# Mountain Building and Destruction: Spain Virtual Field Trip
Topographic analysis

This handout explains how to perform the topographic analysis of a landscape using a Digital Elevation Model (DEM). The software that you will use is called QGIS. We used to use ArcMap but QGIS is free (you can download it on your laptop!) We will use QGIS to analyse the Betics. This handout uses examples from the Betics but the procedure is the same whatever the area you are studying.

But first, let's start with some theory on the shape of landscapes. The basic information that geomorphologists use to interpret landscapes in terms of geology and tectonics is **slope** and **relief**.

RELIEF is the difference in elevation between the lowest and highest points in a given area. It can also refer to the difference in elevation between valleys and summits in a given area. Relief is created by glaciers or rivers eroding into rocks, and/or by tectonics. We focus on rivers incising into rock, see below:
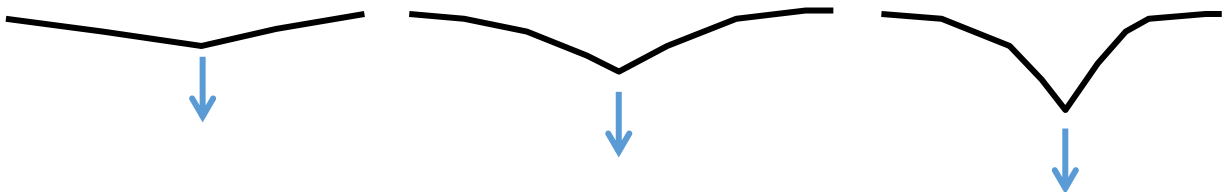
Obviously, rivers cannot erode under sea-level (unlike glaciers) so land must be uplifted for river erosion to happen and relief to be created.

It has been hypothesised that landscapes adjust their slopes and relief to achieve TOPOGRAPHIC STEADY-STATE over geological time scales. Topographic steady-state means that erosion rate equals uplift rate at all points in the landscape so the topography does not change through time. The rationale behind this concept is simple: erosion rates (in rivers and on hillslopes) strongly depends on slope (steep slopes are eroding faster than gently dipping slopes). The concept is illustrated below with two disequilibrium situations (size of arrows is a function of erosion rate):

1) River erodes faster than hillslopes:
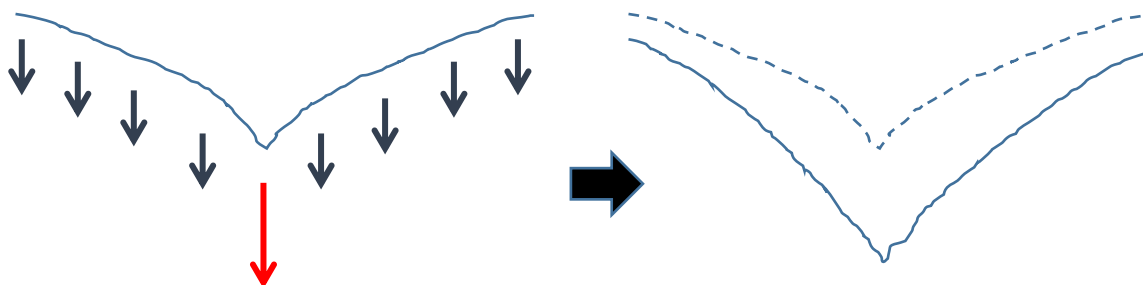
➔ *Relief increases and hillslopes become steeper → erosion rate on hillslopes increases, until it matches river erosion rate.*

2) Hillslopes erode faster than river:
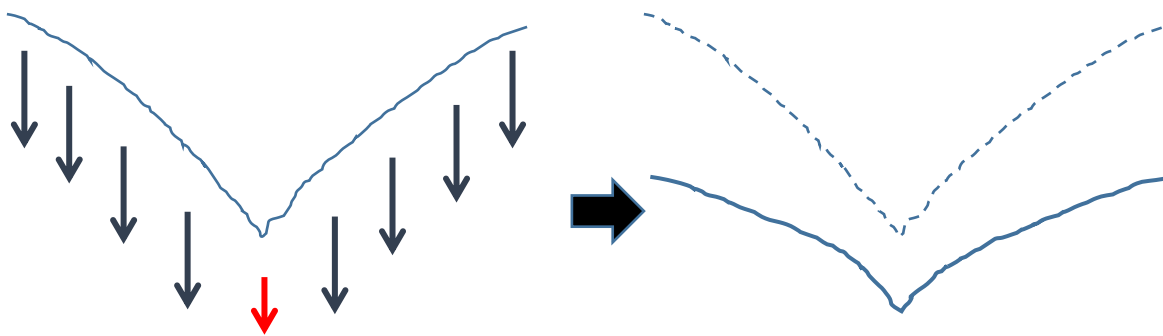
➔ *Relief is reduced and hillslopes become less steep → erosion rate on hillslopes decreases, until it matches river erosion rate.*

What I showed here at the scale of a valley cross-section is valid at the scale of whole landscapes. At topographic steady-state, erosion rate = uplift rate everywhere in the landscape. If uplift rate is high, erosion rate must be high so rivers and hillslopes need to be steep. **In other words, we expect the steepest slopes and the highest amount of relief in the places that are experiencing the highest amount of uplift (tectonically active).** What I just presented simply here is the theory behind this intuitive fact. The tectonically active Himalayas have more relief than tectonically quiescent Great Britain. I refer to the seminal paper by Ahnert (1970) who demonstrated this nicely:
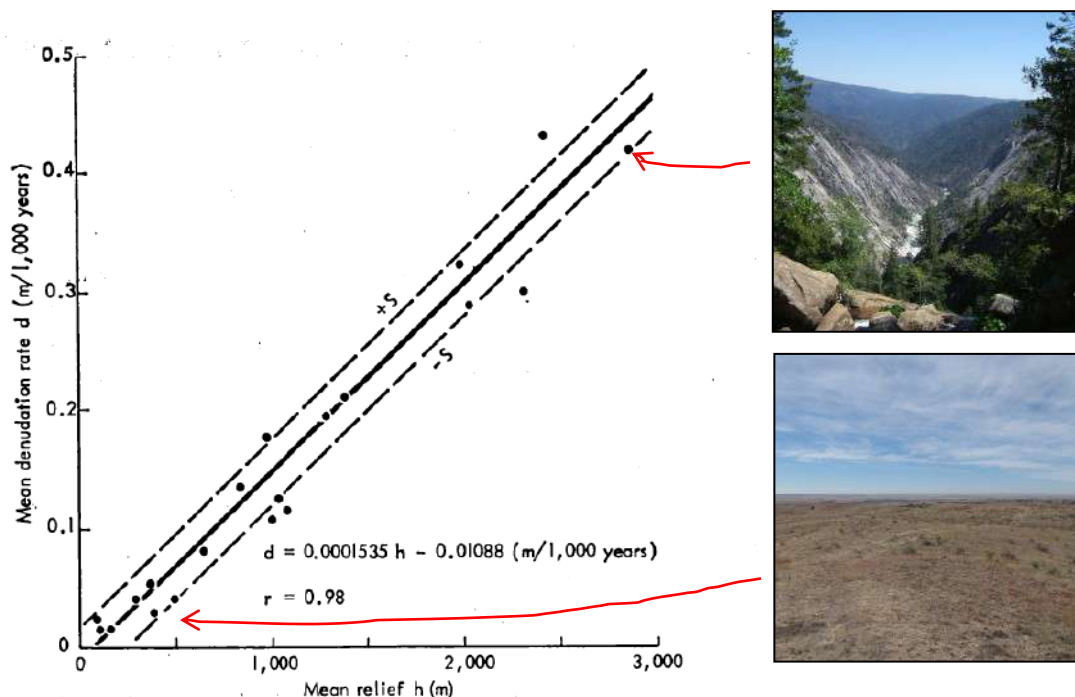

$$d = 0.0001535\,h - 0.01088\ (m/1{,}000\ years)$$

$$r = 0.98$$

Fig. 3. Relationship between mean denudation rate and mean relief.

Note that denudation refers to erosion in this context. Ahnert's paper is on Learn.

Now, this would apply globally everywhere if all rocks were the same everywhere. However some rocks are more resistant to erosion than others. Rivers will cut more easily into some rocks than into others; hillslopes made of some rocks will be eroded more easily than if they were made of other rocks; and rocks that are the most

resistant to erosion by rivers may not be the most resistant to erosion on hillslopes! This makes topographic analysis relatively complicated but here are a few rules of thumb:

RIVERS:
- Generally, a steepening of a river downstream ("knickpoint") results in an increase in erosive power.
- When rivers cut into zones of resistant rocks and/or high uplift rate, they maximise their erosive power by increasing their slopes (which can be detected on the river profile extracted from the DEM: "knickpoints") and/or reducing their width (this is much harder to detect remotely). Note that sometimes rivers both steepen and narrow and sometimes they do one or the other.

HILLSLOPES:
STEEP HILLSLOPES:
- Steep hillslopes are usually found where rocks are resistant to erosion. Cliffs are frequently made of hard rocks, e.g., Salisbury Crags made of basalt, El Capitan in Yosemite made of granite.
- Resistant rocks can form cliffs even in tectonically quiescent landscapes, e.g., Cheddar gorge (SW England) with cliffs made of limestone. This is a local effect due to contrasts in rock resistance to erosion: you can't say that the area around Cheddar is tectonically active because there are steep slopes! Note that limestone may not seem a particularly resistant rock: it is not, compared to granite or basalt for example, but it is, compared to the surrounding rocks in the Cheddar area.
- It is important to make the difference between cohesion and hardness and the scale at which we are considering them: cohesion refers to the strength of the bond between the elements that make up a rock whereas hardness refers to how easily the surface of the rock can be scratched / abraded. A limestone may be more resistant to erosion than a poorly cemented sandstone because the cohesion between grains is higher in the limestone (cemented), despite the fact that the sandstone is made mostly of quartz grains that are harder than the calcite in the limestone. Similarly, the scale is important because a granite may have a very high cohesion because its minerals are strongly interlocked (it is an igneous rock) but if a granite is heavily fragmented, it may crumble and form less steep slopes than a limestone for example! So to summarize, resistance to erosion is primarily controlled by cohesion (at two scales: cohesion between grains / minerals but also cohesion at the scale of the outcrop – fracturing will reduce cohesion) and secondly by rock hardness. A hard rock with poor cohesion (due to fracturing) will be less resistant to erosion than a less hard rock with stronger cohesion. If two rocks have the same degree of cohesion, the hardest will be the most resistant to erosion.
- As a result, some not very hard rocks can form cliffs in particular circumstances. For example, the sandstones in Bryce Canyon (Utah) are relatively soft rocks (not heavily cemented) but they form very spectacular cliffs because (1) they are relatively coherent (not much fracturing) and (2) rivers cut very quickly into them so the hillslope erosion hasn't had the time to "catch up" (so this is an extreme version of case (1) in page 1 – "river erodes faster than hillslopes").

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GENTLE HILLSLOPES:
- First possible <u>cause of low slope is low amount of river erosion</u>, because river erosion is what creates relief. Two potential causes for that:
  - o <u>Tectonically quiescent area</u> (see Ahnert's work): if uplift rate is small or nil, slopes and relief are expected to be reduced over geological timescales.
  - o <u>Rocks that are very resistant to erosion</u> ("cap rock" in which rivers struggle to incise). There is a nice example of that in the Grand Canyon area, with the high elevation plateau in an area which we know is experiencing high amounts of erosion (Grand Canyon!).
- Second possible cause is that the <u>rocks are not very resistant to erosion and cannot sustain steep slopes</u>. It is very unlikely that marls will ever form steep cliffs!
- Third possible cause: <u>sediment has been (or is being actively) deposited</u>. Slopes will be low in a sedimentary basin if nothing modifies the sediment!

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TOPOGRAPHIC ANALYSIS WITH QGIS

I. Making space for your data.

During this course, you will be dealing with large files and thus may need space on your computer: rasters for this project are around 100 MB, so each new raster you will create will add another 100 MB. Create a folder to host your project, and dedicate ~1 GB for it.

II. Downloading the topographic data.

The Digital Elevation Model (DEM) is available on Learn. All the files will be in one zip file that you will have to download and unzip before use. IMPORTANT: place all the files from the zip file and all the files that you will create in a UNIQUE folder. This will simplify your life later. **Avoid spaces and special characters in folder and file names** (GIS software struggle with these).

The exercise will be based on the Betics area, but the approach is the same for any map.

III. Opening QGIS + basic information.

You will first need to download the QGIS software, if you haven't done it already. Note that we will use tools from the SAGA toolbox. The SAGA toolbox came automatically with my QGIS download, but it may not be the case for everyone. Please get in touch if you don't have the SAGA toolbox (or try to install it). I will tell you how to check if SAGA is enabled further down.

Open QGIS. Something like that will appear:
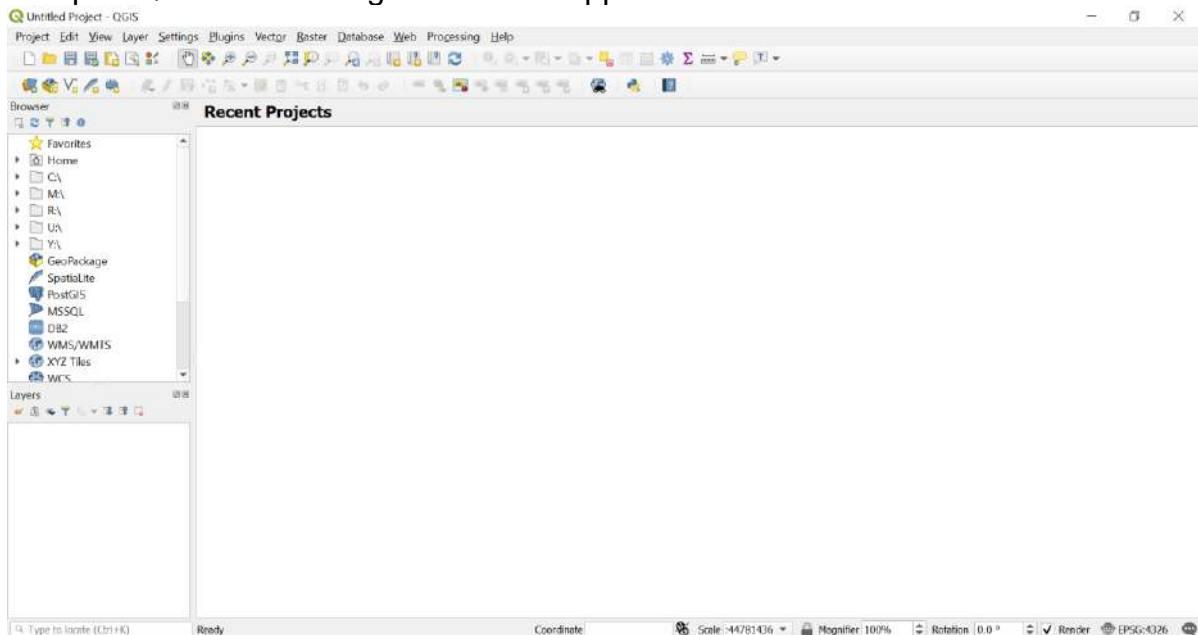
On the left of the QGIS window, two panels should be open: "Browser" and "Layers". If you want to open panels, go to *View → Panels* and select the ones you need. For example, you should select the "Processing Toolbox" panel too. You then need to start a new project, either by clicking the blank sheet icon or going to *Project → New project*. You are now ready to use QGIS. Don't forget to save your QGIS project from time to time.

