CONTINENTAL STRUCTURES, MOUNTAINS, AND BASINS

Sources:
www.google.com
en.wikipedia.org
Thompson Higher Education 2007; Monroe, Wicander, and Hazlett, Physical Geology
CONTINENTAL STRUCTURES, MOUNTAINS, AND BASINS

• Crustal Stress, Strain, and Elasticity
• Geological Planes and Lines
• Primary, Secondary, and Compound structures
• Bedding, Layering, and Foliation
• Folded Rock Layers
• Cleavage, Fractures, and Faults
• Deformation and the Origin of Mountains
• The Formation and Evolution of Continents
CRUSTAL STRESS, STRAIN, AND ELASTICITY

- Applied stresses can deform or strain rocks until they become contorted or fracture.

- Stresses are categorized as compressional, tensional or shear.

- Elastic strain is not permanent and thus, the rock returns to its original shape after the stress is removed.

- Plastic strain and fracture are permanent types of deformation.
TECTONIC STRESSES produce associated reverse, slip, and strike-slip crustal strains that result in **geological structures**; the flexures, fabrics, and **discontinuities in rock** that stem from tectonic processes.
Elastic and Plastic Strains

- Rocks initially respond to stress by elastic deformation and then return to their original shape when the stress is released.
- If the elastic limit is exceeded (curve A) rock deform plastically which is permanent strain (deformation).
- The amount of plastic deformations a rock exhibits before fracturing depends on its ductility.
- If a rock is brittle, they show no plastic deformation before fracturing (curve B).
WITH RESPECT TO AN AZIMUTHAL REFERENCE SYSTEM

**Azimuth**

```
| 0  |
| N  |
| W  |
| E  |
| S  |
```

**Trend**

```
220°
```

**Line 220/30**

```
30°
```

**LINES trend and plunge**

**PLANES strike and dip**

Fig. 2.4
Lines geometrically contained within a dipping plane.
STRIKE, DIP, and DIP AZIMUTH OF GEOLOGICAL PLANES

Sedimentary beds and crystalline foliation or layering that are inclined with respect to Earth's surface are said to **dip**.

**Geological planes are measured and recorded using one of two methods of notation:**

1) **Dip and dip Azimuth**, or

2) **Strike and dip**

The first is easiest and most succinct as all that is needed are two numbers; the dip angle followed by the dip azimuth:

**Dip angle** (0° to 90°) is the angle that the plane makes with a horizontal reference plane (see diagram to the right). The **dip is 0° for a horizontal plane and 90° for a vertical plane**.

**Dip azimuth** (0° to 359°) is the compass direction towards which the plane is tilted.

For example, 74/138 is a plane which dips 74° toward azimuth (or in the compass direction of) 138°.
LINEAR PLUNGE AND TREND

- **Plunge** describes the tilt of lines (*dip* is reserved for planes).

- The plunge is used to express the 3D orientation of a line using the plunge angle, and the plunge azimuth or **trend**.

- Consider the plunging line on the dipping plane to the right and an imaginary vertical plane (pink) containing the plunging line.

- The **trend** is the azimuth along which this vertical plane runs on the dipping plane and the direction towards which the line is tilted.

- The **plunge** is the amount the line is tilted with *horizontal = 0° and vertical = 90°*. 
• Any dipping plane contains an infinite number of lines of varying **plunge** (Fig. 2.4).

• The **strike** line in a dipping plane is a **non-plunging, horizontal line** (line 5; it is not the only one but other strike lines are all parallel to it.)

• Think of the sloping roof of a house as a dipping plane, the line along the roof ridge is a strike line.

• Similarly, the water line from surface water bodies makes strike lines on bounding strata.

• **Geologist use the map symbol:** \[ \text{Dip value} \] to note **the strike and dip of planes** as shown below on the right.
THREE CLASSES OF GEOLOGICAL STRUCTURES

• **Primary** are those which develop at the time of formation of the rocks (for example *sedimentary beds*).

• **Secondary** structures are those that develop in rocks after their formation as a result of their subjection to external forces (for example brittle fractures).

• **Compound** structures form by a combination of events some of which are contemporaneous with the formation of a group of rocks taking part in these "structures“ (for example an unconformity).
PRIMARY GEOLOGICAL STRUCTURES

• Sedimentary bedding and features (like fossils)

• Crystalline (igneous and metamorphic) compositional layering

• Mineral foliation in crystalline rocks
SECONDARY GEOLOGICAL STRUCTURES

- Folds,
- Cleavage,
- Fractures, and
- Faults
MONOCLINES

Rock flexure from otherwise uniform, horizontal strata
FOLDS; ANTICLINES AND SYNCLINES

are fold structures in rock layers in which the oldest rocks occur, respectively, in the center, or on the flanks of the fold.

