Introduction to the Geological Record
Practical: Introduction to Digital Topographic data

During this practical, you will learn how to import topographic data into a software in order to perform a basic topographic analysis. 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!)

The analysis will be performed in the area around the Lake District (that you will visit during your field trip). The *Digital Elevation Model* (DEM) of the area is from SRTM. It is a ~30-m resolution DEM, which means that each pixel is approximately 30 meter wide. The DEM is available on Learn.

During this practical, you will be dealing with a few large files. I strongly recommend that you work on the hard drive of the computer, in the folder “Workspace” on C:

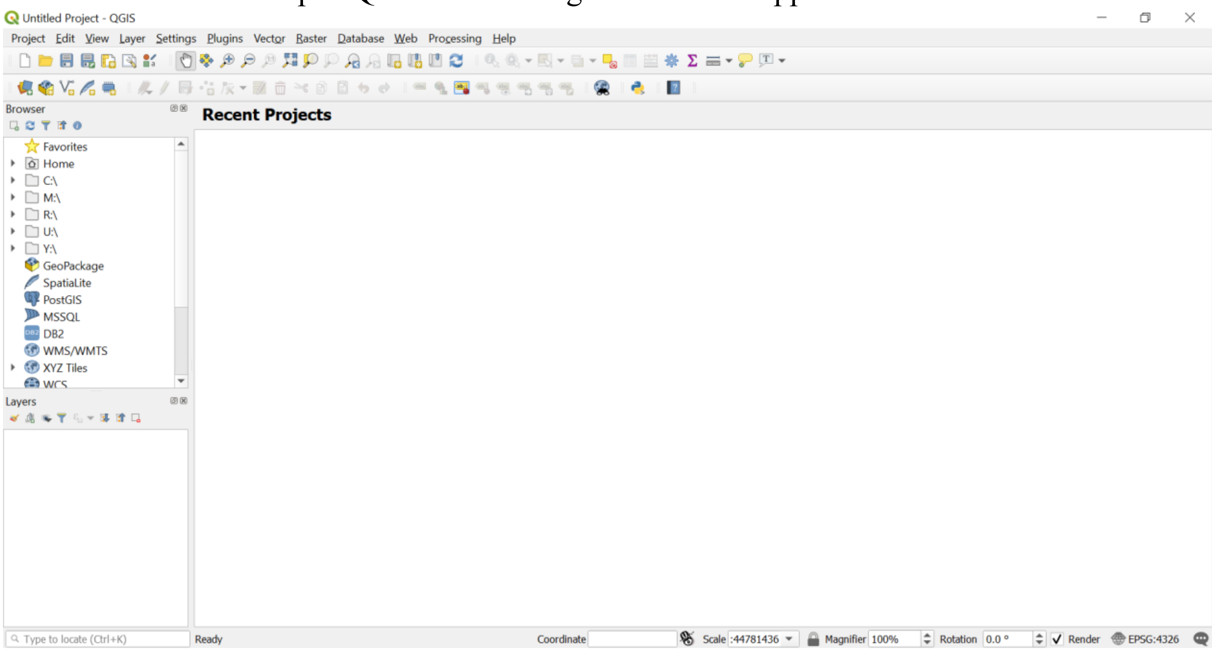
DO NOT FORGET TO COPY WHAT YOU HAVE CREATED IN THIS FOLDER AND PASTE IT ONTO YOUR HOME DRIVE OR A USB STICK BEFORE LOGGING OFF (all your work will otherwise be deleted when you log off). You will need ~100 Mb of space.

I. Downloading the topographic data.

I have put on Learn a zip file containing the DEM of the area and a picture of the geological map of the area. Download the zip file, place it in a folder (e.g., create a “practicalx” folder in “C:/Workspace”) and unzip the file. 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.

II. Opening QGIS + basic information.

Go to “Start” and open QGIS. Something like that will appear:

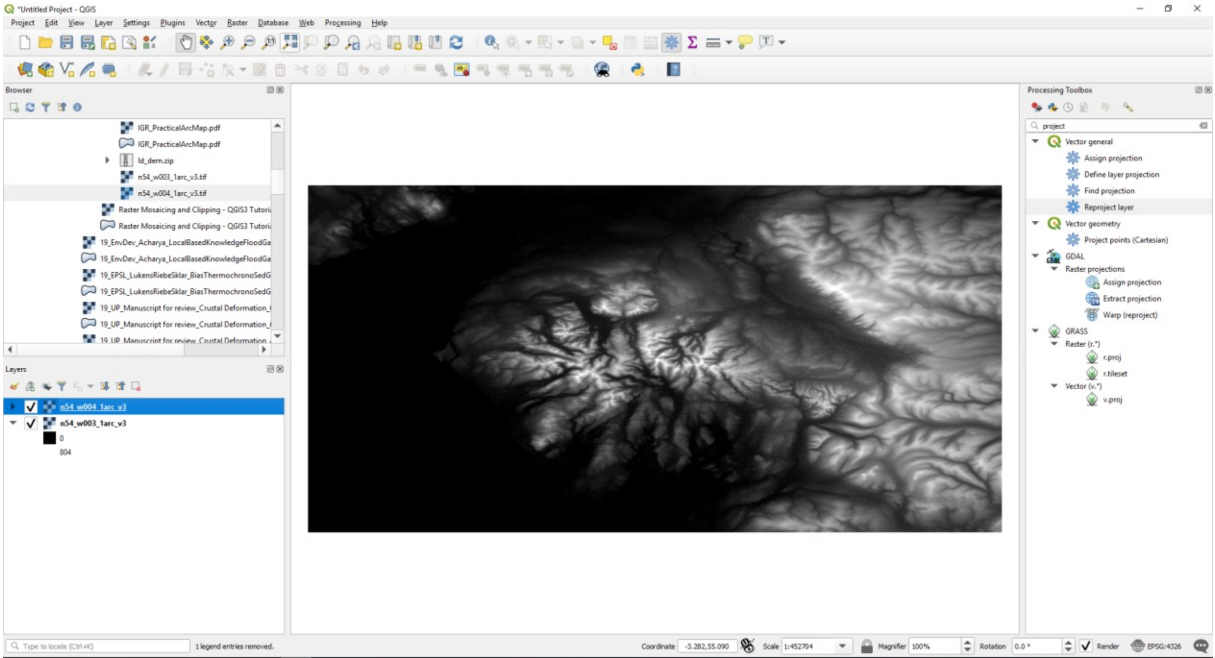


On the left of the QGIS window, two panels should be open: “Browser” and “Layers”. If you want to open panels, go to *View* → *Panels* and select the ones you need. For example, you should select the “Processing Toolbox” panel too. You then need to start a new project, either by clicking the blank sheet 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.

III. Basic Operations with QGIS + initial raster processing.

To begin with, you will load the DEM of the Lake District, downloaded straight from the USGS EarthExplorer (http://earthexplorer.usgs.gov/): using the Browser panel, move to the folder where you have placed the DEM (note the "refresh" arrows at the top, very useful if the data do not appear). Double-click on "n54_w003_1arc_v3" and "n54_w004_1arc_v3", 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).

Now, some important points:

(1) QGIS still sees the two tiles as separate, which may cause problems if we want to look at the shape of the river network for example (rivers will stop at the edge of the tiles).

