University 8 May 1945 – Guelma (Algeria)

Geology L1 (Tutorials)

Geologic map and cross-section

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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. **Igneous (or Magmatic) 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[1] and their relationship is called stratigraphy.
Some fundamental principles are used to determine the relative age of rocks, or 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 layer or fault cuts across a stratum, then it must have formed <u>after</u> that stratum.

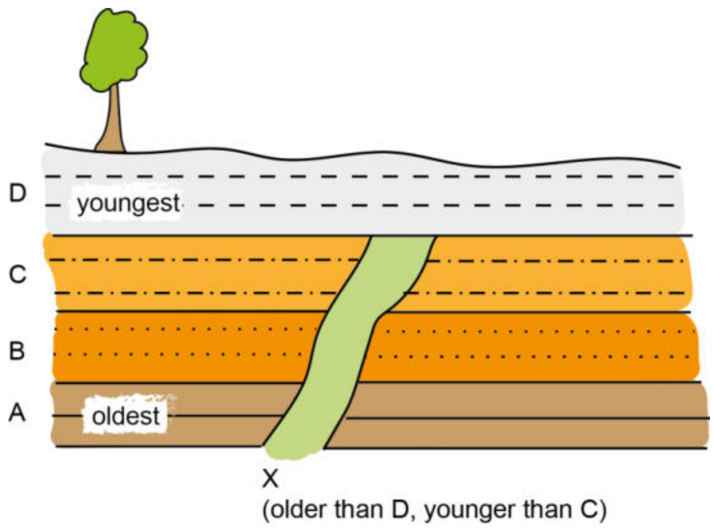


Figure 1: Illustration of the principles of original horizontality, superposition, and cross-cutting relations.

[1] A STRATUM (plur. STRATA) corresponds to a sedimentation unit, with a thickness greater than 1 cm. It can be easily observed on the field (the presence of strata is an important criterion used to identify sedimentary rocks). Synonyms of this word include the terms layer, bed or level.

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**.

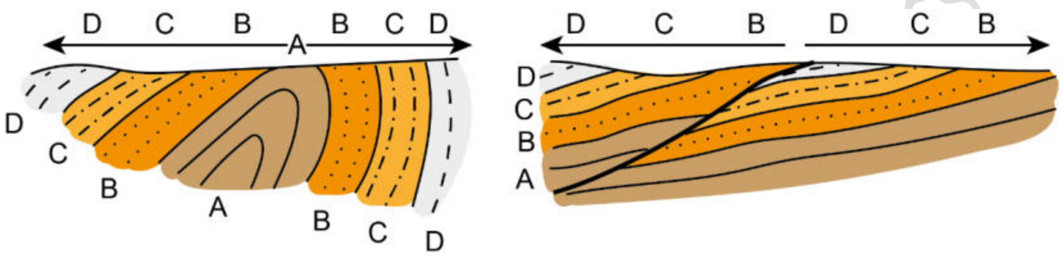


Figure 2: Anticline fold (to the left) and fault (to the right).

1.4. The geologic time scale[2]

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	Periods	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
Precambrian: Archean			
			4000
Precambrian: Hadean			
			4600

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

[2] 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) https://stratigraphy.org/

2. Geologic maps

2.1. Definition

Geologic maps represent the **distribution of different types of rock and surficial deposits**[3], 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, lots of information are available, 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.

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.

[3] Exposures of the bedrock surface are called **outcrops**.

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 of 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**.

