University 8 Mai 1945 – Guelma (Algeria)
Geology L1 (Tutorials): Geologic map and cross-section
(Mrs. DJERRAB)

1. Reminders

1.1. The different types of rocks

There are three types of rocks:

1. **Sedimentary rocks** *(ex: limestone, conglomerate, sandstone, marl, claystone…)*: they are composed of **sediments**, which settle in a sedimentary basin. These sediments are mainly the result of **erosion processes**. They transform into rock under the effect of different processes called **diagenesis**. Sedimentary rocks are arranged in **layers/strata/beds**, of varying thickness (from a few centimeters to a few hundred meters).

2. **Magmatic or igneous rocks** *(ex: basalt, granite)*: these rocks are derived from magma (= molten rocks). Volcanic rocks form during volcanic eruptions (ex: *basalt*), whereas plutonic rocks cool slowly inside the Earth (ex: *granite*).

3. **Metamorphic rocks** *(ex: gneiss, shale, marble)*: they come from the transformation of pre-existing rocks (of sedimentary, magmatic or metamorphic type); under the effect of the increase in pressure and/or temperature.

1.2. The principles of stratigraphy

The study of strata and their relationship is called stratigraphy. Some fundamental principles are used when studying a geological map (others principles exist but are not to be explained here):

1. **Original Horizontality**: Sedimentary rocks are originally deposited in flat horizontal layers (and may later be tilted by faults and folding).

2. **Superposition:** Any sedimentary layer or bed can be assigned an "older" or "younger" age relative to the layers below and above it.

3. **Lateral Continuity:** Layers are originally deposited as continuous layers. So a layer generally has the same age and the same facies over its entire extent, for example over a geological map (= the same thickness, the same type of rock). The layers may be faulted or removed by erosion after their deposition.

4. **Cross-Cutting Relations** - If a body or discontinuity cuts across a stratum, it must have formed after that stratum. This principle is essential in studying all kinds of rocks, not just sedimentary ones. With it, we can interpret geologic events such as faulting, folding, deformation, and emplacement of dikes and veins.

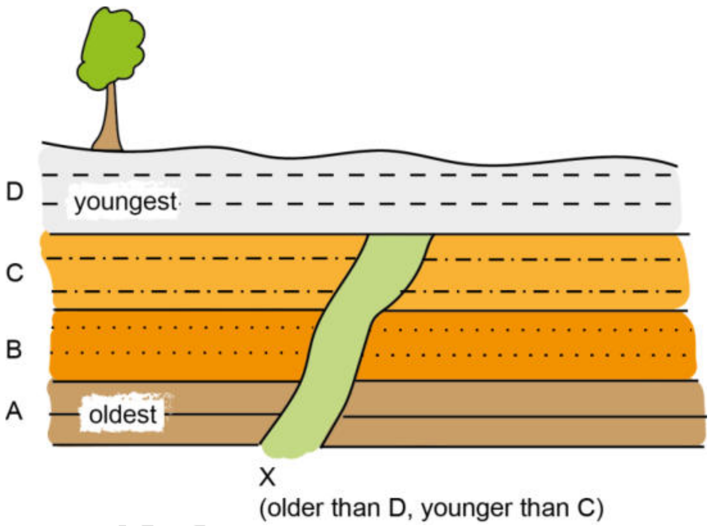


Figure 1: Illustration of the principles of original horizontality, superposition, and cross-cutting relations.

1.3. Folds and faults

Folds and faults are **deformational structures**, also called **tectonic structures**:

- **Folds** are structures where layering is deformed without breaking so that the layering surfaces are curved but continuous: a fold is defined as **"a curved arrangement of originally parallel surfaces".**
- **Faults** represent a different type of response by rocks to the stresses imposed on them. Faults are **fracture surfaces** along which **appreciable displacement** of the layering has taken place: Faults are surfaces in the Earth along which one side moves or has moved with respect to the other.

The study of these structures and deformations is called **Tectonics**.

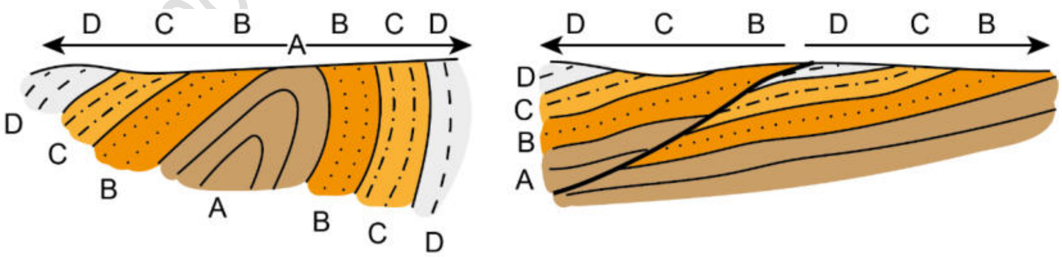


Figure 2: Anticline fold (to the left) and fault (to the right).

1.4. The geologic time scale[1]

The geologic time scale (or stratigraphic time scale) **is the "calendar" for events in Earth's history**.

It **subdivides all time into named units** of abstract time called: **eons** (longest units), eras, periods, epochs, and **stages** (or ages). The enumeration of those geologic time units is **based on stratigraphy**, which is the correlation and classification of rock strata. The **fossil** forms that occur in the rocks provide the chief means of establishing a geologic time scale.

Eons		Eras	Series or Epochs	Numerical ages (Ma)
Phanerozoic		Cenozoic (Tertiary)	Quaternary Neogene Paleogene	66
		Mesozoic (Secondary)	Cretaceous Jurassic Triassic	251
		Paleozoic (Primary)	Permian Carboniferous Devonian Silurian Ordovician Cambrian	538,8
Precambrian	Proterozoic			2500
	Archean			4000
	Hadean			4600

Figure 3 : Simplified stratigraphic time scale (with major divisions).

2. Geologic maps

2.1. Definition

Geologic maps represent the **distribution of different types of rock and surficial deposits**[2], as well as **locations of geologic structures such as faults and folds**.

Rock types or unconsolidated materials are depicted **using different colors**. Maps are based on detailed fieldwork in a variety of terrains.
Measurements taken at the surface are used to predict the location of geologic units and structures at depth and these **predictions are shown on cross-sections** (see below).

