Chapter 6: Three-Point Problems and Insertion of Outcrops

THE INTERPRETATION of map patterns, using structure contours, is further explored in this chapter. Incomplete map patterns of poorly exposed areas can be completed by constructing structure contours for the geological contacts already shown on the map. The method of structure contours can, also, be applied to determine the strike and dip of strata in the subsurface from drill-hole data only. The orientation of any flat, inclined geological surface can be determined using the elevation of at least three points on that surface. Such situations are traditionally referred to as three-point problems, and many examples are included in this chapter.

Contents: Section 6-1 introduces the terms inlier and outlier, commonly used to describe map patterns. The insertion of outcrops, using structure contours, is explained in section 6-2. The determination of azimuth/dip from three elevation points of a rock surface and the completion of the associated map patterns are discussed in sections 6-3 and 6-4 for surface and subsurface data, respectively.

6-1 Inliers and outliers

Shallow dipping rock strata tend to give very intricate outcrop patterns on the map in terrains of pronounced topography (Fig. 6-1). Closed out-

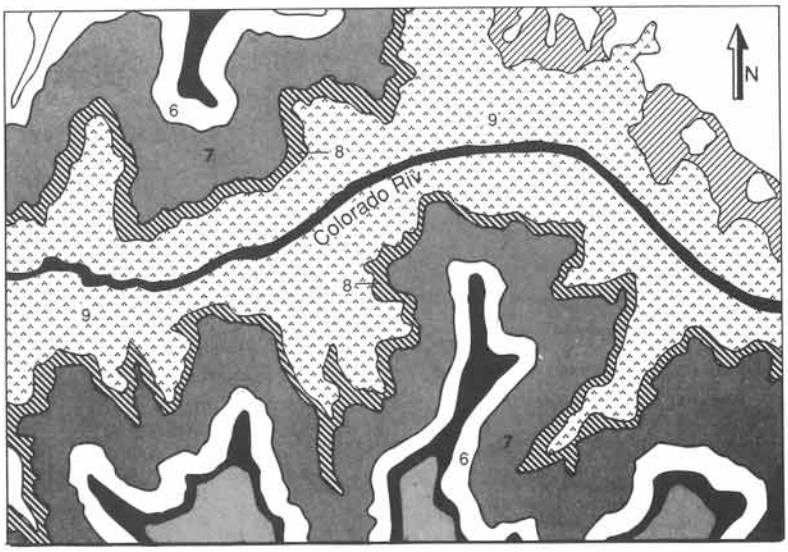


Figure 6-1: *Geological map of the Grand Canyon, mainly comprised of subhorizontal strata. Correlated units are labelled with corresponding numbers.*

crop traces, occurring at the tops of mountains and in the deeper canyons (Fig. 6-2), deserve special attention. The assessment of such outcrop patterns may help to establish an understanding of the *stratigraphic succession* of the rocks exposed in the area. A general rule is that closed outcrop patterns, occupying areas of relatively high elevation, identify the youngest rock units in the area. Such outcrops of younger rock, entirely surrounded by older beds, are called *outliers* or *onliers*. Another general rule is that closed outcrop patterns, occupying topographically low areas, commonly outline the oldest rock formation in the area. Such outcrops of older rock, entirely surrounded by outcrops of younger beds, are called *inliers*. The definitions given here should be used with caution and may not apply to tectonized regions. Folded rock units, with closed outcrop patterns on hill-tops, do not necessarily need to be younger than the underlying rocks. The stratigraphic succession, therefore, is usually determined by internal evidence, such as fossils, graded bedding, and other way-up criteria, and not solely by relative topographic position.

□Exercise 6-1: Examine the outcrop pattern of the map in Figure 6-2. Beds are horizontal and apparently right-way-up. a) Color the inliers in red and outliers in blue. b) Establish the stratigraphic succession for the area in a columnar section.