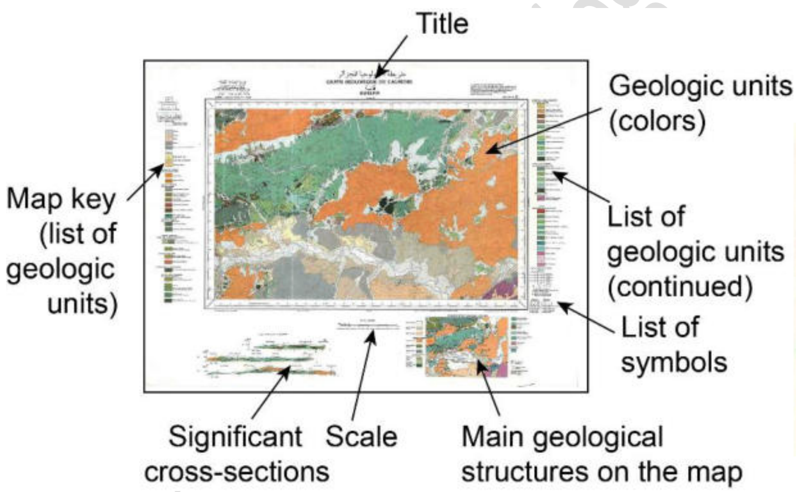


Figure 4 : Main features on a geologic map.

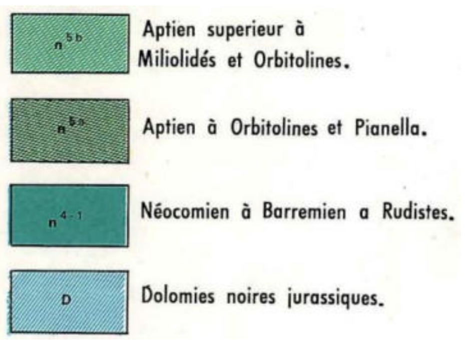


Figure 5 : Part of a map key (list of geologic units).

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.

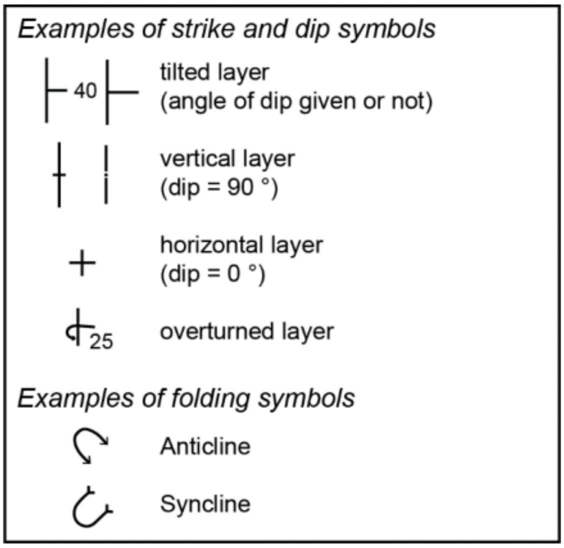


Figure 7 : Dip and folds symbols.

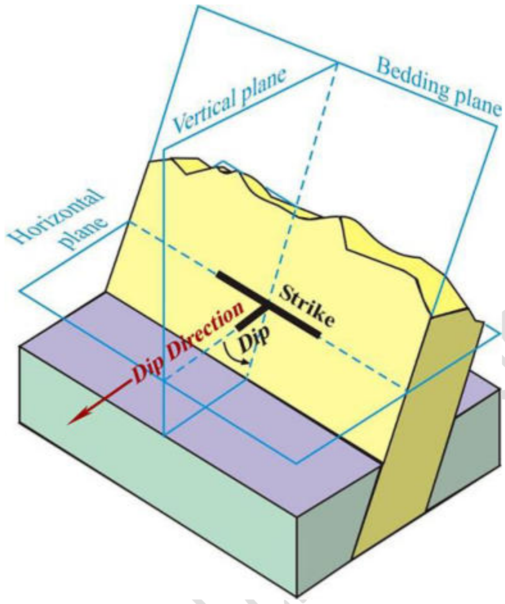


Figure 8 : Measurement of strike and dip (1).

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 point 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 (or symbols) 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).