If something doesn't work in QGIS, make sure that you have enough space on your disk.

IV. Basic topographic analysis operations.

IMPORTANT: *you can be lost very quickly, submerged by the number of files that you will create. I suggest that for each file name, you use a prefix that refers to the area that you are studying (or the exercise number) and a suffix that refers to the type of data. Example: I would use the prefix "sp" for the Spain trip. "sp_hillshd" will be the hillshade file of the area, "sp_slope" will be the slope file, etc.*

To begin with, you will load:
- the DEM of the area (downloaded straight from the USGS EarthExplorer - http://earthexplorer.usgs.gov/), that I have clipped to the extent of interest, called "sp_DEM".
- the geological map that I have georeferenced so that it fits on the DEM, called "GeolGeoref" (we have done the georeferencing exercise in IGR two years ago – if interested, the handout is on my page at https://blogs.ed.ac.uk/mattal/).

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Using the "Browser" panel, move to the folder where you have placed the files (note the "refresh" arrows at the top, very useful if the data do not appear). Double-click on the files, or drag them into the central panel. Click OK. Your window should look like that:
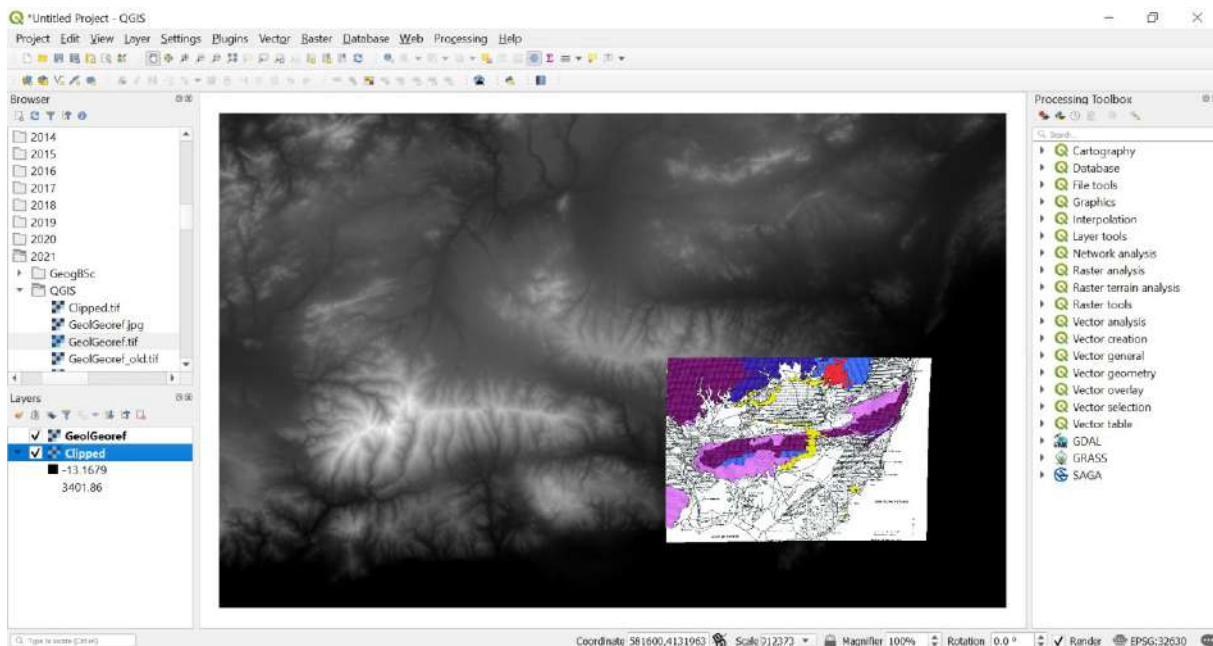
The "Layers" panel shows the different layers displayed. You can hide them, move them up or down (= towards the foreground or background), or change their properties (for example the colour scheme) by clicking on their name. NOTE: right-click and double-left-click do different things!

In terms of colour, you can double-click on a layer and use the tab "Symbology" to change from *Singleband gray* to *Singleband pseudocolour*, choosing a colour scheme in *Color ramp*.

If you right-click on one of the layers in the "Layers" panel, you have the option of removing it. When you remove something from QGIS, the file itself is not deleted: you can import it again if you want.

You can zoom in and out and navigate in the landscape, using the mouse or the *magnifier* and *hand* tools in the toolbar at the top. The magnifier with three arrows will fit the zoom to display all the layers in the window. If you right-click on one of the layers in the layer window, you have the option of "zooming to layer": this can be very useful if you have lost your image by navigating too far away from it.

Reminder: a raster is a grid made of pixels, each with a value that represents a property of the pixel (in the case of a DEM, the value is the elevation of the pixel).

*The topographic data are **from SRTM.** If you double-click on the DEM layer in the "Layers" panel and go to the "Information" tab, the pixel size will be indicated. In this Betics case, the DEM resolution is 26,74 m (each pixel is 26.74 m wide).*

*Note: I have put on my webpage (https://blogs.ed.ac.uk/mattal/) some information about how to download topographic data (ASTER or SRTM), process it in QGIS, import images and georeference them so that they fit on the topographic data. **You can use this information to apply the analysis to the landscape of your choice, e.g., for your dissertation / mapping project**.*

1) Producing a shaded relief map of the area

Shaded relief can enhance some of the topographic features in the landscape. To generate such a map, go to the "Processing Toolbox" panel → *Raster terrain analysis* → *Hillshade*. This will open a window (see below)
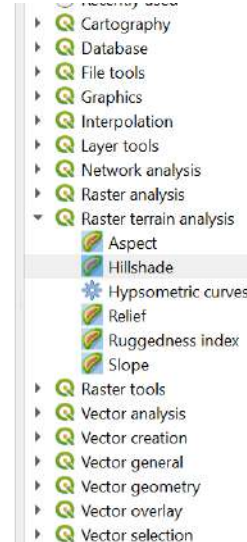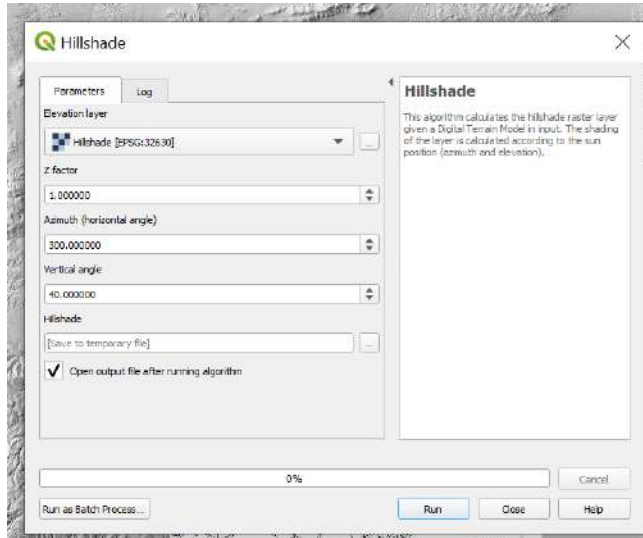

→ select the DEM from the dropdown list as the *Input raster* and click on (…) under *Hillshade* → *Save to file*. Navigate to your destination folder, give a name to the hillshade file (e.g. "sp_hillshd") and click on *Save*, then click on *Run*.

You should obtain something like below: can you spot mountains and basins?
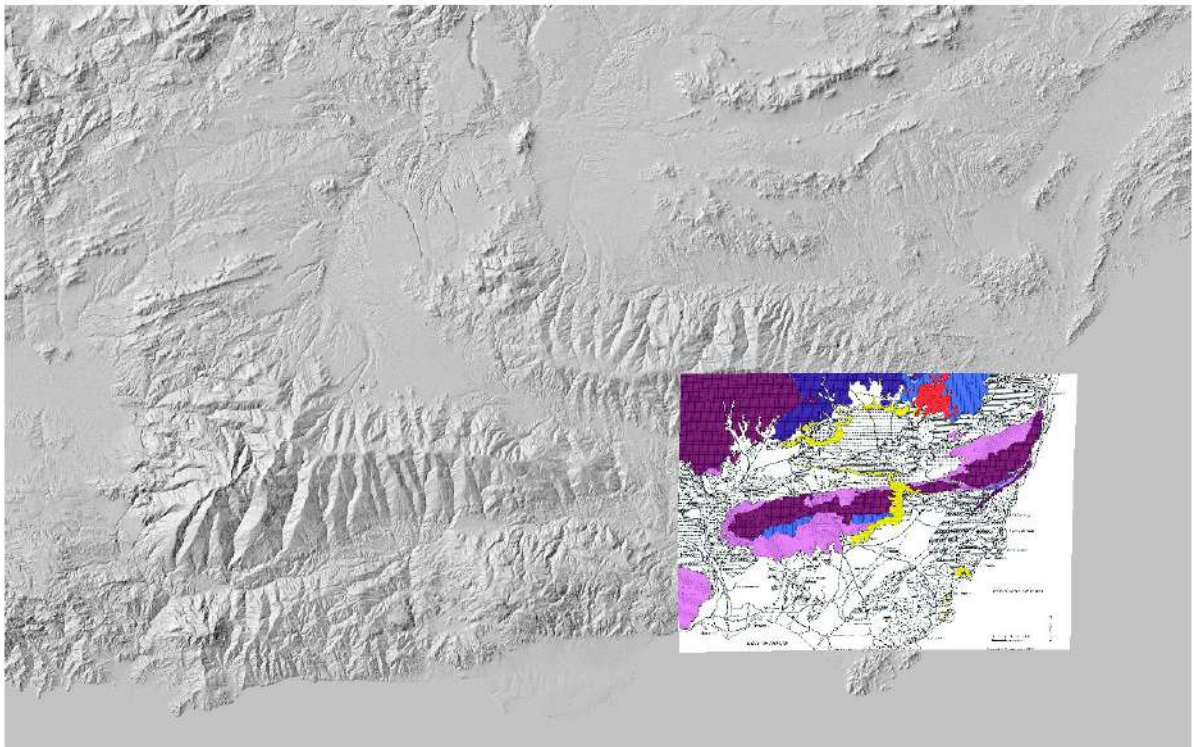
Note that for an enhanced visualisation of relief, you can adjust the transparency of the hillshade layer on top of the DEM: double-click on the hillshade layer in the "Layers" panel, go to the "transparency" tab and select 50 % for example. The result (below) is stunning, isn't it? You can do the same with the geological map.
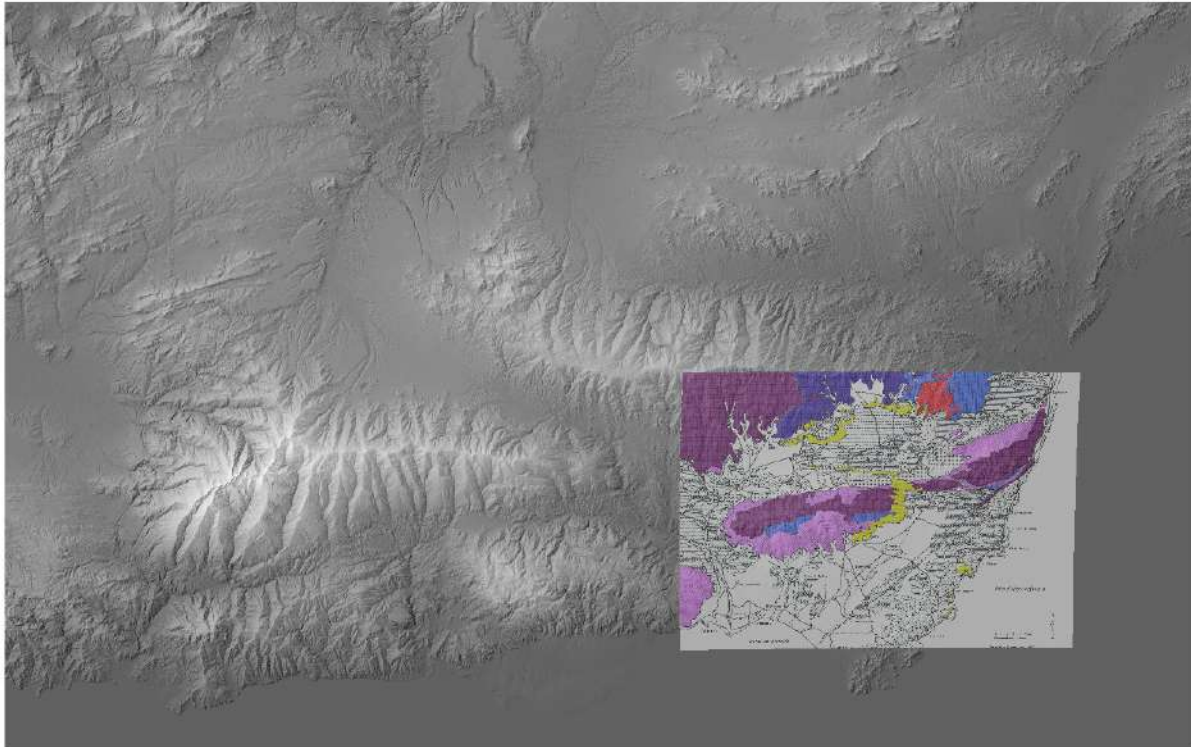
<u>2) Extracting topographic profiles</u>

You may want to know how much relief there is in an area. Topographic profiles can allow you to easily visualise the relief along a line of transect, for example from a ridge line to another, across a valley or along a given path. Let's try to image the relief along a line going across some of the ranges and basins.

You will need to install the "Profile tool" plugin: in the menus at the top, go to *Plugins → Manage and Install Plugins*. Search for "Profile tool" and install it. It will add a new button to your toolbar at the top (the little sunny green hill below).

