University 8 May 1945 – Guelma (Algeria)
Geology L1 (Tutorials): Topographic map and profile
(Mrs. DJERRAB)

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1. Topographic Maps

1.1. Definition

A topographic map (from the Greek *'topos'* = a place and *'graphein'*= the writing) is a **flat representation** (ex: on a sheet of paper) of a part of the Earth's surface. So **topographic maps are two-dimensional representations of a three-dimensional landscape**. They show the basic landmarks of the area, with **man-made objects** (like roads, buildings, and towns…) and **natural objects** (mountains, sources of water, and areas of vegetation…).

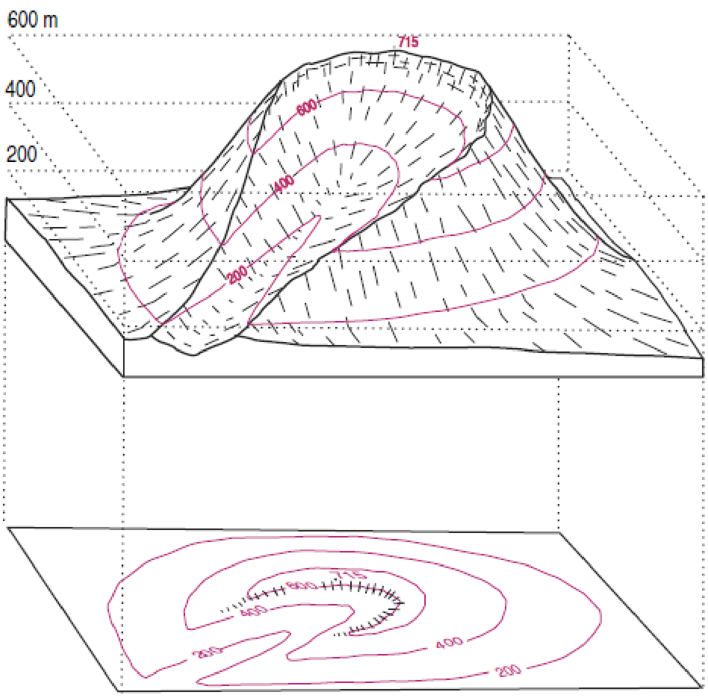


Figure 1: Example of representation of relief (top) on a topographic map (bottom) using contour lines (Sorel & Vergely, 2010).

A bit of history…

Early topographic maps have a rich history, stretching back over **2000 years** with examples from **China** and contributions by **Greek or Roman scholars**, like the **Ptolemy map** from around 150 AD. In the 12th century, Arab scholars, including **Al-Idrissi**, crafted detailed maps (see figure below). However, these maps inevitably harbored errors due to the absence of modern techniques such as satellites. The emergence of **'modern' maps** took place in the **16th century** (**Mercator map**: see figure below).

Figure 2: Examples of old topographic maps. Left: Al-Idrissi (12th century), Right: Mercator (16th century).

1.2. What are the topographic maps used for?

Topographic maps serve a multitude of purposes, catering to both leisure and professional needs. People utilize them for activities like travel, hiking, and orienteering, while government and industry rely on these maps for urban planning, mining, emergency management, and delineating legal boundaries and land ownership. Additionally, topographic maps prove valuable in geological applications, aiding in the creation of cross-sections.

1.3. Map projections

Problem: The Earth's surface is three-dimensional (3D), while the sheet of paper is two-dimensional (2D).

Solution: A map projection is used.

Map projection is the process of **transforming and representing on a flat surface** (in 2D: sheet of paper or computer screen) **points located on the spherical surface** of the Earth (in 3D).

There are **many types of topographic projection**, for various types of maps, in different places on the planet. The projection depends on the surface covered and the type of relief. None is perfect, each has its faults and its qualities.

For example, in the basic Mercator projection, distances and areas are grossly distorted near the map's polar regions.

A topographic map is produced using **geodesy**, and planimetry aided by triangulation processes. Topographic maps are produced today by **restitution and aerial or satellite photographs analysis**. The reconstruction of the relief is done by **stereography**.

1.4 Information present on a topographic map

Different types of information can be found on a topographic map and all around the map (in the frame or margin).

1.4.1. On the map

Today, topographic maps are in color and each color is always used to represent the same type of information:

Color	***Type of information***	***Examples***
Black	Cultural features, geographical names (toponymy), certain symbols, geographic coordinates, and spot elevations[1].	Roads[2], buildings, urban development, railways, power transmission lines, roman ruins, tourist sites…
Green	Vegetation cover	Wooded and cleared areas, orchards…
Blue	Hydrography (water features)	Rivers, lakes, sources, swamps…
Brown (brown/yellow)	Orography (relief features)	Mountains, valleys, cliffs, depressions, contour lines.

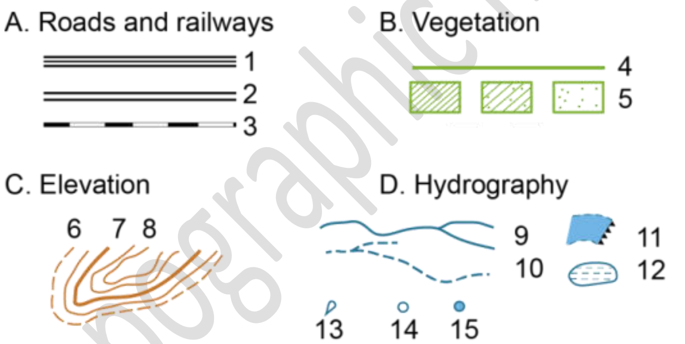


Figure 3: A few examples of elements found on a topographic map.

A – Road (1, 2) and railway (3)
B – Vegetation area (4), Forest and maquis (5)
C – Contour lines (relief): supplementary (6), index (7), and intermediate (8)
D – Permanent river (9), Temporary river or wadi (10), Dam (11), Chott (12), Water source (13), Well (14), Water tower (15).