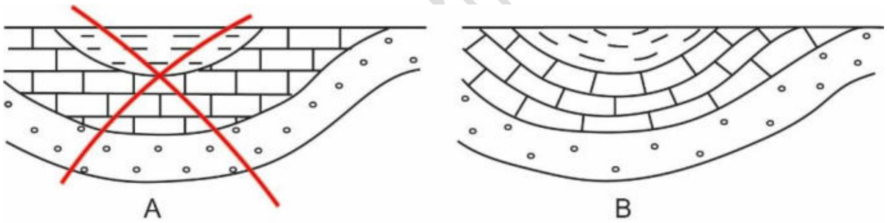


Figure 9 : Pattern disposition.
A : Incorrect. B : Correct.

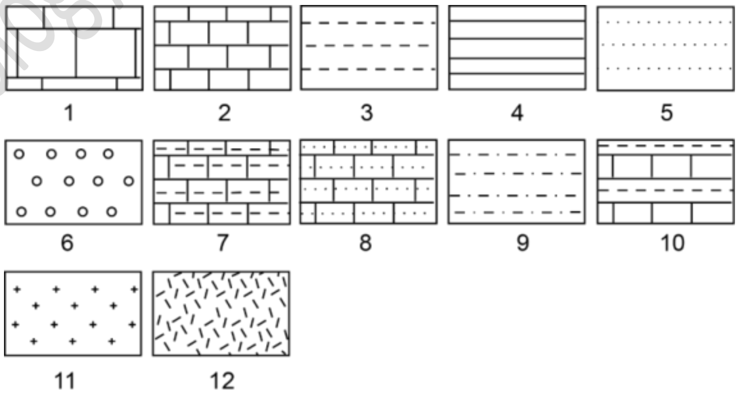


Figure 10 : Examples of geological patterns or symbols.

1 and 2 : Limestone (thick or thin beds), 3 and 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 stays 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.

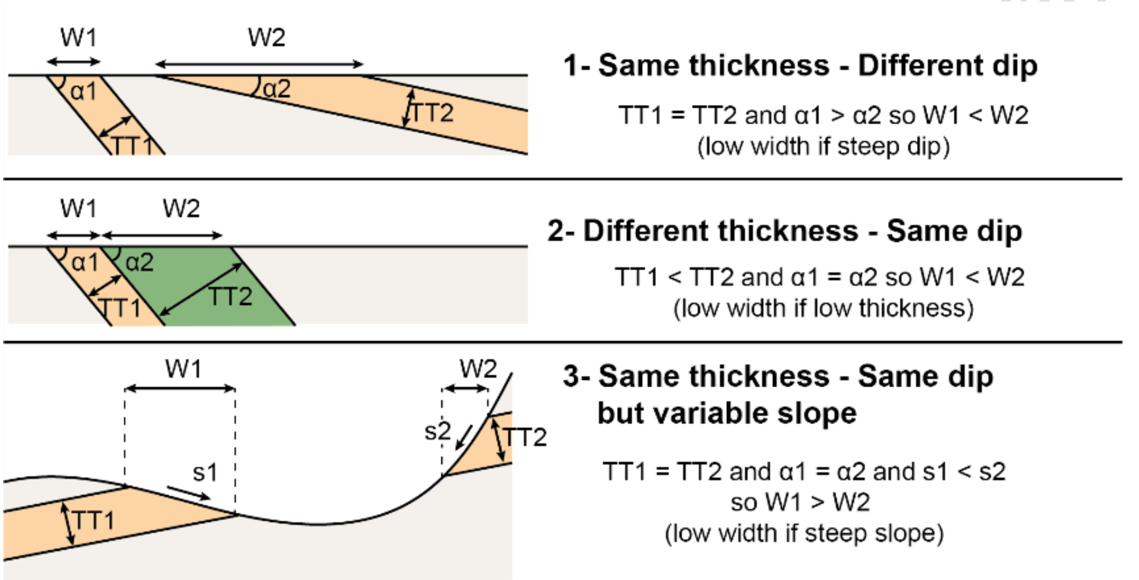


Figure 11 : Different explanation for the width variation.

