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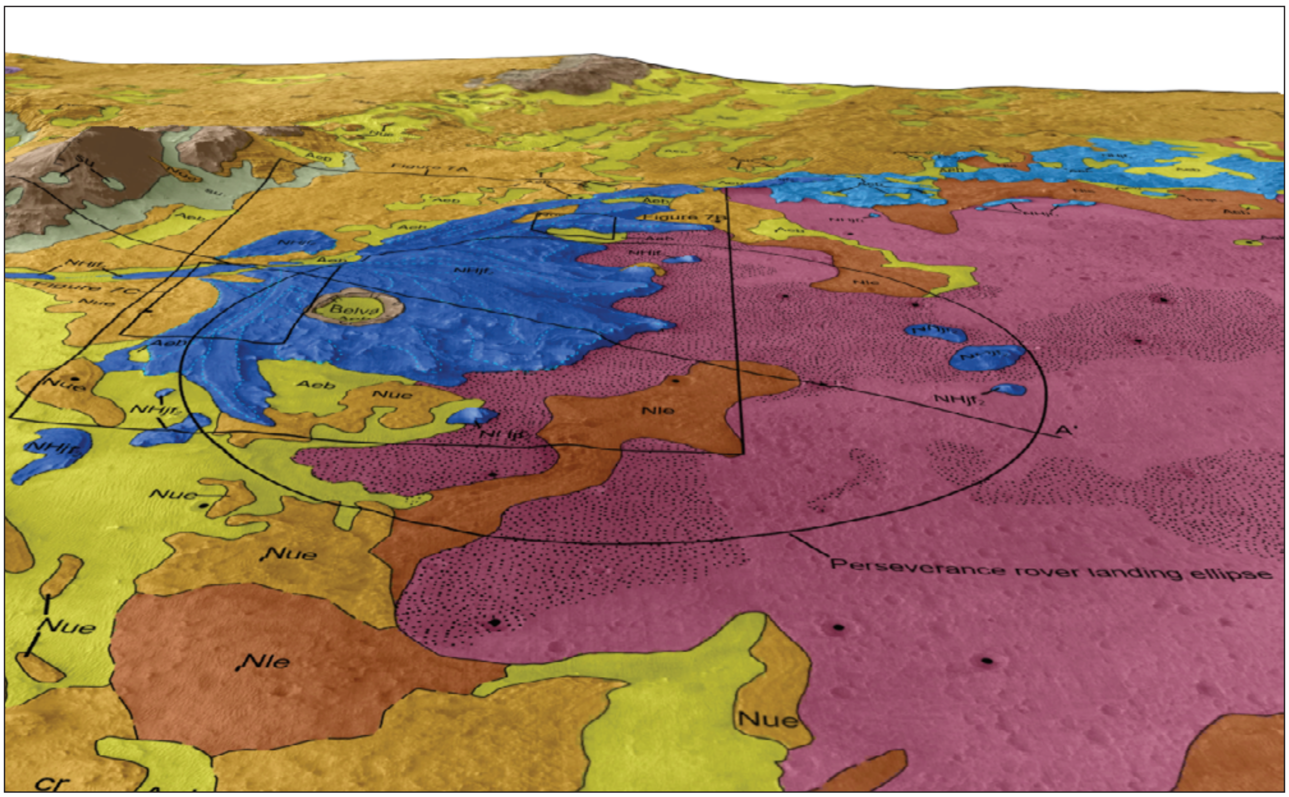
User’s Guide to Planetary Image Analysis and Geologic Mapping in ArcGIS Pro

Chapter 14 of
Section B, U.S. Geological Survey Standards, of
Book 11, Collection and Delineation of Spatial Data



Techniques and Methods 11–B14

U.S. Department of the Interior
U.S. Geological Survey

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By Sarah R. Black

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Cover: Oblique 3D view of the Perseverance rover landing site in Jezero crater, Mars, with the geologic map USGS SIM 3464 overlain on high-resolution topographic data from the Mars Reconnaissance Orbiter. This is a still image from the animation "Fly By of Jezero Crater and SIM 3464" by Trent Hare from November 27, 2020 (https://www.usgs.gov/media/videos/fly-jezero-crater-and-sim-3464).

Contents

Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as °F = (1.8 × °C) + 32.

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as °C = (°F – 32) / 1.8.

Abbreviations

CTX	Context Camera
DEM	Digital Elevation Model
DRA	Dynamic Range Adjustment
DTM	Digital Terrain Model
GDAL	Geospatial Data Abstraction Library (USGS)
GIS	Geographic Information Systems
HiRISE	High Resolution Imaging Science Experiment
HRSC	High Resolution Stereo Camera
MOLA	Mars Orbiter Laser Altimeter
MRO	Mars Reconnaissance Orbiter
NASA	National Aeronautics and Space Administration
PDS	Planetary Data System (NASA)
TRN	Terrain Relative Navigation
USGS	U.S. Geological Survey

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Sarah R. Black

Background

Geologic maps are valuable tools in planetary science. Though planetary geologic maps are similar to terrestrial (Earth-based) geologic maps, the nature of planetary exploration introduces unique challenges for geologic mappers. Terrestrial geologic mappers prepare products from field-based observation, often comparing or refining those with aerial and (or) orbital images. Planetary geologic mapping relies almost exclusively on remote observations, which are made by orbiting spacecraft. Therefore, with a few exceptions for locations with rovers, landers, or crewed surface missions, planetary geologic mappers are not able to observe their map area in detail or at smaller scales. As a result, they must interpret and describe their map features differently than those used in terrestrial geologic maps. For example, terrestrial geologic mappers commonly divide units by lithology (rock type) or grain size. However, planetary geologic mappers often do not have detailed enough information to know what type of rock or grain size is present, and instead must divide the planet's surface into geologic units using differences in tone, color, and surface texture (at multiple scales). Cross-cutting relationships, where apparent, can provide excellent—and often crucial—observations for identifying and subdividing geologic units using orbital datasets.

The process of creating planetary maps has evolved over time, from original hand-drawn maps created during the early 1800s through the late 1900s, to the fully digital products created today. Modern-day planetary geologic mapping uses Geographic Information Systems (GIS) software and tools to visualize data, delineate units and landforms, and accurately convey spatial relationships to a map user using cartographic features represented by points, lines, and polygons.

This tutorial was written to familiarize both new and experienced planetary geologic mappers with ArcGIS Pro, a commonly used GIS software package developed by Esri. This tutorial introduces new planetary geologic mappers to fundamental concepts and best practices in planetary geologic mapping. For mappers with experience using ArcMap (a previous version of ArcGIS), this tutorial will help to familiarize users with new changes in layout and functionality, so current projects may be migrated into the ArcGIS Pro environment. No prior knowledge is required, although a general familiarity with geology, GIS, and planetary science is recommended. This tutorial includes links to helpful glossaries of common GIS terms and other GIS and planetary science resources in appendix 1. For additional information on planetary geologic mapping, see the U.S Geological Survey (USGS) Astrogeology NASA Planetary Geologic Mapping Program website and the Planetary Mapping Guidelines. Numerous ArcGIS tutorials are also available from Esri's Tutorials page, through the Esri Academy catalog, and Esri's ArcGIS Pro Resources page.

Learning Goals and Objectives

Exercise 1

Goal: Upon successful completion of this exercise, both new ArcGIS and experienced ArcMap users will be familiar with the ArcGIS Pro interface.

Objective: By the end of this exercise, users will be able to:

1. Navigate the dynamic menu bar, contents, catalog, and other tool panes.
2. Import existing ArcMap projects.
3. Change between layout and map views.
4. Create a new ArcGIS Pro project.
5. Add data to a project.
6. Adjust layer display properties.
7. Manage map and group layers within the Contents pane.

Exercise 2

Goal: Upon successful completion of this exercise, both new ArcGIS and experienced ArcMap users will be able to use ArcGIS Pro to analyze raster data in a planetary science setting.

Objective: By the end of this exercise, users will be able to:

1. Create and work with mosaic datasets.
2. Understand the difference between raster functions and geoprocessing tools.
3. Use geoprocessing tools to complete a multi-step analysis.
4. Use raster functions to complete a multi-step analysis.
5. Create and use custom raster functions to complete a multi-step analysis.

Exercises 3, 4, and 5

Goal: Upon successful completion of these exercises, both new ArcGIS and experienced ArcMap users will be able to execute common planetary geologic mapping methods and observe best practices for planetary geologic mapping in ArcGIS Pro.

Objective: By the end of these exercises, users will be able to:

1. Create a new feature class.
2. Create and edit features within a feature class.
3. Create polygons from both point and linear features.
4. View and edit a feature class attribute table.
5. Edit symbologies both manually and using a symbology layer file.
6. Create and edit a complete map layout, including placing scale bars, a north arrow, and legend.

Required Files and Preparation

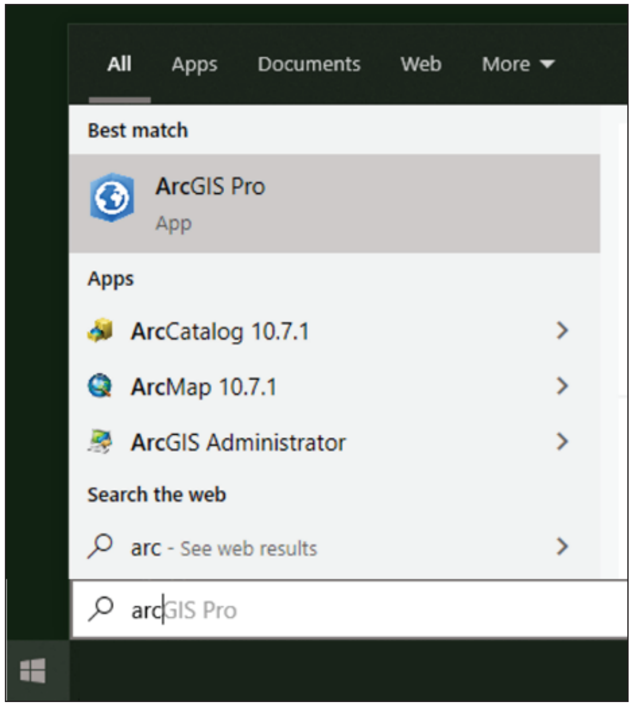
In addition to this document, the user will need to download the associated PlanetaryImageAnalysis.zip file, which contains all the GIS files needed to complete this tutorial. Both are available on the Tutorials page of the USGS Planetary Geologic Mapping Website. After downloading, unzip the PlanetaryImageAnalysis.zip file, and save the unzipped folder (PlanetaryImageAnalysis) to a location of your choice on your computer. You will be opening GIS files from this folder, so make sure you know where you have it saved.

Note: ArcGIS Pro is a Windows-based software. This tutorial is intended to be completed using a PC and ArcGIS Pro version 2.6 or newer. Depending on your version of ArcGIS Pro, you may notice some slight variations in icons, and so forth.