1.4.2. Around the map (within the frame or margin)

Marginal information include:

- **Sheet Name (Title of the map):** Usually found in bold print at the top center of the map. A map is generally named after the largest settlement contained within the area covered by the sheet or the name of the state, a part of which is covered by the map,
- **Sheet Number**: Usually found in bold print in both the upper right and lower left areas,
- **Legend**: Usually located at the upper left margin. Illustrates and identifies topographic symbols used to represent some of the prominent features on the map. The symbols used are not the same on every map (so you should always refer to the legend to avoid errors when reading the map).
- **Meridians** (north/south lines) and **parallels** (east/west lines): they make it possible to obtain the **geographical coordinates** of a point
- **Variable tracking systems** (example: the Lambert kilometer grid),
- **Projection Note**: The projection system is the framework of the map (ex: Mercator).
- **Magnetic Declination Diagram**: Usually located in the top right margin or lower margin of large-scale maps and indicates the angular relationships between true north, grid north, and magnetic north,

[1] The precise elevation can be given at some points on the map. In French, these points are called the '*points côtés*'.

[2] Certain maps indicate the roads with different colors in addition to the black border. *Ex: the most important roads in red, secondary roads in yellow…*

- **Scale** *(l'échelle'):* Found in the center of the lower margin, and indicated as a representative fraction and also as a graphical scale (bar scale),
- **Contour Interval Note**: Found in the center of the lower margin (below the bar scales). *See below for further information,*
- **Unit imprint and Symbol**: On the left side of the lower margin. Identifies the agency that prepared and printed the map with its respective symbol (important information to evaluate the reliability of the map or to anyone intending to use or purchase a similar map).

1.5. Scale and orientation

1.5.1. Scale

To create an accurate picture of the landscape on paper, everything has to be made much smaller. This is done by scaling down the actual size of the land. The amount by which the actual size of the earth's surface has been reduced is known as the scale of a map:

The scale (S) represents the ratio of the distance on the map (= d) to the actual distance on the ground (= D).

Scale S = distance on the map d / actual distance on the ground D

Different scales are used, among the most common on topographic maps are 1/25 000, 1/50 000, 1/100 000, and 1/200 000 (road maps).

Map scale is often confused or interpreted incorrectly, perhaps because the smaller the map scale, the larger the reference number, and vice-versa:

- When the ratio is small (ex: 1/1 000 000), it's a **small-scale map**: This map shows a large area but few details.
- On the contrary, when the ratio is bigger (ex: 1/10 000), it's a **large-scale map**: This map shows a small area but a lot of details.

There are **three types of scale**: written, numeric and graphic.

1.5.1.1. Written scale

A written or verbal scale **uses words to describe the relationship** between the map and the landscape it depicts. A map reader would use a ruler to measure the distances between places.
Ex: one cm represents one km

1.5.1.2. Numerical scale (or ratio scale)

A numerical scale, typically represented as a **ratio** (1/50 000 or 1:50 000), **indicates that one unit** (ex: centimeter) **on the map represents the second number of that same unit on Earth**.
It can be called 'RF' for 'representative fraction'.
Example of numerical scale: 1:10 000 or 1/10 000
(1 cm on the map represents 10 000 cm (= 100 m) on the ground).

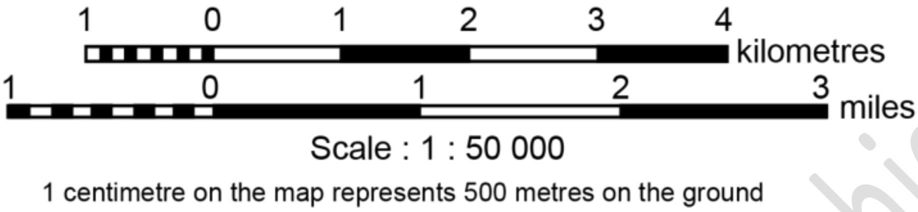
Other examples:
***1**- If two points are 8 km apart on the ground (= D) and 10 cm apart on the map (= d), what is the scale?*
S = d/D= 10 cm/ 8 km => 10 / 800 000 = 1 / 80 000
(you should absolutely use the same unit to give a correct answer)
***2**- If the scale of a map is 1 / 20 000, and if two points are 10 cm apart on the map (= d), what is their distance on the ground (=D)?*
*D = d/S= 10 cm * 20 000 = 200 000 cm = 2 km*

***3**- If two points are 2 km apart on the ground (= D), and the scale map is 1 / 50 000, what is their distance on the map (= d)?*
*d = D * S = 2 km * (1/50 000) = 4 cm*

Scale	***Distance on the ground (D)***	***Distance on the map (d)***
?	8 km	10 cm
1 / 20 000	?	10 cm
1 / 50 000	2 km	?

1.5.1.3. Graphic scale (or bar scale)

A graphic scale is **a bar marked off like a ruler** with labels outlining the distances the segments represent.



This graphic scale is recommended for geological sections for better visualization of dimensions. In addition, this scale is preserved during the reproduction of documents (scans, photocopies, etc.).

1.5.2. Orientation and location

You can find or express a location on a map using geographic coordinates (longitude, latitude) or UTM grid coordinates (easting, northing).

Geographic coordinates are expressed in degrees, minutes, and seconds and can be determined on the map by using the **longitude** and **latitude** indications placed along the edges of the map. Latitude indications are placed along the east and west edges of the map, and longitude along the north and south edges of the map. The longitude and latitude of your location can be determined by projecting your location to the map edges and then by reading the corresponding latitude and longitude values.

