Working Draft

V.20200929

Using QGIS in Mineral Exploration

Version 3.14

Grant Boxer (*FAIG, M GSA*)

Consultant Geologist

PO Box 368
Maylands WA 6931
Australia

CONTENTS

1: SUMMARY

QGIS is an open source GIS program for the display and analysis of GIS data. It has developed significantly in the past few years and is now a valuable tool for the mineral exploration industry, and a viable alternative to the commercially available GIS packages. Although not specifically written for geological applications, QGIS can do most of the required GIS tasks required by today's geoscientists. The terminology is different to the usual earth sciences programs but many QGIS algorithms do the same thing but with a different name. There is no dedicated drill hole or cross section module available for QGIS currently, but discussions and plans are progressing to develop this module in the future. The Geoscience plugin is a basic drill hole display option that is available as a free plugin.

This manual examines QGIS and how QGIS can assist geoscientists in undertake mapping and geoscientific tasks in their day-to-day work. The manual has evolved during several years teaching QGIS to geoscientists in Australia and has been produced to offer a go-to document for earth science related GIS activities.

Accessing data from the internet via web map and web feature servers is illustrated to show how using this data can help with compiling available data for an area. Detailed aerial photography and Google Earth can be easily integrated with mapping data to allow the creation of accurate base maps for a variety of geological applications. A wide range of vector and raster (grid and image) data formats can be easily imported into QGIS, including GPS gpx files.

The presentation options for point, line and polygon data are extensive and easily customised. A variety of geological symbols and pattern fills can be applied to points, lines and polygons. Geochemical and geophysical data can also be presented in a variety of display options. Basic 3D display of map data is also available via the QGIS2threejs plug-in.

QGIS has many plug-ins for specialised tasks and the semi-automatic classification plug-in (SCP), is one example where users can select, download and process ASTER, Landsat and Sentinel 2 satellite data. It is recommended that new users peruse the plugins list to see what plugins are available and for those that may be of use in their work.

Map production is easy in QGIS with the "Print Layout" allowing extensive options for the display and printing of maps.

This document is a working draft and in continuous development. There may be errors and omissions, and these will be rectified as time permits. This manual applies to version 3.14. Please feel free to share this document and please contact me if you find any errors.

2: INTRODUCTION

This document is aimed at the exploration geologist, but the techniques outlined are easily transferrable to other areas. The author has been using QGIS since 2015 and the version used in this document is version 3.14.

The reader is encouraged to join the international online QGIS user forum at http://lists.osgeo.org/mailman/listinfo/qgis-user.

This document will not go into the detail that is covered by the official QGIS User Guide and Training Manuals (https://docs.qgis.org/testing/pdf/en/) and other reference books (e.g. Graser 2016) on QGIS on topics like editing etc., but will discuss those tools used particularly in geological mapping, mineral exploration and remote sensing. See this video for an explanation of some of the advanced editing functions - https://youtu.be/jZYKGrIyVCA.

The original default file format for QGIS was the ESRI shape file (*.shp) and this format has been around for many years and can be read by many software products. It is an old format and has limitations, e.g. field names are limited to 10 characters. QGIS is adopting the new “Geopackage” file format as its default spatial file format. Geopackage files can have different types of vector geometry – points, lines and polygons – and can also include raster images. Geopackage files can be up to 140 TB in size! Layers can be imported into an existing Geopackage by dragging from the Layer panel onto the Geopackage name in the Browser panel. Styling information can be saved into the Geopackage file. When digitising into a Geopackage file, each new feature is auto numbered. Raster images imported into a Geopackage appear to be significantly compressed without any major loss of quality. ESRI and recent MapInfo products can read Geopackage files.

The author has been using QGIS since 2015 after about 20 years using the MapInfo-Discover software. He has been involved in exploration and mining geology for over 40 years, with almost 20 years with CRA Exploration Pty Limited, Argyle Diamonds and Rio Tinto Exploration from 1979 till 1997. The past 20 years (1998 – present) has been engaged in consulting roles to the diamond exploration and mining industry with activities in Australia, Brazil, China, Greenland and India, and exploration for other commodities including base metals, iron ore, and manganese.

3: ABOUT QGIS

QGIS is a user-friendly open source Geographic Information System (GIS) licensed under the GNU General Public License and is an official project of the Open Source Geospatial Foundation (OSGeo). It runs on Linux, Unix, Mac OSX, Windows and Android and supports numerous vector, raster, and database formats.

The Open Geospatial Consortium (OGC) is an international consortium of more than 530 businesses, government agencies, research organizations, and universities driven to make geospatial (location) information and services FAIR - Findable, Accessible, Interoperable, and Reusable. OGC’s members create free geospatial standards. OGC also actively analyses emerging tech trends, and runs an agile, collaborative Research and Development (R&D) lab that builds and tests innovative solutions to members' use cases. For more information visit “ogc.org”.

For those users requiring an introduction to GIS, please see this link https://docs.qgis.org/3.4/en/docs/gentle_gis_introduction/.

QGIS is a volunteer driven project. They welcome contributions in the form of code contributions, bug fixes, bug reports, contributed documentation, advocacy and supporting other users on their mailing lists and gis.stackexchange.com. If you are interested in actively supporting the project, you can find more information under the development menu and on the QGIS Wiki. If you find QGIS valuable in your workplace, please donate to the QGIS project – the details are on the website.

QGIS provides a continuously growing number of capabilities provided by core functions and plugins. You can visualize, manage, edit, analyse data, and compose printable maps.

This document will mainly address workflows for geoscientists but there are many other tools available in QGIS and worthy of some exploration of their functions. Currently QGIS does not have a detailed downhole or cross section display option, but there are groups across the world keen to crowd source the development of the drill hole plug-in. The Geoscience plugin does display drill holes in plan and in cross section but is limited in its features. QGIS does not also handle all the various geophysical processing options, and again there is interest from various groups to develop plug-ins for geophysical processing.

A good explanation of QGIS and where it came from can be found here https://www.youtube.com/watch?v=As4hfPecxoU.

If you find QGIS makes a valuable contribution to your business, please consider making a donation to assist with continual code improvements – see this link https://qgis.org/en/site/getinvolved/donations.html.

Installation options are available on QGIS download page (https://qgis.org/en/site/forusers/download.html) with options to download either the development version (via OS4Geo) or the standalone installers (recommended). Both 64 and 32 bit versions are available.

QGIS has been using ESRI shapefiles as the default spatial file format but the new "GeoPackage" format is far superior and will probably become the default file format for QGIS in the near future.

Shape files have a number of limitations such as field/attribute column names are limited to 10 characters, it lacks a time data type, only supports text fields to 255 characters in length and is limited to 2 GB in size.

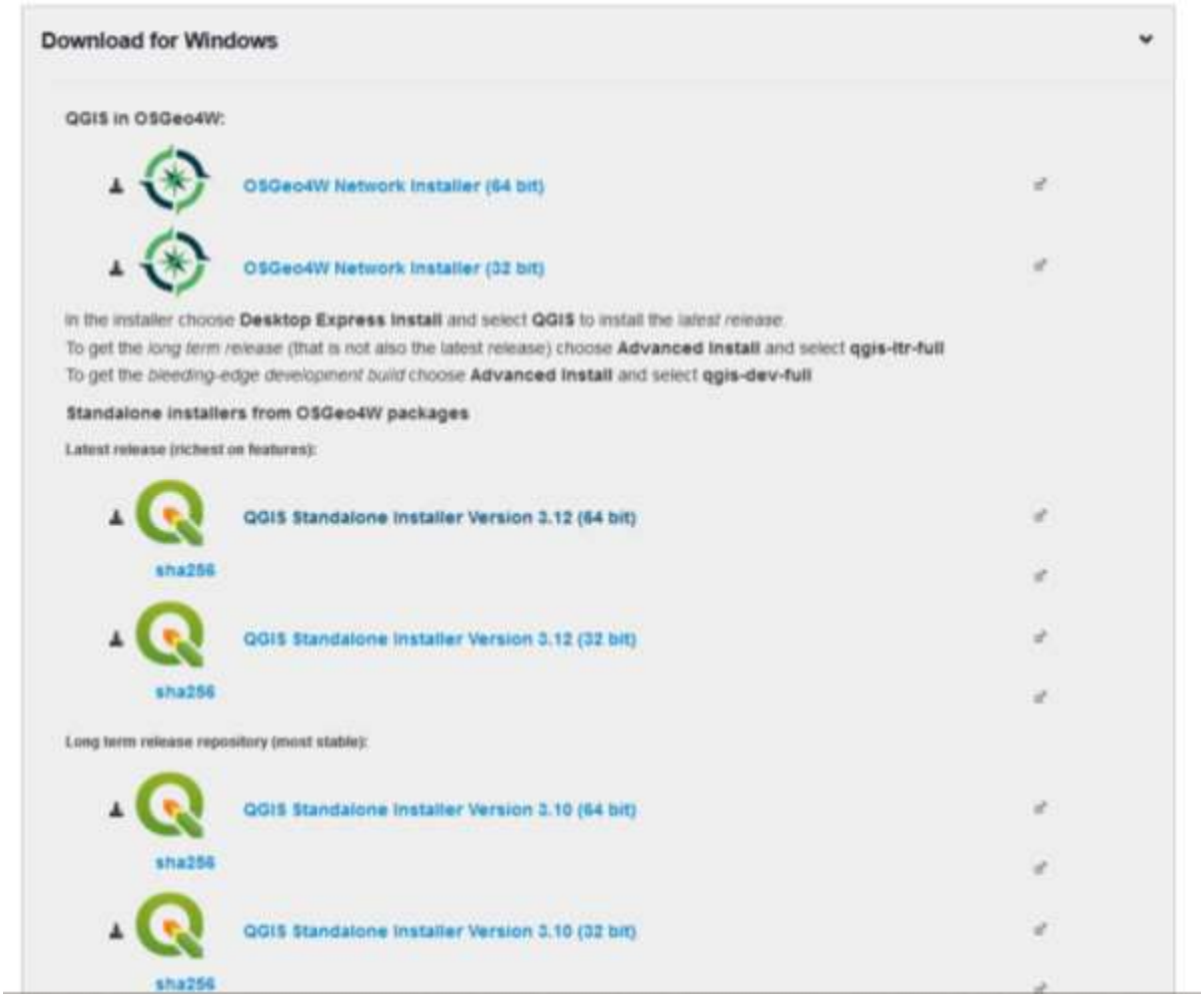
GeoPackage files on the other hand allows point, line vector and raster files to be stored in the one file. Formats/styles can be saved into the Geopackage file and it can be up to 140 TB in size. When adding features during digitising, for example, a Geopackage file will automatically populate the id field with sequential numbers. See this web link for further information https://carto.com/blog/fgdb-gpkg/. Note that Geopackage files are single user only and if you need multiple user access at the same time then PostgreSQL and PostGIS may be required.

4: INSTALLING QGIS

4.1 PC Installation

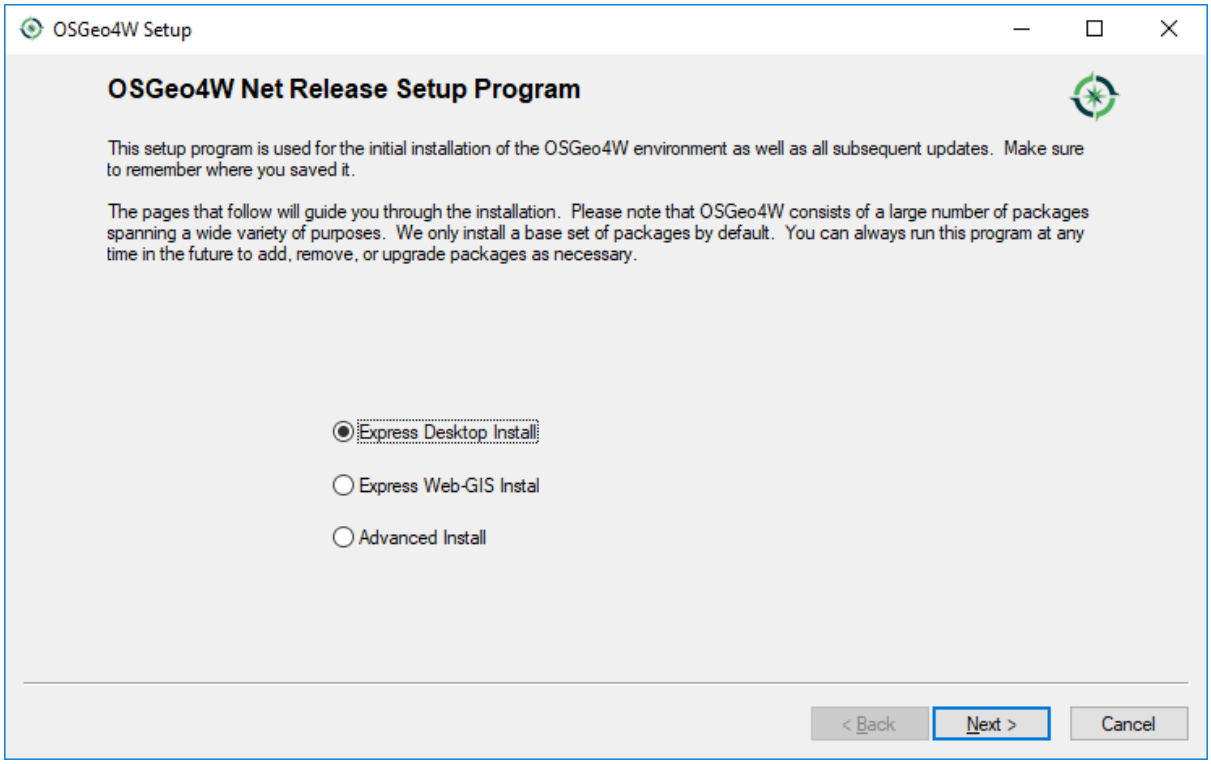
The QGIS program can be downloaded from the QGIS Project website http://www.qgis.org/en/site/ and a choice can be made between 32 and 64 bit versions of the recent release and long term release versions. Note that the v2 options are no longer supported and users and encouraged to use v 3.The Standalone Installers will install the program into the Program Files directory.

The OSGeo4W (Open source geospatial for Windows) option can be also be used and places a small executable file on your PC which can be run when desired to update to the latest versions of the LTR and development versions. This version installs the software into the root directory of your PC (e.g. C:\OSGeo4W64). For first-time users, it is recommended to install the "Standalone" version.

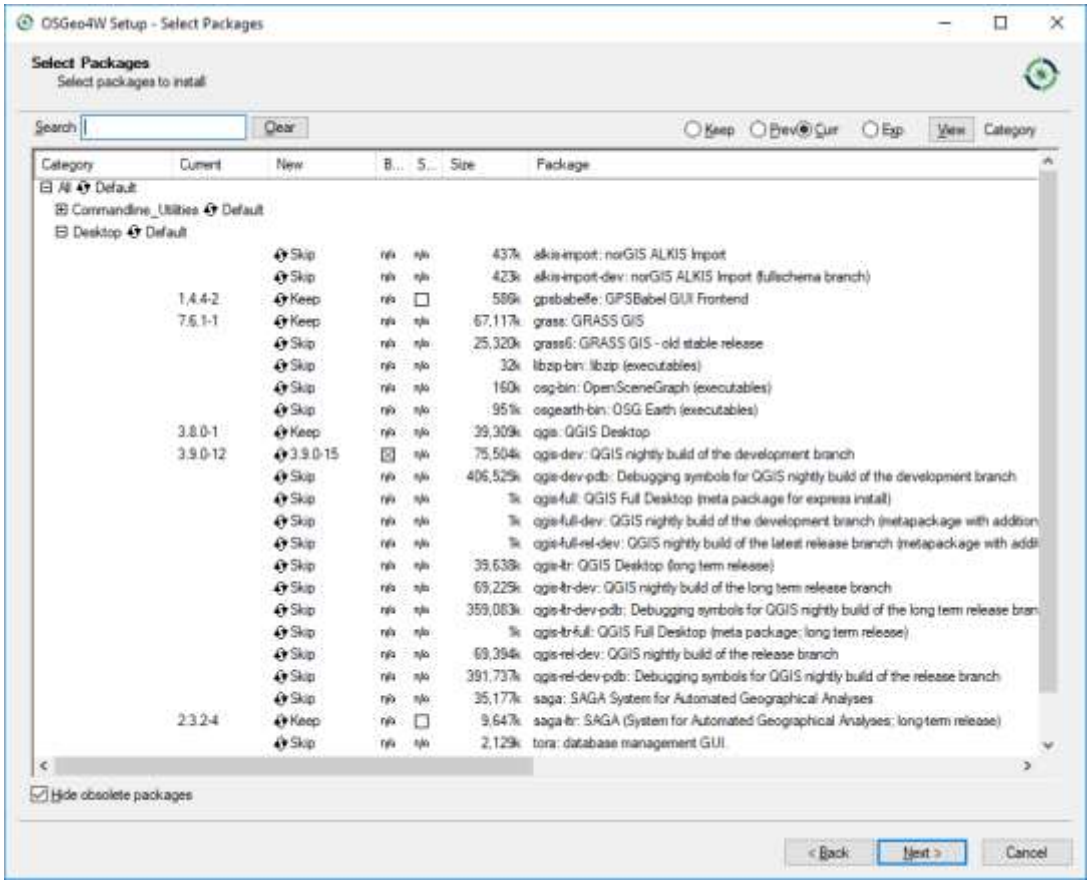


The standalone installer will install the program into the program files folder and create a folder on your desktop with shortcuts to the run the program. It is recommended to run the “QGIS Desktop 3.x with GRASS 7.x.x” version which runs the GIS program and associated GRASS GIS functions.

When you run the OSGeo4W option you see the following screen shot. For a first-time installation, choose the “Express Desktop Install” which will install the programs and required utility files.

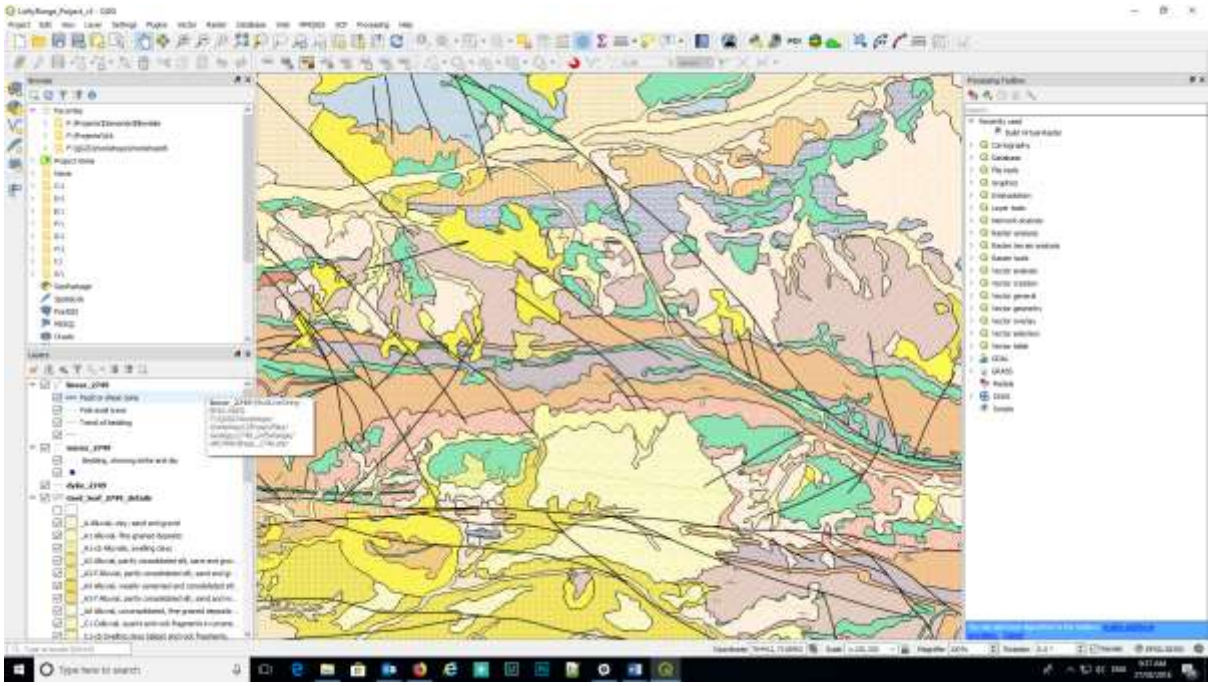


After the initial "Express Desktop Install", you can then check for updates by running the "osgeo4w-setup-x86_64.exe" file again (usually located in the Downloads folder) where you can select "Advanced Install" and select which products you wish to update. The OSGeo4W option can be used instead of the Standalone Installer option.



The select packages window (above) indicates there is an update for v 3.9.0-12 to v 3.9.0-15 in the QGIS development version.

User manual and training documents can be viewed, or pdf versions downloaded from the QGIS web site (https://qgis.org/en/docs/index.html).



The desktop is similar to other GIS applications with menu items along the top and numerous buttons/icons to make it easier to select various options without having to navigate menus. All the menu items and panels are customisable to user preferences. QGIS has operations to import vector and raster data from a variety of formats into QGIS, with excellent editing and analysis tools from the integration of other GIS systems such as GRASS and SAGA. Some of these tools are illustrated in the right-hand panel of the figure above.

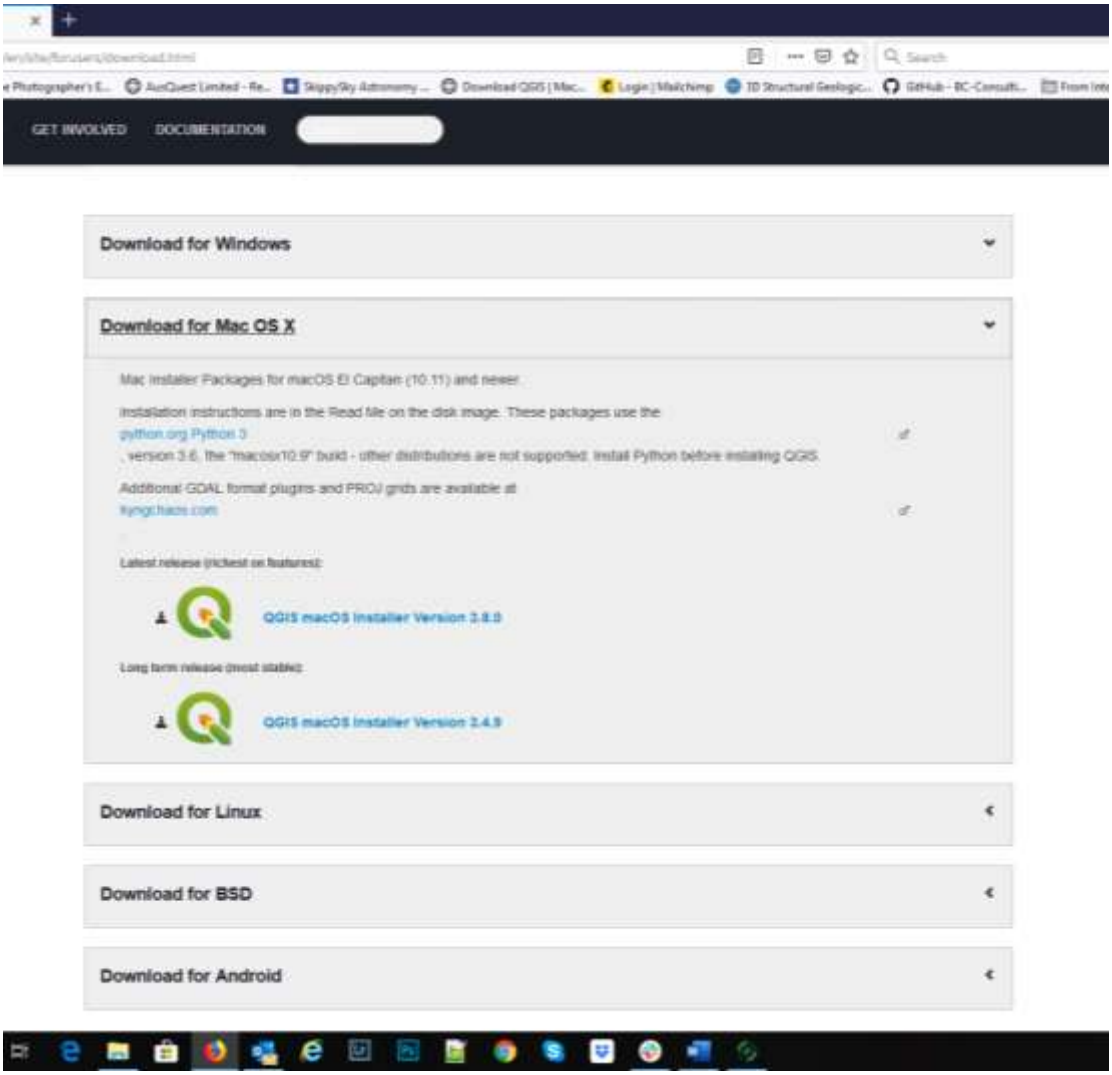
If you need to reset the QGIS window and panel locations, go to Settings > Options > System tab, select the Reset button (right hand side of screen) and re-start QGIS.

The appearance of the desktop can also be changed by using the Settings > Options > General tab and in the Application section find the UI Theme where the appearance of the desktop can be modified. A recent addition here is the “Blend of Grey” option.

4.2 Mac Installation

Installation on a Mac is different than for a PC and it is recommended to download and install QGIS from the QGIS download window.

Install the LTR or the Latest Release version.



To install the custom (geological) SVG files on a Mac, in QGIS, go to Settings > Options > System tab and look for the location of the svg files – something like /Applications/QGIS3.app/Contents/MacOS/../Resources/svg/. Use the Finder to navigate to the Applications folder, then right click on the QGIS program icon, select “Show Package Contents”, open the “Contents” folder and the “Resources” folder. Put the custom (geological) SVG folders into the SVG folder.

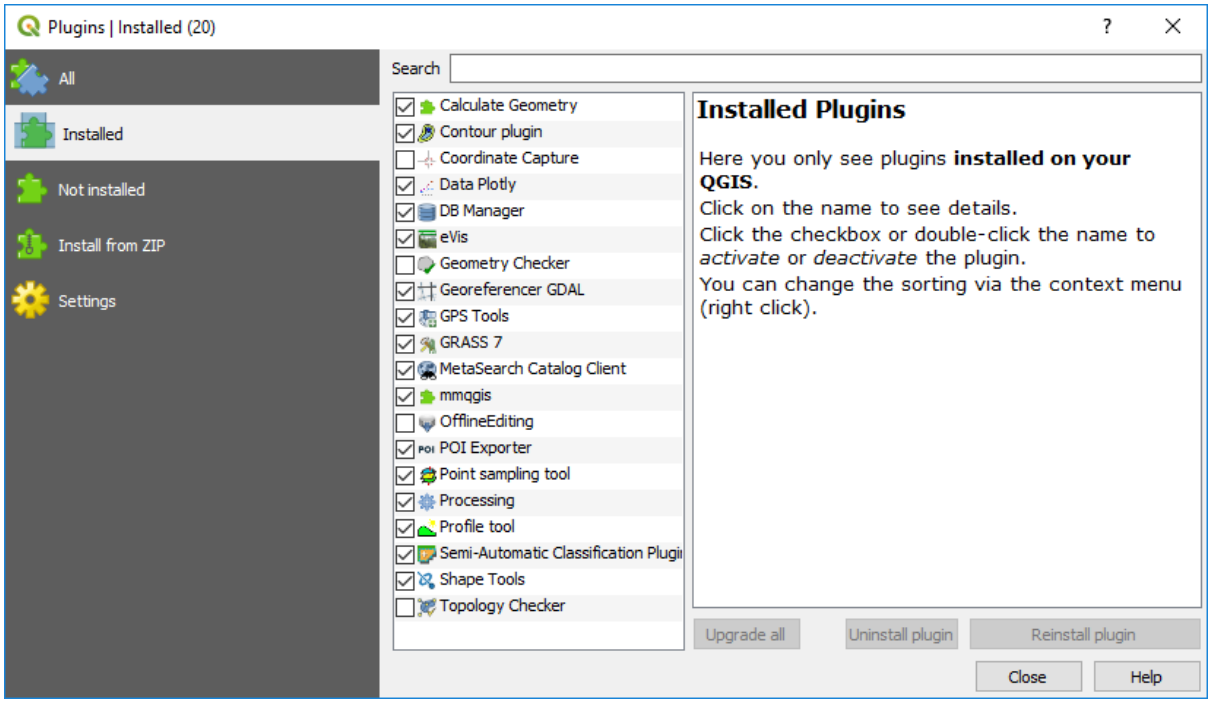
5: PLUG-INS

Plug-ins are small utility programs that greatly expand the capabilities of QGIS. There are currently over 630 plug-ins available for download. These plug-ins are all free and have usually been written to solve a specific problem or task for users. It is recommended that users peruse the plugins list to see what plugins might be applicable to their workflow.

Eleven plug-ins are installed by default in version 3.12 as are listed below.

Coordinate Capture
DB Manager
Geometry Checker
Georeferencer GDAL
GPS Tools
GRASS7
MetaSearch Catalog Client
Offline Editing
Processing
Topology Checker

To use these pre-installed plug-ins, you may need to enable them in the Plug-Ins > Manage and Install Plug-Ins > Installed window. Enable the plug-ins by selecting the check box next to the plug-in.

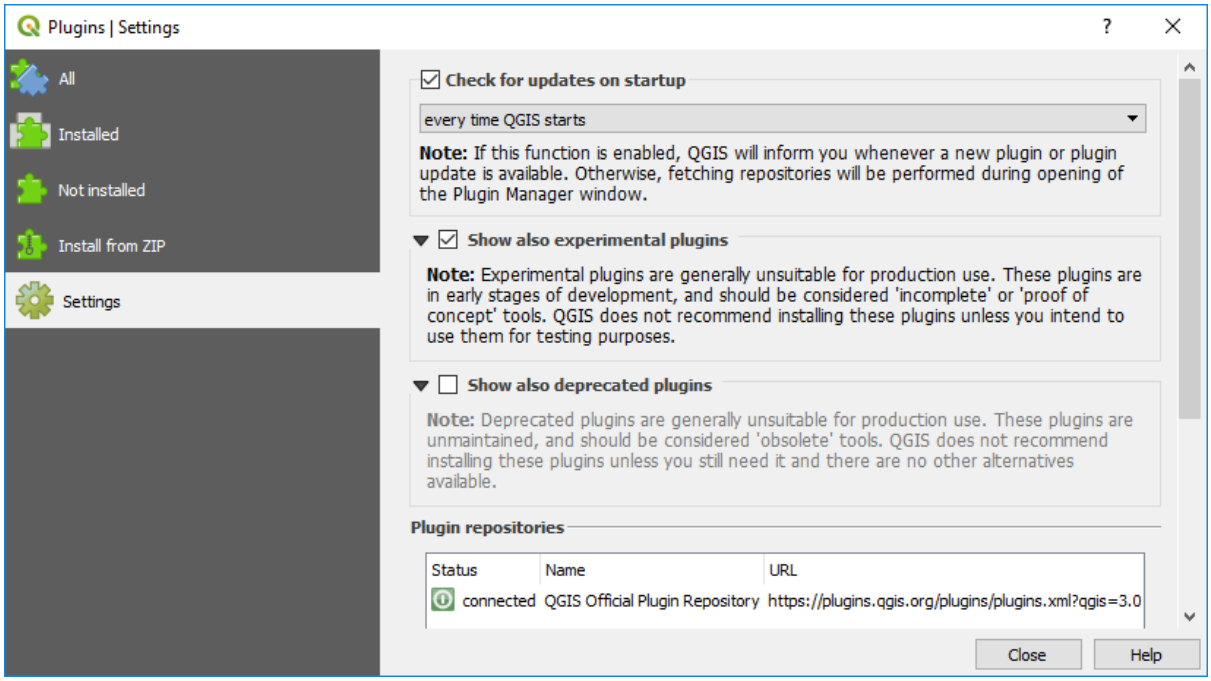


Additional plug-ins that are recommended are as follows;

Data Plotly (graphing of data)
Geoscience (for plotting drill holes on plans and sections
QuickMapServices (add additional services under the extra services option)
QGIS2Threejs (3D viewer)
Semi-Automatic Classification (satellite data selection and processing)
Shape Tools (creation of numerous types of vector objects)
Spreadsheet Layers (used to import Excel spreadsheets)
SRTM Downloader (for accessing SRTM elevation data)

If the QGIS start-up is being significantly delayed during start-up (“Loading Plugins”) then they can be temporarily disabled (Plugins > Installed, tick off those not needed) and only turned on when needed.

In the Plug-Ins > Settings page, check the “Check for updates on start-up” and “Show also experimental plugins”. This will then alert the user to updates of existing plug-ins and the release of new plug-ins whenever QGIS is started. Note that when you first open the Plugins manager, you may see a “New” tab to show you what new plugins have been released since you last opened the Plugin Manager. If you are working off-line with no internet, turn-off the “check for updates on start-up” to skip the web search and update function.



Some managed IT systems block the loading of the Plug-in’s repository data. If this happens, try selecting the Settings > Options > Network, and check the use proxy server. Try again to download the repository. If this loads the repositories, then uncheck this box and try again to install the plugins.

Network managers may also restrict the installation of plugins. If you have problems, contact your network manager.

6: DATA MINING AND PUBLIC DATASETS

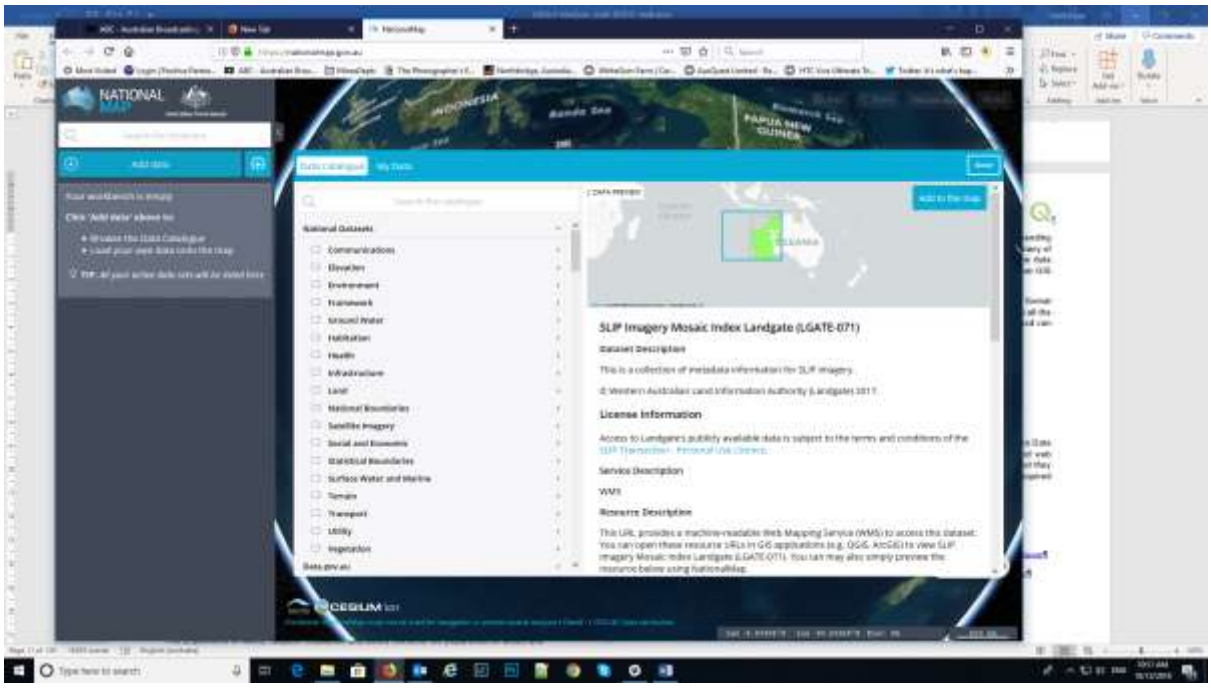
Many government and private corporations have made available datasets for use in GIS programs. There may be usage restrictions and the conditions of use should be checked at the data source. The amount of free data on the web is truly amazing and users are encouraged to explore the web for data.

QGIS has many options to access on-line web datasets. These can be in the form of a WFS (web feature service – vector data), WMS (web map service – raster data) or as a WMTS (web map tile server – tiled raster data, e.g. Google Earth). Australian data can be searched at “data.gov.au” and Western Australian data is available at “data.wa.gov.au”.

Satellite data for the ASTER, Landsat, MODIS and Sentinel missions can be downloaded and processed via the Semi-Automatic Classification plug-in in QGIS or via the USGS EarthExplorer portal and this is discussed below. Remote sensing satellite data (including Hyperion multispectral scanner and radar data) can also be downloaded via the USGS EarthExplorer and ESA (European Space Agency) websites.

6.1 Australian Data Sets

The Australian government has the “National Map” portal (https://nationalmap.gov.au) where data can be accessed for Australia-wide data sets or from the individual states and territories. The WA DMIRS (WA mines dept) data can also be accessed via this portal.



6.2 Geological Survey of Western Australia

The Department of Mines, Industry Regulation and Safety (DMIRS, formerly the Department of Mines and Petroleum, http://www.dmp.wa.gov.au/) is home to the Geological Survey of Western Australia (GSWA). This site contains many data sets, most of which can be downloaded from the "Software and Data Centre" (https://dasc.dmp.wa.gov.au/dasc/). Raster and vector data can also be accessed live via their WMS and WFS services (http://geodownloads.dmp.wa.gov.au/downloads/dasc/Static/Resources/Map_Services/Image_Web_Service_definition.pdf and http://geodownloads.dmp.wa.gov.au/downloads/dasc/Static/Resources/Map_Services/Web_Map_Service_definition.pdf). PDF copies and maps and reports are available from their "Bookshop".

Registered raster files of the 100k and 250k geological map sheets have been mosaiced into 1:1 million map sheet areas and are in jp2 (jpeg2000) format registered in GDA94 MGA grid coordinates. The "jp2" format contains the projection and registration data embedded in the file. Raster files of individual map sheets in either GDA94 lat/long or MGA can also be downloaded from the data centre.

Always check that QGIS is using the current coordinate reference system when it loads these files.

The digital vector files for the 250k and 100k geology sheets vary in their data content depending upon the age of the map sheet edition. The GSWA use ArcView for their GIS system and many of their datasets contain "lyr" style and GeoMap "gmp" files. It has been requested that the data supplied by the GSWA also contain the colour and pattern information to allow users of other GIS systems (like QGIS) to style their maps like the GSWA style. This is a work in progress. North Road Consulting (https://north-road.com/slyr/) are developing a plugin to convert "lyr" style files to QGIS style files and this will go a long way in allowing QGIS users to style their maps in a similar fashion to the Arc GSWA maps.

6.3 Landgate and Open Data WA

The WA government has made available a large variety of GIS datasets through their Open Data portal (data.wa.gov.au). Data from other states can be accessed in a similar manner. Searches can be made on this site and both vector data and web service links are supplied. More detailed datasets are available for WA from Landgate, but they may require a subscription. Many datasets are however free, and registration is no longer required for the free datasets.

Links to some of the WA web services are as follows;

Web Map Server Links

Public:
https://services.slip.wa.gov.au/public/services/SLIP_Public_Services/Property_and_Planning/MapServer/WMSServer

Imagery:
https://services.slip.wa.gov.au/public/services/SLIP_Public_Services/Locate/MapServer/WMSServer

Web Feature Server Links

Maps

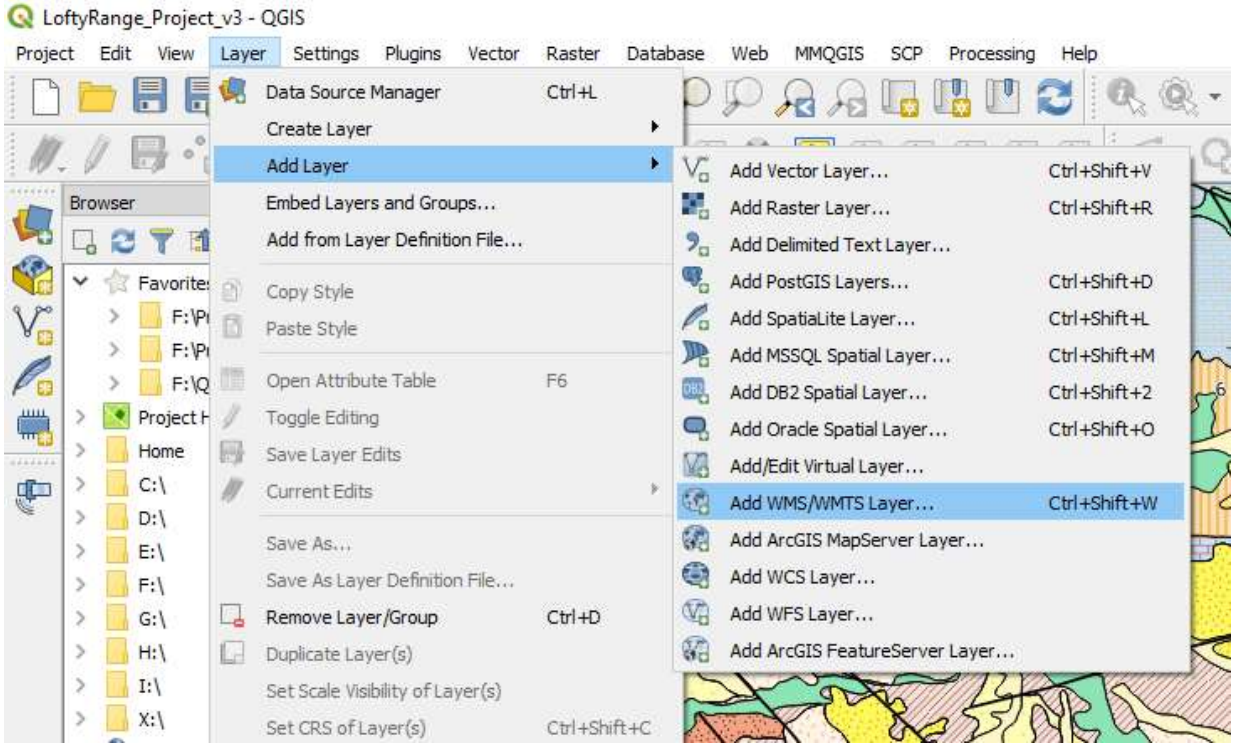
https://services.slip.wa.gov.au/public/services/SLIP_Public_Services/Property_and_Planning_WFS/MapServer/WFSServer

Imagery

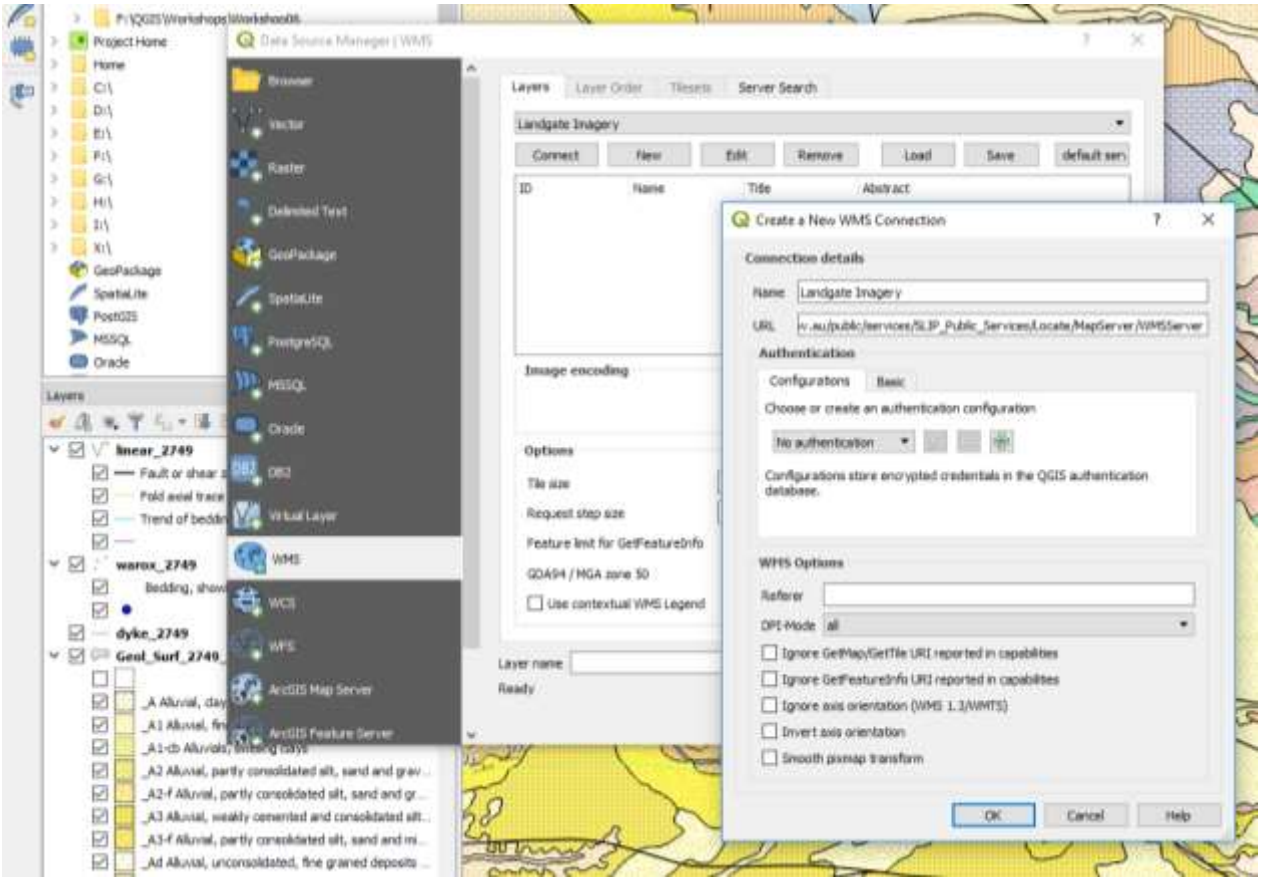
https://services.slip.wa.gov.au/public/services/SLIP_Public_Services/Imagery_and_Maps_WFS/MapServer/WFSServer

Australian Bureau of Statistics: https://www2.landgate.wa.gov.au/ows/wfsabs_4283/wfs

To add WFS and WMS layers to QGIS, use the Layer > Add Layer > Add WMS/WMTS Layer.

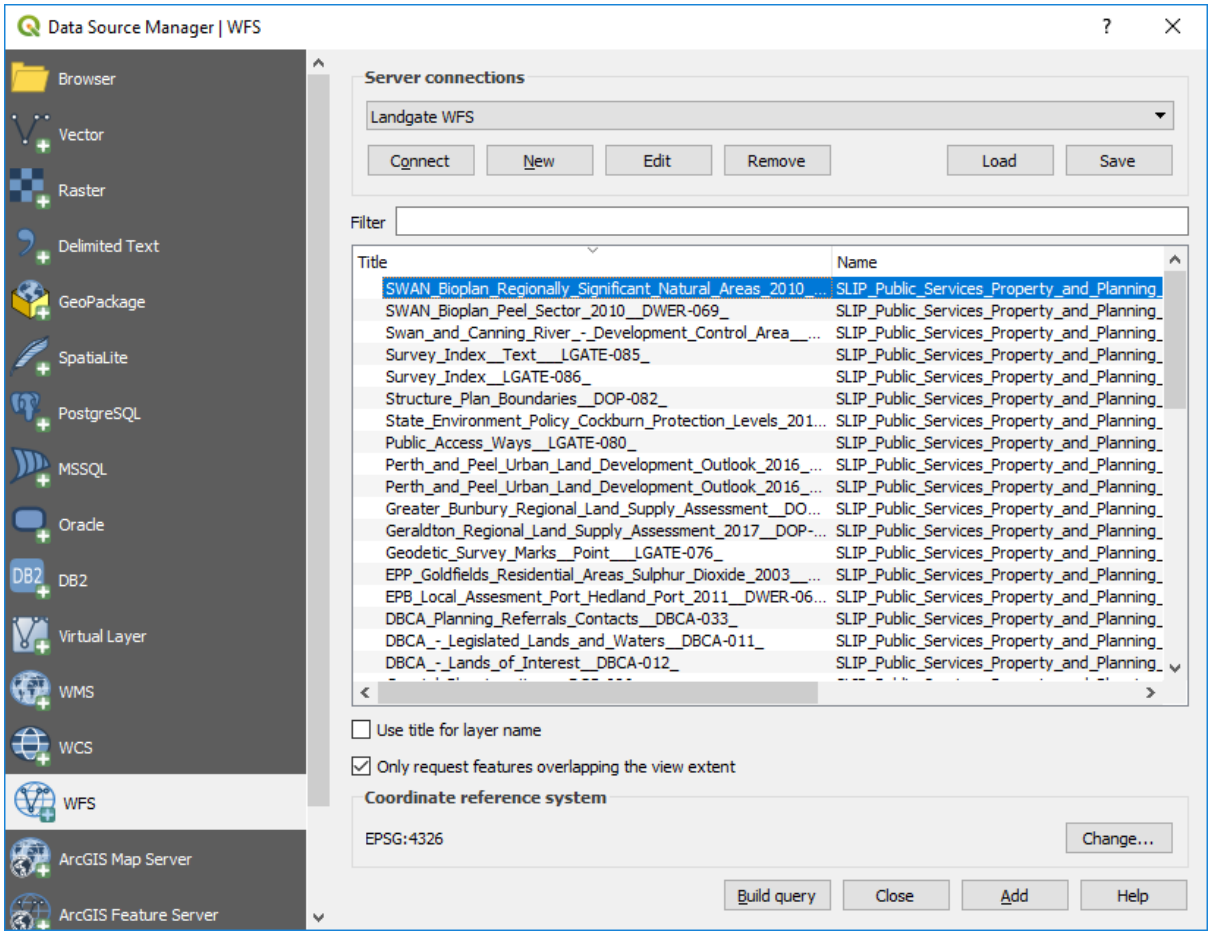


An example of linking to the Landgate imagery is shown below.



Some services may require you to register for a username and password.

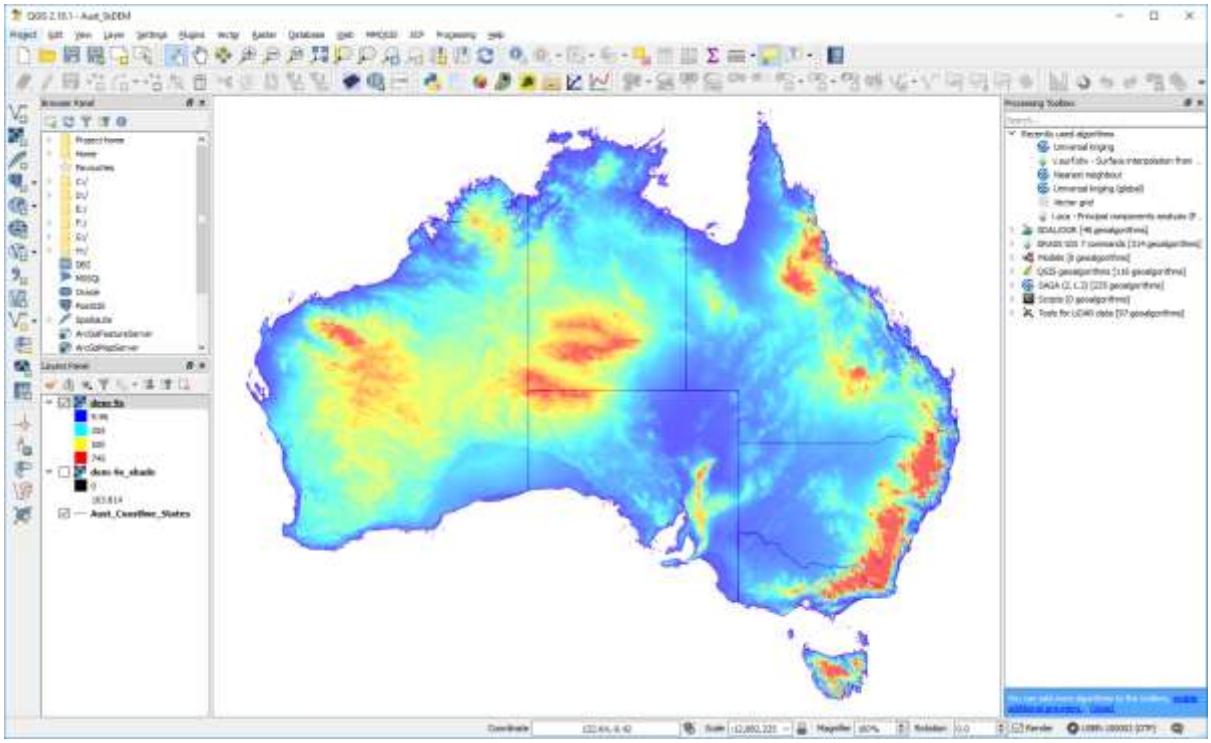
Access to vector data is via the add WFS (web feature server) option. See below for the list of publicly available data (no sign in required) from the Landgate server.



6.4 Geoscience Australia

Geoscience Australia (GA) provides an extensive array of national datasets (see this link for more information “https://data.gov.au/”).

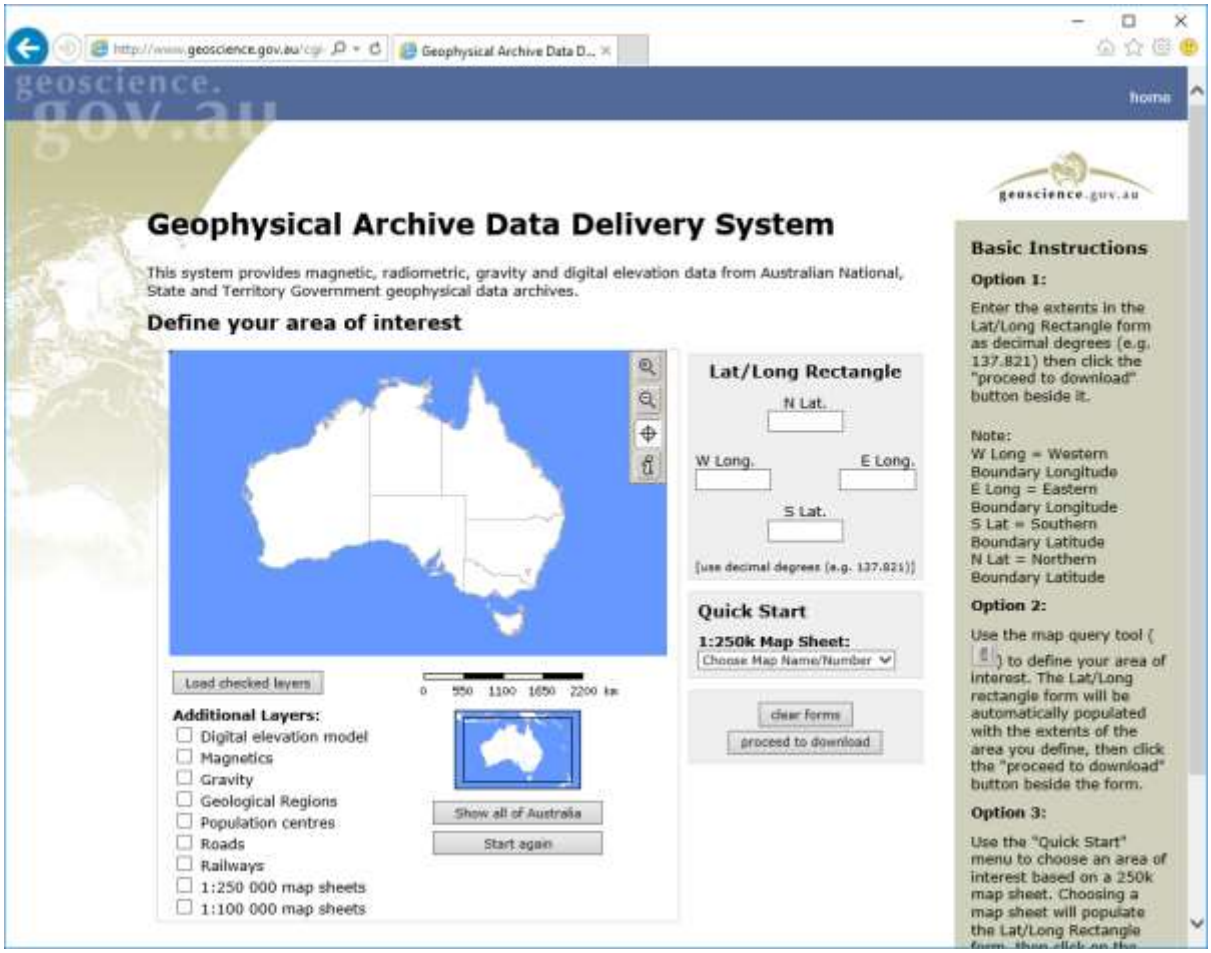
Digital elevation data is also available across Australia from Geoscience Australia (https://elevation.fsdf.org.au/) at a resolution of 1 arc second (approximately 30 m) and is available as a hydrologically conditioned and drainage enforced version (DEM-H). This is a 26 Gb zip file and can be downloaded. The author has cut this into UTM zones which are approximately 7 - 8 Gb in size each zone to improve useability. Depending upon the speed of your PC/laptop, these may need to be further cut into 1:1 million map sheet areas. The 9 second DEM (approximately 250 m) is about 0.8 Gb in size, is also available.



Geoscience Australia, 9 second DEM

Many of these datasets are also available as web services – see this link http://services.ga.gov.au/.

Geophysical data incorporating magnetics, gravity, radiometrics and elevation data can be downloaded as vector (point data) or as grid files. Both national and individual survey data is available for data held by Geoscience Australia via the Geophysical Archive Data Delivery System (GADDS) – Notes GADDS is being upgraded and a new version is due for release by July 2020. The DMIRS will hold data for surveys flown for the GSWA. Data can be filtered by 1:250 000 map sheet area or by geographic coordinates. Check the projection of the dataset before you download, as it may default to geographic coordinates.



Geoscience Australia geophysical data portal.

GA have recently released a new Digital Earth Australia data portal at “https://www.nationalmap.gov.au/”.

6.5 United States Geological Survey (USGS)

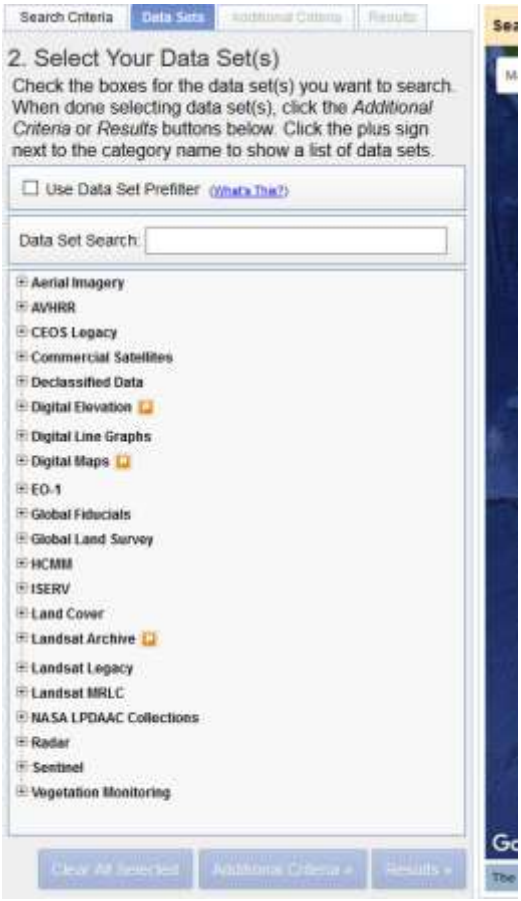
The USGS hold an enormous amount of free data, most of which is accessible via its EarthExplorer portal (http://earthexplorer.usgs.gov/). To download the data, you are required to register (free) and select a username and password.

ASTER and Landsat data are two of the remote sensing datasets available from the USGS. These datasets are also easily accessed via the Semi-Automatic Classification plug-in in QGIS (see Section 11.1). Digital elevation, radar and Lidar data are also available from the USGS.

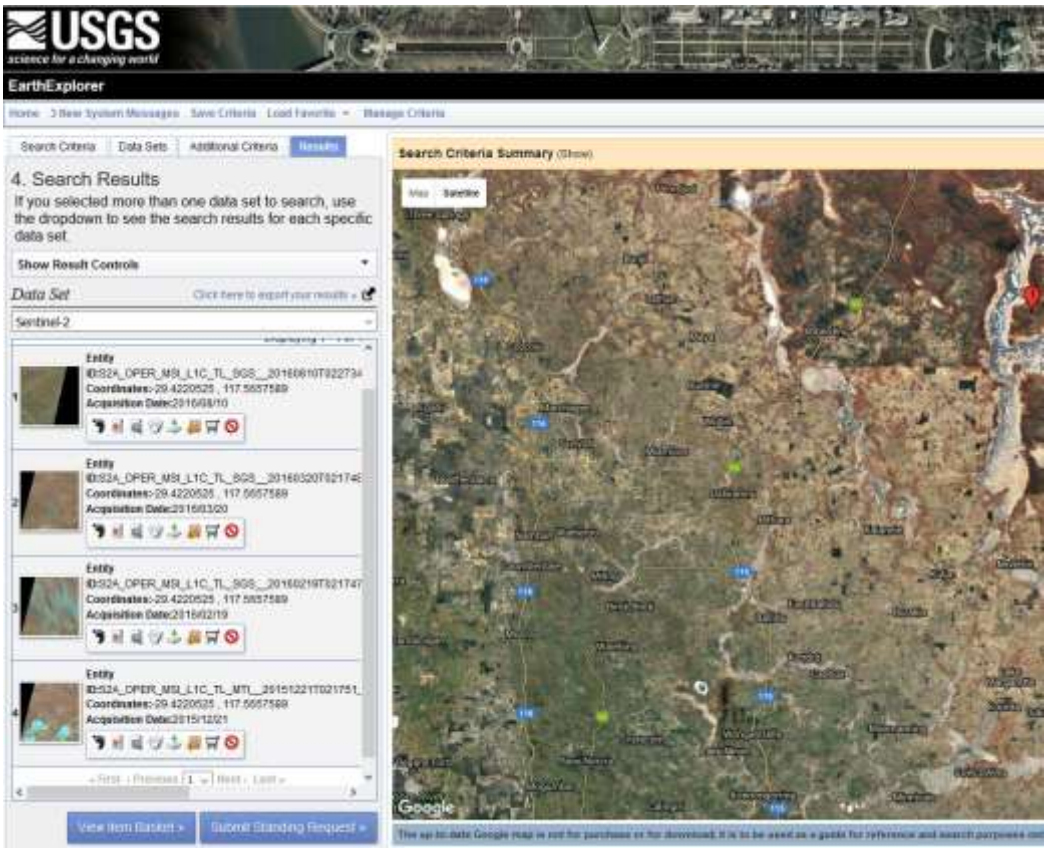
USGS EarthExplorer data portal.

Use the Register button to create a free account or log in if you have an existing EarthExplorer account. Logging in allows you to download datasets.

Enter the search criteria by using a Landsat path/row identifier, or by using the map or by a coordinate. Once you have selected an area, choose the data set you are seeking, add “Additional Criteria” if you want to filter your search, e.g. by date range.



Each of the data categories have a range of datasets available.



If there is data available from your search request, you can then examine the thumbnails of the scenes and select which dataset is the best one for your purposes. The footprint icon will show the area covered by the scene and notepad and pencil icon brings up a better view of the data including its metadata. Click on the download icon to download the data. The format of the data will depend on the data type and this needs to be researched by the user.

6.6 European Space Agency (ESA)

ESA has launched a number of satellites recently in their Sentinel series to observe the land and ocean areas for climate and monitoring purposes (see this site https://sentinel.esa.int/web/sentinel/home). For geological work, the author has found the Sentinel 2 data is most useful. The Sentinel 2 mission monitors variability in land surface conditions, and its wide swath width and high revisit time (5 days) will support monitoring of changes to vegetation within the growing season. The coverage limits are from between latitudes 56° south and 84° north (ESA).

Currently the easiest way to select and download the Sentinel data is via the USGS EarthExplorer portal. Register for a free login and passwords at the portal.

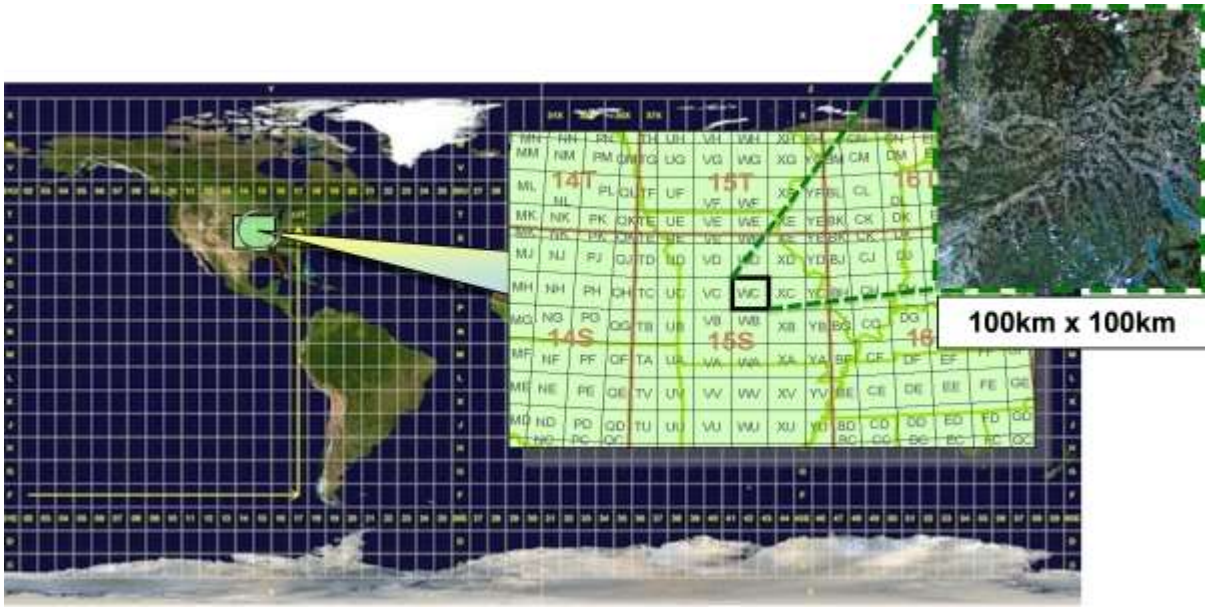
The following description is taken from the ESA Sentinel website.

"Sentinel-2 products available for users are listed in table below.

Name	High-level Description	Production & Distribution	Data Volume
Level-1C	Top-of-atmosphere reflectances in cartographic geometry	Systematic generation and on-line distribution	600 MB (each 100x100 km2)
Level-2A	Bottom-of-atmosphere reflectance in cartographic geometry	Systematic generation and on-line distribution and generation on user side (using Sentinel-2 Toolbox)	800 MB (each 100x100 km2)

Products are a compilation of elementary granules of fixed size, within a single orbit. A granule is the minimum indivisible partition of a product (containing all possible spectral bands).

For Level-1C and Level-2A, the granules, also called tiles, are 100x100km2 ortho-images in UTM/WGS84 projection. The UTM (Universal Transverse Mercator) system divides the Earth's surface into 60 zones. Each UTM zone has a vertical width of 6° of longitude and horizontal width of 8° of latitude. (see Figure 1). Tiles are approximately 600 MB in size. Tiles can be fully or partially covered by image data. Partially covered tiles correspond to those at the edge of the swath.



Level-1C product tiling

The continuous acquisition of Sentinel-2 image data in a given MSI mode is called a "datatake". The maximum length of an imaging datatake is 15,000 km (e.g. continuous observation from northern Russia to southern Africa). All products contain granules/tiles from a single datatake. A datatake is presented inside a product as a set of one or more datastrips (corresponding to acquisition segments downlinked to different ground stations)."

The Sentinel 2 series A and B satellites are of relevance to geology as they have a high spatial resolution and 12 bands of spectral data. The multispectral imager (MSI) covers 13 spectral bands (443 nm–2190 nm) with a swath width of 290 km and spatial resolutions of 10 m (4 visible and near-infrared bands), 20 m (6 red-edge/shortwave-infrared bands) and 60 m (3 atmospheric correction bands). The Sentinel 2 satellites main applications are in monitoring agriculture, forests, land-use change, land-cover change; mapping biophysical variables such as leaf chlorophyll content, leaf water content, leaf area index; monitoring coastal and inland waters; risk mapping and disaster mapping.

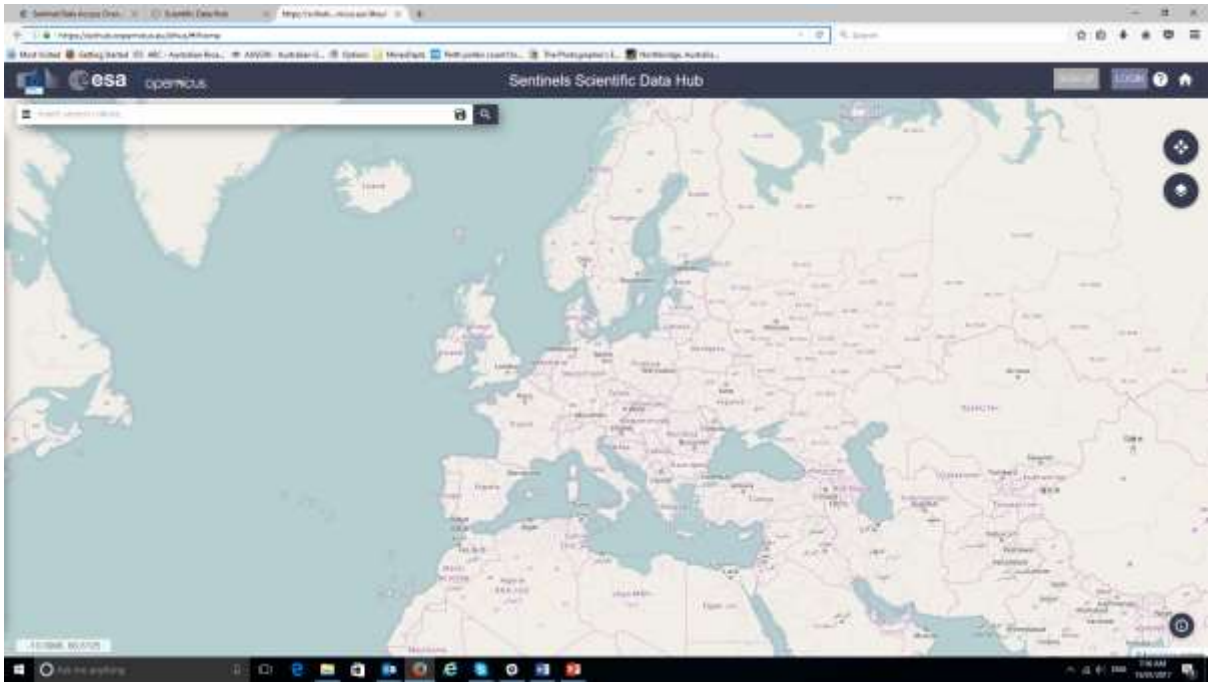
Spectral bands for the SENTINEL-2 sensor

Band number	Central wavelength (nm)	Bandwidth (nm)	Spatial resolution (m)
1	443	20	60
2	490	65	10
3	560	35	10
4	665	30	10
5	705	15	20
6	740	15	20
7	783	20	20
8	842	115	10
8a	865	20	20
9	945	20	60
10	1380	30	60
11	1610	90	20
12	2190	180	20

The table below compares Sentinel 2 with other commonly used satellite sensors.

Common Name	Band Range (µm)	Landsat 5	Landsat 7	Landsat 8	Sentinel 2	MODIS
Coastal	0.40 - 0.45			1	1	
Blue	0.45 - 0.5	1	1	2	2	3
Green	0.5 - 0.6	2	2	3	3	4
Red	0.6 - 0.7	3	3	4	4	1
Pan	0.5 - 0.7		8	8		
NIR	0.77 - 1.00	4	4	5	8	2
Cirrus	1.35 - 1.40			9	10	26
SWIR16	1.55 - 1.75	5	5	6	11	6
SWIR22	2.1 - 2.3	7	7	7	12	7
LWIR	10.5 - 12.5	6	6	10, 11		31, 32

The Sentinel data can also be accessed via the Sentinel portal after registration (Sign Up button), see this link https://scihub.copernicus.eu/dhus/#/home.



After logging on to the portal, scroll to your area of interest and highlight a rectangle for your data search. This method of data selection is less intuitive than the USGS EarthExplorer data access

A Sentinel tile index covering the world can be downloaded as a shapefile from the ESA website.

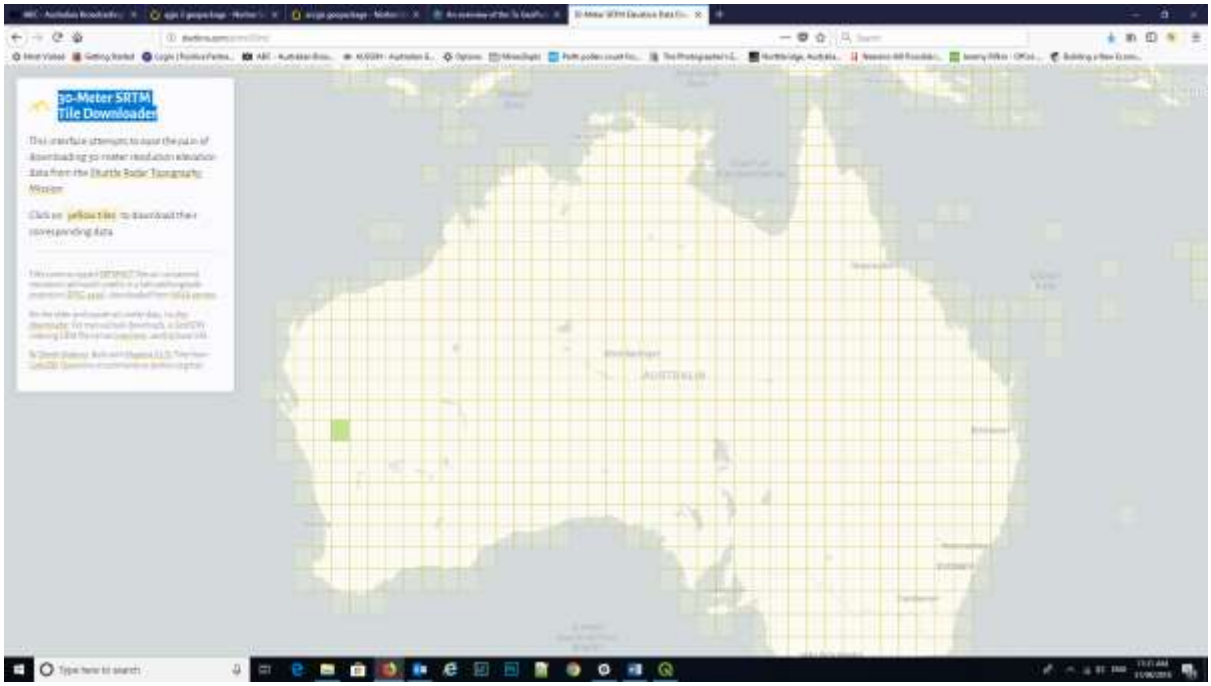
Sentinel 2 data can also be downloaded using the QGIS plug-in “Semi-Automatic Classification” which is discussed below.

Note that radar data is now available from the Sentinel 1 mission.

6.7 30 m SRTM Tile Downloader

The SRTM-Downloader plugin allows the user to download tiles into their map window and these can be saved. Note that you will need a USGS EarthExplorer portal login (free). The dtm tiles are downloaded in one degree tiles in hgt grid format (which QGIS reads with no problem).

You can also use this link to access the 30m SRTM tile data - http://dwtkns.com/srtm30m/. You will need to add your USGS EarthExplorer username and password.



These images are in jp2 (jpeg2000) format which have the image registration information incorporated in the file. QGIS reads and registers these images.

6.8 Coordinate Reference Systems

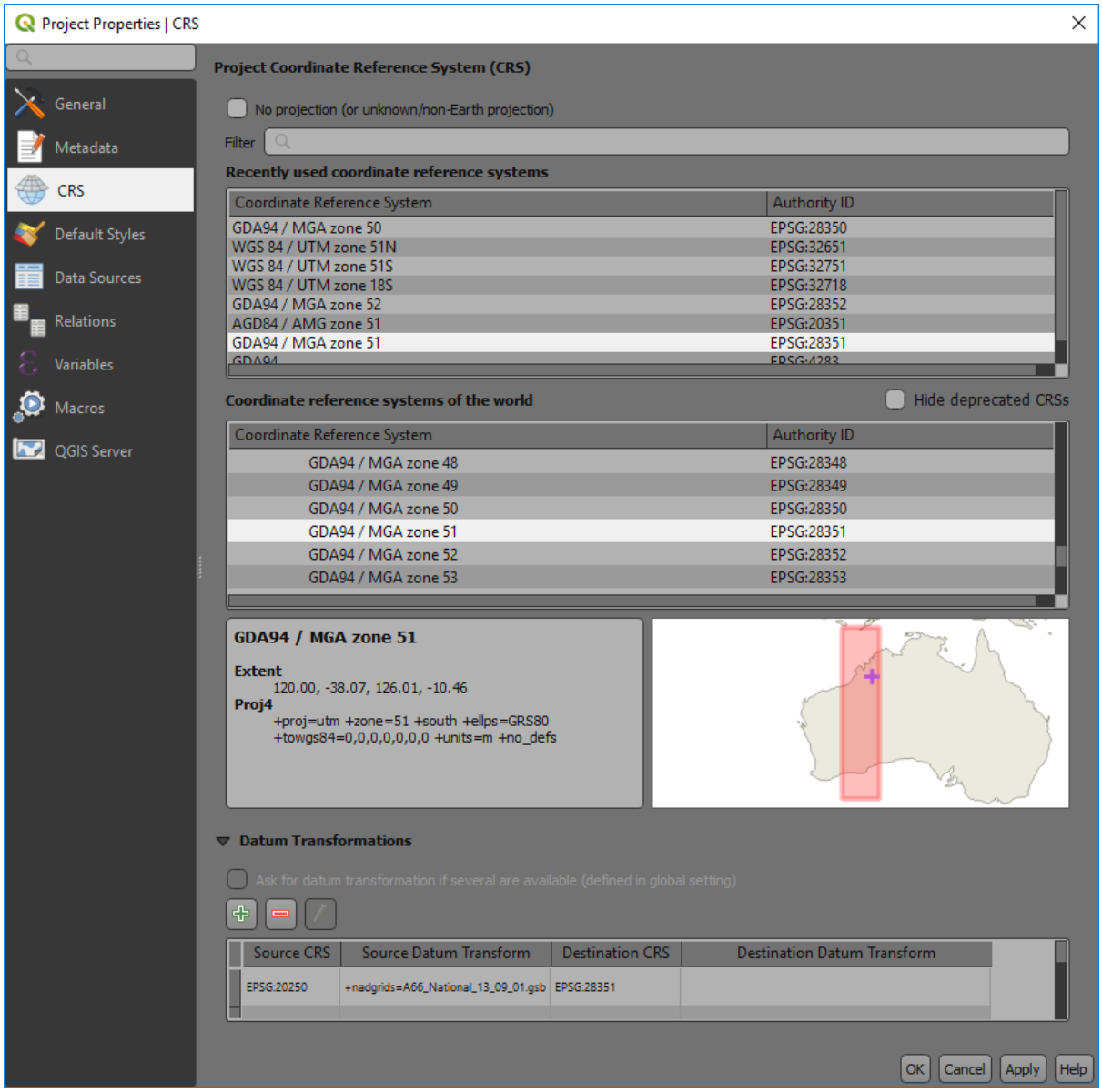
When using GIS data it is very important to know the coordinate reference system (CRS) of the data. Choosing the wrong projection will misplace the data or prevent it from appearing on your map. QGIS can re-project data on-the-fly (OTF) when bringing data into a map window that has a different CRS to the file being imported. If QGIS cannot recognise the projection of the layer being imported it will flash a yellow warning banner and usually defaults the layer projection to WGS 84. Open the layer properties for the layer and correct its projection.