(2) The DEM is distorted, because it hasn't been projected: if you double-click on one of the layers in the "Layers" panel and go to the "Information" tab, you will see that the coordinate system (longitude and latitude) is in degrees. Note also the data type: ***Int16** – Sixteen bit signed integer*; this will be important in the next step.

(3) The area presented is large and we don't need it all. If we remove the parts we are not interested in, operations will be faster and the files generated smaller.

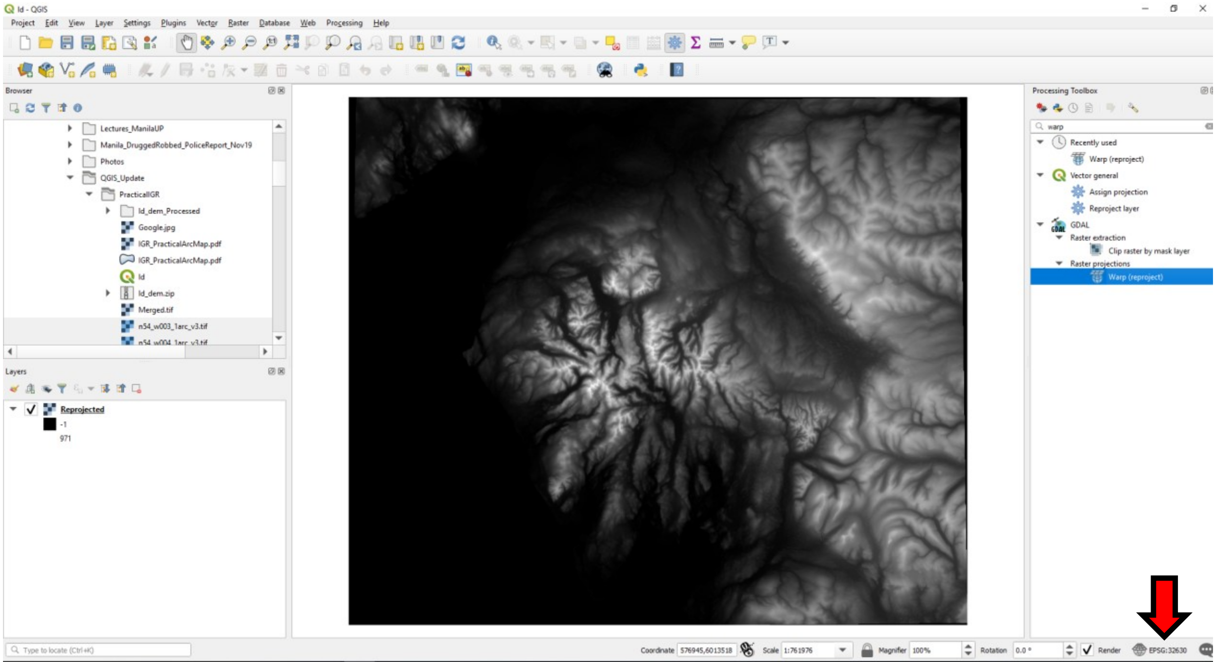
Let's solve these problems:

(1) We are going to ***Merge*** the rasters together: in the "Processing Toolbox" panel, go to *GDAL* → *Raster Miscellaneous* → *Merge*. In the window that appears, click on the (…) button under *Input layers*, select all and click OK. To maintain data integrity, select ***Int16*** as the output data type (see a few lines above!) Click the (…) under *Merged* → *Save to file* → navigate to your working folder and give the output file a name, e.g., "Merged". Then click *Run*. The new file created will appear, being made of one tile. You can now remove the two initial DEM files.

(2) We now need to ***Reproject*** (***warp***) the raster into a metric system. We are going to use Universal Transverse Mercator (UTM), which is widely used. For UTM, we need to specify the zone, as the projection is different for different parts of the world. There are 60 zones, with either north or south (see map at the end of this handout). Most of the UK are in zone 30N, which has the identifier **EPSG:32630** in QGIS (within the WGS 84 frame).

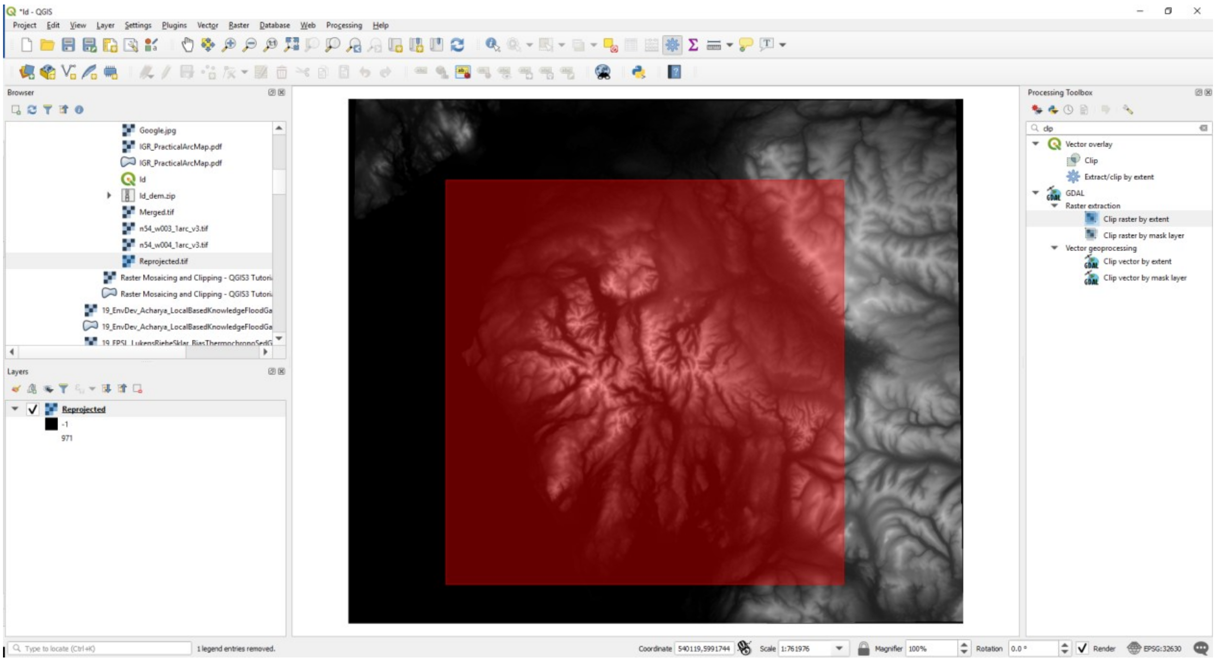
In the "Processing Toolbox" panel, search for *Warp*, which will appear under *GDAL* → *Raster projections* → *Warp (reproject)*. Double-click on it, select "Merged" as the *Input layer*. For the *Target CRS* ("coordinate reference system"), click on the small globe to the right and type **EPSG:32630** in the *Filter* bar: *WGS84 / UTM zone 30N* should appear → select it. In the *Resampling method to use*, select *Cubic*. Finally, click on (…) under *Reprojected*, navigate to your working folder and give the new raster a name, e.g., "Reprojected". Then click *Run*. The new file created will appear, slightly distorted. You can now remove "Merged".

