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01 Geology and Civil Engineering

THE GEOLOGICAL ENVIRONMENT

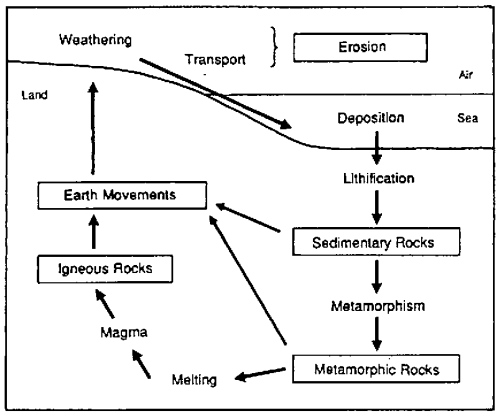
Earth is an active planet in a constant state of change.
Geological processes continually modify the Earth's surface, destroy old rocks, create new rocks and add to the complexity of ground conditions.

Cycle of geology encompasses all the major processes, which must be cyclic, or they would grind to an inevitable halt.

Land: mainly erosion and rock destruction.
Sea: mainly deposition, forming new sediments.
Underground: new rocks created and deformed.

Earth movements are vital to the cycle; without them the land would be eroded down to just below sea level. Plate tectonics provide the mechanism for nearly all earth movements (section 09). The hot interior of the Earth is the ultimate energy source which drives all geological processes.

Geological time is an important concept. Earth is 4000M years old and has evolved continuously towards its present form.
Most rocks encountered by engineers are 10–500M years old. They have been displaced and deformed over time, and some are then exposed at the surface, by erosional removal of rocks that once lay above them.
Underground structures and the ground surface have evolved steadily through geological time.
Most surface landforms visible today have been carved out by erosion within the last few million years, while older landforms have been destroyed.
This time difference is important: the origin of the rocks at the surface may bear no relationship to the present environment. The classic example is Mt Everest, whose summit is limestone, formed in a sea 300M years ago.
Geological time is difficult to comprehend but it must be accepted as the time gaps account for many of the contrasts in ground conditions.



Concepts of scale are important in geology:

Beds of rock extending hundreds of kilometres across country.
Rocks uplifted thousands of metres by earth movements.
Rock structures reaching 1000 m below the ground surface.
Strong limestone crumpled like plasticine by plate tectonics.
Landslides with over 100M tons of falling rock.
Earthquakes a million times more powerful than an atom bomb.
And the millions of years of geological time.

Endless horizontal rocks exposed in Canyonlands, USA

SIGNIFICANCE IN ENGINEERING

Civil engineering works are all carried out on or in the ground. Its properties and processes are therefore significant – both the strengths of rocks and soils, and the erosional and geological processes which subject them to continual change.
Unstable ground does exist. Some ground is not 'terra firma' and may lead to unstable foundations.
Site investigation is where most civil engineers encounter geology. This involves the interpretation of ground conditions (often from minimal evidence), some 3-D thinking, and the recognition of areas of difficult ground or potential geohazards.
Unforeseen ground conditions can still occur, as ground geology can be almost infinitely variable, but they are often unforeseen due to inadequate site investigation.
Civil engineering design can accommodate almost any ground conditions which are correctly assessed and understood.

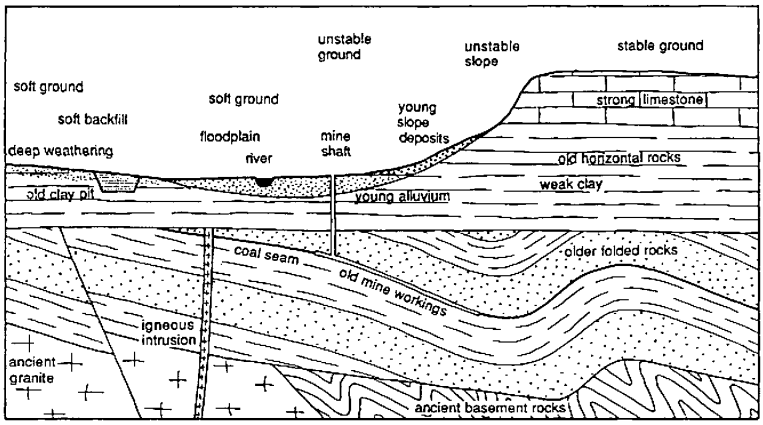
Components of Engineering Geology

The main fields of study:	Sections in this book
Ground materials and structures	02–06
Regional characteristics	09–12
Surface processes and materials	13–18
Ground investigations	07,08,19–23,37
Material properties	24–26,40
Difficult ground conditions	27–36,38,39

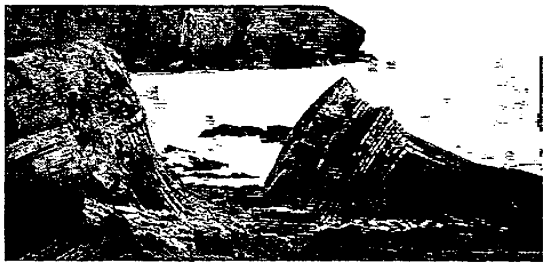
Other aspects – fossils and historical geology, mineral deposits and long term processes – are of little direct significance to the engineer and are not specifically covered in this book.