Note that the CRS in the PROJECT PROPERTIES dialog box affects the way the data is displayed in the map window. The CRS dialog box in the LAYER properties box affects where the points are located on the planet. It is very important to know the CRS of the data being imported into the map window.

The CRS dialog box remembers your recent CRS used and these can be quickly selected from the “Recently Used…” information box. If you have not used a particular projection previously, you can type in the CRS name or EPSG number of the projection into the “Filter” box. For example, the Australian GDA94 geographic CRS has an **EPSG of 4283**. *Note that if you type “GDA94” into the filter box it may give you an option of GDA94 as a Projected Coordinate System (EPSG 4938), this is incorrect and will cause problems when trying to display GDA94 lat/long data.* Always check you have selected the correct CRS.

GDA94 UTM zones can be easily selected by entering the EPSG starting with “283”, then add the zone number, for example GDA94 zone 50 would be EPSG 28350.

WGS84 UTM zones can be selected using “327” then the zone number for the southern hemisphere and “326” plus the UTM zone for the northern hemisphere.



The lower map window shows the area of the world where the projection is valid.

If you are using a local grid with no real world projection, you can select the “No Projection” tick box at the top of the window.

7: GEOLOGICAL DATA

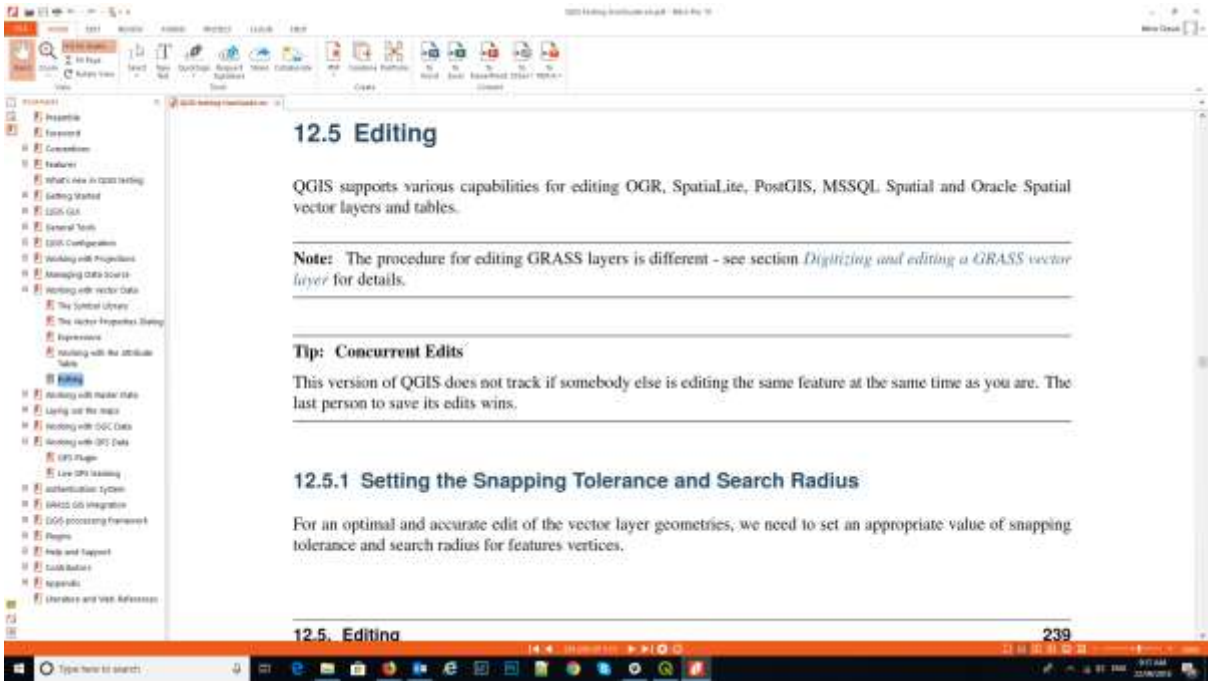
Geological data is varied in nature but is usually either as points, lines or polygons. Geological mapping comprises the collection of points using a GPS, with lines and polygons drawn as an overlay on aerial or satellite images. The following discussion covers a variety of tasks commonly associated with field data collection and interpretation. Detailed editing tasks will not be discussed as there are a numerous resources available on the web, in the QGIS User Manual and various books. A variety of tips and tricks can be found in section 13.

The Android tablet application “QField” is available for tablets and more details on this will be added in the near future. QField can be used in the field for data collection and mapping.

QGIS can sometimes have problems when digitising into layers with differing projections in the map window. It is recommended that digitising be done on layers in one projection at a time. The new file can be reprojected at subsequently into a different projection if required.

Note also turn off the auto-save plugin, if you have this enabled, as it may cause problems during digitising.

Details on the digitising and editing functions can be found in the “QGIS User Guide – Release Testing” (for version 3.12) document which can be found here https://docs.qgis.org/testing/pdf/en/. This guide gets regularly updated.



12.5 Editing

QGIS supports various capabilities for editing OGR, SpatiaLite, PostGIS, MSSQL Spatial and Oracle Spatial vector layers and tables.

Note: The procedure for editing GRASS layers is different - see section *Digitizing and editing a GRASS vector layer* for details.

Tip: Concurrent Edits

This version of QGIS does not track if somebody else is editing the same feature at the same time as you are. The last person to save its edits wins.

12.5.1 Setting the Snapping Tolerance and Search Radius

For an optimal and accurate edit of the vector layer geometries, we need to set an appropriate value of snapping tolerance and search radius for features vertices.

12.5. Editing 239

7.1 Point Data

Field mapping data is collected by various methods. The most basic version and that used by the “old school” is to collect data in a field book and then enter it into a spreadsheet for import into a GIS. Field data collectors vary in their formats and so the user will need to determine what is the best option for their data import. Always include the datum and projection zone (if applicable) when compiling vector data.

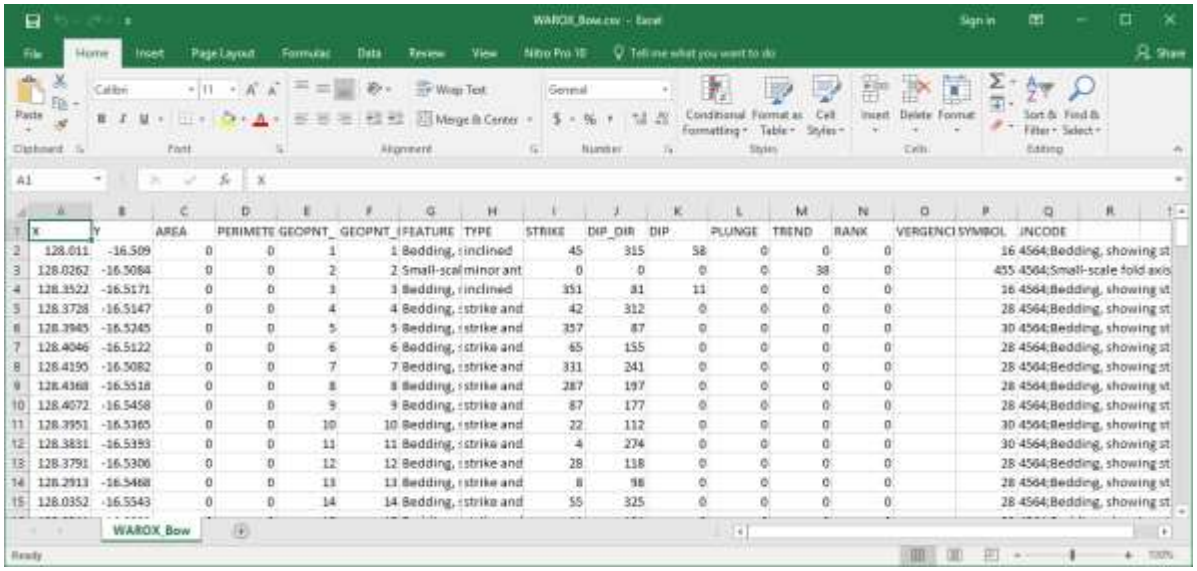
GPS points are easily brought in to QGIS by importing a GPS “gpx” file or in some cases direct download from the GPS. Tracks and waypoints downloaded from the GPS in *.gpx format can be imported via the “GPS Tools” icon located in the left menu bar or via the top menu Vector > GPS > GPS Tools menu. GPX files from Garmin GPS units are usually in WGS84 geographic coordinates (Longitude and Latitude, decimal degree format) by default. GPS points can be uploaded to a GPS using the POI plugin.

Comma separated variable or “CSV” files are a good simple way to import point data and can be an alternative way to import spreadsheet data when there are problems importing Excel files. If you do have a problem with importing an excel file, save the file in CSV format and import into QGIS. Note there can be problems importing large Excel or csv files, e.g. with QGIS scrambling column data, if this is the case, then use the tab delimited text export option from Excel.

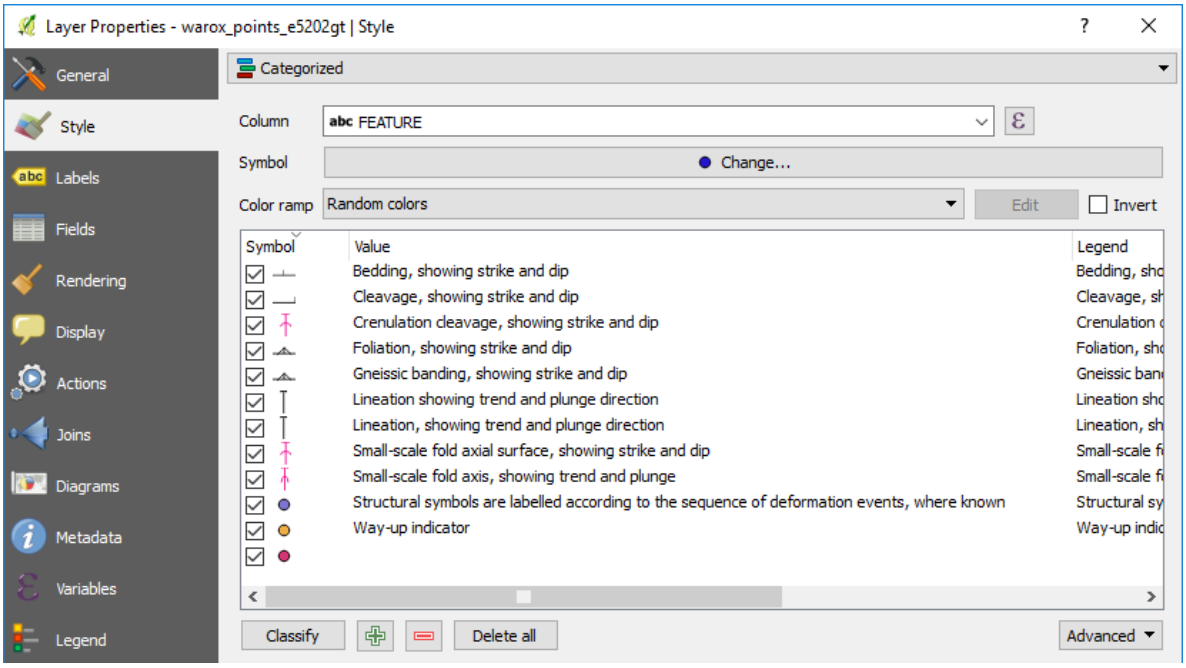
Complex CSV files containing a variety of field types can be imported using CSV format files (*.csvt). QGIS can read field data types from an OGR CSV driver compatible "csvt" file. This is a txt file alongside the data file, but with a "t" appended to the file name extension. The file should just contain one line which lists the type of each field. Valid types are "integer", "real", "string", "date", "time", and "datetime". The date, time, and datetime types are treated as strings in QGIS. Each type may be followed by a width and precision, for example "real(10.4)". The list of types must separated by commas, regardless of the delimiter used in the data file. An example of a valid format file would be: "integer","string","string(20)","real(20.4)".

Another option for importing csv data is to load into Excel and check the field types for each field before importing. Excel files are imported using the “Spreadsheet Layers” plugin. This is found under the Layer > Add Layer > “Add spreadsheet layer” menu. It is especially important to check the data is being correctly imported.

Point geological mapping data such as bedding, joints and outcrop observations can be entered via a spreadsheet where columns can be created to cater for items such as coordinates, observations, and photo references. Remember to always include the datum and map projection data in the file. Symbol file names (full path required) can also be entered into the spreadsheet that will allow QGIS to select the correct symbol and then orientate it using a rotation angle for the correct strike or plunge. An example is shown below of the WAROX (GSWA mapping data, csv format) data from the GSWA Bow 1:100k geological map. Additional columns would be required with symbol file names to allow QGIS to select the appropriate symbol, or alternatively you can choose a “Categorise” symbol style option and edit the symbols for each category manually.

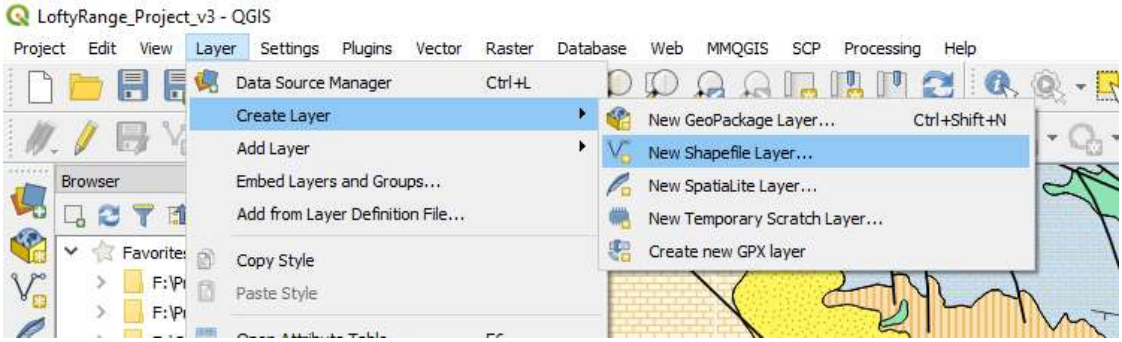


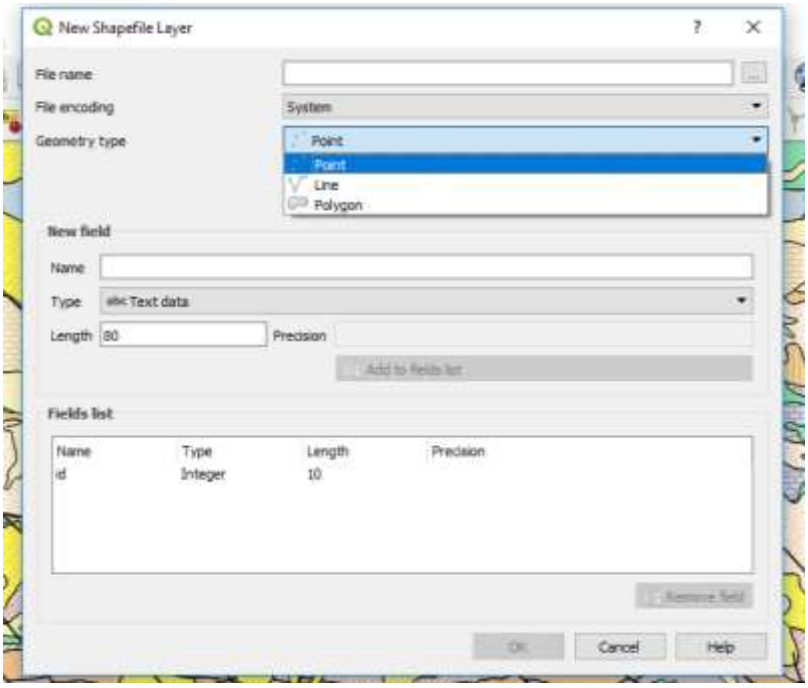
Below is an example of the “categorised” features of the WAROX data for the GSWA Lissadell 250k map sheet with features manually changed by clicking on each symbol. Once this has been done, remember to **save** the symbols by using the “Style” button and “Save style” to a QGIS qml style file (e.g. GSWA_WAROX.qml). This style file can then be used to recall these styles. You can choose the “save as default”, which creates a qml file with the same file name as the shape file and when you open the shape file, the qml file will be used to determine the way the features are displayed for this layer. Styles can also be saved to a Geopackage file.



To create a new empty points layer, use the menu item Layer > Create Layer > New Shapefile Layer and select a point layer type (**especially important to check the geometry type! And CRS**). Add the required data columns and data types (text, integer, decimal number, date) to attach to each point. Remember shapefile column names are limited to 10 characters and any names longer than this will be truncated. When creating a new vector layer to digitise data, ensure the layer is the correct type, i.e. point, line or polygon, that it has the correct map projection and

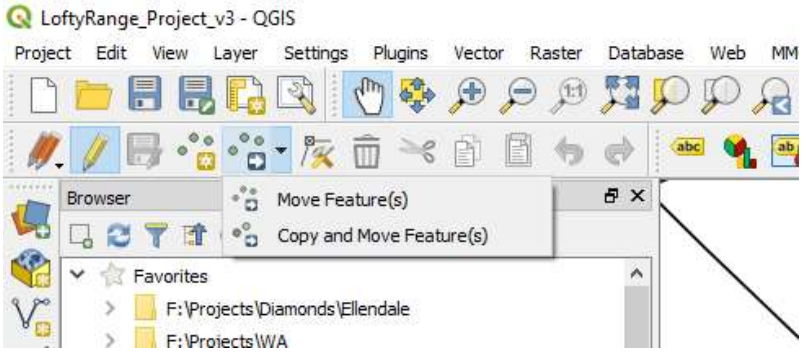
add the necessary columns to be able to enter the relevant field data for each feature. Save the file with an appropriate file name. Note that additional fields can be added later if needed. When digitising into a Geopackage file the feature id will be automatically incremented.





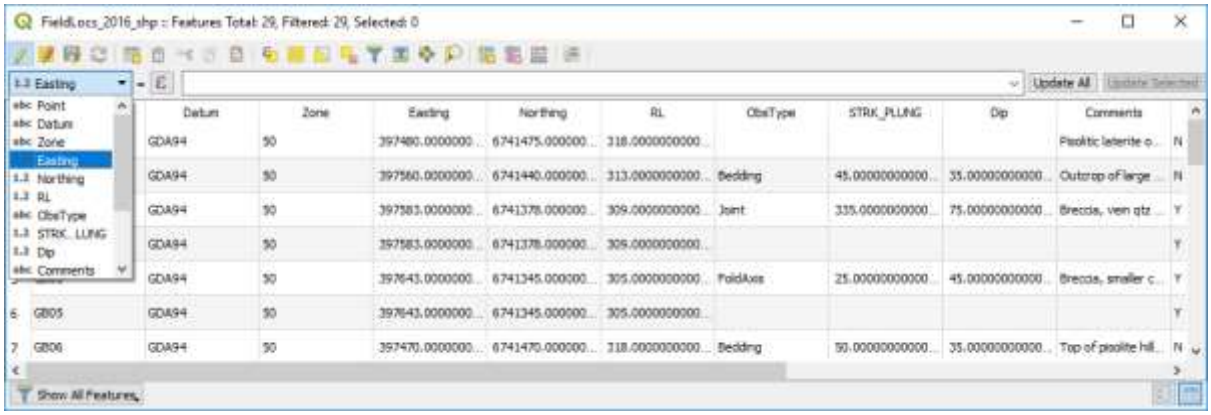
Note the Type “Real”, Length and Precision options where you can restrict the size of the data entered (e.g. UTM eastings length 9 - 6 figures, decimal point and two decimal places). Note that a negative sign, as per the dip, does not use a length, so the dip field in this example could have a length of 5 (00.00 to -90.00).

Points can be moved in the map window by using the “Move Features” icon in the point edit menu. The layer requires to be set as editable. Note that the coordinates in the underlying table will not change and these coordinates need to be updated using the “Update Coordinates” option in the “Attribute Table”.

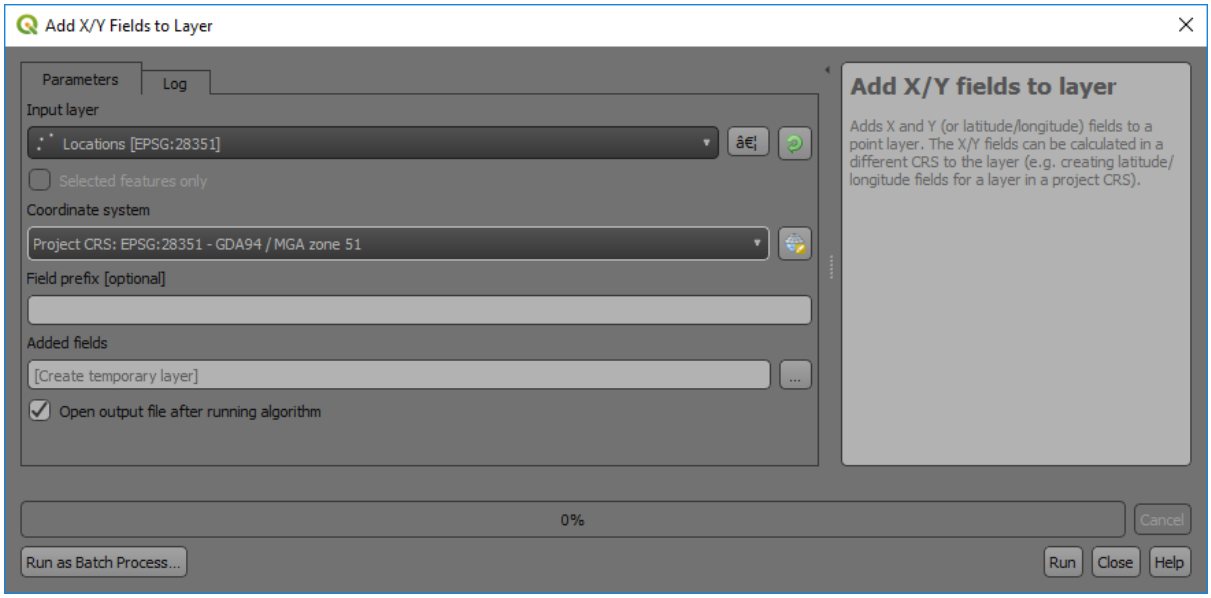


Move tool highlighted in editing toolbar.

If you do move points, remember to update the Easting and Northing values in the table using the geometry operator “$x” for Easting and “$y” for Northing. Remember to select the correct column to update! If you fail to do this the coordinates shown in the table will be incorrect. Remember also that the updated coordinates will be in the project projection coordinates. Also remember to save your edits.



There is a new algorithm that will create X-Y columns from point data and is accessed via the Processing Toolbox > Vector Table > “Add X/Y Fields to Layer”.



7.2 Outcrop Photographs

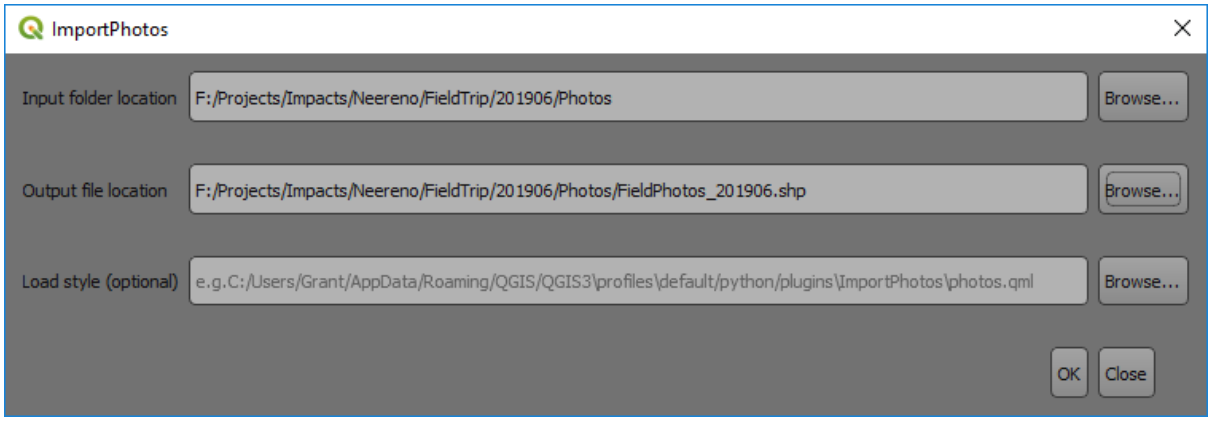
Photographs of outcrops and report pdf files can be attached to an observation point and allow a point and click to access the photo or report.

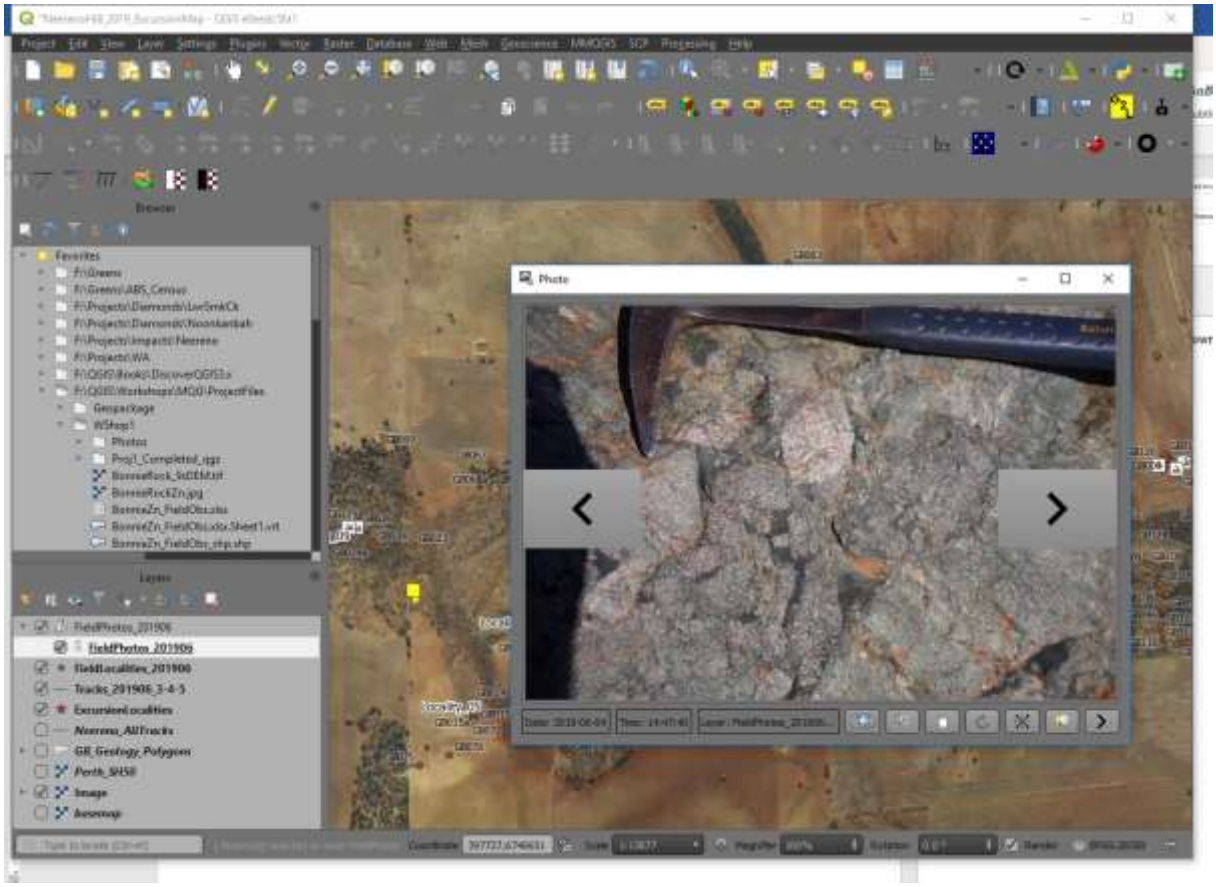
There are three ways to display photos at points. There are two options using the Import Photos plugin, and the third option is going via the Layer Properties > Actions (thanks to Mike Erceg for explaining this process) The last two options require the full path to the photo file to be identified.

Import Photos Plugin

If your photos are geo-tagged, i.e. they have their coordinate locations imbedded in the file, then the easiest option is to use the “Import Photos” plugin. Most smartphones take geo-tagged photos unless the location data option has been turned off for photos. I use a Pentax K-1 DSLR and that camera has an in-built GPS, so all photos are automatically geo-tagged. Most smart phones will have embedded GPS coordinates in the photos unless this location feature has been turned off.

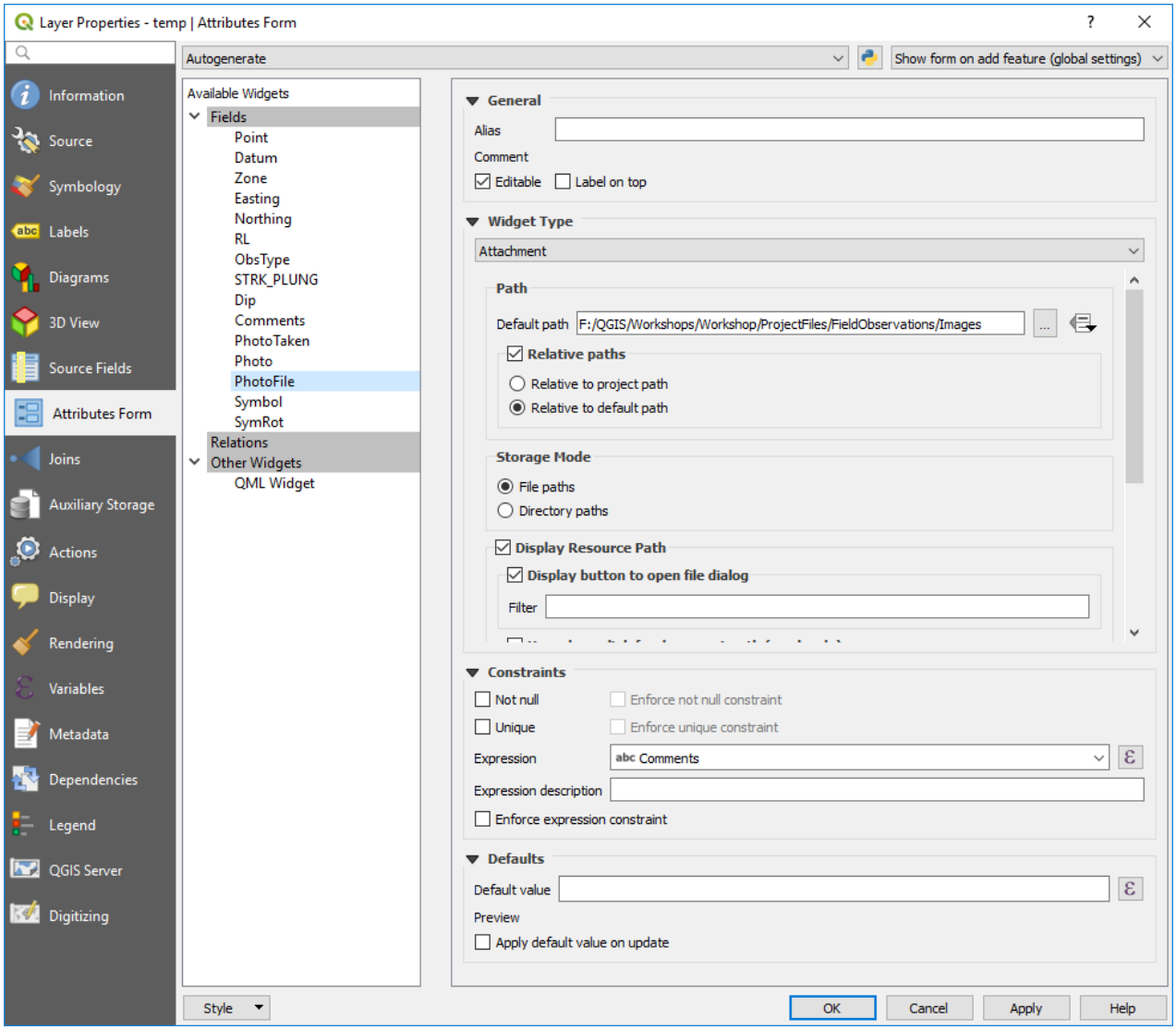
To use the Import Photos plug-in, run the “Import Photos” option and select the directory where the photos are located and where you want to store the resulting shape file (this will have all the photo information extracted from the photo file). Choose a suitable filename and press OK. The layer will them be created and using the Plug-Ins > Import Photos > Click on Photos (use a double click), the photos in those locations will be displayed.



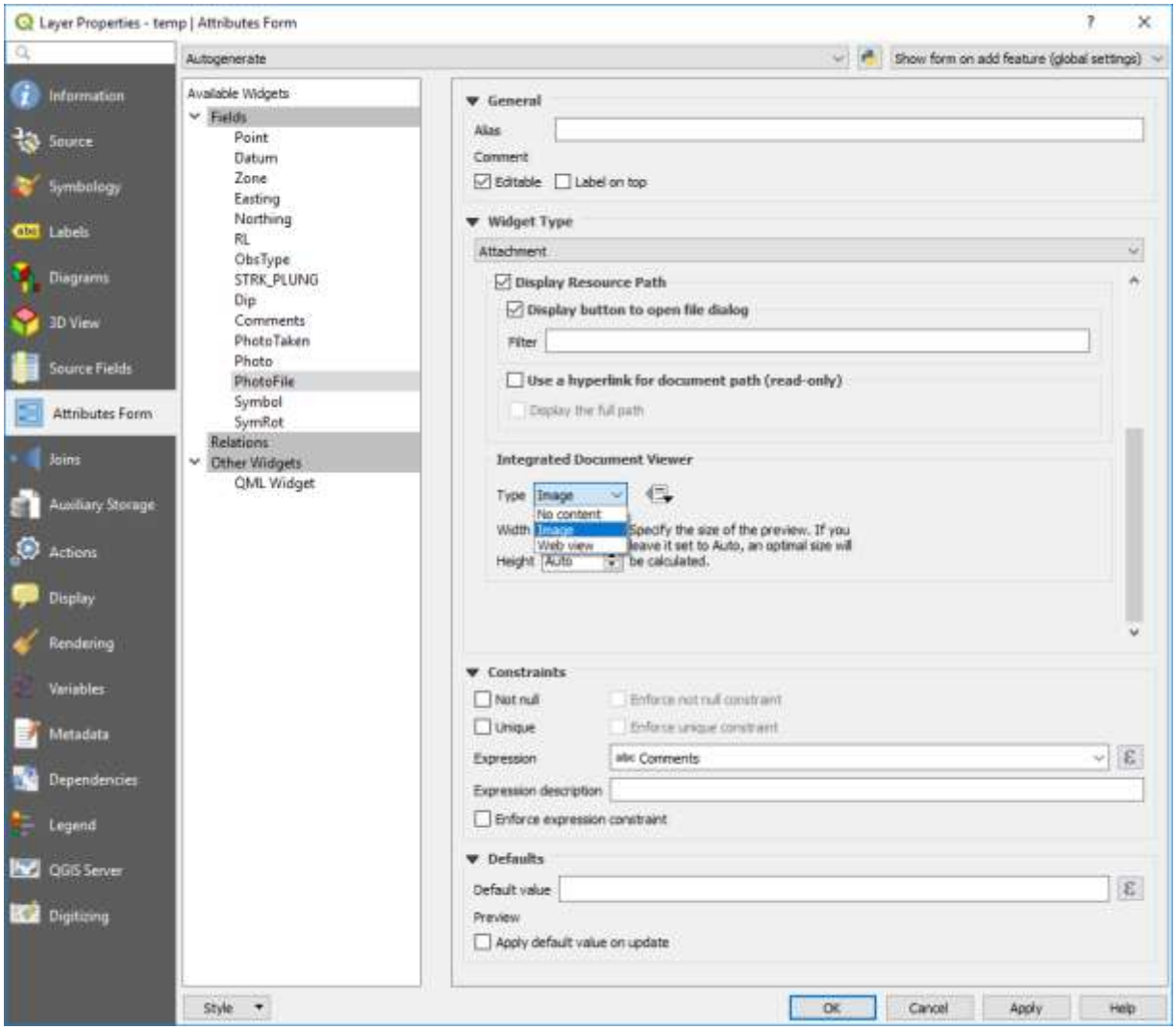


Viewing Photos Using the Import Photos Plugin and File Widget

You can also display photos using a widget in Layer Properties > Attributes Form. If you have used the Import Photos plugin then use this file to display the photos. Select the field with the photo name field (“Name”), then change the widget type to “Attachment”. Enter the default path to the image folder, tick “Relative paths” and “Relative to default path” option. Note the central dialog scroll down box can be difficult to locate but note the scroll bars on the right-hand side.



Scroll down the window the central part of the dialog box, past the “Storage Mode” to the “Integrated Document Viewer” section and select “Image”. Leave the sizes to Auto.



Apply the changes. In the map window, use the “Identify Features” icon to click on a point with a photo (this should open an Identify Features dialog box), then in the identify features dialog box, highlight the point (if you have multiple points in the Identify Features dialog box), open the “form view” (top left icon in the Identify Features dialog box). This will open a new dialog box which may require re-sizing to see the image. If the point with the image is not at the top of the list, select the point and then open the form.

temp - Feature Attributes

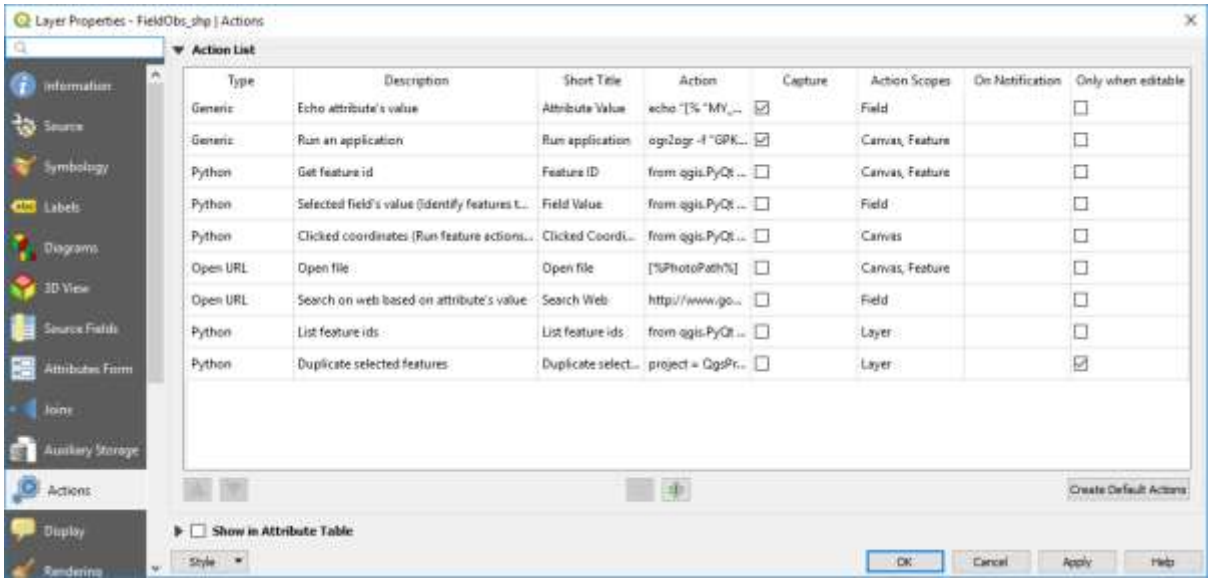
Point	GB22
Datum	GDA94
Zone	50
Easting	395625.000000000000000
Northing	6741413.000000000000000
RL	308.000000000000000
ObsType	Photo
STRK_PLUNG	NULL
Dip	NULL
Comments	Aboriginal stone workshop area, fgr basaltic rocks worked shards
PhotoTaken	Y
Photo	#5854
	Kinyorra\DSC05854.JPG
PhotoFile	
Symbol	NULL
SymRot	NULL

OK Cancel

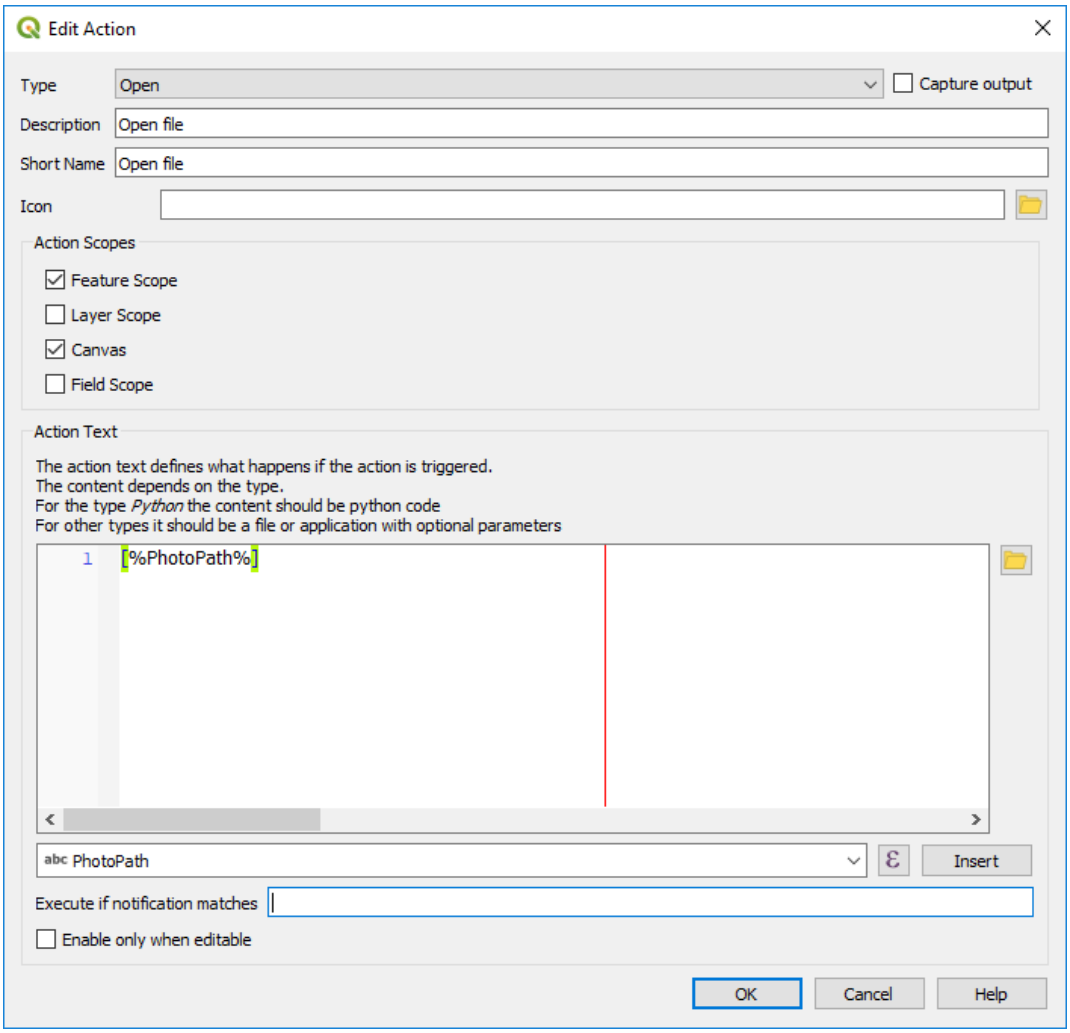
This method of displaying photos allow you to display the comments for example that accompany an image. Note this link is saved with the project and not in the layer properties.

Viewing Photos by the Action Tab

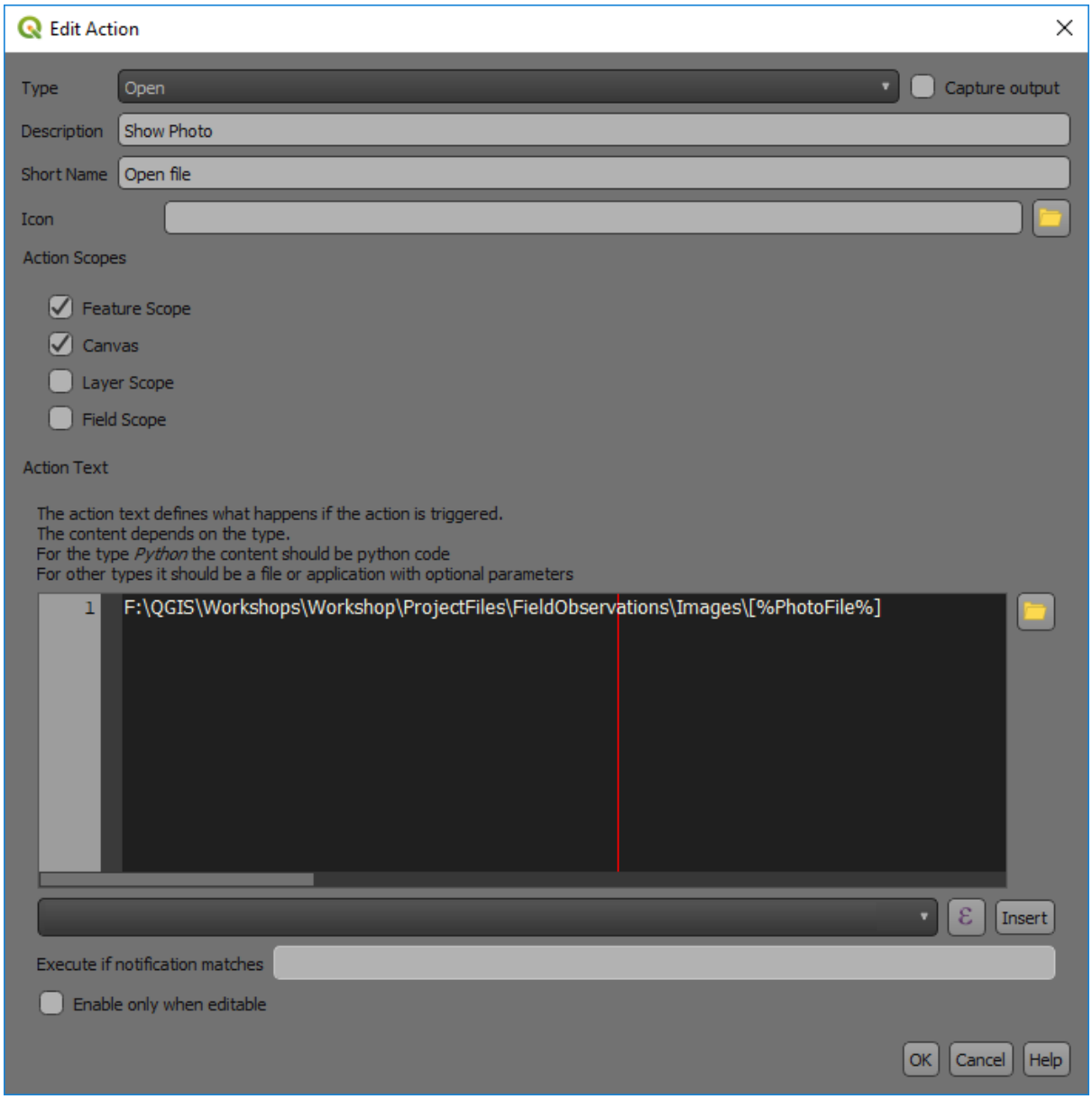
The second method to display photos is to use the Action option, open the Layer Properties of the layer and select the Action tab. Double click on the Open URL – Open File option.



This will open the dialog box shown below.

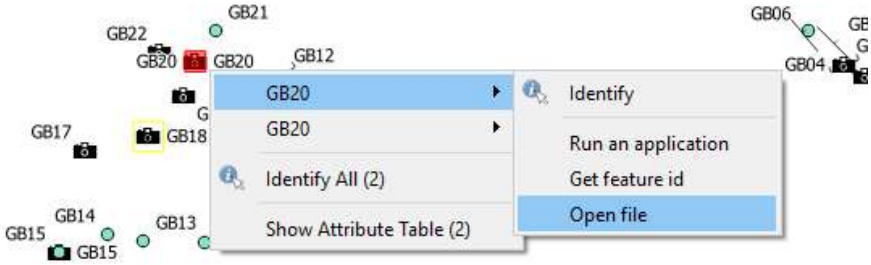


In the dropdown box near the bottom of the box, select the field with the photo location and click “Insert” to put the path into the Action Text window. Use the Windows file explorer to navigate to the directory that holds the photos, copy the path and paste it in front of the square brackets that holds the photo file name (as shown in the image below).

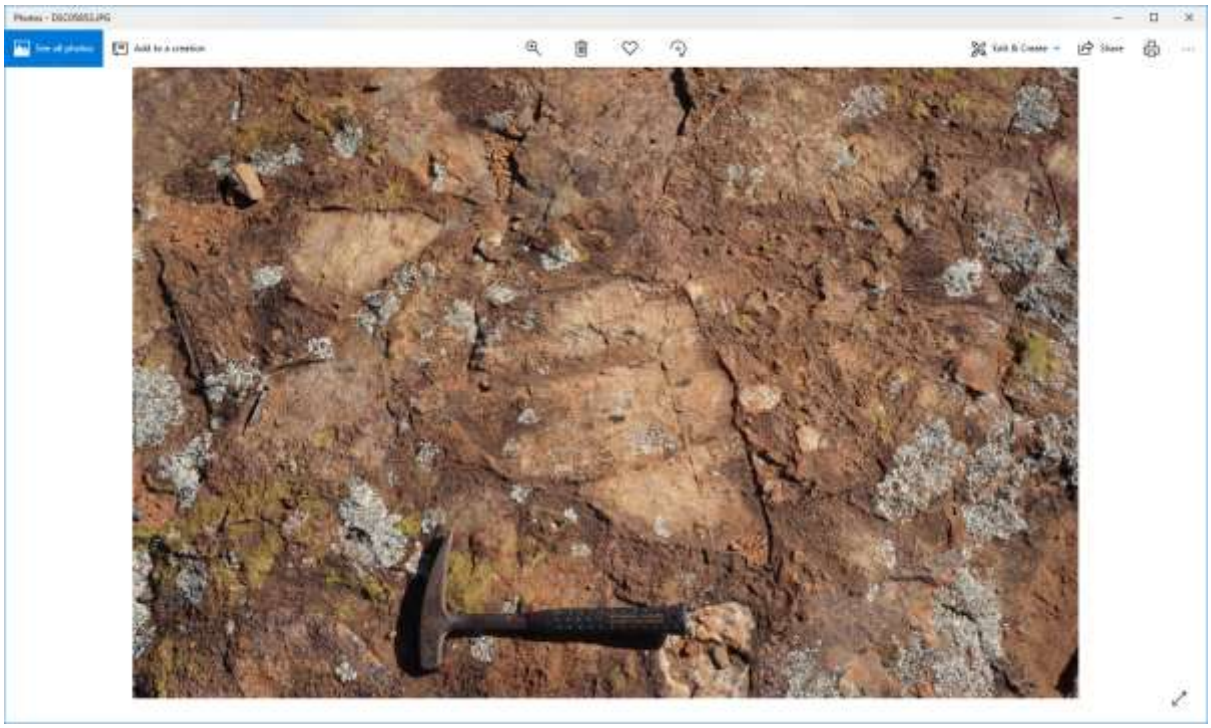


With the “Identify Features” activated for the cursor, right click on a point with a photo and the following will be displayed over the point.

Note there are two photos at this location.



Select the “Open File” option and the photo will be displayed.



temp - Feature Attributes

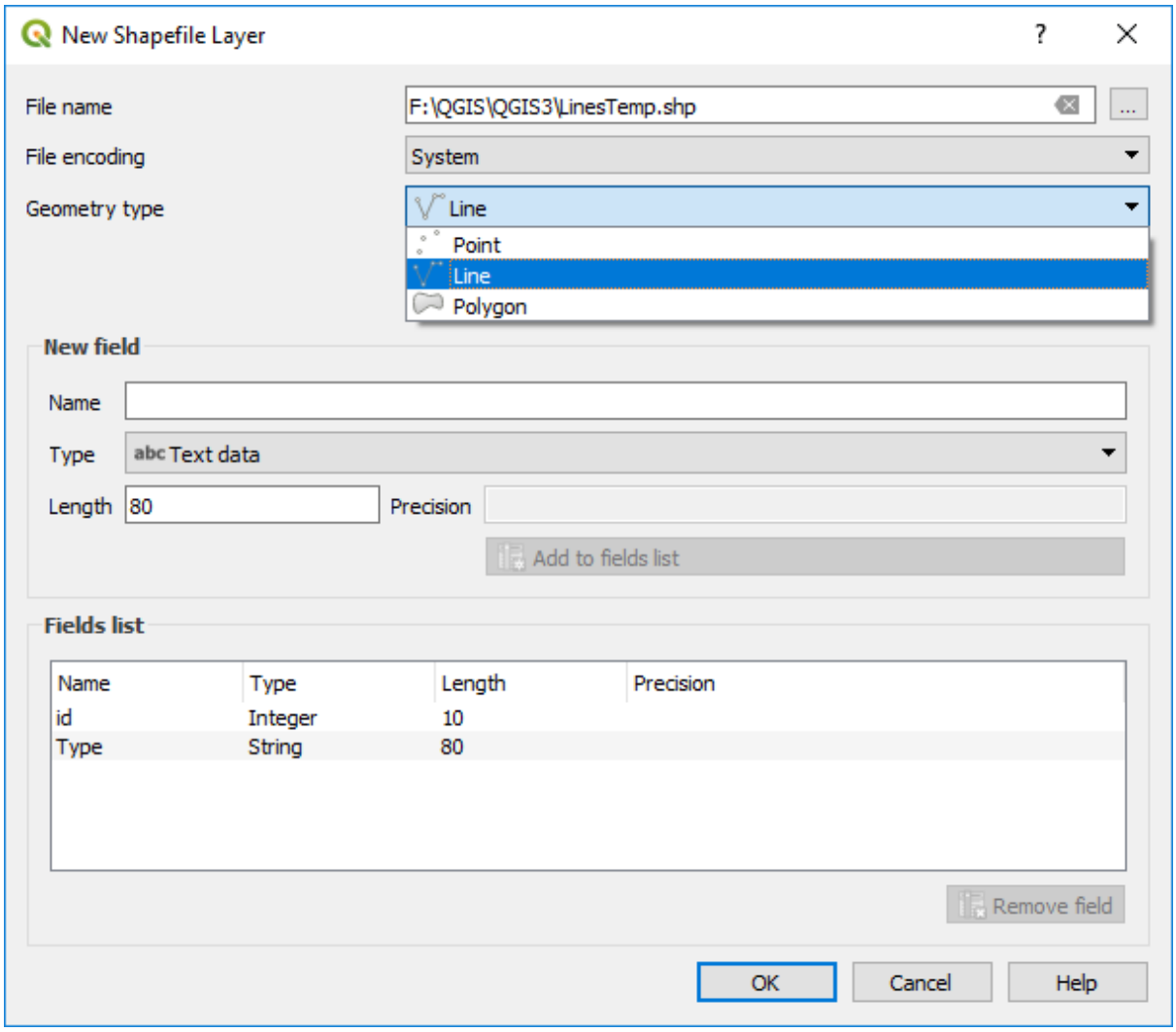
Point	GB22
Datum	GDA94
Zone	50
Easting	395625.000000000000000
Northing	6741413.000000000000000
RL	308.000000000000000
ObsType	Photo
STRK_PLUNG	NULL
Dip	NULL
Comments	Aboriginal stone workshop area, fgr basaltic rocks worked shards
PhotoTaken	Y
Photo	#5854
	Kinyorra\DSC05854.JPG
PhotoFile	
Symbol	NULL
SymRot	NULL

OK Cancel

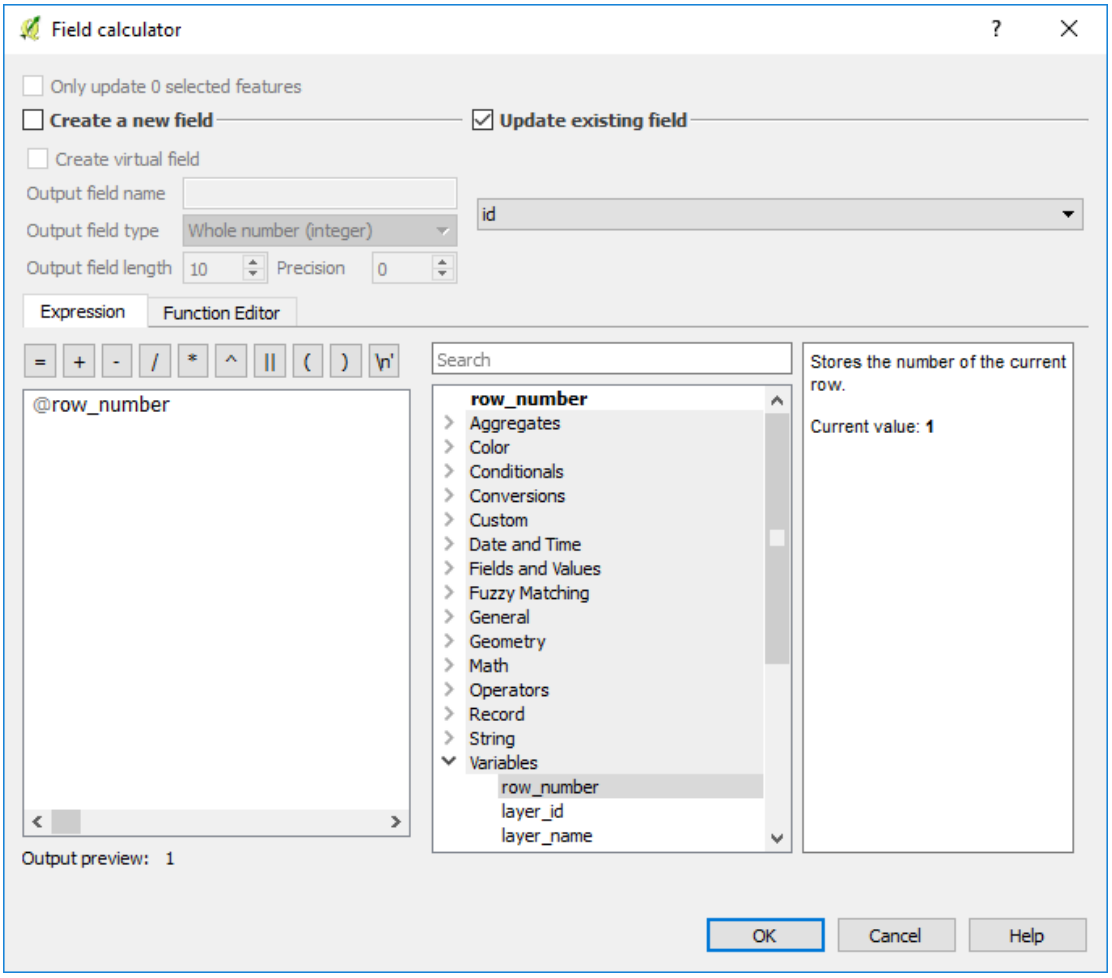
7.3 Line Data

Line data includes such items as contacts, faults and trend lines and are usually plotted on aerial or satellite imagery overlays. Surface mapping data can be digitised by scanning in the hard copy photo overlay into QGIS (via raster registration) and tracing the linear features, or by direct digitising on screen using the field mapping data as a guide.

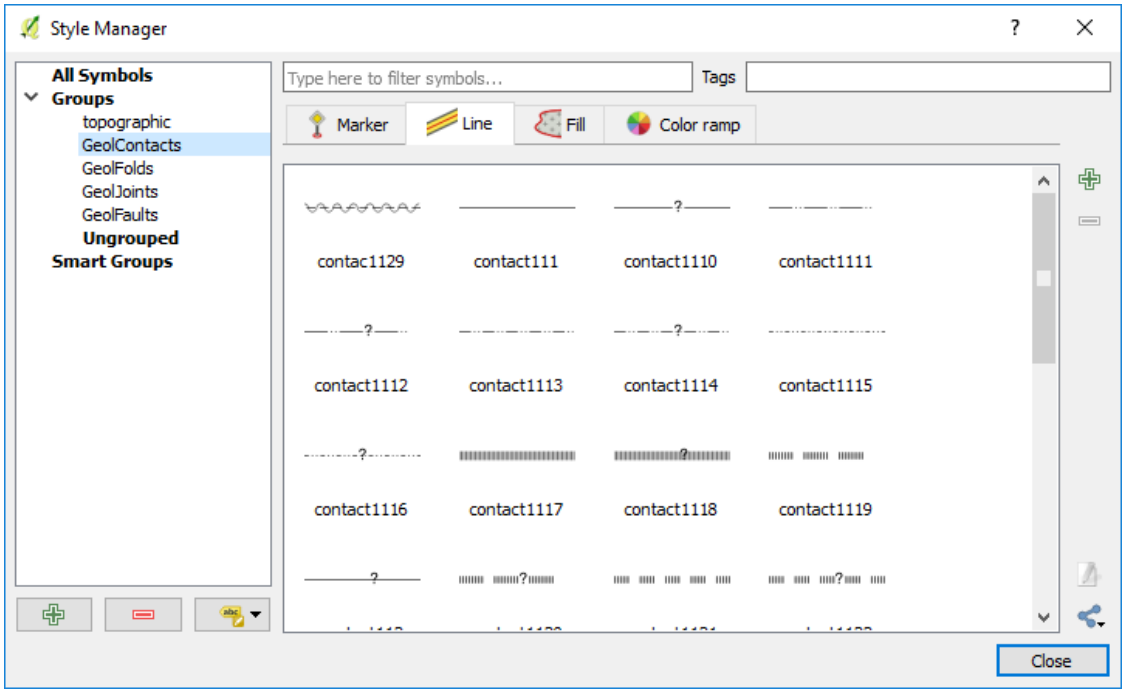
When creating a new vector layer to digitise the data, ensure the layer is the correct type, line type for example, has the correct map projection and add the necessary columns to be able to enter the relevant field data for each feature. Save the file with an appropriate file name.



QGIS can automatically assign a unique id numbers for each line after the creation of a group of lines. Open the Layer Properties > Fields, select the id field and click on the field calculator icon and choose “Update existing field”, select the id field, select the “row number” operator in the Variables list. Now when you save the file it will allocate a unique id to each feature. Thanks to Chris Franklin for noting this feature. If you are digitising into a Geopackage line file, the id field will be autonumbered.



Specific line styles can be added via the top menu Settings > Style Manager option. Geological line styles have been created as *.xml files and are imported using the “import” option, selectable from just above the Close button in the Style Manager dialog box. Import each style to a category, e.g. Contacts, so they are easier to locate.

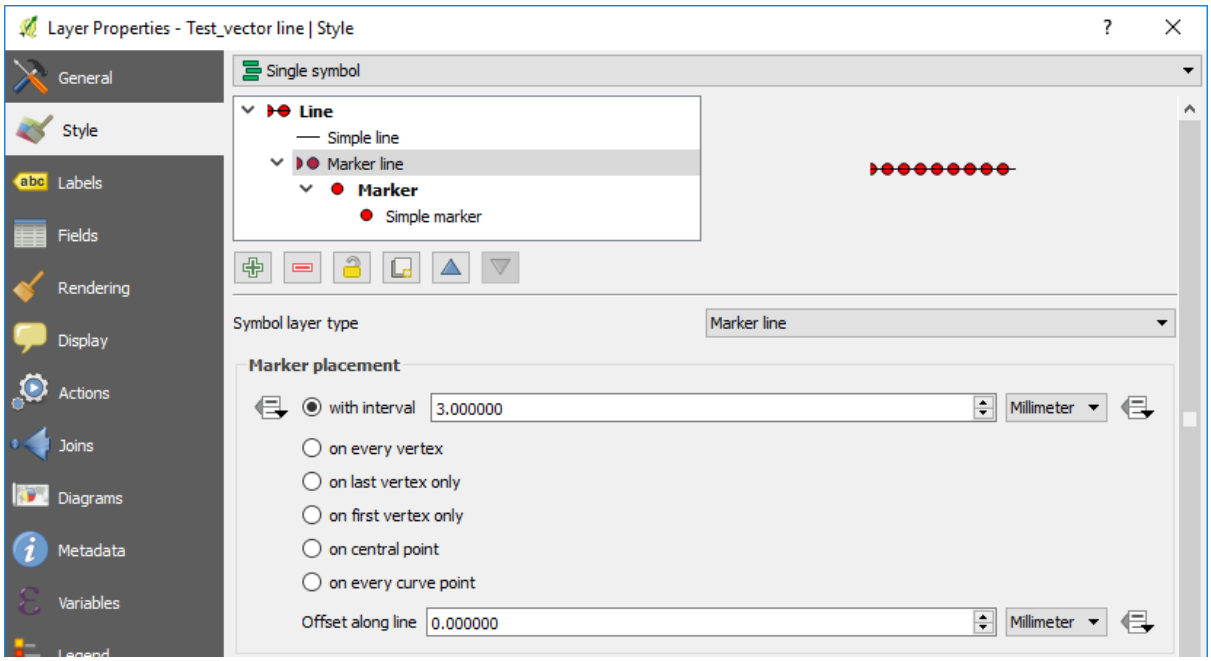


Contact the author if you would like to download these style files for contacts, folds, joints, or faults which are based on the USGS symbol sets.

Note that the line direction can be reversed to get the symbols plotting on the correct side of a line, e.g. fault ticks, using the “Reverse Line Direction” in the Advanced Digitising Toolbar (v3.4 or higher).

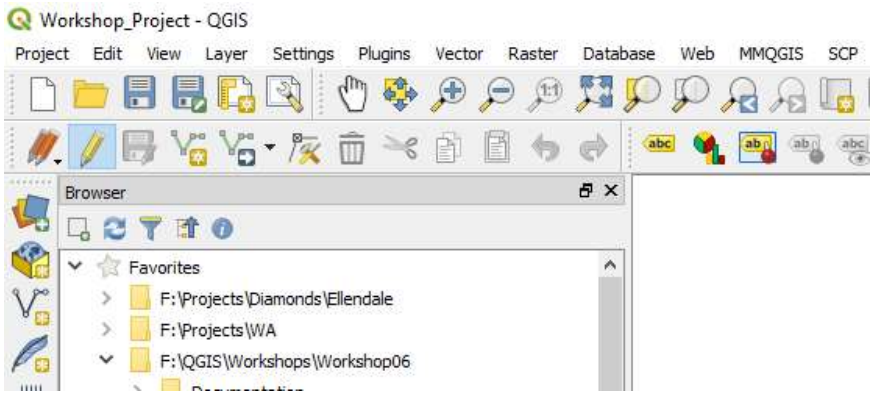
Line styles can also be created directly via the Style tab of the layer menu. Add an extra layer (using the green plus button) to combine lines and markers. There are numerous styles and options to choose from. Remember to save the style using a qml or “Save as Default” option when finished editing the line style.

You can combine many line styles into the one vector line file, providing you have a column by which the lines can be classified, e.g. feature type “contact”.



Lines can be edited by first highlighting the layer in the Layers panel and clicking the enable editing icon (pencil). A pencil symbol will then appear next to the layer being edited in the Layers panel. Remember to save your edits when exiting the edit mode. When the line is editable, there will be red crosses on the vertices. Click on the “node” tool (seventh button along from left, next to rubbish bin) then click near a vertex to highlight the vertices, select the vertex you want to move and simply click where you want to move it to. Note QGIS v3 uses “click-click”, not “click and drag” methodology. To add more vertices, hover over the line and click on the small red cross that appears. This will create a new point which can then be moved.

See the QGIS User Manual here https://docs.qgis.org/testing/pdf/en/QGIS-testing-UserGuide-en.pdf for up-to-date information on editing. The Testing Version applies to v 3.12.



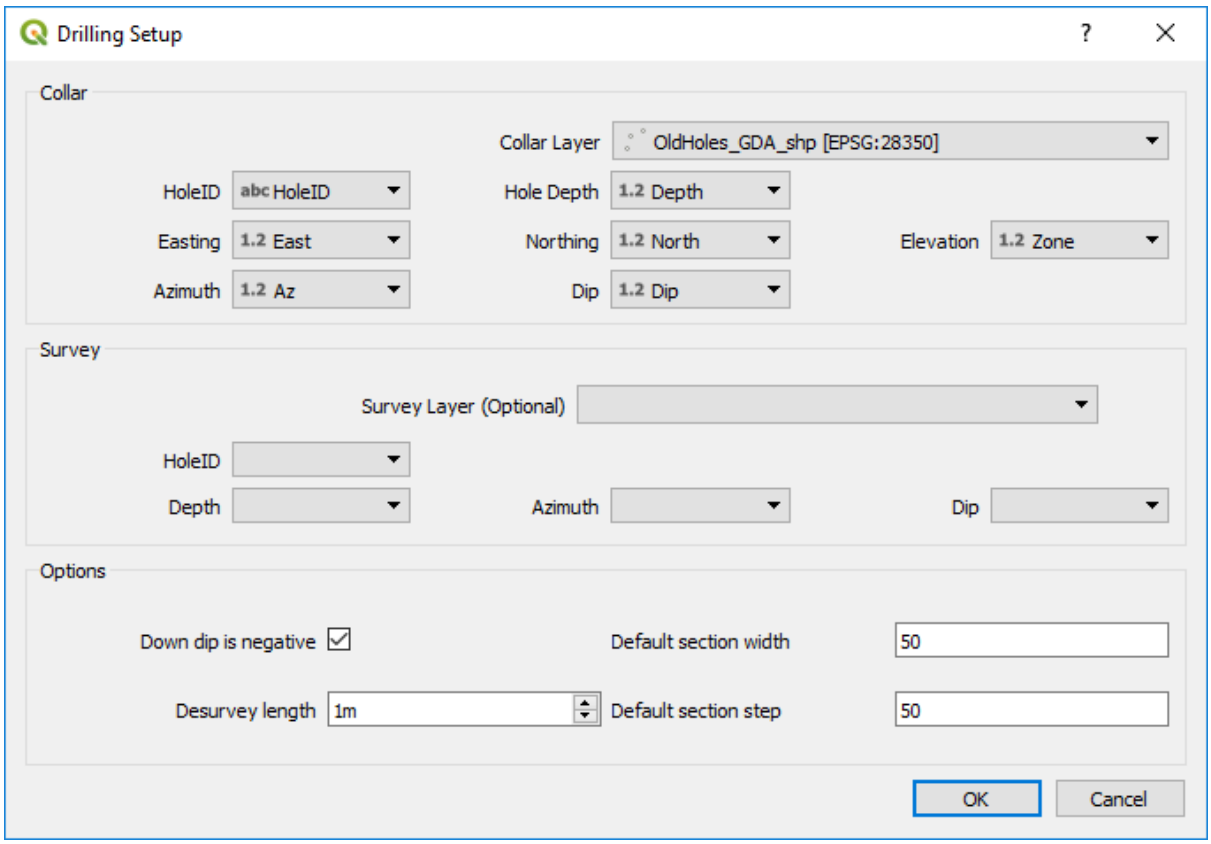
7.4 Plotting Drill Hole Traces and 3D Drill Data Display

There are two options to displaying drill hole traces on maps. One is to create the horizontal trace and use the "Shape Tools" plugin to plot the lines, or you can use the new "Geoscience" plugin. Both methods are described here.

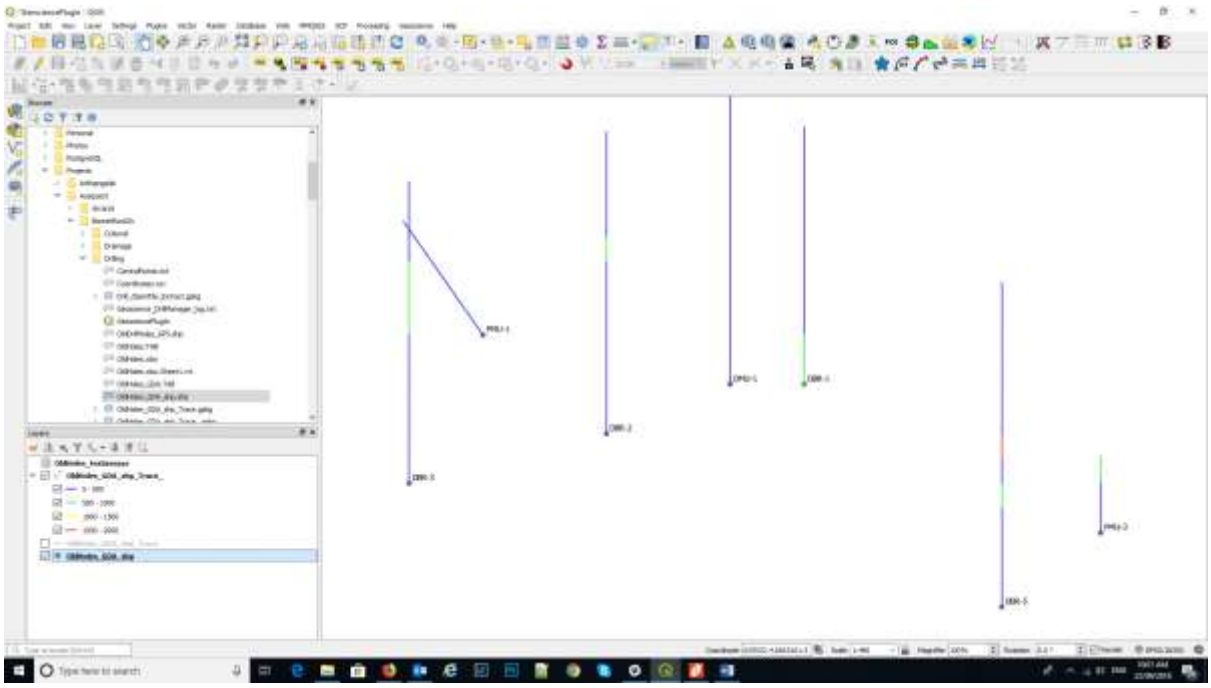
7.4.1 Geoscience Plugin

The "Geoscience" plugin (with thanks to Roland Hill) has allowed the plotting of drill hole traces and colour coding of the drill hole traces in QGIS easy. Cross sections can also be created. The drill set up screen allows you to select the collar and survey files. You will need to install the plugins in the Plugin Manager. See the documentation for more details (https://www.spatialintegration.com/geoscience-plugin-for-qgis/).

If your tables have commonly used field names, then the plugin will pick the fields.



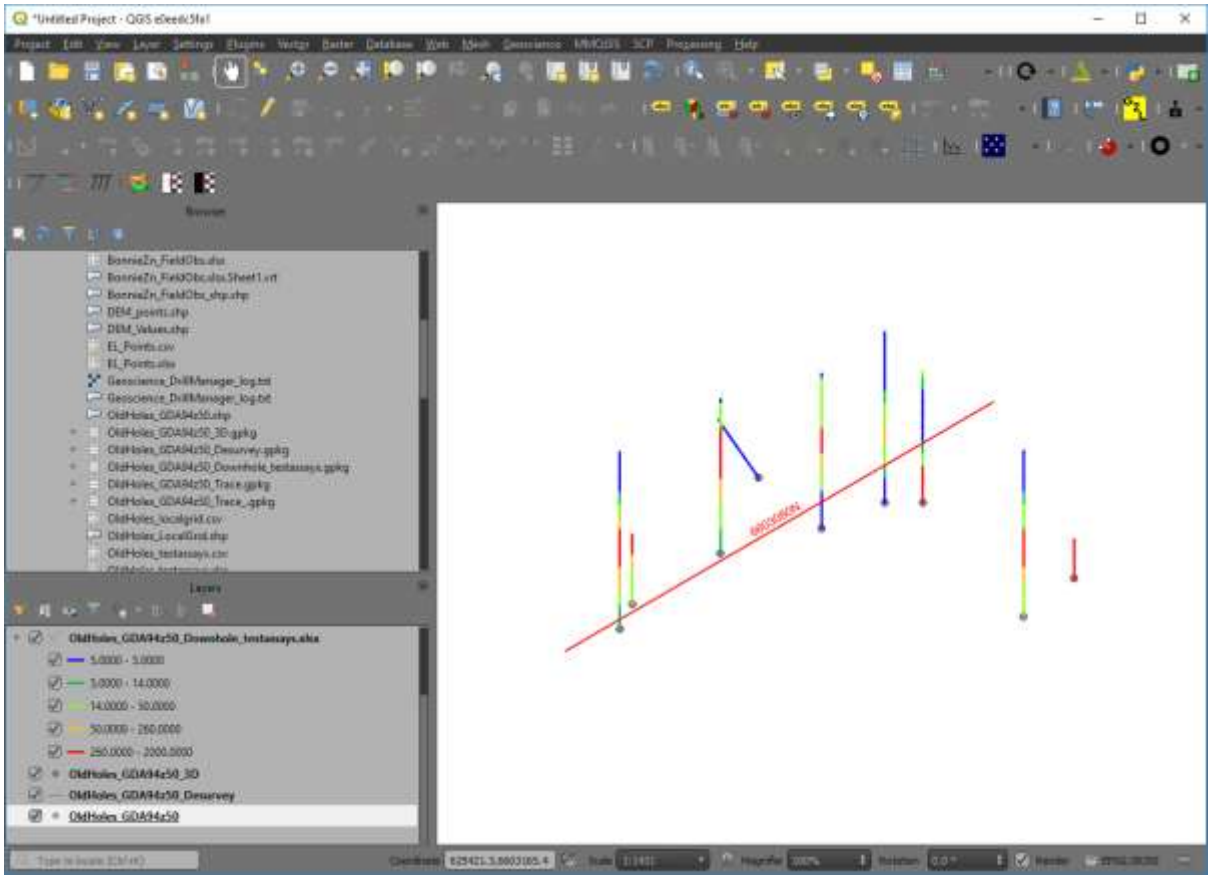
A De-survey option calculates the top and bottom points in xyz coordinates, and creates a desurvey layer which shows the trace of the drill hole. The data to be displayed down the drill hole trace needs to be imported as a non-spatial file with hole id, from, to and data fields. Down hole data can be assays, lithologies, or other data. If the downhole data fields are in a csv file format, make sure this is imported vis the Data Source Manager > Delimited Text option so that QGIS interprets the correct field types. The help menu for the plugin describes the workflow and a link to the web page (https://www.spatialintegration.com/).



