GEOLOGICAL MAPS, TOPOGRAPHIC MAPS,

OUTCROP PATTERNS, and STRUCTURE CONTOURS

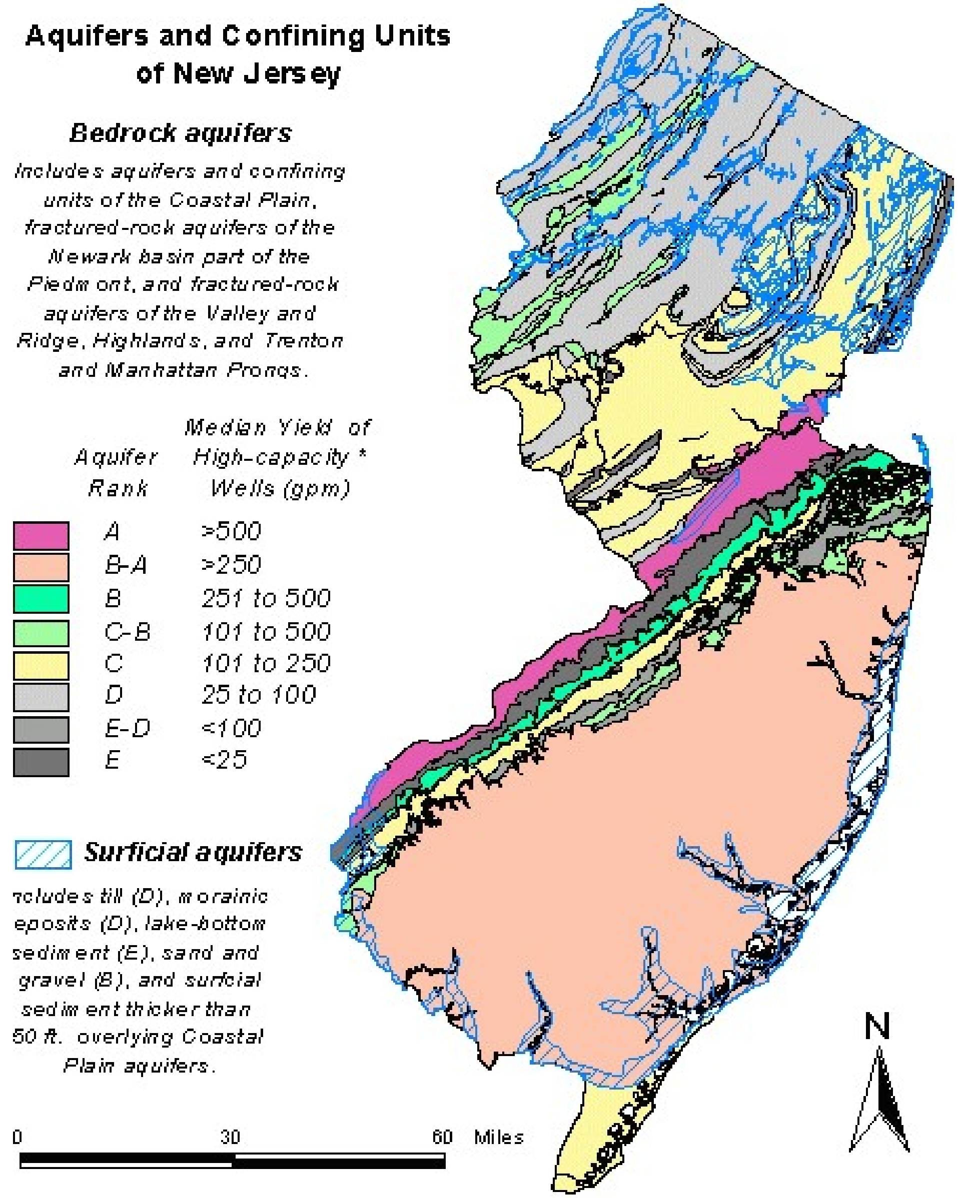
An introduction to the interplay between geology and landforms in two- and three dimensions

Sources:

- Rider/PDFs/Lisle Geol Struct and Maps.pdf
- Geological Structures and Maps: A Practical Guide Nov 12, 2003 by Richard J. Lisle

1. What are geological maps?

Geological maps represent the expression on the earth's surface of the underlying geological strata. For this reason the ability to correctly interpret the relationships displayed on a geological map relies heavily on a knowledge of the basic principles of structural geology. A geological map shows the distribution of various types of bedrock or thick sediment in an area. It usually consists of a topographic map (a map giving information about the form of the earth's surface) which is overlain by shaded or colored polygons that show where different rock units occur at or just below the ground surface. An aquifer map depicts geological map units with respect to their ability to store and transmit groundwater.



* High-capacity wells are industrial wells that are cited and tested for maximum water yields that often greatly exceed domestic-well yields for the same aquifer.