Exercise 1: Introduction to ArcGIS Pro

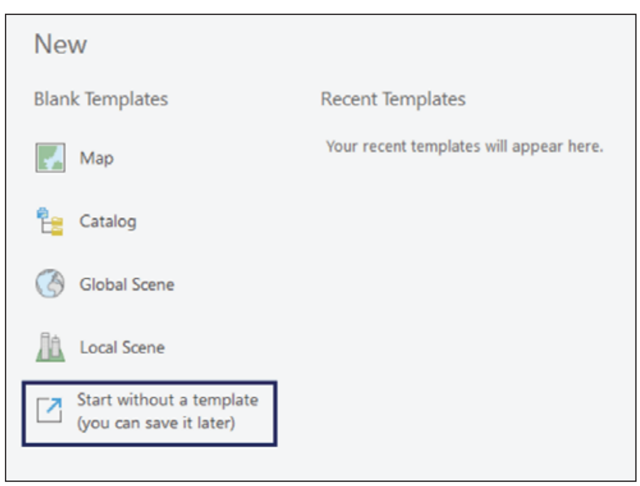
In this exercise you will learn the basics of the ArcGIS Pro interface, including how to create a new project and import preexisting projects in both **.mxd** (ArcMap) and **.aprx** (ArcGIS Pro) formats.

1. From your desktop or Start menu, open **ArcGIS Pro**



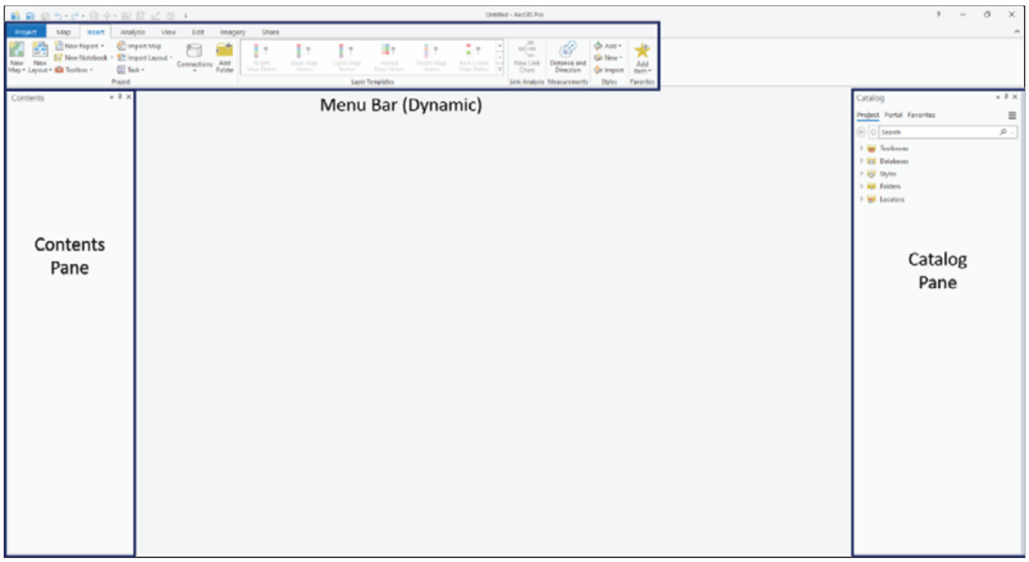
Note: If you haven't previously logged in, you will be prompted to do so at this point; this is how the licensing works for ArcGIS Pro. If you are not logged in, the software will not know you have a license and will not be able to run. If you need to be able to work offline, there is an option to check out a license for offline use in the ArcGIS Pro options. This is accessible to you after you log in for the first time. Often, the number of licenses that are available for offline use are limited in number, so be sure to check with your organization's portal administrator before checking one of these out.

2. A new window will open for ArcGIS Pro with several options to set up a new map project. Select **Start without a template**.



Part 1: The ArcGIS Pro Interface

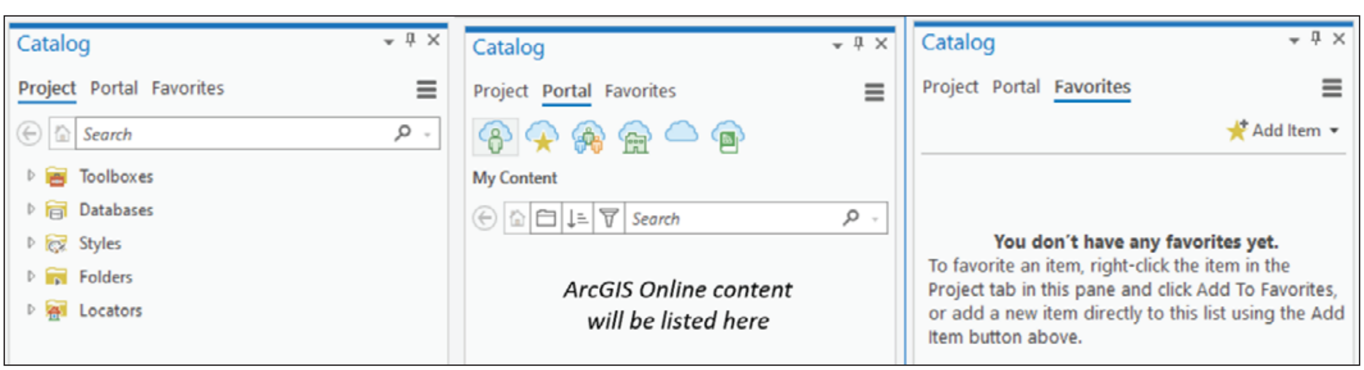
A new map project will open with a blank template. Before adding anything to this new project, take a few minutes to explore the ArcGIS Pro interface:



Across the top of the window is the dynamic **menu bar**. The tabs that are currently displayed (Project, Map, Insert, Analysis, View, Edit, Imagery, and Share) are always visible. Additional tabs will appear as you select items in your project. The menu bar will only display tabs that you can currently use, depending on what type of item you have selected. For example, the raster formatting tabs will automatically appear when you have raster layers selected.

Down the left side of the window is the **Contents** pane. This is where the layers of data that are included in your map will be listed. Once data is added to your map, you will be able to view its symbology, attributes, and other information through this pane. You may also re-order layers within the **Contents** pane list to change how they are displayed relative to (above or below) each other in your map. You can adjust the width of the **Contents** pane by clicking and dragging the right side in and out.

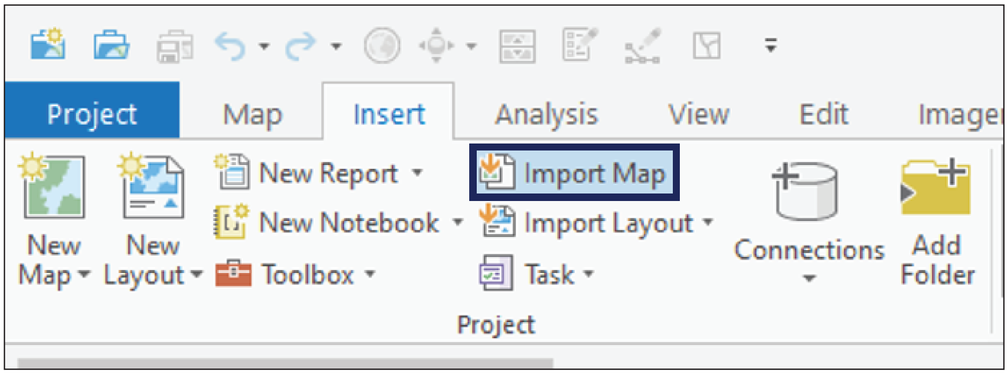
On the right side of the window is the **Catalog** pane. The **Catalog** pane has three tabs that you can switch between at the top. From left to right, they are the Project, Portal, and Favorites tabs. The **Project** tab of the **Catalog** pane is where you can access all the various data sets, folders, and maps that you have connected to your project. The **Portal** tab connects you to items which you and others have hosted online. This includes items which are curated for use in Esri’s “ArcGIS Living Atlas of the World,” and any item that has been shared publicly or with your organization within ArcGIS Online. The **Favorites** tab is where you can find any dataset, folder, map, or other item that you have marked as a favorite. Favorites persist outside of your map projects, so this is a useful place to have datasets or folders which you may need to access often and do not want to have to reconnect to every time you create a new map project. As with the **Contents** pane, you can also adjust the width of the **Catalog** pane by clicking and dragging the left side in and out.



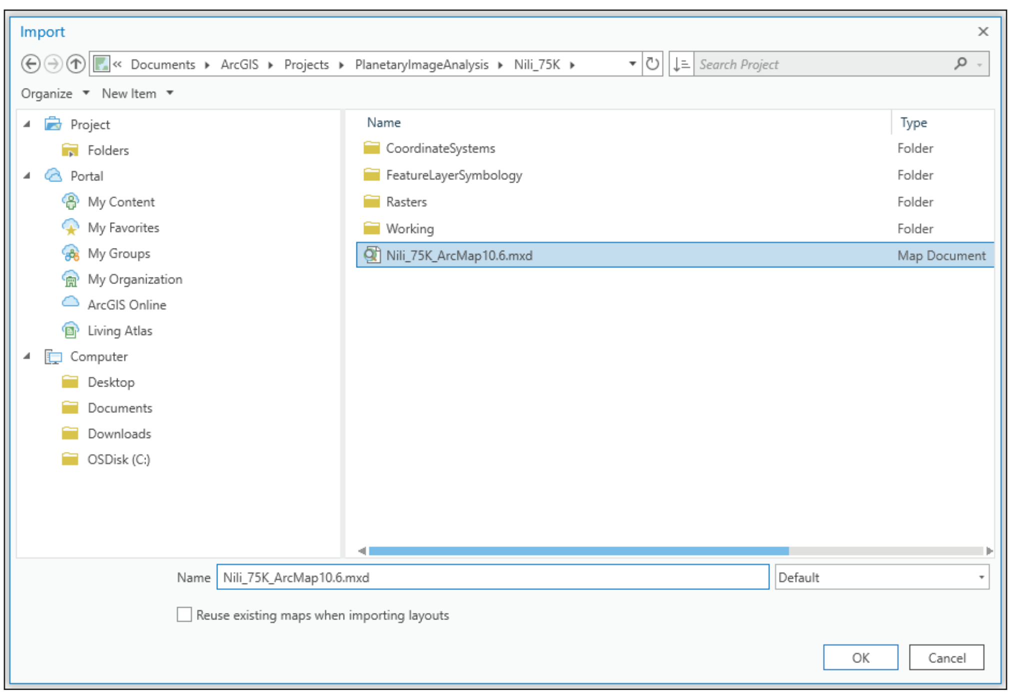
Part 2: Import an Existing ArcMap Project

To begin, you will first import an existing map into your project. Often, you may find that you or a collaborator have a mapping project that already exists in ArcMap (**.mxd** file format), and you need to import it into ArcGIS Pro to continue your work.

