

LAB 1: ORIENTATION OF LINES AND PLANES

Read the introductory section, chapter 1, pages 1-3, of the manual by Rowland et al (2007) and make sure you understand the concepts of **bearing, strike, dip, trend, plunge, and pitch (or rake)**

Structural analysis

The Earth's crust contains structures almost everywhere, and the aims of structural geology are to understand these structures. In general, there are three objectives of understanding which may be achieved in structural geology

- **Descriptive or Geometric** - what are the positions, orientations, sizes and shapes of structures that exist in the Earth's crust at the present day.
- **Kinematic** - what changes in position, orientation, size, and shape occurred between the formation of the rocks and their present-day configuration? Together, these changes are called **deformation**. Changes in size and shape are called **strain**; strain analysis is a special part of kinematic analysis.
- **Dynamic** - what forces operated and how much energy was required to deform the rocks into their present configuration? Most often in dynamic analysis we are interested in how concentrated the forces were. **Stress**, or force per unit area, is a common measure of force concentration used in dynamic analysis.

It is essential in structural geology to keep these objectives distinct. In particular, avoid jumping to dynamic conclusions without first understanding both the geometry and the kinematics of the situation. Much of this course will focus on the descriptive or geometric objective, which is a foundation for further understanding. Once structures are thoroughly described, we will be able to proceed to kinematic and sometimes dynamic conclusions.

Lines and Planes – Basic Considerations

Almost all work on geologic structures is concerned in one way or another with lines and planes. The following are examples of linear features that one might observe in rocks, together with some kinematic deductions from them:

- **glacial striations** (which reveal the direction of ice movement);
- the **fabric** or **lineation** produced by alignment of amphiboles seen in metamorphic rocks (which reveal the direction of stretching acquired during deformation);
- and the **alignment of elongate clasts or fossil shells** in sedimentary rocks (which reveals current direction).

Examples of planar features include:

- **tabular igneous intrusive bodies** such as dikes and sills;
- **bedding planes** in sedimentary rocks;
- the **fabric** or **foliation** produced by alignment of sheet silicates such as mica in metamorphic rocks (which reveals the orientation of flattening during deformation);
- **joints and faults** produced by the failure of rocks in response to stress (and which therefore reveal the orientation of stress at some time in the past).

Notice that in only one case can we make dynamic conclusions from these observations!

Relationship of lines to planes

A few basic geometric principles governing lines and planes are also useful to bring to mind at this point. On any given plane, it's possible to draw an infinite number of lines that are parallel to or '**lie in**' the plane. Some examples are current lineations that lie in bedding planes, and striations on fault planes that lie in the fault plane itself. The orientation of a line that lies in a plane may be specified by **pitch** or **rake** (Fig. 1a).

There's also an infinite number of other lines are not parallel to any given plane (they may pierce the plane). One special line is perpendicular to any given plane: it's sometimes called the **pole** to the plane.