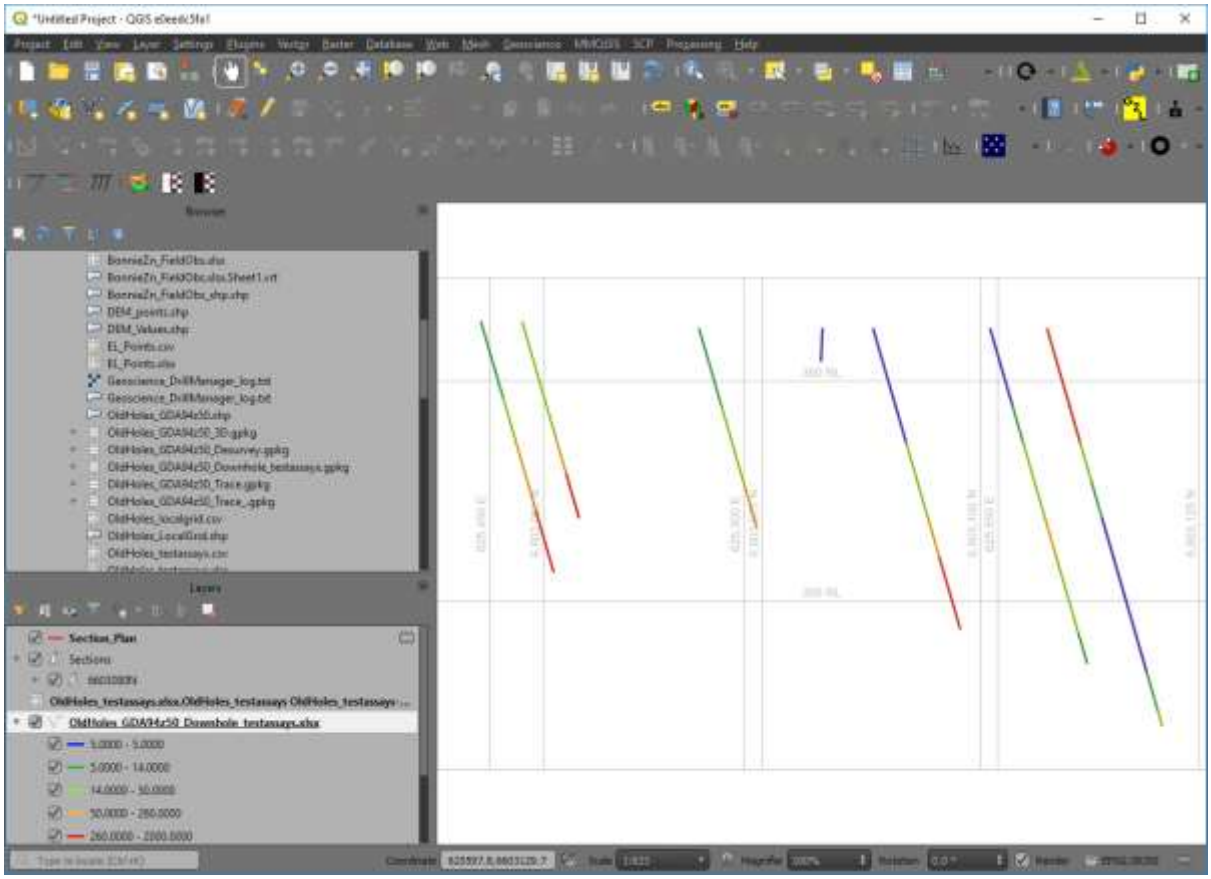
To enable labelling of assay results down hole, create 3D values of the mid-points of the assay intervals. This will then allow the display of multiple assay values by duplicating the assay-mid-point layer and choosing the data to be displayed. To create sample mid-points calculate these using the (x1 + x2)/2 calculation for each of the XYZ from-to fields. To display the lithology as a hole trace colour, make sure you include the lithology layer in the desurvey option, then use the symbology tab to colour by lithology (categorise).

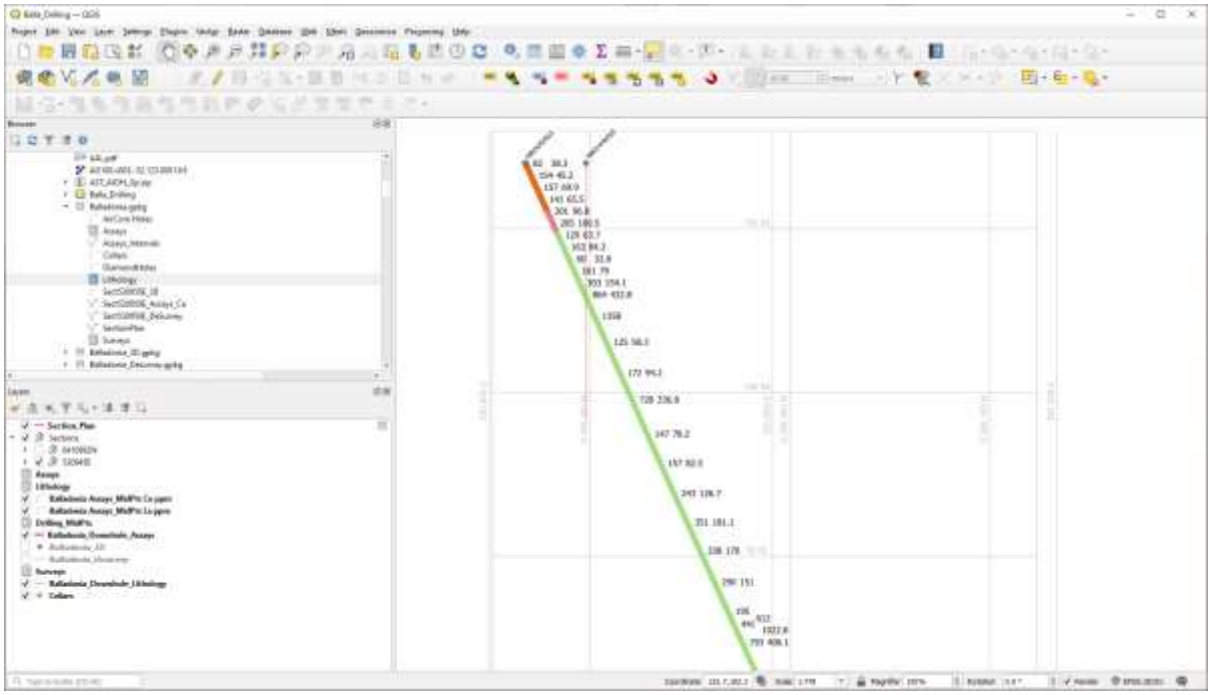
The drill hole traces (the desurveyed layer with the down hole data attached) can be coloured via the “Symbology” tab using any attribute. Note that when you import the downhole data, e.g. assays, make sure the “from”, “to” and assay values are recognised as numbers not text.

To create a cross section, use the “Section Manager” and using the “Use Map Canvas” and select the envelope width, draw the required section line.



The cross section will be created in a “new” location on the map. To get back to the collar positions, right click on the collars layer and “zoom to layer”.



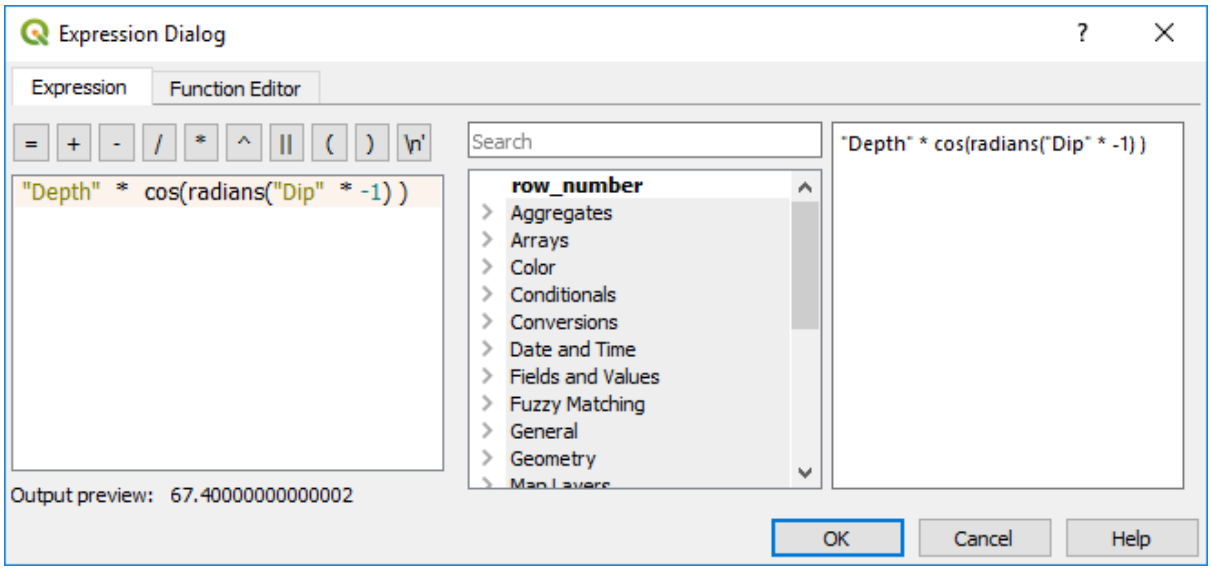


Cross section plot with the hole trace coloured by lithology and the assay values of two elements displayed using their mid-point locations.

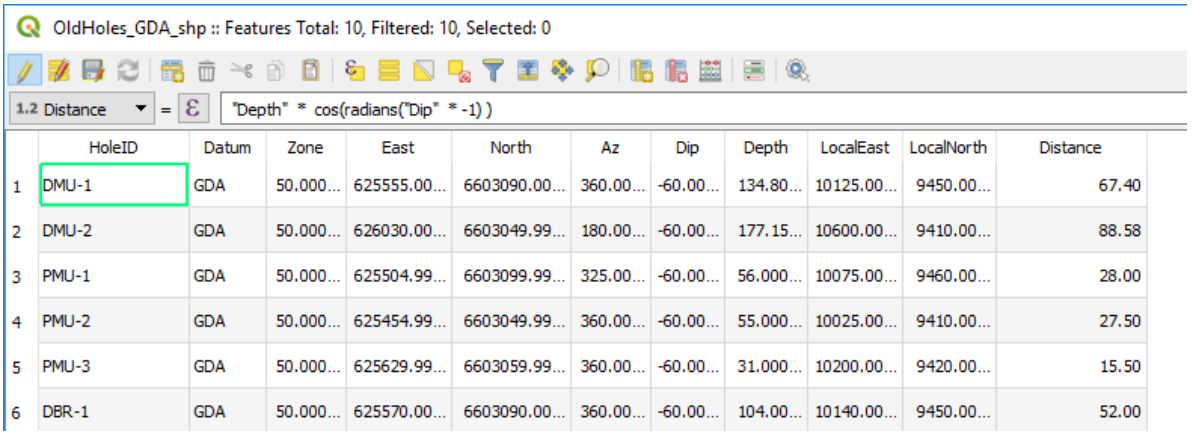
7.4.2 Alternative Way to Plot Drill Hole Traces on Plan

Surface drill hole traces can also be plotted on plans using the Shape Tools plugin. To plot drill hole traces, a collar file with collar coordinates, azimuth and horizontal projected distance columns are required. The horizontal distance – trace length – is calculated using the following formula;

Trace length = hole length * cos(radians(dip))

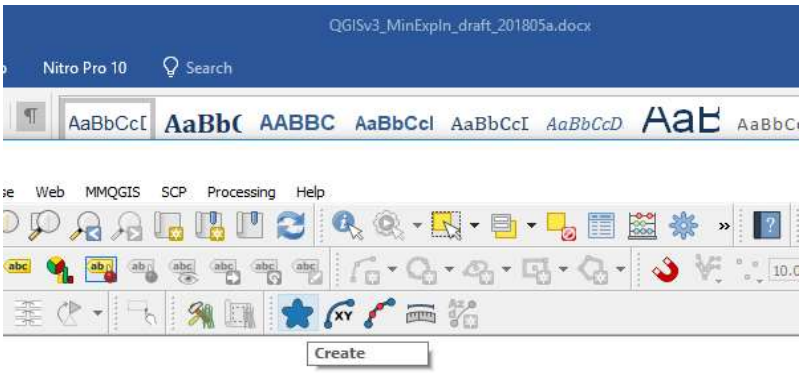


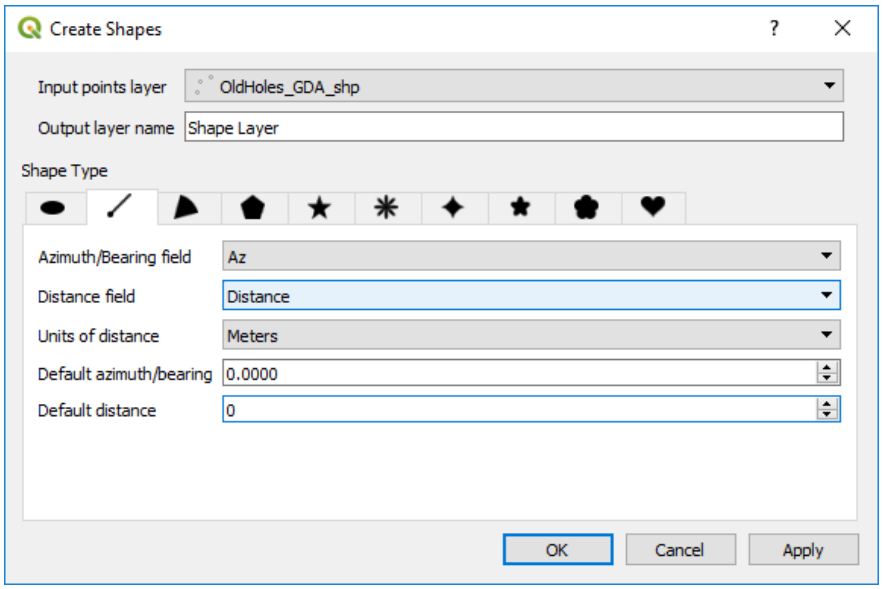
Note if down dip is negative, multiply the dip by -1 (as in the above example).



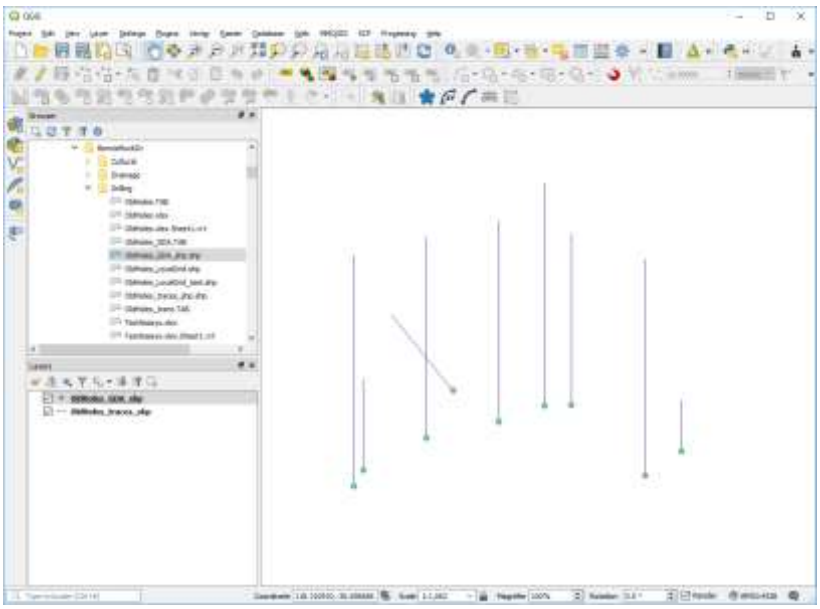
	HoleID	Datum	Zone	East	North	Az	Dip	Depth	LocalEast	LocalNorth	Distance
1	DMU-1	GDA	50.000...	625555.00...	6603090.00...	360.00...	-60.00...	134.80...	10125.00...	9450.00...	67.40
2	DMU-2	GDA	50.000...	626030.00...	6603049.99...	180.00...	-60.00...	177.15...	10600.00...	9410.00...	88.58
3	PMU-1	GDA	50.000...	625504.99...	6603099.99...	325.00...	-60.00...	56.000...	10075.00...	9460.00...	28.00
4	PMU-2	GDA	50.000...	625454.99...	6603049.99...	360.00...	-60.00...	55.000...	10025.00...	9410.00...	27.50
5	PMU-3	GDA	50.000...	625629.99...	6603059.99...	360.00...	-60.00...	31.000...	10200.00...	9420.00...	15.50
6	DBR-1	GDA	50.000...	625570.00...	6603090.00...	360.00...	-60.00...	104.00...	10140.00...	9450.00...	52.00

Using the Shape Tools plugin (from icon task bar) select the Create icon and the Line tab.





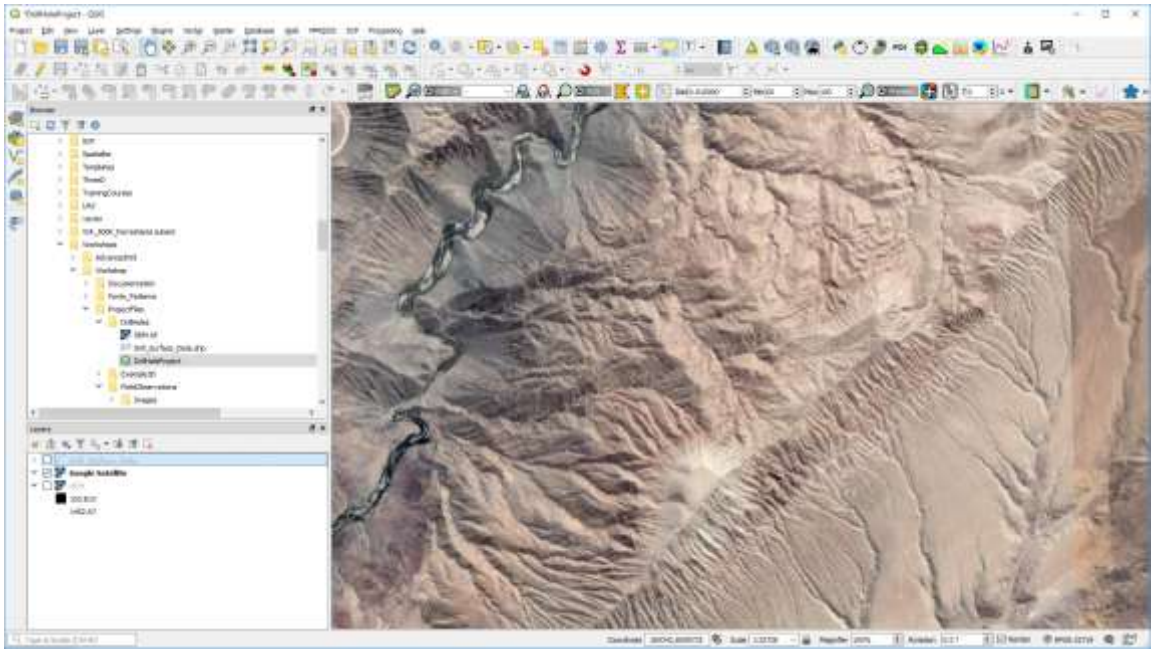
Select the Azimuth column for the hole azimuth and the distance field for the length of the hole trace. Check the units of distance is in metres. The result should look something like below with the hole traces created in a new virtual file – remember to save it with a relevant name.



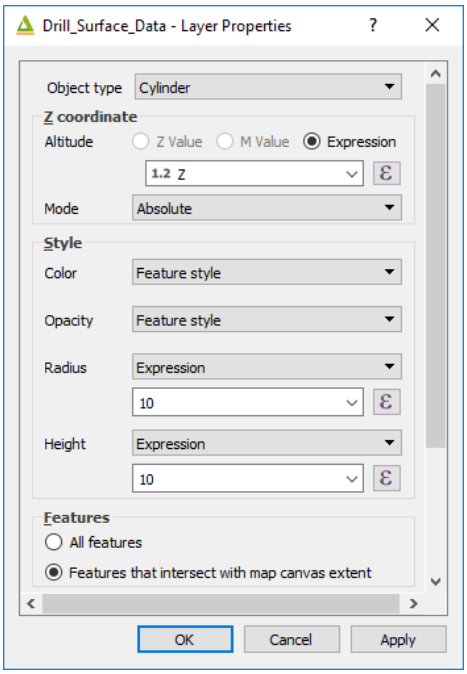
7.4.3 Displaying Drill Hole Traces in 3D

It is also possible to display drill hole data in 3D using the QGIS2threejs plugin. All that is required it to have the 3D coordinates for the sample points to be calculated. This is a fairly basic display option and will hopefully be superseded with the development of the drill hole and cross section module planned for the future. The QGIS2threejs plugin displays the centre points in XYZ coordinate space. The sampling data can be coloured according to any attribute in the file, e.g. assay values of Cu.

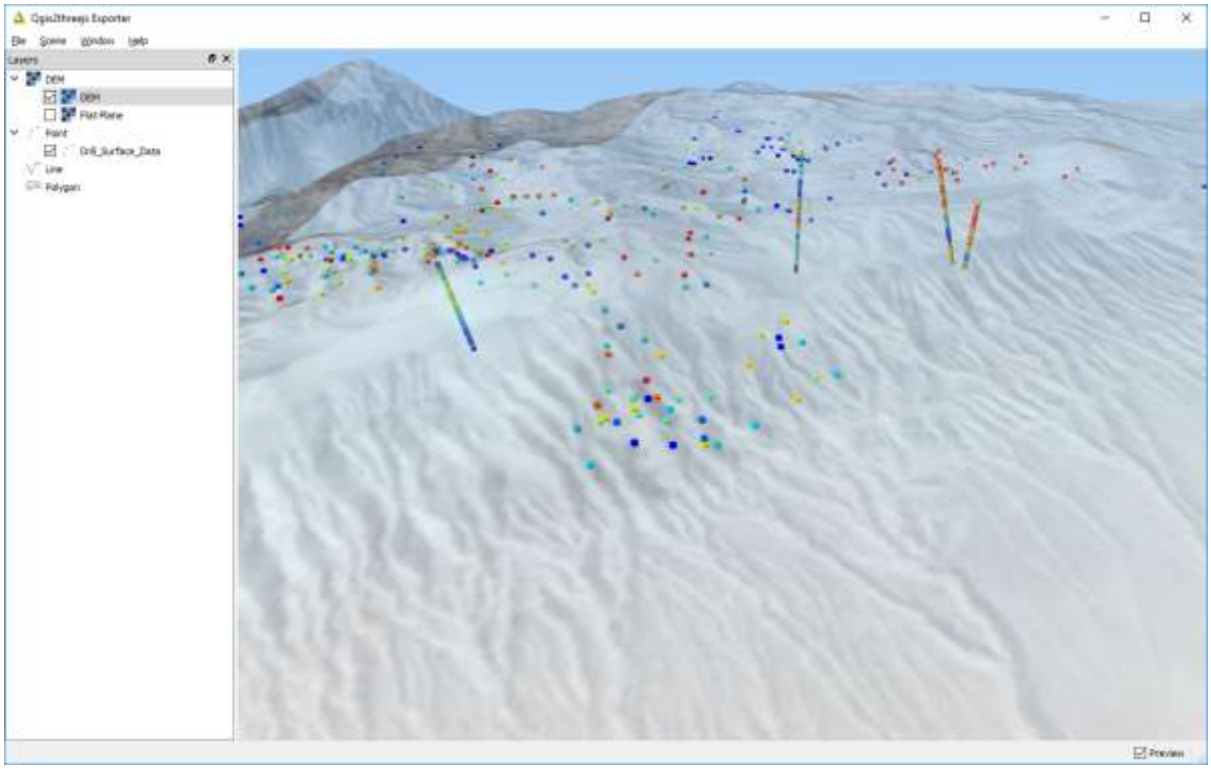
To display the downhole data, the 3D coordinates are required for the drill hole traces. In the example below, the XYZ mid-points have been calculated for assay intervals. In the main map window, then DEM, Google Earth satellite image and the file containing the 3D coordinates of surface and drill hole samples have been loaded. The DEM layer and sample layer are not displayed (but loaded).



When opening the QGIS2threejs plugin, select the DEM for the elevation and right-click on the samples layer to select the z coordinate.

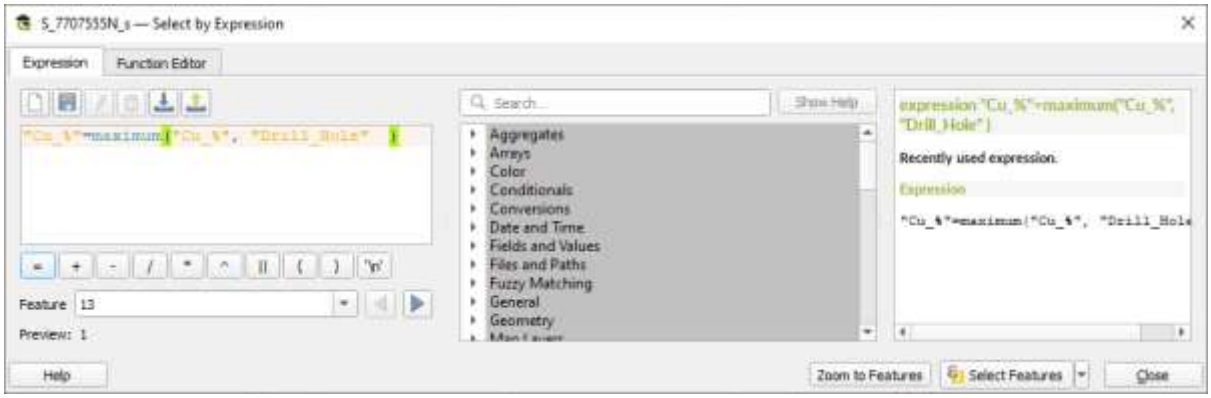


The 3D image can then be rotated and tilted as desired. The surface satellite image has been set to 30% transparency to be able to see through the surface.



It has been noted by the author that some installations using Win7 may be unstable, and it is recommended to use Win10. Always remember to save your projected regularly.

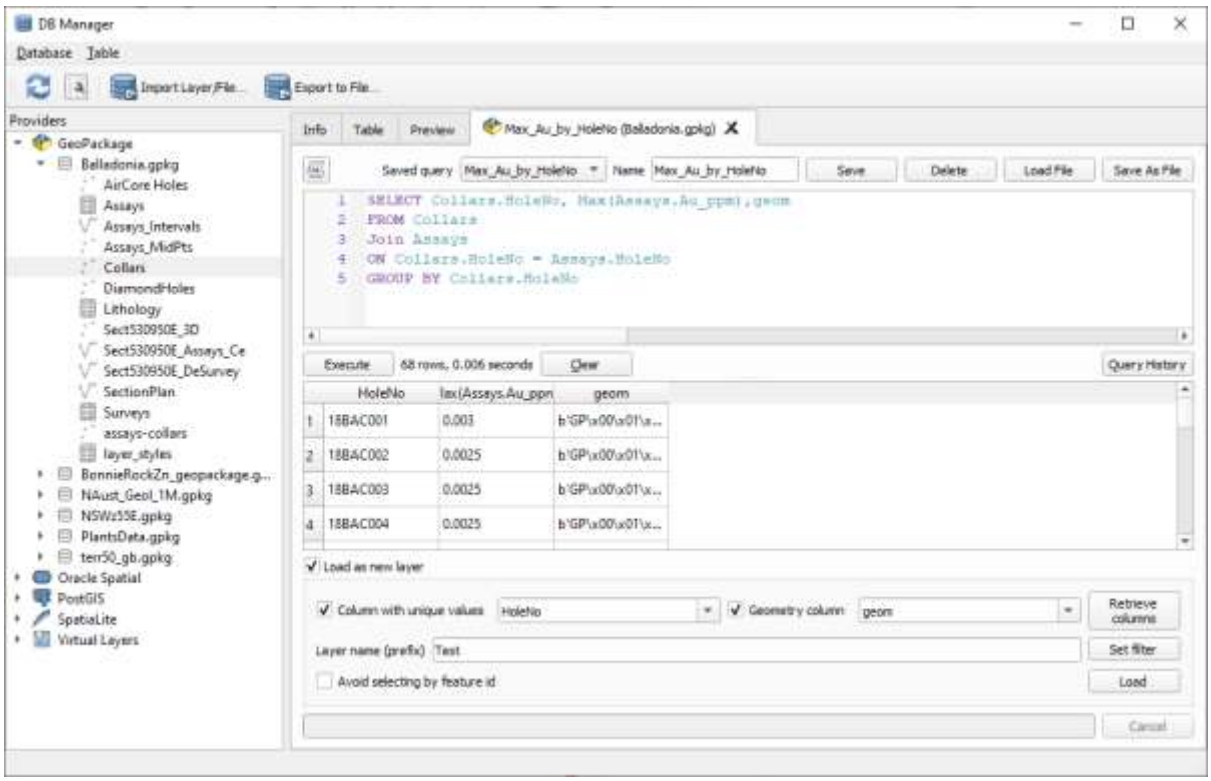
To select the maximum assay value by drill hole, use the “maximum” function.



7.4.4 Extracting Maximum Values for Drill Holes

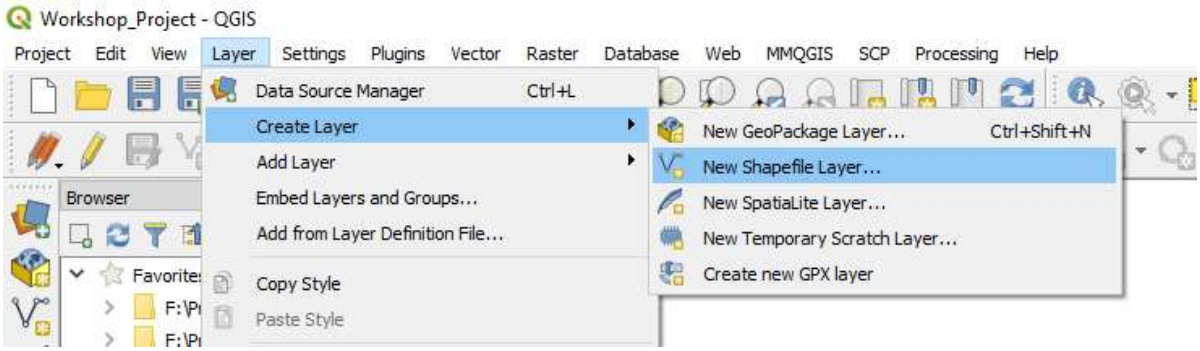
This can be done at least two ways. The first way is to calculate the drill hole statistics and group by drill hole (algorithm “Statistics By Category”). This method requires coordinates for all assay points.

The second method is to use an SQL query on a Geopackage file. Save the collar file and the assay file into a Geopackage, then use the DB Manager to connect to the Geopackage. Open the SQL Window, second icon from left, and then run the SQL query as shown below. Do not forget to add the “geom” column to the query so the resulting layer can be plotted. Each point will have the max value attached.

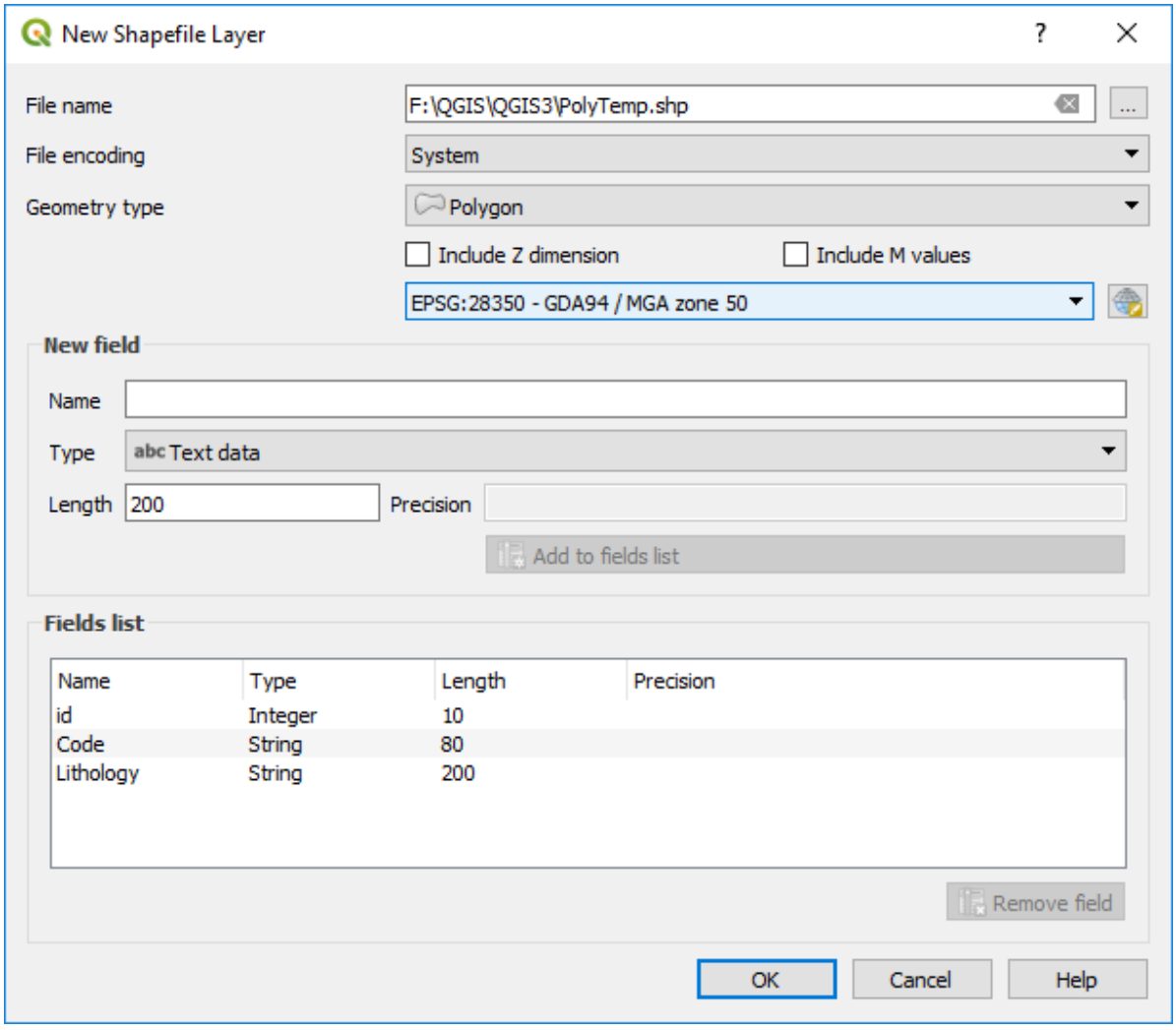


7.5 Polygon Data

Polygon data is added by creating a new polygon layer (Layer > Create Layer > New Shapefile Layer or New Geopackage Layer), selecting type “polygon”, set the projection information and enter the additional fields for the polygon file. Note that if you are creating a Geopackage file, it will auto-number every new feature when digitising.



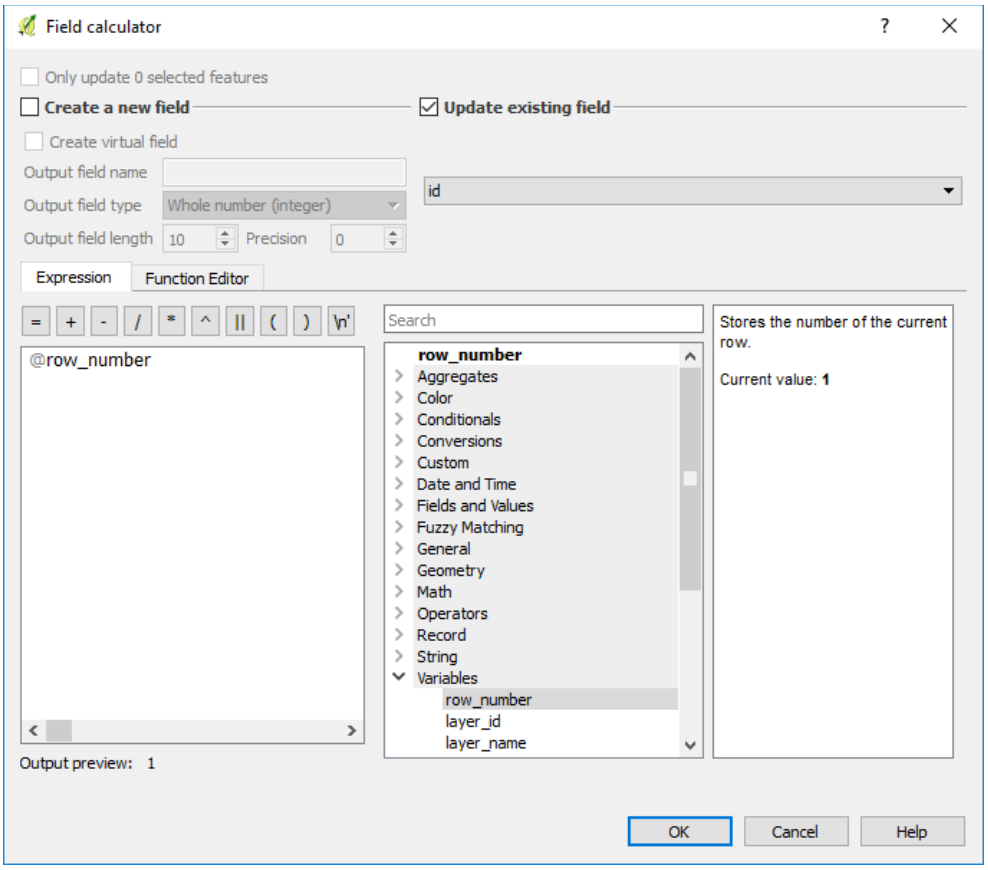
The additional columns might hold data such as geological code, geological descriptions, etc. Remember to select the correct field type (string, number, and precision, etc) and also remember that field names are limited to a length of 10 characters in shapefiles – but not in Geopackage files.



When creating new objects in a shape file, every new polygon should be assigned a unique “id” number. If you keep these unique, then it is easier to select and alter polygons which can be then selected by their id. Note that digitising into a Geopackage file will automatically number the id field.

To add a new polygon, highlight the polygon layer in the Layers panel, and toggle the editing button (pencil icon). Numerous polygon options are available - see the second row of menu. To add a new polygon, use the Add Polygon Feature icon. Hover over each icon for an explanation of the icon actions. If not all the digitising and advanced digitising options are not show, check the top menu View > Toolbars options.

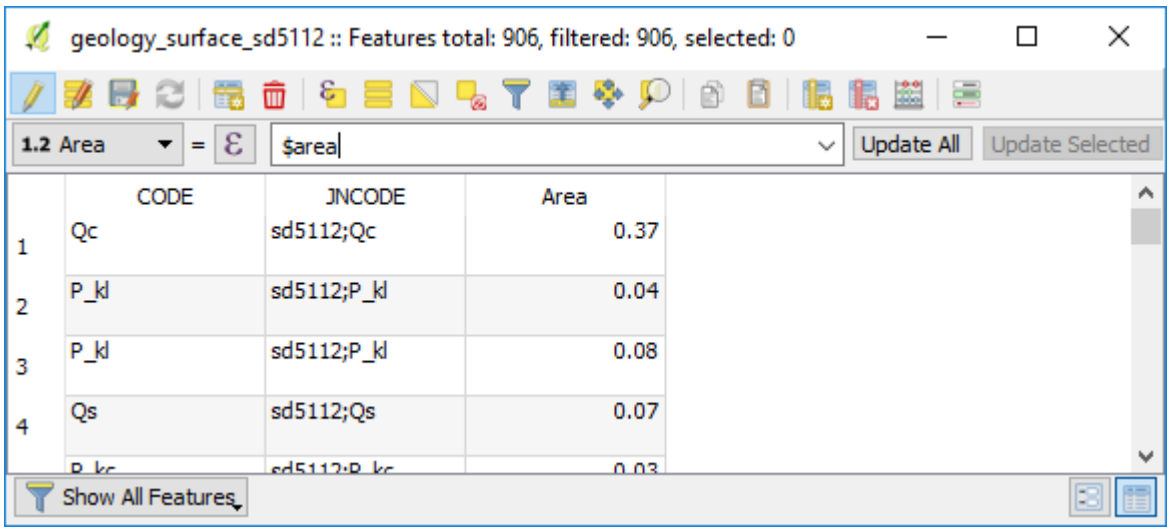
QGIS can also assign a unique id numbers for each polygon in a shape file after digitising is compete. Open the Layer Properties > Fields, select the id field and click on the field calculator icon and choose “Update existing field”, select the id field, select the “row number” operator in the Variables list. Now when you save the file it will allocate a unique id to each feature. Thanks to Chris Franklin for noting this feature.



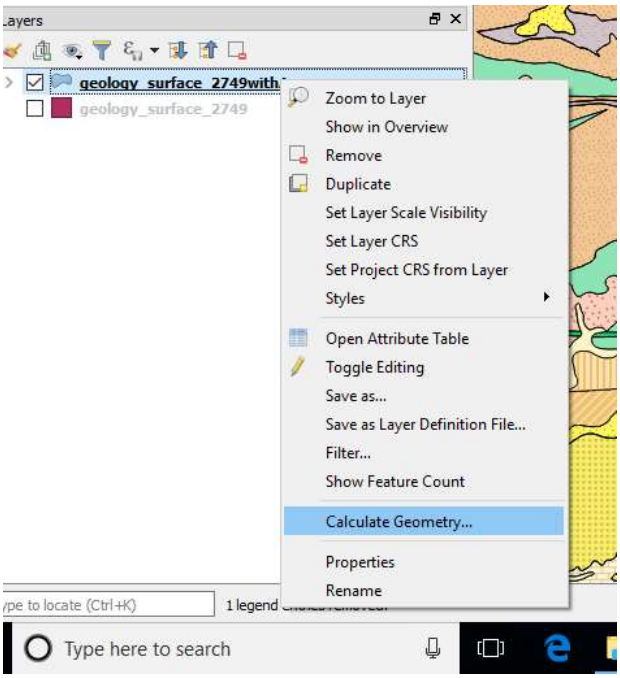
If you want to calculate areas of polygons, add an “Area” column to the polygon table. Note you must set the projection to a metre projection, e.g. UTM, not geographic degree units, and select your units in the Project Properties > General > Measurements dialogue box. You can then populate this field by using the calculation option in the Attribute Table option. Make the layer editable and then use the $area function to calculate the relevant field area.

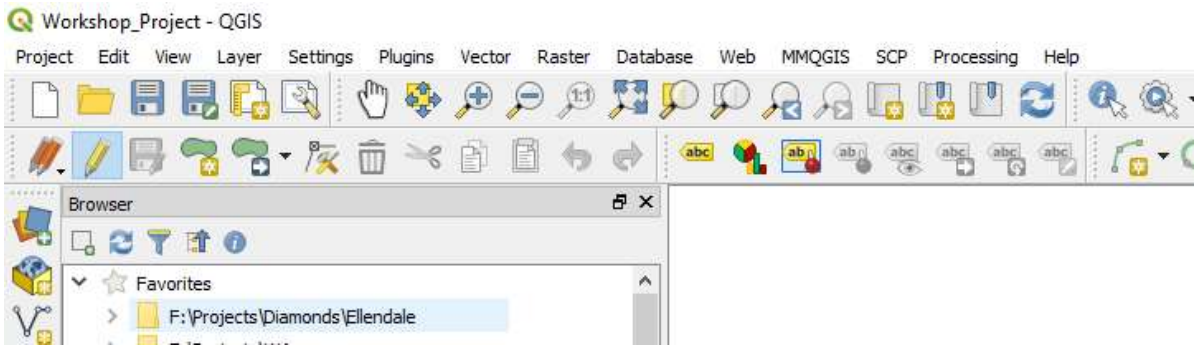
Note that the units of area are set in the Project Properties > General > Measurements dialogue box. These units can be changed on the fly, but you need to refresh the values in the calculated area column to reflect the new units. The area can also be viewed by selecting the Layer

Properties > Display > Field option so that the area can be displayed when you hover the mouse over the polygon when the Info Tool is activated.



Areas can also be calculated via the Calculate Geometry plugin. Right click on the layer name in the Layers Panel and select “Calculate Geometry”. The Calculate Geometry plugin allows you to select your area units. Perimeters can also be calculated this way. Make sure you do some check areas to ensure your results are correct.



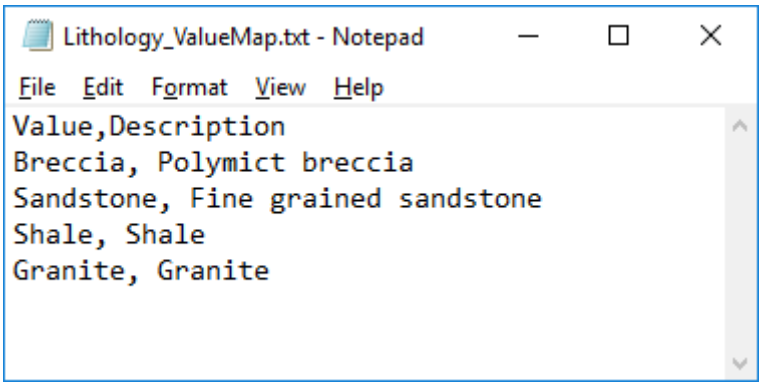


To digitise a polygon, make the layer editable and choose the “Add Feature” polygon icon (4th from the left). Click around the polygon using left mouse clicks and finish the polygon with a right mouse click. Nodes can be shifted and added-deleted using the node icon, as per the line editing options.

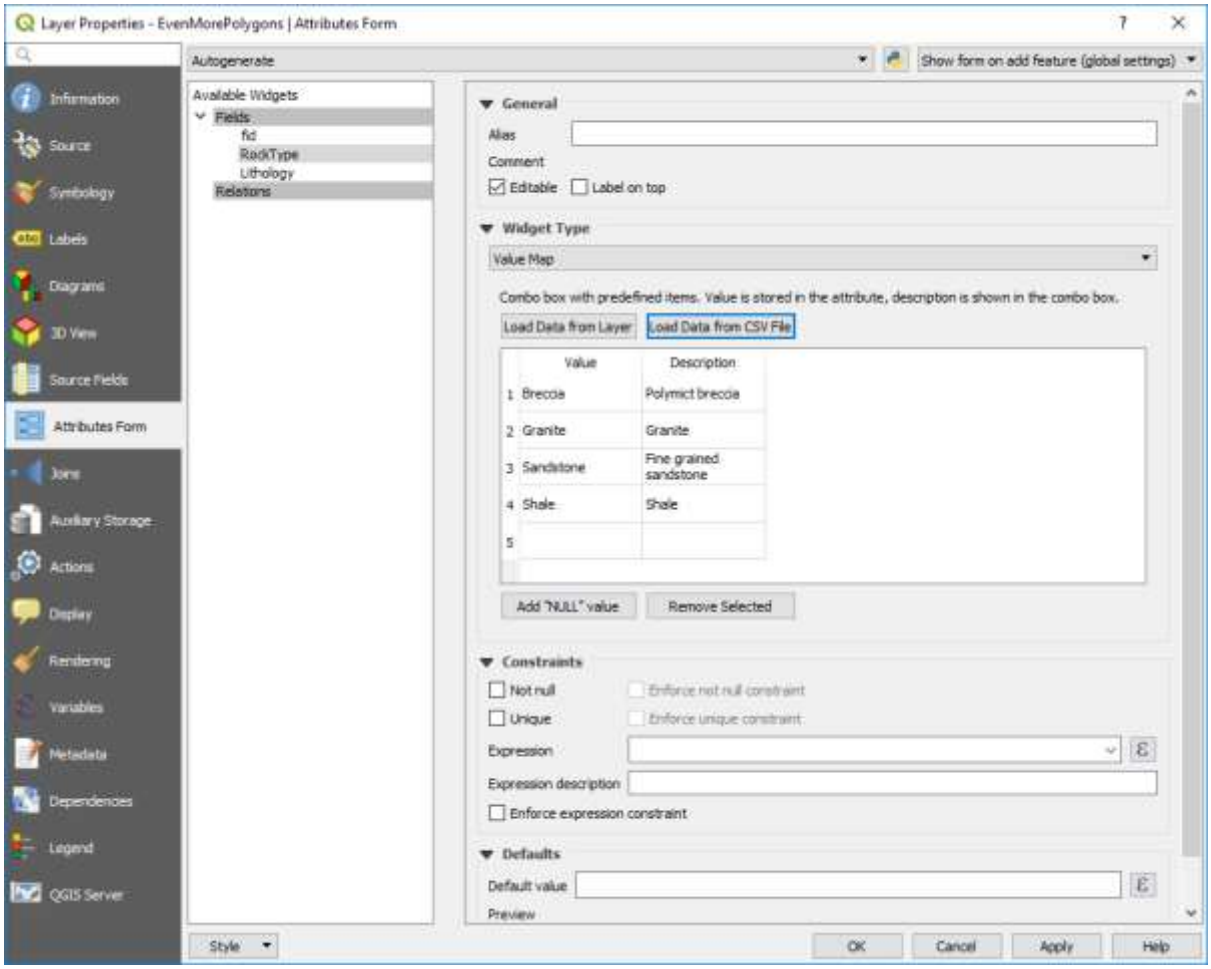
Creating Drop-Down Lists for Data Entry

A **drop-down list** can be created in QGIS to allow for the attribution of vector items. The use of a drop-down list prevents typographical errors in data entry and can be used to restrict non-standard item names. You can use data from an existing layer or use a csv file for the source of the drop-down box data.

The example below shows a csv file that has been used to apply attributes to the polygon layer.



In the Layer Properties, select he Attribute Form tab, and change the widget type to “Value Map”.

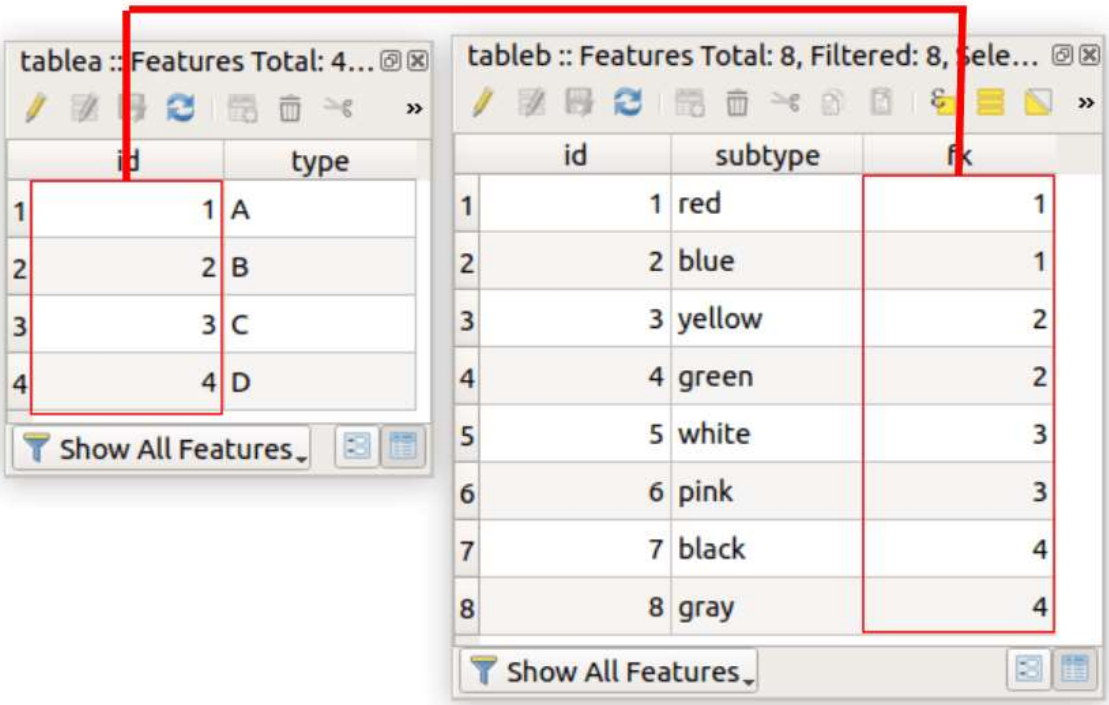


The Form Value Relation is used to apply multiple nested dropdown boxes for use in pre-set data entry options. This is useful for entering specific rock types, geological codes or formation names.

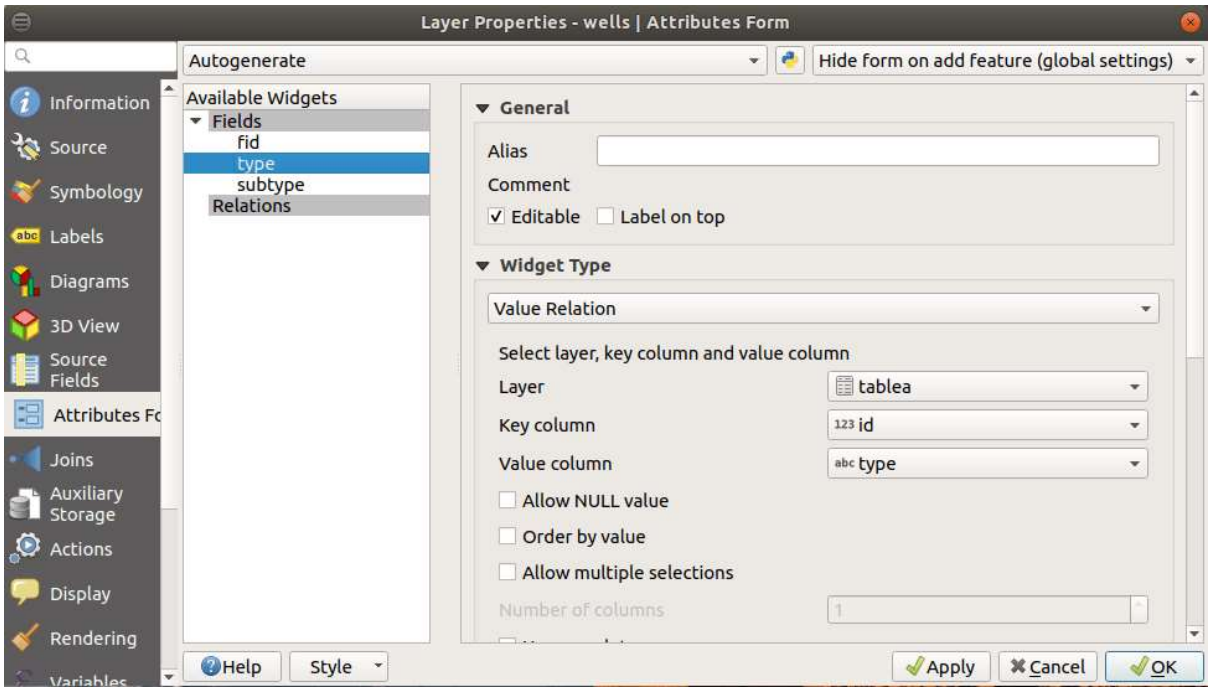
The following is from North Road Consulting who ran a crowd funding campaign to get this into the core component of QGIS.

What happens is you have pick lists that can change based on other values. Have a pipe? It can be made out of W, X, Y, and Z. Is it a Water Pipe? It can only be made of X and Z. Wastewater Pipes can only be made of W and Y.

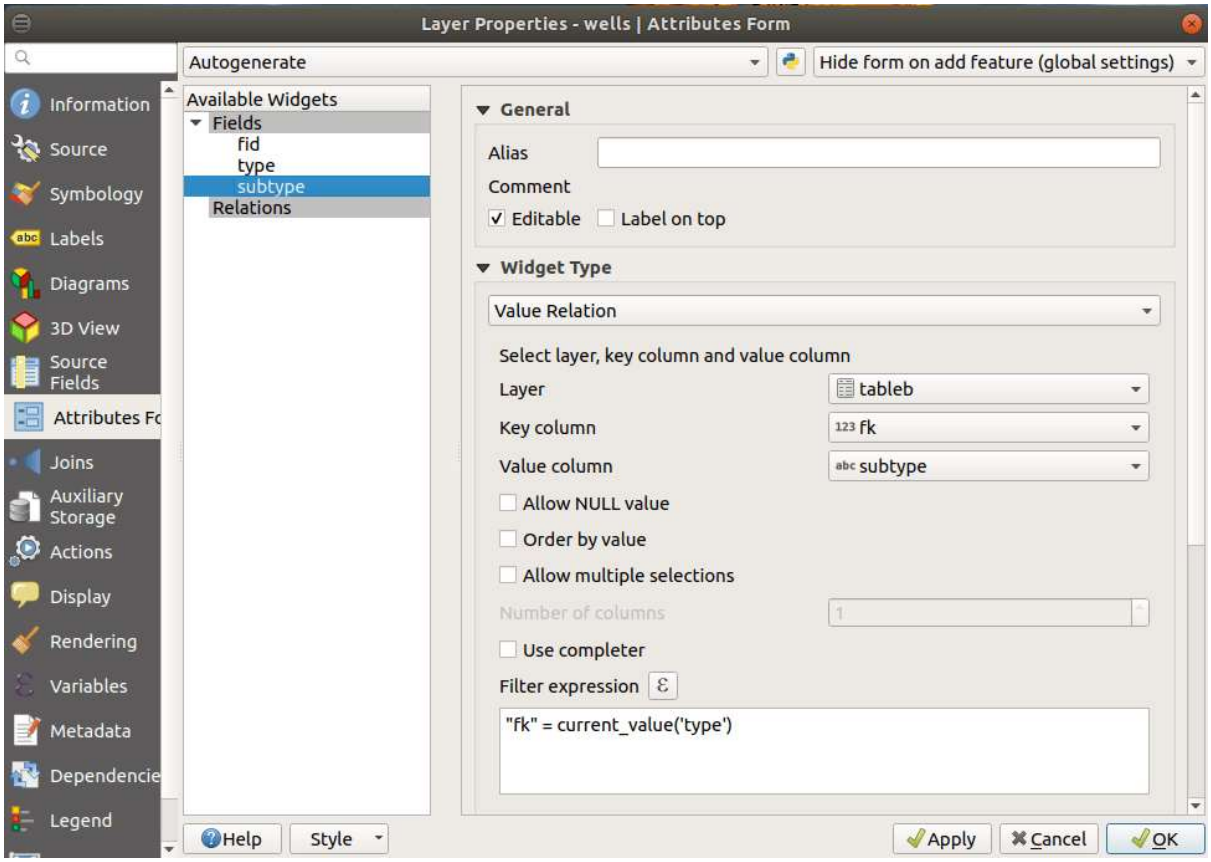
Here is my walk through. I have a point layer and that point layer has a type and a subtype. I stored this all in a Geopackage by the way. The type drives the subtype. You select A and you can only have red or blue. Maybe B is green and white. There are two tables to help with this process tableA is 2 fields: a primary key and a value. TableB has three fields: a primary key, a value, and a foreign key that relates back to Table A. From that you can see Type A can only have a value of Red and Blue. Type D can only be Black and Gray.



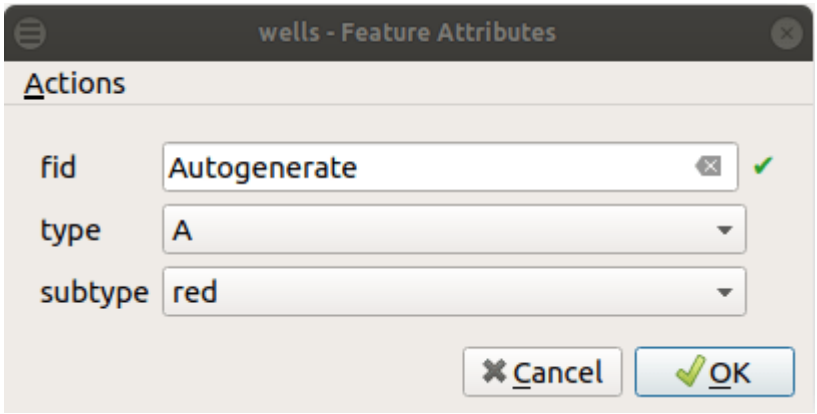
The point layer has two attributes of concern: type and subtype. Type will be A,B,C, or D. Subtype will be a range of colours that Match the Type picked. If you right click the layer and select attribute forms you can assign a form for data entry. In this case for type the key column is the primary key and the value is the type. Note the Widget type is Value Relation!



Lets looks at the subtype field. The key column is the Foreign Key (the part that relates it back to table A). The value column is the subtype. The magic is this – if you look at the filter expression: ***"fk" = current_value('type')*** *. See below.*



The foreign key equals the value of the type widget. When you add a point, you'll see the type drives the subtype.



In summary, if you select type A, you will only get an option to select colours red and blue.

Value Maps and Form Value Relations are useful tools for adding data. For geological data, you might have a list of rock classes (igneous, sedimentary, etc) and a list of lithologies (basalt, granite, sandstone, etc) for polygon data, or observation type (bedding, joint, vein, etc) for point data.

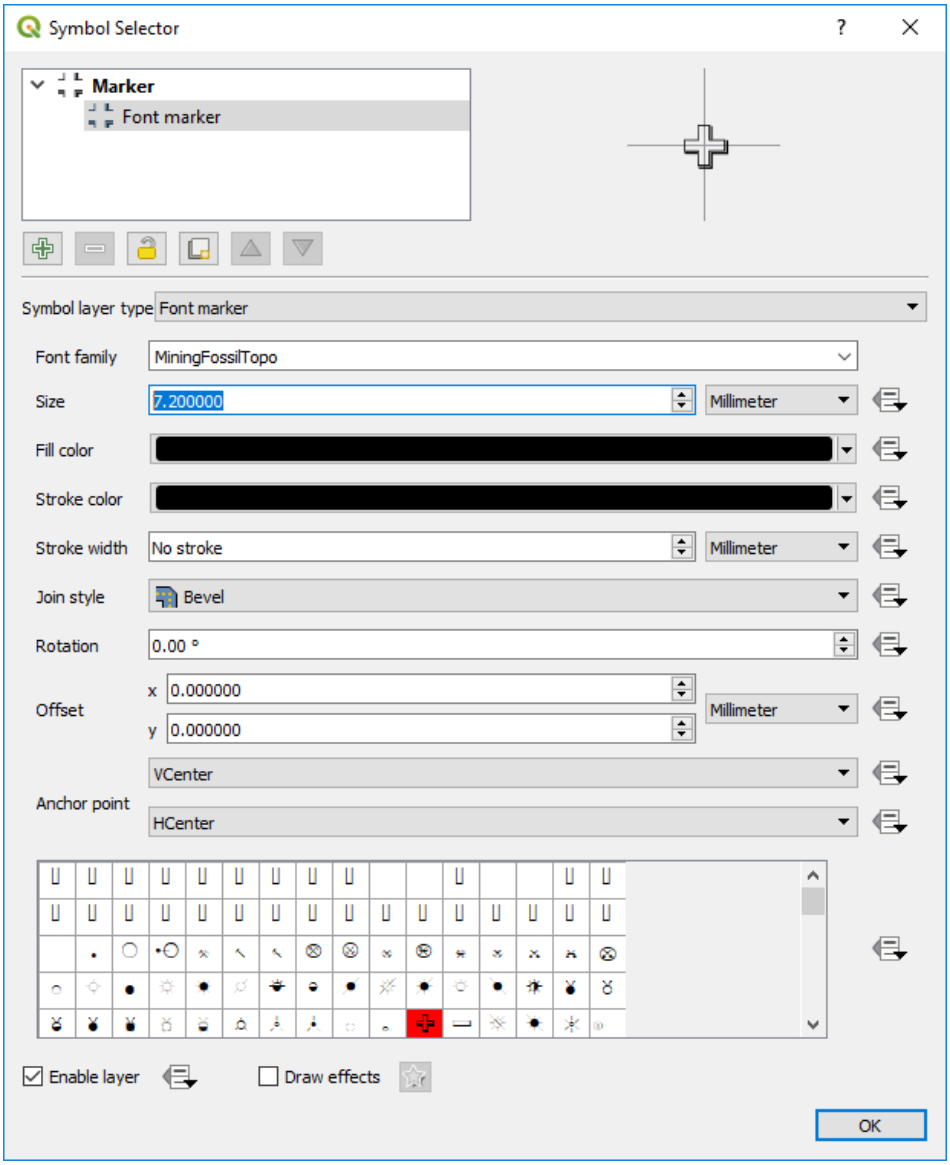
7.6 Geological Symbols and Geological Patterns

Geological symbols can be either specific geological fonts (True Type Fonts) or SVG (scalable vector graphic) symbols. Geological symbols can be downloaded from the internet for free use in QGIS (https://github.com/GISsimbology/symbols). On Windows systems, geological symbol fonts need to be installed by right-clicking on the font file name and selecting Install. Note that some fonts, particularly the ESRI fonts, are proprietary and not free use.

Geological Fonts

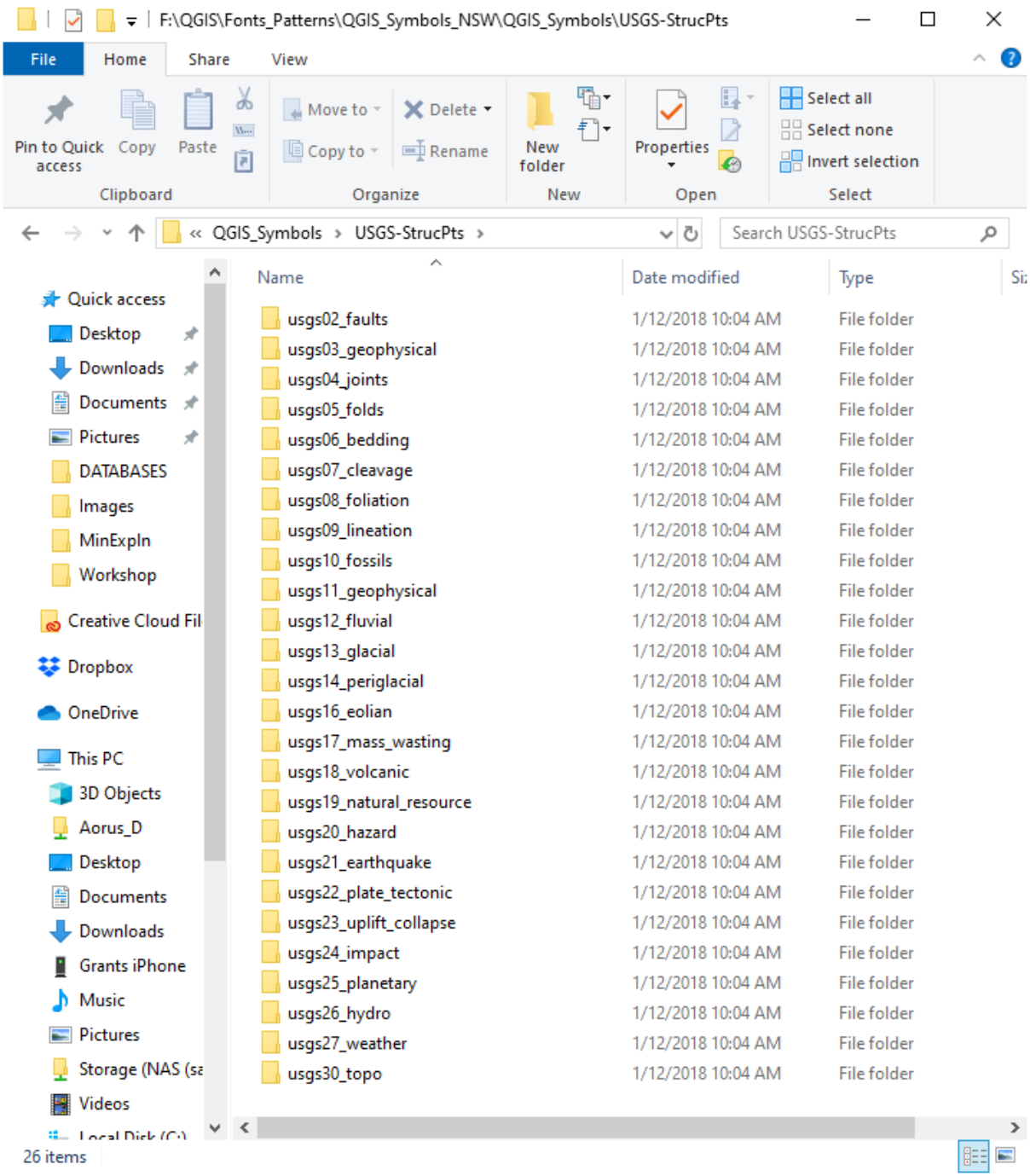
Four font sets are available from Geoscience Australia and include ESRI Geology AGSO 1 to 3 (esri_500.ttf, ESRIGA_0.ttf and ESRIGA_4.ttf), GeoscienceMining (GEOSM_.ttf) and MiningFossilTopo (MINIFT_.ttf). Other geological and cartographic fonts may also be available depending upon what other software you may have installed (previous MapInfo or ESRI fonts may already be installed on your system and could also be used). Fonts installed on Windows can be accessed via the Windows run box and typing “fonts”.

Geological font symbols are accessed via the Layer properties > Style tab and choose the symbol layer type as “font”. All the fonts installed on your computer will be accessible and you will need to search through the installed fonts to find the relevant font file and then the relevant font symbol. Adjust the font size to suit.



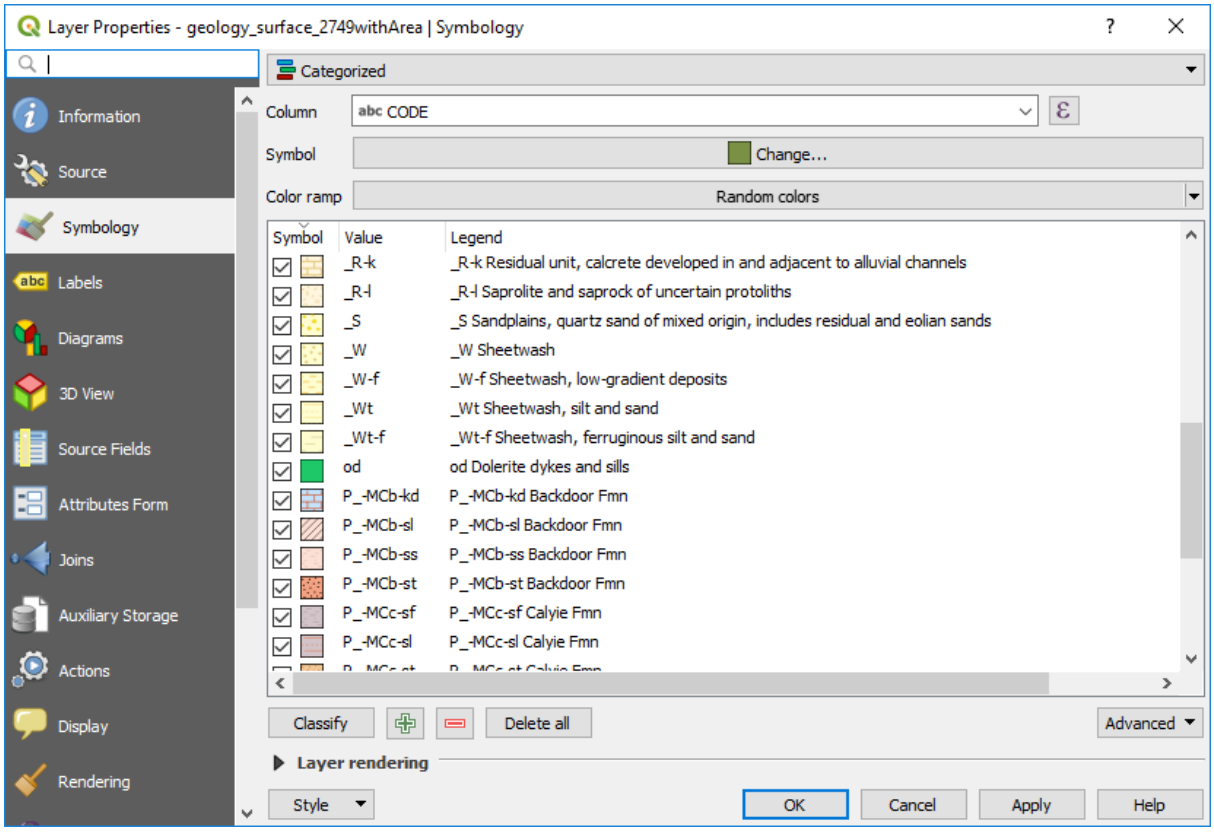
SVG Symbols and Patterns

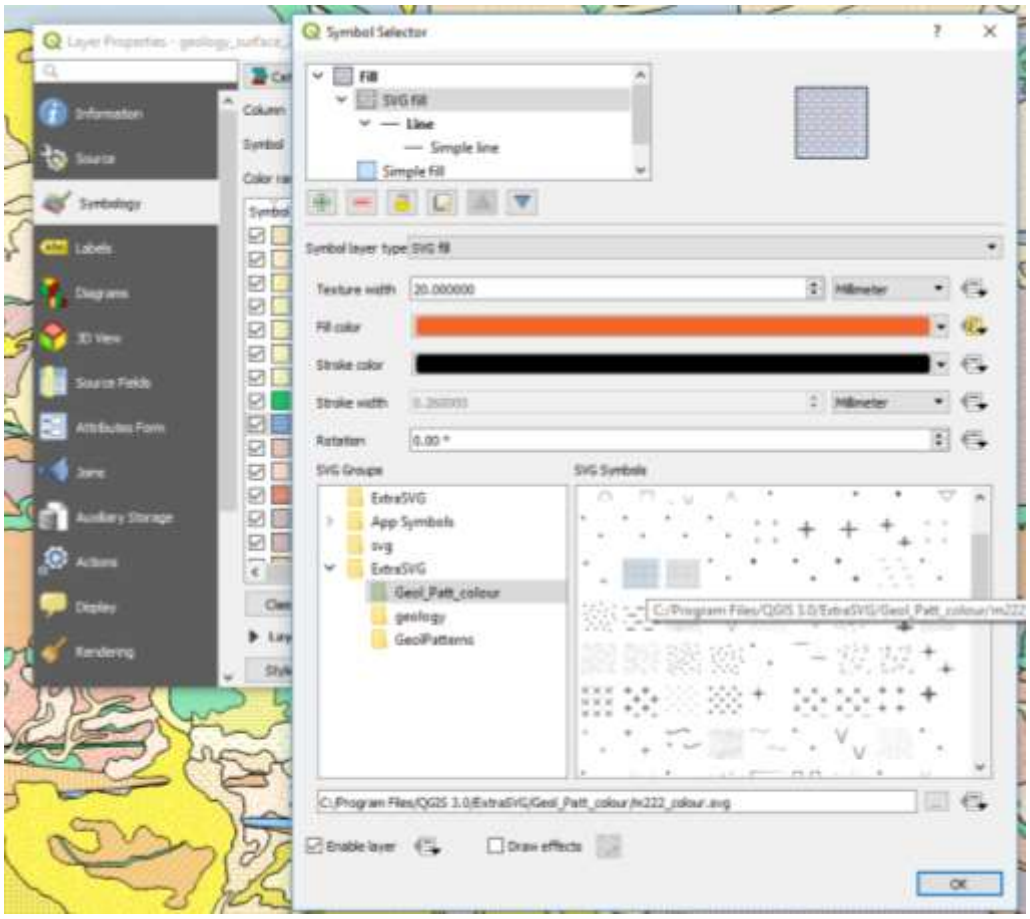
A selection of svg geological pattern files shown in the appendix were initially sourced from Stefan Revets' page (https://sourceforge.net/projects/qgisgeologysymbology/files/?source=navbar) and modified to allow the overprint pattern to be coloured. Also see this page https://github.com/afrigeri/geologic-symbols. An alternative location for geological svg patterns is https://github.com/BC-Consulting/FGDC-4-QGIS. The NSW geological survey also supply symbols for their state wide geological maps (https://search.geoscience.nsw.gov.au/product/9232) and are based on the USGS FGDC symbols and the symbols are supplied in folders based on the FDGC documentation.