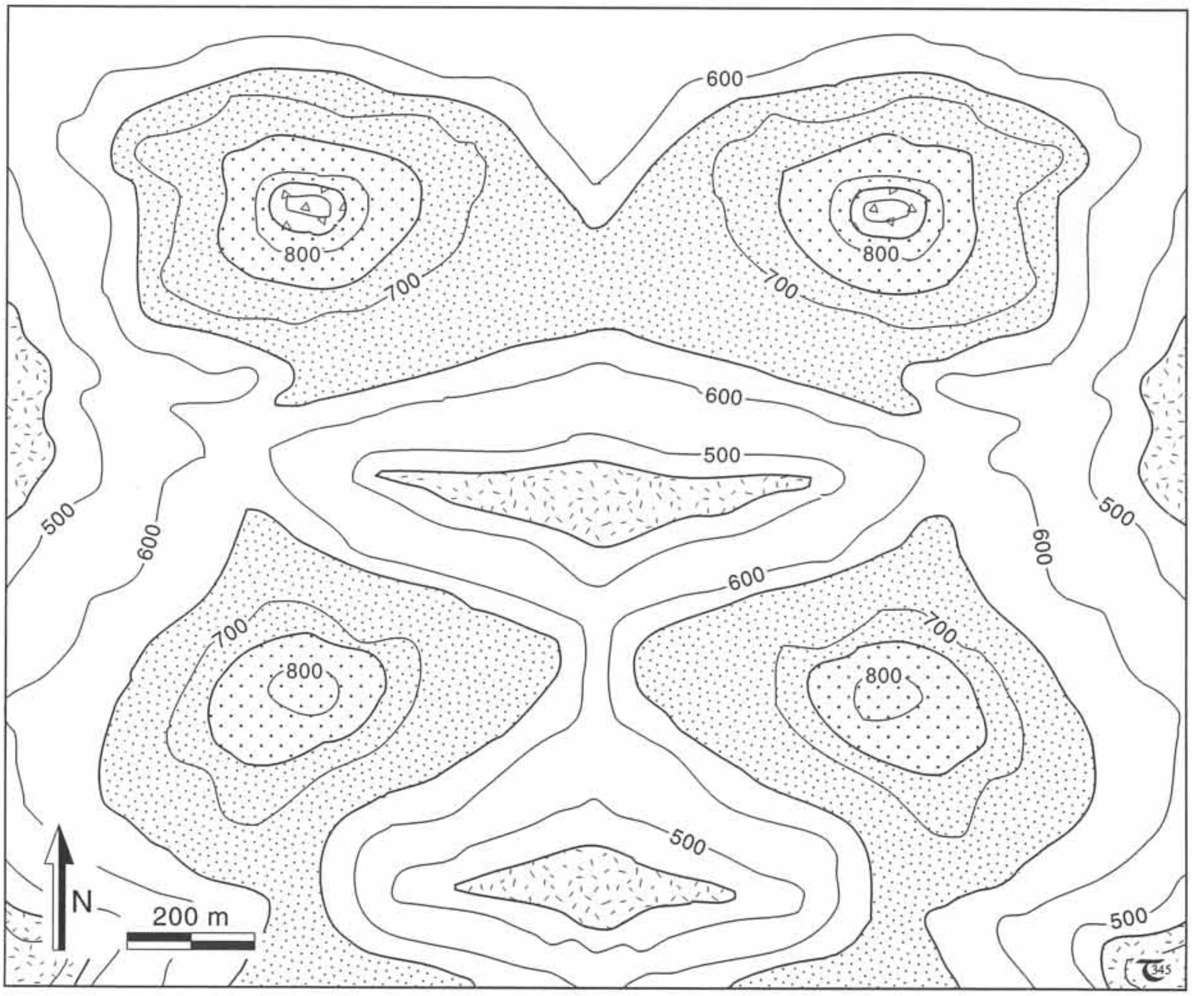


Figure 6-2: *Geological outcrop pattern on topographic base map. See exercise 6-1.*

□**Exercise 6-2: Refer to the geological map of Figure 6-3. a) Determine the azimuth/dip for the uniformly oriented succession, using structure contours. b) Draw a cross-section along line Y-Z. c) Calculate the true thickness of the layers, and make a columnar section. d) Color any inliers in red and outliers in blue.**

