Reading and Understanding Geological Maps

Objectives:
After working through this section, you should:

- Understand the format of a geological survey map
- Be familiar with the presentation of data on such maps
- Recognise simple geological features from a map
- Be able to sketch a cross-section through a map
- Be able to present a summary sketch map

What do geological survey maps show?
Geological data is 3-dimensional; as exploration geophysicists you are interested in the arrangement of rocks below the ground. Although seismic, magnetic and gravity data, among other techniques, will tell you much of what you need to know, all clues help.

Terminology
Before we go any further, we need to define some simple geological terms:
Think about sedimentary rocks (those that form in orderly layers). If the layers of rock are **planar** (horizontal), with constant thickness and continue forever, then these rocks are said to have **layer-cake stratigraphy** (This is rare in practice, but useful for now to help visualise these ideas).

We deal with structures in terms of the orientation of the planes (the boundaries between **units** or **beds**.
Bed is an informal term referring to individual, often relatively thin layers within the rock. Loosely, each bed formed over a short period of time; often, the surface of a bed formed the sediment surface at some point in the past.
Units are a collection of adjoining beds that are grouped together when they have some similarity e.g. mineralogy, palaeontology or particular structures that indicate a common process in their origin. Units must be mappable and distinct from one another, but the contact does not have to be particularly distinct e.g. "when the sandstone component exceeds 75%".
Units are grouped together in stratigraphy as formations and members of formations.

What do the outcrop patterns of these beds tell us?
Outcrop patterns represent the intersection of the 3-dimensional shape of the rock with the land surface.
Where the rocks are flat and the land is not, then boundaries will outcrop along topographic contour lines.
Vertical features *and nothing else* will outcrop as straight lines in hilly terrain. All other orientations will wave across the landscape, cutting across topographic contours.

Understanding the scale and coordinates of a geological map
Maps in general come in a variety of scales depending on the amount of detail needed for different purposes. In all cases, they will show a grid for location (in Britain, the National Grid on land), almost always with North at the top. Points on the map are referred to using coordinates (eastings then northings) which are usually 6 or 8 figure references. The basic

grid square covers 100,000 metres, with northings, for example, given as $^{6}70^{000}$mN, giving an absolute location in metres. When working within a map, it is usual to give 3 figures (e.g. 700N) or 4 figures (e.g. 7000), depending on the scale of the map. Four figure grid references specify locations to within 10 metres. Maps covering a larger area tend to use latitude and longitude in addition or instead. Maps for other countries will use other National Grids.

What is strike and dip?

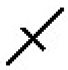
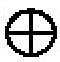
Geologists define the orientation of dipping beds using the terms **strike** and **dip**.

Strike is the azimuth (bearing on a compass) of a horizontal line on a bed i.e. a line perpendicular to the steepest angle of dip). This is always given as a *3 figure number*, e.g. 090 for a bed striking East-West.

Dip is the angle from the horizontal of the steepest gradient of the bedding surface. This is a *2 figure number* (e.g. a horizontal bed has a dip of 00^{o}). It has an orientation and dip arrows always point down dip.

The two combined are given as 256/45 SE, for example, fully defining the orientation of a plane.

Strike and dip are generally marked on maps, using a combination of symbols and figures, these are given below.

Symbol	Description
	Strike and dip of bedding 043/20 NW
	Strike and dip of bedding 043/20 NW
	Strike and dip of vertical bedding
	Strike and dip of horizontal bedding

(*Please note: that*  *can also refer to a linear feature*).

Strike and dip are measured with a **compass/clinometer**, on an area about 10cm x 10 cm. For convenience, we approximate even wavy beds as planes. You can assess in the field how planar the beds are and ensure that you take enough readings. (If you find this difficult to visualise there is a 3D model at the back of this document you can make).

More on outcrop patterns

Outcrop patterns also provide information on the dip direction of simple sedimentary units. Imagine the stratigraphy of an area as a pile of books. Let's start with the books horizontal (they stay on the desk better that way!), so we are considering rocks in which the bedding plane is horizontal.

How these beds look on a map depends on the landscape of the area. If we were in a flat featureless area, then all we would see at the surface would be on type of rock; This would be whichever rock happened to be at the same height as the plain. Therefore, the geological map would show one type of rock only.