3. In the **Project** section of the **Insert** tab (in the menu bar), click **Import Map**

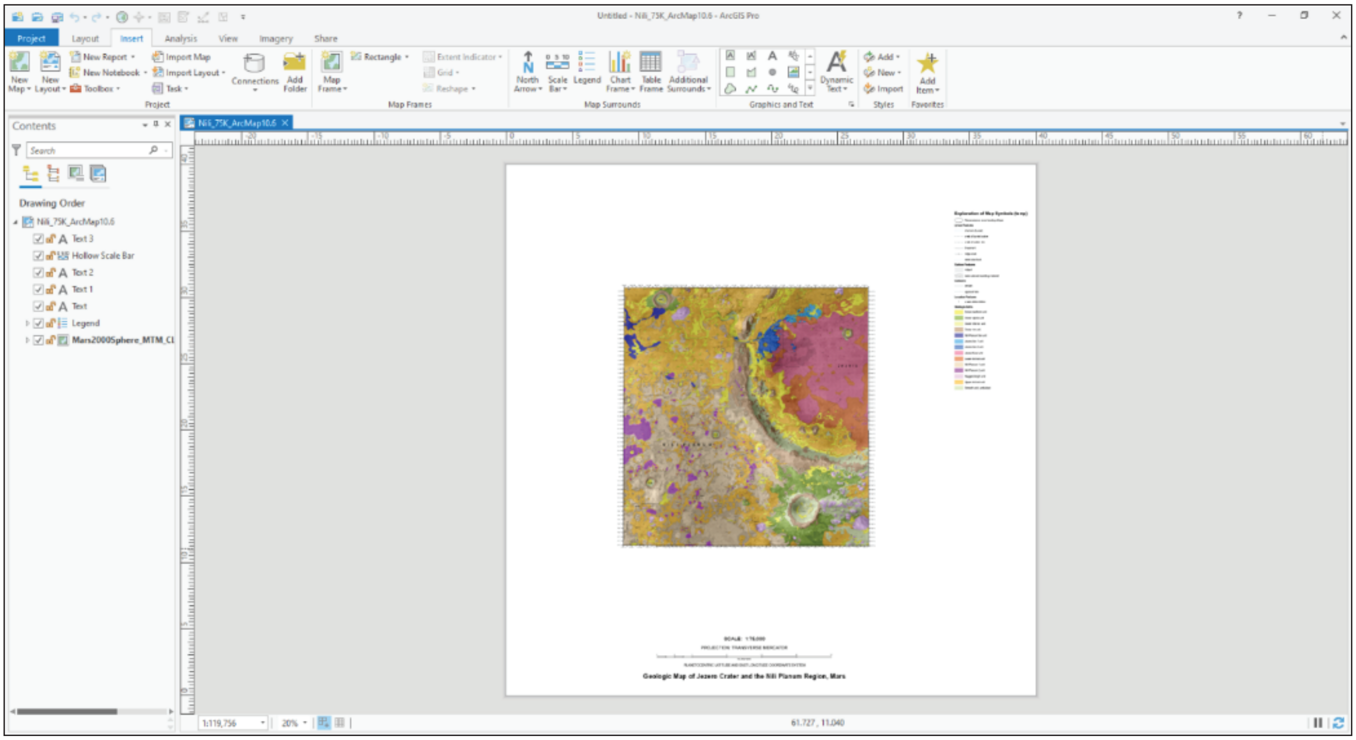


4. In the **Import** window, navigate to the **PlanetaryImageAnalysis** folder, which you unzipped earlier and saved to a location of your choice. Then double click the **Exercise_1** folder to open it and select the **Nili_75K_ArcMap10.6.mxd** Map Document.



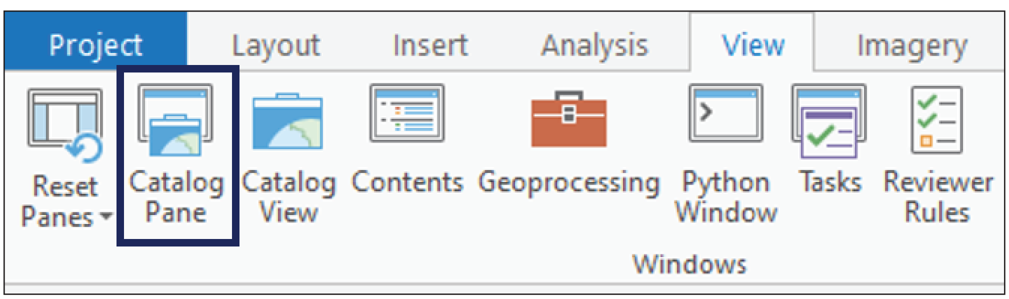
5. Click **OK** to select and import the map.

You will notice this map has imported with the layout format displayed. When opening or importing a pre-existing map document, whether the layout or map view is displayed will depend on how that map document was last saved. (By default, new map documents will open in map view.) When maps are displayed in layout format, the individual map layers are no longer visible in the **Contents** pane. Instead, items like the **scale bar**, **map legend**, and additional labels are listed in the **Contents** pane.



The original GIS map is still present in this file, you only need to access it. When you imported the map, the **Catalog** pane closed (this is not always the case and will also depend on how the ArcMap document was last saved).

6. To re-open the **Catalog** pane, select the **View tab** in the menu bar and click the **Catalog pane** icon.

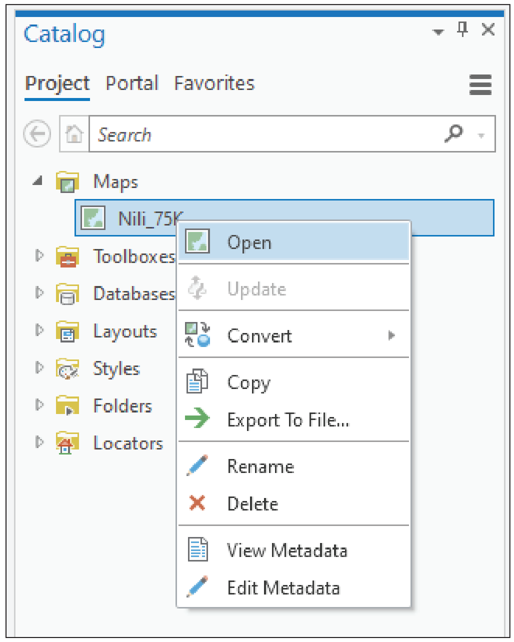


Note: This is where you may also re-open your Contents pane if it is ever closed.

The **Catalog** pane will once again be accessible on the right side of your project window. The original GIS map for this project will be listed under the **Maps** section of the **Catalog** pane.

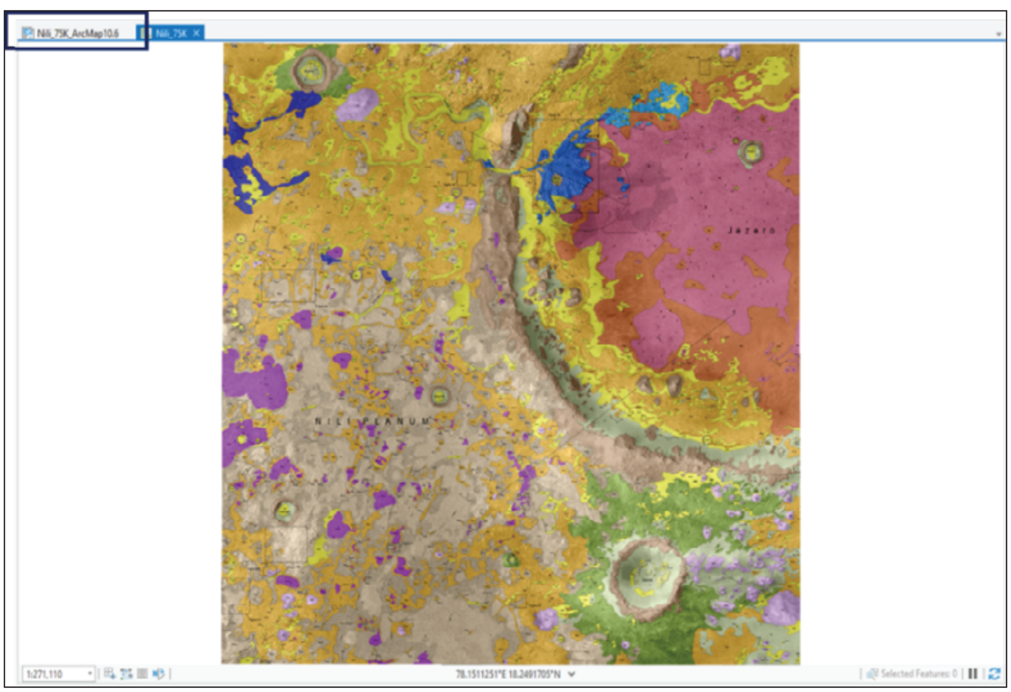
7. Click on the small triangle to the right of the **Maps** icon in the **Catalog** pane to expand that section. You will see a map named **Nili_75K** listed.

8. Right click the **Nili_75K** map and select **Open**. You can also simply double click on the **Nili_75k** map to open it.



The **Nili_75K** map will be added to your project as a new tab in the main window. The layout view is still present in another map tab. However, that is no longer needed.

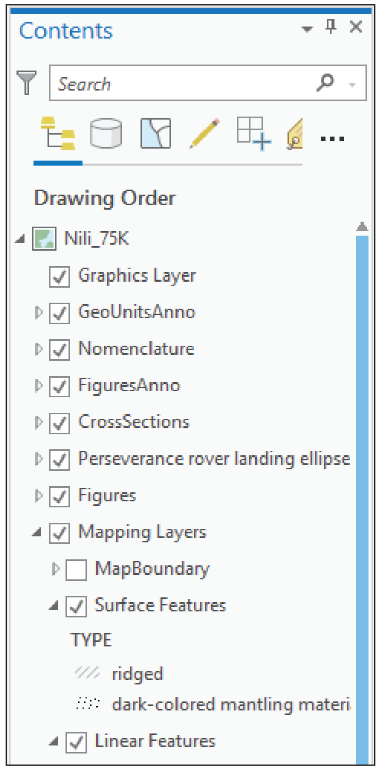
9. Click the small **x** on the **Nili_75K_ArcMap10.6** tab (located at the top of your active map window) to close the layout view.



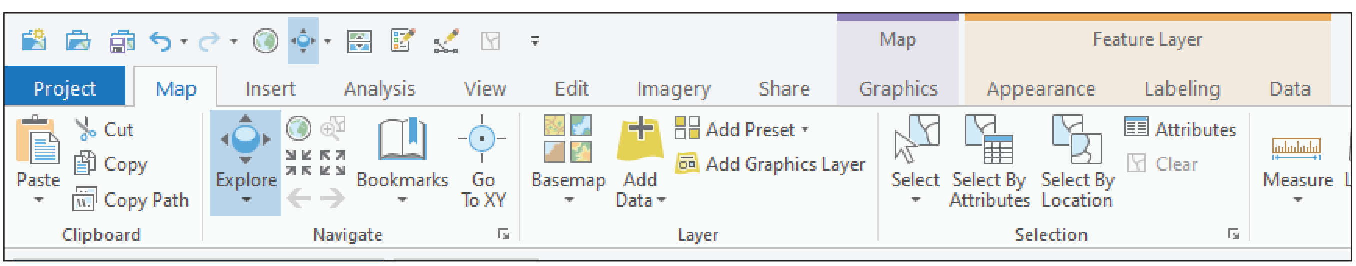
Note: You can still access the layout view if you need it. It will be listed in the ***Catalog*** *pane under* ***Layouts*** *and can be re-opened the same way you opened the map in the previous steps.*

Part 3: Map Layers and the Dynamic Menu Bar

With the map now open, explore the map layers that are listed in the **Contents** pane. By default, the map layers are listed in drawing order, so items at the top of the list are sitting on top of the items below. This becomes important when it comes to making layers transparent and making sure that all features are clearly visible. You can drag map layers up and down within the **Contents** pane list to change their drawing order.