UTM[3] grid coordinates are expressed in meters and can be determined on the map by using the UTM grid lines. These grid lines are equally spaced horizontal and vertical lines superimposed over the entire map. The coordinate value for each grid line can be found along the edge of the map. Northing values can be read along the east or west edges of the map and easting values can be read along the north or south edges of the map. The easting and northing of your location can be determined by projecting your location to the nearest horizontal and vertical grid lines and then reading the corresponding easting and northing values.

The sides of the map are parallel to the **terrestrial meridians** and indicate true north.

True North is also indicated by an arrow pointing vertically upwards.

Magnetic North (given by the compass) **differs from geographic North**. This difference called magnetic declination changes over time. It is indicated on the topographic map (usually at 1/50 000).

Along the edges of the map are the main land **longitudes** and **latitudes**.

[3] UTM = Universal Transverse Mercator (type of projection).

1.6. Relief

The different methods for representing relief features are for example hachures, contour lines, shading, layer-coloring, spot elevations, and so on. Each method has its own merits and demerits in depicting the relief of the land.

1.6.1. Hachures and dark tones

Hachures are small lines drawn to represent slopes. The lines are drawn thicker to represent steeper slopes and thinner for gentle slopes. The slopes above 45° are depicted completely in black color.
Hachures were used on old black and white maps to represent the relief: this method is no more used nowadays (hachuring has largely disappeared from modern map making).

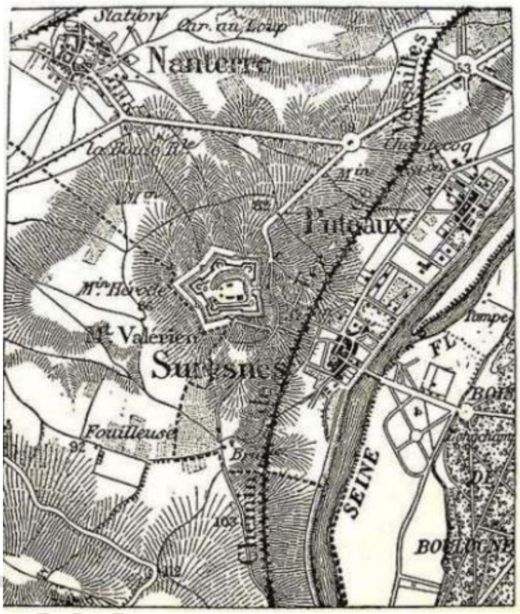


Figure 4: Extract from an old topographic map of the Paris region (France). 1/80,000 scale map dating from the 19th century.

Hachures are drawn from the contour lines in three steps. The relief is first drawn in contour lines (1), then we add hachures (2), and finally, we erase the contour lines (3). In general, this type of map does not include contour interval indication (*see below*):

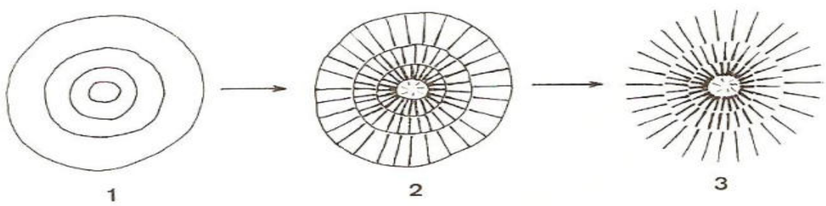


Figure 5: Method used to draw the hachures.

1.6.2. Contour lines

Currently[4], on topographic maps (and geological ones), the relief is represented by **contour lines** (in French: '*les courbes de niveau*').

Contour lines connect a series of points of equal elevation and are **used to illustrate relief** on a map. They show the height of ground above mean sea level (MSL) in meters (or feet…) and can be drawn at any desired interval.

So, if you physically followed a contour line, the elevation (height of the land) would remain the same. In other words, contour lines show the topography of the land.

The contour interval ('*l'équidistance*') represents the **difference in elevation between consecutive contour lines**. It's the **same for the entire map**. It will be listed in the margin of your map, but sometimes you have to figure it out yourself. Usually, the contour interval is equal to **10 m** in areas of low relief, and **20 m** in the mountains.

[4] Contour lines, as we know them today, came into popular use in the mid-1800s along with the rise of resource extraction industries like mining and logging.

There are different kinds of contour lines:

a) **Index lines**: **Heavy, dark lines** (▬▬) [*'les courbes maîtresses'*]

Index lines are the thickest contour lines and are usually **labeled with a number** at one point along the line. This tells you the elevation above sea level.
Contour elevation numbers indicate the direction of elevation by always reading (pointing) uphill.

b) **Intermediate lines: Thinner lines** (——) [*'les courbes normales*]

Intermediate lines are the thinner, **more common**, lines between the index lines. They usually don't have a number label. Typically, one index line occurs for every five intermediate lines.

c) **Supplementary lines: Dotted lines** (- - - -) [*'les courbes intercalaires'*]

Supplementary lines appear as dotted lines, indicating flatter terrain. They allow specifying details on the topography.

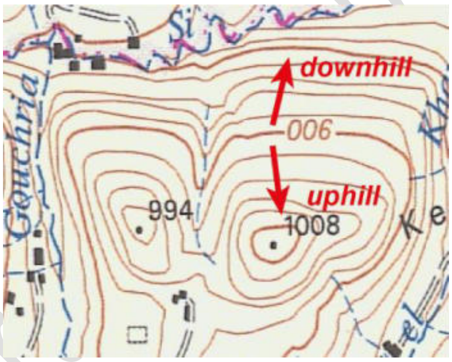


Figure 6: Extract from a topographic map showing contour lines. The index lines are the thickest, and the intermediate ones the thinnest (no supplementary lines visible here). Contour elevation numbers indicate the direction of elevation by always reading (pointing) uphill.

