Chapter 10

Quality Control

10.1 Introduction

This chapter focuses on the quality control of completed interpretations as expressed in maps and cross sections. Quality control means locating and correcting errors in the data and in the interpretation. Problems can arise from data transcription errors, incomplete exposure in the field, interpolation uncertainties between wells and seismic profiles, and missing or misleading information in seismic interpretations. The quality-control issues discussed in this chapter can be broadly categorized as data errors and contouring artifacts, inconsistency of trends, bed thickness anomalies, and impossible fault shapes. Additional techniques for detecting and correcting errors involving the restoration and balancing of cross sections are covered in Chap. 11. Those topics are covered separately because they also include related methods for extracting additional geological information from the data and for making model-based predictions of the geometry. The single best quality control for an interpretation is to build an internally consistent, 3-D model of the entire structure. Many of the individual problems noted in the following sections would be obvious in 3-D. The following sections discuss methods that are commonly applied in 2-D, that is, to geological outcrop maps, structure contour maps, and to cross sections.

10.2 Data Errors and Contouring Artifacts

Before a map is finalized, it should always be examined for data errors, edge effects, and contouring artifacts. Some of these problems are nearly inevitable because of human error in data input and the intrinsic behavior of computer contouring algorithms.

10.2.1 Data Errors

Data errors are a likely possibility where single points fall far from the average surface. Problem points may be recognized by the presence of small closed highs or lows, usually defined by multiple contours that surround an individual point. Such errors commonly arise from mistakes in the interpretation of the unit boundaries or as transcription errors in transferring data to the map. This type of error tends to produce very local highs and lows on a preliminary structure contour map (Fig. 10.1a). Point 1 (Fig. 10.1a) is almost certainly a bad data point as it forms a small, deep depression in the map surface. Point 2 is a closure at an elevation consistent with other elevations on the map

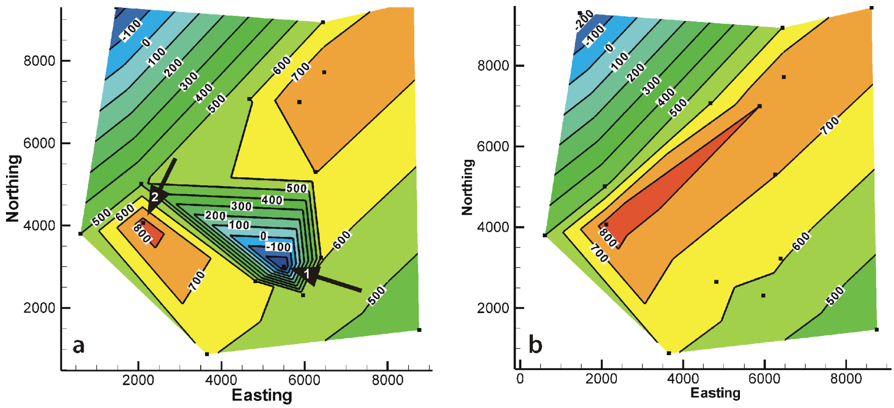


Fig. 10.1. Locating data errors on a structure contour map. **a** Preliminary map with questionable closures. **b** Map recontoured after removal of point 1

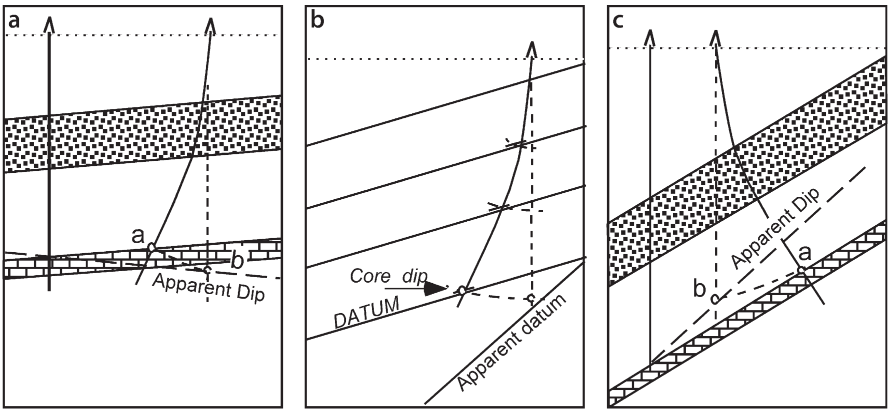


Fig. 10.2. False apparent dips caused by unrecognized well deviation. **a** Apparent dip determined between two wells, one unknowingly deviated down dip. **b** Dip determined from core dip in the unknowingly deviated well. **c** Apparent dip determined between two wells, one unknowingly deviated up dip. (After Low 1951)

and could be real or a bad data point. Removal of point 1 leads to a more structurally reasonable map (Fig. 10.1b) and shows point 2 to be consistent with the revised map. Maps produced by triangulation are the best for recognizing data errors because gridded maps smooth the values and thereby reduce the effect of anomalous values. It is always worth checking a point that produces a one-point closure. Local closures, if actually present, are important because, for example, they might form hydrocarbon traps.

Bad points can arise from a deviated well that is mistakenly interpreted as being vertical, causing both location and thickness anomalies. The log depth to a formation boundary is larger in a well that deviates down dip than in a vertical well at the same surface location (Fig. 10.2a). If the formation boundary is plotted vertically beneath the well location, its depth will be too great. If an apparent dip is then determined between this well and a correctly located formation top in another well, the apparent dip will be wrong, perhaps even in the wrong direction (Fig. 10.2a). If the dip is determined from a core in a deviated well (Fig. 10.2b) that is mistakenly thought to be vertical, then the inferred dip will be too large. The apparent thicknesses are too large in both situations. A well that deviates up dip will result in an apparent steepening of the dip between two wells and thicknesses (if mistakenly corrected for dip) that will be too small (Fig. 10.2c).

10.2.2 Edge Effects

Both humans and computer-contouring algorithms appear to prefer contours that close within the map area. In Fig. 10.3a, the triangulation algorithm has closed the contours on southwest end of the anticline. Based on the available control, open contours to the southwest (Fig. 10.3b) are equally valid and perhaps more geologically reasonable.

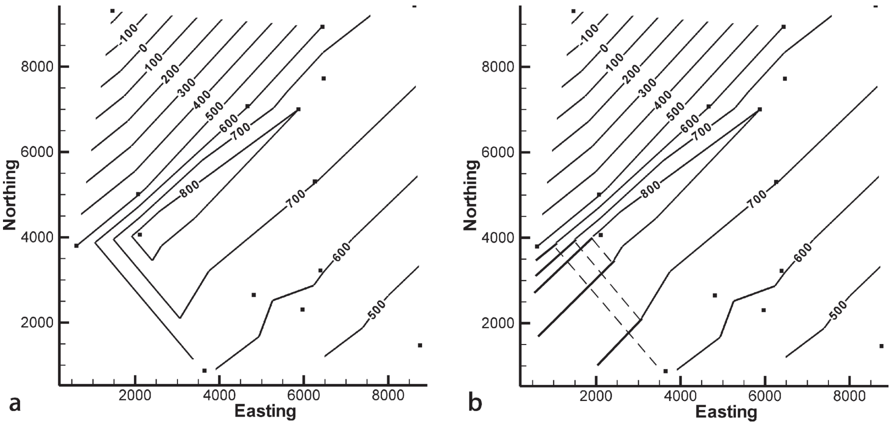


Fig. 10.3. Is the closure real? **a** Anticline closed to the southwest in triangulated map from data in Fig. 3.5. **b** The same structure opened to the southwest (*heavy lines*), deleted contours *dashed*