2. How is such a geological map made?

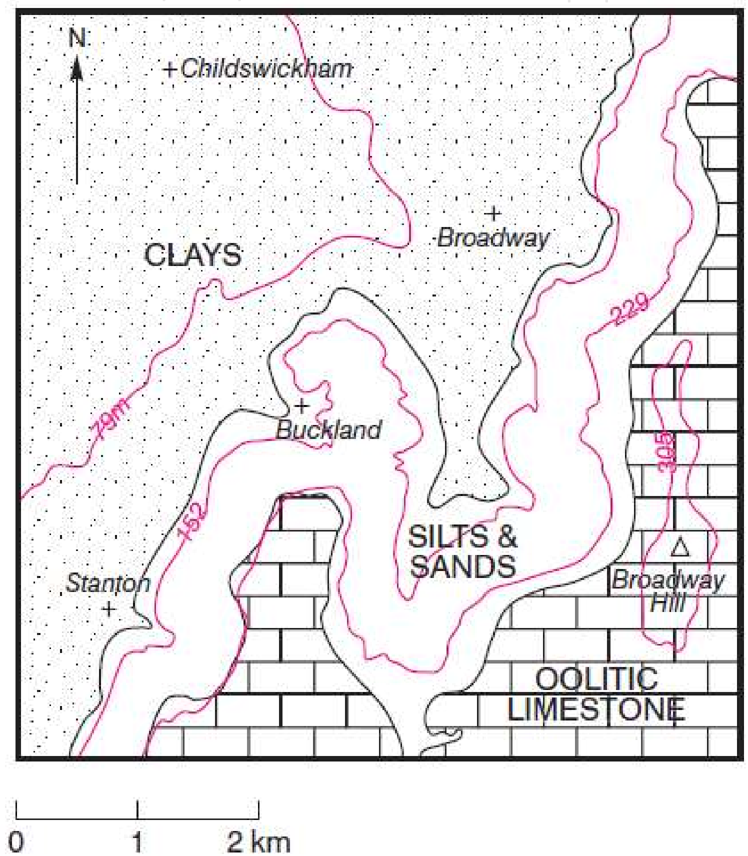


Fig. 1.1 A geological map of the Broadway area in the Cotswolds.

"The geologist in the field firstly records the nature of rock where it is visible at the surface. Rock outcrops are examined and characteristics such as rock composition, internal structure and fossil content are recorded. By using these details, different units can be distinguished and shown separately on the base map. Of course, rocks are not everywhere exposed at the surface.

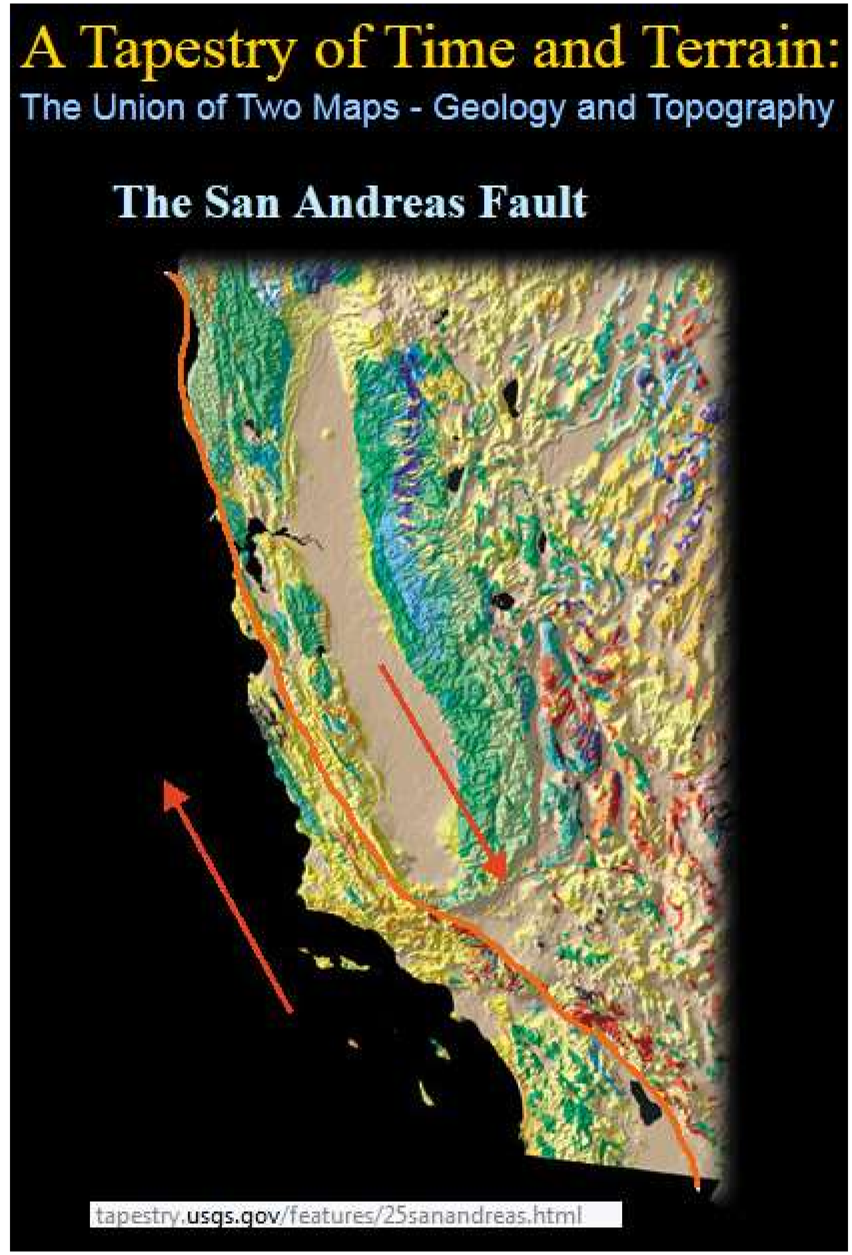
In fact, over much of the area in Fig. 1.1 rocks are covered by soil and by alluvial deposits laid down by recent rivers.

