

THE UNIVERSITY OF
NEW SOUTH WALES



SCHOOL OF BIOLOGICAL, EARTH
AND ENVIRONMENTAL SCIENCES

GEOS1111

Fundamentals of Geology

(6 UOC)



LAB MANUAL

2018

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2 MINERALS IN HAND SPECIMEN

Definition of a Mineral: a naturally occurring inorganic solid which has a definite chemical composition, or a composition that varies between known limits, and an ordered atomic arrangement.

The mineral kingdom is becoming increasingly large as new minerals are being recognised and added to an already large number of minerals. However, the bulk of these need not concern us as the majority of all rocks are made up of only a few minerals. These are generally referred to as the ROCK FORMING MINERALS.

Minerals other than the so-called Rock Forming Minerals are much less abundant, and others that are generally not common may be found in high concentrations in deposits formed by various geological processes. There are some of these that are sought for their economic value. They are referred to as the ECONOMIC MINERALS.

The Rock Forming and Economic Minerals will be studied in the GEOS1111 practicals. Sets of these minerals are located in the drawers around the walls of the 449 laboratory, Biological Sciences Building.

It is essential for students of geology to be able to readily identify the rock forming minerals in hand specimen with no other aid except a hand-lens. To be able to do this there is a requirement to be familiar with a set of properties that all minerals have. We know these as the physical properties of minerals.

It is necessary to learn the physical properties of each mineral which allows it to be identified. In the same way as a doctor identifies an ailment from the symptoms of a patient, a mineral can be identified by determining the physical properties of a mineral that clearly distinguishes it from other similar minerals. The properties that are particular to individual minerals allow them to be distinguished from other minerals and are called the diagnostic properties.

When you are identifying any object it is your tactile responses that first help you to identify it. That is, you examine an object first by sight and secondly, if you are fortunate enough depending on the object you are identifying, by feel. The same applies in the identification of minerals. First, your eyes will tell you a minerals colour, the degree of light reflecting from its surface, the amount of light passing through it, the way the mineral has been broken, and finally the shape that it has. Then on feeling or picking up the mineral it you would immediately sense its texture and notice how heavy it is.

The physical properties of minerals useful in identifying them are described below. They are further discussed in Chernicoff et al.(2002), Chapter 2, p.26-30 or the text Rutley's Elements of Mineralogy by H.H.Read (Allen & Unwin).

Always keep in mind that all properties of a mineral are rarely well developed in every specimen of the mineral.

2.1 COLOUR

Colour is the most obvious property of minerals and it is readily identified. For some minerals, colour is a definite and constant property, and it may be an important diagnostic feature.

However, many minerals exhibit a considerable range of colour, sometimes quite subtle in hue, which normally relates to variations in the chemical composition or to the presence of impurities that cause pigments. For Example:

Varieties of quartz (SiO ₂)	
white or colourless	rock crystal
purple	amethyst
pink	rose quartz
grey	smoky quartz

A few minerals that have a diagnostic colour include:

Sulphur – yellow; malachite – green; azurite – deep blue; pyrite – brassy yellow; galena – silver grey

Even some minerals with constant intrinsic colour may not show this colour on its surfaces. Alteration of the surface due to exposure is often the cause of this. Sometimes the colour of the altered surface aids in identifying minerals but it is the colour of a freshly broken surface that is most revealing.

Due to the many inconsistencies, the colour of a mineral must be treated with caution when using it as a diagnostic property.

Chatoyancy (play of colours), iridescence and opalescence may also be used as diagnostic features.

2.2 STREAK

Streak is the colour of the crushed powder of the mineral which often differs from the colour of the solid mass. With the relatively soft minerals, the streak is determined by scratching it on a rough hard white surface of an unglazed porcelain streak plate and observing the colour of the powder. A streak plate has a hardness of approximately 6.5 so that the streak of minerals harder than this must be obtained by powdering them on harder substances, such as carborundum sand paper.

Streak is useful in many instances because it is often more constant than the colour of the mineral. For example, hematite, which is the common iron ore, varies in colour from red to shiny black yet its streak is diagnostically brick-red.

2.3 LUSTRE

The amount and quality of light that is reflected from the surface of a mineral is called its lustre. There are no sharp divisions between them, but the kinds of lustre distinguished are described in Table 1.

Table 1. Lustre terminology

Lustre	Description
Metallic	This is best compared with the lustre of a metallic substance such as silver, gold, copper, tin, lead, steel, etc. Minerals with metallic lustre are quite opaque.
Sub-metallic	A mineral which lacks the full lustre of the metals
Non-metallic	Adamantine Diamond-like
	Vitreous Glassy
	Sub-vitreous When less well developed
	Resinous Resin-like
	Pearly Pearl-like
	Silky Silk-like
Dull	A mineral that possesses no lustre

2.4 DIAPHANEITY

The relative ability of a mineral to transmit light. The terms of diaphaneity are in Table 2.

Table 2. Diaphaneity terminology

Diaphaneity	Description
Transparent	Capable of transmitting distinct images
Semi-transparent	Images transmitted indistinctly
Translucent	Transmits light but not images
Sub-translucent	Transmits light only at thin edges
Opaque	No light transmitted

Note: many apparently opaque minerals become translucent when cut into very thin sections.

2.5 HARDNESS

The resistance offered by a smooth surface of a mineral to scratching or abrasion is its hardness and it is dependent on the crystal structure. The stronger the binding forces between the atoms, the harder is the mineral.

The degree of hardness is usually determined by observing the comparative ease or difficulty with which one mineral is scratched by another, or by any other implement whose relative hardness has been previously determined.

Harder substances will scratch softer ones while the softer substance leaves a streak on the harder one.

Ten common minerals are arranged in order of increasing hardness to comprise the Mohs' Scale of Hardness (Table 3). By comparison with these standard minerals, the relative hardness of any mineral can be determined.

Table 3. Mohs' Scale of Hardness and hardness of common objects

Hardness	Mineral	Common objects
1	Talc	
2	Gypsum	
		Finger nail (2.0 to 2.5)
3	Calcite	
		Silver coin (3.0 to 3.5)
4	Fluorite	
		Iron nail (4.5)
5	Apatite	
		Knife blade (5.5 to 6.0)
6	Orthoclase	
		Steel file (6.5 to 7.0)
7	Quartz	
8	Topaz	
9	Corundum	Corundum paper (9.0)
		Carborundum (9.5)
10	Diamond	

To determine the relative hardness of any mineral, it is necessary to find which of the minerals of this scale it can and which it cannot scratch.

Satisfactory estimates can be made for most minerals, in the absence of a set of standard minerals, by using the known hardness of common materials (Table 3). It is essential that students compile such a hardness kit for laboratories and practical tests. For example, if a mineral is scratched by a knife blade but not with a silver coin, it has a hardness between 3.0 and 6.0.

In making hardness determinations, the following should be observed:

- Sometimes a softer mineral will leave a streak on a harder one which may be mistaken for a scratch. It can be rubbed off.
- Alteration of the surface of a mineral to a softer material necessitates the use of fresh surface.
- A granular mineral may lose grains when scratched by a softer substance in a fashion resembling a scratch. It is always advisable to make confirmatory mutual scratch tests with the two minerals in question.
- It is advisable to test a mineral with only one short scratch to minimize the disfigurement of a potentially valuable specimen.

2.6 SPECIFIC GRAVITY (DENSITY)

Specific Gravity (S.G.) and relative Density (D) are used synonymously. It is a number that expresses the relative mass of a mineral to that of the weight of an equal volume of water.

Specific gravity determination requires pure specimens and is a fairly tedious analytical procedure, only approximate relative estimates can be made of hand specimens. Minerals can be classed, by mental comparison with known standards, according to the data in Table 4 and Table 5.

Table 4. Relative estimate of Specific Gravity

Relative estimate	Specific Gravity
High	>3.5
Medium	3.2 - 3.5
Low	<3.2

Table 5. Specific Gravity of some common minerals.

Water	1.0	Pyrite	5.0
Sulphur	2.0	Magnetite	5.2
Gypsum	2.3	Galena	7.5
Quartz	2.7	Cinnabar	8.0
Calcite	2.7		
Hornblende	3.3	Gold	19.3
Olivine	3.5		

2.7 CLEAVAGE

The tendency for a mineral to split readily along well-defined planes of weakness is its cleavage. Cleavage follows planes of internal weaknesses in the atomic lattice. This weakness may be due to (1) a weaker type of bonding; (2) greater lattice spacing in the crystal at right angles to the cleavage; or (3) a combination of both. Cleavage, in fact, reveals that a crystal (mineral) has an orderly internal arrangement of atoms.

A mineral possessing perfect cleavage tends to split along certain definite smooth planes and the surfaces of these cleavage planes usually exhibit a high lustre.

Cleavage is not always perfect and, in some minerals, can only be determined with difficulty. If the surfaces thus yielded are only partially smooth, they are referred to as imperfect, interrupted or difficult.

The number of cleavages and their directions may vary, and this governs the shape of the fragments into which the crystal breaks. The angles between cleavages are characteristic of certain minerals.

In describing cleavage, the number of, quality (perfect, good, poor, none), crystallographic direction, and angles between the cleavage planes should all be noted.

e.g. 2 perfect cleavages intersecting at 90°

Cleavage should not be determined by breaking specimens in the lab. It can normally be seen by intersecting and recurring surfaces in crystals.

Note: Not all minerals exhibit cleavage.

2.8 FRACTURE

Where a mineral is broken, other than along a cleavage plane, it breaks along an unpredictable, irregular or curved surface called a fracture. All minerals fracture and some fractures are very characteristic (= diagnostic) for some minerals. A recent fracture will reveal the true colour of a mineral. The different kinds of fracture are described in Table 6.

Table 6. Types of fractures.

Fracture	Description
Conchoidal	Smooth curved concave or convex surfaces, often with concentric undulations resembling the lines of growth on a sea shell. Feature of glassy and cryptocrystalline minerals.
Sub-conchoidal	Less distinct and poorly curved
Fibrous or splintery	Elongate splinters or fibres on the surface.
Hackly surface	Jagged, irregular surfaces with sharp edges on the surface.
Uneven or irregular	Rough, irregular surfaces. Most minerals have an uneven fracture
Even	Nearly-flat to flat surfaces

2.9 HABIT & CRYSTALLINITY

Crystallinity describes the extent of crystalline growth in a mineral. Table 7 lists the terms used for crystallinity. In crystalline minerals the atoms are ordered in a definite 3-dimensional repeatable pattern; in non-crystalline minerals, the atoms are not arranged in any particular order.

Table 7. Crystallinity terminology

Crystallinity	Description
Non-crystalline	Absence of a definite crystalline structure.
Crystalline	Microcrystalline Individual crystal grains are very fine and cannot be seen with a hand lens
	Macrocrystalline Individual crystal grains are visible without magnification.

Habit describes the general overall shape of a crystal. Variation in habit arises from many causes, such as speed and condition of crystal growth and the presence of impurities in the solution from which it crystallised. Crystals that formed in a single locality may therefore be characterised by a particular habit. These shapes are described by the terms in Table 8.

Table 8. Habit terminology and description.

Habit Term	Habit Description	Etymology (from oxforddictionaries.com)
GENERAL		
Anhedral	No evidence of crystal growth shape	from <i>an-</i> 'not' + from Greek <i>hedra</i> 'seat, base'
Subhedral	Some evidence of crystal growth shape	from Latin <i>sub</i> 'under, close to'
Euhedral	Almost all surfaces represent crystal growth shape	from Greek <i>eu</i> 'well', from <i>eus</i> 'good'
EQUAL DIMENSIONS		
Equant	Any shape with near equal proportions	from Latin <i>aequant-</i> 'making equal'
Spherical	Resembling a sphere	
Cubic	Resembling a cube	
Hexagonal, octahedral, dodecahedral	Six, eight, or twelve sided; normally euhedral	
ROUNDED SHAPES		
Spherical	Rounded in equal proportions	via late Latin from Greek <i>sphairikos</i>
Globular	Nearly spherical; rounded	
Colloform	General term for rounded shapes, includes: botryoidal, mammillary and reniform	??from Greek <i>kollōdēs</i> 'glue-like', from <i>kolla</i> 'glue'??
Botryoidal	Small rounded shapes	from Greek <i>botruoidēs</i> (from <i>botrus</i> 'bunch of grapes')
Mammillary	Medium rounded shapes	from modern Latin <i>mamilla</i> diminutive of <i>mamma</i> 'breast'
Reniform	Large rounded shapes	from Latin <i>ren</i> 'kidney'
Amygdaloidal	With in-filled almond shaped cavities	from Greek <i>amugdalē</i> 'almond'
Concentric	Forming layers around a centre nucleus	from Latin <i>concrecere</i> 'grow together'
Oolitic	Small concentric spherical shapes	modern Latin <i>oolites</i> from Greek <i>ōion</i> 'egg'
Pisolitic	Medium concentric shapes (less spherical than oolitic)	from modern Latin <i>pisolithus</i> , from Greek <i>pisos</i> 'pea'
Concretionary	Large concentric rounded masses	from Latin <i>concrecere</i> 'grow together'
Nodular / tuberoso	With irregular nodules	from Latin <i>nodulus</i> , diminutive of <i>nodus</i> 'knot'
Nuggets	Large rounded masses of malleable metals	from Latin <i>tuberosus</i> 'with protuberances'
INEQUIGRANULAR PRISMS		
Flakes	Like platy but more thin	
Platy	Like tabular but more thin	from Greek <i>platus</i> 'broad'
Tabular	Flat rectangular prism, like a matchbox	Old English <i>tabule</i> 'flat slab, inscribed tablet', from Latin <i>tabula</i> 'plank, tablet, list'
Blocky	In-between equant cubic and tabular: More thick than tabular, but more elongate than equant; brick shaped	
Rhombohedral	Bent cube or block, no right angles	
Bladed / lath	Knife like, thinner and longer than tabular, like a plank of wood used for decking	Old English <i>blæd</i> 'leaf of a plant'
Columnar	Two medium and one long dimension; thicker than acicular; column or prism shape. Also commonly refers to aggregates of column/prismatic shaped crystals	Latin <i>columna</i> 'pillar'
Prismatic	Like columnar but more long and slender. Opposite faces parallel. Stubby versions may be termed sub-prismatic	from French <i>prismatique</i> , from Greek <i>prisma</i> 'thing sawn'
Acicular	Needle like; two short and one long dimension	from late Latin <i>acicula</i> 'small needle'
Capillary / filiform	Hair or thread like; slender; thinnest of all	from Latin <i>capillus</i> 'hair'
DISTINCTIVE AGGREGATES		
Fibrous / asbestiform	Aggregate of, often bent, capillary shaped crystals; made up of fibres	from Latin <i>fibra</i> 'fibre, filament, entrails'
Divergent / radiating / spherulitic	Often columnar, acicular, or prismatic crystals (though individual crystals can be of any habit) growing outward from a centre nucleus. Use spherulitic for finer crystals	from Latin <i>radiat-</i> 'emitted in rays', from the verb <i>radiare</i> , from <i>radius</i> 'ray, spoke'
Coxcomb	Flaky, platy, or tabular crystals closely packed	

Table 8 continued.

Habit Term	Habit Description	Etymology (from oxforddictionaries.com)
DISTINCTIVE AGGREGATES <i>cont.</i>		
Druse	Fine euhedral crystals encrusting a surface	via French from German <i>Druse</i> 'weathered ore'
Reticulate	Net-like lattice from crystal intergrowths	from Latin, diminutive of <i>rete</i> 'net'
Rosette	Flaky, platy, tabular, or blanded crystals forming a rose shape	from French, diminutive of <i>rose</i>
Stellate	Radiating crystals forming a star shape	from Latin <i>stellatus</i> , from <i>stella</i> 'star'
Dendritic / arborescent	Branching shapes like a stream or tree or fern	from Latin <i>arborescent</i> - 'growing into a tree', from <i>arborescere</i> , from <i>arbor</i> 'tree' from French, from Greek <i>dendritēs</i> 'tree-like', from <i>dendron</i> 'tree'
Cog-wheel	Cog shaped	
Comb	Aggregate of drusey layers	
Geode	A cavity with euhedral crystals growing into space	via Latin from Greek <i>geōdēs</i> 'earthy', from <i>gē</i> 'earth'
Cruciform	Penetration twins produce cross shape	from Latin <i>crux</i> , <i>cruc</i> - 'cross'
Liquid	Mercury is the only liquid mineral	
Plumose / feather like	Overlapping fine feathery scales	from Latin <i>plumosus</i> 'full of down or feathers'
Scaly	Overlapping platy scales	
Skeletal	Outlines with missing faces	
Stalactitic	Forming stalactites or stalagmites; cone shaped	from Greek <i>stalaktos</i> 'dripping' from Greek <i>stalagma</i> 'a drop'
Mossy	Moss like	
Wheat-sheaf	Shaped like wheat bunched together	
Bow-tie	Like a bowtie or two wheat-sheaf shapes laid end to end	
INDISTINCT AGGREGATES		
Massive	No distinct structure or shape	
Earthy	Dull, massive, clay like	
Granular	Small rounded-angular grains	
Powdery / pulverulent	Loose, powdered mass	from Latin <i>pulvis</i> , <i>pulver</i> - 'dust'
TEXTURAL FEATURES		
Cleavable	Easily cleaved	
Micaceous	Splits into very thin sheets	from Latin, literally 'crumb'
Foliated / foliaceous	Easily separated into flakes	from Latin <i>foliaceus</i> 'leafy' (from <i>folium</i> 'leaf')
Friable	Breaks apart with fingers	from French, or from Latin <i>friabilis</i> , <i>friare</i> 'to crumble'
Banded	Different bands of colour or texture	
Lamellar	Thin layers	from Latin, diminutive of <i>lamina</i> 'thin plate'
Inclusions	Is included inside another mineral	from Latin <i>inclusio</i> (n-), from <i>includere</i> 'shut in'
Intergrown	Intergrown aggregates	from Old French <i>entre</i> - or Latin <i>inter</i> 'between, among'
Disseminated	Small and spread out in a matrix	from Latin <i>disseminat</i> - 'scattered', from <i>dis</i> - 'abroad' + <i>semen</i> , <i>semin</i> - 'seed'
Efflorescences / encrustations	Crystals cover surface after precipitation	from Latin <i>efflorescere</i> , from <i>e</i> - (variant of <i>ex</i> -) 'out' + <i>florescere</i> 'begin to bloom'
Metamict	Non-crystalline mineral formed by radiation destruction of crystalline structure which preserves its original habit	from Greek <i>meta</i> 'with, across, or after'
Striated	Parallel lines on surface	from Latin, literally 'furrow'

2.10 OTHER

2.10.1 Twinning

Twinned crystals consist of two or more portions of the same substance joined in such a way that some crystallographic direction or plane is common to the parts of the twin. Twinning is governed by laws and may of the types described in Table 9.

Table 9. Twinning terminology

Twinning	Description
Contact – simple	Two halves, symmetrical with respect to the twin plane
Contact – multiple (polysynthetic, cyclic)	Multiple repetitions of twinning according to the same law
Penetration	The two parts of the twin cannot be divided into separate halves
Compound (complex)	Where twinning has taken place according to more than one law

2.10.2 Parting

Some minerals, which have been subjected to stress or pressure, develop planes of structural weakness along which they may break. Gliding planes or composition planes of twins (see later) may give rise to parting. This phenomenon resembles cleavage, but it may be distinguished by the fact that not every specimen of a certain mineral will exhibit it.

2.10.3 Tenacity

A further property depending upon the forces of cohesion between the atoms of a mineral, tenacity describes the resistance that a mineral offers to breaking, crushing, bending or tearing. The terms used to describe tenacity are described in Table 10.

Table 10. Tenacity terminology

Tenacity	Description
Brittle	Breaks or powders easily
Tough	Strongly resists tearing apart
Malleable	May be hammered into shape or thin sheets
Ductile	Can be drawn (stretched) into strands
Sectile	Can be cut by a knife into brittle shavings
Flexible	Will bend but does not resume its original shape
Elastic	Will bend and springs back to original position

2.10.4 Odour

Especially important with sulphide minerals which emit a sulphur smell, which is particularly strong when they are struck.

2.10.5 Taste

Some minerals have a particular taste. The most common mineral that has a distinctive taste is halite (= rock salt = NaCl).

2.10.6 Magnetism

Some minerals are attractive to a magnet. The most important of these is the iron ore mineral magnetite.

2.10.7 Fluorescence

Some minerals glow (fluoresce) in the presence of ultra-violet light. Strangely enough uranium ores and minerals that contain uranium impurities are highly fluorescent.

2.10.8 Mode of occurrence

Other minerals with which a mineral is typically associated with and their relationship to each other are often valuable factors in the identification of minerals. For example, at the extreme, quartz is never found with olivine in natural rocks.

2.10.9 Crystal form

THE CRYSTAL SYSTEMS

Definition of a Crystal: bodies bounded by surfaces, usually flat, arranged in a definite plan which is an expression of the internal arrangements of the atoms.

The morphology (shape) of crystals is three dimensional and as a convention the morphology of a crystal is represented by axes to which planes (i.e. faces) of a crystal may be referred to. These reference axes are known as the Crystallographic Axes. On the basis of the arrangement of the crystallographic axes all minerals can be divided into one of seven (7) crystal systems (Figure 1).

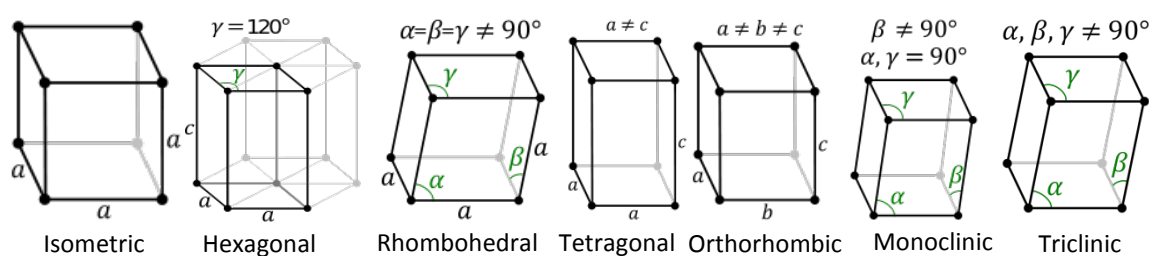


Figure 1. The seven crystal systems. Image source: [Daniel Mayer](#) CC BY-SA 3.0.

A brief description of the seven crystal systems is as follows:

ISOMETRIC (CUBIC):

Three axes (a_1 , a_2 , a_3) all of equal length and at 90° , indistinguishable from one another, e.g. Garnet.

HEXAGONAL and TRIGONAL

Four axes. Three axes (a_1 , a_2 , a_3) of equal length mutually at 60° to each other in the same plane, and the fourth axis (c) at right angles to that plane, e.g. Beryl (hexagonal), Quartz (trigonal).

TETRAGONAL

Three axes at 90° to each other. Two axes (a_1 , a_2) of equal length, while the third (c) is of different length and is coincident with the main symmetry axis of the crystal. For this shape envisage a stretched or compressed cube, e.g. Zircon.

ORTHORHOMBIC

Three axes (a , b , and c) mutually at 90° to each other with each axis being of a different length. A figure formed by the stretching or compression of a cube along two of its crystallographic axes, e.g. Olivine.

MONOCLINIC

Three axes (a, b, c) each of different length with two at right angles to each other in the same plane, and the third axis is inclined to that plane, e.g. Orthoclase.

TRICLINIC

The system with the ultimate lack of symmetry. Three axes (a, b, c), each of different length and all mutually non-perpendicular, e.g. Plagioclase.

NOTE: The Crystal System of a mineral cannot be determined from any old hand specimen. If the mineral has a well-formed crystal form it may then be possible to do so. However, the unit cell of a mineral will have the symmetry of the crystal system and it is only if the mineral has ideal growth conditions that it will form to the shape of the unit cell.

3 PETROLOGY

3.1 INTRODUCTION

Petrology is the branch of the geological sciences which deals with the composition (mineralogy and chemistry) and origin of rocks.

All of the properties and attributes of a rock are collectively called its lithology, and a description of the lithology of a rock includes the colour, size, shape and arrangement of its components, mineral composition, induration and porosity. Rocks that differ in any or several of these components are said to be lithologically different.

Of the many thousands of rock types on the Earth and planets, they can be simply classified into three main groups depending on their mode of origin: igneous rocks, sedimentary rocks, and metamorphic rocks.

3.1.1 *Igneous Rocks*

Igneous rocks form from the solidification of hot molten magma. A magma, usually consists of a silicate melt (liquid) which may contain crystals (solids) and volatiles (e.g. H₂O, CO₂), either dissolved in the melt or as a separate gas-phase (fluid). Two basic types of igneous rocks are formed: (1) **intrusive igneous (plutonic & hypabyssal) rocks**, which cool from a magma that does not reach the Earth's surface; and (2) **extrusive igneous (volcanic) rocks**, which solidify from a magma that is extruded onto the Earth's surface during volcanism.

3.1.2 *Sedimentary Rocks*

Sedimentary rocks are divided into three main types:

- (1) Clastic rocks – composed of fragmental detritus derived from the weathering and erosion of pre-existing rocks.
- (2) Chemical rocks – deposited from chemical precipitates.
- (3) Organic rocks – composed of organic remains such as coral reefs, shells of marine invertebrates or vegetation.

The clastic rocks are derived from material that has been transported by either water, wind, ice or gravity and is deposited in sedimentary basins such as lowlands, lakes and seas. The chemical and clastic rock tend to form at their place of origin = in situ.

3.1.3 *Metamorphic Rocks*

Metamorphic rocks are those which have been derived from pre-existing rocks by alteration by heat and/or pressure. The degree of metamorphism can be to such an extent that the original nature of the rock is completely obliterated. The mineralogy of the original rock is modified to form new mineral assemblages which are stable in the new pressure and/or temperature conditions. Two basic types of metamorphic rocks are formed: (1) **contact metamorphic rocks** – those formed from contact with high temperature magmas; and (2) **regional metamorphic rocks** – formed by high pressure and/or increased temperature.

The three major rock groups are not independent of one another, as illustrated by the rock cycle (Figure 2). The processes of weathering and erosion, metamorphism and melting are constant and interrelated so that there are no sharp divisions between igneous, sedimentary and metamorphic rocks. For example, fragments of igneous rocks deposited under water and compacted, may quite correctly be referred to as a sedimentary rock. Also, it may occasionally only be a matter of opinion whether a sedimentary or an igneous rock, which has undergone only slight modification, should be

classified as a metamorphic rock. However, the classification of the vast majority of metamorphic rocks is not usually in doubt.

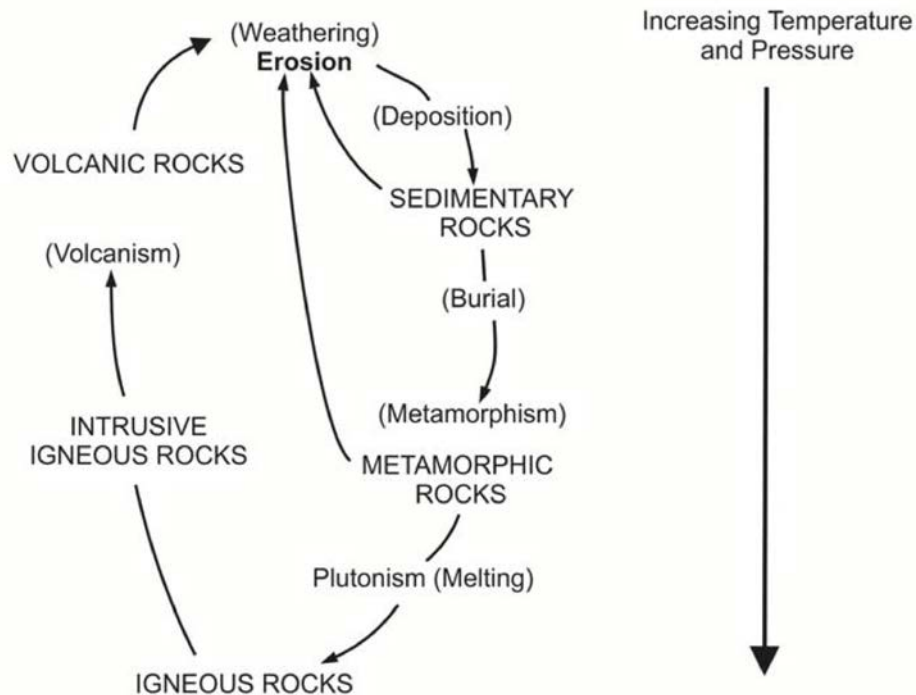


Figure 2. The rock cycle.

3.2 HAND-SPECIMEN EXAMINATION

A considerable amount of information can be gained as to the identity of rocks merely by macroscopic examination of a hand specimen i.e. an examination using one's eyes and/or a x10 hand lens. Much more information can be gained by the examination of a thin, transparent slice of rock (called a thin section) using a petrological microscope. But, as a microscope cannot be taken into the field, it is critical for students to learn to identify rocks using the macroscopic techniques only. Most rocks are, in fact, named from their macroscopic characteristics alone.

Rocks that are available for us to study are predominantly those that are exposed at the Earth's surface. At the surface they are subject to weathering which generally has the effect of decreasing the hardness of the constituents and eventually, in many cases, completely altering them. Thus, as far as possible, determinations of a rock's characteristics should be made on the "freshest" material available. **The hardness and other physical properties of a mineral or rock should not be tested on any weathered surface.**

If there is any banding or structures of any kind in the rock, these features should be examined in both section view (at right angles) and plan view.

In examining and describing a rock, note one by one the characteristics essential to its identification, together with any features of importance from a descriptive point of view. In other words, try to individualise the specimen. Do not be misled by the general appearance but maintain an open mind until all observations are completed and then use the information in identifying and naming the rock.

It must be realised that there are limitations to macroscopic diagnosis. For example, it may be difficult to distinguish between orthoclase and plagioclase feldspars if no twinning is evident, or impossible to differentiate augite and hornblende if cleavages cannot be distinguished. The

constituents of the rock may even be too small for accurate identification. Hence, there may be doubt in the mind of even the most experienced observer as to the exact identity of a rock and in such circumstances, the only course is to give a provisional name, to be confirmed or modified later with the aid of the petrological microscope.

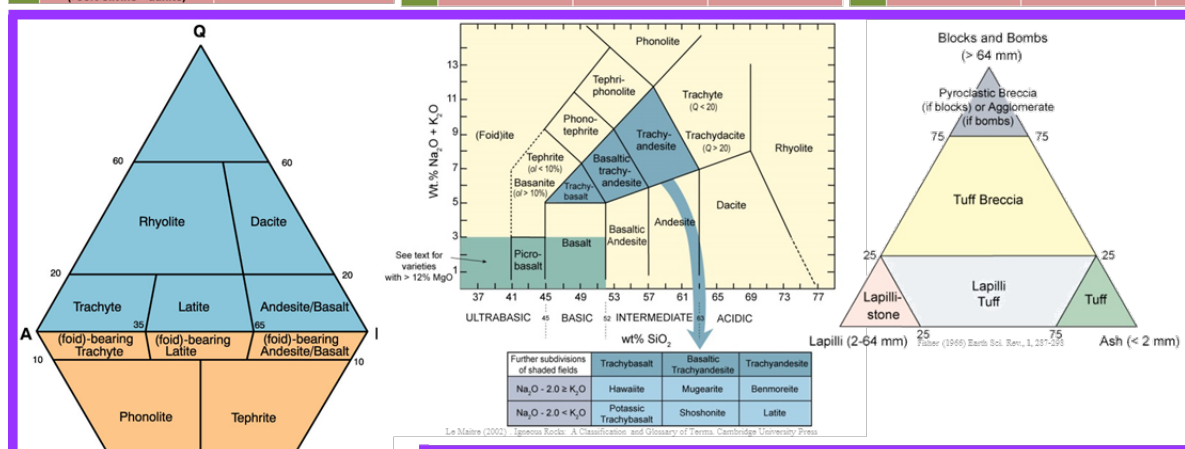
3.3 IGNEOUS PETROLOGY

Igneous rocks are those rocks that have solidified from a molten magma. Magma is usually a silicate melt (LIQUID) which may contain crystals (SOLIDS), and volatiles that are present as a separate gas phase or may be dissolved in the melt. The type of Igneous rock that forms is determined by the composition of the magma and the rate that it cools and crystallises.

3.3.1 *Classification*

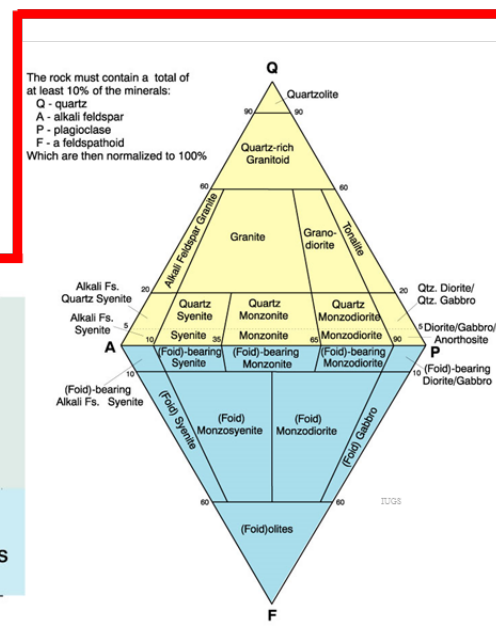
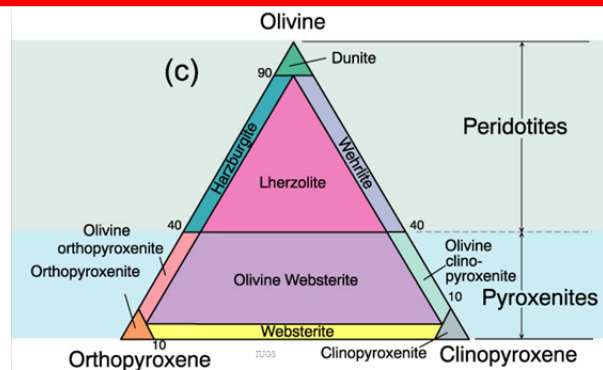
The following is a classification of igneous rocks based on texture, the silica content weight % (SiO_2), and the amount and type of feldspars present, along with IUGS classification charts of igneous rocks.

Ultra-BASIC/MAFIC Igneous Rocks (SiO ₂ <45%, Quartz absent)			BASIC/MAFIC Igneous Rocks (SiO ₂ <55% Quartz absent)			INTERMEDIATE Igneous Rocks (SiO ₂ 55-66% Quartz <10%)			ACID /FELSIC Igneous Rocks (SiO ₂ >66% Quartz >10%)							
Fine	Ultramafic		Grain Size	Feldspar Content			Grain Size	Feldspar Content			Grain Size	Feldspar Content				
	MgO content			Orth < Plag	Orth ≈ Plag	Orth > Plag		Orth < Plag	Orth ≈ Plag	Orth > Plag		Orth < Plag	Orth ≈ Plag	Orth > Plag		
	>12%		Fine	Basalt	Trachybasalt	Basanite	Fine	Andesite	Trachyandesite	Trachyte	Fine	Dacite	Rhyodacite	Rhyolite		
	Komatite (low K, high Mg, generally Archean age) Kimberlites (ultrapotassic, form vents)														Picrobasalt	
Coarse/medium	Olivine content		Med	Dolerite (diabase)			Med	Microdiorite			Med	Micogranodiorite				
	>40%			Coarse	Gabbro	Foid syenite		Coarse	Diorite	Monzonite		Syenite	Coarse	Granodiorite	Adamellite	Granite
	Peridotites (>90% olivine = dunite)															



**VOLCANIC /
PYROCLASTIC**

PLUTONIC



3.4 SEDIMENTARY PETROLOGY

Sedimentary Rocks are the most abundant rock type of the Earth's crust and are of major importance to humankind, providing sources of fuel (coal, petroleum), groundwater and building materials as well as concentrations of important elements such as iron, aluminium, titanium, uranium, etc.

Sedimentary rocks are divided into three main types: (1) **clastic rocks**, composed of fragmental detritus derived from the weathering and erosion of pre-existing rocks; (2) **chemical rocks**, deposited from chemical precipitates; and (3) **organic rocks**, consisting of organic remains such as coral reefs, shells of marine invertebrates or vegetation.

Characteristically the clastic sedimentary rocks are composed of a framework of particles (or grains or clasts), with a matrix (smaller grains) infilling the framework, and a cement (post-depositional) infilling of voids within the framework and pores. A sediment becomes rock by post-depositional physical and chemical conditions which induce lithification (or diagenesis). The creation of a sediment and the transformation of it into a sedimentary rock is a segment of the rock cycle.

The particles in clastic sedimentary rocks are derived from the decay of pre-existing rocks which may be igneous, metamorphic or sedimentary. The particles may be rock fragments, mineral grains (crystals), or clays. At the Earth's surface the exposed rocks are continually subjected to weathering (physical and chemical) which causes the rocks to either disintegrate into smaller particles, or alter to new minerals. The physical weathering agencies (rain, ice, wind) are erosive and they generally remove sedimentary particles from their source (provenance) and transport them to other sites where they are deposited, in a sedimentary basin. If the sedimentary basin is large enough sediments are buried by successive input of sediment and, under the influences of overburden pressure and geothermal temperature, both including a factor of time of application, are converted into sedimentary rocks. By other processes (metamorphism and tectonics), the sedimentary rocks may be again uplifted and eroded; and so the cycle continues.

Deposits of sediments in sedimentary basins may be very thick and take many million years to form. Furthermore, the processes of sedimentation vary through time and control the type of sediment deposited. Thus, for example, a sandstone may be overlain by a shale which in turn may be buried by a coal, each having a different sedimentary process. A layer of sediment is called a stratum (pl. strata) and in the broad sense the study of sedimentary rocks comes under the heading of **stratigraphy**

Understanding of stratigraphy or the disposition and nature of sedimentary rocks involves the basic principle of Uniformitarianism and the idea that "the present is the key to the past."

We thus think of sedimentary rocks in terms of:

- (1) SEDIMENTOLOGY - the study of processes of sediment formation.
- (2) LITHIFICATION - conversion of sediment into sedimentary rocks.
- (3) SEDIMENTARY PETROLOGY & PETROGRAPHY - the description and study of sedimentary rocks and their constituents.

All sedimentary rocks may be considered in terms of mineral composition, texture, maturity, structure, fabric and lithification.

3.4.1 Texture

Relates to the particle size, shape and surface texture of the sediment particles. Some surface textures are typical of a depositional environment: frosting of sand grains, for example, is created by wind-induced grain to grain impact (= sand blasting) in an aeolian terrain. Particle shape, sphericity

and roundness are controlled by a number of factors. The shape of pebble-sized articles is controlled by parent rock type and subsequent history. Sphericity and roundness of sand- size particles increase away from their source area.

Particle sizes are grouped according to a variety of size scales of which the most common are the Wentworth and Phi (Φ) grade scales (Table 11). Note that the scales refer to unconsolidated particles. Terms for both unconsolidated and consolidated (lithified = rock) types are included in Table 11. Although most sediments have a dominant grain size, there could be a distinct size distribution. Thus, sediments are normally analysed for their particle size distribution. There are three basic statistical measures of a sediment particle size distribution. **Mean particle size** (self-explanatory) is merely the average particle size. The particle size reflects the capacity of the transporting medium. **Sorting** is a measure of the extent of particle size variation and is commonly expressed in simple terms such as poorly sorted, well sorted, moderately sorted etc., although these terms are well defined statistical values in particle size distribution analyses. Sorting of a sediment can be readily assessed from plots of frequency histograms of particle size (Figure 3) and cumulative frequency curves. To some extent sorting is a measure of the depositional environment e.g. a dune sand may be very well sorted whereas a glacial till is very poorly sorted (Figure 3). **Skewness** is the measure of the bias of particle sizes in a sediment and terms such as coarse skewed, fine skewed etc. The quality of skewness is also readily determined from a histogram of particle size frequency (Figure 3). Skewness reflects the dominance of a transporting medium.

Often sediments have a bimodal size distribution i.e. the sediment consists of two dominant particle sizes (e.g. sand and clay, with lack of a silt size fraction).

The measurement of particle size for unconsolidated sediments is usually achieved by sieving or elutriation (application of the fact that particular particle sizes settle at particular rates in water). For consolidated sediments (rock), these methods of analysis are not applicable; and thin sections of the sediments must be cut. However, thin sections only allow grain size measurements in two-dimensions.