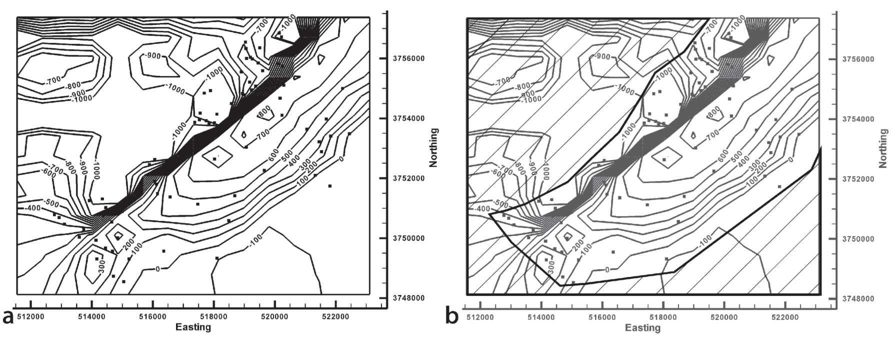


Fig. 10.4. Edge effects on a map of the Sequatchie anticline. Control points are *solid squares*. **a** Map from Fig. 3.23a. **b** Same map with region of no data *shaded* (diagonal lines)

Gridding algorithms typically extend the contours to the edges of the grid, regardless of whether or not data are present to support the extrapolation. Figure 10.4a is a map produced by a computer kriging algorithm over a rectangular region. The region without any data to control the contours is shaded in Fig. 10.4b. The closed highs and lows within the shaded area are completely spurious.

A TIN network may contain extremely elongated triangles along the edges of the data, implying a relationship between widely separated points. Such widely separated points are not necessarily geologically related and probably should not influence the shape of the surface between them. The TIN network should be examined for such problems and such long-distance connections might be removed. Some computer programs eliminate triangles for which one or two of the angles are smaller than a threshold value. This tends to reduce the problem but does not eliminate it.

10.2.3 Excessive Detail

Excessively wiggly contours or areas containing multiple, small, structural closures may be contouring artifacts (Krajeweski and Gibbs 1994). Closed contours that do not contain control points should be viewed with suspicion as artifacts of the gridding algorithm (Fig. 10.5). This type of artifact only occurs with gridding algorithms and is more likely when using high-order surfaces (e.g., kriging with quadratic drift and grid-node densities much greater than the control-point density).

Another type of artifact may arise if data from multiple sources, such as different seismic surveys, are contoured together, because their datums may be different. Each

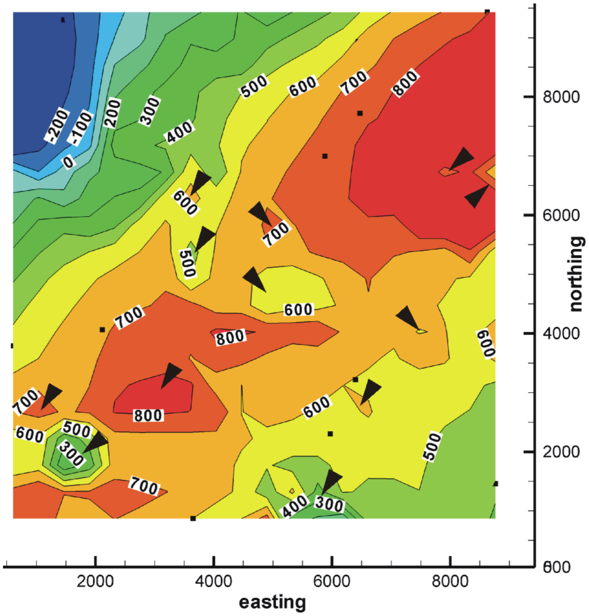


Fig. 10.5. Structure contour map from Fig. 3.11d. Control points are *small squares*. *Triangles* point to local closures unjustified by control points

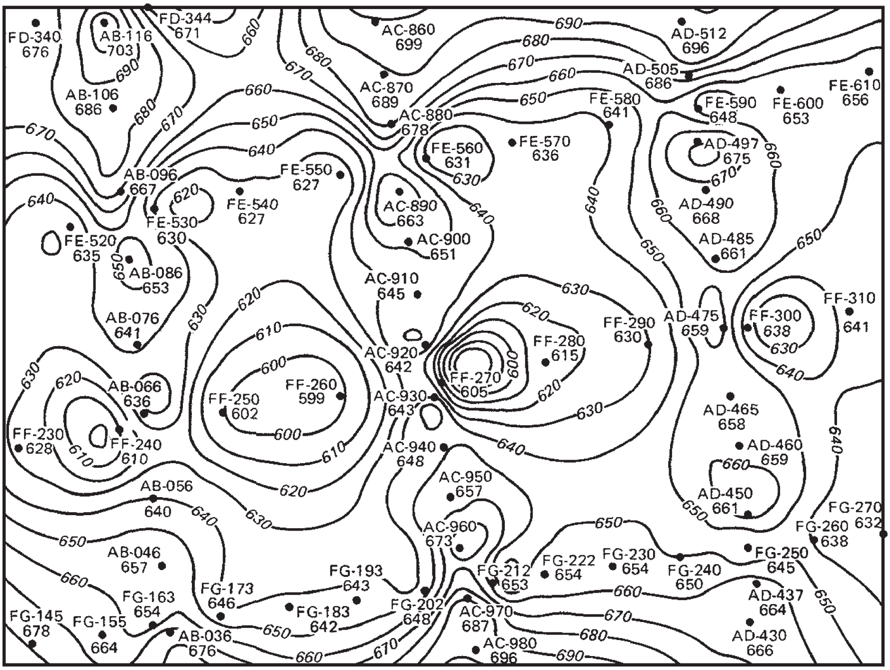


Fig. 10.6. Cloverleaf structure contour pattern produced by data along three north-south seismic lines mis-tied to three east-west lines. Control points are indicated by *dots*. Contours are concentrated along lines of data collection. (Jones et al. 1986)

data set can be internally consistent, but one may have elevations systematically shifted with respect to the other. Cloverleaf patterns of highs and lows (Fig. 10.6) characterize this type of problem (Jones et al. 1986; Jones and Krum 1992). Two-dimensional seismic lines in areas of dipping units have the additional problem that the reflections on lines parallel to strike may be shifted laterally from the surface location of the line, leading to a similar datum shift between lines that are at right angles to one another (Oliveros 1989). Mis-ties between reflectors and incorrect stacking velocities can lead to similar cloverleaf patterns.

10.3 Trend Incompatibilities

The basic principle of trend compatibility is that the trends obtained from different parts of the total data set, which may include structure contour maps, geological contact locations and bedding attitude measurements, must agree, or a reason for any discrepancies must be found.