Deducing the rock unit which underlies the areas of unexposed rock involves making use of additional data such as the type of soil, the land's surface forms (geomorphology) and information from boreholes. Geophysical methods allow certain physical properties of rocks (such as their magnetism and density) to be measured remotely, and are therefore useful for mapping rocks in poorly exposed regions. This additional information is taken into account when the geologist decides on the position of the boundaries of rock units to be drawn on the map. Nevertheless, there are always parts of the map where more uncertainty exists about the nature of the bedrock, and it is important for the reader of the map to realize that a good deal of interpretation is used in the mapmaking process."

3. What is a geological map used for?

The most obvious use of a geological map is to indicate the nature of the near-surface bedrock. This is clearly of great importance to civil engineers who, for example, have to advise on the excavation of road cuttings or on the siting of bridges; to geographers studying the use of land and to companies exploiting minerals. The experienced geologist can, however, extract more from the geological map. To the trained observer the features on a geological map reveal vital clues about the geological history of an area.

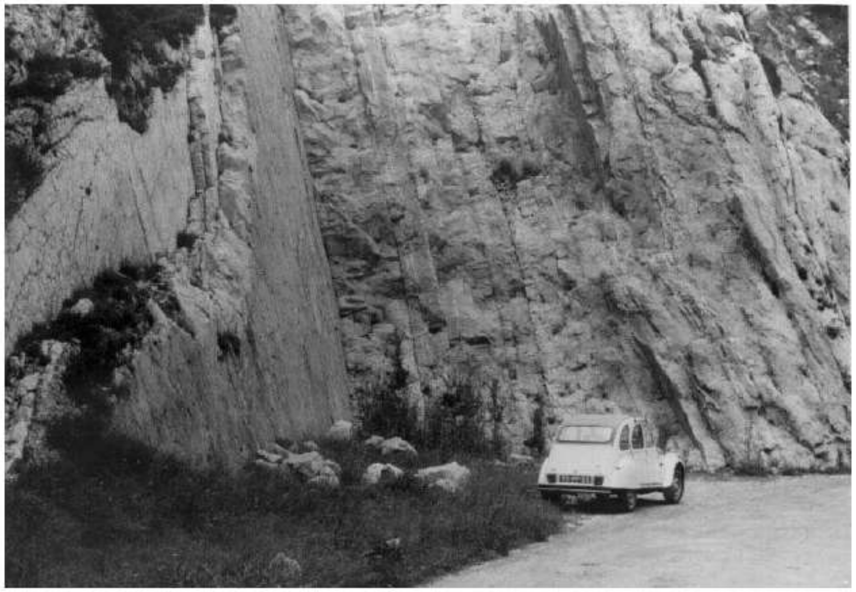
Furthermore, the bands of color on a geological map are the expression on the ground surface of layers or sheets of rock which extend and slant downwards into the crust of the earth. The often intricate pattern on a map, like the graininess of a polished wooden table top, provides tell-tale evidence of the structure of the layers beneath the surface. To make these deductions first requires knowledge of the characteristic form of common geological structures such as faults and folds.



4. Outcrop patterns of uniformly dipping beds

In some areas the sediments exposed on the surface of the earth still show their unmodified sedimentary structure; that is, the bedding is still approximately horizontal. In other parts of the world, especially those in ancient mountain belts, the structure of the layering is dominated by the buckling of the strata into corrugations or folds so that the slope of the bedding varies from place to place. Folds, which are these crumples of the crust's layering, together with faults where the beds are broken and shifted, are examples of complex geological structures that we will work with later. Here, we first consider planar beds with a uniform slope brought about by the tilting of originally horizontal sedimentary rocks.

Fig. 2.1A Horizontal bedding: Lower Jurassic, near Cardiff, South Wales.



Cretaceous Limestones dipping at about 80° in Teruel Province, Spain.

5. Representing surfaces on maps

The geological map in Fig. 2.9A shows the areal distribution of two rock formations. The line on the map separating the formations has an irregular shape even though the contact between the formations is a planar surface (Fig. 2.9B). To understand the shapes described by the boundaries of formations on geological maps it is important to realize that they represent a line (horizontal, plunging or curved) produced by the intersection in three dimensions of two surfaces (Fig. 2.9B, D). One of these surfaces is the ***'geological surface'*** – in this example the surface of contact between the two formations. The other is the ***'topographic surface'*** – the surface of the ground. The topographic surface is not planar but has features such as hills, valleys and ridges. As the block diagram in Fig. 2.9B shows, it is these irregularities or topographic features which produce the sinuous trace of geological contacts we observe on maps. If, for example, the ground surface were planar (Fig. 2.9D), the contacts would run as straight lines on the map (Fig. 2.9C).