Click on the button: a new window will appear, which will draw the profile in real time (see below). Click on the "sp_DEM" layer in the QGIS "Layers" panel, then click on "add layer" in the new window: this will specify that "sp_DEM" is the layer that contains the elevation data that we want to sample. Then trace the line along which you would like the profile to be traced (see example below). Double-click when you are finished.
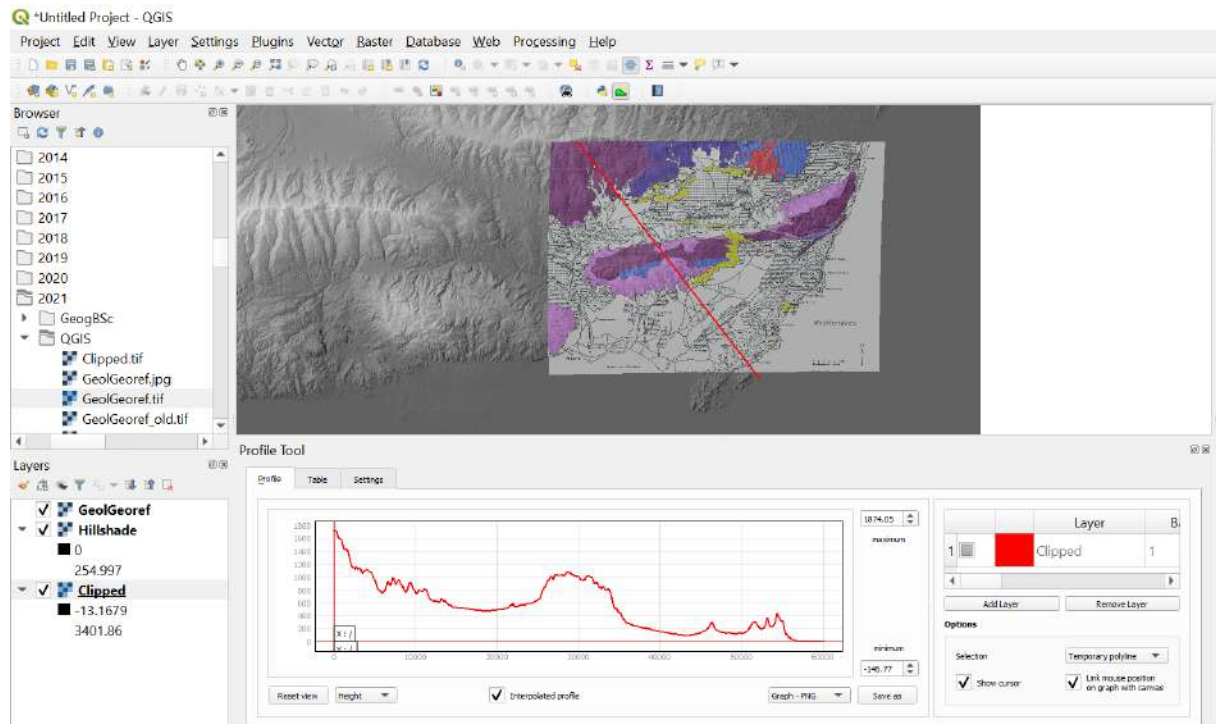
If you are not happy with your line, trace a new line – it will automatically delete the previous one. When you are happy with your line, you can save the profile as an image ("Save as" button under the profile). You can also use the tab "Table" and *Copy the data to clipboard (with coordinates if you wish)* → you can then paste the data in Excel for example, and produce a graph that you can edit. Elevation is in meters in this case. Note: the left tip of the profile corresponds to the point where your line begins (it is West if you have traced your line from W to E, it is East if you have traced it from E to W).

So, how would you describe the relief in your area?

3) Performing a slope analysis

Slope is probably one of the most useful pieces of information that can be used to assess how geology affects topography. The steepness of the slope is usually (but not always!) correlated to the resistance of the rocks exposed. To generate such a map, go to the "Processing Toolbox" panel → *Raster terrain analysis* → *Slope*. This will open a window → select the DEM from the dropdown list as the *Input raster* and click on (…) under *Slope* → *Save to file*. Navigate to your destination folder, give a name to the slope file (e.g. "sp_slope") and click on *Save* and *Run*.

You can change the colour scheme to highlight differences in steepness (double-click on sp_slope → "Symbology"), and zoom in areas of interest. You can also display the geological map on top to see if there is any relationship with the geology (see example below).

How would you describe the relief in the area? Where are the steepest slopes, and how steep are they? In which range are most slopes?
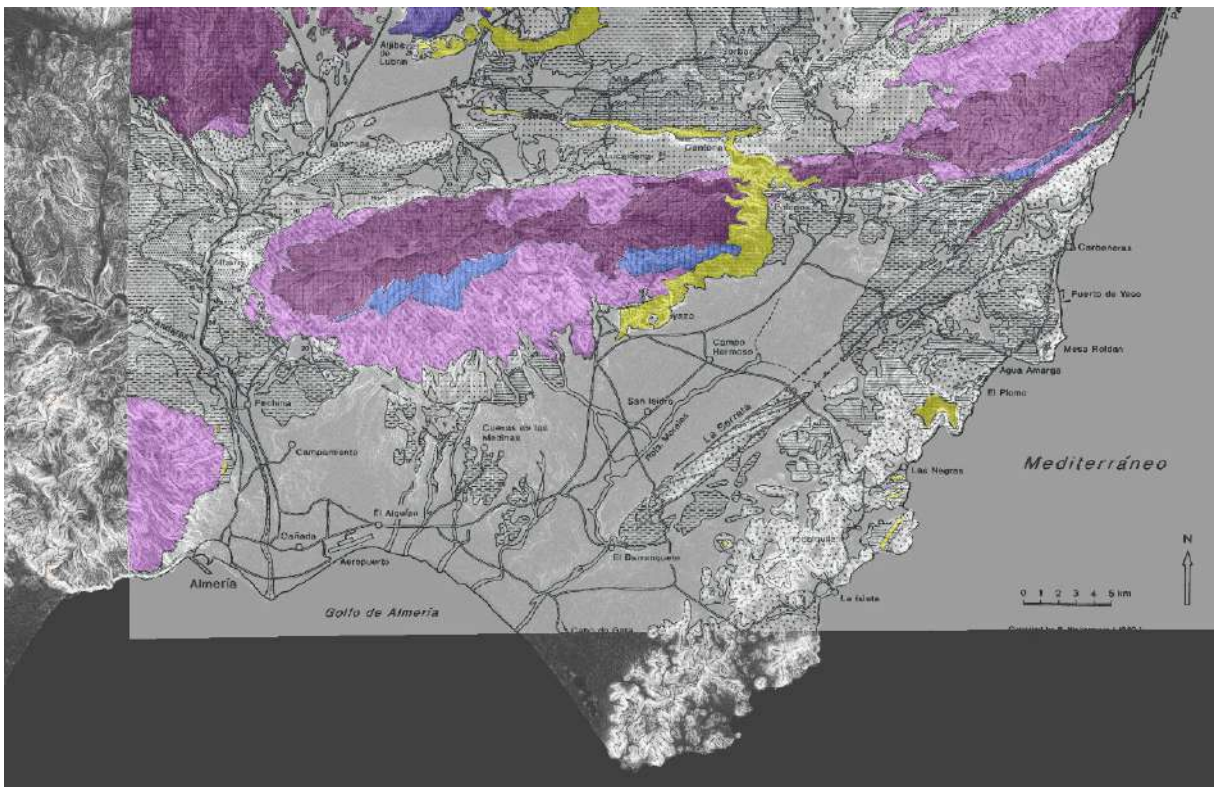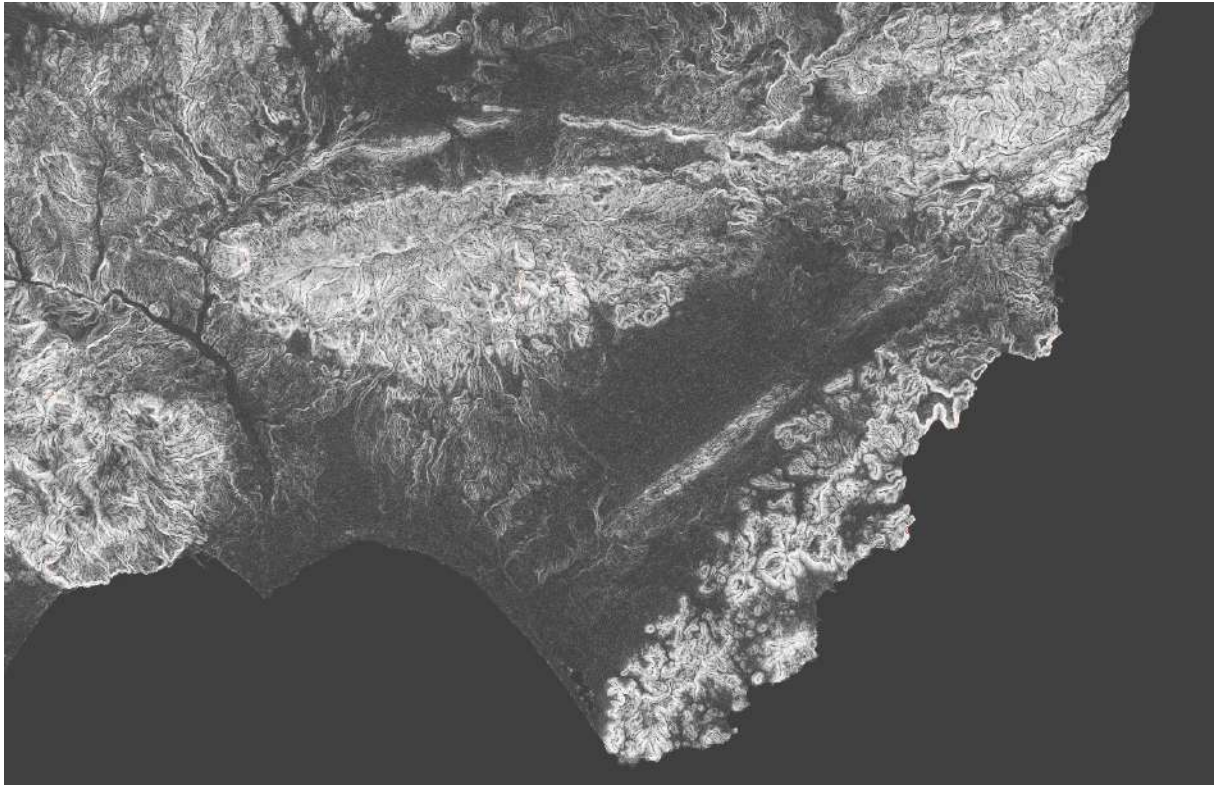
NOTE: the bright red - purple – blue colours are basement rocks, and the yellow is a coral reef from the Messinian. See caption at the end of this handout.
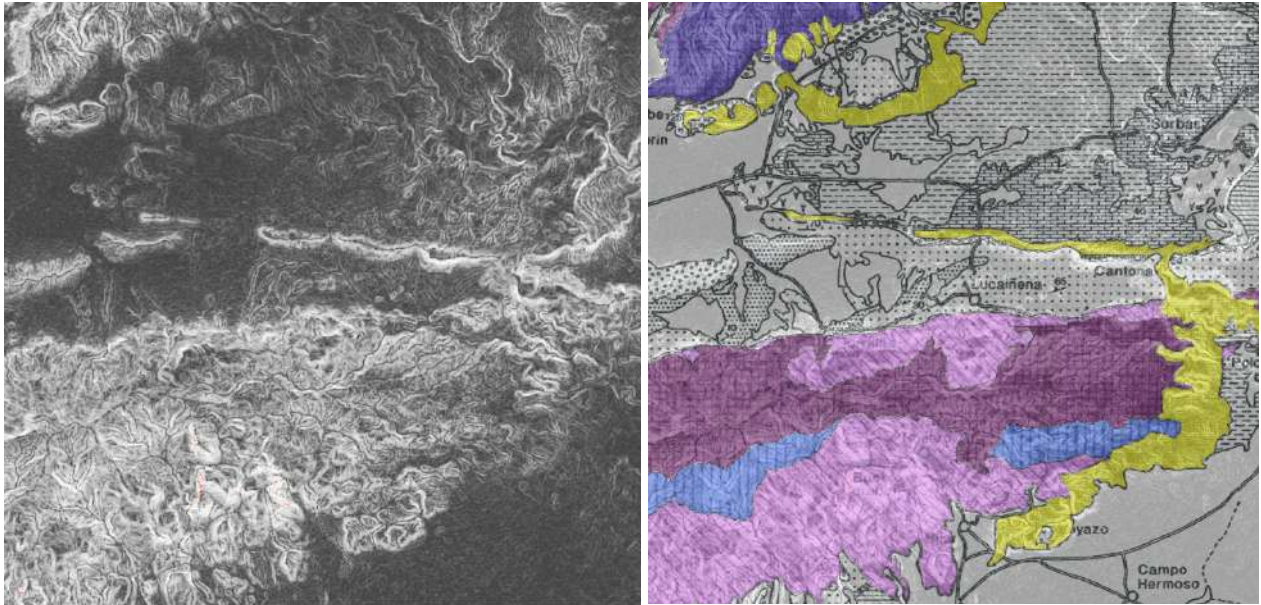
You will notice that the intervals for the colour values are designed to enhance the differences in slope (if you expand the "sp_slope" information in the "Layers" panel). You may want to display intervals with "cleaner" boundaries, in particular if you want to create a map with a key (we won't do that today). In the "Symbology" tab, you can choose to change the mode to *Equal interval*, set the maximum value to a round number (e.g., 75 rather than 73.1747) and choose a number of classes that leads to round boundaries (e.g., 16). See for example below. Once you have made your selection, click on *Classify* and OK.
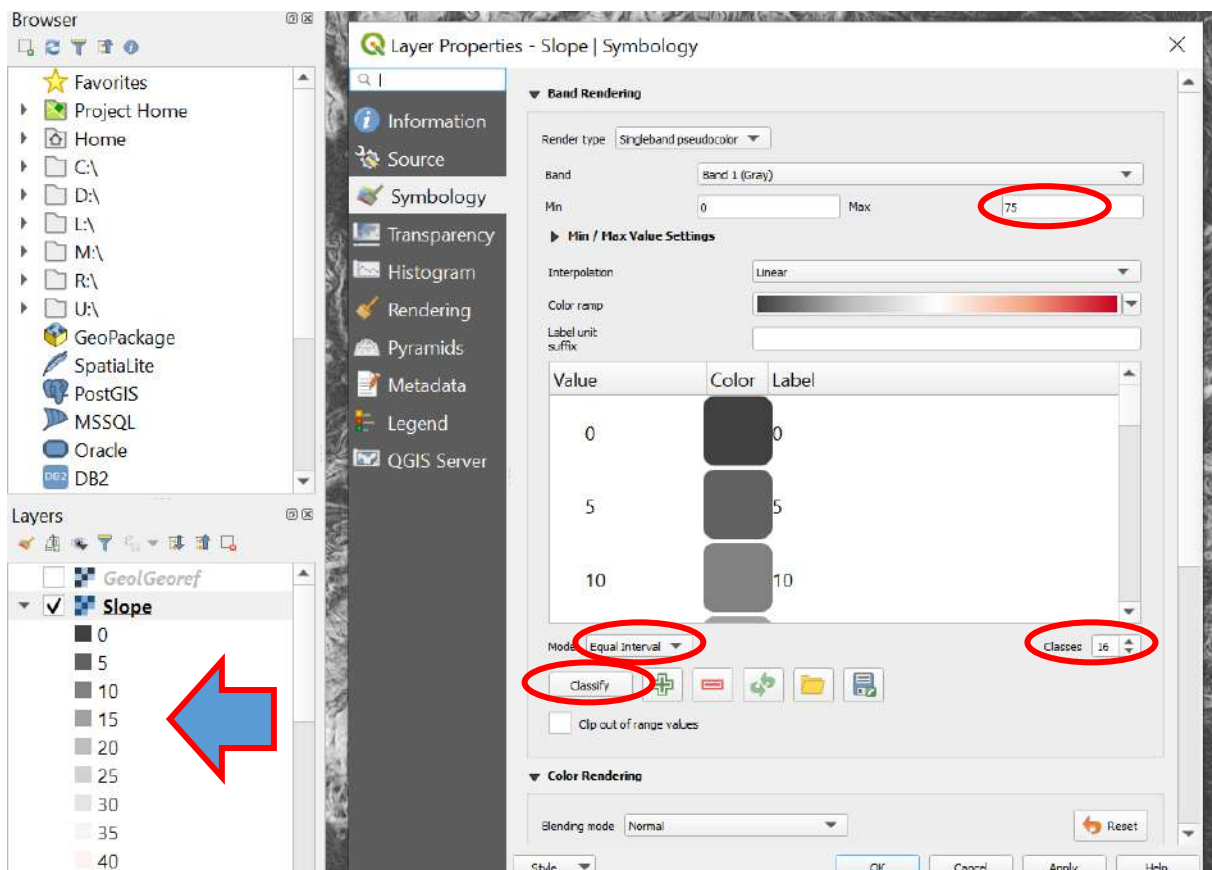
VI. Extracting river catchments.