Structure contours are a valuable aid in evaluating the validity of the contact locations on a geological map. To test the preliminary geologic map of Fig. 10.7a, find the orientations of the structure contours implied by both the top and bottom

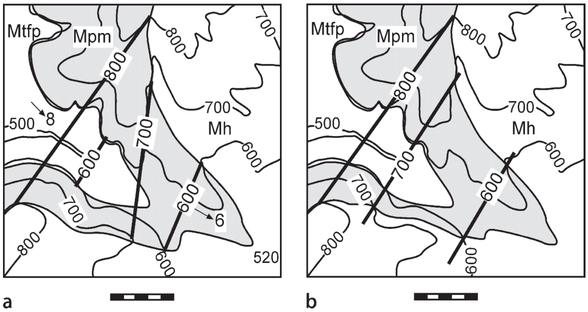


Fig. 10.7.
Geologic map. Units from youngest to oldest are Mh, Mpm, Mtfp. Topographic elevations are in feet and the scale bar is 1000 ft. **a** Structure contours (*heavy lines*) determined from the intersection of mapped formation boundaries with the topographic contours. **b** Revised geologic and structure-contour map

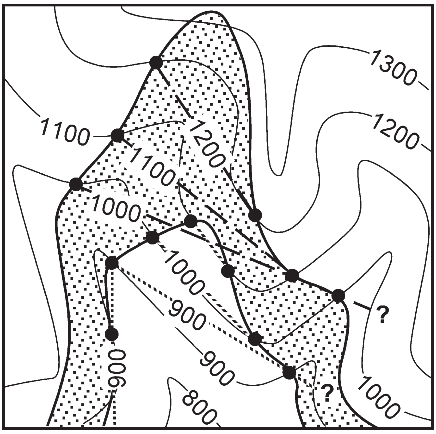


Fig. 10.8.
Structure contours on the top and base of an outcropping unit on a topographic map. Structure contours drawn between closest corresponding elevations across the V formed by the outcrop trace. *Solid dots* are control points; *long dash contours* are on top of the bed; *dotted contours* are on the base of the bed. *Question marks* show where structure contours indicate that the bed surface should intersect the topographic surface but no intersection is observed

boundaries of the Mpm (Fig. 10.7a). The 800-ft and 600-ft contours are parallel, but the 700-ft contour is quite different, suggesting that the contact locations producing the 700-ft contour could be wrong. The map is improved by changing the least certain outcrop trace to make the 700-ft contour to be parallel to the others (Fig. 10.7b). The revised map becomes a new working hypothesis which should be field checked.

The consistency between a structure contour map and bedding attitudes from outcrop measurements or dipmeters provides a powerful test of the interpretation. The fold axis trend must be consistent with the structure contour trend. The potential problem is illustrated with the map in Fig. 10.8. If the formation boundary elevations are sampled at individual points around the structure, they will be contoured as shown (previously discussed in Sect. 5.5). A problem will be recognized only if compared to the trend of the fold axis, which trends north–south with zero plunge. The correct structure contours are shown in Fig. 10.9a. This interpretation would be clear with good exposure in the field (Fig. 10.9b), but in the subsurface could not be interpreted without knowledge of the fold axis.

A few locations with dip information can be used to test and control the structures. The information provided by a small number of formation tops alone can be contoured in numerous ways as evidenced by the two maps (Fig. 10.10a and 10.10b)

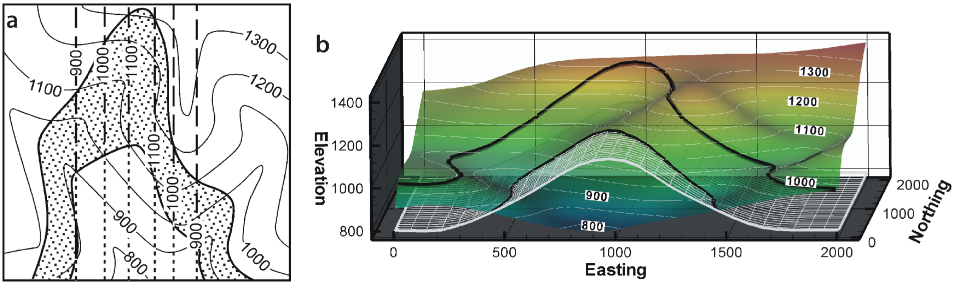


Fig. 10.9. Correct interpretation of the map in Fig. 10.8. **a** Structure contours on the base of the bed, based on knowledge that the fold axis trends north–south with zero plunge (after Weijermars 1997). *Long dashes* indicate contours below ground, *short dashes* indicate contours projected above ground. **b** 3-D view of fold. Trace of the upper boundary is shown on the topography. The lower boundary is rendered as an outcrop trace and as a 3-D mesh

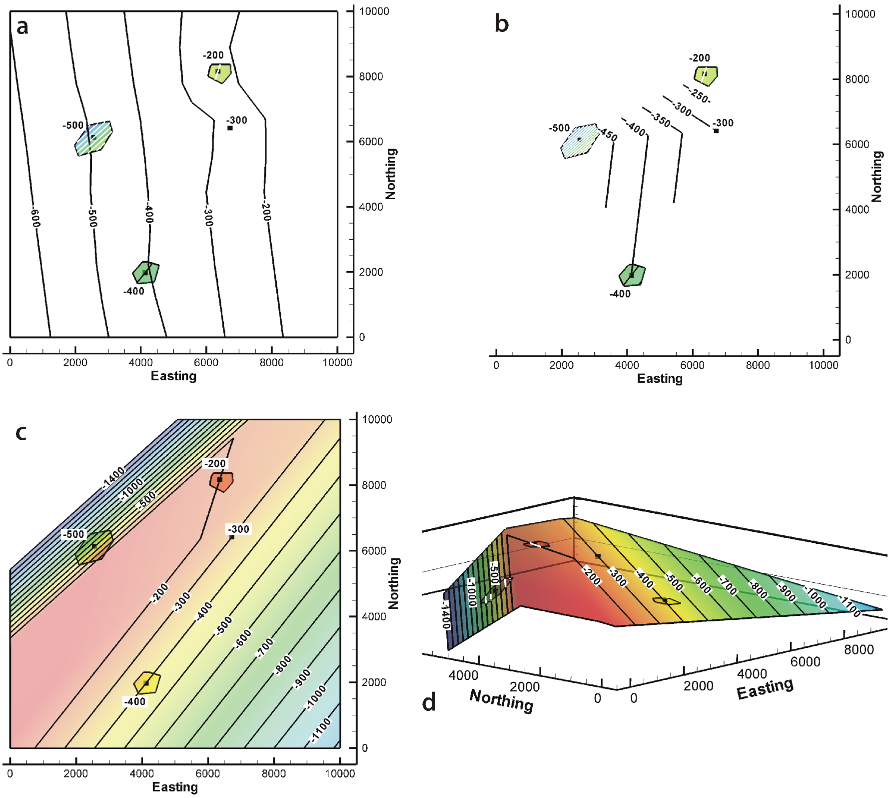


Fig. 10.10. Structure contour maps based on the four labeled points. Dips are known at the 3 points surrounded by *polygons*. **a** Kriged contouring based on elevations. **b** Triangulation contouring based on elevations. **c** Dip-domain map based on contour direction and spacing from 3 known bedding attitudes. **d** 3-D oblique view NE of **c**

derived by applying different computer contouring techniques to identical data. If dip information is available from even a few locations, the derived contour directions and spacings (Sect. 3.6.1) greatly constrain the interpretation. The map in Fig. 10.10c has been produced by extending the known dips in 3-D until they intersect to define boundaries with the adjacent domains, then contouring the resulting structure by triangulation. The map so constructed (Fig. 10.10c,d) agrees perfectly with the known dips.

Any conflict between the structure contours and the local bedding attitudes should be investigated. Local attitude measurements with a compass in outcrop or from a dipmeter in the subsurface can be accurate yet not reflect the map-scale structure. Small-scale bedding variations, cross bedding, or minor folding, can all lead to bedding attitudes that diverge from the trend that should appear on the structure contour map. The regional trend will be clearer, in spite of any small-scale variability of the bedding attitudes, if the fold axis is found using multiple attitude measurements (Sect. 5.2).

10.4 Bed Thickness Anomalies

Many quality-control measures are ultimately based on the concept that bed thicknesses should remain constant or be smoothly varying. This concept is applied as a quality control tool to the compatibility between multiple horizons on maps and cross sections, the internal consistency of composite-surface maps, and the geological likelihood of the growth history given by the expansion index.