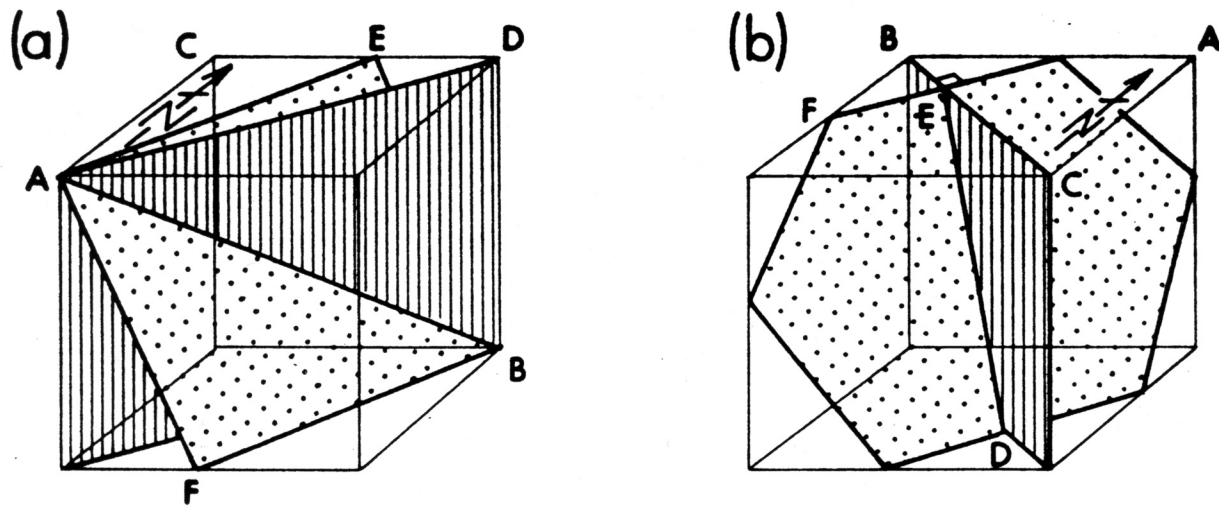


Fig. 1. On the left (a), the trend of AB is CAD (BD is vertical) and its plunge is DAB. The pitch of AB in the stippled plane is the angle EAB. On the right (b), the dip direction of the stippled plane is equal to $ABC + 90^\circ$ (because AB is east-west and has a bearing of 090°), its dip to CED, and its strike to BFE (also equal to ABC in this case because FB is north-south, and AB is east-west).

Intersecting planes

The intersection of two non-parallel planes produces, or occurs at, a line, which happens to lie in, or be common to, both planes (Fig 1b). If we move the planes in space parallel to themselves, the location of the line of intersection will change, but not its orientation. There are many applications of intersecting planes that you will meet in this course. The following are particularly important:

- The intersection of a geological surface with the topographic surface (the ground) is called the **surface trace** (or just **trace**) of that surface. Geological maps are typically divided into areas of different colours (for different rock units) that are bounded by lines; these lines on the map are the **traces** of the geological surfaces that separate the units.
- The truncation, at an unconformity, of an older planar rock unit or surface by a younger one with a different orientation in space produces a line which may be called the **subcrop** limit.
- The intersection of a fault plane with a planar rock unit that the fault displaces produces a line called the fault **cut-off**.
- The two sides or limbs of many folds intersect on a line called the fold **axis**.

Contours

Contours are widely used in the Earth Sciences to show the variation of some quantity over the Earth's surface. A **contour** is a curving line that separates higher values of the quantity from lower values. A contour can therefore also be thought of as a line connecting points at which the measured quantity has constant value. Each contour line is labelled with this constant value; a map covered with contour lines is a useful expression of the spatial variation of the measured quantity,

Often, the measured quantity is the elevation of the Earth's surface, above or below sea level. A **topographic contour** can be considered as a line on the ground separating points of higher and lower elevation. It can also be thought of as the line of intersection of the ground surface with a horizontal plane. Below sea level, contours showing the elevation of the sea floor are known as **bathymetric** contours.

A **structure contour** (Fig. 2) is a contour line on a geologic surface, such as the top or bottom of a rock formation, a fault, or an unconformity. Just like a topographic contour, a structure contour is the line of intersection of a geologic surface with a horizontal plane. Because structure contours are by definition lines of constant elevation, they trend parallel to the strike of geologic structures. They are sometimes called **strike lines**.

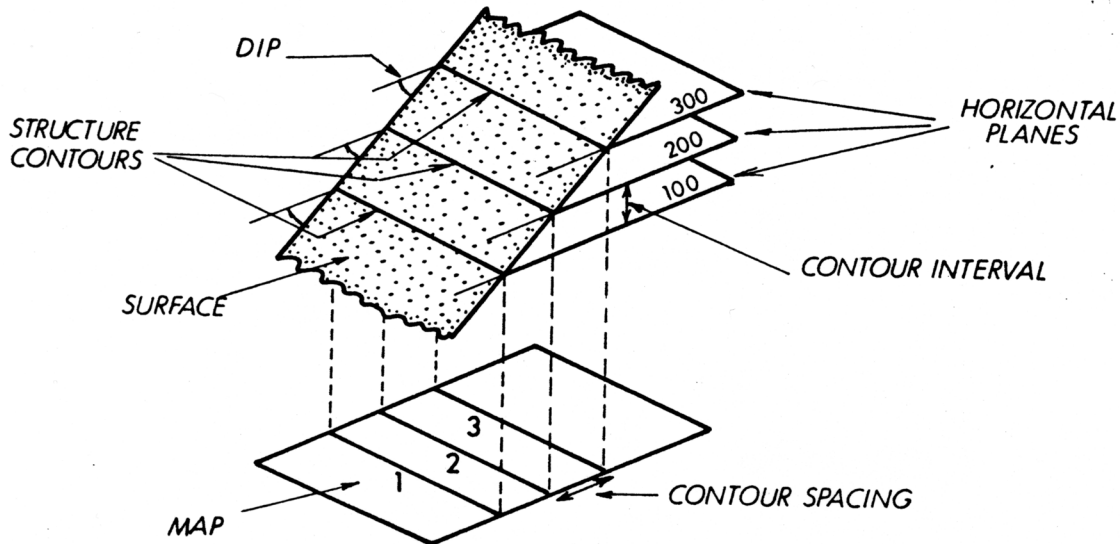


Fig. 2 Diagram illustrating the relationship between contour interval, contour spacing, and dip.

