EXERCISE 7

BALANCED CROSS SECTIONS AND RETRODEFORMATION

Supplies Needed

- calculator
- metric ruler
- scissors
- tape

PURPOSE

Deformation of the Earth's surface is one of the most visible results of active tectonics, but it is not the whole story. Some faults ("buried reverse faults") can cause large earthquakes (for example, the 1994 Northridge earthquake that struck the Los Angeles region) even though they never break the surface. Two of the most useful tools for studying faults that do not break the surface are 1) balanced cross sections, and 2) retrodeformation. This exercise will acquaint you with these two tools and show you how they can be applied to problems in active tectonics, active folding, and earthquake hazard.

BALANCED ("Retrodeformable") CROSS SECTIONS

Geological structures include folds, faults, joints, and other evidence of deformation within the Earth's crust. The majority of such structures around the world formed in the ancient geologic past, but others are actively forming today. Cross sections through the crust in zones of active deformation often reveal that layers of rock and other geologic features mimic patterns of deformation at the surface, but show much more dramatic change because the rocks usually are much older than surface features.

Geological structures are vitally important in the field of petroleum exploration. Faults and folds are responsible for trapping oil and gas in concentrated pockets. Exploration geologists spend a lot of their time trying to locate these kinds of structures. The petroleum industry uses a variety of sophisticated techniques to probe the subsurface, including exploratory drilling that can determine rock type and bedding orientation several kilometers below the surface, and seismic-reflection profiling that determines large-scale relationships below the surface. This type of information is extremely useful in studies of active tectonics.

Balanced Cross Sections and Retrodeformation

The key to interpreting geologic structures, whether active or inactive, is the construction of *cross sections* that show the types of rock present beneath the surface; the orientations of bedding at different locations and depths; and the presence of folds, faults, and other geologic structures. Geologists typically have only localized data, and they must extrapolate across data-poor areas in order to construct regional cross sections. Such extrapolation is not haphazard, but is based on models of how geologic structures should look. A geologic cross section is said to be *balanced* if the thickness of each sedimentary layer is the same throughout the profile. To construct a balanced cross section, follow these steps:

A) Construct a topographic profile along the line of section. Typically, a cross section shows deformation most clearly if it is oriented perpendicular to the strike or trend of the structures. In addition, the profiles should have no vertical exaggeration unless bedding and structures in the area are extremely subtle. An unexaggerated profile shows true bedding thicknesses regardless of the dip of the layers. Without vertical exaggeration, the surface topography will look quite gentle on most profiles.

B) Add the geology visible at the surface, including rock types, boundaries between different units, bedding dips at different locations, and the location of any faults that rupture the surface. This information can come from geologic maps and/or field mapping.

C) Add information from wells.

D) Extrapolate between locations where you do have information to where you do not. In general, it's best to begin with stratigraphic contacts, infer folds from changes in dip, and then add faults where abrupt breaks in the sequence are indicated. The *Kink Method*, outlined in Exercise A, is one technique for systematically extrapolating dips across a cross section.

E) Check if the cross section is *retrodeformable*.

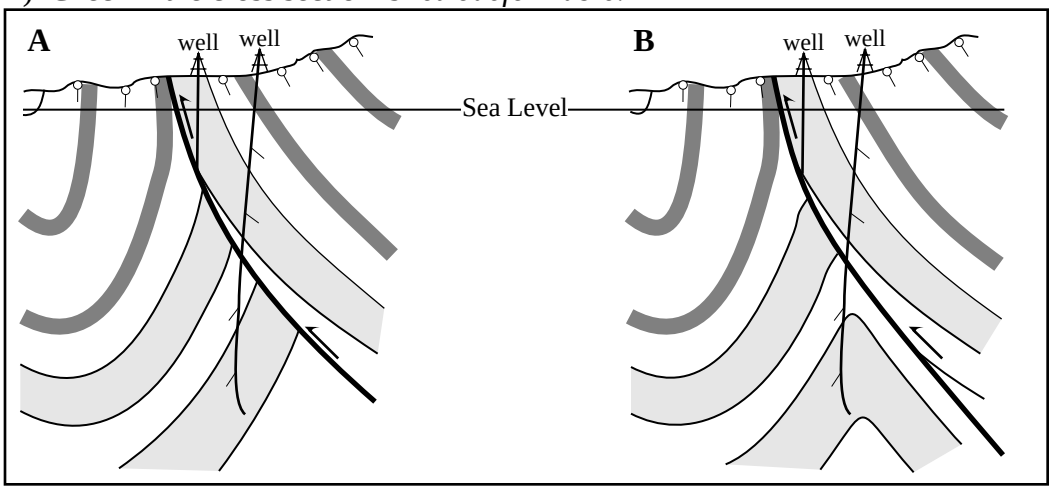

Figure 7.1. Two interpretations of surface geology and well data on a faulted anticline in western Taiwan. Interpretation A is not retro-deformable; Interpretation B is. (After Suppe, 1985)