Sphericity is a measure of the closeness of a grain's outline to that of a sphere. **Roundness** is a measure of the smoothness of a grain's shape. Although these are independent parameters, sphericity and angularity may be compared as in Figure 4.

Some surface textures are typical of a depositional environment: Frosting of sand grains, for example, is created by wind-induced grain to grain impact (= sand blasting) in an eolian terrain. Particle shape, sphericity and roundness are controlled by a number of factors. The shape of pebble-sized articles is controlled by parent rock type and subsequent history Sphericity and roundness of sand- size particles increases away from their source area.

Table 11. Wentworth and Phi grain size scales.

Particle diameter (mm)	Phi value (ϕ)	Wentworth Grade	Rock Type
64	-6	cobble	conglomerate
4	-2	pebble	
2	-1	Granule	granulestone
1	0	Very coarse	sandstone
0.5	1	Coarse	
0.25	2	Medium	
0.125	3	Fine	
0.0625	4	Very fine	
0.002	8	Silt	siltstone
		Clay	claystone

Note: $\phi = -\log_2 d$, where d = particle diameter

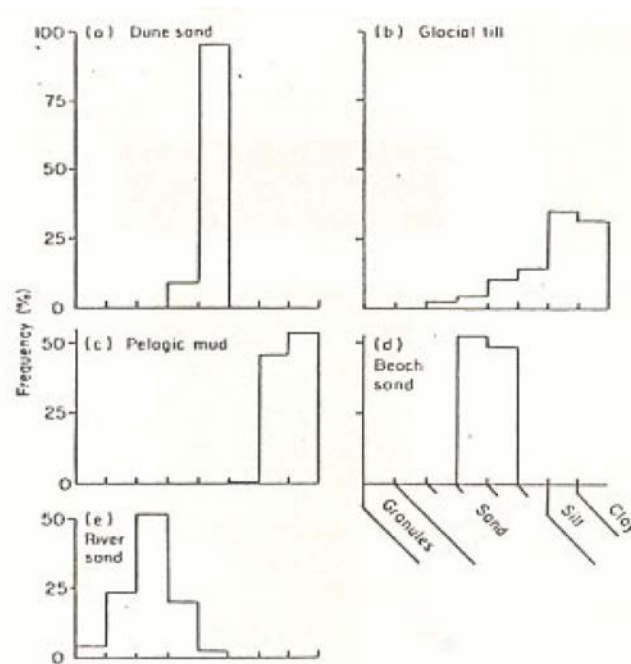


Figure 3. Grain size histograms: (a) dune sand, (b) glacial till, (c) pelagic (deep ocean) mud, (d) beach sand, and (e) river sand (from Selley, 1976). Compare the different qualities of sorting and skewness.

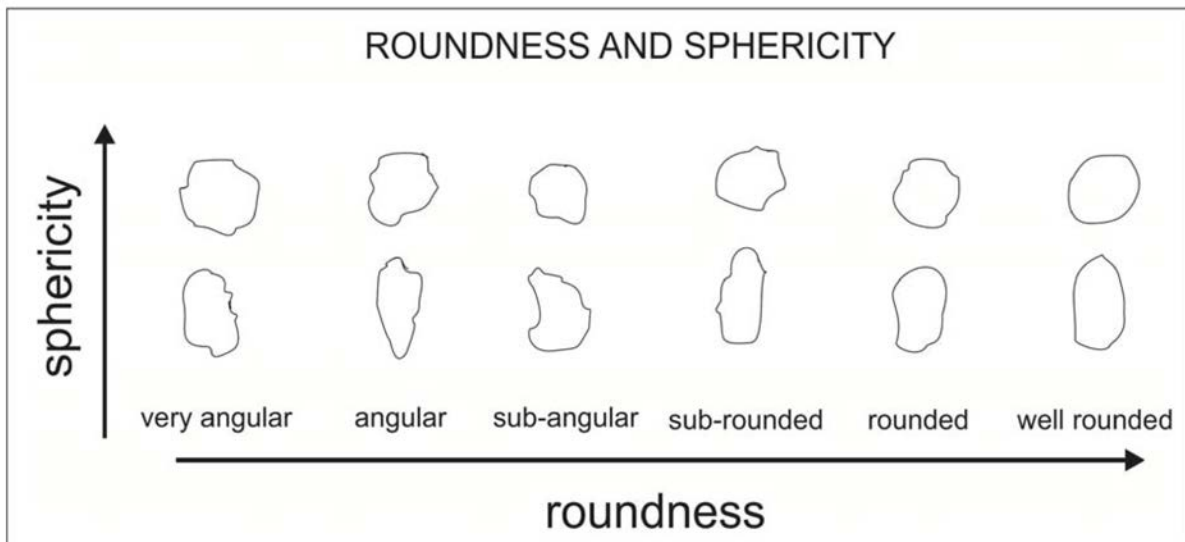


Figure 4. The qualities of roundness and sphericity.

3.4.2 Mineral composition

Depends on the nature of the source rock, on the weathering processes and transportation processes which may have introduced a degree of sorting. Although more than 150 minerals have been identified in sediments, fewer than 20 form the bulk of known sediments and sedimentary rocks. Most sediments are composed of only <6 minerals and many sediments are monomineralic. Minerals that are stable at high temperatures in igneous rocks (e.g. olivine, pyroxene) rarely survive weathering. Minerals stable at low temperatures in igneous rocks are resistant to weathering, and may also form authigenic minerals (e.g. muscovite, quartz). The rate of weathering is generally the reverse of Bowen's reaction series.

3.4.3 Structure

Any type of sedimentary structure including laminations, bedding, cross-bedding, ripples, scour and fill, bioturbation (burrowing by organisms), etc. (Selley, 1976 claims that "Colloquially, a sedimentary structure is deemed to be large enough to be seen by the naked eye, yet small enough to be carried away by a group of healthy students!"). Sedimentary structures may be distinguished as either Primary or Secondary structures.

Primary structures are those generated at the time of deposition, whereas Secondary structures develop during lithification, essentially from chemical processes.

3.4.4 Maturity

There are two main qualities of maturity of sediments:

Physical maturity is a measure of the textural changes that have taken place to the sediment as a product transportation e.g. a physically mature sediment will contain particles that are well rounded; a physically immature sediment will contain particles that are angular and of low sphericity.

Chemical maturity is a measure of the abundance of unstable mineral constituent in a sediment, and is a product of provenance of the sediment, weathering, transportation and burial. e.g. a chemically immature sediment would contain an abundance of unstable minerals, such as olivine, pyroxene and/or amphibole and rock fragments; a chemically mature sediment would be dominated by the very stable minerals such as quartz and clays.

3.4.5 Fabric

The spatial arrangement and orientation of particles. Economically important properties of rocks such as porosity and permeability depend on the fabric of the sedimentary rock.

$$\text{porosity} = \frac{\text{volume of total pore space}}{\text{volume of total rock space}} * 100\%$$

EFFECTIVE POROSITY is the amount of mutually interconnected pore space in a rock. PERMEABILITY is the ability of a fluid to flow through a porous solid.

3.4.6 Lithification

The process of turning a sediment into a rock and it includes both physical and chemical processes. Some workers restrict the term diagenesis to the chemical processes of lithification. Clay on deposition may have a porosity of 50-80%. On burial, interstitial water is expelled and the clay compacted to firstly a mudstone, then to a shale. Sand is relatively incompressible yet loses primary porosity by cementation. Carbonates may rapidly lose their primary fabric through recrystallisation or silicification. Most diagenetic changes tend to increase a rock's density and to decrease its effective porosity.

3.4.7 Classification of sedimentary rocks

Selley (1976) recognises five main genetic classes of sedimentary rocks:

Allochthonous (= transported from site or origin)

1. Terrigenous clastics, e.g. mudrocks, sandstones and conglomerates;
2. Pyroclastic deposits, e.g. ash, tuff, volcanoclastic sands and agglomerates;

Autochthonous (= formed in place)

3. Chemical precipitates, e.g. coal, limestone;
4. Organic deposits, e.g. coal, limestone;
5. Residual deposits, e.g. laterite, bauxite.

As with most classifications of geologic data though, this one also has several inconsistencies. For example, many limestones are organic in origin yet detrital in texture. Cannel coal is not strictly autochthonous. Many evaporites are diagenetic in origin.

3.4.8 References

Chernicoff, Fox & Tanner 2002 Earth Geologic Principles and History Houghton Mifflin Company

Greensmith, J.T., 1989. Petrology of Sedimentary Rocks. 7th Edition, Unwin Hyman.

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Selley, R.C., 1976. An Introduction to Sedimentology. Academic Press. Skinner and Porter. 1993, The Dynamic Earth. Wiley

3.5 METAMORPHIC PETROLOGY

Metamorphic rocks are those which have been derived from pre-existing rocks through alteration by heat and/or pressure. Two basic types of metamorphic rocks occur: **Contact metamorphic rocks** are those that are formed from contact with high temperature magmas and **regional metamorphic rocks** are formed by high pressure and/or increased temperature.

3.5.1 Composition

The mineralogy of metamorphic rocks reflects the composition of the original rock. The overall bulk chemistry of the rock may be little changed by metamorphism and only the mineralogy changes to a mineral assemblage which is stable in the new pressure and/or temperature conditions. Thus, a metamorphic rock may have a very similar composition to the parent igneous or sedimentary rock.

The common rock forming minerals (quartz, calcite, feldspars, pyroxene, amphibole, biotite and muscovite) are widespread in metamorphic rocks, but there is a group of minerals that are particular to metamorphic rocks. These metamorphic minerals include talc, garnet, chlorite, serpentine, epidote, muscovite and biotite. Sillimanite, kyanite, andalusite, staurolite and cordierite are a particular set of minerals that occur in aluminium-rich metamorphic rocks, such as those derived from clay-rich sedimentary rocks (e.g. mudstones, shale).

3.5.2 Fabric

The fabric of metamorphic rocks differs from those of igneous rocks because the metamorphic fabric develops by growth of crystals, usually of several different mineral species, competing with one another for space, in a solid medium. The growth of the crystals is a product of increased temperature and/or pressure.

The original layering or bedding of a rock (S_0) may be preserved in a metamorphic rock, but an introduced metamorphic fabric is different and includes foliation, lineation, porphyroblasts, and relict structures.

1. FOLIATION (S_1) (OR SCHISTOSITY)

The term foliation is applied to any planar structure of metamorphic origin which is formed by the parallel preferred orientation of crystals. A foliation is invariably present in metamorphic rocks that have been subjected to directed stress (e.g. shear or compression). The type of foliation is particular to the rocks as detailed below.

The main textural terms used for metamorphic rocks are:

(a) Non-foliated Rocks

- Hornfelsic: fine grained, lacking directional orientation of approximately equidimensional grains.
- Granoblastic: medium to coarse grained, lacking directional orientation of approximately equidimensional grains.

(b) Foliated Rocks

Slaty. A closely spaced system of parallel cleavages which allows the rock to be split into thin plates (= fissile). Slaty cleavage is dominantly expressed in fine grained mudrocks, and is commonly associated with minute flakes of chlorite and mica orientated parallel to the cleavages, which merge into the phyllitic texture described below. Slaty cleavage (S_1) is usually orientated axial to folds, perpendicular to the stress direction.

Phyllitic. Texture characterised by mineral grains that are just visible to the unaided eye. The grains, mainly chlorite and mica, are orientated parallel to the cleavages and impart a sheen to the cleavage surface. Original sedimentary bedding (S_0) is often apparent with the phyllitic cleavage (S_1) cutting across it.

Schistose. The mineral grains are clearly visible, and the cleavage may or may not be pronounced. The cleavage is related to the preferred parallel orientation of fibrous and/or platy minerals. A knotted schistose structure is produced where the cleavage is distorted by porphyroblasts (see later) or crystal aggregates.

Gneissic. The mineral grains are visible and are coarsely foliated. Minerals are segregated into bands ranging up to several centimetres thick. Cleavage is poor or absent.

2. LINEATION (L)

Lineation (L) refers to a linear pattern visible on the foliation plane formed by:

- (a) small parallel crenulations
- (b) trains and streaks of mineral grains
- (c) intersection of foliation (S_1) and bedding planes (S_0)

3. PORPHYROBLASTS

Large crystals of one or more minerals within finer grained minerals are called porphyroblasts. They are the metamorphic equivalent of a phenocryst. But unlike phenocrysts which crystallise first within a liquid melt, porphyroblasts "grow" out of the minerals which surround them, in the solid state.

4. RELIC STRUCTURES

Structures inherited from the parent rock can give valuable information about the pre-metamorphic history of some metamorphic rocks. e.g. relic cross-bedding in quartzite (meta quartz sandstone) indicates a sedimentary origin, relic pillow lavas in greenschist (meta basalt) indicate a submarine volcanic origin.

3.5.3 Grades of Metamorphism

The degree of metamorphism indicated by particular minerals that are stable with a certain range of pressure and/or temperature conditions is referred to as metamorphic grade. It is continuous, with no sharp boundaries between grades, from low through to high grades.

The changes that occur in rocks under the influence of increasing temperature include:

- 1. increase in grainsize with the recrystallisation of minerals
- 2. bulk mineral changes in the rock by minerals becoming unstable and their being replaced with newly formed, more stable minerals

3.5.4 Classification of Metamorphic Rocks

The most common classification of metamorphic rocks is based on texture and mineralogy. The texture is very much dependent on the setting and origin of the metamorphism and there are two main subdivisions as outlined below:

1. LOCAL METAMORPHISM

Contact Metamorphism

Rocks surrounding intrusive magma bodies are metamorphosed by the very high temperatures of the magma. The rocks are recrystallised by the heat and they are characterised by lacking a foliation,

and a texture of equigranular crystalline grains. The fine-grained parent rocks, such as mudstone or basalt, are metamorphosed to a very fine equigranular crystalline texture called hornfelsic, whereas coarser rocks, such as a sandstone or granite, are metamorphosed to a coarse, "sugary", equigranular crystalline texture called granoblastic. The general appearance of some of the contact, nonfoliated metamorphic rocks may resemble igneous rocks, but the key to their distinction is the mineralogical differences.

2. REGIONAL METAMORPHISM

Regional Dynamothermal Metamorphism (may be prograde or retrograde).

Occurs on scales of a few hundred to several thousands of square kilometres and is related to orogenesis (= mountain building). The metamorphism occurs at high pressure as a result of the combination of lithostatic (= load) pressure and widespread directed stress of deformation, and variable temperature as related to depth from the surface. The orientation of the stress directions controls the orientation of the resultant metamorphic fabric. The stress is penetrative (i.e. the whole regional volume of rock is encompassed) and generates a penetrative structure and fabric. The resulting rocks are strongly foliated e.g. slate, phyllite, schist and gneiss.

Regional Burial Metamorphism

Has no genetic relationship to orogenesis (directed stress) or magmatic intrusions (extreme heat). Merely a product of burial pressure and commonly occurs in the lower portions of thick piles of sediment in sedimentary basins. Original fabrics of the rocks are largely preserved but mineralogical compositions are changed to stable minerals within the load pressure. These changes may be hardly visible in hand specimens.

OTHER TYPES OF METAMORPHISM

Dynamic Metamorphism

A product of the mechanical crushing and grinding in shear (fault) zones. Any fabric produced is parallel to the fault movements, and the crushed rocks in the shear zone, which may be partly recrystallised, are called cataclastites. Extreme effects of dynamic metamorphism results in rocks called mylonites.

Hydrothermal Metamorphism

The result of hot solutions and gases (from magma) that percolate through fractures in rocks. Rocks adjacent to the fractures are mineralogically changed (= hydrothermal alteration). e.g. minerals such as pyroxene and olivine are altered to serpentine, and a hydrothermally metamorphosed basic or ultrabasic parent rock would give rise to the rock called serpentinite.

3.5.5 Recognition of Metamorphic Rocks

Metamorphic rocks may be readily recognised by one or a combination of the following characteristics:

- banding, foliation, schistosity (S1) or lineation (L) within the rock
- parallel orientation of mineral grains
- mosaic of grains
- presence of two or more planar structures such as a foliation plane (S1) at an oblique angle to a bedding plane (S0)
- the presence of the following minerals, even in the smallest abundance; muscovite, chlorite, kyanite, andalusite, staurolite, sillimanite and garnet.

4 ROCK FORMING MINERALS EXERCISE (WK 2) & ECONOMIC MINERALS EXERCISE (WK 11-13)

Complete the following tables of mineral properties using the information provided in Section 0 and on Moodle. Remember to focus on distinguishing properties.

4.1 ROCK FORMING MINERALS (WK 2)

SAMPLES TO WORK THROUGH

1. Quartz	5. Biotite	8. Augite	12. Magnetite
3. Orthoclase	6. Muscovite	9. Olivine	13. Hematite
4. Plagioclase	7. Hornblende	10. Calcite	18. Talc
			20. Kaolinite

4.2 ECONOMIC MINERALS (WK 11-13)

SAMPLES TO WORK THROUGH

1. Graphite	9. Sphalerite	17. Siderite	25. Rhodonite
2. Sulphur	10. Galena	18. Cerussite	26. Garnierite
3. Corundum	11. Stibnite	19. Magnesite	RF 18.. Talc
5. Pyrolusite	12. Chalcopryrite	20. Gypsum	31. Beryl
6. Cassiterite	12a. Arsenopyrite	21. Barite/baryte	34. Chrysocolla
7. Molybdenite	13. Pyrrhotite	23. Fluorite	RF 14. Pyrite
8. Bornite	14. Wolframite	24. Halite	25. Rhodonite

Economic minerals grouped by chemical composition

Native elements:

Graphite
Sulphur

Sulphides:

Molybdenite
Stibnite
Arsenopyrite
Sphalerite
Galena
Bornite
Chalcopryrite
Pyrrhotite
Pyrite

Oxides:

Corundum
Cassiterite
Wolframite
Pyrolusite

Carbonates:

Siderite
Cerussite
Magnesite
Malachite
Azurite

Halides:

Fluorite
Halite

Sulphates:

Gypsum
Baryte

Silicates:

Talc
Chrysocolla
Garnierite
Beryl
Rhodonite

Samples in tables are group via similar looking minerals (some repeated due to variable properties and may appear similar to multiple groups)

5 PETROLOGY EXERCISES

Complete the following tables of rock properties using the information provided in Section 2 and on Moodle.

5.1 IGNEOUS ROCKS

SAMPLES TO WORK THROUGH

1. Granite	2. Gabbro	11. Andesite	5. Obsidian
7. Granodiorite	4. Rhyolite	17. Basal	9. Pegmatite

5.2 SEDIMENTARY ROCKS

SAMPLES TO WORK THROUGH

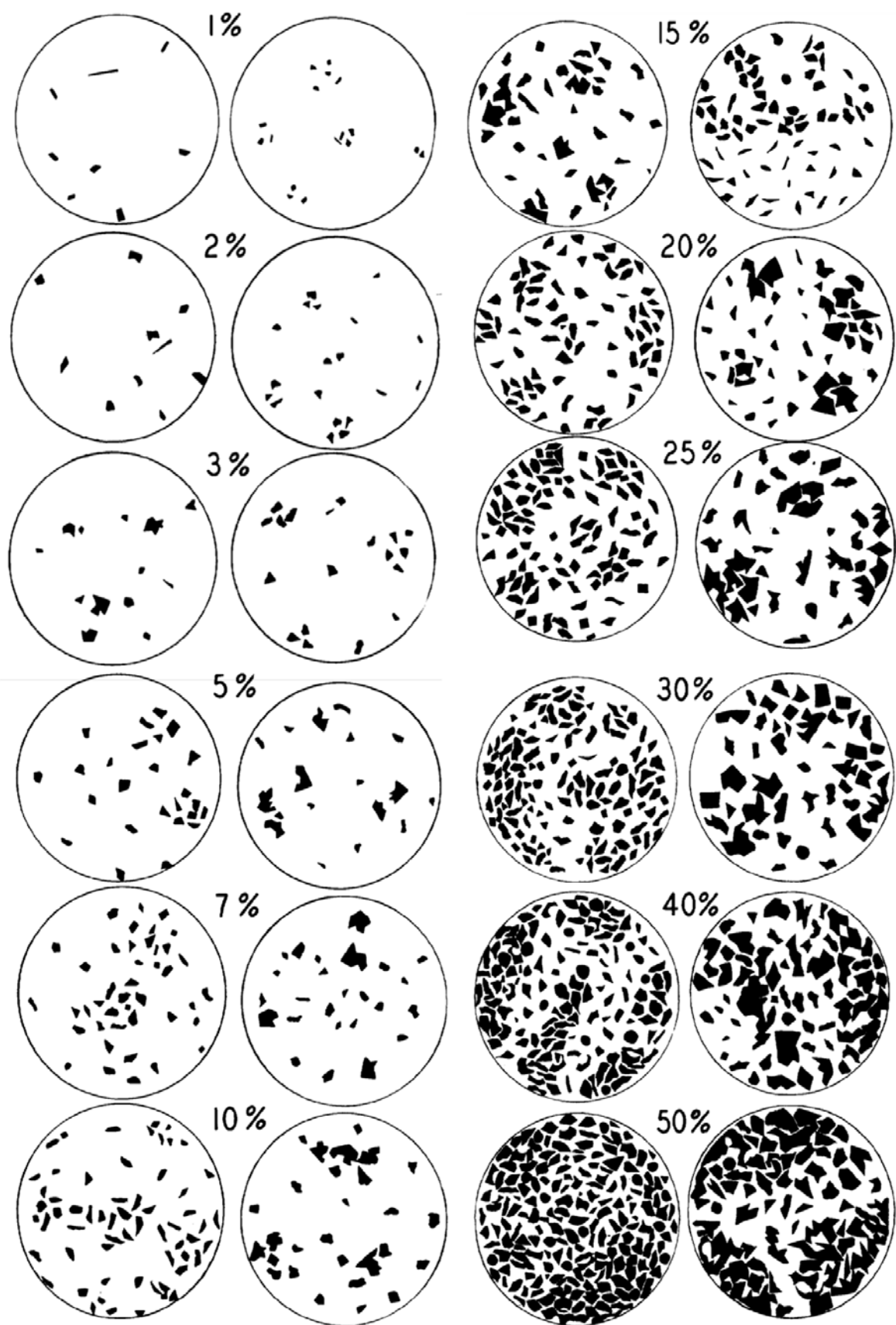
19. Conglomerate	21. Lithic sandstone	27. Fossiliferous limestone	24. Chert
20. Quartz sandstone	22. Shale	30. Coal	25. Laterite

5.3 METAMORPHIC ROCKS

SAMPLES TO WORK THROUGH

31. Quartzite	34. Slate	36. Schist
38. Marble	35. Phyllite	37. Gneiss

In addition to these rock samples, we will also take a look at some common metamorphic minerals.



from Terry and Chilingar 1955, after Shvetsov 1954

Rock Forming Mineral Description Sheet

Mineral	Chem. Formula Crystal System	Colour	Streak	Lustre	Diaphaneity	Hardness	Density	Cleavage	Fracture	Habit	Crystallinity	Other
1. Quartz	SiO ₂ Hexagonal/Trigonal						2.65			Euhedral/subhedral/anhydral Shape:		
3. Orthoclase	KAlSi ₃ O ₈ Monoclinic						2.57			Euhedral/subhedral/anhydral Shape:		
4. Plagioclase	NaAlSi ₃ O ₈ – CaAl ₂ Si ₂ O ₈ Triclinic						~2.7			Euhedral/subhedral/anhydral Shape:		
5. Biotite	KFe ²⁺ ₃ AlSi ₃ O ₁₀ (OH) ₂ Monoclinic						~2.8			Euhedral/subhedral/anhydral Shape:		
6. Muscovite	KAl ₂ (AlSi ₃ O ₁₀)(OH) ₂ Monoclinic						~2.8			Euhedral/subhedral/anhydral Shape:		
7. Hornblende	Monoclinic {Ca ₂ }{Fe ²⁺ ₄ Al}{AlSi ₇ O ₂₂ }(OH) ₂ - {Ca ₂ }{Mg ₄ Al}{AlSi ₇ O ₂₂ }(OH) ₂						~3.3			Euhedral/subhedral/anhydral Shape:		
8. Augite	(Ca,Na,Mg,Fe) ₂ (Si,Al) ₂ O ₆ Monoclinic						~3.3			Euhedral/subhedral/anhydral Shape:		
9. Olivine	Fe ₂ SiO ₄ - Mg ₂ SiO ₄ Orthorhombic						3.2-4.3			Euhedral/subhedral/anhydral Shape:		
10. Calcite	CaCO ₃ Hexagonal/Trigonal						2.71			Euhedral/subhedral/anhydral Shape:		
12. Magnetite	Fe ²⁺ Fe ³⁺ ₂ O ₄ Isometric						5.18			Euhedral/subhedral/anhydral Shape:		
13. Hematite	Fe ₂ O ₃ Hexagonal/Trigonal						~5			Euhedral/subhedral/anhydral Shape:		
18. Talc	Mg ₃ Si ₄ O ₁₀ (OH) ₂ Triclinic						~2.7			Euhedral/subhedral/anhydral Shape:		
20. Kaolinite	Al ₂ Si ₂ O ₅ (OH) ₄ Triclinic						2.6			Euhedral/subhedral/anhydral Shape:		

IGNEOUS ROCKS

NAME	MINERAL COMPOSITION		STRUCTURE	TEXTURE		CLASSIFICATION		ENGINEERING PROPERTIES	USES
	MINERAL	%		GRAIN SIZE	CRYSTALLINITY	% SiO ₂	LOCATION		
1 GRANITE	1. 2. 3. 4. 5.		Massive (no structure) Banded Veined Jointed Vesicular Amygdaloidal	Coarse (>5 mm) Medium (1-5 mm) Fine (<1 mm)	Glassy Microcrystalline Crystalline Porphyritic	Acid Intermediate Basic Ultrabasic	EXTRUSIVE - Volcanic INTRUSIVE - Hypabyssal - Plutonic	Weight: Heavy/Medium/Light Microporosity: High/Mod/Low Comp Strength: High/Mod/Low Abrasion Resist: High/Mod/Low Excav. Stability: High/Mod/Low	Bad Minerals: Weak/Unstable -Concrete aggregate -Road base -Rock fill
7 GRANODIORITE	1. 2. 3. 4. 5.		Massive (no structure) Banded Veined Jointed Vesicular Amygdaloidal	Coarse (>5 mm) Medium (1-5 mm) Fine (<1 mm)	Glassy Microcrystalline Crystalline Porphyritic	Acid Intermediate Basic Ultrabasic	EXTRUSIVE - Volcanic INTRUSIVE - Hypabyssal - Plutonic	Weight: Heavy/Medium/Light Microporosity: High/Mod/Low Comp Strength: High/Mod/Low Abrasion Resist: High/Mod/Low Excav. Stability: High/Mod/Low	Bad Minerals: Weak/Unstable -Concrete aggregate -Road base -Rock fill
2 GABBRO	1. 2. 3. 4. 5.		Massive (no structure) Banded Veined Jointed Vesicular Amygdaloidal	Coarse (>5 mm) Medium (1-5 mm) Fine (<1 mm)	Glassy Microcrystalline Crystalline Porphyritic	Acid Intermediate Basic Ultrabasic	EXTRUSIVE - Volcanic INTRUSIVE - Hypabyssal - Plutonic	Weight: Heavy/Medium/Light Microporosity: High/Mod/Low Comp Strength: High/Mod/Low Abrasion Resist: High/Mod/Low Excav. Stability: High/Mod/Low	Bad Minerals: Weak/Unstable -Concrete aggregate -Road base -Rock fill
4 RHYOLITE	1. 2. 3. 4. 5.		Massive (no structure) Banded Veined Jointed Vesicular Amygdaloidal	Coarse (>5 mm) Medium (1-5 mm) Fine (<1 mm)	Glassy Microcrystalline Crystalline Porphyritic	Acid Intermediate Basic Ultrabasic	EXTRUSIVE - Volcanic INTRUSIVE - Hypabyssal - Plutonic	Weight: Heavy/Medium/Light Microporosity: High/Mod/Low Comp Strength: High/Mod/Low Abrasion Resist: High/Mod/Low Excav. Stability: High/Mod/Low	Bad Minerals: Weak/Unstable -Concrete aggregate -Road base -Rock fill
11 ANDESITE	1. 2. 3. 4. 5.		Massive (no structure) Banded Veined Jointed Vesicular Amygdaloidal	Coarse (>5 mm) Medium (1-5 mm) Fine (<1 mm)	Glassy Microcrystalline Crystalline Porphyritic	Acid Intermediate Basic Ultrabasic	EXTRUSIVE - Volcanic INTRUSIVE - Hypabyssal - Plutonic	Weight: Heavy/Medium/Light Microporosity: High/Mod/Low Comp Strength: High/Mod/Low Abrasion Resist: High/Mod/Low Excav. Stability: High/Mod/Low	Bad Minerals: Weak/Unstable -Concrete aggregate -Road base -Rock fill
17 BASALT	1. 2. 3. 4. 5.		Massive (no structure) Banded Veined Jointed Vesicular Amygdaloidal	Coarse (>5 mm) Medium (1-5 mm) Fine (<1 mm)	Glassy Microcrystalline Crystalline Porphyritic	Acid Intermediate Basic Ultrabasic	EXTRUSIVE - Volcanic INTRUSIVE - Hypabyssal - Plutonic	Weight: Heavy/Medium/Light Microporosity: High/Mod/Low Comp Strength: High/Mod/Low Abrasion Resist: High/Mod/Low Excav. Stability: High/Mod/Low	Bad Minerals: Weak/Unstable -Concrete aggregate -Road base -Rock fill
5 OBSIDIAN	1. 2. 3. 4. 5.		Massive (no structure) Banded Veined Jointed Vesicular Amygdaloidal	Coarse (>5 mm) Medium (1-5 mm) Fine (<1 mm)	Glassy Microcrystalline Crystalline Porphyritic	Acid Intermediate Basic Ultrabasic	EXTRUSIVE - Volcanic INTRUSIVE - Hypabyssal - Plutonic	Weight: Heavy/Medium/Light Microporosity: High/Mod/Low Comp Strength: High/Mod/Low Abrasion Resist: High/Mod/Low Excav. Stability: High/Mod/Low	Bad Minerals: Weak/Unstable -Concrete aggregate -Road base -Rock fill
9 PEGMATITE	1. 2. 3. 4. 5.		Massive (no structure) Banded Veined Jointed Vesicular Amygdaloidal	Coarse (>5 mm) Medium (1-5 mm) Fine (<1 mm)	Glassy Microcrystalline Crystalline Porphyritic	Acid Intermediate Basic Ultrabasic	EXTRUSIVE - Volcanic INTRUSIVE - Hypabyssal - Plutonic	Weight: Heavy/Medium/Light Microporosity: High/Mod/Low Comp Strength: High/Mod/Low Abrasion Resist: High/Mod/Low Excav. Stability: High/Mod/Low	Bad Minerals: Weak/Unstable -Concrete aggregate -Road base -Rock fill

CLASTIC SEDIMENTARY ROCKS

ROCK NAME	TEXTURE		COMPOSITION		STRUCTURE AND COHERENCE		OTHER FEATURES			ENGINEERING PROPERTIES		USES
19 CONGLOMERATE	<u>PARTICLE SIZE</u> Pebble Sand Silt Clay	<u>PARTICLE SHAPE</u> Angular Subangular Subrounded Rounded Well rounded	CLASTS	Lithic fragments - volcanic - sedimentary Quartz grains Feldspar grains Clay particles	STRUCTURE	Massive Poorly bedded Well bedded Laminated Bioturbation	MATURITY	<u>PHYSICAL</u> - Mature - Immature	<u>CHEMICAL</u> - Mature - Immature	Weight: Heavy/Medium/Light	Bad Minerals:	-Road base
	<u>SORTING</u> Well Moderately Poorly	<u>DISTRIBUTION</u> Unimodal Bimodal		Lithic particles Clay						Microporosity: High/Mod/Low	Weak/Unstable	_____
20 QUARTZ SANDSTONE	<u>PARTICLE SIZE</u> Pebble Sand Silt Clay	<u>PARTICLE SHAPE</u> Angular Subangular Subrounded Rounded Well rounded	CLASTS	Lithic fragments - volcanic - sedimentary Quartz grains Feldspar grains Clay particles	STRUCTURE	Massive Poorly bedded Well bedded Laminated Bioturbation	MATURITY	<u>PHYSICAL</u> - Mature - Immature	<u>CHEMICAL</u> - Mature - Immature	Weight: Heavy/Medium/Light	Bad Minerals:	Building stone
	<u>SORTING</u> Well Moderately Poorly	<u>DISTRIBUTION</u> Unimodal Bimodal		Lithic particles Clay						Microporosity: High/Mod/Low	Weak/Unstable	_____
21 LITHIC SANDSTONE	<u>PARTICLE SIZE</u> Pebble Sand Silt Clay	<u>PARTICLE SHAPE</u> Angular Subangular Subrounded Rounded Well rounded	CLASTS	Lithic fragments - volcanic - sedimentary Quartz grains Feldspar grains Clay particles	STRUCTURE	Massive Poorly bedded Well bedded Laminated Bioturbation	MATURITY	<u>PHYSICAL</u> - Mature - Immature	<u>CHEMICAL</u> - Mature - Immature	Weight: Heavy/Medium/Light	Bad Minerals:	-Road base
	<u>SORTING</u> Well Moderately Poorly	<u>DISTRIBUTION</u> Unimodal Bimodal		Lithic particles Clay						Microporosity: High/Mod/Low	Weak/Unstable	(low use roads)
22 SHALE	<u>PARTICLE SIZE</u> Pebble Sand Silt Clay	<u>PARTICLE SHAPE</u> Angular Subangular Subrounded Rounded Well rounded	CLASTS	Lithic fragments - volcanic - sedimentary Quartz grains Feldspar grains Clay particles	STRUCTURE	Massive Poorly bedded Well bedded Laminated Bioturbation	MATURITY	<u>PHYSICAL</u> - Mature - Immature	<u>CHEMICAL</u> - Mature - Immature	Weight: Heavy/Medium/Light	Bad Minerals:	Aquitard,
	<u>SORTING</u> Well Moderately Poorly	<u>DISTRIBUTION</u> Unimodal Bimodal		Lithic particles Clay						Microporosity: High/Mod/Low	Weak/Unstable	pottery

NON-CLASTIC SEDIMENTARY ROCKS

ROCK NAME	TEXTURE	COMPOSITION	STRUCTURE AND COHERENCE		ORIGIN AND DEPOSITIONAL ENVIRONMENT		ENGINEERING PROPERTIES		USES
27 FOSSILIFEROUS LIMESTONE	Cryptocrystalline	Silica	STRUCTURE	Massive	ORIGIN	Residual deposit	Weight: Heavy/Medium/Light	Bad Minerals:	Cement
	Fine crystalline	Calcium Carbonate		Poorly bedded		Organic accumulate	Microporosity: High/Mod/Low	Weak/Unstable	industry
	Coarse crystalline	Skeletal (shell) fragments	COHERENCE	Well bedded	ENVIRO.	Carbonate precipitate	Comp Strength: High/Mod/Low	_____	_____
	Concretionary (pisolitic)	Organic Material		Laminated		Skeletal accumulate	Abrasion Resist: High/Mod/Low		
	Amorphous (non-crystalline)	Al and Fe oxides and clay		Bioturbation		Deep marine or hot springs	Excav. Stability: High/Mod/Low		
30 COAL	Cryptocrystalline	Silica	STRUCTURE	Massive	ORIGIN	Residual deposit	Weight: Heavy/Medium/Light	Bad Minerals:	Fuel
	Fine crystalline	Calcium Carbonate		Poorly bedded		Organic accumulate	Microporosity: High/Mod/Low	Weak/Unstable	_____
	Coarse crystalline	Skeletal (shell) fragments	COHERENCE	Well bedded	ENVIRO.	Carbonate precipitate	Comp Strength: High/Mod/Low	_____	
	Concretionary (pisolitic)	Organic Material		Laminated		Skeletal accumulate	Abrasion Resist: High/Mod/Low		
	Amorphous (non-crystalline)	Al and Fe oxides and clay		Bioturbation		Deep marine or hot springs	Excav. Stability: High/Mod/Low		
24 CHERT	Cryptocrystalline	Silica	STRUCTURE	Massive	ORIGIN	Residual deposit	Weight: Heavy/Medium/Light	Bad Minerals:	Historically as
	Fine crystalline	Calcium Carbonate		Poorly bedded		Organic accumulate	Microporosity: High/Mod/Low	Weak/Unstable	weapons
	Coarse crystalline	Skeletal (shell) fragments	COHERENCE	Well bedded	ENVIRO.	Carbonate precipitate	Comp Strength: High/Mod/Low	_____	_____
	Concretionary (pisolitic)	Organic Material		Laminated		Skeletal accumulate	Abrasion Resist: High/Mod/Low		
	Amorphous (non-crystalline)	Al and Fe oxides and clay		Bioturbation		Deep marine or hot springs	Excav. Stability: High/Mod/Low		
25 LATERITE	Cryptocrystalline	Silica	STRUCTURE	Massive	ORIGIN	Residual deposit	Weight: Heavy/Medium/Light	Bad Minerals:	- Road base
	Fine crystalline	Calcium Carbonate		Poorly bedded		Organic accumulate	Microporosity: High/Mod/Low	Weak/Unstable	- Ore if Al is
	Coarse crystalline	Skeletal (shell) fragments	COHERENCE	Well bedded	ENVIRO.	Carbonate precipitate	Comp Strength: High/Mod/Low	_____	high enough
	Concretionary (pisolitic)	Organic Material		Laminated		Skeletal accumulate	Abrasion Resist: High/Mod/Low		
	Amorphous (non-crystalline)	Al and Fe oxides and clay		Bioturbation		Deep marine or hot springs	Excav. Stability: High/Mod/Low		

METAMORPHIC MINERALS

Match the following metamorphic minerals to their diagnostic properties:

Talc (RF18)
Garnet (RF17)
Chlorite (RF26)
Serpentine (metamorphic rock sample 47)
Epidote (RF 23)
Muscovite (RF 6)
Biotite (RF 5)
Sillimanite (RF 24)
Kyanite (RF 15)
Staurolite (RF 19)

perfect basal cleavage · elastic · foliaceous · dark coloured
Hardness = 7 · euhedral elongate prisms · brown colour · penetration twinning
hardness = 1 · soapy feel · pale cream/green/white colour
bladed & striated habit · blue/grey/green colour · cleavage 2 perfect (@ 80°) and 1 good.
green colour · platy habit · hardness 2-2.5 · greasy
hardness = 6-7.5 · euhedral dodecahedra shape · dark red-brown colour
perfect basal cleavage · elastic · foliaceous · light coloured
yellow-green colour · fibrous or net-like habit · pearly/waxy/silky lustre
acicular or fibrous habit · hardness = 6.5-7.5 · colourless/white
perfect basal cleavage · dark or forest green colour · hardness = 6-6.5

NON-FOLIATED METAMORPHIC ROCKS

ROCK NAME	COLOUR	HARDNESS	COMPOSITION	TEXTURE	PROBABLE PARENT ROCK	CLASSIFICATION		ENGINEERING PROPERTIES		USES
						TYPE	GRADE			
31 QUARTZITE (METAQUARTZITE)	White-cream	3	Calcite	Hornfelsic	Quartz sandstone	Contact Regional	High	Weight: Heavy/Medium/Light	Bad Minerals: ???	
	Brown	7	Silica (quartz)	Granoblastic	Limestone		Medium Low	Microporosity: High/Mod/Low Comp Strength: High/Mod/Low Abrasion Resist: High/Mod/Low Excav. Stability: High/Mod/Low	Weak/Unstable	
38 MARBLE	White-cream	3	Calcite	Hornfelsic	Quartz sandstone	Contact Regional	High	Weight: Heavy/Medium/Light	Bad Minerals: Building stones, pavements	
	Brown	7	Silica (quartz)	Granoblastic	Limestone		Medium Low	Microporosity: High/Mod/Low Comp Strength: High/Mod/Low Abrasion Resist: High/Mod/Low Excav. Stability: High/Mod/Low	Weak/Unstable	

