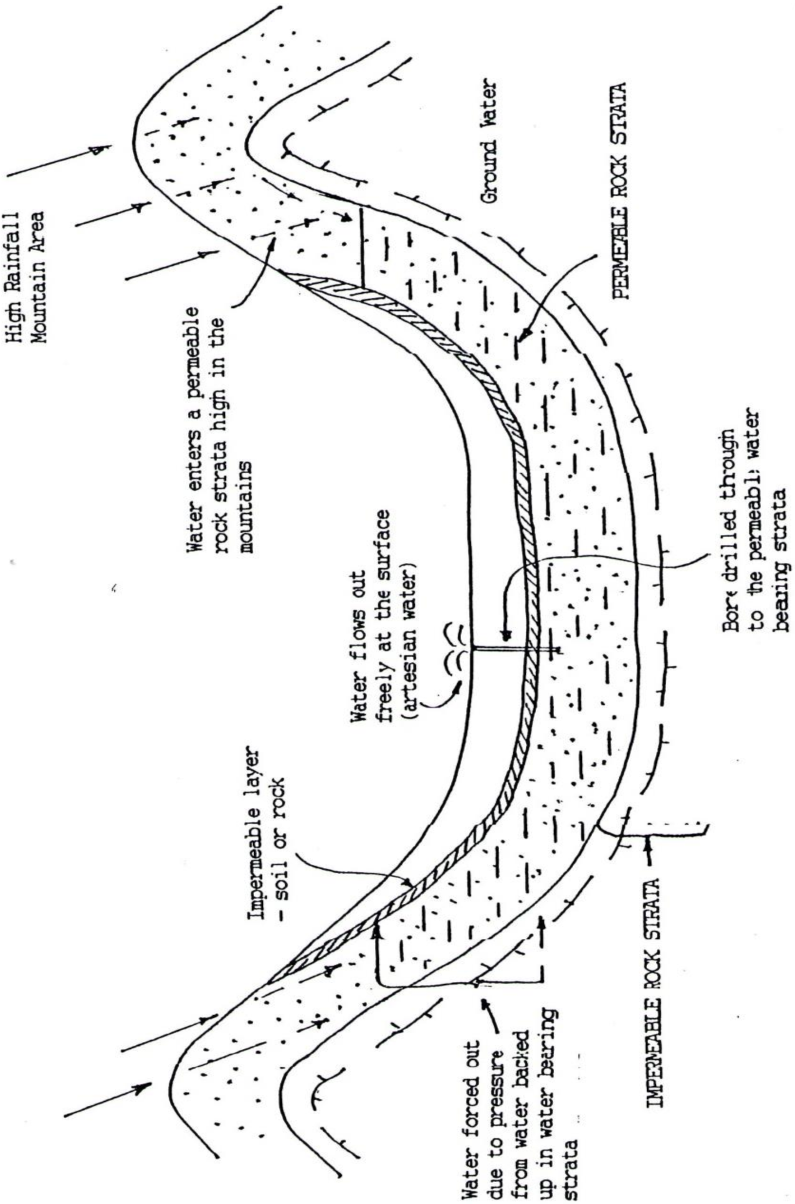


Figure 2: Example of an Artesian Bore

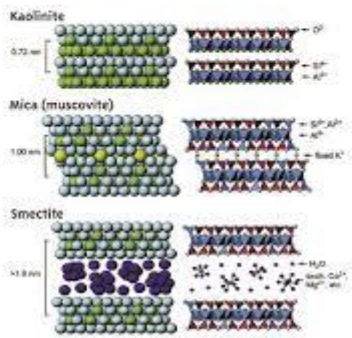
next step is to look more closely at the way in which water is stored in the soil.

To understand this, we must first take a look at water in tubes. When we suck up water into a range of glass or plastic tubes of different diameters we can see an interesting effect. Water will drain out of larger tubes but be retained by smaller tubes. In physical terms, when the surface tension between the water and the inside surface of the tube is greater than the weight of water in the tube the water will not drain. Alternatively, when the weight of water is greater than the surface tension, the water will drain freely. In most soil we have both kinds of pores - those which will drain freely (providing there is not a restrictive layer underneath) and those which will tend to retain water against the force of gravity.