Interpretation of cross sections can be subjective, especially where the hard data is sparse. Step E on the previous page is crucial because it checks whether the subjective processes of extrapolation and interpretation result in a model that is feasible. Presumably, all sequences of rocks originally were undeformed before they were folded and faulted. If the sequence was deformed, then at least on paper and in the human imagination, it also can be *undeformed.* Figure 7.1 shows two interpretations of the same cross section, one that is not retrodeformable and one that is. The process of checking retrodeformability is outlined later in this exercise.

THE KINK METHOD OF EXTRAPOLATION

Extrapolating bedding orientations across zones without data need not be a random act. Fortunately, even intensely deformed rock layers follow certain rules. The shape of one stratum is constrained by the shape of the strata above and below it. The Kink Method makes two assumptions about folded strata:

A) that folds are parallel, which means that the thickness of any given stratum (measured perpendicular to bedding) is locally uniform,

B) that folds consist of zones of uniform dip that are separated by distinct *kinks* (see Figure 7.2 below).

The second assumption above commonly is found to be true in the field. Even where folds consist of broad curves, the curves often consist of many small, straight-line segments. The kinks in different layers are connected to kinks in underlying layers along lines called *axial surfaces* (the lines on the cross section are surfaces in three dimensions). Each axial surface bisects each kink, meaning that it cuts the angle of the kink exactly in half (for example, you can see that $\gamma_1=\gamma_2$ and $\gamma'_1=\gamma'_2$ on Figure 7.2).

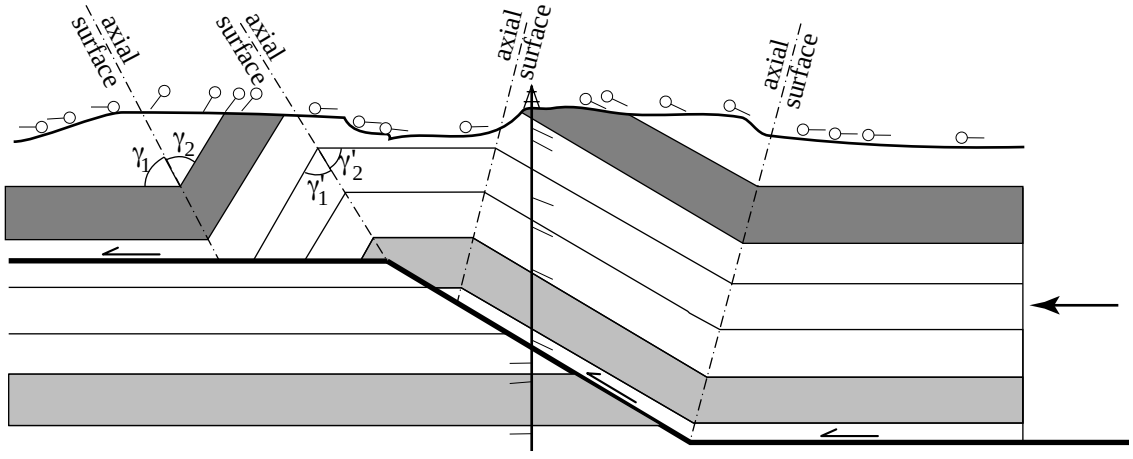

Figure 7.2. An anticline that consists of four kinks. The anticline grew as a result of slip on the underlying fault ramp. (After Suppe, 1983)

Balanced Cross Sections and Retrodeformation

1) Use the rules of balanced cross sections and the Kink Method to complete this section:

