第四章地震與震源機制

姓名

地震學

June 9, 2026

章節大綱

地震的形成

- 地震源於斷層突然滑動
- 岩石因板塊運動累積應力
- 當應力超過岩石[F]度時發生破裂
- 儲存的彈性能量轉[F][F]地震波

$$\text{應力累積} \longrightarrow \text{斷層破裂} \longrightarrow \text{地震波傳播}$$

聖安德列斯斷層

彈性回彈理論

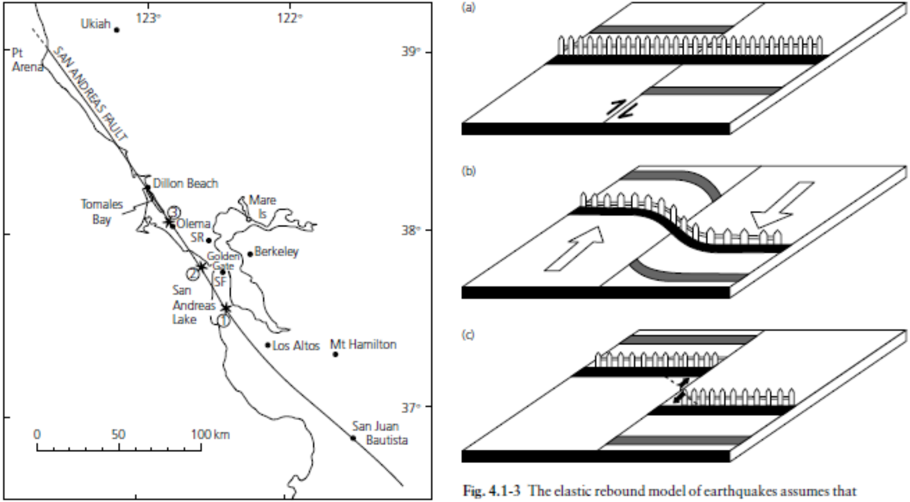


Fig. 4.1-3 The elastic rebound model of earthquakes assumes that between earthquakes, material on the two sides of a fault undergoes

震源與震央

震源（Focus）

地震實際發生的位置

震央（Epicenter）

震源正上方的地表位置

- 利用地震波到時與振幅資料可推求震源位置。

斷層幾何參數

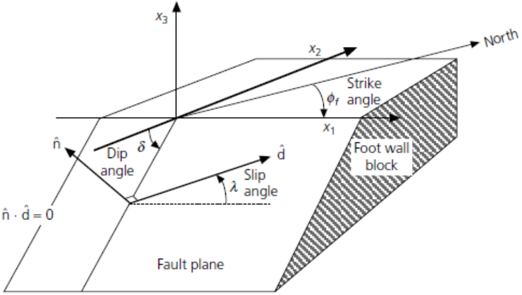


Fig. 4.2-2 Fault geometry used in earthquake studies. The fault plane, with normal vector n̂, separates the lower, or foot wall, block from the upper hanging wall block (not shown). The slip vector, d̂, describes the motion of the hanging wall block with respect to the foot wall block. The coordinate axes are chosen with x_3 vertical and x_1 oriented along the fault in the plane of the earth's surface, such that the fault dip angle, δ, measured from the $-x_2$ axis, is less than 90°. The slip angle λ is measured between the x_1 axis and d̂ in the fault plane. ϕ_f is the strike of the fault measured clockwise from north. (After Kanamori and Cipar, 1974. *Phys. Earth Planet. Inter.*, 9, 128–36, with permission from Elsevier Science.)

- **Strike（走向角）:** ϕ
- **Dip（傾角）:** δ
- **Slip（滑移角）:** λ

震源機制（Focal Mechanism）

利用觀測資料：

- P 波初動方向
- 地震波振幅
- 多測站觀測資料

反推出震源參數：

- 斷層面方向
- 滑移方向
- 應力狀態

Fault Plane 與 Auxiliary Plane

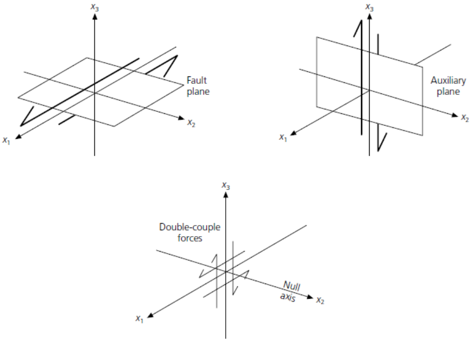


Fig. 4.2-5 A fault-oriented coordinate system for describing the radiation pattern of an earthquake. The body forces equivalent to the faulting are a pair of force couples acting about the null axis. (After Pearce, 1977.)