SOME ENGINEERING RESPONSES TO GEOLOGICAL CONDITIONS

Geology	Response
Soft ground and settlement	Foundation design to reduce or redistribute loading
Weak ground and potential failure	Ground improvement or cavity filling; or identify and avoid hazard zone
Unstable slopes and potential sliding	Stabilize or support slopes; or avoid hazard zone
Severe river or coastal erosion	Slow down process with rock or concrete defences (limited scope)
Potential earthquake hazard	Structural design to withstand vibration; avoid unstable ground
Potential volcanic hazard	Delimit and avoid hazard zones; attempt eruption prediction
Rock required as a material	Resource assessment and rock testing



Ground profile through some anonymous region in the English Midlands.
Most rocks were formed 200–300M years ago, when the area was near the equator in a deltaic swamp, disturbed by earth movements then left in a shallow sea.
The ground surface was shaped by erosion in the last million years, when the alluvium and slope deposits partly filled the river-cut valley.
The more difficult ground conditions are provided by the floodplain, soft sediments, deep rockhead, unstable slopes, old mines and the backfilled quarry.



Folded rocks exposed along the South Wales coast

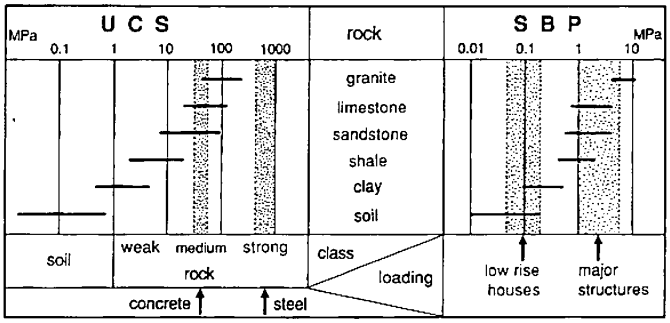
STRENGTH OF THE GROUND

Natural ground materials, rocks and soils, cover a great range of strengths: granite is 4000 times stronger than peat soil.
Some variations in rock strength are summarized by contrasting strong and weak rocks in the table.
Assessment of ground conditions must distinguish:

- Intact rock – strength of an unfractured, small block; refer to UCS.
- Rock mass – properties of a large mass of fractured rock in the ground; refer to rock mass classes (section 25).

Note – a strong rock may contain so many fractures in a hillside that the rock mass is weak and unstable.
Ground conditions also vary greatly due to purely local features such as underground cavities, inclined shear surfaces and artificial disturbance.

Strong Rocks	Weak Rocks
UCS > 100 MPa	UCS < 10 MPa
Little fracturing	Fractured and bedded
Minimal weathering	Deep weathering
Stable foundations	Settlement problems
Stand in steep faces	Fail on low slopes
Aggregate resource	Require engineering care



UCS:
Unconfined (or uniaxial) compressive strength: load to cause failure of a cube of the material crushed between two flat plates with no lateral restraint. (Strong and weak limits are simplified; see section 24 for BS criteria.)

SBP:
Safe (or acceptable) bearing pressure: load that may safely be imposed upon rock in the ground: the estimated (or measured) ultimate bearing pressure to fail the rock (allowing for fractures and local zones of weakness) divided by a safety factor between 3 and 5.

ROCKS AND MINERALS

Rocks: mixtures of minerals: variable properties.
Minerals: compounds of elements: fixed properties.

Rock properties broadly depend on:

- strength and stability of constituent minerals;
- interlocking or weaknesses of mineral structure;
- fractures, bedding and larger rock structures.

All rocks fall into one of three families, each with broadly definable origins and properties.

Most rock-forming minerals are silicates – compounds of oxygen, silicon and other elements.

Rock properties can show extreme variations. It is useful to generalize, as in the table below, in order to build an understanding of geology, but it must be accepted that rocks are not engineered materials and their properties do vary from site to site.
For example: most sedimentary rocks are quite weak, and limestone is a sedimentary rock, but some of the limestones are very strong.

Rock family	Igneous	Sedimentary	Metamorphic
Material origin	Crystallized from molten magma	Erosional debris on Earth's surface	Altered by heat and/or pressure
Environment	Underground; and as lava flows	Deposition basins; mainly sea	Mostly deep inside mountain chains
Rock texture	Mosaic of interlocking crystals	Mostly granular and cemented	Mosaic of interlocking crystals
Rock structure	Massive (structureless)	Layered, bedded, bedding planes	Crystal orientation due to pressure
Rock strength	Uniform high strength	Variable low; planar weaknesses	Variable high; planar weaknesses
Major types	Granite, basalt	Sandstone, limestone, clay	Schist, slate

02 Igneous Rocks

Magma is generated by local heating and melting of rocks within the Earth's crust, mostly at depths between 10 and around 100 km. Most compositions of rock melt at temperatures of 800–1200°C. When the magma cools, it solidifies by crystallizing into a mosaic of minerals, to form an igneous rock.