FOLIATED METAMORPHIC ROCKS

ROCK NAME	FOLIATION	COMPOSITION		PROBABLE PARENT ROCK	CLASSIFICATION		ENGINEERING PROPERTIES		USES
					PRESSURE	TEMPERATURE			
34 SLATE	Slaty Phyllitic Schistose Gneissic	Quartz	Clay minerals	Shales or siltstone	High Medium Low	High Medium Low	Weight: Heavy/Medium/Light	Bad Minerals: Floors, facing stones	
		Plagioclase	Chlorite				Microporosity: High/Mod/Low Comp Strength: High/Mod/Low Abrasion Resist: High/Mod/Low Excav. Stability: High/Mod/Low	Weak/Unstable	
35 PHYLLITE	Slaty Phyllitic Schistose Gneissic	Orthoclase	Hydrous mica	A granitic rock	High Medium Low	High Medium Low	Weight: Heavy/Medium/Light	Bad Minerals: ???	
		Biotite	Garnet				Microporosity: High/Mod/Low Comp Strength: High/Mod/Low Abrasion Resist: High/Mod/Low Excav. Stability: High/Mod/Low	Weak/Unstable	
36 MICA SCHIST	Slaty Phyllitic Schistose Gneissic	Muscovite		A granitic rock	High Medium Low	High Medium Low	Weight: Heavy/Medium/Light	Bad Minerals: ???	
							Microporosity: High/Mod/Low Comp Strength: High/Mod/Low Abrasion Resist: High/Mod/Low Excav. Stability: High/Mod/Low	Weak/Unstable	
37 GNEISS	Slaty Phyllitic Schistose Gneissic	Quartz	Clay minerals	Shales or siltstone	High Medium Low	High Medium Low	Weight: Heavy/Medium/Light	Bad Minerals: ???	
		Plagioclase	Chlorite				Microporosity: High/Mod/Low Comp Strength: High/Mod/Low Abrasion Resist: High/Mod/Low Excav. Stability: High/Mod/Low	Weak/Unstable	
		Orthoclase	Hydrous mica	A granitic rock					
		Biotite	Garnet						
		Muscovite							

ECONOMIC MINERALS

Mineral	Chem. Formula Crystal System	Colour	Streak	Lustre	Diaphaneity	Hardness	Density (g/cm ³)	Cleavage	Fracture	Habit	Crystallinity	Other	Uses
1. Graphite	C Hexagonal									Euhedral/subhedral/anhydral Shape:		<u>Greasy feel</u>	Electrodes, lubricants
7. Molybdenite	MoS ₂ Hexagonal									Euhedral/subhedral/anhydral Shape:			Ore of Mo, seals, lubricants
11. Stibnite	Sb ₂ S ₃ Orthorhombic									Euhedral/subhedral/anhydral Shape:			Ore of Sb, semiconductors, solder
12a. Arsenopyrite	FeAsS Monoclinic (pseudo orthorhombic)									Euhedral/subhedral/anhydral Shape:			Ore of As
Distinguishing features													
9. Sphalerite	(Zn,Fe)S Isometric									Euhedral/subhedral/anhydral Shape:			Ore of Zn, Cd castings, galvanised iron
10. Galena	PbS Isometric									Euhedral/subhedral/anhydral Shape:			Pb ore; Pb used in shielding, paints
Distinguishing features													
3. Corundum	Al ₂ O ₃ Trigonal									Euhedral/subhedral/anhydral Shape:			Gem: sapphire (blue), ruby (red)
6. Cassiterite	SnO ₂ Tetragonal									Euhedral/subhedral/anhydral Shape:			Sn ore, solders, plating
14. Wolframite	MnWO ₄ – FeWO ₄ Monoclinic									Euhedral/subhedral/anhydral Shape:			W ore; W used in hard steels
17. Siderite	FeCO ₃ Trigonal									Euhedral/subhedral/anhydral Shape:			Fe ore
5. Pyrolusite	MnO ₂ Tetragonal									Euhedral/subhedral/anhydral Shape:			Mn ore, batteries
8. Bornite	Cu ₅ FeS ₄ Isometric / Tetragonal / Orthorhombic									Euhedral/subhedral/anhydral Shape:		<u>Associated with chalcopyrite</u>	Imp. Cu ore

Mineral	Chem. Formula Crystal System	Colour	Streak	Lustre	Diaphaneity	Hardness	Density (g/cm ³)	Cleavage	Fracture	Habit	Crystallinity	Other	Uses
12. Chalcopyrite	CuFeS ₂ Tetragonal									Euhedral/subhedral/anhydral Shape:			Main ore of Cu - electrical
13. Pyrrhotite	FeS (varies) Monoclinic and hexagonal									Euhedral/subhedral/anhydral Shape:		<u>Magnetic</u>	Associated with other ores, particularly Ni
RF 14. Pyrite	FeS ₂ Isometric									Euhedral/subhedral/anhydral Shape:			Gangue
12a. Arsenopyrite	FeAsS Monoclinic (pseudo orthorhombic)									Euhedral/subhedral/anhydral Shape:			Ore of As
8. Bornite	Cu ₅ FeS ₄ Isometric / Tetragonal / Orthorhombic									Euhedral/subhedral/anhydral Shape:		<u>Associated with chalcopyrite</u>	Imp. Cu ore
Distinguishing features													
23. Fluorite	CaF ₂ Isometric									Euhedral/subhedral/anhydral Shape:			Additive to glass; flux; acid manufacture
24. Halite	NaCl Isometric									Euhedral/subhedral/anhydral Shape:		<u>Taste</u>	Foodstuffs; chemical industry
18. Cerussite	PbCO ₃ Orthorhombic									Euhedral/subhedral/anhydral Shape:			Pb ore; exploration indicator
20. Gypsum	CaSO ₄ .2H ₂ O Monoclinic									Euhedral/subhedral/anhydral Shape:			Building boards; cement; fertilizer
21. Barite/baryte	BaSO ₄ Orthorhombic									Euhedral/subhedral/anhydral Shape:			Drilling muds; paint; industrial mineral
RF 18. Talc	Mg ₃ (Si ₄ O ₁₀)(OH) ₂ Triclinic									Euhedral/subhedral/anhydral Shape:		<u>Soapy feel</u>	Industrial mineral; plastic and paint filler; toiletries
19. Magnesite	MgCO ₃ Trigonal									Euhedral/subhedral/anhydral Shape:			Cement refractory
Distinguishing features													

Mineral	Chem. Formula Crystal System	Colour	Streak	Lustre	Diaphaneity	Hardness	Density (g/cm ³)	Cleavage	Fracture	Habit	Crystallinity	Other	Uses
16. Malachite	Cu ₂ CO ₃ (OH) ₂ Monoclinic									Euhedral/subhedral/anhydral Shape:			Cu exploration indicator; semi-precious
34. Chrysocolla	CuSiO ₃ ·2H ₂ O Orthorhombic									Euhedral/subhedral/anhydral Shape:			Cu exploration indicator
26. Garnierite	Ni Mg silicate n/a									Euhedral/subhedral/anhydral Shape:			Ni ore contaminated with Fe and SiO ₂
23. Fluorite	CaF ₂ Isometric									Euhedral/subhedral/anhydral Shape:			Additive to glass; flux; acid manufacture
31. Beryl	Be ₃ Al ₂ (Si ₆ O ₁₈) Hexagonal									Euhedral/subhedral/anhydral Shape:			Be ore; Gem
Distinguishing features													
2. Sulphur	S Orthorhombic									Euhedral/subhedral/anhydral Shape:		<u>Smells like rotten egg</u>	Waste
15. Azurite	Cu ₃ (CO ₃) ₂ (OH) ₂ Monoclinic									Euhedral/subhedral/anhydral Shape:			Cu ore; exploration indicator
25. Rhodonite	MnSiO ₃ Triclinic									Euhedral/subhedral/anhydral Shape:			Gem; mineralisation indicator
Distinguishing features													

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6 MAPPING AND GEOLOGICAL STRUCTURES

A Geology map shows the geology of an area upon a base map. A base map may be either of two main types (1) planimetric maps, that have areal detail such as settlements, roads and streams etc on a planar surface where no relief is shown, or (2) topographic maps, which show relief in addition to the planimetric detail. It is the topographic map that is most useful for detailed studies.

6.1 BASIC CONCEPTS FOR GEOLOGICAL MAPPING TOPOGRAPHIC MAPS

There are many types of topographic maps and every country, perhaps even state, has their own preferred rendition. However, there are certain features that are common to all topographic maps and they must be fully understood before attempting to interpret geological maps.

6.1.1 Projection

A map is a two-dimensional (flat surface) representation of the three-dimensional Earth's surface in which shape, size and relative positions of natural or man-made features are illustrated at greatly reduced scale.

The Earth is a spherical body and to project the detail of the surface of this sphere onto a flat surface requires some manipulation. There are many different ways of manipulating projections of the Spherical Earth, but the more common are the Mercator projection which relates the sphere to a cylinder in which it preserves directional accuracy, and the Mollweide projection which is calculated mathematically and it preserves areal accuracy.

It is important to realise that no projection can preserve all of the properties of the curved surface.

6.1.2 Scale

This is the ratio of the distance measured on the map to the actual distance on the ground. The distances measured on the ground are naturally represented by much smaller distances on the map. The scale can be shown as a ratio or fraction e.g. 1:100,000 or 1/100,000 which can be interpreted as 1 cm on the map represents 100,000 cm (= 1 km) on the ground. The scale can be shown graphically in which a line representing distances on the map, such as 1 km, is drawn adjacent to the map. The scale can be described such as 4 km to 1cm or 4 cm to 1 km. This method has a tendency to be confusing yet is still in common use. The graphic scale is most useful as it will always be true if the scale of the map is changed by reduction or enlargement.

Australia is patchily covered by 1:25,000, 1:50,000, 1:100,000 and 1:250,000 topographic maps. The 1:25,000 topographic maps are the most useful of these maps since they contain the greatest detail and they are readily available. They can be found in most tourist information centres and Country stationary stores throughout NSW.

6.1.3 Grid References

The internationally accepted lines of latitude and longitude are a grid superimposed on the Earth and they are the points of reference for any location, for example Sydney is located at 33°53' S 151°12' E. The dimensions of the lines of latitude and longitude are as follows:

1 degree of latitude = 111 km

1 degree of longitude varies from 0 (poles) to 111 (equator) km

A 1:25,000 topographic map has the approximate dimensions of 20 km x 25 km. These dimensions are much smaller than the dimensions of one degree of latitude or longitude and therefore latitude and longitude are of little use for referencing the location of features on these scale maps. Consequently, the Australian grid system was established and all topographic maps have a network

of equally spaced lines superimposed on the map which relate to this grid system. The location of features on the map can be accurately designated in terms of their position within the grid, as a grid reference. The grid lines on the topographic maps are given a two figure number and the lines orientated north-south are referred to as eastings, and those orientated east-west referred to as northings. A grid reference is six figure number, with the easting given before the northing. The third digit to the eastings and northings is from an estimate in tenths of the position from the grid lines (Figure 5).

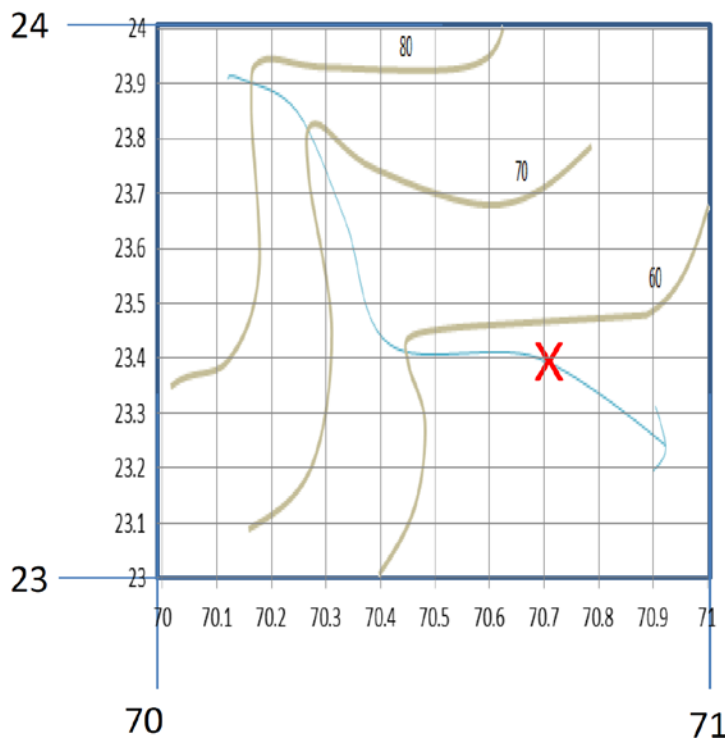


Figure 5. Navigating a map grid system using eastings and northings.

Grid reference
of x = 707234

(divide into sub
units and
remove
decimal point)

6.1.4 Legend

The legend of a map is an explanatory grouping of all the symbols used on the map. The standard symbols used on the NSW 1:25,000 topographic sheet are given in Figure 6.

Horizontal control point; Spot elevation		• 904
Sand; Sand dunes		
Sand ridges; Pinnacle; Cliff		
Forest, wood or scrubland; Rainforest		
Pine plantation; Urban recreation parkland ..		
Orchard, plantation or vineyard; Windbreak ..		
Watercourse (presence of water not implied)		
Perennial lake; Non-perennial lake		
Bore or well; Spring; Tank or small dam		
Subject to inundation; Swamp		
Saline coastal flat; Wreck, bare or awash		
Foreshore flat; Lighthouse		
Mangrove; Tidal ledge or reef; Shoal		
Breakwater; Rock, bare or awash		
Wharf; Jetty or pier		
State or territory boundary		
Reserved area boundary		
Prohibited area boundary		

Figure 6. Standard symbols used on a topographic map.

6.1.5 Directions

The magnetic compass is an instrument providing a direction (or bearing). At any given location on the Earth's surface the north-seeking end of the compass needle always points to a direction called magnetic north. True or geographical north is always at an angle (declination), about 11o to the west in Sydney, of the magnetic pole. Both geographic and magnetic north directions are usually shown on a topographic map.

If you face north, your back is to the south, the east is on your right and west on your left. These (N, S, E and W) are the four cardinal points of the compass. By regularly dividing the ninety degrees between each cardinal point we can generate the thirty two points of the compass (Figure 7).

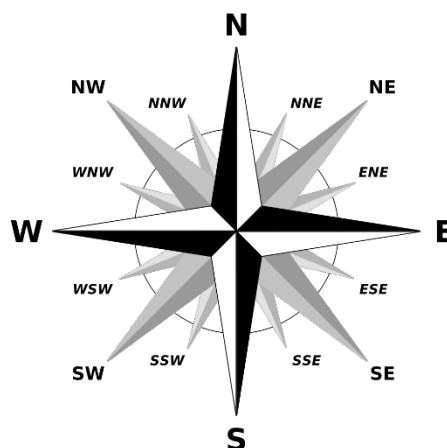


Figure 7. The cardinal points divide directions into four quadrants; the NE, SE, SW and NW quadrants. Image source: [Brosen](#) CC BY 2.5.

A direction within a quadrant may be specified by the angle between the direction and a cardinal point. This constitutes a bearing. Thus, a direction making an angle of 30° with the east cardinal point would have a bearing of $E\ 30^\circ N$ (Figure 8).

Bearings refer to directions as the angle away from the closest cardinal point (e.g. $N42^\circ E$) whereas azimuth refers to an angle clockwise from north (doesn't need a cardinal reference) and is usually given as three digits e.g. 042°

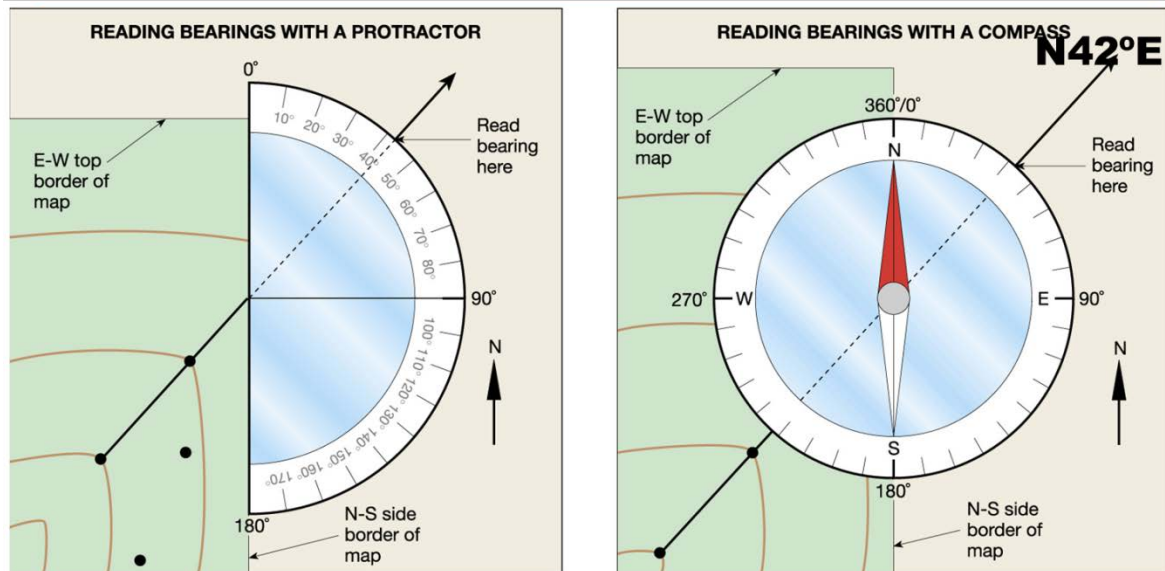


Figure 8. Bearing versus azimuth. Image source: Laboratory Manual in Physical Geology (8th edition).

A better and the preferred notation of direction utilises the clockwise division of the compass scale into 360° . The azimuth is the angle between north and the required direction; this it is read off as so many degrees east (clockwise) of North and is usually written as a three-figure number. Thus, 28° east of north is written 028° , 170° east of north is 170° (Figure 8) and north is usually written 360° rather than 000° . This method is less prone to errors in interpretation than that using bearings.

6.1.6 Distance

For measuring distances on maps a pair of dividers can be used, or less accurately, a ruler. A piece of string can be used to follow an irregular line and then straightened and measured. A sheet of paper can also be used by placing its edge along the direction of measurement and adding each short, straight section until a total length is obtained.

6.1.7 Elevation

Elevation and altitude are synonymous and mean the number of metres (or feet) above a datum (usually sea level). Elevation is measured relative to a reference datum, usually sea level. Elevation on topographic maps is shown in two ways (1) spot heights and (2) contours.

Definition of a Contour: a line that joins all points on the land surface of equal elevation or altitude.

The contour interval is the difference in elevation between two adjacent contour lines. Contours on any topographic map are drawn at a constant interval and all topographic maps have the contour interval clearly indicated.

Topographic maps show the shape of the land-surface by using contour lines. The smaller contour interval the more detailed and more realistic the depiction of the land-surface becomes. A 1:25,000 topographic map has a contour interval of 10 m which gives the greatest land surface detail

whereas the 1:250,000 map has a contour interval of 50 m which outline only the major land surface detail.

As well as representing the shape of the land surface, contour lines also afford information on the gradient (steepness of slope) of a surface (Figure 9).

Contour lines are spaced evenly when the slope of the ground is uniform. If the lines are relatively widely spaced the slope is gentle and if they are close together the slope is steep (Figure 9). Most slopes in nature are not uniform. A slope that has a steep top portion tapering down to a gently sloping lower slope are referred to as concave slopes (Figure 9), and a slope that has a gently sloping upper slope dropping off to a steeper lower slope is a convex slope.

Contours always bend upstream to cross a river and this can be used to determine the direction of flow of a river.

6.1.8 Topographic Profiles

A topographic profile is a section through the land surface showing the surface irregularities of the land in cross-section is . Such profiles or sections can be drawn from a contour map by the following procedure:

1. Fold a piece of blank paper to make a straight edge.
2. Lay this straight edge on the map along the line where the profile is to be taken.
3. Mark on the paper the exact place where each contour line meets the straight edge.
4. Number each mark on the paper to correspond to the elevation of the relevant contour lines.
5. Construct a vertical scale on a sheet of graph paper ranging from sea-level to the maximum contour height intersected.
6. Lay the straight edge with the markings along the horizontal scale of the graph paper.
7. Transfer the location of each contour line onto the graph paper by marking the correct height vertically above the mark.
8. Join the transferred points on the graph paper with a smooth line to represent the topography.

6.1.9 Vertical Exaggeration

In drawing profiles (or sections), the horizontal (H) scale should be the same as the original map scale. The vertical (V) scale is arbitrarily chosen and if the vertical scale is the same as the horizontal scale (i.e. $V = H$) a profile is said to be drawn at natural scale. However, if the vertical scale is different from the horizontal scale then vertical exaggeration (V.E.) has been introduced. Vertical Exaggeration is simply calculated as V/H .

Examples:

Horizontal scale (H)	Vertical scale (V)	Vertical Exaggeration (V.E.)
1cm = 100m	1 cm = 20 m (= 5cm = 100m)	5
1cm = 100m	1 cm = 25 m (= 4cm = 100m)	4
1cm = 100m	1cm = 50m (= 2cm = 100m)	2
1cm = 100m	1cm = 200m (= 0.5 cm = 100m)	0.5

Scale is arbitrarily chosen and the vertical exaggeration is recorded as $V = 10 \times H$ scale, for example when choosing 10 times vertical exaggeration. If the vertical and horizontal scales are kept the same (i.e. $V = H$), the inclination of rock strata, faults and folds may be drawn beneath the surface without requiring any mathematical correction. It is preferable to keep $V=H$ in all cross sections.

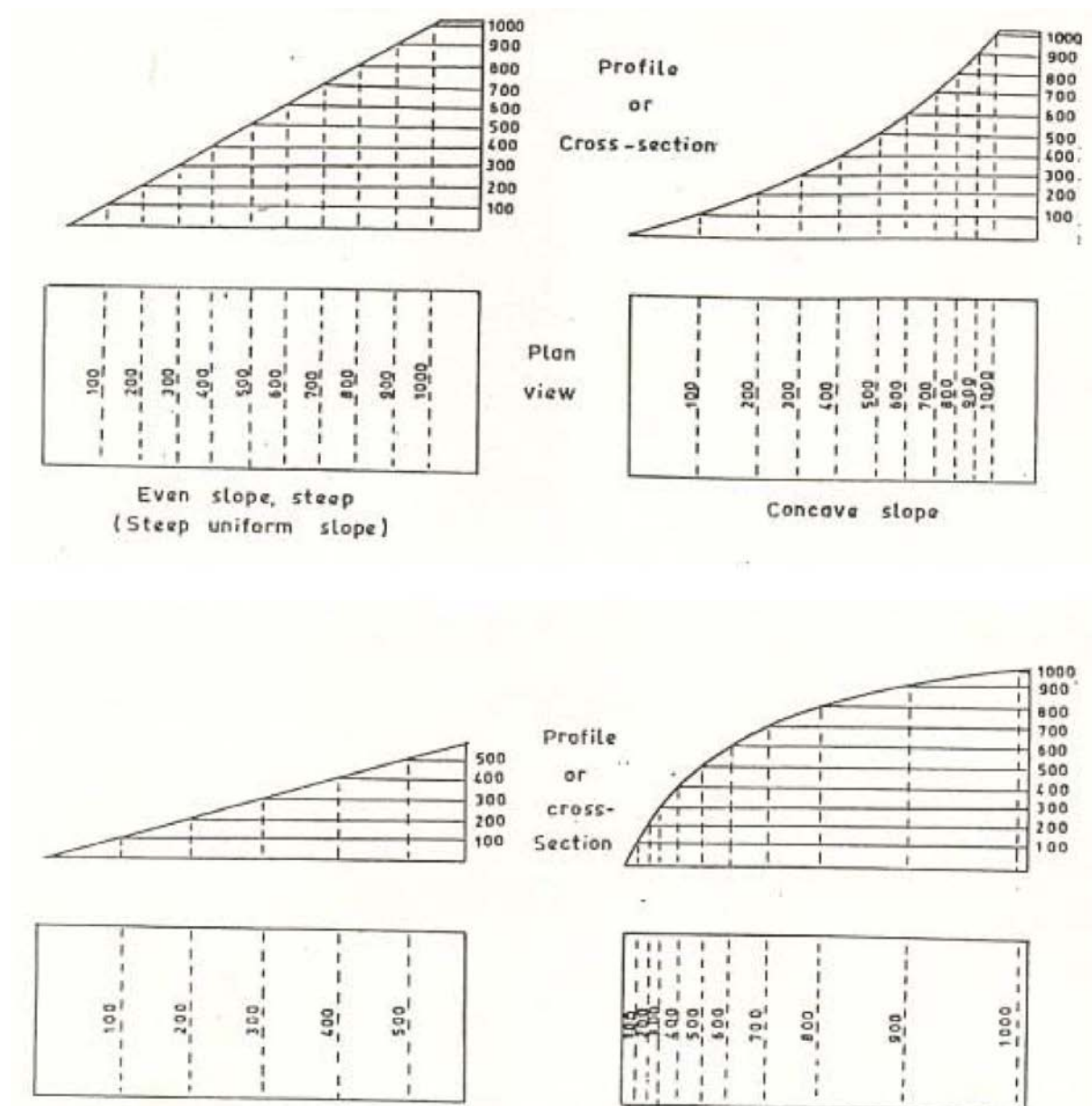


Figure 9. Slopes and contour lines.

6.2 THE STRATIGRAPHIC COLUMN

Stratigraphy is the study of the sequence and correlation of stratified rocks leading to the placement of these rocks into a universally accepted time scale. The subtleties of stratigraphic correlation will not be dealt with at this early stage.

The stratigraphic column is a tabular representation of the succession of the sedimentary rocks in an area under consideration (Figure 10).

Suffice it to say that each component of the succession is represented by its true thickness on an appropriate scale in a sequence derived by deducing the order of deposition.

When compiling a stratigraphic column, the lithologies with their thicknesses are shown on one side while the geological ages are shown on the other

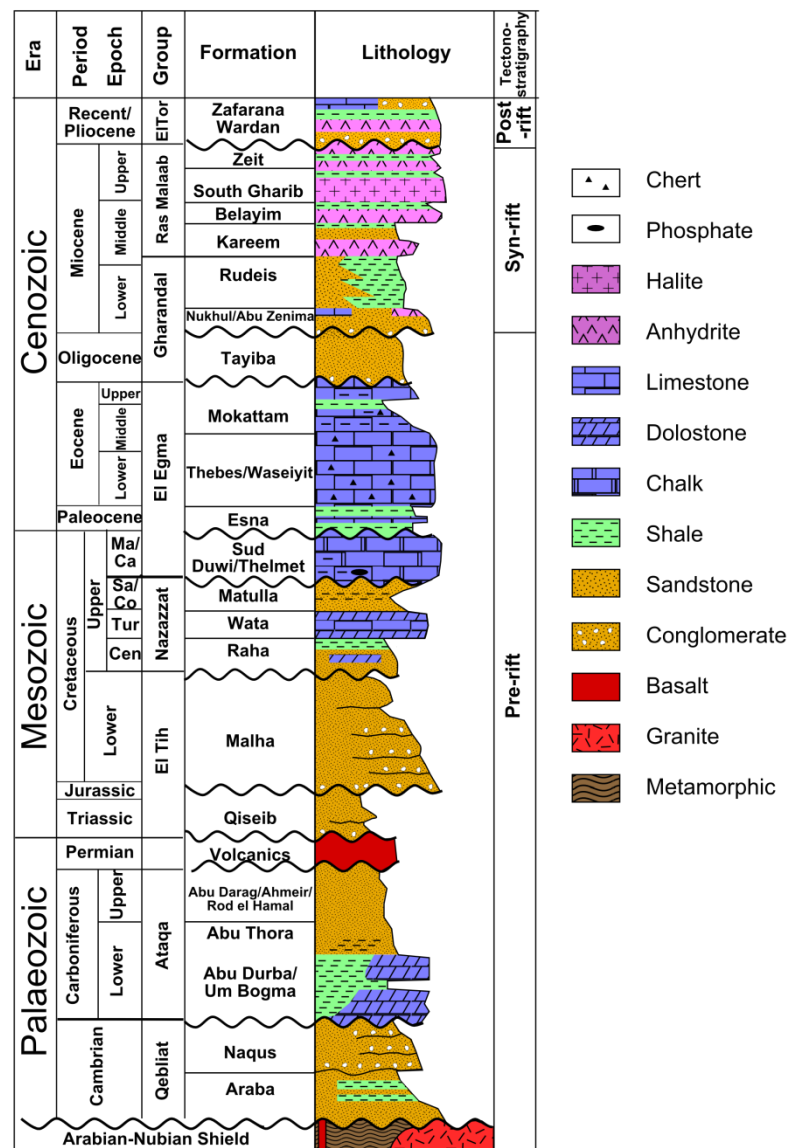


Figure 10. A stratigraphic column. Image source: [Mikenorton](#) CC BY-SA 3.0.

6.3 PLANES AND LINES

6.3.1 Horizontal and tilted strata (Planes)

Sediments are deposited in a body of still water in essentially horizontal layers as a conformable series. Any variation in the sediment supplied results in the stratification of the final rock sequence (Figure 11a). A sedimentary sequence may be uplifted to form mountains and land masses. The layers may become tilted, bent or folded (Figure 11b). Once exposed to the elements, erosion begins to wear away the sequence and a land surface forms (Figure 11c). Finally, the land surface is eroded flat to expose the truncated edges of the layers. The layers or strata dip downward into the ground and form parallel outcrops on the surface (Figure 11d and e).

NOTE: the symbols representing the different lithologies remain parallel to the bedding planes.

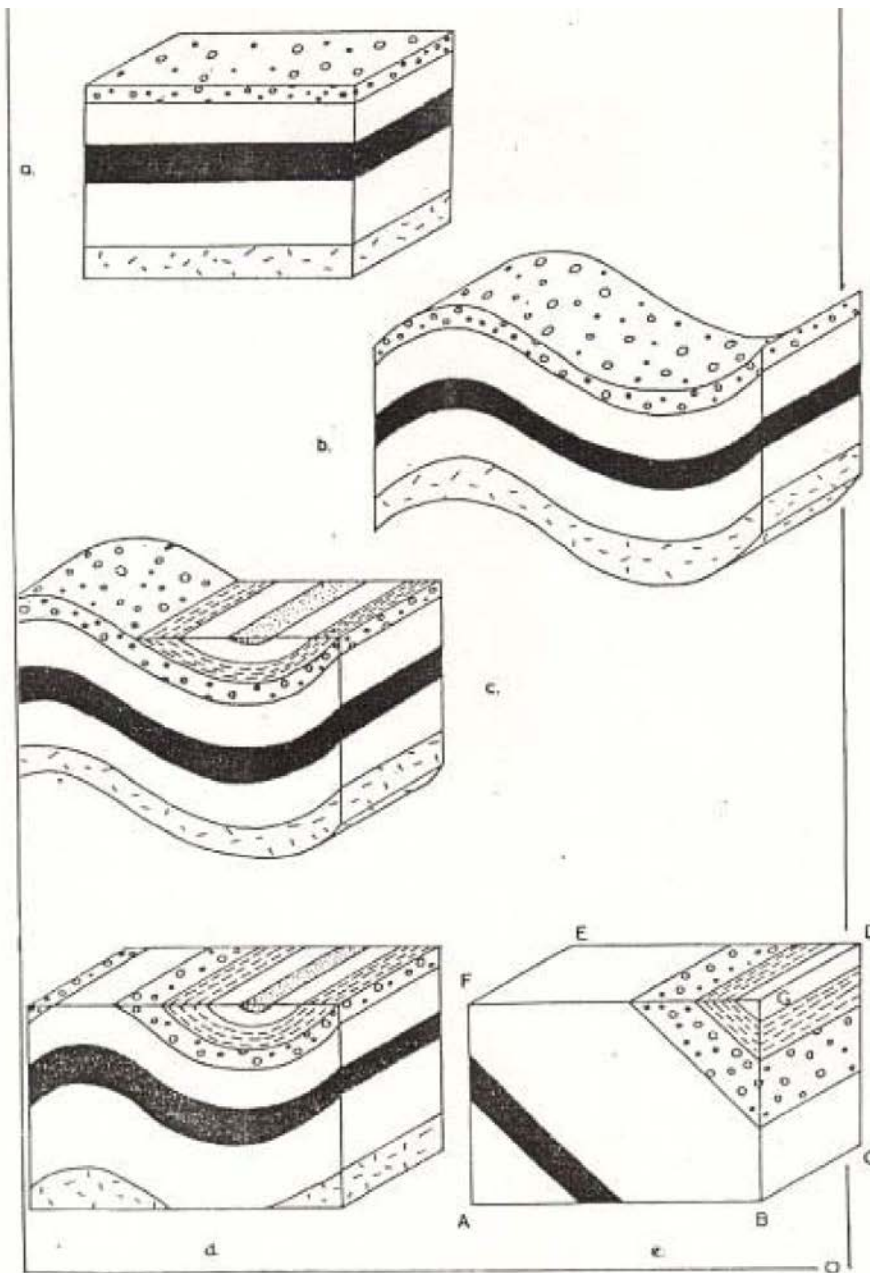


Figure 11. Block diagram depicting the formation of inclined strata.

If we draw only one vertical face of such a block (Figure 11e) it becomes a cross-section (Figure 12). It can then be seen that the layered sequence is inclined to the horizontal plan DEFG and the beds are said to exhibit dip. They intersect the horizontal plan in lines parallel to EF and DG. This is the strike direction. Thus we have:

STRIKE

The direction of the intersection of an inclined plan (or stratum) with a horizontal surface (OE, Figure 13).

DIP

The dip is the angle between an inclined plane (the bedding plane) and the horizontal measured in a vertical plane perpendicular to the strike. This is the true dip and is the maximum inclination of the bed. In specifying the dip of a rock unit it is necessary to state the direction in terms of a compass bearing and the amount in degrees from the horizontal (COA, Figure 13).

If we know the dip and the width of the outcrop, the true thickness of a bed can be calculated (Figure 14).

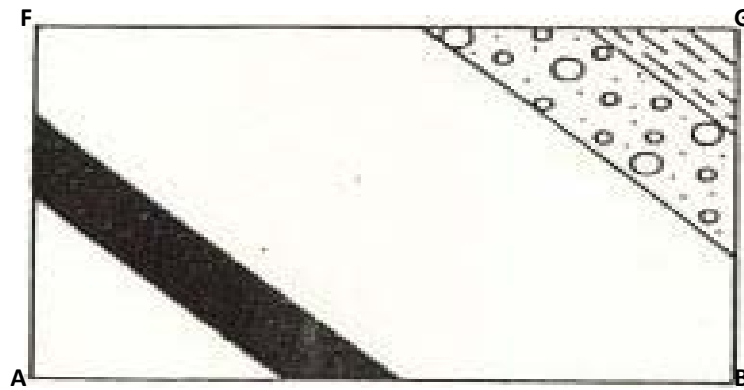


Figure 12. Cross-section showing inclined strata.

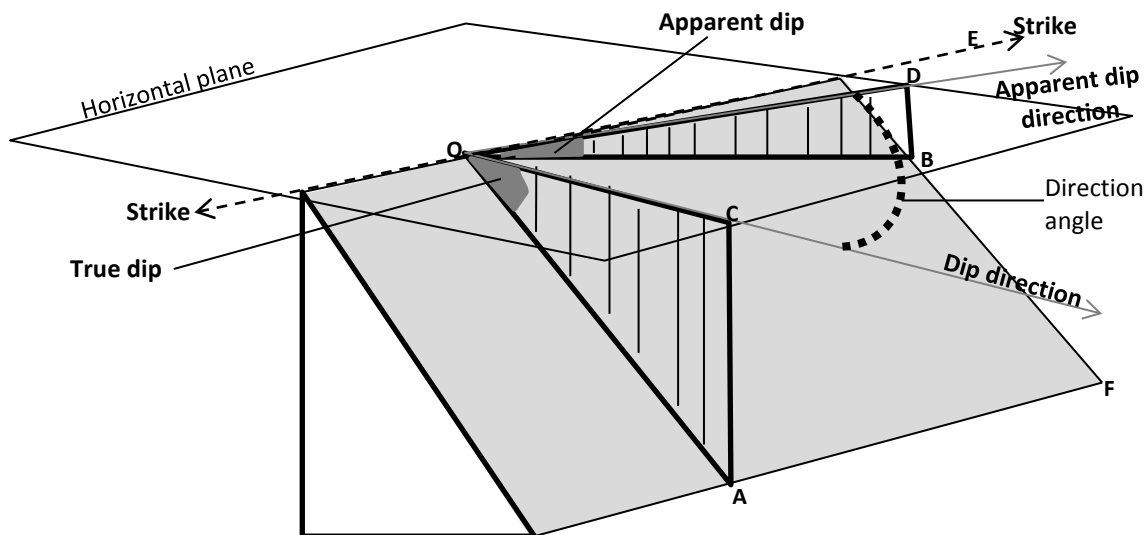
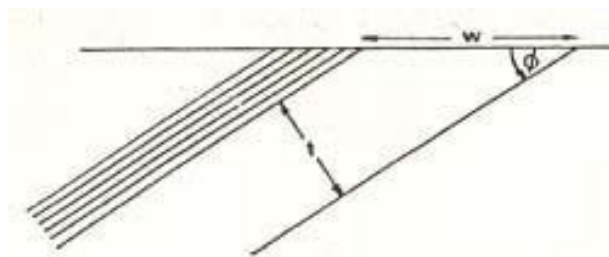


Figure 13. Diagram showing relationship between true and apparent dips. The direction of line O-C (i.e. the dip direction) is perpendicular (right angles or 90°) to the strike direction.



w = outcrop width
 ϕ = dip of bed
 t = true thickness

$$\sin(\phi) = \frac{t}{w}$$

Figure 14. Calculation of the true thickness of a bed from dip and outcrop data.

There are two common ways of representing the inclination or attitude of a planar feature in geology:

1. By giving the strike as an azimuth or a bearing and giving the angle of dip in degrees and the approximate direction of dip.

e.g. (i) 030° strike, 60° dip towards SE 030, 60°SE

e.g. (ii) N30°E strike, 60° SE dip N30°E, 60°SE

2. By giving the dip angle and the exact direction of dip (i.e. the direction of the vertical plane containing the dip angle).

e.g. 60° towards 120° 60° → 120°

The dip symbol for planes used in mapping is . The long stroke indicates the direction of strike, the short stroke indicates the direction of the dip and the number is the amount of dip in degrees.

—+— Indicates vertical dip (90°)

 Indicates horizontal dip (0°)

APPARENT DIP

The angle between an inclined plane and the horizontal, measured in any vertical plane other than that containing the true dip, is called the apparent dip. It is always less than the true dip and varies between horizontal (0°) and the true dip angle according to the direction in which it is measured. The true dip may be calculated from the measurement of two apparent dips.

DIRECTION ANGLE

The angle between the directions of true dip and the direction in which the apparent dip is measured is called the direction angle. (COD, Figure 13).

6.3.2 Determination of the True Dip from two Apparent Dips

ORTHOGRAPHIC CONSTRUCTION (GRAPHICAL METHOD)

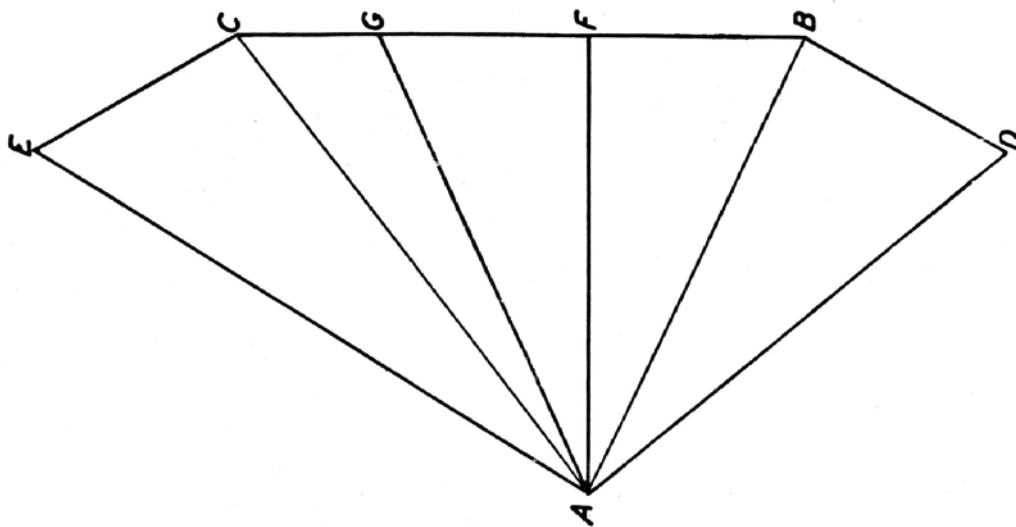


Figure 15. Construction for finding true dip from two apparent dips.