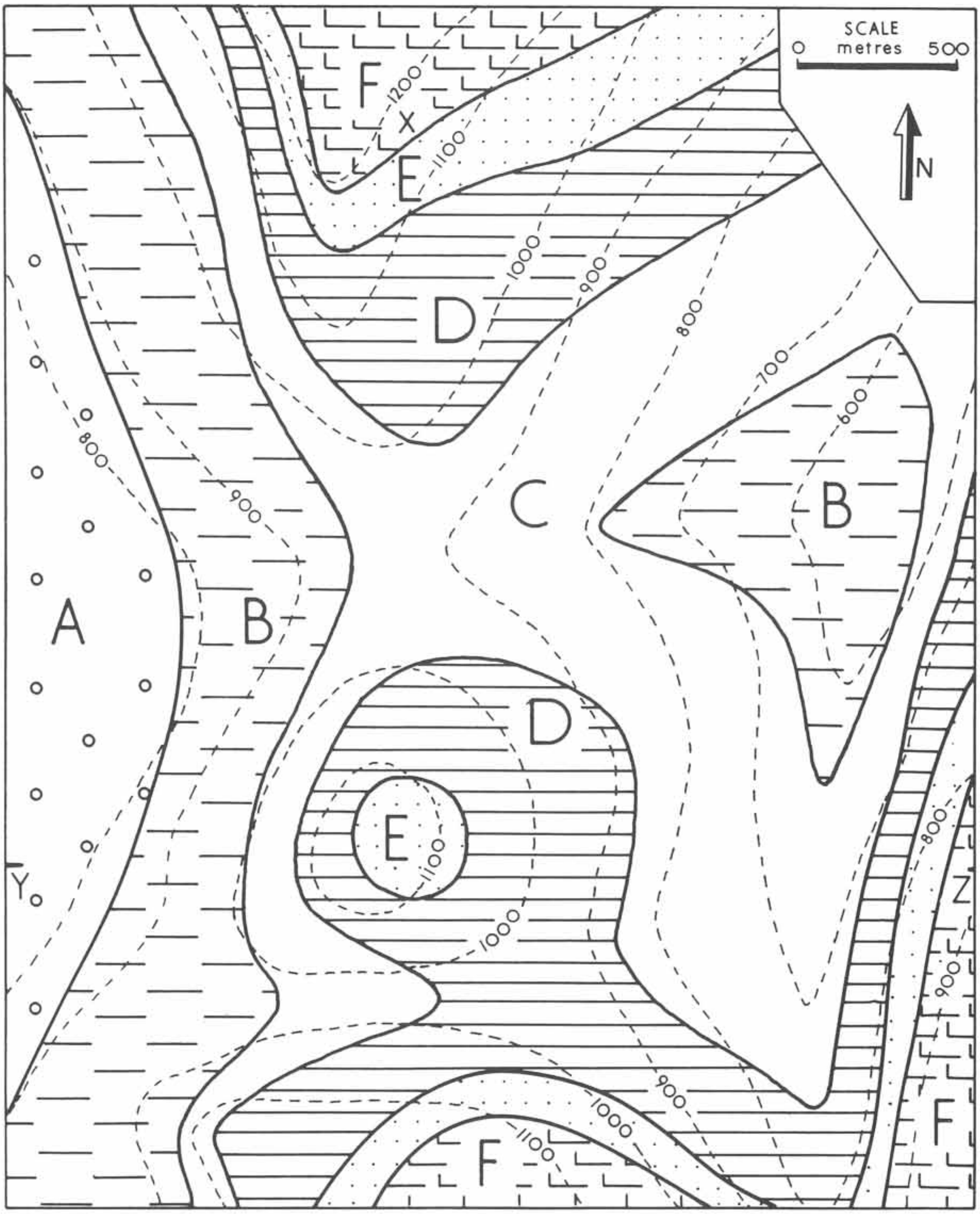


Figure 6-3: *Map of geological outcrops on topographic base map. See exercise 6-2.*

6-2 Insertion of outcrops

A stratigraphic layer reaches the surface in any location where the topographic contour cuts a structure contour. This fact can be utilized to complete the outcrop pattern of a geological stratum if the structure contours and the topography contours are both known. Figure 6-4 illustrates a geological boundary inserted where its structure contours intersect the topography. However, if a terrain is mapped, for example, from aerial photographs, structure contours will not be known initially, and the outcrop pattern itself may still be incomplete. *Finding, at least, a few locations, where the boundary of a bed is exposed at the same elevation, may allow the construction of its structure contours.* The remainder of the geological map can then be completed by inserting the geological boundaries where the structure contours intersect the topography. Join the intersection points in a smooth continuous curve to complete the outcrop pattern.

☐Exercise 6-3: A uniformly oriented coal bed is exposed at three locations - A, B, and C, as indicated on the map of Figure 6-5. Two structure contours are included to start you off. a) Complete the outcrop pattern of the coal bed for the entire map area. b) What is the orientation of the coal bed (azimuth/dip)? c) Color blue all rocks overlying the coal bed.

If the exact trend of the outcrop between two points is doubtful, determine the outcrop location by interpolation. Sketch a topographic contour half-way between two existing ones, and draw the corresponding strike line. This gives an additional outcrop point and facilitates the completion of the interconnected outcrop-pattern. Also, remember that an outcrop boundary can cross a topographic contour line only where it is, also, crossed by a structure contour and nowhere else.