10.4.1 Compatibility between Structure Contour Maps

The structure of nearby stratigraphic horizons is usually fairly similar. If unit thicknesses are approximately constant, the shapes of nearby horizons will be nearly the same. The compatibility of maps on closely spaced horizons is indicated by structure contours that are nearly parallel (Fontaine 1985) and separated by approximately constant distances (in gently dipping beds). A significant difference in trends on adjacent surfaces suggests a possible misinterpretation of one or both of the surfaces. The structure contours on different horizons cannot intersect without implying a structural or stratigraphic discontinuity. Only faults and unconformity surfaces can cut across stratigraphic boundaries.

Mapping different horizons independently can easily lead to incompatible surfaces. Figure 10.11 shows structure contour maps on two closely spaced horizons on the same part of the Sequatchie anticline. In this example more control data were generated for the lower surface (Fig. 10.11b) by means of vertical projection (Sect. 3.6.2). To determine if the maps are compatible, they are superimposed (Fig. 10.12). The superposed contours are approximately parallel and so are compatible by this criterion, except in the shaded region of second-order folding on the southeast limb of the major anticline (Fig. 10.12a). Disharmonic folding is implied by the folds confined to the Mtfp. This may be geologically reasonable if the mechanical stratigraphy is appropriate (Sect. 1.5.1) but should be checked.

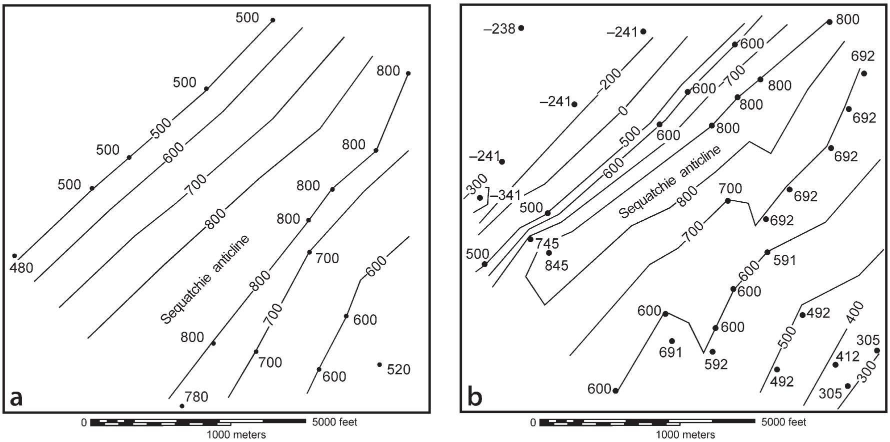


Fig. 10.11. Structure contours on adjacent horizons. Control points are labeled. Contour interval is 100 ft. **a** Top of the Mpm. **b** Structure contour map on the top of the Mtfp, 108 ft stratigraphically below the Mpm

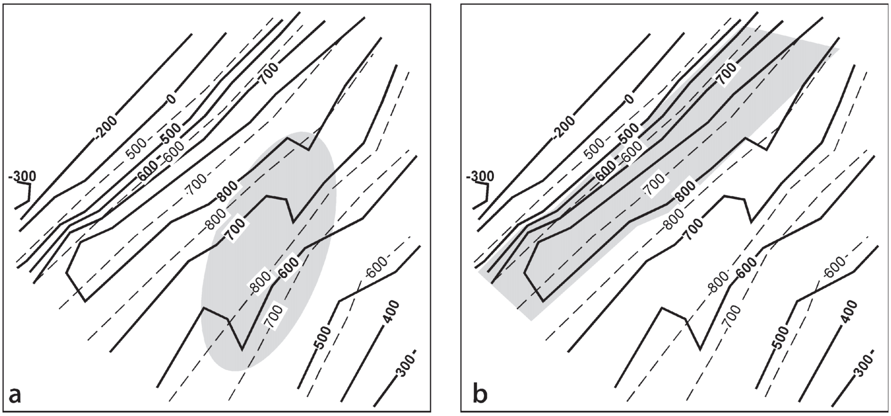


Fig. 10.12. Testing for compatible surfaces by superimposing structure contour maps. Structure contour map of the top Mpm (*dashed contours*) overlain on the composite map of the top Mtfp (*solid contours*). **a** *Shaded area* is a zone of contour shape incompatibility. **b** *Shaded area* shows approximate area where the stratigraphically higher surface (Mpm, *dashed lines*) lies below the stratigraphically lower surface (Mtfp, *solid lines*)

A comparison between elevations of the two maps in Fig. 10.11 reveals a fatal flaw in the interpretation: the upper stratigraphic surface lies below the lower stratigraphic surface in the shaded area of Fig. 10.12b. This indicates a glaring lack of compatibility between the two surfaces. Usually it will be the map with the lesser amount of control that should be corrected. A cross section would also reveal this problem and make it easy to visualize, one of the reasons that cross sections should always be part of the quality control process.

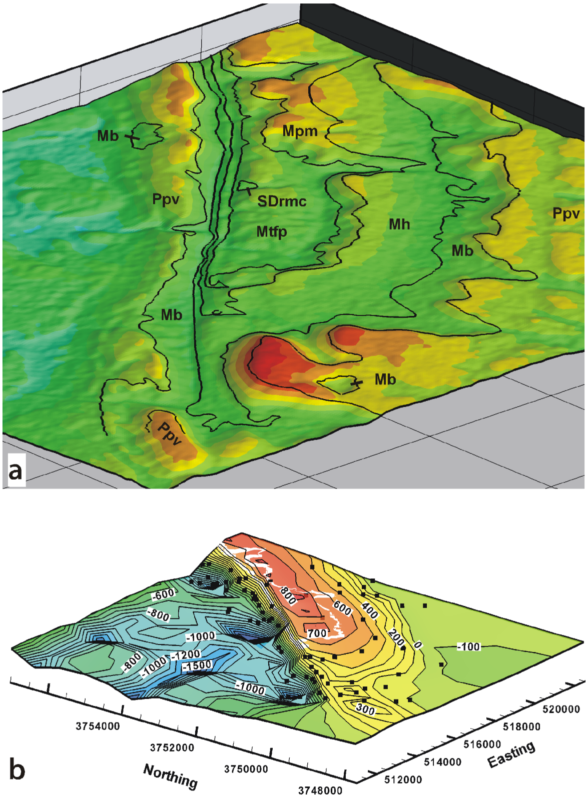


Fig. 10.13. Compatibility of geological contacts in outcrop. **a** Geological map of the southern Sequatchie anticline at Blount Springs, Alabama on a 30 m DEM base from Fig. 2.4. Oblique view to NE. Distance between grid lines, 1 km. *Thick black lines* are geologic contacts. **b** Composite structure contour map of the top Mtfp, oblique view to NE (from Fig. 3.23b)

A composite surface map (Sect. 3.6.2) provides a method for the simultaneous testing of a complete geological map for internal consistency. It is very difficult to determine by inspection alone whether the outcrop traces on a geological map (e.g., Fig. 10.13a) are consistent with one another. The composite surface map of a representative horizon provides such a test. If the composite-surface map shows a realistic structure, without unexplained peaks and valleys, as in Fig. 10.13b, then the combined data are internally consistent. Because outcrop trace locations, dips and thicknesses all work together to produce the final map, all of this information is tested by the composite surface map.