3.2.3. Determination of the thickness of a layer

To produce a detailed geological cross-section, it is necessary to know the thickness of the layers. Several scenarios are possible:

- The thickness of the layers may simply be indicated **in the map legend** or in the accompanying explanatory notes.
- **When the layers are horizontal** (see Figure 12), their thickness can be determined using contour lines (in this case, it will be necessary to know the contour interval of the map). The thickness of the most recent layer (located on the surface) cannot be determined because erosion may have caused part of it to disappear.
- **When the layers are vertical** (Figure 13A), the thickness can be determined using the map scale (this simply involves calculating the distance between the base and the top of the layer).
- **When the layers are tilted** (Figures 13B and 15), we can use a formula to calculate the thickness. The calculated value depends on two parameters:

TT = W.sin(α), with TT = true thickness, W = outcrop width and α = dip

The dip (α) can be given directly on the map (it can also be calculated), and the outcrop width (W) varies according to the three parameters mentioned in the previous paragraph (dip, layer thickness and topographic slope).
Consequently, this calculation formula can only be used if the terrain is flat (the boundaries of the layer under study must be at the same altitude).

3.2.4. Disposition of the strata

a) 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**.

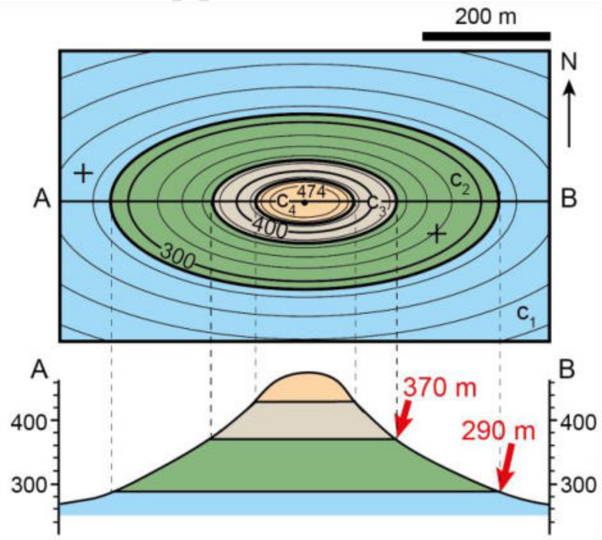


Figure 12 : Horizontal strata, on a map (top) and cross-section (bottom).
The thickness of layer C_2 (in green) is determined using contour lines. It is equal to 80 m.

b) 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**.

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).

