8.2.3 GEOLOGICAL STRUCTURE[1]

Geological structure is the study of the permanent deformation of and rock failure created by the changes in stress within the Earth's crust. These changes are largely due to the tectonic processes discussed in previous sections—tectonic plate movement and subduction, volcanic activity, and intrusive igneous activity.

Besides the scientific interest, knowledge of geological structures provides insight into the location of valuable resources such as aquifers, coal seams, petroleum traps and ore deposits.

8.2.3.1 Crustal Deformation

Enormous **stress** is placed on the Earth's crust, particularly at the boundaries of the lithospheric plates and where convection currents in the mantle tug and tear at the crust above. Stress is a force and when a stress is imposed on rock material it will deform—change in volume or shape. These changes, the response of a rock to stress, are known as **strain**.

There are three types of **stress** that commonly occur within the crust:

Compressional—forces that squeeze rocks together. Rocks tend to shorten laterally and thicken vertically when exposed to compressional stress;

Tensional—forces that stretch and tend to pull a body apart. Tension extends the crust causing it to thin and lengthen. Rifting, like that which created the Great Rift Valley of Africa, is a result of tension.; and

Shear—forces that push two sides of an object in opposite directions. Shearing stress cuts the crust into parallel blocks displacing them horizontally relative to one another. Shearing takes place along the San Andreas Fault where the Pacific Plate is moving past the North American Plate.

In response, there are two type of **strain** that result:

Elastic Deformation—changes in shape of rock that are reversible. Deform it, remove the stress, and it returns to its original shape (like a rubber band or a piece of elastic);

Plastic Deformation—changes in shape of rock that are permanent and not reversible (like folding–see below).

The reaction of rock material to an imposed stress depends on the prevailing temperature and pressure conditions. As stress is imposed on rock it starts to deform up to its **yield point**. Before it gets to the yield point, the rock will undergo elastic deformation. Like a rubber band, if the stress is released before reaching the yield point, the rock material will return to its original shape. Beyond the yield point (also known as the **elastic limit**) however, behaviour will be either:

Ductile—Under high pressure and temperature conditions (rocks at depth in the Earth's crust), the rock may become ductile and undergo plastic deformation upon reaching the yield point. In this case, once the rock changes shape, even if

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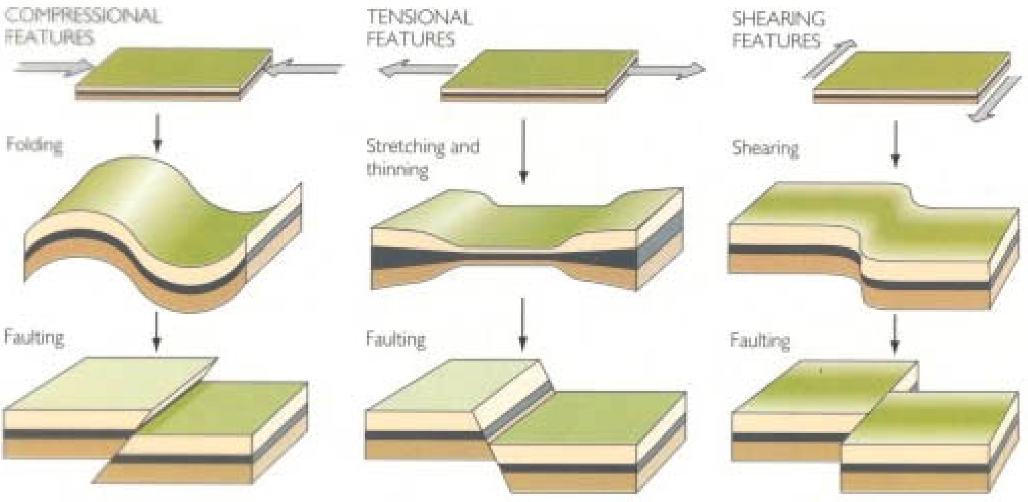
[1] http://courses.missouristate.edu/EMantei/creative/glg110/GeoStruct.html
http://epswww.unm.edu/facstaff/brearley/eps101/eps101fold.htm
http://gpc.edu/~pgore/geology/geo101/crustaldeform.php
http://homepage.usask.ca/~mjr347//prog/geoe118/geoe118.044.html
http://www.physicalgeography.net/fundamentals/10l.html
http://www.uwgb.edu/DutchS/EarthSC202Notes/folds.htm
http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/tectonics_landforms/deformation.html

the stress is released, the rock will not return to its original form. The higher the temperature of the rock the more plastic it becomes. Pressure, however, must not exceed the internal strength of the rock and deformation must be applied slowly or the rock will fracture (exhibit brittle behaviour) regardless. Folding is an example of ductile behaviour; or

Brittle—Under low temperature and pressure conditions (rocks close to surface of the Earth), once the rock reaches its yield point it will break—called brittle failure. Brittle failure may also occur if a stress is imposed suddenly. The formation of faults is an example of brittle behaviour.

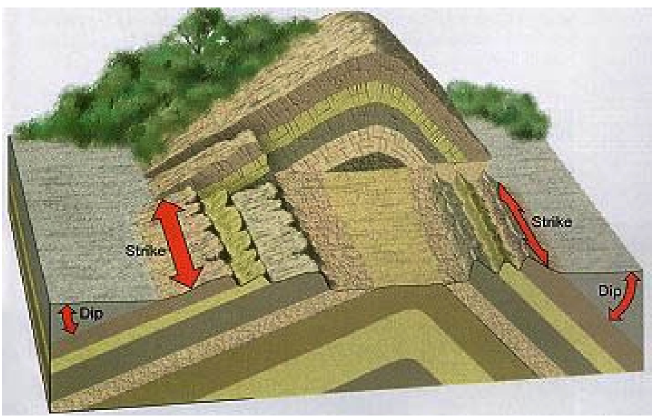


Ductile and brittle response to different stresses[2]

8.2.3.1.1 Describing the Orientation of Layers of Rock

When we describe the orientation of sedimentary rock units, we must keep in mind that these rocks were originally deposited as sediment in horizontal (flat) layers. Tectonic forces cause the rock layers to be tilted, folded and/or uplifted, and we can ultimately find sedimentary rocks in any orientation, including vertical.

If we examine a small area of a layer of rock, we can describe its orientation in space using two directional components:

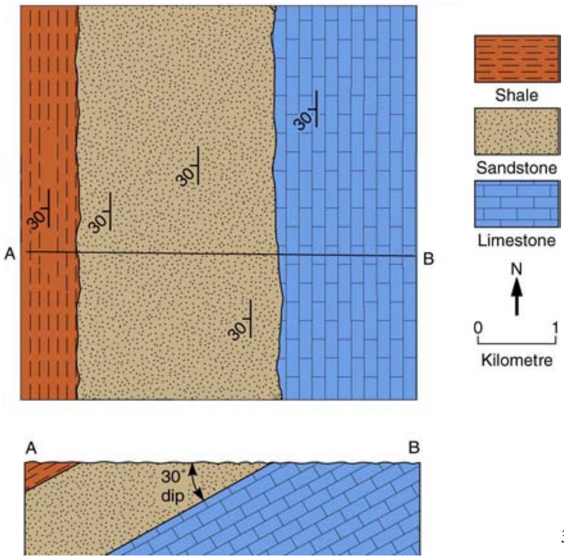


Strike—an imaginary line with compass direction constructed on the surface of a sedimentary bed or fault in which all points on that line are of equal elevation (the compass direction is usually expressed as a bearing); and

Dip—the angle between the horizontal and an imaginary line constructed down-slope on a sedimentary bed or fault. The dip direction is perpendicular to the strike direction (usually expressed as a bearing) and the angle of dip is measured from the horizontal plane to the top of a bed or fault (a dip angle may not exceed 90°).