Why are we using geologic maps?
Geologic maps are **suited to solving problems involving Earth resources, hazards, and environments**. Geologic maps are the primary source of information for various aspects of land-use planning, including the siting of buildings and transportation systems. Thus, a geologic map is a major tool for communicating geologic information to other geologists, various professionals and also to the public.

2.2. Description

On the map and around the map, we will find lots of information, both topographical and geological:

2.2.1. General information

To give the map reader an indication of where features on the map are located in the real world, geologic maps display the geology overlain on a representation of the land surface that is known as a **base map** (= it's a topographic map !). **Base maps may show streams, roads, and other cultural features, and may also include elevation contour lines** that show land surface topography. Base maps all have the goal of getting you oriented and situated on the map.

[1] The most widely used standard charts showing the relationships between the various intervals of geologic time is the ***International Chronostratigraphic Chart***, which is maintained by the ***International Commission on Stratigraphy*** (ICS)
[2] Exposures of the bedrock surface are called **outcrops**.

So, on the map (and its margin), we will find the **same type of information as those present on the topographic map**; for example: the title and number of the map, type of projection used, contour lines and contour interval, geographical grid, scale, magnetic declination, meridians and parallels…

2.2.2. Geologic information

Colors and letters

Geologic maps use color to represent various types of geologic features or units (a particular type of rock with a known age range). Geologic units are indicated by colors that can range from yellows and reds to purples and greys. These colors are **standards**, which means that the same colors are always used for the same stratigraphic unit (but you should always refer to the legend to be sure of the meaning of a color):
For example: purple is used for Triassic layers, blue for Jurassic and green for Cretaceous.

Geologic units are also assigned a set of letters. The set is usually composed of an initial capital letter followed by one or two lowercased letters. The capital letter represents the age of the geologic unit. The lower-cased letters indicate the geologic unit's name or the type of rock of which it is comprised.

Examples:

- **For sedimentary rocks**, we use a letter for periods and a number for stages or series: *k = Cambrian, t = Triassic, j = Middle to Upper Jurassic /* j^5 *= Oxfordian,* j^6 *= Kimmeridgian (stages bellowing to the Jurassic period)*
- **For recent superficial formations** (Quaternary): *F = alluvial deposits, G = glacial deposits…*
- **For volcanic, plutonic and metamorphic rocks**, we use Greek letters: *β: basalt, ρ: rhyolite, γ: granite, ξ: micaschiste, ζ: gneiss…*

Map key (or legend)

To help the user understand a geologic map, a map key is always provided. A map key is a **table that displays all the colors and symbols used** on the map.

What can we find on the map key?

- **The list of geologic units**, starting with the most recently geologic unit (on top) and finishing with the oldest (at the bottom): it gives a description of the type of rocks and their age, next to the color that represents them on the map.
- **The list of all symbols used on the map**, such as different types of lines, the strike and dip marks and the faults.
- If necessary, a map key also contains other important information, such as **the locations of fossils, deposits of precious metals** (such as gold or silver), or **quarries**.

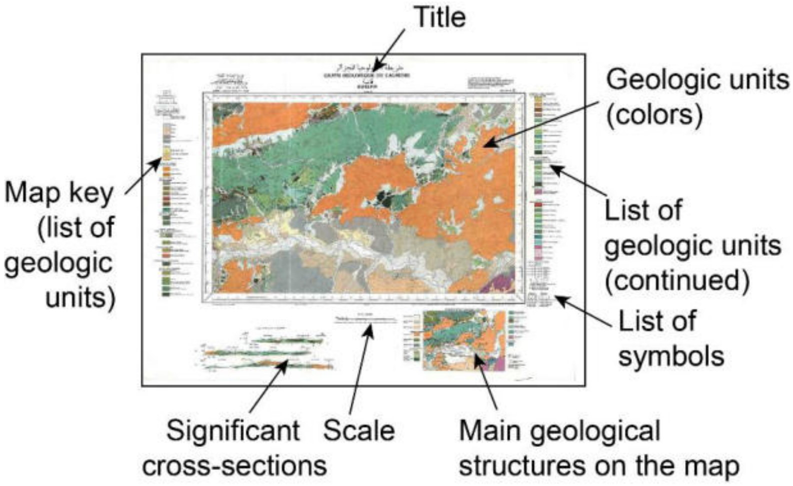


Figure 4 : Main features on a geologic map.

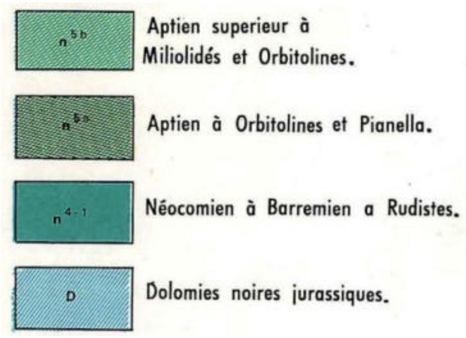


Figure 5 : Part of a map key (list of geologic units).

Contact and fault lines

When **two geologic units are located next to each other**, the place where they meet is called a **contact**. The two main types of contacts are depositional contacts and faults:

- **Depositional contacts** are indicated by a **thin line**, and correspond to the place where the two units meet. We use dotted lines when the contact is not directly visible on the surface.
- **A fault line** is indicated by a **thick line** (dotted thick lines if the fault is not directly visible on the surface). Faults are cracks or fractures in Earth's crust which take place after the geologic units have formed.

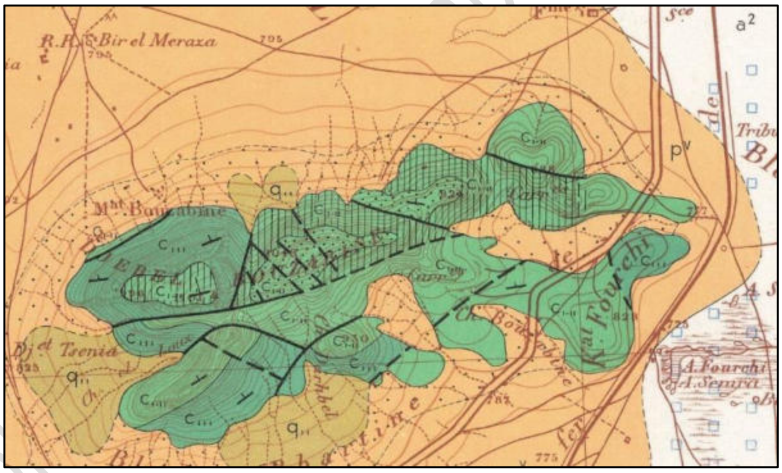


Figure 6 : Extract of a geologic map showing depositional contacts (continuous or dotted thin lines) and fault lines, visible or not (continuous or dotted thick lines).
Visible layers: Cretaceous (green), Pliocene (orange), Quaternary (white and beige).