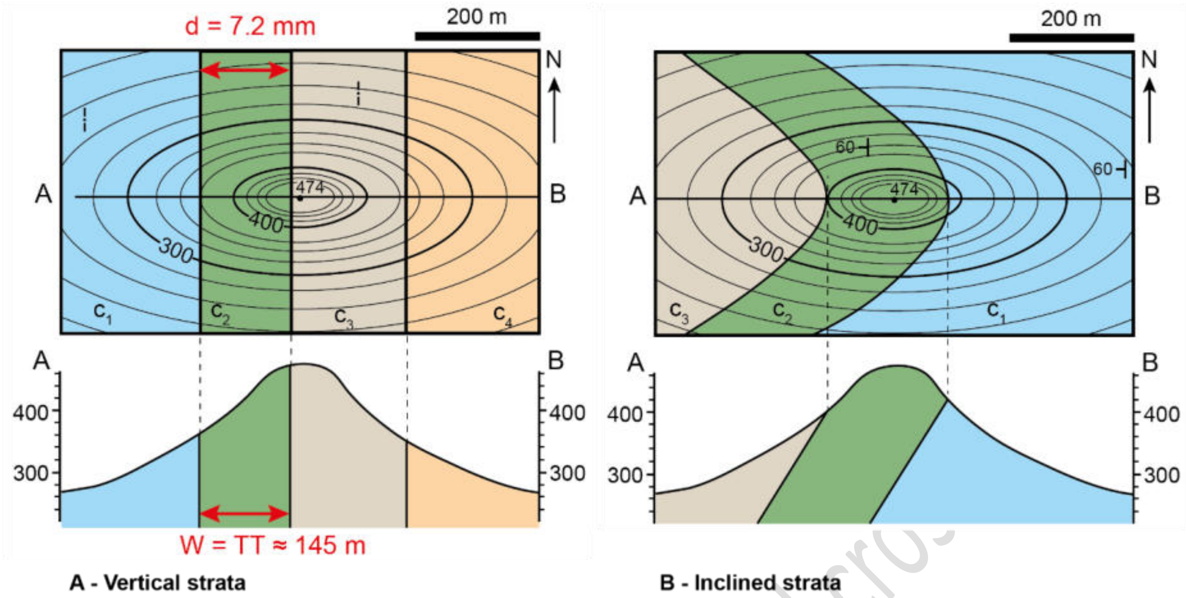


Figure 13 : Inclined strata, on a map (top) and cross-section (bottom).
On the left, the thickness of layer C_2 (in green) is determined using the scale. The distance on the map (d) corresponds to a width (W) of 145 m (and in this case the width is equal to the thickness 'TT').

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

c) **Horizontal geological surface** (fig 14.c): the **outcrop trace is parallel** to the topographic contours.
d) **Vertical geological surface** (fig 14.b): the outcrop trace is a **straight line** parallel to the strike; it ignores topographic contours.
e) **Dipping surfaces**: the outcrop traces show **V-shapes as they cross valleys** and ridges; these regions are particularly useful in determining strike and dip.
   a. In general, the **V-shape points in the direction of dip** (This is the "rule of V") (see fig 14.a and d)
   b. **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).

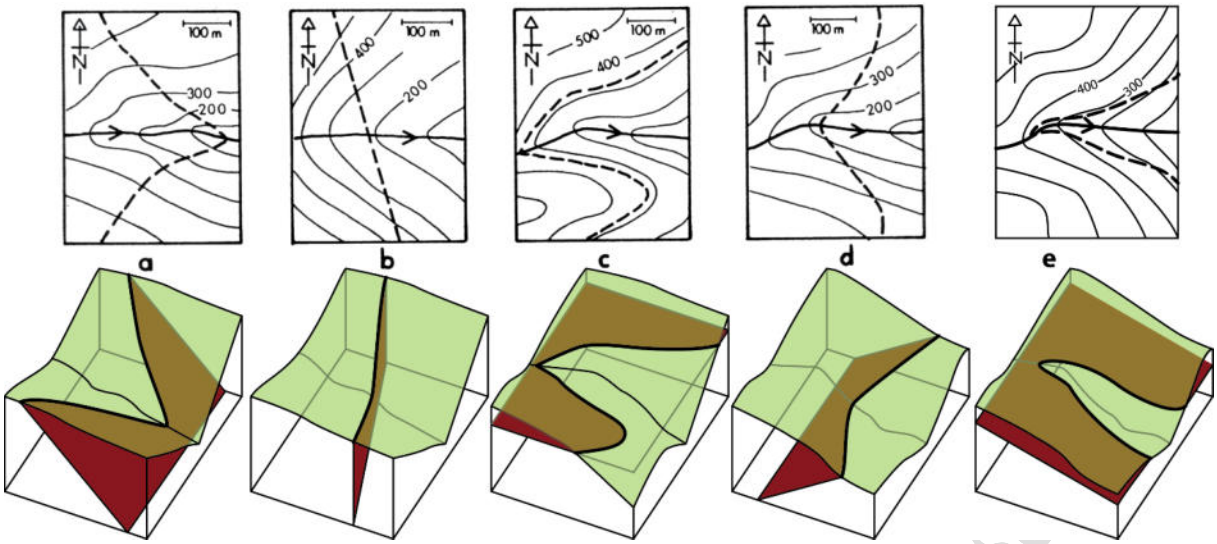


Figure 14 : Sketch maps and block diagrams showing the outcrop traces (dashed lines) of geological surfaces of different orientation: (a) Dip to the east; (b) Vertical; (c) Horizontal; (d) Dip to the west; (e) Dip to the east but less steep than valley (2).