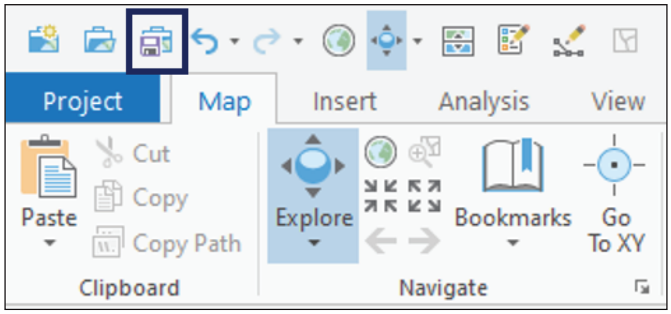
10. This map contains several different types of layers. Click on the layers in the **Contents** pane and note how the tabs in the menu bar change as you select different types of layers.



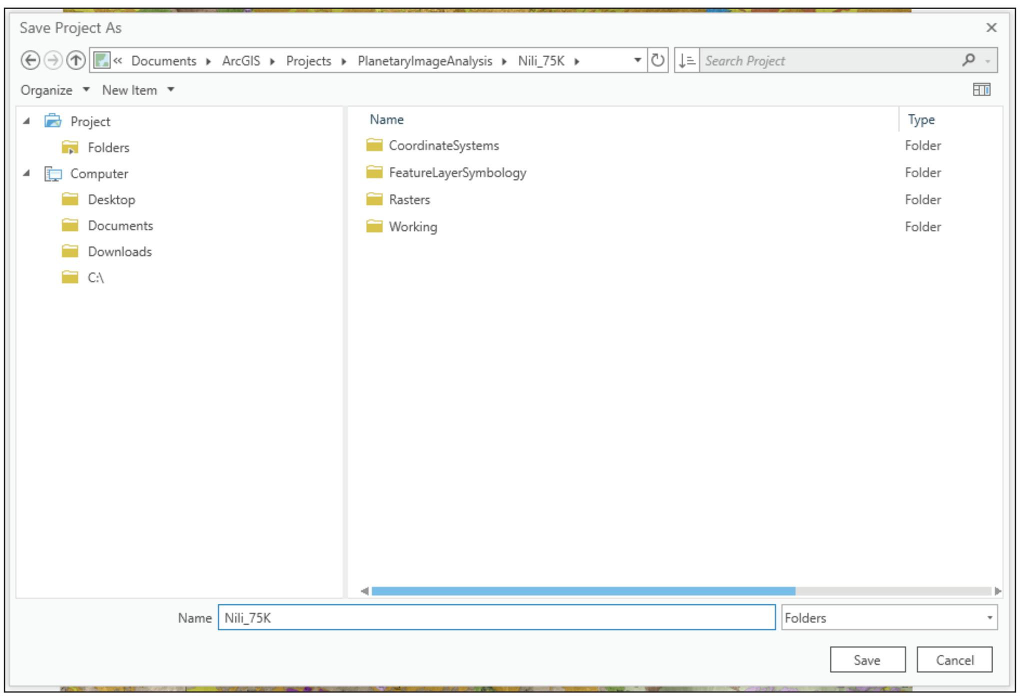
As you select different types of layers in the **Contents** pane, the menu bar will detect what type of data is present and will automatically display the appropriate tabs at the top of the screen. When vector layers (points, lines, and polygons) are selected, the **Feature Layer** tabs are displayed, as seen in the example above. When a raster layer (images and other datasets) is selected, the **Raster Layer** tabs are displayed. The first eight tabs (**Project**, **Map**, **Insert**, **Analysis**, **View**, **Edit**, **Imagery**, and **Share**) are always displayed.

Part 4: Saving Your Map Project

11. To save your new map project, click on the small **save** icon in the upper left corner of the ArcGIS Pro window.

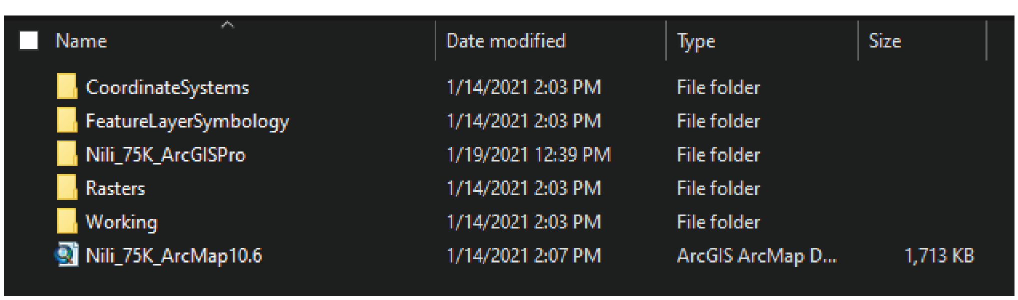


12. Navigate to **PlanetaryImageAnalysis\Exercise_1**. This is where the original ArcMap document is, and where you will save your new ArcGIS Pro version.



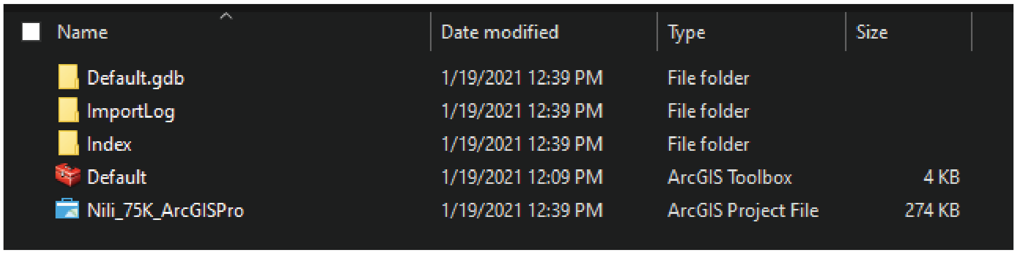
13. Name your Project **Nili_75K_ArcGISPro** and click **Save**.

14. In your Windows File Explorer, navigate to the **PlanetaryImageAnalysis\Exercise_1** folder and observe the new file structure.



By default, when you save a new project in ArcGIS Pro, it will create a new folder in the directory where you assign the project to be saved. All project files will be saved into this folder.

15. Double click on the **Nili_75K_ArcGISPro** folder to open it and observe the file structure.



All project files are located within the **Nili_75K_ArcGISPro** folder, including the **ArcGIS Project File (.aprx)**. The **.aprx** file is the ArcGIS Pro equivalent to the ArcMap **.mxd** file type. If you wish to re-open this map project later, you can do so with the **.aprx** file. When saving a new ArcGIS Pro project, all the additional project files such as the default toolbox and default geodatabase (**.gdb**) are automatically created and saved in this same directory. *(Note: **.aprx** files are not backwards compatible and can not be opened with ArcMap software.)*

16. Return to the ArcGIS Pro window and exit from your map project by clicking the **x** in the upper right corner. You can return to this project at any time through the **.aprx** file you created in the previous step.

Summary

In this exercise you became familiar with the ArcGIS Pro interface and learned how to import pre-existing ArcMap projects. In some instances, imported map projects will open in layout display. In this exercise you learned how to use the **Catalog** pane to access both the layout and map displays within the ArcGIS Pro interface. You also explored the dynamic menu bar and observed how the menu bar tabs automatically update as you select different map layers and features. This allows the dynamic menu bar to only show you tools and tabs that you are currently able to use. As a final step, you saved the imported map project as a new ArcGIS Pro project file (**.aprx**) and observed the default file structure. When saving a new ArcGIS Pro project, the project file and all automatically generated associated files (such as the default toolbox and default project geodatabase) will automatically be saved in the designated folder. Once an ArcGIS Pro project has been created and saved, it can be reopened using the **.aprx** project file.

To Prepare for the Next Exercise

To prepare for Exercise 2, you will first need to exit this ArcGIS Pro project. Click the small **x** in the upper right corner of your ArcGIS Pro window to close it.

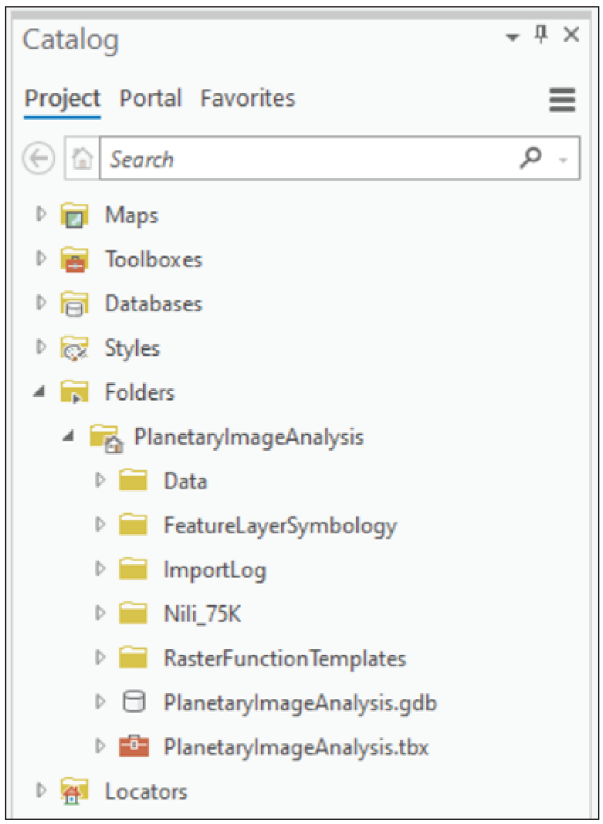
Exercise 2: Working with Rasters

In this exercise, you will begin working within a new ArcGIS Pro project, rather than importing an existing ArcMap document. If you have not already done so, be sure to exit the ArcGIS Pro project from Exercise 1 before you begin.

1. In your Windows File Explorer, navigate to the **PlanetaryImageAnalysis\Exercise_2 folder** and double click the **PlanetaryImageAnalysis_Exercise_2 project file** (**.aprx**) to open it in ArcGIS Pro.

The **PlanetaryImageAnalysis_Exercise_2** project will open in ArcGIS Pro. Data has not yet been added to the map, so the map tab will appear empty, and no map layers are listed in the **Contents** pane.