- Fault Plane：真正斷層面
- Auxiliary Plane：輔助面
- Double-Couple Force 描述震源

P 波與 S 波輻射模式

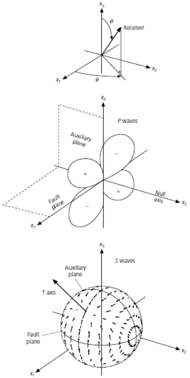


Fig. 4.2-6 The body wave radiation pattern for a double couple source has symmetry in the spherical coordinate system shown, corresponding to the axes in Fig. 4.2-5. θ is measured from the x_3 axis, the normal to the fault (x_1–x_2) plane, and ϕ is measured in the fault plane. The *P*-wave radiation pattern has four lobes that go to zero at the nodal planes, which are the fault and auxiliary (x_2–x_3) planes. The *S*-wave radiation pattern describes a vector displacement that does not have nodal planes but is perpendicular to the *P*-wave nodal planes. *S*-wave motion converges toward the T axis, diverges from the P axis, and is zero on the null axis. (After Pearce, 1977, 1980.)

輻射振幅分布

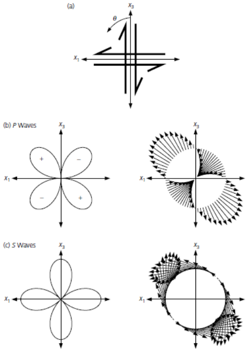
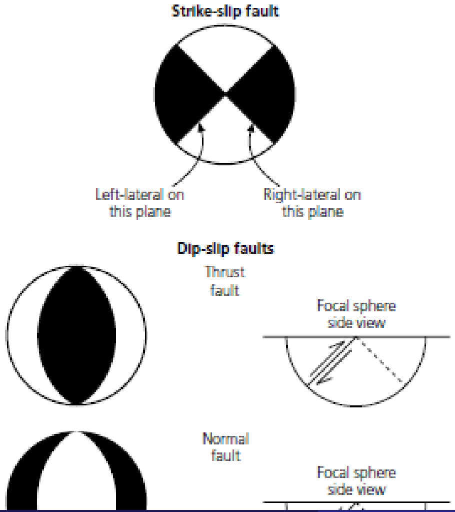


Fig. 4.2-7 Radiation amplitude patterns of *P* and *S* waves in the x_1–x_3 plane. a: Fault geometry, showing the symmetry of the double couple about the x_2 axis. b: Radiation pattern for *P* waves, showing the amplitude (*left*) and direction (*right*). c: Same as (b), but for *S* waves.

Beach Ball Diagram



- **黑色區域**： Compression（擠壓）
- **白色區域**： Dilatation（擴張）
- 反映斷層運動型態與應力分F

不同滑移角的 Beach Ball

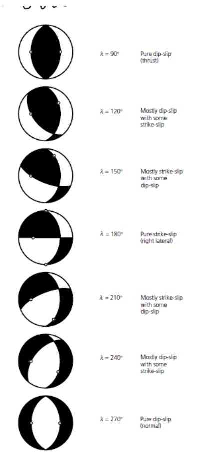
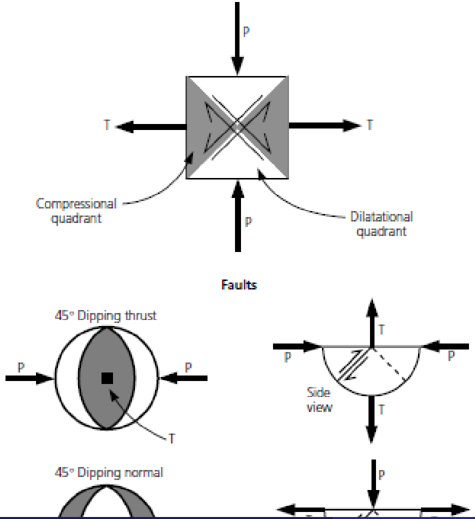


Fig. 4.2-15 Focal mechanisms for earthquakes with the same N–S-striking fault plane, but with slip angles varying from pure thrust, to pure strike-slip, to pure normal faulting.

P 軸與 T 軸



軸向	意義
P-axis	最大壓縮方向

實際震源機制案例

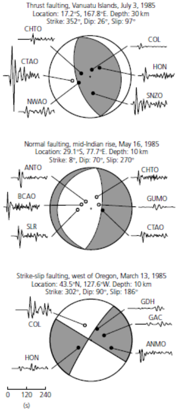


Fig. 4.2-17 Focal mechanisms and some seismograms for three different earthquakes. Compressional quadrants are shown shaded.

逆衝斷層 (Thrust) | 正斷層 (Normal) | 平移斷層 (Strike-slip)

波形模擬（Waveform Modeling）

觀測訊號卷積公式：

$$u(t) = x(t) * e(t) * q(t) * i(t)$$

- $x(t)$： 震源函數 (Source)
- $e(t)$： 地球介質效應 (Propagation Path)
- $q(t)$： 衰□效應 (Attenuation)
- $i(t)$： 儀器響應 (Instrument Response)

傅立葉頻譜分析

將時間域訊號轉F至頻率域：

$$U(\omega) = X(\omega) \cdot E(\omega) \cdot Q(\omega) \cdot I(\omega)$$

主要學術用途：

- 正向波形模擬 (Forward Modeling)
- 震源參數反演 (Source Inversion)
- 介質 Q 值與頻譜分析

第四章重點整理

1. 地震源於斷層破裂與彈性回彈
2. Strike、Dip、Slip 描述斷層幾何
3. P 波初動可反推震源機制
4. Beach Ball 描述斷層型態
5. P 軸與 T 軸反映應力狀態
6. 波形模擬可提升震源解精度

Thank You