c) Folded strata

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

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):
  - **The oldest strata are found in the centre of anticlines. Anticlines are folds that close up (think Λnticline),**
  - On the contrary, **youngest strata** can be found in the **center of the synclines. Synclines are folds that open up (**think sVncline).

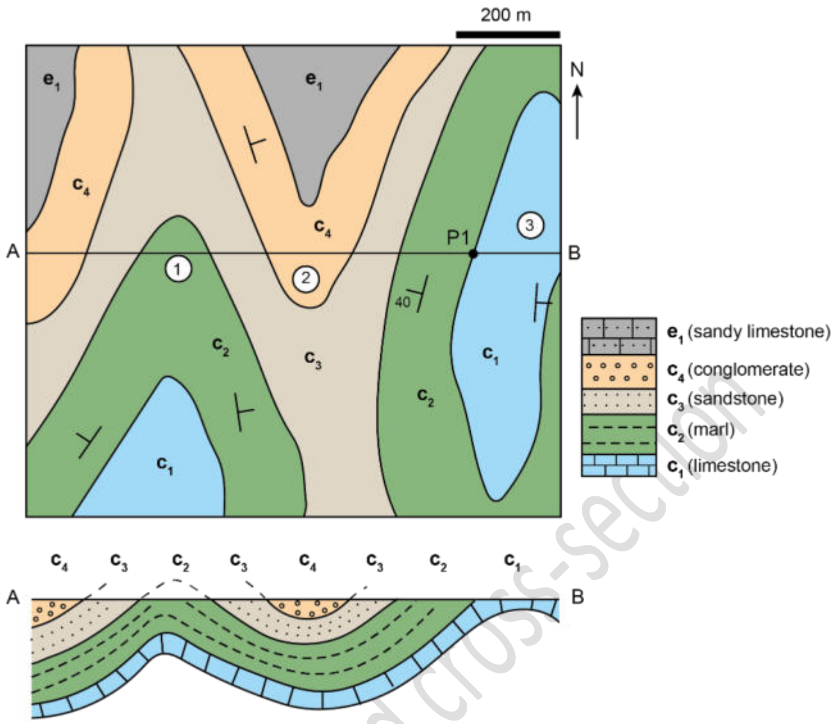
Figure 15 : Folded strata, on a map (top) and cross-section (bottom). (The topographic features are no to be seen in this figure).

The cross-section drawing uses the colors shown on the map, as well as the standard symbols for each type of rock.

Structures 1 and 3 are anticlines. Layer c_1, the oldest, is visible in the center.

Structure 2 is a syncline. Layer e_1, the most recent, is visible in the center.

Right: stratigraphic column with thicknesses to scale.



Calculating the thickness for layer c_2 at point P1 gives us:

- **The dip (α) is equal to 40°**
- **The outcrop width (W) at this location is 150 m**
- **The thickness of the layer is therefore equal to: TT = W.sin α ≈ 96 m.**

Depending on the inclination of the axial plane, we can have different types of folds (see next figure).