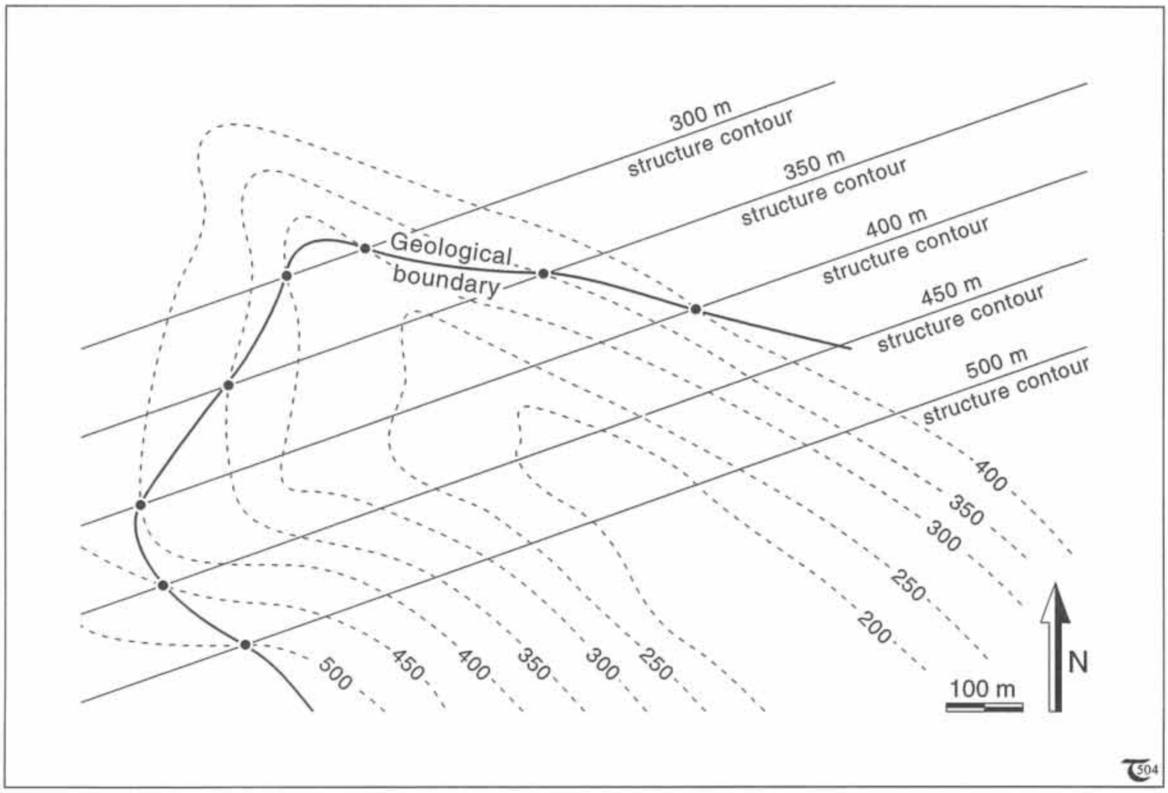


***Figure 6-4:** A geological boundary can be constructed at the intersections of structure and topographic contours.*

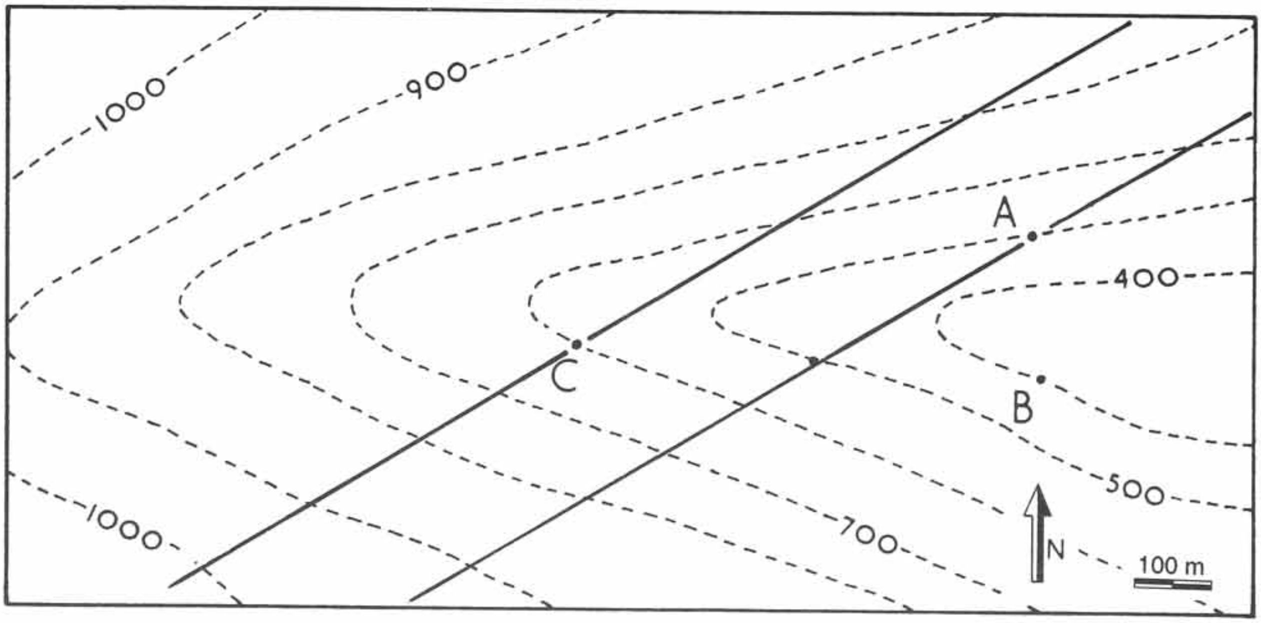


Figure 6-5: Incomplete outcrop pattern of coal bed on topographic base map. See exercise 6-3.

☐Exercise 6-4: The outcrop of a thick, uniformly oriented sandstone formation is shown in the map of Figure 6-6. The base of the sandstone is, also, exposed at location A. a) Construct structure contours for the base of the sandstone, using 25 m contour spacing. b) Complete the outcrop pattern. c) Does the grit crop out at D? d) Construct a section X-Y across the map, as indicated.

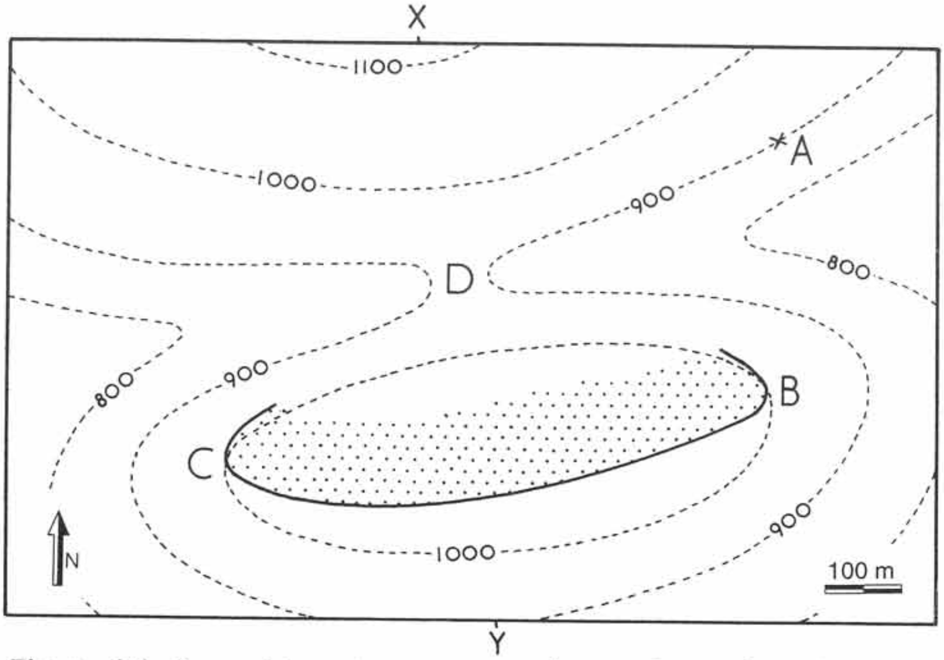


***Figure 6-6:** Incomplete outcrop pattern of a sandstone formation on a topographic base map of 100 m contour spacing. See exercise 6-4.*