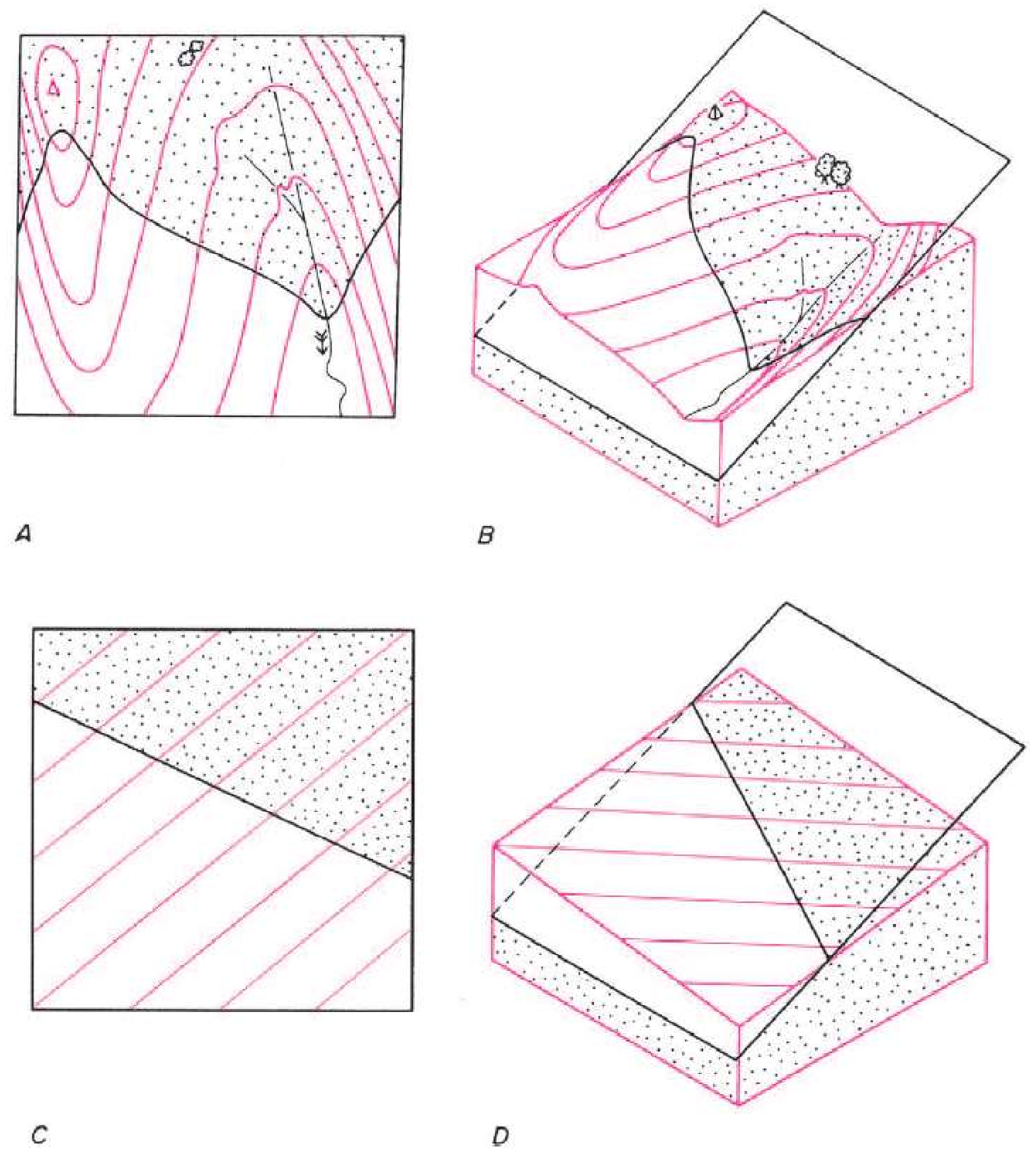


Fig. 2.9 The concept of outcrop of a geological contact.

5. Representing surfaces on maps

The extent to which topography influences the form of contacts depends also on the angle of dip of the beds. Where beds dip at a gentle angle, valleys and ridges produce pronounced ‘meanders’ (Fig. 2.10A, B). Where beds dip steeply the course of the contact is straighter on the map (Fig. 2.10C, D, E, F). When contacts are vertical their course on the map will be a straight line following the direction of the strike of the contact.