2. In the **Catalog** pane, click on the small triangle to expand the **Folders** section. You will see the **PlanetaryImageAnalysis** project folder listed. This is the home folder for your project. Click on the small triangle to expand the **PlanetaryImageAnalysis** folder and view its contents.



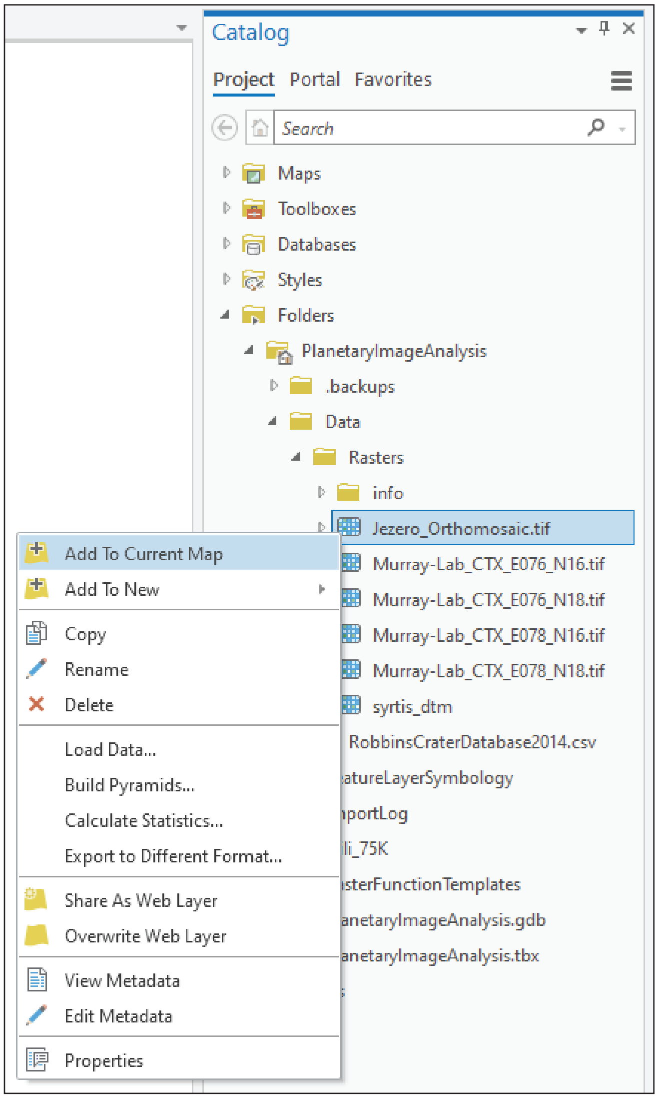
*Note: In the future, you may find times when you need to access a different folder that is not already present in the **Catalog** pane. To do this, right click the **Folders** heading in the **Catalog** pane and select **Add Folder Connection**. Navigate to the folder you wish to access, select it, and click **OK** to add it to the list.*

Part 1: Adding Data and Working with Map Layers

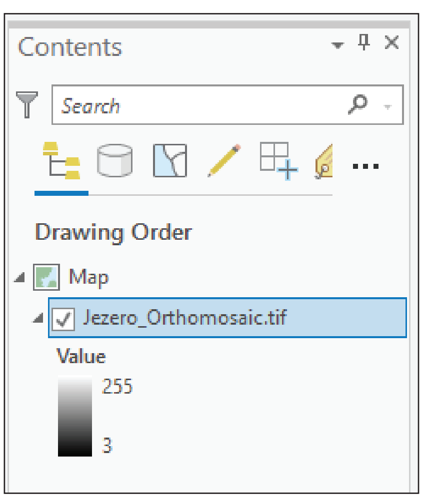
To begin working with your map, you will need to add data.

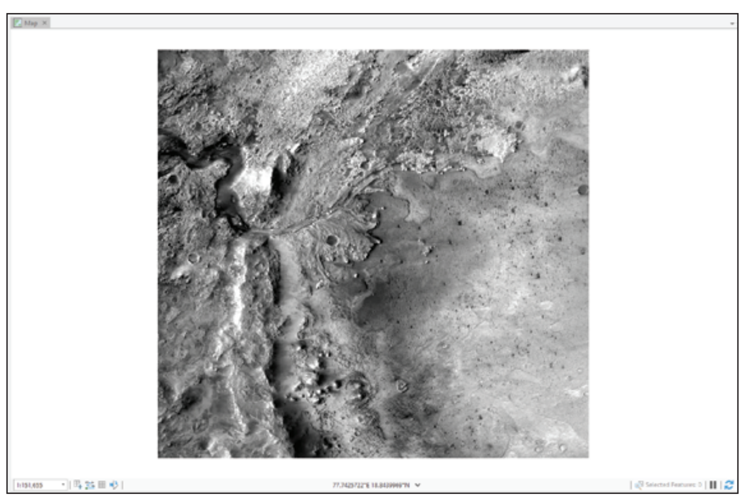
3. In the **Catalog** pane, click on the small triangle to expand the **Data** section of the **PlanetaryImageAnalysis** folder. Then click on the small triangle to expand the **Rasters** folder and view its contents.

4. Right click on the **Jezero_Orthomosaic.tif** item and select **Add to Current Map**.



The **Jezero_Orthomosaic.tif** image will be added to your map. You should now see the image displayed in the map window and see the map layer listed in the Contents pane.

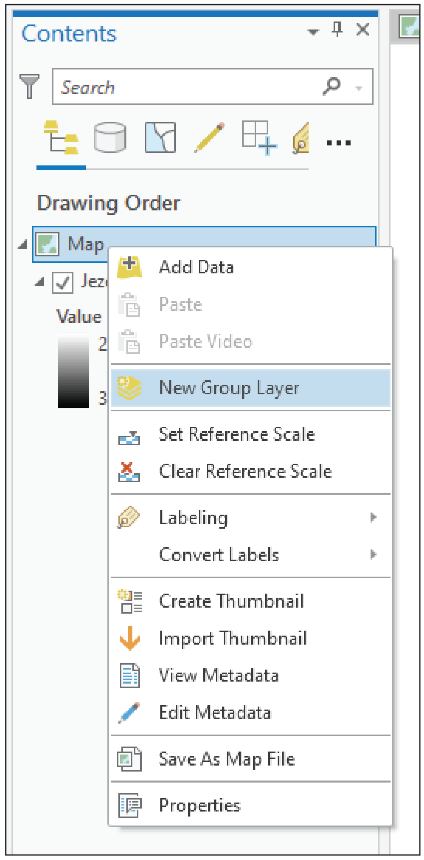




5. Click on the **save** icon in the upper left corner or your ArcGIS Pro window to save your project. Do this often while you work. *(Note: You will not be prompted again to save your work in this tutorial. Make sure you continue to do so.)*

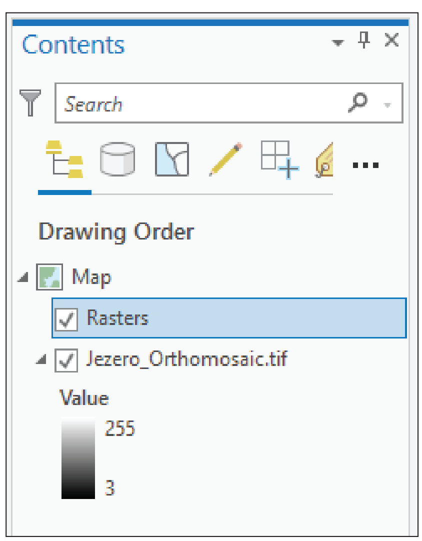
When working in a GIS, it is not uncommon to end up with many layers in your map. You can organize and group these layers in the **Contents** pane.

6. At the top of the **Contents** pane, right click **Map** and select **New Group Layer.**

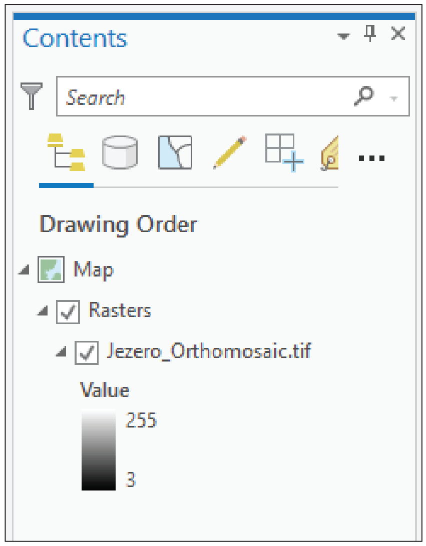


The **New Group Layer** is now listed at the top of your map contents.

7. In the **Contents** pane, click the **New Group Layer** and then hover over it to activate the text. Rename the group **Rasters**. Press **enter** to apply your changes.



8. Click and drag the **Jezero_Orthomosaic.tif** layer into the **Rasters** group. Then click on the small triangle next to the **Rasters** group to expand it and view its contents.



You can click and drag map layers to move them in and out of the group layers at any time while you are working. In the future, if you wish to quickly group multiple map layers which are already present, you can use control+click to select the desired layers and then right click and choose **Group**. This will create a new group which automatically includes the selected layers.

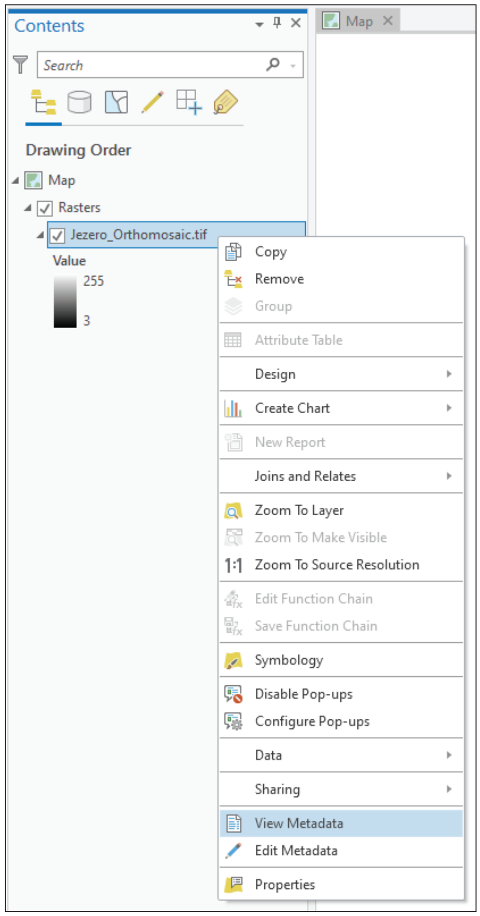
For planetary mapping, it is typical to have two main group layers: one for rasters (base imagery and other pixel-based data); and one for the mapping features themselves, which are vector-based (points, lines, and polygons). You can also follow the same process as you did above to make additional groups within those if desired. Group layers are useful for keeping your data and map layers organized. Additionally, you can quickly collapse or expand entire groups to see their contents by clicking on the triangle next to the group layer name. You can also quickly turn all active (checked) group layers on or off by checking or unchecking the box next to the group layer name.