VOLCANIC ERUPTIONS

Eruptions may be violent and explosive if a viscous magma has a high gas pressure, or may be quiet and effusive if the magma is very fluid. There is a continuous range of eruptive styles between the two extremes, and a single volcano may show some variation in the violence of its individual eruptions.

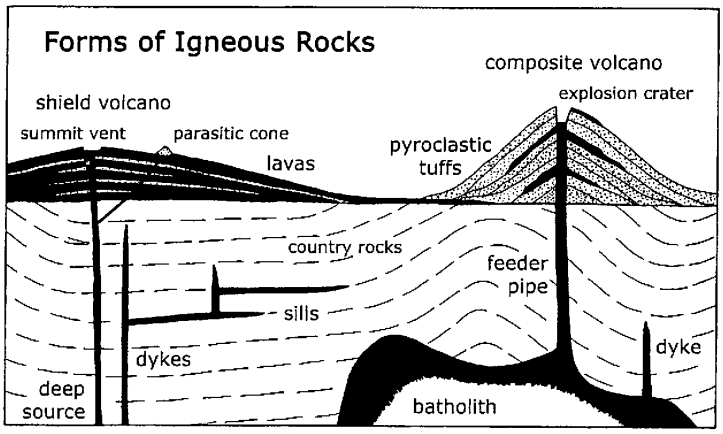
Pyroclastic rocks (meaning fire fragmental) are formed of material, collectively known as tephra, thrown into the air from an explosive volcano. Most tephra is cooled in flight, and lands to form various types of ash, tuff and agglomerate, all with the properties of sedimentary rocks. Some tephra, erupted in turbulent, high-temperature, pyroclastic flows, lands hot and welds into ignimbrite, or welded tuff.

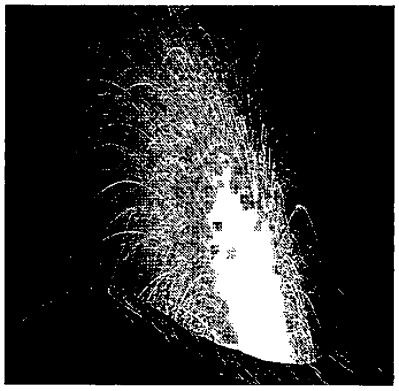
EXTRUSIVE IGNEOUS ROCKS

These form where magma is extruded onto the Earth's surface to create a volcano.
Lava is the name for both molten rock on the surface, and also the solid rock formed when it cools.
Fluid basaltic lavas flow easily to form low-profile shield volcanoes, or near-horizontal sheets of flood basalt.
More viscous lavas, mainly andesitic, build up conical composite, strato-volcanoes, where lava is interbedded with ash and debris, that are thickest close to the vent.

INTRUSIVE IGNEOUS ROCKS

These are formed when magma solidifies below the surface of the Earth. They may later be exposed at the surface when the cover rocks are eroded away.
Batholiths are large blob-shaped intrusions, roughly equidimensional and commonly 5–50 km in diameter. Most are of granite.
Dykes are smaller sheet intrusions formed where magma has flowed into a fissure. Mostly 1–50 m wide; may extend for many kilometres; generally of dolerite. Sills are sheet intrusions parallel to the bedding of the country rocks into which the magma was intruded.





Molten lava ejected from the summit vent of Stromboli volcano.

GRANITE

TYPE	Acid igneous; coarse grained, large scale intrusive (plutonic).
MINERALOGY	Coarse interlocking crystal mosaic with no textural orientation. Quartz 25%, feldspar 50%, micas 15%, mafics 10%.
OCCURRENCE	Large batholiths, exposed at surface by subsequent erosion. Cooled as large bodies 3–15 km beneath surface.
EXAMPLES	Britain: Land's End. USA: Yosemite.
STRUCTURES	Commonly massive and very uniform. Widely spaced sheet jointing, curved due to large exfoliation (caused by cooling and stress relief).
WEATHERING	Slow decay of feldspar to clay, leaving quartz to form sandy soils. Spheroidal weathering leaves rounded corestones in soil matrix.
STRENGTH	High strength with all physical properties good. UCS: 200 MPa. SBP: 10 MPa.
FOUNDATIONS	Very strong rock, except where partially decayed to clay near the surface or along some deep joint zones.
HYDROLOGY	Groundwater only in fractures.
VALUE	Excellent dimension, decorative and armour stone and aggregate.
VARIETIES	Syenite and diorite: have less quartz and are slightly darker. Gabbro: basic, and is much darker. Larvikite: a dark coarse syenite with distinctive internal reflections. Many strong rocks are referred to as granite within the construction trade.

Microscope view, 5 mm across: clear quartz, cloudy feldspar, cleaved mica.