10.4.2 Compatibility of Thicknesses on Cross Sections

A cross section is a powerful tool for checking and improving the structural interpretation presented on an outcrop map or on multiple structure contour maps. First be sure the cross section matches the map from which it was constructed. In section view, poorly controlled map horizons may be improved with information from other horizons (c.f. Sect. 6.4). Errors in mapping on one horizon can be recognized as incompatibilities with the geometry of horizons above or below. Many of the mapping pitfalls noted pre-

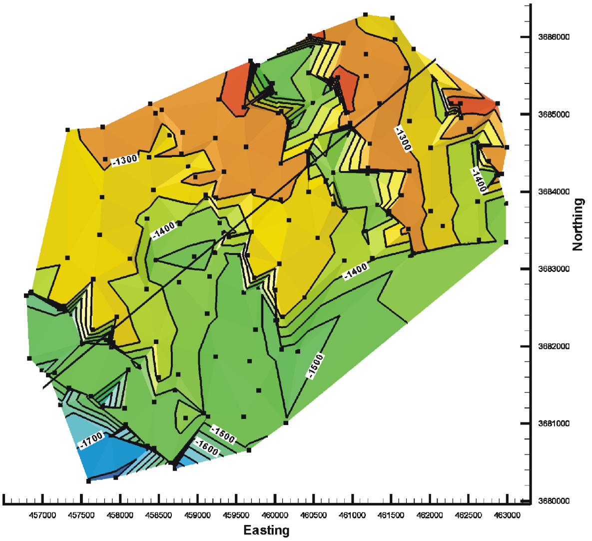


Fig. 10.14. Preliminary map of top Mary Lee structure contours in the southeast Deerlick Creek coalbed methane field, Black Warrior Basin, Alabama. Data from Groshong et al. (2003b). Control points are *squares*. Easting and northing in meters, elevations in ft. Trace of cross section in Fig. 10.15 is shown

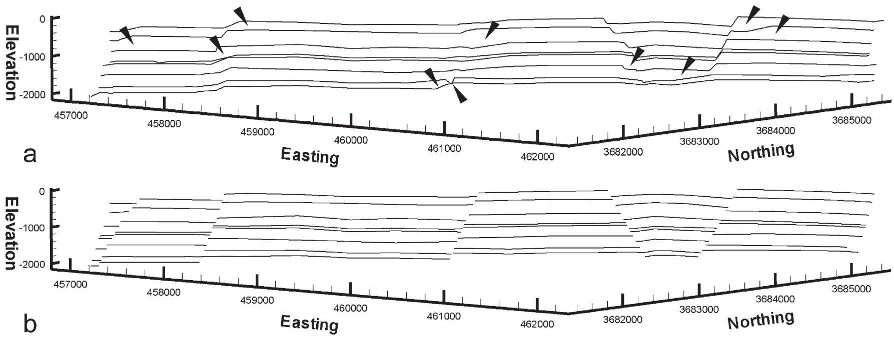


Fig. 10.15. Cross section of SE Deerlick Creek coalbed methane field. Horizontal view to NW. No vertical exaggeration. Easting and northing in meters, elevations in ft. **a** Preliminary interpretation of all horizons. *Arrows* point to thickness anomalies. **b** After locating faults and re-mapping

viously and their correct interpretations are immediately obvious on a cross section. A valid cross section must be compatible with the structure laterally adjacent to the section as well. Accurate interpretation in three dimensions is demonstrated by means of maps and cross sections that are each internally consistent and consistent with each other.

The preliminary structure contour map in Fig. 10.14 shows excessively wiggly contours and some trends that might represent faults. A cross section of the preliminary contour maps on multiple horizons is constructed by slicing the maps. The section (Fig. 10.15a) shows numerous thickness anomalies and discontinuities that can be resolved by inserting faults (Fig. 10.15b). Once the faults are mapped and the marker surfaces re-mapped (Sect. 8.3.2), the thickness anomalies disappear, and the new marker-surface map is much simpler (Fig. 10.16).

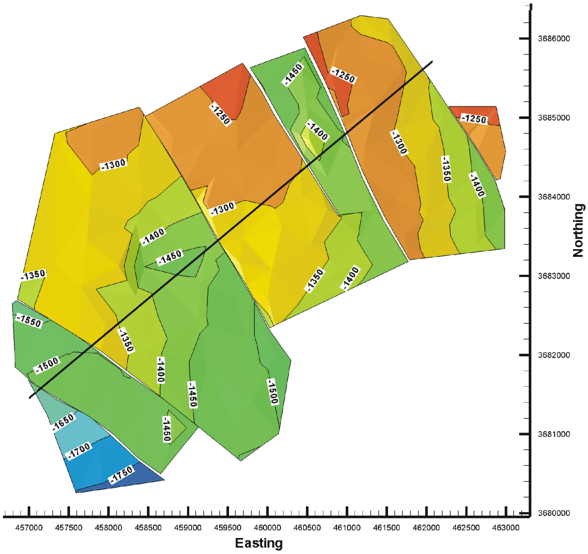


Fig. 10.16.
Top Mary Lee structure contour map (same data as Fig. 10.14) after reinterpretation of all map horizons to include faults. Easting and northing in meters, elevations in ft

10.4.3
Realistic Growth History

The growth sediments, deposited during deformation, contain a record of the structural evolution. The implied evolution must be compatible with the regional structural style and evolution. Apparent inconsistencies in the indicated geological evolution may indicate errors in the interpretation. The expansion index plot across a fault (Sect. 7.7.4) is very helpful in recognizing and fixing this type of problem. The appropriate form of the plot is determined from the local structural style. For example, in an extensional region, a reasonable expectation is that the sense of displacement on normal faults does not reverse and, consequently, that the expansion index must always be greater than one. A value of less than one means that the downthrown side received less sediment than the upthrown side which, in turn, implies that the downthrown side was high (upthrown) during the interval having an $E < 1.0$. In this situation, an $E < 1.0$ could indicate a miscorrelation, either of the units or of the fault cuts. In Fig. 10.17, if the top three units are correlated, E is less than one in unit 2. A better interpretation is that the thin unit 2 on the hangingwall is part of a thicker interval that correlates with unit 2 on the footwall (interpretation 2). Another possibility is that the abnormally thin unit in well B on the downthrown side of a fault has been truncated by another fault (Fig. 10.18a). Inserting fault f_2 at the proper location (Fig. 10.18b) results in the correct form of the expansion-index diagram. The expansion index increases steadily downward for the reinterpreted fault blocks.

The growth history should agree with the stratigraphic separation on the fault. Within the growth interval on a normal fault, the separation is expected to increase down the dip. The throw across the fault can be plotted against depth (Fig. 10.18). A misinter-

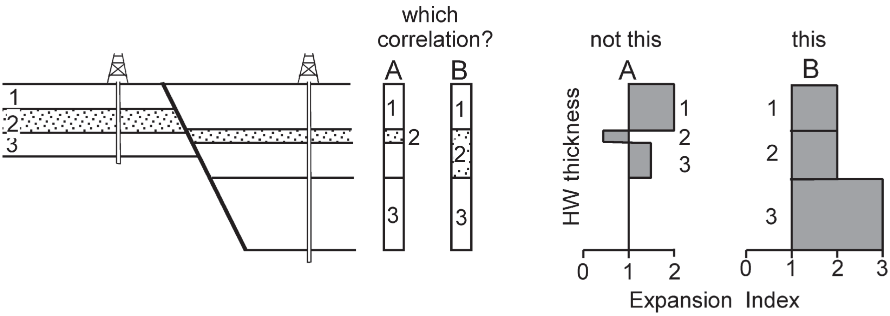


Fig. 10.17. Use of the expansion index to test unit correlations. An expansion index of less than one implies reverse fault movement or a miscorrelation across a normal fault