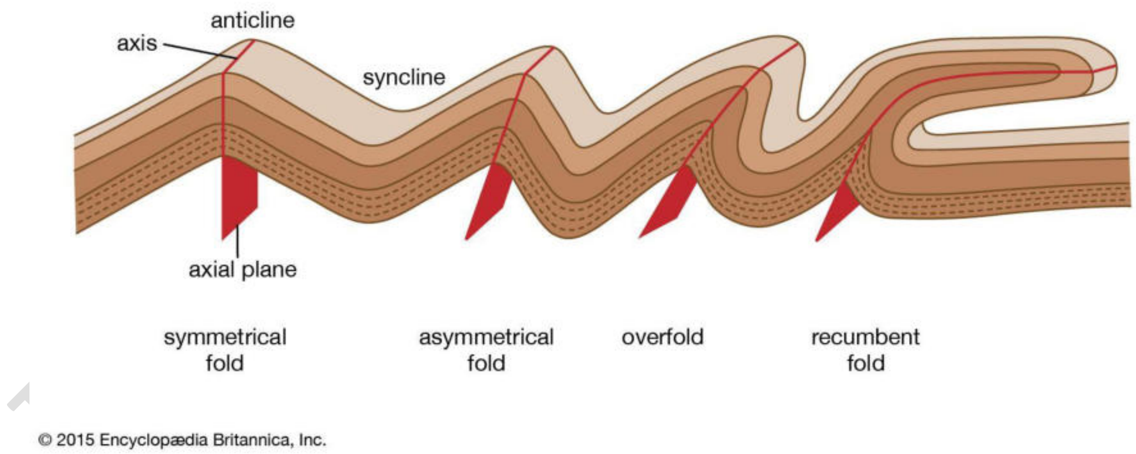


Figure 16 : Different types of folds (https://www.britannica.com).

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[4]. 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.

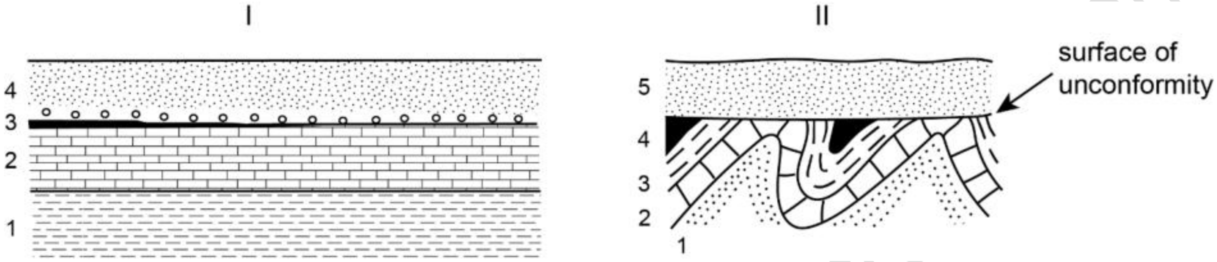


Figure 17 : Transgression and unconformity.

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)

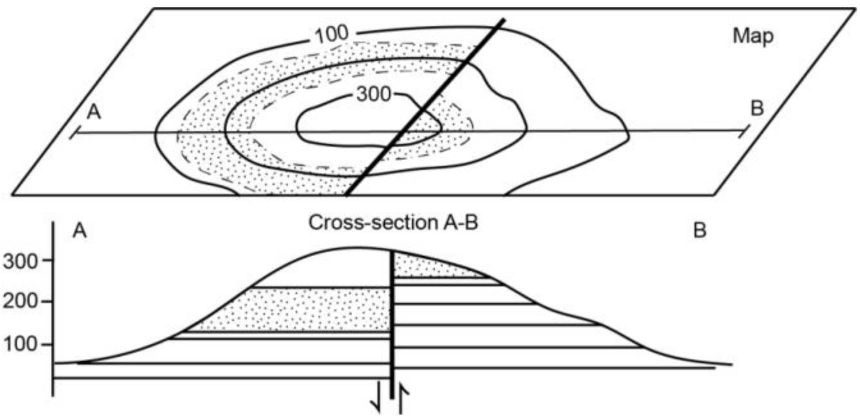


Figure 18 : Vertical fault crossing a hill (map and cross-section).

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[4] 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) 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.