On most maps, the contours, whether topographic, bathymetric, or structure contours are drawn for elevations separated by a constant interval: for example, contours on a map might be drawn at 310, 320, 330, 340 m etc. The spacing of the contours is called the **contour interval** (in this example the contour interval is 10 m).

Although contours typically have a constant vertical spacing, their horizontal spacing on the map may be very variable. The dip of the surface controls the separation of contours. Where a surface is steeply dipping the contours are close together; where the surface is near horizontal the contours are far apart. The horizontal component of the spacing of structure contours, recorded on the map is called the **contour spacing**. The dip δ of a surface is given by

$$\tan \delta = \text{contour interval} / \text{contour spacing}$$

If a surface is **planar** (ie the strike and dip are constant) then the contours will be **parallel, equally spaced, straight lines**. Thus the orientation of a planar, or nearly planar surface can readily be determined from the bearing and spacing of its structure contours.

Contours and surface traces

On a geologic map a geologic surface such as the boundary between two map-units appears as a surface or topographic trace. For practical purposes, very thin rock units will also appear as a surface trace. Where there is topographic relief, these traces can be used to draw structure contours and to determine orientations of inclined geologic surfaces.

The precise orientation of a surface can be determined from its topographic trace because its position and elevation are known everywhere the trace crosses a topographic contour line. These points can be used for drawing structure contours. Thus, for example, the 500 m structure contour is constructed by connecting all points where the trace crosses the 500 m topographic contour. Once a number of structure contours have been drawn, the orientation of the surface may be determined as described above (Fig. 3, 4).

Conversely, if structure contours of a surface are known, its trace can be determined by connecting points where the geologic and topographic surfaces have the same elevation, i.e. the trace connects points where structure and topographic contours with the same elevation cross one another. These should be points where that geological surface or boundary is exposed or crops out.

Where the elevation of a structure contour is greater than topographic elevation, this means the geological surface is “above ground”, and has thus been removed by erosion at that location. Conversely, where the elevation of a structure contour is less than topographic elevation, this means the geological surface is subsurface or below ground, and can be encountered by excavation or drilling.