The analysis above was performed on slopes across the whole DEM. You are now going to look at the geometry of the drainage network and focus your analysis on catchments of your choice. To extract the fluvial network, you need to perform a series of operations. All the tools that you will use can be found in the Toolbox window, including the SAGA suite that should have been installed automatically if you use the latest version of QGIS.

To check if SAGA is enabled, search for "SAGA" in the Processing toolbox: you should see many tools appearing. If not, you will need to install SAGA.

Note that if you want to learn more about QGIS, there is a series a seven free webinars by Kurt Menke and Hans van der Kwast, that "*demonstrate the 7 chapters of the book QGIS for Hydrological Applications - Recipes for Catchment Hydrology and Water Management*". This is excellent, and a lot of the work that is presented in this handout has been inspired by these webinars (in particular chapter 4): https://www.youtube.com/playlist?list=PLeuKJkIxCDj17t2MmPhBZIkLI2FQ8S_ea
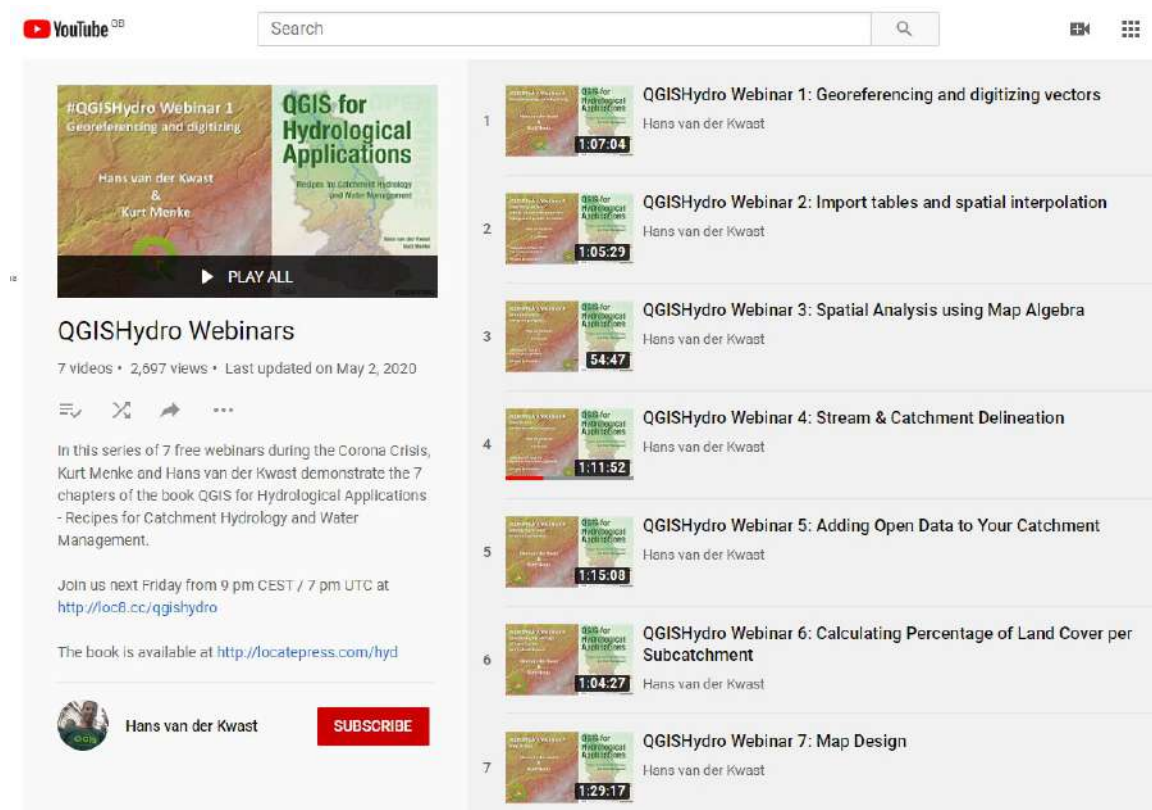
NOTE: TRY TO THINK ABOUT WHAT EACH OF THESE OPERATIONS DOES: it will make your practical much more interesting! You can use the QGIS "help" (in the software or online) or ask questions in the Discussion Board.

1. Fill: it is important to fill the sinks in the DEM (rivers don't go uphill: they fill sinks). Search for "fill" in the processing toolbox and use the "Fill Sinks (Wang & Liu)". Make sure you select your DEM and not any other random file as the input, give a name to the "Filled DEM" by clicking on (…) → Save to file (e.g., sp_fill), and uncheck Flow Directions and Watershed Basins (we will look at these later). Click Run (it takes a bit of time).

The filled DEM should look very similar to the original one. I suggest you remove the original DEM if you are planning to run a hydrology analysis (as in this case), just to make sure you don't use it by mistake.

2. Define the stream network, using the Strahler method. Search for Strahler: you will find a "Strahler order" tool in the SAGA suite. Use your filled DEM as input, and "Save to file" (e.g., sp_strahler). You should see a stream network, and each stream segment will have a given Strahler order: streams start as order 1; when two order 1 streams meet, the order increases to 2; when two order 2 streams meet, the order increases to 3, etc.

The result is not visually very pleasant: go to View → Panels → Layer Styling, which will open a new panel where you can modify the styling in real time.

> *NOTE: the Layer Styling panel is identical to what you would see if you just double-clicked on a layer and opened the Symbology tab.*

Because the orders are integers and ordered, it makes sense to use "Paletted / Unique Values" instead of the default singleband grey: make sure your Strahler raster is selected at the top of the layer styling palette, select the "Paletted / Unique Values" from the drop-down menu, select Blues in the colour ramp (these are rivers!) and click "Classify".
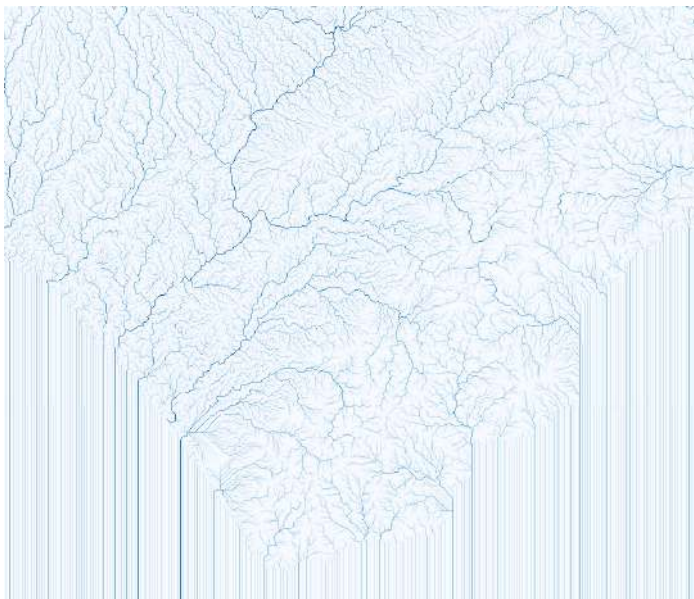

The river network will appear in great detail, probably too great to be useful (and yes they are straight in the sea). To retain only the largest streams and define the river network, we can use the Raster Calculator: Click on Raster in the main Menu bar → Raster Calculator.

This will open a Calculator that can make calculations across the whole raster.

Double click on the Strahler raster, then on >=, and then type 3, to say "we will retain all pixels with a Strahler order greater or equal to 3" (you may choose different values for different purposes). Click on (…) in the top right of the calculator to save the file (e.g., sp_streamnet), and click ok. The result is either 1 (condition is true) or 0 (condition is false). To keep only the values = 1 (that is, the stream network): go to the layer styling panel, select "palette / unique values" and press "classify. The results should look like the figure on the next page.
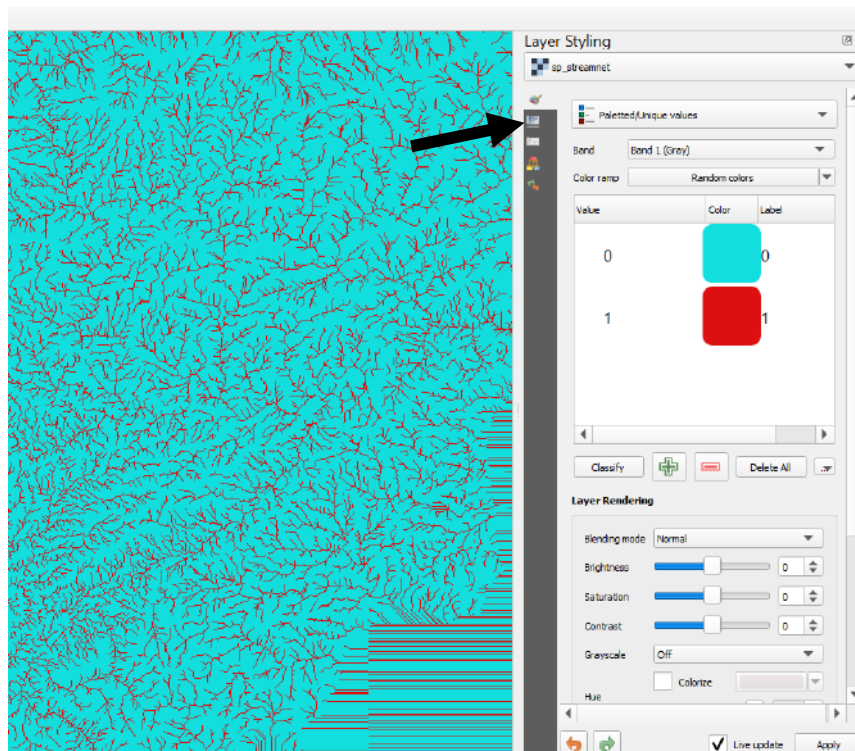
Double-click on the colour square for 1 (the big red square) and select a blue colour (rivers), then click on the button with the triangle next to "select colour" near the top, then press the "transparency" button shown by the arrow to the left. This will open a new panel, where we can specify an "additional no data value". There, type 0: this means that all data points with a value of 0, will become "no data" and vanish from the display.

If you just show the hillshade and stream network, you will start seeing how it develops around hills and basins:
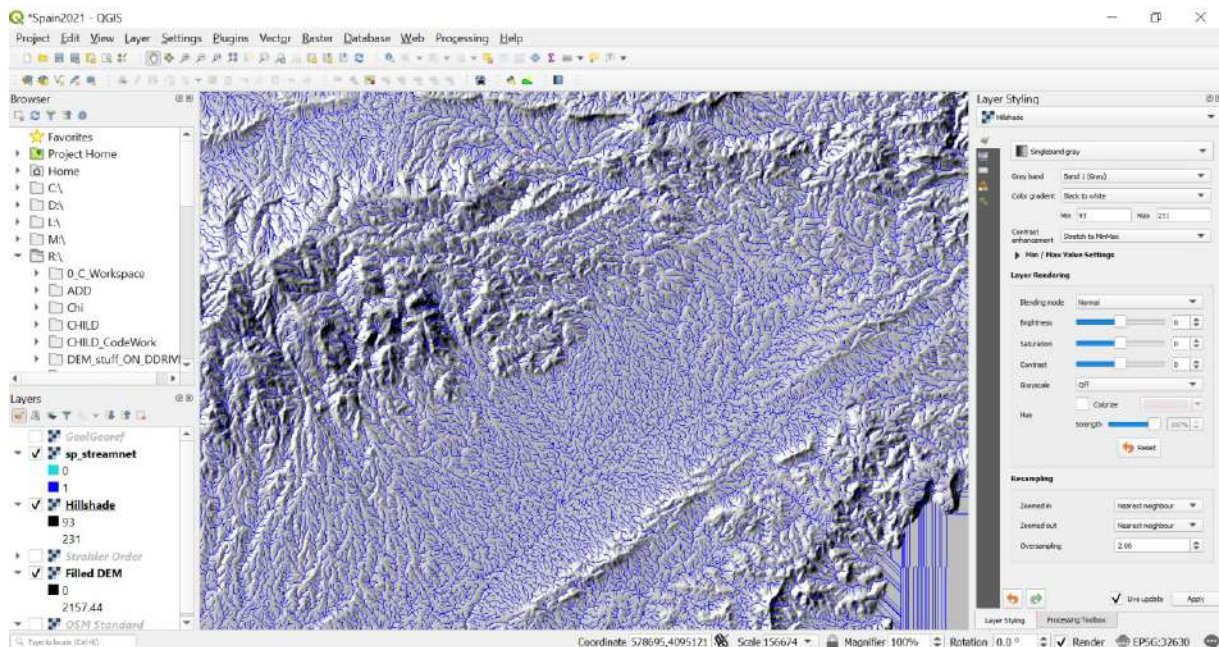
This is a quick and efficient way of visualising the river network. To actually delineate stream networks and catchments, we will use another SAGA tool: search for "**channel network and drainage basins**" in the Processing Toolbox. This will open a large window:

Elevation: make sure this is your filled DEM.

Threshold: this is the Strahler order threshold for streams. We used 3.

Flow direction: this could be a useful file to have, so click (…) and save to file.

Flow connectivity: not interested today → uncheck.

Strahler order: we have it already → uncheck.

Drainage basins: this is a **raster** of drainage basins, not that useful → uncheck.

Channels: this will be a shapefile containing the stream network (= vectors), so click (…) and save to file (e.g., sp_channels).

Drainage basins: this one is a **shapefile** (= vectors) of the basin, much more useful that the other one, so click (…) and save to file (e.g., sp_basins).

Junctions: not interested today → uncheck.

➔ Run. It will take a bit of time but will be worth it!

The result is messy, so we will need to work on the styling:

➔ Remove the flow direction layer for now, and hide the basins.
➔ If you right click on "channels", you can "**open attribute table**". The attribute table contains information about each feature in the layer, including "ORDER". This is the Strahler order, recalibrated based on the threshold we specified: threshold was 3, so 3 became 1, 4 became 2, 5 became 3, etc. What we have here is information that tells us how "large" a river segment is, since the Strahler order increases downstream. We can use that information to make beautiful and informative displays.