[2] http://www.arc.losrios.edu/~borougt/GeologicStructuresDiagrams.htm

Dip and strike are recorded on maps using special symbols that resemble a "T" with an elongated top bar. The top bar of the "T" is oriented on the map in the precise orientation of the strike of the rock unit. The short vertical bar of the "T" points in the direction of dip. There is almost always a number accompanying these strike and dip symbols, and that number refers to the angle of dip.



[3]

8.2.3.2 Folded Structures

Folding is the bending of rocks in the Earth, usually at depth and as a result of compressional tectonic forces such as plate collisions. Because they are often formed in neat layers, the effects of folding are most easily recognised in sedimentary rock strata.

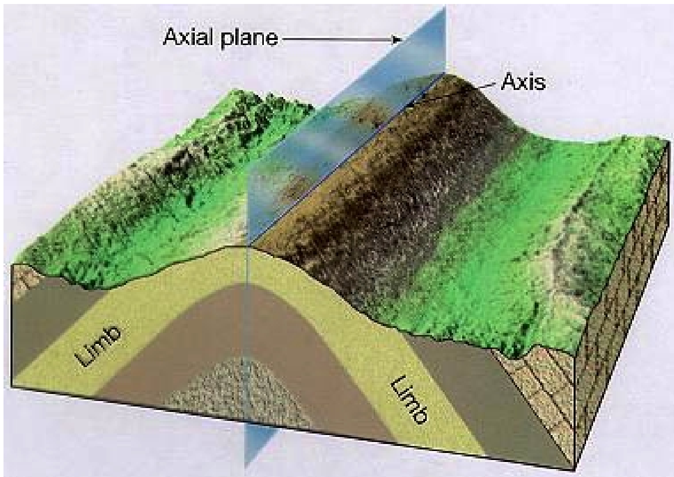
8.2.3.2.1 Elements of Folded Structures

There are three basic terms used in defining folded structures:

The **Limbs** are the two sides of any individual fold;

The **Axial Plane** is an imaginary surface that divides a fold as symmetrically as possible, with one limb on either side of the plane; and

The **Fold Axis** is the line made by the lengthwise intersection of the axial plane with the beds of the fold.



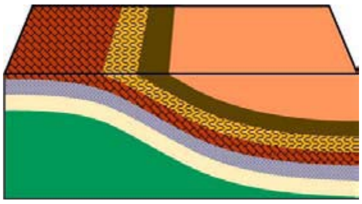
8.2.3.2.2 Types of Folds

When rock strata undergo plastic deformation, the result is usually a series of folds, much like the way a carpet might wrinkle when pushed on one end. The up-folds and the down-folds are adjacent to, and grade into one another.

Different types of folds have different names—**monoclines**, **anticlines** and **synclines**—and may be overturned or recumbent.

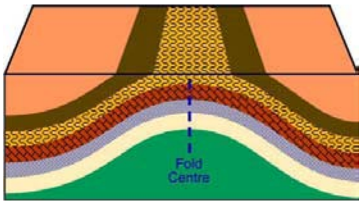
[3] http://www.indiana.edu/~g103/G103/week9/wk9.html

A **monocline** is the simplest type of fold. It involves a slight bend in otherwise parallel layers of rock. There is only one direction of dip in a monocline.



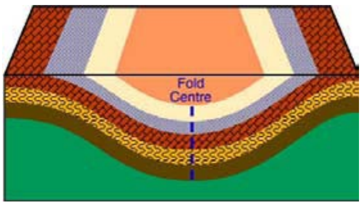
A monocline at Colorado National Monument, Fruita, CO, USA[4]

An **anticline** is an upwards, arch-like fold, with the limbs dipping way from the centre of the structure. An eroded surface reveals rocks becoming progressively younger away from the fold axis.



An anticline on NJ Route 23, USA[5]

A **syncline** is a fold where the rock layers are warped downward. An eroded surface reveals rocks becoming progressively older away from the fold axis.



Tremont Syncline, Schuylkill County, PA, USA[6]

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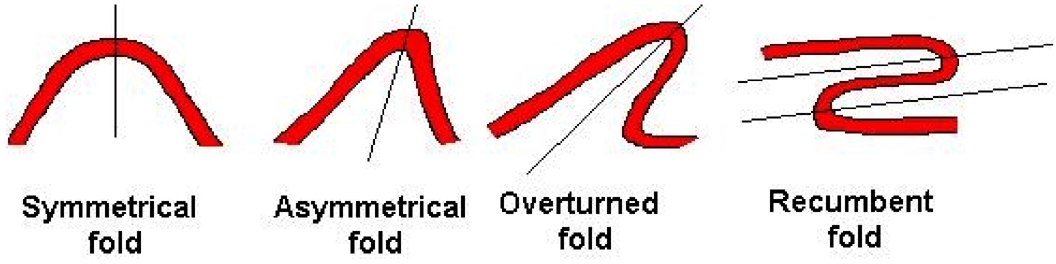
4 http://upload.wikimedia.org/wikipedia/en/e/e3/Monocline.JPG
5 http://3dparks.wr.usgs.gov/nyc/images/fig40.jpg
6 http://www.dcnr.state.pa.us/topogeo/classroom/images/syncline.jpg

8.2.3.2.3 Fold Shapes

More complex fold types can develop in situations where lateral pressures become greater. The greater pressure results in anticlines and synclines that are inclined and asymmetrical.

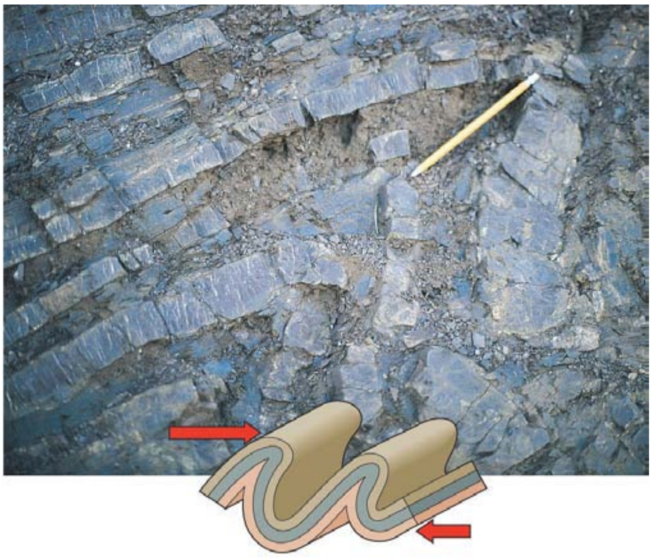


Variations in fold symmetry

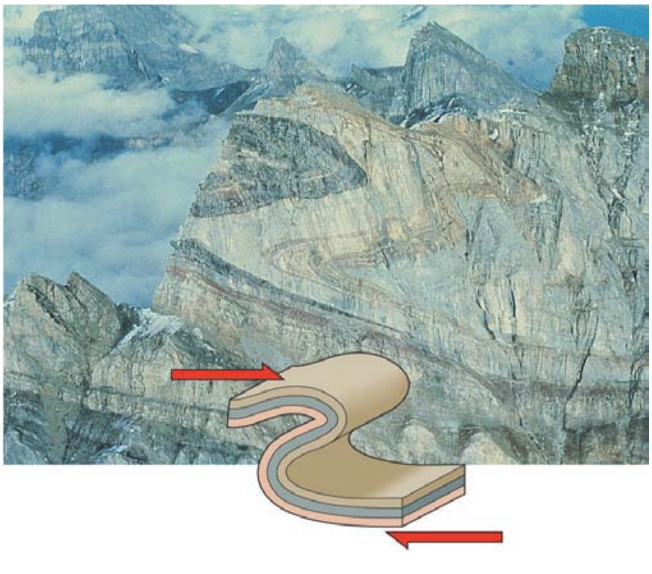
A **symmetrical fold** is a fold with the limbs showing a more or less mirror image relationship with respect to the axial plane.