1.6.3. Slope calculation (or gradient)

('le calcul de la pente)

The gradient is a mathematical formula usually used to **measure how steep or gentle a slope is**. It measures **how much the elevation of a slope changes** as one moves horizontally over the surface. In other words, it measures the rate at which the slope is rising or falling. The gradient is **expressed as a percentage, an angle, or a ratio**; and **can be calculated from contour lines** on a topographic map.

To find the gradient between two points, two values should be determined:

- the **horizontal distance D (run),**
- the **vertical distance h (rise).**

The gradient is obtained by dividing the rise over the run:

$$\text{Gradient} = \frac{Elevation\ between\ two\ points}{Distance\ between\ two\ points} = \frac{Rise}{Run} = \frac{h}{D}$$

Example of slope calculation (see figure 7):

In percentage:

Gradient = h/D * 100, i.e. G = 200/750 * 100 = 26.6 %.

In degree:

tgα = h/D = G/100 = 0.266 we obtain α ≈ 15 °

Notes:

- For a slope of 100% we have α = 45°; for α = 90° the slope is infinite.
- The more the contour lines are spaced out, the lower the slope (and vice-versa).

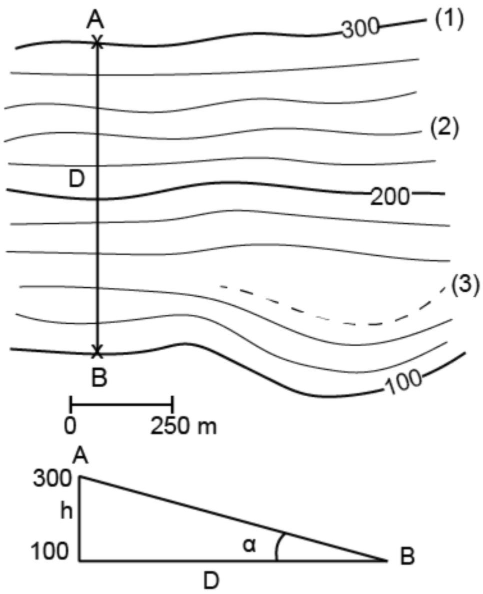


Figure 7: Contour lines and topographic slope (1: index line, 2: intermediate line, 3: supplementary line, α: slope between A and B, h: vertical distance between A and B, D: horizontal distance between A and B).

2. The topographic profile

2.1. Definition

A topographic profile is a **cross-sectional view** along a line drawn through a portion of a topographic map. Drawing it **allows us to know the exact landform** depicted in the toposheet.

So, **a topographic profile is the representation of the relief variation on a sheet of paper** (or computer). It is therefore the section by a vertical plane of the topographic surface. It is very important for geologists because it is used as a basis for geological sections.

2.2. Relationship between, vertical and horizontal scale (on the profile)

In our case, the vertical and horizontal scales will be the same, because the work on the topographic profile precedes the realization of a geological section.

But it is not obligatory to build a topographic profile using the same scale (sometimes taking a larger vertical scale – for example, 10 times larger – than the horizontal one helps to highlight the details of the ground).

Caution: Multiplying the heights by a certain coefficient multiplies the slope (expressed as a percentage) in the same way.

Indeed if: $G = h/D \times 100$ and $G' = (h \times 10) / D \times 100$, we have $G' = 10\,G$.

2.3. Identifying the different types of relief on a map and topographic profile

2.3.1. Mountains and depressions

(in French: '*montagnes et dépressions, ou cuvettes*')

Definition:

A **hill** is an area of high ground; generally, smaller and rounder than a mountain, and less steep.
A **mountain** is a very tall hill, generally with a minimum size of 600m, but varies around the world.
A **peak** is a mountain with a pointed top.
The **summit** represents the highest point of a mountain (or hill, peak).
A **basin** or **depression** represents a low point (= hollow area). It could be for example crater volcanoes, or dolines (due to karstic erosion linked to the infiltration of rainwater).

In both cases, the contour lines are **concentric** and **form a ring** around the peak or the center of the depression. The highest area on the peak could be indicated by a little point (see figure below) or by a triangle. Sometimes there is a number giving the precise elevation (but not necessary).

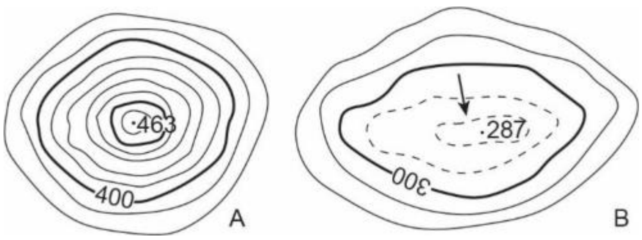


Figure 8: Summit (to the left) and depression (to the right).
A: Spot elevation 463 is surrounded by contour lines lower than it, it is a summit.
B: Spot elevation 287 is surrounded by contour lines higher than it, it is a depression. Here, the arrow indicates the center of the depression (not always indicated).

The shape of the summits can vary: symmetrical (the slope is equal on all sides), asymmetrical (one of the sides has a steeper slope), angular, rounded, or of complex shape (see the following figure).