Open the Layer Styling panel and select "Channels" (see below left). Select "Graduated" and use "ORDER" as a column. Set "Precision" to 0 (ORDER is an integer) and select "Size" as the method: this means the line will get thicker with increasing Strahler order! Set size from 0.1 to 0.5 mm (you can play with that if you want to). Set the classes to 7 in this case and click "Classify". You can also change the colour to blue: click on the "Symbol" panel, which will open a new window (below right). Here you can select a simple line, and choose the colour. When you are done, the result should be pleasant (see next page).
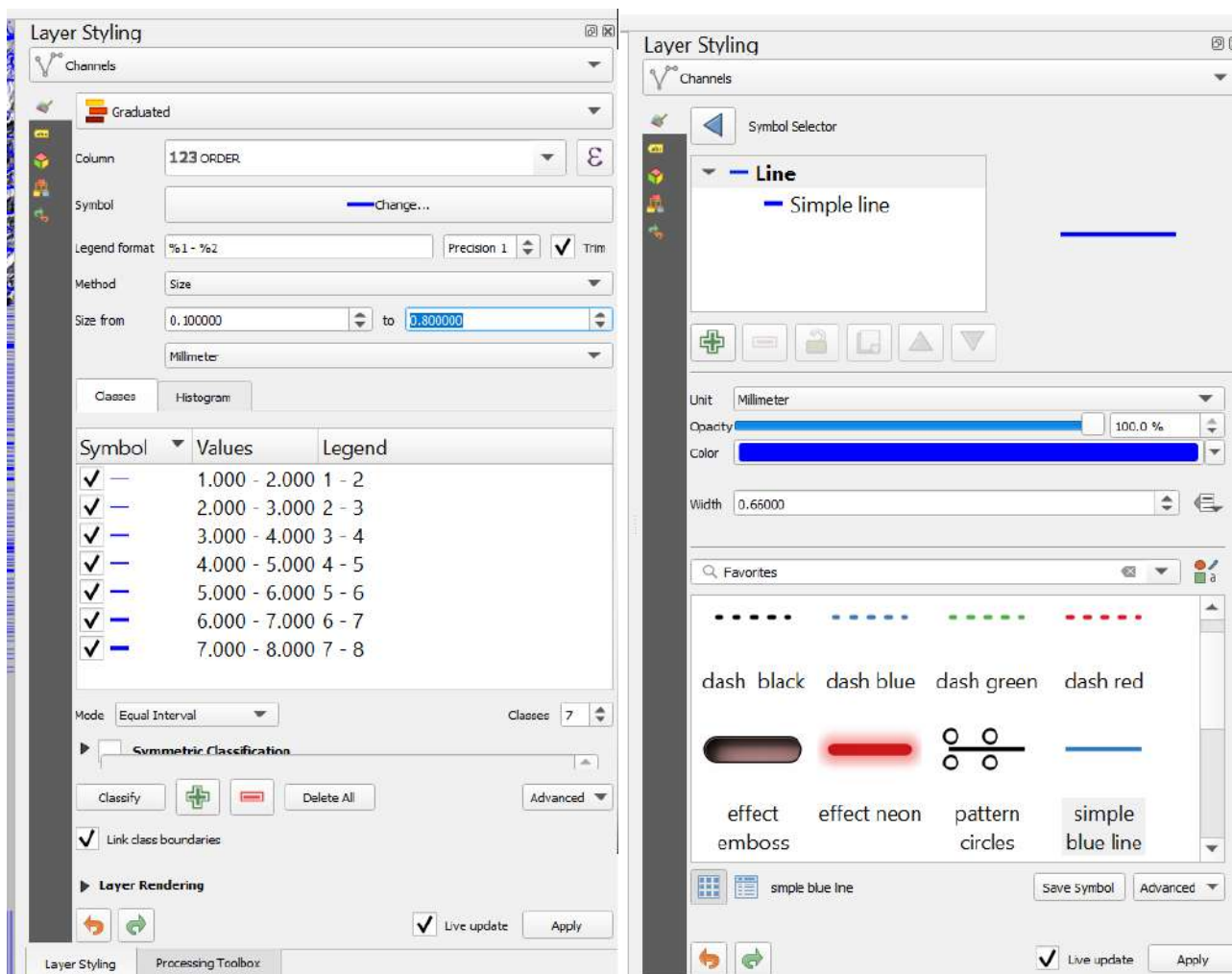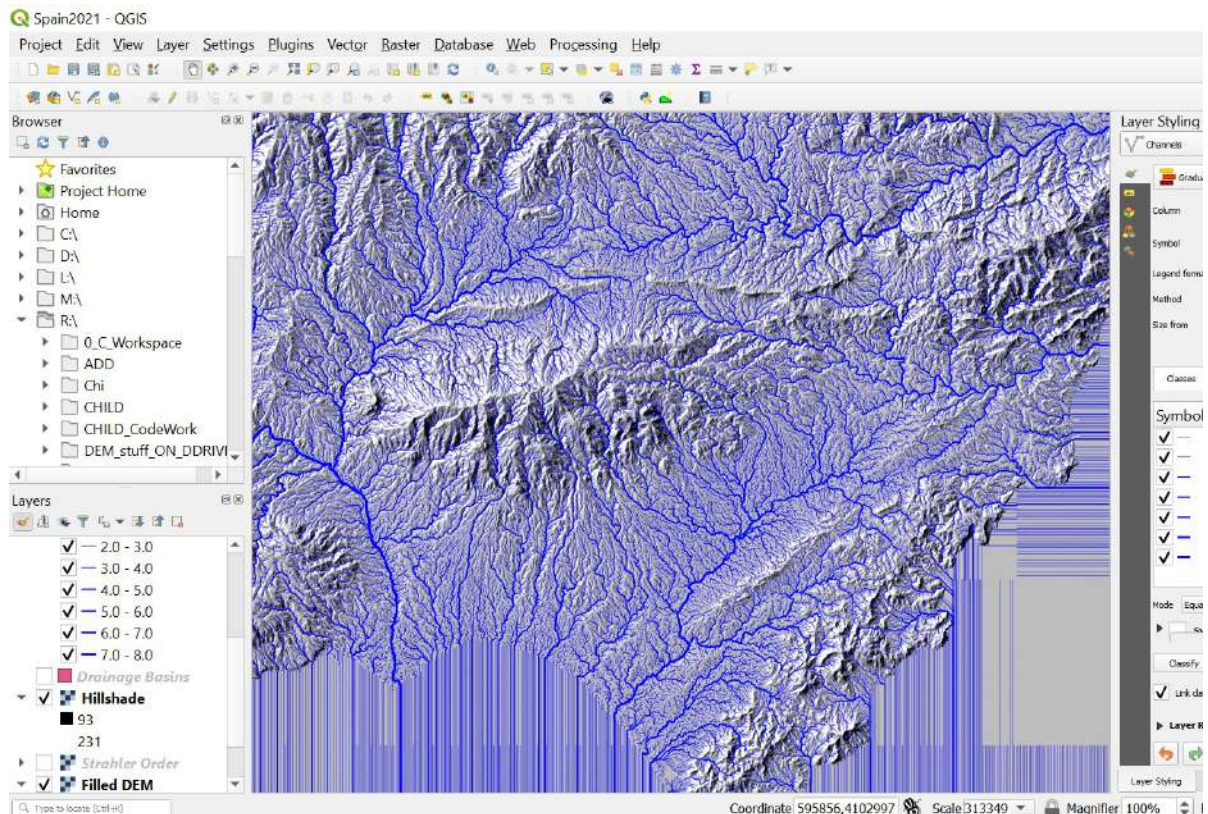
If you now make the "basins" visible, you can edit their styling as well, in particular maintain only the boundaries: in the Layer Styling panel, select the drainage basin layer. Click on "Fill" and select one of the favourite "outlines", e.g., the red outline. You can adjust the thickness accordingly, by clicking on "simple line" and adjusting the stroke width.
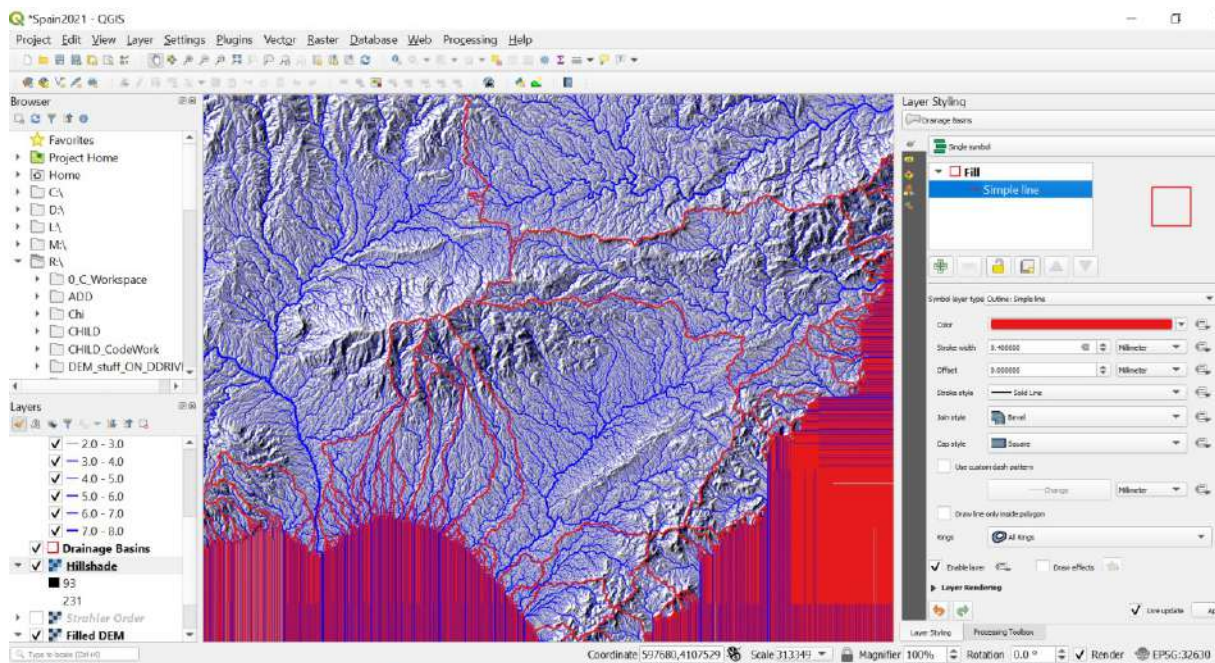
In a short amount of time, you have delineated all major river basins and stream network in the area! How do the different features (hills in particular) influence their shape?

Now, let's imagine we want to focus only on one catchment: we can extract any catchment by specifying an outlet. Let's try to extract the narrow catchment that flows West-East to the sea between the Sierra Alhamilla and Sierra Cabrera.

Search for **Upslope Area** in the processing toolbox. It needs target X and Y coordinates. Now, it is important to pick a pixel that is exactly on the main stream, otherwise the tool may extract a tiny subcatchment that is on the side of the main channel: zoom in the area of interest until you can see the stream and the pixels (see below). You can then hover the mouse over the pixel of interest and record the coordinates at the bottom of the screen (circled).
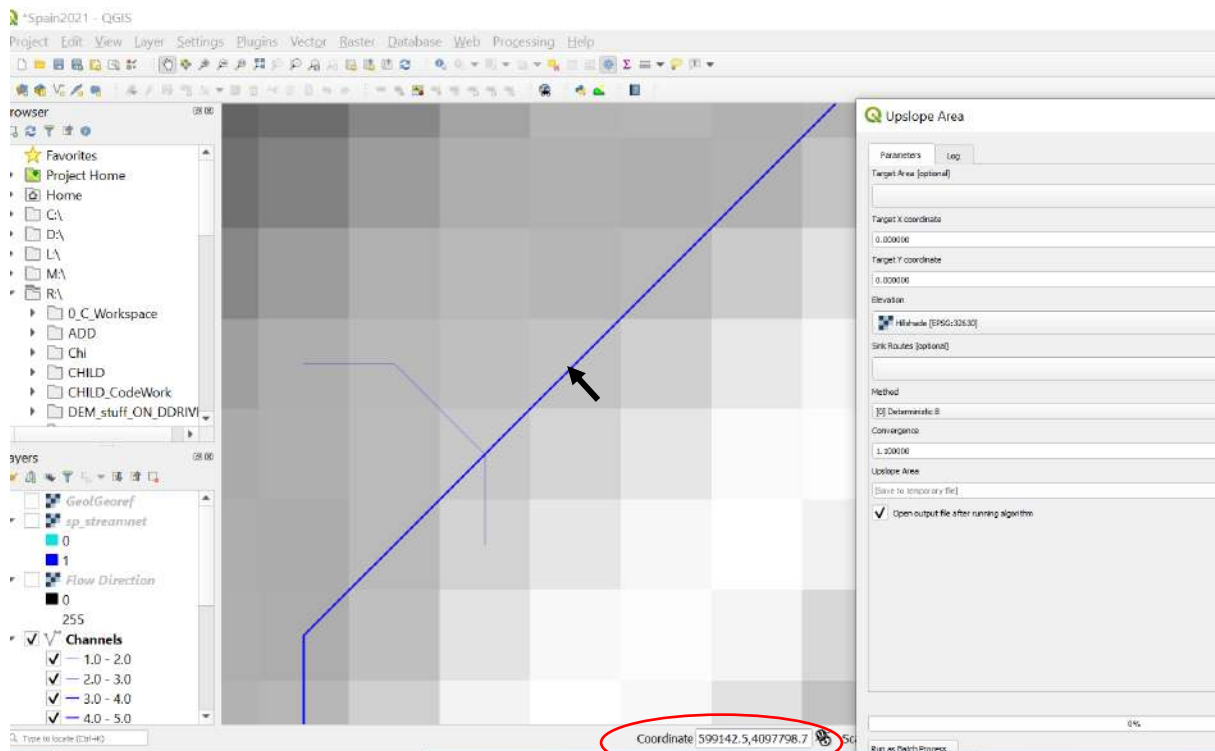

Select the Filled DEM as "Elevation", keep the method as Deterministic 8, and "Save to file" (e.g., sp_catchment). Then Run.

If this is done properly, you should see the catchment in white on a black background. If you look at the details of this new layer in the Layers panel, you will see that pixels in the catchment have a value of 100, and those outside a value of 0. To retain only the outline of the catchment, we need to turn it into a polygon: go to "Raster" in the main menu → "Conversion" → "Polygonise". Select the raster you have created with the upslope area function, click on (…) under "Vectorized" → Save to file. SAVE AS TYPE "SHP files" (= shapefile) and give a name (e.g., sp_catchment_p) → Run.

The result will not be outstanding, because the polygon data still contains the pixels inside and outside the catchment, with values of 100 and 0, respectively: if you right click on the new layer and open the attributes table, you will see these two types of data.