An **asymmetrical fold** is a fold that has one limb dipping more steeply than the other.

An **overturned fold** is a fold in which the axial plane is tilted to such an extent that the limbs on either side dip in same direction (*i.e.* one of the limbs is overturned—tilted beyond the vertical).



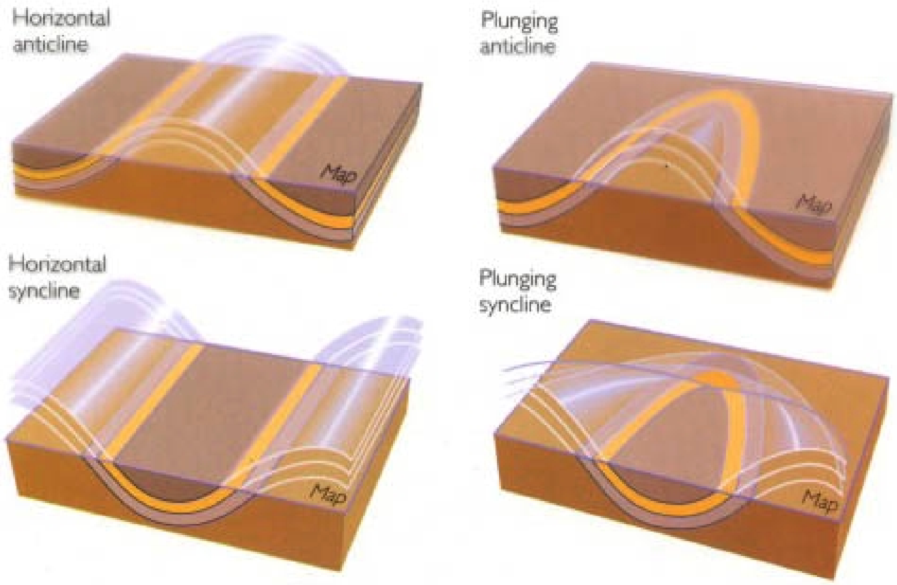
A **recumbent fold** is a fold that is so extreme that the axial plane is lying on its side, or is essentially horizontal.[7]



[7] http://www.indiana.edu/~g103/G103/week9/wk9.html

8.2.3.2.4 Fold Axis Orientation

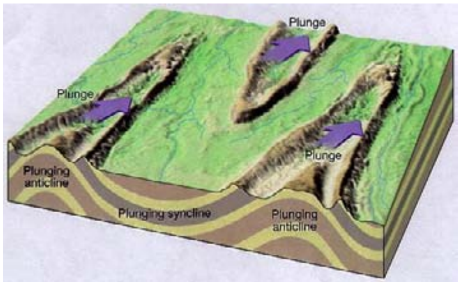
In all the illustrations provided so far, the fold axis has been horizontal for the purpose of simplicity. In practice, however, folds are rarely so neat—the fold axis usually tilts one way or the other. A fold whose fold axis is not horizontal, but dips away at some angle, is called a **plunging fold**. Most anticlines and synclines have some degree of plunge.



Plunging Folds

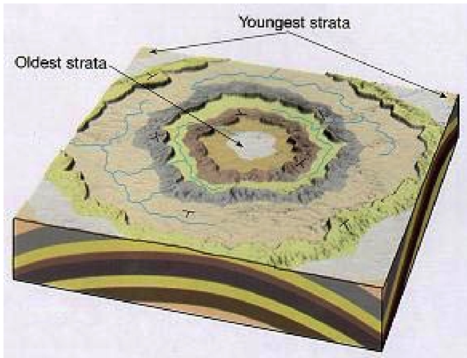
In non-plunging folds, contact lines separating formations shown in the surface view are parallel and straight—the contact lines in one of the two profile views are horizontal and parallel, while those in the other profile view are arched up or down (*cf.* left side illustrations above). In plunging folds contact lines in the surface view are curved—contact lines in one of the profile views dip in the direction of plunge, while those in the other profile view are arched up or down (*cf.* right side illustrations above).

The surface contact lines between formations are convex (closed) in the direction of plunge for the anticline and concave (open) in the direction of plunge for the syncline. Topographically, what appears is often something like that illustrated.

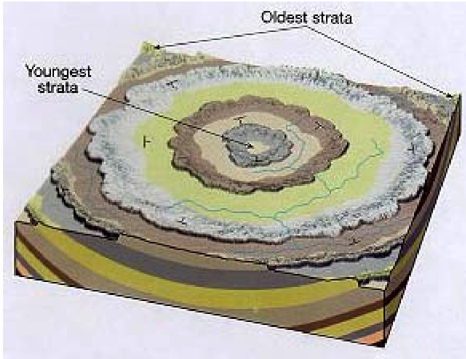


There are two other variations on folded structures—domes and basins.

A **dome** is an up-arched series of strata with beds on all sides dipping away from the centre throughout 360°. An eroded surface reveals that the rocks become progressively younger away from the centre of the structure.



A **basin** is a down-arched series of strata with beds on all sides dipping in towards the centre throughout 360°. An eroded surface reveals that the rocks become progressively older away from the centre of the structure.

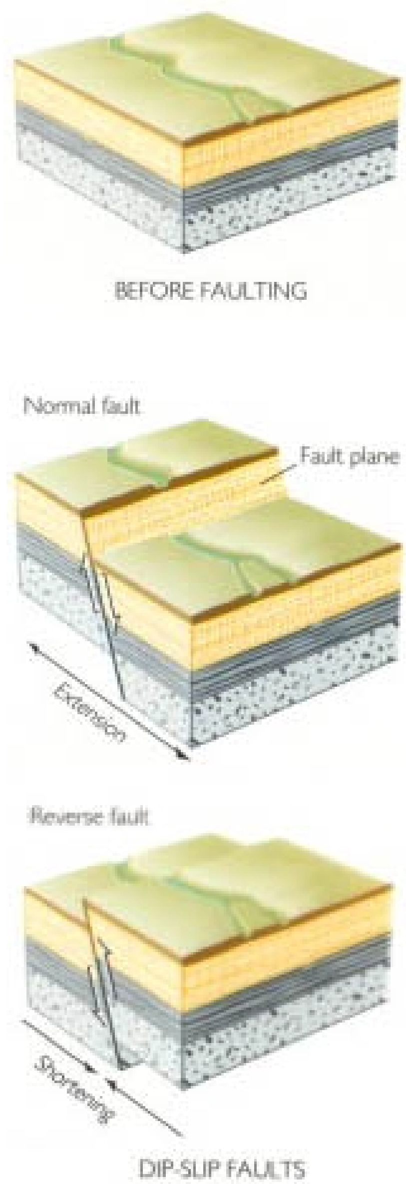


8.2.3.2 Fault Structures

Faulting is a brittle response to stress in the Earth's crust. When faulting occurs, rock strata fracture and move, the direction of movement—vertical, horizontal, or a combination of both—being related to the nature of the applied stress.