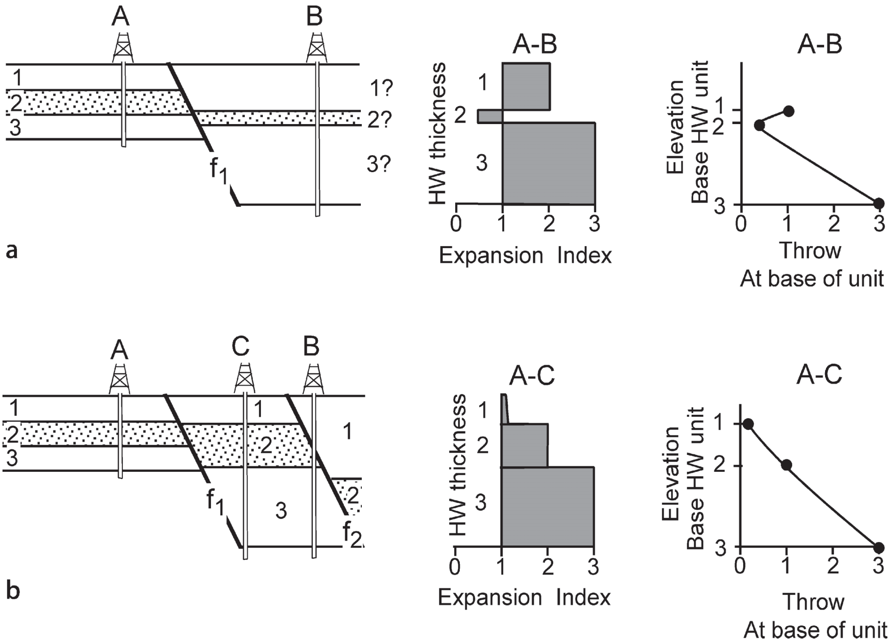


Fig. 10.18. Presence of a fault interpreted from anomalies in the expansion index and vertical separation. **a** A misinterpretation of the hangingwall of fault f_1 that gives an expansion index of less than one for unit *2* and a fault throw that decreases and then increases with depth. **b** The anomalous thinness of unit *2* in well *B* is explained by normal fault f_2. *C* is a well that would penetrate an unfaulted section in the hangingwall of the fault f_1

preted growth stratigraphy (Fig. 10.18a) shows the separation to decrease downward and then to increase again. The correct interpretation (Fig. 10.18b) shows a continuing increase of vertical separation downward.

10.5
Unlikely or Impossible Fault Geometries

It is surprisingly easy to create interpretations that include impossible or at least very unlikely 3-D fault geometries. Faults placed on single-horizon structure-contour maps or on geological outcrop maps without regard to the implied 3-D fault shape are the most likely to cause problems. The quality of a fault interpretation can be assessed using the implied fault shape and the cutoff-line geometry of hangingwall and footwall. A final quality-control issue is the distinction between a fault and an axial surface.

10.5.1
Fault Shape

Fault surfaces should always be mapped. The shape of an undeformed fault should be planar, smoothly curved, or have a stair-step shape. A very irregular fault (Fig. 10.19) probably cannot move and so is unlikely to be a correct interpretation unless the fault has been folded by a later event.

Structure contour maps of faulted horizons are commonly shown without contours on the faults. Contouring the implied fault surface, by matching elevations across the fault, is a very simple and effective test of the interpretation. Incorrect interpretations of the fault-bedding relationships will show unreasonable or impossible contour patterns for the fault surface. The implied fault surface in Fig. 10.20 has a spiral shape, possible perhaps, but not very likely. In more complex situations, crossing contours may occur on the implied fault, an even less likely result.

Implied structure contours may reveal problems in addition to unlikely fault shapes. In Fig. 10.21a the implied structures on the fault are parallel and so are reasonable. But once the fault contours are extended across the map (Fig. 10.21b) a problem becomes

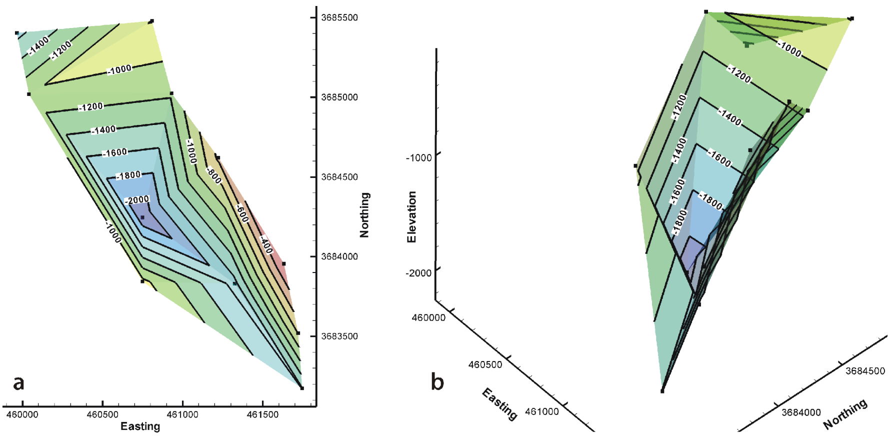


Fig. 10.19. Map of two faults from the Deerlick Creek area (Fig. 7.32) interpreted as being a single fault. *Squares* are the positions of fault cuts, *contours* are on the fault surface. **a** Structure contour map, synclinal shape is unreasonable. **b** 3-D view to the NW of the inferred synclinal fault

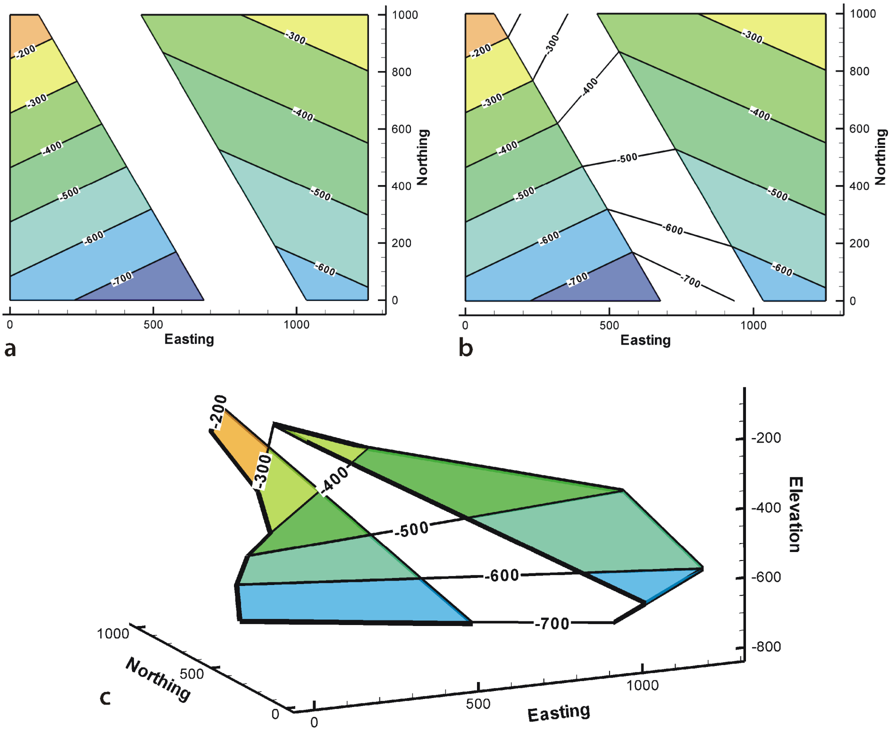


Fig. 10.20. Interpretation of unlikely fault geometry from implied structure contours. **a** Structure contour map of offset marker without contours on fault. **b** The implied fault contours found by connecting equal elevations of the hangingwall and footwall bed cutoffs. **c** 3-D view to NE showing the implied spiral fault shape

apparent. The map shows the marker bed to be above the fault on both sides of the fault gap. Normally an offset bed will occur on both sides of the fault. This is not required for a fault where erosion has removed beds from one side, but otherwise is anticipated. The 3-D view (Fig. 10.21c) makes it clear that both segments of the marker bed are in the hangingwall of the fault. Either the map in Fig. 10.21a is wrong or the fault has truncated a steeply plunging synform, the trough of which has yet to be located. Finding the synclinal hinge of the marker-bed in the footwall would validate the map.

