LECTURE 3 THE GEOMETRIES OF FAULTS (CONTINUED)

LECTURE PLAN

1) CONTRACTION FAULTS (THRUSTS AND REVERSE FAULTS).
2) STRIKE-SLIP FAULTS

Found in compressional tectonic regimes. Where they form at a high angle to unfolded stratigraphy $>30^\circ$, they are called reverse faults. Low angle examples ($<30^\circ$) are called thrusts.

Thrusts often exhibit a staircase trajectory (Ramp/Flat Geometry). Long bedding parallel glide zones are called Flats. Short steep angled fault which cuts across the stratigraphy are called Ramps. The following terminology should be noted:-

- hanging-wall ramp
- hanging-wall flat
- hanging-wall cut-off
- footwall ramp
- footwall flat
- footwall cut-off

Movement over a footwall with ramps and flats forces geometrically necessary folds to grow, known as fault-bend folds (snakes head structures in McClay’s book). The anticlines which form are rootless anticlines under these circumstances.

Folds which accommodate strain at the terminations of faults (fault tips) are known as fault propagation folds or tip-line folds.
Convergence is taken up by parallel sets of thrust faults dipping towards the Alps, located in the major valleys shown in the view. Also note the rivers systems emerging from the thrust belt.

Thrust belts contain parallel sets of thrust faults that act together to take up the convergence between the Earth's plates.

Time sequence of thrusting along the blue line. Thrust form in a sequence known as piggy-back thrusting where new faults form beneath older faults and carry them piggy-back.
The Moine Thrust Belt, formed during the Caledonian Orogeny (Silurian-Devonian), is the classic thrust belt. Pre-Cambrian rocks of the Moine Group are thrust over Cambrian Sediments. Some thrusts also imbricate the Lewisian Basement Gneisses (also Pre-Cambrian), thrusting these gneisses onto the Cambrian Sediments. These cross-sections are taken from the Assynt Sheet which we will study in Practical 10.
3D Geometry

1) Slipped region surrounded by a zone of deformation known as a ductile bead. Takes the form of a cleavage front, or an anticline-syncline pair.

Thrust fault terminations are known as a tip-line. The tip line often exists within a tip line fold (fault propagation fold).

2) Complex ramp geometries can exist in 3-dimensions. Frontal Ramps:- Perpendicular to the movement direction. Lateral Ramps:- Parallel to the movement direction. Oblique Ramps:- Oblique to the movement direction.

Thrust faults may be linked by strike-slip faults which root into the floor thrust.

Complex internal strains result as the hanging-wall moves over a ramp and is folded and then unfolded.

In higher grade terrains, thrusting may be accompanied by intense folding and the development of penetrative foliations. A stair-case trajectory may not develop.

3) Back-thrusts may develop producing triangle zones and pop-ups.
Basic Rules for thrust faults

1) Thrusts bring older rocks over younger rocks.

2) Thrusts cut up through the stratigraphy in their movement direction.

3) Generally propagate in the direction of movement.

4) Younger thrusts carry older thrusts in their hanging-wall. This is known as a piggy-back thrust geometry.

5) Higher thrust sheets are rotated and folded as lower thrust sheets move over ramps.

6) Ramp angles are generally 15-30° to bedding unless the rocks close to the thrust contain high strains and are intensely folded.

Movement direction of thrust faults

1) The Bow and Arrow rule. In plan view, thrusts are commonly curved. The movement direction is generally normal to the "string" formed by connecting the two ends of the bow.

2) Movement is normal to frontal ramps and the folds above frontal ramps.

3) Movement is parallel to lateral ramps.

4) Movement direction can be documented by measuring the orientation of lineations on fault planes or the orientation of mineral stretching lineations at higher grades.

5) In high-grade, ductile regimes, folds which initially form perpendicular to the movement direction may become rotated into parallelism.
5) STRIKE-SLIP FAULTS

These are generally vertical faults with horizontal movement directions and have either left-lateral or right-lateral offsets.

The orientation of the structures associated with strike-slip faults can be easily remembered by drawing a regional strain ellipse. Folds and contraction faults are $90^\circ$ to the maximum principle compressive stress, whereas extensional features are $90^\circ$ to least compressive stress.

Strike-slip faults grow through development of Riedel Shears orientated at about $30^\circ$ to the maximum principle compressive stress. The major through-going wrench fault is orientated at $45^\circ$ to the maximum principle compressive stress, and grows by the linking and coalescence of existing R1 shears and P Shears.

Strike-slip faults are also associated with en echelon folds whose axis are $90^\circ$ the maximum principle compressive stress.

Bends in the fault trace can be cause by P or R1 shears becoming dominant and controlling the majority of displacement. These are termed releasing bends and restraining bends.

The result is a complex zone containing uplifted and thrust bound areas, down-dropped pull-apart basins and a central principal displacement zone.
The North Anatolian Fault and Dead Sea Fault are large strike-slip faults. Opening of the Red Sea drives Arabia northeast. This northeast motion drives Anatolia to the west. The North Anatolian Fault has some clear pull-apart basins at releasing bends.
The Atyn Tagh Fault allows Tibet to escape to the east out of the way of the northward motion of India. The fault terminates to the east into a fold-thrust belt with anticlinal mountain ranges upthrust due to the left-lateral motion on the strike-slip fault. These mountain ranges are pressure ridges formed at restraining bends. The splaying style of fault pattern is known as a horse-tail structure.
STRUCTURE OF THE SAN ANDREAS FAULT SYSTEM, WESTERN U.S.A.
View onto the San Andreas Fault near Santa Monica from Stein (2003) Scientific American. Note the uplifted areas and basins around the fault.

THIRTEEN MILLION PEOPLE in and around Los Angeles live among a complex network of earthquake-prone faults [white lines], including the famous San Andreas. Some scientists now think that each of the major shocks that have rocked the region since the 1850s [ovals] probably influenced the timing and location of subsequent ones.
View onto the San Andreas Fault near Los Angeles from Stein (2003) Scientific American. Note the uplifted areas and basins around the fault.
Releasing bends are associated with pull-apart basins and restraining bends are associated with localised compressional deformation.

When the movement sense is oblique to the orientation of main fault areas of transtension and transpression occur.
The 2010 Haiti Earthquake (Mw 7.0)

The earthquake occurred on a transform fault.
Topographic expression of the Enriquillo Fault from Space Shuttle SRTM 100m DEM data. The trace of the fault is very clear in the topography.


Steven E. Schulz and James P. Evans, 2000, *Mesoscopic structure of the Punchbowl Fault, Southern California and the geologic and geophysical structure of active strike-slip faults*, *Journal of Structural Geology*, 22, 913-930


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Fernando NiñoHervé Philip and Jean Chéry, 1998. The role of bed-parallel slip in the formation of blind thrust faults, Journal of Structural Geology, 20, 503-516


Michel Corsini, Alain Vauchez, Renaud Caby, 1996. *Ductile duplexing at a bend of a continental-scale strike-slip shear zone: example from NE Brazil*, *Journal of Structural Geology*, 18, 385-394