Vertical or dip-slip faults are those which result from movement along the dip of the fault. If the angle of dip is not 90 degrees, the side of the fault with the portion of land which appears to be hanging over a lower portion before movement is called the **hanging wall** and that on the bottom, the **foot wall**.

A **normal fault** is one where the hanging wall slips down relative to the foot wall, as a result of tensional stress.



Normal dip-slip fault in Death Valley canyon walls, Yosemite National Park, CA, USA[8]

A **reverse fault** is one in which the hanging wall moves up relative to the foot wall, as a result of compressional stress. A reverse fault with a low dip angle is called a thrust fault.

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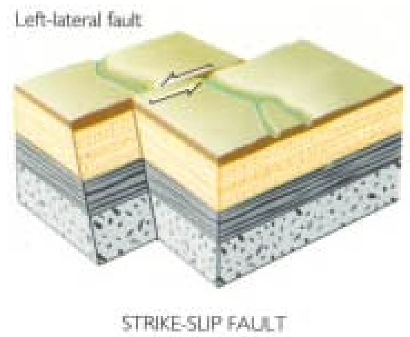
[8] http://virtual.yosemite.cc.ca.us/ghayes/images/DSC07933 Normal fault with Laura for scale b.JPG

Horizontal, **strike-slip** or **transform** faults occur when rocks on either side of a fault slip sideways. Movement can be *left lateral* or *right lateral*. The best example of right lateral strike slip fault is the San Andreas fault in California.



Looking down the fault line in the front plan view, the right side of the fault appears to have moved towards you if a right lateral fault or left side moves towards you if a left lateral fault.

An aerial view of the San Andreas Fault in California, USA, looking northwest[9]

An **oblique fault** is one in which there is movement in both the vertical and horizontal planes, *i.e.* where there are both major dip slip and strike slip components.

8.2.3.3 Joints

Joints, also products of brittle behaviour, are fractures in rocks where there is no appreciable displacement of one side relative to the other (*cf.* faults, where there is movement).

[9] http://openlearn.open.ac.uk/mod/resource/view.php?id=100266#FIG007_003

Joints form in several different ways[10]:

- During the deformation of the rocks, such as when folding occurs. These types of joints are particularly common in the apical region of folds and are evident in most of the photographs of folds presented in **Section 8.2.3.2** above;
- As a result of contraction during cooling of igneous rocks. In basalt lava flows, for example, joints develop perpendicular to cooling surfaces, and generally form columns with five or six sides[11]—called **columnar jointing**.

Columnar jointing, Organ Pipes National Park, Victoria

In granite, joints tend to form in mutually perpendicular sets of three, with the result that the rock ultimately fractures into rectangular blocks. Subsequent weathering wears away the edges of these blocks, often yielding characteristic granite tors;

Jointing in granite outcrops—Freycinet National Park, Tasmania

[10] http://www.dmtcalaska.org/course_dev/explogeo/class10/notes10.html

[11] Five and six-sided polygons provide the largest volumes and smallest surface area that form a space-filling pattern

- In granite batholiths, when cracks form parallel to the topographic surface—a process known as **sheeting**. These types of joints result when uplift and erosion removes the confining pressure of the overlying rock layers. As the rocks rebound, they tend to break into slab-like layers.

Sheeting in granite rock, Yosemite National Park, CA, USA[12]

Cracks similar to joints develop in soil when it contracts on drying.

Broadwell dry lake bed, CA ,USA[13]

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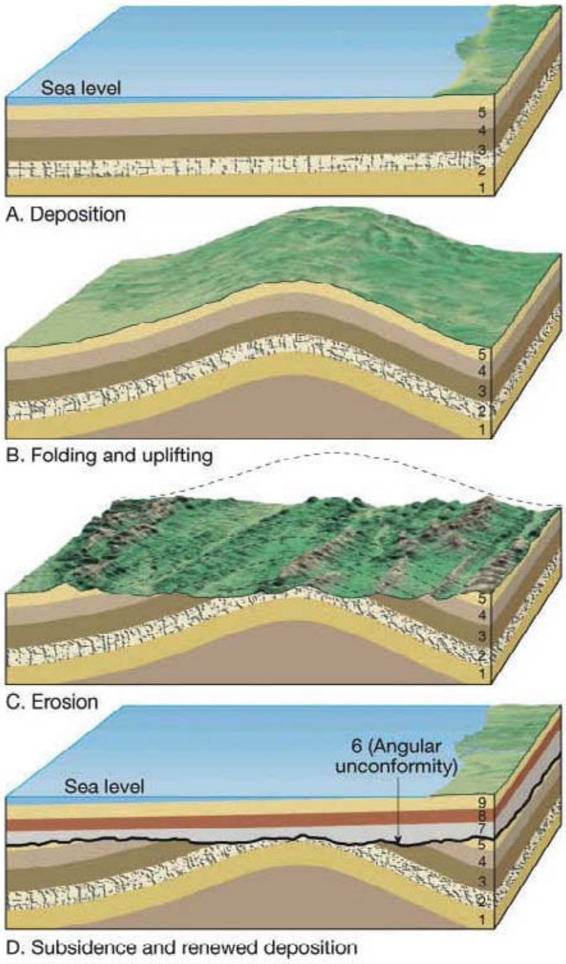
[12] http://geology.csustan.edu/Kuehn/Photos/Yosemite_Mono_Oct02/med/set2_pic00_sheeting.jpg
[13] http://icons.wunderground.com/data/wximagenew/l/Leia/552.jpg

8.2.3.4 Unconformities

An unconformity is a buried erosion surface separating two rock masses or strata of different ages. An unconformity occurs when tilted, folded or faulted rocks are exposed at the surface, eroded, and later submerged and covered by more sediments, providing a definite break between the two rock types. In general, the older layer was exposed to erosion for an interval of time before deposition of the younger, but the term is used to describe any break in the sedimentary geologic record.

The rocks above an unconformity are younger than the rocks beneath (unless the sequence has been overturned), the unconformity representing time during which no sediments were deposited. The result is a gap, in some cases encompassing millions of years, in the stratigraphic record. The interval of geologic time not represented is called a **hiatus**.