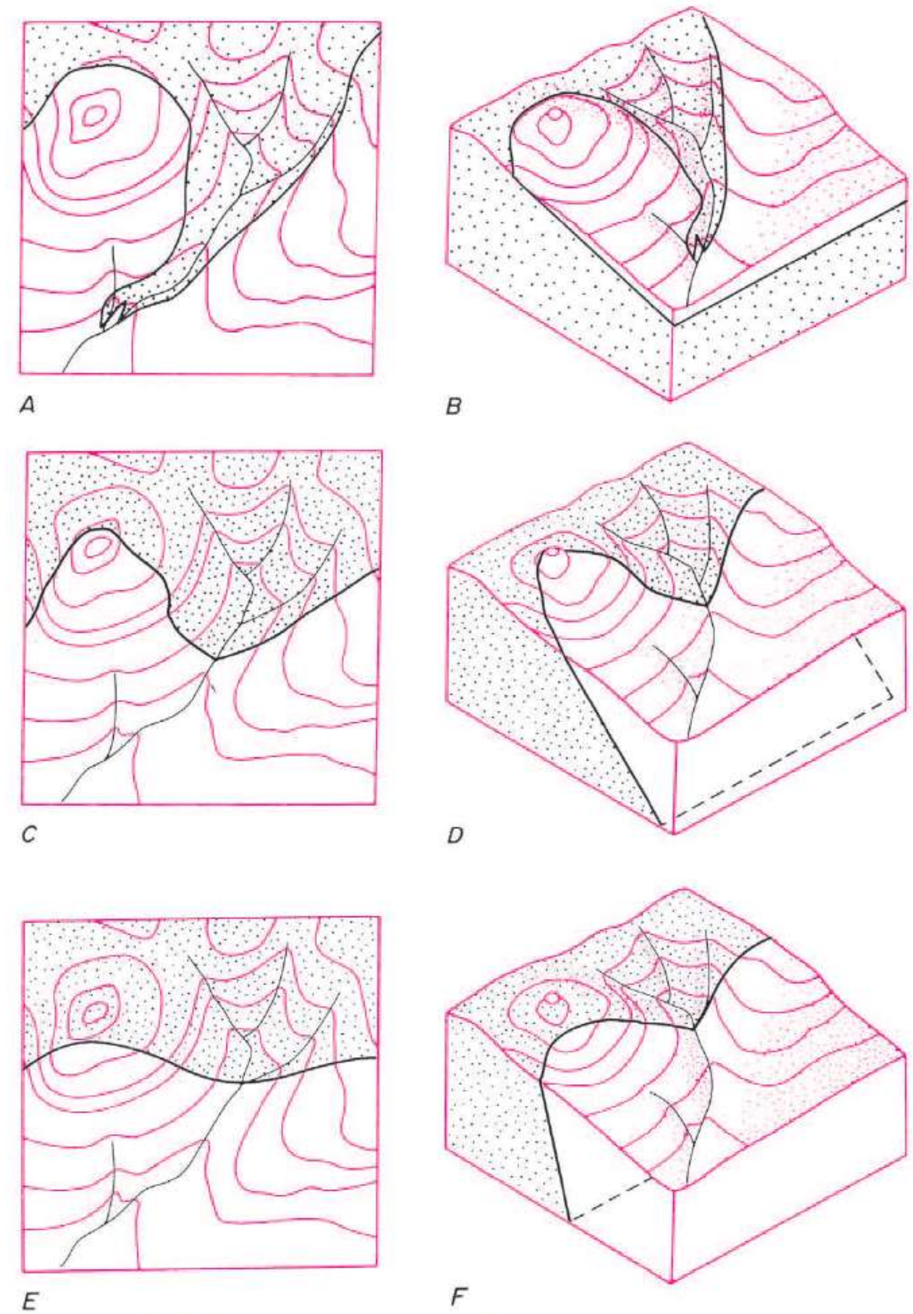


Fig. 2.10 The effect of the angle of dip on the sinuosity of a contact's outcrop.

6. Properties of contour maps

In the previous section two types of surface were mentioned: the geological (or structural) surface and the ground (topographic) surface. It is possible to describe the form of either type on a map. The surface shown in Fig. 2.11B can be represented on a map if the heights of all points on the surface are specified on the map. This is usually done by stating, with a number, the elevation of individual points such as that of point X (a spot height) and by means of lines drawn on the map which join all points which share the same height (Fig. 2.11A). The latter are *contour lines* and are drawn usually for a fixed interval of height. Topographic maps depict the shape of the ground usually by means of *topographic contours*. *Structure contours* record the height of geological surfaces.

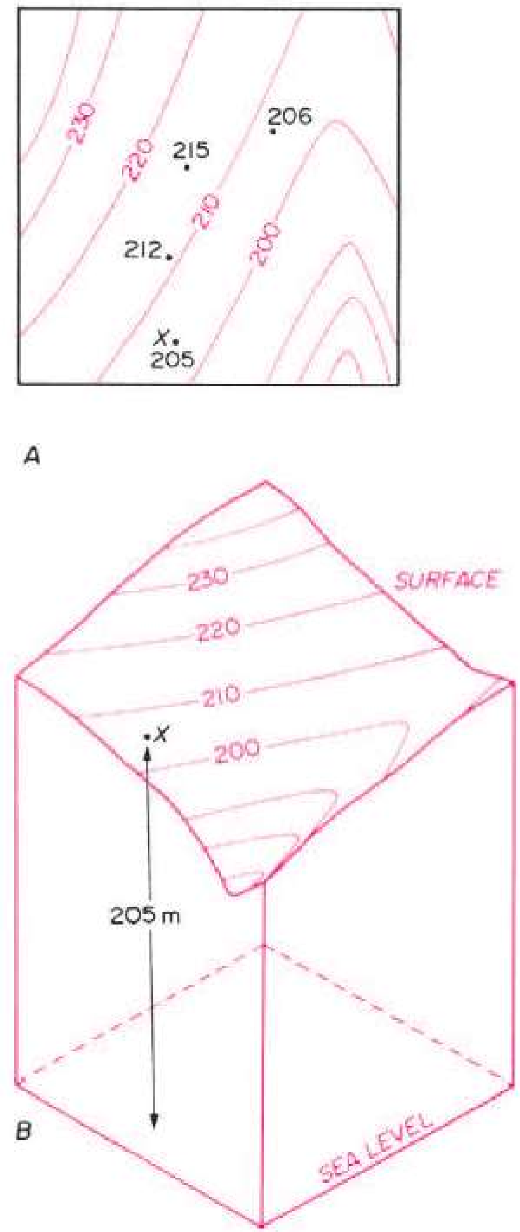


Fig. 2.11 A surface and its representation by means of contours.

8b. V-shaped outcrop patterns

A dipping surface that crops out in a valley or on a ridge will give rise to a V-shaped outcrop (Fig. 2.17). The way the outcrop patterns vee depends on the dip of the geological surface relative to the topography. In the case of valleys, patterns vee upstream or downstream (Fig. 2.17). The rule for determining the dip from the type of vee (the 'V rule') is easily remembered if one considers the intermediate case (Fig. 2.17D) where the outcrop vees in neither direction. This is the situation where the dip is equal to the gradient of the valley bottom. As soon as we tilt the beds away from this critical position they will start to exhibit a V-shape. If we visualize the bed to be rotated slightly upstream it will start to vee upstream, at first veeing more sharply than the topographic contours defining the valley (Fig. 2.17C). The bed can be tilted still further upstream until it becomes horizontal. Horizontal beds always yield outcrop patterns which parallel the topographic contours and hence, the beds still vee upstream (Fig. 2.17B). If the bed is tilted further again upstream, the beds start to dip upstream and we retain a V-shaped outcrop but now the vee is more 'blunt' than the vee exhibited by the topographic contours (Fig. 2.17A). Downstream-pointing vees are produced when the beds dip downstream more steeply than the valley gradient (Fig. 2.17E). Finally, vertical beds have straight outcrop courses and do not vee (Fig. 2.17F).