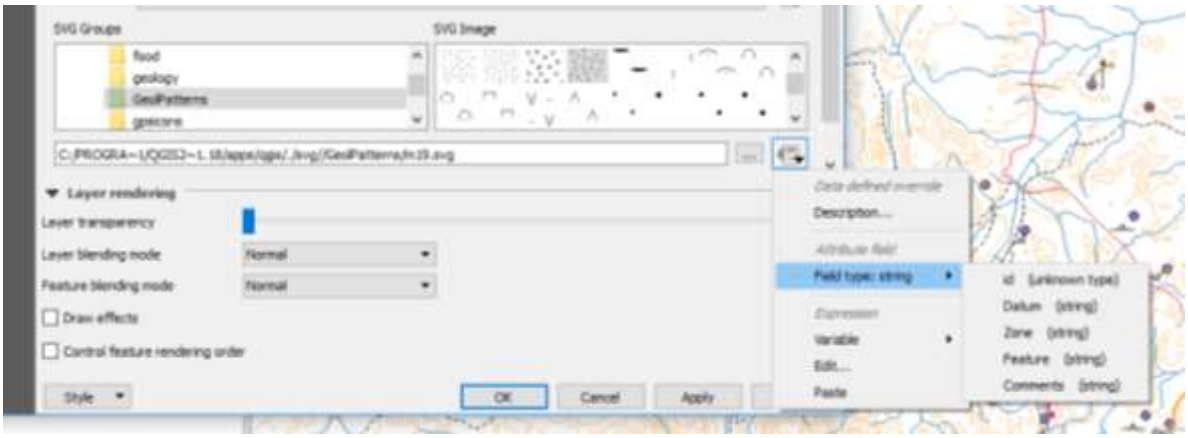
SVG files can be stored anywhere but the default location for the standalone install option is the Program folder, for example C:\Program Files\QGIS 3.12\apps\qgis\svg. Note that if you install QGIS via the OS4Geo option, the svg files will be located in the "C:\OSGeo4W64\apps\qgis\svg" for the long-term release version, or the "C:\OSGeo4W64\apps\qgis-dev\svg" folder for the development version. It is recommended that this folder is used for the additional geological symbol and patterns so QGIS will find these by default and you will not require to specify and additional svg directory location. If you upgrade your version of QGIS, you may need to copy your extra svg files back into this folder.

To use the geological patterns, for example, you would categorise the layer based on a geological code and then allocate each code a specific pattern fill and background polygon layer. The image below shows the result of "Categorising" the geology and colouring each geological code type.

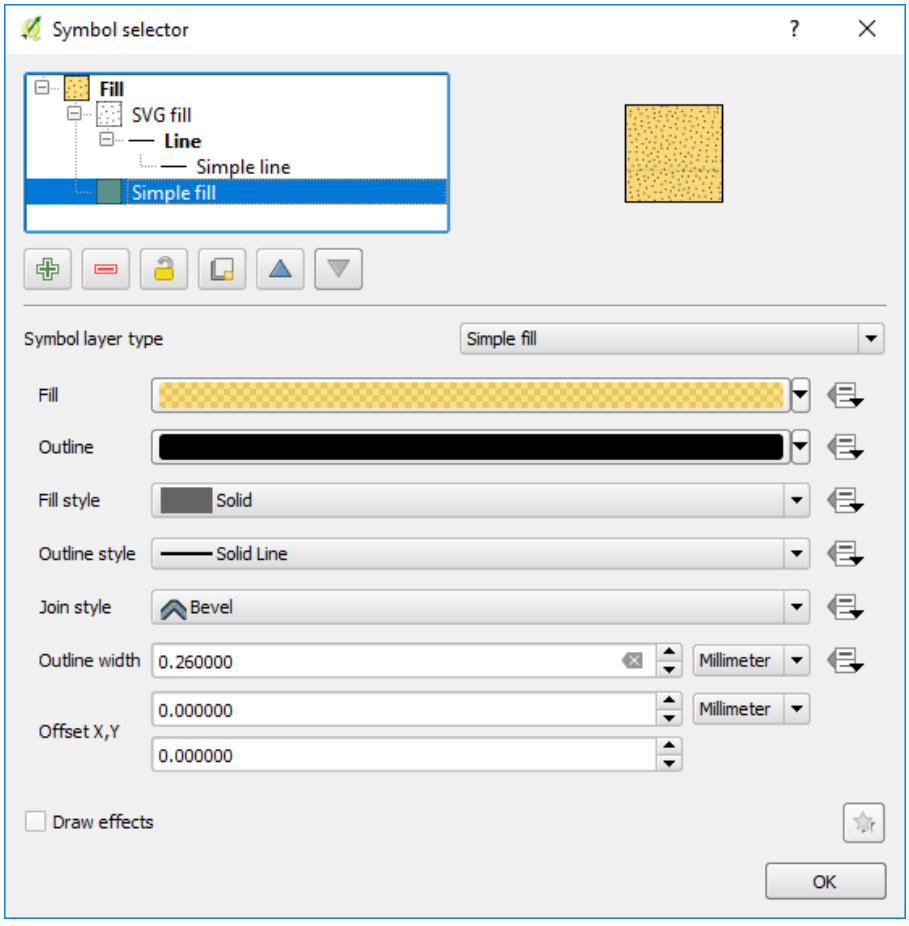

Layer Properties - geology_surface_2749withArea | Symbology
Information
Source
Symbology
Labels
Diagrams
3D View
Source Fields
Attributes Form
Joins
Auxiliary Storage
Actions
Display
Rendering
Categorized
Column
abc CODE
Symbol
Change...
Color ramp
Random colors
Symbol
Value
Legend
_R-k
_R-k Residual unit, calcrete developed in and adjacent to alluvial channels
_R-l
_R-l Saprolite and saprock of uncertain protoliths
_S
_S Sandplains, quartz sand of mixed origin, includes residual and eolian sands
_W
_W Sheetwash
_W-f
_W-f Sheetwash, low-gradient deposits
_Wt
_Wt Sheetwash, silt and sand
_Wt-f
_Wt-f Sheetwash, ferruginous silt and sand
od
od Dolerite dykes and sills
P_-MCb-kd
P_-MCb-kd Backdoor Fmn
P_-MCb-sl
P_-MCb-sl Backdoor Fmn
P_-MCb-ss
P_-MCb-ss Backdoor Fmn
P_-MCb-st
P_-MCb-st Backdoor Fmn
P_-MCc-sf
P_-MCc-sf Calyie Fmn
P_-MCc-sl
P_-MCc-sl Calyie Fmn
Classify
Delete all
Advanced
Layer rendering
Style
OK
Cancel
Apply
Help


Symbol Selector
Fill
SVG fill
Line
Simple line
Simple fill
Symbol layer type
Texture width
Fill color
Stroke color
Stroke width
Rotation
SVG Groups
SVG Symbols
ExtraSVG
App Symbols
svg
ExtraSVG
Geol_Patt_colour
geology
GeolPatterns
Enable layer
Draw effects
OK

Note that you have options for size and rotation of the patterns or symbols. The SVG symbols and patterns have discrete file names which can be used to automatically assign symbols and patterns in the “Data Driven Override” of the layer properties file window.

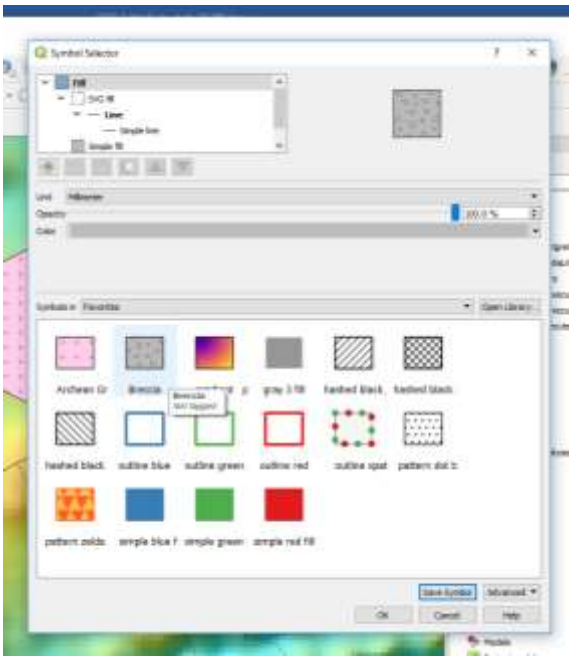


Coloured backgrounds can be added to the polygon fill by adding another layer in the Symbol Selector dialog box. Add a new symbol layer by using the green plus symbol and move it to the bottom using the down arrow key below the display box.

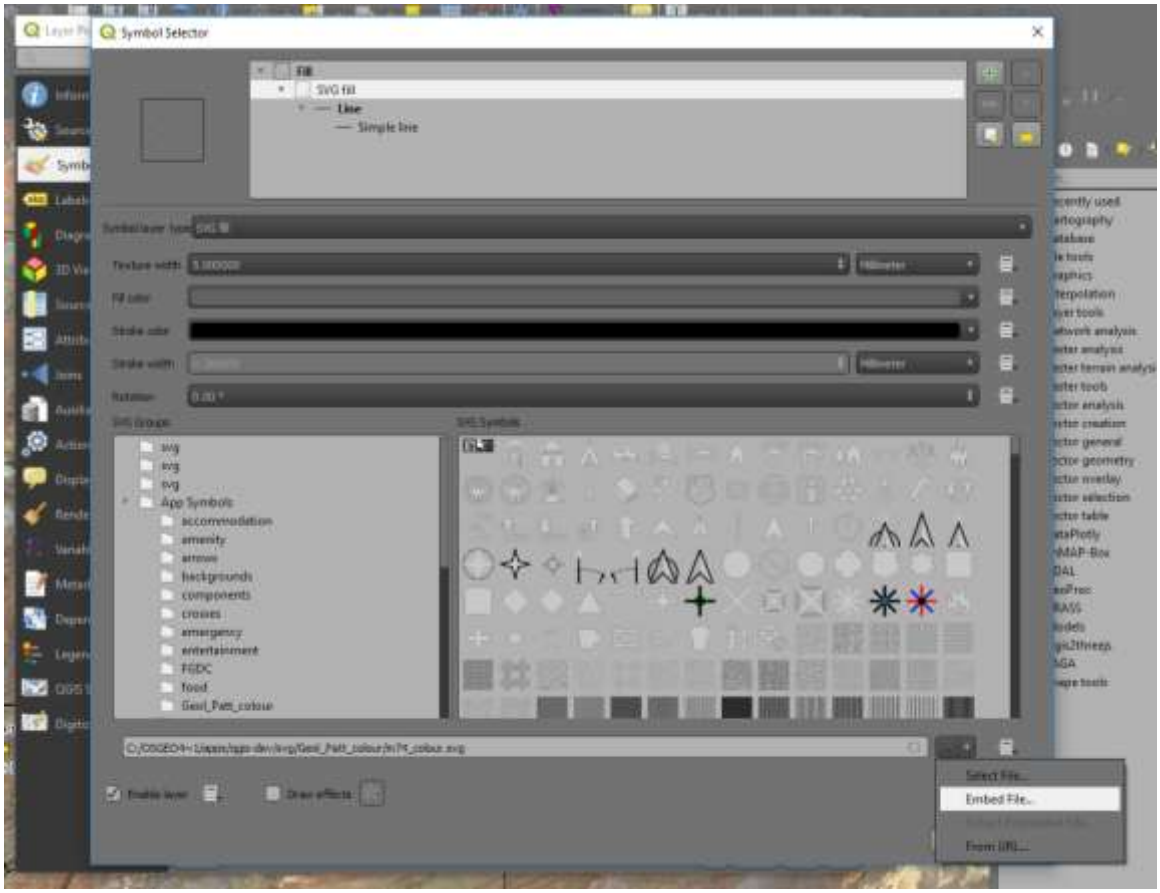


For assistance in selecting colours, go to the “Color Brewer” web site (http://colorbrewer2.org) where there is a vast array of colours and their specifications available. Colour specifications can be specified in QGIS via their hex, RGB or CYMK number.

If you have favourite fill styles, these can be saved as “Favourites” which are then quickly accessible via the Symbol Selector dialog box.



The svg fills can also be “embedded” into the file via the “Advanced” options and this allows the files to be used by other users that may not have the relevant svg files installed on their machines.

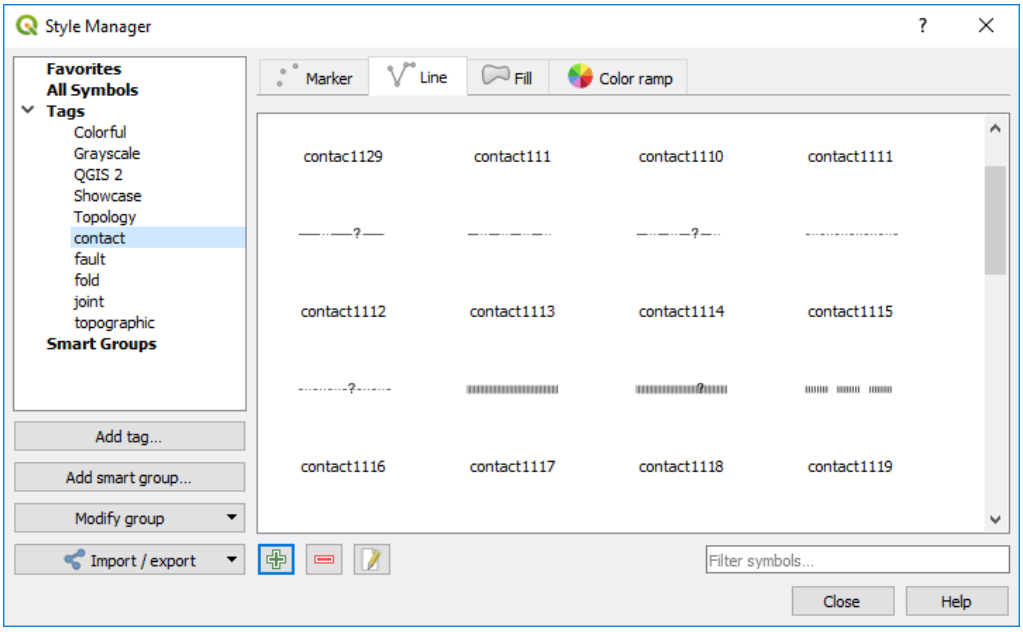


7.7 Geological Line Styles

Linear geological features can be displayed by manually editing the line style in the Layer Properties > Style tab, or by using line styles set up in the top menu Settings > Style Manager window. Full details of how to construct various line styles can be found in a comprehensive document put out by the USGS and can be found here https://ngmdb.usgs.gov/fgdc_gds/geolsymstd/fgdc-geolsym-all.pdf.

Style (*.xml) and symbol (svg) files can be found here at Stefan Revett's site https://sourceforge.net/projects/qgisgeologysymbology/files/ and in the NSW QGIS Symbols in the "\QGIS_Symbols\FDGC_GeologySymbology\svg" folder. Line styles include geological contacts, faults, folds, and joints and are based on the FDGC symbology.

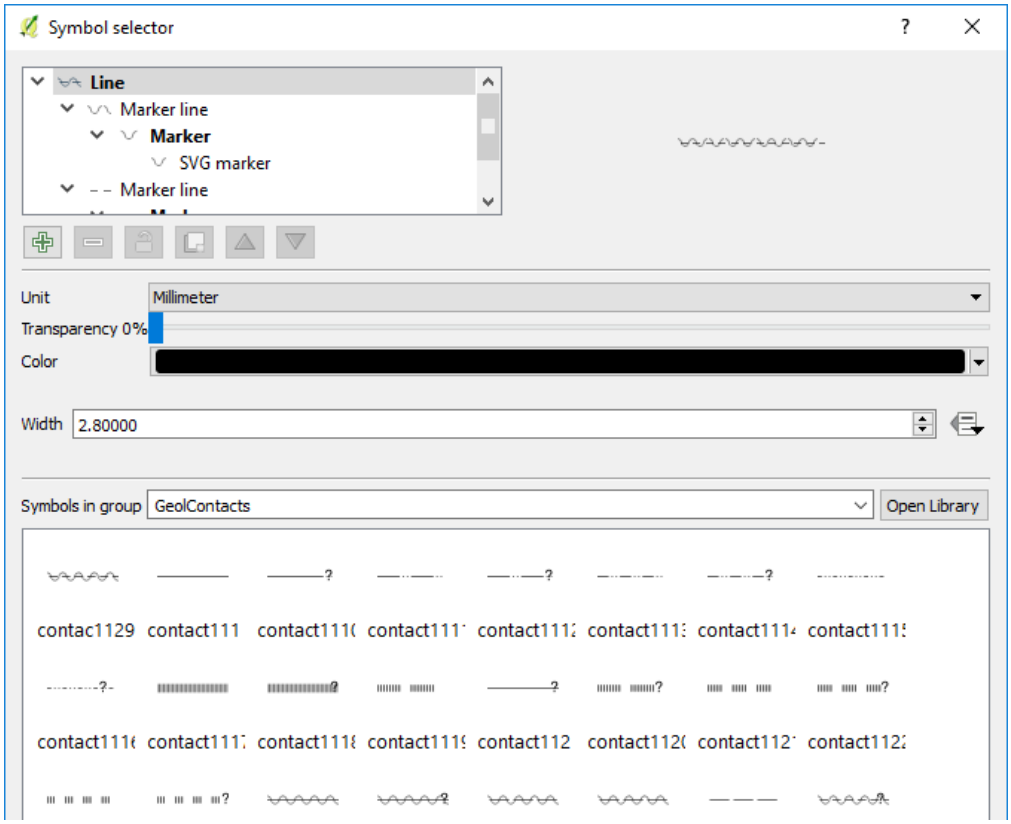
On the main menu, go to Settings > Style Manager and select the Import option in the small box down on the lower left-hand side of the dialog box (looks like two blue lines with dots). Save each group with a name ("tag") so that you can easily identify which line style group you want to display.



Navigate to where your line styles are stored. Import each one (e.g. contact, fold, fault and joint). Remember to add a “tag” so they can be easily selected in the Style Manager.

In the Symbol Selector dialog, select the “Symbols in group” drop-down box, select GeolContacts (or whatever you called this line style group). Select the line style you want and hit OK. This method can be used to modify all the other line styles. To save these line styles remember to save the Style as default in the main Style tab window (under Style > Save as Default).

If you have multiple line styles, make sure you have a column in your table to allow the line types to be “Categorised” so that specific line types can be allocated to different line types.



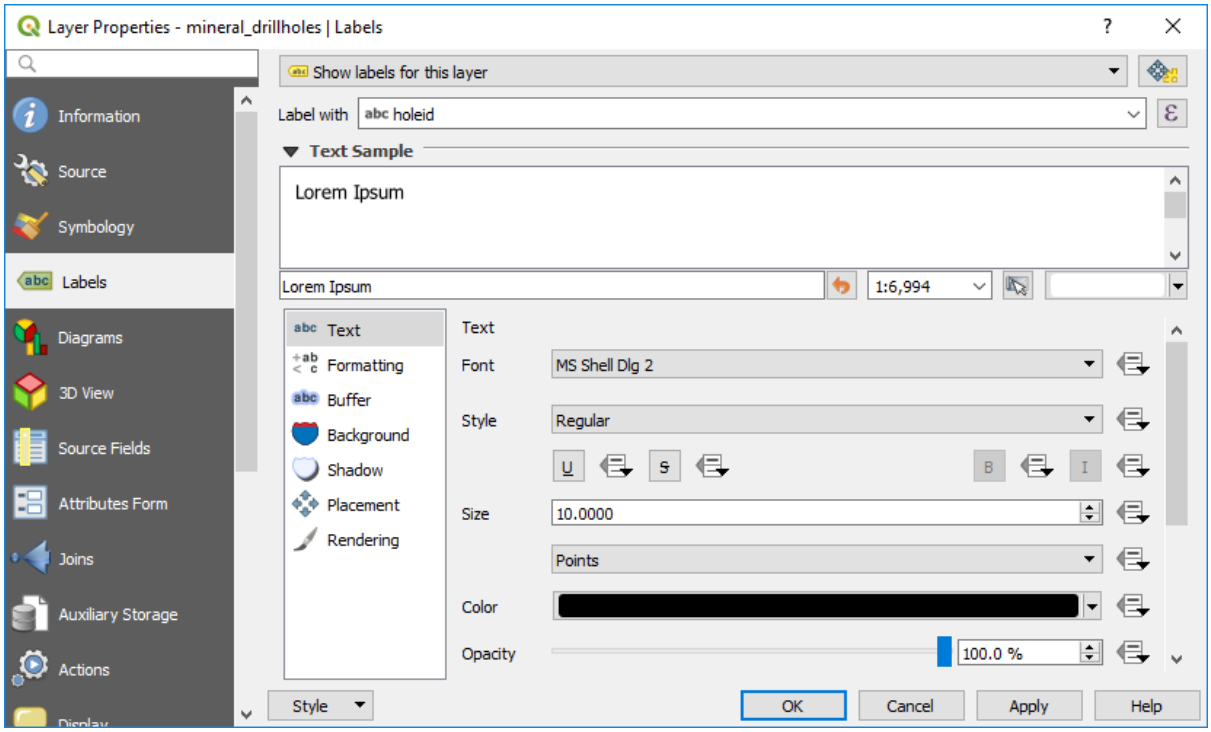
Any of these line styles can be edited manually by selecting the layer in the top window. Note that you change the line direction, e.g. fault ticks on other side, by using the “Reverse Line Direction” in the “Advanced Digitising Toolbar”.

7.8 Labelling Features

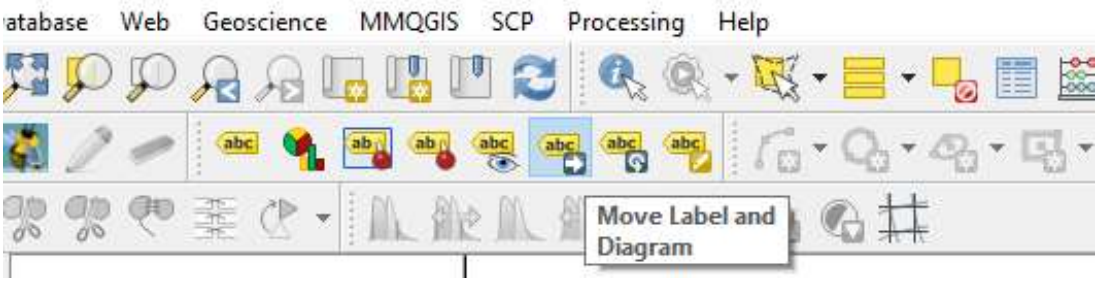
Features can be labelled via the Labels tab in the Layer Properties window for each layer. There are many ways to place labels and format them. I will give some examples typically used in geological applications below but there are many other options which you are encouraged to explore (see QGIS User Guide – section 12.3.3 and Graser and Peterson 2016 – Part 2). Note that you can have the labelling panel open and docked by pressing F7, and when you make changes to the labels these are immediately displayed in the map widow. This method removes the requirement to click OK/apply to see changes.

Labelling points

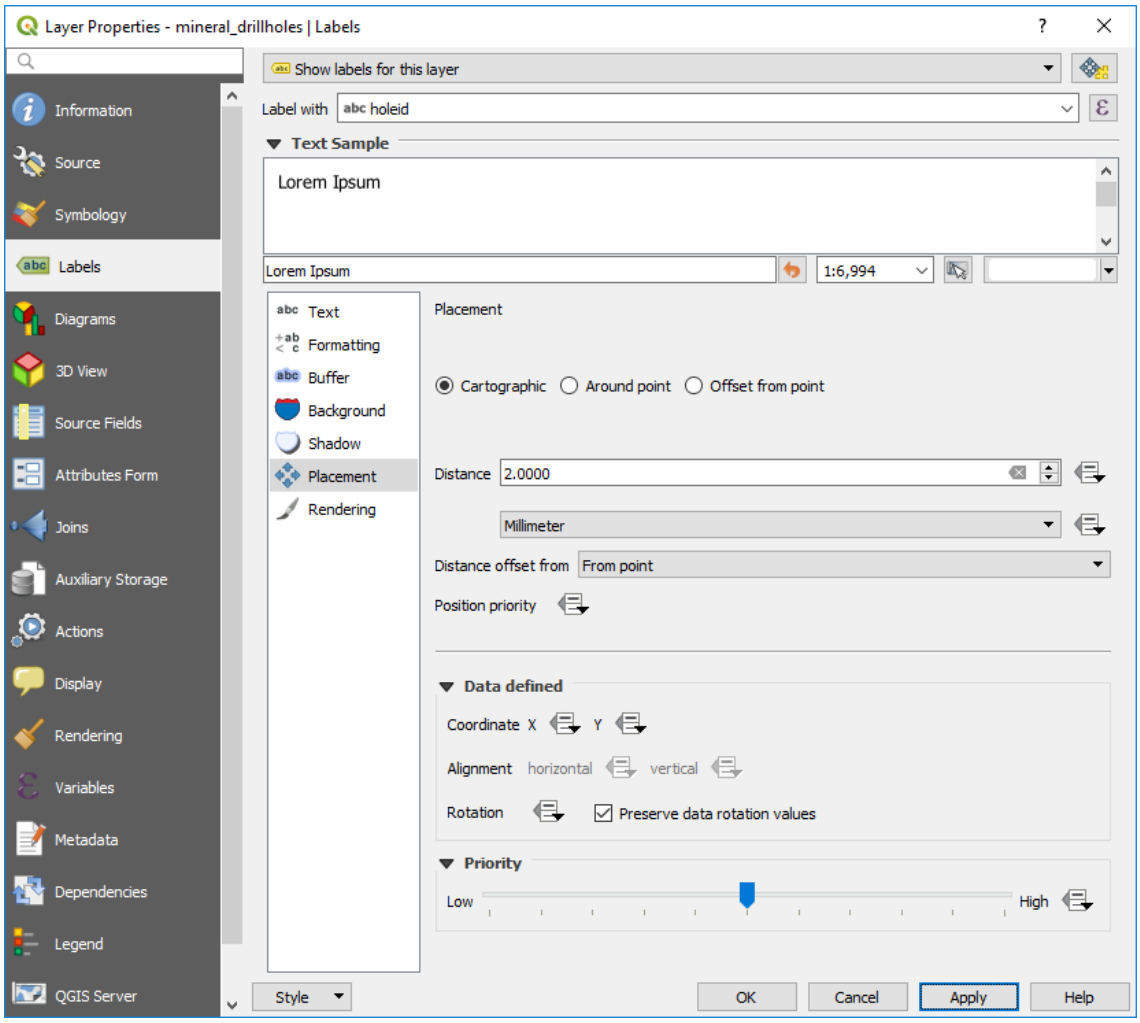
The Labels tab shows a variety of labelling options such as font type and size, whether you want a halo around the label (buffer) which is useful when the labels are over a coloured background. The Formatting section allows you to specify multi-line labels and word wrap options. The Placement options allow you to test different ways to display your labels.



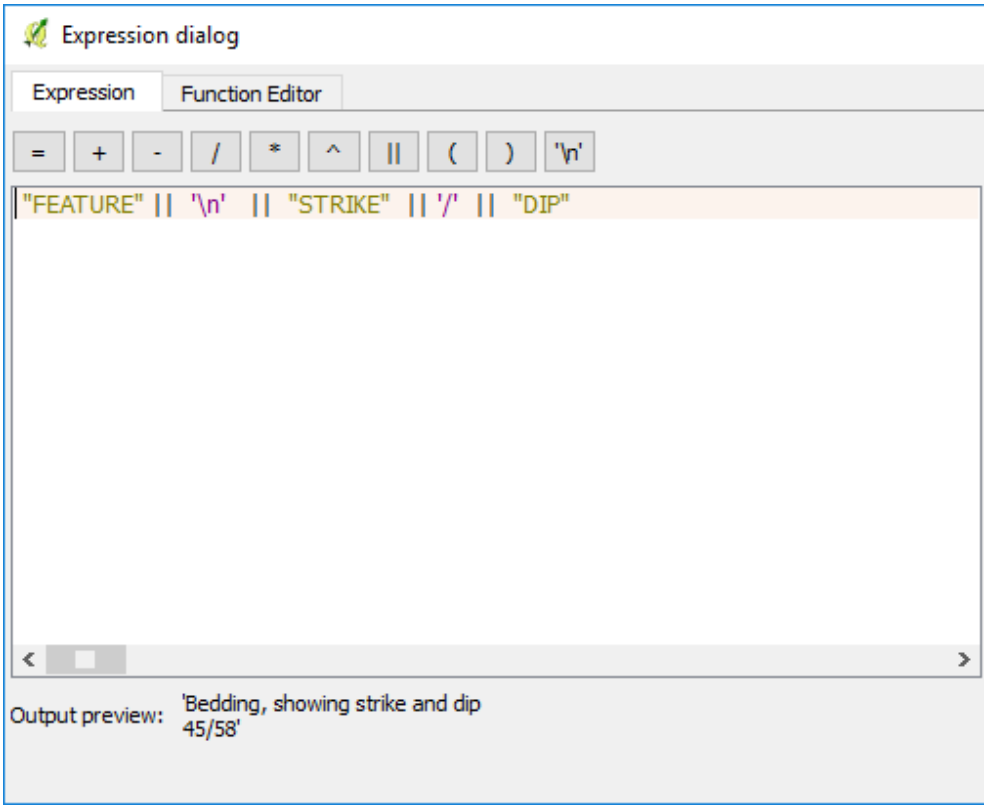
Note that to manually move individual labels, use the “Move Label or Diagram” option in the labelling toolbar.

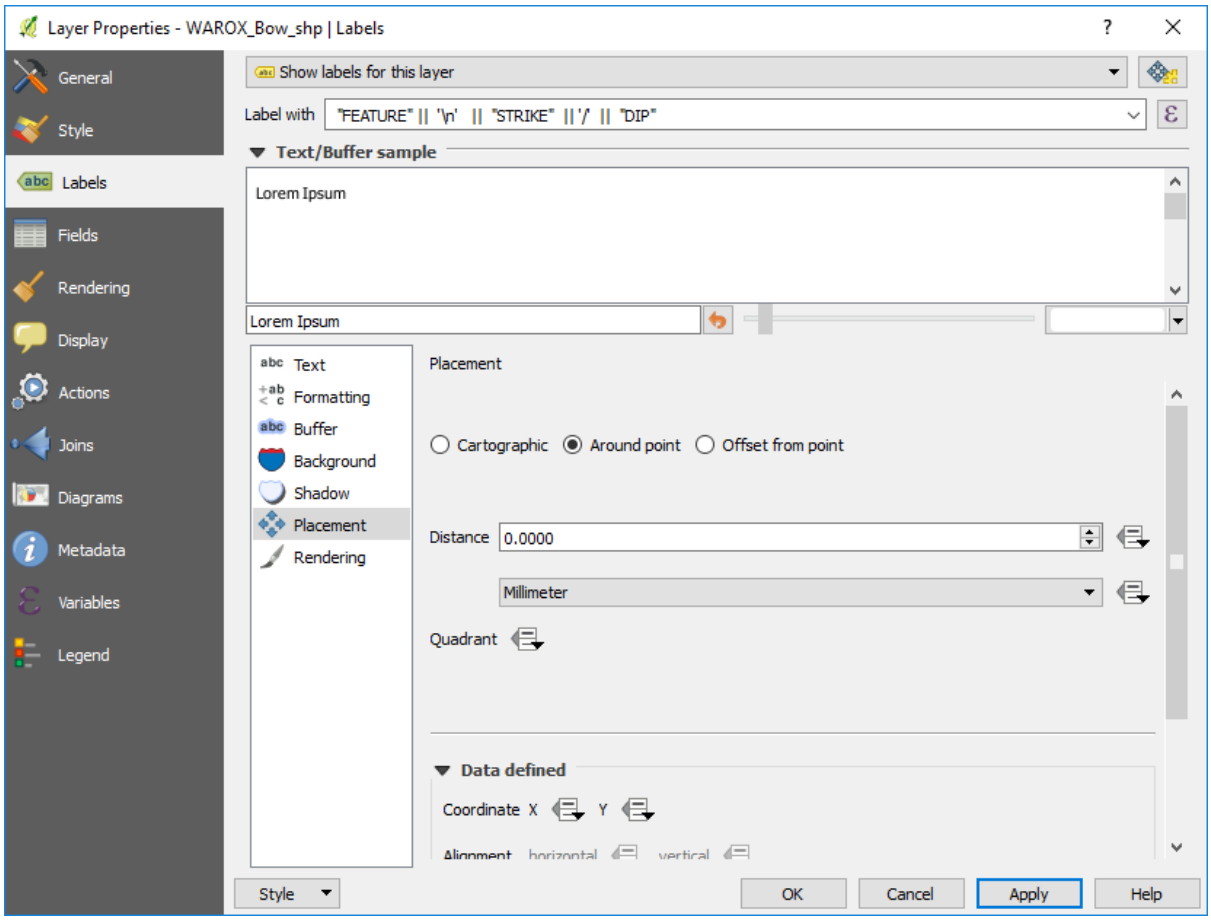


There are three placement options and it is suggested to test these options for each application. The “Cartographic” option (points only) will move labels to suit the display. If you need a “halo” around the labels, use the Buffer option. To rotate all the text labels, use the Labels > Placement > Offset from point > Rotation option. This option is useful for labelling drill holes along grid lines.

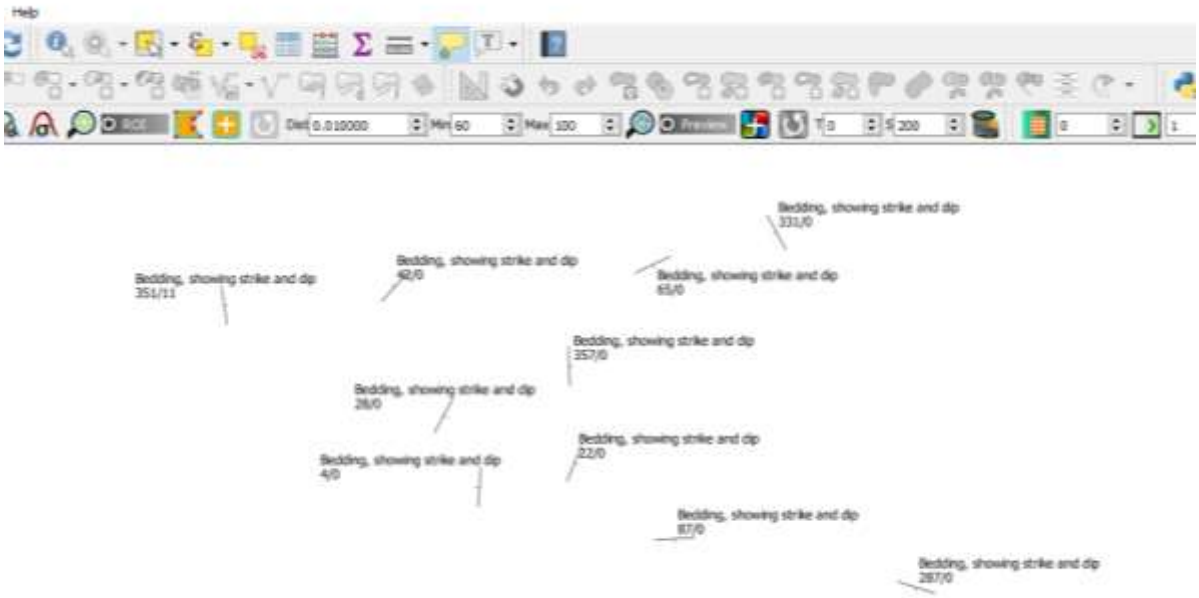


Multi-attribute labels can be created using the expression editor. Note the “Output Preview” in the lower left of the dialog box which shows how the labelling will appear.

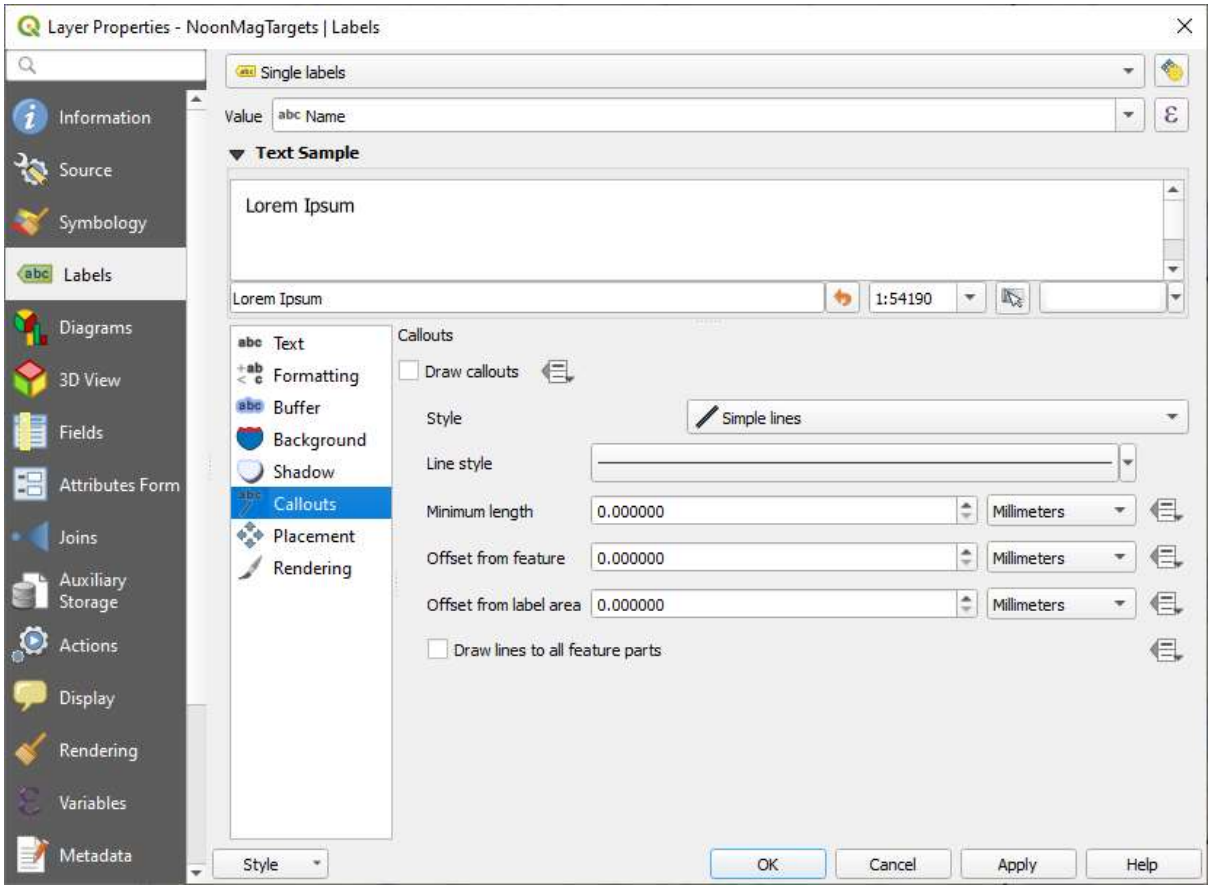

Expression dialog
Expression
Function Editor
= + - / * ^ || ( ) '\n'
"FEATURE" || '\n' || "STRIKE" || '/' || "DIP"
Output preview:
'Bedding, showing strike and dip
45/58'


Layer Properties - WAROX_Bow_shp | Labels
General
Style
Labels
Fields
Rendering
Display
Actions
Joins
Diagrams
Metadata
Variables
Legend
Show labels for this layer
Label with
"FEATURE" || '\n' || "STRIKE" || '/' || "DIP"
Text/Buffer sample
Lorem Ipsum
Lorem Ipsum
Text
Formatting
Buffer
Background
Shadow
Placement
Rendering
Placement
Cartographic
Around point
Offset from point
Distance
0.0000
Millimeter
Quadrant
Data defined
Coordinate X
Y
Style
OK
Cancel
Apply
Help

An example is shown below displaying the structure type with strike and dip.

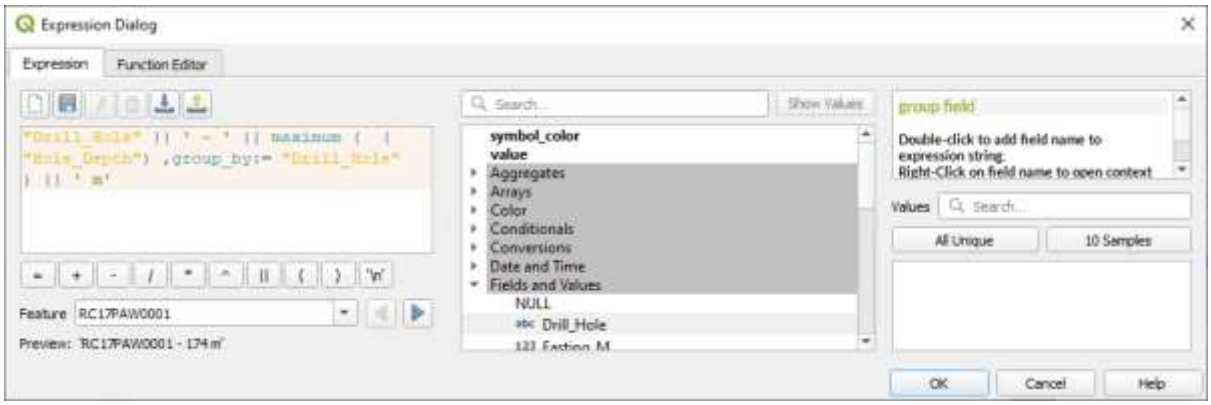


In the Layer Properties > Label there is an option to add “call-outs” where lines can be automatically created to join a point to a label.



Labelling drill holes with collar names and depths of holes can be achieved using the expression editor in the labelling tab. Note to check the Preview to ensure your syntax is correct.

"Drill_Hole" || ' - ' || maximum (("Hole_Depth") ,group_by:= "Drill_Hole") || ' m'

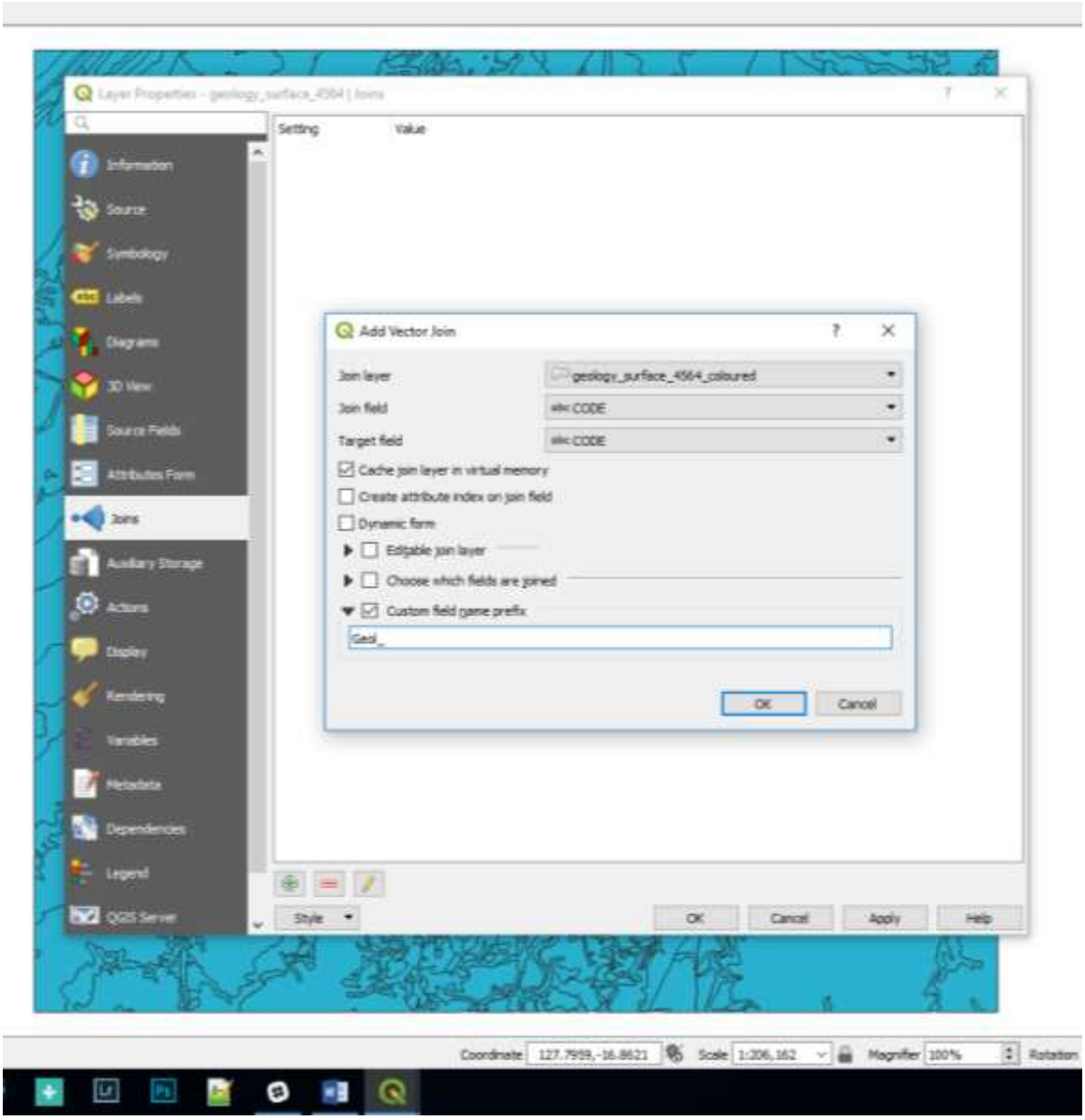


7.9 Joining Spatial and Non-Spatial Data

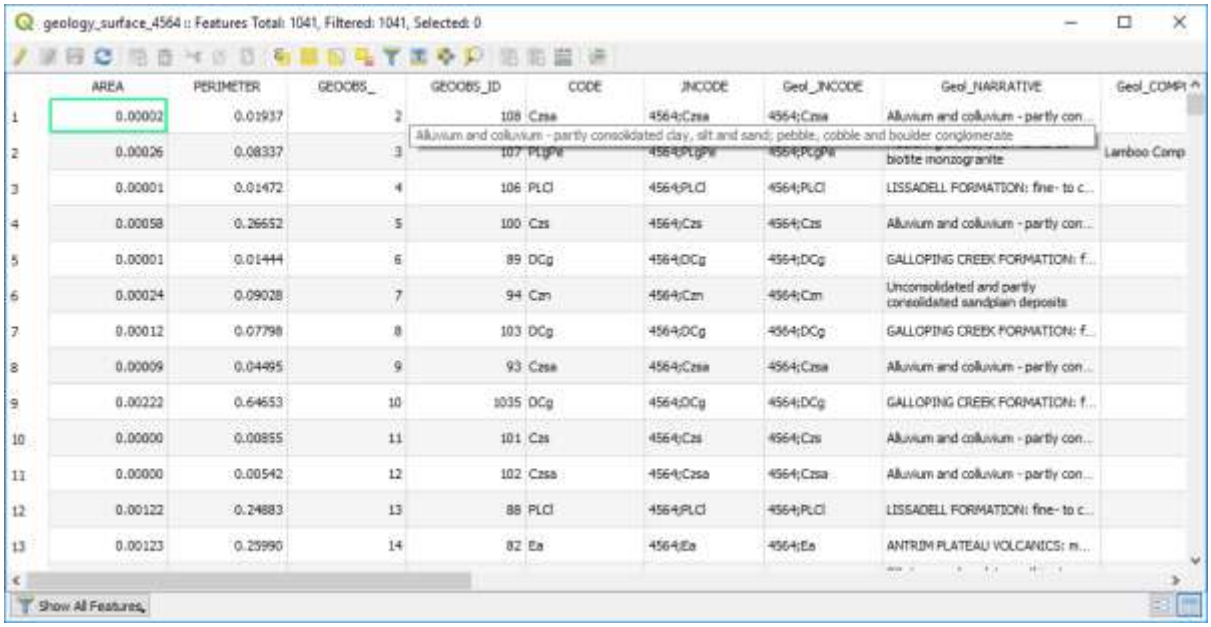
Joins are done via the Layer Properties dialog box. Open both the spatial file (i.e. the layer that is spatially located) and the non-spatial file (without spatial reference). The non-spatial file can be opened by the spreadsheet or text file import and with “No geometry” selected. The non-spatial layer will appear as a spreadsheet icon in the Layer properties panel. Select the spatial layer in the Layers panel you wish to join, open its Layer Properties > Join tab, press the green plus to add a new join, select the join fields (which must have data in common in both layers to allow it to join).

The example below (Bow 100k map sheet) shows the join of the geological polygons with the geological descriptions (from an Excel file) for each of the geological codes for the polygons.

Individual fields can be selected for the join using the “Choose which fields are joined”. Select the “Custom field name prefix” and change it to a short abbreviation, remembering that shape files can only have a maximum field name size of 10 characters and this may cause problems later as field names may have been truncated.



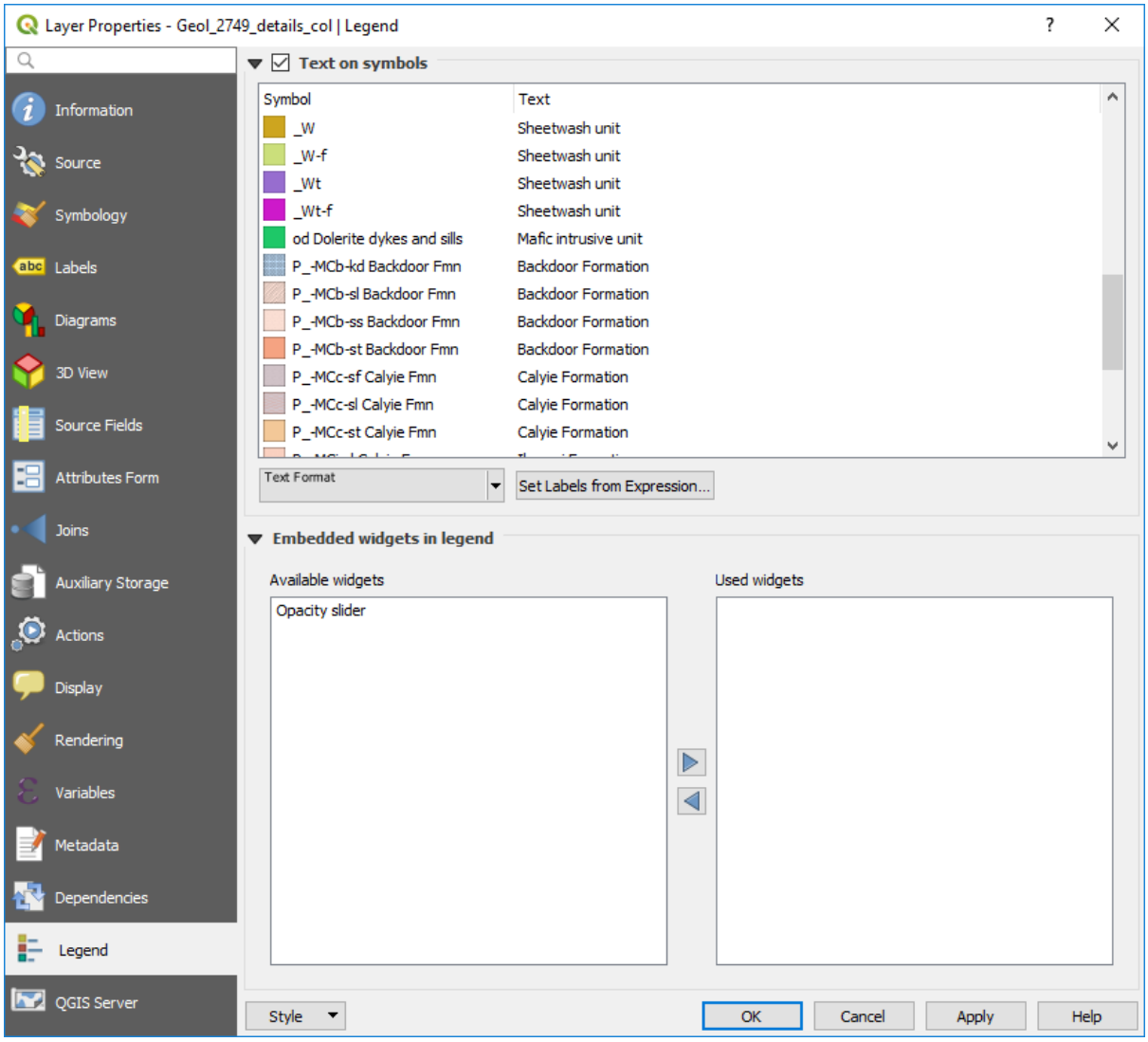
After clicking “Apply”, examine the join results by opening the layer attribute table and ensuring the join has been successful.



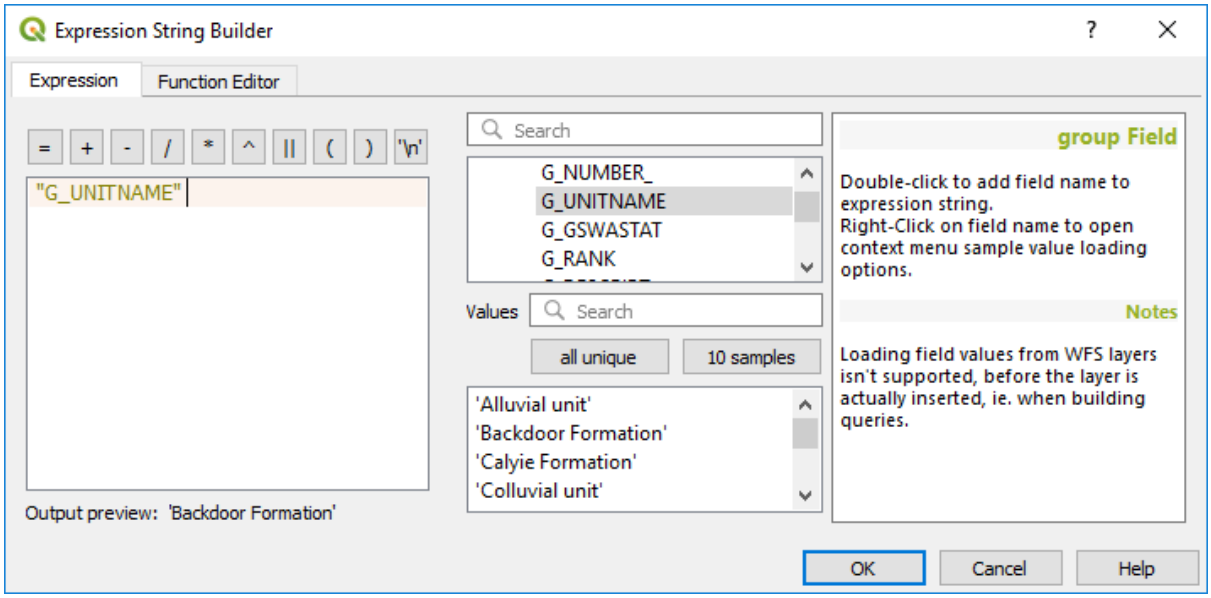
To make this a permanent join, use the “Save As” option by right-clicking on the layer name in the layers panel, and saving the file as a new shapefile layer. If you do not save this joined file, the join will not be permanent, as it is a virtual join only. You may also need to copy the polygon styles from the original shape file to the new spatial file. To do this, right click on the layer name, go to Styles > copy styles > all style categories, then right click on the layer where you want to appy these styles, and paste > paste styles > all style categories. Remember to use the layer properties > Style tab and “save as default” to create a qml file that will automatically apply these styles when the file is re-opened.

7.10 Geological Legends

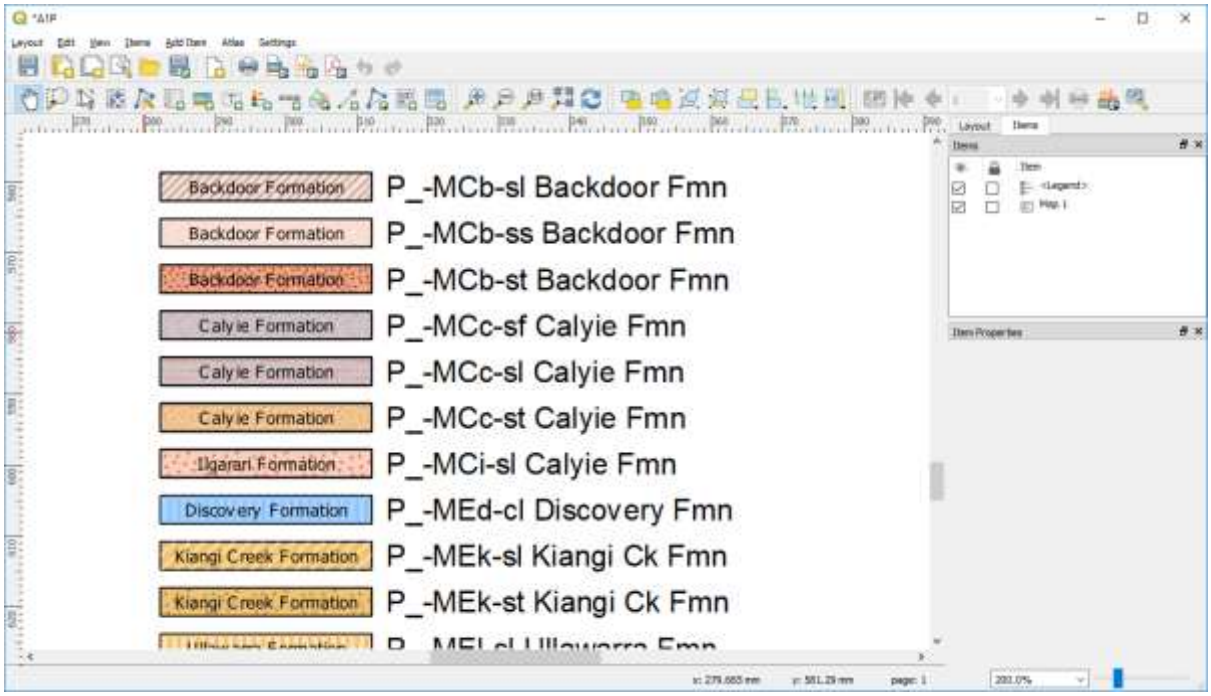
Geological legends in QGIS can be created but the program really needs a plugin to create a geology specific style of legend. Geologists use QGIS very differently to the majority of QGIS users and this would need to be pushed by the geoscience user community. Detailed geological information, e.g. formation names, can be imported into the legend using the Legend tab in the Layer Properties > Legend tab. Note that you may have to join the geological information to the geological polygons, as in the case of GSWA geological data, before you create a more detailed legend.



In the window above, the label text has been selected using the “Set Labels from Expression” which then opens the expression builder window (below).



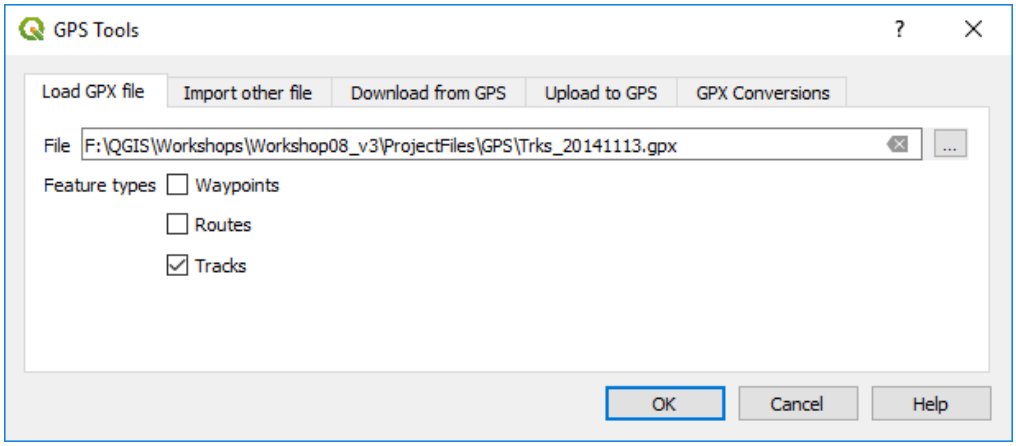
The legend will be displayed in the print layout window as shown below.



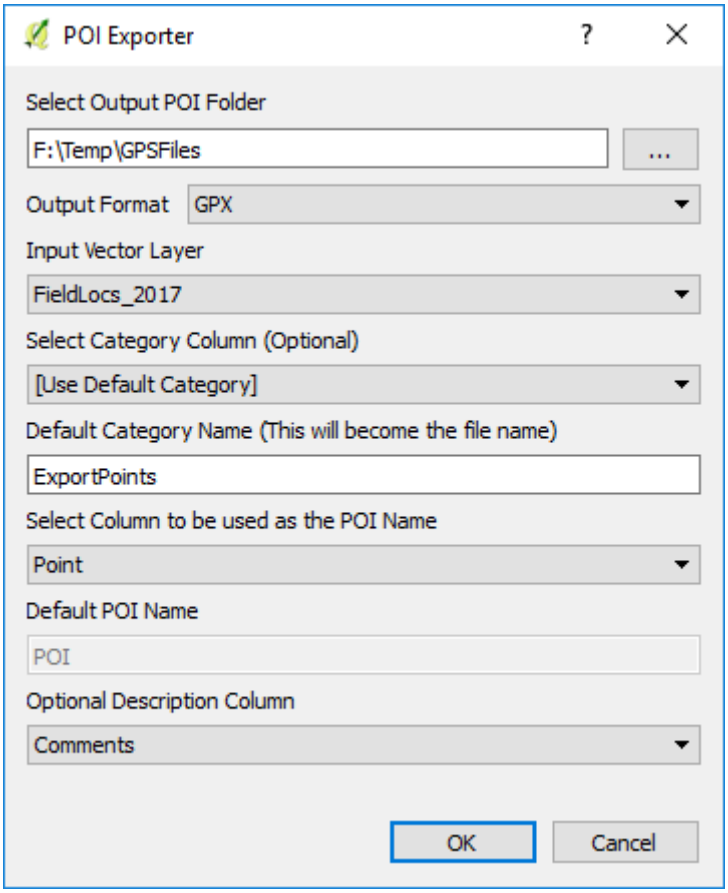
Work is in progress to automatically assign geological patterns and descriptions from the GSWA polygon colouring information and pattern fills with the vector data for their digital maps.

7.11 Importing and Exporting GPS Data

To import points and tracks from a gpx file collected using a GPS unit, use the menu item Vector > GPS > GPS Tools, select the gpx file to upload and the data type (tracks or waypoints). After you have imported the point or track file to QGIS, save it as a shape file to enable editing of this data. If this option is not available in your Vector tools, turn it on in the Plugin Manager.

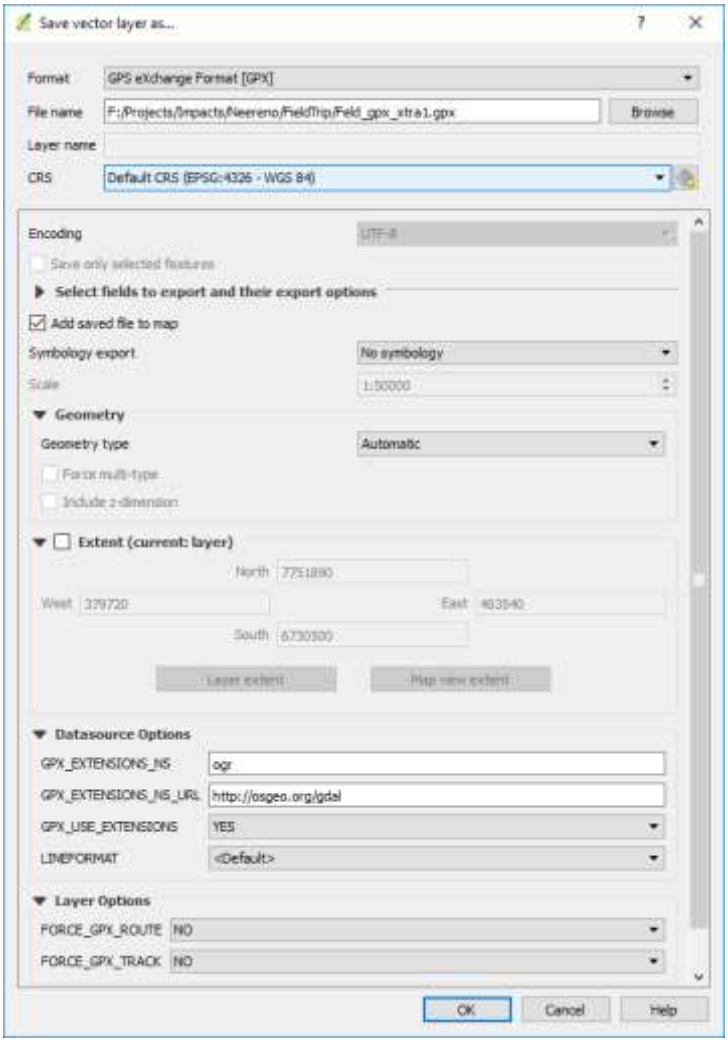


To send data to your GPS device, use the POI ("point of interest") plug-in. The plug-in allows you to select the layer you want to upload, the column containing the point names (or ids) and an optional comments column (up to 254 characters). The plug-in creates a gpx file which can then be easily uploaded to your gps via a direct file transfer or GPSBabel (for older models). The projection of the layer does not need to be in WGS84. Select the folder where you want the file to go, select the layer to export as a gpx, enter the filename in the "Default Category Name" box, then select the column to be used as the "POI" name. The "Optional Description Column" can be used to upload other columns such as a site description into the "Comment" and "Description" fields of the gpx file.

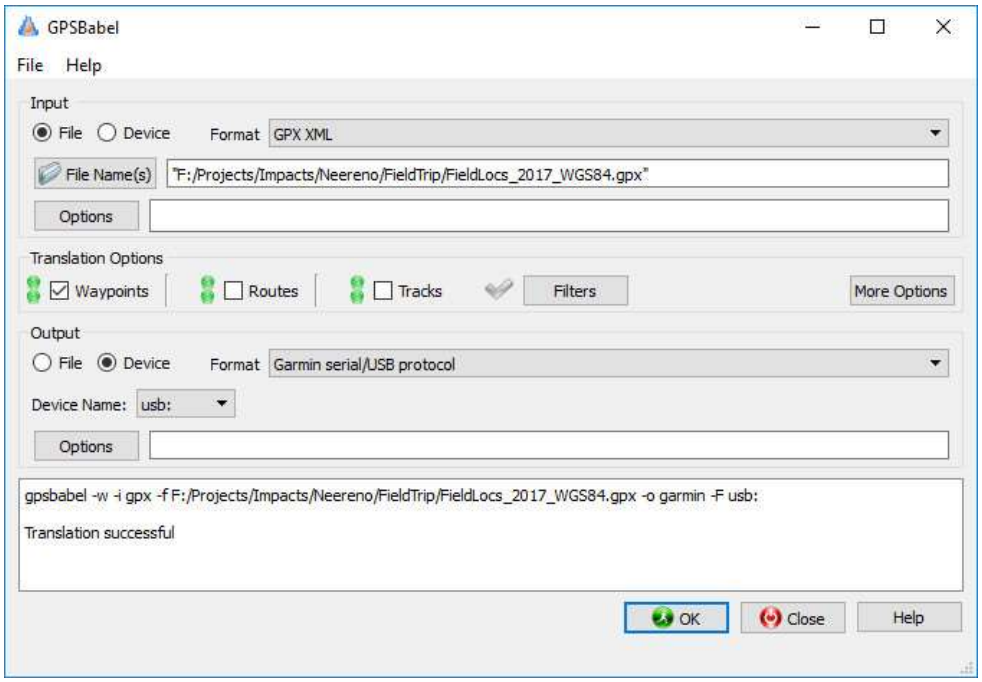


If you have problems with the gpx files, you may have to download the free "GPSBabel" utility (https://www.gpsbabel.org/) or purchase the GPS Utilities program (http://www.gpsu.co.uk/, US$60). The GPS Utilities program has a vast array for GPS formats that you can read or write. After you imported the GPX file into QGIS, remember to save the GPS layer as a shp file to allow for editing of the data.

Note that when uploading points to a GPS via a gpx file, you may need to save the shape file in a WGS84 (Lat/Long) projection and add two new text fields for "Name" and Desc". Note that to include a long description in the DESC (Description) field, such as an outcrop observation, ensure you make the string length to be 254 characters. Note that some GPS units will only display a certain number of characters, for example the Garmin etrex Vista C only displays 30 of the 254 characters. Copy your point id's from your location reference column into the "Name" field using the attribute table. Do the same to copy any comments into the "Desc" field. Save the shape files as a gpx file with GPX USE EXTENSION "YES" before uploading to the GPS. The point id's will then appear as your waypoint names and the comments will appear in the notes section.



Open GPSBabel and select the gpx file to be uploaded, check Device “Garmin serial/usb” and device name “usb”.



The lower window will confirm if the upload has been successful.

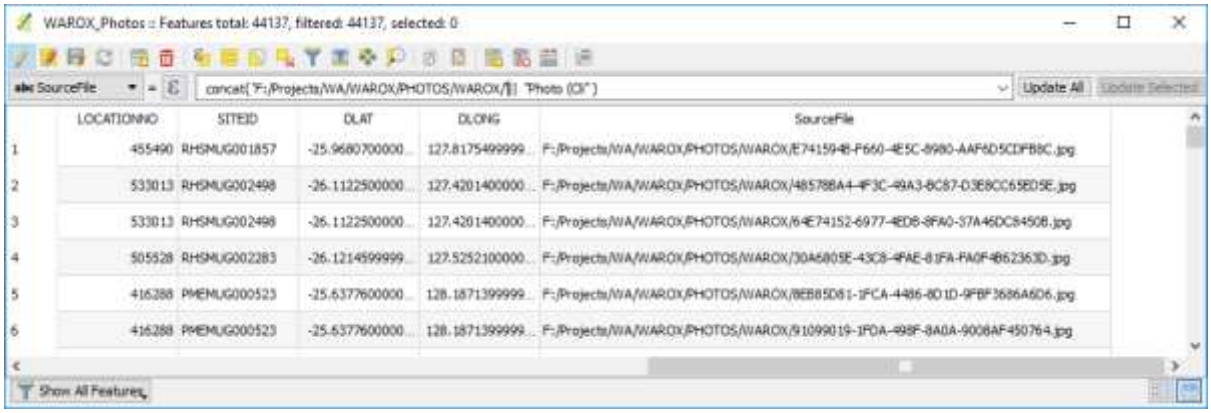
A live link to your GPS can be accessed via the View > Panels > GPS Information panel with various connection, display, and digitising options. This allows the user to have QGIS running and a live map link via the gps.

7.12 Using the GSWA WAROX and WAMINES data

The WAROX (2019 edition) database contains the GSWA field locations, sample sites, outcrop photos and petrography reports. The Microsoft Access database supplied by the GSWA contains pre-defined queries to make it easier to access the data. The query “qry_detailed” allows the user to extract the GSWA observation sites and “qry_summary” indicates if photographs have been taken of outcrops. The query “qry_photos” contains the photo information. Note the location of the photos is in the LocationID field and needs to be joined to the “qry_summary” to assign a location to each photo. To import this data into QGIS, export the query as a csv (qry_detailed.csv), ensuring you select the first row as field names, and then import this into QGIS via the CSV import option. Change the projection to GDA94 from the default WGS84. The Access queries can also be modified to allow the extraction of observation sites with photos only.

In QGIS, open the layers attribute table, make editable and add another column (called something like “SourceFile”) of type string (text) with width of 100 characters. Save this update. This “SourceFile” column will hold the file location and photo number that will allow QGIS to display the photo for this location. The next step will concatenate the directory path and photo file name into the “SourceFile” column.

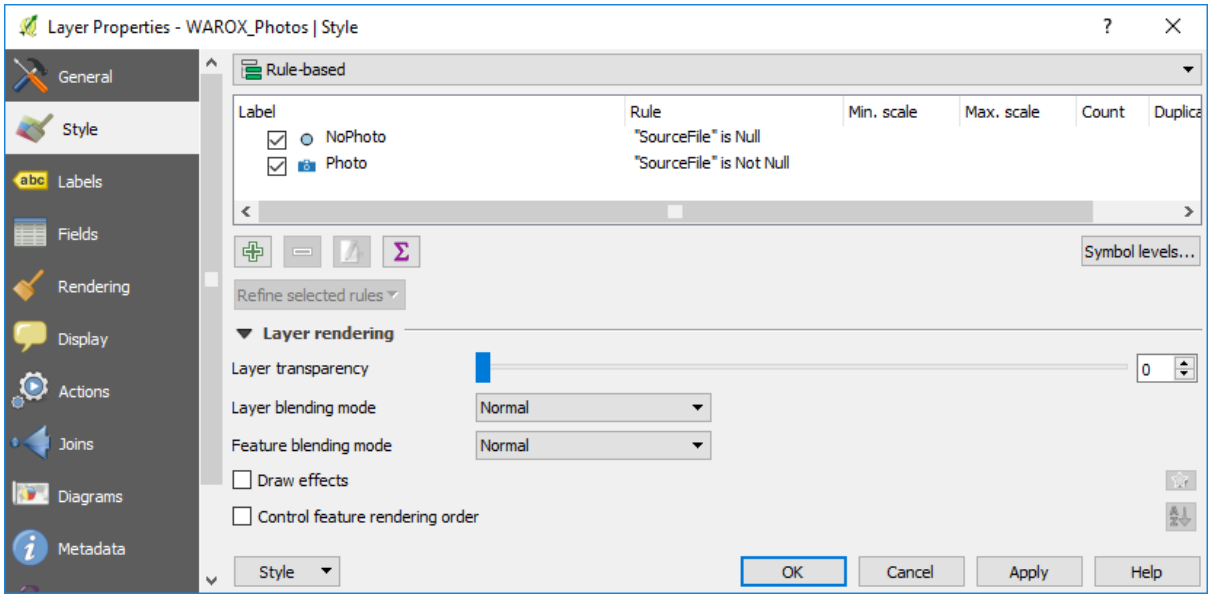
Click in the column selector to select the “SourceFile” column and then enter the following expression in the expression editor “concat(‘*directory location*’||”SourceFile”) substituting the directory location to point to where you have saved the WAROX photos. Note you need to change the default back slash (\) to a forward slash (/) in the directory path or you will get “?” replacing the back slashes. Save the file.

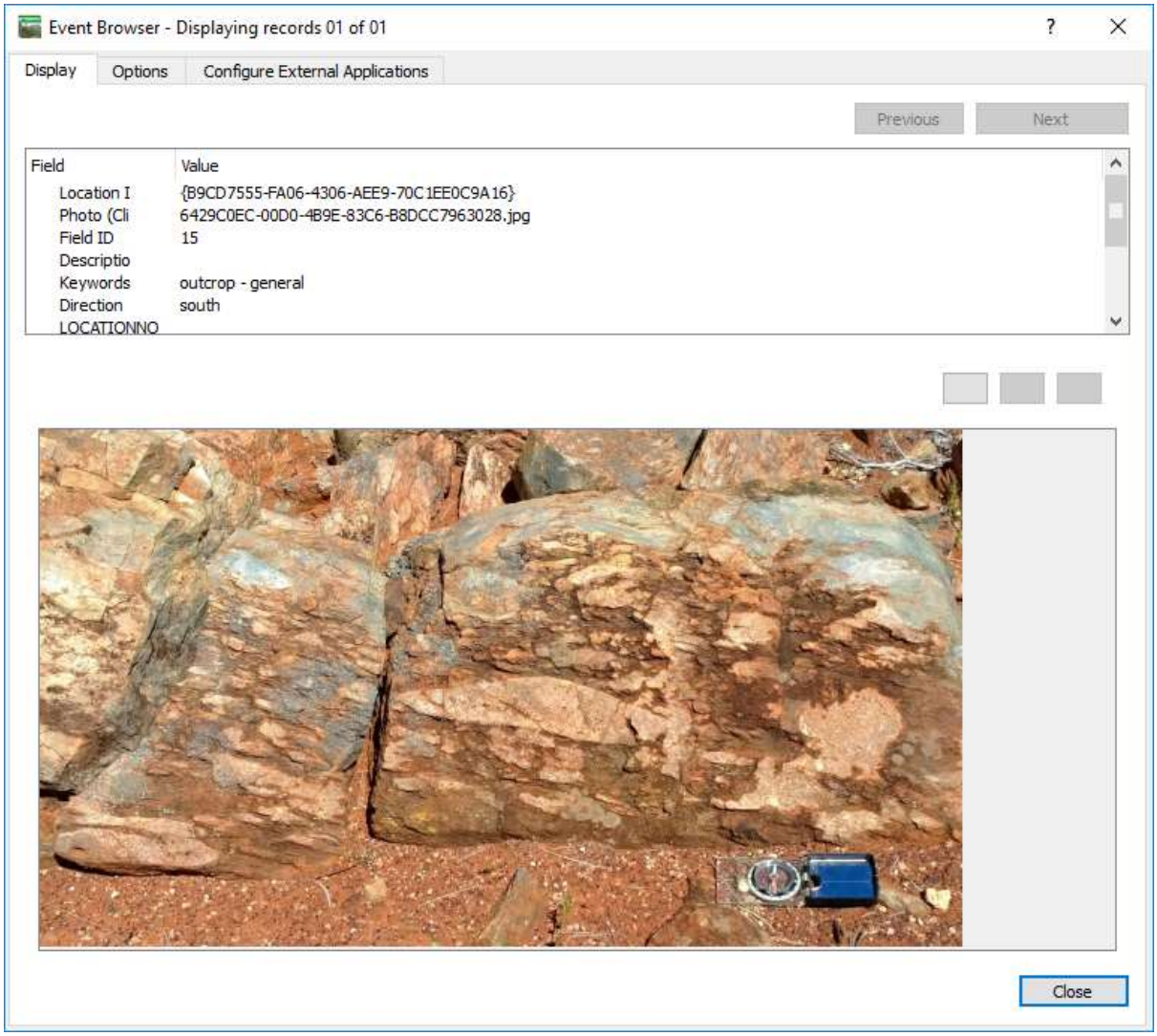


You may want to Categorise the points into those with and without photos using a “Rule based” styling using photo SourceFile is Not Null for points with photos (meaning there is a photo link), and no photo when SourceFile is Null (no photo link). I have used a photo icon to indicate if there is a photo available at a particular location.