Formation of an unconformity[14]

Hutton's Unconformity, Siccar Point, Berwickshire, Great Britain
Red sandstone on grey shale which has been tilted almost vertically[15]

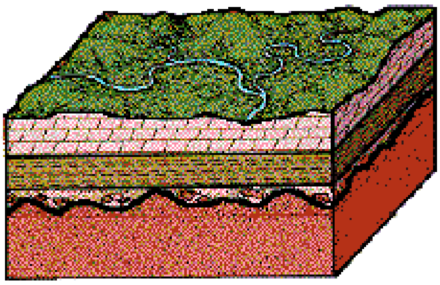
[14] Copyright © 2005 Pearson Pretice Hall, Inc.
[15] Photograph by Anne Burgess—http://www.geograph.org.uk/view.php?id=4343

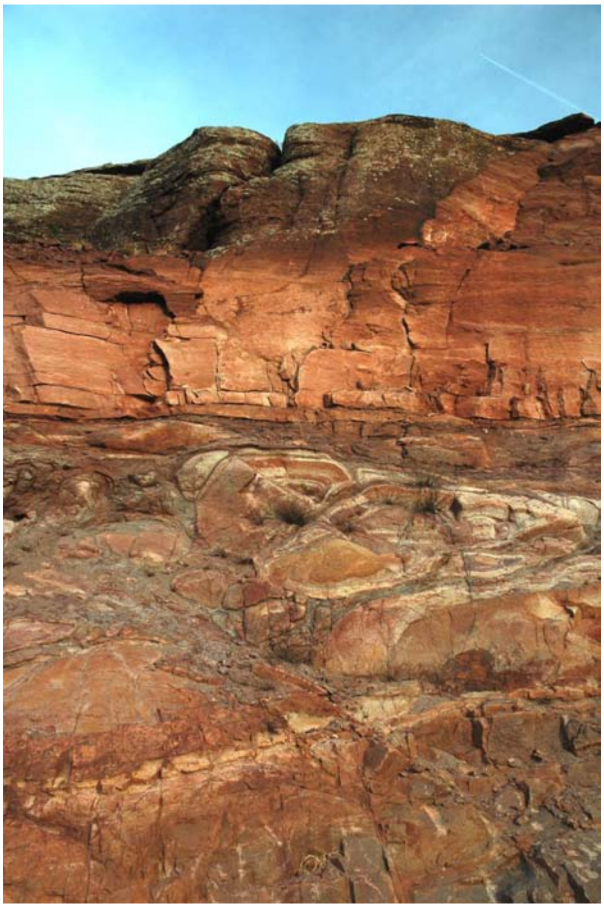
Three types of unconformity are generally recognised: nonconformity, angular unconformity and disconformity.

8.2.3.4.1 Nonconformity

A nonconformity is the unconformity that exists between sedimentary rocks and metamorphic or igneous rock when the sedimentary rock lies above and was deposited on the pre-existing and eroded metamorphic or igneous rock.

The difference between a nonconformity and the boundary of an igneous intrusion into country sedimentary rock will be apparent from the absence of metamorphosed material in the case of the nonconformity.





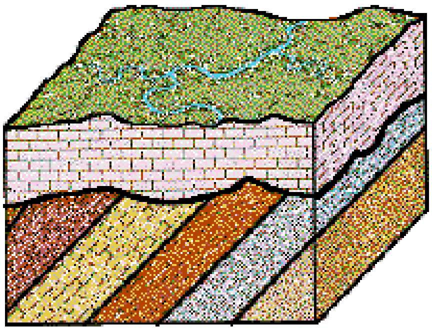
Nonconformity on State Route 87, near mile post 258 north of Payson, AZ, USA
Cambrian Tapeats sandstone on Precambrian granite[16]

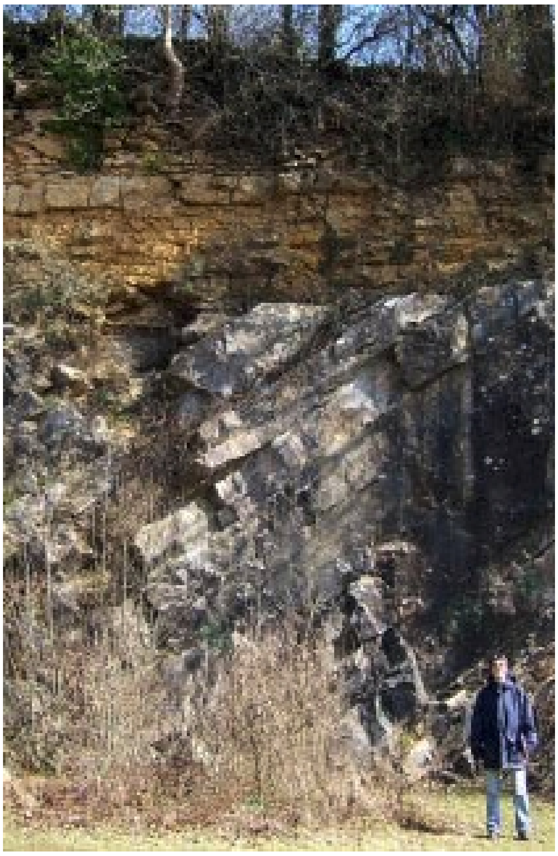
[16] http://www.gc.maricopa.edu/earthsci/imagearchive/payson_nonconformity.htm

8.2.3.4.2 Angular Unconformity

An unconformity where horizontally parallel strata of sedimentary rock are deposited on tilted and eroded layers that may be either vertical or at an angle to the overlying horizontal layers is known as an angular unconformity. The whole sequence may later be deformed and tilted by further orogenic activity.

This was the first type of unconformity to be recognized[17]. In fact, the term unconformity was originally used to describe the geometric relationship between the underlying and overlying bedding planes.





Angular unconformity at Vallis Vale, 3 km from Frome, Somerset, Great Britain
Jurassic Inferior oolite (a form of limestone) over dipping Carboniferous limestone[18]

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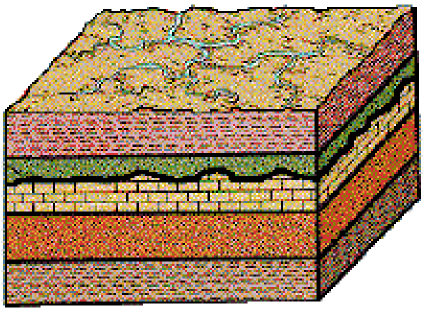
[17] See Hutton's Unconformity, p11, named after Scottish geologist James Hutton (1726–1797) who suggested that the "present is the key to the past" and proposed the Theory of Uniformitarianism.

[18] Photograph by Andrew Swift and Julian Bateson
http://www.charnia.org.uk/field_excursion_programme_2006_weekend.htm
http://www.english-nature.org.uk/imagelibrary/image_details.cfm?id=112472

8.2.3.4.3 Disconformity

A disconformity is an unconformity between parallel layers of sedimentary rock that represents a period of erosion or non-deposition.



A paraconformity is a particular type of disconformity in which the separation is a simple bedding plane—*i.e.* there is no obvious buried erosional surface.

Disconformity near Gladeville, TN, USA
The two strata are separated by around one million years[19]

8.2.3.4.4 Capital Hill Unconformity

The Capital Hill Unconformity (State Circle, Canberra), illustrated on the following page, is an angular unconformity separating beds of Camp Hill sandstone and State Circle Shale. Both formations belong to the Silurian system deposited about 425 million years ago, but close inspection of the shale indicates that it was folded, uplifted and eroded before the sandstone sediments were deposited on top. Subsequent earth movements have folded and fractured the beds. The photographs show the State Circle road cutting that reveals the unconformity, starting from the westernmost end moving to the central section, behind Old Parliament House, where the unconformity is most evident. The cutting continues to the east, revealing more folding and faulting of the upper sandstone beds.