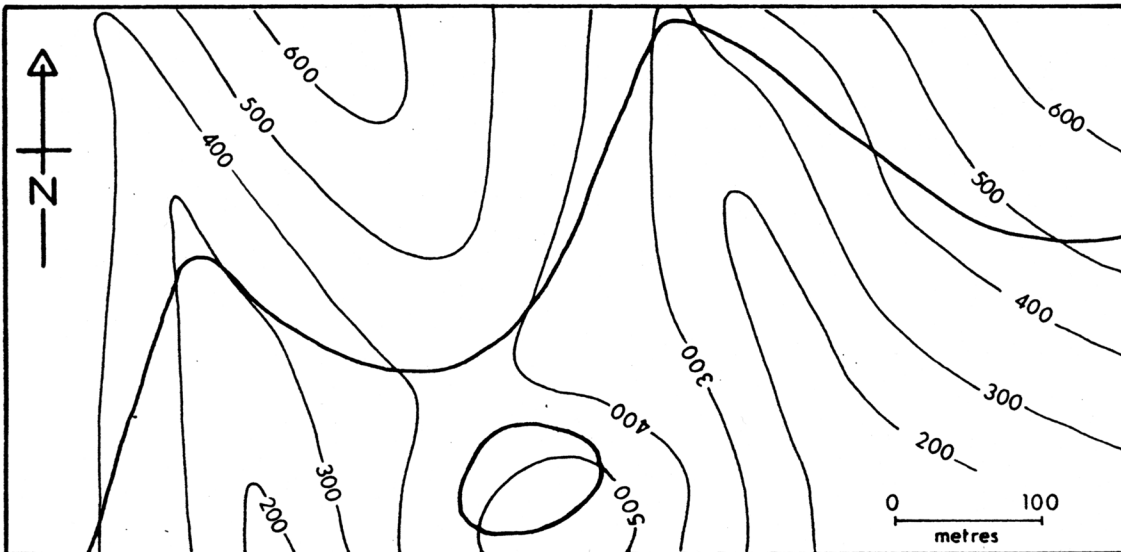


Fig. 3. Map showing outcrop of a single geological surface

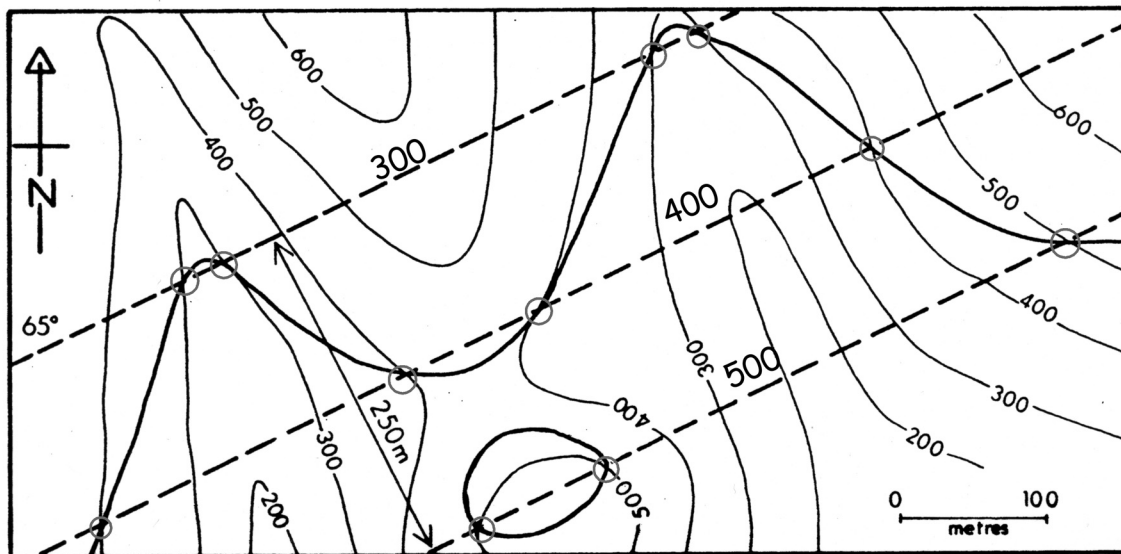


Fig. 4. Structure contour construction on map of single geological surface; the strike and dip of the surface can be determined from the contour orientation and spacing.

Some general considerations when constructing geologic traces (Fig. 5):

- The outcrop trace of horizontal geological surfaces is parallel to the topographic contours.
- The outcrop trace of vertical geological surfaces is parallel to the strike and ignores topographic contours
- For planar surfaces with shallow dip (gentler than the typical hill slopes of topography in the region) the outcrop trace will generally follow topographic contours.
- In such regions, the relative position of a top or bottom contact of a unit can be inferred from the local topography. For example, if the position of the bottom trace of a unit is known then the top of the unit must be exposed at a higher elevation.
- A geologic trace should *never* cross a topographic contour except where the identical structural and topographic contours intersect.

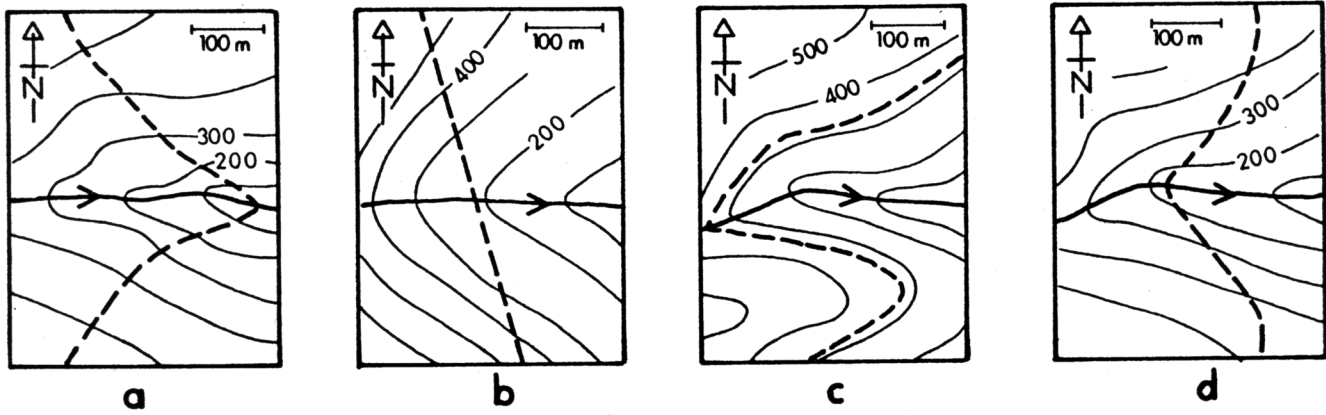


Fig. 5. Sketch maps showing the topographic traces (dashed lines) of geological surfaces of different orientation. (a) Surface dips E. (b) Vertical surface, strikes SSE. (c) Horizontal surface. (d) Surface dips W.