The QGIS window is still displaying the data in the old coordinate system. In the bottom right, there is a little globe with the display system indicated (see below): click on it and select EPSG:32630. The DEM should now be displayed without distortion, as shown below. If you double-click on the "Reprojected" layer in the "Layers" panel, and go to *Information*, you will see that the units are now *meters*. The size of the pixels is also indicated, in meters too.



(3) Now, let's ***Clip*** the area of interest, to boost the process and save space! Search for "clip" in the "Processing Toolbox" and select *Clip raster by extent* under *GDAL* → *Raster extraction*. In the window that opens, select your *Reprojected* raster as the input layer and click (…) under *Clipping extent* → *Select extent on canvas*. This is a very convenient tool, as you can directly draw a box in the window to select the area of interest, as shown below. As you release the mouse button, the extent is specified automatically. Then click on (…) under *Clipped (extent)* → *Save to file* → navigate to your working folder and give your clipped raster a name, for example "ld" for Lake District. This will be your base DEM for the rest of the analysis.

Remove all the other layers and keep only "ld".
Well done, you are finished with the initial processing!

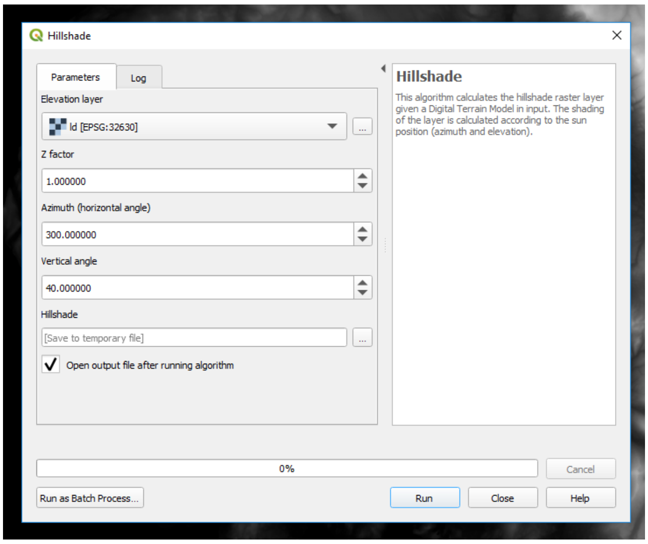


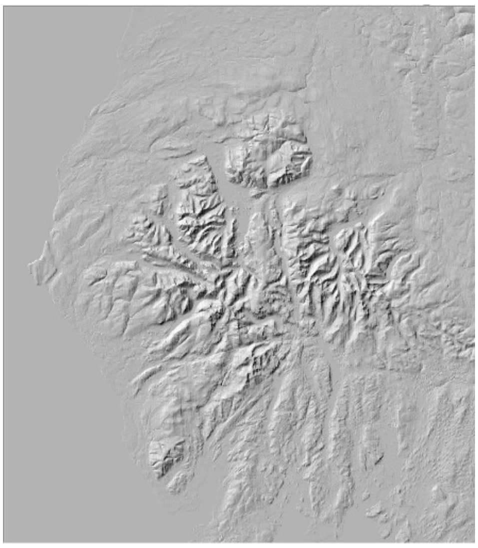
IV. Basic topographic analysis operations.

<u>IMPORTANT:</u> 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: you can use the prefix "ld" for the Lake District exercise. "ld_hillshd" will be the hillshade file of the area, "ld_slope" will be the slope file, etc.

<u>1) Producing a shaded relief map of the area</u>

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 left) → 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. "ld_hillshd") and click on *Save*, then click on *Run*. You should obtain something like below right: can you spot hills, valleys and ridges?





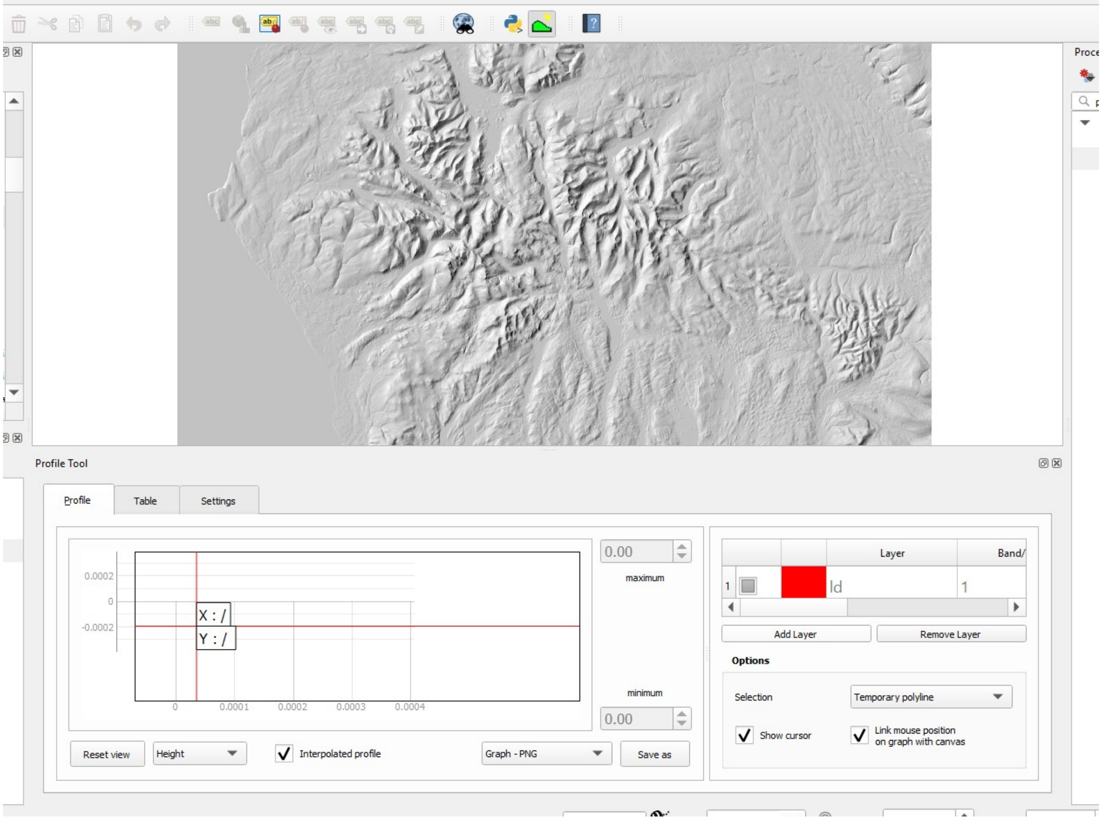
Note that for an enhanced visualisation of relief, you can adjust the transparency of the hillshade layer on top of the DEM: double-click on the hillshade layer in the "Layers" panel, go to the "transparency" tab and select 50 % for example. The result is stunning, isn't it?

