

I. Primary structures

A. Primary structures in sedimentary rocks

1. Stratification

a) Map-scale units: formations, groups, members

Many sedimentary, and some igneous rock are **stratified**: formed in layers (**strata**) laid down parallel with the Earth's surface (**principle of original horizontality**) and with the oldest on the bottom, youngest on the top (**principle of superposition**). Stratified units dominate many geological maps. They are conventionally shown in different colours.

The primary unit of mapping in stratified rocks is the **formation**. One of the first jobs in mapping a new area is to define formations.

A formation must be:

- Mappable at whatever scale of mapping is commonly practised in a region.
- Defined by characteristics of lithology that allow it to be recognized
- It must have a **type section** that exemplifies those characteristics
- It must be named after a place or geographical feature

Other rules for defining formations are contained in the *North American Stratigraphic Code* and the *International stratigraphic code*.

Formations may be organized into **groups**.

Smaller mappable units may sometimes be recognized within formations. These are known as **members**.

Formations, groups, and members are all **lithostratigraphic units**. This means that they are based on lithological characteristics alone; age is not part of the definition

b) Outcrop-scale: bedding, lamination

Of course strata are often seen at outcrop scale too, and are one of the main characteristics that allow us to recognize sedimentary rocks.

Layers thicker than 1 cm are known as beds. Layers thinner than this are laminations.

Several sedimentary processes (storms, turbidity currents) suspend large amounts of sediment in a sudden event, and allow it to settle out slowly, producing a **graded bed**. Graded beds are useful

indicators of 'way-up': i.e. in highly deformed rocks, they indicate whether or not the strata are overturned. However, graded beds must be used with caution because there are sedimentary processes that can produce **inverse grading**. For example, densely moving masses of colliding grains, avalanching down a steep slope, tend to interact so that the large grains rise to the top. Therefore graded bedding should only be used as a way-up indicator if it is seen multiple times in a succession of strata.

c) Thickness calculations

Measured sections, showing the thicknesses of strata in a columnar format, are used often in stratigraphy and sedimentology. When strata are well exposed, it's possible to measure the thickness of each bed with a tape measure. However, it's often necessary to measure diagonally across dipping strata, so apparent thicknesses must be corrected for the difference between the measured direction and the direction that's perpendicular to strata (the pole to bedding).

There are numerous trigonometric formulas to convert true thickness to apparent thickness for different combinations of dipping planes and plunging lines of section. However, all are variations on a single basic formula.

$$\text{True thickness} = \text{Apparent thickness} \times \cos(\theta)$$

where θ is the angle between the line of section and the 'ideal' direction represented by the pole to stratification. This angle can easily be determined from a *stereographic projection*.

2. Structures generated by currents, way-up indicators

We have already mentioned graded bedding as an indicator of way-up. Many other sedimentary structures can be used as way-up indicators.

a) Bedforms and cross-stratification

Amongst the most useful is **cross-stratification**. Cross-stratification results from the migration of **bedforms** during sedimentation. Bedforms are waves on the bedding surface produced by the action of either currents or waves.

Bedforms are generally classified into larger forms, called **dunes**, and smaller types called **ripples**. By convention:

- cross-stratification produced by dunes is called **cross-bedding**;
- cross-stratification produced by ripples is called **cross-lamination**.

Cross-stratification indicates way-up most effectively because it produces **truncations** of laminations, that resemble small-scale

angular unconformities. The laminations that are truncated are always below the truncation surface.

Even if truncations cannot be seen, it's sometimes possible to use cross laminations by noting that most bedforms have ridges that are sharper - more pointed - than the troughs. However, in strained rocks it's sometimes the case that the curvature of surfaces is modified. Truncations therefore give a more certain indication of way-up than lamination shape.

b) Sole markings

Sole markings are a second type of sedimentary structure that is useful for structural geologists. Sole markings are formed when coarse sediment (usually sand) is deposited rapidly (usually by a current) on a muddy substrate. Sole markings include:

- **Groove casts:** grooves are made by currents dragging objects across the mud; these are then filled by sand and preserved as molds on the base of a sandstone bed.
- **Flute casts:** currents produce scoop-like depressions in the mud that fade out in a down-current direction; these are then filled by sand and preserved as molds on the base of a sandstone bed.
- **Load structures:** bulges in the bottom of a sandstone bed formed when denser sand sinks into less dense wet mud. Corresponding narrow tongues of mud penetrating upward between load structures are called **flame structures**
- **Bioturbation structures (trace fossils):** horizontal burrows and trails are filled by sand and preserved as molds on the base of a sandstone bed.