• They can be identified by their strikes and dips.
FOLD TYPES

Recumbent folds with horizontal axial planes

Overturned folds with inclined axial planes

Overturned folds in Switzerland

Upright, open, inclined fold with steeply dipping axial plane

Overturned folds with inclined axial planes
PLUNGING FOLDS

Sheep Mt. Anticline, Wyoming
Secondary Geological Structures - Folds

Soft-sediment folding developed in the Dead Sea (Photo © Ian Alsop).

Second Valley, South Australia

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Texture Development in Metamorphic Rocks

Sedimentary Textures

Granular Textures

Foliated Textures

- Folding
- Clay minerals follow bedding
- Compression

- Granite sandstone
- Great enlargement
- Limestone

- Slatey Cleavage
- Clay minerals convert to chlorite

- Schistosity
- New chlorite minerals line up perpendicular to directed stress
- Chlorite goes to mica, qtz, feldspar

- Banding
- Mica, qtz, feldspar completely intermixed
- Dark mafic (biotite/amphibole) segregate into bands separate from light colored qtz/feldspar
Fluid loss, dissolution seams, and *stylolites*

a) Fluids can escape along dissolution seams, when certain rocks dissolve at high $T$ & $P$s.
ROCK CLEAVAGE in structural geology describes a type of planar rock feature that develops as a result of deformation and metamorphism.

- **Slaty cleavage** results from low-grade metamorphic recrystallization of mud and silt into platy minerals like chlorite at the microscopic scale.

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**Fig. 7.1 A:** Slaty cleavage. Electron microscope image (scale bar is 20 µm long) of a Cambrian roofing slate to show the alignment of flaky minerals (mainly chlorite). This is typical of the microscopic structure of slaty cleavage. (Photograph: Prof. W. Davies.)

**Fig. 7.1 B:** Slaty cleavage in the field. Bedding dips gently to the left; cleavage more steeply to the left of the photograph.
SLATY CLEAVAGE

AN EXAMPLE OF THE DEVELOPMENT OF CLEAVAGES

JOHN G. BROUGHTON

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A

Flow Cleavage Plane Stretching in "a"
Gross Joint
Strike Joint
Bedding Plane Slikensiding in "a"
Diagonal Joint
SLATY CLEAVAGE

Origin of Slaty and Fracture Cleavage in the Delaware Water Gap Area, New Jersey and Pennsylvania

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SLATY CLEAVAGE
SPACED CLEAVAGE
SPACED CLEAVAGE within coarser-grained clastics and carbonates results from fluid loss, mineral dissolution and recrystallization along cleavage planes.
**CRENULATION CLEAVAGE** is used to describe second or multiple, overlapping cleavage sets.

![Diagram of crenulation cleavage](image1)

- Slaty cleavage (1)
- Crenulation cleavage (2)

*Fig. 6. Folding of calcareous silt bed in Martinsburg slate, 1 1/2 miles northwest of Brunswick on US 3, 40*

*Fig. 7. Shearing and transport parallel to slaty cleavage, offsetting calcareous siltstone bed. Same location as Fig. 6. Solid black area is quartz-carbonate vein.*

*Fig. 7.2 Crenulation cleavage. A. The microscopic appearance of crenulation cleavage (set of planes sloping at 80° towards the left of the photograph). This crenulation cleavage is parallel to the axial planes of small folds which fold an earlier (inner) foliation and bedding (appears vertical, labelled S1). Taydeckie Slates, Cluny, Scotland. (Photograph Dr. D. Bornefalk.) B. Crenulation cleavage (running diagonally across the photograph, top right to bottom left, Precambrian schists, Anglesey.*
BRITTLE ROCK FRACTURES

• Joints are fractures along which any movement which may have occurred is perpendicular to the fracture surface.

• Joints, the commonest structures, form in response to compression, tension, and shearing.