To get rid of the pixels outside the catchment, click on the edit button in the attribute table (little pencil to the left, circled black below), select the dataset made of 0 by clicking on the corresponding row number (the data will become highlighted), and bin it with the bin button (circled red below). Click on the edit button again and save.
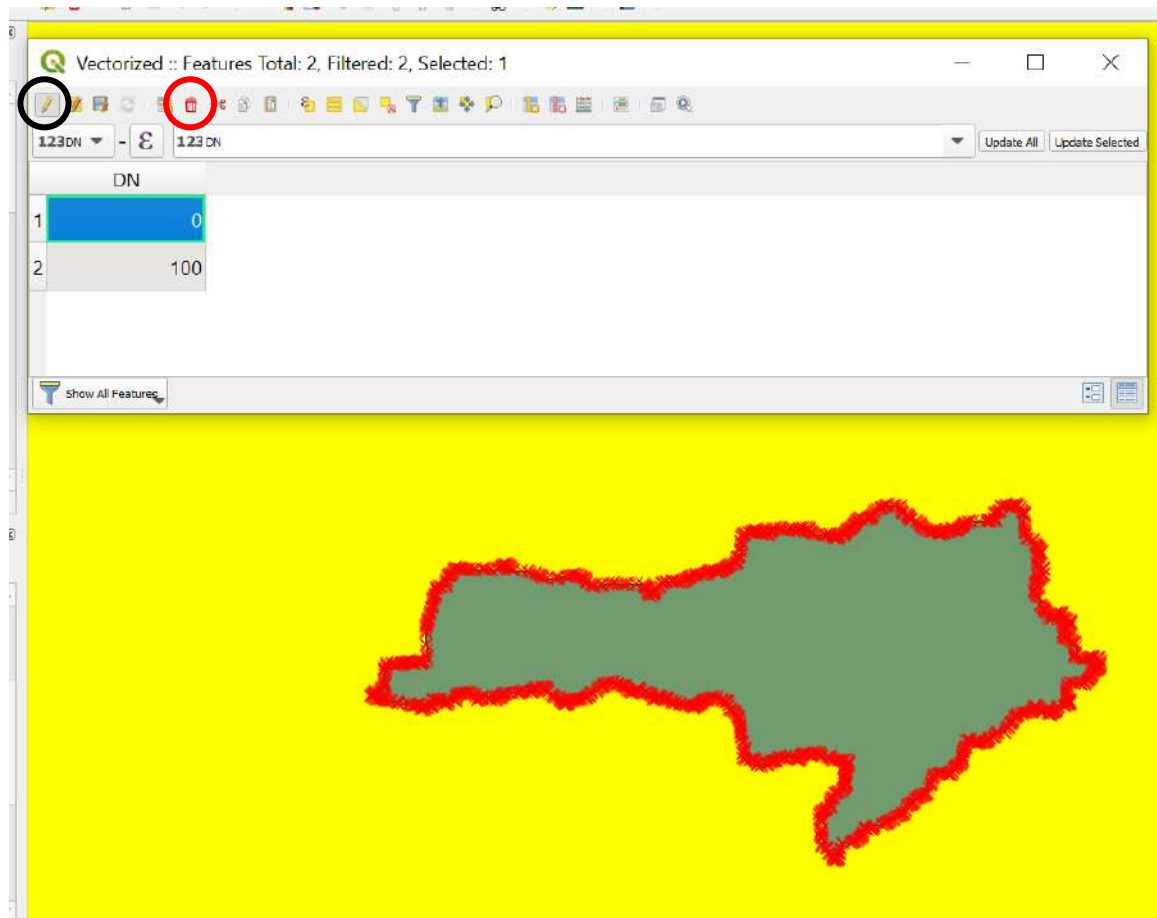

Your catchment polygon does now exist, and can be styled as well (e.g., outline only):
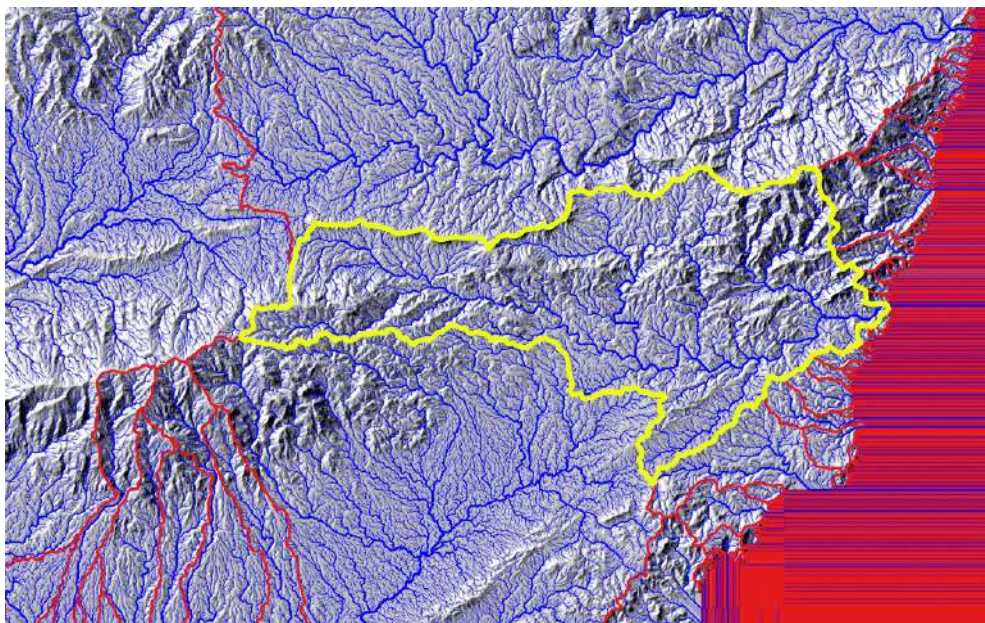
What is the interest of delineating catchments? Well, you may want to focus the analysis on that particular catchment: operations will be much faster and the files generated smaller. It is also good for display purpose, as you will see. To proceed with catchment-specific operations, you can use the polygon as a mask.

Let's first clip the channels to the catchment boundaries: to do this, go to Vector on the main menu (remember, the streams are vectors, in contrast to the rasters) → Geoprocessing tools → Clip. Here, select the channels as the input layer, your catchment polygon as the overlay layer, and save as a **shapefile** (SHP):
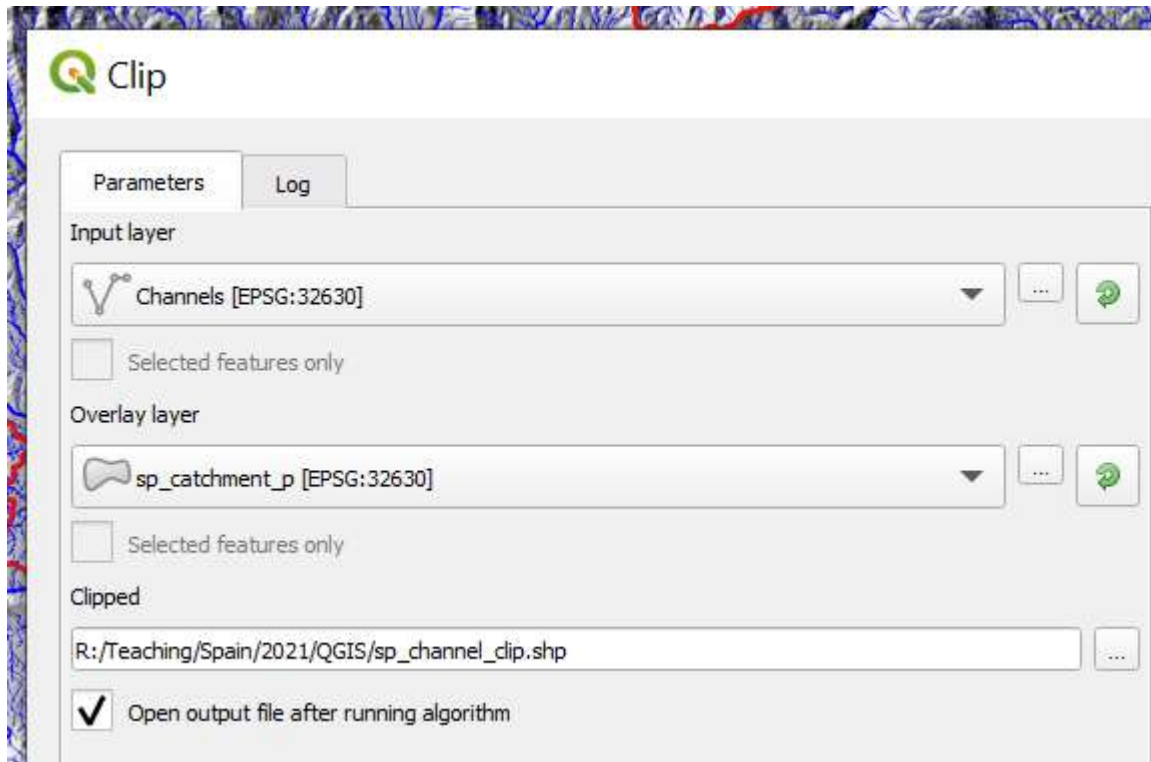

→ Run

The clipped streams will appear in their default format, i.e. a line. Something really cool I discovered in this YouTube webinars is this:

You can copy and paste styles between layers! Right-click on the original stream layer in the layer panel → Styles → Copy style → All style categories. Then go to the new clipped stream layer, right-click on it → Styles → Paste style → All style categories!

Let's now clip the DEM to the catchment boundaries: to do this, go to Rasters on the main menu → Extraction → Clip raster by mask layer. The principle is the same: select the filled DEM as the input layer, your catchment polygon as the overlay layer, and save as file (e.g., DEM_Clip_catch). Run. Job done!
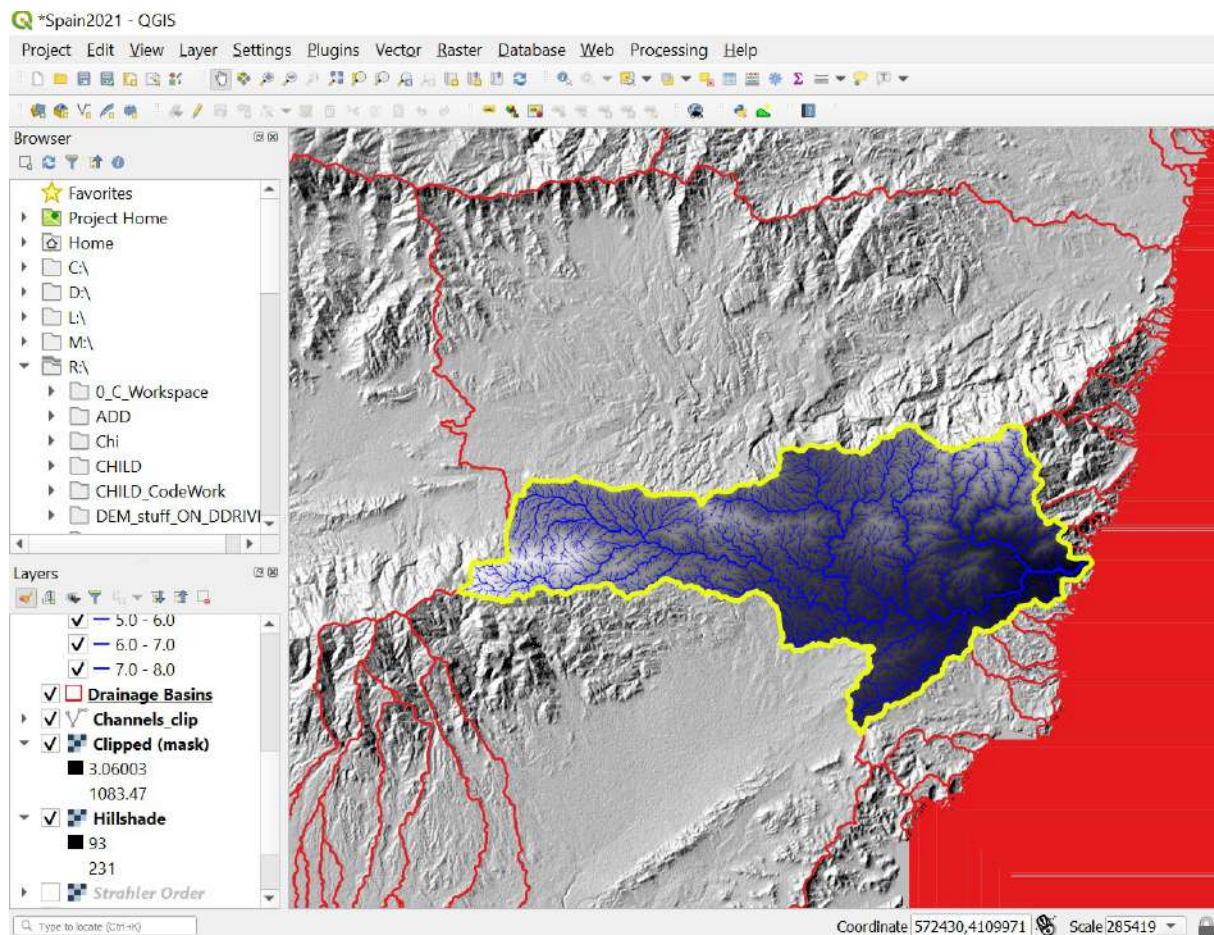
You can now run your analysis only on this catchment if you want to! Note that to obtain the visual result above, I had to reorganise the order of some of the layers in the Layers panel (just select and move up or down).
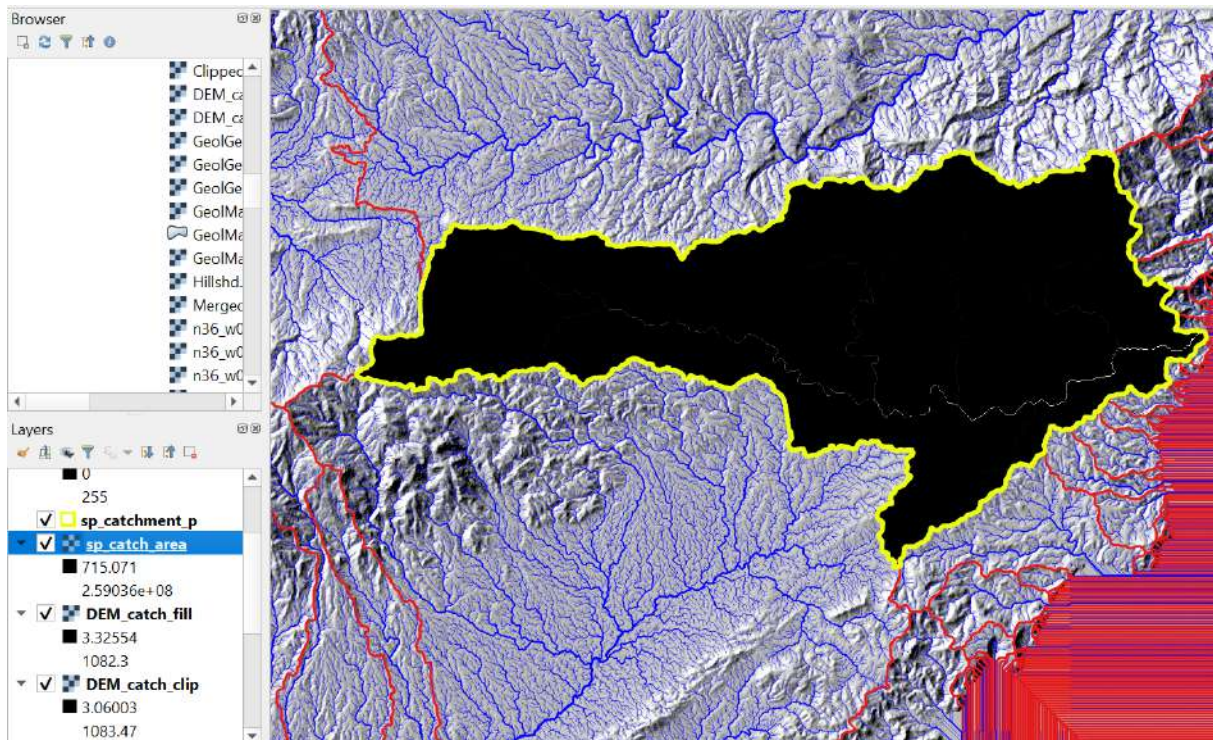
VII. Extracting river profiles

As mentioned earlier, river profiles can provide very useful information that can be interpreted in terms of tectonics or change in rock types. The river is steepening locally: is this because it cuts into more resistant rocks? Is there an active fault here?

A river profile is the representation of **elevation** as a function of distance downstream. So we need to trace the river, and extract elevation along its trace. Additional information that can be useful is **drainage area**: that is the area that is draining into each pixel. Drainage area increases downstream, and it jumps at tributary junctions. People have also shown relationships between drainage area, slope and channel width…

Let's focus on the catchment we have extracted (note that you can choose to work in a different catchment if you want to). Search for "**catchment area**" and open the Catchment area function in SAGA. Select your catchment DEM (DEM_Clip_catch) and (…) → Save to file (e.g., sp_catch_area). Click Run.

The stream network which is the location of greater flow accumulation should appear faintly in white / grey. It is not very obvious because the values are skewed, with the main channel having far greater values than the surroundings. Note that in my case, the values range from 715 to $2.59.10^8$ m^2 (see in the Layers panel). 715 m^2 is not surprising: considering the pixels are 26.74 m in size, the smallest area a pixel can have is 26.74 x 26.74 = 715 m^2.