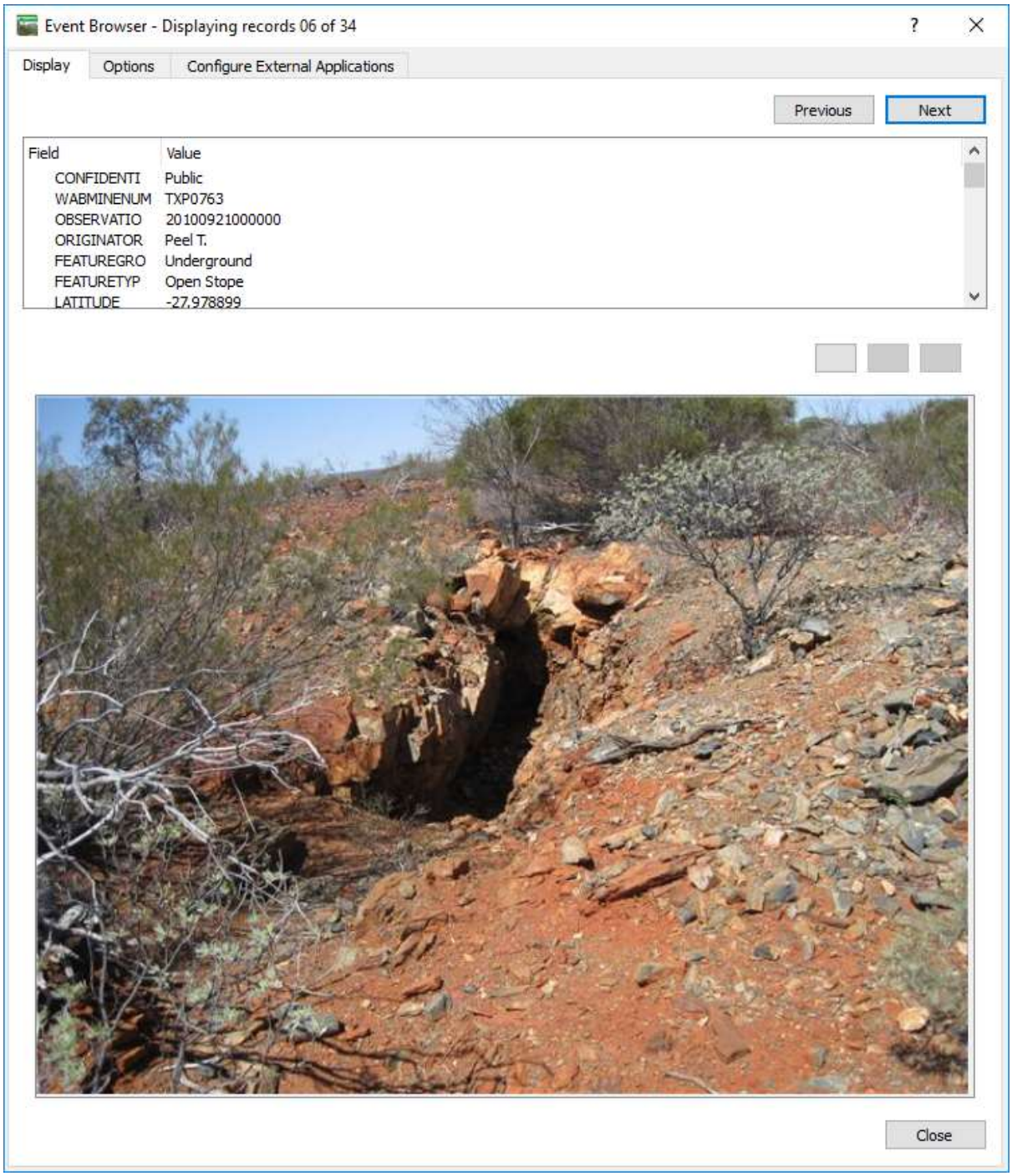
After saving the file, you can then use the eVis plug-in (Database > eVis > EVis event id tool) to click on and display photos linked to that site. The Action properties for the layer can also be used

to display photos. An example below shows the WAROX points displayed to indicate whether a photo was available at that location.

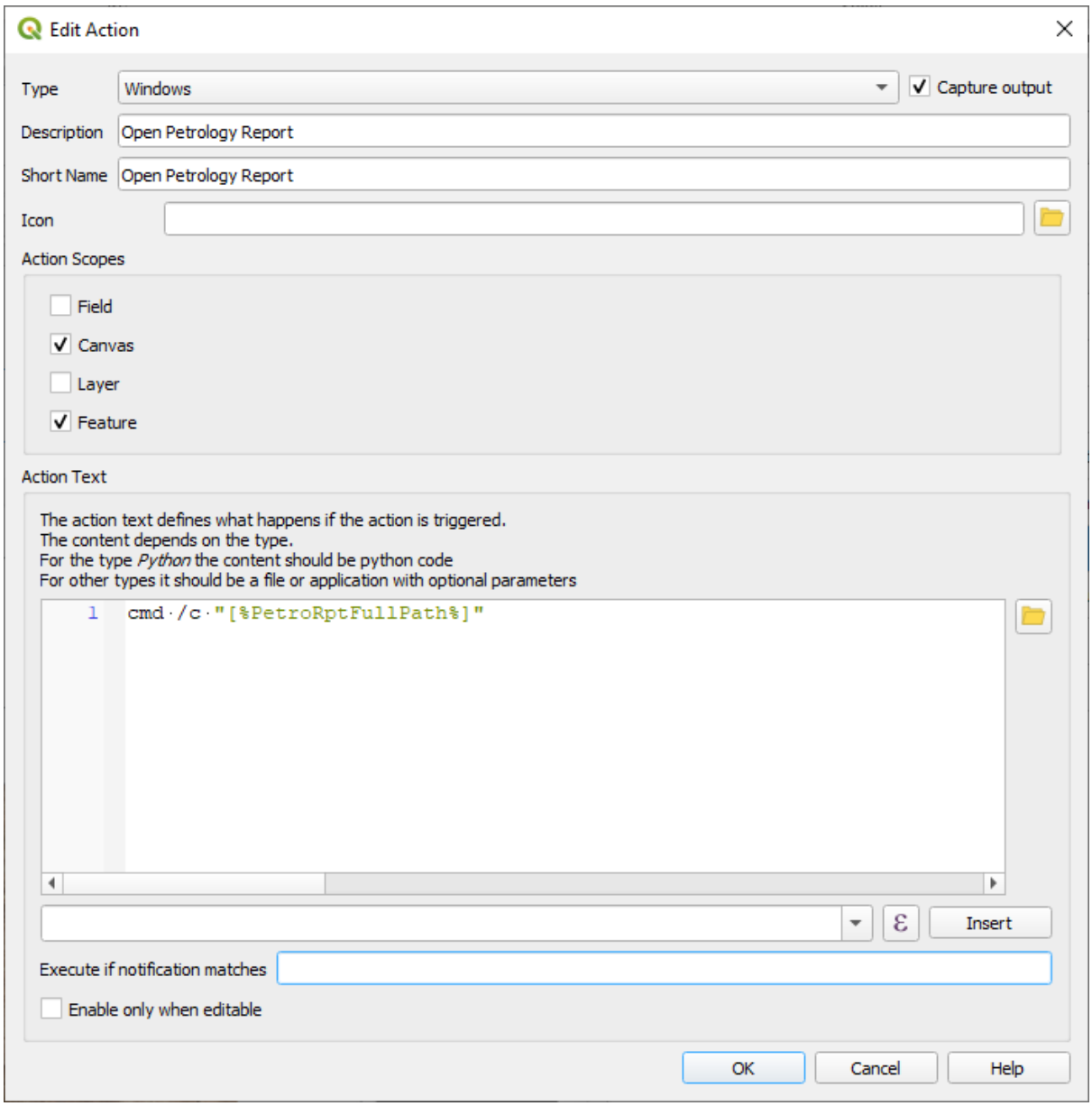




A similar process can be used to display linked petrographic reports and photos in the WAMINES database. See below an example from the WAMINES database. To display pdf files, you will need to add the pdf display program in the “Configure External Applications” tab.



PDF files can also be displayed via the Action tab, add the cmd /c command to the action text.



7.13 Converting Local (Non-Earth) Grids to Real World Coordinates

There is no easy way to convert non-earth coordinates but there is a way by using the v.transform algorithm. The algorithm requires an x, y coordinate for the grid origin and an optional rotation amount. This data is should be available from the mine surveyor or can be calculated. The author uses a small python program that uses 2 common sets of points to calculate a grid origin and rotation amount. The workflow below is for point data and within one UTM zone in metre coordinates only. If you would like a copy of this python code, please contact me.

Using a new project workspace, change **project projection** to “no projection” then open the local grid file using the local coordinates (e.g. drill holes in local coordinates). Check that the local coordinates in the map window look correct.

Run the v.transform algorithm with the points in local grid coordinates. To find this algorithm display the Processing Toolbox in the RHS of the map window, type v.tr in the search box and the v.transform algorithm should now be displayed. Double click on it to open the v.transform dialog box. Use the parameters for x, y and rotation.

Allocate the new projection to the points by **firstly**, setting the projection of the transformed layer to your desired UTM projection (**very important to do this first**) via the Layer Properties > Source tab, then change the project projection to your UTM projection. Close the original local coordinates file and zoom to the extent of the new transformed layer to check the transformation was successful.

This will produce a transformed (virtual) layer which will need to be “Exported As” to save the file permanently.

7.14 Creating a Grid Layout

A regular grid of points can be created via a table of coordinates or using the “Regular Points” algorithm. Other create grid options are available in the Processing Toolbox, but these two methods are the simplest.

To create a grid, from a table of coordinates, use the “Create points from Table” algorithm located in the Processing Toolbox under the Vector Creation list. Input the table that contains the coordinates, select the X and Y coordinate fields, with optional Z and M fields as well, check the CRS and run. The algorithm will create a series of points with id’s only. Use the attribute table to add Easting and Northing fields if desired to attach the point coordinates.

To create a grid of points using the map window, use the “Regular Points” algorithm in the Vector Creation list. The extent of the grid can be entered manually or defined by the map window extent. Set the grid spacing and check the CRS and run. The resulting grid can be rotated (using the Vector Geometry > Rotate algorithm) or the “Rotate Feature” on the map window icons (next to the “Move Points” icon). Both methods allow the user to select the point for rotation and the amount of rotation.

If you want to create non-square or hexagonal grids, for example, use the “Create Grid” option under the Vector Creation options.

7.15 GeoPackages

The following is from the Open Geospatial Consortium (OGC) website (https://www.geopackage.org/).

GeoPackage is an open, standards-based, platform-independent, portable, self-describing, compact format for transferring geospatial information.

The GeoPackage Encoding Standard describes a set of conventions for storing the following within an SQLite database:

- *vector features*
- *tile matrix sets of imagery and raster maps at various scales*
- *attributes (non-spatial data)*
- *extensions*

To be clear, a GeoPackage is the SQLite container and the GeoPackage Encoding Standard governs the rules and requirements of content stored in a GeoPackage container. The GeoPackage standard defines the schema for a GeoPackage, including table definitions, integrity assertions, format limitations, and content constraints. The required and supported content of a GeoPackage is entirely defined in the standard. These capabilities are built on a common base and the extension mechanism provides implementors a way to include additional functionality in their GeoPackages.

What all this means is that you can create a Geopackage with vector data containing point, line and polygon data with their respective stylings, and also include raster data files.

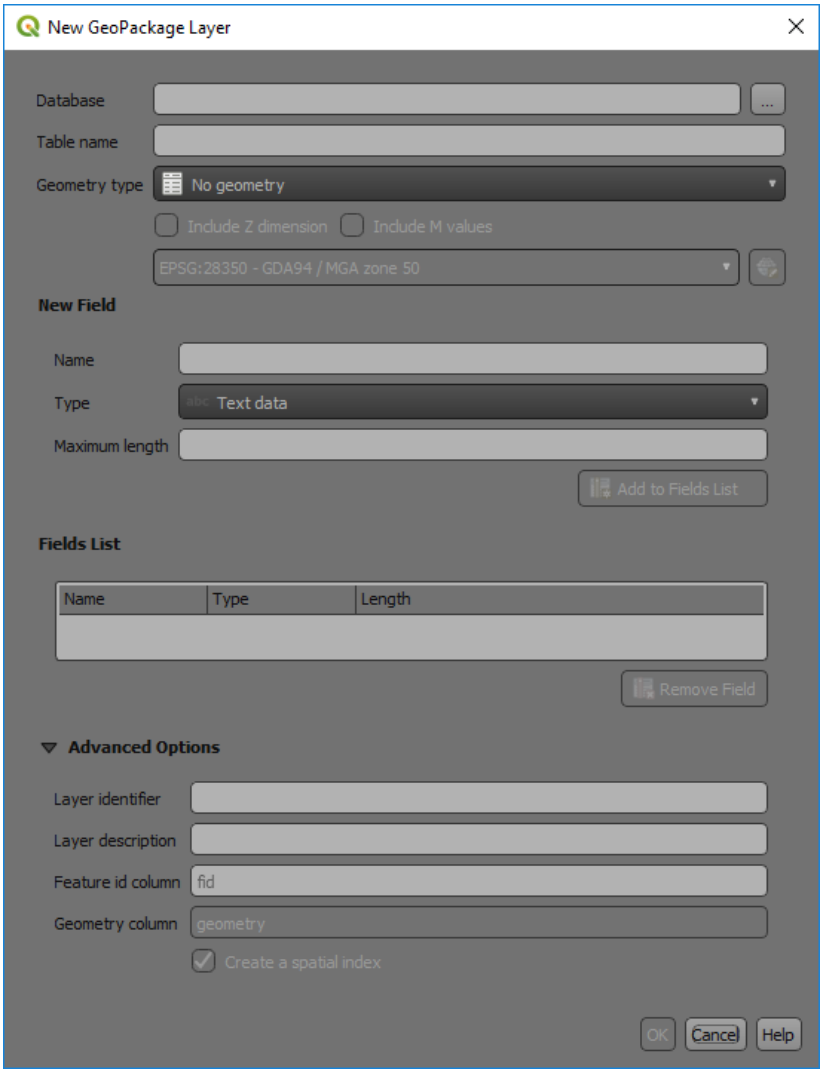
Field names are not restricted to 10 characters, as is the case with shape files.

GeoPackages can be used to transfer complete projects with all the data and display attributes – see the end of this section for details.

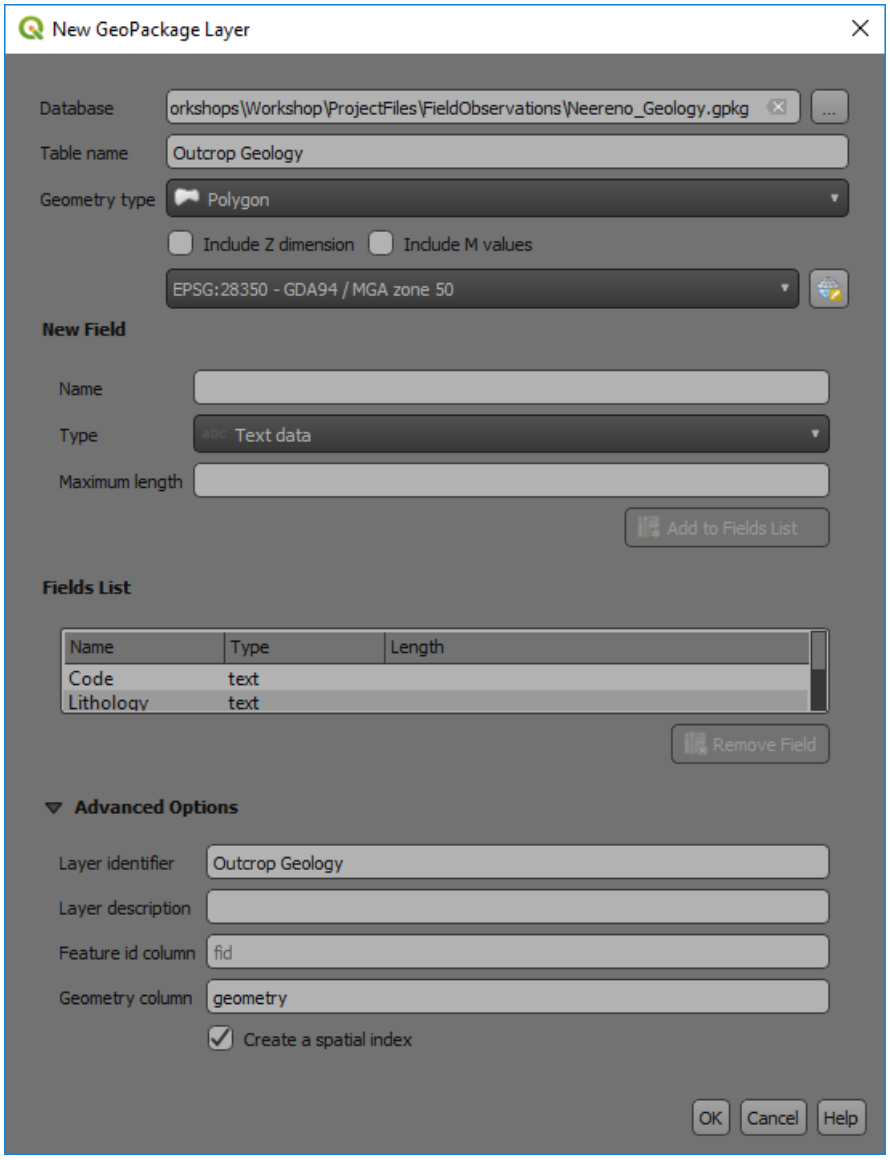
When digitising into a Geopackage file, the id field is automatically incremented. The data is spatially indexed so panning and window refreshes are much faster.

Geopackages have a .gpkg file extension.

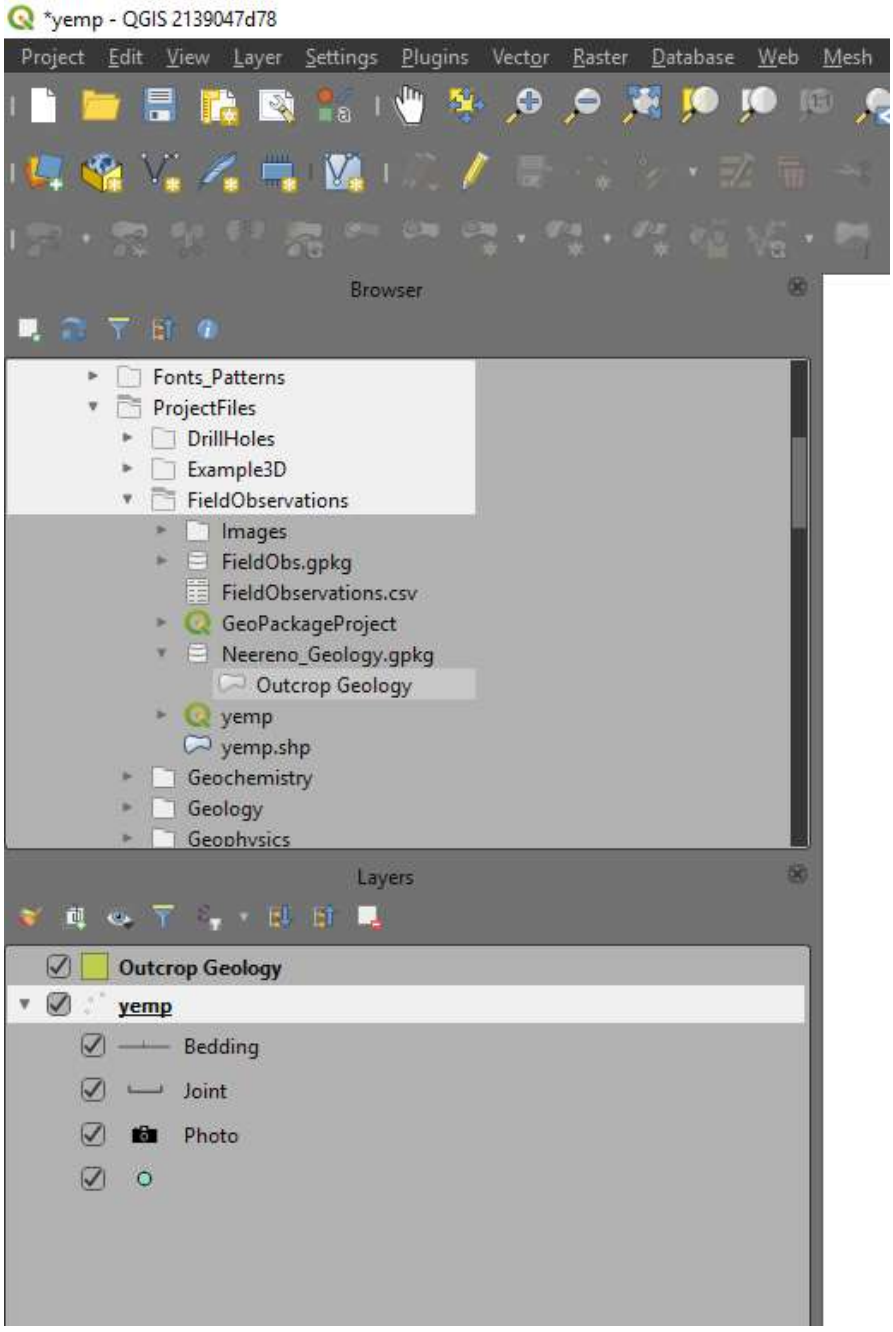
To create a new blank GeoPackage, use the Layers > Add New Layer and select Geopackage. The following dialog box will appear.



The database name will be the new Geopackage name and make sure you selected the three dots to the right of the entry field to ensure you know where it will be saved. The table name will be the layer within the Geopackage. Ensure you select the correct geometry for the layer and the correct CRS of the data. Add your required fields for the table/layer and press OK to create a Geopackage.

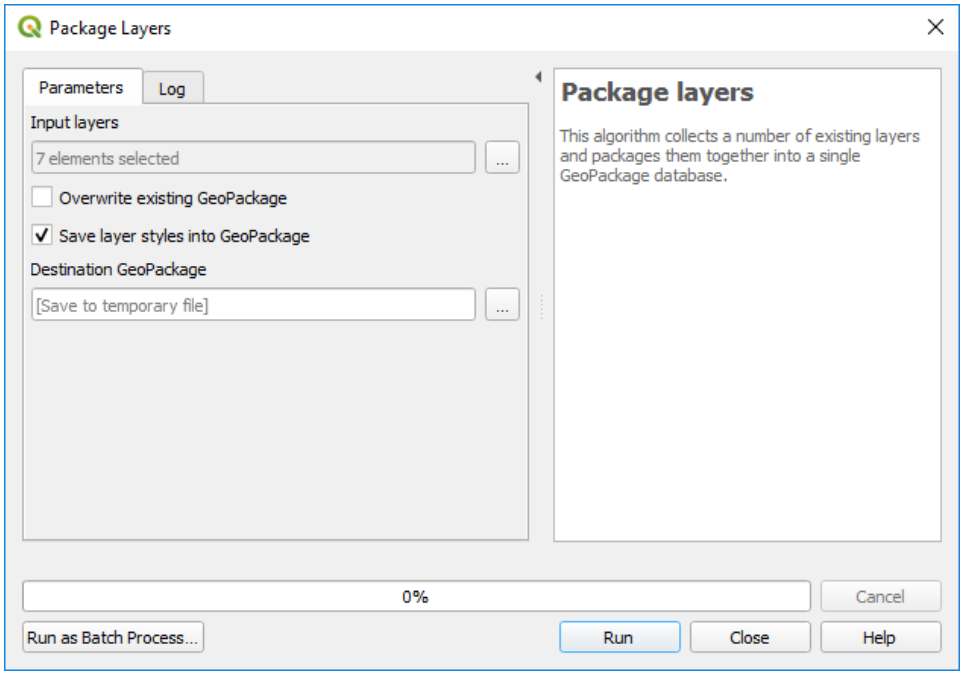


Once a Geopackage has been created, shape files in the layers panels can be selected and dragged into the browser panel and added to the Geopackage file by overlying the layer on the Geopackage name (a small plus symbol will be displayed when overlayed in the correct place).



Geopackages can also be used to store complete projects. Currently this requires three steps.

Firstly, use the Processing Toolbox > Database > Package Layers algorithm to package all the vector layers into a Geopackage – this algorithm only saves the vector layers. Ensure you tick the “Save layer styles into GeoPackage” (only available in versions 3.8 and higher).



The next step is to drag the raster layers into the new GeoPackage, then close the original layers.

The last step is to re-open them using the GeoPackaged files. Reorder the layers as required and save the project into the same folder as the GeoPackage.

You will then have a GeoPackage file ***.gpkg and an associated project file (***.qgz) which when moved together will be the complete project data package.

Note that Geopackages can only be edited by single-user at a time.

8: DISPLAYING GEOCHEMICAL DATA

Geochemical data is usually in the form of an excel spreadsheet or as a text file. Open the file in QGIS via the “Spreadsheet Layers” or CSV file open options depending upon the format of your data. See section 6 above for opening spreadsheet and csv files, and the potential use of CSV format files (*.csvt) for large complicated csv files. If you have problems importing large csv files exported from Excel, save the file as a tab-delimited text file and import this into QGIS.

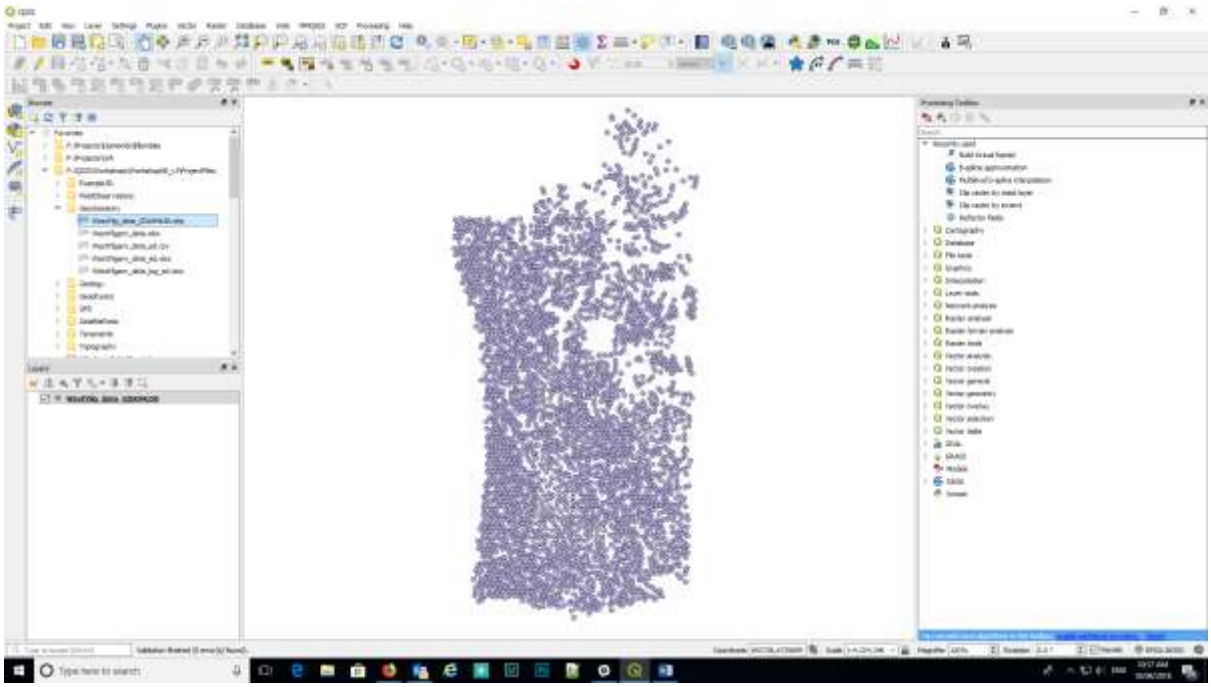
IoGAS has created a QGIS plugin for its export files and can be downloaded from the ioGAS website (https://reflexnow.com/download-qgis-plugin-for-imdex-iogas/).

When loading your data, ensure the data has been loaded into QGIS as the correct field type, i.e. as a number, not as a string (text) field. This can be checked using the layer’s Layer Properties > Fields tab.

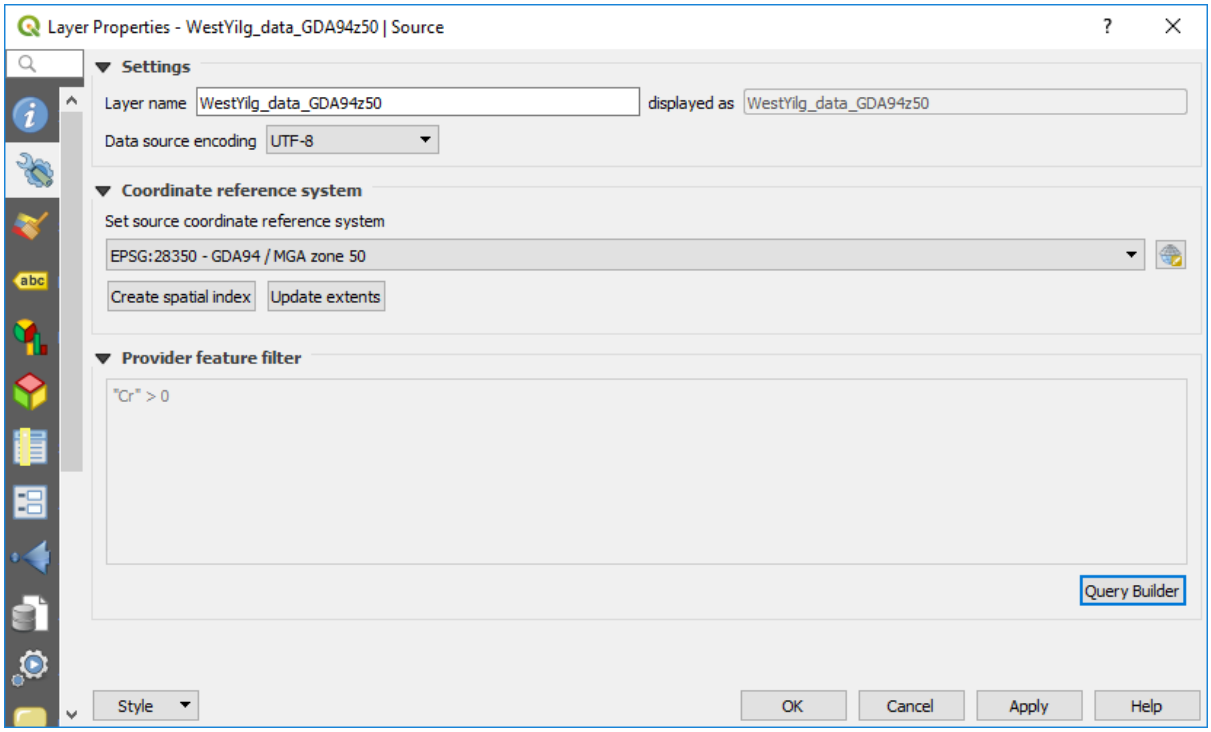
When the data has been imported into QGIS, make sure you check the correct coordinate system has been selected.

Use the View > Statistical Summary option to display the statistics for a particular field. This helps to identify potential problems with the data such as negative values representing below detection limit data.

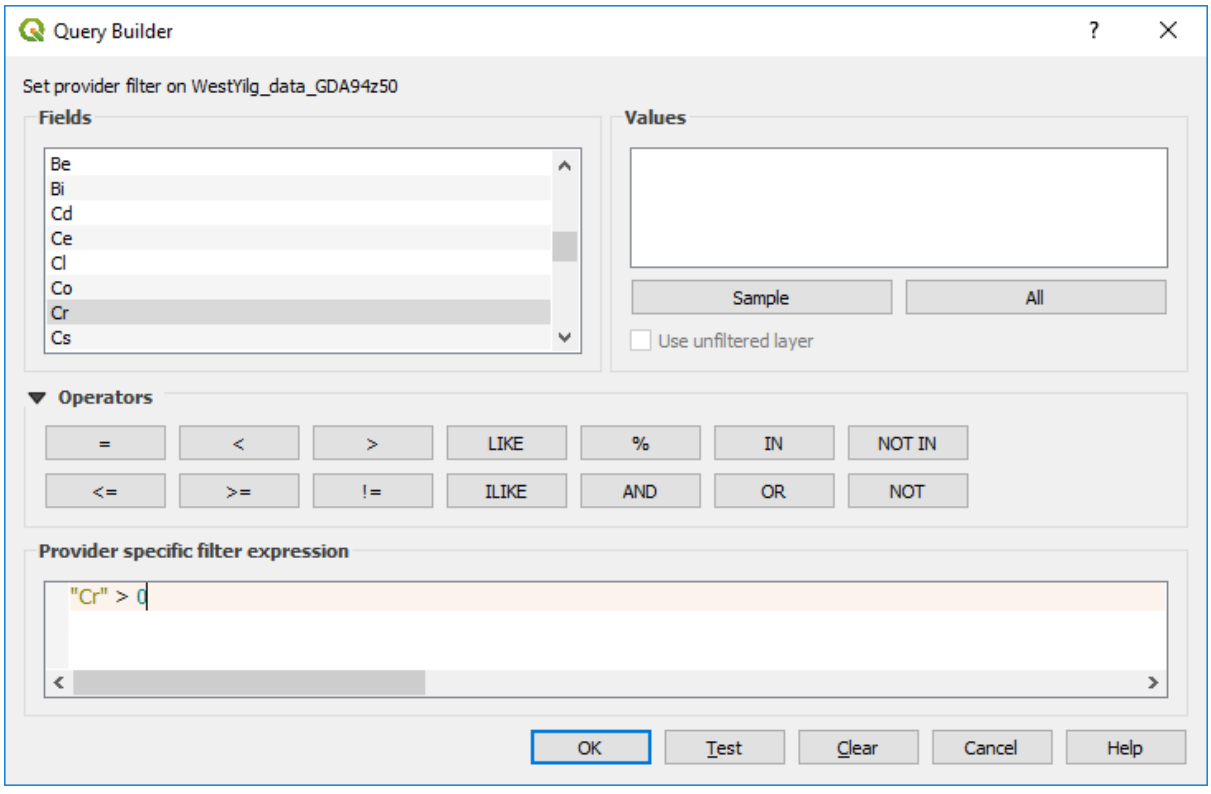
Geochemical point data can be displayed as points and can be coloured or sized according to value.



To filter out bad data, use the “feature filter” in the Source tab of the Layer Properties to filter out all the negative numbers (below detection or not assayed) – see the following image as an example for the Cr data.



Use the query builder, as shown below. Note that this has only been done for Cr values in this example.

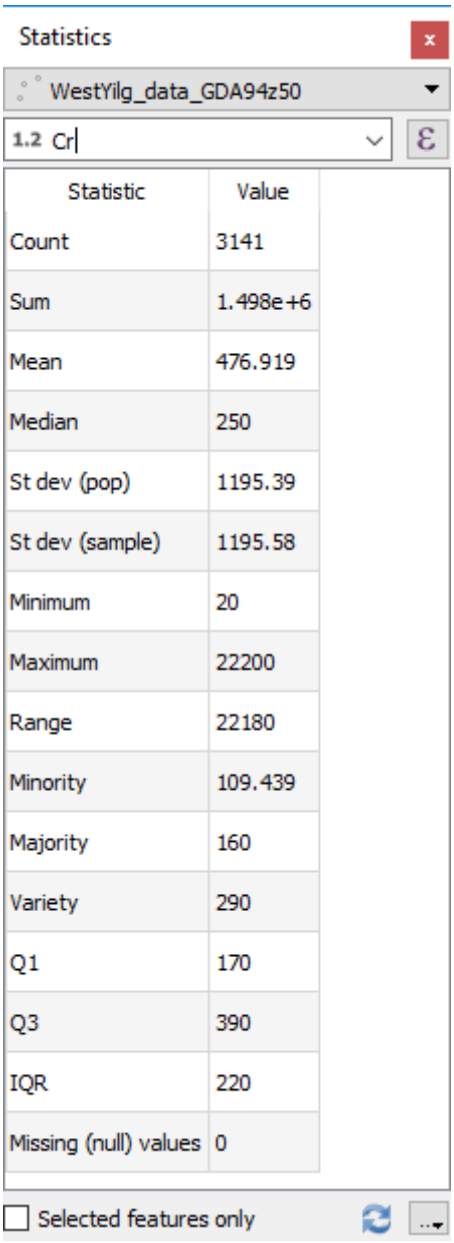


This is important for geochemical data so the negative values do not influence the statistics of the data.

Univariate statistics can be calculated using the View > Statistical Summary panel. This opens a panel under the browser panel, where you can select the layer and data field for which field you

want to calculate statistics. The mean, standard deviation, first quantile, third quantile and the Inter Quartile Range (IQR) are among some of the calculated results.

To examine the statistics of the data, use the View > Statistics Panel and select the field to be queried.



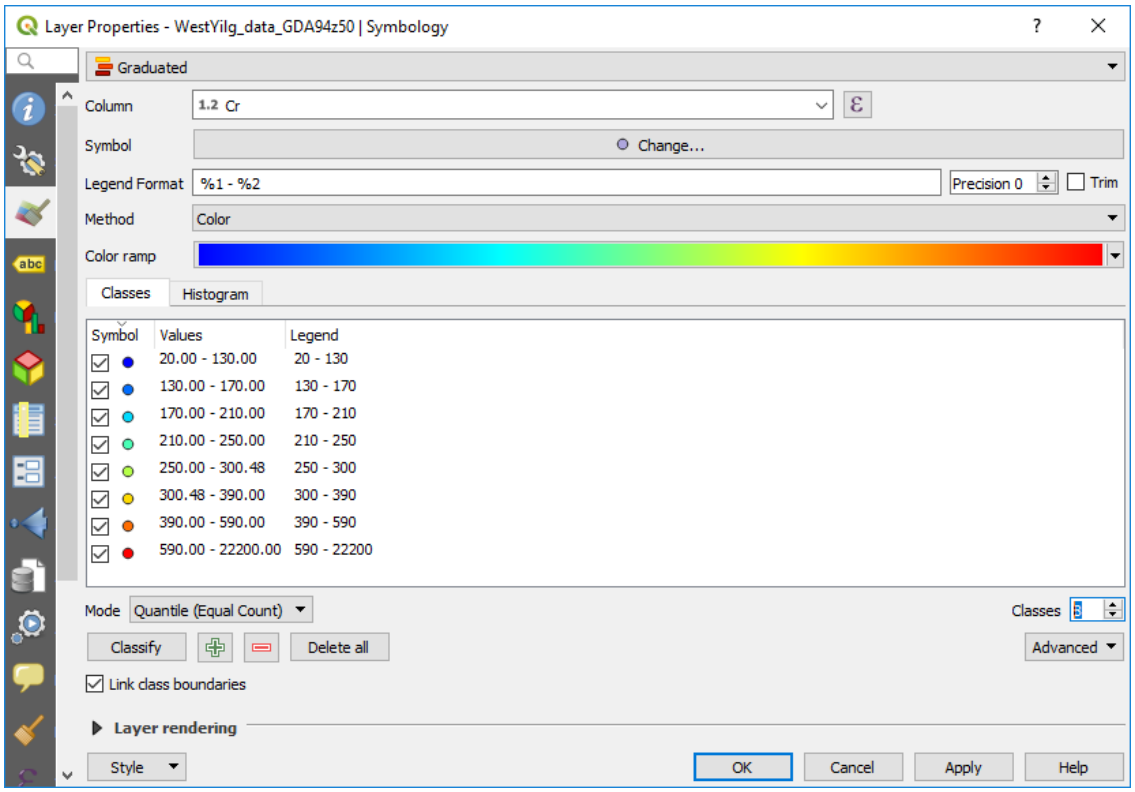
Statistic	Value
Count	3141
Sum	1.498e+6
Mean	476.919
Median	250
St dev (pop)	1195.39
St dev (sample)	1195.58
Minimum	20
Maximum	22200
Range	22180
Minority	109.439
Majority	160
Variety	290
Q1	170
Q3	390
IQR	220
Missing (null) values	0

In this example note that the first and third quantiles are 170 and 390 ppm Cr with an IQR (inter quartile range) of 220. Geochemist's would say that any values over 720 ppm Cr (Q3 + (1.5 * IQR) are anomalous.

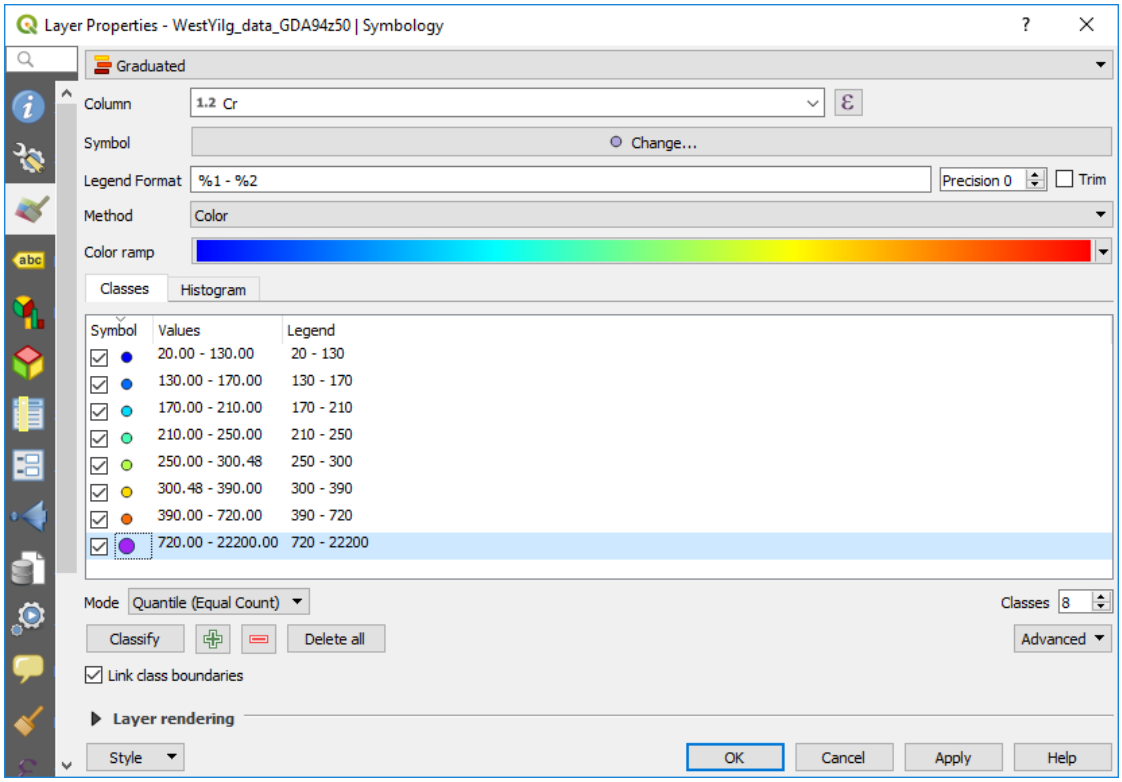
To colourise your data, use the Layer Properties > Style tab to select the way you want the data displayed. The simplest way is to use the "Graduated" option and colour the point values. Note that this works on numeric values only. Select the column you wish to colour the points by and the desired colour ramp and hit the "Classify" button. Under the display window, you can also select

the way the points are coloured. You can use a variety of methods. You can also manually edit the ranges in the display window.

To colour the geochemical data by assay value, select the Style tab in the layer properties panel. Select the Graduated option in the top drop-down box. Select “Cr” as the field to be displayed. Select a suitable “colour ramp”, select Mode “Quantile (Equal Count)”, change Classes to 8, hit “Classify” (if you forget to hit Classify you will not any colours!). You will note that the boundary between the second and third quantile is 170 ppm (Q1) and the boundary between the sixth and seventh range is 390 ppm (Q3). Other display modes may be more applicable, and this will depend upon your data and how you want to display the data.



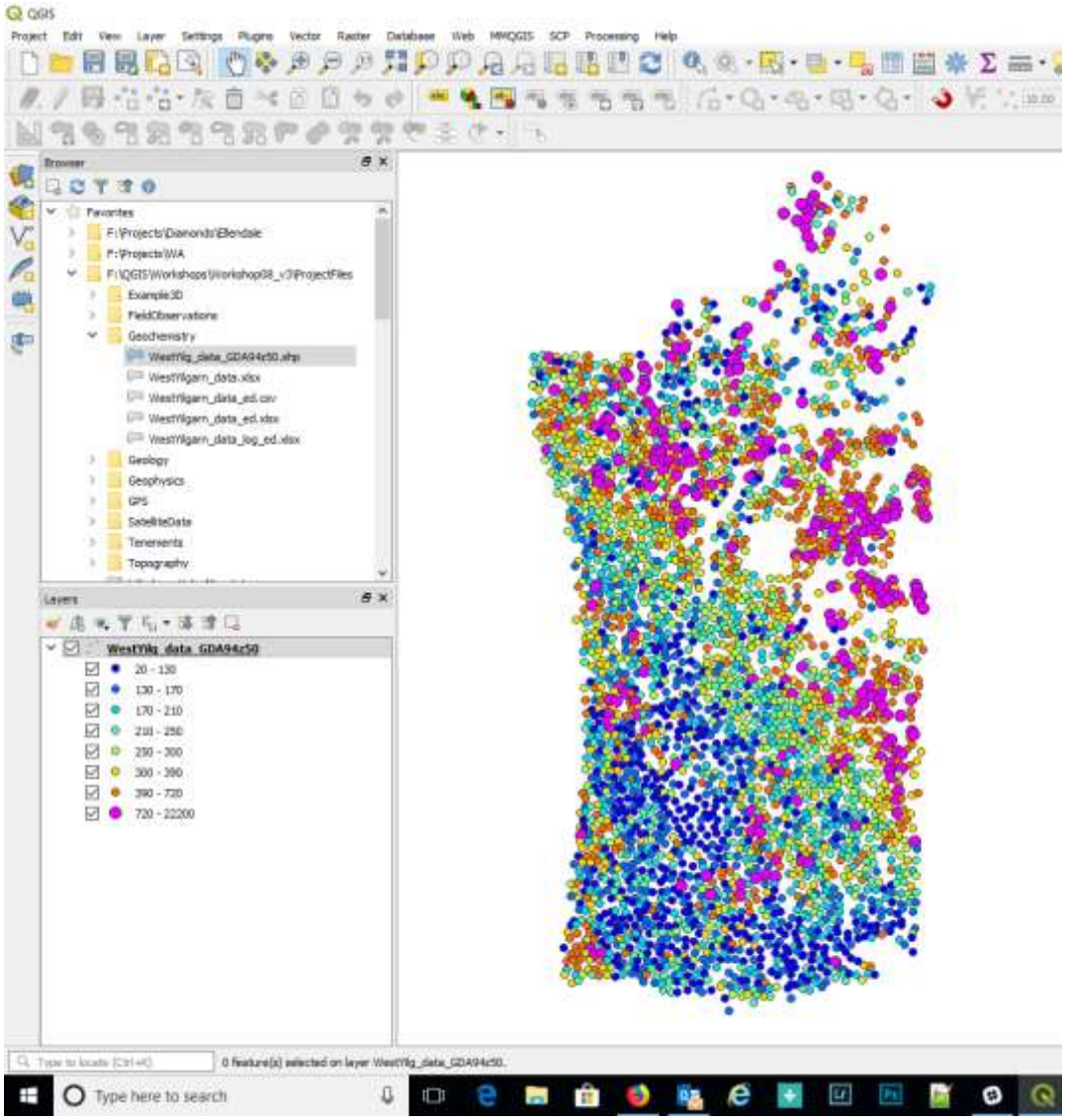
The top two classes are below 170 ppm (25th percentile) and the bottom two classes are greater than 390 ppm (75th percentile). You can manually edit the second last range so that its upper value is 720 ppm (anomaly threshold) and it will automatically update the eighth data range.



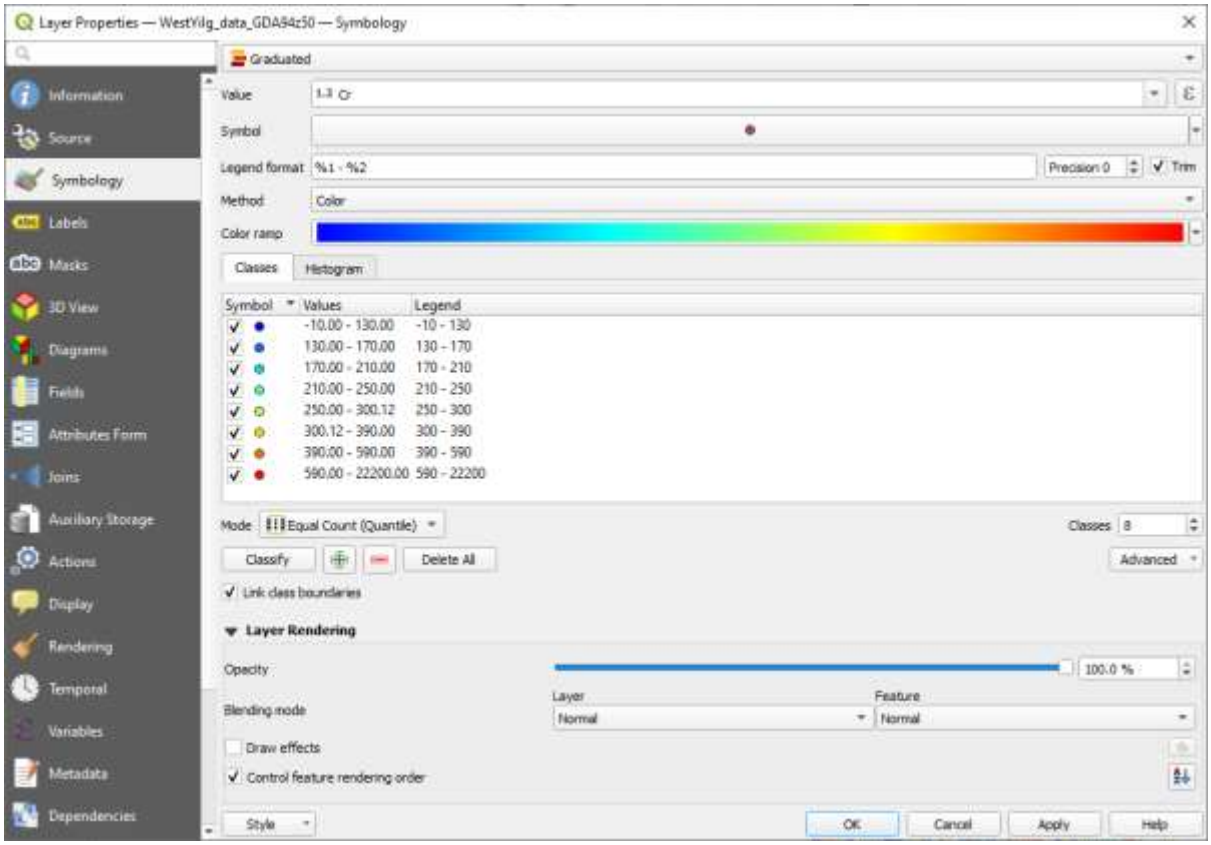
In the figure above I have selected the >720 ppm and enlarged the symbol.

Other options are available for the display of the data – see the “Mode” drop-down box.

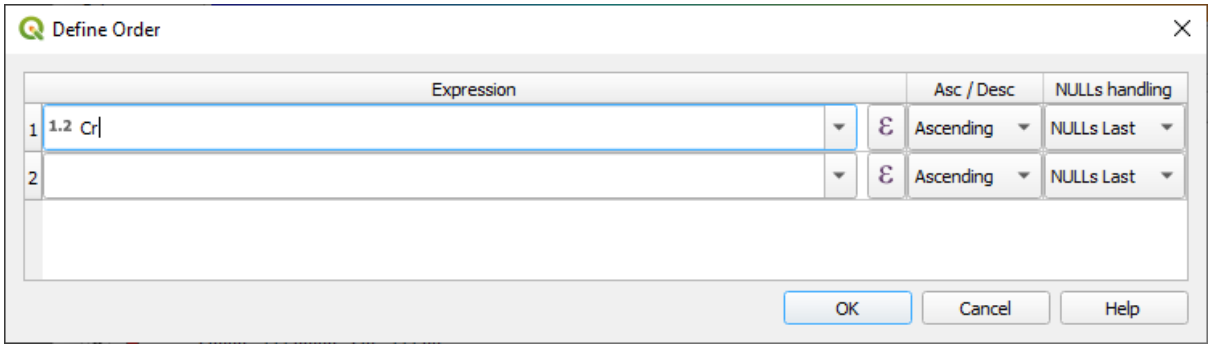
Note you can vary the displayed number of decimal places in the legend by using the “Precision” option in the dialog box.



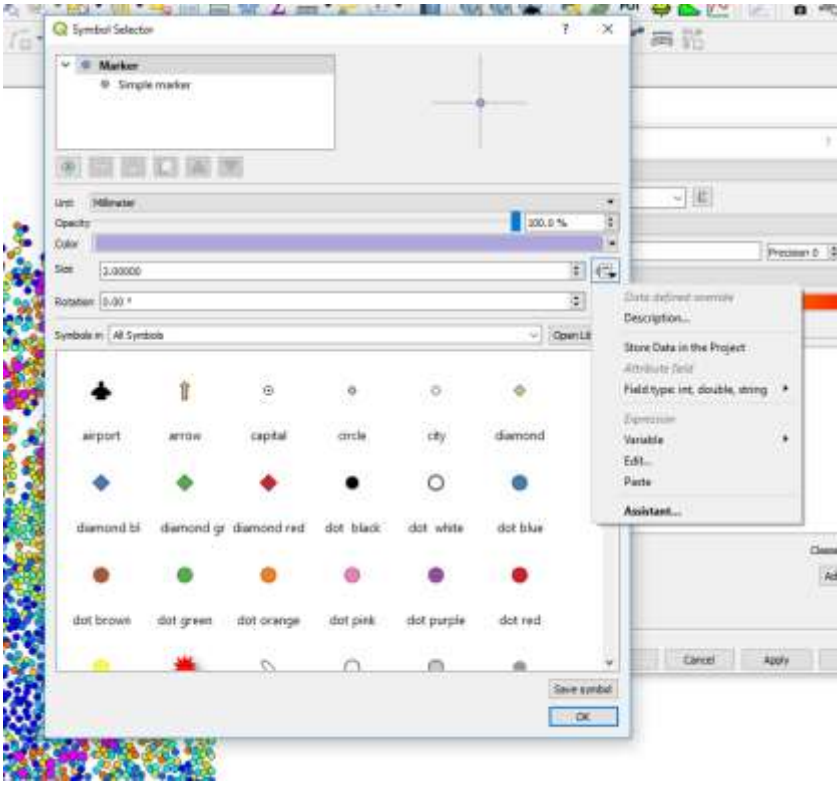
The drawing order can be varied so that all the high values are plotted on top. To do this scroll down the Symbology dialog box to the “Layer Rendering” option, turn on the “Control feature rendering order”, then click the sort icon on the right-hand side.

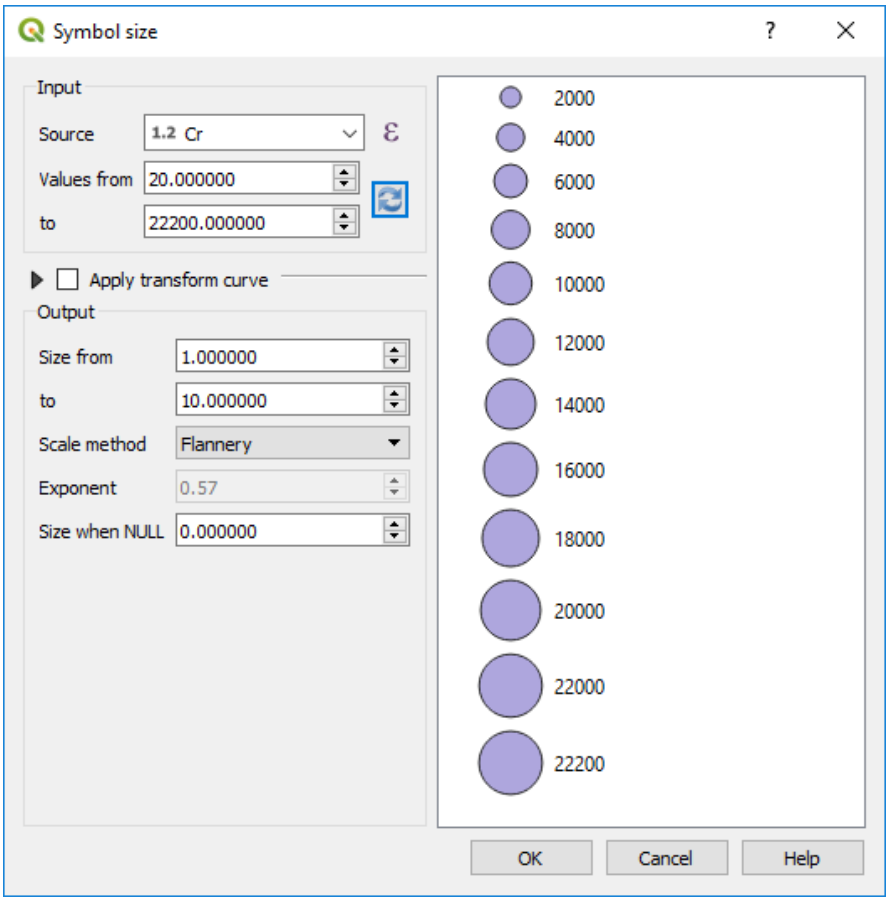


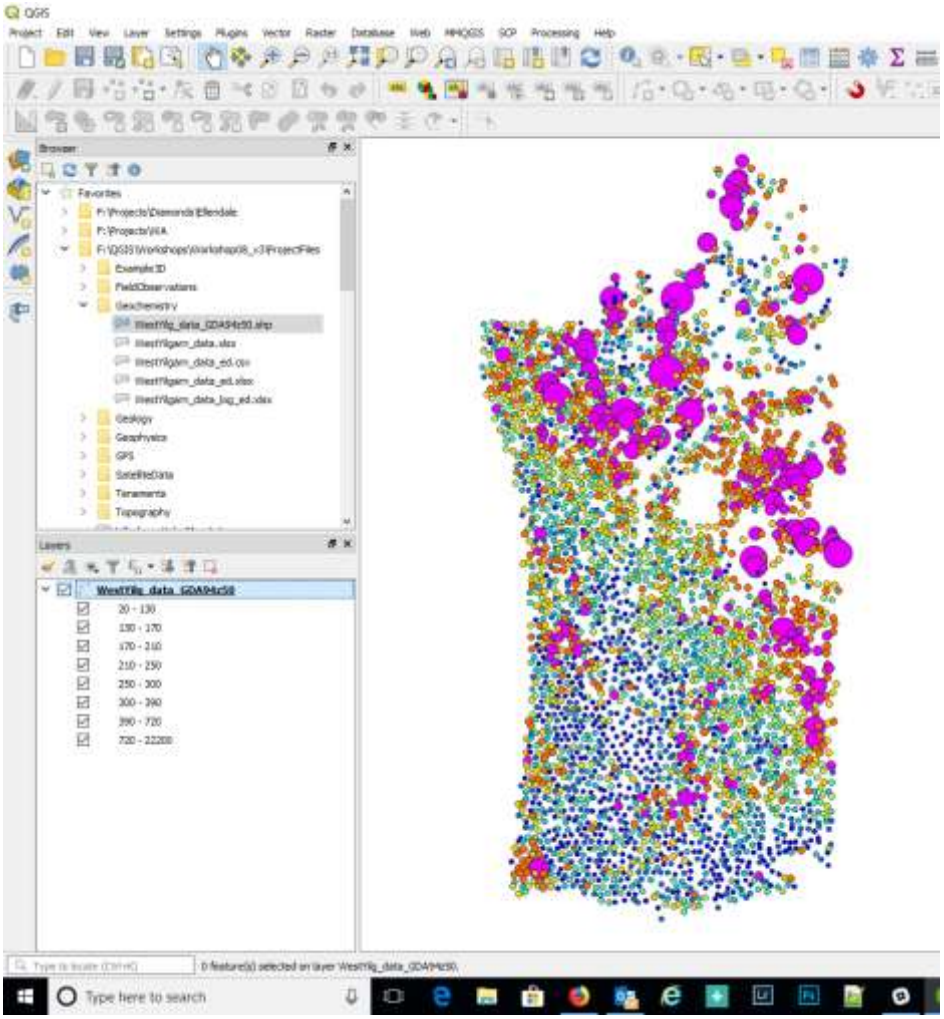
Select field to use for the ordering and whether you ascending or descending order.



Points can also be classified by size. Click in the Symbol box (where it says “change”) to bring up the symbol selector window. Highlight the “Marker” layer in the top left, then click on the far-right hand side of the Size options where there is a little square box with a down arrow. This is the “Data Driven Override” button. Click on this and scroll down to “Size Assistant” where you can select the symbol size by the field “Cr”. Select the field to use for the size, then refresh so that QGIS can calculate the data range in that field. Select OK to apply. Close the layer properties window.

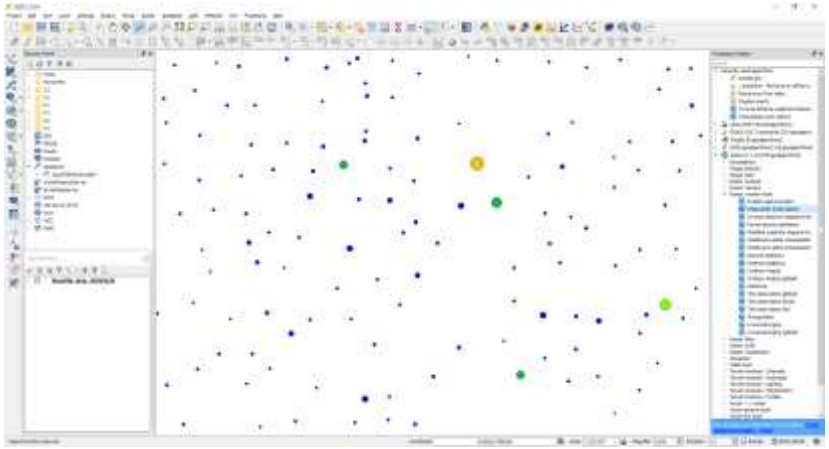

Symbol Selector
Marker
Simple marker
Unit
Opacity
Color
Size
Rotation
Symbols in
All Symbols
Open Library
airport
arrow
capital
circle
city
diamond
diamond bl
diamond gr
diamond red
dot black
dot white
dot blue
dot brown
dot green
dot orange
dot pink
dot purple
dot red
Save symbol
OK
Description...
Store Data in the Project
Field type: int, double, string
Variable
Edit...
Paste
Assistant...
Cancel
Apply

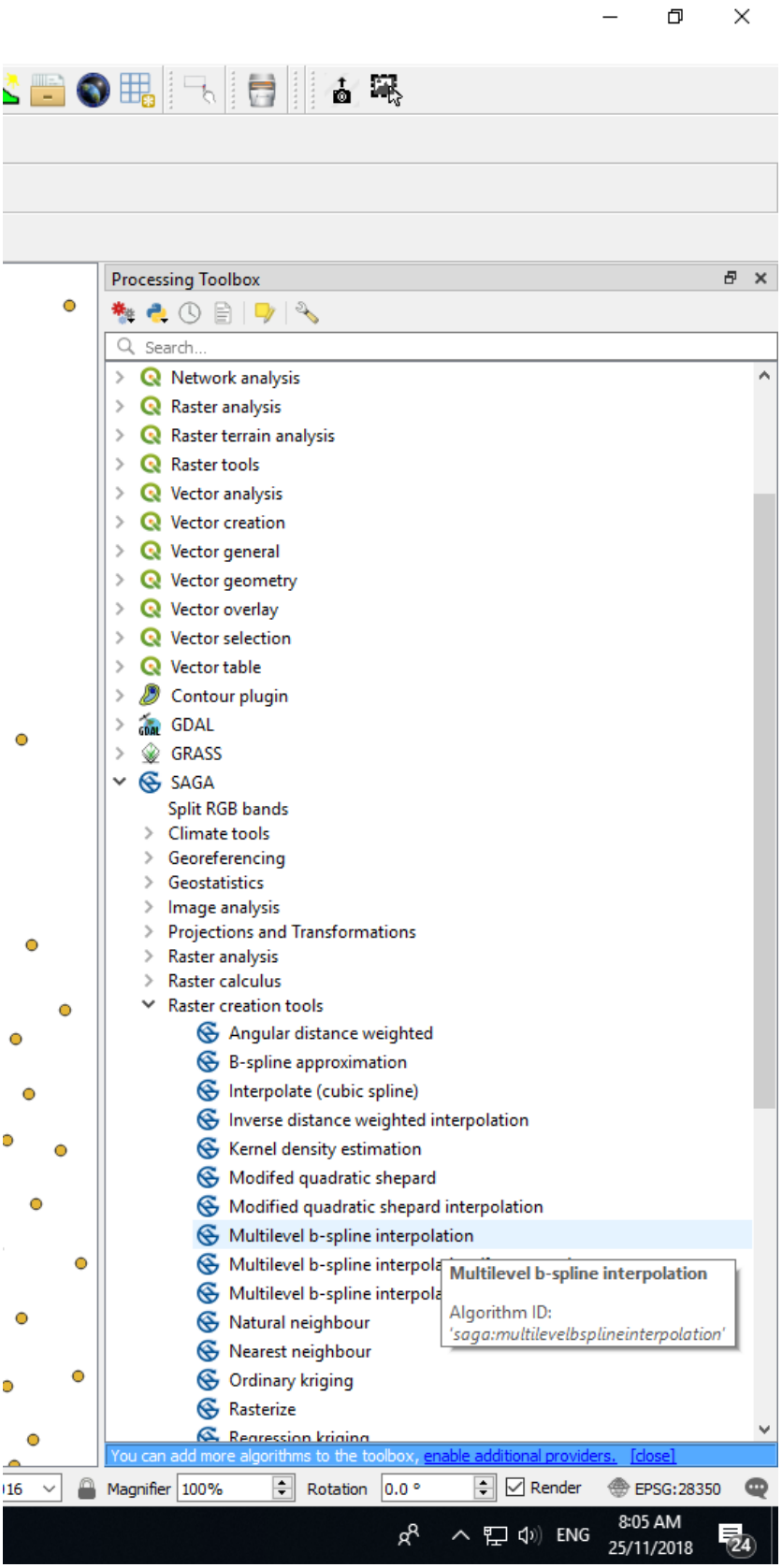

Symbol size
Input
Source
1.2 Cr
Values from
20.000000
to
22200.000000
Apply transform curve
Output
Size from
1.000000
to
10.000000
Scale method
Flannery
Exponent
0.57
Size when NULL
0.000000
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000
22200
OK
Cancel
Help



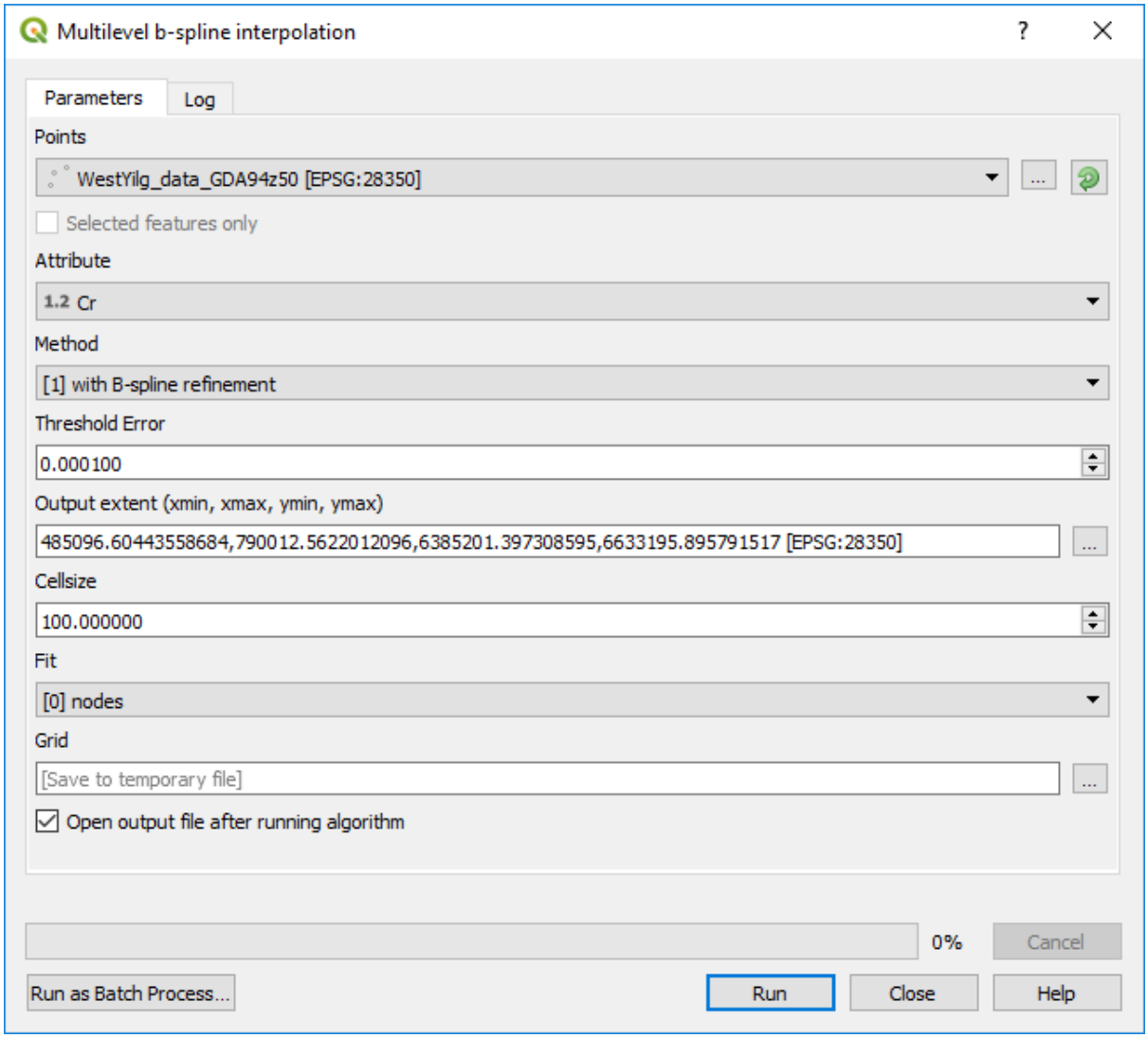
To create a grid of the geochemical data, zoom to an area of data that you want to grid and open the Processing Toolbox (right hand side window) > SAGA > Raster Creation Tools > Multilevel b-spline. Select the field to grid and click select and enter a file name (if you want a permanent file output) and location to where you want to write the grid file. **It is important to make sure QGIS can write to the folder (not the default Program Files folder), otherwise the operation will fail.**

Zoom in to a subset of the data, as shown in the figure below.

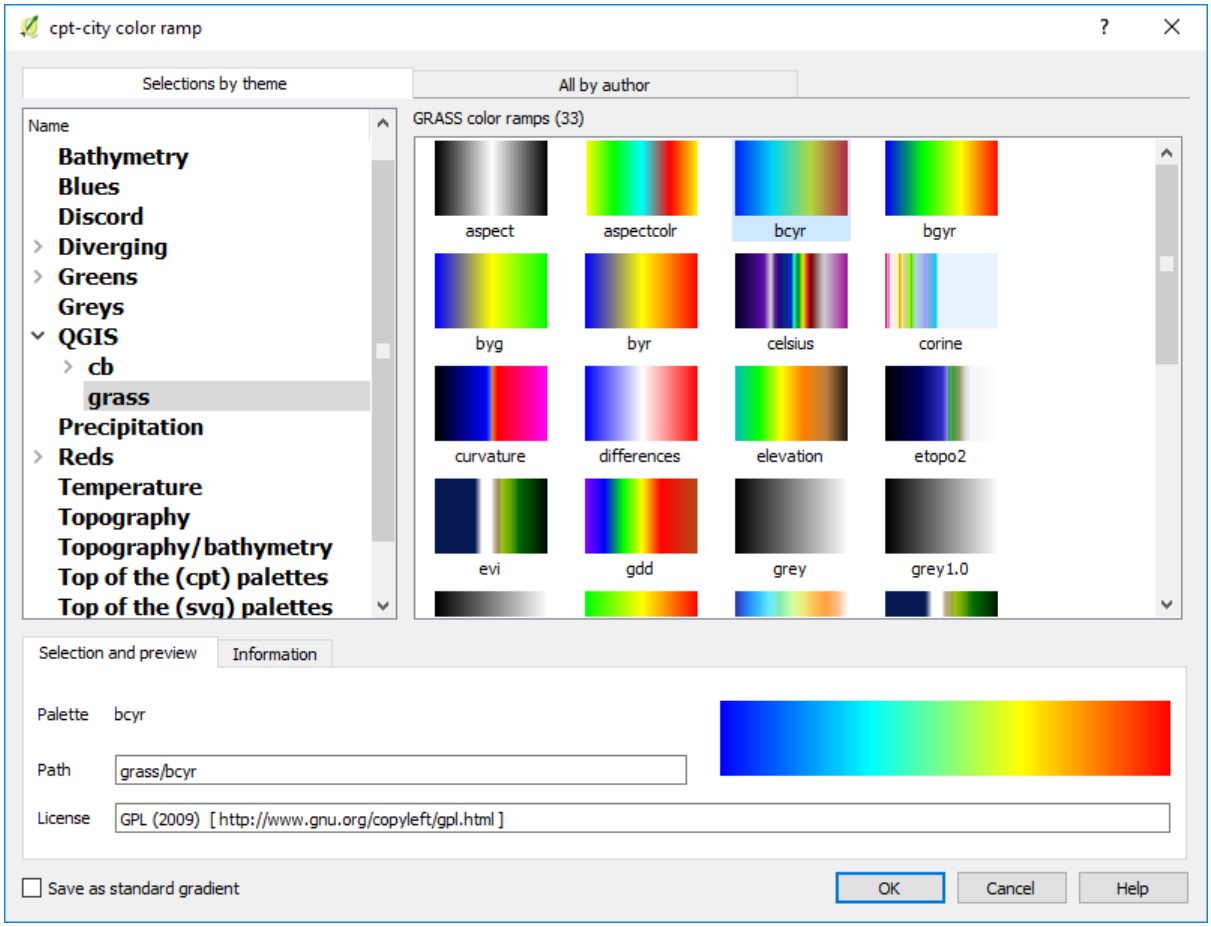




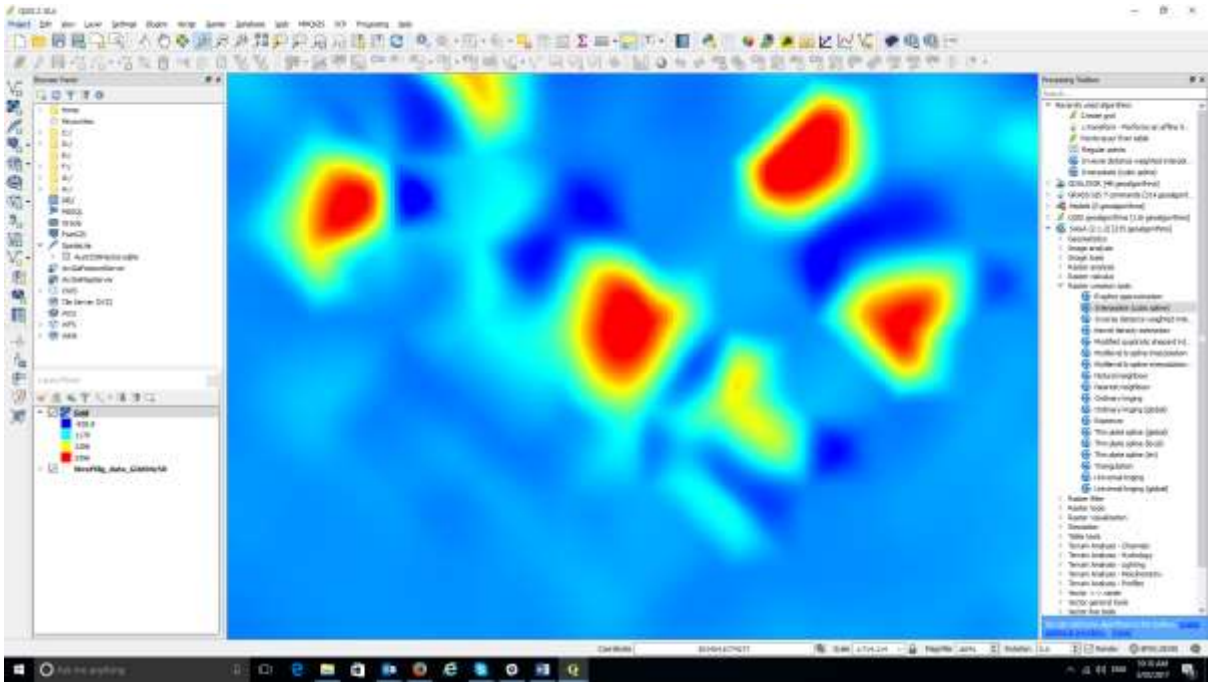
To limit the area over which the grid will be calculated, use the canvas extent for the “Output extent” (click on the … to see the extent options).



The default grid colouring is greyscale. To add colour to the grid, open the Layer Property > Style tab and select pseudocolour as the render type. If you can't see the desired colour ramp, scroll to the bottom of the colour ramp display box and select "New Colour Ramp", then Colour Ramp Type "cty-city". A large range of colour ramps can then be selected.



A common ramp to use is the QGIS > grass “bcyr” colour ramp. Save this as a standard gradient (lower left-hand tick box) and save “Save Color Ramp” with a suitable name (e.g. Default Colour Ramp).



There are a variety of gridding option in QGIS (see menu item raster > interpolation) but I have found the SAGA gridding tools, which includes b-spline, inverse distance and kriging, to be the best for geochemical data. Note that the spline method will not be exact and will overshoot and undershoot some of the point values. Check a few different methods to find one that suits you best.