But if the area had hills and valleys that cut through the horizontal layers of rock, then we would see more than one rock type (i.e. more than one colour of rock on the map). If the map has topographic contours on it, then the boundaries between rock types will outcrop in shapes that follow the contours (because the beds are horizontal, the boundaries between them can exist only at particular heights. That is the height at which they outcrop.

So, horizontal beds produce distinctive outcrop patterns. The pattern is also clear if the map is small scale; This is because flat beds produce elaborate, crenulated outcrop patterns that reflect small details of the landscape. Look out for outcrops that zig-zag across streams, for example.

The other extreme comes from areas with vertical beds. Here the books are lined up as if on a shelf. Vertical beds can outcrop only as straight lines, completely unaffected by the topography.

The general case is when the rocks are dipping. They outcrop along lines that do not follow the contours, nor are they straight lines. They mark the intersection of the shape of the boundaries between beds, with the landscape surface in three dimensions.

Gently dipping beds outcrop in patterns that are almost the same as topographic contours, but the bed boundaries cross them occasionally. Steeply dipping beds outcrop in lines that are close to straight, cutting across many topographic contours. The shape of the outcrop can help you assess the dip of the bed and especially the relative dips of different beds in the same landscape.

Dip direction from outcrop

We can understand the direction of dip if we know the relative ages of the rocks. Look at the **stratigraphic column** at the side of a map. This shows the units visible on the map in their order of formation (oldest at the bottom, youngest at the top).

Returning to the pile of books concept; where the units are tilted, the order in which they appear on the map tells you the direction of dip: Dip direction is from older to younger. (*Please note: This won't work in areas of complex structure, where beds may be upside down!*)

Outcrop patterns will change in response to changes in dip, thickness and of course, the topography of the land surface.

True and apparent dip

True dip is a line perpendicular to the strike and is the steepest line along the plane of the bed. Whereas apparent dip is the angle from a horizontal line that is not perpendicular to the strike. (If you find this difficult to visualise there is a 3D model at the back of this document you can make).

Dip variations

Folds and **faults** are the most common causes of variation in strike and dip; see attached sheets for brief examples. Folding and faulting, followed by subsequent erosion and deposition of a younger rock produces an **unconformity** (see figure below).
Unconformities are variations to the simplest case of sedimentary rocks. They are identifiable on maps as place where more than one younger rock is in contact with several older rocks (in the simplest case). Unconformities make useful time markers.

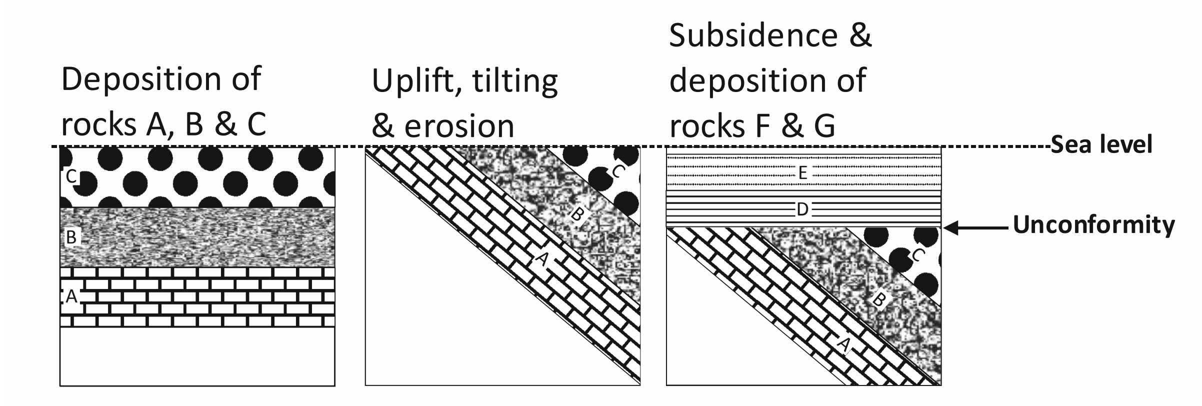


Figure 1: Stages in the development of an unconformity

Reality

But in many cases, sedimentary rocks are not of uniform thickness, nor do they continue the same forever. In some cases, the stratigraphic column on the side of a map specifies bed thicknesses and variations in the type of rock of a particular age (**facies variations**) are also shown in some cases.
In cases where sediment thicknesses are known to vary significantly, a special type of map is used to illustrate this (an **isopach** or **isopachyte map**), which show contours of bed thickness. These are very useful in sedimentary basin analysis, where sediment thickness is an important variable for modelling.