WORK IN PROGRESS

I was hoping there would be a simple tool to extract **one** channel in QGIS, but there isn't. We will therefore not extract river profiles for the time being, until I have figured out a way of selecting one channel.

The idea is that we would select a source point, and then some code would trace the channel downstream, as in the example on the next page (I have traced the channel roughly in Powerpoint).
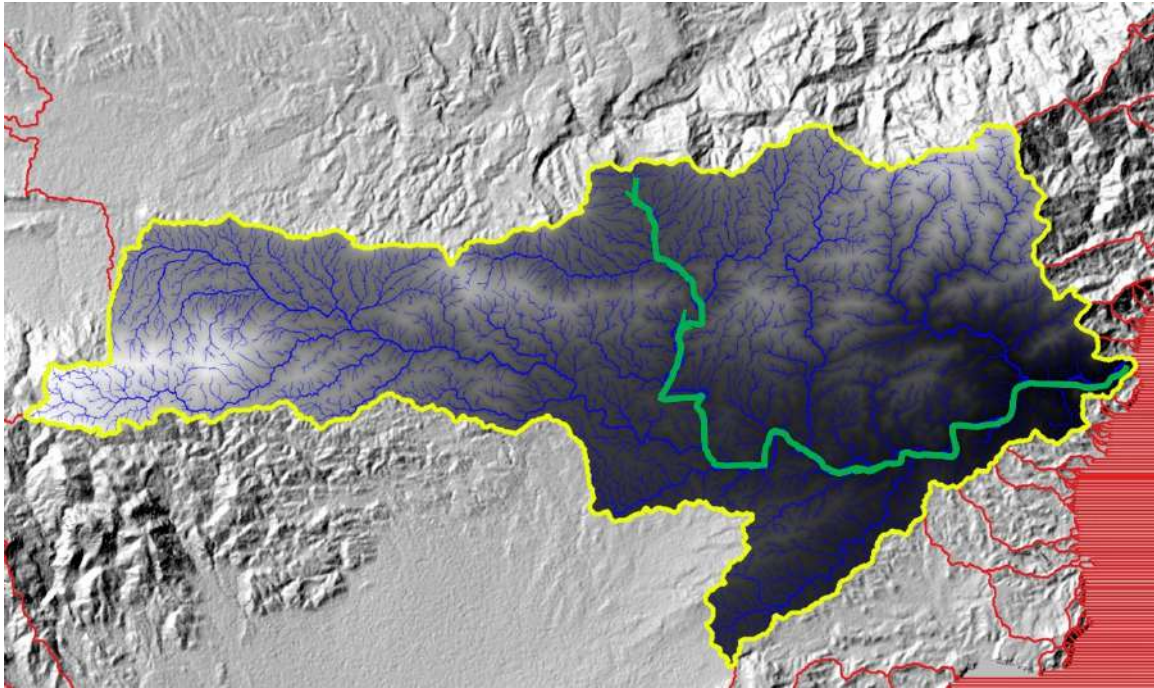
We would then extract elevation and catchment area along the trace of the channel, following the example shown in this video:
https://www.youtube.com/watch?v=TrBSfeIC5sI

You will see that they already have a channel line before they start on the video. I will get to the bottom of this!

IX. Visualizing the landscape in 3D

This is incredibly easy in QGIS (provided the software doesn't crash, which unfortunately happens often, but it did happen with ArcMap as well – make sure you save your project from time to time!)

Go to View in the main menu → **New 3D Map View**.

A new window will open, replicating what is on your QGIS window. You can make it bigger.

Click on the spanner button (circled to the right). This will open a new window where you can set up a series of useful parameters.
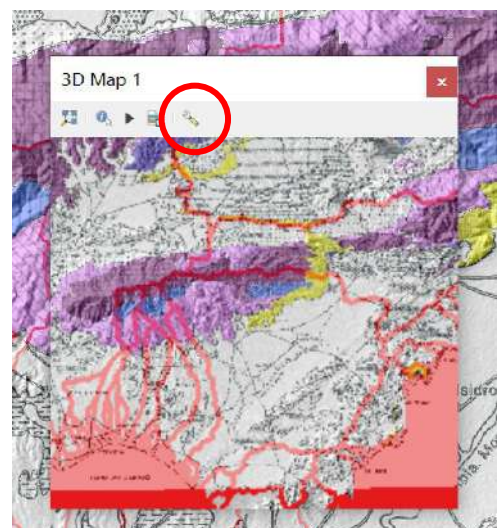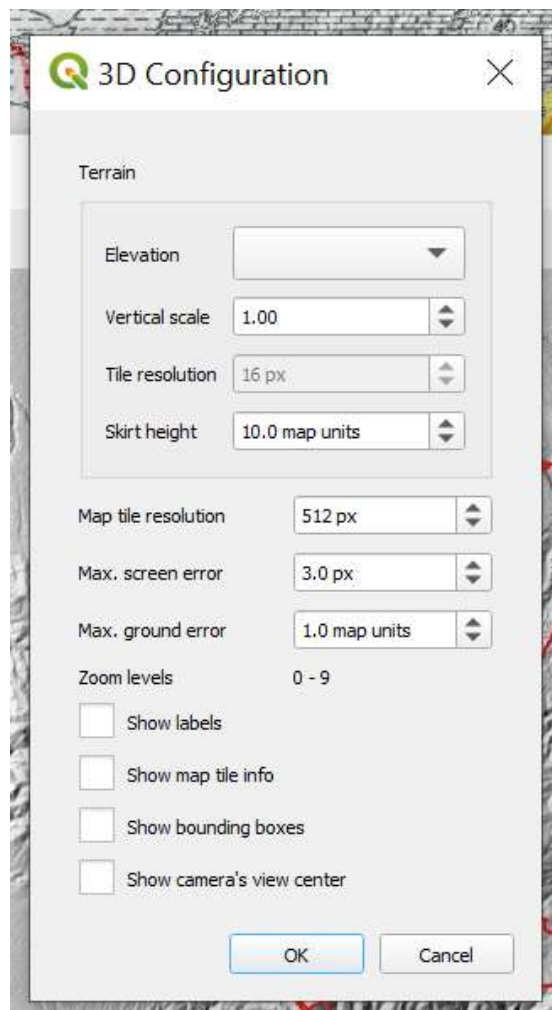
"Elevation" is the source of elevation: use your DEM.

"Vertical scale" is the vertical exaggeration. You may use 3 in this landscape. We will leave the rest as is.

Your 3D scene is now set! The layers in the 3D scene are identical to those in the QGIS window, and they are automatically updated: you can add or hide layers to generate the most informative views.

To navigate, use the mouse:
- Hold right + move, or scroll up and down: zooms in and out.
- Hold left + move: moves the map.
- Hold left + control + move: tilts and rotate the map.

It takes a bit of practice but becomes fairly intuitive. Feel free to explore your landscape!

See some examples below.

Topography + river network + catchments, looking NW:
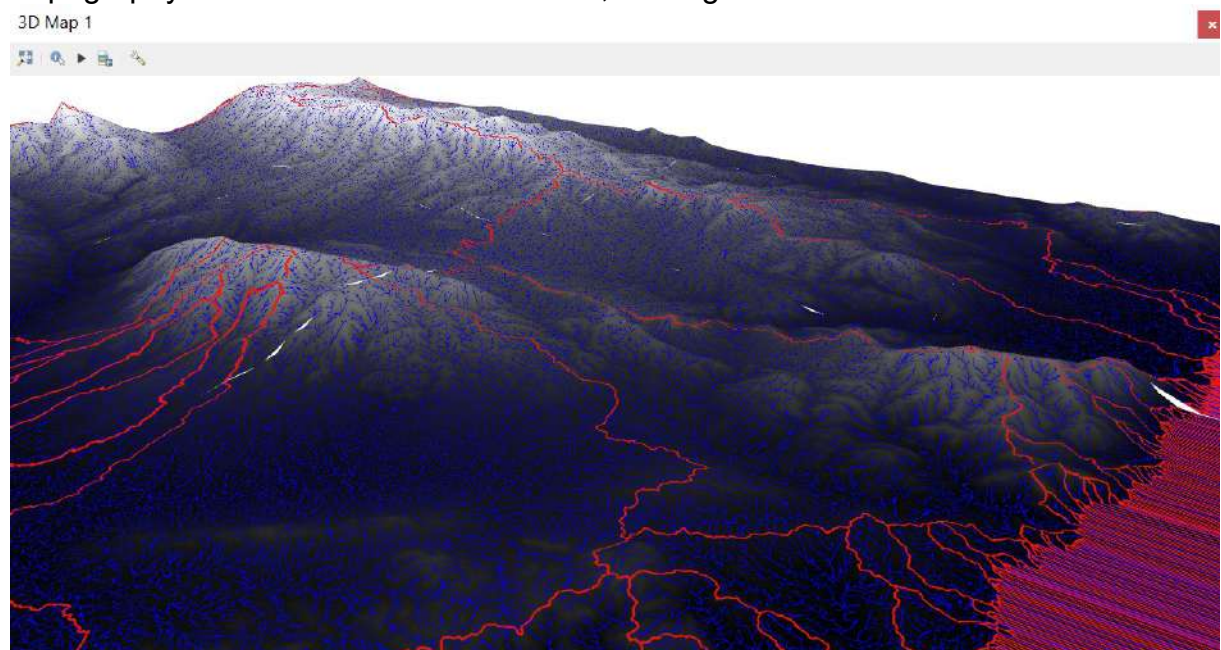
With hillshade:
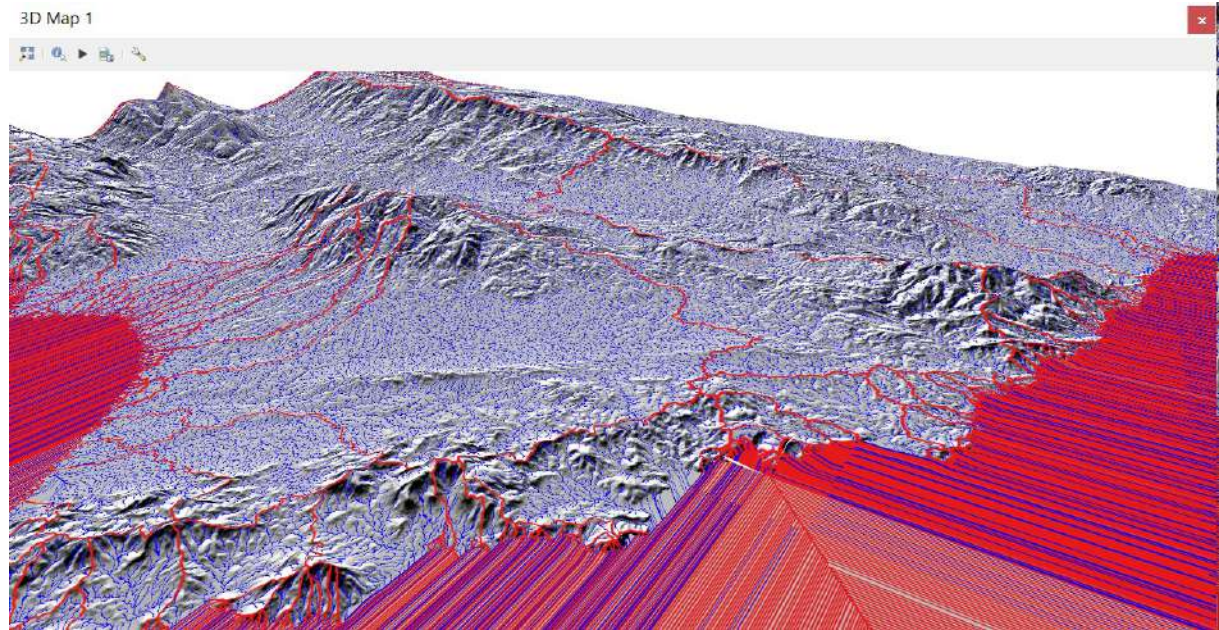
With geology:

With distribution of slopes in the study catchment (red = steep):

Topography + hillshade + slopes in the study catchment, looking east:

With geology:
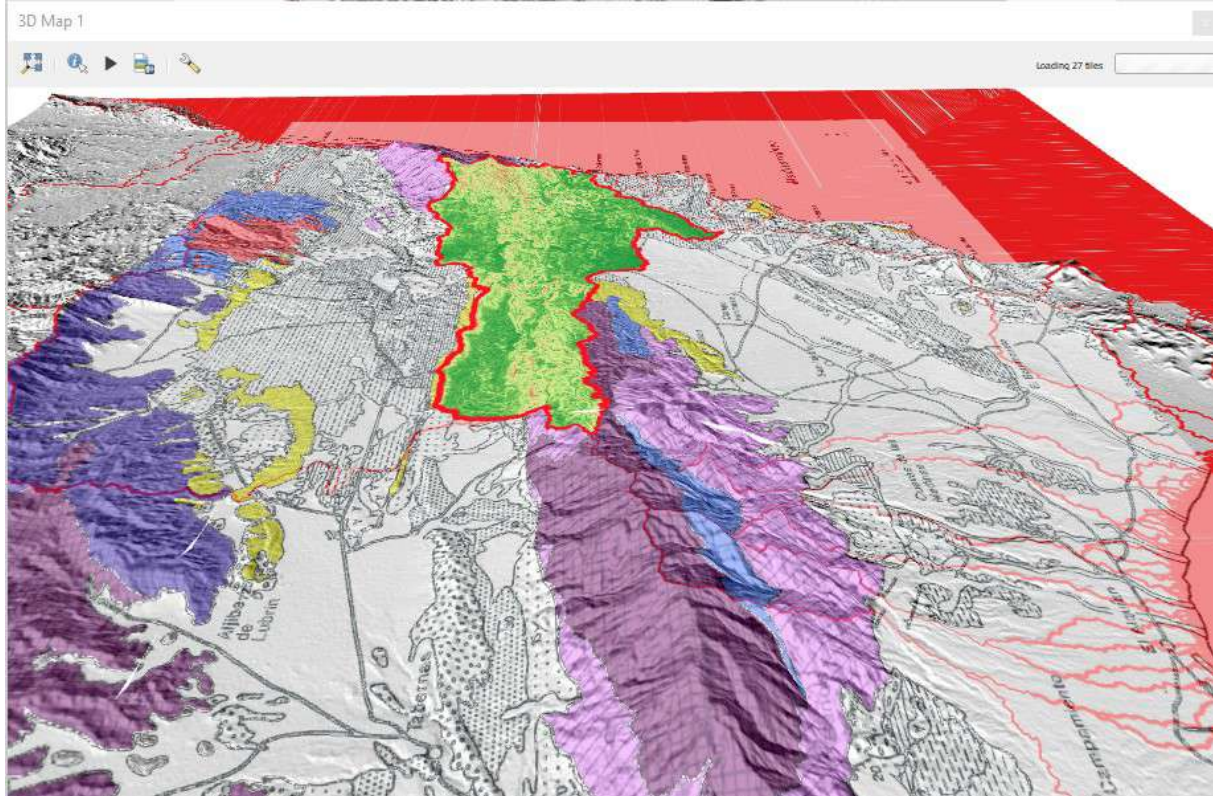
With rivers:
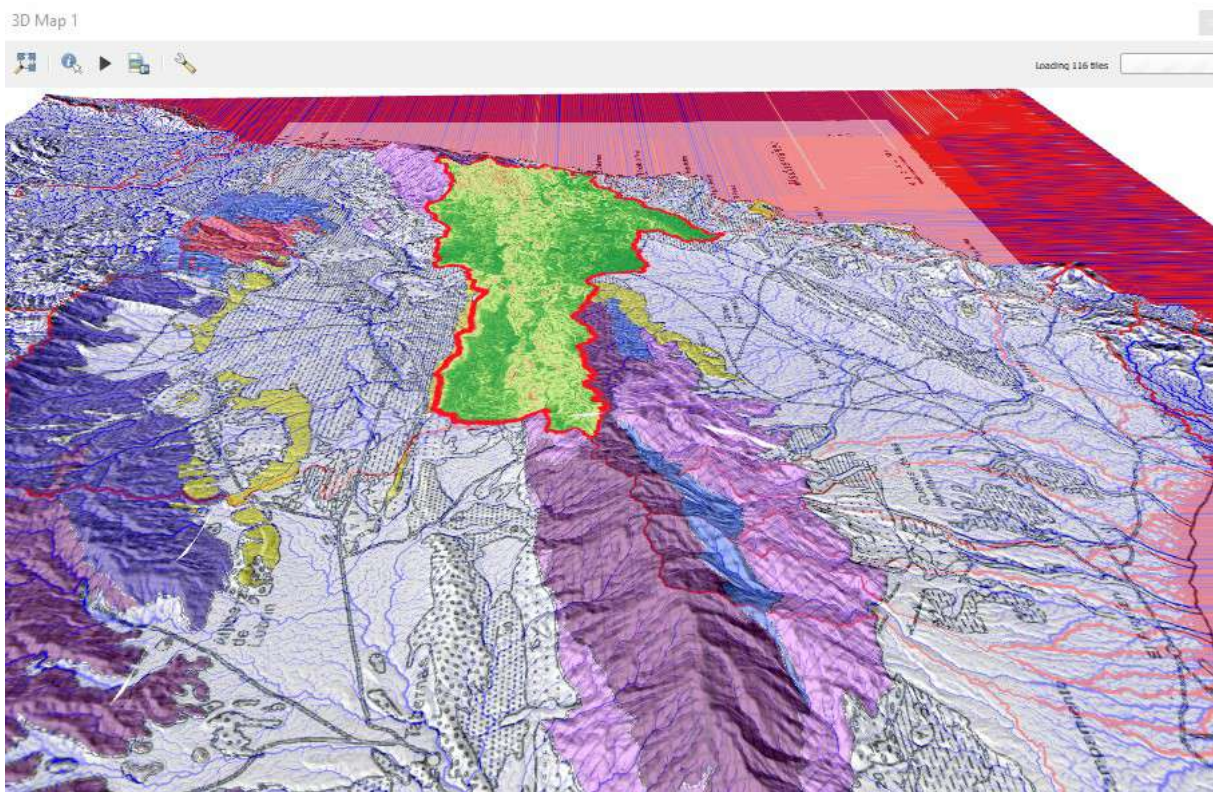
You can also save the scenes with the "save as image" button, just to the left of the spanner button.