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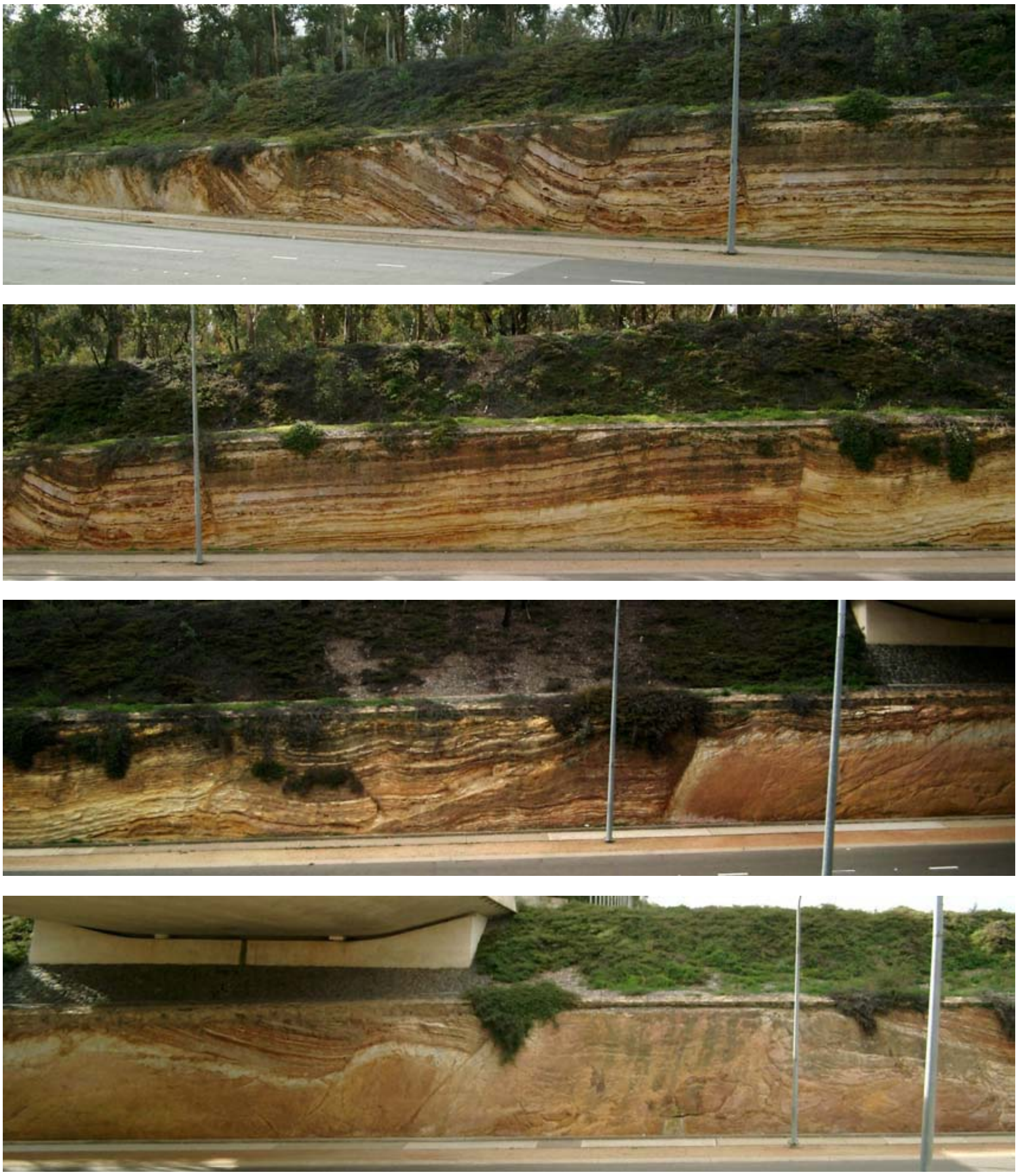
[19] Photographs by Bruce Railsback
http://www.gly.uga.edu/railsback/FieldImages/GladevilleDetail.jpeg
http://www.gly.uga.edu/railsback/FieldImages/GladevilleDistant.jpeg



Capital Hill Unconformity (west, moving to centre), Canberra, ACT

Capital Hill Unconformity (central section), Canberra, ACT

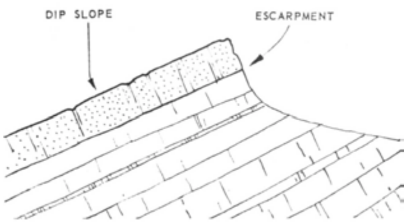
8.2.3.5 Structural Landforms

Structural landforms are those that are created as a result of tectonic plate movement and the subsequent deformation of the Earth's crust. They are of particular interest to geologists because they often provide a key to the location of a range of natural resources. Oil and natural gas, for example, are formed and found trapped in sub-surface folds. Faults, joints, and fractures can provide passageways for ground water and a host for valuable deposits of ores of ores and minerals. Also, as discussed in the previous section, the identification of unconformities revealed in these landforms can be used to mark geologic time boundaries.

The more obvious structural landforms include volcanoes, discussed previously, eroded folded structures such as cuestas, and rift valleys, which result from complex faulting.

8.2.3.5.1 Folded Landforms

Cuestas, from the Spanish word for slope, are formed via the erosion of gently tilted or folded rock layers. A cuesta has a characteristic steep slope, called an **escarpment**, where the rock layers are exposed on their edges. An erosion resistant layer slopes away more gently, the **dip slope**, on the opposite side of the ridge.



A cuesta—Table Top Mountain, SE NSW

8.2.3.5.2 Faulted Landforms

Faulting gives rise to a number of landforms, including scarps, rift valleys and fault block mountains. A **fault scarp**, or **escarpment**, is the exposed face of a fault. It may be only a few centimetres or many metres high. Fault scarps are often very prone to erosion, especially if the material being uplifted consists of unconsolidated sediment.

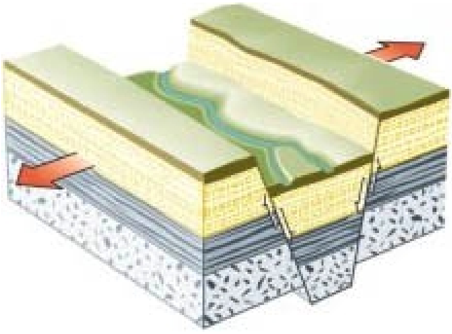
Serengeti rift valley escarpment, [20]

[20] http://www.georgefisher.com/images/Serengeti/IMG_0462.JPG

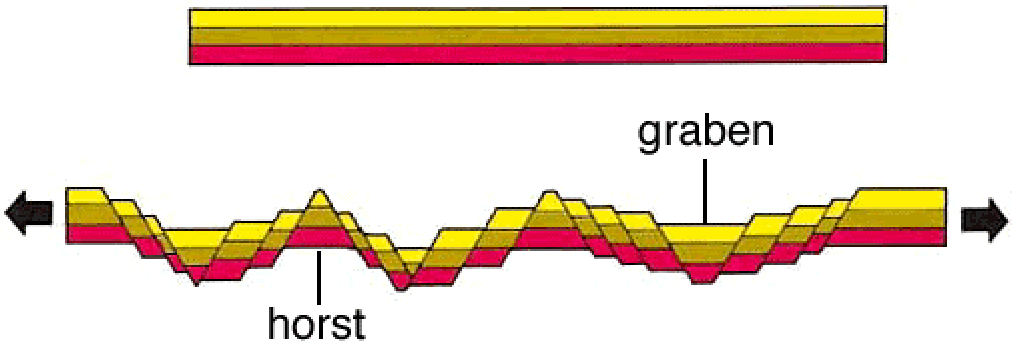
A **rift valley** or **graben** is formed when the block between two faults sinks under tensional stress.