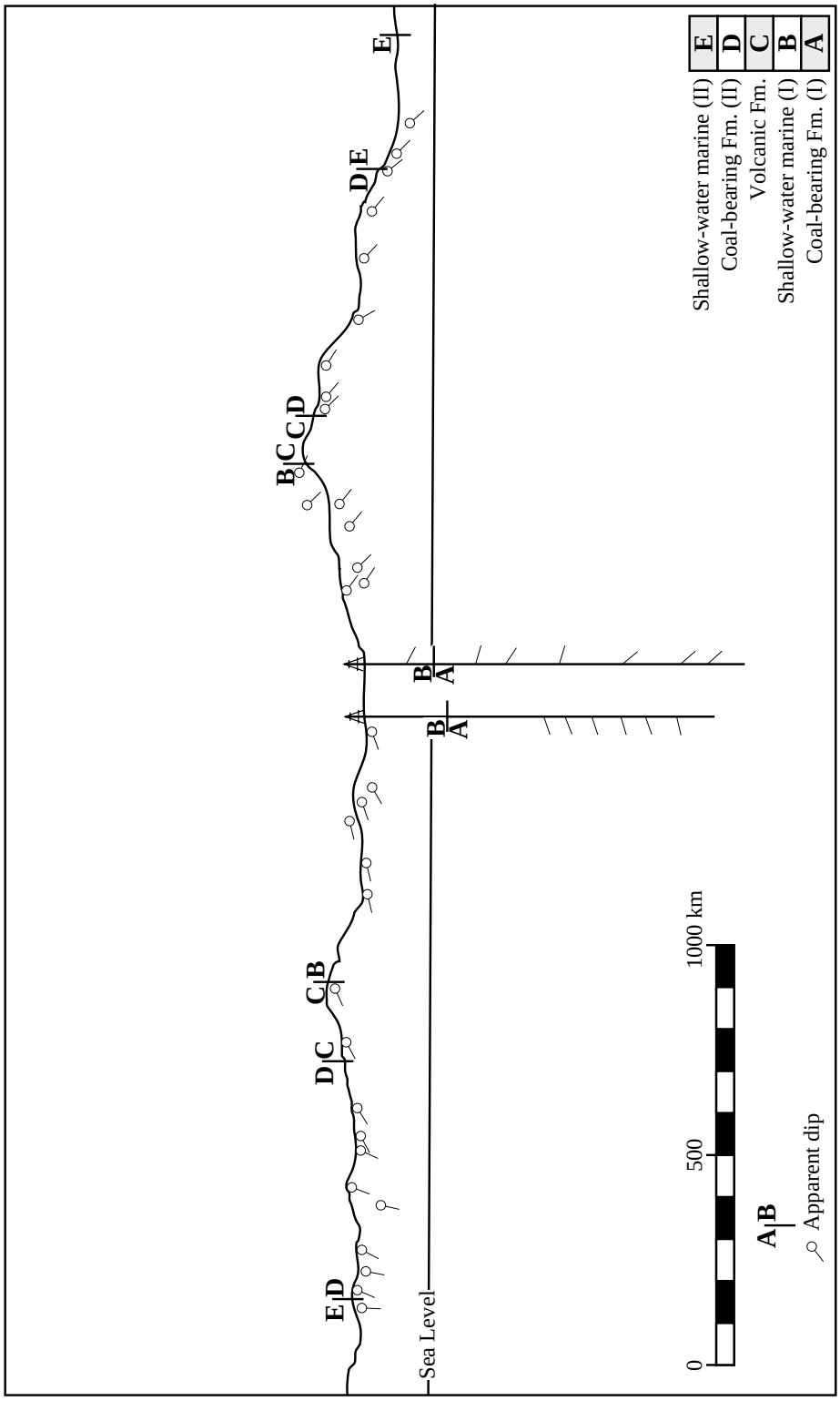

Figure 7.3. Unfinished cross section of the Shantzechiao anticline, Taiwan. (After Suppe, 1985)

RETRODEFORMATION

Figure 7.4 is a balanced cross section of a portion of the Taiwan fold-and-thrust belt. You will test whether this interpretation of the surface geology and the well-hole data is retrodeformable, and if it is, you will measure the amount of deformation that has occurred. Follow these steps:

A) Plot the axial surfaces of the folds onto the cross section.

B) Using scissors, cut the cross section into pieces by cutting along every fault plane and every axial surface. Place the pieces on an empty desk or tabletop.