Strike and dip symbols, folding symbols

Originally, bedrocks are horizontal, but, due to tectonic stresses, they can tilt thereafter. To identify such a bed on a geologic map, a strike and dip symbol is used. Both strike and dip-direction are compass directions, measured with reference to north.

- **The line of strike is the intersection between the bedding plane and the horizontal plane**. Within a dipping plane the line at right angles to the strike line is the line with the steepest plunge.

Example: If we think of the sloping roof of a house as a dipping plane, the lines of the ridge and the eaves are equivalent to strike lines.

- **The dip is the slope of a geological surface.**

There are two aspects to the dip of a plane:

- **The dip-direction is perpendicular to the strike**: it is a line at the intersection of a vertical plane and the horizontal plane. It represents the compass direction towards which the plane slopes;
- **The dip itself is the angle of inclination**, measured from horizontal down to the bedding plane. It is most efficiently expressed as a two-digit number that varies between horizontal (00°) and vertical (90°). Please note that this angle is not always indicated on maps.

The dip is measured with a **magnetic compass** which incorporates a device called a **clinometer**.

- **Folding symbols** could also be given on a map: they indicate where and what kind of fold is present.

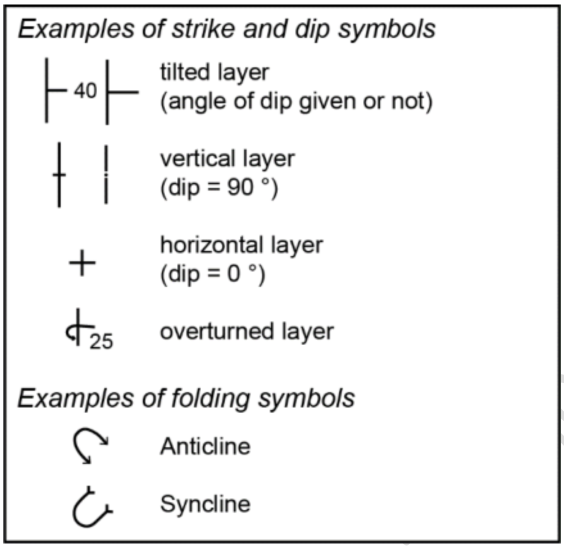


Figure 7 : Dip and folds symbols.

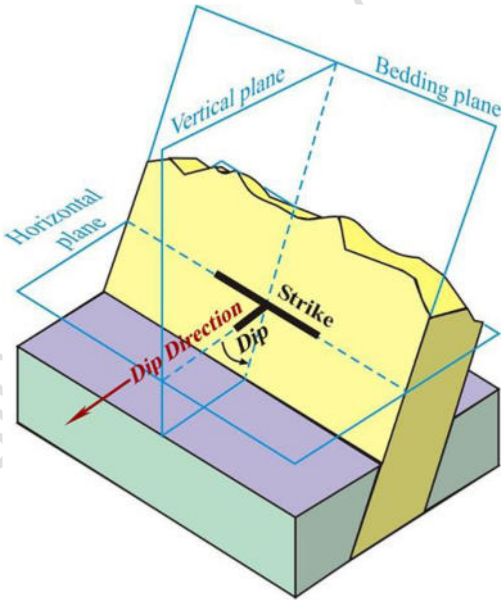


Figure 8 : Measurement of strike and dip (1).

Note: if the dip is not indicated on the map, it can however be estimated by studying contacts lines and their relationship with contour lines, as well as the thickness of the beds.

3. Geological cross-section

3.1. Definition

In geology, a cross-section (or cross section) is a **diagram representing the geologic features intersecting a vertical plane**, and is **used to illustrate an area's structure and stratigraphy** that would otherwise be hidden underground.

The features described in a cross section can include **rock units, faults, topography**, and more. They often accompany geologic maps.

Cross sections are **made by interpreting and extrapolating** a broad range of information about a region's geological characteristics (data from the surface, geologic maps). A lot of information cannot be directly observed, so there is always an **amount of uncertainty about the accuracy** of the final product.

Differences between the topographic profile and the geological cross-section:

- ***For the topographic profile***: no extrapolation / every points is pick off from the map.
- ***For the geological cross-section***: lot of extrapolation / only outcrops visible, hidden strata organization should be understood. It is therefore necessary to understand and interpret.

3.2. Useful information

3.2.1. Colors or patterns ?

On the map, the different rocks are identified by colors and letters.

On the cross-section, colors as well as patterns could be used, but:

- **Colors are generally used for a numerical work** (using a computer): they could be combined or not with patterns. But whatever you choose, there are some conventions to respect (standard colors).
- **Patterns are preferred for a traditional work** (using a sheet of paper), indeed colors are difficult to clearly reproduce.

Which pattern for which rock?

Each kind of rock is represented by a special pattern, usually quite the same all around the world. Different patterns could also be mixed for intermediate rocks.

But keep in mind that:

- **The pattern type should be correctly chosen:** it generally reminds the aspect of the rock (for example small dots for sand, small dashes for clay),

And

- **The pattern disposition on your cross-section should always follow the dip** (see figure below).

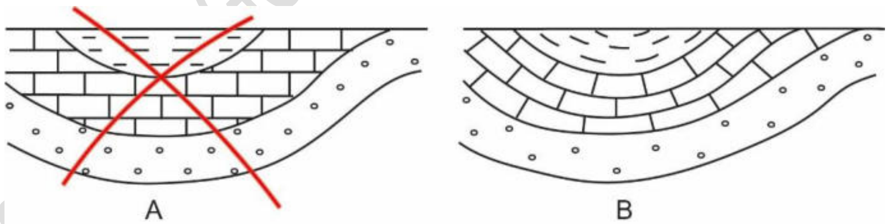


Figure 9 : Pattern disposition.
A : Incorrect. B : Correct.