9: GEOPHYSICAL DATA IMPORT AND DISPLAY

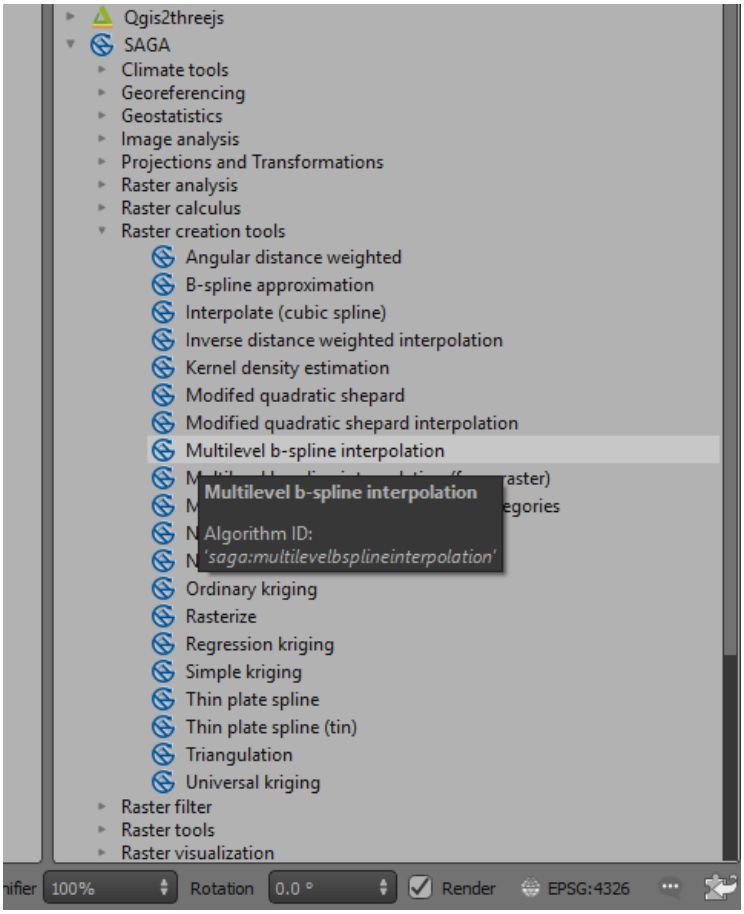
9.1 Data Import

Geophysical data usually comes as located data files (text) or grid files. QGIS can read many grid formats with *.ers, and *.tif (geotiff) files the most common, and these can be loaded by dragging the file name from the Browser Panel into the map window. Note that Geosoft *.grd files require conversion to *.ers files via their free viewer Oasis Montaj program (available from www.geosoft.com).

When opening located data text files, remember that shape files can only have field names up to 10 characters in length. If your text files have longer field names, then it is suggested you use a free text editor like Notepad++ (https://notepad-plus-plus.org/) or ATOM (https://atom.io/, for large files) to modify the field names.

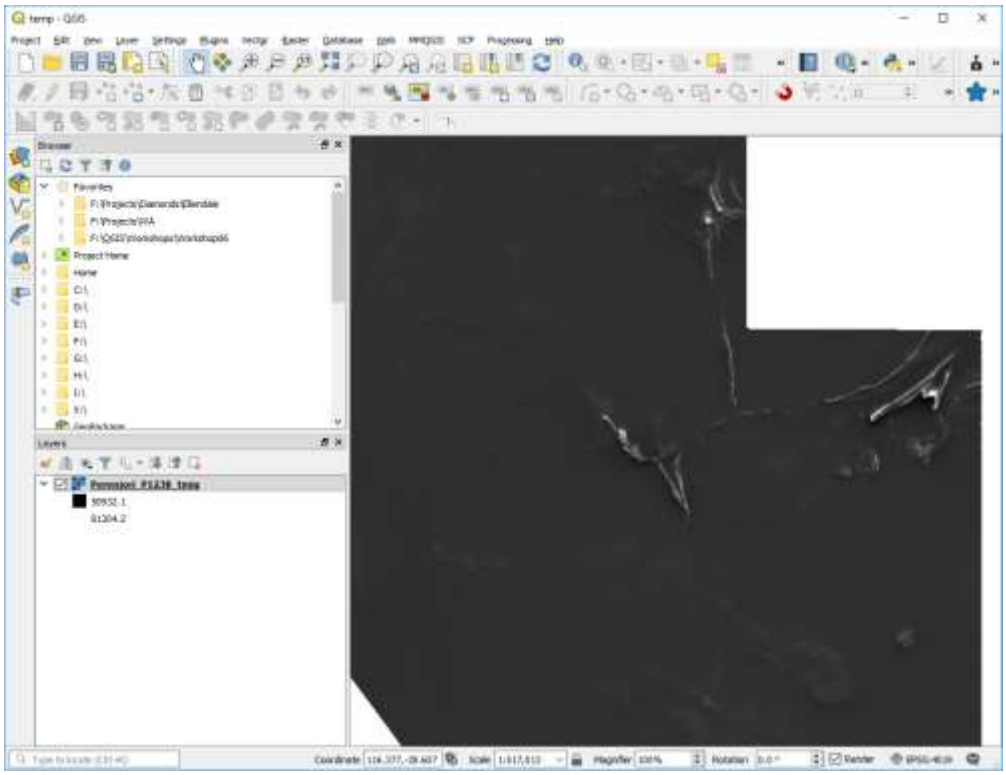
Alternatively, after you have imported the located data, you can save it as a Geopackage file which does not have the 10 character field length restriction.

There are numerous methods to create grids of located data. I typically remove the tie lines by using a filter based on the Line number before I create the grid. One method I have found useful is to use the SAGA > Raster creation tools and use the “Multilevel b-spline interpolation” option.



Grid files are treated as raster files and are usually displayed as greyscale by default. To change the display, open the layer properties dialog and select “Style”. A variety of options are available including changing the colour ramps, colour stretch and display value limits. For a coloured image, use the Render Type > “Singleband Pseudocolour” option.

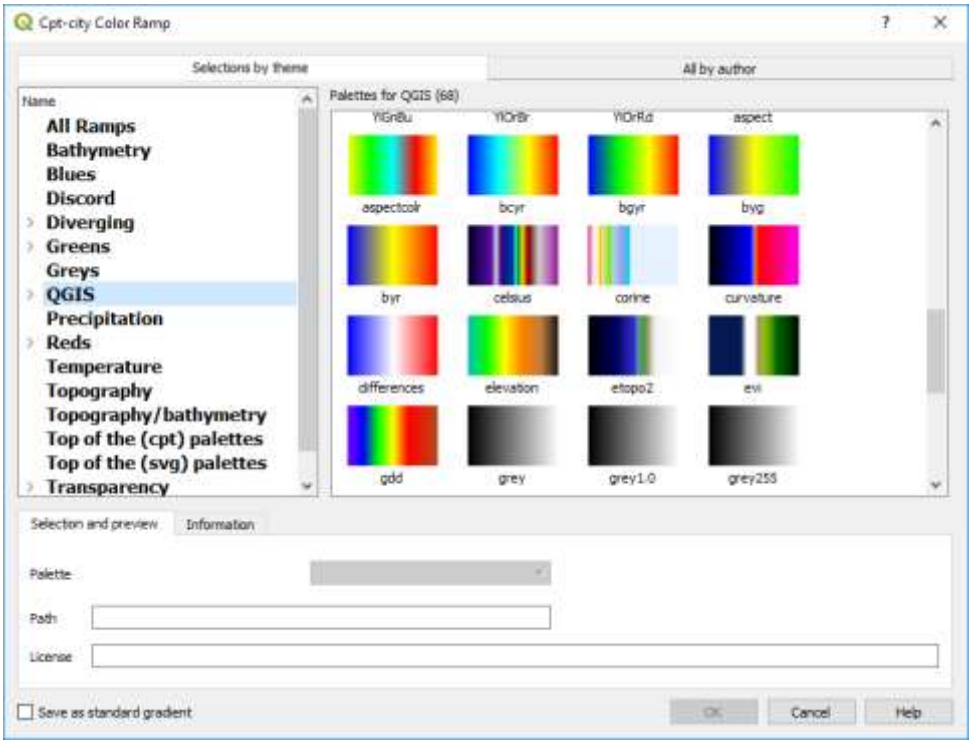
You may also want to create a polygon file as an outline of the area to be gridded. This can then be used to clip the grid to the data.



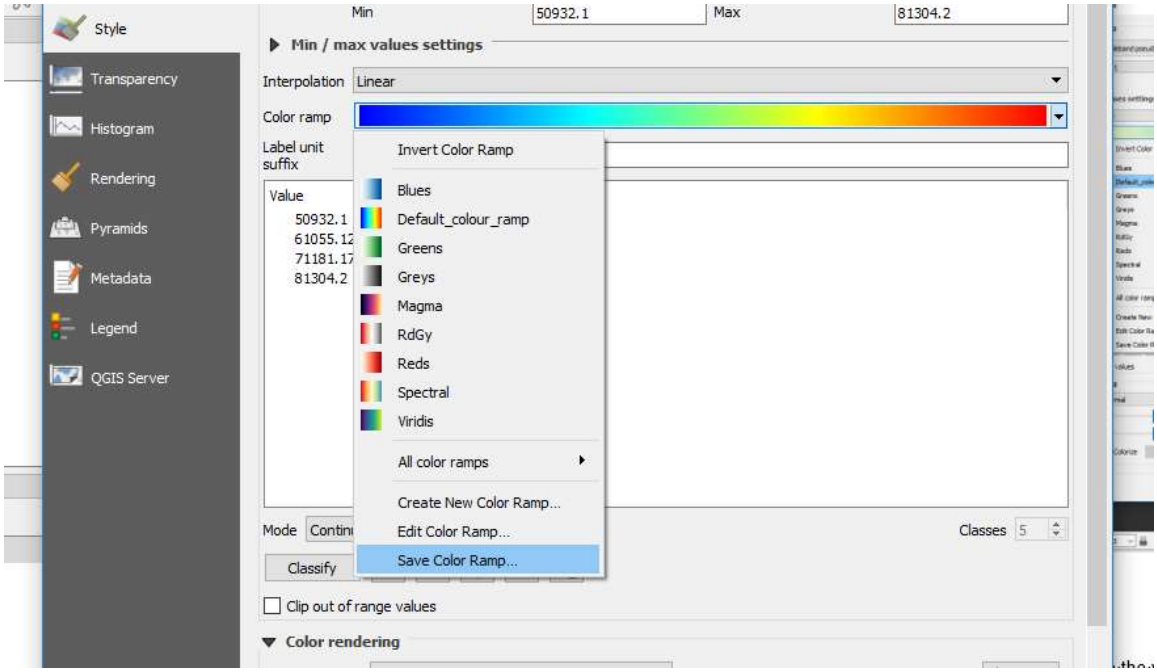
9.2 Colour Ramps

Additional colour ramps are available by clicking on the down arrow to the right of the “Color ramp” dialog box and selecting “Create New Color Ramp…”, select “Catalog: cpt-cty” from the drop-down box to display a variety of available colour ramps.

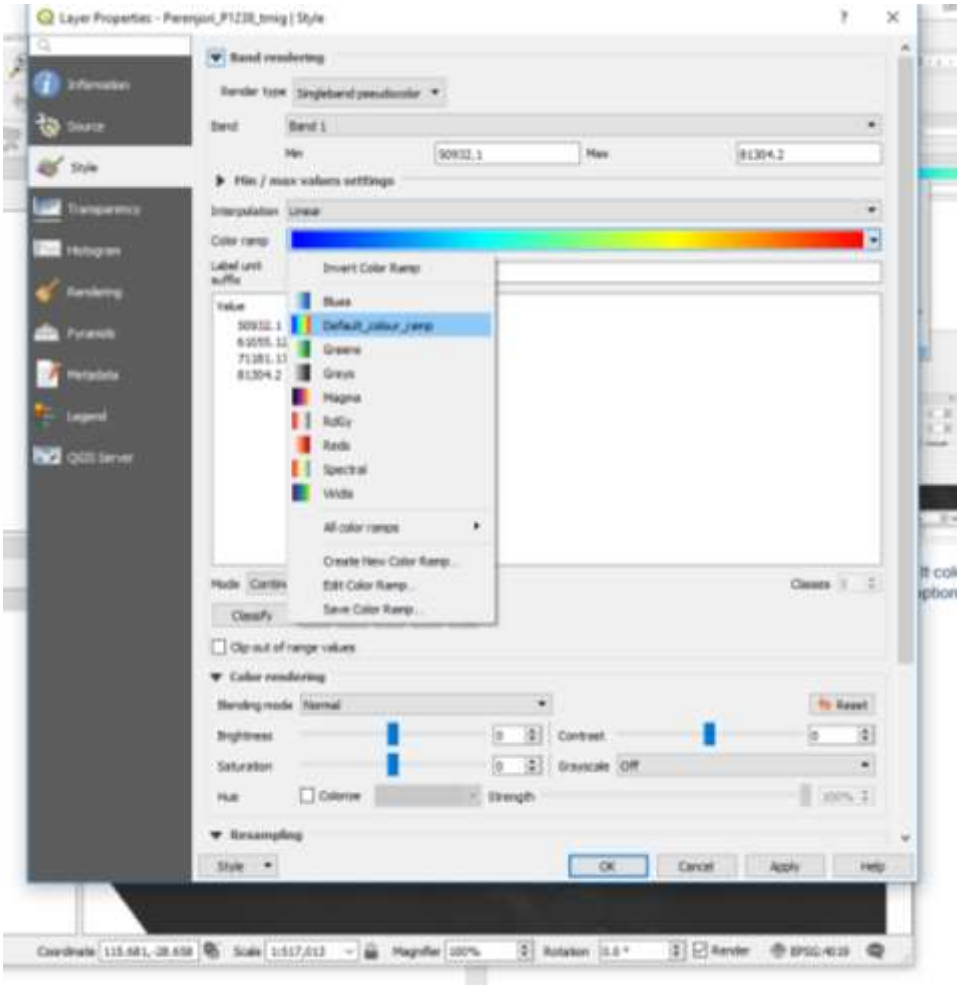
Colour ramps have also been developed by the Centre for Exploration Targeting (CET) in Perth that have better colour perception. These can be reviewed and downloaded from here “https://peterkovesi.com/projects/colourmaps/”. Download the QGIS xml file and import via the Options > Style manager dialog box. My preference is to use the CET-R1 to CET-R3 ramps which are rainbow style colour ramps and they have the blue to magenta colour ranges which work well for shading magnetic images for example.



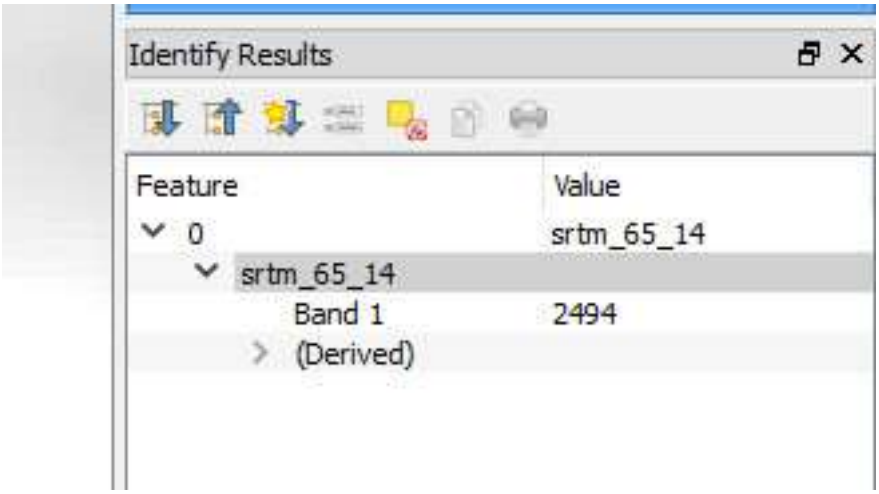
The “bcry” is a also good option for colouring geophysical data grids. Select the “Save as standard gradient” tick box in the lower left of the dialog box, then the Save Color Ramp.



Save the color ramp with a name, e.g. default colour ramp, and “Add to favorites” so it shows up on your quick colour ramp select options.



Note that you can use the information icon to examine the values of a pixel or grid location. If the value is not displayed in the Identify panel, try minimising the left-hand side column, as sometimes the column width is too wide for the panel to display the cell value on the right-hand side.

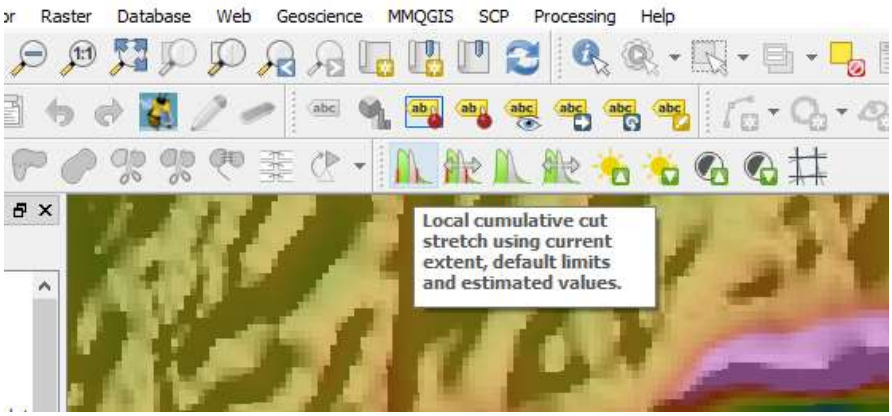


If you open a grid file and have difficulties displaying the data, e.g. with 1VD magnetic images, zoom in to a small area of the grid and then “Stretch to Current Extent” (available as a right click on the layer name in the Layers panel) to stretch the data to something visible.

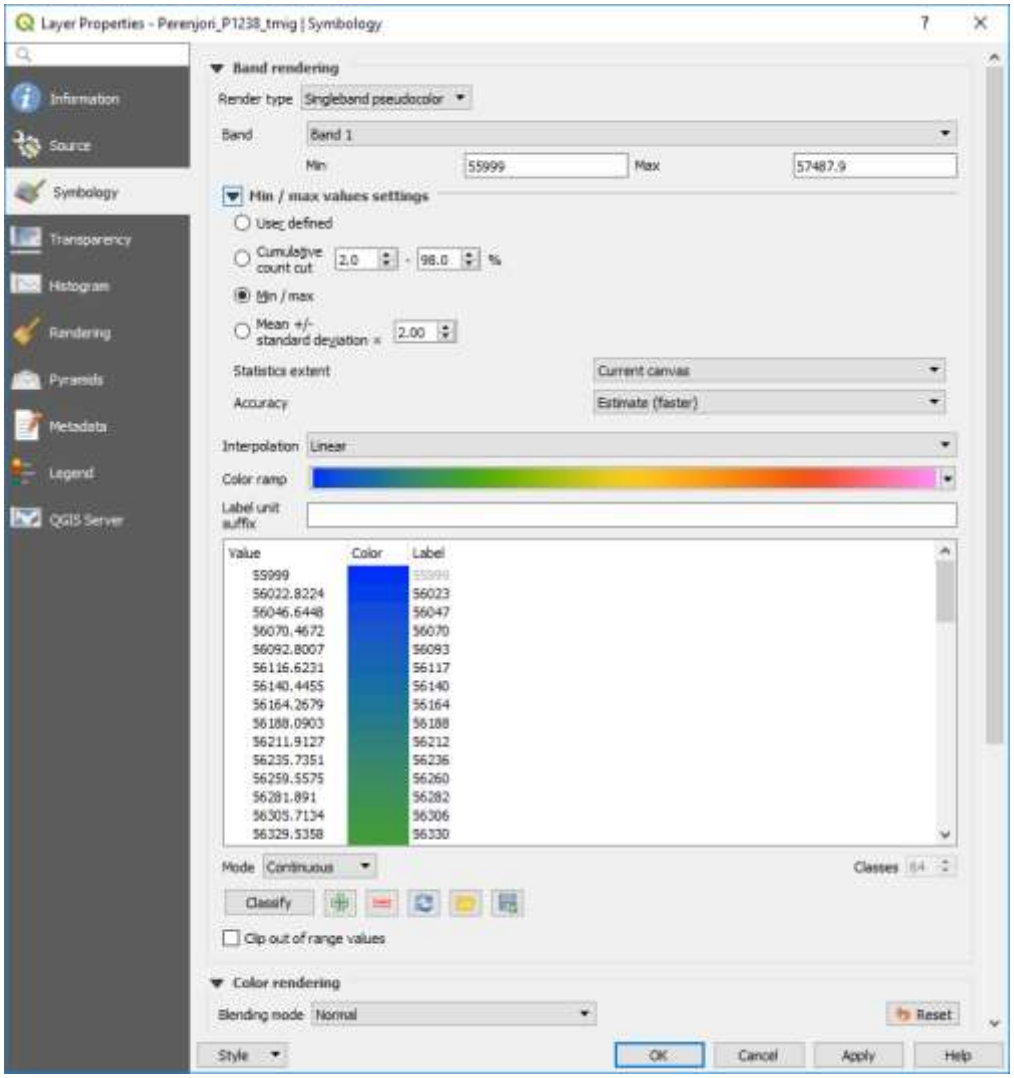
9.3 Custom Data Stretch

The Raster toolbar has a collection of basic display options to change how the image is displayed.

Images can be stretched to the entire image or window extent. See the mouse over for how these icons work.



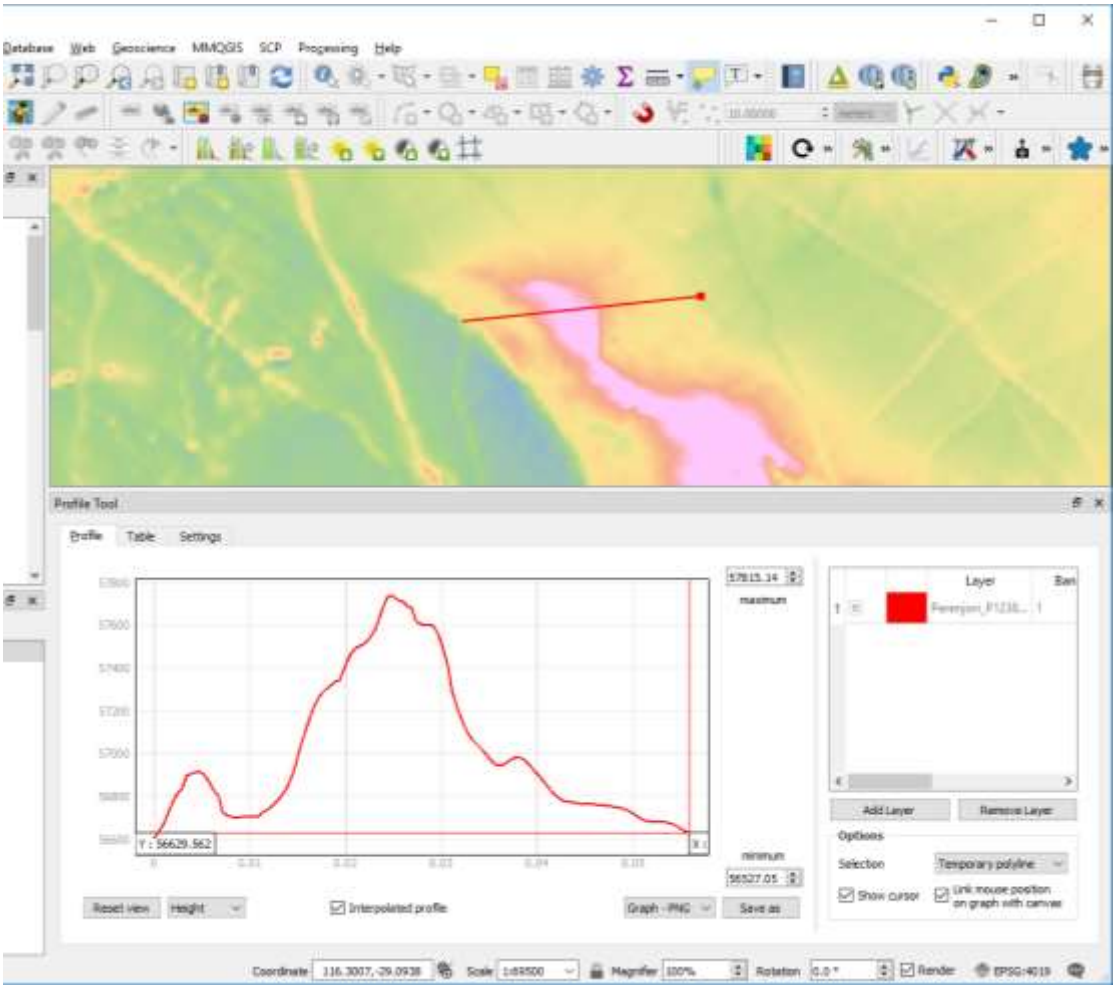
Display settings can also be selected in the Symbology tab of the Layer Properties.



9.4 Profiling Gridded Data

To obtain a profile across any gridded data, use the “Profile” plugin. Open the Profile plugin (usually on the menu bar) and use the “Add Layer” button to add the layer from where you want the values extracted. Draw a line using one click to start and a double click to complete the line.

The resulting profile values can by copied to the clipboard (under the Table tab) for use in programs like Excel.



9.5 Creating Stacked Profiles and Colour Bars

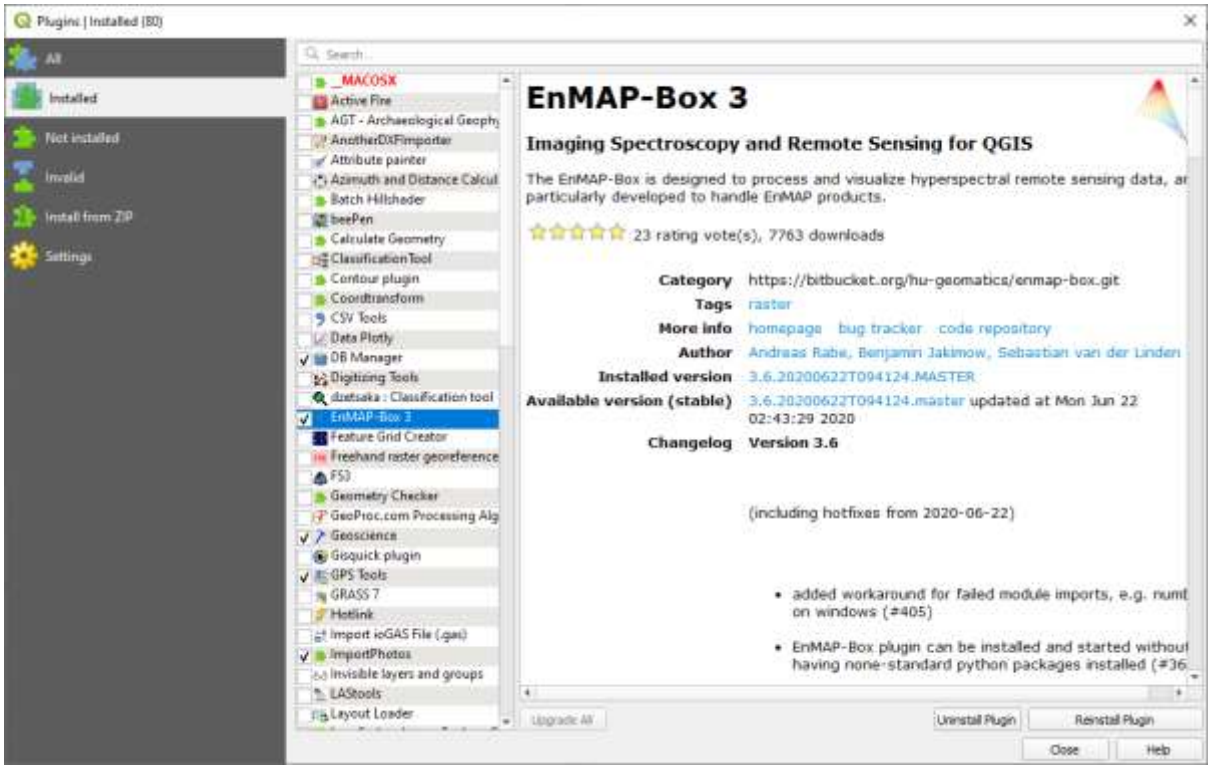
Creating “stacked profiles” of data, especially magnetic data is important for the identification of small discrete features in wide spaced aeromagnetic data. One example is in the search for kimberlite pipes in regional (>300 m) spaced line data.

This algorithm has been created by Benoit at GeoProcessing (http://www.geoproc.com/be/plugins.xml) in South Africa and is part of their “GeoProc” toolset. The stacked profile tool allows the user to import located line data to plot stacked profiles of the data. It is important that the located data is in "point" format not multi-point data format.

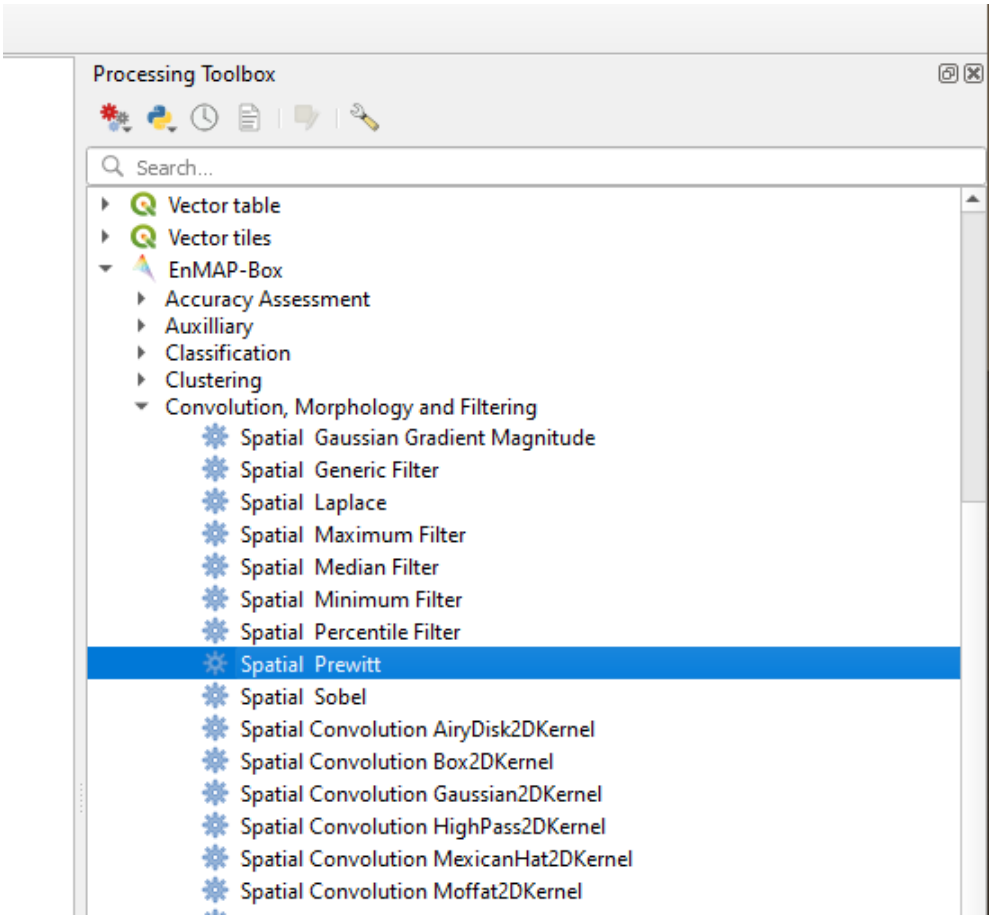
Coloured bar scales can also be created for coloured images using the Composer > Create Colour Scale Bar” tool. There are some dependencies that require installation for these to work so please read the installation instructions. The plugin loads the menu items into the Processing Toolbox.

9.6 First and Second Vertical Derivatives

First vertical derivative images can be created using the EnMap Box plugin and can be downloaded from this link (https://www.enmap.org/enmapbox.html). This plugin has been designed to cater for a new satellite due to be launched later in 2020 and has a large variety of tools for remote sensing data including filtering.



When the plugin is installed it puts and additional link in the Processing Toolbox.



The Spatial Prewitt filter creates a first vertical derivative (1vd) image, the Spatial Laplace filter creates a second vertical derivative (2vd) image and the Spatial Gaussian Gradient Magnitude filter creates a type of analytical signal image.

Clipping of the resultant images may be required and set the background with no data to zero or -99999 so it can be set to transparent.

Note also when creating images for use in MapInfo, create ERMapper ers grid files.

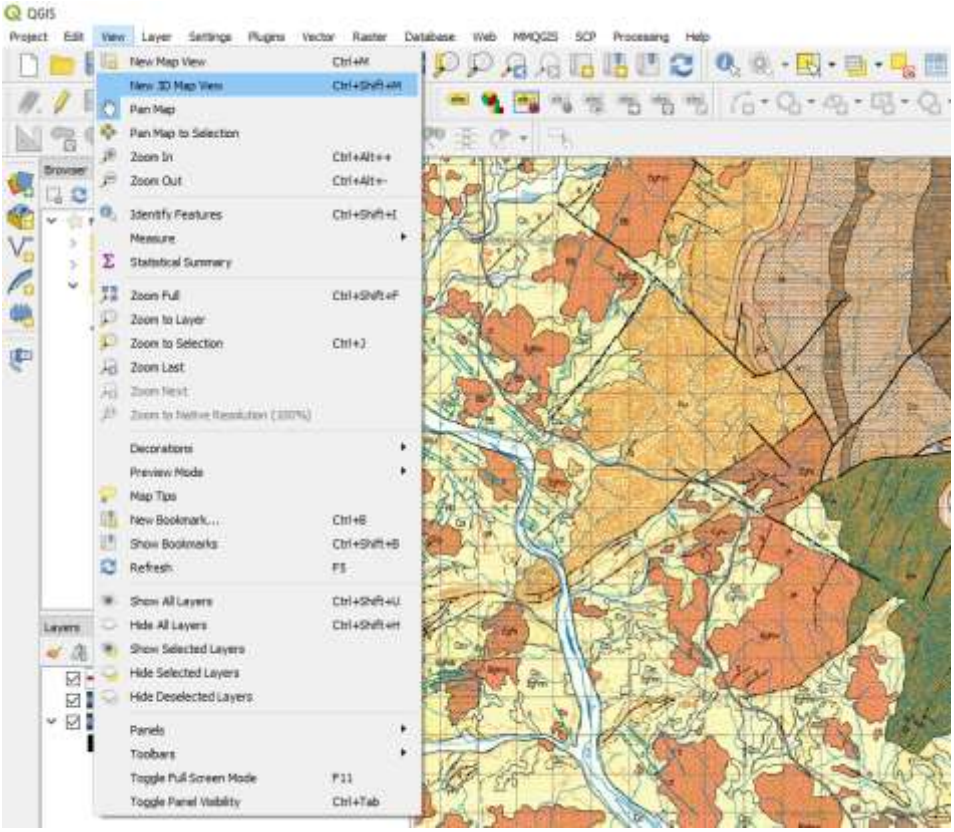
10: 3D IMAGE DISPLAY

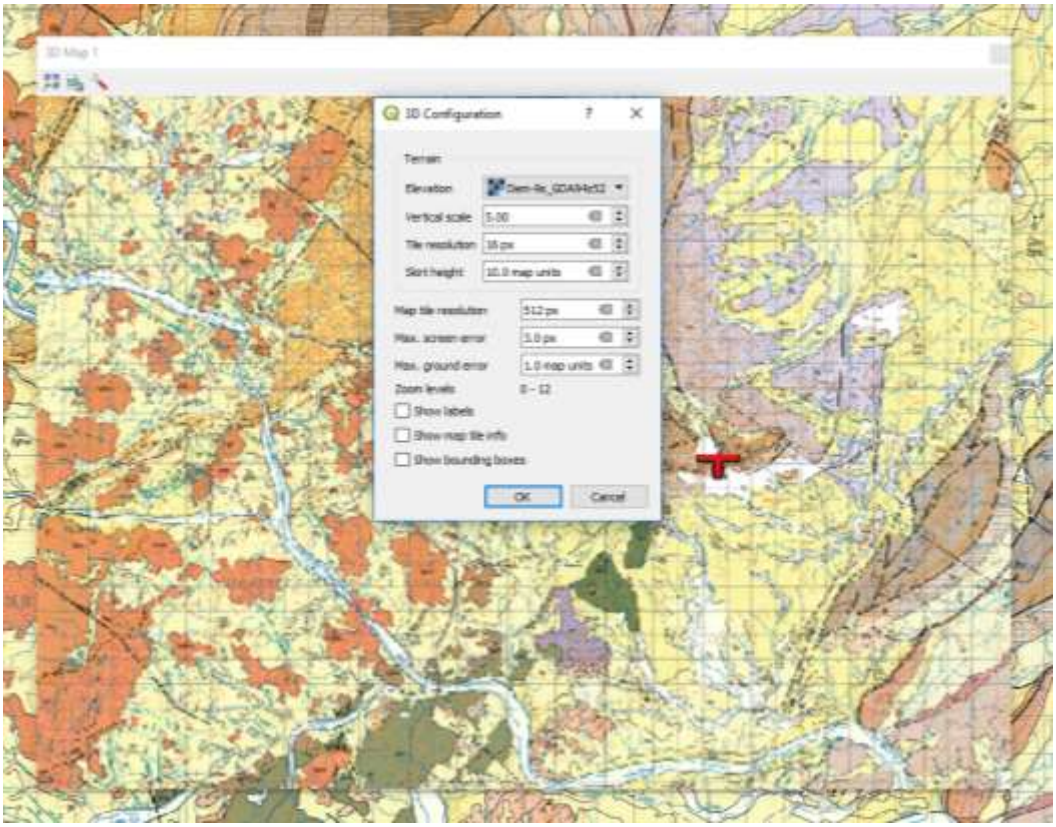
QGIS v3 now has a 3D view capability built in as a standard part of the program (3d Map View) or by using the QGIS2threejs plugin. The options for the 3D Map View are limited at this time but a recent crowd funding effort has enabled planning and extra programming for the 3D options to be greatly improved. The QGIS2threejs is the best option at this time for viewing geological data in 3D. Downhole drill hole traces can be displayed if the 3D coordinates have been calculated.

10.1 3D Map View

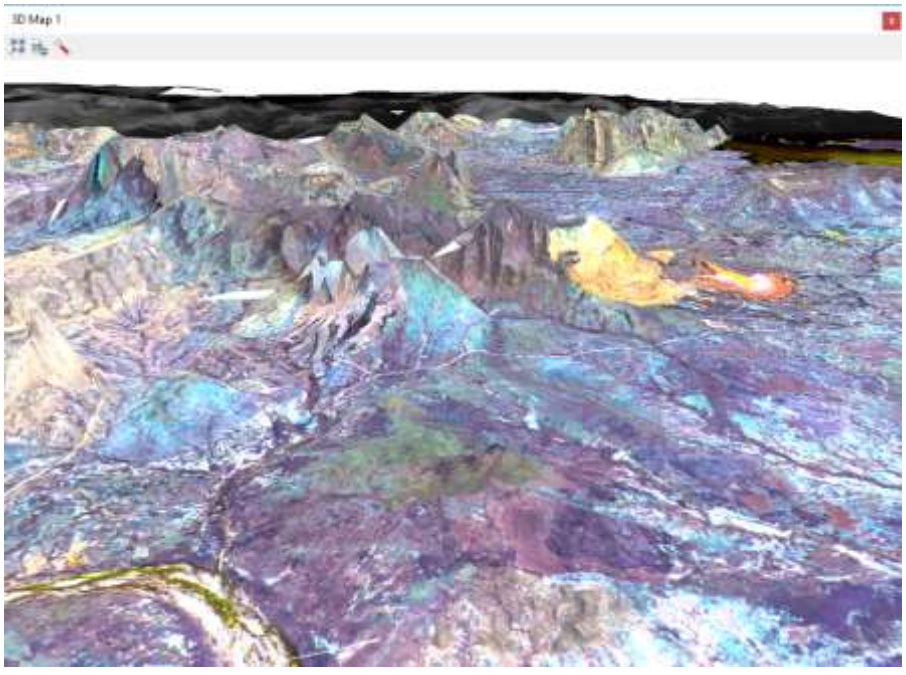
The layers require to be projected, i.e. not a geographic projection, lat/long, and they should all be in the same projection.

To run the 3D view, place the layers into the map window with the DEM layer at the bottom of the layer stack. Go to the View > New 3D Map View menu item and create a 3D map window. Resize the window to suit and select the little spanner symbol to open-up the options dialog.





Select the layer to be used as the “Elevation”, set the vertical exaggeration and press OK. Use the hand icon to move the display in the window. To tilt the display to see the 3D effect, hold the shift key and drag the mouse towards down. With the shift key depressed you can also rotate the image. Scroll speed will be dependant upon the size of your grid files and the speed of your PC.

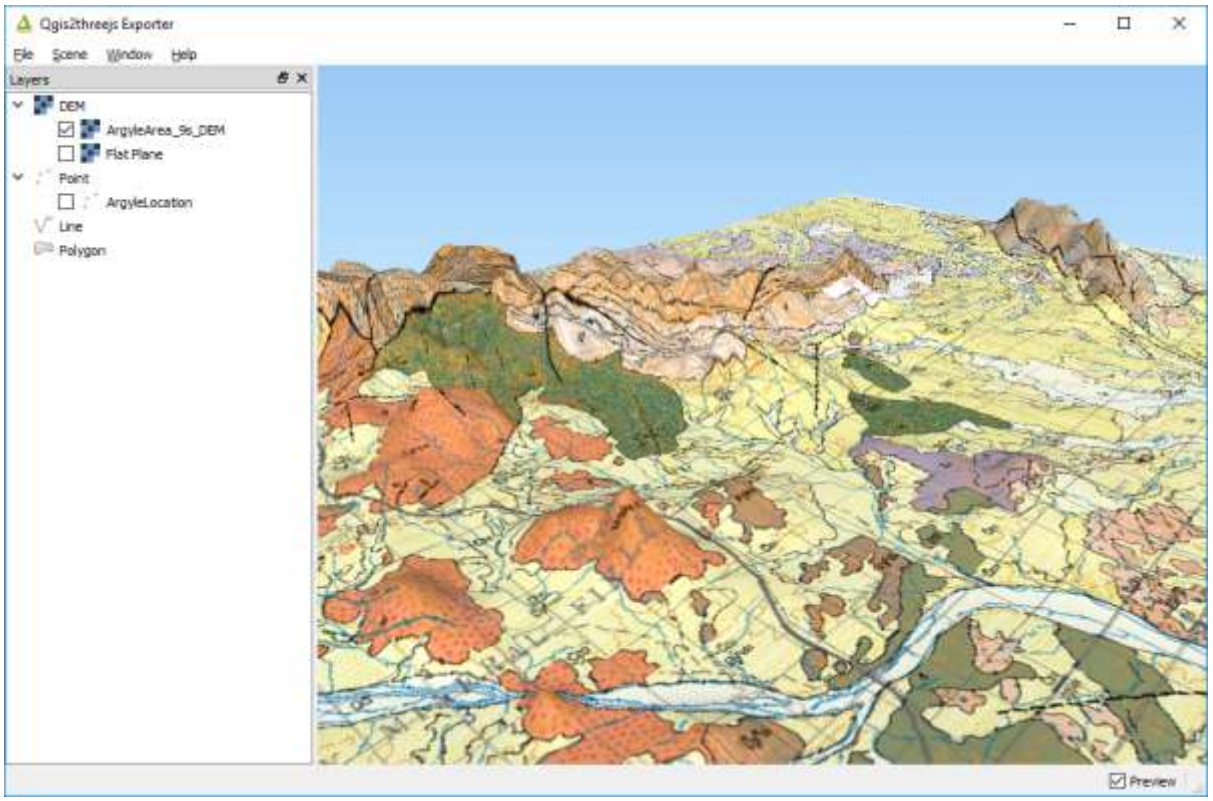


Any image displayed in the map window can be used for 3D display.

10.2 QGIS2Threejs Plugin

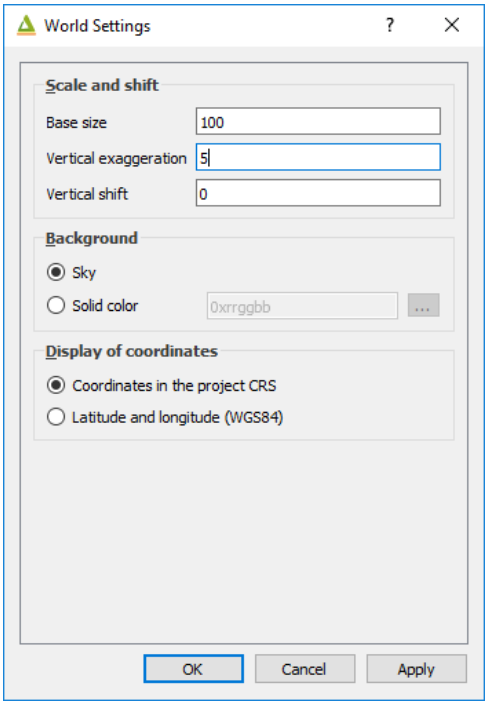
This plugin is more flexible than the 3D map view at the present stage of its development for geological application. The layers require to be projected, i.e. not a geographic lat/long projection, and they should all be in the same projection. If you have data in 3D, i.e. with x, y and z coordinates, then this plugin can display the data. If you get weird effects, you may have a lat/long layer in the map window which may be causing problems. Close any lat/long layers and re-run the plugin.

To use this plugin, load a DEM or any type of grid file over which you would like to drape data. For example you may wish to drape a satellite image or geological map over a digital terrain model

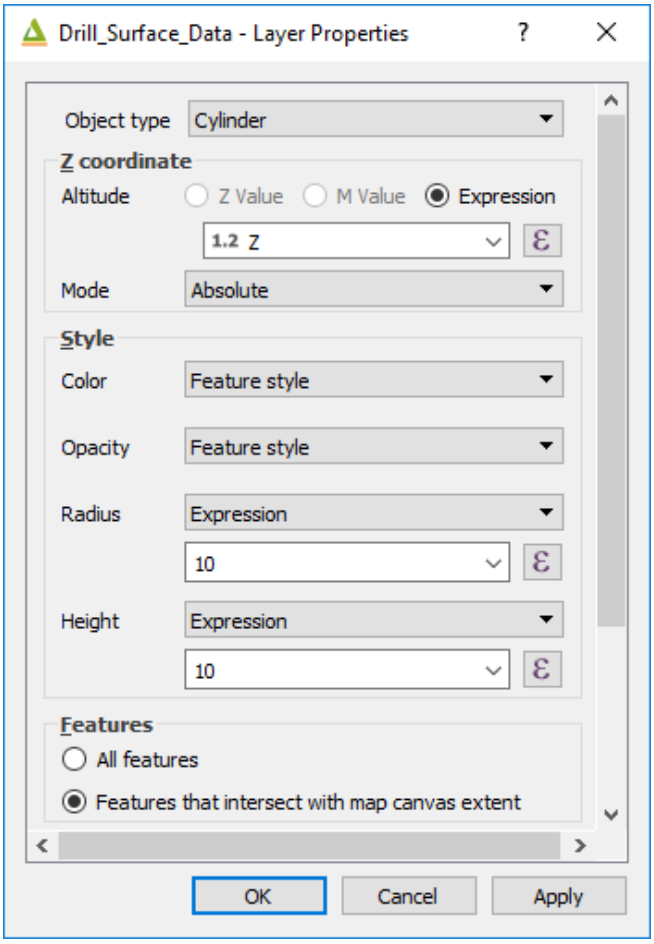


Make sure the grid is on the bottom, with the layers to be draped on top of the DEM/grid layer. Run the QGIS2Threejs plugin and select the DEM layer.

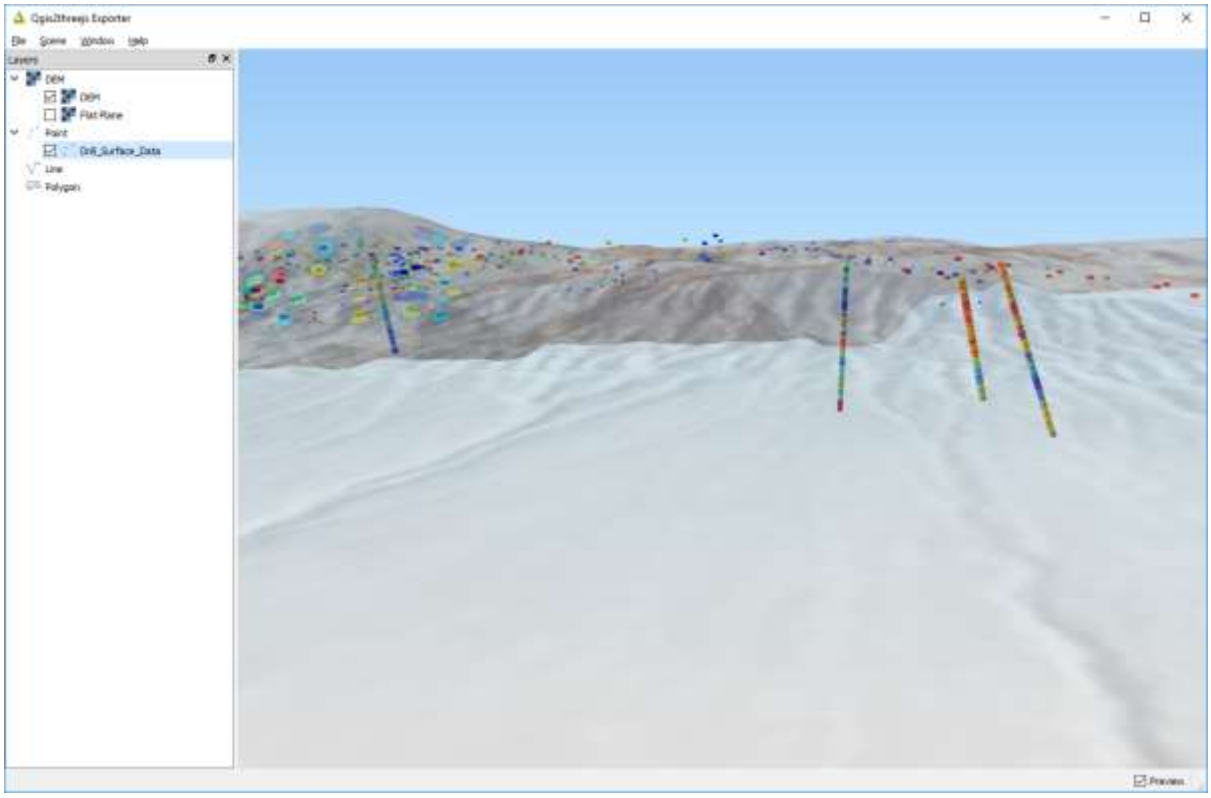
Vertical exaggeration can be changed using the Scene > World Settings dialog box.



If you have vector data with a z (e.g. RL or elevation data) then right click on the vector layer name in the QGIS2Threejs window and select the z value to use in the “Z Coordinate” options. Downhole drill hole data can be plotted using this method.



The image below shows a Google Earth image, draped over a SRTM digital terrain model, with a vector file of surface samples and drill hole sampling.



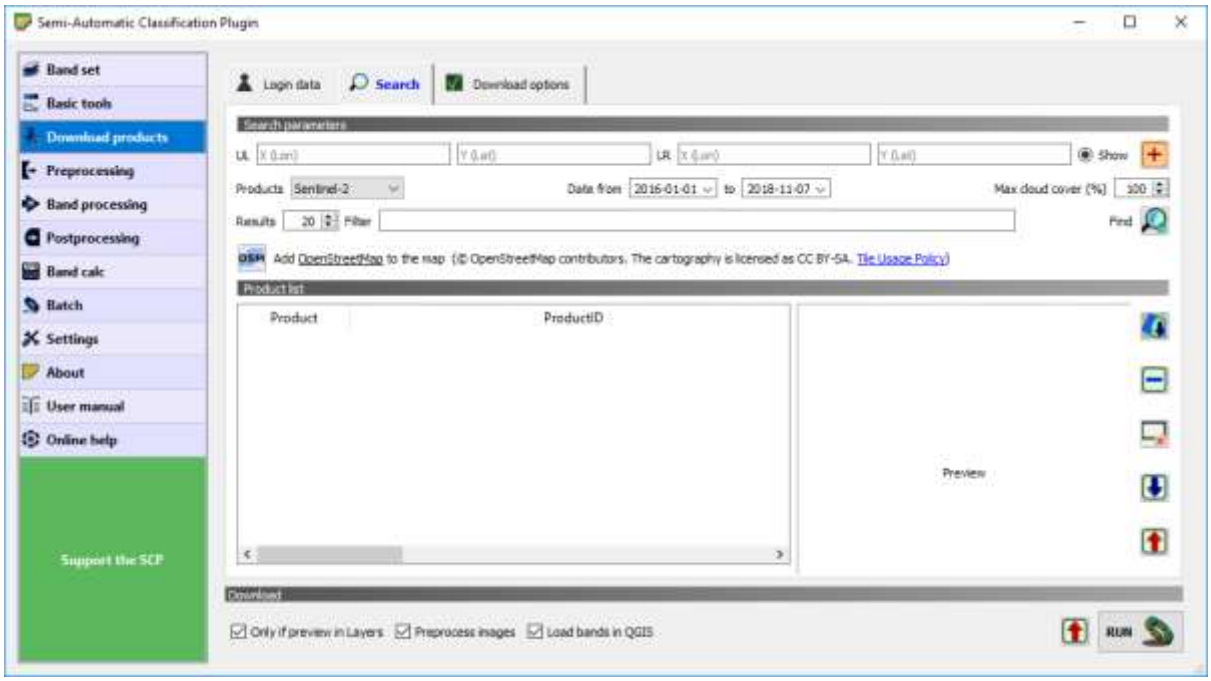
11: REMOTE SENSING

The availability of free satellite and other remote sensing data has created unique opportunities for the display of this data to assist geological interpretation and analysis. QGIS can display the normal satellite images but it also has a powerful plugin, the Semi-Automatic Classification (SCP) plug-in, which can be used to source, select, download and process satellite imagery. Video tutorials are available on the web (https://www.youtube.com/watch?v=GFrDgQ6Nzqs) and cover a variety of remote sensing applications including land cover classification.

To download ASTER and Landsat data, you are required to register (free) at the USGS EarthExplorer portal. These registration details will be required to be entered on the SCP download/login window. Sentinel data download requires (free) registration at the ESA Sentinel data access portal. Note that it might take three or four days for your registration at ESA to become active. Recently, the search times on the ESA site via the SCP plugin have been very slow and it has been my experience lately that the USGS EarthExplorer portal is the fastest way to select and download ASTER and Sentinel data.

11.1 Using the Semi Automatic Classification Plugin

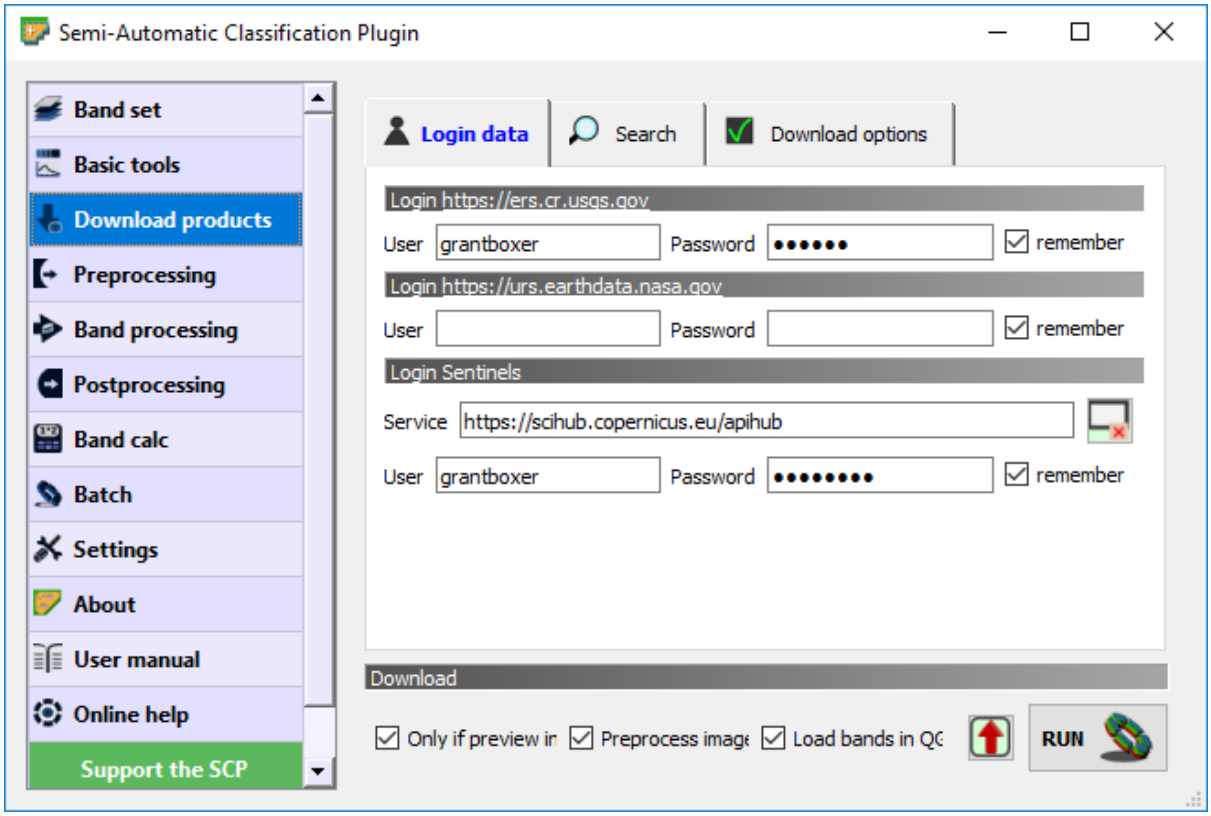
Selection, downloading and processing of satellite remote sensing data can be achieved using the Semi Automatic Classification Plugin (SCP) written by Luca Congedo (https://fromgistors.blogspot.com/p/semi-automatic-classification-plugin.html). After installing the plugin you can open the plugin via the main menu bar. Note the plugin automatically adds panels and toolbars which I normally close to free up window space.



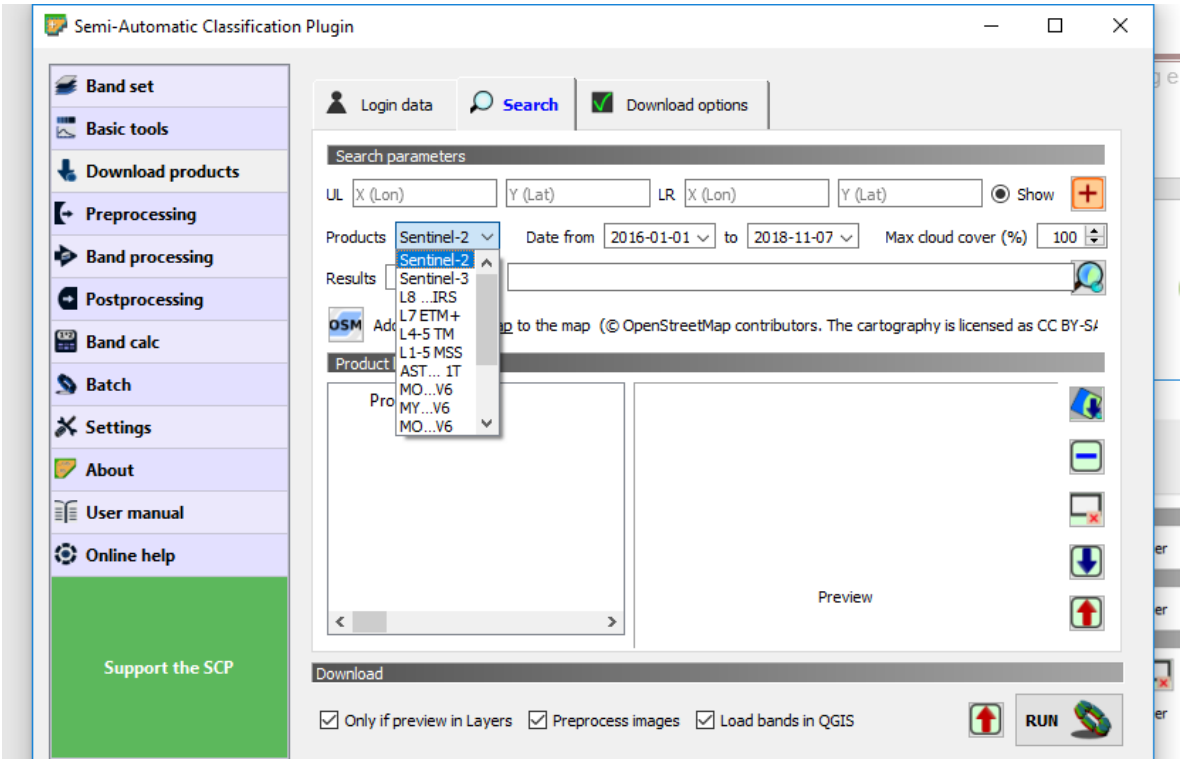
The main SCP window shows tabs for downloading data, as well as a variety of other pre and post processing options, band calculations and tools for land cover classification.

To download data you need to register with the USGS via their EarthExplorer portal (free registration, http://earthexplorer.usgs.gov/) for ASTER and Landsat data and with the European Space Agency (ESA) via their Sentinel data access portal (https://scihub.copernicus.eu/dhus/#/home). Enter these login details into the relevant sections of the SCP Download Products > Login data tab. Make sure you click “Remember” so you don’t have

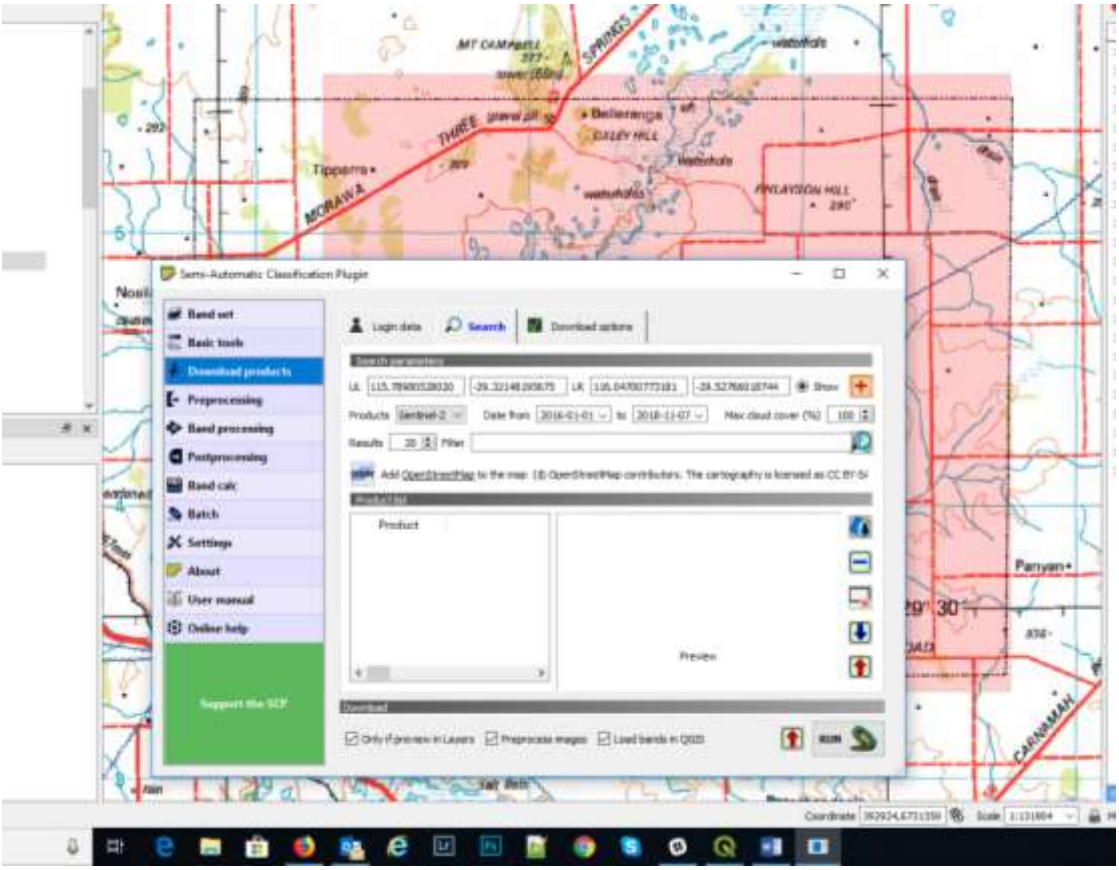
to re-enter your login details each time. Note also that logins with ESA make take a couple of days to initialise.



Once all the logins are complete, then you are ready to download data. Have the area that you wish to obtain data displayed in your QGIS map window as we will create a search area directly into this window. Click on the Search tab of the Download Products window.

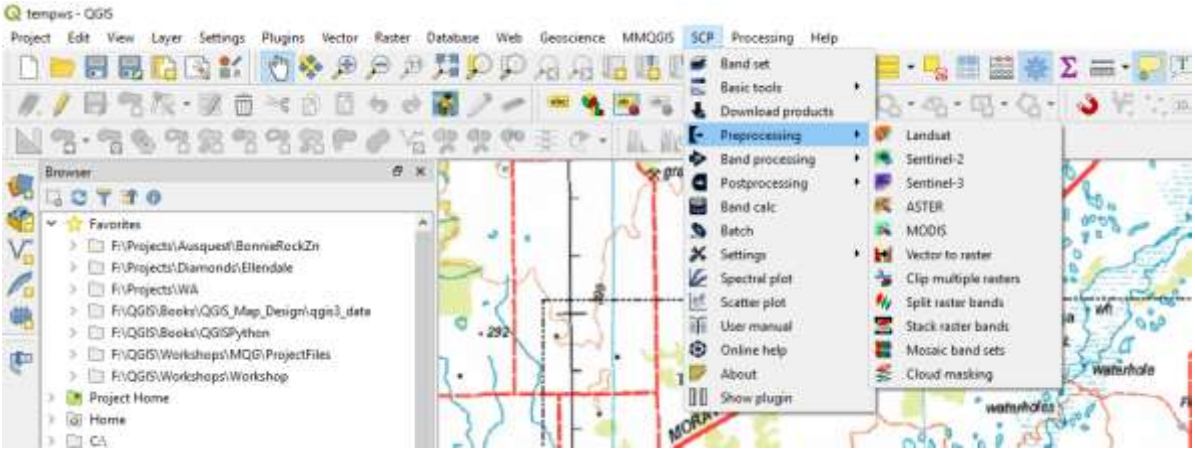


The required product can be selected via the “Products” dropdown list. To select a search area, click on the orange-red cross in the top RHS of the window, then left click the top left hand side of the map area, then right click on the lower right hand side to set your search area. This will then populate the search area parameters.



You can further refine your data search by entering for example a Sentinel 2 tile number into the "Filter" window to speed up searching and ensuring you only download the required tiles. You can select the maximum allowable cloud cover and any date ranges. Note that for ASTER data only download data prior to 1st April 2008 as the SWIR became non-operational after that date.

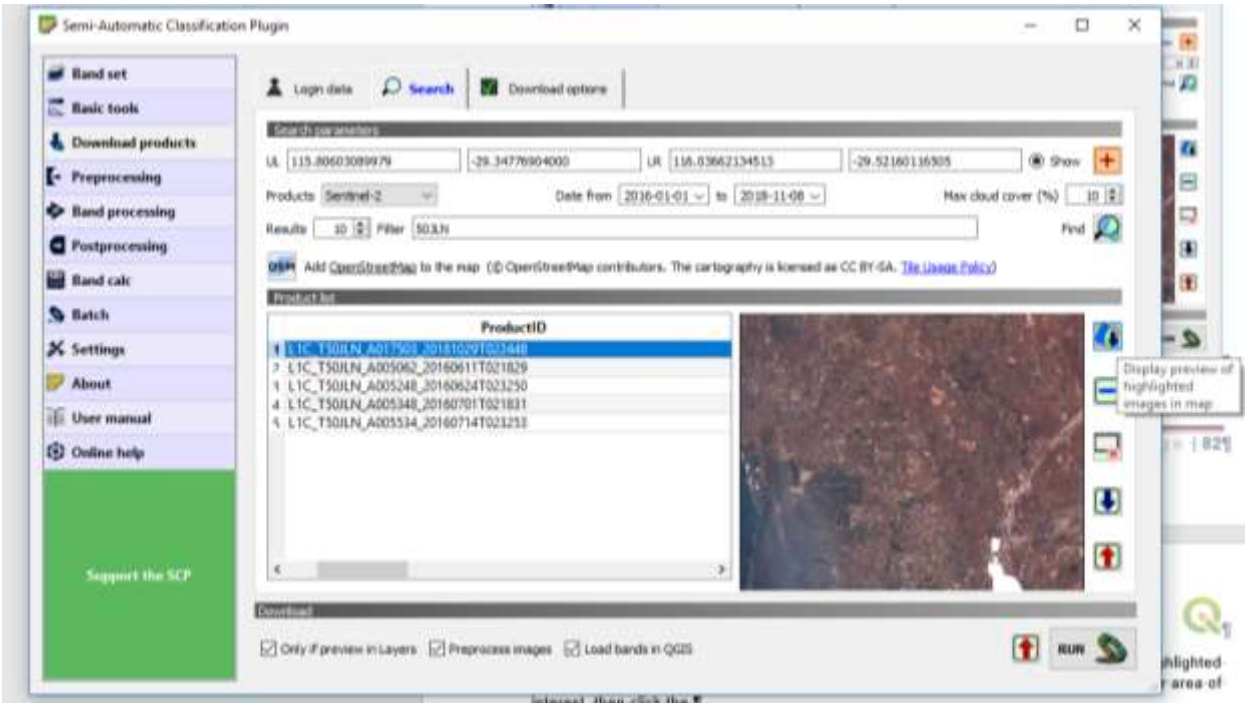
Once you have selected the search area, open the "Preprocessing' window.



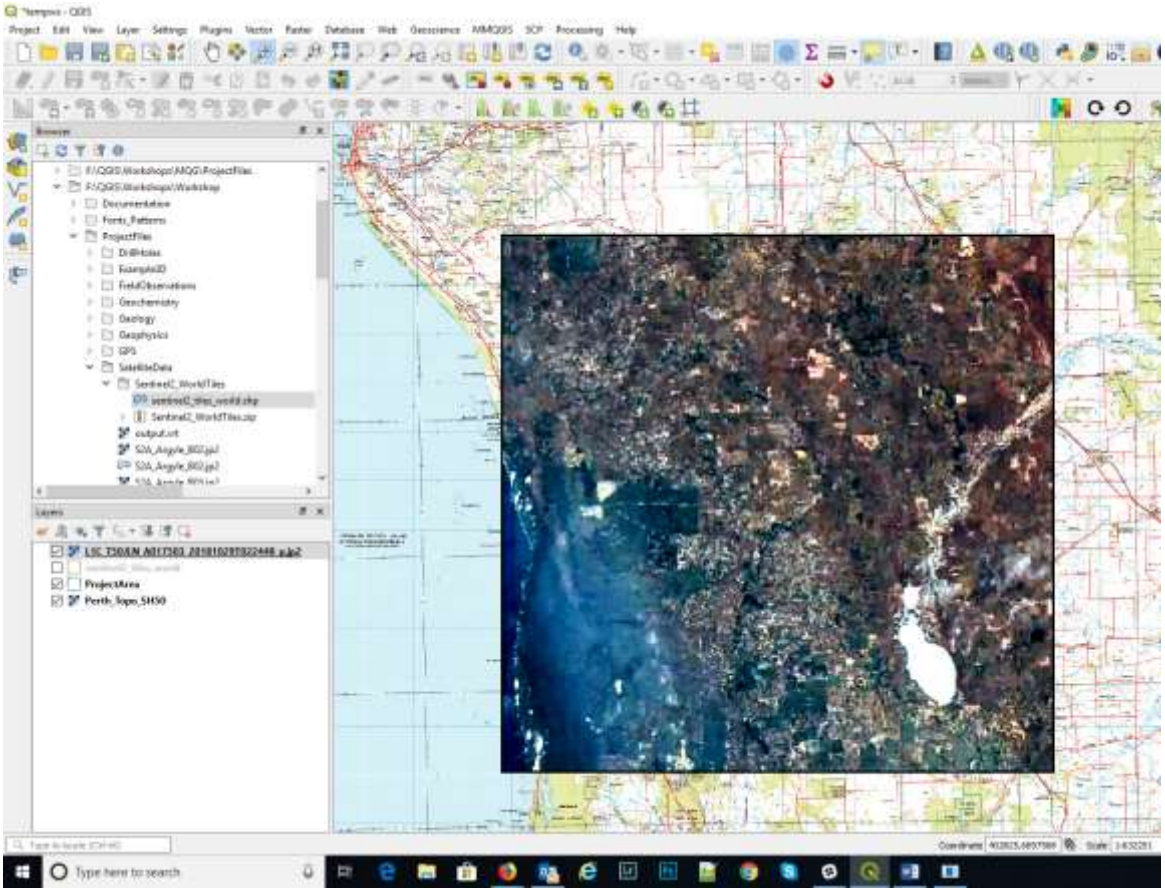
The Preprocessing window allows SCP to do atmospheric and other adjustments to the source satellite data after download, e.g. DOS 1 atmospheric correction on L1C corrected Sentinel 2 data. Note that preprocessing will only occur if the "Preprocess Images" check box is ticked in the Download window. If you download Sentinel 2 L2A data, the atmospheric corrections have already been applied. Note also the other check boxes to limit what gets downloaded and what is displayed in the map window.

Once you have set your search parameters, click the "Find" icon.

SCP will search the data for tiles fitting the search parameters. The time to retrieve the data will depend upon internet speed. If you get a time-out error or cannot connect type message, check your login details.



A list of selected tiles will be shown in the ProductID window and each item can be highlighted and viewed in the RHS window. Note that you can now choose between Sentinel 2 L1C and L2A processing levels. The L2A data has been corrected for atmospheric effects. Check that the scene is suitable, e.g. no cloud over your area of interest, then click the icon “Display preview of highlighted images in map”. This will then download a low-resolution full scene image into your map window to ensure it covers the correct area.



To download this data, return to the Download products window and make sure the “Download” “Only if preview in Layers” is checked on. This will ensure only those layers you have in the map window will be downloaded. If all OK, click the run button and save it to the required location. The download and pre-processing may take some time, 10-20 minutes, and it is advised not to use QGIS during this time as it may crash the process. Other programs on your PC may be used.

The download process will entail downloading all the band data, then running the selected corrections, before displaying the final set of image bands into your map window. These bands can then be used to create RGB images and allow band ratios to be calculated.

Note that you can create a multiband tiff file that holds all the band data in one tiff file. This can be created via the Raster > Miscellaneous > Build Virtual Raster option, and by selecting all the bands and then using the “Highest” resolution, so that the pixel sizes of all the bands will be the same (“pansharpened to the smallest pixel size). Processing of this multiband file is now possible in the SCP or Orfeo Tool Box plugins.

The SCP Plugin also allows the user to do a multitude of other task including Principal Components Analysis (PCA). Note that to use PCA all the images must have the same pixel size, and this may require “resampling” of the image (use the Processing Toolbox > SAGA > Raster Tools > Resampling algorithm).

11.2 ASTER Data

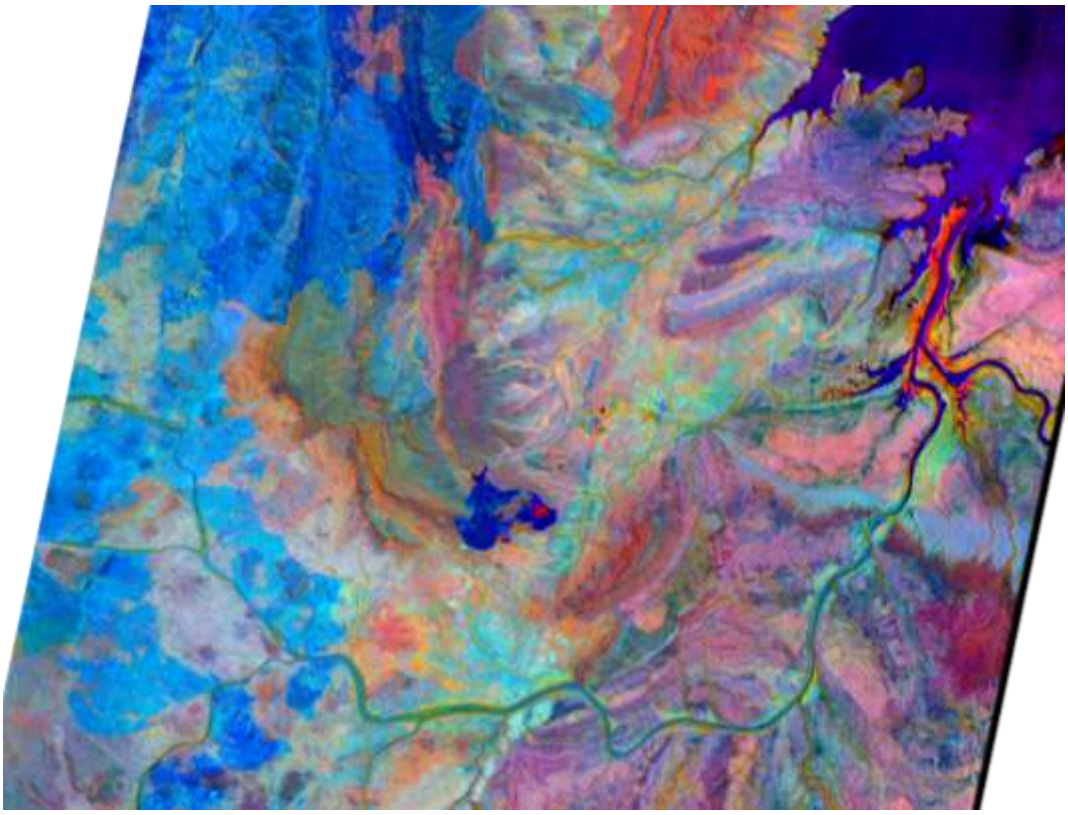
Details of the ASTER (Advance Spaceborne Thermal Emission and Reflection Radiometer) scanner bands are shown in the figure below (from Abrams and Hook 2016).

ASTER data is now freely available worldwide but note that the SWIR sensor (bands 4 to 9) became inoperable on 1st April 2008, and therefore only data acquired before this time will be suitable for mineral mapping.