• Faults are fractures along which the opposite sides have moved relative to one another and parallel to the fracture surface.
BRITTLE ROCK FRACTURES

extensional regime

\( \sigma_{\text{MAX}} \)

cross fracture

normal fault
extension fractures

compressional regime

\( \sigma_{\text{MIN}} \)

extension fractures

\( \sigma_{\text{MAX}} \)

BRITTLE ROCK FRACTURES
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BRITTLE ROCK FRACTURES


45X

Crossed Nichols

Plane polarized

100X

Mechanically twinned calcite grains

Ablite grains grew first along fracture walls

Bitumen (hydrocarbon) dendrites

Pyrite crystals
BRITTLE ROCK FRACTURES


a

Sedimentary bedding

Conjugate vein arrays

b

Maximum principal stress

Vein array

Least principal stress

(tensile)

Array boundary

Area of detail

Vein

70–85°
BRITTLE ROCK FRACTURES

The dip of brittle fractures determines the direction of rock slump

**PROFILE VIEW**

fracture dip ($\Delta$) = 70°,
$\alpha$ = 20°

MODE I fracture dipping at angle $\Delta$=70°
length (L) P1:P3 = 1 unit
$\delta$ = displacement = maximum fracture aperture = 0.1 unit
$\psi$ = displacement along the x-axis = c($\cos(\alpha)$) $\approx$ 0.09 units
$\varepsilon$ = displacement along the z-axis = d($\sin(\alpha)$) $\approx$ 0.03 units
$\beta_x$ = extension along the x-axis = ($\text{t}_x - \text{t}_h$)$\times$ $\approx$ 9%
$\beta_z$ = extension along the z-axis = ($\text{t}_z - \text{t}_y$)$\times$ $\approx$ 3%
$\omega = \text{dip} = \sim 1.5^\circ$

dip ($\omega$) of strata as a result of MODE 1 fracturing is $\sim 1.5^\circ$ in the direction opposite fracture dip
NEOTECTONICS AND FRACTURE DIP

New Jersey – New York USA historical seismicity (Sykes, 2006), vertical crustal motion (mm/yr) based on continuously-operated receiving stations in 2010 (CORS), and predicted neotectonic fracture strike and dip directions.
FAULT TERMINOLOGY REVIEW
FAULT TERMINOLOGY REVIEW

- Fault plane
- Striae
- Strike direction of fault
- Dip angle of fault
- Fault offset (displacement)
FAULT TYPES

I can’t seem to keep a fence up in this country. I think I’ll get into road-building instead...

(Overhang collapses into rubble)

(wide zone of rubble and broken ground)
TYPES OF FAULT SLIP

- All movement is in the direction of dip along dip-slip faults.

- **Dip-slip faults** are categorized as normal or reverse.

- **Normal faults** form in response to tensional forces, and reverse faults form in response to compressional forces.

- Faults in which all movement is in the direction of the strike of the fault plane are known as strike-slip faults.

- **Strike-slip faults** are classified as right-lateral or left-lateral depending on the apparent direction of relative offset between blocks.

- **Oblique-slip faults** have both strike-slip and dip-slip components of movement.
FAULT TYPES

Section of the San Andreas Fault in the Carrizo Plain, western California; U.S. Geological Survey

Strike-slip fault system at Bramber Nova Scotia

www.britannica.com/blogs/2011/02/how-fault-lines-form/

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TECTONICS and OROGENY

• **TECTONICS** (from the Latin *tectonicus*, meaning "building") is concerned with the orogenies and tectonic development of cratons and tectonic terranes as well as the earthquake and volcanic belts which directly affect much of the global population.

• **OROGENY** (from the Greek *oros* for "mountain" plus *genesis* for "creation" or "origin") refers to forces and events leading to a large structural deformation of the Earth's lithosphere (crust and uppermost mantle) due to the engagement of tectonic plates.

• Response to such engagement results in the formation of long tracts of highly deformed rock called orogens or orogenic belts.

• *Orogens* develop while a continental plate is crumpled and is pushed upwards to form mountain ranges, and involve a great range of geological processes collectively called *orogenesis*.  

![Diagram of the Earth's crust and mantle showing tectonic plate interactions.](image)
GEOLOGIC PROVINCES

- A **craton** is the stable core of a continent.

- A **shield** is a broad exposed area of a continent's craton, and all continents have at least one shield.
CONTINENTAL MOUNTAINS AND BASINS

• MOUNTAIN is a designation for any area of land that stands significantly higher, at least 300 m (1000 ft) than the surrounding country.

• Mountain building can involve faulting and folding, but can arise without these types of deformation.

• CONTINENTAL BASIN is a designation for an area of land that currently or historically had surface elevation that is lower in relation to the surrounding country with a thick pile of strata deposited within the crustal depression.