1. Plot AB and AC in the directions of apparent dip.
2. At A make the angles BAD and CAE equal to the apparent dips in the directions AB and AC respectively.
3. At any point B along AB, draw perpendicular, intersecting AD at D. Similarly, along AC, erect the perpendicular, making CE = BD.
4. Join B to C. Draw AF perpendicular to BC. Along BC mark of FG = BD. Join A to G.
5. AF is the required direction of true dip and GAF is the angle of true dip.

DETERMINATION OF AN APPARENT DIP FROM THE TRUE DIP

Orthographic Construction

- Plot AB in any convenient direction. Make the angle BAC equal to the true dip.
- Draw CD perpendicular to AB. Make the Angle BAD equal to the direction angle. Draw DE perpendicular to AD and equal to BC. Join E to A. The angle DAE is the required angle of apparent dip.

Apparent Dip Diagram

The apparent dip may be read off a set of curves shown in Figure 16, providing that the angle is known between the directions of apparent and true dip (DOC, Figure 13).

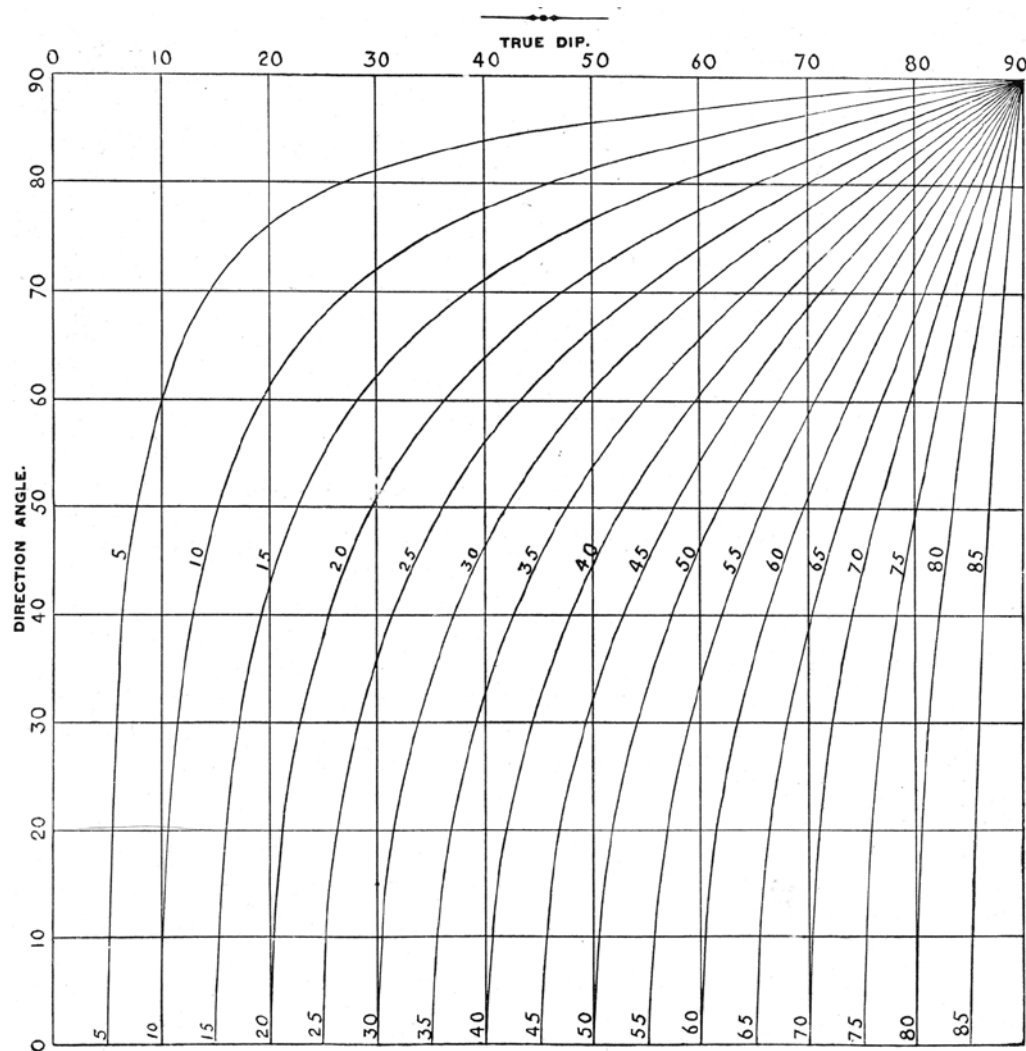


Figure 16. Apparent dip diagram (or nomogram). The curved lines are the apparent dip calculated from finding the intersection between the true dip (vertical lines) and direction angle (horizontal lines).

6.3.3 Lines (orientation and representation)

Linear features are commonly encountered in rocks. Lines can be formed by

1. Intersection of two or more planes. (e.g. fault plane intersecting bedding plane) or (trace of tilted state on a horizontal plane)]
2. Preferred dimensional orientation of minerals or grains (e.g. metamorphic lineation)
3. Fine trough-like features, microfolds or crenulations. (e.g. sedimentary grooves)

PLUNGE

The plunge is the angle between the line and the horizontal measured in a vertical plane. Angle COA, is the plunge of the line of the true dip, as well as being the true dip angle and angle DOB is the plunge of the line of the apparent dip (Figure 13).

DIRECTION OF PLUNGE

The bearing of the line measured down plunge OA is the direction of plunge of the true dip and OB is the direction of plunge of apparent dip. (Figure 13).

Another method of measuring the orientation of a line in a plane (e.g. slickensides, sedimentary grooves) is by measuring the angle between the strike direction of the plane and the trace of the line, measured in the plane. This angle is known as the rake or pitch. Angle EOB (Figure 13) is the rake or pitch of the apparent dip direction in the plane OAFE.

The symbol for lines in mapping is . The arrow points in the direction of plunge and the number is the amount of plunge in degrees.

6.3.4 Structure Contours

Just as topography can be represented on a map by topographic contours, so interfaces or surfaces of contact between rock units can be represented in the form of contours by structure contours. Structure contours are the normal projection onto a map plane of the intersections of successive equally spaced horizontal planes with a given geological structure (Figure 17). From the offset between the structure contours on the top and the bottom of a bed and the dip of the bed, the true thickness of the bed can be calculated (Figure 14).

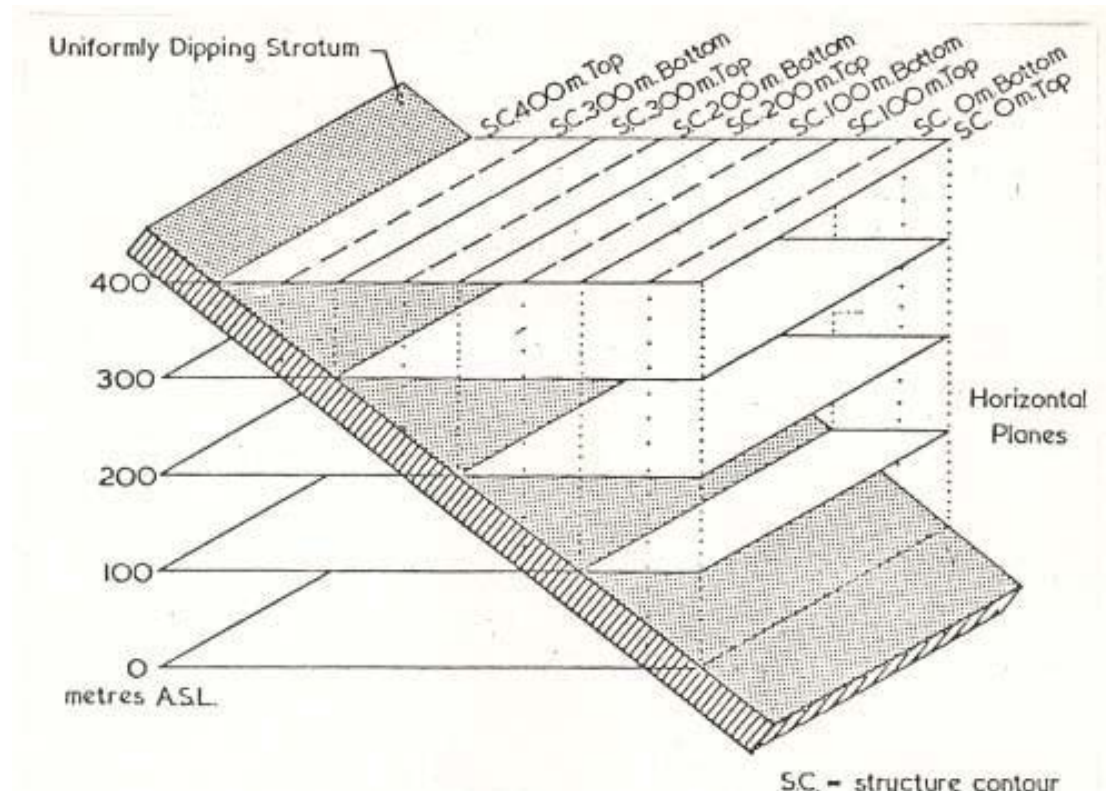


Figure 17. Diagram showing offset between structure contours of the top and bottom contact of a uniformly dipping stratum.

6.3.5 Outcrops

The intersection of a geologic structure with the topographical surface of a given area provides an outcrop pattern. From a knowledge of the outcrop pattern, using topographic contours, a set of structure contours for the geological structure can be constructed and so the occurrence of the rock body at depth can be predicted. This operation holds true for the converse, since the outcrop pattern of a particular contact can be drawn from a knowledge of structure contours and topographic contours.

The following conclusions can be made:

1. Where a topographic contour and a structure contour of the same elevation intersect, the geological feature outcrops at that point.
2. Where a structure contour of a given height and a topographic contour of greater/lower elevation cross, then the geological feature is below/above the ground surface at a depth equal to the contour difference.

6.3.6 Three Point Problems

If three points are marked at random on a flat surface, no other flat surface will pass through all three points unless it coincides with the original plane.

If three points are known to be on the one surface contact, or think bed, which is also known to be a dipping plane, this dip can be calculated and the outcrop of the feature on a given topographic surface delineated.

THREE POINT PROBLEM EXAMPLE:

If A (400 m), B (300 m) and C (600 m) are three points with their respected elevations.

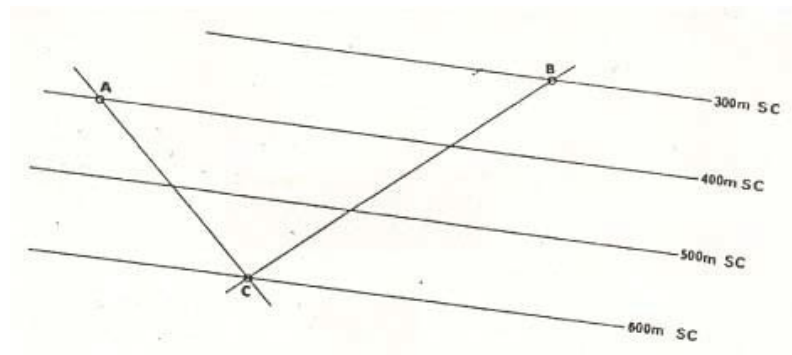


Figure 18. Construction of structure contours given three points on a plane.

1. Fall from C to A is 200 m so divide AC into two 100 m intervals (Figure 18). The midpoint represents a point on plane ABC at 500 m.
2. Fall from C to B is 300 m so divide CB into three 100 m intervals.
3. Join points of equal elevation to give structure contours.

N.B. Always leave structure contours construction on completed exercises.

6.4 GEOLOGICAL STRUCTURES

Structural Geology: Study of the structural (as opposed to the compositional) features of rocks, the geographic distribution of the features and their causes.

Structural geology deals with ways in which rocks respond to the application of deforming forces and with the structures that result from deformation. The subject is complicated by the enormous range of chemical and mineralogical composition that rocks may have and the large range in physical and chemical environments in which deformation occurs. Each rock type possess different mechanical properties, and these properties depend on the conditions under which deformation takes place. The result is a great variety of responses that manifest themselves in the diverse structures displayed in the crust of the earth. It is, of course, these structures, such as various types of folds, faults, foliations, lineations, and joints, that are of direct interest to the field geologist and of greatest importance for delineating the form of an ore body, the extent of an oil field, or the structural history of an area.

6.4.1 Types of Geological Structures

Conformable (concordant) series – Two or more strata deposited parallel, one immediately after the other (Figure 11).

Homocline – All strata dip in the same direction with constant uniform dip (Figure 11e).

Hiatus – A time gap between parallel strata.

Unconformable (discordant) series – If a conformable series is tilted or folded and then eroded, the next submergence will result in the following (younger) stratus being deposited on the truncated ends of the older strata at an angle (the angle of discordance) (Figure 19).

An unconformity is represented on a geological map by the symbols in Figure 20.

Outlier – A small area of (generally sedimentary) rock surrounded on all sides by rocks older than itself.

Inflir – A small area of (generally sedimentary) rock surrounded on all sides by rocks younger than itself.

Flow – A sheet of volcanic rock that has flowed on the surface of the ground as lava.

Neck – The pipe or conduit of a volcanic eruption. When exposed by denudation, it shows a small area of igneous rock surrounded by country rock.

Dyke – A more or less wall-like mass of igneous rock intruded into a fissure in a pre- existing rock mass across the existing stratification.

Sill – Injection of igneous rock parallel or nearly parallel with the stratification of flat- lying or gently dipping beds.

Batholith – A large mass of plutonic rock which has invaded the Earth's crust at a great depth from the surface.

Folded strata – Sedimentary and metasedimentary rocks within the Earth's crust deform by a process known as folding. Folds are defined by a curvature in some recognisable set of surfaces (usually bedding), of which the probably original configuration is known (almost flat-lying for bedding). There is no clear evidence on details of the process by which folding takes place and many conflicting theories exist. Folding or deformation of rocks in general seems always to accompany some form of regional metamorphism. In highly folded regions foliations such as slaty cleavage, crenulation cleavage and schistosity are oriented parallel to the axial plane of folds (that is they bisect the interlimb angle).

Geological sections of folds (with horizontal fold axes) are constructed by projecting dips of various beds from different points on the surface and sketching in the shape of a given stratigraphic boundary as a smooth curve. Some types of folds are:

Anticline – A fold in which the flanks diverge downwards and the stratigraphically older rocks occur on the concave side of the fold (Figure 21a).

Syncline – A fold which is concave upwards with the stratigraphically younger rocks in the flexure formed of older rocks (Figure 21b).

Monocline – a local steepening of an otherwise uniformly dipping or horizontal sequence of rocks, so that an anticlinal bend occurs above and a synclinal bend at a lower level (Figure 21c).

In general these terms have a stratigraphical significance. The plane where the dip changes direction is termed the fold axis and in plan is denoted by a line with two arrows pointing the way in which the strata dip on the limbs of a fold. The arrows point towards a synclinal axis (Figure 22a) and away from an anticlinal axis (Figure 22b). The axis may be horizontal (Figure 22a, b) or plunging (Figure 21, a & b).

Faulting – Fractures is the general term for a break in the rock sequence. If the movement is microscopic across the fracture then the discontinuity is called a **joint**, but if the break is visible and measureable the discontinuity is termed a **fault**. Faults interrupt and offset an otherwise continuous stratum. Faulting may occur along a plane or a curved surface or along a wide zone of shattered, brecciated rocks. In elementary mapping a fault is usually assumed to be a planar surface with strike and dip measured as for bedding planes. Sometimes to avoid confusion with the dip of strata associated with the fault, the inclination of the fault plane is measured from the vertical and called the hade (angle CAD, Figure 23). This is the complement of the dip. The side of the faulted area that appears to have moved upward relative to the other side is referred to as the upthrow side (or hanging wall). Conversely the other side is the downthrown side or footwall (Figure 23).

The amount of displacement which has taken place across a fault plane can be specified. It can occur in any direction within the fault plane and can be resolved into components (Figure 23).

The total displacement is called the net slip (AB) and it can be resolved into two components within the fault plane:

1. Dip slip – The component of displacement in the direction of the dip of the fault (AC).
2. Strike slip – The component of displacement parallel to the strike of the fault (BC).

The positions of displaced outcrops of a marker horizon on the ground surface may be due to the joint operation of faulting and denudation. The actual displacement of the outcrops depends upon:

1. The dip of the fault
2. The throw of the fault
3. The dip of the marker horizon
4. The amount of denudation

The dip slip can be further resolved into two components within the vertical plane normal to the strike of the fault:

- a. Heave – the horizontal component of dip slip (DC)
- b. Throw – The vertical component of dip slip (AD).

THE RELATIONSHIP BETWEEN THE DIRECTION OF DIP OF THE FAULT AND THE DOWN- THROW SIDE:

1. Normal fault.

The dip of the fault plane is towards the downthrown side (Figure 25a). These types of faults were historically first identified from coal mines in Britain, where they commonly dipped steeply and were abundant. They reflect extension of the rock sequence.

2. Reverse fault.

The dip of the fault plane is away from the downthrown side (Figure 25b). Low angle, reverse faults with dips less than 45° are termed thrust faults.

3. Vertical fault.

The fault plane dips at 90° and relative movement is commonly horizontal. Where horizontal movement can be demonstrated, the fault is termed a wrench, tear or strike-slip fault.

RELATIONSHIP BETWEEN THE STRIKE OF THE FAULT AND THE STRIKE AND DIP OF THE DISPLACED GEOLOGICAL UNIT.

1. Strike fault.

The strike of the fault is parallel to the strike of the displaced unit.

2. Dip fault.

The strike of the fault is parallel to the dip of the displaced unit.

3. Oblique fault.

The strike of the fault is at an angle to both the strike and dip of the displaced unit.

When planar dipping beds are faulted it is usually only possible to specify the dip slip and the components of dip slip. To determine the complete elements of a fault it is necessary to have some transgressive marker (e.g. a dyke, fold axis) as well as the dipping beds. In general, to ascertain the complete displacement of a fault, it is necessary to find the distance, measured within the fault plane, between two points from either side, which were originally coincident. These two points are called **piercing points**. Problems of this type can be solved by means of structure contours.

In the case of a vertical fault with purely vertical movement, the throw is measured directly from any vertical section and the heave is nil. For a dipping fault, **throw** and **heave** are determined from a vertical section across the map which must satisfy three conditions:

1. It must be parallel to the true dip of the fault plane or only the apparent throw and heave can be measured
2. It must cut the same marker horizon on either side of the fault.
3. It must be in such a position that a surface profile can be drawn.

Joints – Fracture planes that appear to be incipient faults with no visible displacement are classified as joints. This lack of visible displacement in a direction parallel to the plane of a joint distinguishes it from a fault.

Joints are the commonest of secondary structures in rocks and although apparently the simplest, being merely cracks, they include a variety of types of diverse origin.

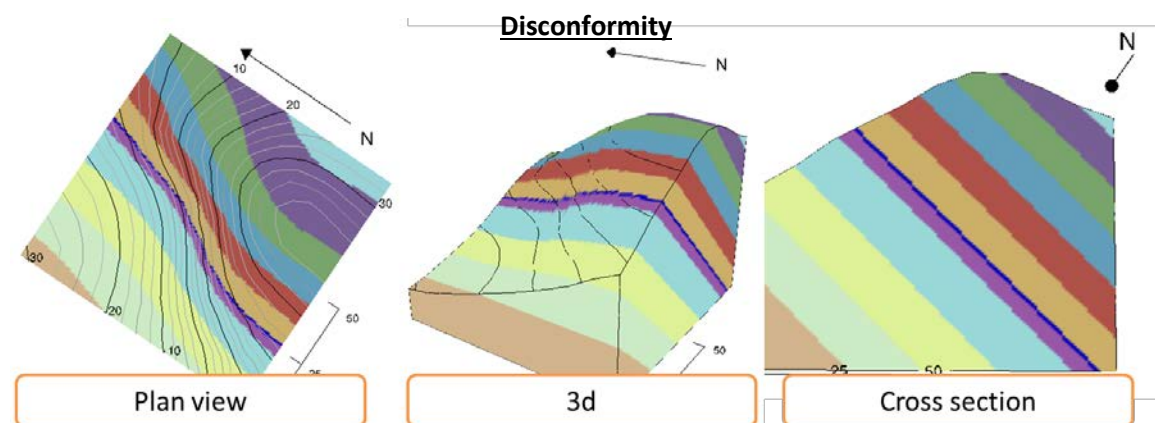
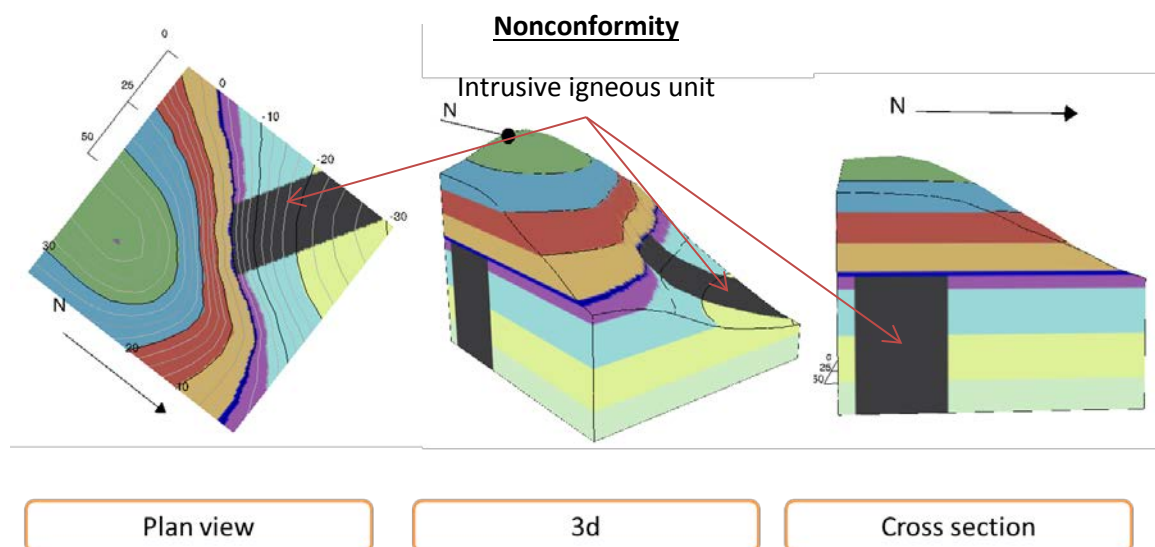
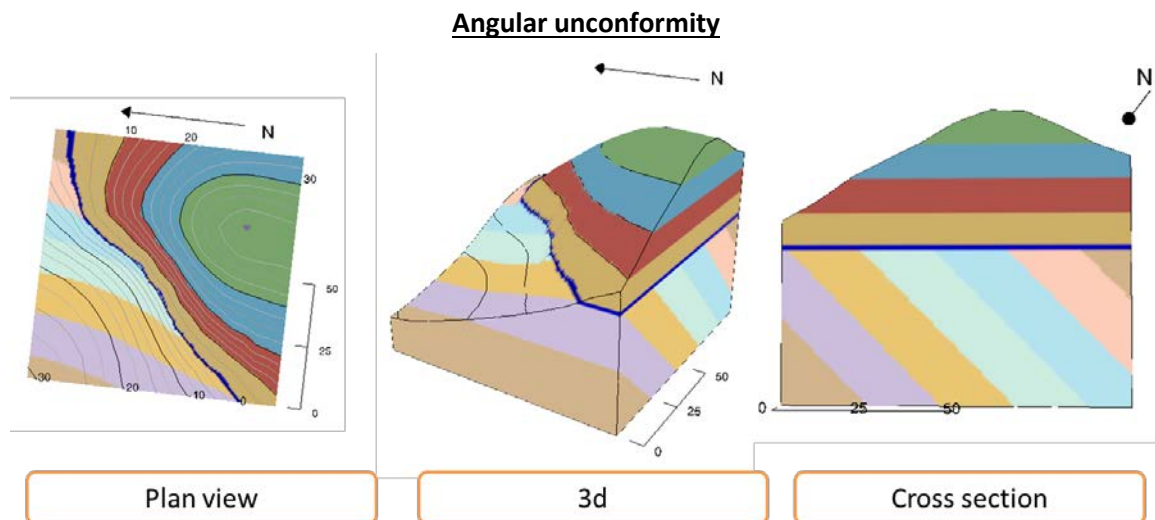


Figure 19. Block diagram illustrating types of unconformable strata. Images made in [VisibleGeology](https://www.visiblegeology.com/).

	<i>Unconformity</i>
	<i>Angular unconformity</i>
	<i>Disconformity</i>
	<i>Nonconformity</i>

Figure 20. Unconformity symbols used in geological maps Image source: [Emerton, L.](#) CC BY 4.0.

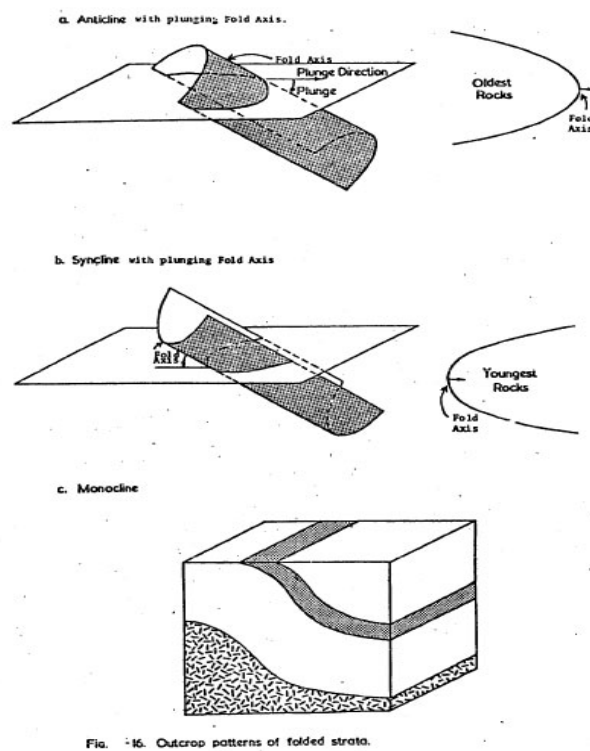


Figure 21. Outcrop patterns of folded strata.

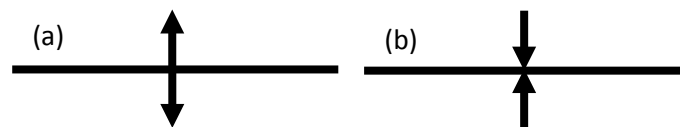


Figure 22. Symbols used to denote anticlinal (a), and synclinal (b) axes.

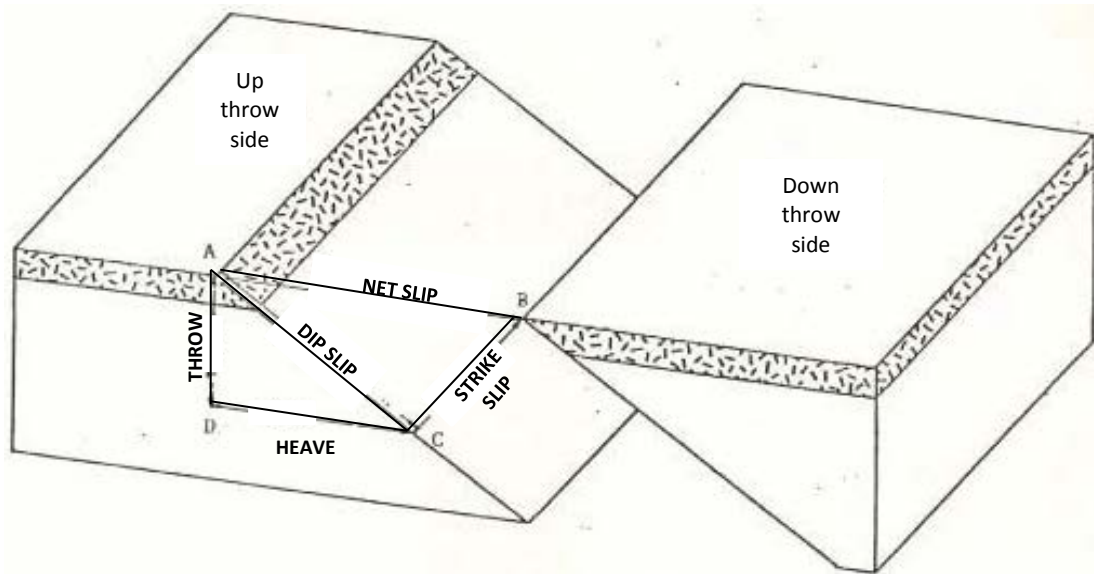


Figure 23. The components of the displacement of a fault.

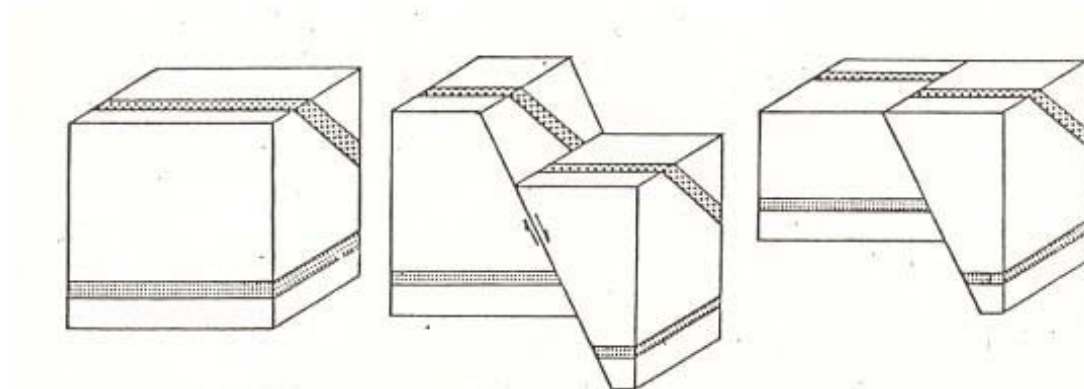


Figure 24. The effect of dip slip faulting and denudation on marker horizons.

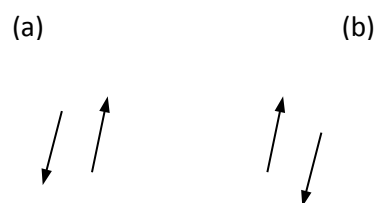


Figure 25. Cross-sections illustrating normal (a) and reverse (b) faulting. Image source: [USGS](https://www.usgs.gov/). Public Domain

6.5 PROCEDURES IN FIELD MAPPING

In mapping a specific area, a frequently used technique is traversing. This method involves walking over the area making notes of observations and measuring directions and distances covered. Any recognizable landmarks or surveyed points are called 'stations' and are numbered in order of observation. The routes taken between the stations are called the legs of the traverse. These measurements locate the position of the traverse. There are various methods of traversing over a given area:

1. Linear traverse – The observer walks over an area in a straight line keeping a constant bearing. One or more such traverses can be made over an area.
2. Open traverse – Each leg of the traverse is a straight line but bearing is changed at every station. The observer heads off in a new direction at each station, noting the change in bearing.
3. Closed traverse – Essentially the same as an open traverse but this time the observer makes his way back to the first station. The field measurements may indicate that the traverse has been closed but on draughting, the unavoidable inaccuracies made during the traverse result in the last station not coinciding with the first. A correction, in the form of an error distribution, must be applied to close the traverse shown in Figure 26.
 - a. Scale down the traverse and draw a straight line, equal in total length to the entire traverse, divided up proportionately for each leg (Figure 27).
 - b. Measure the misclosure between the first and last stations and call it x .
 - c. Draw an equally scaled perpendicular equal to x over the last station.
 - d. Join the end of the perpendicular to the first station.
 - e. Project each station vertically up to the tie line to give the error at each station. The stations must be moved a scaled up amount in a direction parallel to x (Figure 28).
 - f. Connect the relocated stations to obtain the correct plot of the traverse. There should be no misclosure remaining now.

In lithological mapping the boundaries or contacts of each lithological unit are delineated. This is done by a geologist traversing over a given area, noting the distribution of the different rock types occurring in the area. Structural and any other geological features of importance are also noted and all measurements are recorded.

Inference and deduction may play a part in a mapping programme, for example where older formations are intermittently concealed beneath younger ones.

Accurate plotting of the positions of field traverses is easily facilitated by GPS.

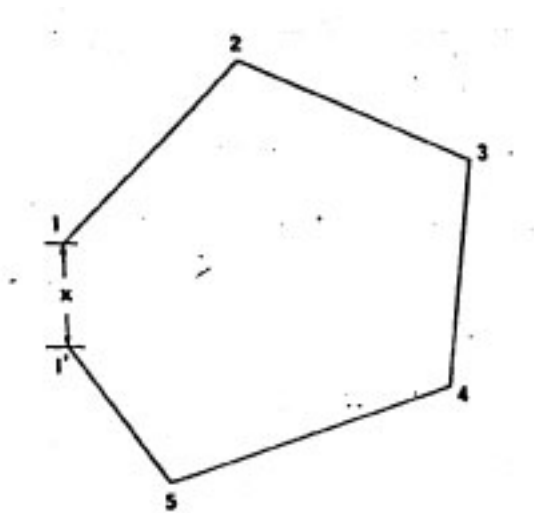


Figure 26. Scaled down traverse showing misclosure 'x'.

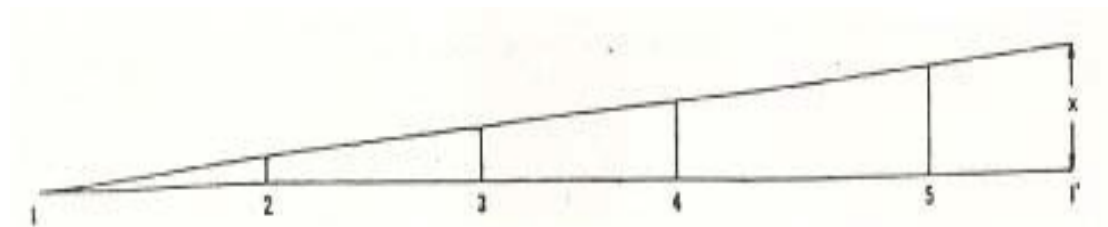


Figure 27. Misclosure 'x' divided proportionately between five stations

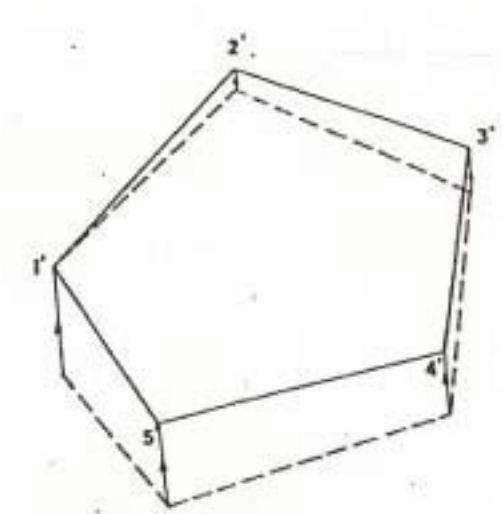


Figure 28. Corrected plot of traverse.

6.6 GEOLOGICAL HISTORY

A geological history is a statement of the sequence of geological events that have occurred in a particular area and may be derived from study of geological maps and cross-sections. If three stratigraphic units are deposited one on top of the other, the one at the bottom is the oldest and the one at the top is the youngest. Geological histories are worked out by a series of logical deductions from rock-formation relationships, such as, for example, the simple rules of stratigraphic superposition. In conjunction with known conditions of origin of the various rock types, derived in many cases from direct observation of similar deposits in the process of formation, or in other cases by laboratory experiments, a logical sequence of geological events can be inferred (Figure 29).

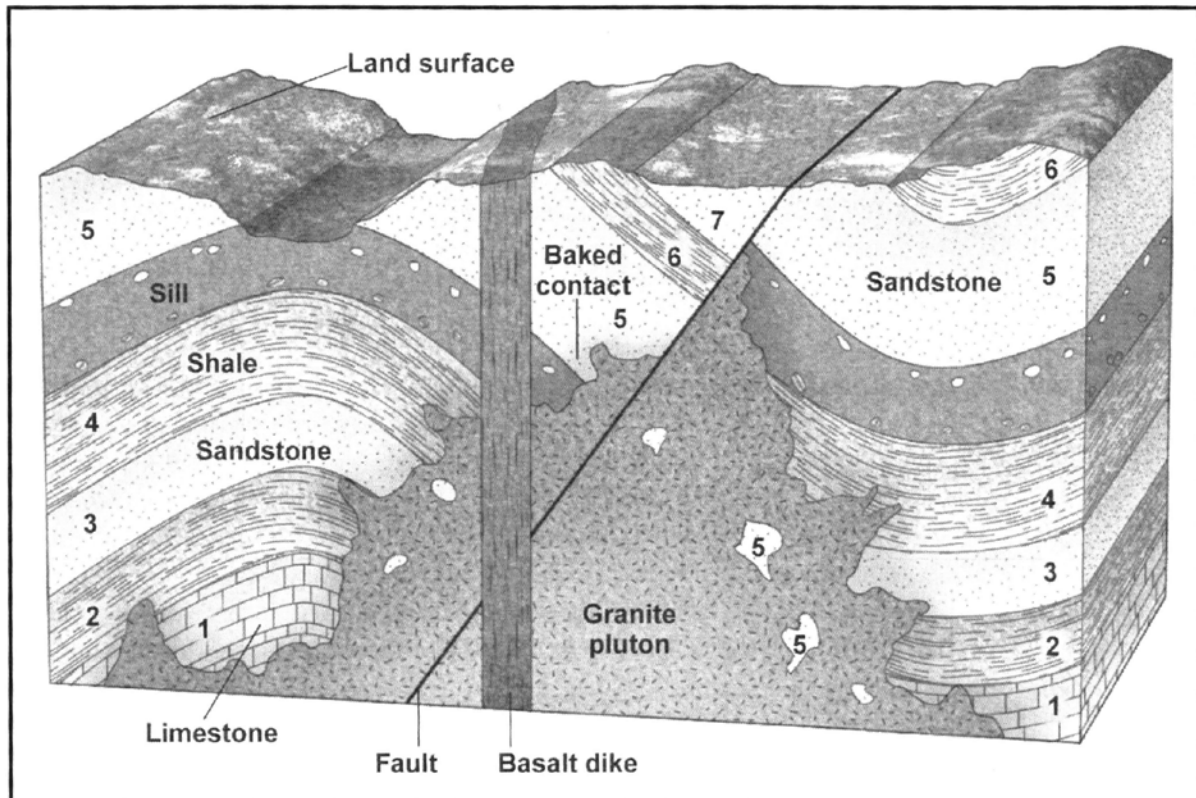
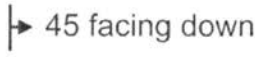


Figure 29. A hypothetical geological section. Image source: Marshak 2012, Norton and Company.

- A sequence of horizontal strata accumulates (units 1-7). Superposition dictates that unit 1 is the oldest.
- An igneous sill intrudes. Inclusions of 4 and 5 in the sill confirm that it is younger.
- Folding, uplift, and erosion take place. Folding occurs after the intrusion because the intrusion is itself folded.
- A granitic pluton intrudes the folded sediments and bakes the country rock. Xenoliths are incorporated in the magma
- A fault cuts the granitic intrusion and the folded sediments.
- A basalt dike cuts across the block, feeding a volcano. The dike cools, the volcano and the land are eroded.