<u>2) Extracting topographic profiles</u>

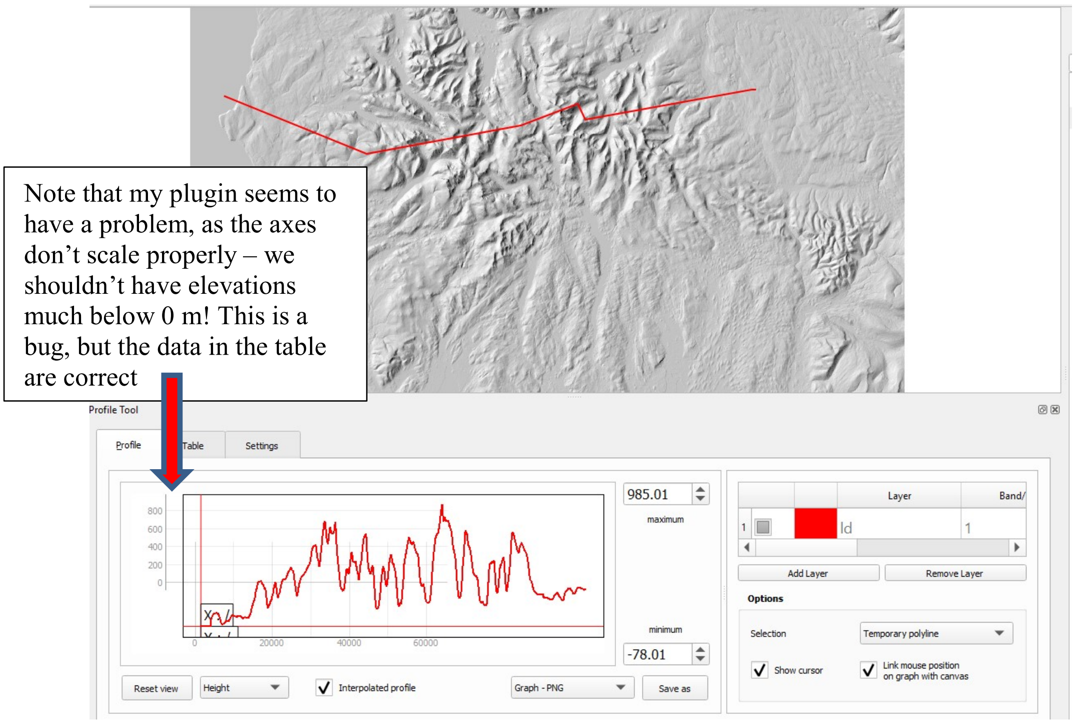
You may want to know how much relief there is in an area. Topographic profiles can allow you to easily visualise the relief along a line of transect, for example from a ridge line to another, across a valley or along a given path. Let's try to image the relief along a line going across the whole Lake District massif from the coast to the eastern side of the massif. We will try to cut through a couple of the prominent valleys in the area.

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 "add layer" to specify "ld" as 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.



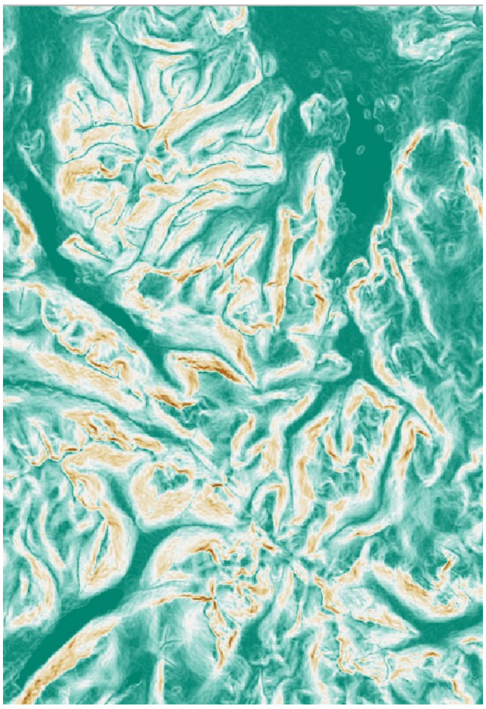
If you are not happy with your line, trace a new line – it will automatically delete the previous one. When you are happy with your line, you can save the profile as an image. You can also use the tab "Table" and *Copy the data to clipboard* → you can then paste the data in Excel for example, and produce 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 the Lake District?

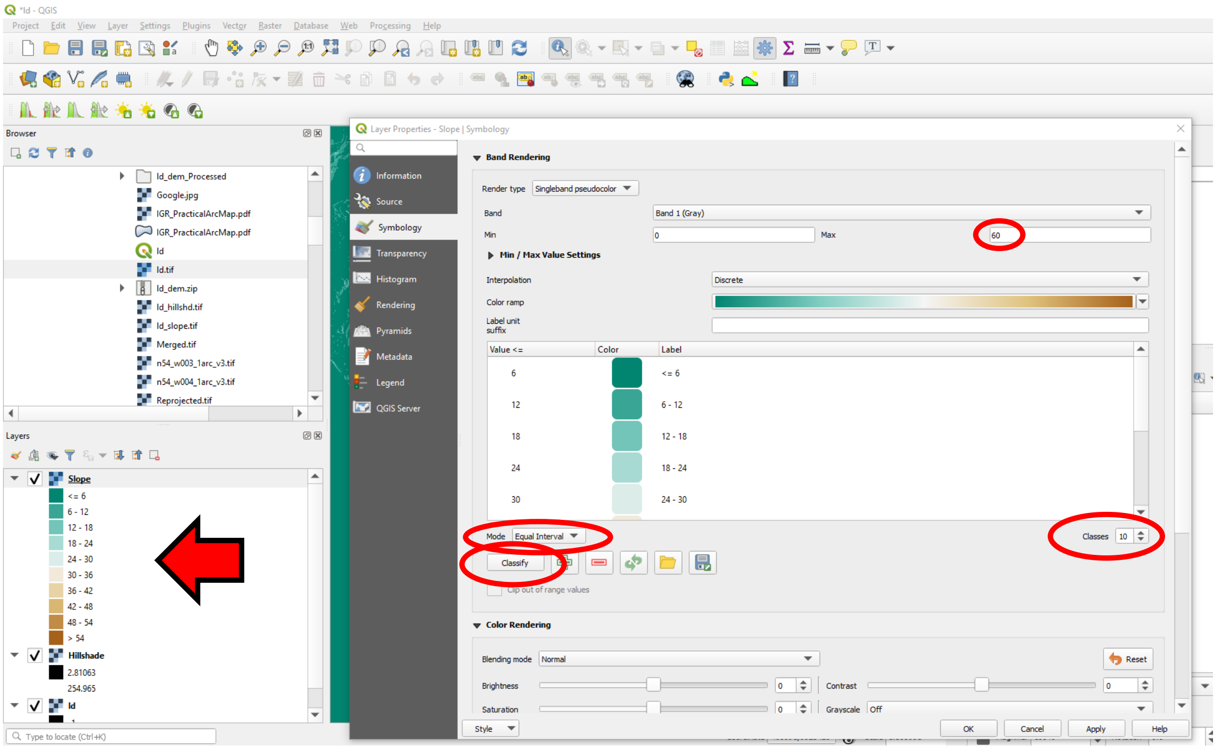
3) Performing a slope analysis

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. "ld_slope") and click on *Save* and *Run*. You should obtain something like the image below left. You can change the colour scheme to highlight differences in steepness (double-click on ld_slope → "Symbology"), and zoom in areas of interest (see below right).