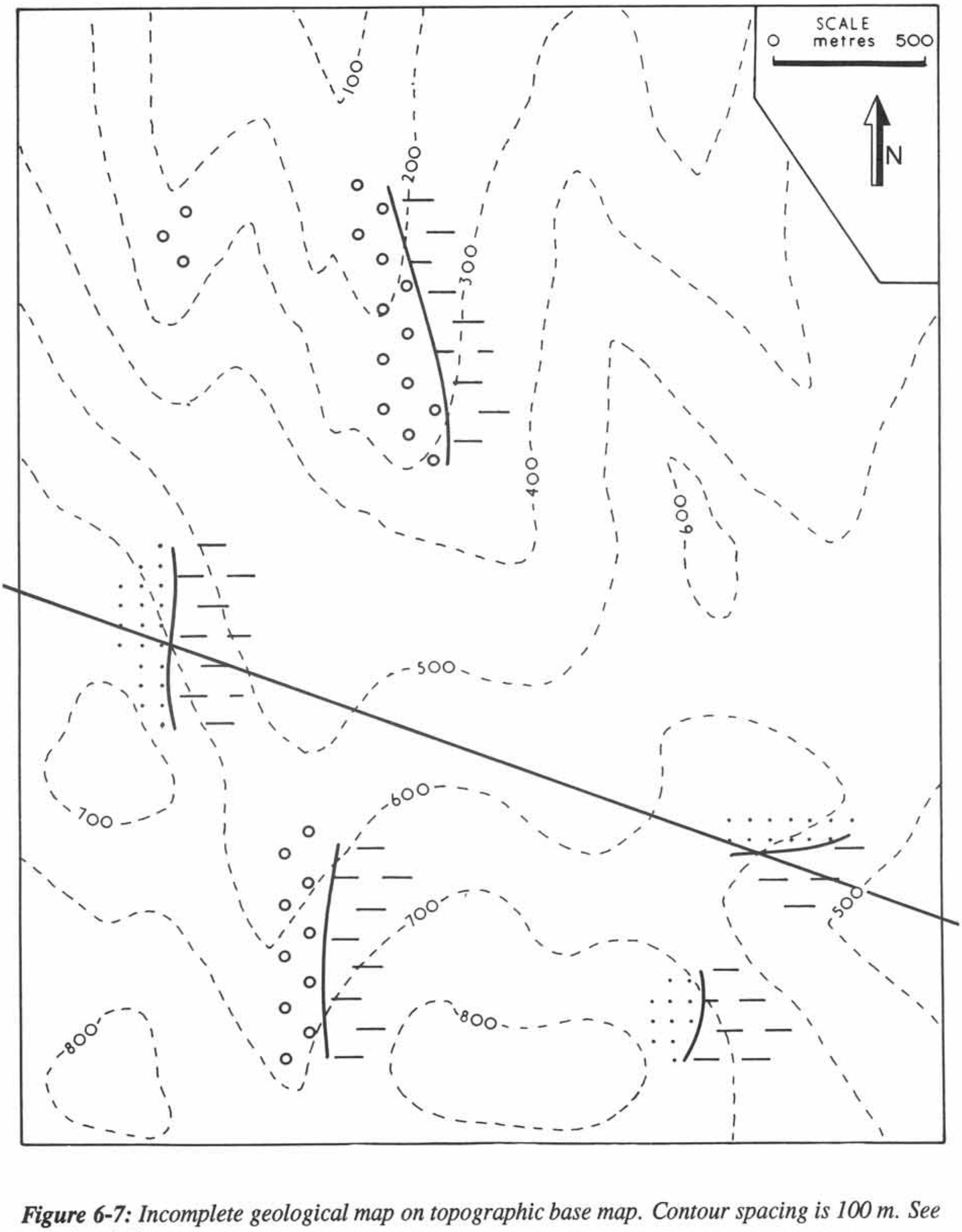


Figure 6-7: Incomplete geological map on topographic base map. Contour spacing is 100 m. See exercise 6-5.

□Exercise 6-5: The incomplete map of Figure 6-7 shows all the geological information that could be mapped from the aerial photographs of a heavily forested area. Field reconnaissance has further revealed that the three rock types identified are conglomerate, shale, and sandstone. It is, also, known that all strata in this area have a uniform orientation. Complete the geological map by inserting the boundaries between all the beds, using the principle of structure contours. Remember that structure contours of uniformly dipping layers are always parallel. One structure contour, inferred from the outcrop pattern, is drawn on the map to get you started. Construct the other structure contours, and then complete the continuation of the geological boundaries and insert lithologic symbols.

6-3 Three-point problem technique

The simple geometric fact that three points define a plane is exploited extensively in the preparation and interpretation of geological maps. In geology, the *three-point problem* refers to the situation where the stratum orientation needs to be abstracted from three points of known elevation. If the elevation of a bed is known at three or more points, defining two crossing lines in the same plane, it becomes possible to calculate the strike/dip or azimuth/dip of such planes. Two points of equal elevation can be connected to define the strike line. A third point, either up or down dip, will be sufficient to determine the dip of the surface.

Consider a particular three-point problem, defining the top of a limestone bed in three locations A, B, and C (Fig. 6-8). The respective elevations of these points are 450, 525, and 650 meters above the sea level datum. The strike line has to be found by construction, because none of the three points is at similar height. Take the lowest and the highest of the three points, in this case points A and C, and connect them by a straight line. Subdivide the length AC into equally scaled distances to find a point of the same elevation as the intermediate point B. The strike line is now fixed on the map by connecting the two points at 525 meters. This, also, is the 525 m structure contour for the top of the limestone bed. Assuming that the limestone

□Exercise 6-6: Determine the azimuth/dip of the limestone bed of the three-point problem in Figure 6-8.