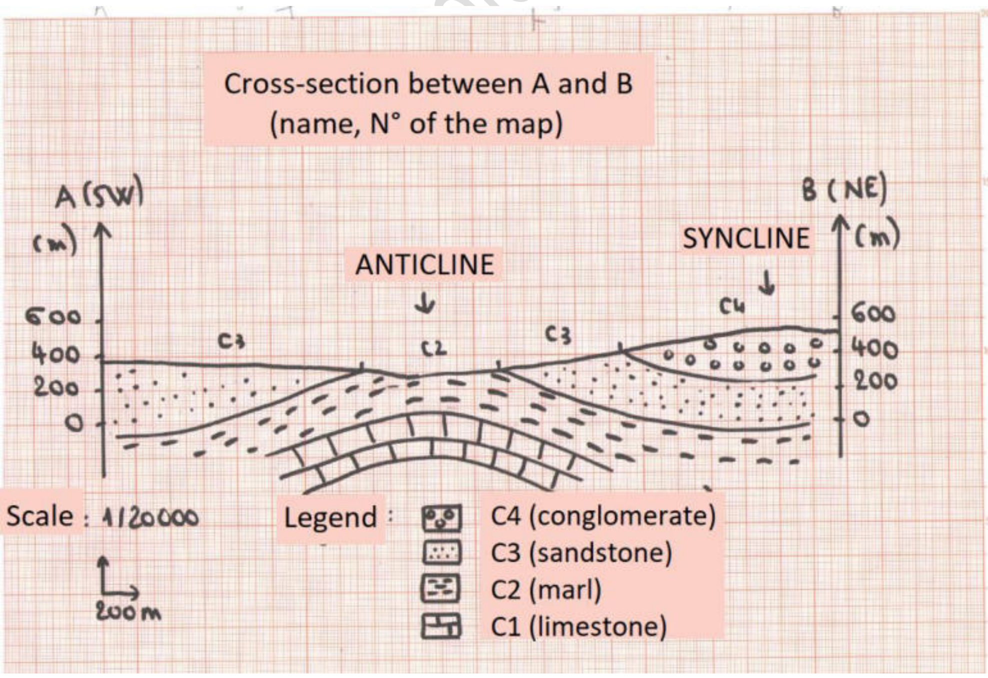

Figure 19 : Example of a cross-section.

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Books:

FOUCAULT A. & RAOULT J.F., 1966: *Coupes et cartes géologiques*. *Travaux pratiques de Géologie de 1er et 2ème cycle*. Société d'édition d'enseignement supérieur, Paris, 146 p.

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/@tpgeologie
  - Playlist concerning the cartography ("TD Géologie de 1ère année SNV"): https://youtube.com/playlist?list=PLjepoOw2WVmh18Iv6bLIhYDUuqxojZIxS

English / French glossary

English	French
Base map	Fond topographique
Clay	Argile
Conglomerate	Conglomérat
Contour interval	Equidistance
Contour lines	Courbes de niveau
Cross-section (geological)	Coupe (géologique)
Depositional contact	Contour géologique (contact normal)
Deposits	Gisements
Fault (normal, reverse, strike-slip)	Faille (normale, inverse, décrochement)
Fault line	Ligne de faille (contact anormal)
Fold (anticline, syncline, symmetrical, overfold, recumbent)	Pli (anticlinal, synclinal, droit, déversé, couché)
Geologic map	Carte géologique
Geologic time scale	Echelle des temps géologiques
Geologic unit	Unité géologique
Layer	Couche
Limestone	Calcaire
Map key (or legend)	Légende
Marl	Marne
Outcrop	Affleurement
Principles (original horizontality, superposition, lateral continuity, cross-cutting relation)	Principes (horizontalité, superposition, continuité, recoupement)
Quarry	Carrière
Rock (sedimentary, igneous, metamorphic)	Roche (sédimentaire, magmatique, métamorphique)
Sandstone	Grès
Scale	Echelle
Stratigraphy	Stratigraphie
Stratum (plur. Strata)	Strate
Dip	Pendage
Tectonics	Tectonique
Valley	Vallée

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