Part 2: Metadata

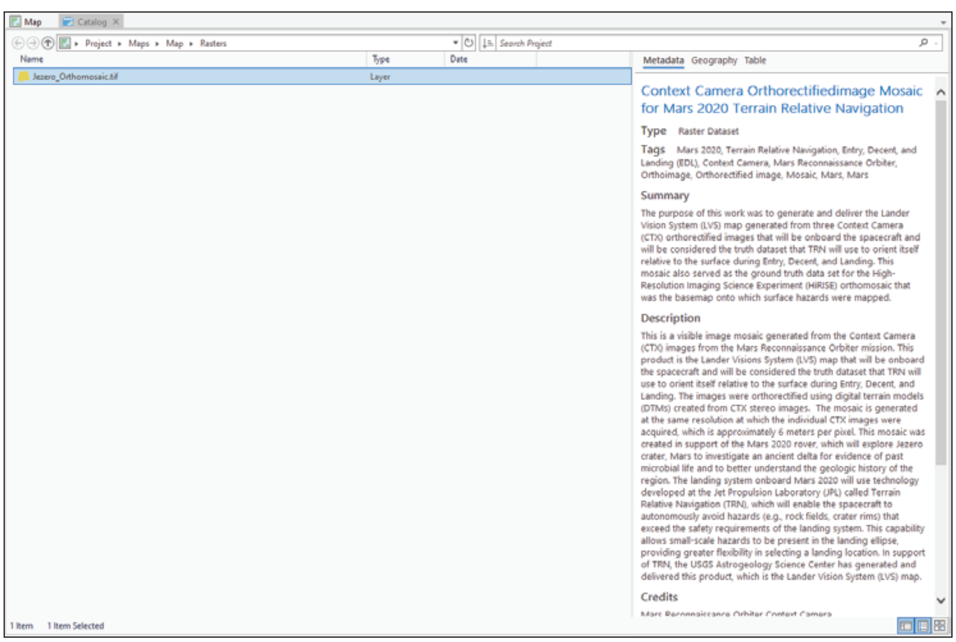
Robust GIS applications like ArcGIS Pro enable researchers to use, process, and integrate data from a variety of sources, often to create new products for further analysis. However, for data products to be usable by others, they must contain appropriate metadata. Metadata (data about data) is information which describes a dataset, including what it is, where it is, how it was created, how it was intended to be used, and who to contact with questions. There are a variety of ways to describe data, but in many instances the planetary science community has established standards for metadata content and encoding. This increases the likelihood (but does not guarantee) that each dataset will include the appropriate and necessary information for those who wish to work with it. Metadata standards also support more than human readability, which is often accomplished with README text files. They also enable machine-to-machine readability, which is what drives much of the interoperability of data across data long-term data archives like the NASA Planetary Data System (PDS) and other repositories like the NASA Solar System Treks platform. Supporting machine-to-machine readability also supports analyses through machine learning, artificial intelligence, and other applications and tools. In short, good metadata makes it so you and others can find and make sense of existing datasets. Without appropriate metadata, datasets may not be findable or usable.

The **Jezero_Orthomosaic.tif** image you are viewing in your map was created by the USGS Astrogeology Science Center for the Mars 2020 Perseverance rover Terrain Relative Navigation (TRN) team. This orthomosaic was made using images from the Mars Reconnaissance Orbiter's Context Camera (CTX) and is one of the highest-accuracy images ever created of Mars, with a horizontal accuracy of 9.6 meters (m) (each pixel in this image represents 6 m on the ground). The corresponding High Resolution Imaging Science Experiment (HiRISE) TRN orthomosaic has a horizontal accuracy of 1.1 m and a resolution of 25 centimeters per pixel (cm/pixel). These high levels of accuracy were necessary because these images were used by the Mars 2020 rover's TRN analysis to automatically (and successfully) identify a safe place to land in Jezero crater. Here, you will explore the metadata that is attached to the CTX orthomosaic of Jezero crater using the ArcGIS Pro interface. If desired, you can also explore the metadata for the HiRISE orthomosaic at the link above.

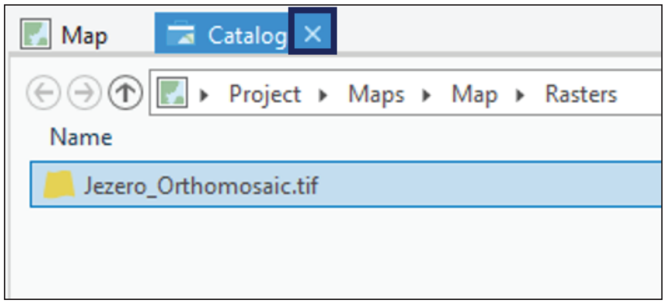
9. In the Contents pane, right-click on **Jezero_Orthomosaic.tif** layer and select **View Metadata**.



This will open a new **Catalog** tab in the main viewing area of the ArcGIS Pro interface. The **Catalog** tab contains a list of your map layers on the left, and item metadata on the right.



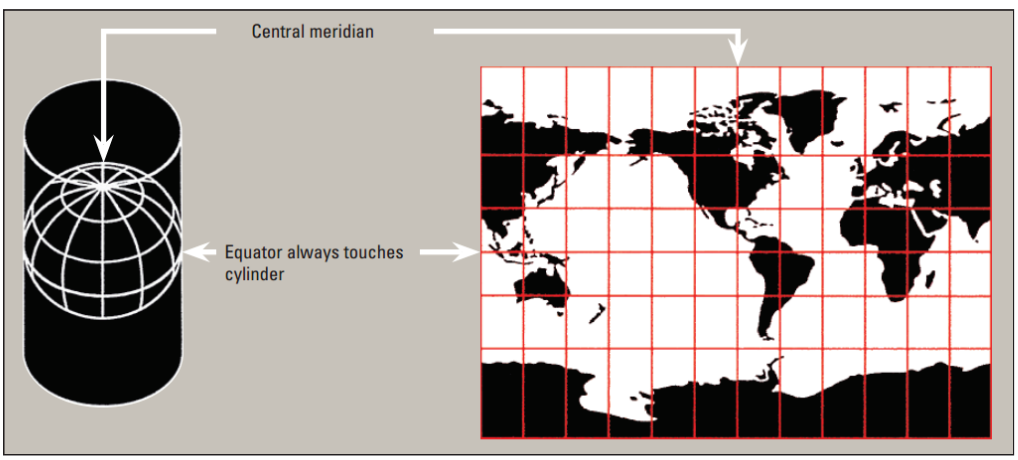
10. Take a minute to read through the metadata that is provided for the **Jezero_Orthomosaic.tif** image to get a sense of what is often included in this supporting information. When you have finished, click on the small **x** in the **Catalog** tab to close it and return to your map.



To learn more about working with and creating your own metadata, see appendix 2.

Part 3: Projections

Map projections are mathematical equations for transforming a three-dimensional (3D) body onto a two-dimensional (2D) plane or Cartesian (X, Y linear distance-based) coordinate system. All modern GIS applications use these defined Cartesian systems as the underlying method to geolocate or accurately position all data sets. It is also the key to how GIS applications provide their spatial analysis capabilities like determining the length or orientation of a line to calculating the safest path for a rover to traverse across the landscape.

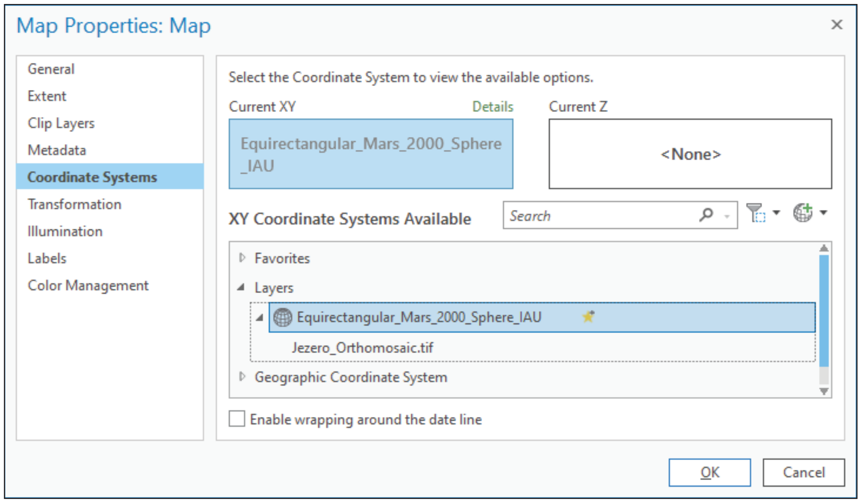


Subset of the U.S. Geological Survey Map Projections poster showing the Miller cylindrical projection. Image Credit: U.S. Geological Survey, 2007, Map projections: U.S Geological Survey Poster, 2 sheets, at https://www.usgs.gov/media/files/map-projections-poster.

GIS applications continue to get better at hiding the complications for using map projections. When the data is properly defined, once loaded into ArcGIS Pro the data will automatically be correctly positioned to match the projection that is assigned to the map itself—even when every loaded dataset may be defined using a unique map projection. One of the most significant challenges in planetary versus terrestrial mapping is that local coordinate systems are not established, so users must often create their own custom projections based on the latitude, extent, and scale of the map. To learn about more advanced map projection issues and techniques, see appendix 3.

ArcGIS Pro supports real-time on-the-fly transformations which allows a user to overlay data sets defined using different map projections. But a critical first step in any ArcGIS Pro project is to make sure the projection of the map frame itself is correctly set. Fortunately, when starting with an empty map frame, ArcGIS Pro will inherit the map projection from the first loaded layer. In this case, the first layer you added to the map was the **Jezero_Orthomosaic.tif** image.

11. In the **Contents** pane, right click on the title for the map frame (by default this is named "**Map**") and select **Properties**. In **the Map Properties** window, select the **Coordinate Systems** tab.

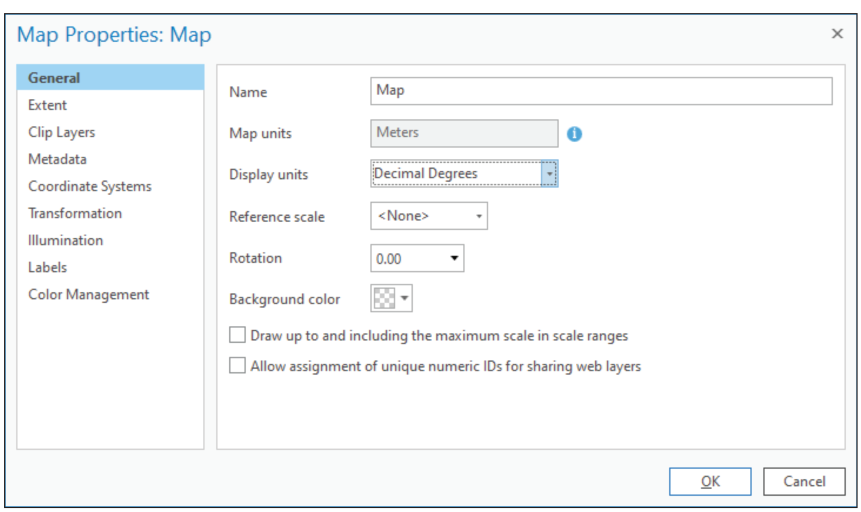


The map frame has inherited the projection from the **Jezero_Orthomosaic.tif** layer (called **Equirectangular_Mars_2000_Sphere_IAU**). If you wanted to change the map frame projection, you could do so here by searching for **Mars** in the **Search** bar and selecting a different option. With the map frame correctly set for your project, you can load additional data sets, and all of them should project on-the-fly (when needed). If a data set does not correctly project when added to the map, it is likely that the data set's map projection is undefined or incorrectly defined.