How would you describe the relief and the valley shapes in the area? Where are the steepest slopes, and how steep are they? In which range are most slopes?

You will notice that the intervals for the colour values are designed to enhance the differences in slope (if you expand the "ld_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., 60 rather than 57.8352771) and choose a number of classes that is a multiple of that number (e.g., 10). See for example below. Once you have made your selection, click on *Classify* and OK.



V. Georeferencing images on the DEM.

The information displayed in QGIS so far is derived from the DEM so it allows you to visualise mostly relief and geomorphology. However, you may want to investigate how the geomorphology relates to other properties of the landscape: vegetation, human activity, geology… In this section, you will learn how to take such information from other sources and superimpose it on the topographic information in QGIS. In this case, we will use the geological map (which is in the zip file on Learn) but you can do that with any sort of image (e.g. GoogleMap if you want to look at vegetation for example).

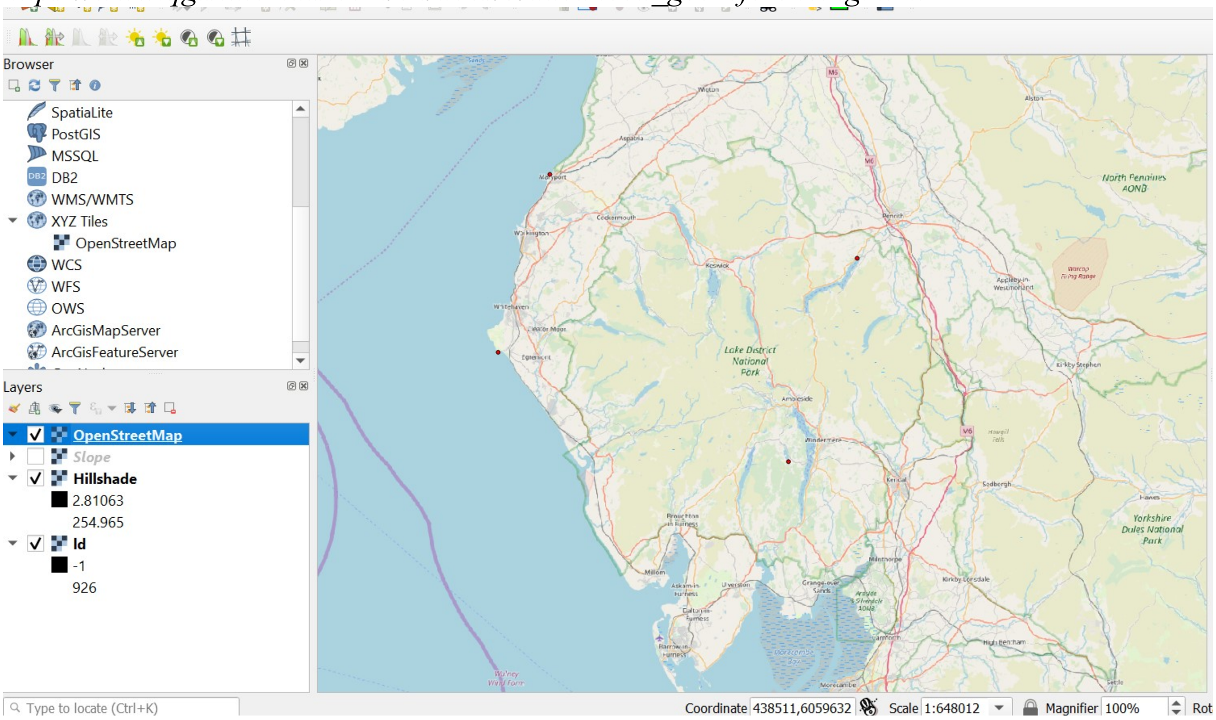
We will need to georeference the images to make sure that they are superimposed (nearly) perfectly on top of the topography. To proceed, we will use tie points which are remarkable points that are easily recognisable on the different images, such as: **summits, coastal features, tributary junctions, lake features (termination, island, spur), major road junctions, etc.**

To help with the process, QGIS allows you to easily import a base map from OpenStreetMap: in the “Browser” panel, click on “XYZ Tiles”: the *OpenStreetMap* layer should appear underneath. Double-click on it or drag it into the window. You now have a very useful base map that is automatically displayed in the coordinate system that you are working in (in this case UTM 30N). You can see that it will be much easier to locate tie points on this map than on the DEM!

If you navigate too far away from the Lake District, you can always “zoom to layer” (right-click on one of your “ld” rasters).

Thank you Ujaval Gandhi for your tutorial!

https://www.qgistutorials.com/en/docs/3/advanced_georeferencing.html

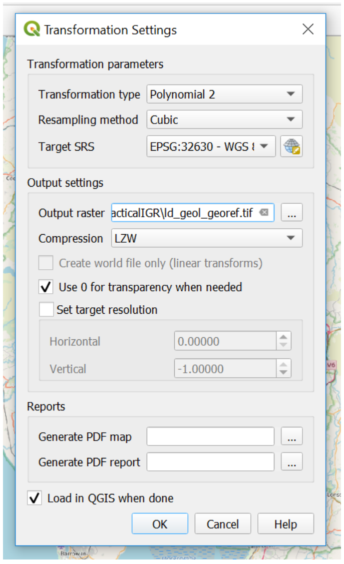


We can now start the process: in the menu, got to *Raster* → *Georeferencer*.