Calculating bed thickness

True thickness (*t*) is measured perpendicular to upper and lower surface of the bed. *V* is vertical thickness that would be encountered in a borehole. The true thickness of a bed can be obtained from the outcrop width (w) and dip as follows:

*True thickness (t) = width of outcrop (w) x sin*θ *(angle of dip)*

Synthesis of geological maps

The data presented on even simple geological maps can be very confusing. We need to simplify it, in order to answer whatever questions we have about the area. There are two ways to do this, which may be appropriate in different cases:

- Cross section (precise or sketch)
- Sketch map

Begin by dividing the map up into geologically sensible regimes (use faults and unconformities to define domains on the map). Put these boundaries onto your sketch map (as well as grid refs and scale). Then, look at the map and deduce the orientation of the rocks in each area: Which way do they dip? Are they steep or shallow? Are there folds? Are there important faults? Etc.

Use a key and colour or shade your map to show important groups of rocks. Show the dip direction and amount for each domain.

Hints and tips for sketch/summary maps

A good sketch map:

- Is the same shape as the original map
- Is easy to relate to the original map, i.e. it uses similar colours and ornament, if needed, and has grid lines, key and scale shown clearly.
- Is a sketch, i.e. it reproduces the general form of key boundaries without following every twist and turn on the map.
- Reproduces accurately, but not in full detail, significant outcrop shapes, boundaries and cross-cutting relationships.
- Gives indications of topography, for example showing spot heights on high ground and major rivers to show valleys.
- Summarises complex stratigraphy, for example by grouping units with similar histories together and treating them as one unit.
- Highlights important features such as major faults and folds by marking them and showing as much information deduced from the map overall as possible. For example, folds can be shown as axial traces, synformal or antiformal, with younging directions marked. Faults traces should show dip direction, downthrow side and throw (if known), marked according to convention.
- Is annotated, to indicate complexities not easily summarised, e.g. “region of many parallel steep faults” or “many thin bedded-parallel igneous intrusions”.
- Shows representative dip directions and dip amounts where feasible.
- Is neat and easy to read.

A bad sketch map:

- Has a shape and form different from the original map.
- Does not have grid lines numbered, has no scale, and it is hard to tell which bit of it refers to what part of the original map.
- Uses colours and ornament that do not relate to those of the original map, uses too many colours or uses ornaments without a key.
- Does not have a key.

- Is a detailed reproduction of the original map, right down to the drift in the stream valleys. (If you want a smaller reproduction of the map, use a photocopier!)
- Retains all the stratigraphic detail of the original.
- Does not highlight the important features of the map as a whole: any analysis of this small map is as difficult as, if not harder than, analysis of the original. The idea is to sort out what is important and show these features on your sketch.
- Does not give any clue to topography.
- Does not show dip or even dip directions.
- Has no helpful annotation.
- Is messy, has imprecise line work and is generally hard to read.

Cross-sections
Cross-sections show the thicknesses, dip directions and relationships between units on a vertical slice through a map. They are a useful way of synthesising data. Accurate sections match exactly with the rocks that outcrop along the section line. Sketch sections sacrifice precision for a clear representation of the structure and often combine information from across the map onto a section to make it representative of the area as a whole.
Cross-sections generally are most useful to geologists when the horizontal scale equal to the vertical one (this means that dip amounts on the section are accurate). Any form of vertical exaggeration alters dips and can produce misleading structures. Both types of cross-section will show clearly such features as unconformities, folds, faults, sediment thickness changes, igneous intrusions.
A sketch map is a simplified diagram of the map, highlighting important information and neglecting both detail and superfluous aspects of the geology. They will look very different depending on their purpose. In general, such sketch maps will also highlight features such as unconformities, faults, folds and igneous intrusions. But they may also illustrate features such as fault density, mineralisation or porosity.