ASTER Users Handbook

Subsystem	Band No.	Spectral Range (μm)	Spatial Resolution, m	Quantization Levels
VNIR	1	0.52-0.60	15	8 bits
	2	0.63-0.69		
	3N	0.78-0.86		
	3B	0.78-0.86		
SWIR	4	1.60-1.70	30	8 bits
	5	2.145-2.185		
	6	2.185-2.225		
	7	2.235-2.285		
	8	2.295-2.365		
	9	2.360-2.430		
TIR	10	8.125-8.475	90	12 bits
	11	8.475-8.825		
	12	8.925-9.275		
	13	10.25-10.95		
	14	10.95-11.65		

Table 1: Characteristics of the 3 ASTER Sensor Systems.



An example of ASTER band combinations using ratio 4/7 (red), 4/3 (green) and 2/1 (blue)around the Argyle mine area.

ASTER bands and band ratios for geological applications are shown in the tables below (from ASTERDataProcessing_GA7833.pdf available from Geoscience Australia).

Common ratio & band combinations

Features	Red	Green	Blue	Reference
Vegetation and visible bands**	3, 3/2, or NDVI	2	1	
AlOH minerals/advanced argillic alteration***	5/6 (phen)	7/6 (musc)	7/5 (kaol)	Hewson (CSIRO)
Clay, amphibole, laterite	$(5x7)/6^2$ (clay)	6/8 (amph)	4/5 (lat)	Bierwith
Gossan, alteration, host rock	4/2 (goss)	4/5 (alt)	5/6 (host)	Volesky
Gossan, alteration, host rock	6 (goss)	2 (alt)	1 (host)	
Decorellation (envi)	13	12	10	Bierwith
Silica, carbonate, basic degree index	(11x11)/10/12 (silica)	13/14 (carb)	12/13 (basic)	Bierwith
Silica, carbonate	(11x11)/(10x12)	13/14	12/13	Nimoyima
Silica	11/10	11/12	13/10	CSIRO
Discrimination for mapping	4/1	3/1	12/14	Abdelsalam
Discrimination in sulphide rich areas	12	5	3	
Discrimination	4/7	4/1	(2/3) x (4/3)	Sultan
Discrimination	4/7	4/3	2/1	Abrams (USGS)
Silica, Fe^{2+}	14/12	(1/2) + (5/3)	MNF Band 1	Rowan (USGS)
Enhanced structural features	7	4	2	Rowan (USGS)

*Comments by Hewson
**Equivalent to Landsat RGB 432
***Alunite/pyrophyllite, mica, kaolinite/dickite

Band rations are easily calculated in the SCP plug-in. My personal experience for using the ASTER data in Western Australia and Peru, is that the discrimination ratios using ratio 4/7 (red), 4/3 (green) and 2/1 (blue) works well in most situations. The AlOH minerals/Advanced argillic alteration combination and the Alunite-Kaolinite-Pyrophyllite image also works well for detecting alteration associated with porphyry copper mineralisation.

Commonly used ratios

Feature	Band or Ratio	Comments	Reference
Iron			
Ferric iron, Fe^{3+}	2/1		Rowan; CSIRO
Ferrous iron, Fe^{2+}	5/3 + 1/2		Rowan
Laterite	4/5		Bierwith
Gossan	4/2		Volesky
Ferrous silicates (biot, chl, amph)	5/4	Fe oxide Cu-Au alteration	CSIRO
Ferric oxides	4/3	Can be ambiguous*	CSIRO
Carbonates / Mafic Minerals			
Carbonate / chlorite / epidote	(7+9)/8		Rowan
Epidote / chlorite / amphibole	(6+9)/(7+8)	Endoskarn	CSIRO
Amphibole / MgOH	(6+9)/8	Can be either MgOH or carbonate*	Hewson
Amphibole	6/8		Bierwith
Dolomite	(6+8)/7		Rowan, USGS
Carbonate	13/14	Exoskarn (cal/dolom)	Bierwith, Nimoyima, CSIRO
Silicates			
Sericite / muscovite / illite / smectite	(5+7)/6	Phyllic alteration	Rowan (USGS); Hewson (CSIRO)
Alunite / kaolinite / pyrophyllite	(4+6)/5		Rowan (USGS)
Phengitic	5/6		Hewson
Muscovite	7/6		Hewson
Kaolinite	7/5	Approximate only*	Hewson
Clay	$(5x7)/6^2$		Bierwith
Alteration	4/5		Volesky
Host rock	5/6		Volesky
Silica			
Quartz rich rocks	14/12		Rowan
Silica	(11x11)/10/12		Bierwith
Basic degree index (gnt, cpx, epi, chl)	12/13	Exoskarn (gnt, px)	Bierwith, CSIRO
SiO2	13/12	Same as 14/12	Palomera
SiO_2	12/13		Nimoyima
Siliceous rocks	(11x11)/(10x12)		Nimoyima
Silica	11/10		CSIRO
Silica	11/12		CSIRO
Silica	13/10		CSIRO
Other			
Vegetation	3/2		
NDVI	(3-2)/(3+2)	Normalised difference vegetation index	

Other possibly useful ASTER band calculations and combinations are listed below.

Abrams Ratio – 5/7, 4/5 and 3/1 in RGB

Sabin Ration – 5/7, 3/1 and 3/5 in RGB

Mineral Indices of Ninomiya (2004)

OH Minerals Index – (Band 7/ Band 6) * (Band 4/Band 6)

Kaolinite Index – 4/5 * 8/6

Alunite Index – 7/5 * 7/8

Calcite Index – 6/8 * 9/8

Porphyry Alteration Index – 4, 6 and 8 and RGB (advanced argillic and phyllic alteration in pink to red colours)

Alunite and kaolinite enhanced by 4/5 or 4/6

Sericite – phyllic alteration enhanced by 5/6

Propylitic alteration enhanced by 5/8

Remember the resulting images may have artefacts caused by low sun angles, clouds, etc. so be cautious in using the data. Remote sensing vendors can undertake more advanced processing and interpretation of this data, and the rough processing described herein should be used with caution.

11.3 Landsat Data

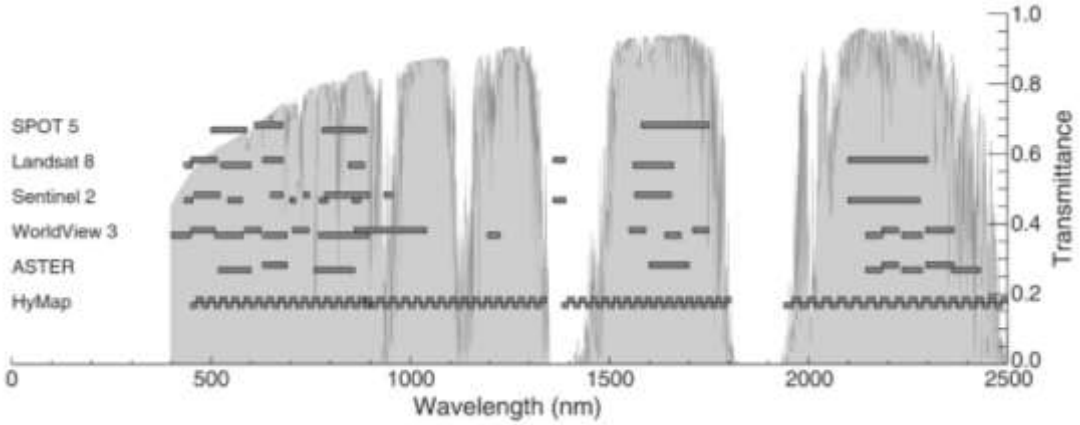
Landsat 8 data is collected over 11 bands as illustrated below.

Band Reference Number	Band Description	Band Center (nm)
1	Coastal Aerosol (Operational Land Imager (OLI))	433
2	Blue (OLI)	482
3	Green (OLI)	562
4	Red (OLI)	655
5	Near-Infrared (NIR) (OLI)	865
6	Short Wavelength Infrared (SWIR) 1 (OLI)	1610
7	SWIR 2 (OLI)	2200
8	Panchromatic (OLI)	590
9	Cirrus (OLI)	1375
10	Thermal Infrared Sensor (TIRS) 1	10800
11	TIRS 2	12000

Landsat 8 band combinations are usually bands 4, 3 and 2 in the R, G and B channels for an aerial photo type image, whereas the combination of bands 6, 4 and 2 typically enhances the geology. Band 8 is used to pan-sharpen the 30 m images to 15 m resolution. The SCP plug-in will automatically pan-sharpen the RGB images if this option is selected.

11.4 Sentinel 2 Data

The Sentinel 2 satellites are designed for earth observation and the figure below illustrates the comparison with the other satellite data bands (from van der Meer et al 2014). The Sentinel satellite constellation has been launched by the European Space Agency (ESA) and the derived data is available free of charge. See ESA website (https://sentinel.esa.int/web/sentinel/home) for more detail on the available data and data access. You need to register (free) on the Sentinel web site to be able to download the Sentinel data.



When using Sentinel 2 data, it is recommended to use bands 4, 3 and 2 (for RGB) for the natural aerial photo type image and a combination of bands 12 or 11, 4 and 2 (for RGB) which can enhance the geology in a scene. Users should experiment with various band ratios to find which is the most suitable for their application.

The following list of recommended band combinations is from the Sentinel education web page (https:/Sentinel-hub.com/develop/education).

Natural Colour	B4 (red), B3 (green), B2 (blue)
Colour Infrared (vegetation)	B8, B4, B3
False Colour (Urban)	B12, B11, B4
Agriculture	B11, B8, B2
Vegetation Index	(B8 – B4)/(B8 + B4)
Moisture Index	(B8A – B11)/(B8A + B11)
Geology	B12, B4, B2
Bathymetric	B4, B3, B1
Atmospheric Penetration	B12, B11, B8A
SWIR	B12, B8A, B4
NDWI	(B3 – B8)/(B3 + B8)
SWIR-2	B2, B11, B12

The figure below from van der Meer et al 2014 compares ASTER ratio mineral mapping to the equivalent bands in the Sentinel 2 data.

Sentinel-2 band ratios as an analogue of ASTER band ratios, used as proxies for mineralogy. Modified after Kalinowski & Oliver (2004). The table is limited to ratios that fall in the wavelength range of Sentinel-2.

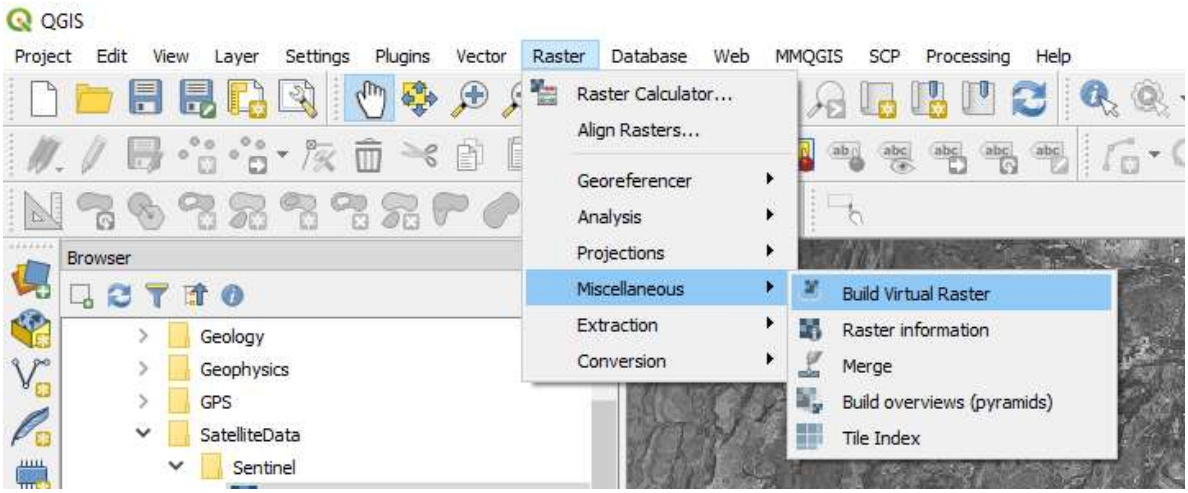
Feature	ASTER	Sentinel-2
Iron		
Ferric Iron, Fe3+	2/1	4/3
Ferrous Iron, Fe2+	5/3 + 1/2	12/8 + 3/4
Laterite	4/5	11/12[a]
Gossan	4/2	11/4
Ferrous silicates (Biotite, chloride, amphibole)	5/4	12/11[a]
Ferric oxides	4/3	11/8
Carbonates/Mafic minerals		
Carbonate/Chlorite/Epidote	(7 + 9)/8	–
Epidote/Chlorite/Amphibole	(6 + 9)/(7 + 8)	–
Amphibole/MgOH	(6 + 9)/8	–
Amphibole	6/8	–
Dolomite	(6 + 8)/7	–
Silicates		
Sericite/Muscovite/Illite/Smectite	(5 + 7)/6	–
Alunite, Kaolinite, Pyrophyllite	(4 + 6)/5	–
Phengitic	5/6	–
Muscovite	7/6	–
Kaolinite	7/5	–
Clay	$(5 \times 7)/6^2$	–
Alteration	4/5	11/12[a]
Host rock	5/6	–
Other		
Vegetation	3/2	8/4
NDVI	(3 − 2)/(3 + 2)	(8 − 4)/(8 + 4)

[a] ASTER bands 5–7 fall within band 12 of Sentinel-2.

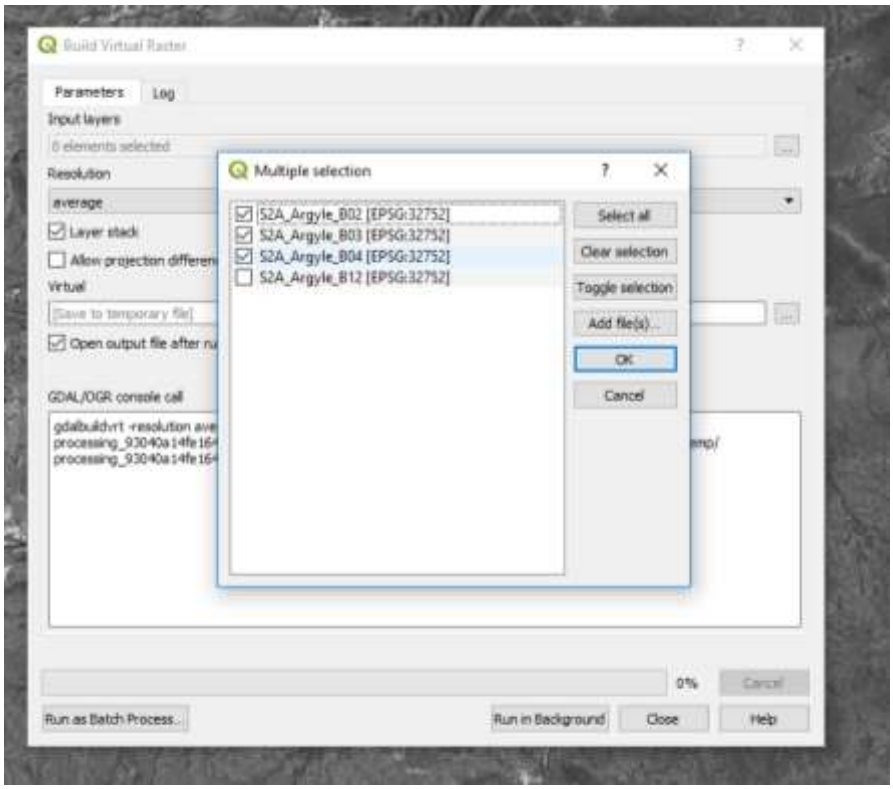
11.5 Creating RGB Images

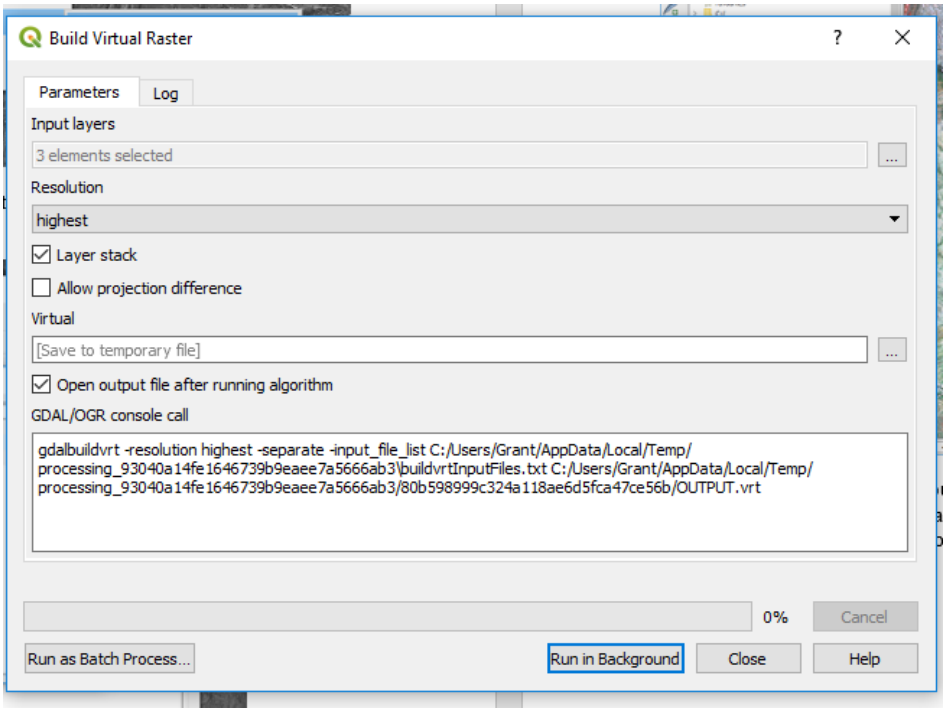
There are two methods available to create a coloured image (“rgb”) of remote sensing or any other 3 band data set. We can use the Raster > Miscellaneous > Build Virtual Raster option or the “Vitual Raster Builder” plugin. Ensure you have the files in the correct order as it assigns the red channel to the lowest image, green to the middle image and blue to the upper image in the Browser panel.

The Raster option is shown below.



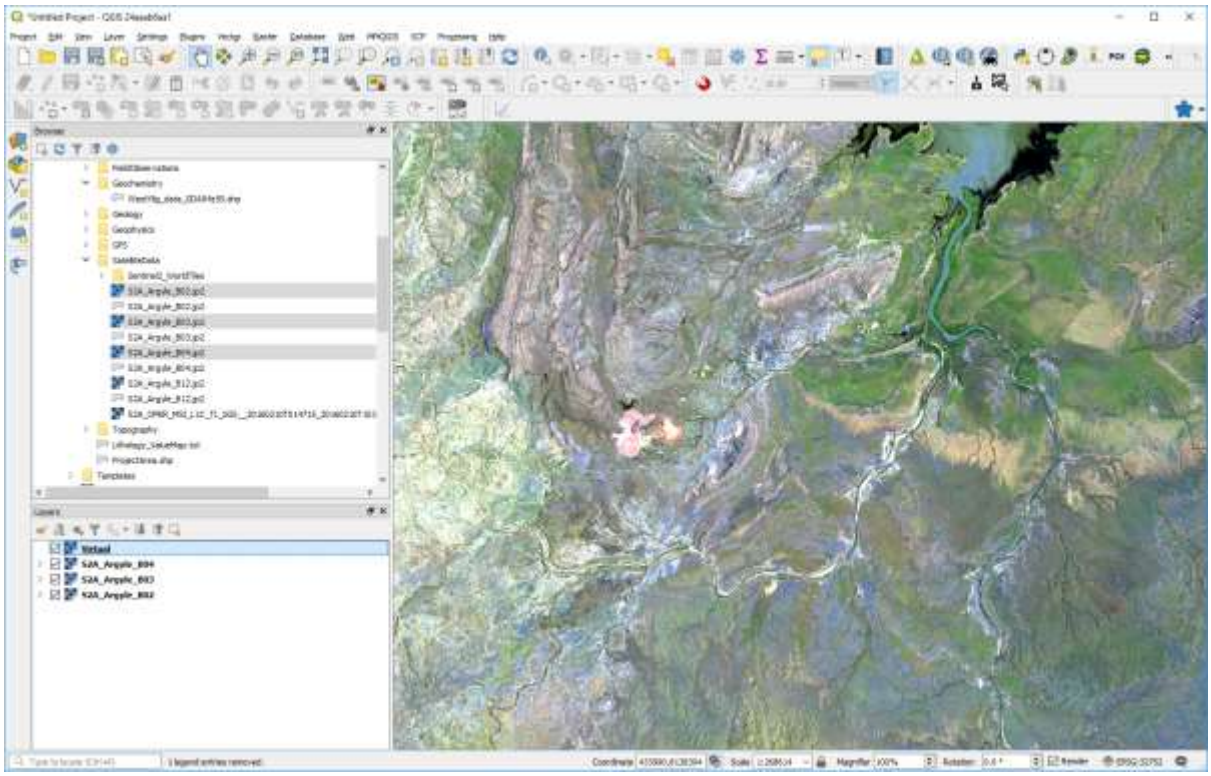
The Build Virtual Raster window will be displayed. Select the input layers as the ones to use for the RGB composite.





Select the “Highest” resolution to ensure you obtain the highest resolution possible and is similar to “pansharpening” where the larger pixels will be resampled to match the smaller pixels. Press “Run in Background” and the composite colour image will be produced as a virtual image.

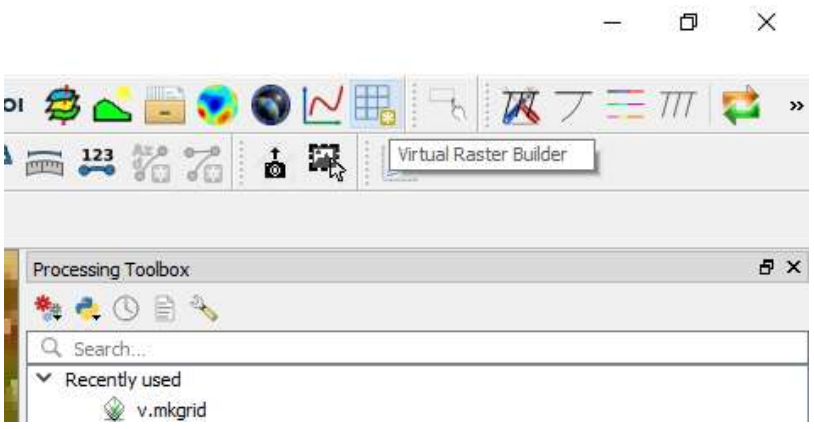
To save this file permanently, you need to right-click on the “Virtual” file name and save as a chosen file format, usually GeoTiff.

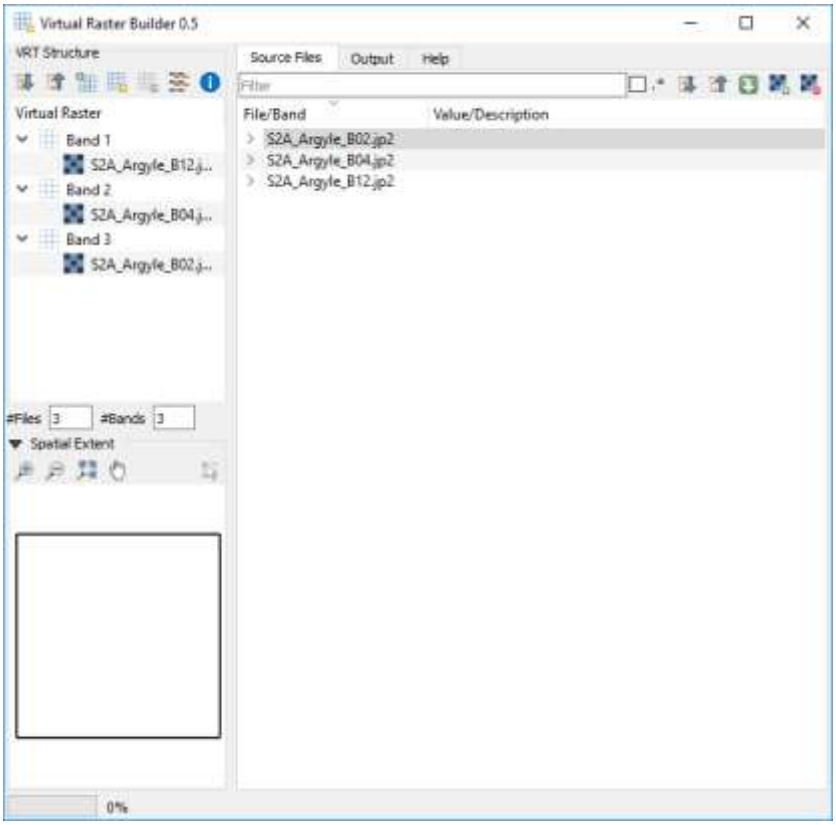


To adjust the colour stretch, zoom into a part of the image where you want to see more detail and then use the Layer panel to right click on the RGB layer and select “Stretch using current extent”. This can be done multiple times until you get the desired result (see below for example). Alternatively you can activate the “Raster Toolbar” and use the toolbar to adjust the colour stretch.

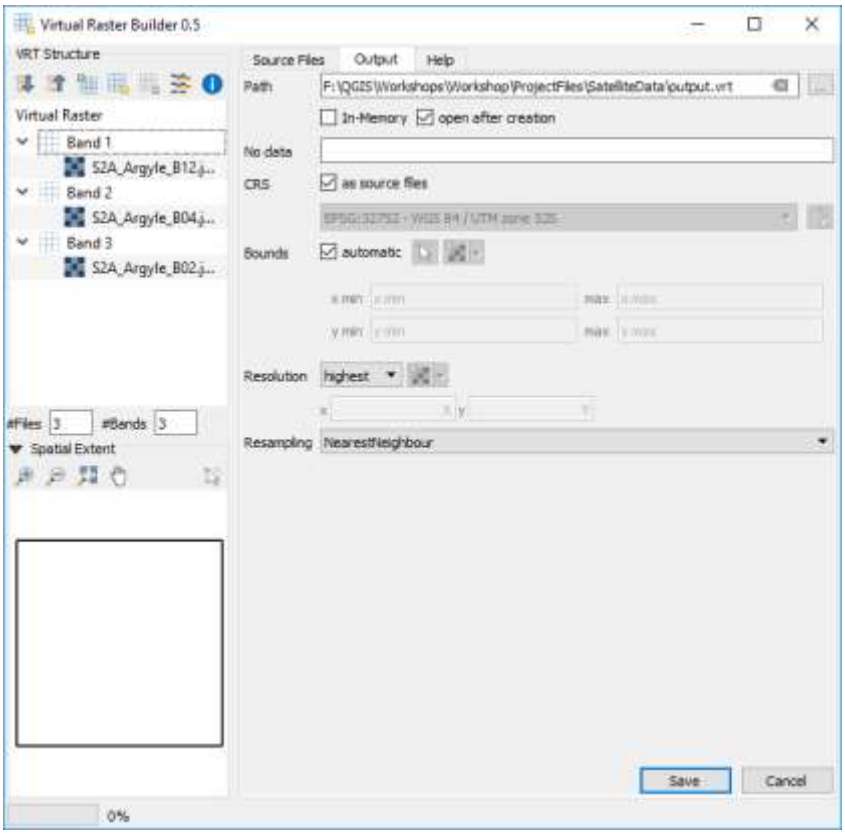
The “Virtual” RGB image is currently only a temporary file. To create a permanent image, right click on the image layer in the Layers panel and select “Save As” Select the “Rendered Image” option, click the “Browse” and select the folder and required file name. Change the coordinate system if required. When all is OK, click OK. It may take some time to create the tiff file depending upon the size of the image and the speed of your computer.

The other option for producing the RGB image is by using the “Virtual Raster Builder” plugin.

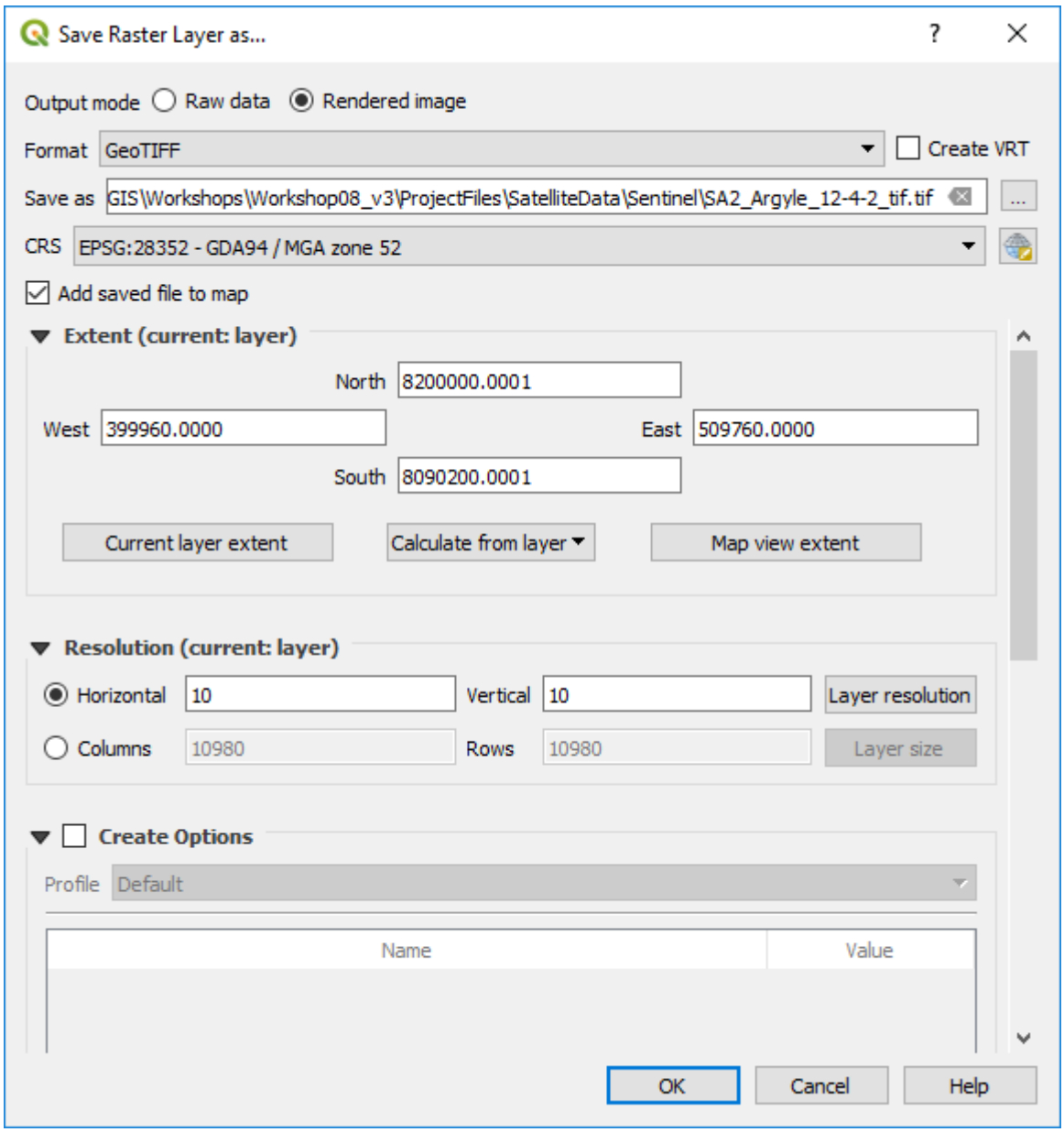




Add the files via the “Source Files” tab and these can be renamed in the left hand side window for reference purposes, e.g. Band1 can be renamed to Band12. The RGB creation is done via the “Output” tab and this creates a temporary virtual file.



The resulting RGB image can be saved via the Save Raster layer option.



Note there are options for saving as a geopackage or GeoTiff file and modifying the output projection Geopackage files are much more compact (smaller) than equivalent GeoTiff files.

To merge adjacent satellite images/bands, use the Processing Toolbox > SAGA > Raster tools > Mosaic raster layers. Option settings that have worked in merging adjacent ASTER scenes are Interpolation – “4 B-Spline”, Overlapping areas – “6 feathering”, Blending distance – “1000”, Match – “regression”, Cell size – “15” (or 30 m, 60 m, 90 m - to match the relevant pixel sizes for the images being merged), Fit – “Cells” and save to a file. All other setting as default.

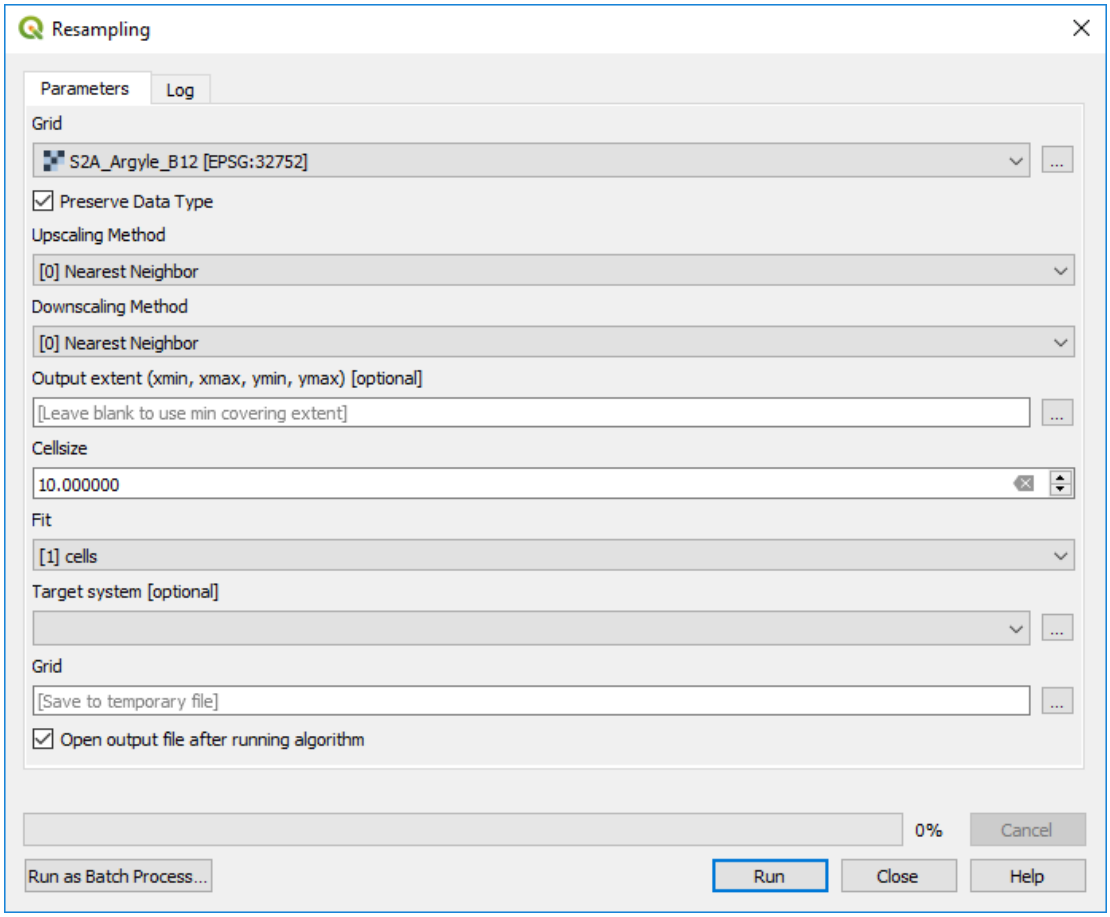
If you have problems merging adjacent satellite images where you get edge effects between adjacent scenes, try downloading and installing SAGA (http://www.saga-gis.org/en/index.html). This a powerful and free GIS analysis program and has a good help file (https://sourceforge.net/projects/saga-gis/files/SAGA%20-%20Documentation/SAGA%205%20User%20Guide/. The mosaicking option is found in the

Geoprocessing > Grid > Grid System > Mosaicking menu item. Use the Match option “match histograms of overlapping area”.

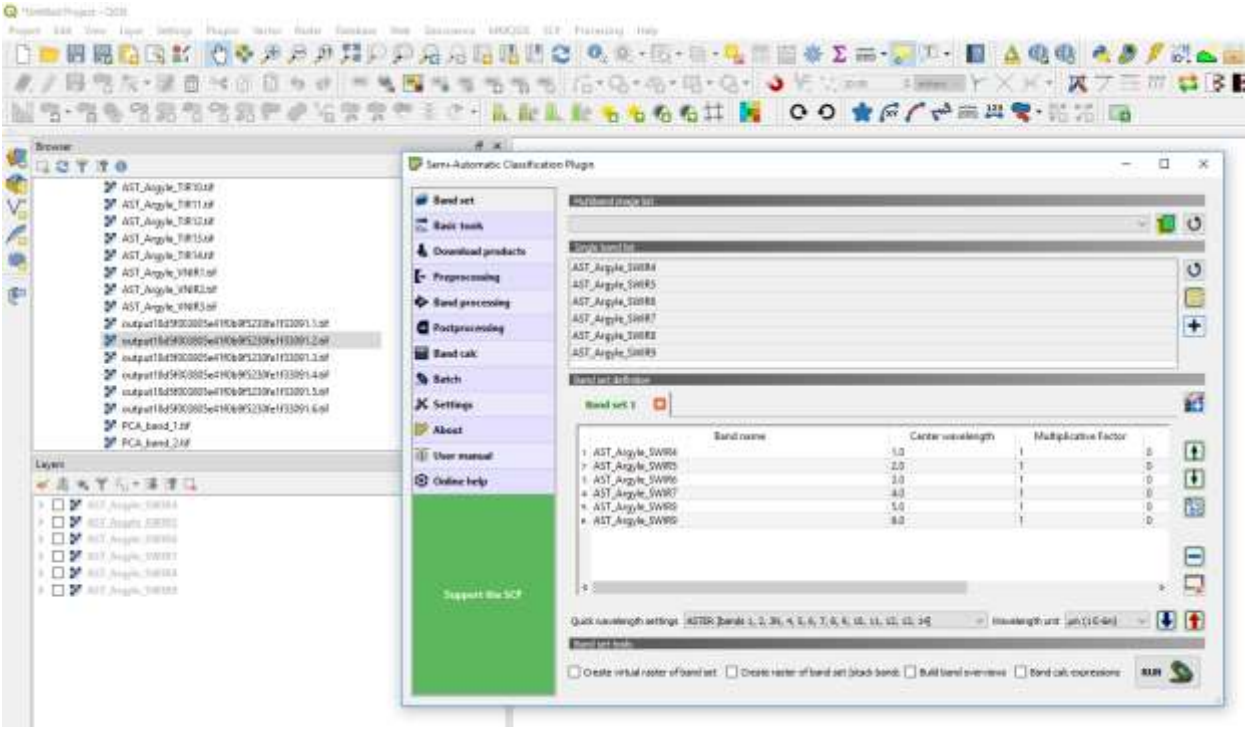
11.6 Principal Components Analysis (PCA)

Principal Components Analysis (PCA) can be undertaken using the Semi-Automatic Classification plugin or via the Orfeo Tool Box (https://www.orfeo-toolbox.org/CookBook/QGISInterface.html). The input files for the PCA analysis require they have the same pixel size and may require resampling if necessary (see Processing Toolbox > SAGA > Raster Tools > Resampling). The easiest way to ensure the a common pixel size is to create a multiband raster using the Build Virtual Raster and selecting the “Highest” resolution option.

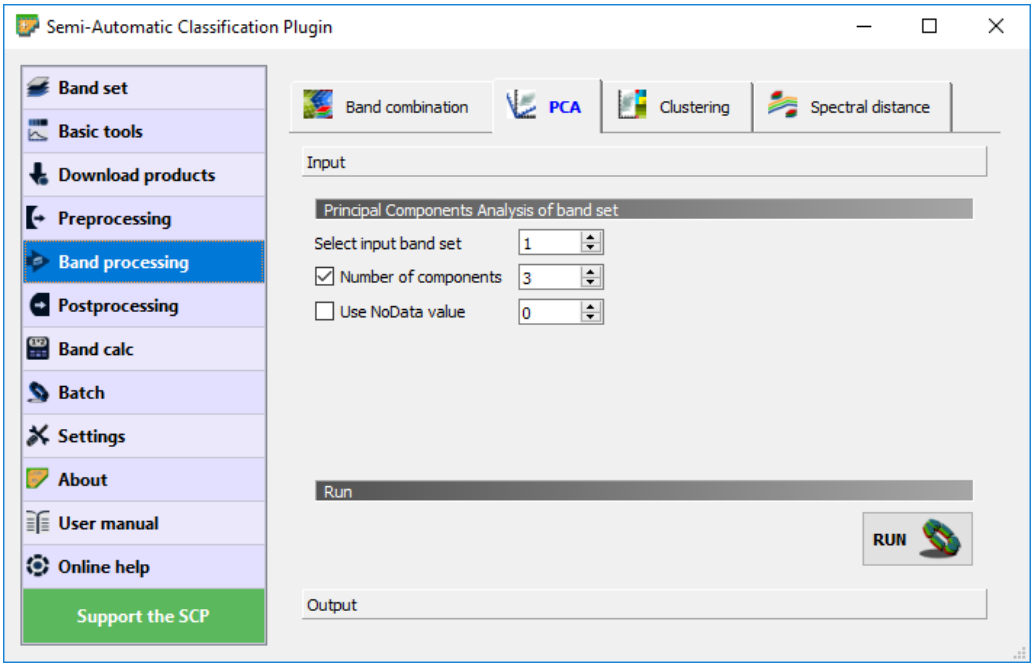
If you need to resample the raster to a different cell/pixel size, ensure you check the cell size and “Fit” to cell, otherwise it will offset the resulting image.



In the SCP plugin, create a Band Set using the Band Set tab. Press refresh to show what bands are available (in the Layers panel) then select the layers to be used for the band set – highlight the required bands, then click the plus symbol “Add band to band set”. This set of bands will be used in the PCA analysis.



Click on the Band Processing tab and select PCA. Check that the input band set is correct, select 3 components (required for an RGB colour image) and press Run. Select the target directory for the results to be saved. Note in the image above I have used the SWIR ASTER bands for the PCA analysis.



This process will produce three PCA images, PCA1, PCA2 and PCA3. Use the Virtual Raster Builder plugin to produce the RGB image (as above).

12: MAP PRODUCTION

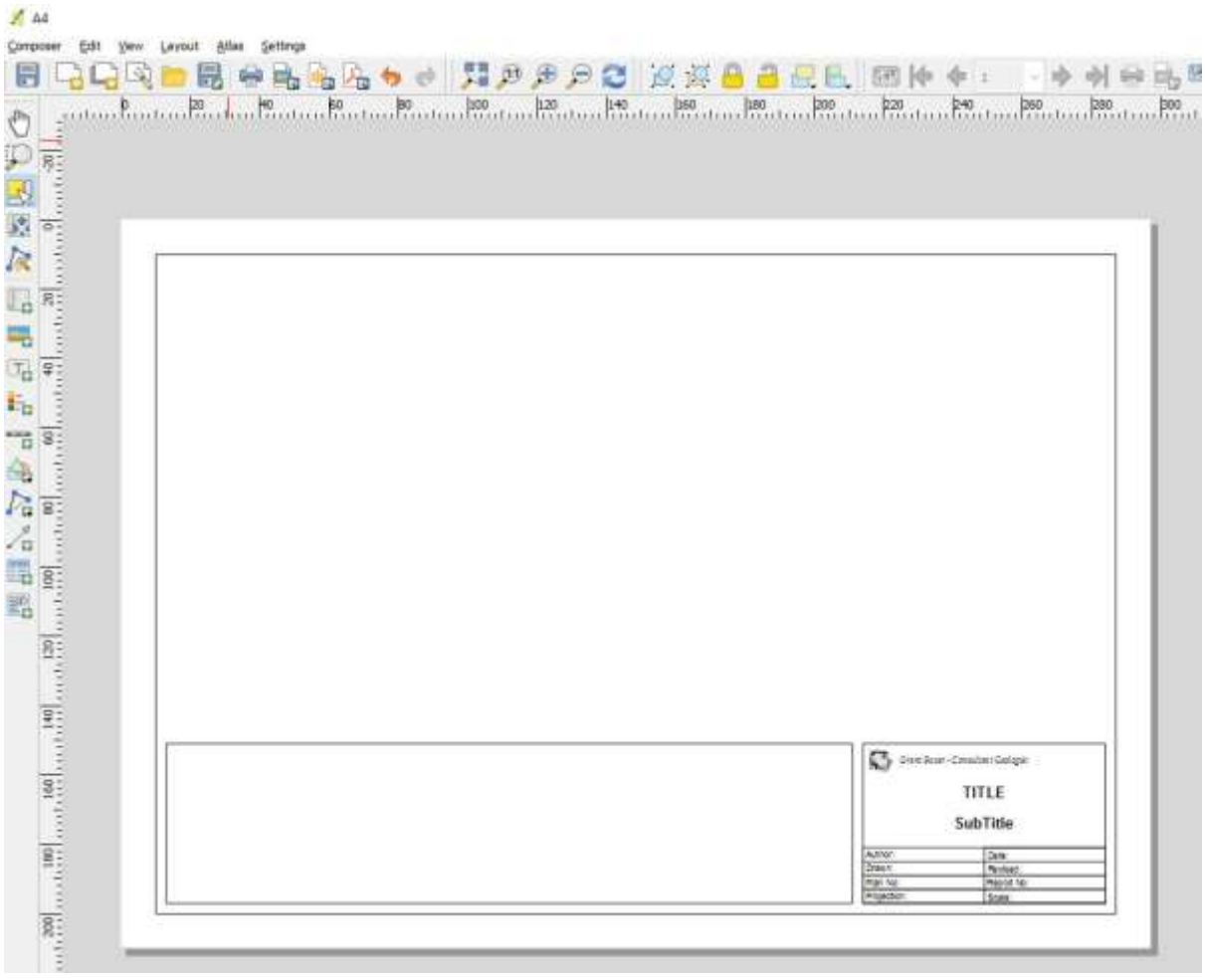
12.1 Print Layout

The Print Layout is the tool to produce maps for output. Various standard page sizes can be selected as well as creating custom sizes. Everything to do with the final map design is done in the print layout. Map creation is described in Hands-On Workshop 1. If you lose tab views, click on the “Views” menu option in the layout window and scroll down to Panels to reselect them for display.

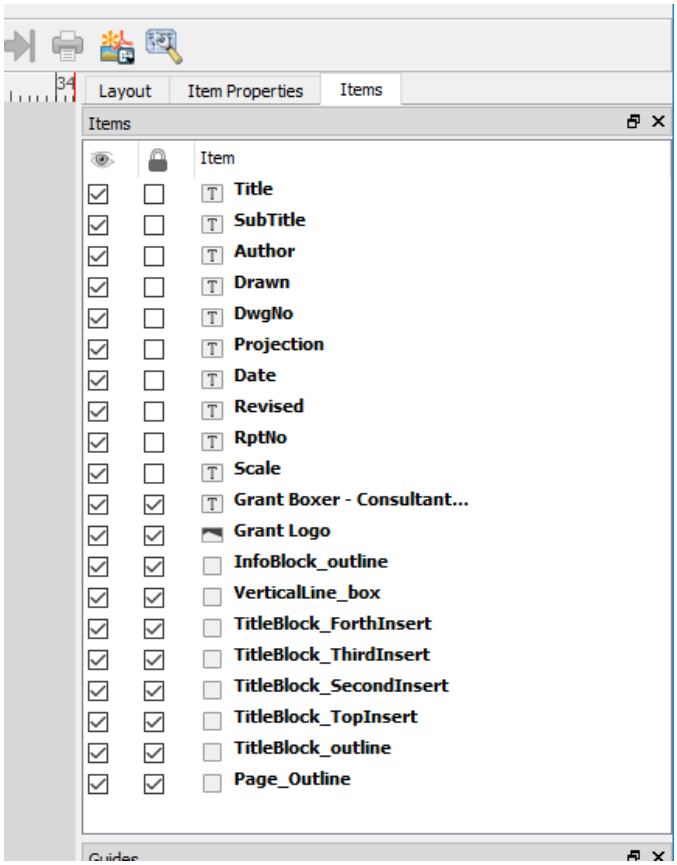
To ensure you get true scale plots, it is important to have the main map projection in a metres projection (i.e. UTM) and not in a geographic lat/long projection. Problems may be created with the scale not being correct on the map output when the main map window is in a lat/long projection.

12.2 Map Templates

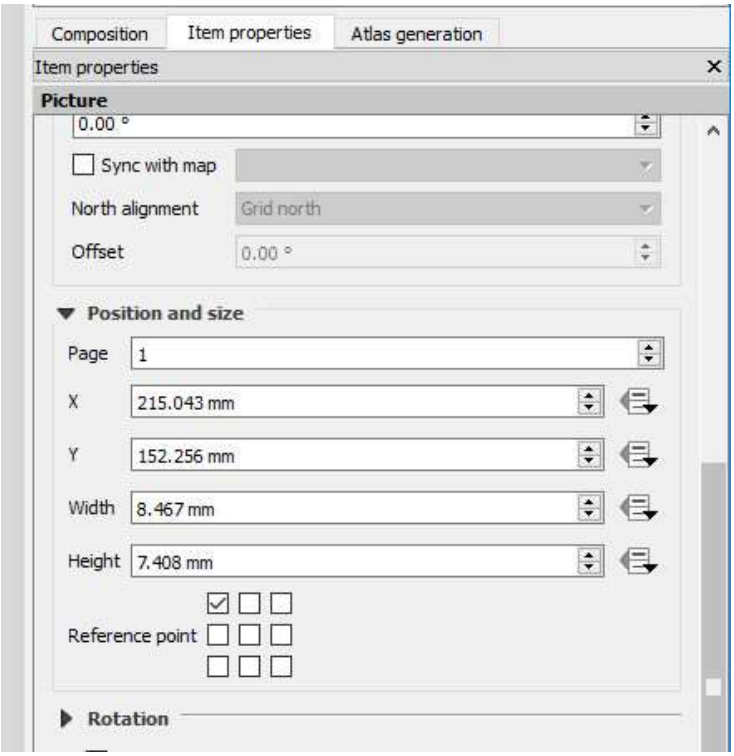
Templates can be constructed for use with a variety of map sheets sizes, e.g. A4, A3, A2, A1 and A0 in either landscape or portrait orientation. Frames and title blocks are simply constructed as rectangles and standard text boxes added into the rectangles. Shapes and text boxes are selected from along the left-hand side margin of the map composer window. The figure below illustrates an example of a template complete with title block. Templates can be dragged into the print layout window from the Browser panel, which will then automatically set the correct page size.



Each item of the template is listed in the Item panel and can be turned on or off and edited. Note that the position of the features can be set and adjusted using the “Position and Size” options in the item properties dialog box. Each item, e.g. page frame, insert box, logo, etc., has its own item properties and these can be varied independently.

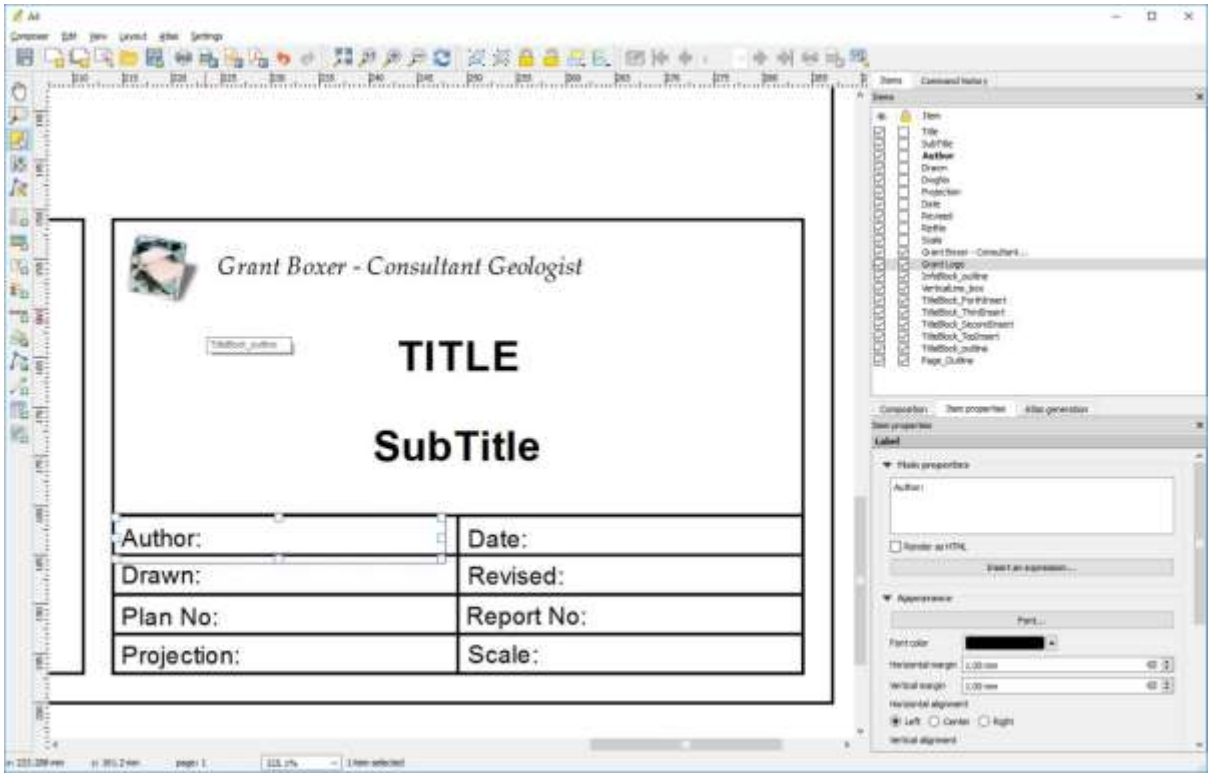


The image above shows all the items that map up the map frame.



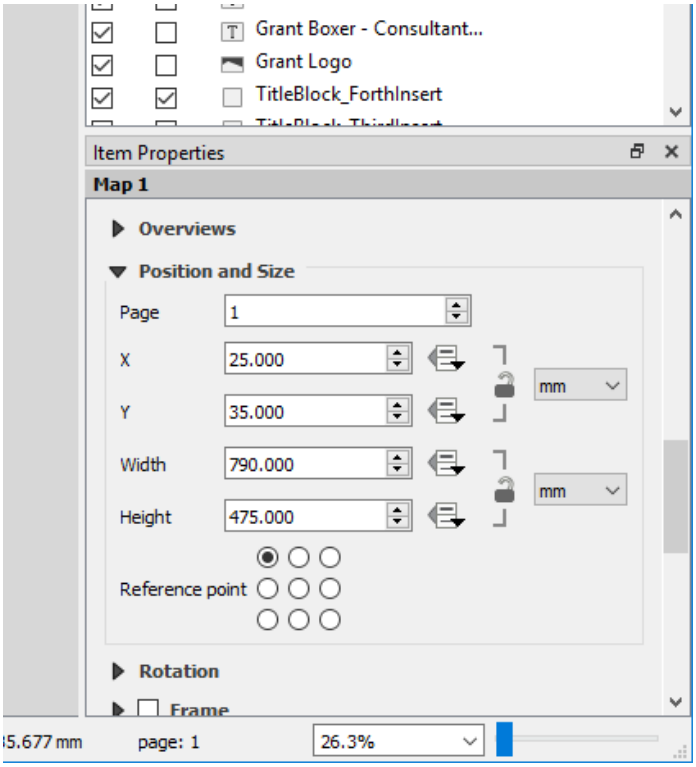
The example above is the “Logo” item (diamond image on the layout) and its location is referenced to the top left-hand corner of the page as shown in the 3 x 3 box array. It is located 215 mm to the right and 152 mm below the top left hand corner of the page, with a width of 8 mm and a height of 7 mm.

Each text box has a location and is edited as required in the Label > Main Properties window. The image below shows the “Author” field selected and the details can then be added to the existing text, or changed as required. If the text boxes require adjustment, use the position and size options attached to the item.

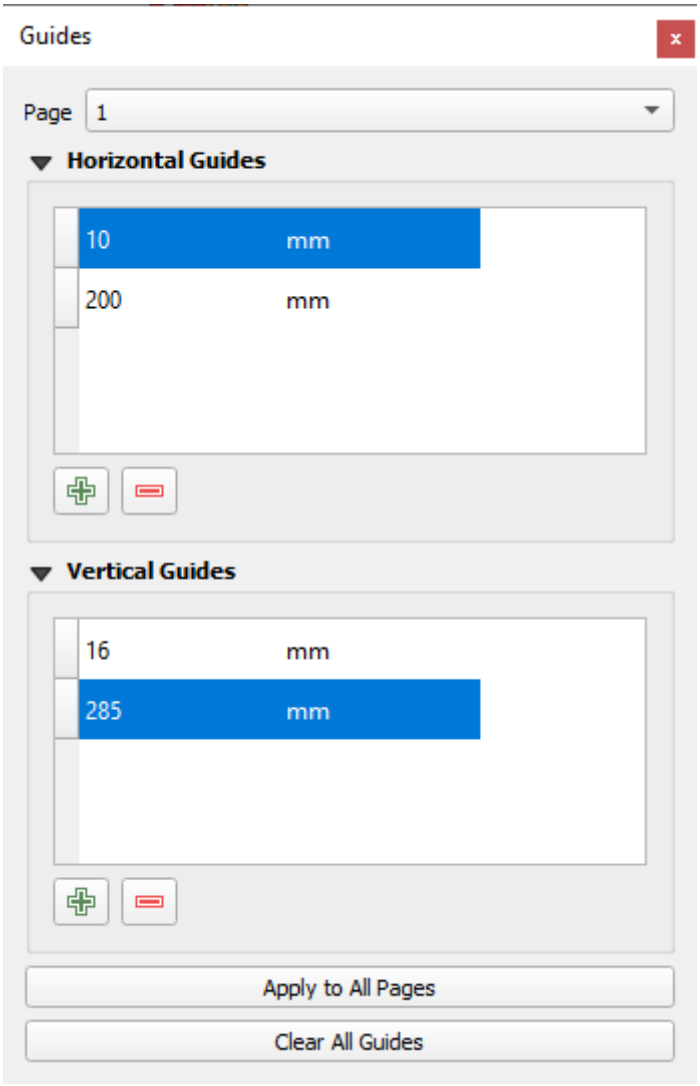


Note that these templates may require adjustments for different printers and plotters depending on their “print area”.

The position and size of the inserted map window can be adjusted under the “Map” item properties and using the “Position and Size” options. The reference point in the figure below shows the measurements from the top LHS of the page.

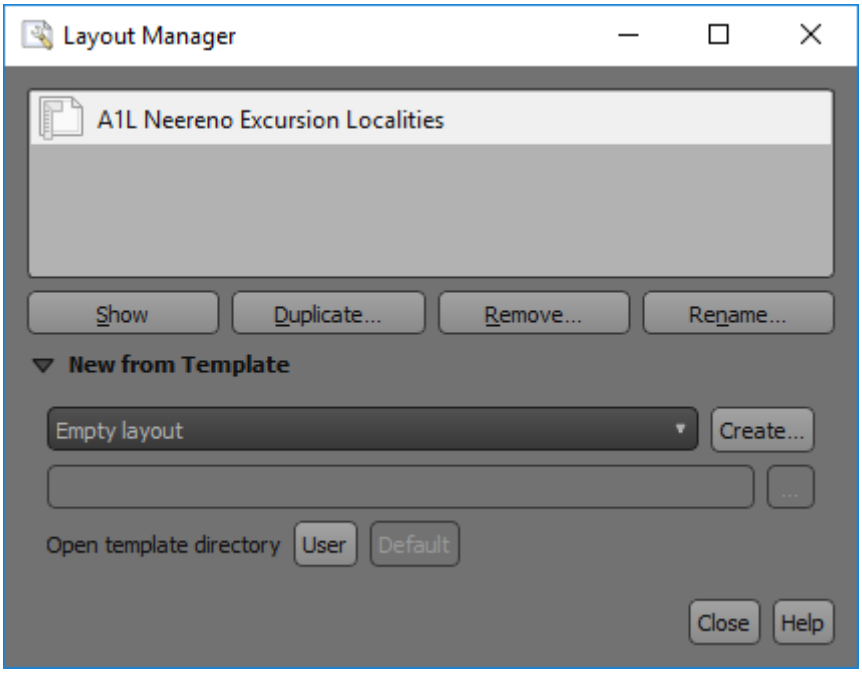


To insert a map of fixed/pre-determined size, in the Print Layout, select the View > Manage Guides and set the horizontal and vertical guide lines. The inserted map windows can then be adjusted to fit these guide lines. Grids can also be used to align map items.



12.3 Layout Manager

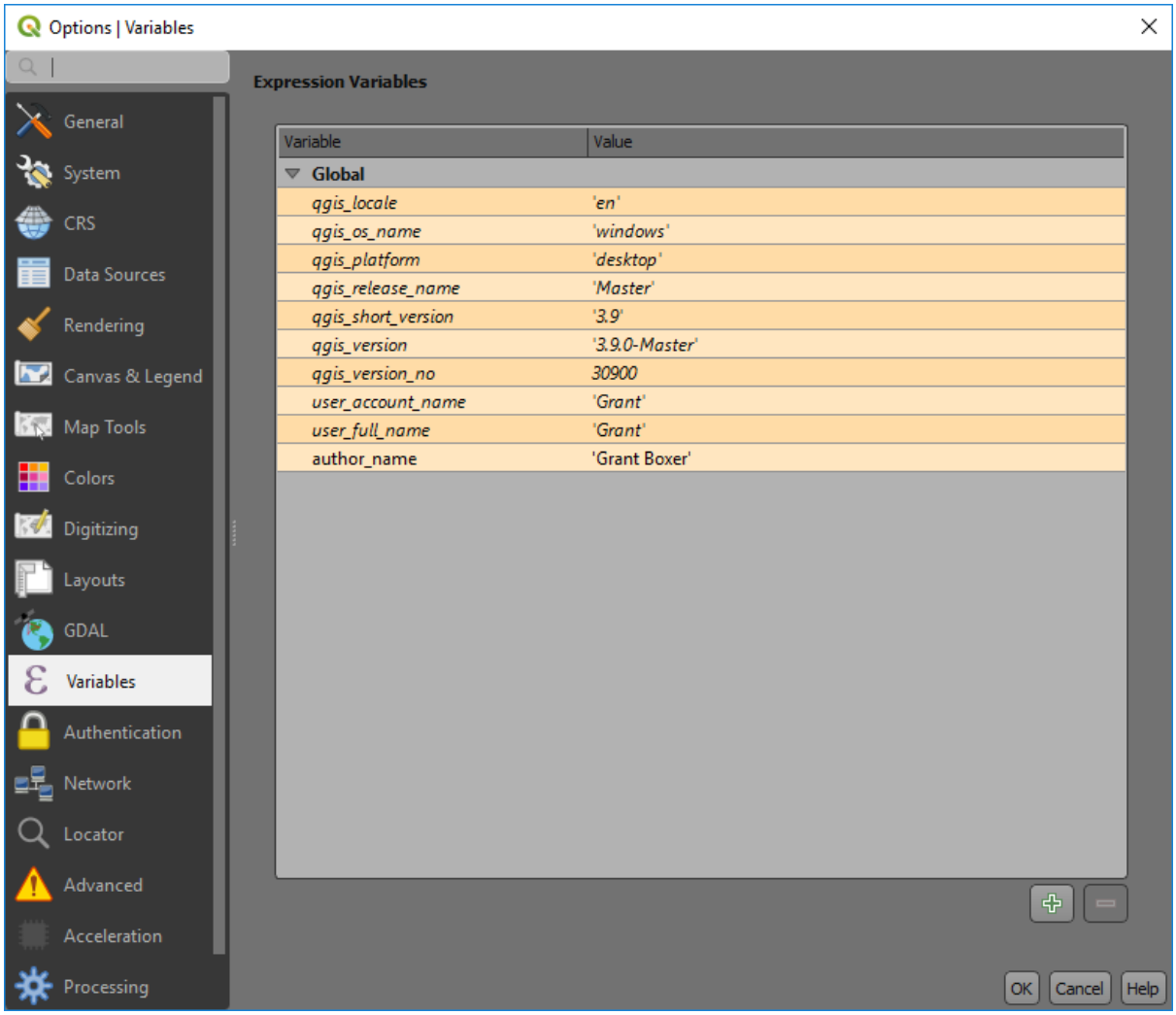
The layout manager shows what layouts are attached to the project. You can have many layouts of different sizes and configurations all saved with the project. If you have a set layout where you need different themes on maps, you can use the duplicate button to make a copy of the layout. Note that you need to “lock” layers in a layout to prevent a refresh from re-drawing the layout display.



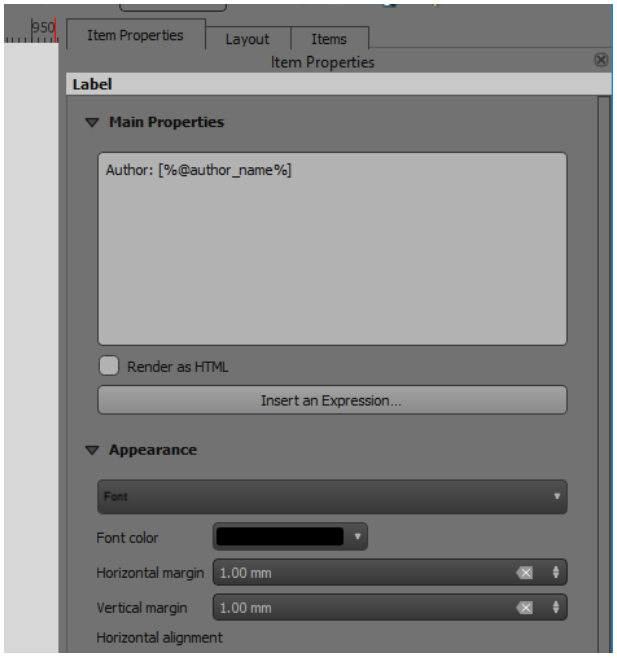
12.4 Using Variables to Display Information

Variables can be used to populate information in text boxes, e.g. the map author's name, QGIS version, or the file path to the Project file. There are various types of variable and they can be applied globally, for a specific project or layout.

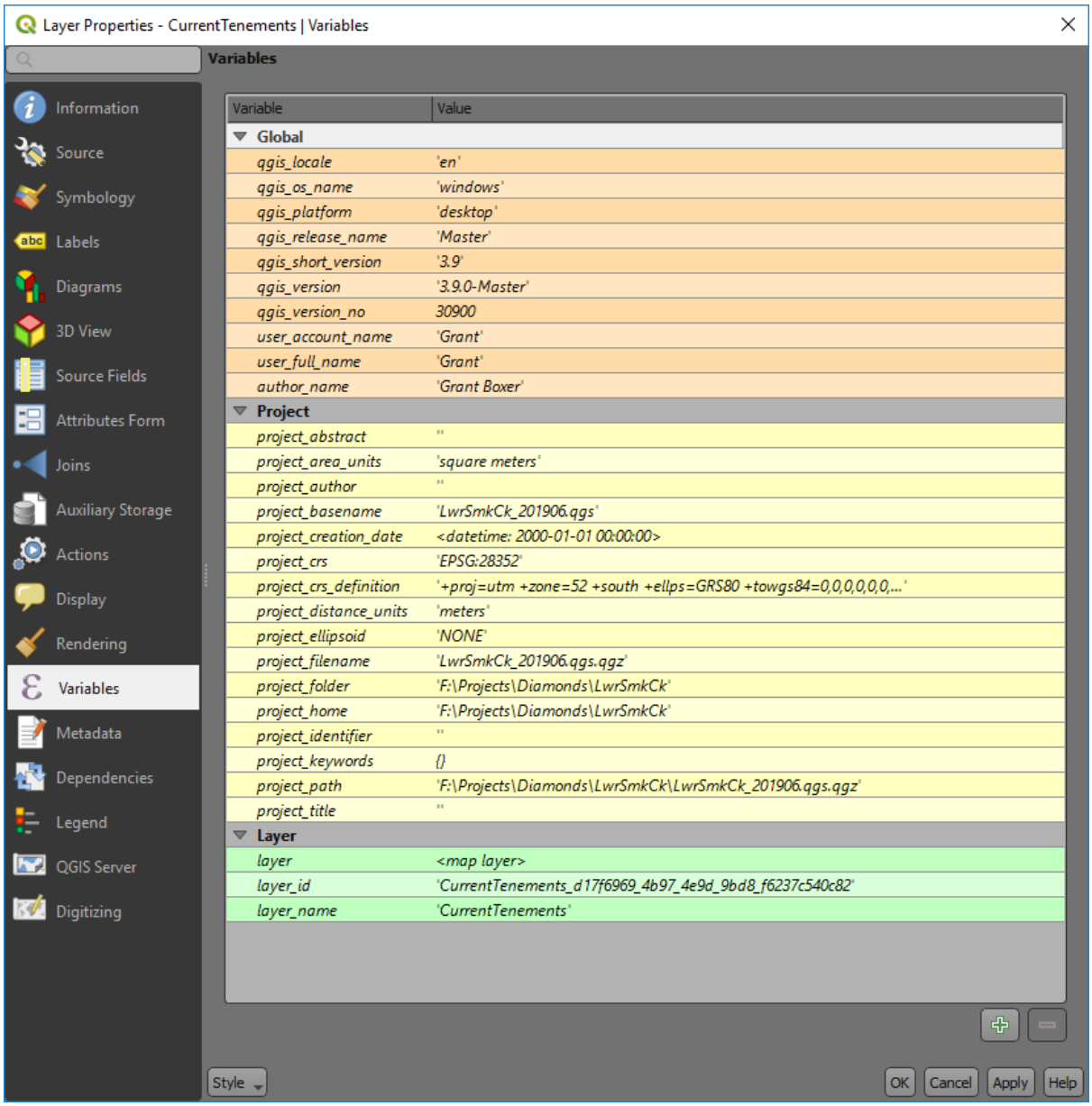
Global variables apply to QGIS overall and they can be found in the manin menu item Settings > Options and the Variable tab.



A number of default global variables are added by QGIS. Note that I have added a new variable name “author_name” with its value being Grant Boxer. I can then use this variable to add my name anywhere on a layout by using the [%@author_name%] statement.



There are similar windows for the Project Properties and Layer Properties.

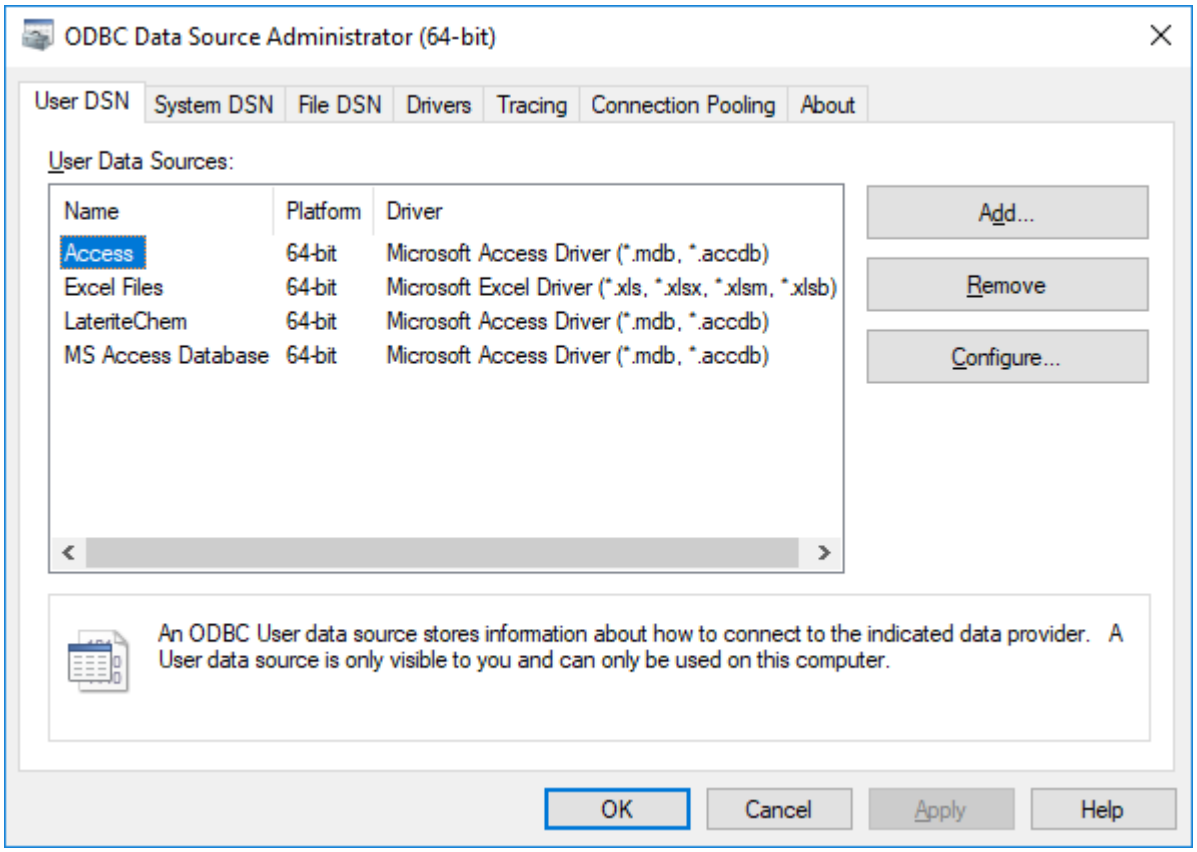


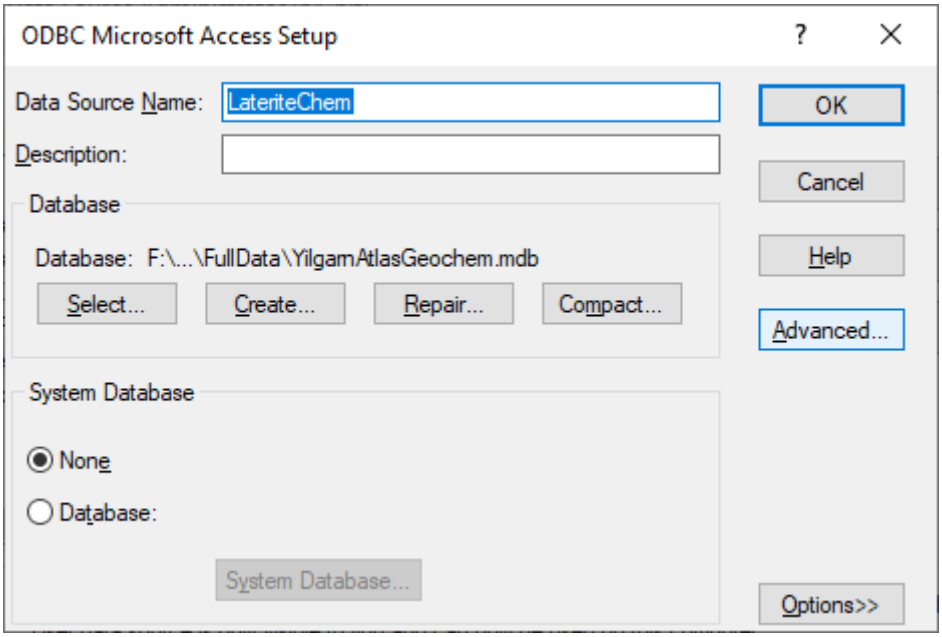
13: MISCELLANEOUS TRICKS AND TIPS

13.1 Access Databases

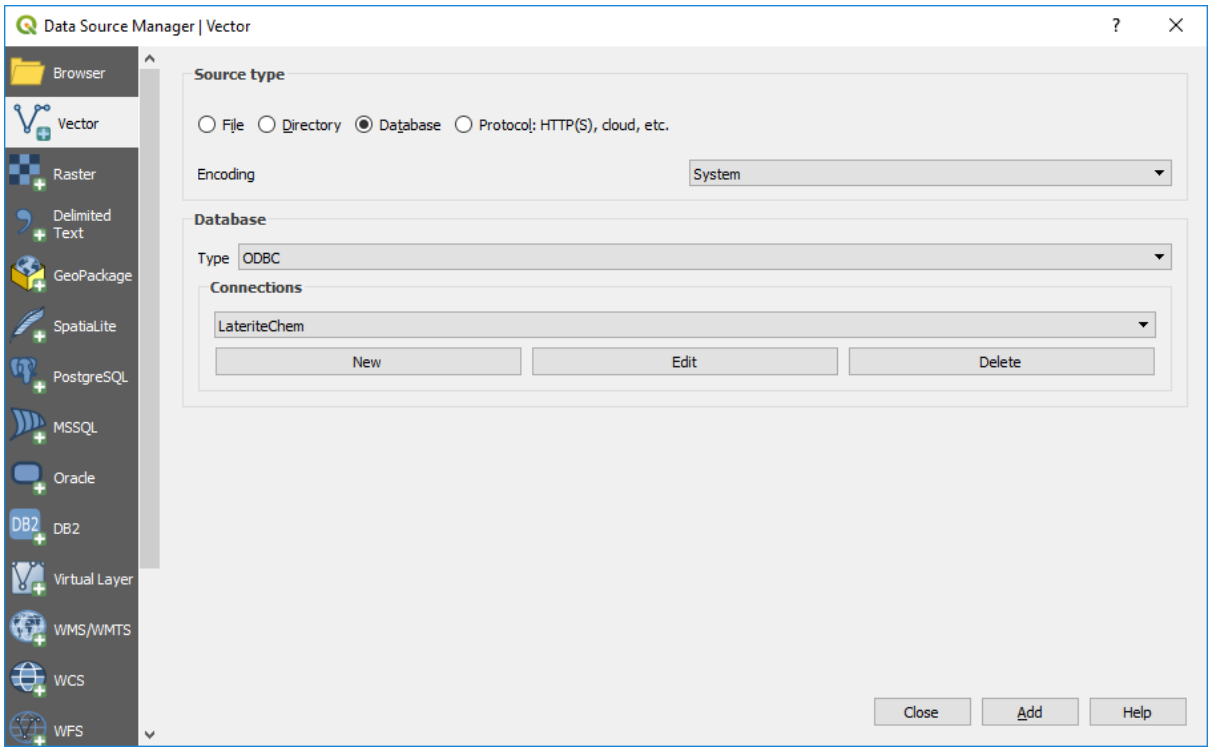
Connecting to an Access database requires some additional steps than required for the open source database programs.