GEOLOGICAL SYMBOLS

DIP AND STRIKE

 20
  45 facing down
  vertical
  horizontal
  overturned

CLEAVAGE

 70 vertical cleavage

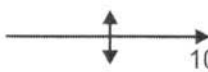
JOINTS

 strike & dip
  vertical

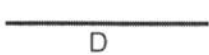
FOLDS

 anticline

 syncline

 anticline, plunge known

FAULTS

 position accurate, D = downthrown side

 displacement known

 normal fault, square on younger rocks

 thrust fault, triangles on older rocks

 position inferred

SHEAR ZONE



LINEATION

 50
 plunge of lineation

OTHER SYMBOLS

 landslide

DYKES



GEOLOGICAL BOUNDARIES

 position accurate

 position approximate

 position inferred

FOSSIL LOCALITIES

 marine fossils

 plant fossils

 spores and pollen

Geological Timescale

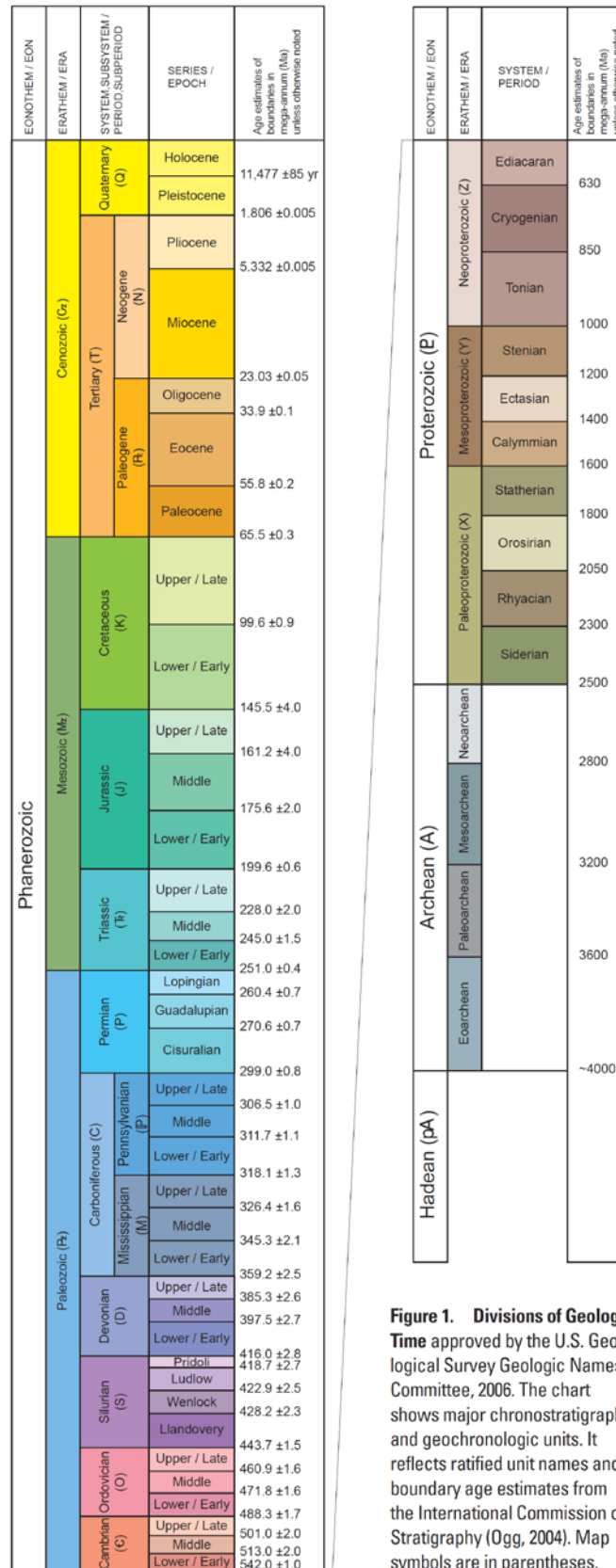


Figure 1. Divisions of Geological Time approved by the U.S. Geological Survey Geologic Names Committee, 2006. The chart shows major chronostratigraphic and geochronologic units. It reflects ratified unit names and boundary age estimates from the International Commission on Stratigraphy (Ogg, 2004). Map symbols are in parentheses.

Source: U.S. Geological Survey Geologic Names Committee, 2007, Divisions of geologic time—Major chronostratigraphic and geochronologic units: U.S. Geological Survey Fact Sheet 2007-3015, 2 p.

7 MAPPING EXERCISES

Mapping Exercise 1a: Contours and Profiles

Mapping Exercise 1b: Stratigraphy

Mapping Exercise 2: Horizontal Strata

Mapping Exercise 3: Tilted strata – 3-point problem

Mapping Exercise 4: Faulted Strata

Mapping Exercise 5: Folded Strata

Mapping Exercise 6: Sydney Geology Map

Mapping Exercise 7: Topographical Features 1

Mapping Exercise 8: Topographical Features 2

Mapping Exercise 9: Horizontal Strata

Mapping Exercise 10: Topographic Contours, Distances & Bearings

Mapping Exercise 12: Three Point Problems

Extras:

Mapping Exercise 13

Mapping Exercise 14

Mapping Exercise 15

Mapping Exercise 16

Mapping Exercise 17

Mapping Exercise 18

Mapping Exercise 19

MAPPING EXERCISE 1A: CONTOURS AND PROFILES

A Contour is a line joining points of equal elevation, above or below sea level (or some other datum). Therefore, a contour is a line on the ground surface that is horizontal, or in another sense, a contour is a line of intersection of a horizontal plane with the ground surface.

Using contours, the shape of any land surface can be simply depicted; although the accuracy of the shape is determined by: (1) the SCALE of the map; and (2) CONTOUR INTERVAL. A large contour interval (e.g. 50 m) depicts the land surface much less accurately than a small interval (e.g. 10 m), but by using the smallest interval it may clutter the map and obscure other detail. Thus, in choosing a contour interval it will be determined by the range in elevation regarding the scale of the map.

PART 1- TOPOGRAPHIC MAPS

USING BOTH THE 1:250,000 AND 1:25,000 SHEETS

1. What is the contour interval on the

1:250,000 sheet.

1:25,000 sheet:
2. If you were to go the Lands Department, where you can buy these maps, what details would you need to give them to get the two maps that you are working on.

USING THE 1:25,000 SHEET ONLY

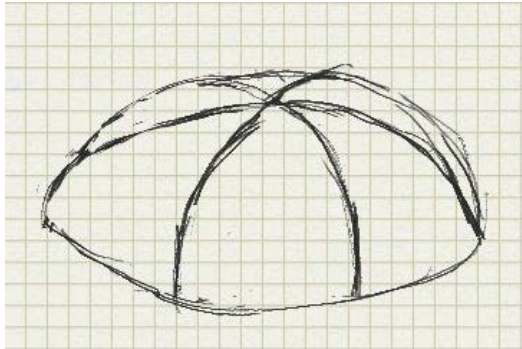
3. Some of the contours are different i.e. some are thick lines while most of them are thin. What is the significance of this?
4. What is the pattern of the contours in:
 - (a) steep land surfaces:
 - (b) flat or nearly flat surfaces:

5. Sketch the contour pattern of a river valley (in a straight part of the river or stream)
6. On topographic maps there is another indication of elevation e.g. • 325 What are these and how do you interpret them?
7. How many millimetres is equivalent to 1 km on the map?
8. Find the highest point on the map and work out its grid reference:
9. Find the lowest point on the map and work out its grid reference:
10. Determine the latitude and longitude of the most easterly point on the map.
11. Sketch below a topographic profile from GR 820230 to GR850230:

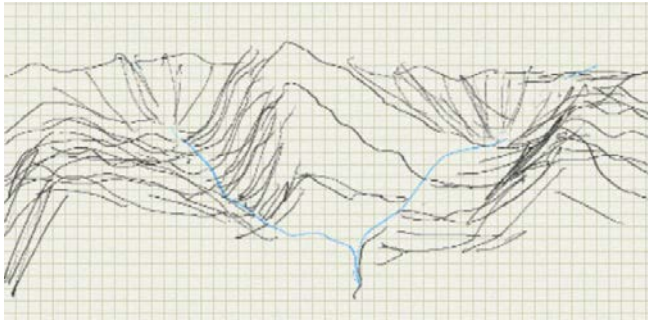


PrintFreeGraphPaper.com

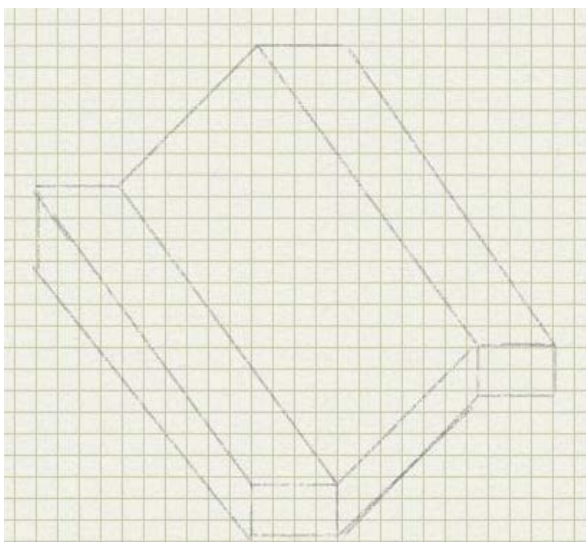
Draw contour lines (lines joining points of equal elevation) on the 3d drawings then try and represent those features to the right by creating a 2d map using topographic contours (you can make up elevations to help show what is happening with your contour lines)



A dome



Two streams divided by a ridge

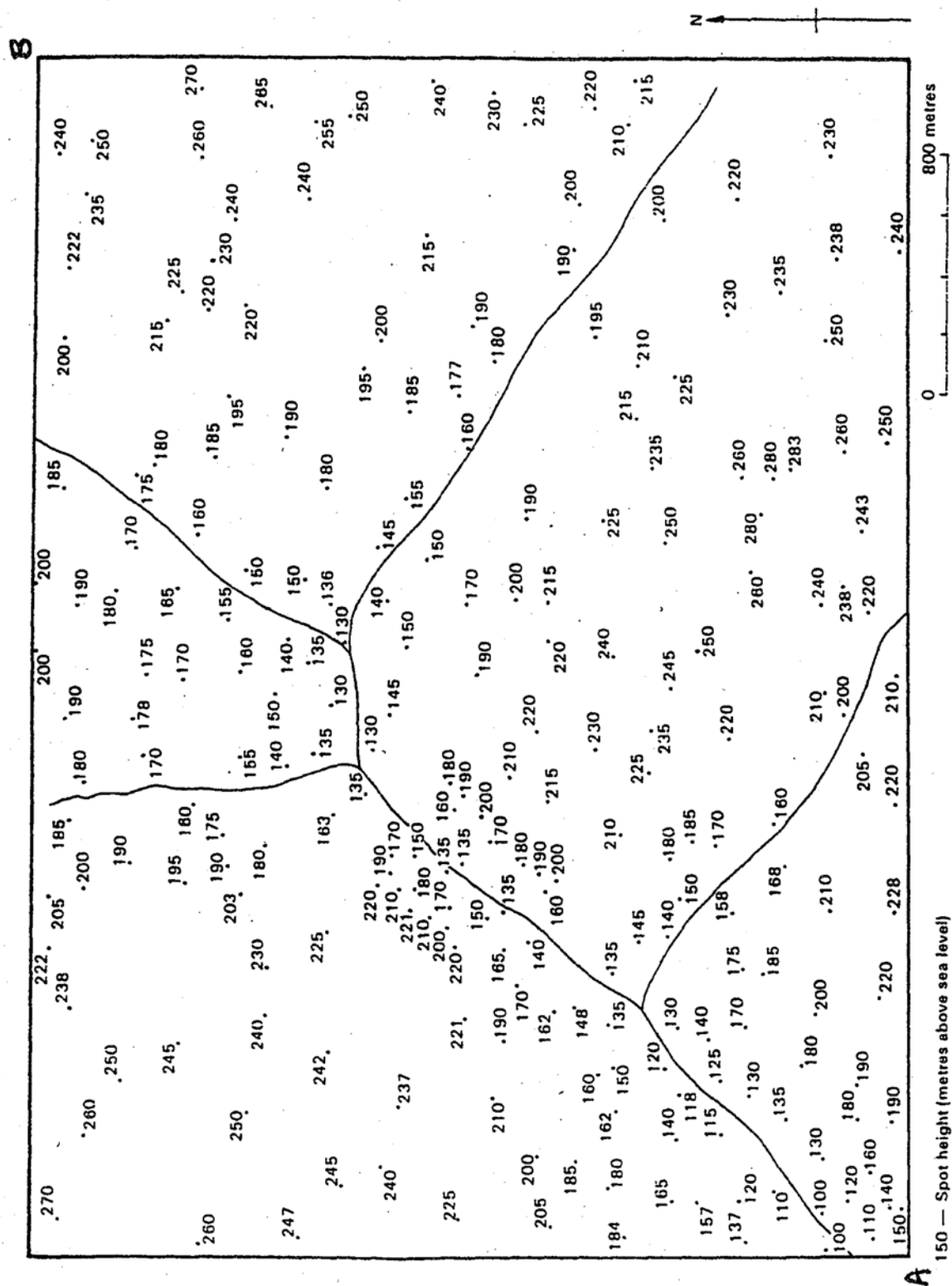


A planar feature which is sloping (don't worry about the horizontal sections)

PART 2 - FROM BASIC DATA TO A TOPOGRAPHIC MAP

On the map below, several spot heights (elevations) are shown together with a stream system. These spot heights alone do not give an impression of the land surface.

1. Construct a contour map, using a contour interval of 20 metres. (Note: 0 metres is sea level).
2. Draw a topographic profile along the line A - B, with VE = 4.
3. Comment on the shape of the land surface and describe possible geological controls on this shape.



MAPPING EXERCISE 1B: STRATIGRAPHY

PRINCIPLE OF ORIGINAL HORIZONTALITY

In any layered sedimentary rock sequence, it is assumed that the layers were originally laid down horizontally, or near horizontally.

PRINCIPLE OF SUPERPOSITION

In undisturbed sedimentary rock sequences, the uppermost rock stratum is the youngest, and any stratum is younger than the strata it overlies.

PRINCIPLE OF INTRUSIONS

Any intrusive body (igneous or sedimentary) that intrudes another body of rock must be younger than that which it intrudes.

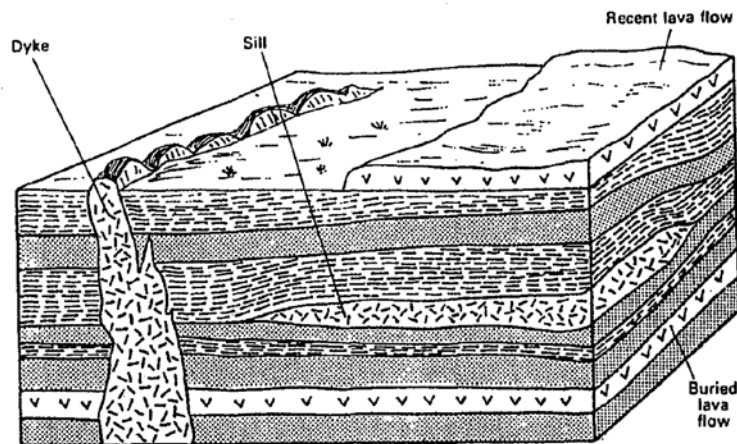
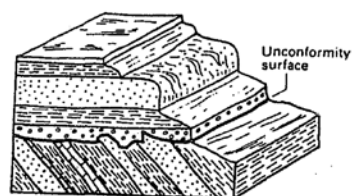


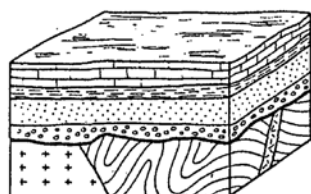
Illustration of the principles of superposition and intrusions. The oldest, near horizontal, sedimentary strata is at the base and the youngest is on top. The dyke cuts across the sedimentary strata and is obviously younger than them. The sill is also younger than the sedimentary sequence, as it intrudes them, but its relationship to them in respect of its timing is unclear.

UNCONFORMITIES

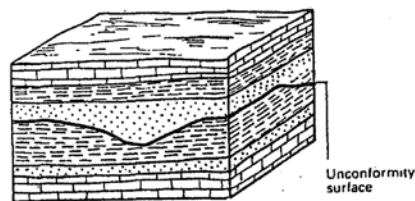
It is common to find sequences of rock strata that appear to have been cut-off by other strata. This generally denotes a break in deposition (and time) because of a change in the environment of deposition e.g. a deposition site may have changed to one of erosion due to uplift (by tectonism). The surface indicating the break in deposition is called an Unconformity, of which there are three main types:



ANGULAR UNCONFORMITY
The lower strata have been tilted and eroded before the deposition of the upper sequence



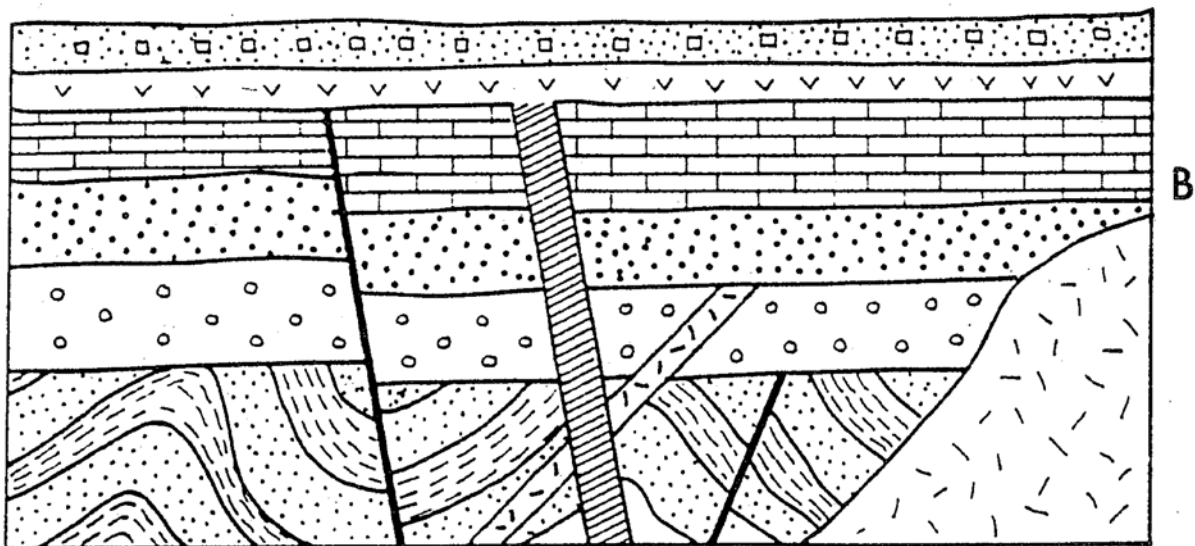
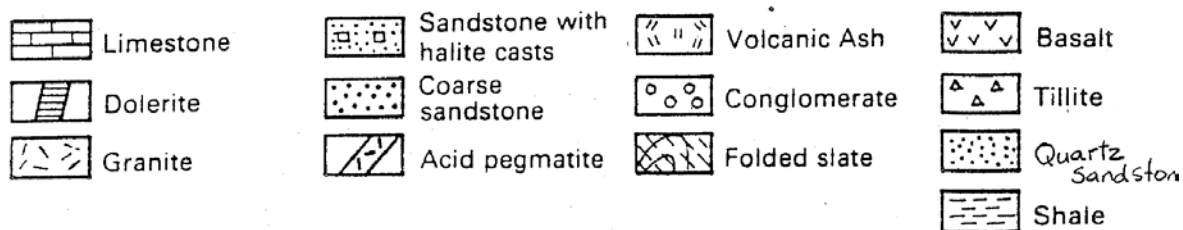
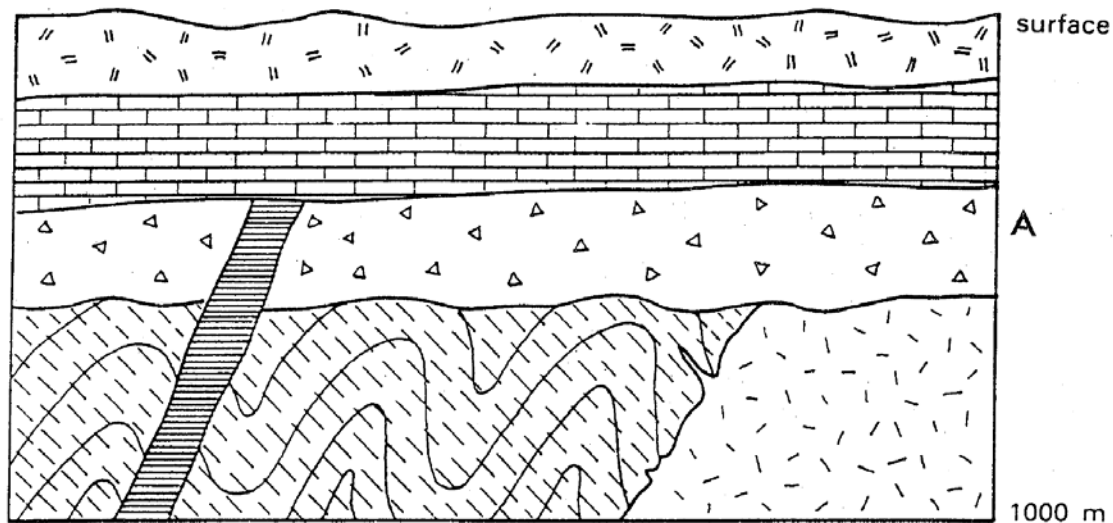
NONCONFORMITY
The sedimentary sequence overlies intrusive igneous rocks or metamorphic rocks

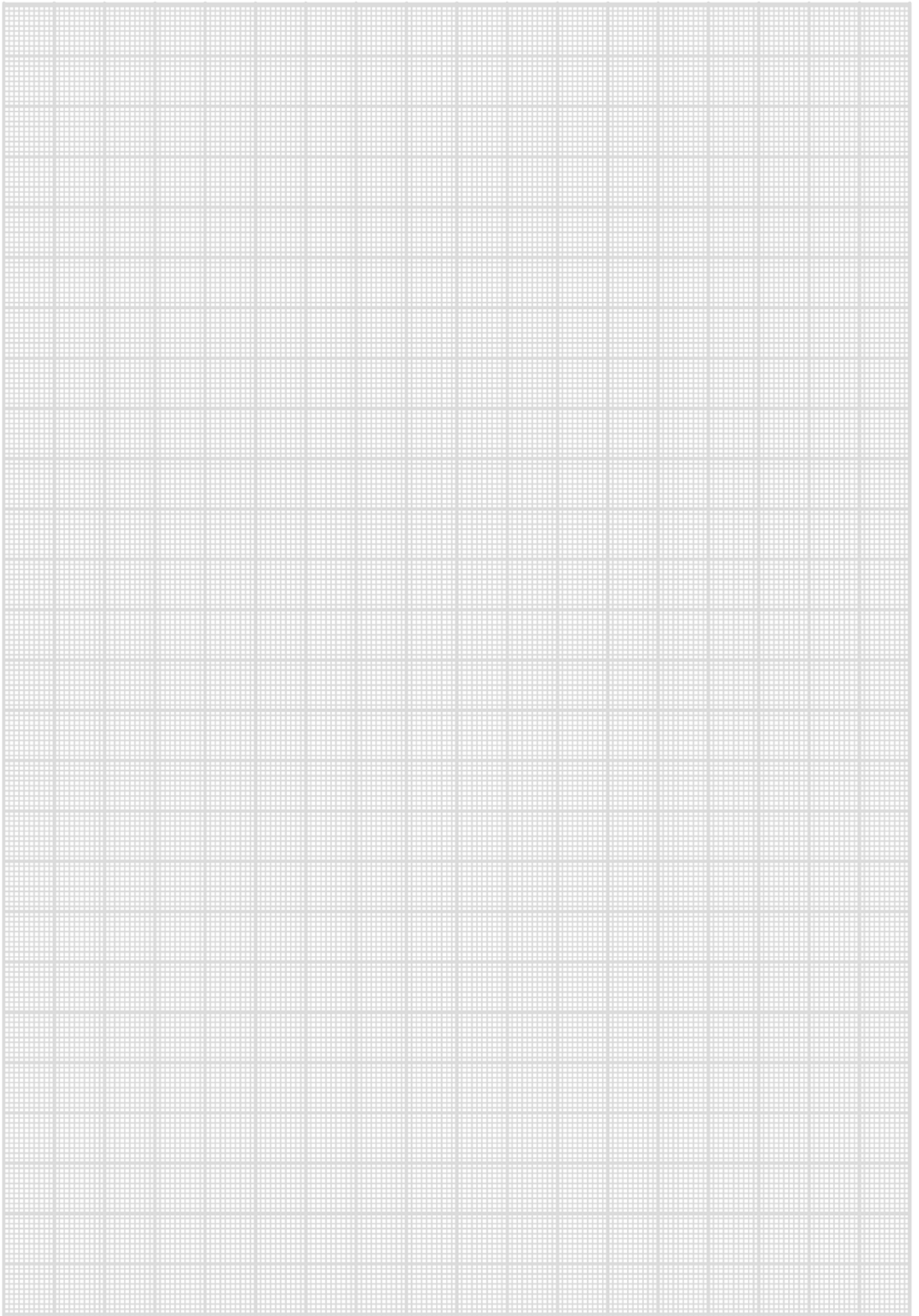


DISCONFORMITY
No angular discordance, but an erosion surface exists where the sandstone has filled a channel cut in shale

Exercise: For each of the two stratigraphic cross-sections, describe the sequence of geological events, using the principles of original horizontality, superposition and intrusions.

Construct a stratigraphic column for each, putting each rock type and unconformity in, their positions of relative age, and describe the probable cause for the unconformities. On each section indicate the unconformity surfaces.





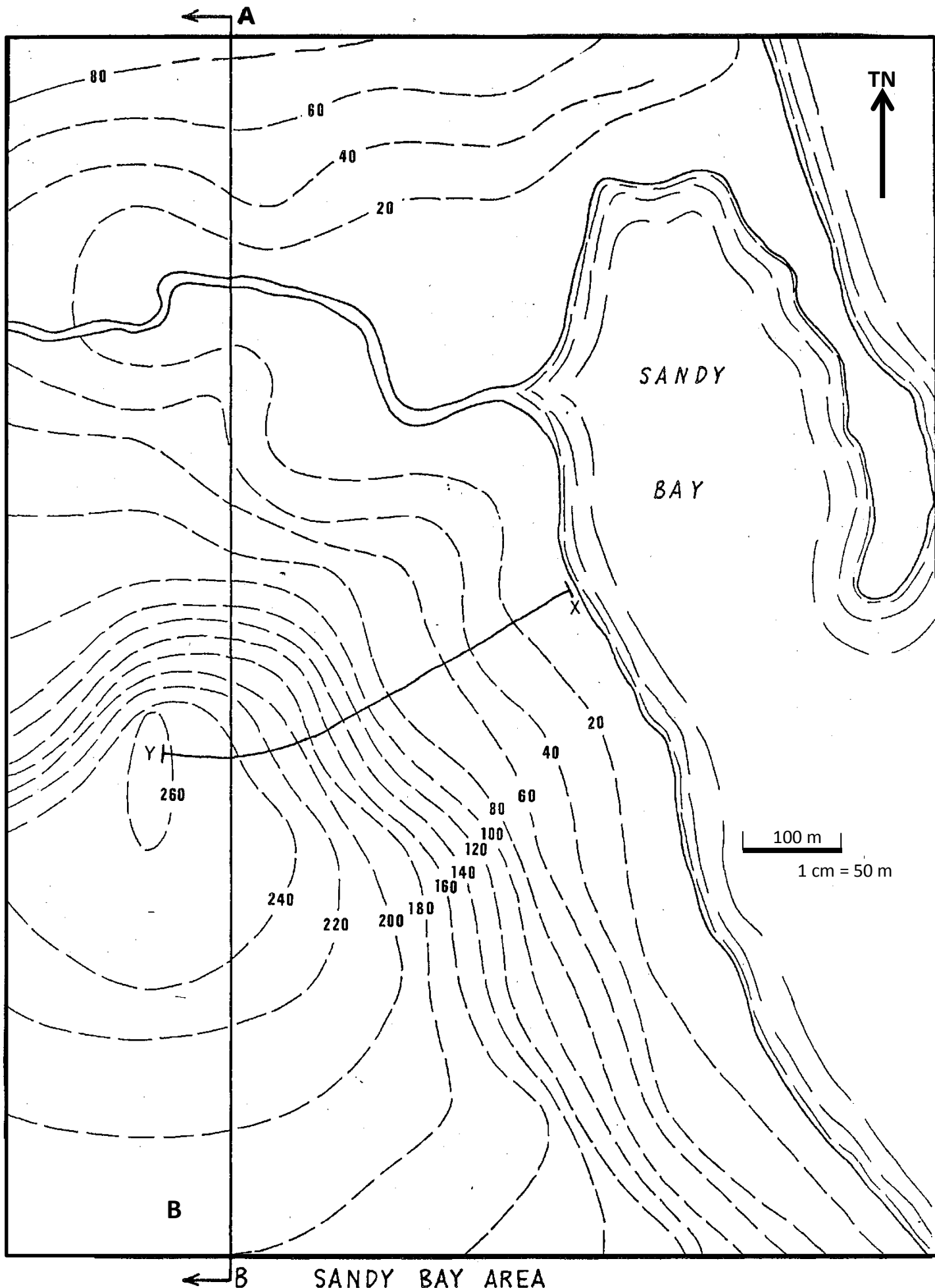
MAPPING EXERCISE 2: HORIZONTAL STRATA

By using contours, the Topographic Map of the Sandy Bay area has been constructed. A geologist made a traverse from Point X, on the coast, to Point Y, on the summit of the hill in the southwestern part of the map. Their findings were as follows:

- A. All the rock strata in the area are horizontal.
- B. From 15 m to 140 m a.s.l Quartz Sandstone crops out, although within this sandstone is a 25 m thick Conglomerate unit, whose top is exposed at 100 m a.s.l.
- C. Shale crops out in the hillside from 140 m a.s.l to the top of the hill, and within the shale is a 15 m thick Dolerite Sill (useful for road material), whose base is found at 190 m a.s.l.
- D. Below 15 m a.s.l recent alluvial Sands mantle the Quartz Sandstone (= basement), and on the river flats these sands contain rutile and zircon.

Your Tasks:

- 1. Complete a Geological Map of the Area. i.e. plot the full outcrop of all rock units.
- 2. Show on your map the best place to locate a Quarry to extract Dolerite.
- 3. Draw a stratigraphic column (to scale, with oldest at the bottom and youngest at the top)
- 4. Draw, at natural scale, a Geological Section (topography + geology) from A - B.

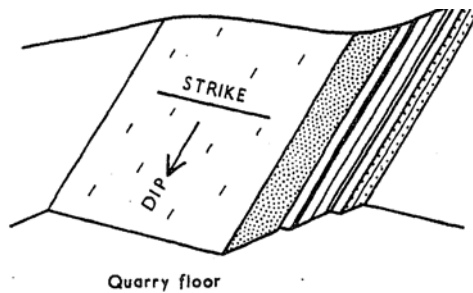


CONTOUR INTERVAL = 20m

Elevations in metres above sea level (a.s.l)

MAPPING EXERCISE 3: TILTED STRATA – 3-POINT PROBLEM

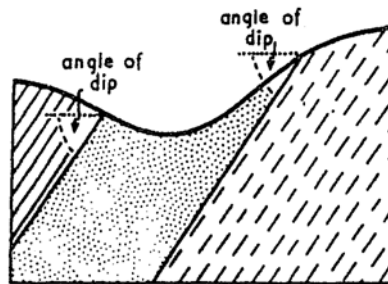
If the height (or depth) of a geological feature (e.g. bedding planes, faults, veins, etc), is known at three or more points, it is possible to determine its true orientation, which in the geological sense is Strike and Dip:



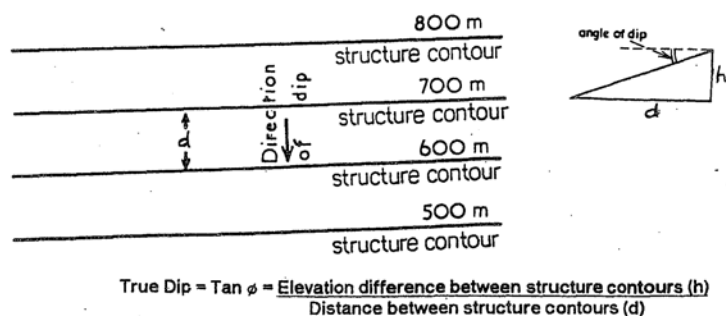
Strike is the direction of the horizontal on an inclined plane and it is generally denoted as a compass bearing (e.g. North = 000° or 360°, East = 090°, South = 180°, West = 270°).

Dip, or more correctly expressed, True Dip is the angle measured between an inclined plane and the horizontal (regardless of the slope of the ground). Thus, Dip is expressed as an angle between 0° = horizontal and 90° = vertical. The direction of True Dip is always at right angles to the Strike direction.

Express Strike and Dip this way: Strike, Dip → Dip Direction, e.g. 097°, 18° → 187°



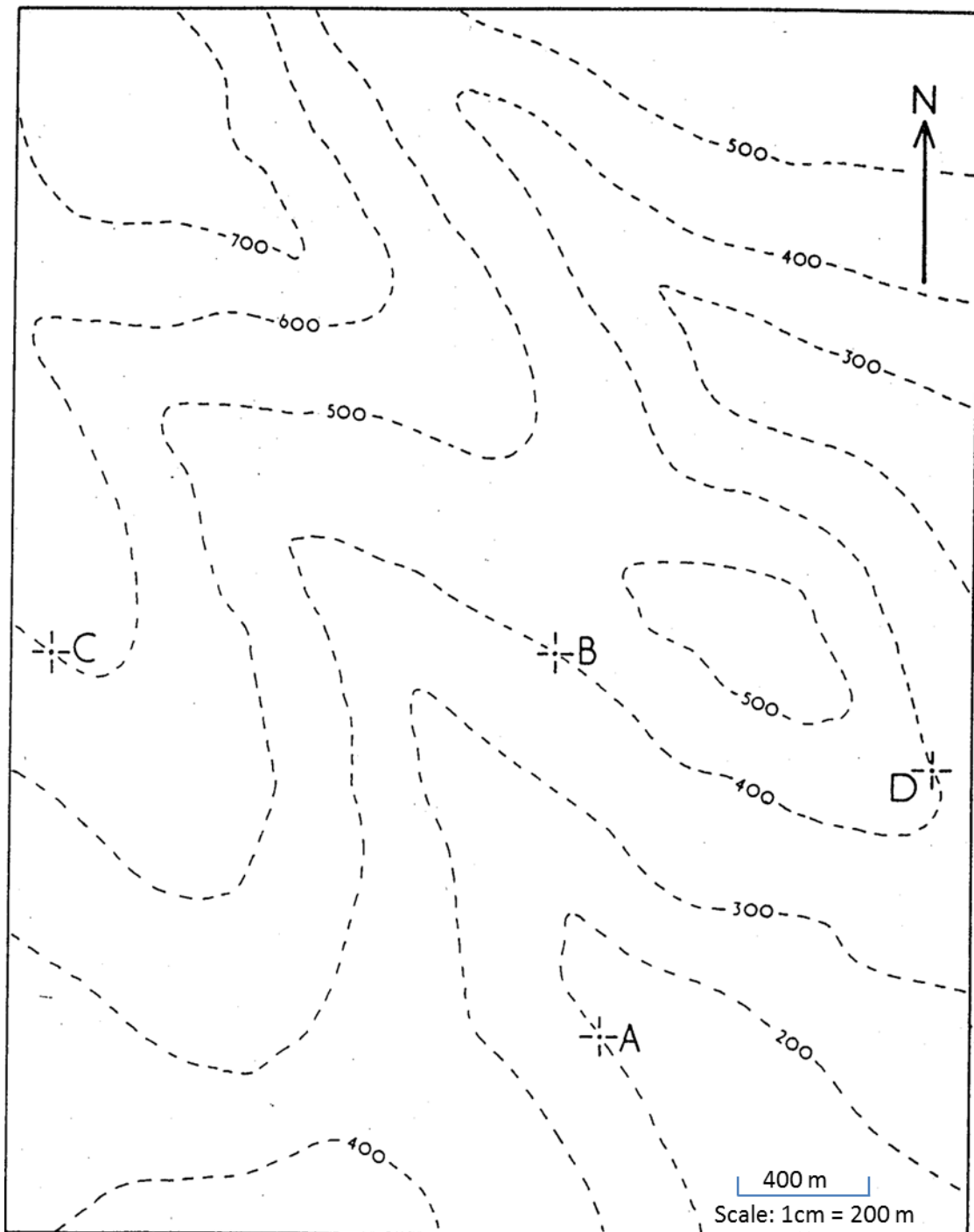
A Structure Contour is a line joining all points of equal elevation on a geological surface and once they are constructed, the direction of the structure contours is equivalent to the direction of Strike, and the spacing of the structure contours allows one to calculate Dip. Structure contours are also used to plot the outcrop of geological features since the structure contours (elevations of the geological feature), are readily compared with topographic contours (elevations of the ground surface).



Your Tasks

A, B, and C are three points at which the same 5 m thick gold-bearing sandstone bed outcrops. Underlying the sandstone bed is pebbly sandstone and overlying it is shale.

1. Determine the Strike and Dip (include Dip Direction) of the sandstone bed.
2. Draw on the map the outcrop of the sandstone bed.
3. If a hole was drilled at Point D, at what depth would the sandstone bed be encountered?



Procedure:

1. **Solve the 3-point problem first:** Join the three points (Points A, B, and C) to form a triangle. Determine the other elevations (of the gold-bearing sandstone bed) on the sides of the triangle in 100 m intervals (we want 100 m intervals as the topographic contour lines have 100 m intervals). For example, since Point A is at 200 m elevation and Point C is at 600 m elevation, then by dividing the line A-C by 4, the location of the 300, 400, and 500 m elevations on the A-C line can be determined (assuming here that the dip of the sandstone bed is uniform).
2. **Now draw in structure contours:** Structure contours are lines connecting points of equal elevation along a geological feature. Connect points of the same elevation from the sides of your 3-point problem triangle. These first few structure contours give you the orientation and spacing of all structure contours. Continue with structure contours until they cover the whole map.
3. **Determine the strike and dip:** strike from the orientation of the structure contours and the dip from the spacing of the structure contours
4. **Draw outcrop line of bed:** Determine points at which structure contours (i.e. elevations of the gold-bearing sandstone bed) and topographic contours of the same elevation intersect. By connecting points together with a thick line, you are plotting the outcrop of the sandstone bed.
5. **Determine the depth to the bed at Point D:** Compare the elevation of the ground surface (topographic contours) to the elevation of the bed (structure contours) at Point D.

MAPPING EXERCISE 4: FAULTED STRATA

Faults are fractures along which displacement of the rocks has taken place, in response to opposing forces. The displacement can be of any magnitude (i.e. a few centimetres to many kilometres) and it can be either in a vertical or horizontal sense. A fault may be a plane or curved surface, and many are marked by a zone of crushed, brecciated rock that is produced by the movement of the fault. However, for the purposes of our elementary mapping, faults are regarded as a planar surface, which have a strike and dip, the same as bedding planes.

The side of the fault that appears to have moved upwards relative to the other side is referred to as the UPTHROWN side, and conversely the other is the DOWNTHROWN side.

The amount of displacement along a Fault can be specified according to whether it is Dip Slip or Strike Slip.

Strike Slip = displacement parallel to the strike of the fault

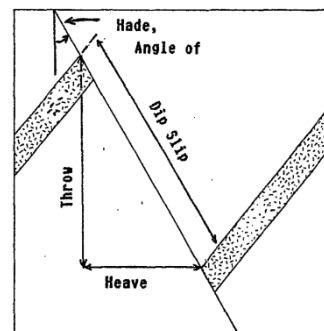
Dip slip = displacement in the direction of the inclination of the fault.

The dip slip is further resolved according to:

Heave - the horizontal component of displacement

Throw - the vertical component of displacement

Faults on geological maps are generally distinctive in that they dislocate and displace strata or offset structures.



abruptly

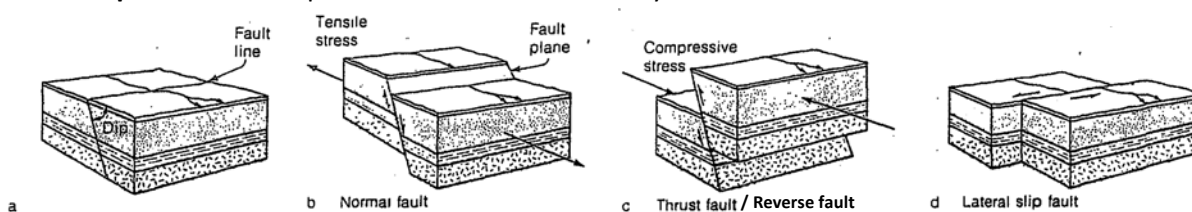
downthrown

TYPES OF FAULTS

Normal Fault - The slope of the Fault is in the direction of the side. These faults are a product of extension.