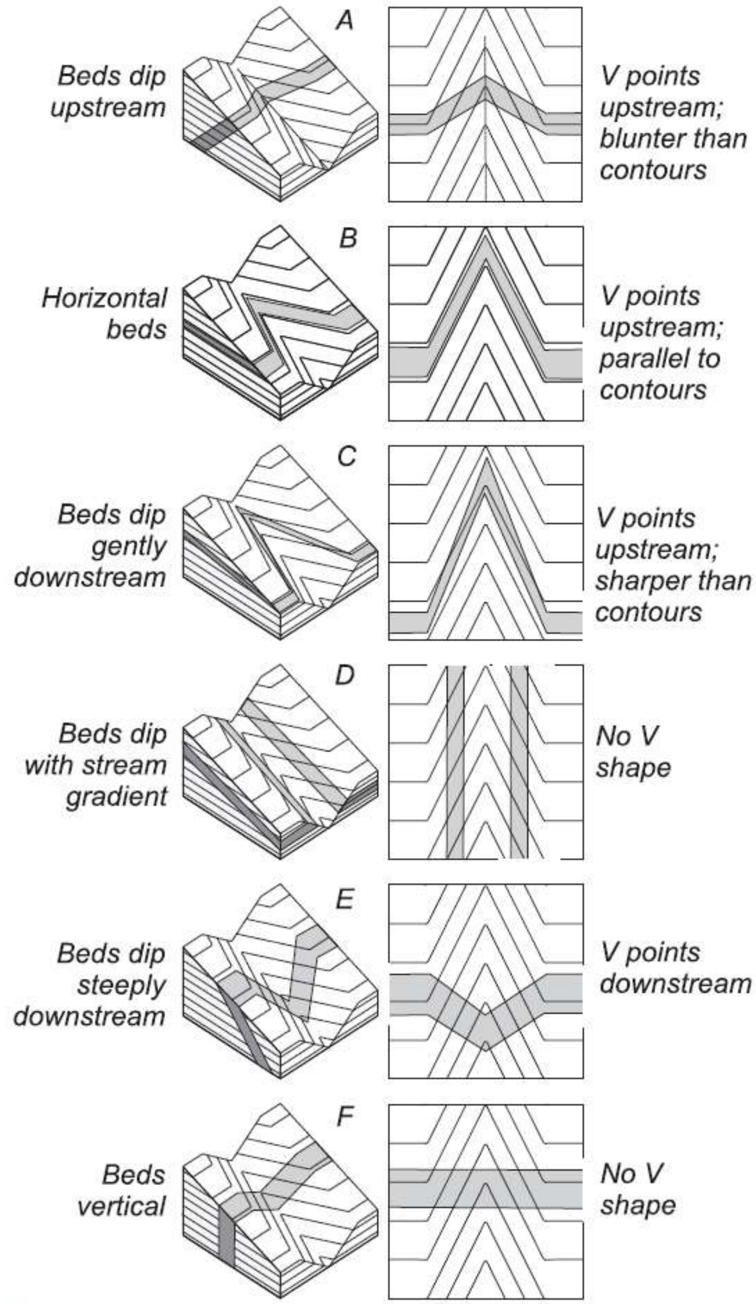


Fig. 2.17 To illustrate the V-rule.

8a. V-shaped outcrop patterns

WORKED EXAMPLE

Complete the outcrop of the thin limestone bed exposed in the northwest part of the area (Fig. 2.18A). The dip of the bed is 10° towards 220° (220/10).

This type of problem is frequently encountered by geological mappers. On published geological maps all contacts are shown. However, rocks are not everywhere exposed. Whilst mapping, a few outcrops are found at which contacts are visible and where dips can be measured, but the rest of the map is based on interpretation. The following technique can be used to interpret the map. Using the known dip, construct structure contours for the thin bed. These will run parallel to the measured strike and, for a contour interval of 10 metres, will have a spacing given by this equation (see Section 2.9).

Contour spacing = (contour interval / Tangent (angle of dip))

Since the outcrop of the bed in the northwest part of the map is at a height of 350 metres, the 350 metre structure contour must pass through this point. Others are drawn parallel at the calculated spacing. The crossing points of the topographic contours with the structure contours of the same height, yield points which lie on the outcrop of the thin limestone bed. The completed outcrop of the thin limestone bed is shown in Fig. 2.18B.