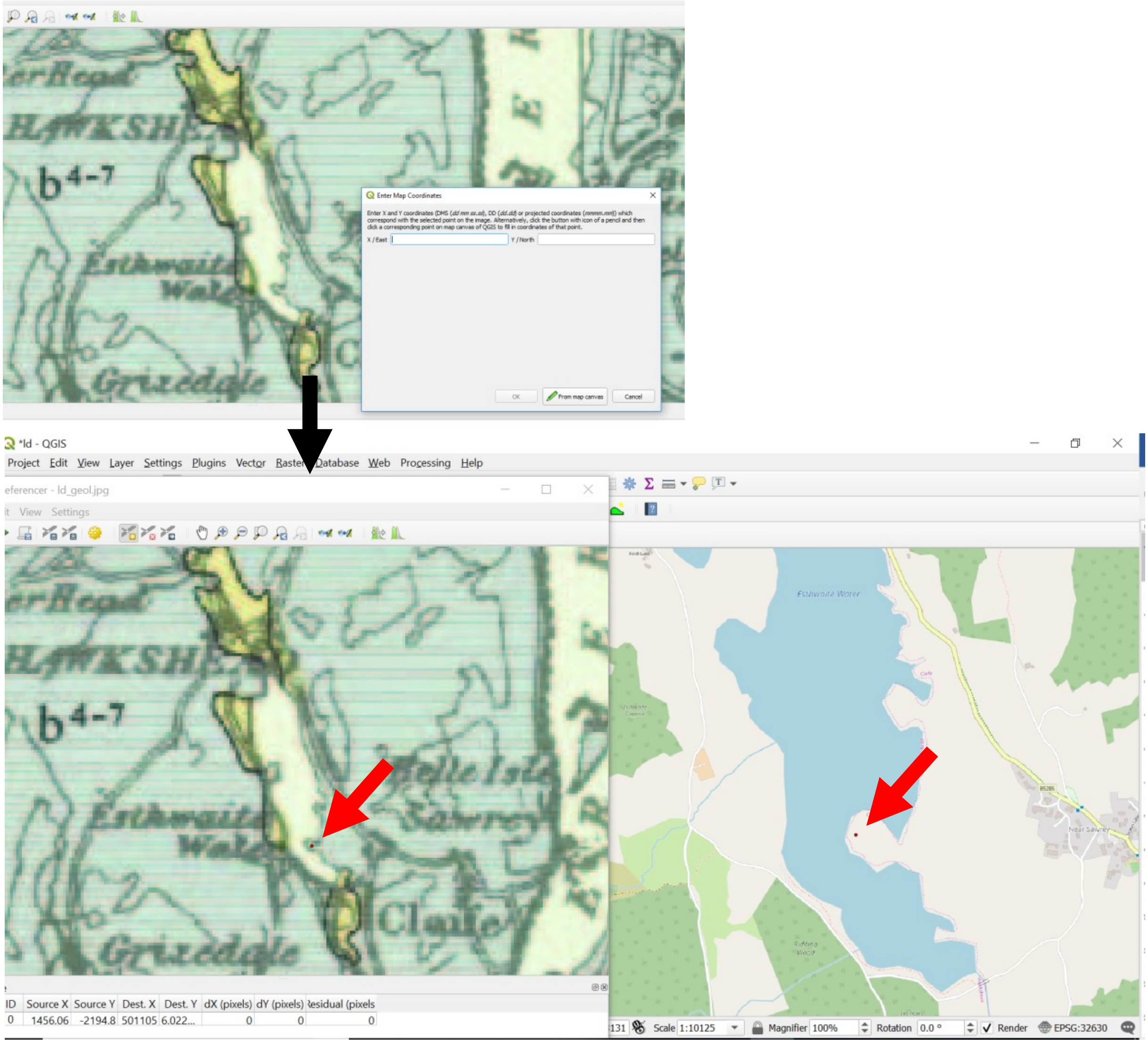
If you do not see the Georeferencer, you will need to install the plugin from *Plugins* → *Manage and install Plugins* → search for the *Georeferencer GDAL*.

A new window will open: go to *File* → *Open Raster* → select the raster that you want to georeference (in this case, select "ld_geol", but that could equally be a GoogleMap screenshot that you would have saved as a JPG file).

In the window, go to *Transformation Settings*: this will open a new window where we will specify the settings. There is a range of transformation types and resampling methods available, and you can learn more about it in your own time. We will select *Polynomial 2* for the transformation type and *Cubic* for the resampling method. **The *Target SRS* is very important**: this is the coordinate system in which the new raster will be projected. Use the drop down menu and select *UTM 30N (EPSG:32630)*, which we have been using. Click on (…) next to *Output Raster*: navigate to your working folder and give a name (e.g., "ld_geol_georef"). Tick "*Use 0 for transparency when needed*" and "*Load in QGIS when done*", then click OK.



We are now ready to select the tie points. With this method, we will need at least 6 points, distributed across the map. On the geological map, locate your first target and zoom to it. In the case below, I am focusing on a distinctive protrusion in Esthwaite Water. Go to Edit → Add Point (or on the equivalent icon) → click on your target. A new window will open, where you have to specify the coordinates of this point. Click on the "*From map canvas*" button: you can then directly click on the target on the OpenStreetMap raster → the coordinates will be collected directly from there. Then click OK. You now have your first tie point (see below)! Five to go!



Notes:

- The software can be a bit slow between panels: be patient and don't click madly if the system becomes unresponsive! Just wait.
- Be aware that landscapes change rapidly! *OpenStreetMap* is regularly updated, so some features may differ from your old map. Coastal erosion can be rapid (2 m / year = 100 m in 50 years!), as can be urban development (Maryport on the west coast has two lighthouses – I suspect the one on the geological map is the old one!)
- In our example, we select the coordinates of the tie points "*from map canvas*" but you can enter these coordinates directly if you know them. This applies for example if you can read the coordinates on the map that has been scanned, see for example: http://www.qgistutorials.com/en/docs/georeferencing_basics.html.
  For another cool example, see: http://fredgibbs.net/tutorials/qgis/overlaying-historic-maps-with-qgis.html.

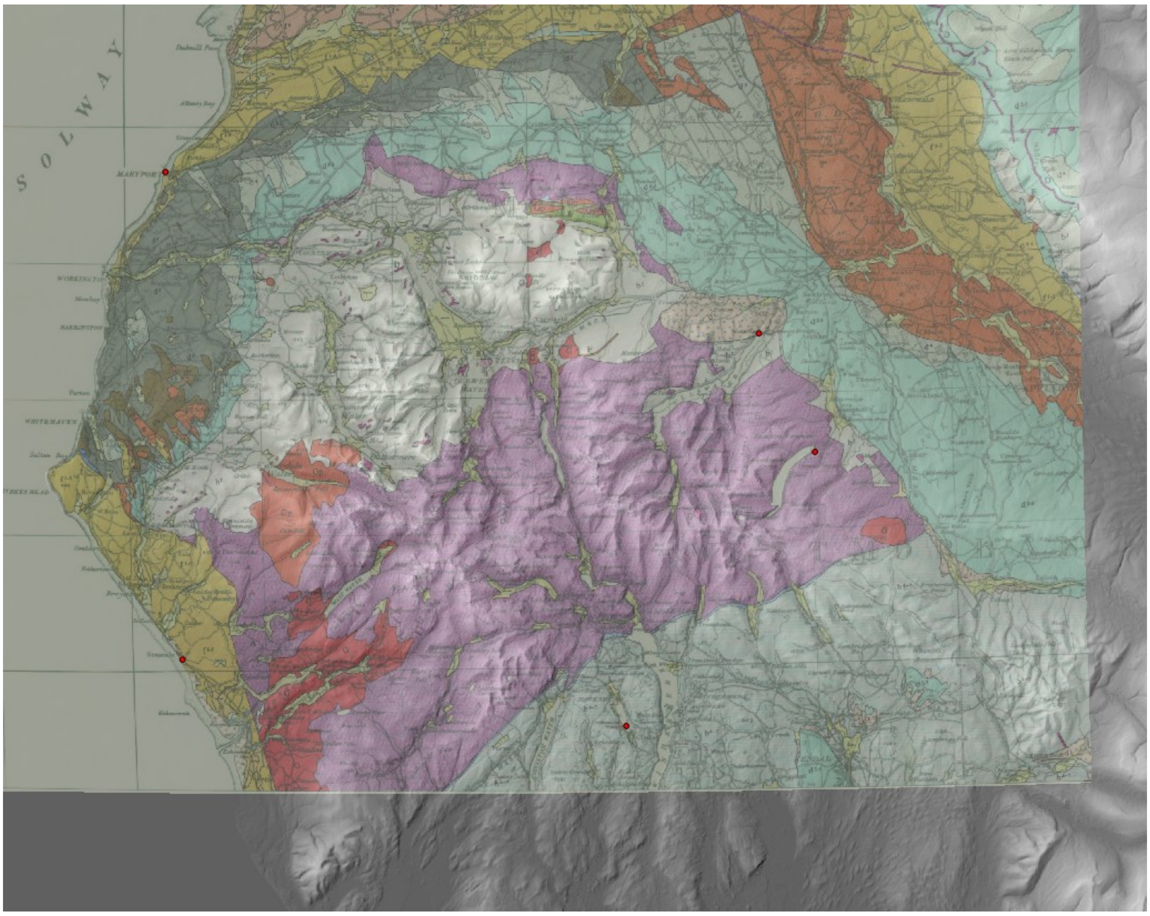
Repeat the operation so that you have six points in total. Note that the points will appear in the "*GCP table*" (for Ground Control Point) under the geological map. If you make a mistake, you can easily right-click on the erroneous point in the table and delete it.