Reverse Fault - The slope of the Fault is in the direction away from the downthrown side. Low angled Reverse Faults are termed Thrust Faults. These faults are a product of compression.

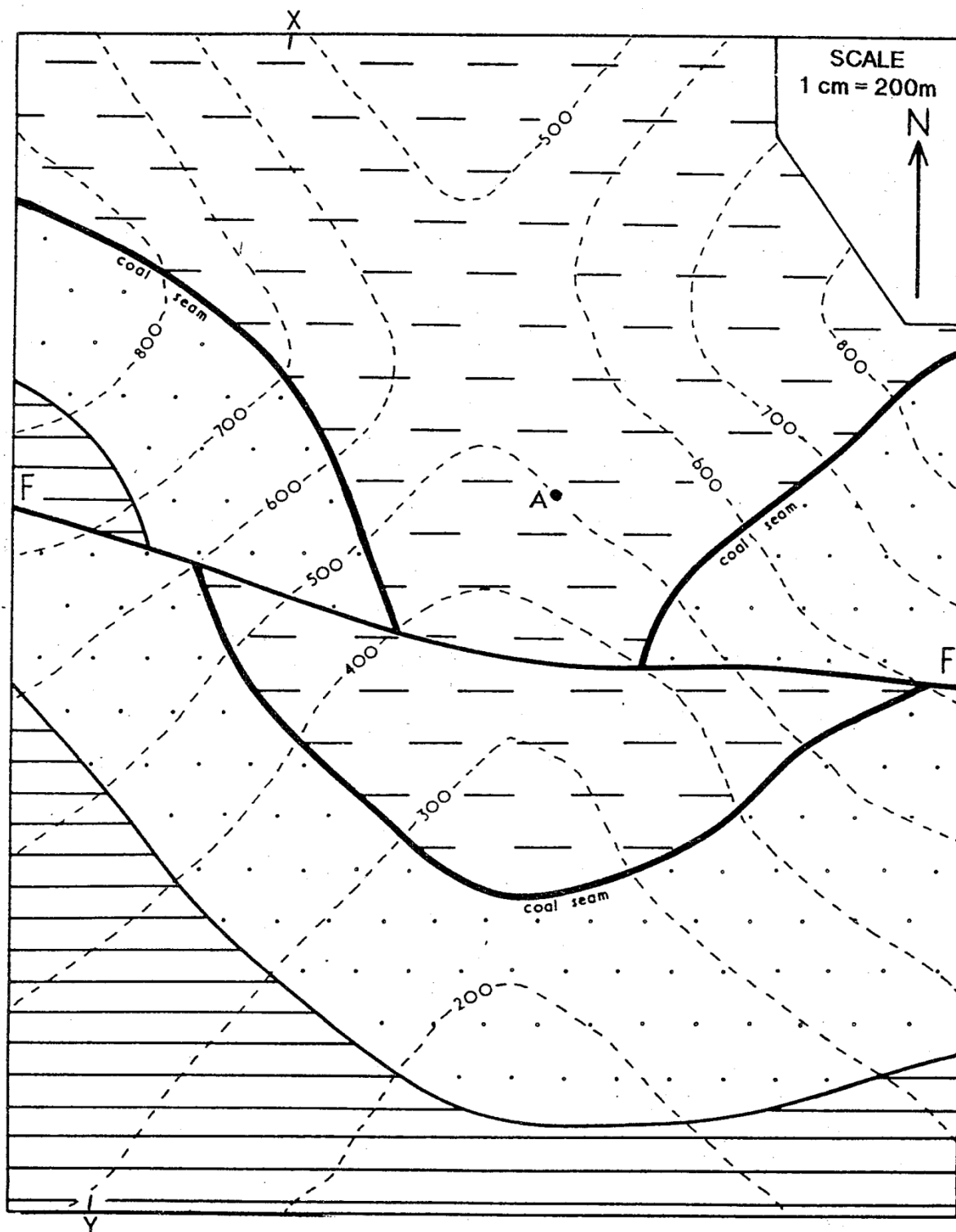
Lateral Slip Fault - The displacement occurs horizontally.



Your Tasks:

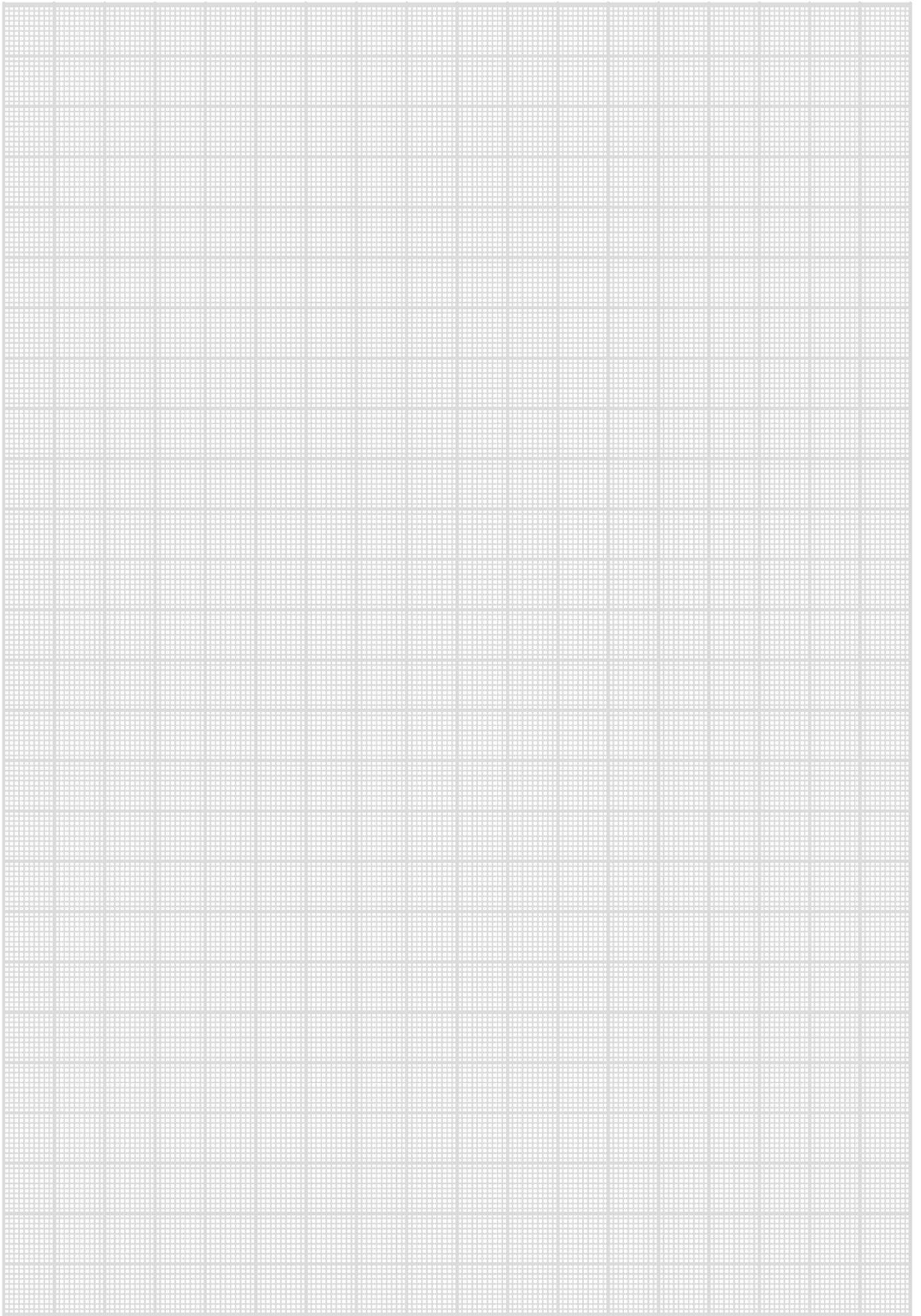
The thick line F-F is the outcrop of a fault. The other thick line is the outcrop of a thin, but continuous Coal Seam which acts as a distinct marker horizon. Draw a Geological Section from X to Y.

1. What type of Fault is it? Determine the throw and heave of the fault.
2. Determine the dip of the sedimentary units and the fault both from measuring off your structure contours and from the cross section (they should come out the same)
3. Determine the strike and dip direction of the sedimentary units and the fault based on your structure contours.
4. What is the depth of the Coal Seam at A.
5. Indicate (with shading) the areas where the Coal Seam would be penetrated by a borehole (= the areas where it has not been eroded).
6. Indicate the areas in which a borehole will penetrate the Coal Seam twice.



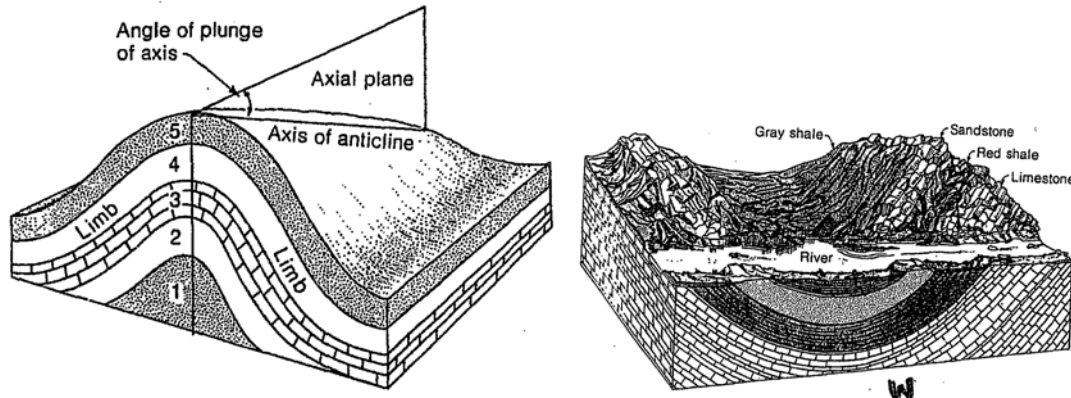
Procedure:

1. Plot structure contours for the fault and sedimentary units on both sides of the fault.
2. Use a separate colour for each set of contours
3. Draw the topographic profile (using the topographic contours)
4. Draw the geology on the topographic profile (using the structure contours)
5. Calculate dip from spacing of contours. Determine strike using protractor.
6. Interpret structure contours for rest.



MAPPING EXERCISE 5: FOLDED STRATA

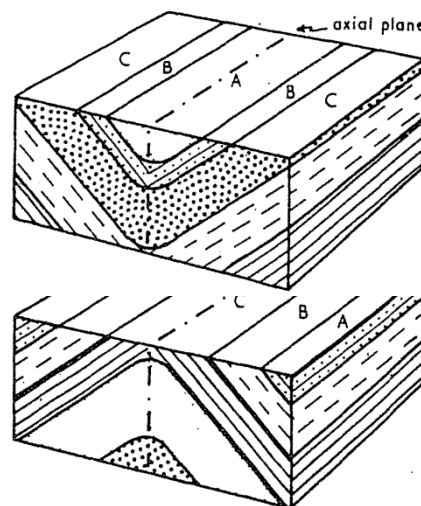
Exercises 3 and 4 have demonstrated inclined (dipping) strata, but it is rare that any inclination is constant over a wider area, and as a rule, inclined strata are a part of much larger structures called Folds. The inclined strata are usually the sides of folds known as the limbs and the most sharply curved part of the fold is called the hinge or crest. The plane that divides a fold into symmetrical halves is the axial plane and the line of the axial plane along the hinge is the fold axis. If the fold itself has been tilted the angle of the fold axis from the horizontal is known as the plunge.



If the strata have the same dip on each limb of the fold, then it is called a **symmetrical fold** and if the axial plane is vertical then it is an **upright fold**. The converse are the **asymmetrical** and **recumbent folds** respectively. Where the strata in a fold are bent upwards into an arch it is an **anticline**, and where they are bowed downwards into an inverted arch the fold is a **syncline**.

Synclines - The beds on opposite limbs dip inwards towards and flatten to horizontal on the axis of the syncline. In eroded youngest strata occur in the centre of the fold with older strata cropping out with increasing distance from the

Anticlines - The beds on opposite limbs dip away from each other and flatten to horizontal on the axis of the anticline. In eroded oldest strata occur in the centre of the fold with progressively younger strata cropping out with increasing distance from the synclinal axis.



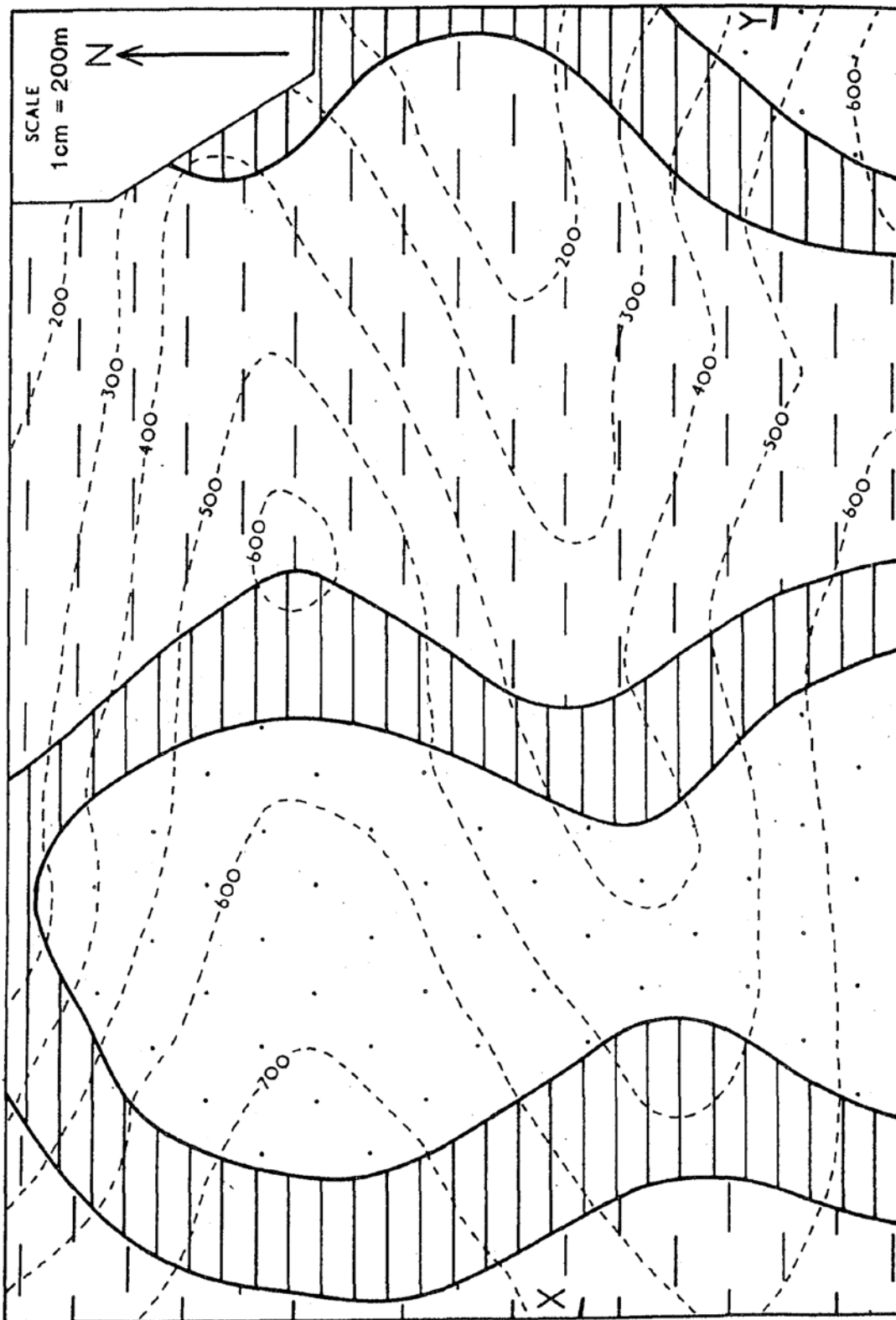
each other synclines the progressively synclinal axis.

other and anticlines the younger strata

Your Task:

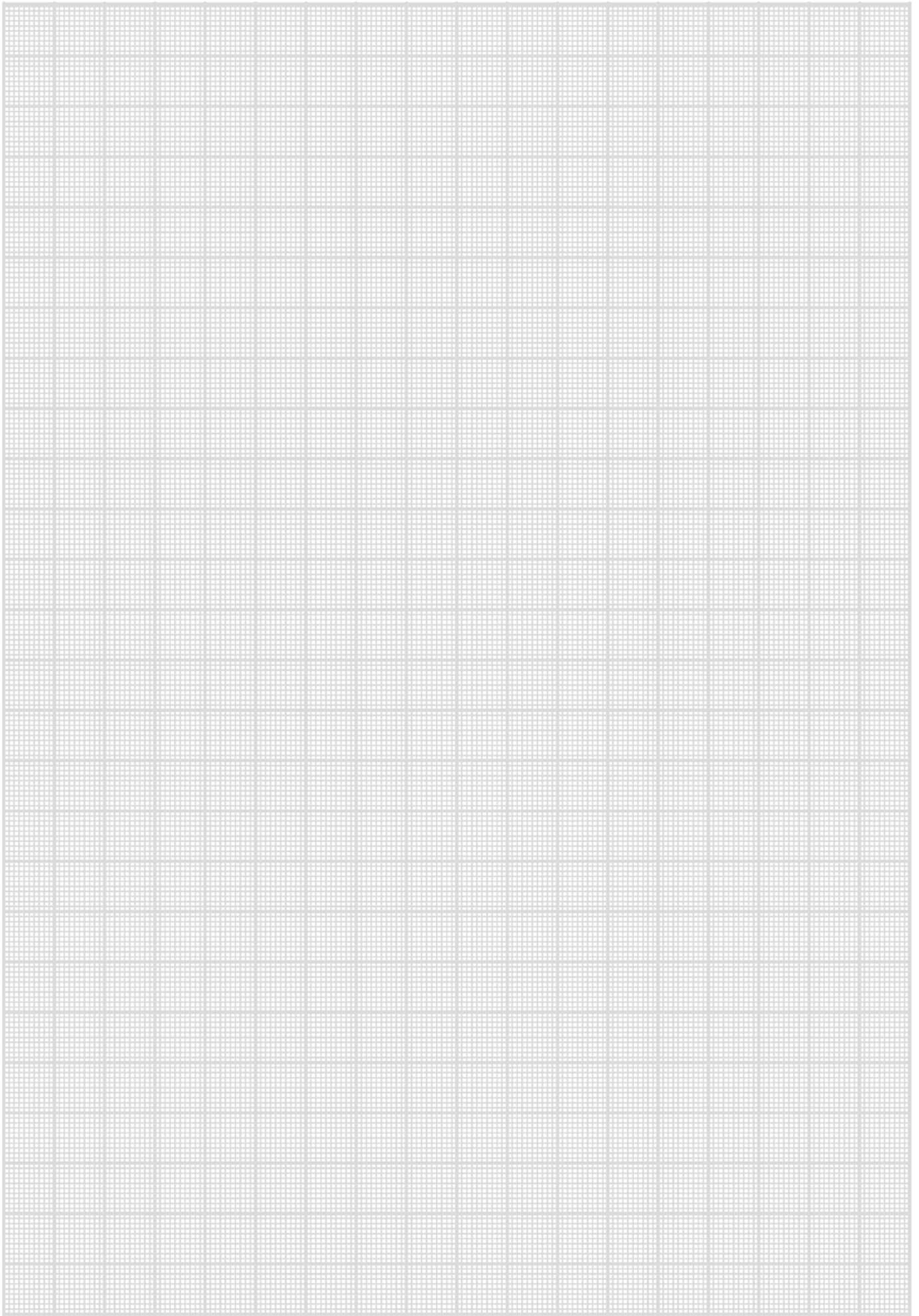
1. Determine the dip and strike of the shale bed on the folds.
2. Draw on the map the approximate position of an anticlinal axis and a synclinal axis.
3. Draw a geological section along X - Y.
4. The fold is: Symmetrical/Asymmetrical Upright/recumbent (delete those not applicable).

limbs of the



Procedure:

1. Draw at least 3 structure contours on the same surface of the shale bed in the three places it crops out. Use a different coloured pencil for each different surface.
2. Determine strike using protractor to measure the orientation of the structure contours and calculate dip using the spacing of the structure contours and elementary trigonometry.
3. Draw the topographic profile (using topographic contours)
4. Draw the surface of the shale bed on the topographic profile (using the structure contours determined in 1. Put other geology on profile



MAPPING EXERCISE 6: SYDNEY GEOLOGY MAP

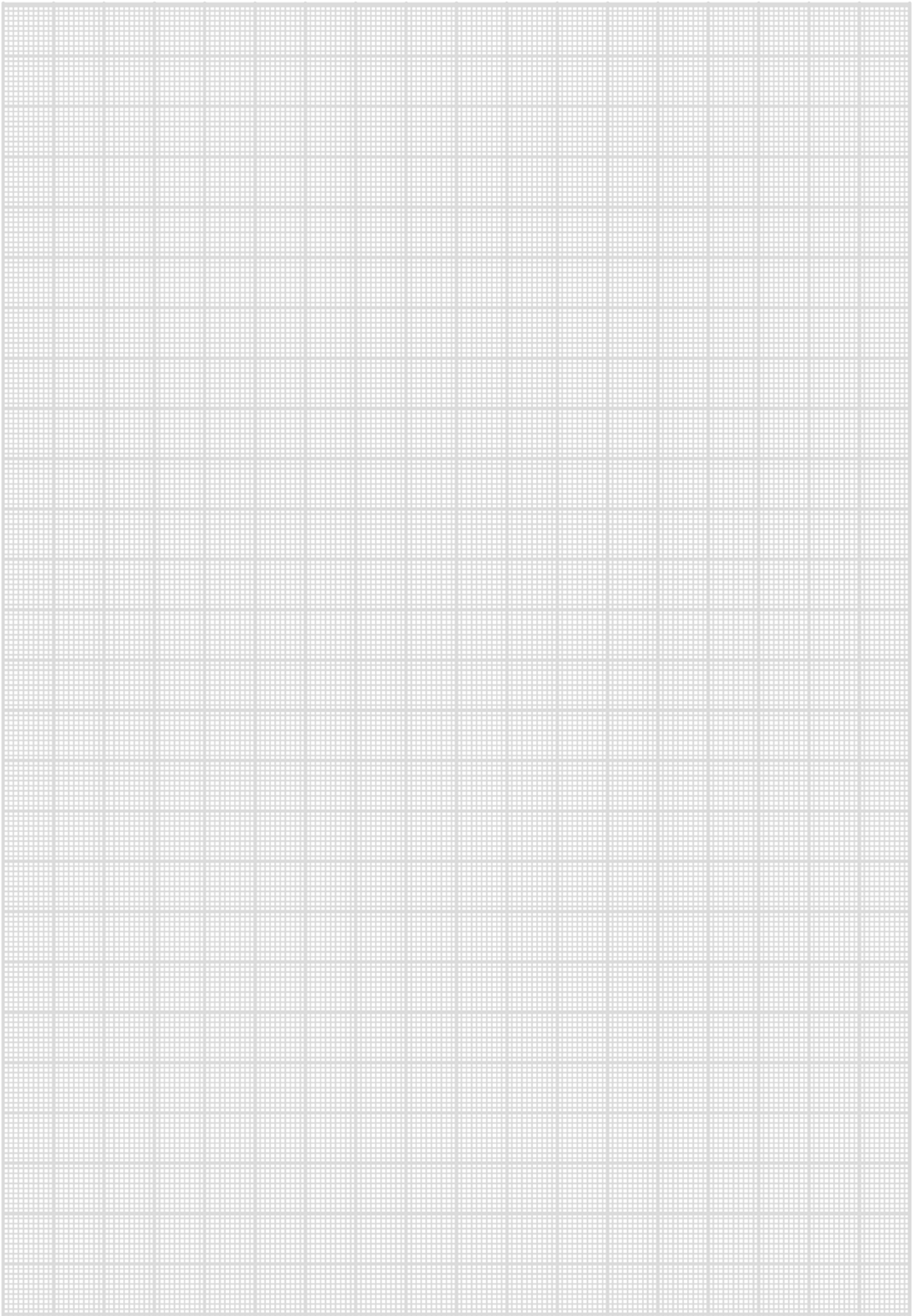
PLEASE DO NOT DRAW ON THESE MAPS

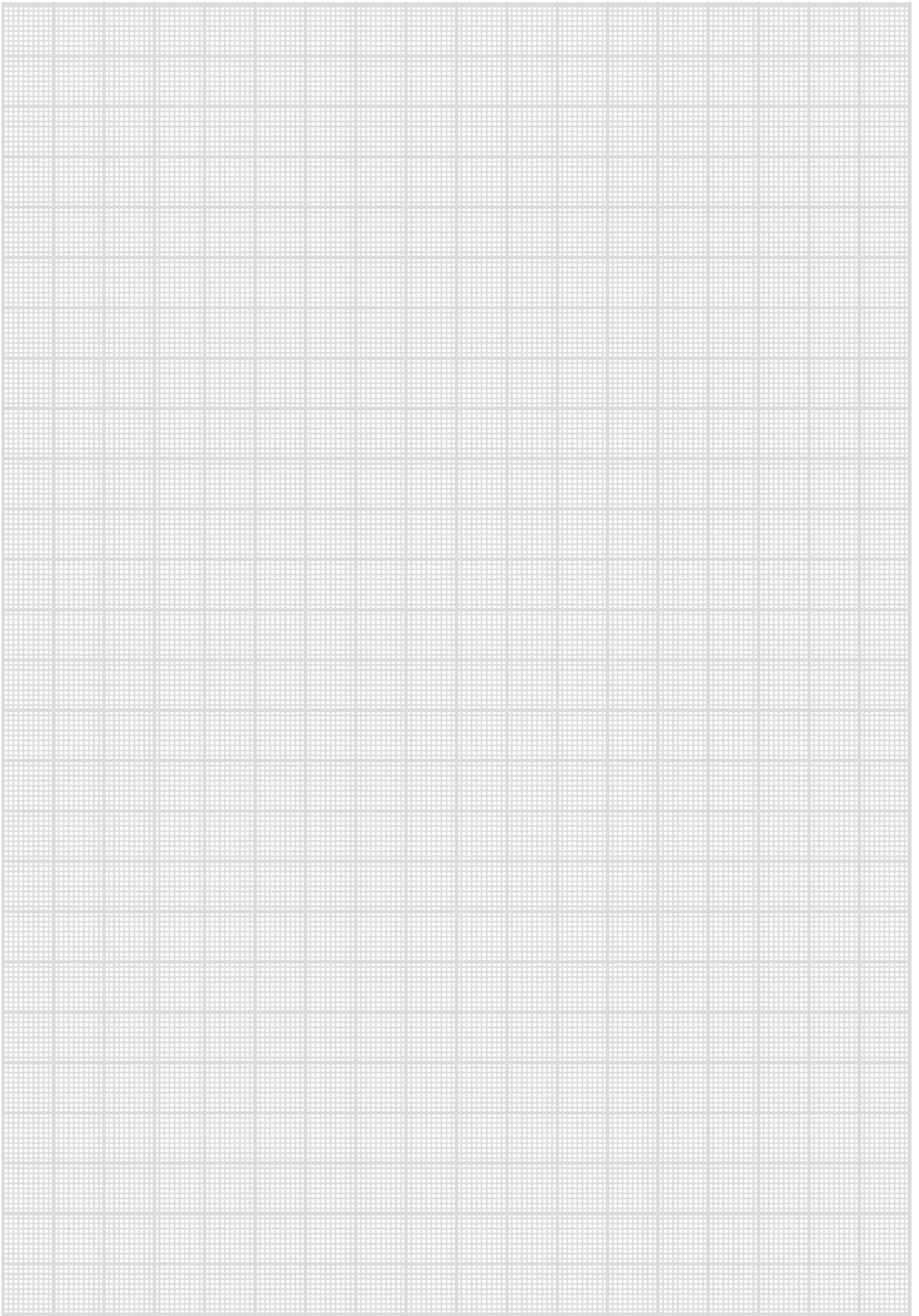
300820, 300855, 350855, 350820

These four 6 figure numbers are grid references (Easting:Northing) on the Sydney Geology (and Topography) map, and they define the corners of an area that you (a company geologist) are commissioned to prospect for gold.

Some initial predictions as to where to begin looking for potential gold-bearing localities can be made from basic observations of this published 1:250,000 geology map, before you set foot in the field. You are now going to make these basic observations and follow them up with your predictions.

1. How and where does gold form?
2. Draw a sketch map (to scale) of the geology in the prospect area, labelling for the Exploration Manager, who is not a geologist, the principle rock types and geological structures (folds, inliers, outliers, intrusions, unconformities etc).
3. Sketch a cross section from Jenolan Caves (G.R 302822) to Mt Tomah (G.R. 342855). (Use the Section A-B to assist you here).
4. Compile a stratigraphic column of the area (including unconformities in the appropriate places).
5. Describe for your company where you are going to concentrate your field work. Mark this area on your geology map.





The accompanying plan or map shows the positions of trigonometrical stations and some points fixed by plane table survey, as well as a portion of a roadway which crosses the main creek at H. This road has a uniform grade from K to H of 1 in 6.4, and up from H to L of 1 in 12.5

- angle of elevation K to A = 4° angle of depression M to R = -13°
- uniform slopes: A to G, C to Q.
- concave slope: R to M.
- convex slopes: A to B, A to N, P to E.

Scale: 500 m = 1 cm. Spot heights are in metres.

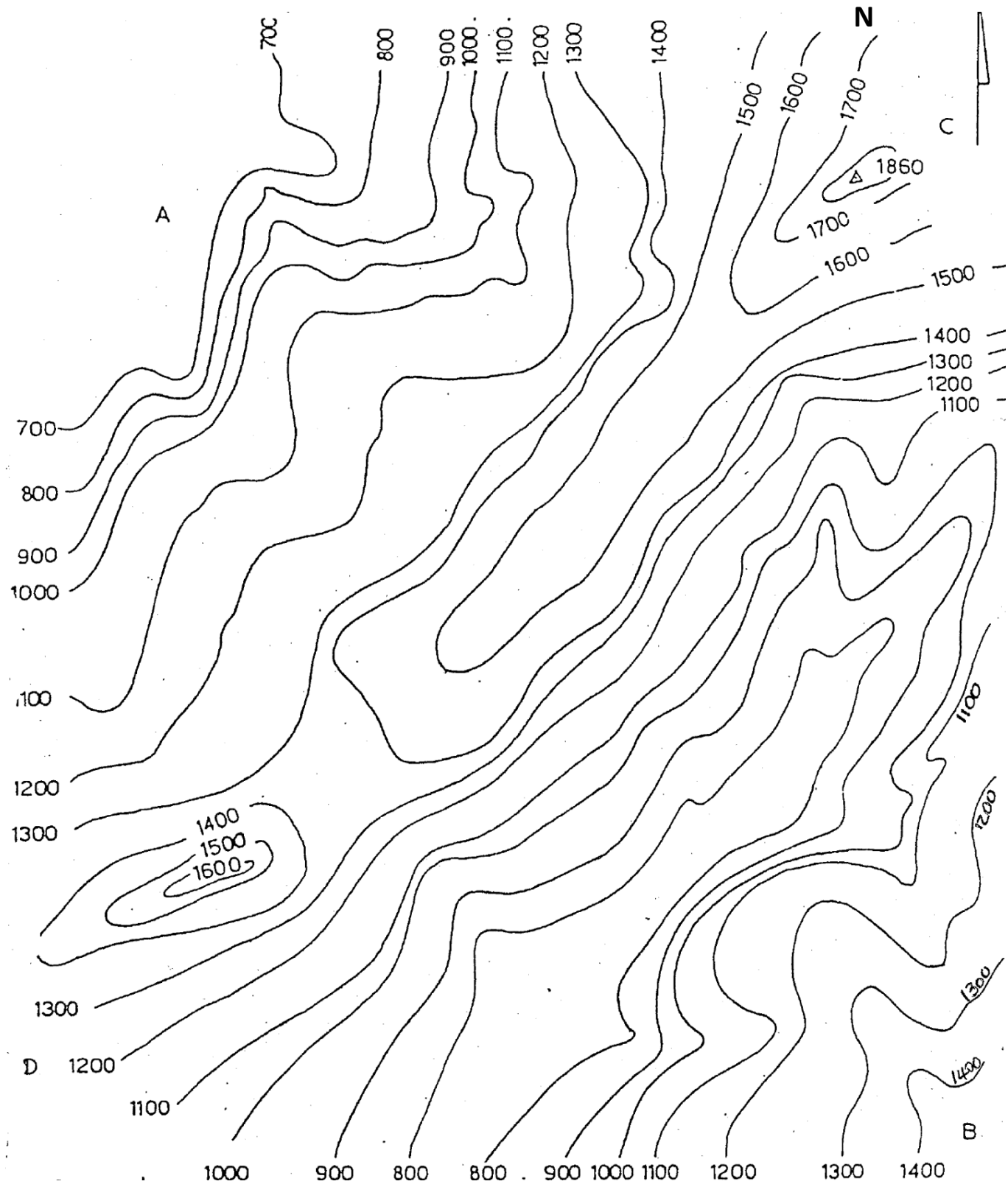


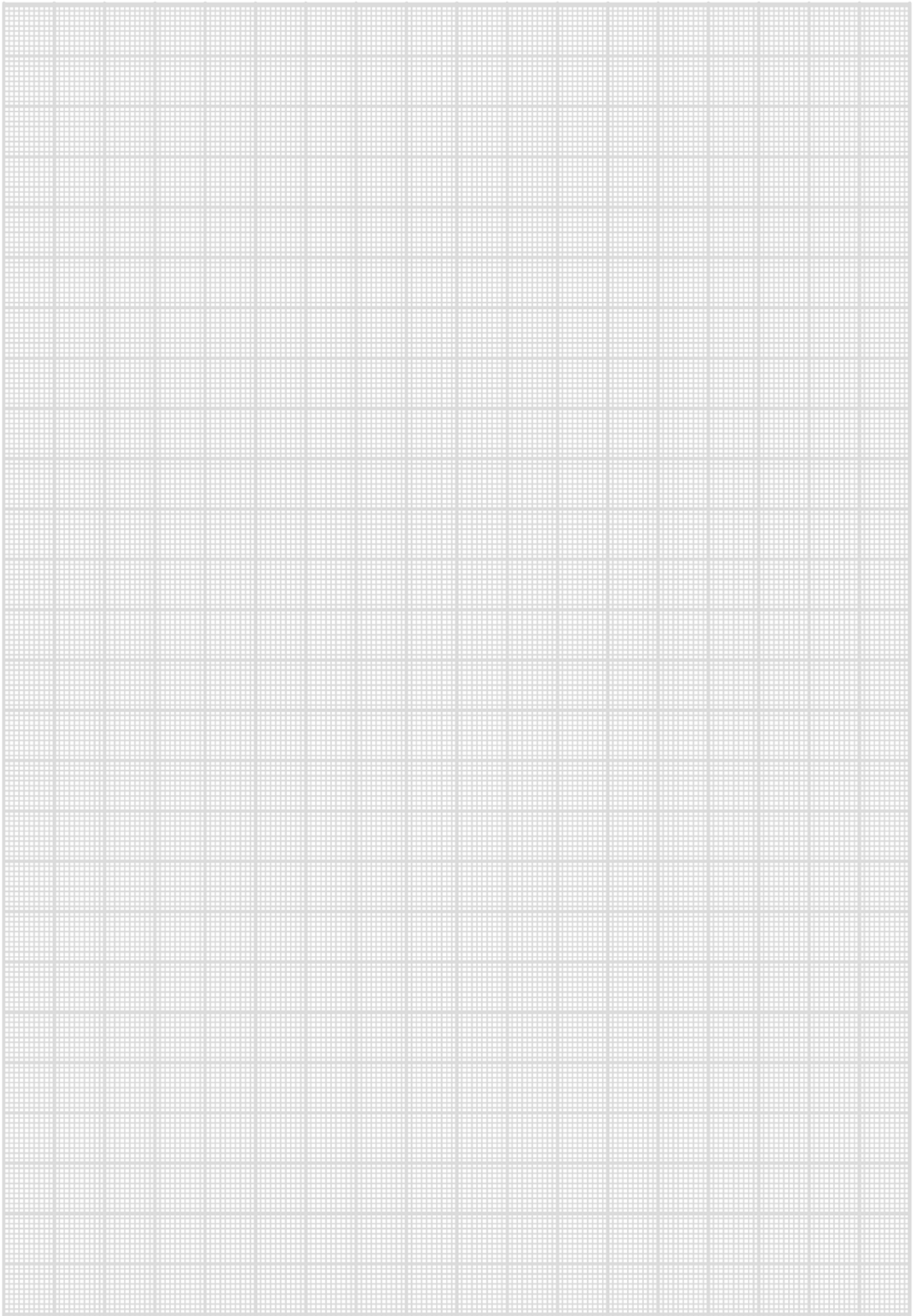
MAPPING EXERCISE 8: TOPOGRAPHICAL FEATURES 2

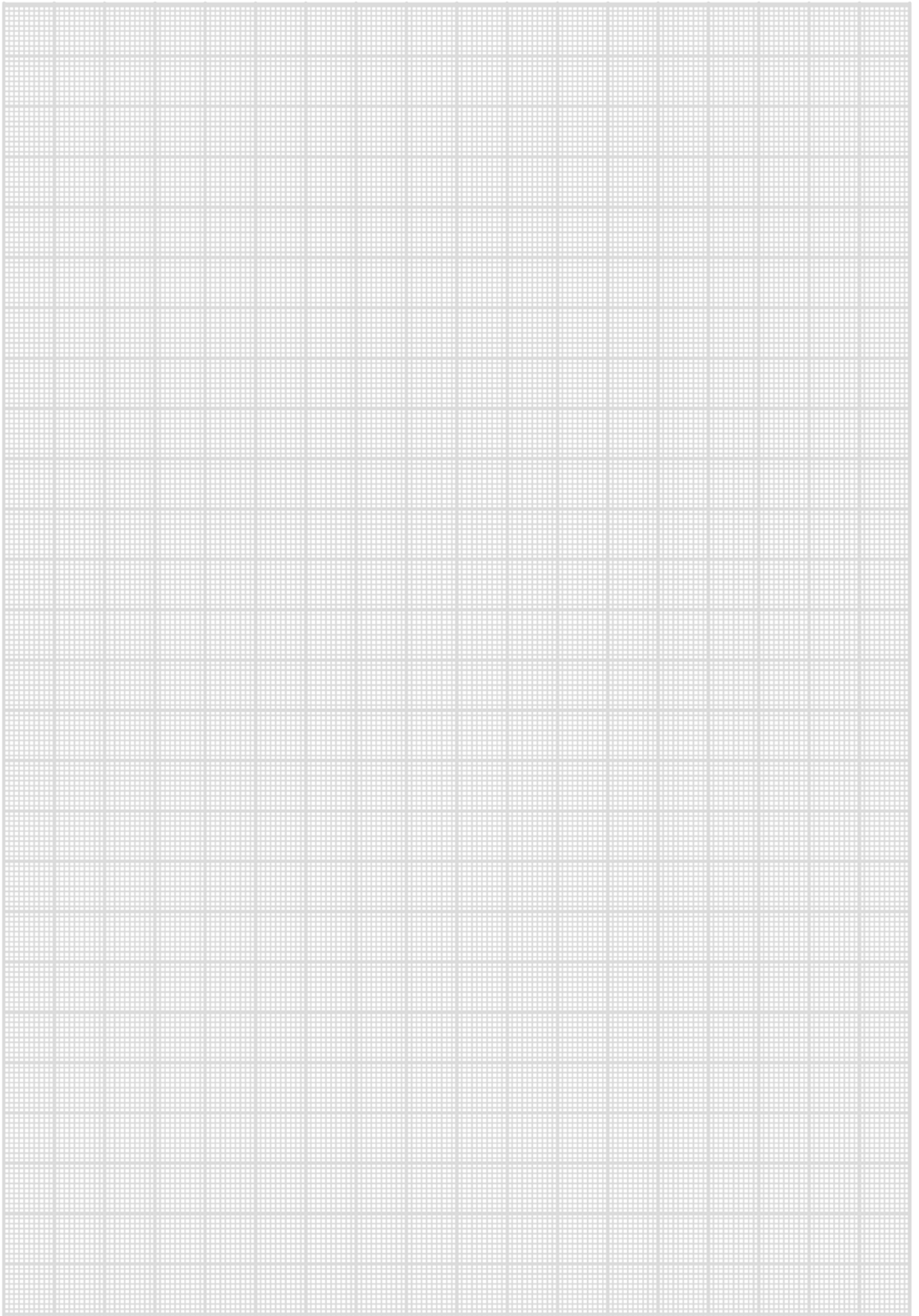
The accompanying plan or map shows a small area of country. The numbers represent height in metres above sea level.