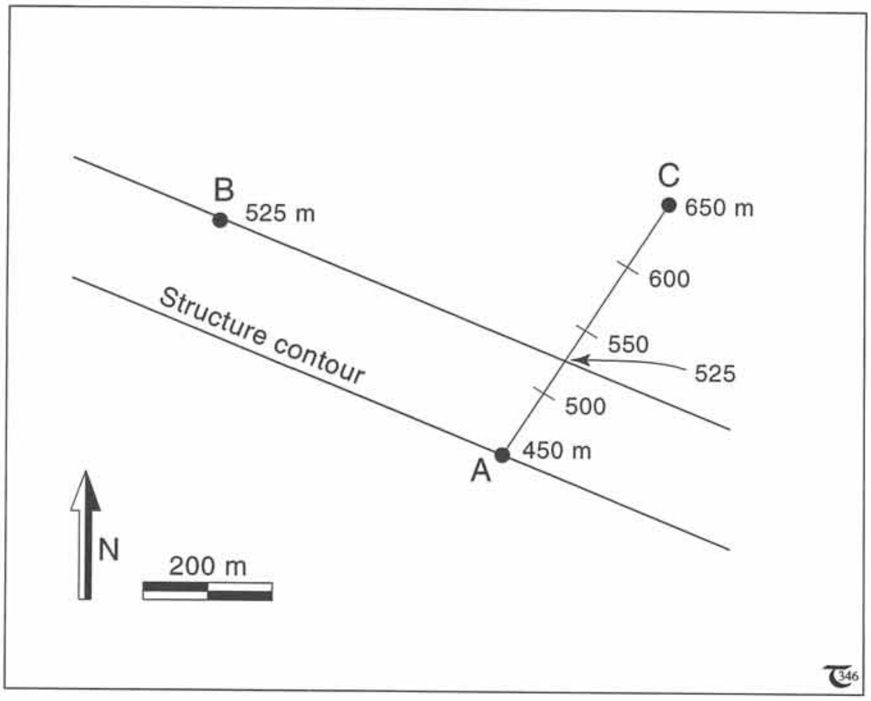


***Figure 6-8:** Construction of structure contours from three points on the structure with known elevations (A,B,C).*

bed dips uniformly, all other structure contours will be parallel to the strike line constructed. Structure contours of convenient spacing can be constructed accordingly.

The three-point problem is usually combined with a topographic base map, which allows the insertion of outcrop patterns. Figure 6-9a shows a base map with a coal bed observed in outcrops A, B, and C. It is essential, in order for the method to work, that all layers are homoclinal - they must possess uniform dips. The three points of observed coal outcrops are all located on topographic elevation contours. These points, also, lie on structure contours of corresponding elevation. Interpolation fixes the strike of the structure contours (Fig. 6-9b). Subsequently, the outcrop boundaries can be inserted where the structure contours and topographic contours meet (ringed points). Join the ringed points by a smooth curve to complete the outcrop pattern.

□Exercise 6-7: The continuous line on the map of Figure 6-10 indicates the outcrop pattern of a two-meter, thin coal seam. The coal is exposed in three locations - A, B, and C. All coal seams in the area are known to be uniformly dipping. a) Determine the azimuth/dip of the exposed coal seam. b) Complete the outcrop pattern of the coal seam, assuming that the thin layer can be represented as a single line on the scale of the map. This implies that structure contours for the top and bottom of the coal seam coincide. c) At what depth would the coal layer be struck in a borehole sunk at location D?