Note: strictly speaking, all these structures should be called molds, not casts. However, the term 'cast' is more commonly used.

3. Structures generated by soft-sediment deformation

Recently deposited sediment may undergo deformation while it is unlithified. Soft-sediment deformation structures can be challenging for the structural geologist as they are difficult to distinguish from tectonic structures, formed after the sediment was lithified. There are a number of categories:

- **Mudcracks:** these are formed by shrinkage of mud as it dries out. Mudcracks are most visible when they are filled by overlying sediment that is different. They thin downwards to a point and therefore can be good way-up indicators.
- **Convolute lamination:** sand that is deposited under water is often initially very loosely packed. Subsequently, the grains

may settle into a denser packing, and the water between the grains escapes upward. As this occurs, the water may **fluidize** the sand. Any laminations may become deformed into complex chaotic folds. Convolute lamination is only a good way-up indicator if it is truncated by younger laminations.

- **Slump structures:** sediments that are deposited on a slope may undergo catastrophic slope failure, and start to move under the influence of gravity. Beds may be tightly folded as a result of this type of process. Slump folds can be difficult to distinguish from tectonic folds, and are not particularly effective as way-up indicators. However, if the way-up is known from other structures, slump folds can be used in sedimentology and basin analysis as indicators of **paleoslope**

B. Primary structures in igneous rocks

1. Intrusions

Intrusions by their nature do not typically show stratification, and cannot usually be used to determine tilting or way-up. However, in unravelling the structural history of a complex region, it is important to know the relative timing of intrusions, and this is where contact relationships are all important.

Exocontact features are formed in then **host rock** (also known as **country rock**) by the effect of an intrusion. A metamorphic aureole (baked zone) is often recognizable from changes in texture or mineralogy. There may be minor intrusions where magma has filled cracks branching off the main intrusion. These are called **dykes** (dikes in the US) unless they are parallel to strata in the host rock, in which case they are **sills**.

Endocontact features are formed within an intrusion, where it comes in contact with the host rock. A **chill zone** is typically finer-grained than the bulk of the intrusion. **Xenoliths** are pieces of host rock that broke off and are surrounded by the intrusion.

2. Volcanic rocks

Volcanic rocks are typically stratified, but bedding is often much less clear than in sedimentary rocks. Sometimes the contacts between volcanic flows are conspicuous because they are weathered. Soil layers called 'bole', consisting of soft, clay-rich weathered lava are sometimes visible.

Lava erupted under water typically forms baaon-like **pillows** typically 0.5 - 2 m in diameter, formed by rapid chilling. Later pillows conform in shape to those beneath them in a flow, giving a general indication of way-up.

Thick lava flows may shrink and crack as they cool, producing **columnar joints**. These typically form perpendicular to the base and top of a flow. As a result, the columns are elongated in the direction of the *pole to bedding* and therefore can be used to estimate the bedding orientation where bedding cannot be observed directly.

Note that columnar joints are common in sills too. Sills can be distinguished from flows only by looking at their contacts: sills show intrusive contacts top and bottom, whereas flows typically show one weathered surface.

C. Unconformities

Unconformities are ancient surfaces of erosion and/or non-deposition that indicate a **gap or hiatus** in the stratigraphic record.

Subtle unconformities are very important in the analysis of sedimentary successions. A **sequence** is a package of strata bounded both above and below by unconformities. It may be that an unconformity is a sequence boundary, but that determination depends on finding another unconformity in the succession, either higher up or lower down stratigraphically.

a) Disconformities

A **disconformity** is a contact between parallel strata whose ages are significantly separated. How can it be recognized? The erosion surface may be recognized by weathering and erosion features as channels, fossil soil (**paleosol**), and clasts of the older unit. If the only evidence for a time gap is from missing fossil zones, the surface is a **paraconformity**.

b) Angular unconformities

An **angular unconformity** is seen in the angular **discordance** between older, generally tilted or more strongly deformed strata below, and younger, horizontal or less strongly deformed strata above. Of course, subsequent tilting of the entire succession could alter the orientations, but there will still be a discordance between strata above and below the unconformity. Bedding in the younger sequence tends to be parallel to the plane of unconformity, or more nearly so.

c) Nonconformities

The term **nonconformity** is used to describe the contact between **younger** sedimentary strata deposited upon an eroded surface of **older** crystalline (igneous or metamorphic) rocks in which distinct layers cannot easily be recognized. (In other words it is impossible to say whether the unconformity is angular or not.) Be careful to distinguish a nonconformity from an **intrusive contact**.