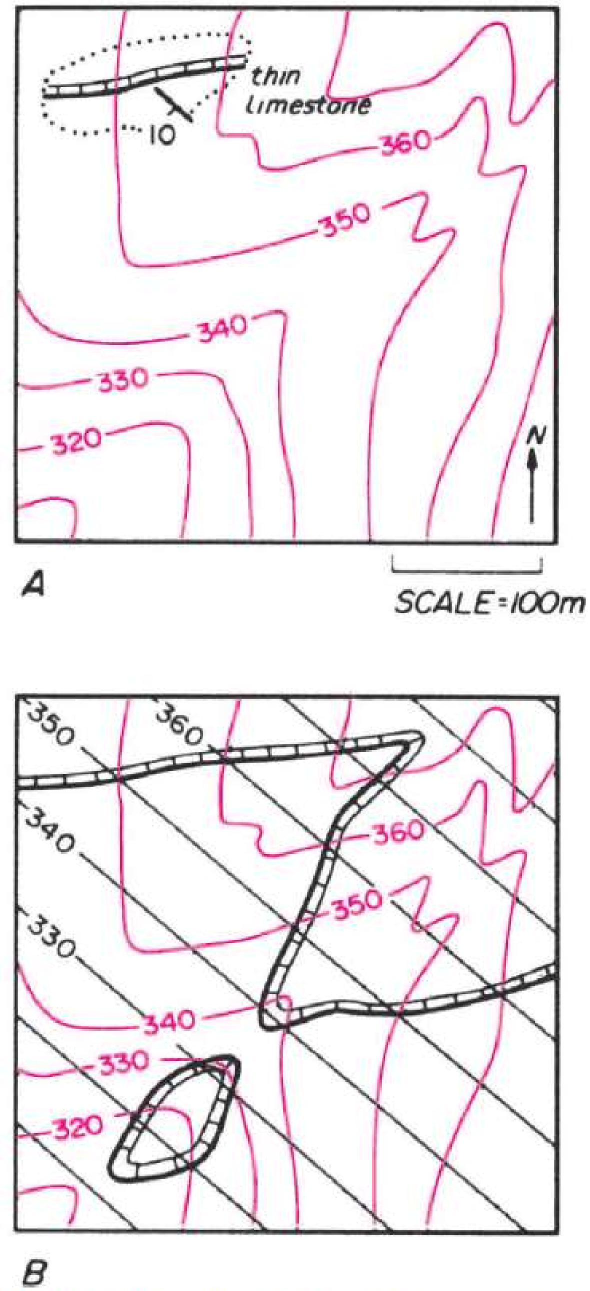


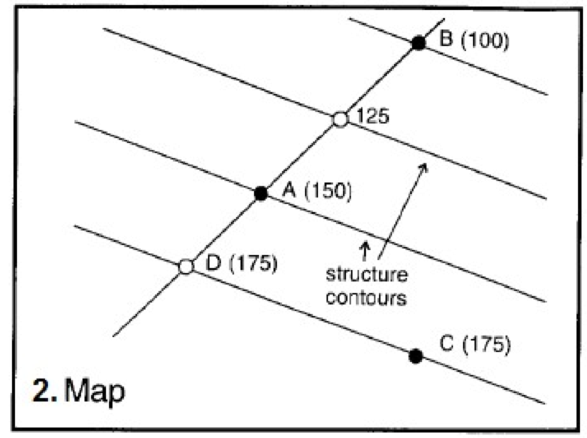
Fig. 2.18 Interpreting the shape of a geological contact in an area of limited rock exposure.

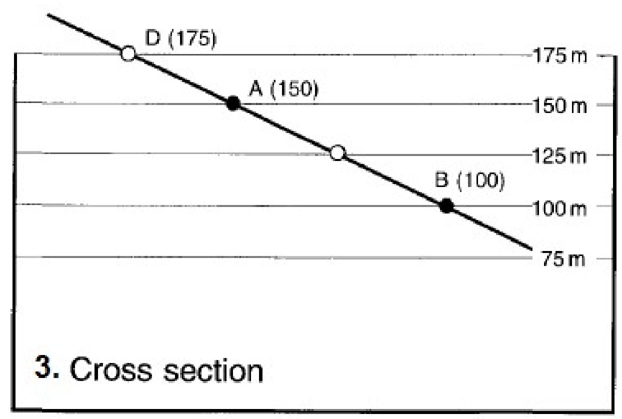
1a. Structure Contour Maps

Earlier we considered surfaces described by contours. If, instead of contours, a number of spot heights are given for a surface, then it is possible to infer the form of the contours. This is desirable since surfaces represented by contours are easier to visualize. The number of spot heights required to make a sensible estimate of the form of the contour lines depends on the complexity of the surface. For a surface which is planar, a minimum of three spot heights are required.

A sandstone-shale contact encountered at three localities A, B *and* C *on Figure 1 has heights of 150, 100 and 175 m respectively. Assuming that the contact is planar, draw structure contours for the sandstone-shale contact.*

Consider an imaginary vertical section along line *AB* on the map. In that section the contact will appear as a straight line since it is the line of intersection of two planes: the planar geological contact and the section plane. Furthermore, in that vertical section the line representing the contact will pass through the points *A* and *B* at their respective heights (Fig. 3). The height of the contact decreases at a constant rate as we move from *A* to *B*. This allows us to predict the place along line AB where the surface will have a specified height (Fig. 2). For instance, the contact will have a height of 125 m at the mid-point between *A* (height equals 150 m) and *B* (height equals 100 m). In this way we also locate the point *D* along *AB* which has the same height as the third point *C* (175 m). In a section along the line *CD* the contact will appear horizontal. Line *CD* is therefore parallel to the horizontal or strike line in the surface. We call *CD* the 175 me structure contour for the surface. Other structure contours for other heights will be parallel to this, and will be equally spaced on the map. The 100 m contour must pass through *B*.





1b. Structure Contour Maps

Outcrop patterns of geological surfaces exposed on the ground

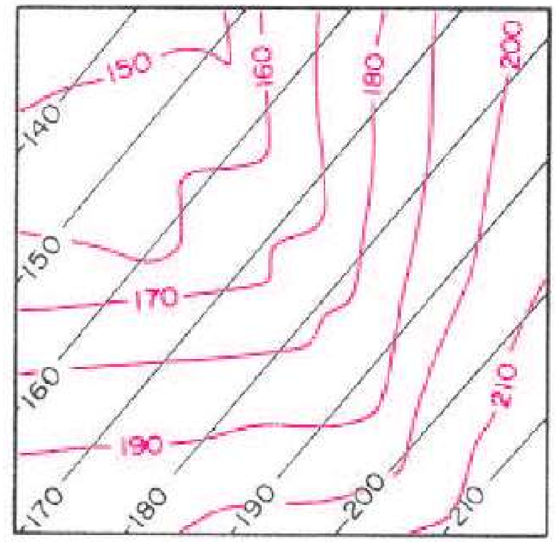
We have seen how both the land surface and a geological surface (such as a junction between two formations) can be represented by contour maps. The line on a geological map representing the contact of two formations marks the
intersection of these two surfaces. The form of this line on the map can be predicted if the contour patterns defining the topography and the geological surface are known, since
along the line of intersection both surfaces will have equal height.