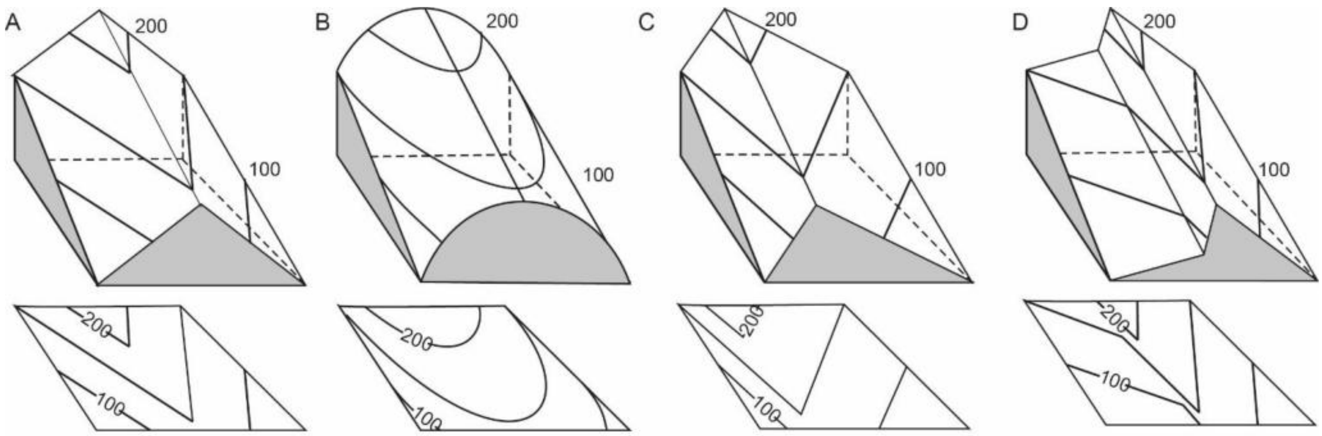


Figure 9: Types of summits.
A : Symmetrical and angular; B : Symmetrical and rounded;
C: Asymmetrical and angular; D: Complex shape.

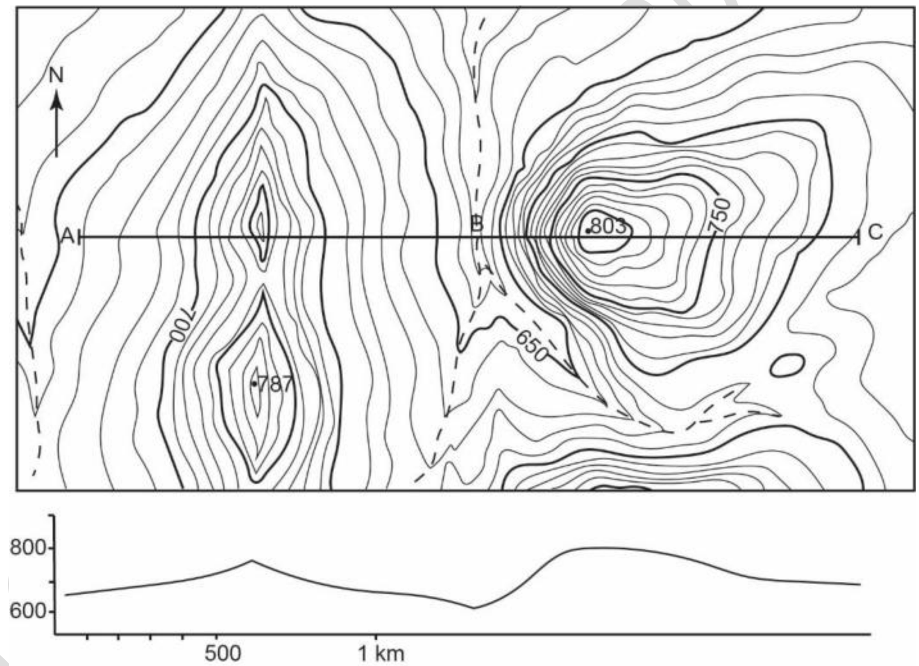


Figure 10: Recognizing the shape of reliefs on a map.
Spot elevation 787 (to the west): angular and substantially symmetrical relief
Spot elevation 803 (to the east): rounded and asymmetrical relief.
ABC: line corresponding to the topographic profile.

2.3.2. Slopes

(*'les versants'*)

The slope is the **area between the highest point and the lowest point**, i.e. between the **crest** and the **thalweg**.

The ***thalweg***[5] (or ***talweg***) is a line following the lowest part of a valley whether under water or not.

[5] This is a German word, and both orthographs are correct.

The shape of the slope can vary a lot:

a) Constant slope

The following figure shows two examples of constant slopes.
The contour lines always have the same distance between them.

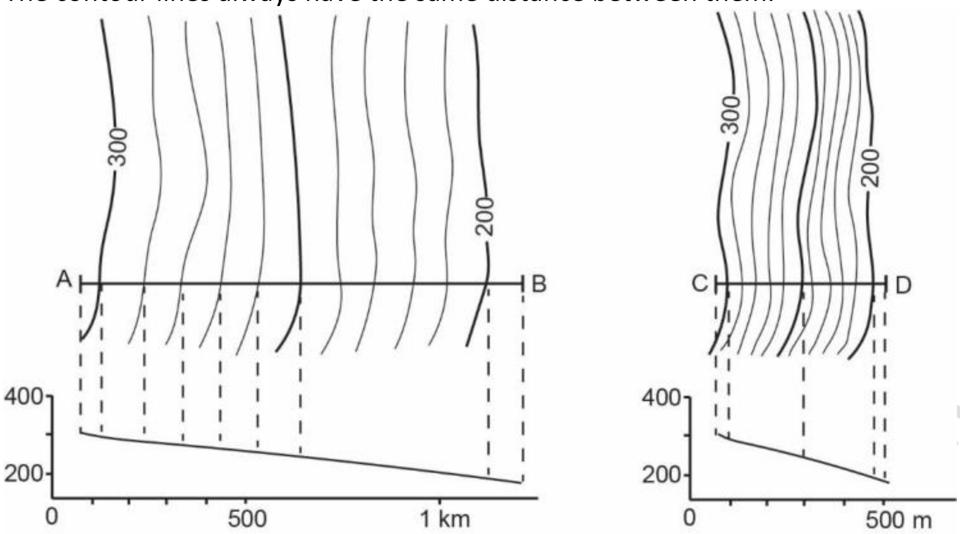


Figure 11: Constant slope.
Profile AB: Contour lines spaced out, gently slope. Profile CB: Tight contour lines, steep slope. To represent these slopes in section, you simply have to determine the positions of points A and B, or C and D.

b) Regularly variable slope

The contour lines are tighter and tighter or more and more separated but in a regular way. The slope could be concave (to the left) or convex (to the right).