When you have your six tie points, the error for each point will be indicated as dX and dY. If there is a point with a very large error, it may be human error: delete it and select a new one. Note that in the example below the error is "xxxxe-13", which means xxxx 10^{-13}, which is very small. So I have done a good job!

GCP table

Visible	ID	Source X	Source Y	Dest. X	Dest. Y	dX (pixels)	dY (pixels)	Residual (pixels)
✓	0	1456.06	-2194.8	501105	6.02273e+06	-2.27374e-13	0	2.27374e-13
✓	1	410.167	-916.583	467298	6.0634e+06	-5.68434e-14	-4.54747e-13	4.58286e-13
✓	2	1548.41	-302.635	503529	6.08309e+06	-2.27374e-13	-1.7053e-13	2.84217e-13
✓	3	1770.54	-1292	510844	6.05155e+06	2.27374e-13	-2.27374e-13	3.21555e-13
✓	4	437.783	-2039.62	468547	6.0276e+06	0	-6.82121e-13	6.82121e-13
✓	5	1891.01	-1567.35	514952	6.04285e+06	2.27374e-13	-2.27374e-13	3.21555e-13

If you're happy with your work, go to *File* → *Start georeferencing*. The geological map will be warped so that each of the tie points appears with the corresponding coordinates. If you have done a good job, the map will appear in the right place: hide the OpenStreetMap layer and change the transparency (or rather "*Global opacity*"). You should see something like that:

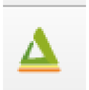


You can now close the Georeferencer window and save the tie points.

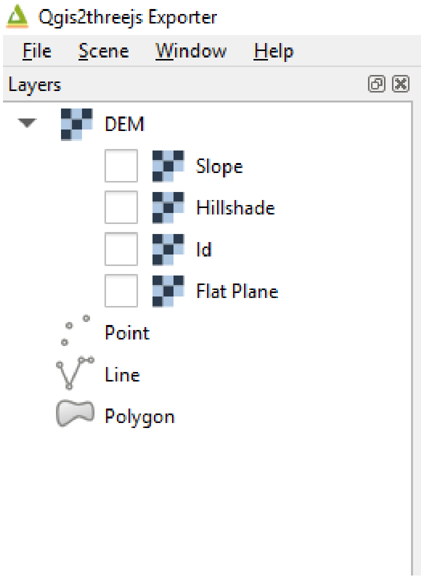
Is the landscape morphology reflecting the underlying geology? Explore, and share your ideas.

VI. Visualizing the landscape in 3D using…

Visualising information in 3D can enhance some of the observations even further. The **Qgis2threejs** plugin has been designed to permit such visualisation in a professional manner. Go to *Plugins* → *Manage and install plugins* → search for *Qgis2threejs* → install it.

The following icon will appear in the toolbar: 

Click on it. A new window will appear, with a "Layers" panel. In this panel, the rasters in your QGIS project are displayed under "DEM". This means you can select which raster will be used for assigning elevation values. Tick "ld"; note that you have the option of a "Flat Plane" too, in case you want to display another type of information on top of the flat plane (see for example this short and fast video showing the display potential using what seems to be a different version of *Qgis2threejs*: https://www.youtube.com/watch?v=edPiNvZJScM).

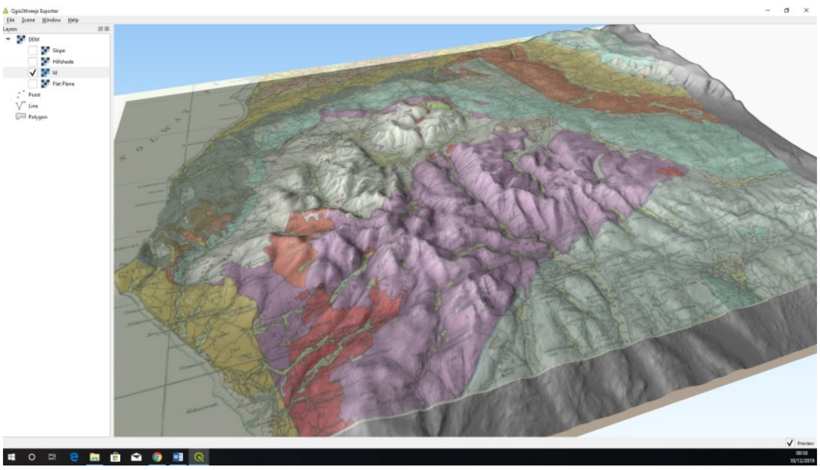


The moment you tick the DEM layer, your 3D scene will appear, displaying the layers that are displayed in your QGIS project. If you want to remove a layer from the 3D, go to your QGIS main window and hide the layer → the 3D should update automatically.

To enhance features, you can exaggerate the relief vertically: go to *Scene* → *Scene settings* → change *Vertical exaggeration* (try to use 3). You can navigate through your landscape with the mouse (try left-click, right-click and scroll) or keyboard.

You can export the 3D scene to the Web: *File* → *Export to Web…*

You can save the scene as an image: *File* → *Save scene as* → *Image*.