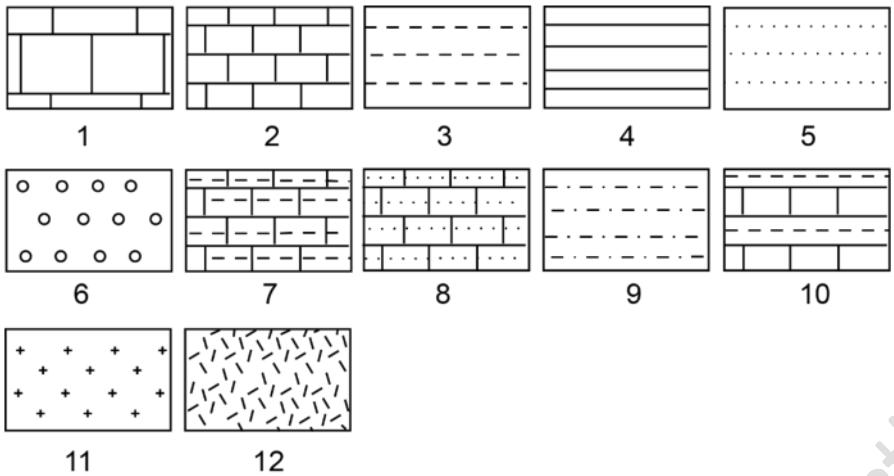


Figure 10 : Examples of geological patterns.

1 et 2 : Limestone (thick or thin beds), 3 et 4 : Clay or marl, 5 : Sand or sandstone, 6 : Gravels or conglomerate, 7 : Argillaceous (or shaly) limestone, 8 : Sandy limestone, 9 : Sandy marl (or argillaceous sand), 10 : Interbedded limestone and marl, 11 : Granite (magmatic rock), 12 : Metamorphic rock.

3.2.2. Difference between thickness and width of a layer

On a geologic map, **the thickness of a layer stay the same (according to lateral continuity principle), but its width on the map can vary a lot**. It depends on three factors: the true thickness (TT), the topographic slope and the dip:

- The true or stratigraphic thickness of a unit is the distance between its bounding surfaces measured in a direction perpendicular to these surfaces (see 'TT' on the figure below)
- The width of outcrop of this unit is usually different from the TT. In some case, the width (W) can be equal to TT, but it can be much greater.
- The width is the same as the true thickness when the ground is flat and the layer vertical.

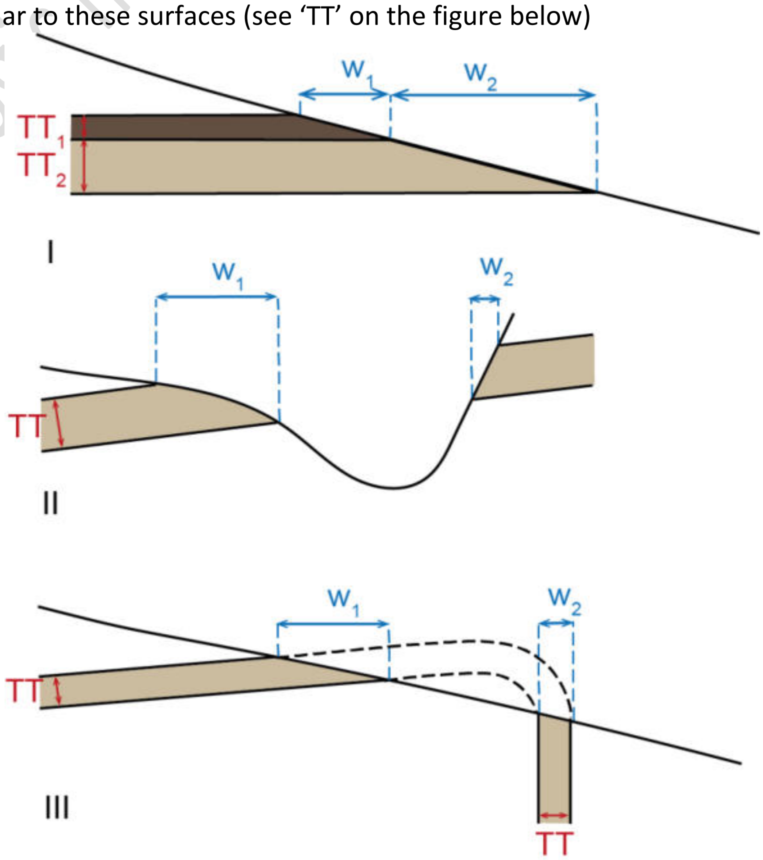


Figure 11 : Different explanation for the width variation.

I. The true thickness varies (the width of outcrop is bigger when the thickness is great: w2 > w1)
II. The slope varies (the width of outcrop is bigger when the slope is low: w1 > w2)
III. The dip varies (the width of outcrop is bigger when the dip is low: w1 > w22)

In case of a flat ground, the true thickness can be determined thanks to the following formula:

TT = a.sin(angle), with TT = true thickness, a = outcrop width and angle = dip

3.2.3. Disposition of the strata

- **Horizontal or sub-horizontal strata (< 5°)**

When sediment is initially deposited, it is laid down in horizontal layers (= strata).
Horizontal bedding usually indicates that **little or no structural deformation** has occurred to a sedimentary succession after deposit. Horizontal bedding may give rise to **very simple geological maps**.

Recognize horizontal strata on a map

- **Depositional contacts are parallel to the contour lines**: their projection on a map **never intersects** the contour lines,
- When the ground is flat (plateau or plain), **only the youngest layer outcrops** and is therefore represented on a geological map,
- The **dip symbols are all identical** (+),
- The **oldest layers are visible at the bottom of the valleys**.