10.5.2 Fault Separation

The stratigraphic separation from a fault cut in a well must agree with the heave and throw shown by the structure contour map of the faulted surface. Suppose the well that cuts the normal fault at the location shown in Fig. 10.22 has a stratigraphic separation of 75 m, is this consistent with the map? The map indicates a heave of 24.6 m and a throw of 64.5 m (Sect. 8.2). From Eqs. 8.1 or 8.2, the stratigraphic separation on the fault should be 47.6 m, a significant difference. The alternative strategy is to find

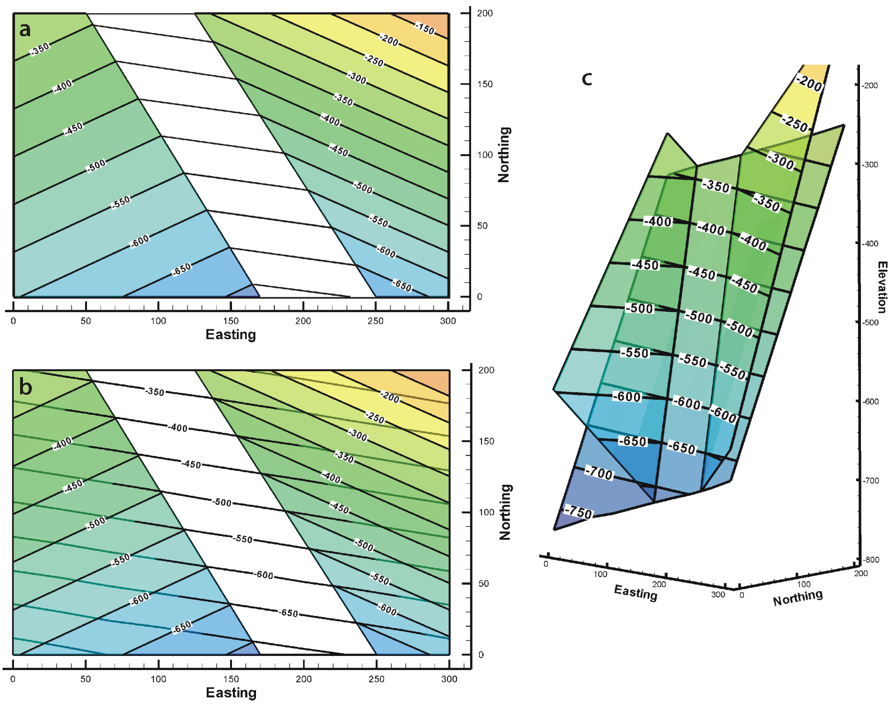


Fig. 10.21. Questionable relationship between marker bed and fault. **a** Structure contour map of marker bed with contours across fault gap. Fault resembles a simple normal fault with missing section. **b** Fault contours extended across the map. **c** 3-D oblique view shows both segments of the marker belong to the hangingwall

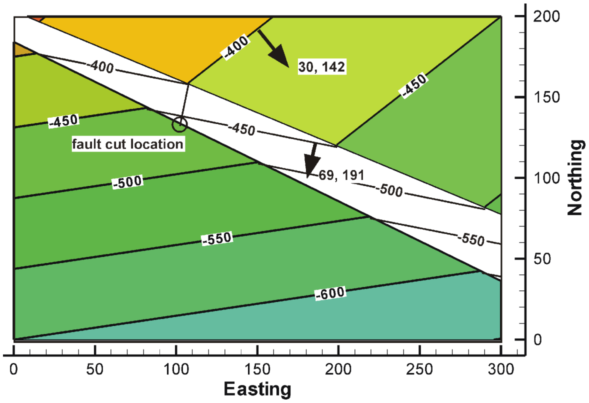


Fig. 10.22. Structure contour map of a normal fault (from Fig. 8.5a)

the heave and throw from Eqs. 7.5–7.6 or 7.7–7.8 and compare to the values on the map. The discrepancy is revealed by either method and requires that the fault cut interpretation be changed or the map reinterpreted.

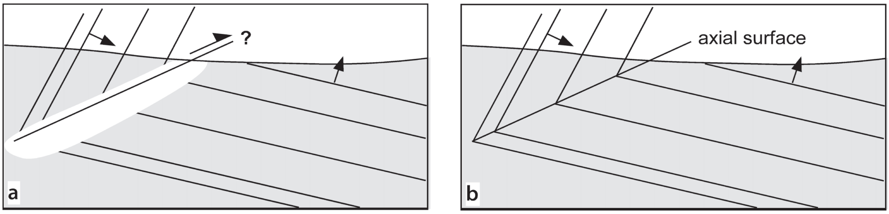


Fig. 10.23. Axial surface vs. fault, cross-section view. *Full arrows* indicate stratigraphic facing (up) direction. **a** Dip change used to infer location of a fault, *half arrow* indicates possible displacement direction. **b** Extrapolated markers meet, showing an axial surface is present, not a fault

The defining feature of a fault is the separation of a marker surface. It is tempting to map a fault anywhere the dip changes rapidly (Fig. 10.23a) in either outcrops or on seismic profiles. At such locations, the continuity of beds or reflectors may be difficult to establish, leading to the inference of a fault. If extrapolation of the markers towards each other shows that they can meet without offset (Fig. 10.23b), then the probability that the feature is an axial surface must be considered. Dip-domain fold hinges can be very tight. Faults with no stratigraphic separation are probably axial surfaces with large dip change. Of course strike-slip and oblique-slip faults cutting folds may have locations where the stratigraphic separation is zero even though the slip may be significant. In such situations it is expected that fault separation will appear elsewhere along the fault surface, demonstrating that displacement has, in fact, occurred.

10.5.3
Fault Cutoff Geometry

The geometry of the cutoff lines of marker surfaces against the fault provides a test of the quality of the interpretation. The relationships are nicely shown on an Allan diagram (Sect. 8.4). The Allan diagram of the normal fault shown in Fig. 10.24 represents a reasonable throw distribution along a fault. The throw increases from SE to NW and is approximately constant down the dip of the fault at any one location.

The Allan diagram from Fig. 10.24 has been modified in Fig. 10.25 to show typical fault-separation problems. At point 1 the throw on marker 5 is significantly more than on the markers above and below it. At point 3 the throw is significantly less than on markers above and below. The lack of consistency along the fault and up and down the fault, makes the interpretation of marker 5 suspect. Lesser throw on one horizon, as at point 3, might be explained by a change in lithology to a rock type that favors folding. Nevertheless the interpretation should be checked. The reversal of separation at point 2 implies a significant problem. Only a strike-slip fault would be expected to show reversals of separation along strike. But the strike slip would not be confined to a single marker horizon, suggesting an error in the interpretation.