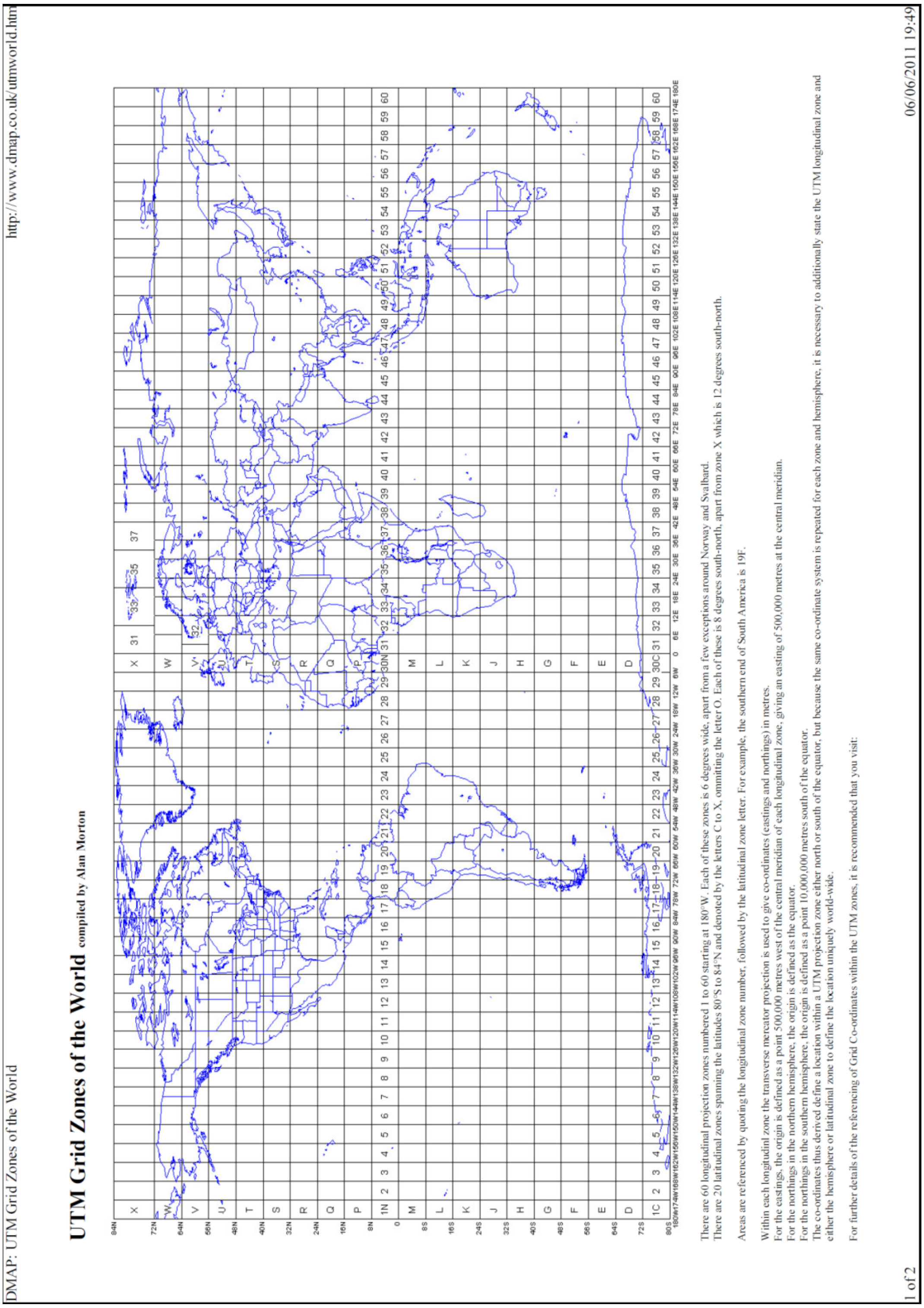


So, is the shape of the landscape reflecting the underlying geology? Explore the landscape and try to determine whether some of the geological features could have been picked by looking at the landscape. If some observations contradict your intuition (e.g., would you expect granite surrounded by slate to stick out in the landscape, or the opposite?), then try to think about the processes that have shaped this landscape over the last tens of thousands of years… Feel free to discuss with the demonstrators.

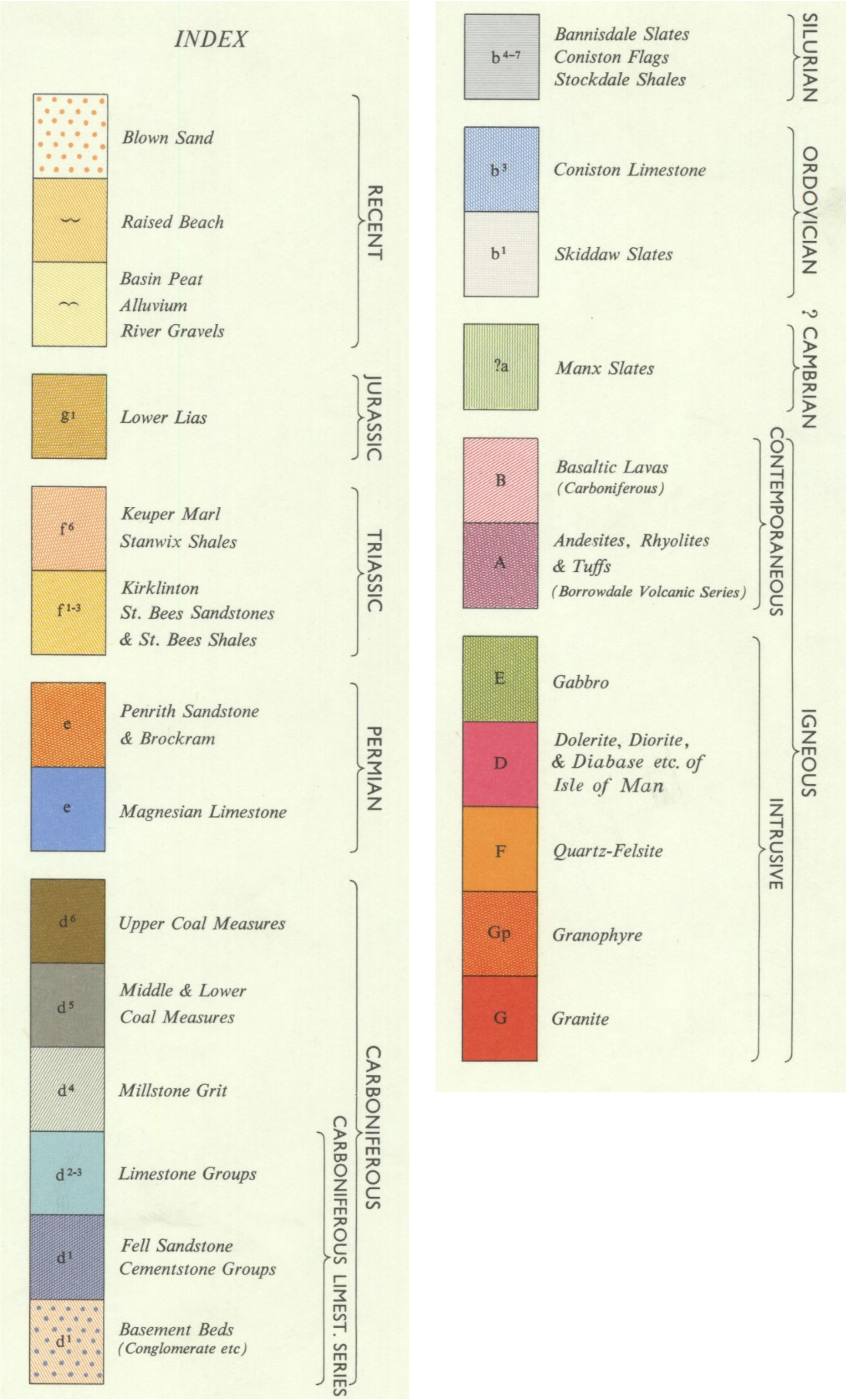
REMINDER: IF YOU HAVE WORKED ON C:/WORKSPACE, DON'T FORGET TO COPY YOUR WORK ON YOUR HOME DRIVE OR ON A USB STICK BEFORE LOGGING OFF. Your work will be deleted when you log off otherwise.

Please note: the geological map is provided for teaching use, not for personal use (copyright BGS).

UTM zones:



Geological map caption:



M. Attal, December 2019