> ***Tip:*** *When adding the first layer to a new map, always pick the data set that you trust the most and (or) is defined in the map projection you wish to work in. ArcGIS Pro now comes with many tools that can accurately calculate lengths, areas, and orientations (angles) for your defined collected features data sets by using geodesic calculations. That means regardless of the map projection (and the potential errors incurred by that map projection), it will accurately calculate those measures. For example, within the* ***Add Geometry Attributes*** *geoprocessing tool, you will find options to calculate geodesic area and lengths. However, for these measurements to be useful, you must start with an accurately (and appropriately) defined map projection.*

While you are in the **Map Properties** window, you can also change how the coordinate units are displayed. This does not change how the data is projected, it only affects how the cursor location coordinates are displayed at the bottom of your map window (for example, converting from projected meters to degrees). By default, the coordinate display will always show positive east longitudes.

12. In the **Map Properties** window, click on the **General** tab. Then click on the **Display units** dropdown menu and observe the options that are available. End with **Decimal Degrees** selected.

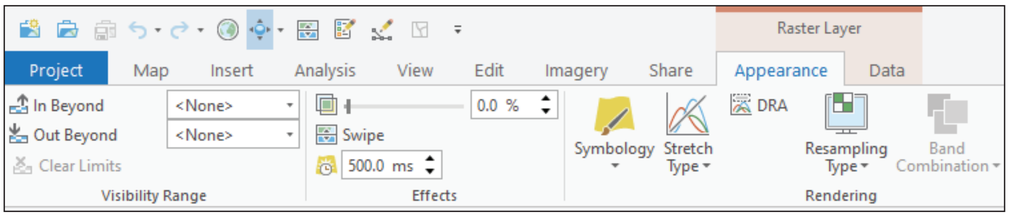


13. Click **OK** to exit the **Map Properties** window and return to your map.

Part 4: Modifying Display Properties

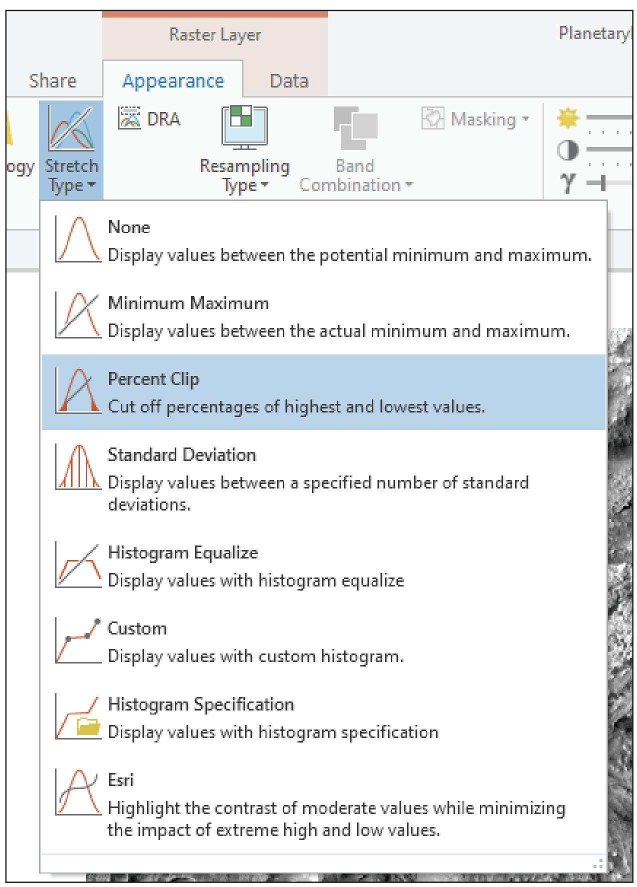
There may be times when you need to adjust how your raster image or data is displayed. You can do this using the tools in the **Raster Layer Appearance** tab.

14. In the **Contents** pane, click on the **Jezero_Orthomosaic.tif** layer to select it. With this layer selected, the **Raster Layer** tabs (**Appearance** and **Data**) are now visible in the menu bar at the top of your screen. Select the **Raster Layer Appearance** tab to view the tools that are available.



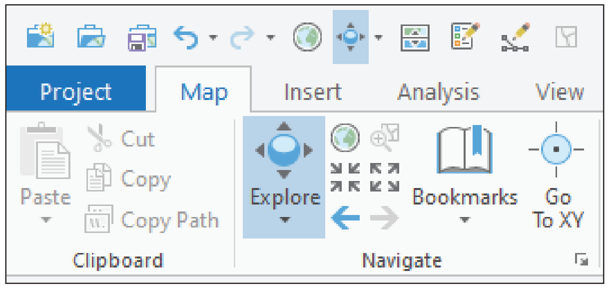
In the **Raster Layer Appearance** tab, you can change several layer properties. This includes common tasks such as setting a **visibility range** (scales at which the layer will turn on or off as you zoom in and out), adjusting the **transparency**, accessing the **symbology** settings, and changing the **stretch**, **brightness**, and **contrast**.

15. In the **Rendering** section of the **Raster Layer Appearance** tab, select the **Stretch Type** dropdown menu and choose a different stretch type. Experiment with different stretches to see how they compare. When you are done, return to the **Percent Clip** stretch. Additional details regarding each of these stretch options and how they work are available through Esri at their ArcGIS Pro Resources page.



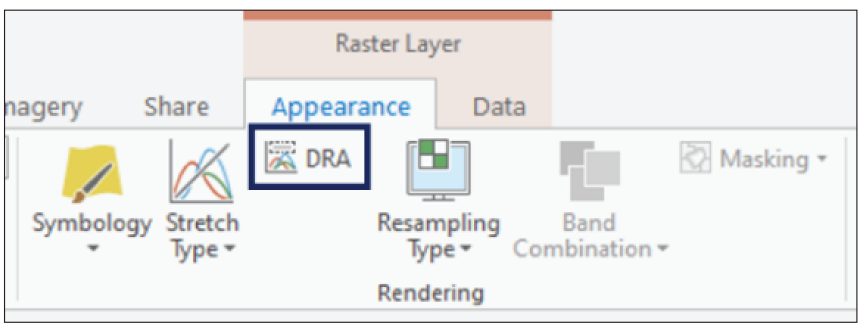
Another option for the stretch is to turn on the **DRA** (Dynamic Range Adjustment) setting. By default, stretches are applied using the range of pixel values for the entire raster, regardless of whether you are viewing the whole raster or a small section of it. When **DRA** is turned on, the stretch is automatically adjusted as you zoom and pan and will only use the values of the pixels within your current display extent (the area you are viewing at that moment).

16. In the **Navigate** section of the **Map** tab, make sure the **Explore** icon is selected. It should already be highlighted in blue as a default. If it is not, click on it to select it.



With the **Explore** tool selected, you can use your mouse to pan around the map and use the scroll wheel of the mouse to zoom in and out.

17. In the **Rendering** section of the **Raster Layer Appearance** tab, click the **DRA** icon to turn this setting on. Then explore your image and see how the stretch changes as you zoom in and out and pan around the scene. When you are done, click the **DRA** icon again to turn this setting off.

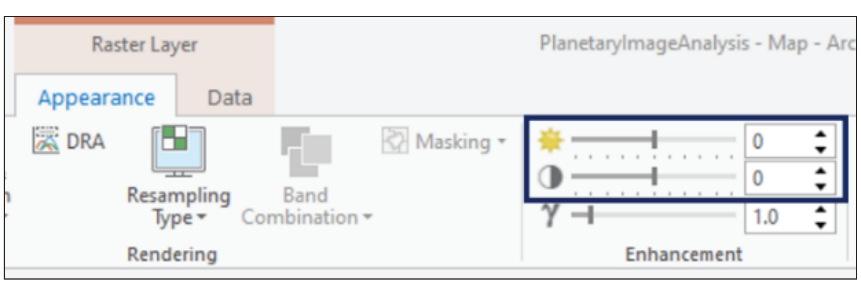


DRA can be helpful in picking out more subtle variations and small-scale details that may be lost when the stretch is applied using the entire raster. However, using the **DRA** setting is not always appropriate—it will depend on what you are doing and the data you are viewing. Knowing whether **DRA** will be helpful or not usually involves experimentation with the specific dataset(s) with which you are working.

18. In the **Contents** pane, right click on the **Jezero_Orthomosaic.tif** layer and select **Zoom to Layer** to return to the full extent of this layer.

In the **Raster Layer Appearance** tab, you can also manually adjust the **Brightness** and **Contrast** for your whole layer.

19. In the **Enhancement** section of the **Raster Layer Appearance** tab, move the **Brightness** and **Contrast** slider bars up and down to see how those change your image. When you have finished, click on the **Brightness** and **Contrast** icons to the left of the slider bars to reset the values to their starting points.

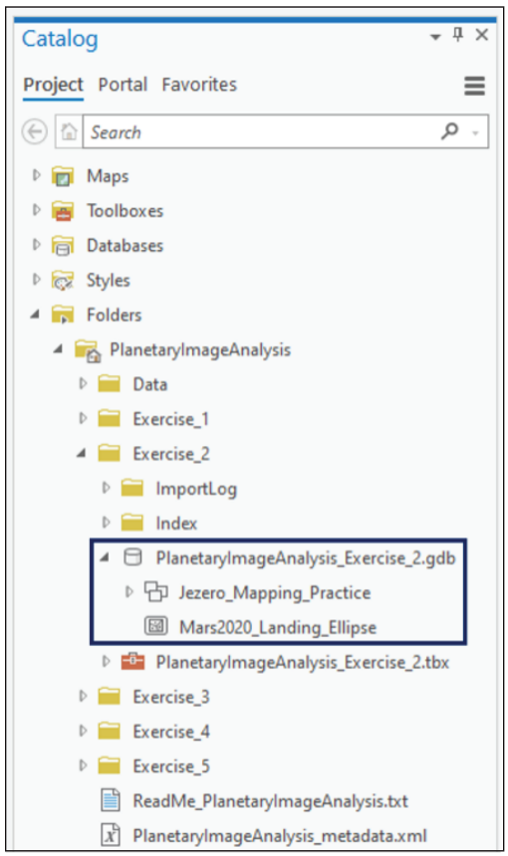


Part 5: Mosaic Datasets

For these exercises, you will be working with a larger area than is covered by the **Jezero_Orthomosaic.tif** image. Instead, you will use multiple tiles of imagery from the Mars Reconnaissance Orbiter Context Camera (CTX). When working with sets of images, it is often beneficial to put those images in a mosaic dataset. A mosaic dataset is a single layer in your map, which contains a collection of images that can be analyzed and manipulated as one. Individual images within a mosaic dataset can also be queried and added to your map individually, allowing you to work seamlessly with anything from one individual image, to hundreds of images at once.