A stratigraphic separation diagram shows the fault separation in terms of the units juxtaposed across the fault along a single line, for example along the map trace of the fault (Sect. 7.7.3). The curves for the hangingwall and footwall are not expected to cross (Fig. 10.26), because this implies that either (1) the fault changes from a thrust to a

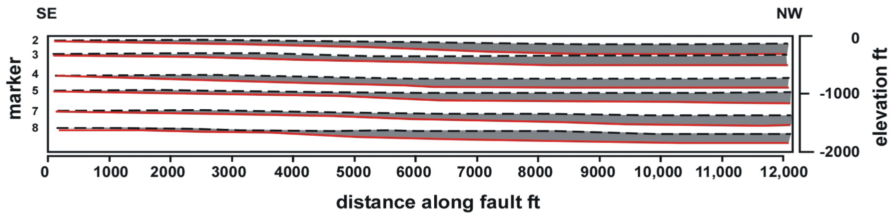


Fig. 10.24. Allan diagram of throw (projection to a vertical plane) for a normal fault in Deerlick Creek coalbed methane field (data from Groshong et al. 2003b). *Dashed line* is FW cutoff, *gray shading* shows fault throw. Base of the gray is the HW cutoff

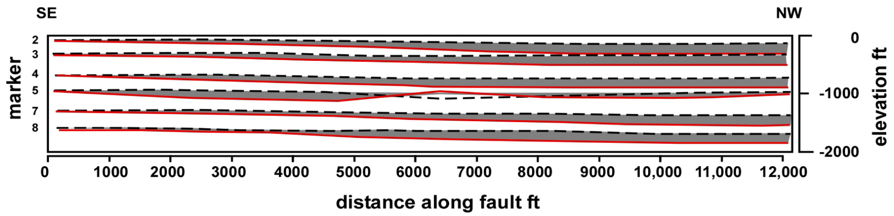
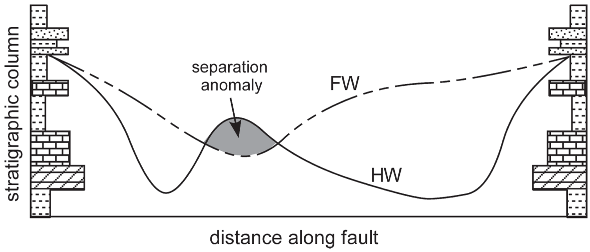


Fig. 10.25. Allan diagram showing inconsistent throw at numbered locations. *Dashed line* is FW cutoff, *gray shading* shows fault throw

Fig. 10.26.
Stratigraphic separation diagram showing a separation anomaly. *FW curve:* Stratigraphic position of the thrust in the footwall; *HW curve:* stratigraphic position of the fault in the hangingwall



normal fault or from a normal fault to a thrust, or (2) the fault is out of the normal evolutionary sequence and cuts an older fold or fault. A separation anomaly requires careful attention to the correlation of the fault cuts and to the interpretation of the fault if the correlation is accepted. A strike-slip fault might have an apparent separation anomaly like that in Fig. 10.26.

10.6 Exercises

10.6.1 Cross-Section Quality

Critique the cross section in Fig. 10.27. What might be the origin of any problems?

10.6.2 Map Validation

The structure contour map of the top of a faulted limestone (Fig. 10.28) fits the well information and explains the hydrocarbon trap. Is the interpretation valid? Based on the map as presented, what kind of faults are present? In which direction do they dip? Where are the structural closures on the map? Could any of them be new hydrocarbon traps? Why or why not? Draw implied structure contour maps on the faults. Is the original map correct? Construct an improved map that honors all the well data.

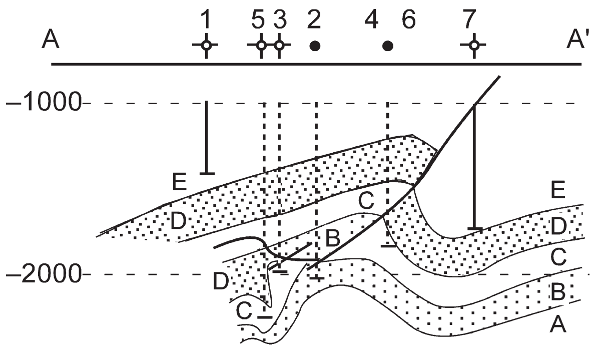


Fig. 10.27. Cross section of a compressional anticline (after Brown 1984). Elevations are in feet, *dashed wells* are projected to the line of section, *solid circles* represent oil producers, *open circles* are dry holes

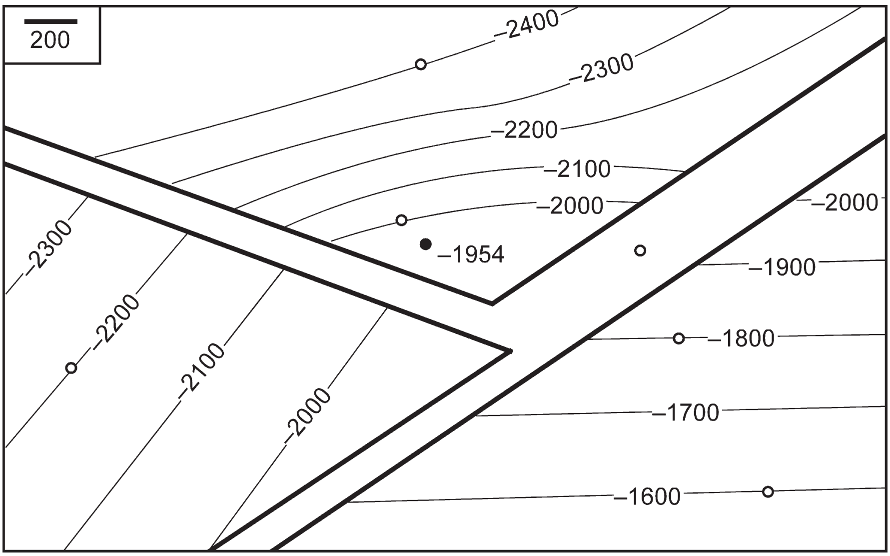


Fig. 10.28. Hypothetical structure contour map of the top of the Appling Bend Limestone gas reservoir. Contours are depths below sea level. The *solid circle* is a gas well, *open circles* are dry holes. The limestone is missing in the well in the fault gap. Choose the measurement units to be in either feet or meters. Elevations below sea level are negative

10.6.3 Map and Fault Cut Validation

Is the fault in Fig. 10.29 valid? If not, can it be corrected? The well near the center of the map is thought to have a stratigraphic separation of 15.0 m. Is that correct? If not, what is stratigraphic separation is consistent with the map?

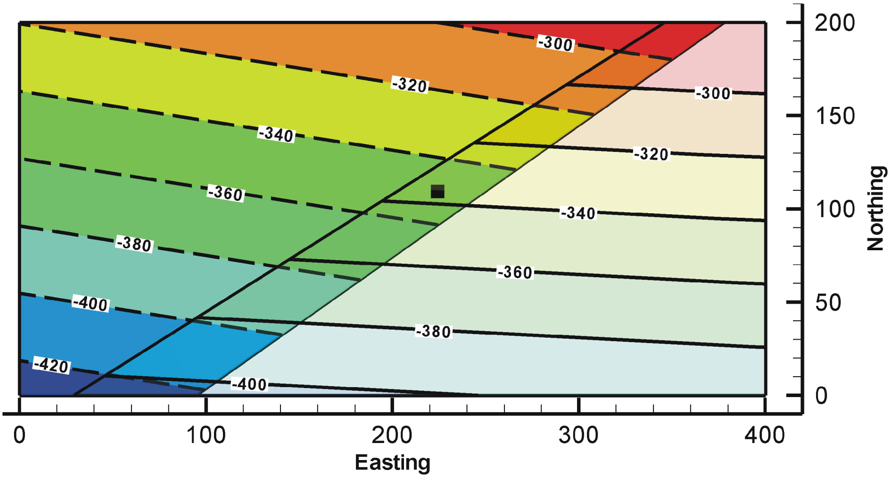


Fig. 10.29. Structure contour map of an offset horizon. Scale in m, *small square* is a well location