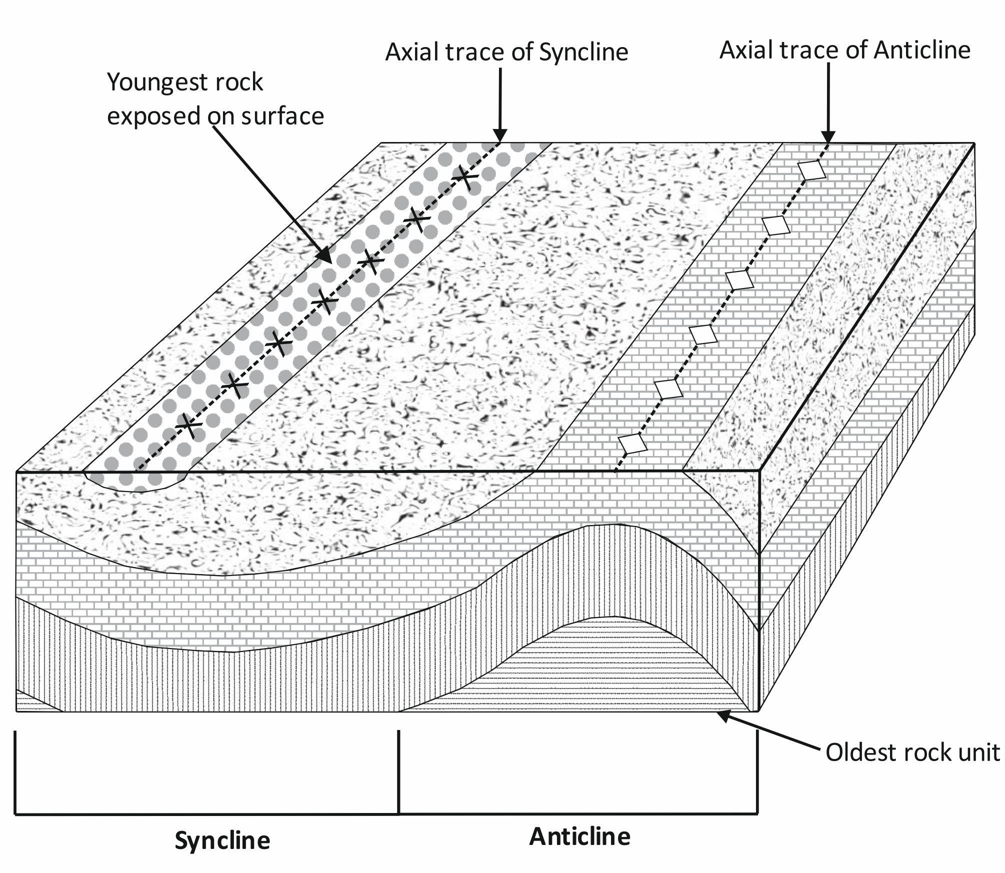
Structure contours
Structure contours are simply contours of height drawn on a particular geological surface (e.g. a bedding plane, a coal seam or a fault). They are usually drawn as height above some datum or reference height, such as sea level. They are a clear way of representing what may be a complex shape in the rock underground. You draw them on the basis of the information that is available (often depths to a particular layer from boreholes or seismic sources).

In summary:

- If the structure contours are **straight, parallel** and **equidistant**, then the surface is **planar**. Its strike is constant and parallel to the strike of the structure contours.
- If structure contours are **curved**, then the **strike** of the bed **varies**. If the separation of the structure contours varies, the dip of the bed varies.

Folds

When rocks are folded, they also assume typical outcrop patterns, as shown in figure 2 below (characteristically forming V-shapes in valleys and ridges).



Faults

Faults are surfaces in the Earth across which there has been some displacement, usually by **cataclasis** (the deformation of rock via crushing and shearing). Faults are usually narrow in proportion to their length and breadth, often planar or gently curved and exist mainly in the top 10-15 kilometres of the Earth's crust. Below this depth, rock deforms in a plastic fashion, without fracturing. Because faults involve displacement, one of the targets of geologists is to quantify this displacement (ideally as a vector). To do this, they need a unique marker that can be identified in the rocks on each side of the fault (this is rare). It is usual for faults to offset beds (i.e. planar features). This is not enough information to determine the movement of the fault. It can tell you the offset on the fault (the separation between units that were once continuous).

Offset is described in terms of the horizontal offset, called **heave;** and the vertical offset called **throw** (see figure 3).