The 3D scene is a wonderful to visualize landscapes, analyse the geometry of rivers, the distribution of slopes, and eventually relate your observations to the geology.

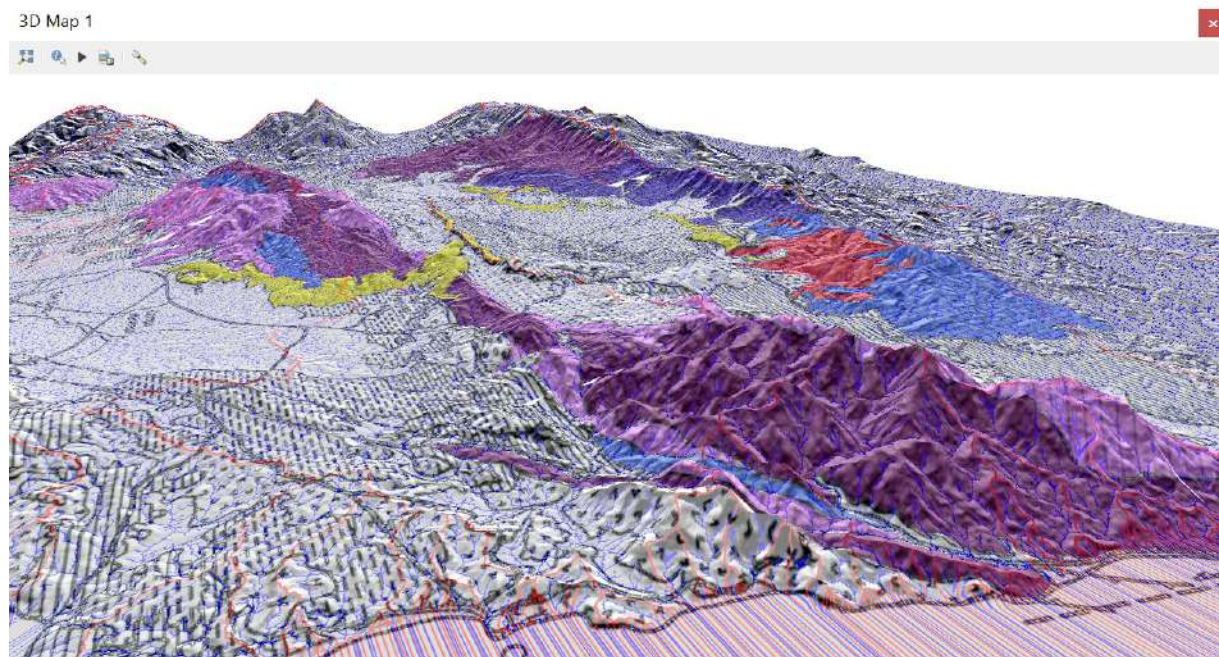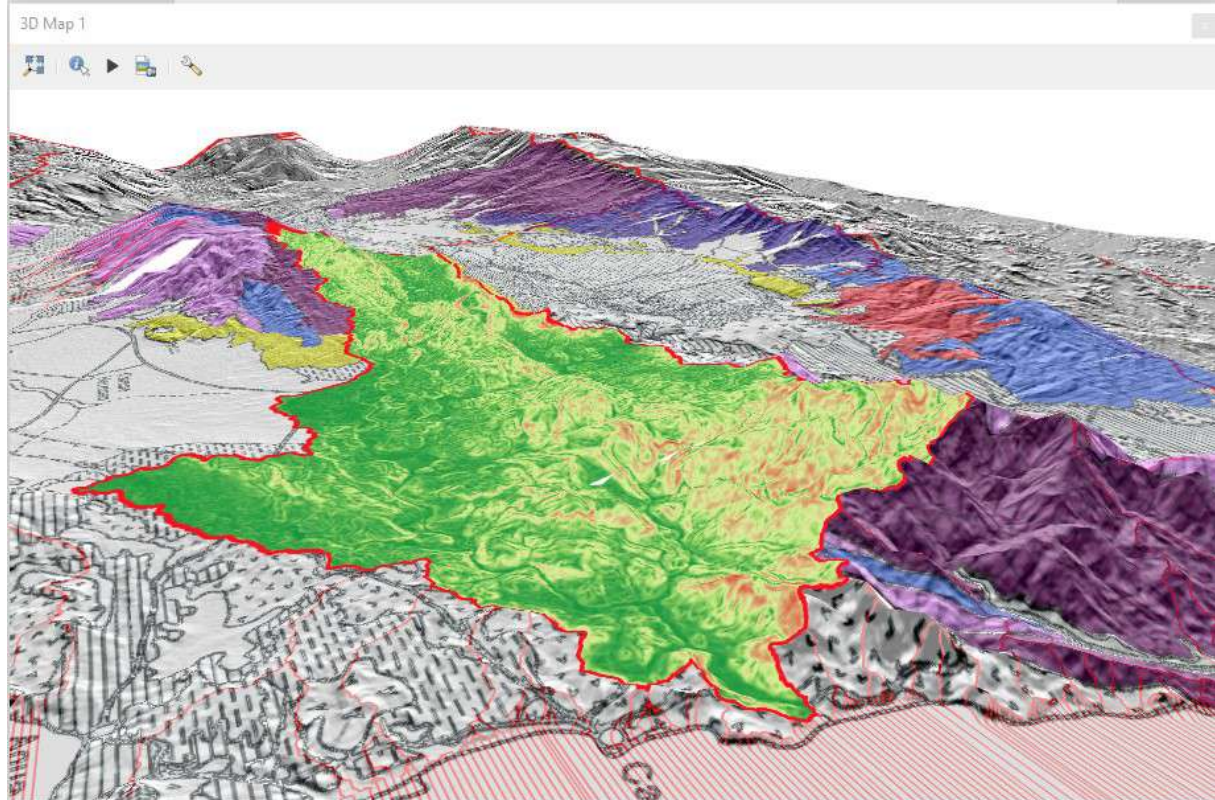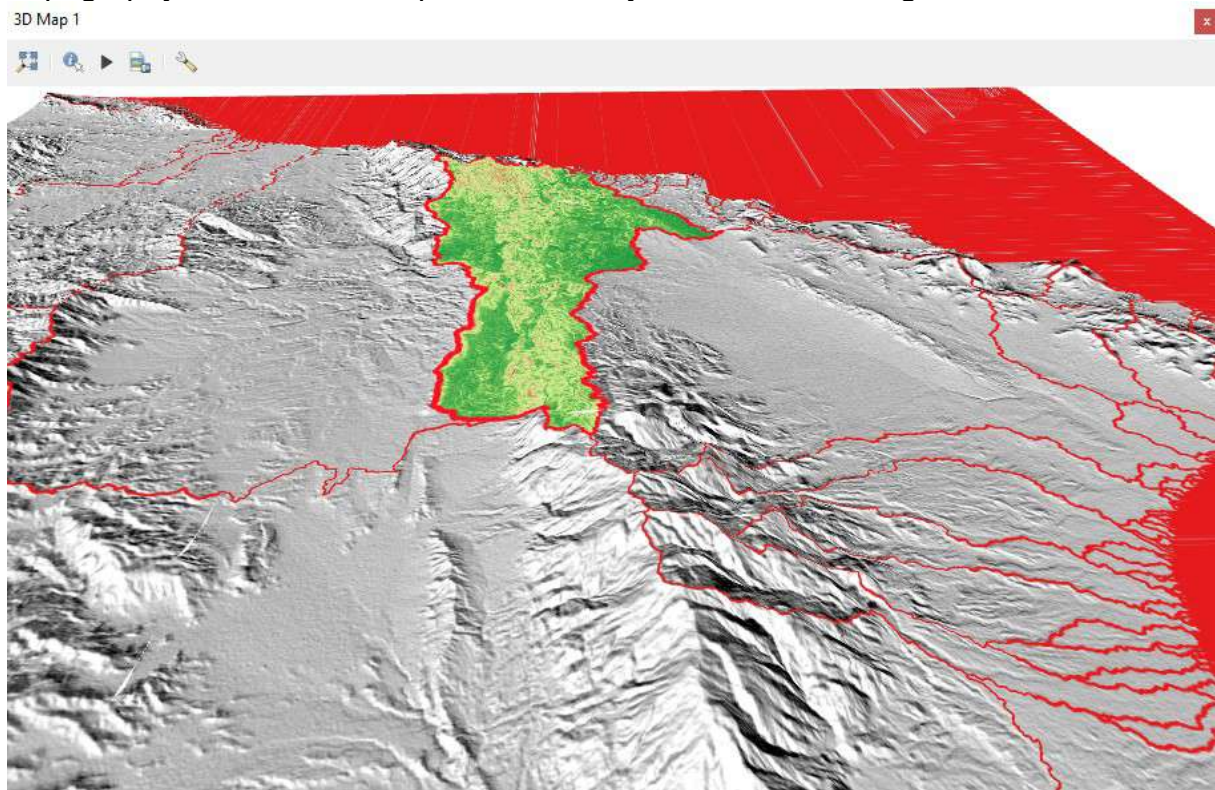Note that in this case, I have georeferenced pictures of the geological maps so the precision may not be extremely good, but it may be good enough for basic visualising purpose.

Students may draw the map from their 4th year dissertation in a drawing software, import it and georeference it in QGIS, and visualise it in 3D. Additionally, many national geological surveys now have digital versions or even shapefiles of their geology available for download, which will map exactly where the different rock types should be.

BGS version for the UK: http://www.bgs.ac.uk/data/services/digmap50wms.html
USGS version for North America: https://ngmdb.usgs.gov/gmna/

CAPTION FOR GEOLOGICAL MAP:

- Quaternary (2 - 0 Ma)

  Conglomerates

- Pliocene (5 - 2 Ma)

  Continental (Gochar Fm)
  cgl. sst. sh

  Marine fan (Abrioja Fm)
  sst

  Marine (Cuevas Fm)
  cgl. sst. lst

- Messinian (7 - 5 Ma)

  Coastal plain & barrier (Zorreras mb)
  cgl. sst. lst. sh   (Sorbas mb)

  Gypsum (Yesares mb)

  Turbidites (Santiago mb)
  cgl. sst   Vera Basin

  Reef lst (Cantera mb)

  Marl (Abad mb)   Turre Fm

  Cgl & sst (Azagador mb)

- Serravallian - Tortonian (15 - 7 Ma)

  Marine marl

  Turbidite
  cgl. sst   Chozas Fm

  Continental & marine cgl

- Burdigalian - Serravallian (22 - 15 Ma)

  Cgl. sst. sh   (Umbria Fm)
                    (Mofar Fm)

B. VOLCANIC ROCKS

  Calcalkaline (15 - 7 Ma)
  Lamproites (5 Ma)

C. BETIC BASEMENT

- Higher Betic Units

  Alpujarrides
  (Permo-Triassic)

- Nevado-Filabride Complex
  Higher Nevado-Filabrides

  Bedar granite
  (Permian)

  Marble, micaschist, amphibolite
  & serpentinite
  (Triassic - Palaeozoic)

  Nevado-Lubrin Unit

  Brecciated marble
  Rauhwacke
  (Triassic?)

  Tahal schist
  (Permian?)`

  Nevada schist
  (Palaeozoic)

SUMMARY

You have been given tools to analyse landscapes. Now, you need to think about how you can use them to gain some understanding of how geology affects landscapes and how you can use landscapes to infer geology. The table below gives a non-exhaustive list of the features that you can look for.

	Observations in ArcGIS	Diagnostic features to look for
Plan view observations	Topography (elevation + shaded relief)	Location of valleys, ridges, depth of valleys, height of ridges (relief), presence of linear features in the landscape (e.g. faults, layers, dykes)
	Fluvial network	Geometry of the network: shape of basins (round? elongated? distorted?), signs of river paths affected by structures (e.g. faults, layers, dykes)
	Slope maps and slope distributions (histograms)	Distribution of slopes across the landscape and relation to geology (e.g. resistance to erosion)
	Geological map (not always available)	Exposure of the different rock types + geological structures (e.g. faults, etc).
Profile observations	Topographic profiles	Steepness of hillslopes, depth of valleys
	River profiles	Steepness of rivers, presence of knickpoints along the rivers
3D observations	All the above in 3D viewer or Google Earth	All the above (better visualisation in 3D?)

All the features above could be interpreted in terms of structure (presence and orientation of faults, rock layers, magmatic features) and differences in rock resistance to erosion.

So, what can you say about the Betics landscape?

M. Attal, 2020.