Your Tasks

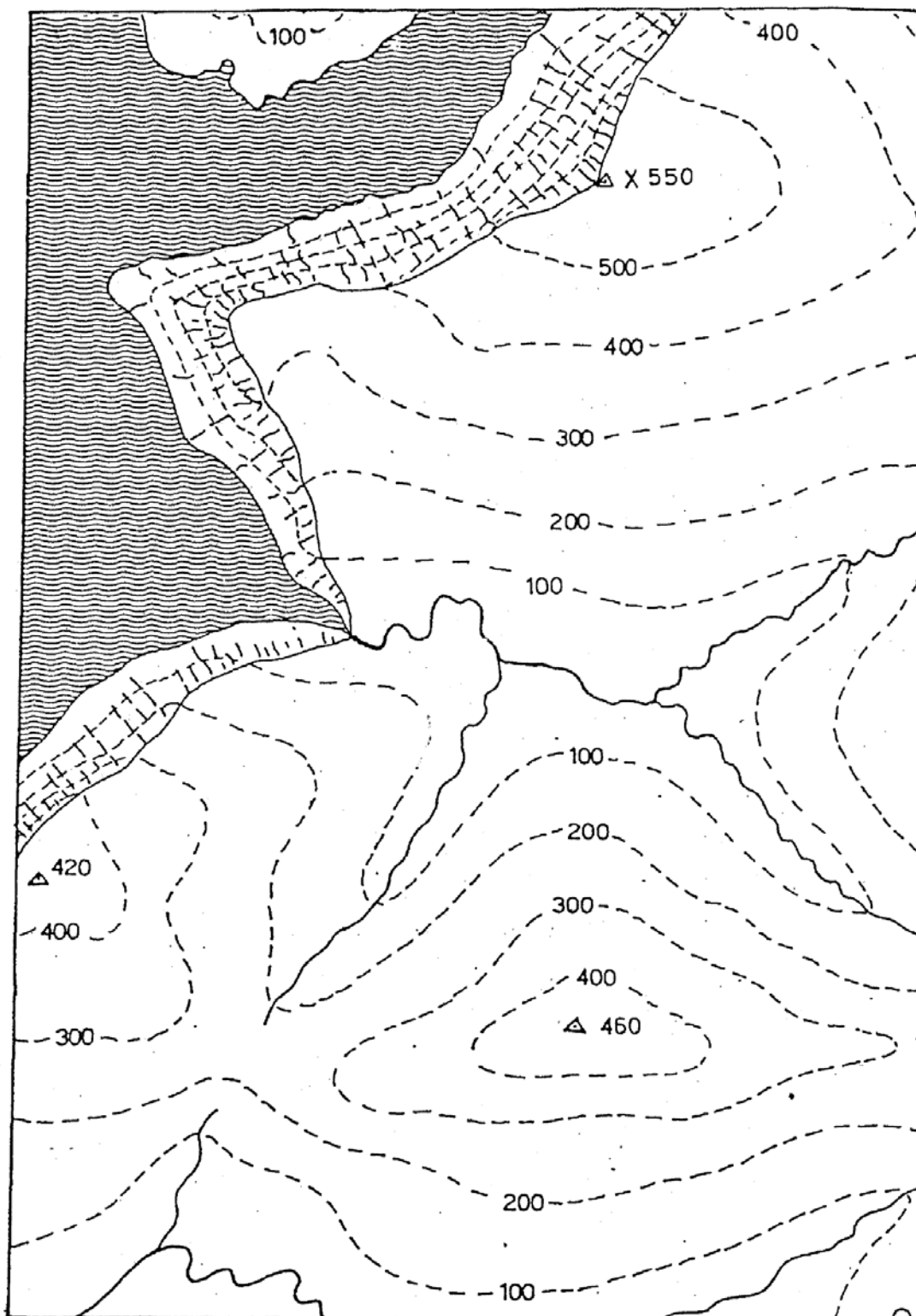
1. Interpret the map by marking on it the: streams, ridges, spurs, and peaks.
2. Indicate the nature of the dominant slopes and spurs.
3. Draw a profile from A to B and C to D using a scale of 500 m = 1 cm.
4. Draw a profile from A to B exaggerating the vertical scale three times.







MAPPING EXERCISE 9: HORIZONTAL STRATA



A measured vertical section of the strata exposed on the cliff face from point X **downwards** is as follows:

0 - 150 m	shale
150 - 200 m	limestone
200 - 350 m	marl
350 - sea level	sandstone

Plot the boundaries of these horizontal strata, colouring or shading each formation.

MAPPING EXERCISE 10: TOPOGRAPHIC CONTOURS, DISTANCES & BEARINGS

1. Draw topographic contours on the map provided using a contour interval of 50 metres. State the direction between the following points both as azimuth and bearing: -

D-F

N-L

N-F

M-F

F-L

2. Determine the straight-line distances between the following:

N & L

D & F

N & F

N & F

M & F

F & L.

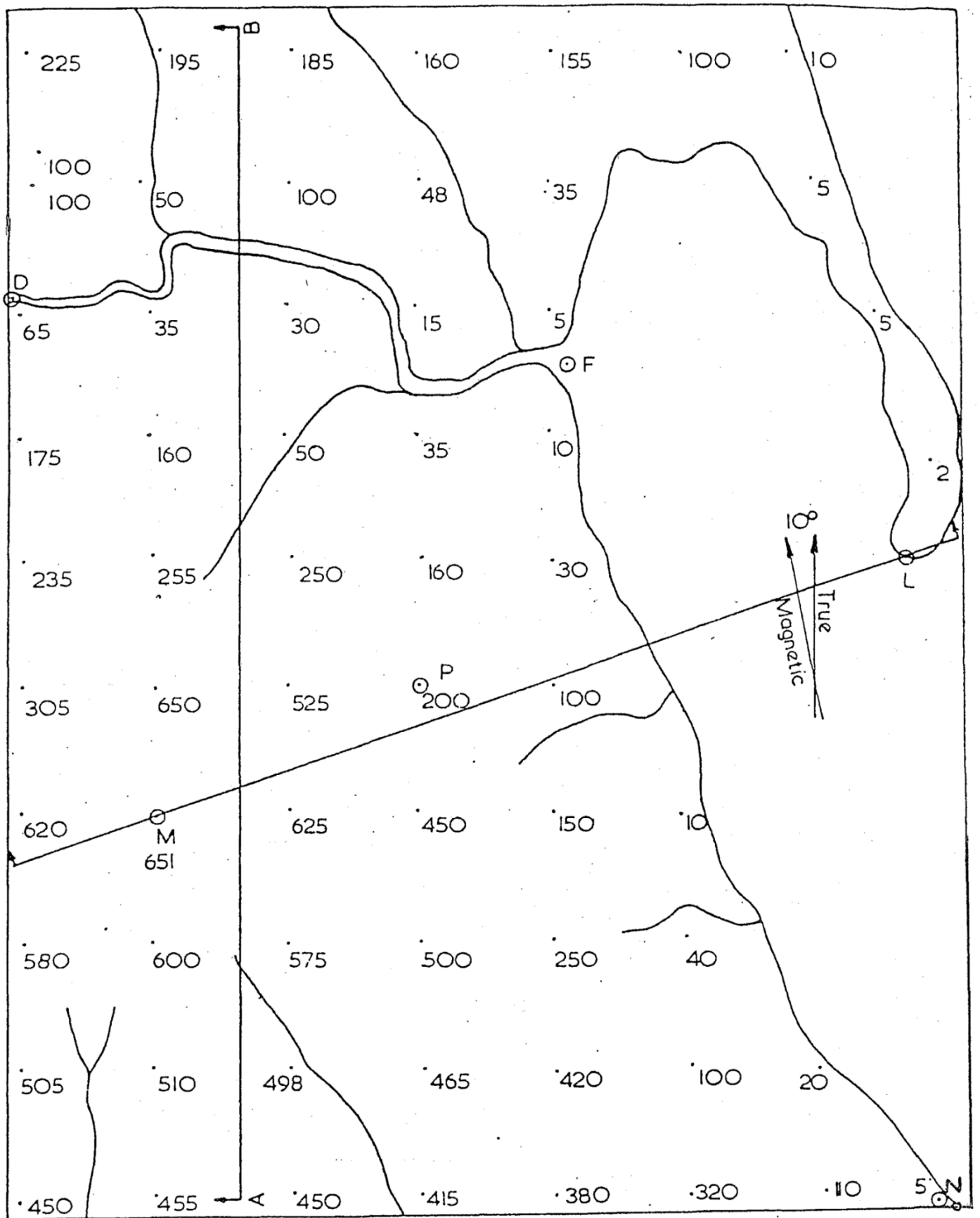
3. Determine the distances, D to F along the river; N to L along the shore and N to F along the shore.

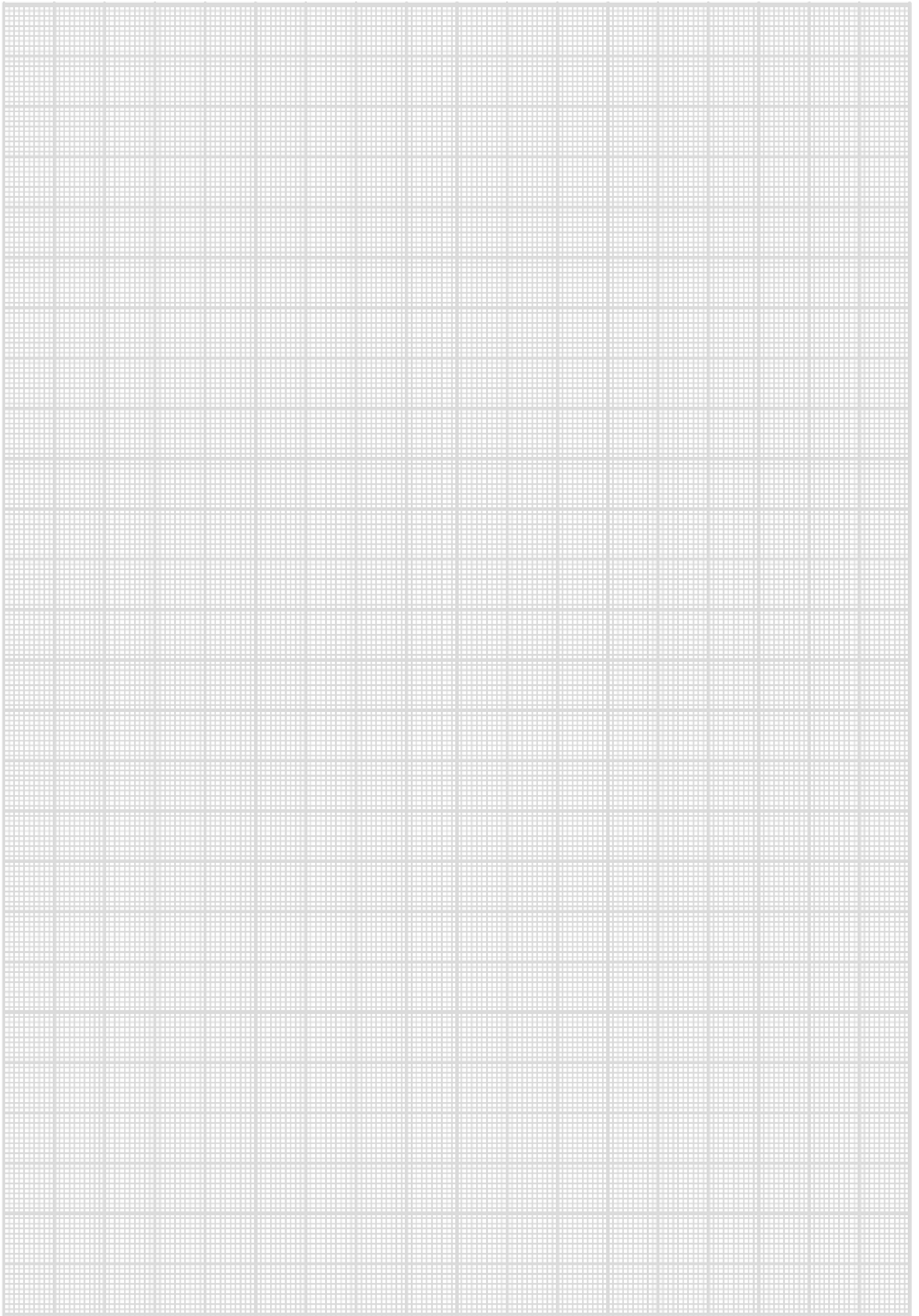
4. Determine the average gradients in metres per kilometre between M and F and D and F.

5. Plot the outcrop of a horizontal limestone bed 50 metres in thickness, the bottom of which outcrops at P.

6. Plot the outcrop of a horizontal dolerite sill 20 metres thick. The elevation of the bottom of the sill is 460 metres above sea level.

7. Draw a topographic and geological profile along the lines A to B and M to L.





MAPPING EXERCISE 11: THREE POINT PROBLEMS

1. Use a scale of 100 metres = 1 centimetre. Consider the lower left-hand corner of the page as the origin.

The following points are on an outcropping coal seam:

Point A N 760 m, elevation 610 m

Point B N 1520 m, E 250 m, elevation 250 m

Point C N 880 m, E 1070 m, elevation 850 m

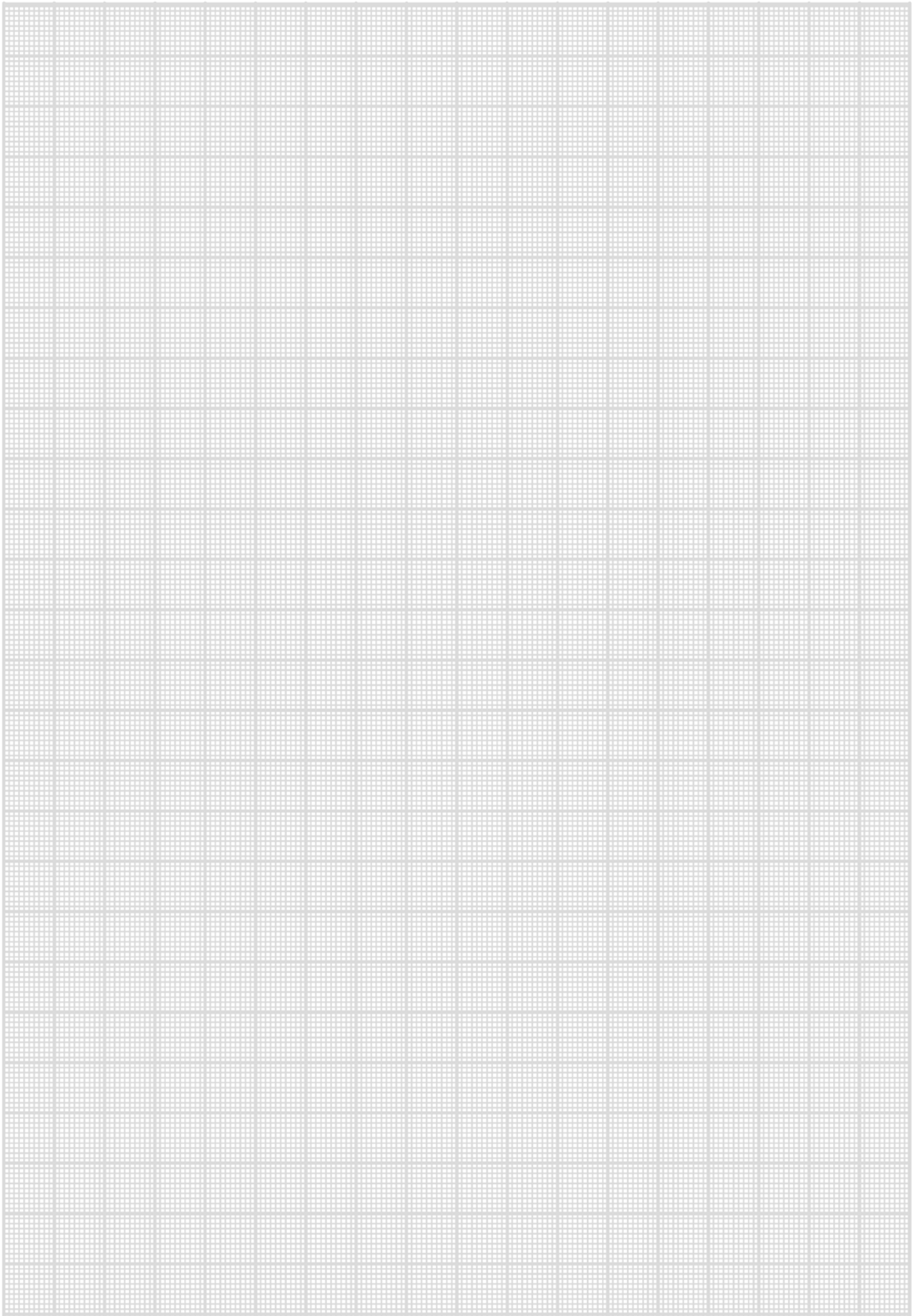
Determine: 1) the true dip, and 2) the strike direction of the coal seam.

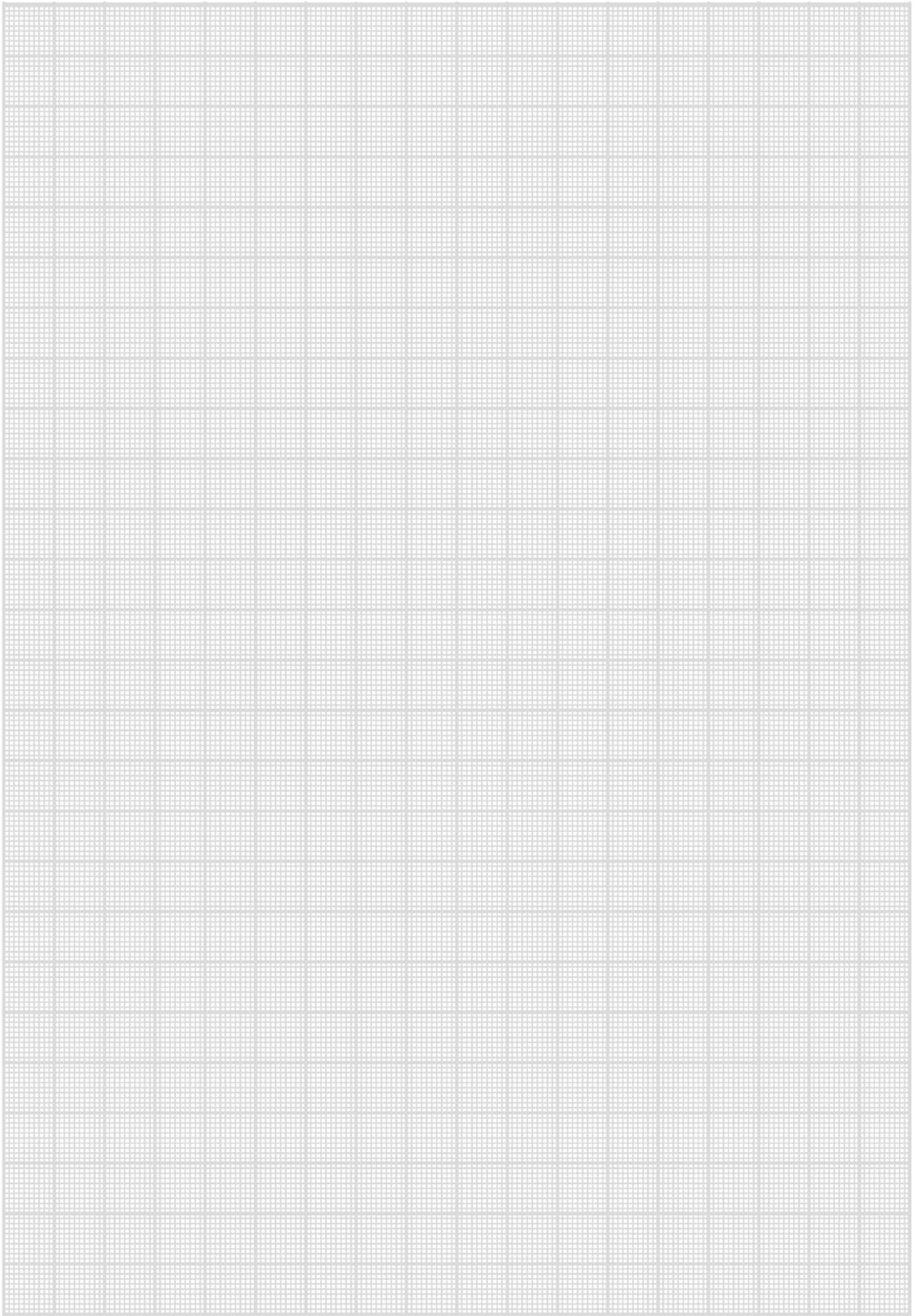
2. Use a scale of 100 metres = 1 centimetre. Consider the lower left-hand corner of the page as the origin.

Point A (N 700 m, E 800 m, elevation 400 m) is on top of a sandstone bed with an apparent dip of 32° in a direction N 48° E.

Point B (N 1200 m, E 600 m, elevation 600 m) is on top of the same bed.

What is the strike and true dip of the sandstone bed?





MAPPING EXERCISE 12: THREE POINT PROBLEMS

A seam of coal is mapped at three points A, B and C which form a triangle whose sides are:

AB = 500

BC = 750

CA = 900 metres

B is northeast of A

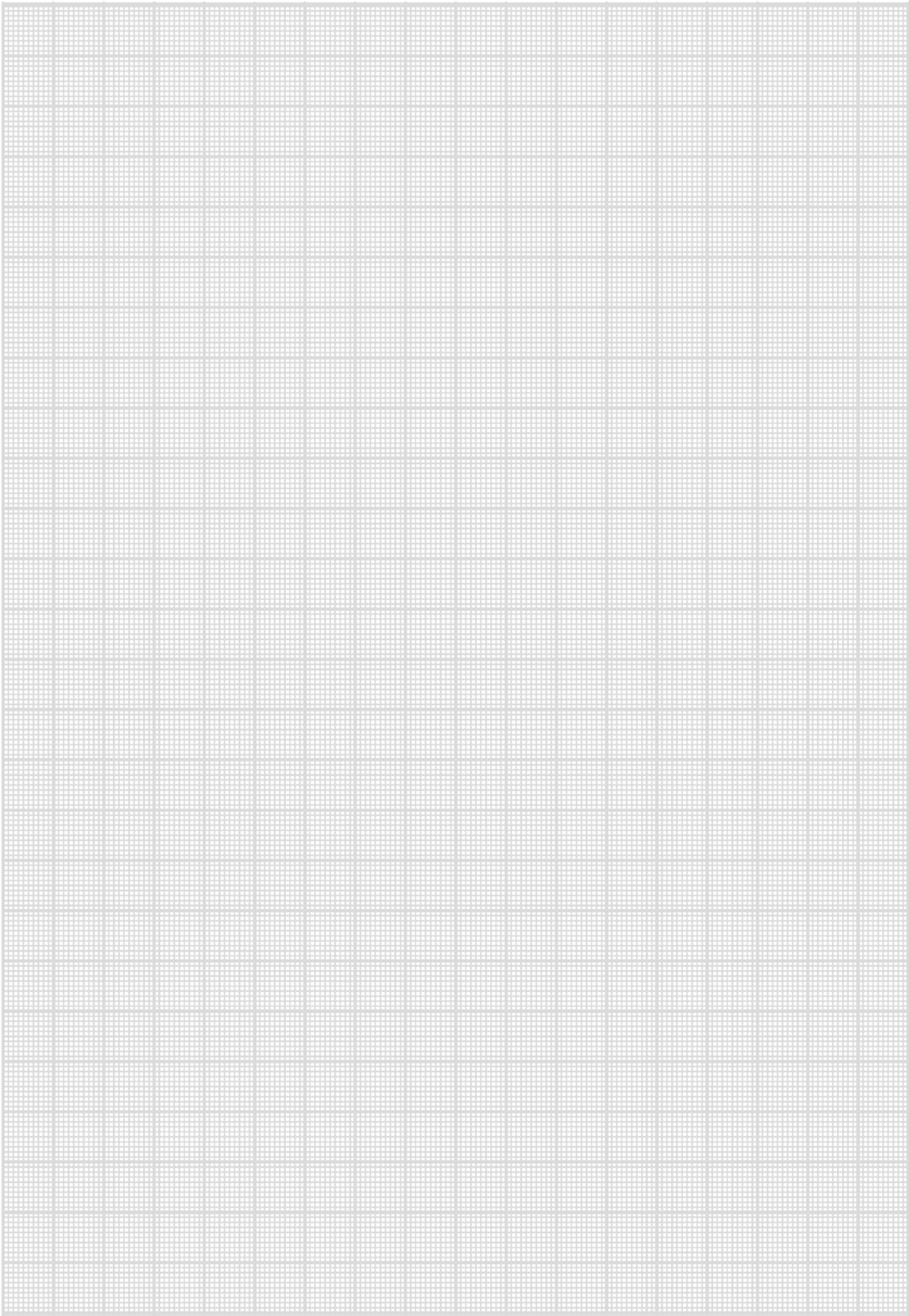
C is southeast of B

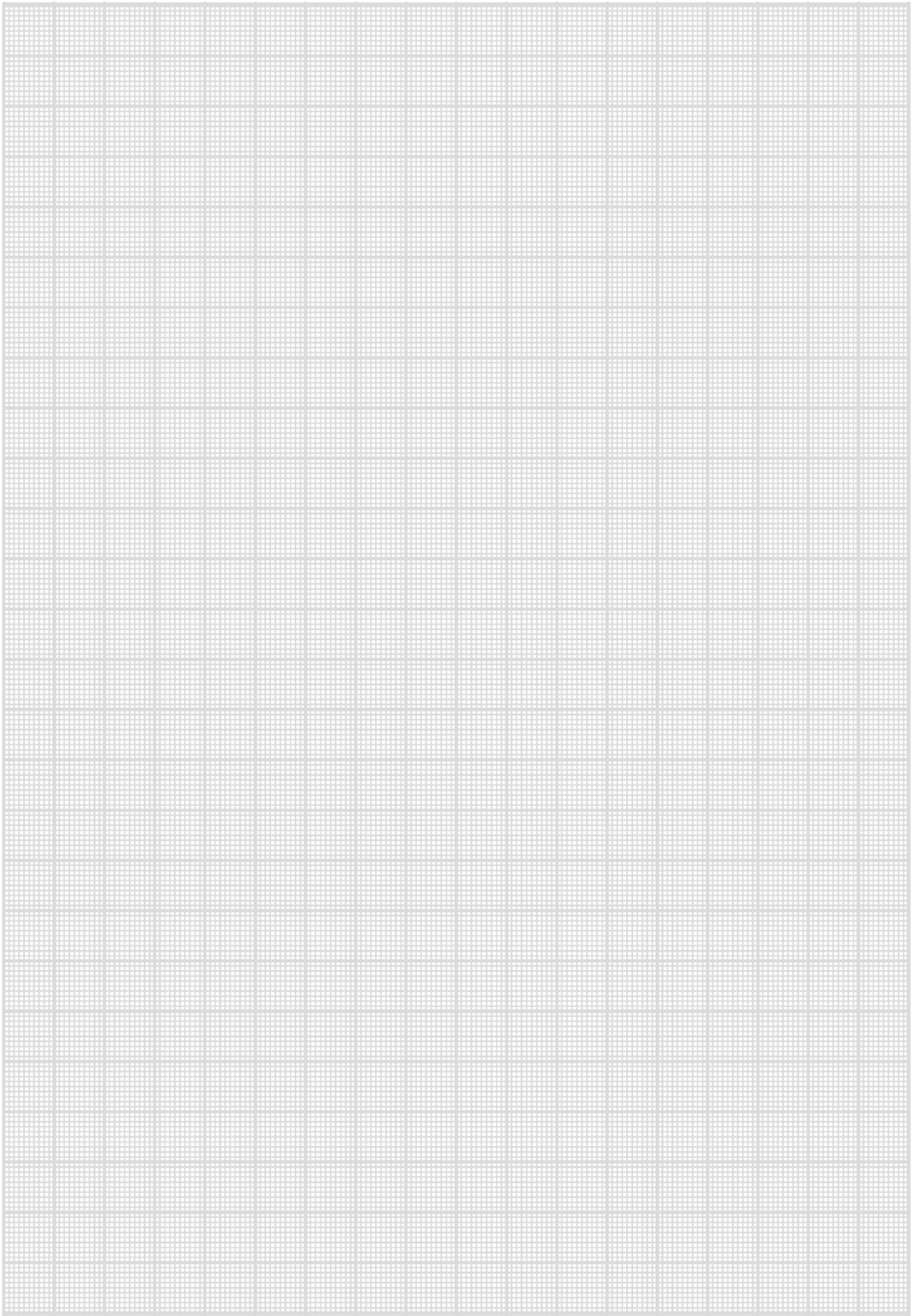
The level of the coal is 200 metres above datum at A, 280 metres at B and 100 metres at C.

1. Find the dip and strike of the seam by using the structure contour method.
2. Assuming a uniform dip, at what depth below surface would the seam be found at D, 180 metres due south of B, if the ground level at D is 230 metres above datum?

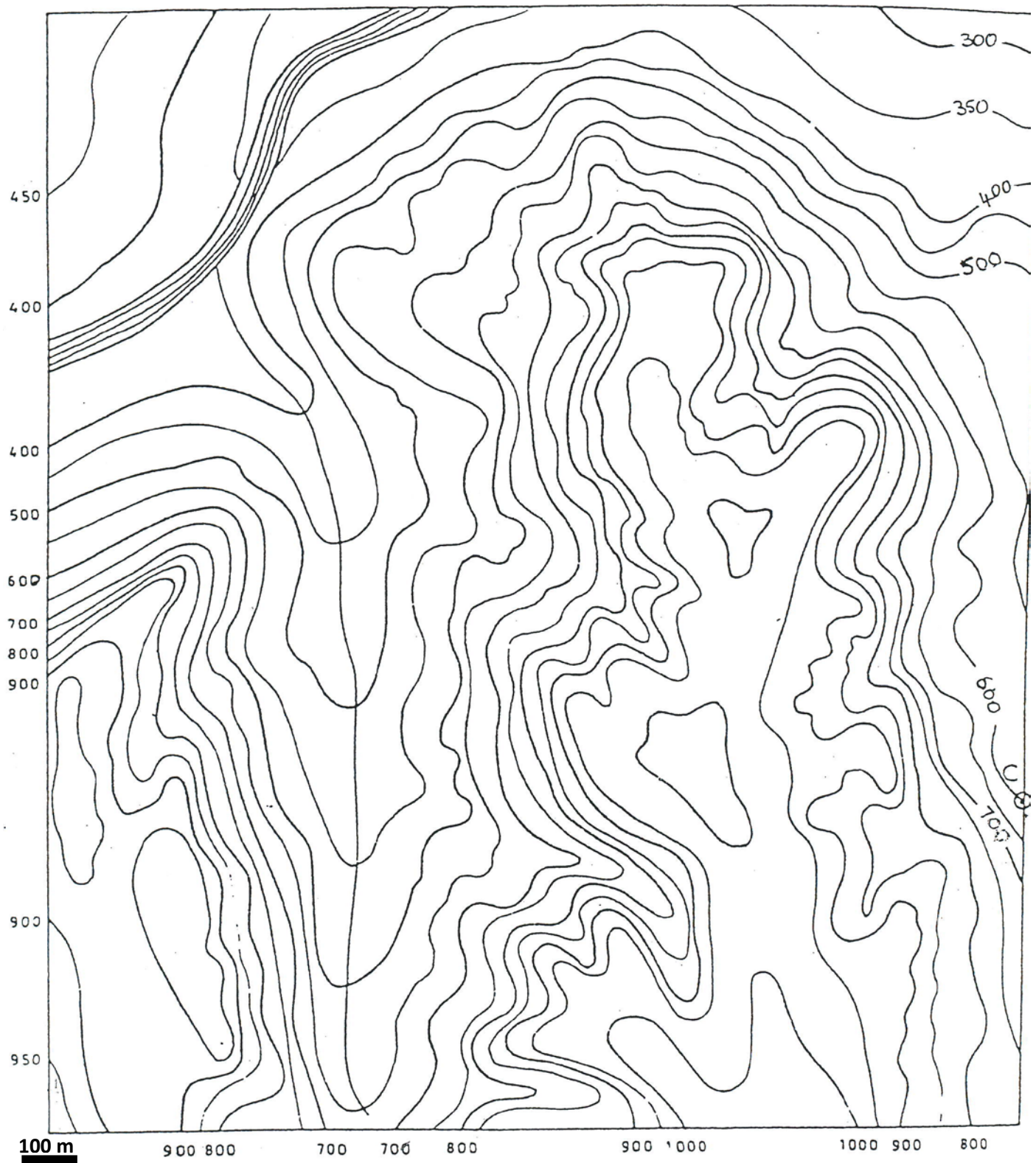
Please use two methods: 1) graphic and 2) calculation.

Scale: Assume 1 cm = 100 m





MAPPING EXERCISE 13



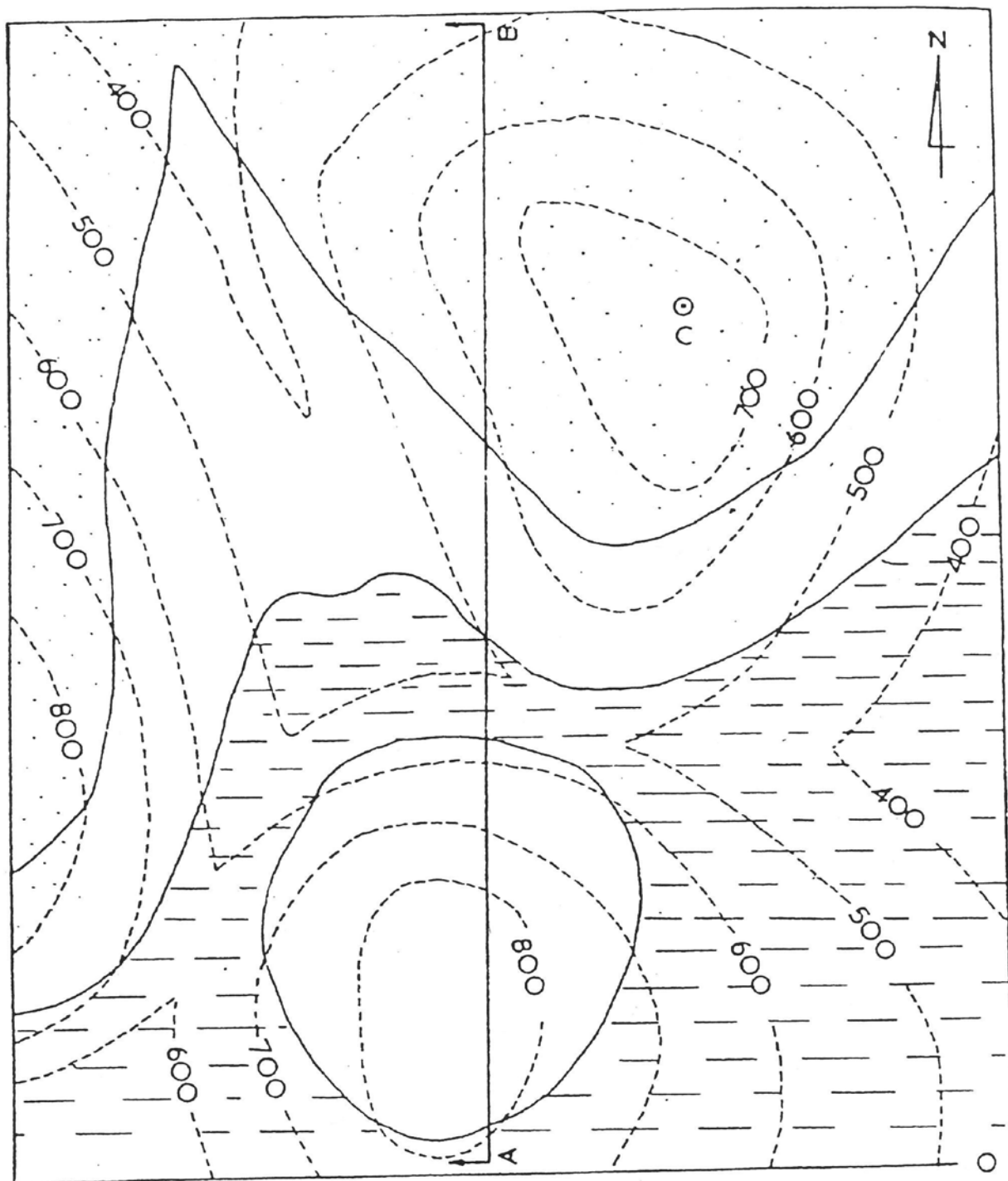
Point C is at the top of a uniformly dipping coal seam. The seam is 45 metres thick, strikes N-S and dips 15° towards the east. The coal is underlain by shale and overlain by sandstone, all being of Permian age.

Plot the outcrop of the coal seam and complete a geological map.

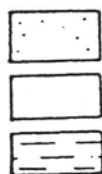
Hint: You will need to draw structure contours for both the top and the basal contacts of the coal seam.

MAPPING EXERCISE 14

1. Mark on the map the structural contours on top of the shale
2. Prepare a topographic profile and cross section on the line A-B
3. Determine the following:
 - i) The dip of the formation
 - ii) The strike of the formation
 - iii) The true thickness of the limestone
4. A vertical drill hole is to be put down at point C. Determine the following:
 - i) What is the elevation of the collar?
 - ii) What rock does the hole collar in?
 - iii) At what depth is the sandstone-limestone contact?
 - iv) At what depth is the limestone-shale contact?
5. Is the limestone the same thickness throughout the area?
6. In what order were the rocks deposited in this area?