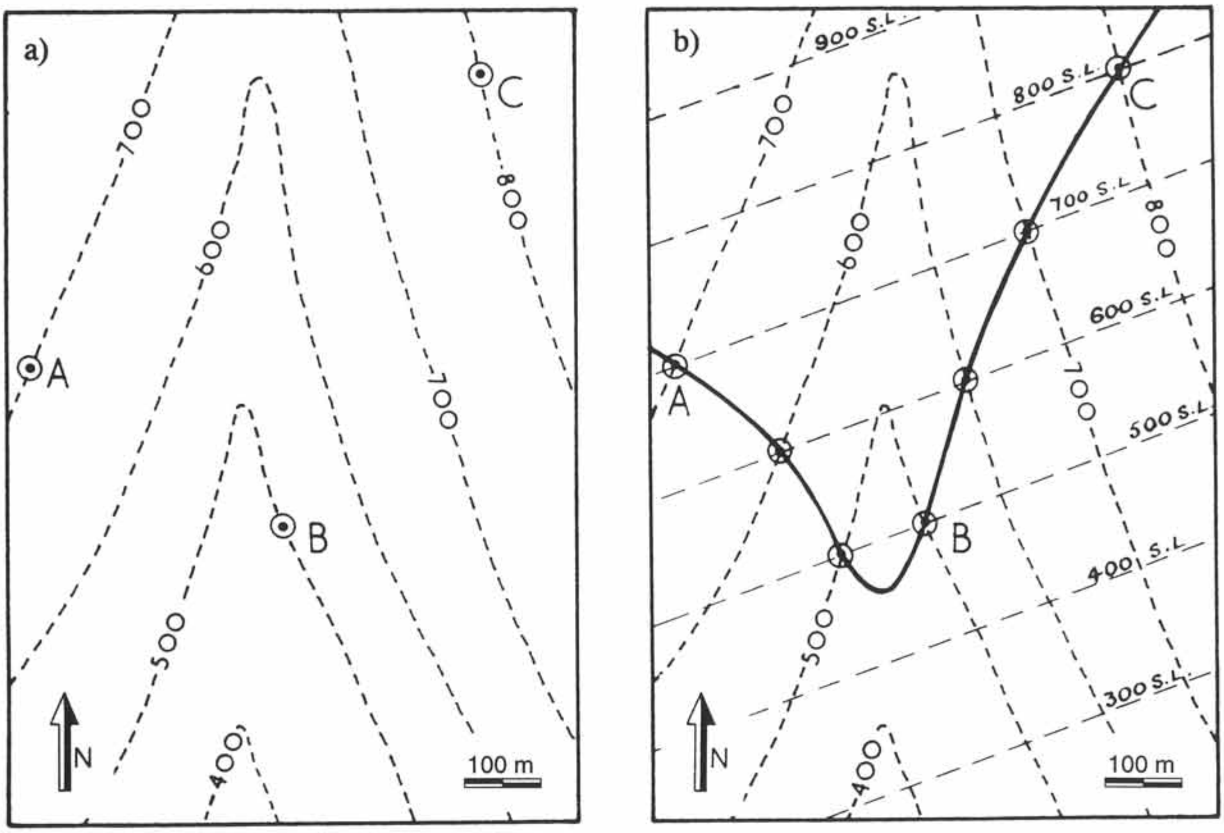


***Figure 6-9:** a) Topographic base map with three observed coal outcrops: A,B,C. b) Construction of structure contours allows completion of coal outcrop pattern by interpolation in a smooth curve.*

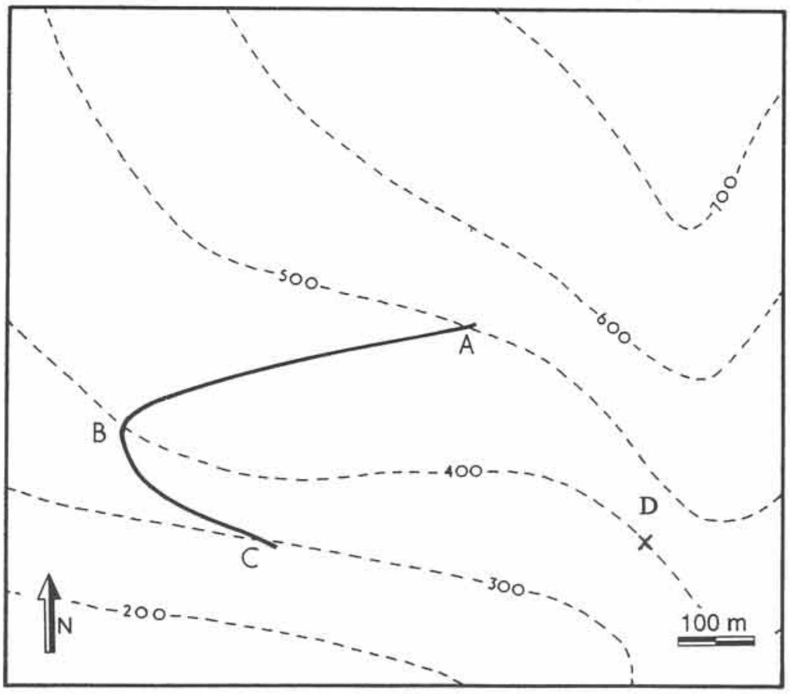
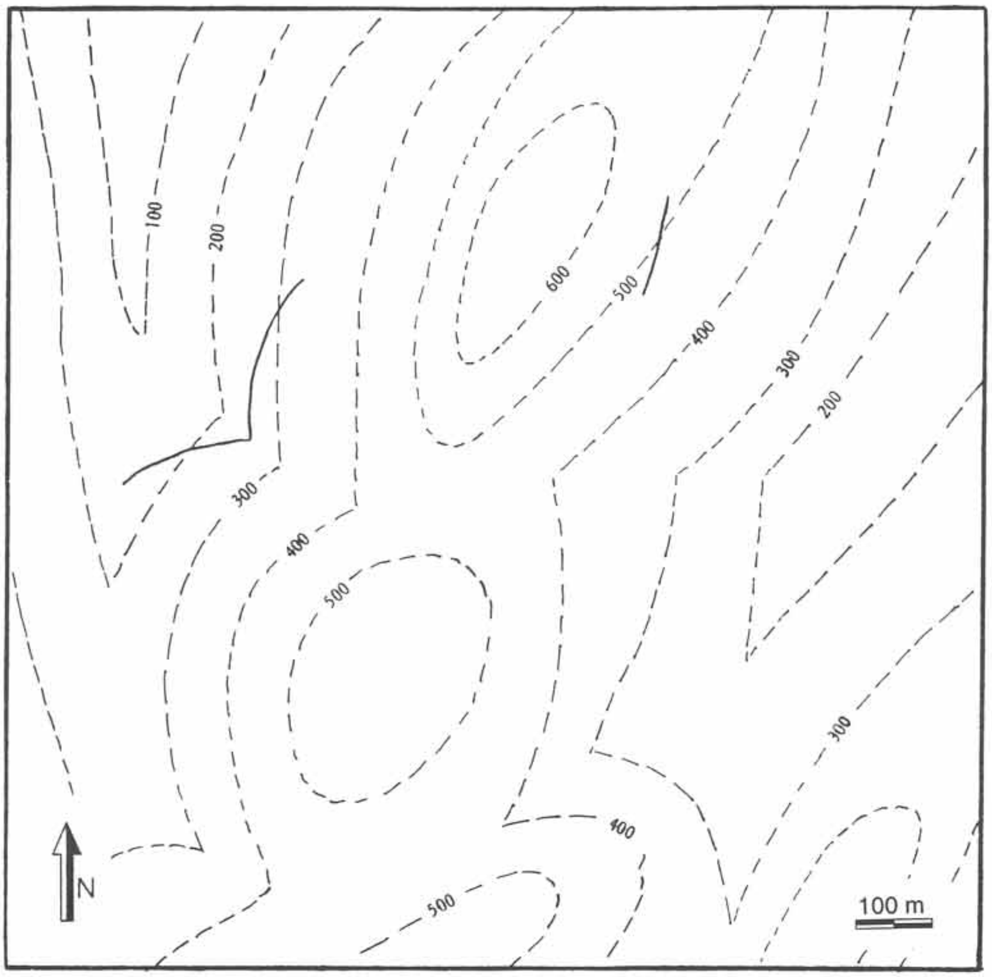