There are many circumstances in which you cannot tell heave or throw (e.g. if horizontal beds are displaced horizontally, heave and throw are both zero. Consider the example of dipping beds with measurable heave and throw; displacement could be solely horizontal, solely vertical or oblique.

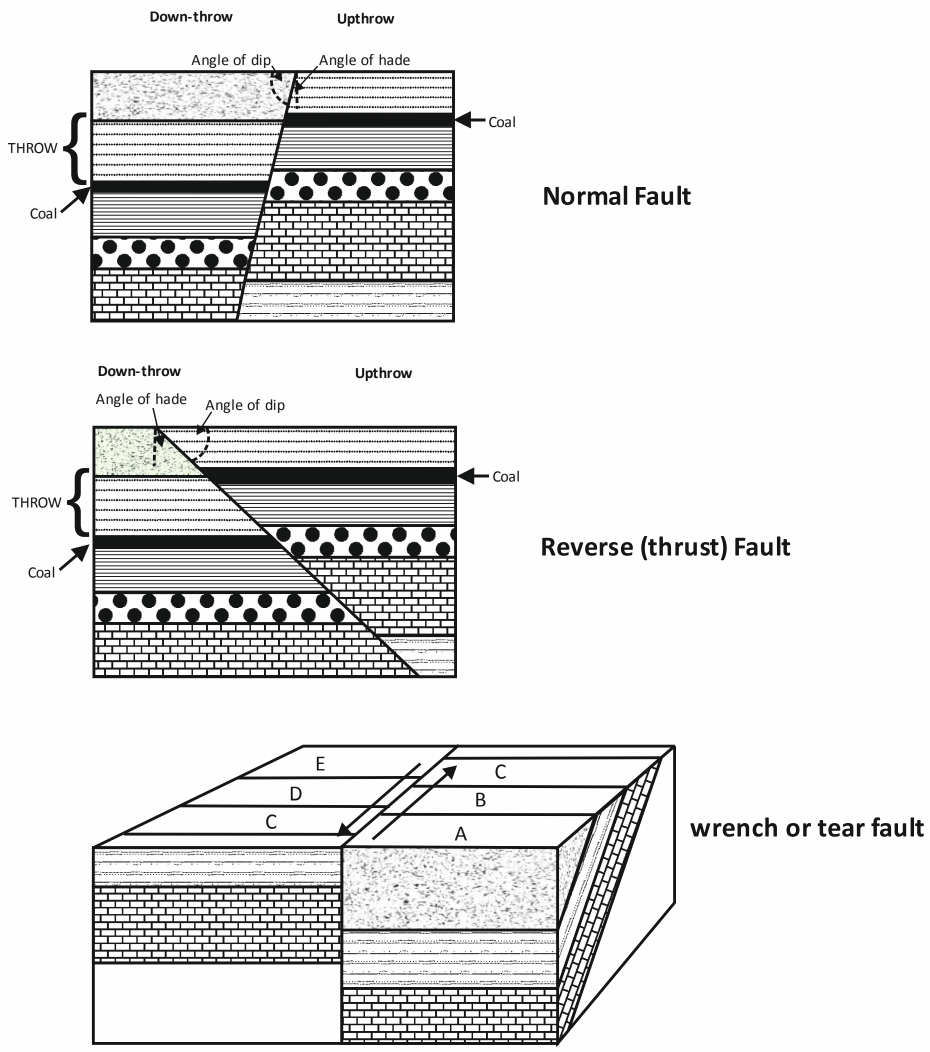


Figure 3: Examples of normal, reverse/thrust and wrench/tear faults.

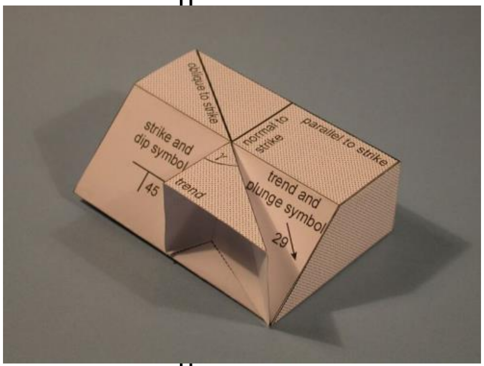
Reference material:

