2A: Normal Faults

On normal faults, the hanging wall has moved down relative to the foot wall. These faults are generally steeply dipping, with a dip angle of $60^\circ$ or greater. Low-angle normal faults have a dip of below $45^\circ$, accomplishing more extension per unit slip. How these faults are able to form and slip at such a low angle is a mechanical mystery.

Structures Formed by Normal Faults

A **horst** is an upthrown block between oppositely dipping normal faults. A **graben** is a downthrown block between oppositely dipping normal faults.

A **half-graben** is the tilted hanging wall basin of a normal fault.
Large faults are often associated with smaller, secondary faults. When these faults dip in the same direction as the main fault, they are **synthetic faults**, and when oppositely-dipping, they are called **antithetic faults**.

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**Extension, Reconstruction, and Balancing Problems**

The amount of **extension** is the length gained in a region. **Extension strain**, also known as **elongation strain**, is the change in length of a region divided by the original length:

\[ e = \frac{\Delta L}{L_0} \]

Reconstruction of an originally planar, horizontal marker is a straightforward way to measure extension and extension strain. Simple reconstructions like these, however, are not always possible geologically. Balancing a graben, for example, is challenging without producing gaps or overlaps.

In practice, faults bounding grabens may change angles or become damage zones instead of single simple planes, and rocks may undergo significant breakup to fill in spaces.
Listric Normal Faults

Listric normal faults have decreasing dip with depth. Slip causes tilting in the hanging wall, resulting in a rollover fold.

Listric fault surfaces often have irregular, strongly curved fault corrugations, also called mega-mullions, which indicate the slip (down-dip) direction. Similarly to grabens, listric normal faults balance poorly without other structures eliminating gaps at the fault plane or in the hanging wall:

If the magnitude of extension is small, imbricate listric faults can accommodate extension, forming an imbrication fan to prevent gaps.

If extension is great, the same problems with gap formation develop in the block with the rollover fold, regardless of the presence of an imbrication fan. Greater extension strain thus requires antithetic or synthetic domino faulting in the hanging wall, where slip on imbricate faults allows rotation and avoids gap formation.
Once a large amount of rotation has occurred by domino faulting, a new set of steeply dipping imbricate faults may form and slip will be continued along these.

**Detachment Faults**

Large offset on a listric normal fault may juxtapose mid-crustal rocks against basin sediments. When this occurs, the fault is called a **detachment** or **detachment fault**. The hanging wall of a detachment fault is known as the **upper plate**, and the foot wall as the **lower plate**.
As extension is accomplished, removal of the hanging wall load on the foot wall causes isostatic uplift of the foot wall. This may result in doming of the fault plane and exposure in a **basement window** of metamorphosed foot wall rocks, called a **metamorphic core complex**. Fault plane corrugations are often visible on the fault surface where exposed in a basement window.

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**Normal Fault Zone Features**

An **accommodation zone** is a region between faults that accomplishes deformation in a more distributed fashion. This term applies equally well to all fault types, but the geometry of these zones is often best expressed in areas of normal faulting, especially when a deformed marker, such as a lava flow, is preserved over a wide region. Common accommodation zone features include **relay ramps**, which form between two *en echelon* normal faults, and **transfer faults**, which are strike-slip faults linking two dip-slip faults.

![Hat Creek Fault](image)

This image shows the Hat Creek Fault cutting basalt flows of the Modoc Plateau in northeastern California. Multiple scales of relay faulting are visible here; some relay ramps have been cut by subsequent generations of faulting.

Normal faulting can create basins that fill in with sediment as the fault slips. This leads to a characteristic fanning geometry of sedimentary layering, with strata increasing in thickness toward the foot wall. The process which creates these **growth strata** is called **growth faulting**.

![Growth strata](image)
Deeper strata have greater offsets and more tilting, as they have been subject to motion on the fault plane for a longer period of time. Systematic changes in sedimentary rock type are also frequent in these basins. Transfer zones commonly create small topographic lows, which become significant channels for sediment input to the hanging wall basin.

In zones of rifting, the main rift-bounding faults may change orientation, or **rift polarity**. This is common in rift valley lakes in East Africa.

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**Summary**

**List of Terms**

1. Normal fault
2. Low-angle normal fault
3. Horst
4. Graben
5. Half-graben
6. Antithetic fault
7. Synthetic fault
8. Extension
9. Extension strain
10. Elongation strain
11. Listric fault
12. Rollover fold
13. Fault corrugation
14. Mega-mullion
15. Imbricate faults
16. Imbrication fan
17. Domino faulting
18. Detachment
19. Basement window
20. Metamorphic core complex
21. Accommodation zone
22. Relay ramp
23. Transfer fault
24. Growth strata
25. Growth faulting
26. Rift polarity

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