400 m



Sandstone

Limestone

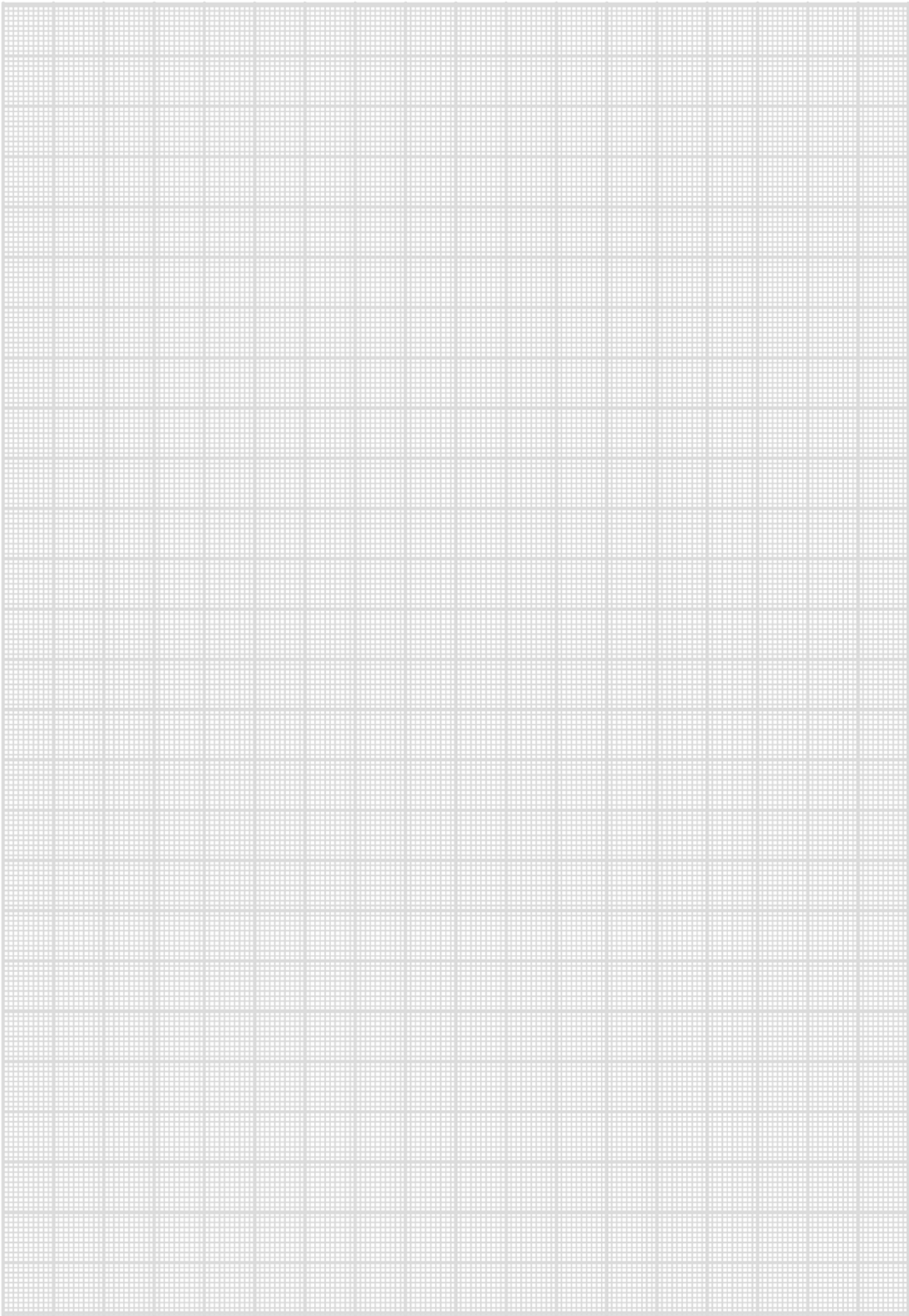
Shale



Geological contact



Topographic contour-100m interval



MAPPING EXERCISE 15

The direction of dip of beds can usually be recognised by observing the way in which the outcrops are deflected (or "V") as they cross a valley. This is one of the first things to be looked for when inspecting a geological map, because once the direction of dip is recognised, the strike direction can also be deduced.

The direction of dip also indicates the order of the stratigraphic succession: the beds become younger in the dip direction and older in the opposite direction; provided the beds have not been overturned.

On the following page, plot the outcrop of a 160 m thick bed whose base is exposed at:

Map 1: Point A, dipping at 18° towards the east

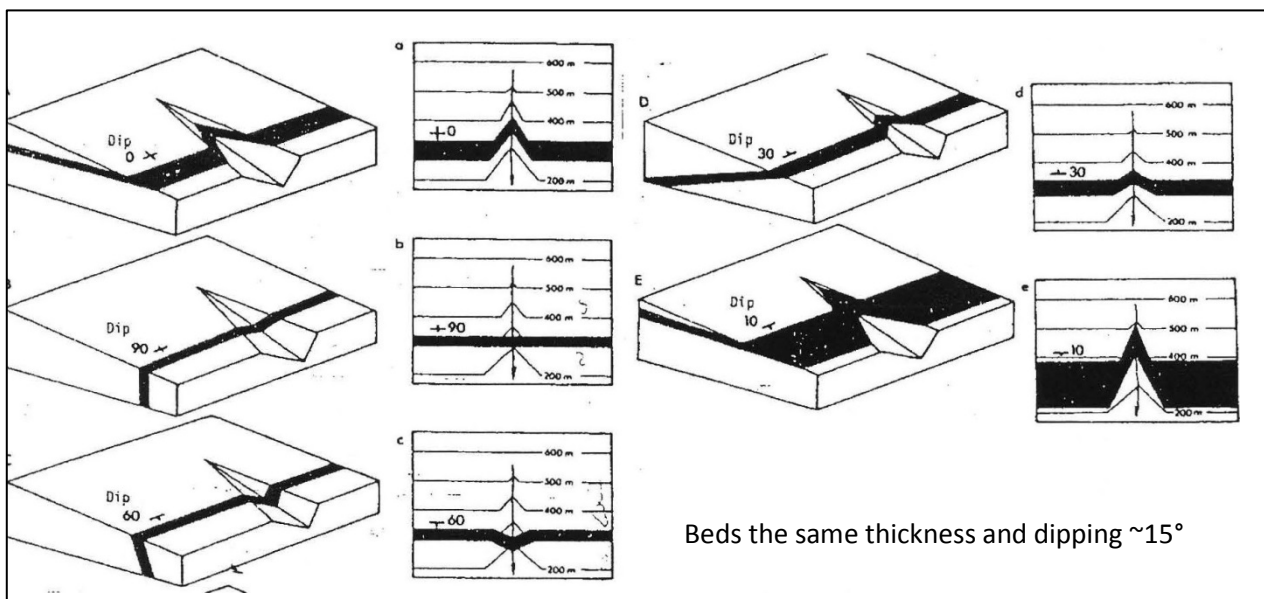
Map 2: Point B, dipping at 9° towards the west

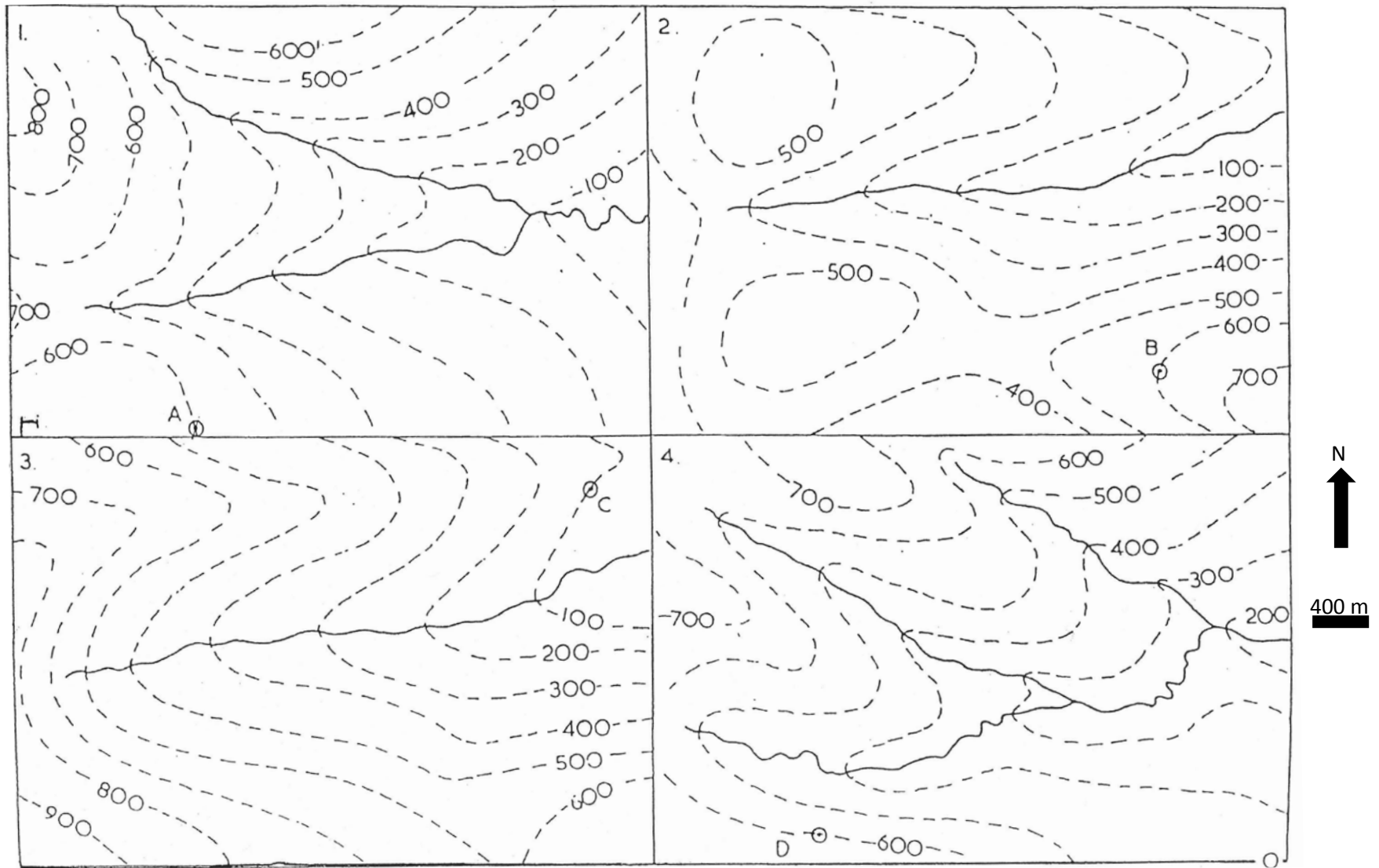
Map 3: Point C, dipping at 5.5° towards the east

Map 4: Point D, dipping at 90° , top of the bed facing towards 315°

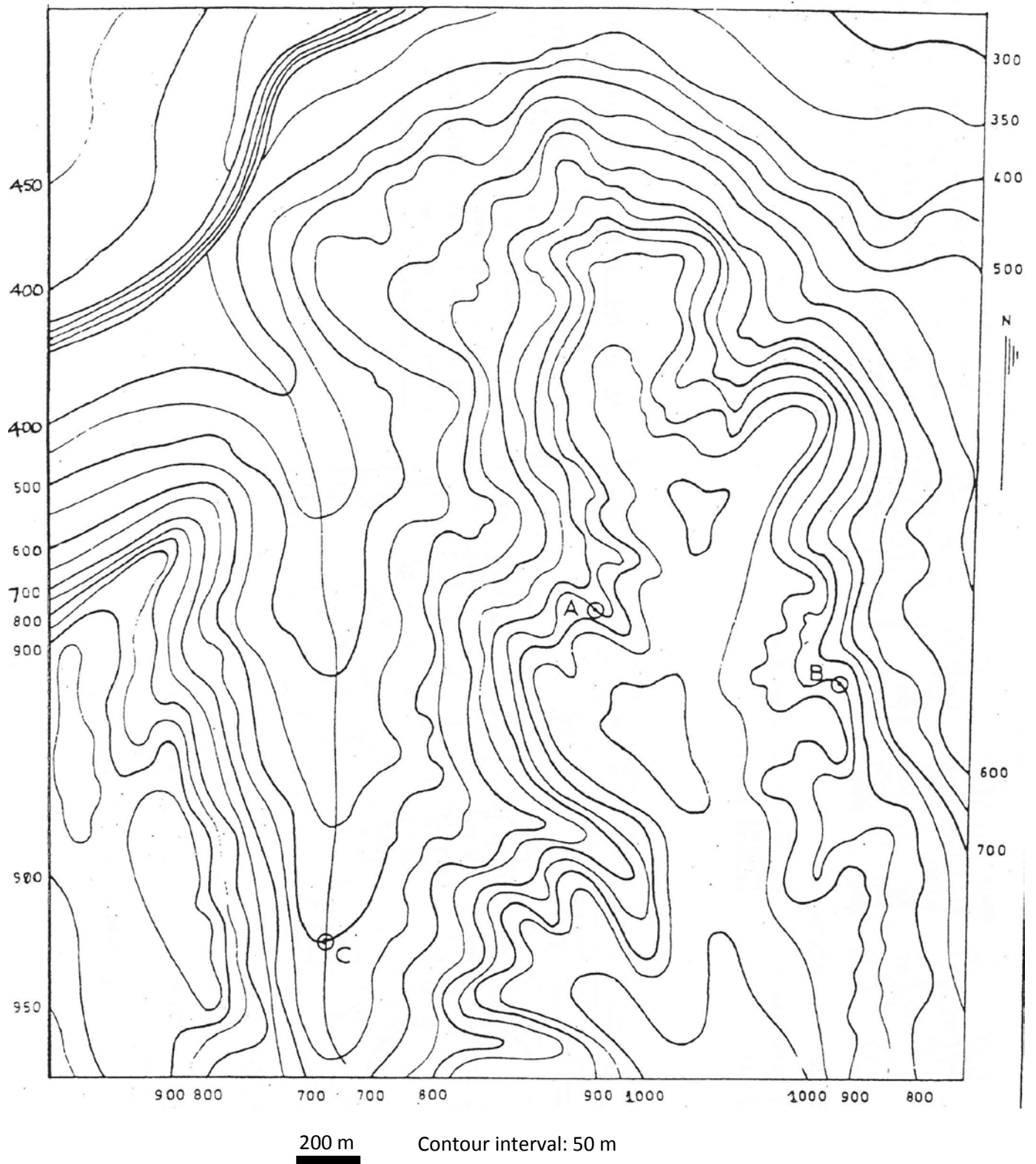
Note from your construction the relationship of the "V" to the direction of dip and the topography.

Illustrations below from Rickard, M. Geological Map Interpretation. Department of Geology, ANU.



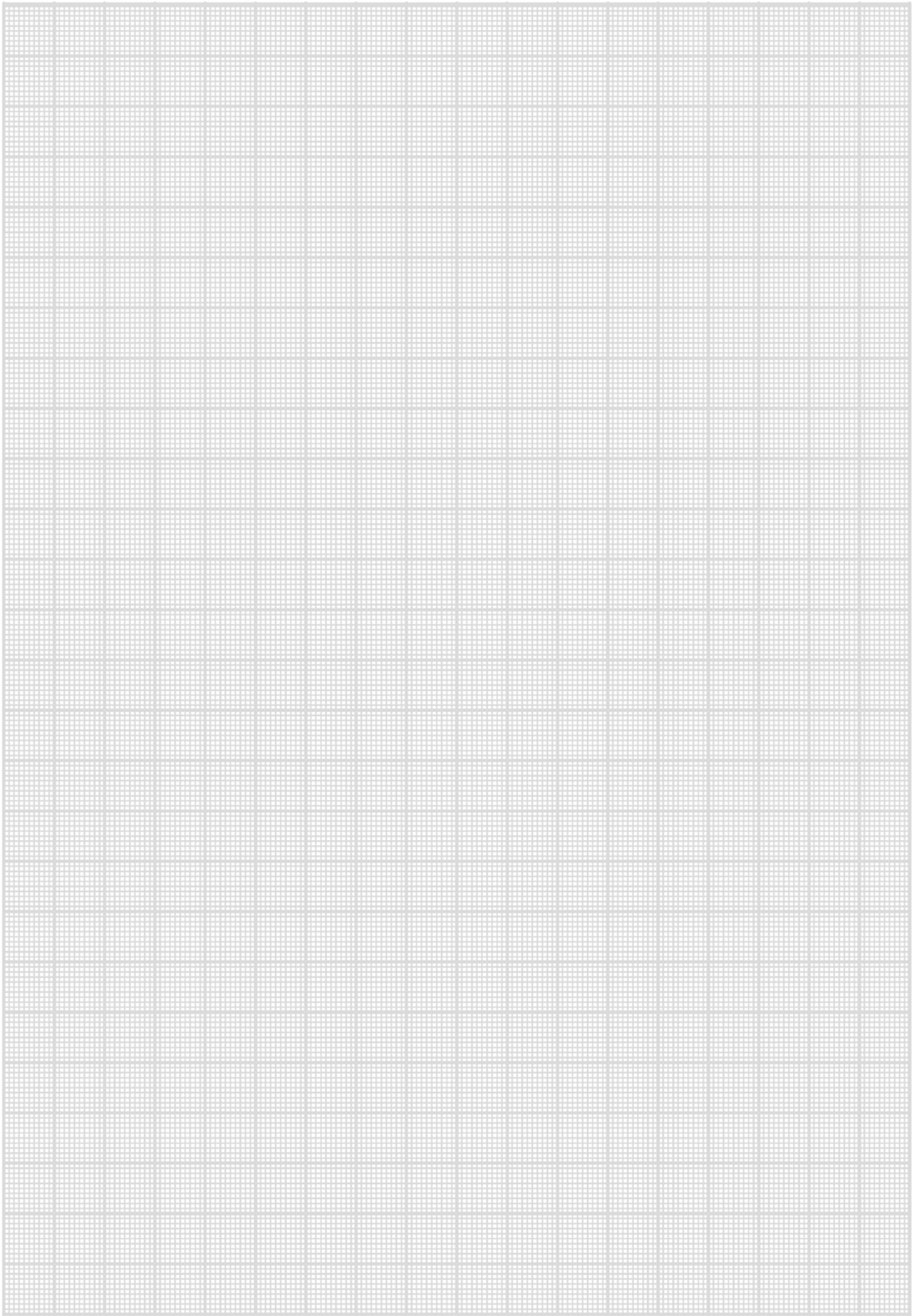


MAPPING EXERCISE 16

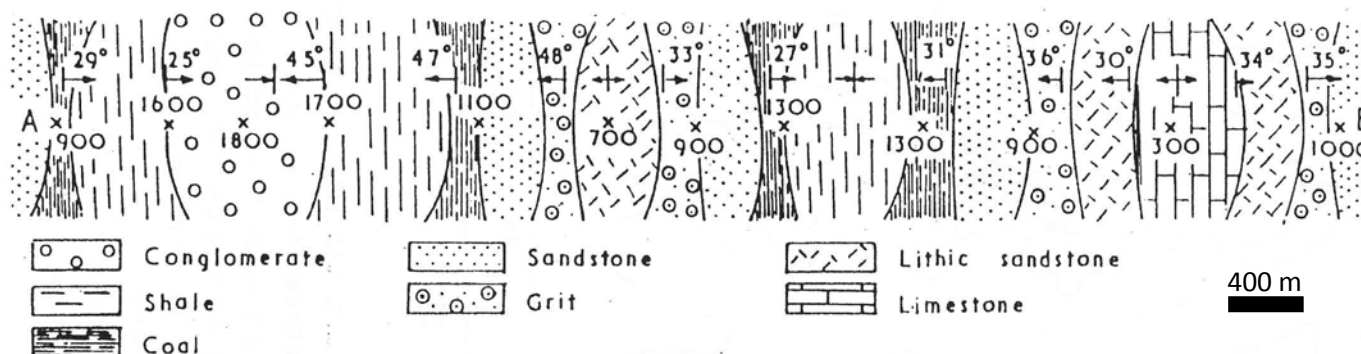


A thin conglomerate bed – containing boulders of greywacke, red limestone, siltstone and shale boulders – outcrops at A. Immediately below it, the boundary between greywacke and overlying shales dips at 30° to 252° . At B, the conglomerate occurs above a thin red limestone bed which dips at 30° to 353° . Greywacke and siltstone are above and below the limestone respectively. At C, the conglomerate is overlain by a thick sequence of sandstones.

1. Plot the outcrop of the conglomerate and greywacke formations
2. Determine the dip of the conglomerate and the thickness of the greywacke.
3. Draw a cross section, normal to the strike of the conglomerate, through A.
4. Describe briefly the geological history of the area

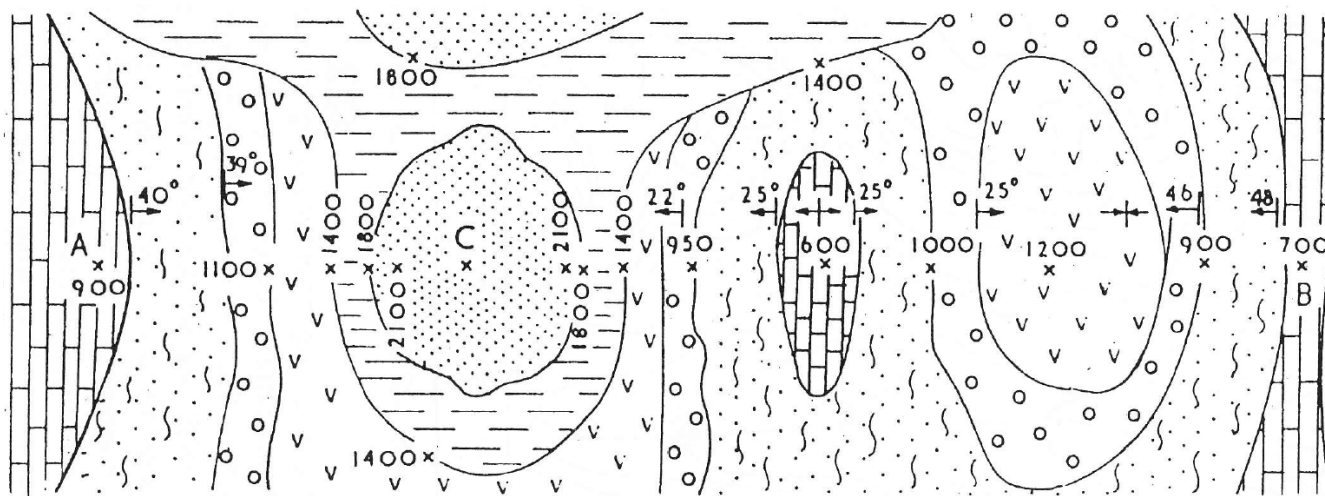


MAPPING EXERCISE 17



Anticlines and Synclines

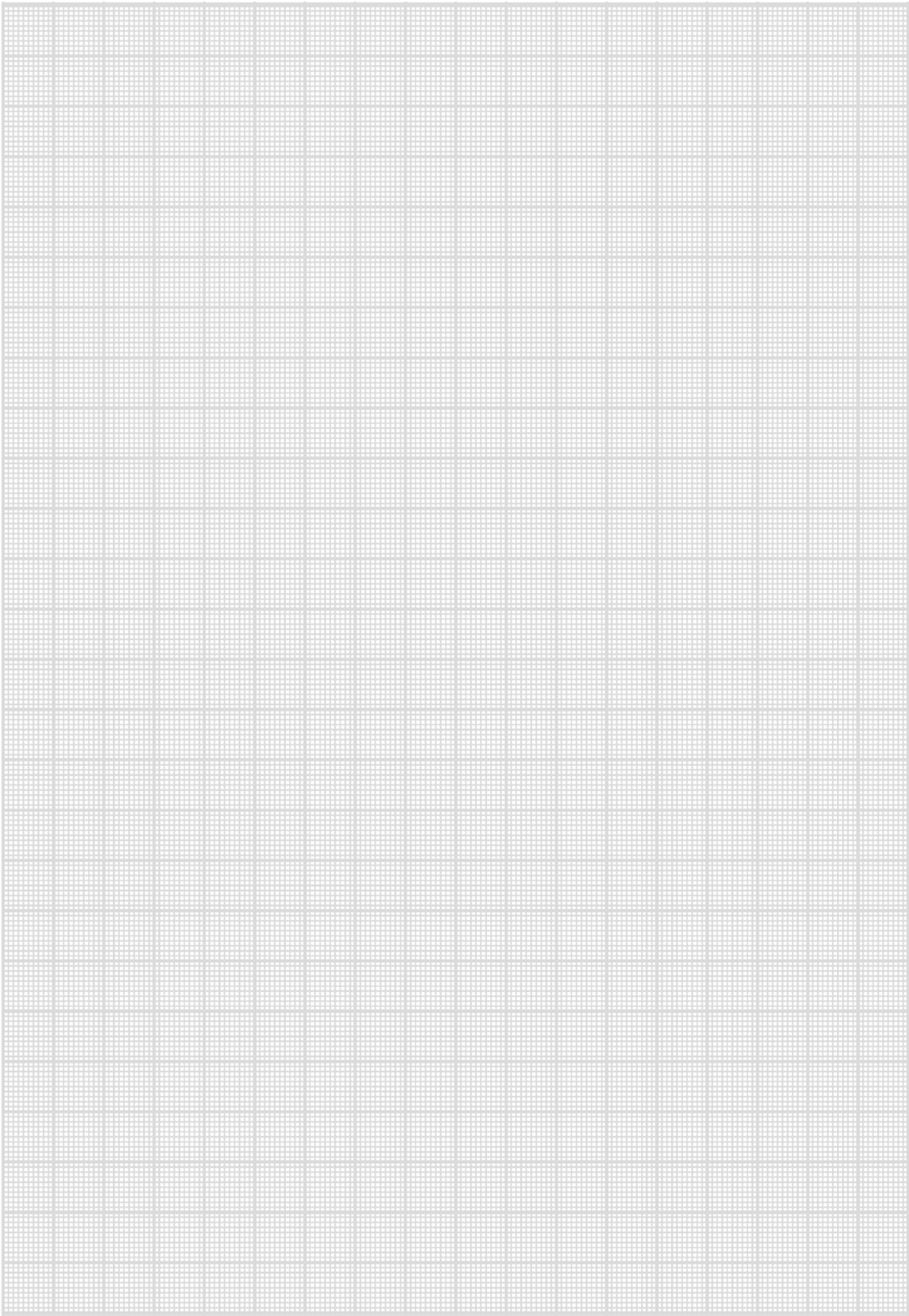
On this map are shown the outcrops of a series of sedimentary rocks; a surface which is not level. The heights of certain points above sea-level are shown. Draw a section from A to B, and briefly describe the geological history of the area.



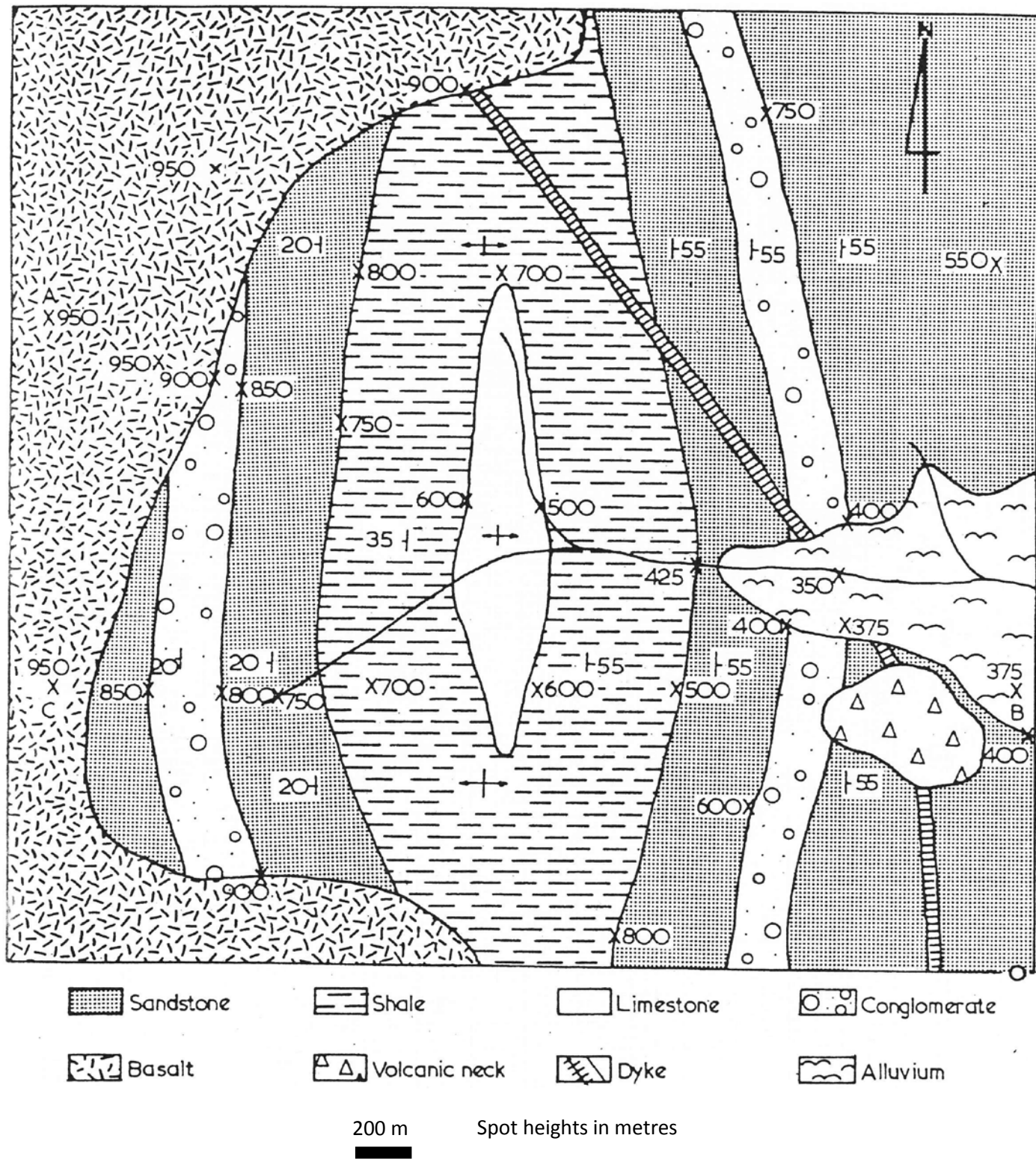
Outlier and Inlier

Draw a geological section from A to B on the map on the left. Find the thickness of the Silurian conglomerate and sandstone. Determine the approximate depth to conglomerate in a vertical bore at point C.

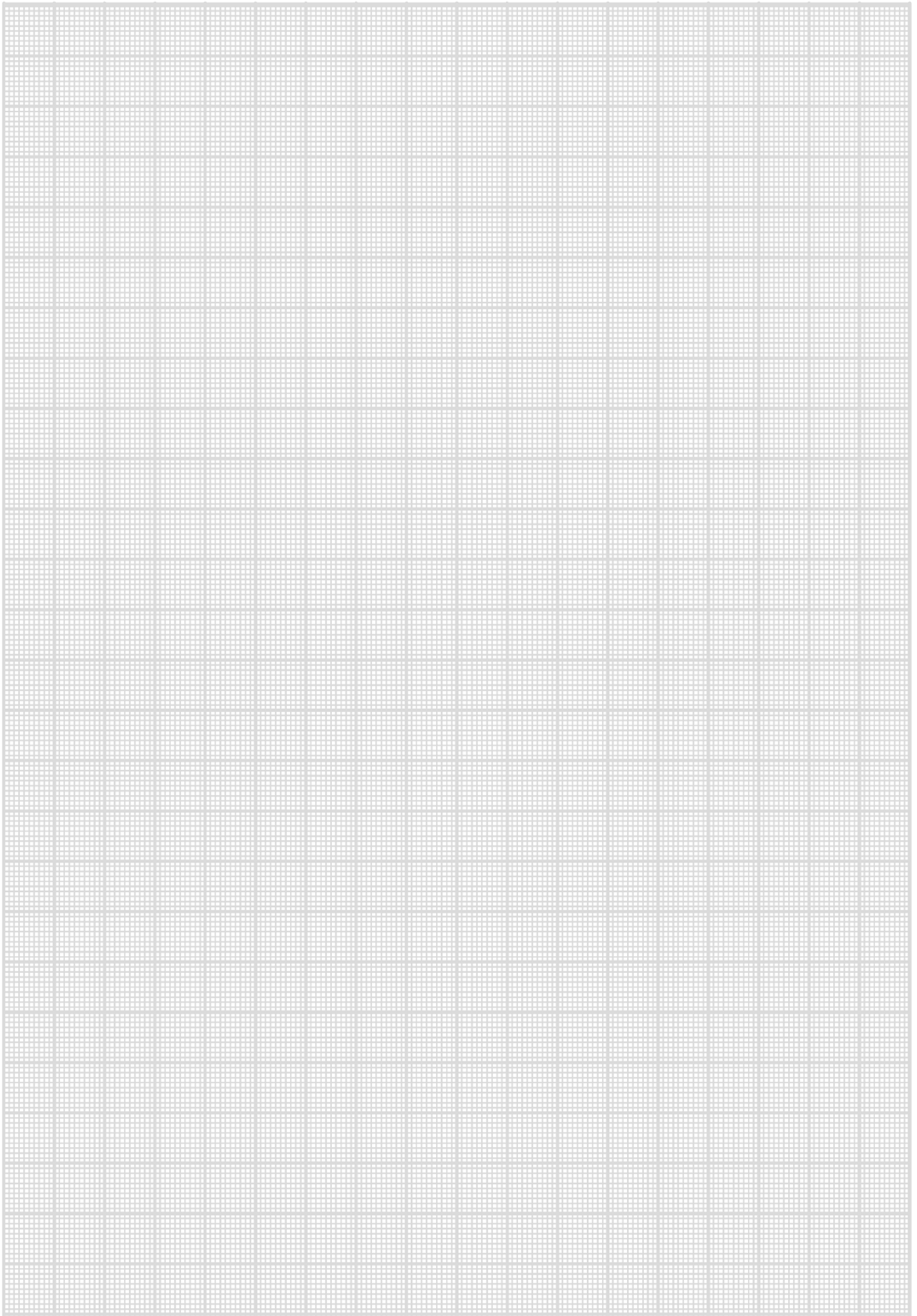
Discuss the geological history of the area and make a list of geological structures recognised on the map and section. Heights are given in metres above sea-level.

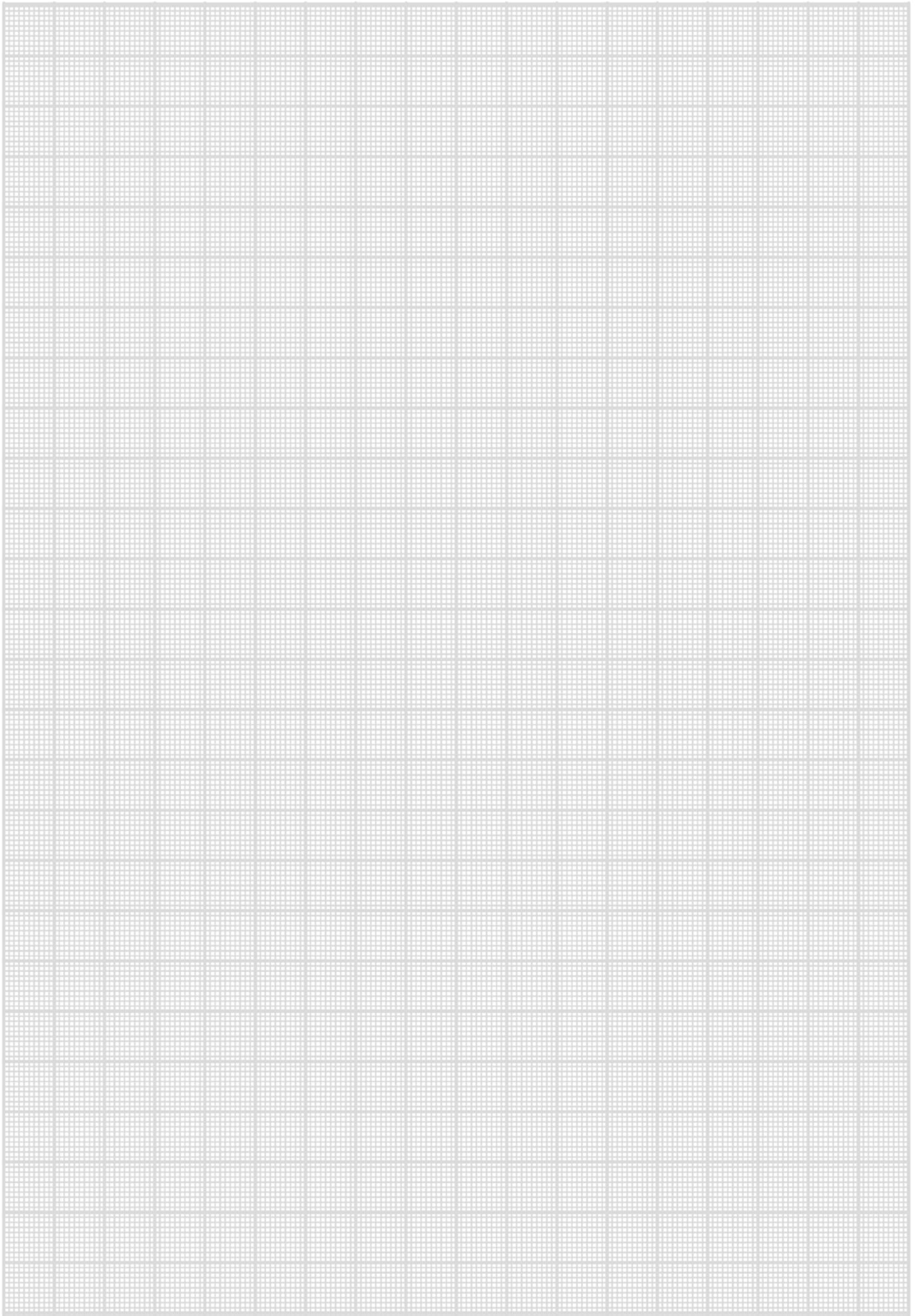


MAPPING EXERCISE 18



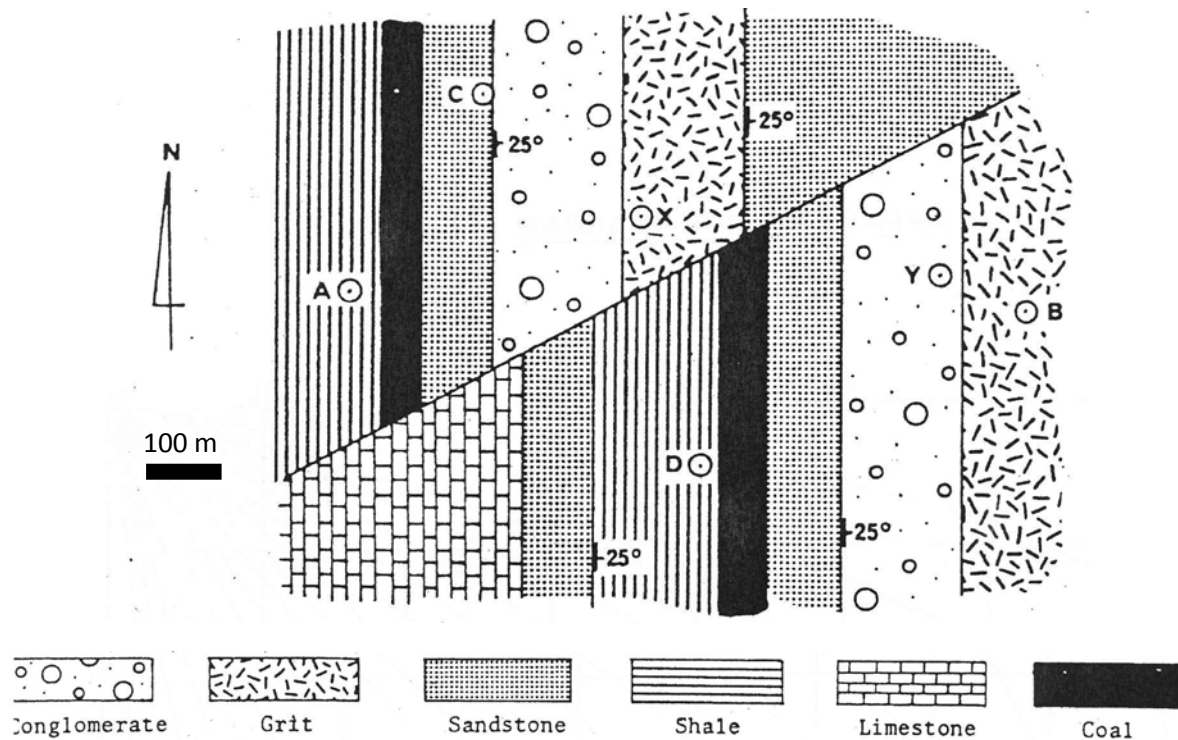
Draw sections along AB and CB and tabulate the geological history of the area.





MAPPING EXERCISE 19

The map below represents an outcrop on a surface levelled by erosion.



Problem 1.

Assuming the fault to be vertical, draw a cross section through A and B to show the true dip of the beds.

Problem 2.

If the normal fault dips at 50° towards 330° determine the following (using the apparent dip diagram, Figure 16, where necessary):

- Draw a cross section through A and B
- Draw a cross section perpendicular to the strike of the fault through C and D and for the fault, find the following:
 - The dip slip
 - The throw
 - The heave
- Find the depths of coal in vertical bores at points X and Y and in each case state the vertical thicknesses of the various rocks passed through if the bores are 200 metres deep. Also determine the true thickness of each bed represented in the diagram.

Problem 3.

If the displacement is only in the direction of the strike of the fault which is dipping at 35° towards 330°, find the throw and heave.