When water enters the soil, it tends to move downwards through the larger pore spaces and cracks. But from here it quickly moves into smaller pores and even into the soil aggregates themselves. When it comes to the individual soil particles it either forms a film around individual soil particles (in the case of sand and silt particles) or is bound chemically to the particle (in the case of clay and humus particles).

Clay particles are not simply rock fragments; they are specific minerals which consist of tiny platelets loosely tied together. When water comes near them the plates separate and water is bound chemically in the inter-plate spaces. This is the reason that clay swells when wet.

Clay



Clay platelets with water in between

Humus behaves in a similar way to clay. A soil with a lot of humus can hold a lot of water. Soil with mainly sand and silt particles, on the other hand, is unable to store anywhere near as much water as soil high in clay or humus. Sand and silt particles are mainly solid rock fragments and can only store water as a film around the particles.

Summarising

- Soil high in clay and/or humus tends to store a lot of water.
- Soil consisting mainly of sand and silt particles stores only a small amount of water.

This is important to remember when working out how often to water the soil for plant growth. While rain is in progress, the soil pores, large and small, will tend to be full of water. As the rain stops and the soil continues to drain, the larger pores will eventually empty out, providing that there is no restrictive layer preventing the excess water from draining away.

Even though the large pores have no free water, they will still contain a lot of water vapour. This can be quite important to plants as it is easy for them to extract it from the soil.

If there is a restrictive layer preventing drainage, and the large pores are not able to drain, we say that the soil is saturated and contains free water. This is not a good soil condition for plant growth; except in the case of some especially adapted water tolerant plants, e.g. swamp species, mangroves, etc.

We can summarize the storage of water in soil as follows:

- Some will be bound chemically to clay and humus particles.
- Some will form a film around silt and sand particles.
- Some will exist as water vapour between the soil particles.

- When the soil is wet, e.g. immediately after a rain, many of the soil pores will hold water against gravity (drainage).

- When the soil is very wet - either during rain or because of a restrictive sub-surface layer - the large pores, cracks and burrows of insects, worms and soil mammals will also contain free water.

The ideal soil is one which has the ability to store large amounts of water against gravity but drains freely soon after rain ceases and tends to contain no free water in the large pores. To give you an idea of the amounts of water that can be held by soil that is free draining, look at the table below:

Coarse Sand	16mm
Fine Sand	33mm
Sandy Loam	43mm
Loam	76mm
Clay Loam	91mm
Clay	127mm

Maximum amount of water stored in the top 30cm of free draining soil of different texture after drainage has stopped:

NB Not all of the water stored in the soil is available to plants. Texture again plays a part; sandy soil gives up its water more easily than clay soil. Sandy soil needs to be watered little and often. Clay soils can be watered less frequently.

Soil depth is important for water storage. A sandy soil which is deep may be a good soil to grow things in, while a clay soil can be good for growth even though it is shallow.

Evaporation of Soil Water

Water can be lost from the soil by evaporation from the surface. This is influenced both by heat and wind. The relative humidity in the air also affects evaporation.

One way of preventing loss of water through evaporation is by MULCHING, i.e. laying lawn clippings, almond shells, bark chips or black plastic sheets on the ground surface. Wet soil with no mulch may lose as much as 10mm of water in a few days whereas a mulched soil may take up to six weeks to lose the same amount of water. Mulching also helps to keep the soil receptive to water intake by preventing raindrop splash.

The main problem with mulch is to get enough of it. In broad acre farming we have to reply on cultivation methods which leave as much grassy top cover as possible. Cereal stubble makes good mulch and there are machines that chop up stubble and leave it on the surface.

Wheat stubble

Maize stubble being used as mulch for the next crop

Soil Air

Plant roots need air and so do most of the useful bacteria, fungi and animal life found in the soil.

The amount of air available in the soil depends a lot on the moisture conditions prevailing. If the soil is saturated there will be a lack of air; if the soil is dry, there will be plenty of air, but growth may be restricted by a lack of water.

Ideally the soil needs to supply both water and air at the same time. A free draining soil with high water storage potential and numerous large pores is the ideal.