C) Undeform the sequence. You'll do this by rearranging the pieces so that the different strata are in the right order and the thickness of each stratum is uniform or varies systematically. As you place each piece in its undeformed position, tape it down on your tabletop. Note that small gaps are unavoidable at the kinks; in the rocks, slip parallel to bedding or other internal deformation occurred in these locations.

D) Answer the following questions:

2) What distance has Fault A slipped? To get distance along the fault plane, remember that this cross section has no vertical exaggeration (VE=1).

3) What is the minimum distance that Fault B has slipped?

4) Why is your answer above a *minimum* distance? (i.e.: What happened to the portion of the layer right above Fault B where the words "Fault B" are printed?)

5) Calculate the minimum amount of *crustal shortening* across this profile as a result of faulting and folding. You can calculate shortening as follows:

*(width of the profile before retrodeformation) ÷ (width of the profile after retrodeformation) * 100%*

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Acknowledgements: The author would like to thank Dr. John Suppe of Princeton University for his permission to use the figures in this exercise.

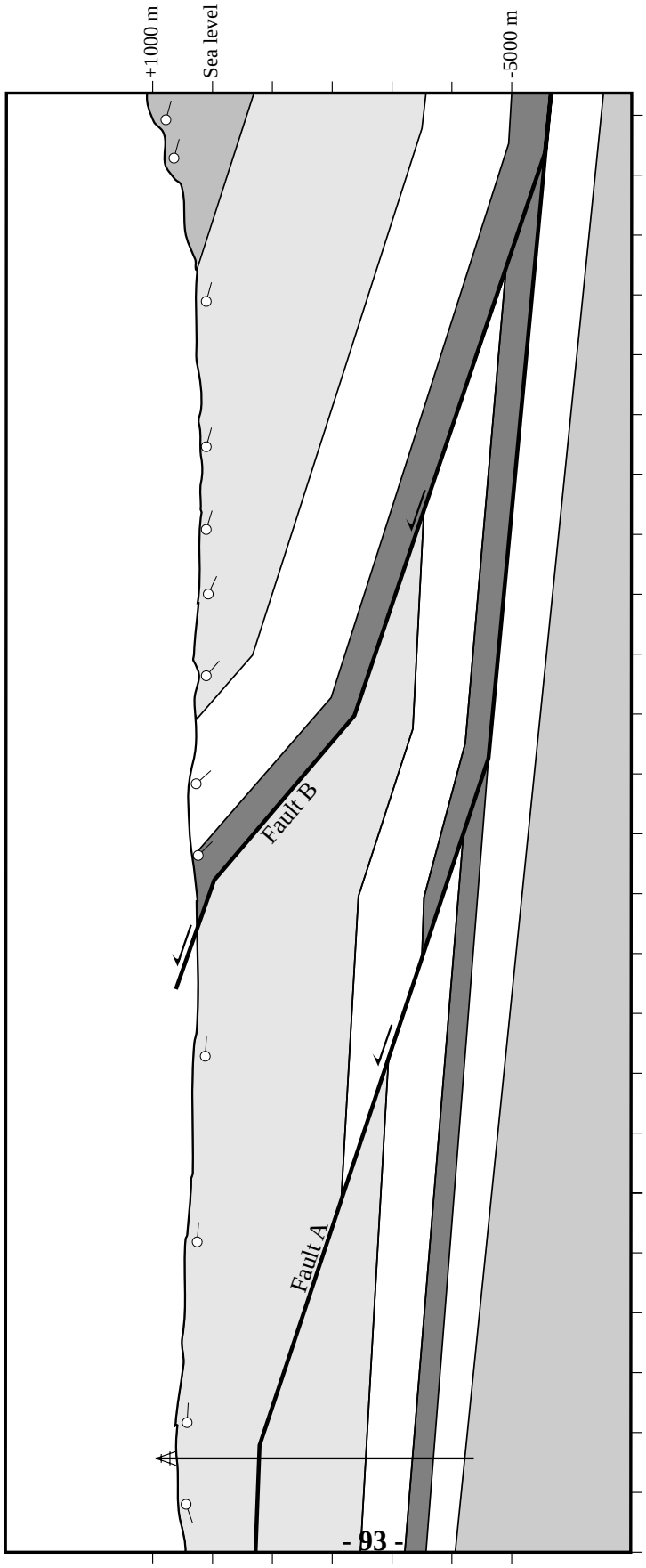

Figure 7.4. Balanced cross section. (After Suppe, 1985)