A **block mountain** or **horst** is formed when the rocks between two faults are thrust upwards relative to the surrounding terrain.

Horsts and grabens usually occur together and the faulting involved is usually quite complex, as illustrated below.

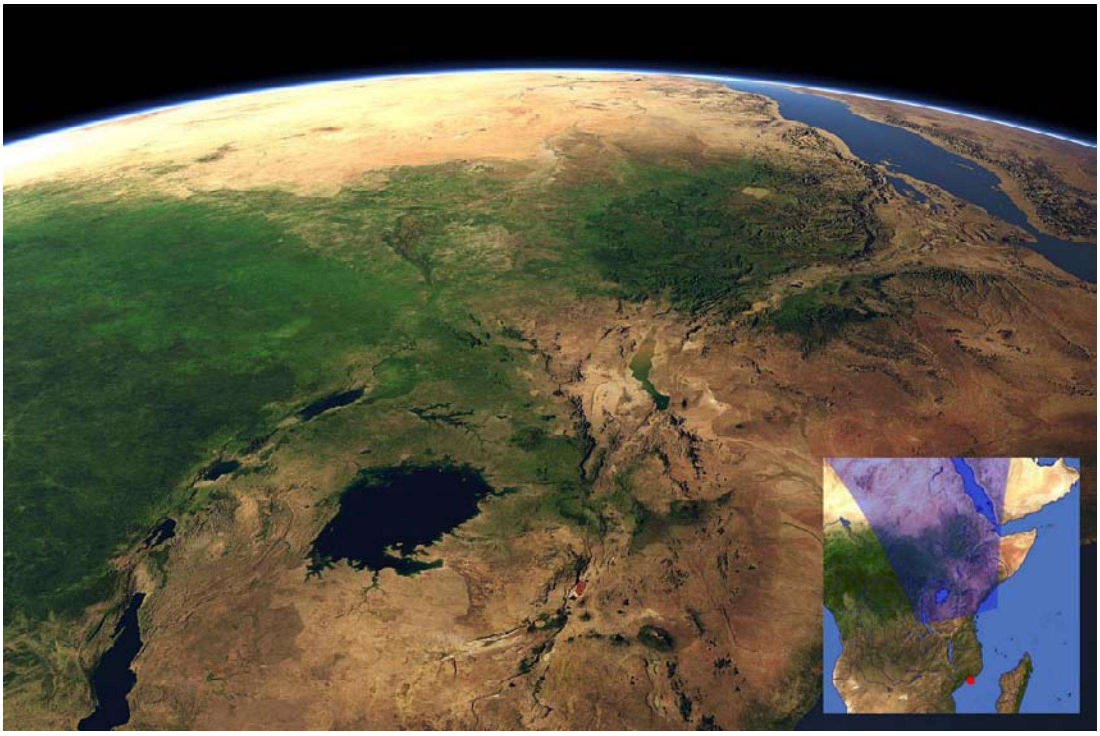


Formation of a graben



Schematic cross section of typical horst and graben pairs[21]

The Great African Rift Valley is a large breach in the crust of the earth where the African continent is slowly splitting into two parts. Many lakes can be seen along the rift, among them Lake Victoria, the largest lake of Africa.



The Great African Rift Valley, Africa[22]

[21] http://www.glossary.oilfield.slb.com/DisplayImage.cfm?ID=108
[22] http://earth.imagico.de/view.php?site=eafrica

8.2.3.5.3 Landforms in the Canberra Region[23,24] *Section incomplete*

Canberra is located in a graben, between the Cotter (west) and Cullarin (east) horsts.

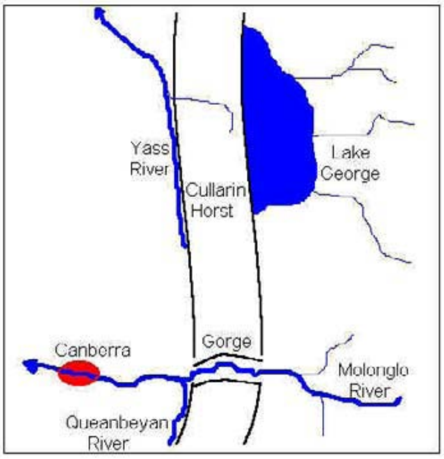
- *Photo of Canberra valley*

Cullerin Horst/ Lake George Fault

A fascinating example of how faulting can dominate a landscape and create unusual features is illustrated by the Lake George area northeast of Canberra.

Lake George is very shallow, and shrinks rapidly in size when it dries out, expanding quickly after good rains in its small catchment region to the east.

The lake was created when the Cullarin Horst was uplifted. This uplift effectively 'beheaded' the small stream that drained what is now the Lake George area before the uplift occurred. Thus the horst became in effect a natural dam, creating Lake George as a consequence.



Cullarin Horst and Lake George[25]

But further south, the Molonglo River was big enough to cut down through the horst as the uplift occurred, maintaining its course and creating the Molonglo Gorge.

Notice also how both the Yass and the Queanbeyan Rivers are located along the fault line on the western edge of the horst. Thus faulting has affected not only the development of ranges and basins in Australia, but has extensively affected the location and nature of some of our river systems as well.

- *Photo of Lake George escarpment*
- *Photo of Molonglo Gorge*
- Cutting on the Ridgeway?