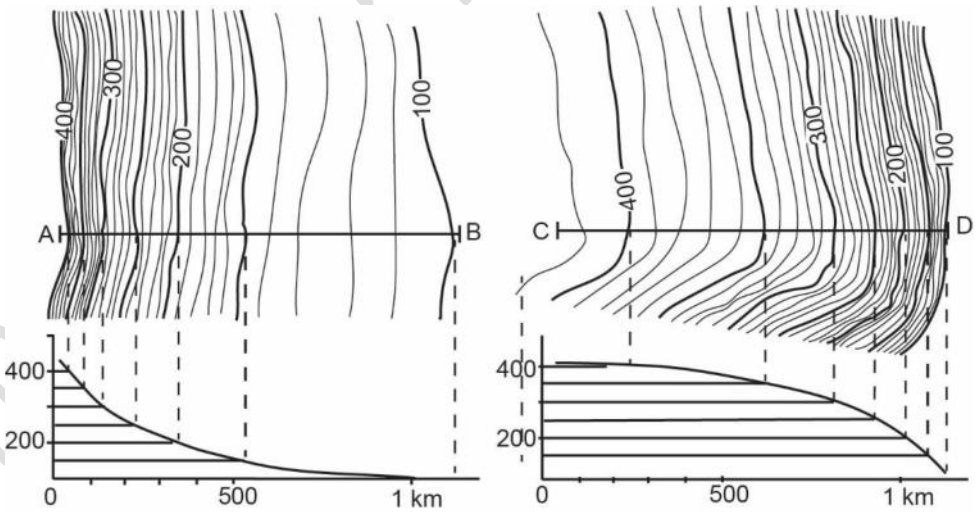


Figure 12: Concave (to the left) and convex (to the right) slope.

- **Concave slope: the contour lines are more and more distant going downwards.**
- **Convex slope: the contour lines are tighter and tighter going downwards.**

c) Break in slope

Breaks in slopes can be seen when the contour lines diverge or tighten abruptly. The following example shows a double break in slope:

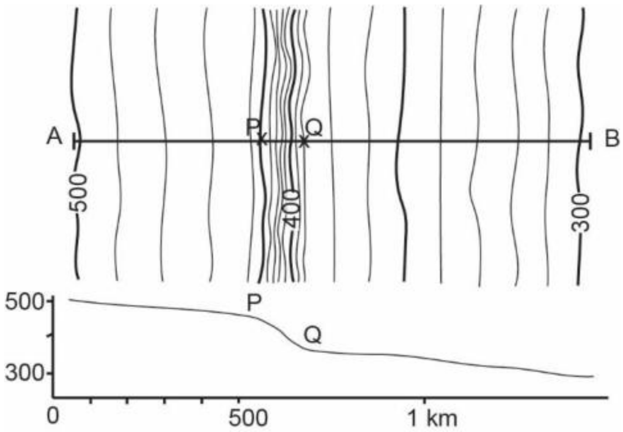


Figure 13: Break in slope.
The spacing of the contour lines changes abruptly at P and Q because of the breaks in slope.

d) Usual slope profile

The slopes frequently have a convex profile in their upper part and concave in their lower part.

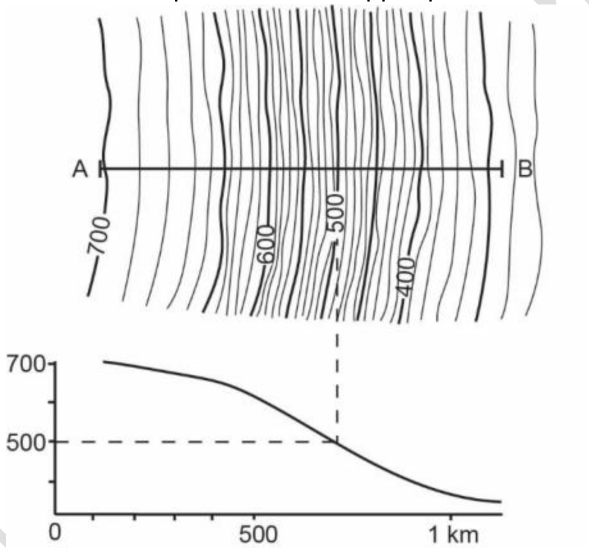


Figure 14: Usual profile of a slope (convex in the upper part, concave in the lower part).

2.3.3. Cliffs

(*'les falaises'*)

A **cliff** is a vertical or near-vertical feature; it is an abrupt change of the land. The slope is very steep.

Cliffs can be shown by contour lines **very close together** and, in some instances, **touching each other**: sometimes the contour lines are so tight that they become **unreadable**. We can also find **tick marks** pointing toward the low ground (figure below).

The **height of the cliff** is equal to the difference in altitude between the summit and the base. For example, in the following figure (AB section), the height is 710m – 550 m = 160 m.