Figure 6-10: *Incomplete outcrop pattern of coal seam on topographic base map. See exercise 6-7.*

□Exercise 6-8: Refer to the map of Figure 6-11. a) Determine the attitude of the coal seam. b) Complete the outcrop pattern. c) Also, complete the outcrop pattern of two other coal seams, which are, respectively, two hundred meters vertically above and below the one first mapped.

Figure 6-11: *Incomplete outcrop pattern of coal seam on topographic base map. See exercise 6-8.*



6-4 Three-point problems for borehole data

Three-point problems need not necessarily be limited to surface data only. The principle has many applications to mining and to petroleum and engineering geology, through usage of borehole data. The line of argument used to solve three-point problems from subsurface data is the same as that used for points exposed at the surface. The depth at which layers are encountered in boreholes is commonly measured downwards from the ground surface - the drilling depth. For the solution of three-point problems, the elevation of the layers needs to be calibrated to sea-level datum. This is simply achieved by substracting the drilling depths from the topographic elevations of the drill sites.

□Exercise 6-10: Draw your own map for the following situation. Borehole B in an oilfield is 5,000 feet due north of borehole A, and borehole C is 10,000 feet due east of borehole A. The top and bottom of a reservoir sandstone bed are reached at the following altitudes relative to sea level:
A) -2,500 and -2,700 feet,
B) -2,800 and -3,000 feet, and
C) -3,000 and -3,200 feet. Determine both the azimuth/dip and the true thickness of the sandstone.

□Exercise 6-9: Refer to the map of Figure 6-12. The top of a five-meter-thick hydrocarbon reservoir is encountered in drill cores at locations A, B, and C, at respective depths of 450, 350, and 250 meters. All pay-zones in the area are known to dip uniformly. a) Determine the azimuth/dip of the hydrocarbon reservoir. b) Determine if the reservoir is cropping out anywhere, and, if so, complete the outcrop pattern, assuming that the thin layer can be represented as a single line on the scale of the map. c) An important one meter thick stratigraphic marker horizon is found in borehole A at a fifty-meter depth. Map the outcrop trace of this marker horizon. d) Color the rocks in the map area on top of the marker horizon.

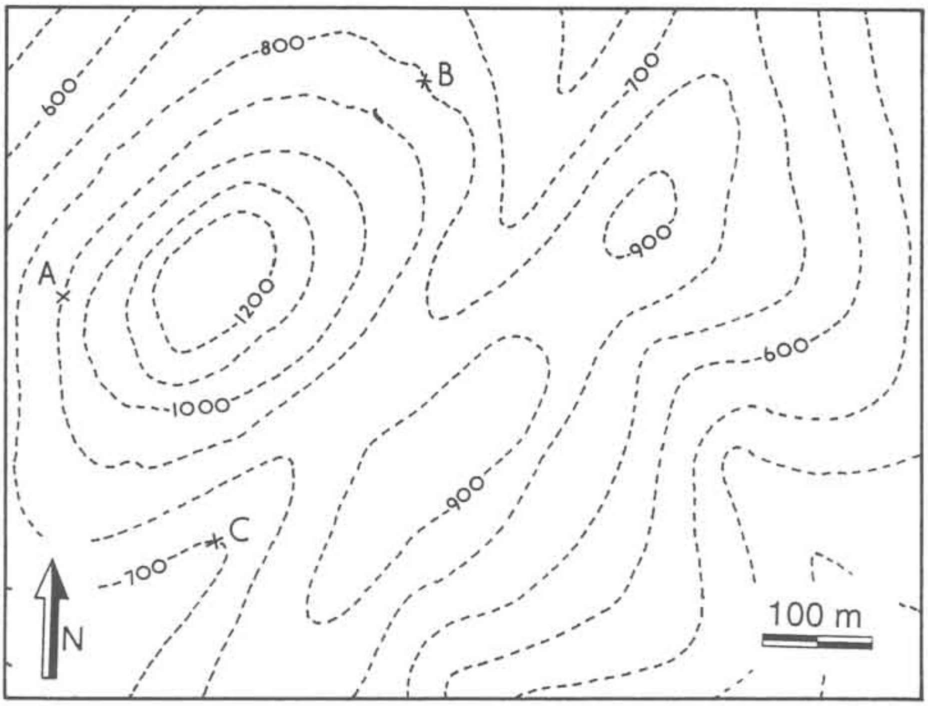


Figure 6-12: Topographic base map with location of three boreholes (A, B, and C). See exercise 6-9.