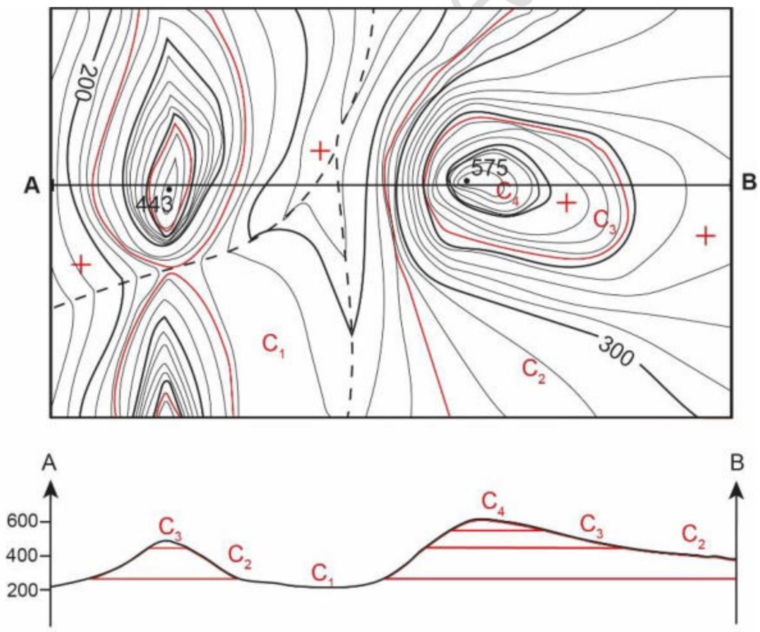


Figure 12 : Horizontal strata, on a map (top) and cross-section (bottom).
On the map, topographic information is given in black color (contour lines, valley, peak) and geologic information in red color (depositional contacts, letters for the different layers, dip symbols).

- **Inclined strata (uniformly dipping beds)**

Inclined bedding is the simplest form of rock deformation: strata become tilted relative to their original (horizontal) disposition. In this case, **the orientation of the inclination is the same for all strata**.

The two parameters used to describe the bedding plane are the dip and the strike (see above).

Recognize inclined strata on a map

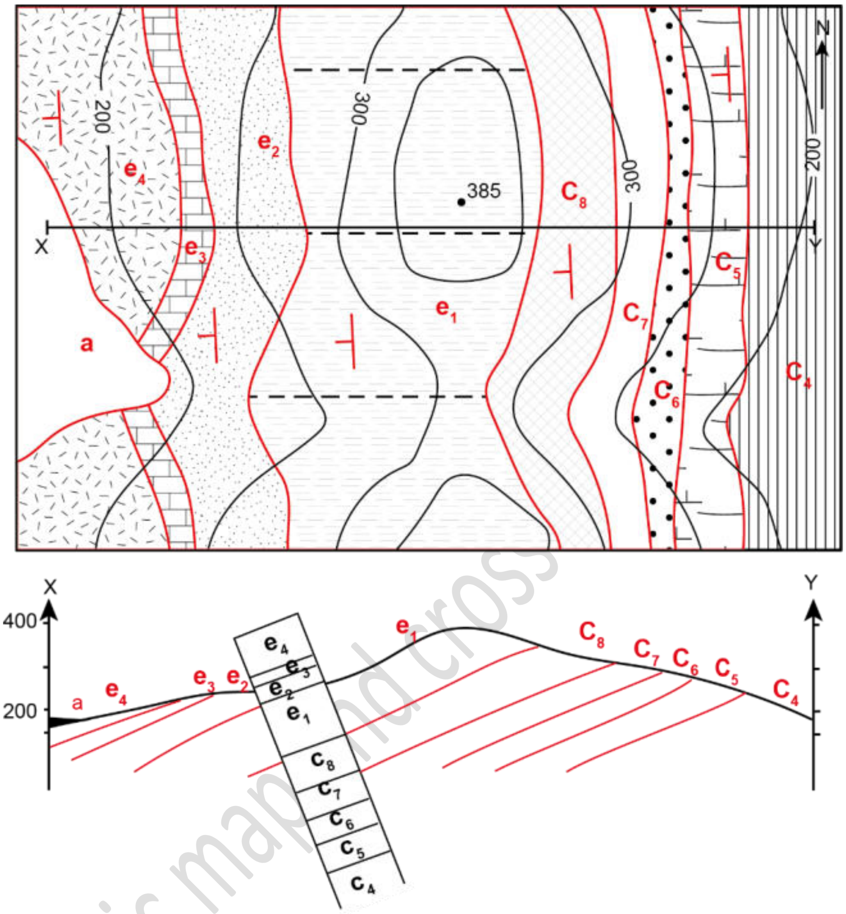
- **The bedding planes are inclined** (could also be **vertical**): their projection on a map **always intersects** the contour lines
- **The dip symbols are all identical** (├ or ┼ ╎)
- **When depositional contacts cross valleys**, the contacts are bent, or deflected. The direction and amount of bending depends on the slope of the valley and the dip of the beds. **The Rule of "V"** is helpful for **determining the general dip** of a bed on a geological map or block diagram if it is not shown by a symbol (see figure below).

Figure 13 : Inclined strata, on a map (top) and cross-section (bottom).

On the map, topographic information are given in black color and geologic information in red color. The layer 'a' is superficial (recent deposit): this kind of deposit is not shown on cross-sections (unless by a slight thickening on the left part).

All the layer are inclined toward West.

***Note*: To construct the cross-section, we can use a little paper column indicating the thickness of the layers.**



Explanation of the 'rule of 'V' *(figure below):*

- **Horizontal geological surface** (fig 14.c): the **outcrop trace is parallel** to the topographic contours.
- **Vertical geological surface** (fig 14.b): the outcrop trace is a **straight line** parallel to the strike; it ignores topographic contours.
- **Dipping surfaces**: the outcrop traces show **V-shapes as they cross valleys** and ridges; these regions are particularly useful in determining strike and dip.
  - In general, the **V-shape points in the direction of dip** (This is the "rule of V") (see fig 14.a and d)
  - **The only exception occurs when the dip is in the same direction as the slope of the valley, but gentler than the gradient** of the river; then the V-shapes point up-dip. For planar surfaces with shallow dip (gentler than the typical hill slopes of topography in the region) the outcrop trace will generally follow topographic contours quite closely, crossing them at widely spaced intervals (see fig 14.e).