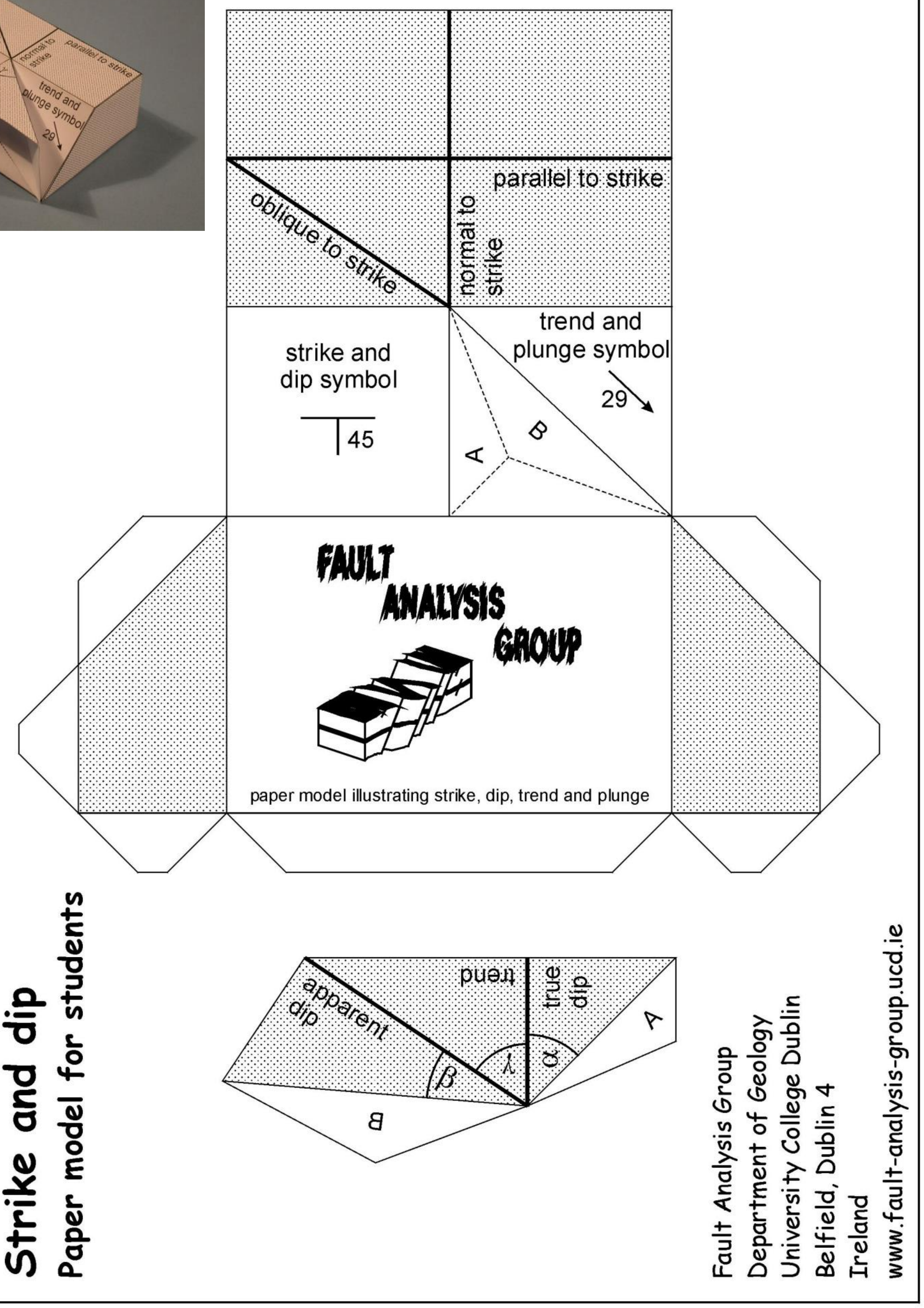
You are recommended to purchase a copy of the following book:

An Introduction to Geological Structures and Maps - 8th (2011) Edition
George M Bennison
Paul A Oliver
Keith A. Moseley
Hodder Education, London

These and other paper models are available from:
Fault Analysis Group, Department of Geology, University College Dublin, Belfield, Dublin 4, Ireland
www.fault-analysis-group.ucd.ie

3 dimensional model of strike and dip





3 dimensional model of true and apparent dip