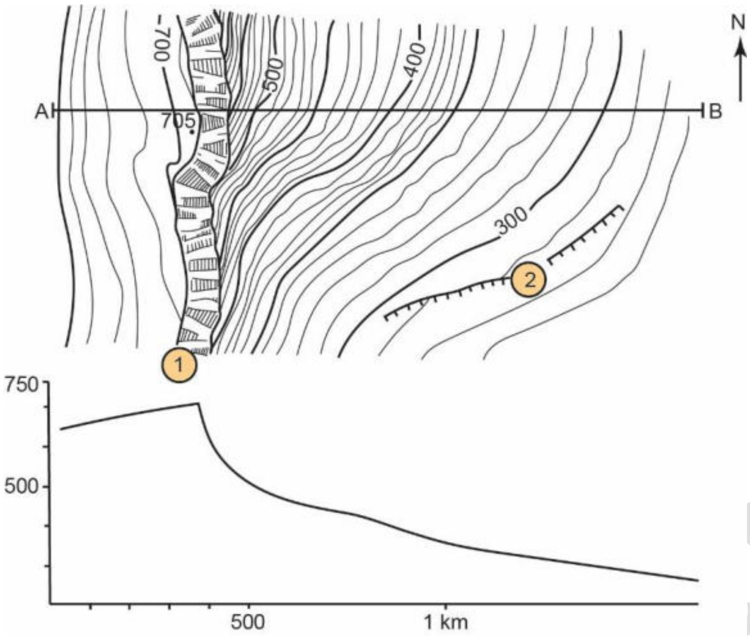


Figure 15: Cliff.
1: Cliff facing East.
At the top, the altitude is maximum and the contour lines are spaced out. There is a spot elevation / At the foot of the cliff: the altitude is lower and the contour lines are tighter.
2: Small cliff facing SSE.

2.3.4. Ridges and valleys

(‘*les crêtes et les vallées*’)

Definition:

A **valley** is a landform with a depression in which water, if present, would flow down.
A **ridge** is a landform with an elevated crest that slopes down on the sides. Of course, water never runs along ridge tops.
A **thalweg** (or **talweg**) is a line following the lowest part of a valley whether under water or not.
A **crest line** is a line passing through the highest points of the relief.

Ridges and valleys are **both indicated by ‘V’ or ‘U’ shaped contour lines** (fig.16, 17):

- ***For a valley***, the ‘V’ or ‘U’ points **uphill** (**upstream**[6]), toward higher elevation:
    - A V-shaped valley has a fluvial origin: it is narrow and incised.
    - A U-shaped valley has a glacial origin: it is wide with a flat bottom and vertical edges.
- ***For a ridge***, on the contrary, the ‘V’ or ‘U’ points **downhill** toward lower elevation. The shape (U or V) gives information on the shape of the mountain (rounded or pointed, symmetrical or not).

[6] Upstream and downstream are translated in French by ‘*amont*’ and ‘*aval*’.

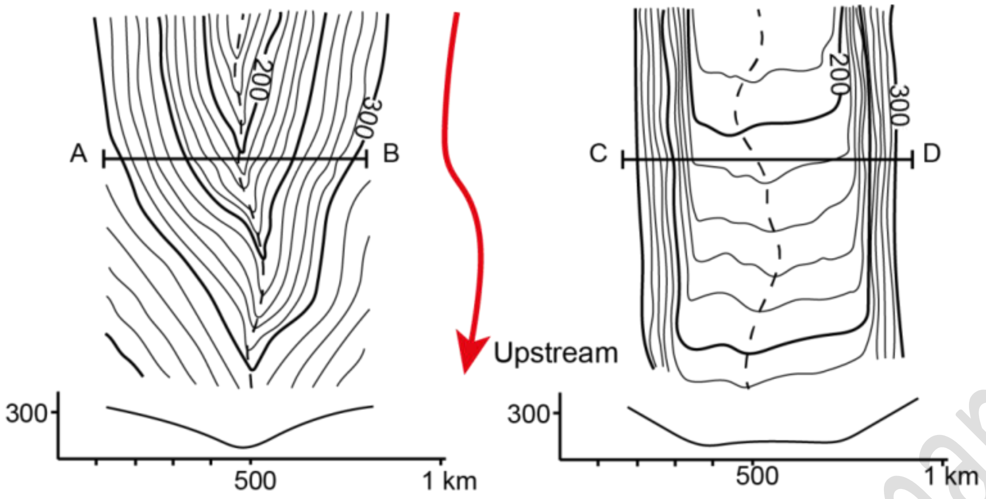
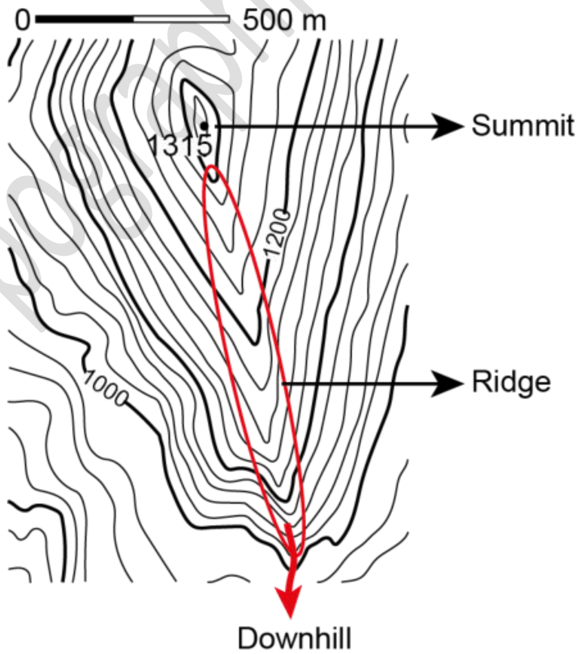


Figure 16: Valleys. Contour lines point upstream (red arrow).
Profile AB: V-shaped valley. Profile CD: U-shaped valley. The drawing of the contour lines reflects the shape of the valley; they are close together on the slopes and spread out in the flat part, where their path is hesitant.

Figure 17: Ridge. Contour lines point downhill (red arrow).
They surround an angular and symmetrical summit (point at 1315 m).