• Impact basins are not currently recognized on Earth
PLATE TECTONICS AND MOUNTAIN BUILDING

- Mountain systems, which consist of several mountain ranges, are the result of plate movements and interactions along plate boundaries.
Convergent boundaries exist where one plate is *subducted* beneath another and crust is destroyed, and/or two plates with continental crust on their leading edges collide, and mountains are formed.

**Type 1  ocean – ocean**

**Type 2  ocean – continent**

**Type 3  continent – continent**
Orogenesis along oceanic-oceanic plate boundaries includes deformation, igneous activity, island arc formation, and metamorphism.
MOUNTAIN BUILDING AT CONVERGENT OCEAN AND CONTINENTAL PLATES

• Subduction of oceanic lithosphere along an oceanic-continental plate boundary also results in orogeny.

• Accretion of terranes along convergent oceanic-continental plate boundaries is also recognized as causing mountain building.

• Terrane is a geographic term referring to a particular area of land and differs from terrain.
MOUNTAIN BUILDING AT CONVERGENT PLATES
Examples of alpine folding and faulting in continental mountain belts
THE WILSON CYCLE
results in a continental margin going through periodic passive and active tectonic phases

• Prior to 200 million years ago, the west coast of South America was a passive margin.

• The Andes Mountains formed as a result of ocean-continental plate convergence and subduction.
BLOCK FAULTING is another way for mountains to form

Basin and Range – SOUTHWEST USA

Paleobotanical evidence suggests that the Basin and Range Province of Nevada was not uplifted within the last 5 million years as has previously been thought.

Researchers at the University of Arizona have found that plants in western Nevada grew approximately 3 km above sea level some 15 million years ago.

This would indicate that the Province collapsed from a higher elevation, rather than being uplifted. EOS, July 15, 1997.
DOMES AND BASINS are circular to oval structures which have rock layers occurring in age-position contexts which are the same as anticlines and synclines, respectively.

- Continental basins are commonly referred to as transentional or transpressonal pull-apart basins that result from extentional or transcurrent tectonics where the continental plate is stretched, sheared and the crust breaks up.
SOME GREAT BASINS OF THE WORLD

Congo Basin, Africa

Amazon Basin, Brazil

Caloris Basin, Mercury

Anabar shield

Yakutsk basin

360 KM

1300 KM

365 KM

380 KM
CONTINENTAL DIVERGENT BOUNDARIES AND RIFT BASINS


Icelandic rifts

East-African rift

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CONTINENTAL DIVERGENT BOUNDARIES AND RIFT BASINS

Eastern North American continental rift system and the Newark basin
CONTINENT-CONTINENT CONVERGENCE

• Mountain systems such as the Himalayas occur within continents, distant from present plate boundaries as the result of continent-continent collisions and suturing.
India-Asia Collision

- Many models have been put forward to explain how the ongoing collision between India and Asia has produced the world’s highest mountains, the Himalayas, and the most expansive plateau, the Tibetan Plateau.

- One proposed model suggests that the Asian lithospheric mantle developed through subduction beneath Asia after the first collision first occurred.

- If so, this would mean that the lithospheric mantle is not deformed along with the crust and that continental collisions happen similarly to the way that oceanic crust is subducted in ocean trenches. EOS, June 28, 1994.
Himalayan Mountains of Tibet
CRATONS, SHIELDS, AND OROGENESIS

- The **craton** is the stable core of a continent.

- A **shield** is a broad exposed area of a continent's craton.

- All continents have at least one shield.

- Cratons form by the accretion of eroded continental material, island arcs, and igneous rocks on continental margins produced during orogenesis.
- Cratons originated by the accretion of eroded continental material, island arcs, and igneous rocks on continental margins produced during orogenesis.
d) Subduction renews and continental crust increases in volume.

e) Proto-continents collide rapidly building larger land mass.

- Felsic and related metamorphic rocks
- Relic and metamorphosed island arc rocks

f) A full-scale craton develops in time.
NORTH AMERICAN CRATON

The craton of North America evolved during the Precambrian by collisions of smaller cratons along belts of deformation known as orogens, and by accretion along the southern and eastern margins of the continent.
NORTH AMERICAN CRATON

- Since that time, continental accretion has resulted from orogenies along the margins of the craton.

- Currently, the Gulf Coast and East Coast are passive margins.
NORTH AMERICAN CRATON

- The west coast is an entirely different tectonic setting from the East or Gulf coasts
NORTH AMERICAN CRATON
NORTH AMERICAN CRATON