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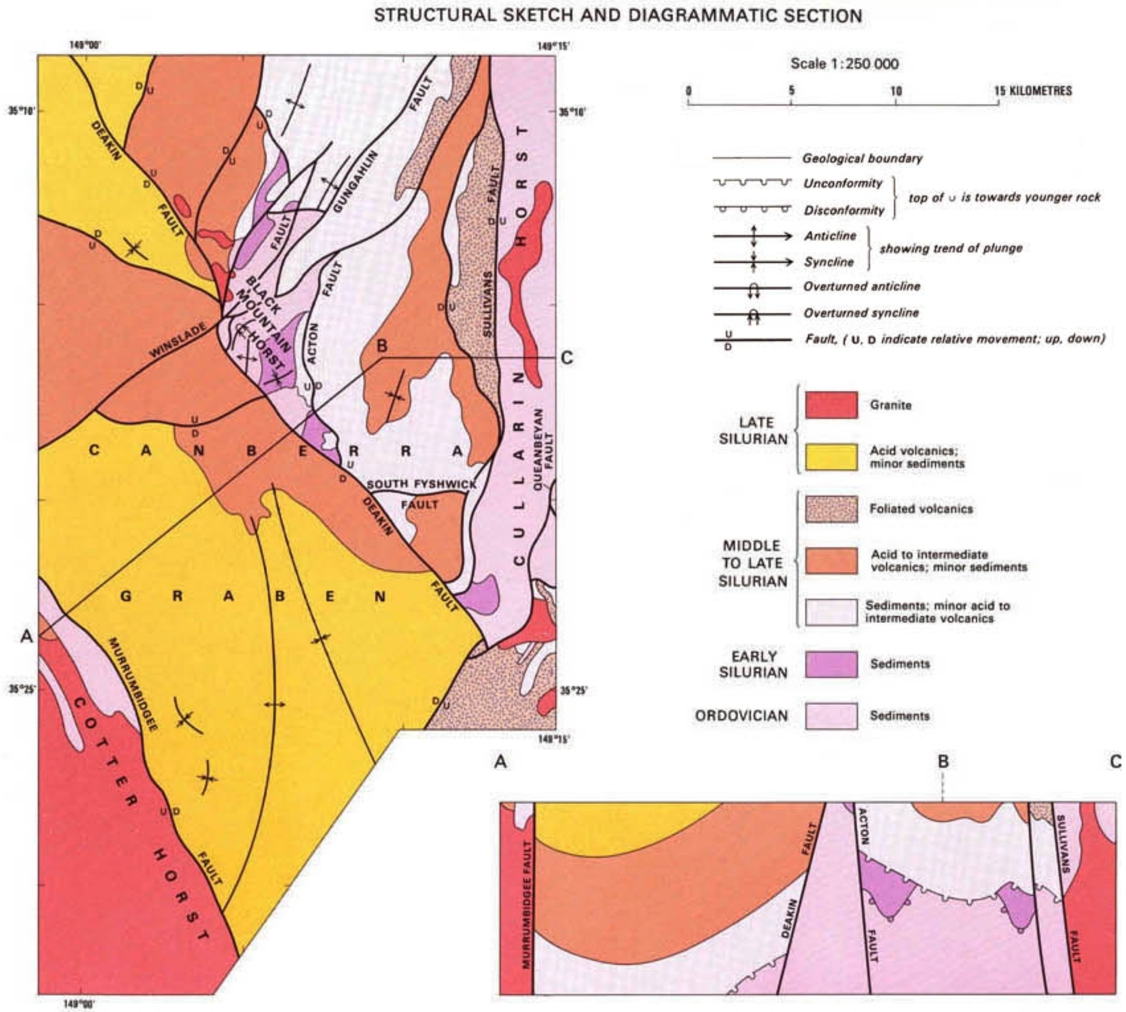
23 http://en.wikipedia.org/wiki/Geology_of_the_Australian_Capital_Territory
24 Rocks and Fossils Around Canberra
Henderson, G.A.M. and Strusz, D.L. ISBN 0-644-01720-1 (AGPS 1982)
25 http://humanities.cqu.edu.au/geography/GEOG11023/week_5.htm#Folding and faulting



Geology of the Canberra Region[26]

[26] Satellite images from Google Earth, June 2007
Geological data from map entitled Geology of Canberra, Queanbeyan and Environs, Bureau of Mineral Resources, 1980

Volcanic intrusions

- Ginns Gap quarry (Eagle Hawk Hill, Federal Highway)
  - Samples collected appear to be a blue-grey andesite, with relatively high iron content, given the amount of iron oxide in weathered samples

- Mt Mugga Mugga quarry
  - Mugga Mugga Porphyry is a blue-grey rhyodacite containing phenocrysts of quartz, feldspar and biotite. Some samples show larger veins of feldspar and what appears to be haematite. There is a large rock (around 2 m high and 1 m across), on the right as you enter the base of the quarry, which shows both of these features. There is a vein of feldspar, about 0.5 m up on the northern face, and two bands of what appears to be hematite higher up—the rock has broken neatly along the top band (bottom image below).

Deakin Anticline

To the east of the sports ground in Deakin is an outcrop of rock that shows the various parts of a typical fold. Looking towards the oval, the bedding outline of two anticlines is clearly visible. The crest of the anticline nearest to the Deakin shops (see photograph) can be followed along the top of the outcrop, and it can be seen that the anticline is not horizontal, but plunging gently to the south.

NE Corner of the Deakin Anticline site

Close examination also reveals that, as well as the bedding, there is a strong cleavage, which is parallel to the axial plane of the anticline. This sort of cleavage is known as axial plane cleavage, and its relationship to the bedding can be used to predict in which direction lies the nearest anticlinal axis.

Axial Plain cleavage in the Deakin Anticline

Other Places of Geological Interest

- Mt Painter (volcanics)
- Black Mountain (sandstone)
- Mt Ainslie (volcanics)
- Mt Taylor (volcanics)

8.2.3.6 Changes in Sea Level

Changes in sea levels can result from changes in the volume of the sea, which might accompany the freezing or thawing of the polar ice caps, or from rising land levels, which might be the result of either tectonic activity or isostatic recovery of the land when ice sheets melt. In any case, these changes may give rise to such features as **raised beaches**, when the sea level falls, and **submerged forests** and **rias** (drowned river valleys) when the sea level rises.

There are many examples of raised beaches on the western coasts of Ireland and Scotland, most likely the result of isostatic recovery of the land. Raised beaches in New Zealand, however, are more usually the result of tectonic activity. The youngest raised beach in the photograph on the right (closest to the present-day shoreline), below, was uplifted 6.4 metres by the 1855 Wairarapa earthquake. Older ridges have been dated and are associated with earthquakes occurring in 2900 BC, 1100 BC and 1460 AD.

Raised beaches, west coast of Scotland[27]

Raised beaches, Turakirae Head, NZ[28]

In contrast to the retreating seas in the north of the British Isles, the southern part of England is host to submerged landforms, including submerged forests. Various examples can be found at locations such as Ynyslas[29] on the coast of Wales, and Bournemouth[30] on the south coast of England where it is believed that vegetation would have thrived when the English Channel was dry. Submerged mangroves have also been found off the coast of Queensland, near Cairns.

As a submergent coastline, the south coast of England also contains many rias[31]. Rias form where sea levels rise relative to the land. When this happens, valleys that were previously at sea level become submerged. The result is often a very large estuary at the mouth of a relatively insignificant river (or else sediments would quickly fill the ria).

The east coast of Australia also features several rias around Sydney, including Port Hacking and Sydney Harbour itself. The deeply indented shape of the Port Hacking

27 http://www.stacey.peak-media.co.uk/Scotland/WesterRoss/Westercoast.htm
28 http://www.teara.govt.nz/EarthSeaAndSky/MarineEnvironments/CoastalShoreline/1/ENZ-Resources/Standard/7/mi
29 http://www.bbc.co.uk/wales/mid/sites/coast/pages/5.shtml
30 http://www.soton.ac.uk/~imw/bourne.htm
31 http://en.wikipedia.org/wiki/Ria

ria illustrated reflects the dendritic pattern of drainage that existed before the rise in sea level that flooded the valley.

Port Hacking, Sydney, NSW[32]

[32] Satellite photograph from Google Earth, June 2007
Aerial photograph by Stephen Codrington
http://upload.wikimedia.org/wikipedia/commons/b/bf/PortHacking-Sydney-Ria.jpg

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See also http://www.prenhall.com/tarbuck for additional on-line resources

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All photographs without specific credit to the contrary by Peter and Steven Harrison

- 2006
  - Jointing in granite outcrops—Freycinet National Park, Tasmania
- 2007
  - Columnar jointing, Organ Pipes National Park, Victoria
  - Capital Hill Unconformity, Canberra, ACT
  - Deakin Anticline, Canberra, ACT
  - Ginn's Gap Quarry, Federal Highway, NSW
  - Mt Mugga Mugga Quarry, Canberra, ACT
  - Table Top Mountain, Table Top, NSW