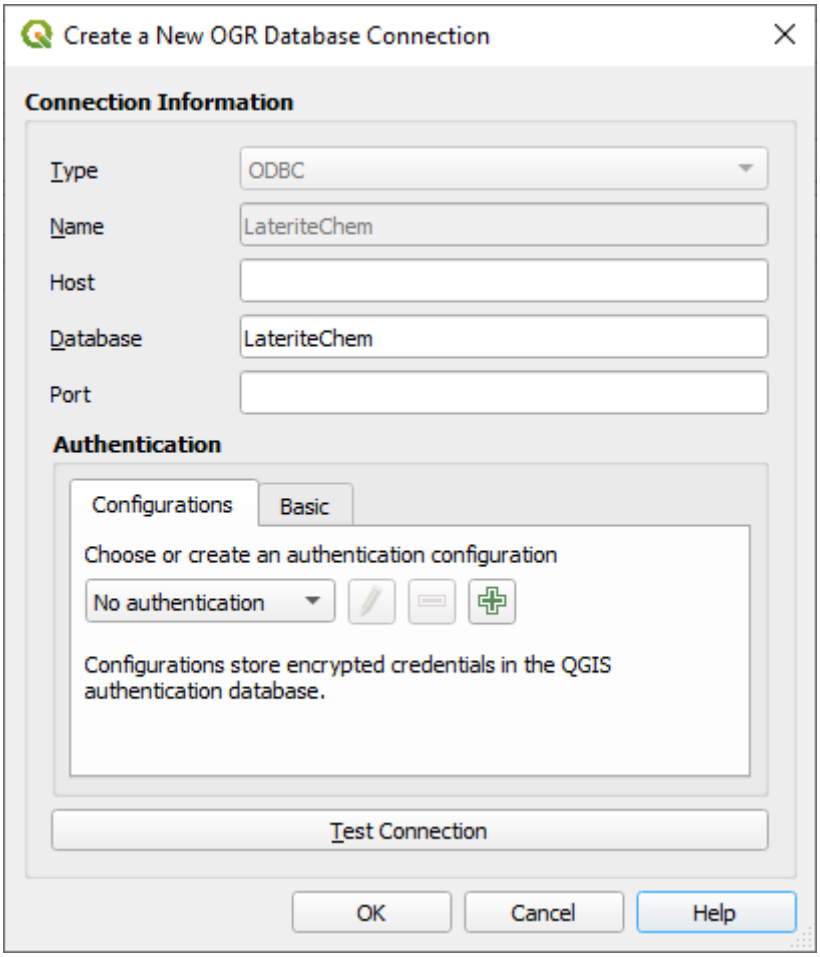
Open the 64-bit ODBC admin window (via the Windows search box) and add another “Access 64-bit line”, select the database name and location in the User DSN tab – e.g. “LateriteChem”.



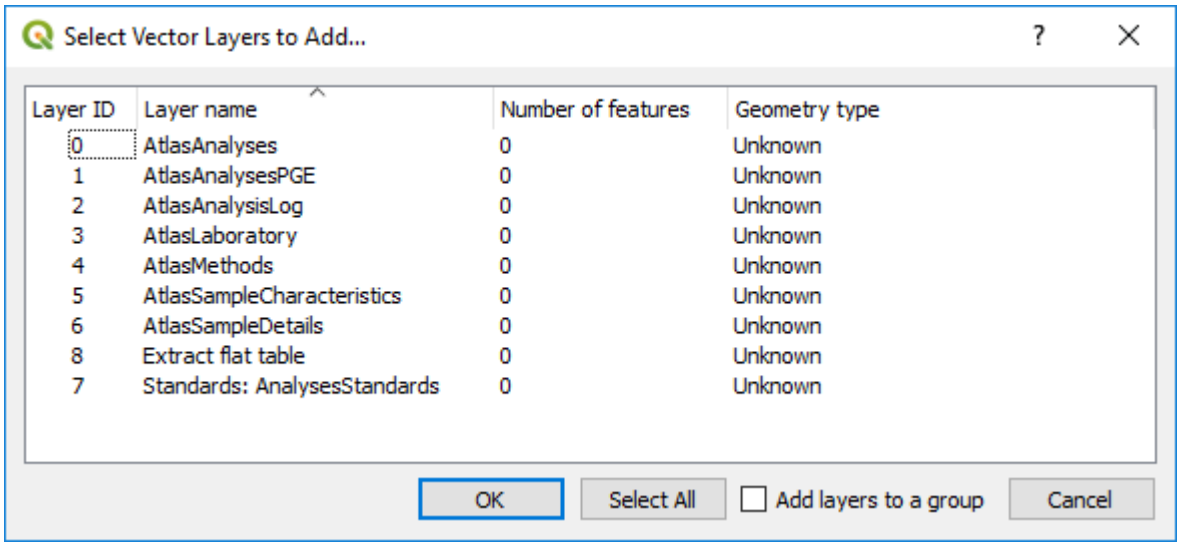


In the Open Data Source Manager, select the Add Vector option, and type of Database. Connect to the database and Add.





The next window will display the tables available for import.



If the table has spatial data, e.g. coordinates, then after import, use the Processing Toolbox > Algorithms > Vector Creation > Create Points Layer from Table, and select the field for the coordinates and the applicable Coordinate Reference System.

13.2 AutoSaver Plug-In

The Auto-Saver plug-in will save your project at regular intervals. I have had problems with this turned on during digitising and I recommend it is turned off when creating new files.

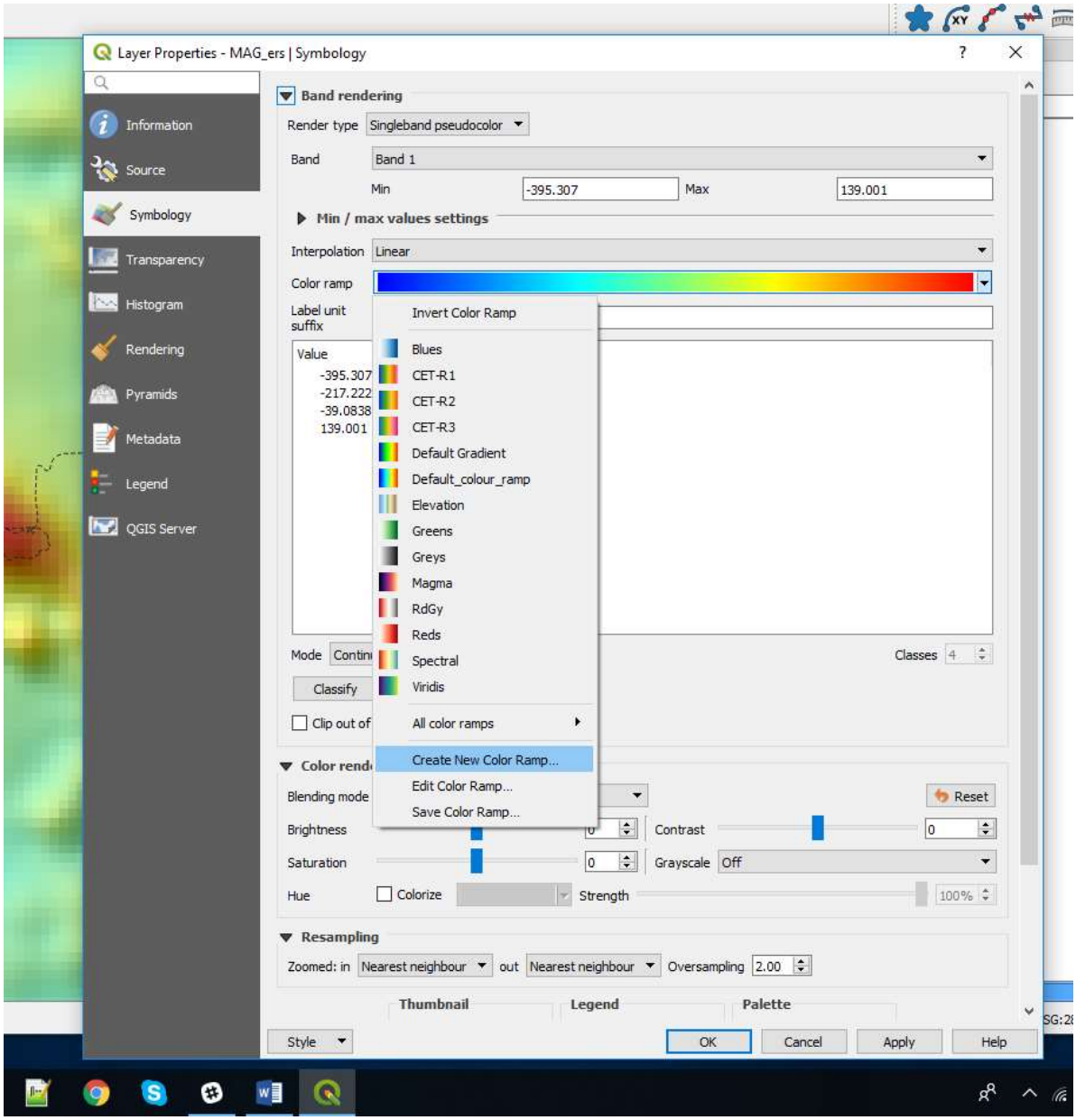
13.3 Spatial Bookmarks

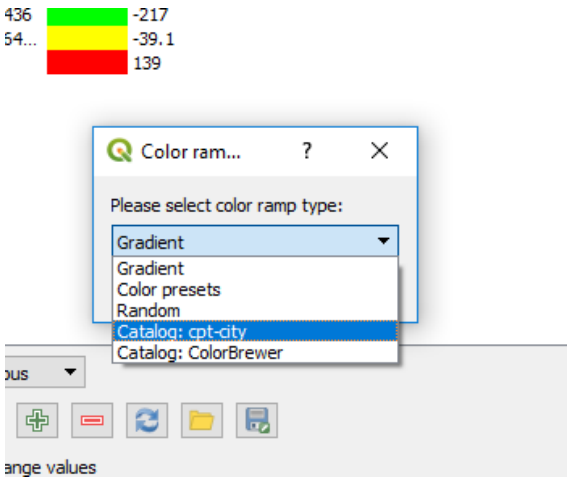
Bookmarks are used to remember the extents of a map window and they are saved with the project data. When a bookmark is saved, the bookmark list panel is displayed. Bookmarks are created via View > New Bookmark or via the Browser panel.

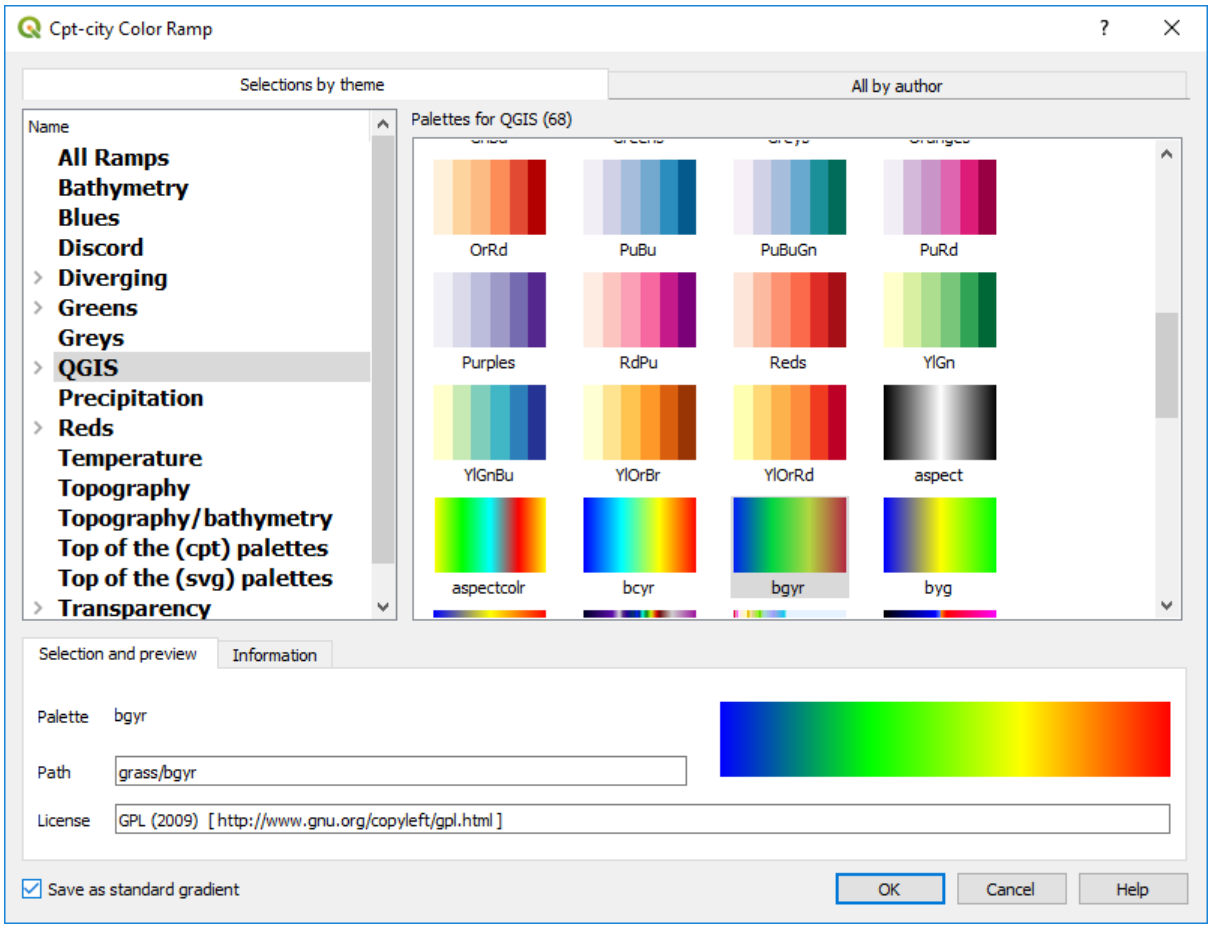
13.4 Colour Ramps

To add additional colour ramps to the default option use the “Create New Colour Ramp” from the drop down box to the right of the Color Ramp selection box,. The preset colour ramps are shown in the “Color Ramp” dialog box and I recommend the Catalog: cpt-city option which will display the next dialog box.

There are many different groups to select from, but I prefer the QGIS tab, and the continuous colour bands, e.g. “bgyr”.

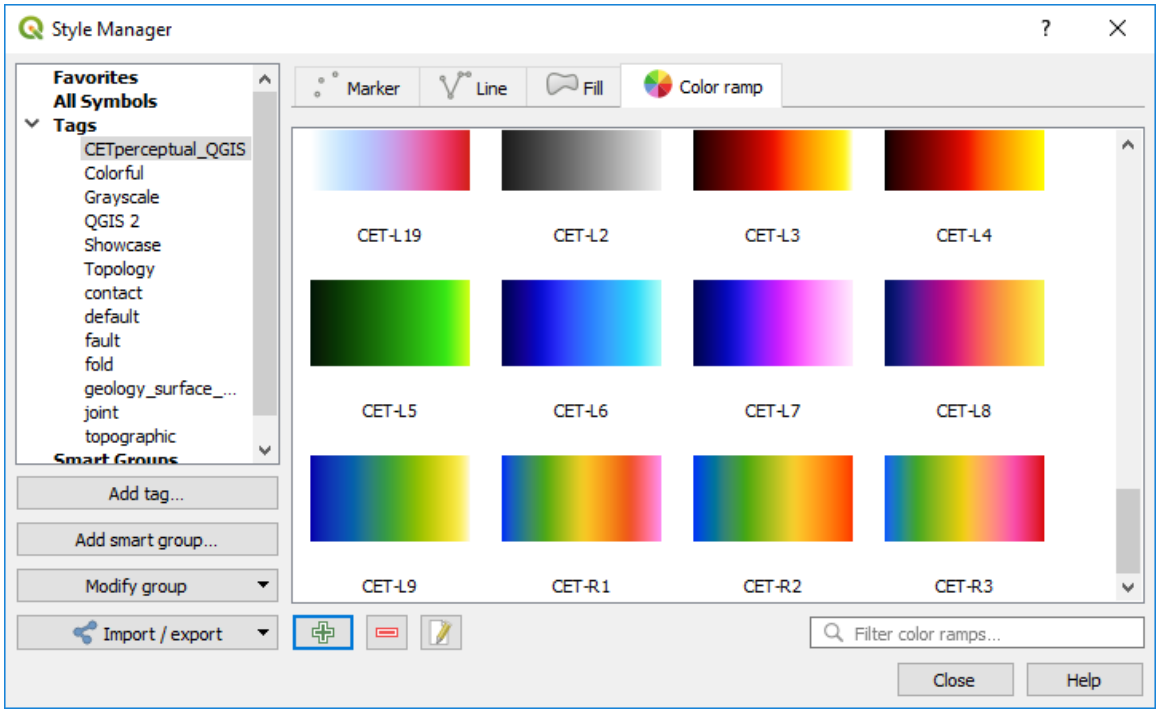

Layer Properties - MAG_ers | Symbology
Information
Source
Symbology
Transparency
Histogram
Rendering
Pyramids
Metadata
Legend
QGIS Server
Band rendering
Render type
Singleband pseudocolor
Band
Band 1
Min
-395.307
Max
139.001
Min / max values settings
Interpolation
Linear
Color ramp
Label unit suffix
Value
-395.307
-217.222
-39.0838
139.001
Invert Color Ramp
Blues
CET-R1
CET-R2
CET-R3
Default Gradient
Default_colour_ramp
Elevation
Greens
Greys
Magma
RdGy
Reds
Spectral
Viridis
All color ramps
Create New Color Ramp...
Edit Color Ramp...
Save Color Ramp...
Mode
Classify
Classes
Clip out of
Blending mode
Reset
Brightness
Contrast
Saturation
Grayscale
Off
Hue
Colorize
Strength
100%
Resampling
Zoomed: in
Nearest neighbour
out
Nearest neighbour
Oversampling
2.00
Thumbnail
Legend
Palette
Style
OK
Cancel
Apply
Help


436
54...
-217
-39.1
139
Color ram...
Please select color ramp type:
Gradient
Gradient
Color presets
Random
Catalog: cpt-city
Catalog: ColorBrewer
ange values



New colour ramps can also be imported via the Style Manager dialog box.

The Centre for Exploration Targeting (CET) in Perth have developed colour ramps that are better for visual perception (see this link https://peterkovesi.com/projects/colourmaps/). They are available in a QGIS xml format that can be imported via the Style Manager. These styles can then be access as favourites. My preference for data grids such as magnetics is to use the CET-R1 colour ramp.



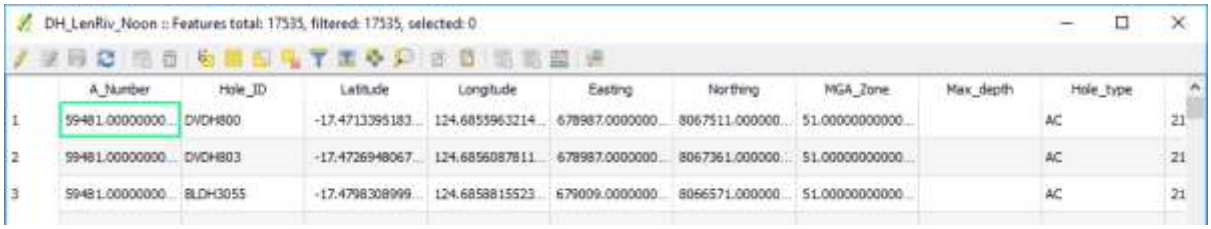
13.5 Colour Selection

To assist in selecting colours for maps, you can visit the ColorBrewer website (http://colorbrewer2.org) where rgb, hex and cymk values of a huge variety of colour options can be viewed and selected as required.

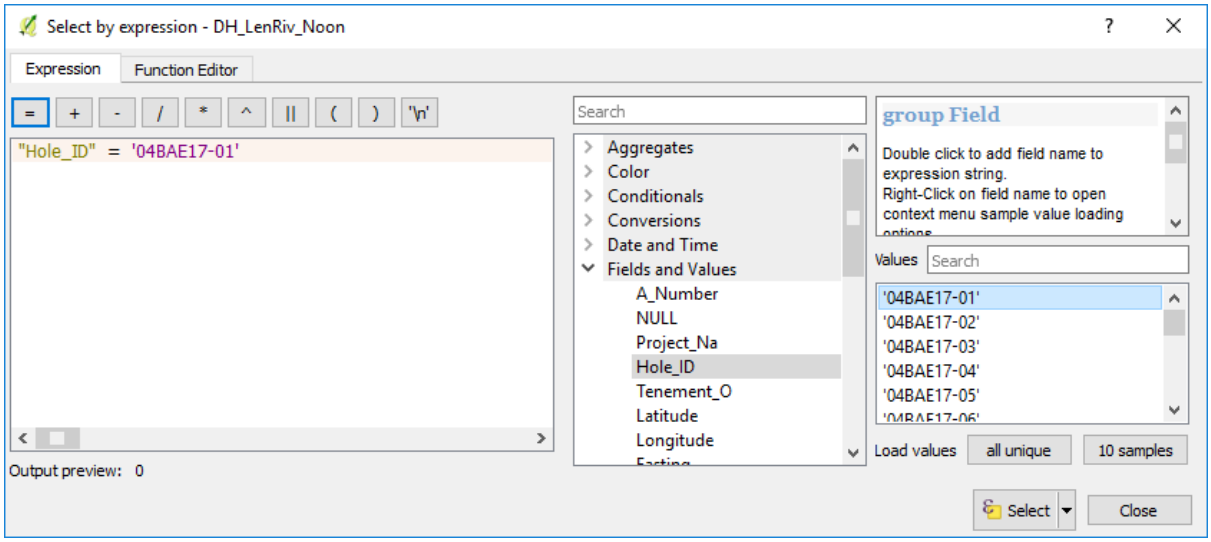
Data Searching

When searching large datasets, a number of options can be used. Spatial searches can be done in your map window but text searches are best done via the Expression form.

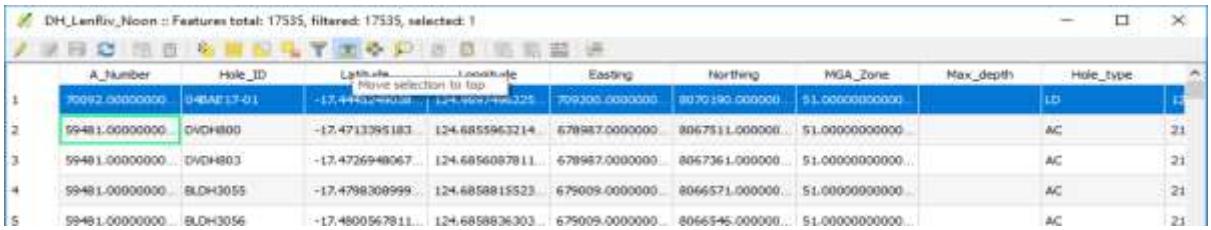
Highlight the layer in the Layers panel, bring up its attribute table and click on the “Select Features Using an Expression” button.



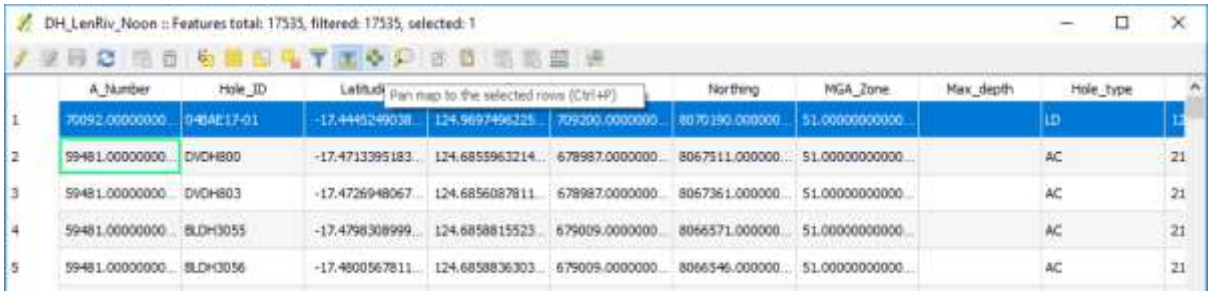
This will bring up the expression editor window. Click on the central panel to select the field to search in, then press “all unique” in the lower right hand side of the dialog box to show all the entries in this field. You can filter by entering values into the “Values” window. Double click the field name to enter it into the left hand panel. Use the function button to add a function, e.g. “=” and then double click on the value to search for in the right hand panel. Hit select to run the query.



Go to the attribute table and select the “Move selection to top” of the table. This may take a little while in large datasets but it will display the selected record(s) at the top of the table and highlight them.



To show these on the map, select the “Pan map to selected rows” icon and the map will pan to the area of the selected features.



13.6 Digitising Toolbar (PlugIn)

Every tool is activated as soon as the active layer is of an appropriate type and in edit mode. Keep in mind that some tools need that the current layer's CRS matches the project CRS.

As a general rule of thumb your **editing layer's CRS and the project's CRS should match**. It makes life easier. If you need results in a different CRS, transform the layer after you have finished your digitizing session.

All edits can be undone/redone using QGIS' standard undo/redo capabilities.

Description of the tools

Split multi part to single part

applies to: MultiPoint, MultiLine and MultiPolygon layer

1. batch mode: The selected multi-part features in the active layer are split into single part and added to the layer as new features, keeping the attributes of the original (multi-part) feature.
2. interactive mode: click on any multi-part feature. The feature will be split into single parts which are added to the layer as new features, keeping the attributes of the original (multi-part) feature.

Split off one part and add it as new feature

applies to: MultiPoint, MultiLine and MultiPolygon layer

Click on any part of a multi-part feature. The part will be deleted from the original feature and added as a new (single-part) feature to the layer keeping the attributes of its parent (multi-part) feature.

Split features

applies to: Line, multiLine, polygon and multiPolygon layers

Works exactly like *Split Features* tool in QGIS' *Advanced Digitizing Toolbar* when applied to non-multi features. When applied to multi features the user is asked via a dialog (see below) which of the newly created geometries (fraction of a part) should become the new feature. The other fraction stays as part within the original multi feature. Thus it replaces QGIS' *Split Parts*, too, which is of limited use, because its application results in an invalid geometry if the split-off part is not edited any further. The dialog shown when splitting multi-part features has four buttons:

1. Cancel aborts the current splitting operation and leaves all features untouched.
2. No to All aborts the splitting of the **current** feature and leaves it untouched.
3. No leaves the currently highlighted fraction in the multi-part feature.
4. Yes accepts the currently highlighted fraction for becoming the new feature.

Merge selected features

applies to: any layer with a primary key field, i.e. a database layer

This works as the *Merge selected features* button in QGIS Core, except that Core's *Merge selected features* deletes all selected features and then inserts a new feature. DigitizingTools' method offers the user to choose which feature to keep by choosing its primary key value. This feature's geometry is updated with the combined geometry of all selected features, while all other selected features are deleted. This feature will be removed once #13490 is closed and implemented.

Exchange attributes between selected features

applies to: any vector layer

Exchanges the attributes between two selected features of the active layer. Reasoning: when splitting features in a layer coming from a database provider the user can thus control which feature is going to keep the primary key value (important for related tables).

Cut with polygon from another layer

applies to: line and polygon layer (multi or single part)

Choose another layer whose selected features are used like a cookie cutter on the active layer. Everything that falls under the cutter feature(s) is erased. If a selection exists in the active layer only selected features are cut. In case a feature would completely disappear, a message is issued to the user, asking if this feature should be deleted.

Clip with polygon from another layer

applies to: line and polygon layer (multi or single part)

Choose another layer whose selected feature is used like a cookie cutter on the active layer. Everything that falls under this feature will survive, everything outside will be erased. If a selection exists in the active layer only selected features will be clipped.

Fill ring

applies to: polygon layer (multi or single part)

Fill rings (islands) in polygons with new features. This tool has two modes:

1. batch mode: all rings in the selected features are filled with new features. The attribute set for all features is identical and can be entered once if form popup after feature creation is not suppressed.
2. interactive mode: click into any the ring. A new feature is snuggled into the ring.

Fill gap

applies to: polygon layer (multi or single part)

Fill gaps between the selected polygons of the active layer with new features. The algorithm has to union all selected features first, thus the selection is necessary to speed up the process, especially if the layer contains **many** features. This tool has two modes:

1. batch mode: all gaps between the selected features are filled with new features. The attribute set for all features is identical and can be entered once if form popup after feature creation is not suppressed.
2. interactive mode: click into the gap to be filled. A new feature is snuggled into the gap.

Fill gap (all visible layers)

applies to: polygon layer (multi or single part)

Fill gaps between the polygons of all visible layers with a new feature: click into the gap to be filled. A new feature is snuggled into the gap.

Split selected features with selected line from another layer

applies to: line and polygon layer (multi or single part)

Splits all selected features of the active layer with the selected line feature of another layer. The splitting creates new features (not multi features). Each new feature resulting from being split retains its original attributes.

Flip line

applies to: line layer (multi or single part; does not make too much sense with multi part, though)

Flip the direction of a line, i.e. reverse the node order within the line. This tool has two modes:

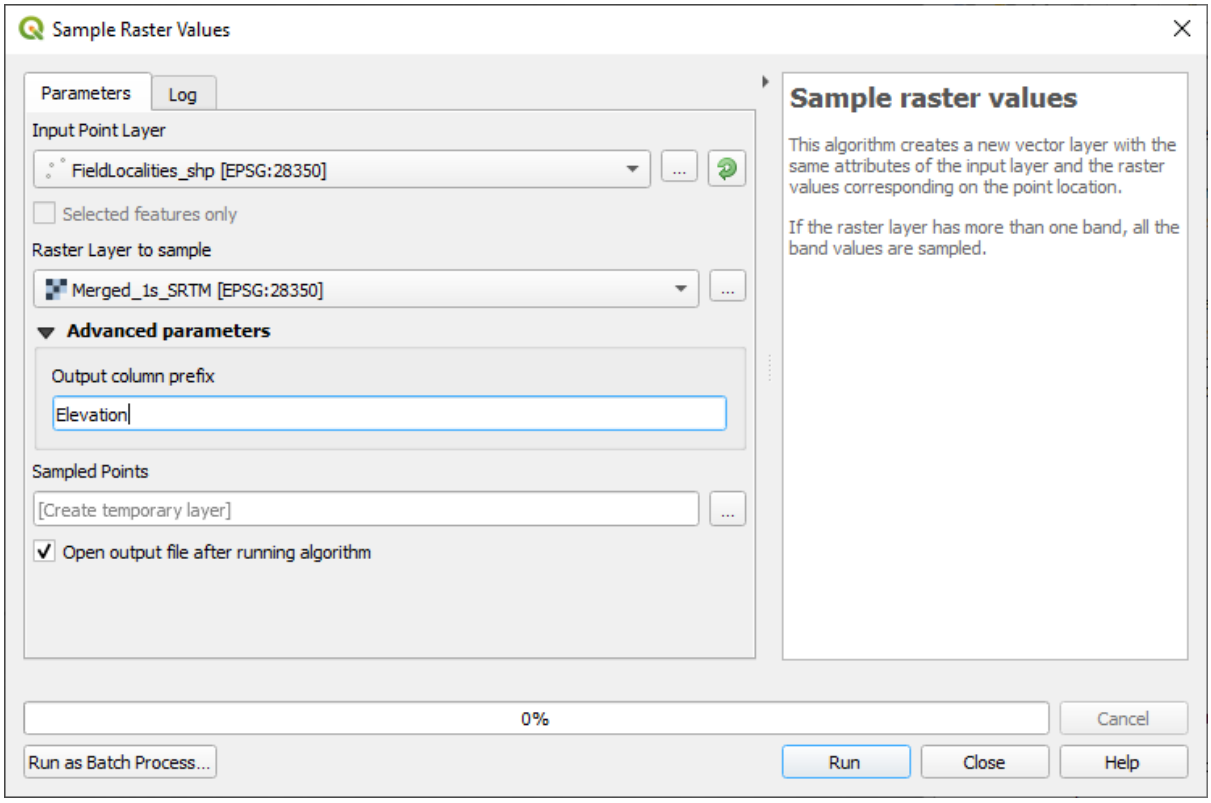
1. batch mode: all selected lines are flipped.
2. interactive mode: click any line feature to have it flipped (successful clicking depends on layer's snap settings).

13.7 Favourites

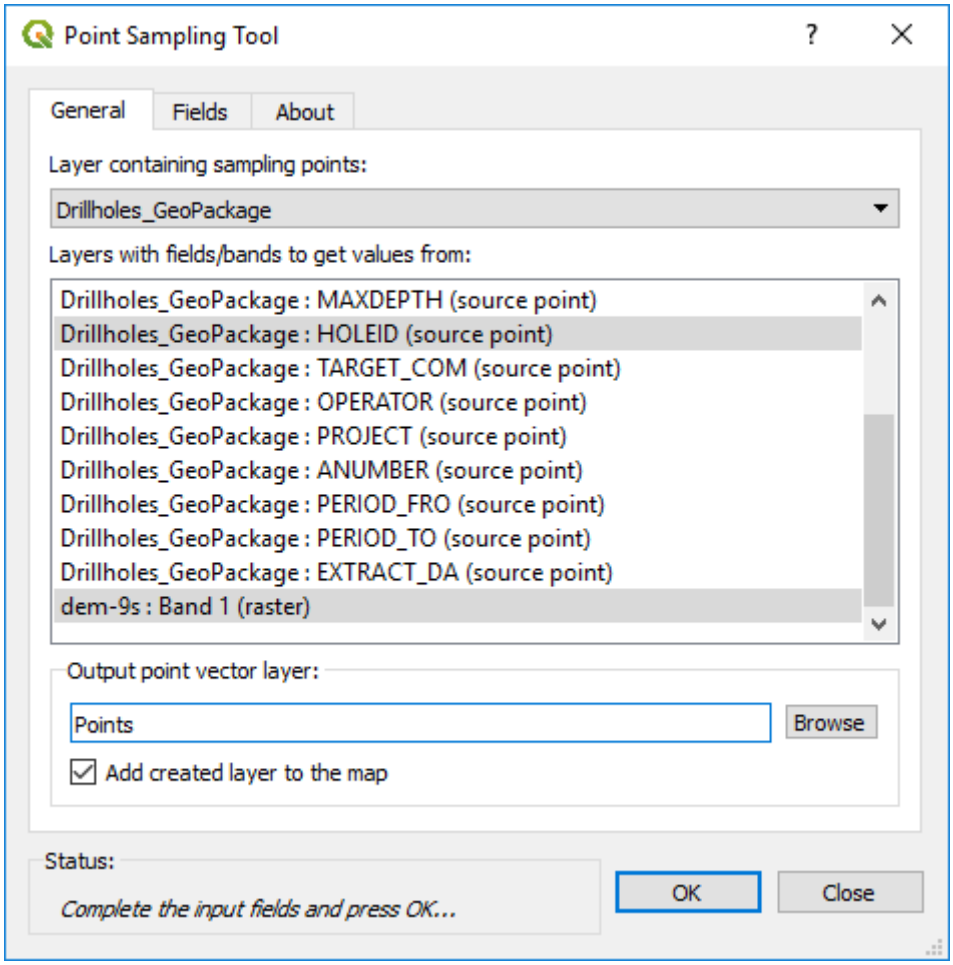
To add a directory as a Favourite for quick access, right click on the “Favourites” item in the Browser panel, then add directory. The favourite directory will then make it much quicker to access commonly used files.

13.8 Point Sampling of Raster Data

To find point values in a raster grid, use the Processing Toolbox > Raster Analysis > Sample Raster Values algorithm. This creates a new layer which can then be used to overwrite the original layer with the new values.



The Point Sampling plug-in tool can also be used to sample points in a grid, e.g. drill hole collar elevations using a digital elevation grid. The output creates a separate file with the resulting values. The point and grid layers need to be in the same projection. The tool is found under the Plugin > Analysis > Point Sampling Tool.



Select the layer containing the points to be used for the data extraction (drill holes), then select the fields to be exported with the points (Hole number), and then select the layer with the elevation data (e.g. dem-9s:Band 1). This will then create a file with hole number and elevation. This will then need to be joined to the drill collar file for example. I find it quicker to use the v.what.rast algorithm above, as this automatically undated the data field.

13.9 Profile Tool

This plug-in allows the user to put a line across a grid and obtain a profile along the line.

13.10 Points to Lines and Polygons

To create a line or polygon from a list of coordinates, for example an excel spreadsheet with tenement corners, use the Processing Toolbox > SAGA > Vector Line Tools > Convert Points to Lines and/or Convert Lines to Polygons.

13.11 QPackage

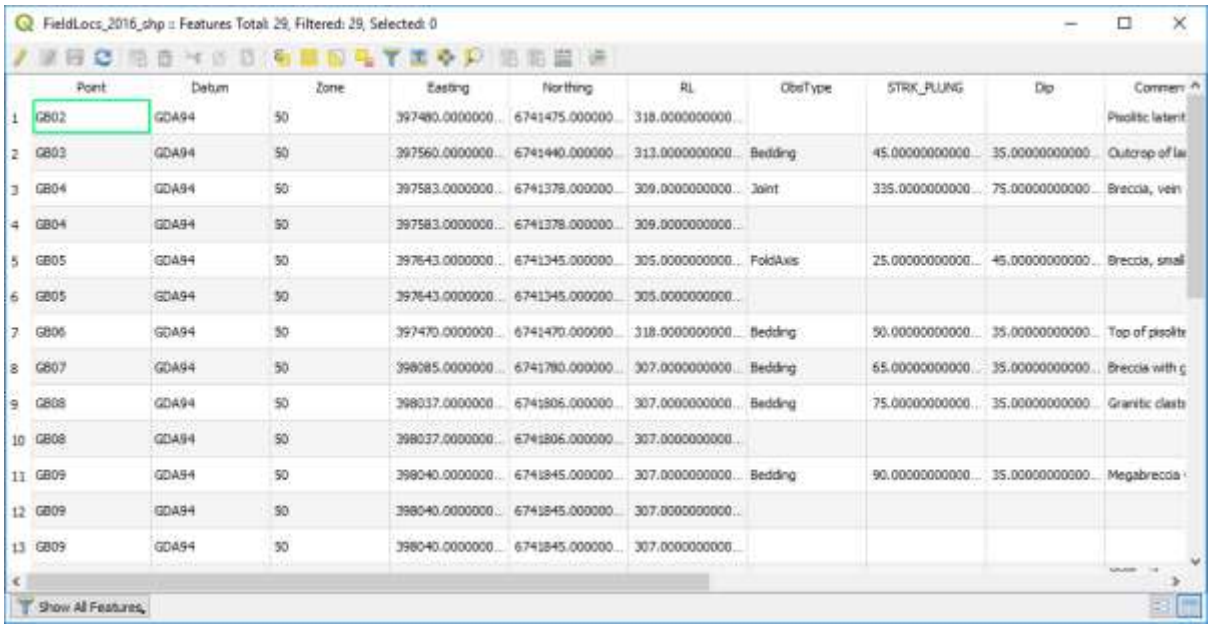
The QPackage plug-in allows the user to create a project file with an associated folder holding all the relevant layers for that project. Note that this will only copy vector files.

13.12 Quick Rectangles, Circles, Ellipse Shapes

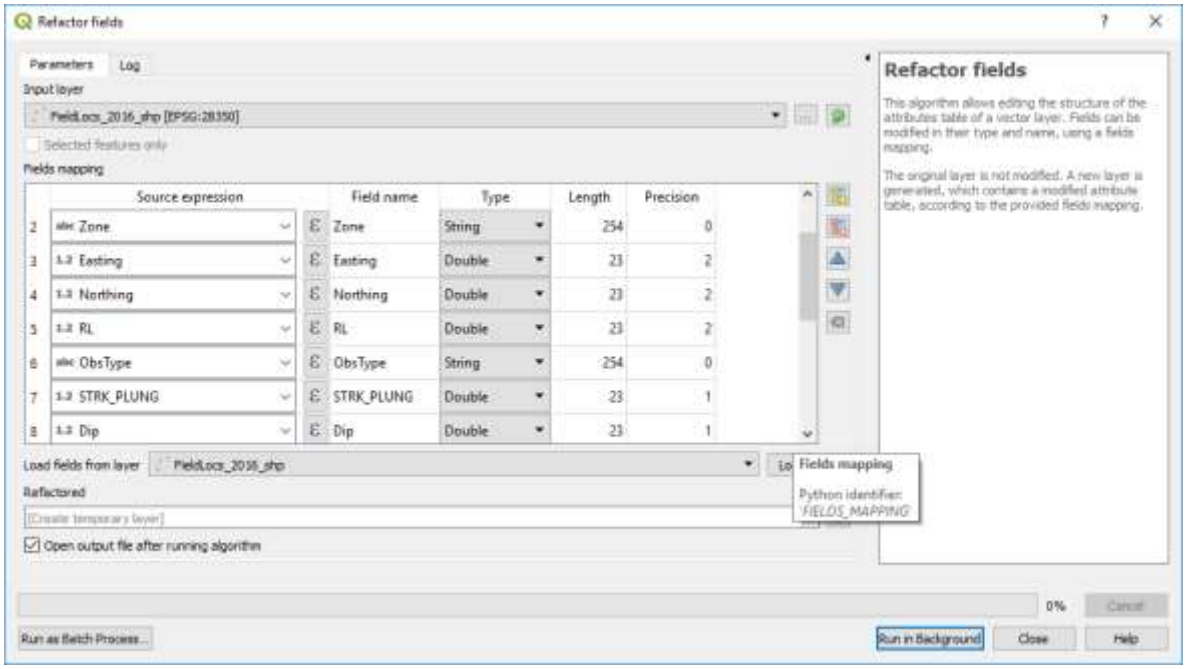
The Shape Digitising tool bar allow the creation of vector shapes, e.g. rectangle and circles.

13.13 Refactor Field

The Refractor Field algorithm allow the modification of a tables' attributes. Be careful using this!



Note the fields with way too many decimals. These can be fixed using the Processing Toolbox > Vector General > Refactor Fields.



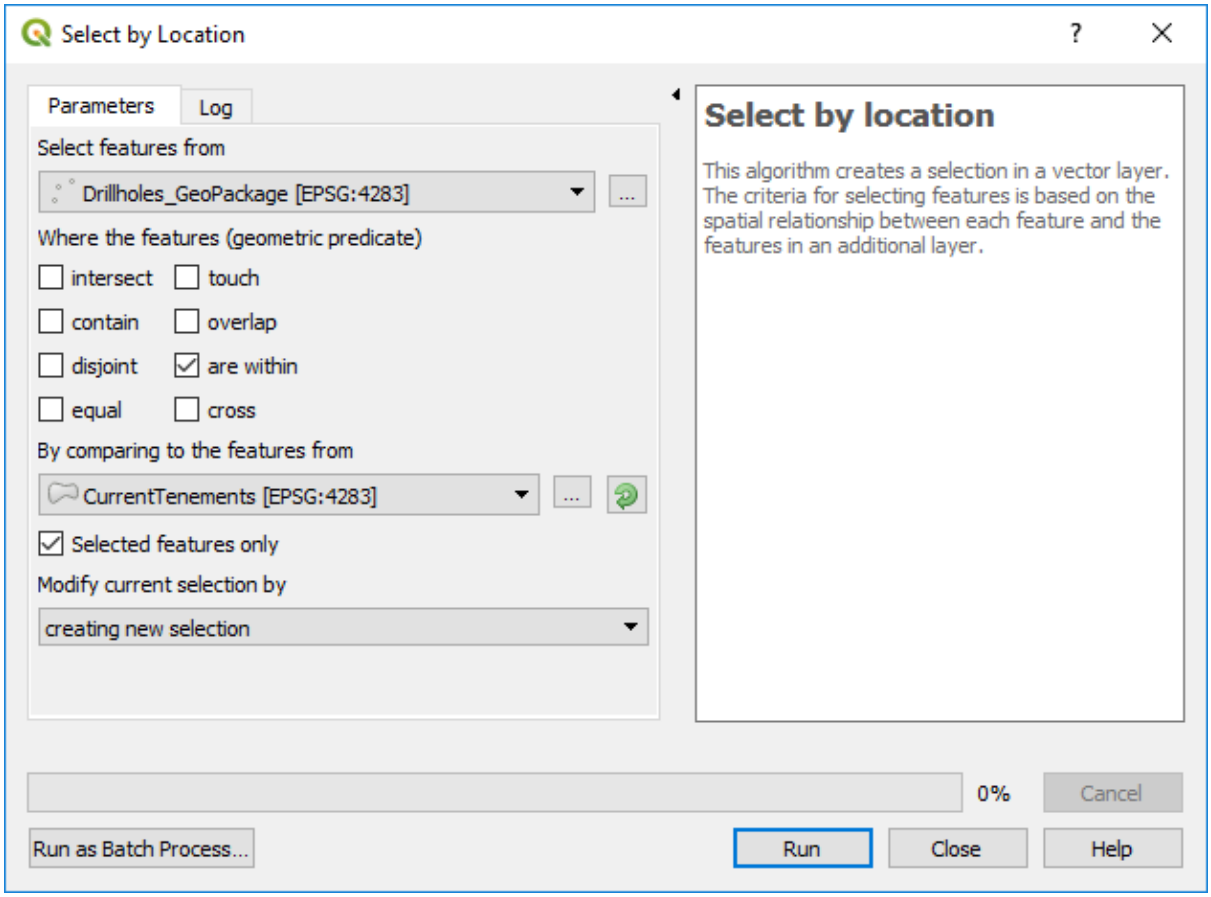
Field names, types and other info can be changed in this window.

13.14 Selecting Drill Holes by Tenement

To select drill holes in a tenement, simply highlight the drill hole layer in the Layers panel, then in the top menu bar choose, select Features by polygon, then right click on the polygon you want to use to select the drill holes, the select layer (e.g. tenements layer) will be listed, just select that

layer and the holes will selected for that tenement. Note this may not worked with layers in different projections.

The other method that can be used is the Processing Toolbox > Vector Selection > Select by Location algorithm.



If you hold the "Alt" key while making a selection QGIS, it switches from an "intersects" type selection to a "contains" selection mode. (This also works while holding the shift modifier to add to a selection, or ctrl to subtract from a selection!).

13.15 Spatialite Databases

A Spatialite database is a simple, single file database structure that can hold very large files but with the advantage that the data is spatially referenced. The spatial referencing allows the data to be quickly displayed when panning across a map. This is very useful for data such as the 250k vector data (from GA) for Australia or the large GSWA open file drill hole database.

The use of Spatialite database files can rapidly increase the speed of accessing large data sets. As an example, the entire 1:250 000 Geoscience Australia Australia-wide topographic vector data in zipped shapefile format is 1.01 Gb in size (GA file 64058.zip) and comprises many layers including road, rivers, etc. This file can be loaded into a Spatialite database file of about 3 Gb, but although a large file, the data is spatially indexed, and re-drawing of the data is very fast when panning from area to area.

Another spatialite option is to use the new GeoPackage file format which can store large datasets comprising vector, raster and non-spatial data.

13.16 Extracting Colour Styling Information from MapInfo Files

Colour polygon information can be extracted from MapInfo files using an RGB extraction routine in the MapInfo-Discover module.

14: REFERENCES

Abrams M and Hook S. 2016 (downloaded) ASTER User Handbook, Version 2. Jet Propulsion Lab, Pasadena.

Bureau of Mineral Resources. 1989. Symbols Used on Geological Maps. Geoscience Australia, publication GA21883.

Cutts A and Graser A. 2018. Learn QGIS – Fourth Edition. Packt Publishing, Birmingham.

Graser A. 2016. Learning QGIS – Third Edition. PACKT Publishing, Birmingham.

Graser A and Peterson G N. 2016. QGIS Map Design. Locate Press.

Janousek V, Farrow C M and Erban V. 2006. Interpretation of Whole-Rock Geochemical Data in Igneous Geochemistry: Introducing Geochemical Data Toolkit (GCDkit). Journal of Petrology, vol. 47, no. 6, p 1255-1259.

Kalinowski A and Oliver S. 2004. ASTER Mineral Index Processing Manual. Geoscience Australia, publication no. GA7833.pdf.

McQueen K G. 2017. Identifying Geochemical Anomalies. Downloaded from http://crcleme.org.au/Pubs/guides/gawler/a7_id_anomalies.pdf, 2nd April 2017.

QGIS Project. 2017. QGIS User Guide – Release 2.14. Downloaded from http://docs.qgis.org/2.14/pdf/. Dated Jan 18th 2017.

San B and Sumer E O. 2004. Comparison of band ratioing and spectral indices methods for detecting alunite and kaolinite minerals using ASTER data in Biga region, Turkey. ResearchGate tba.

Strumberger V. 2016. Use of QGIS in Mineral Exploration, Vol.1. Download from author at Velizar.strumberger@gmail.com.

USGS. 2006. FGDC Digital Cartographic Standard for Geologic Map Symbolization (PostScript Implementation). US Geological Survey.

Van der Meer F D, van der Werff H M A and van Ruitenbeek F J A. 2014. Potential of ESA's Sentinel-2 for geological applications. Remote Sensing of Environment, vol. 148, pp. 124-133.

Yamaguchi Y and Naito C. 2003. Spectral indices for lithologic discrimination and mapping using the ASTER SWIR bands. International Journal of Remote Sensing, vol. 24, no. 22, p 4311-4323.

APPENDIX

Lithologic Patterns for Geological Maps

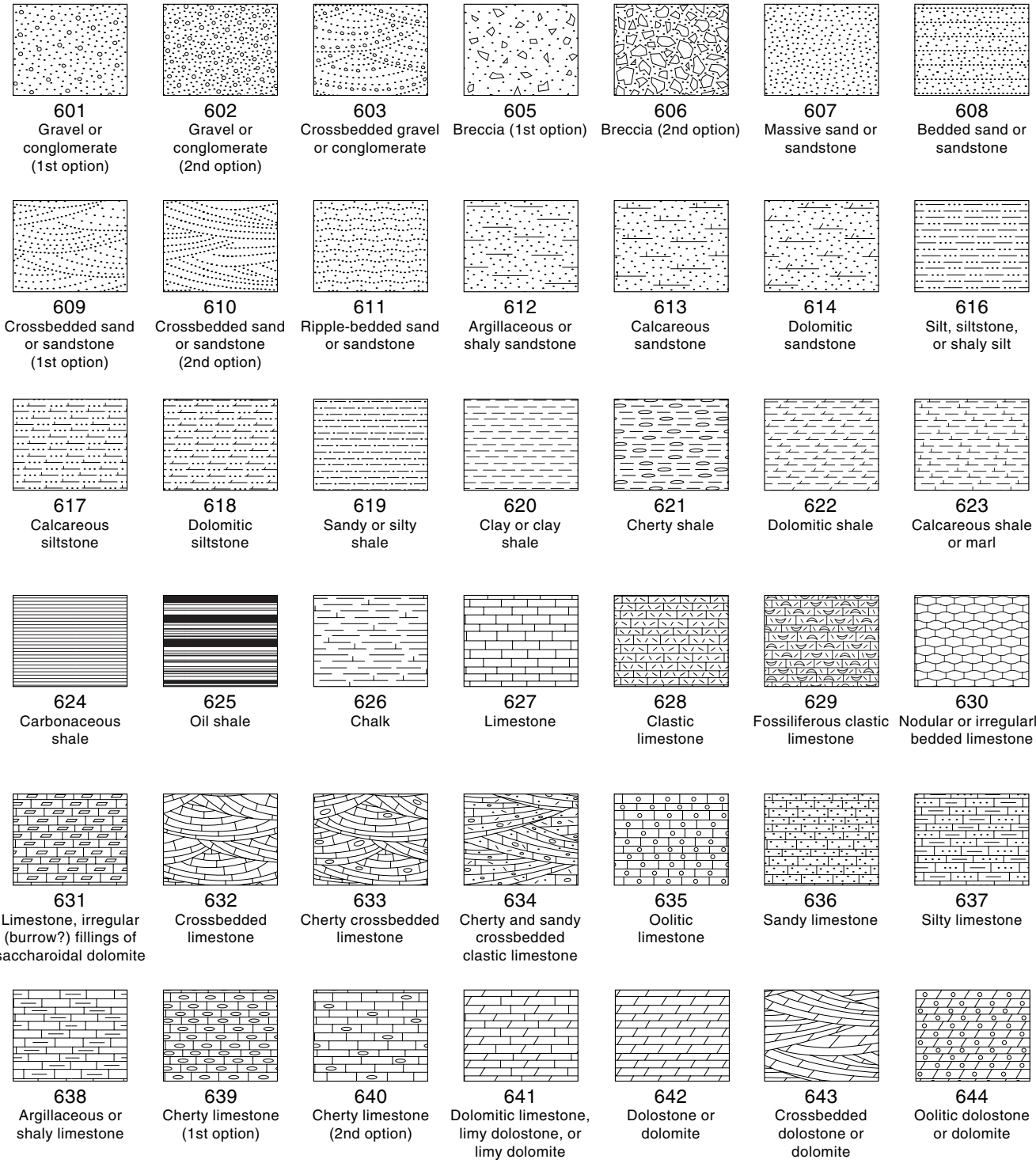
USGS

(FGDC STD-013-2006)

37—LITHOLOGIC PATTERNS

[Lithologic patterns are usually reserved for use on stratigraphic columns, sections, or charts]

37.1—Sedimentary-rock lithologic patterns



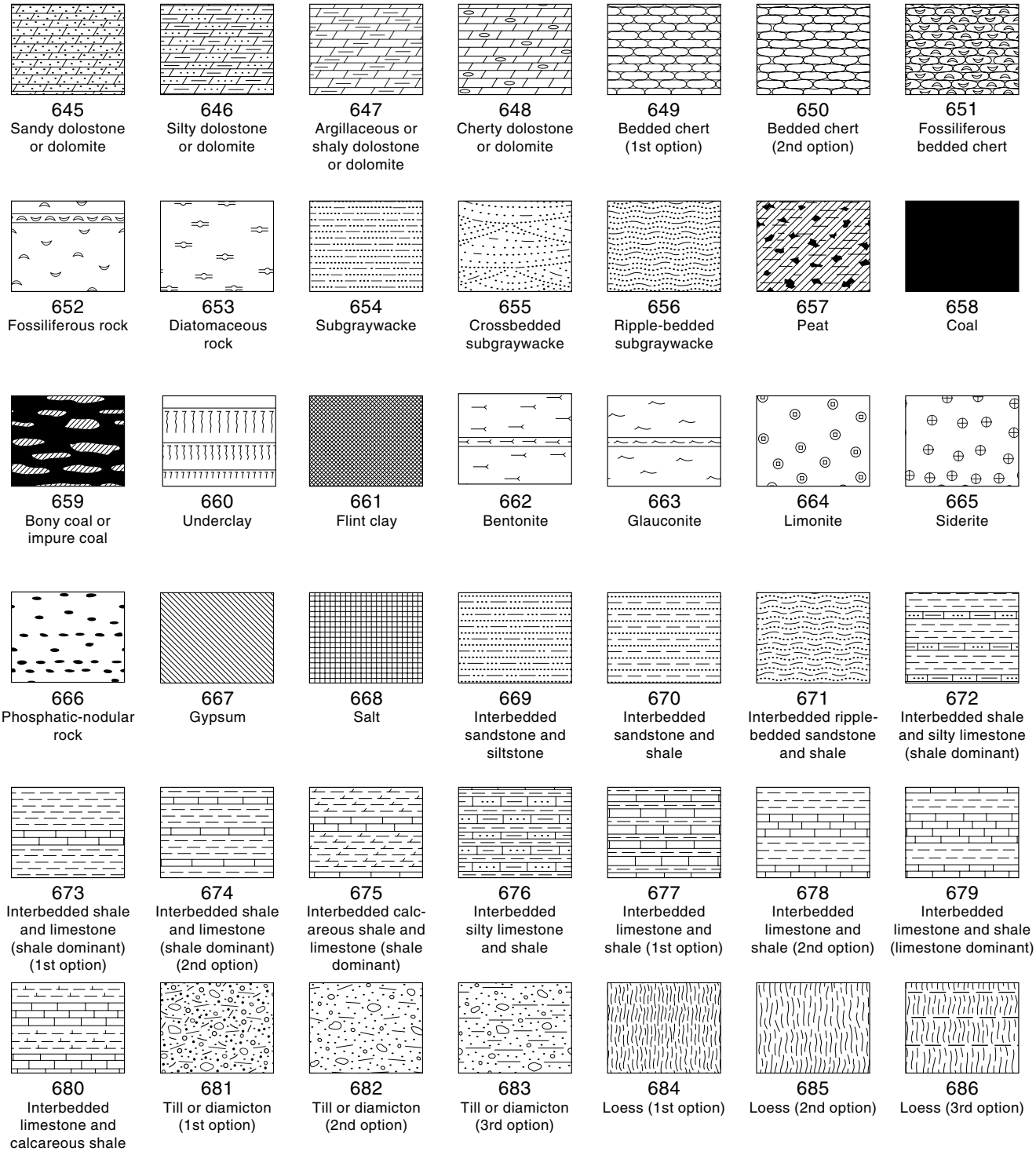
601 Gravel or conglomerate (1st option)
602 Gravel or conglomerate (2nd option)
603 Crossbedded gravel or conglomerate
605 Breccia (1st option)
606 Breccia (2nd option)
607 Massive sand or sandstone
608 Bedded sand or sandstone
609 Crossbedded sand or sandstone (1st option)
610 Crossbedded sand or sandstone (2nd option)
611 Ripple-bedded sand or sandstone
612 Argillaceous or shaly sandstone
613 Calcareous sandstone
614 Dolomitic sandstone
616 Silt, siltstone, or shaly silt
617 Calcareous siltstone
618 Dolomitic siltstone
619 Sandy or silty shale
620 Clay or clay shale
621 Cherty shale
622 Dolomitic shale
623 Calcareous shale or marl
624 Carbonaceous shale
625 Oil shale
626 Chalk
627 Limestone
628 Clastic limestone
629 Fossiliferous clastic limestone
630 Nodular or irregularly bedded limestone
631 Limestone, irregular (burrow?) fillings of saccharoidal dolomite
632 Crossbedded limestone
633 Cherty crossbedded limestone
634 Cherty and sandy crossbedded clastic limestone
635 Oolitic limestone
636 Sandy limestone
637 Silty limestone
638 Argillaceous or shaly limestone
639 Cherty limestone (1st option)
640 Cherty limestone (2nd option)
641 Dolomitic limestone, limy dolostone, or limy dolomite
642 Dolostone or dolomite
643 Crossbedded dolostone or dolomite
644 Oolitic dolostone or dolomite

For more information, see general guidelines on pages A-i to A-v.

37—LITHOLOGIC PATTERNS (continued)

[Lithologic patterns are usually reserved for use on stratigraphic columns, sections, or charts]

37.1—Sedimentary-rock lithologic patterns (continued)



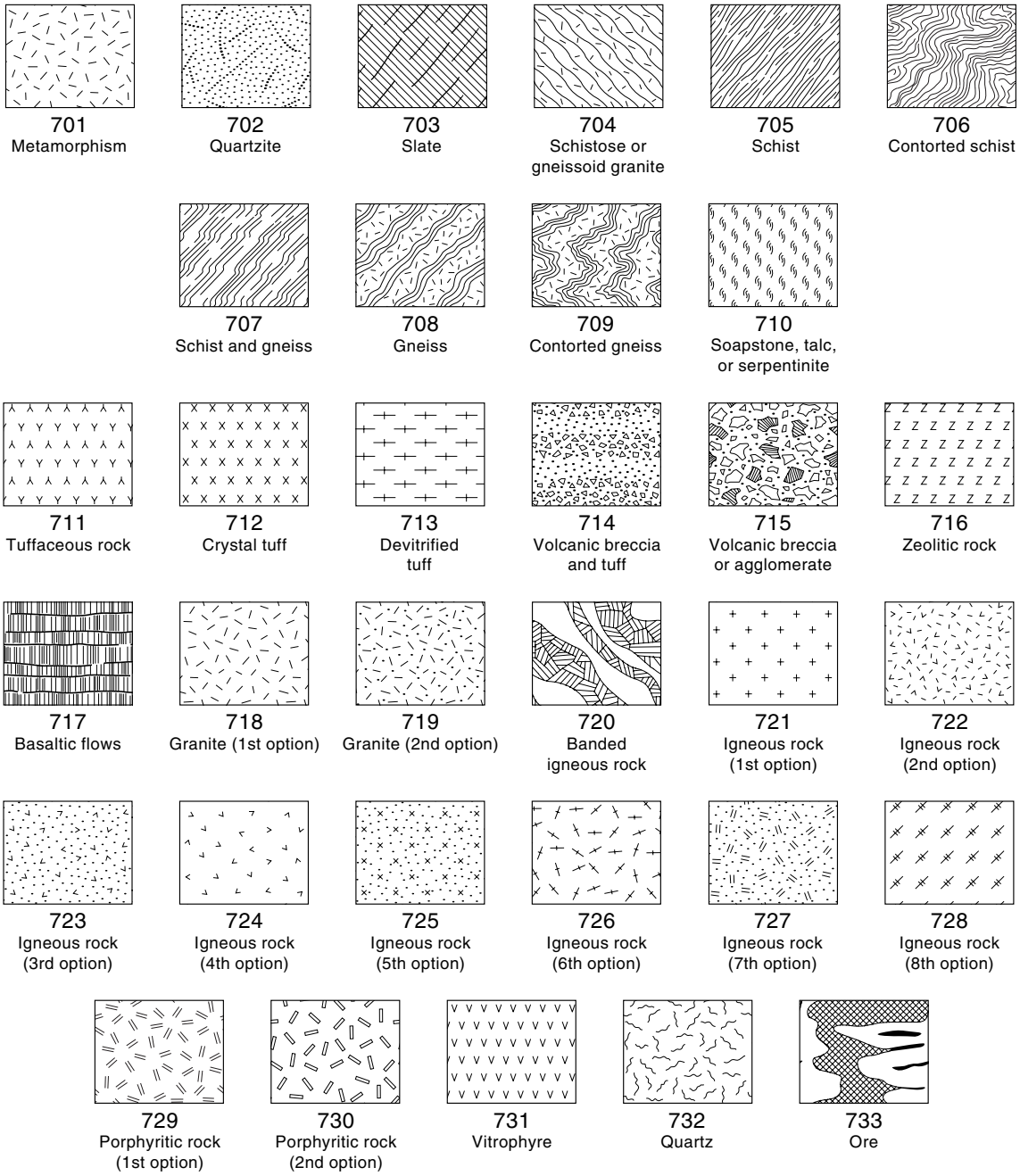
645 Sandy dolostone or dolomite
646 Silty dolostone or dolomite
647 Argillaceous or shaly dolostone or dolomite
648 Cherty dolostone or dolomite
649 Bedded chert (1st option)
650 Bedded chert (2nd option)
651 Fossiliferous bedded chert
652 Fossiliferous rock
653 Diatomaceous rock
654 Subgraywacke
655 Crossbedded subgraywacke
656 Ripple-bedded subgraywacke
657 Peat
658 Coal
659 Bony coal or impure coal
660 Underclay
661 Flint clay
662 Bentonite
663 Glauconite
664 Limonite
665 Siderite
666 Phosphatic-nodular rock
667 Gypsum
668 Salt
669 Interbedded sandstone and siltstone
670 Interbedded sandstone and shale
671 Interbedded ripple-bedded sandstone and shale
672 Interbedded shale and silty limestone (shale dominant)
673 Interbedded shale and limestone (shale dominant) (1st option)
674 Interbedded shale and limestone (shale dominant) (2nd option)
675 Interbedded calc-areous shale and limestone (shale dominant)
676 Interbedded silty limestone and shale
677 Interbedded limestone and shale (1st option)
678 Interbedded limestone and shale (2nd option)
679 Interbedded limestone and shale (limestone dominant)
680 Interbedded limestone and calcareous shale
681 Till or diamicton (1st option)
682 Till or diamicton (2nd option)
683 Till or diamicton (3rd option)
684 Loess (1st option)
685 Loess (2nd option)
686 Loess (3rd option)

For more information, see general guidelines on pages A-i to A-v.

37—LITHOLOGIC PATTERNS (continued)

[Lithologic patterns are usually reserved for use on stratigraphic columns, sections, or charts]

37.2—Metamorphic-rock, igneous-rock, and vein-matter lithologic patterns



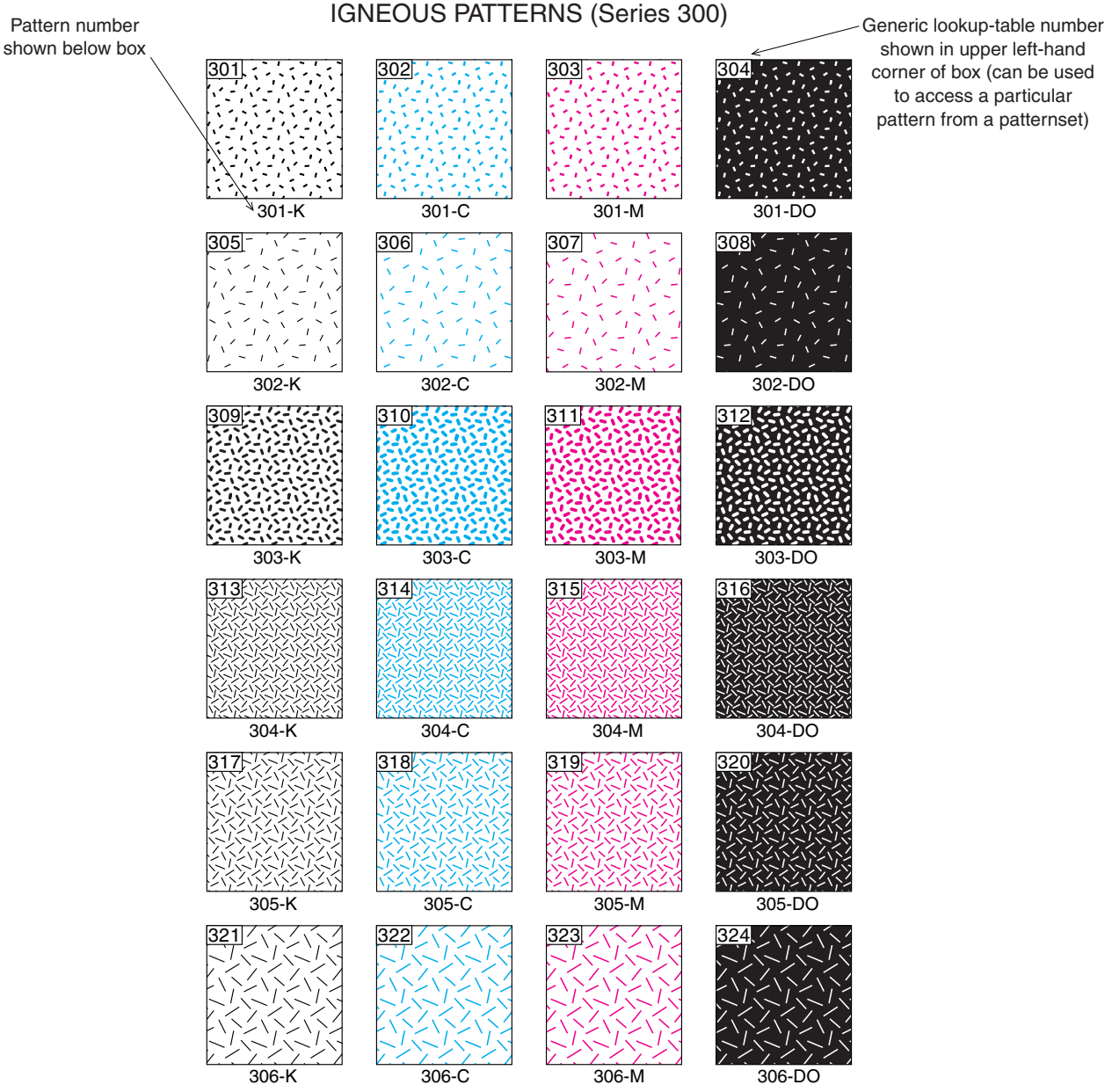
*For more information, see general guidelines on pages A-i to A-v.

38—EXPLANATION FOR PATTERN CHART

DISCUSSION*
This diagram provides some basic information on how to use the new Pattern Chart, which is enclosed in the sleeve on the inside back cover of this standard volume. For more specific information on the use of patterns (and color) on geologic maps, see Section 5, entitled "Guidelines for Map Color and Pattern Selection," in the accompanying introductory text. Most patterns on this new chart were designed (in Adobe Illustrator 8.0.1) to closely replicate patterns in the informal "Technical Cartographic Standards" volume (U.S. Geological Survey, ca. 1975). In some cases, however, lineweights of pattern elements had to be increased to facilitate higher resolution (1800 dpi) digital output; therefore, some patterns may not plot or print correctly if output at lower resolutions. Each pattern has been assigned a new pattern number (see below each box). In addition, each pattern now has associated with it a generic look-up table number that can be used to access a pattern if it has been incorporated into a patternset.

DESCRIPTION	
Abbreviations used in pattern numbers:	• K, black; C, cyan; M, magenta; DO, dropout; R, red; B, brown
Overprint patterns have white background	• Pattern is in front. One bounding box (having Fill and Stroke set to 'None') is in back • White background is transparent (underlying map-unit color will be visible)
Dropout patterns have black background	• Pattern is in front. Two bounding boxes are in back: box directly beneath pattern has Fill set to 100% black and Stroke set to 'None'; box to rear has both Fill and Stroke set to 'None' • Black background represents underlying map-unit color. If white pattern is used "as is," it will knock out the underlying map-unit color; if pattern is changed to one of the CMYK values in the underlying map-unit color, it will knock out the other CMYK value(s) in map-unit color

IGNEOUS PATTERNS (Series 300)

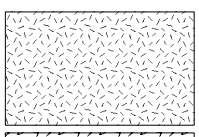


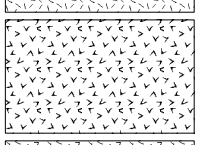
**For more information, see general guidelines on pages A-i to A-v.*

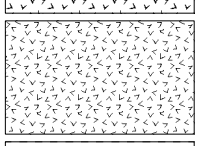
Geoscience Australia

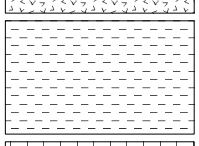
Proposed shadeset : pattern94.shd 19 Jul 95

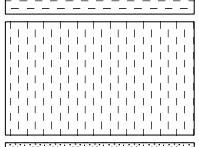
(some patterns still to be created)

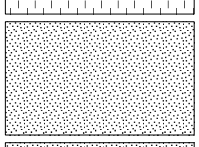
1  m16.xbm

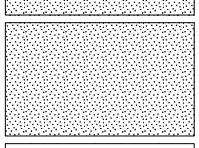
2  m18.xbm

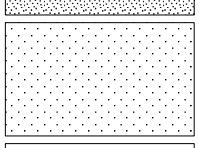
3  m19.xbm

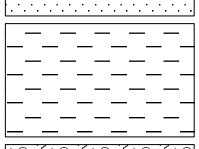
4  m1h.xbm

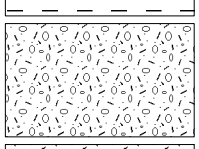
5  m1v.xbm

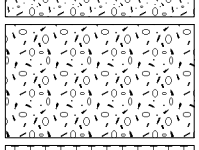
6  m22.xbm

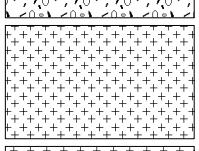
7  m25.xbm

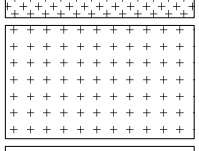
8  m26.xbm

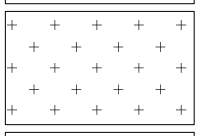
9  m2h.xbm

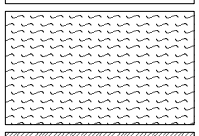
10  m31.xbm

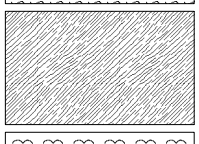
11  m32.xbm

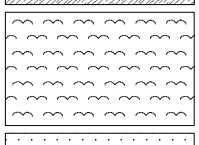
12  m35.xbm

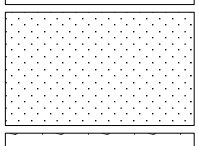
13  m38.xbm

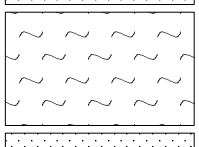
14  m39.xbm

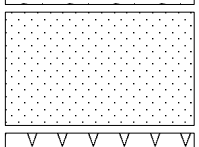
15  m43.xbm

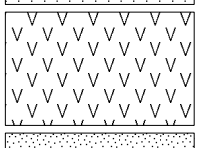
16  m45.xbm

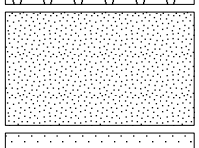
17  m46.xbm

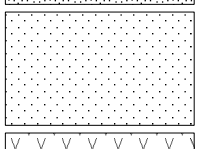
18  m48.xbm

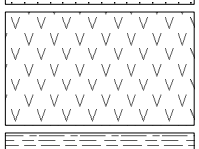
19  m51.xbm

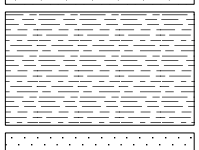
20  m52.xbm

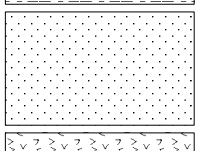
21  m54.xbm

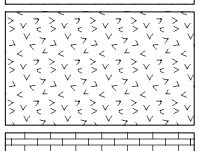
22  m56.xbm

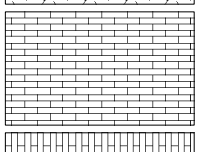
23  m57.xbm

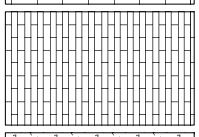
24  m58.xbm

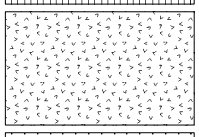
25  m5h.xbm

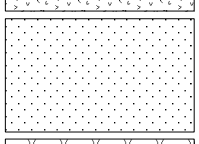
26  m61.xbm

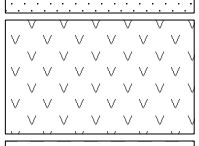
27  m66.xbm

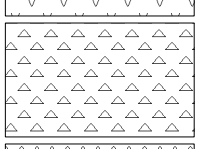
28  m67h.xbm

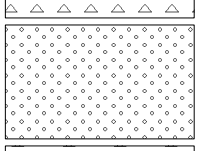
29  m67v.xbm

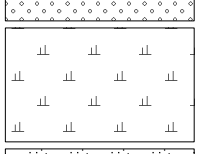
30  m72.xbm

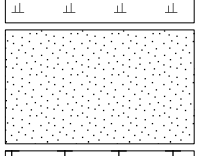
31  m73.xbm

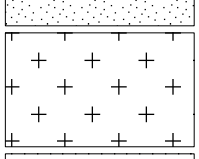
32  m74.xbm

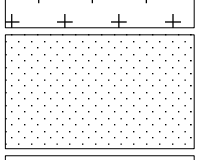
33  m78.xbm

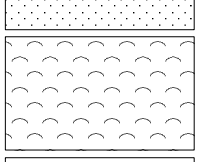
34  m82.xbm

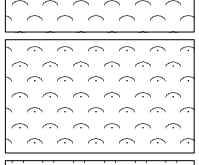
35  m85.xbm

36  m89.xbm

37  m92.xbm

38  m93.xbm

39  m200.xbm

40  m201.xbm

41 m202.xbm

42 m203.xbm

43 m204.xbm

44 m205.xbm

45 m206.xbm

46 m207.xbm

47 m208.xbm

48 m209.xbm

49 m210.xbm

50 m211.xbm

51 m212.xbm

52 m213.xbm

53 m214.xbm

54 m215.xbm

55 m216.xbm

56 m217.xbm

57 m218.xbm

58 m219.xbm

59 m220.xbm

60 m221.xbm

61 m222.xbm

62 m223.xbm

63 m224.xbm

64 m225.xbm

65 m226.xbm

66 m227.xbm

67 m228.xbm

68 m229.xbm

69 m230.xbm

70 m231.xbm

71 m232.xbm

72 m233.xbm

73 m234.xbm

74 m235.xbm

75 m236.xbm

76 m237.xbm

77 m238.xbm

78 m239.xbm

79 m240.xbm

80 m241.xbm

81 m242.xbm

82 m243.xbm

83 m244.xbm

84 m245.xbm

85 m246.xbm

Geological Survey of Western Australia

GSWA - Series Mapping Patterns — June 2017

Constructed with Adobe Illustrator CS6 — Map Production Manual Section - 17

'b' Patterns

b1 b1i b2i b3

'c' Patterns

c1 c1-2 c1-3 c2 c3 c3-2 c3-3 c3-4 c3-5 c3-6 c3-7 c3-8 c4 c5

'd' Patterns

d101 d101-2 d101-3 d102 d105 d105-2 d105-3 d110 d110-2 d111 d112 d113

'l' Patterns

l1 l11 l12 l13 l14 l102 l102-2 l103 l104 l107 l111 l112 l113 l114

'l' Patterns (cont.)

l114d l115 l115d l116 l118 l120

'm' Patterns

m1 m1-2 m2 m2-2 m5 m5-2 m6 m6-2 m10 m10-2 m12 m12-2 m13 m13-2

'm' Patterns (cont.)

m14 m15 m16 m16-2 m19 m19-2 m19-3 m20 m20-2 m22 m22a m22b m22c m22d

'm' Patterns (cont.)

m22-2 m23 m23-2 m24 m24-2 m25 m26 m26-2 m29 m30 m31 m33 m35 m36

'm' Patterns (cont.)

m36e m38 m38e m40 m41 m59 m59e m59-2 m59-2e m70 m70-2 m70-3 m70-4 m71

'm' Patterns (cont.)

m71-2 m74 m74-2 m75 m76 m76-2 m76-3 m76-4 m77 m78 m79 m79-2 m82 m82-2

'm' Patterns (cont.)

m85 m86 m90 m90-2 m91 m91-2

'p' Patterns

p1 p2 p3

'x' Patterns

x1 x2

named Patterns

m paw1 paw2 paw3 w waves

June 2017