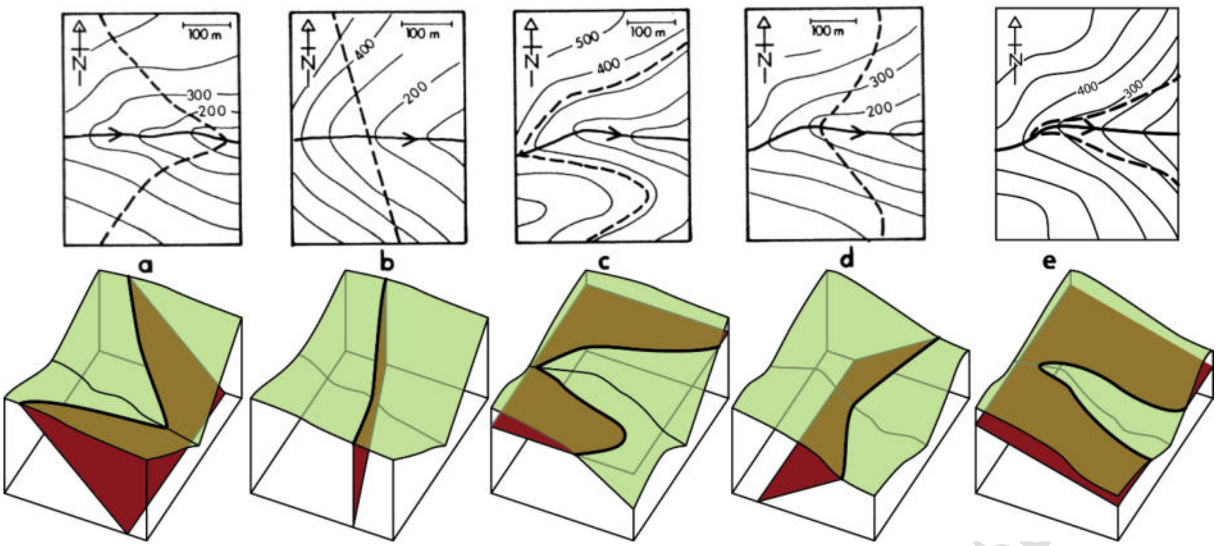


Figure 14 : Sketch maps and block diagrams showing the outcrop traces (dashed lines) of geological surfaces of different orientation: (a) Dip to the east; (b) Vertical; (c) Horizontal; (d) Dip to the west; (e) Dip to the east but less steep than valley (2).

- **Folded strata**

A geological surface which is curved is said to be folded. In case of folding, strata can have different direction of inclination.

The two main types of folds are anticlines and synclines (but the symmetry and orientation of these fold structures can be highly variable):

- **Anticlines close up** (think nticline),
- **Synclines open up** (think s ncline).

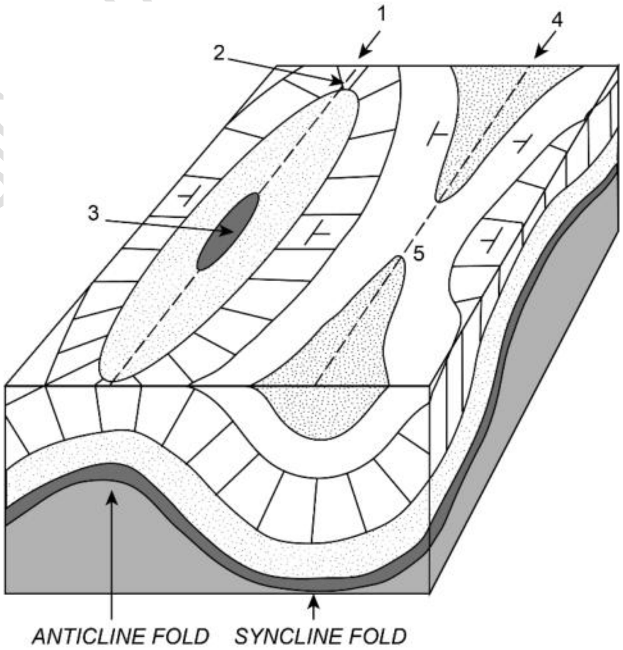


Figure 15: Anticline and syncline folds.

1: anticline fold axis, 2: peri-anticline termination, 3: center part of the anticline 4: syncline fold axis, 5: peri-syncline termination.

Recognize folded strata on a map

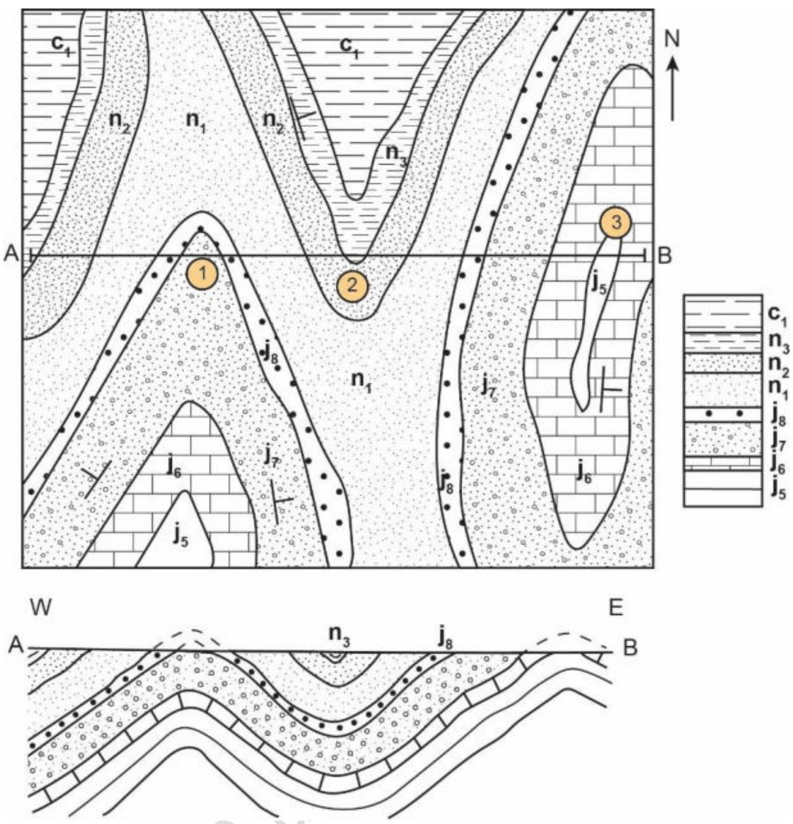
- As for inclined strata, the depositional contacts always intersect the contour lines
- The dip symbols are different (├ or ┤ or ┼ or ┴ ┆)
- Folded strata are characterized by elongated **concentric outcrops** (see figure below):
  - **Oldest strata** can be found in the **center of the anticlines**
  - On the contrary, **youngest strata** can be found in the **center of the synclines**

Figure 16 : Folded strata, on a map (top) and cross-section (bottom). (The topographic features are no to be seen in this figure).