A rule to remember: *A geological surface crops out at points where it has the same height as the ground surface.*

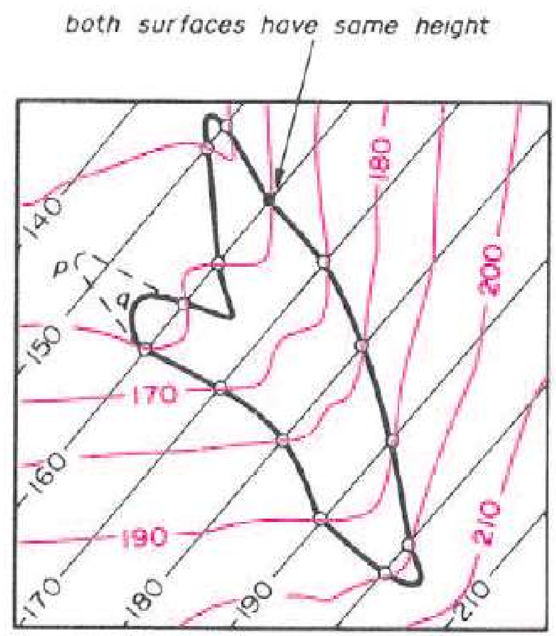
WORKED EXAMPLE
Given topographic contours and structure contours for a planar coal seam (Fig. A) predict the map outcrop pattern of the coal seam.

Points are sought on the map where structure contours intersect a topographic contour of the same elevation. A series of points is obtained in this way through which the line of outcrop of the coal seam must pass (Fig. B). This final stage of joining the points to form a surface outcrop would seem in places to be somewhat arbitrary with the lines labeled *p* and *q* in Fig. B appearing equally possible. However *p* is incorrect, since the line of outcrop cannot cross the 150 m structure contour unless there is a point along it at which the ground surface has a height of 150 m.

Another rule to remember: *The line of outcrop of a geological surface crosses a structure contour for the surface only at points where the ground height matches that of the structure contour.*



A



B

1c. Structure Contour Maps

Buried and eroded parts of a geological surface

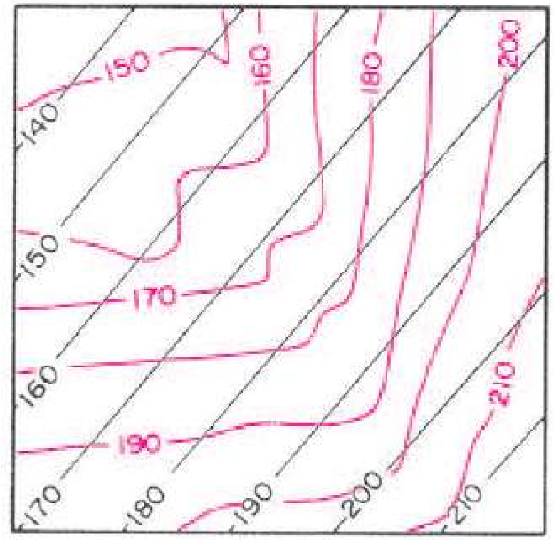
The thin coal seam in the previous example only occurs at the ground surface along a single line. The surface at other points on the map (a point not on the line of outcrop) is either buried (beneath ground level) or eroded (above ground level). The line of outcrop in Fig. B divides the map into two kinds of areas:

(a) areas where height (coal) > height (topography), so that the surface can be thought to have existed above the present topography but has since been eroded away, and (b) areas where height (coal) < height (topography) so that the coal must exist below the topography, i.e. it is buried. The boundary line between these two types of areas is given by the line of outcrop, i.e. where height (coal) = height (topography).

WORKED EXAMPLE

Using the data on Fig. A shade the part of the area where the coal has been eroded.

The outcrop line of the coal forms the boundary of the area underlain by coal. The sought area is where the contours for the topography show lower values than the contours of the coal.



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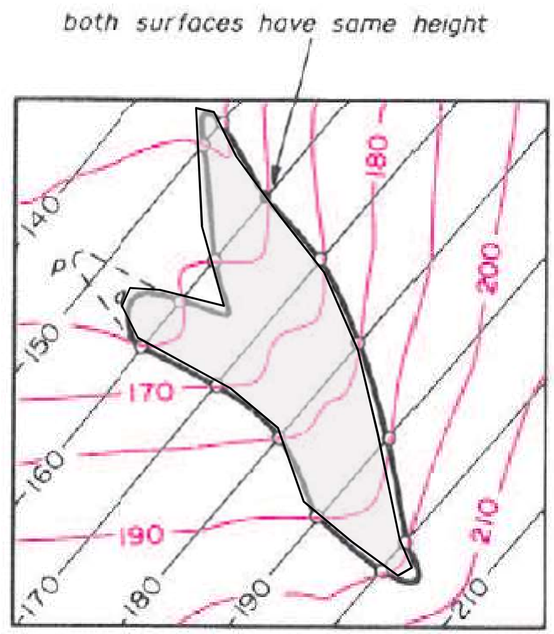

B