2.4. How to establish a topographic profile?

To establish a topographic profile, you need a graph paper.
The different steps are as follows:

1. Choose an imaginary line that crosses the main features of the relief of the map and draw it with a pencil (for example the line AB in the example below).
2. Fold a sheet of graph paper and press it against this line. Indicate on the sheet the extremities of your profile (A and B), and all the contour lines (with small dashes).
3. Prepare your graph paper, with the altitude on the A and B axis (vertical or ordinate axis) and the distance on the horizontal axis (abscissa). Pay attention to the scale of the map.
4. Pick off the elevations (with points) on your paper sheet.
5. Connect the points on your cross-section with a smooth curve.
6. Note the important pieces of information for locating the profile: scale, orientation, title (and possibly geographical coordinates).

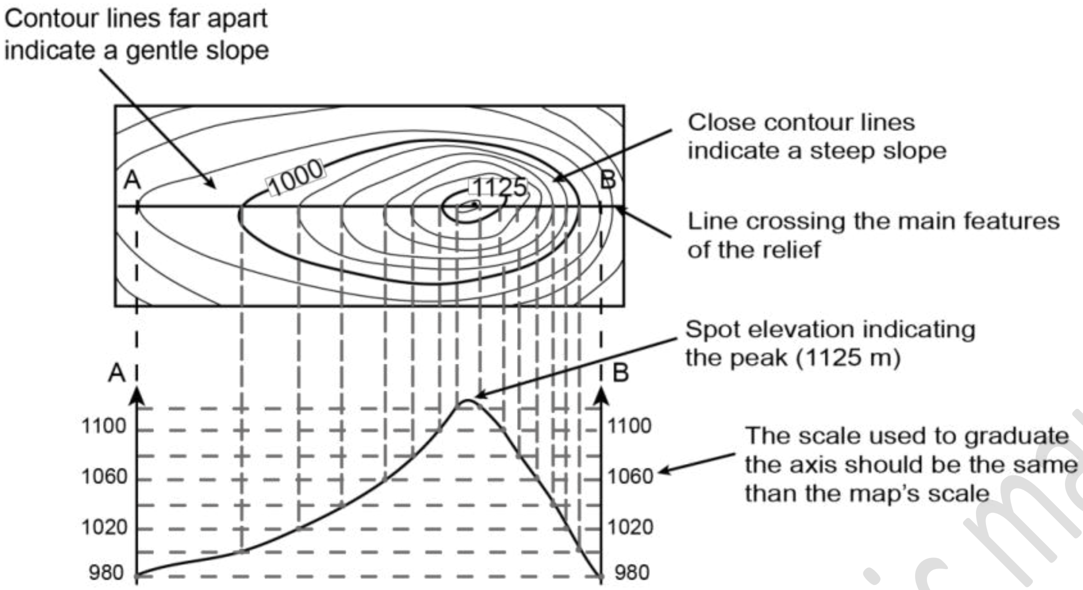


Figure 18: Topographic map (at the top) and corresponding topographic profile (at the bottom) and the way it is established (dotted lines).

Example of a topographic profile:
You can notice on the edge of the graph paper the dashes used to indicate the different contour lines. The title can be placed above or below the profile. Please note that the drawing of the profile must be well centered in the sheet so that it is possible to note easily the important information all around.

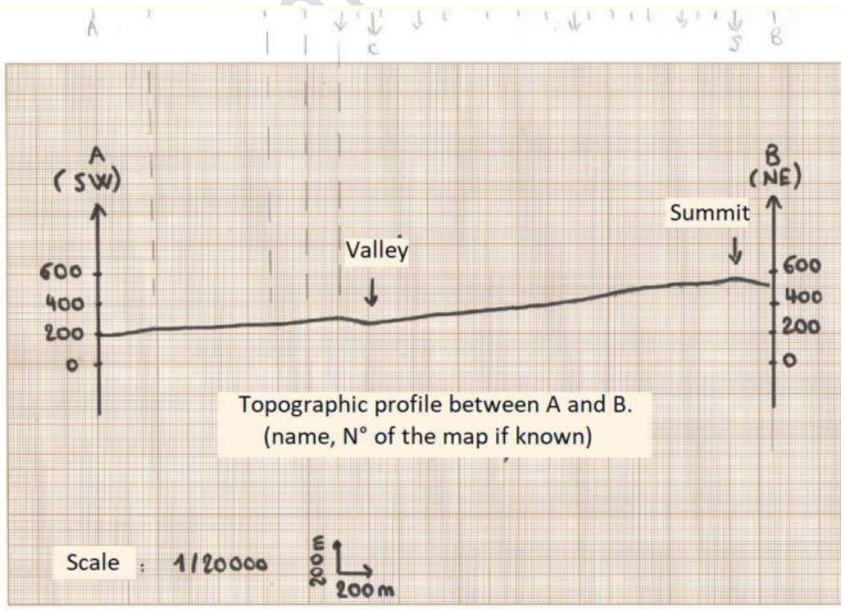


Figure 19: Example of a topographic profile.

Bibliography

Books:

- FOUCAULT A. and 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.
- SOREL D. and VERGELY P., 2010 : *Initiation aux cartes et aux coupes géologiques*. Edition Dunod, 2nd edition, 120 p.

Various websites:

- L'histoire de la cartographie en 30 cartes (History of cartography in 30 maps) : publication de l'Institut Géographique National (IGN), France, août 2021 : https://www.ign.fr/reperes/30-cartes-qui-racontent-lhistoire-de-la-cartographie
- Fundamental of mapping, history, type of maps, coordinates, projections, (etc.): https://www.icsm.gov.au/education/fundamentals-mapping/overview-fundamentals-mapping
- Mapping basics (general information about topographic maps, colours, scale, contour lines…): https://www.nrcan.gc.ca/sites/nrcan/files/earthsciences/pdf/topo101/pdf/mapping_basics_e.pdf

And useful videos, for example:

- "How to Read a Topo Map" (3'47''): https://youtu.be/CoVcRxza8nI
- "Topographic Maps" (8 videos): https://youtube.com/playlist?list=PLnAeuYnCyxWkoeyHtINsTScjGG46GusEq
- 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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