1 and 3: **Anticlines (oldest layer j5 is located in the center)**

2: **Syncline (youngest layer c1 is located in the center).**

On the right: Stratigraphic column giving the thickness.



Depending on the dip of the layers, we can have different types of folds (see next figure).

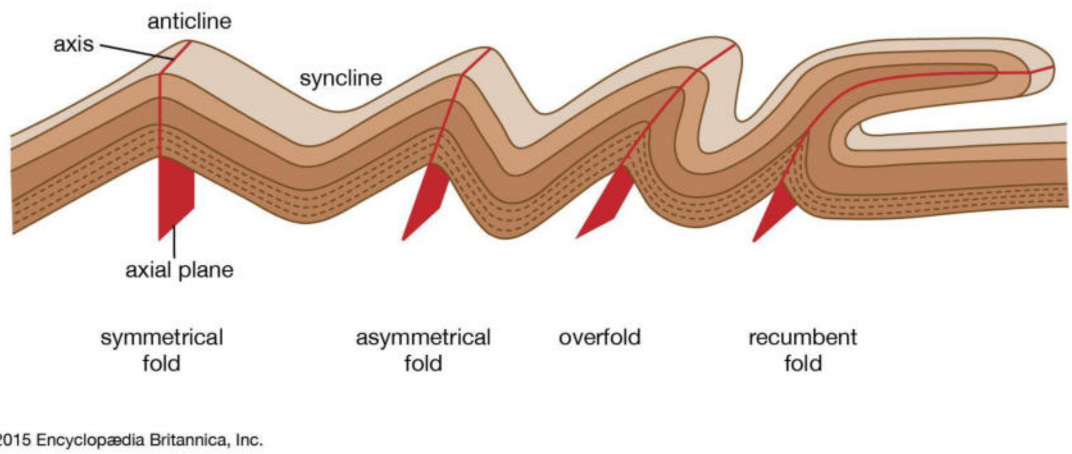


Figure 17 : Different types of folds (https://www.britannica.com).

d) Transgressions, regressions, unconformities

Note: this part is not for L1 students.

The **sea level varies over geological time**:

- A **transgression** occurs when a shoreline migrates landward (for example when sea level (or lake level) rises).
- A **regression** occurs when a shoreline migrates seaward (for example when as sea level (or lake level) falls).

Relative changes in sea level over time cause unconformities[3]. Erosion strips away materials exposed to waves and currents:

- A rise in sea level causes a transgression which creates space underwater for sediments to be deposited. New (younger) material is deposited on the scoured surface.
- When sea level falls it causes a regression, and sediments are not deposited or are eroded away.

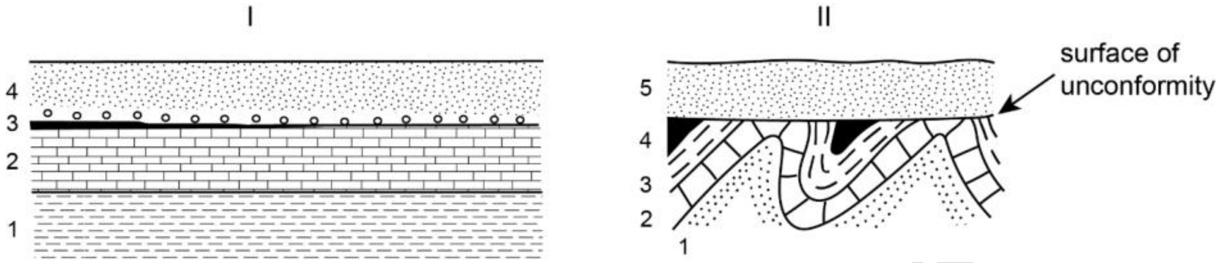


Figure 18 : Transgression and unconformity.

I- Transgression. The layer '4' has formed during a transgression and covers the underlying series.

II- Unconformity. We observe an unconformable boundary between the layer '5' and the layer '4'. Layers 1 to 4 have been folded and eroded before its deposit.

Note: Recent continental formations (Quaternary) often hide the geological contours (e.g., alluvium, scree, glacial deposits, etc.). This is a special case of 'unconformity'. The hidden layers should be drawn without taking into account these recent formations (extrapolation): of course, they are not part of a fold.

Most of the time, these formations have a low thickness and will not be represented on the section or else by a simple thickening of the line (see figure above).

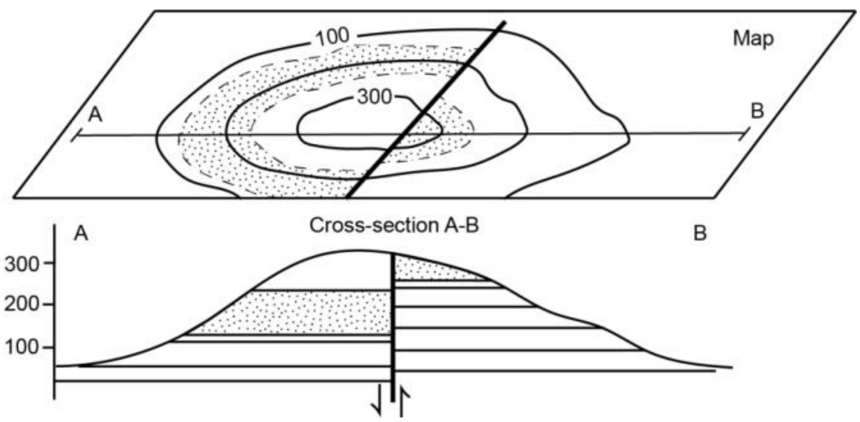
d) Fault lines

Note: this part is not for L1 students.

