Notes IX
Thrust tectonics

Fall 2005

1 Reading assignment

Chapter 6 in Twiss and Moores is the relevant chapter. Make sure you understand and are familiar (i.e. you could write a caption and label them) with the figures in the chapter. Figures 6.11, 12, 15, and 19 are particularly germane to what you need to take away. Viz.: you should be familiar with the general geometry of thrust faults and their associated folds; the geometry of thrust belts; how that geometry is associated with various tectonic settings.

The material covered in the lab on fold and thrusts is obviously relevant.

2 Jargon

Make sure all these are familiar to you!

autochthonous – allochthonous – klippe – fenster/window – decollement – thick-skinned vs. thin-skinned thrusts – duplexes – vergence – tear faults – fault-propagation folds – fault bend folds – ramps – flats – foreland – hinterland – vergence – nappe – backthrust – admissible cross-section – accretionary prism

3 Geometry, general characteristics

A thrust or a reverse fault is a dipping fault whose hanging-wall is translated up-dip. Generally, when the fault dips less than 45°, it's called a thrust fault, steeper faults are called reverse faults. This is not, however, a hard and fast distinction.

Thrusts are commonly low angle faults. According to mechanical models of faulting (where maximum compressive stress is at acute angles to fractures), these are associated with sub-horizontal σ_1. In particular, thrust faults and thrust belts are associated with convergent margins (subduction zones, collision zones) and tectonic thickening of the crust.

Movement of the hangingwall up and over the footwall material creates the canonical stratigraphic signature of a thrust fault: older rocks are placed above younger rocks, stratigraphy is repeated. (What does this assume?). This characteristic signature of thrust faults is something that can be used to recognize thrust faults even if they have subsequently been folded or reactivated as normal faults.

Listric geometries are common, as are subhorizontal segments linked by short dipping segments. These last are referred to as "flats" and "ramps". Movement of material above ramps and flats requires deformation of the material in the hangingwall of the thrust, in particular, ramp-flat geometries are associated with characteristic folds in the hangingwalls of thrusts called fault bend folds.

Folds are often associated with "blind" faults. Since a blind fault terminates in the middle of the rock mass, offset along the fault has to be transferred into more distributed (ductile?) strain past the buried fault tip: i.e. folds. Folds form at the tips of blind faults (characteristically, an anticline forms in the hangingwall and a syncline forms in the footwall). More generally, when the slip rate along a fault exceeds the rate that fault tip itself propagates, the fault will be blind for much of its history and fault propagation folds form.

Thrust faults and their folds can commonly occur during sedimentation. Growth stratal patterns then reflect the kinematics and geometry of the growing folds and slip on the thrust faults and permit placing tight time constraints on how the geometries evolved through time. This is exactly analogous to growth strata in extensional environments.

Fold and thrust belts are commonly associated with the deformation of layered sediments (especially passive margins). The sedimentary layering provides a pre-existing mechanical anistropy along which faults propagate. That is, sedimentary layering provides ideal initial conditions for ramp-flat geometries.

In many fold and thrust belts, thrust faults dip in the same direction and all join together at a low-angle master fault at depth. This is the decollement. Fold and thrust belts where all the deformation occurs in the hanginwall of a shallow (i.e. upper 5 – 10 kms of the crust) decollement is known as a thin-skinned thrust belt. Conversely, thrust faults that penetrate into the middle crust (or deeper?) are called thick-skinned faults. Thin-skinned thrust belts generally occur during the deformation of horizontally layered sedimentary rocks and the deformation does not penetrate into the "basement" to those rocks (eg. crystalline rocks without horizontal mechanical anisotropy). Conversely, thrusts that involve crystalline basement are generally termed thick-skinned.

The decollement separates undeformed material in its footwall from the system of "imbricate" (meaning stacked like shingles) thrust faults that deform and thicken the hangingwall material. The decollement also serves as the fault along which the entire fold and thrust belt is translated towards the undeformed material in front of the fold and thrust belt (the foreland). The general uniformity of fault dip and sense of translation (i.e. material is being translated towards the foreland) leads to the concept of vergence. Vergence is just the name for a structural geometry that suggests or implies a sense of tectonic transport. Dipping thrust faults are said to verge towards the foreland; overturned fold nappes also have vergence (here vergence is indicated by "the sense of overturn" or the asymmetry of the fold). Not all thrusts in a thrust belt have uniform vergence (i.e. dip): thrust faults that have a vergence opposite to the rest of the faults in the belt are called backthrusts.

A common structural association in thrust belts is duplex structure. At its simplest, a duplex consists of two or more dipping thrusts that are bound above and below by sub-horizontal faults. These are called the floor and roof thrusts. The actual mechanism by which duplexes can form varies, but generally involves (1) an initial ramp flat geometry; (2) breaking of a new ramp fault. If the new ramp fault breaks in front (i.e. towards the direction of transport), then the old ramp is now in the hangingwall of the thrust and is subject to being deformed into hangingwall fault bend anticlines and synclines. If the new fault breaks behind the initial ramp, the initial ramp is now in the footwall of the thrust and is not subsequently deformed.

4 Restoration of balanced cross-sections

Line and area-balancing of cross-sections are techniques that are particularly applicable to fold and thrust belts. Generally, a cross-section is said to be balanced when it is admissible (i.e. it contains no glaring geological impossibilities or inconsistencies) and retro-deformable (it is possible to undo the deformation, moving rocks back to their initial, pre-deformational configuration). Fold and thrust belts are particularly suitable for this because retro-deforming a cross-section assumes that there has been no movement of material in or out of the plane of section. Since fold and thrust belts are often characterized by consistent foreland translation of rock, it is possible to draw a cross-section parallel to this direction of tectonic transport. Moreover, thin-skinned fold and thrust belts are particularly suited to retrodeforming (or restoring) since deformation occurs in the upper kilometers of the crust. Therefore most of the deformation is accomplished by faults which are expected to brittle and sharp; folds are likely to be concentric or kink-band folds, with little ductile flow of material from limbs to hinges and so forth.

5 Critically tapered wedges

See discussion of critically tapered wedges in the solution to the lab on fold and thrust belts. Make sure you can reason out what the likely response of a critically tapered wedge to imposed changes in wedge angle by processes like erosion or sedimentation.

6 Mechanical paradox of overthrusts

See discussion of the mechanical paradox of overthrusts from the lab.

7 Review questions

1. How and why are thrust belts associated with crustal thickening and mountain-building?
2. Fig. 6.15 in TM shows a cross-section of a duplex structure from the Canadian Rockies. Is this section balanced? How does balancing a section provide a test of geological interpretation (which most any cross section surely is).
3. Consider two thrust belts that deform identical rocks (i.e. same mechanical properties, eg.), with identical tectonic boundary conditions (i.e. convergence rates of the foreland to the thrust belt are the same). One of these is located such that it receives strong monsoonal precipitation; the other is located in a continental interior in the rain-shadow of a large mountain range and so received very little rain. Speculate how the evolution of the two thrust belts might differ, esp. in terms of the width of the thrust belt, the sequence of thrusting, and other possible differences.