Fault line is a **type of geological contact**, and is indicated on a map by a **thick line** (or dotted lines if the fault is hidden). In case of a fault line:

- Two different geological units are in contact, ant their limits do not fit
- Fault lines are necessary younger than the geological units crossed (according to cross-cutting relations principle)

Figure 19 : Vertical fault crossing a hill (map and cross-section).



[3] An unconformity is a surface between successive strata that represents a missing interval in the geologic record of time, and is produced either by: a) an interruption in deposition, or b) by the erosion of depositionally continuous strata followed by renewed deposition.

3.3. How to construct a cross-section?

The different steps to create your cross-section are:

1. Locate the points between which you will be constructing a cross-section for and draw a line on your map (for example: between the point A and B in the figure below).
2. Firstly, you should construct the topographic profile between these two points.
3. Observe the geologic map in this region. Pay close attention to any strike and dip symbols, geologic contacts, and ages of the rock types. You can highlight important information on your map with colors.
4. Take a sheet of scrap paper. Place the paper along the map where you want to draw a cross-section.
5. At each geologic contact, make a mark on the paper. Position the marks in the direction you believe the rocks are dipping. To determine this, use any strike and dip symbols. If they are not provided, you can use for example the ages given to determine the geologic structure, or the rule of 'V' in the valleys.
6. Transfer the marks from your paper to your topographic profile.
7. Sketch in and complete any structures, paying careful attention to dip angles (if provided).
8. Incorporate a legend into the cross-section to explain the types of geologic materials present, and to give some important information (title, scale, orientation…).

Note: Because the length of the studied area is often much greater than the depth, the diagram's scale can be vertically exaggerated to emphasize the depth or height of features and make them more visible, but the use of exaggerated vertical scales on cross-sections should be avoided.

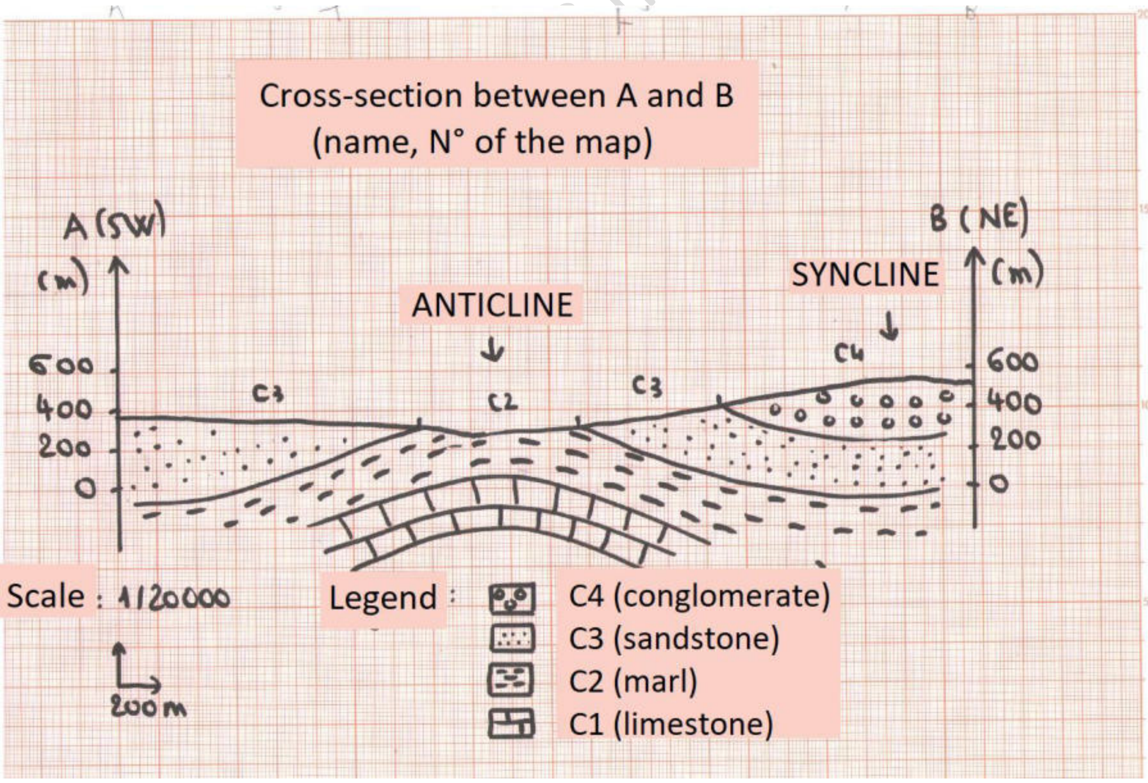


Figure 20 : Example of a cross-section.

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LISLE R.J., 2004: *Geological Structures and Maps. A practical guide* (Third edition). British Library Cataloguing in Publication Data, 106 p.

Various websites:

(1) Geological maps: https://opengeology.org/historicalgeology/tools-of-historical-geology/geologic-maps/
(2) Geological structures: a practical information: https://openeducationalberta.ca/introductorystructuralgeology/chapter/b-orientation-of-structures/
(3) How can you determine the true thickness of a layer? (according to the dip angle and the outcrop width):
https://sciences-paysages.fr/geologie/epaisseurCoucheGeologique.htm
https://www.southalabama.edu/geography/allison/GY403/LABMAN_chapt7.pdf

And useful videos, for example:

- *THE GEOLOGICAL MAP "Drawing the Earth's skin" (9'47''): https://youtu.be/qdz9DN74ukY*
- GEOCOAST - Using Geological Compass: Measuring Strike, Dip & Dip Direction (4'17''): https://youtu.be/FbXhooadhZw
- My own youtube channel 'TP Géologie L2', where you can find lots of videos to help you with the courses and TD of Geology: these videos have been recorded in French, but you can activate the subtitles:
  - Home page: https://www.youtube.com/channel/UCc3Oy3cKuIxhcet3HvBs_YA
  - Playlist concerning the cartography ("TD Géologie de 1ère année SNV"): https://youtube.com/playlist?list=PLjepoOw2WVmh18Iv6bLIhYDUuqxojZIxS

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