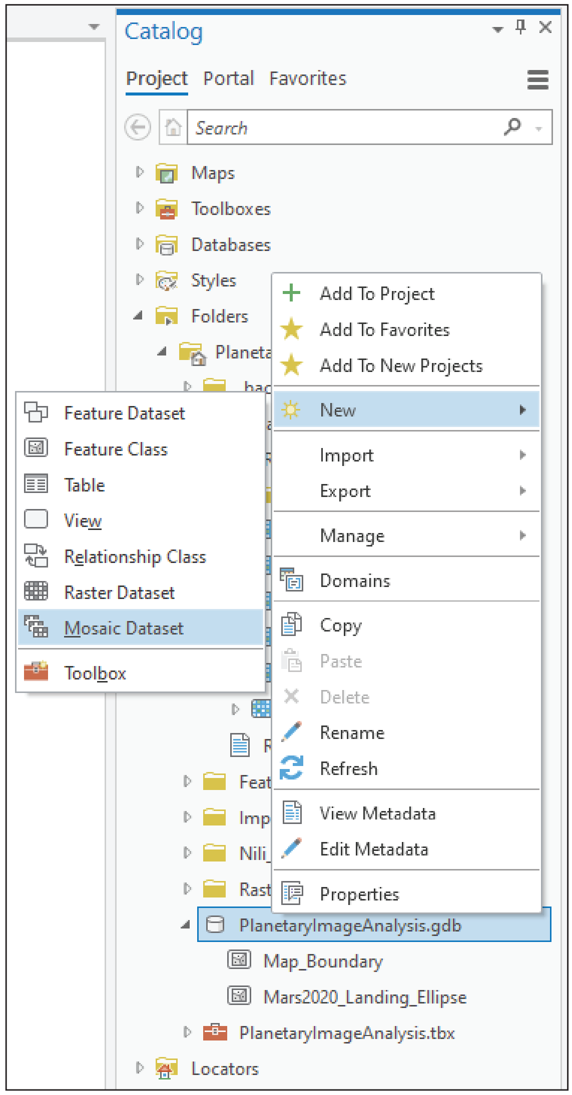
You will begin by creating the mosaic dataset item. Once the mosaic dataset has been created, you can then add images and edit its properties.

20. In the **Catalog** pane, click on the small triangle next to the **PlanetaryImageAnalysis\Exercise_2** folder to expand and view its contents. Then click on the small triangle next to the **PlanetaryImageAnalysis_Exercise_2.gdb** (geodatabase) to expand it. The **PlanetaryImageAnalysis_Exercise_2 geodatabase** is located in the **PlanetaryImageAnalysis\Exercise_2** folder.



When you begin a new project from scratch, your geodatabase is empty. In this case, two items: the **Mars2020_Landing_Ellipse feature class**, and the **Jezero_Mapping_Practice feature dataset** have already been added to your project geodatabase. You will add additional items to it as you work. The project geodatabase is where you can store both raster and vector features for your map. Storing map features in a geodatabase allows you to easily share them with collaborators.

21. In the Catalog pane, right click the **PlanetaryImageAnalysis_Exercise_2 geodatabase** and select **New → Mosaic Dataset**.



The **Create Mosaic Dataset** tool will open in the **Geoprocessing** pane.

22. Set the following inputs in the **Create Mosaic Dataset** tool:

    Output Location: **PlanetaryImageAnalysis_Exercise_2.gdb** (this is already set as the default)

    Mosaic Dataset Name: **CTX_mosaic**

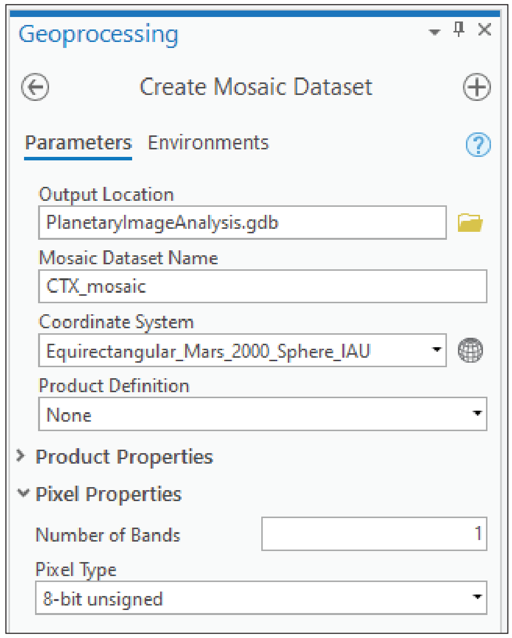
    Coordinate System: **Current map [Map]** *(Note: the coordinate system will automatically populate when you select this option)*

    Product Definition: **None**

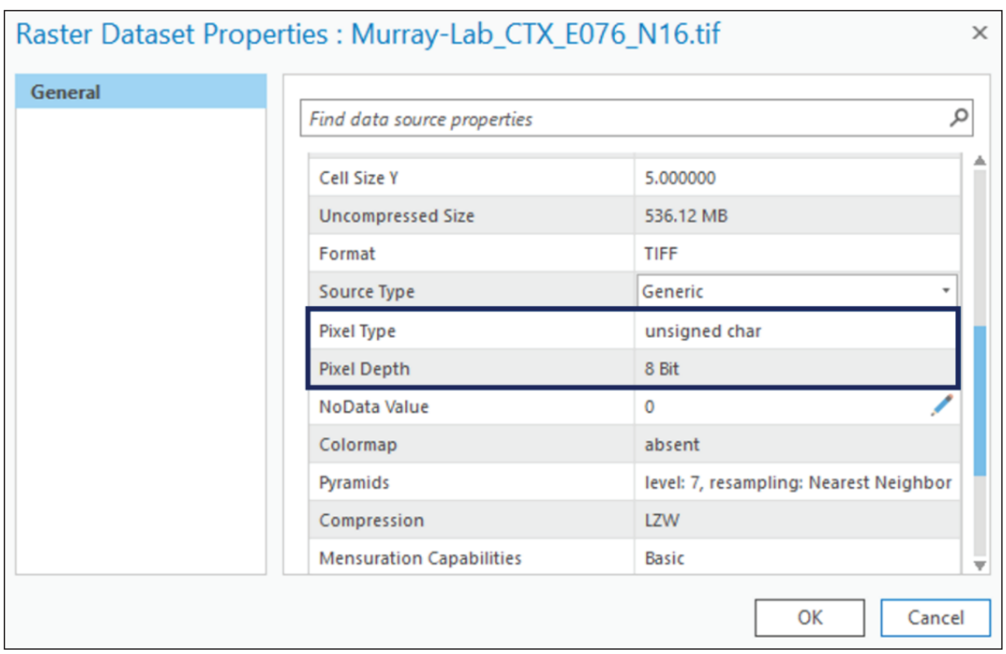
23. Expand the **Pixel Properties** section of the **Create Mosaic Dataset** tool and set the following inputs:

    Number of Bands: **1**

    Pixel Type: **8-bit unsigned**



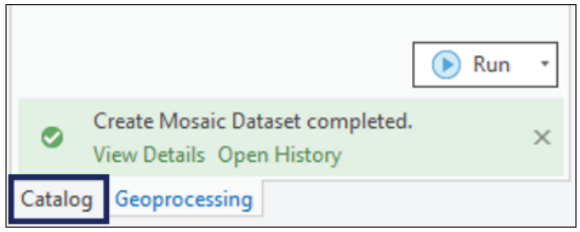
*Note: The **Pixel type** is based on the images you will be adding to the mosaic dataset. This information can be found by right clicking in the **Catalog** pane on one of the images you will be using and selecting **Properties**. The pixel type is described under **Raster Information** in the **Pixel Type** and **Pixel Depth**.*



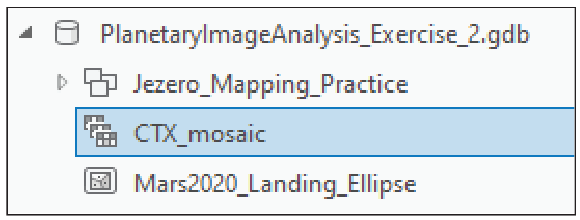
24. Click **Run** to create your new mosaic dataset.

Once the **Create Mosaic Dataset** tool has completed, you will see a green message box at the bottom of the **Geoprocessing** pane.

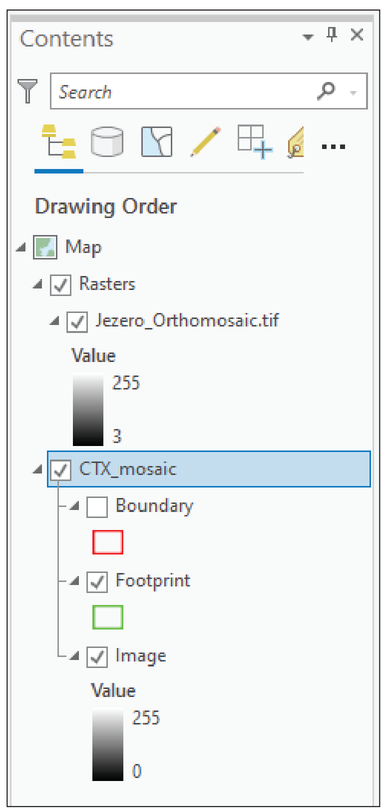
25. Click on the **Catalog** tab at the bottom of the **Geoprocessing** pane to return to the **Catalog** pane.



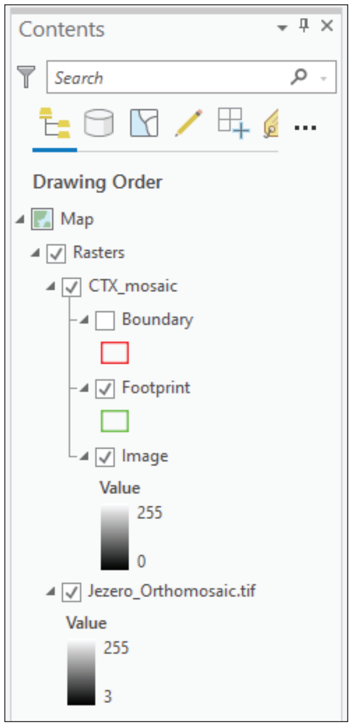
The new mosaic dataset (**CTX_mosaic**) will now be listed in the **Catalog** pane under the **PlanetaryImageAnalysis_ Exercise_2 geodatabase**.



The mosaic dataset (**CTX_mosaic**) has also been automatically added to your map and is now listed in the **Contents** pane.



26. In the **Contents** pane, click on the **CTX_mosaic** layer and drag it into the **Rasters** group, on top of the **Jezero_ orthomosaic.tif** layer.

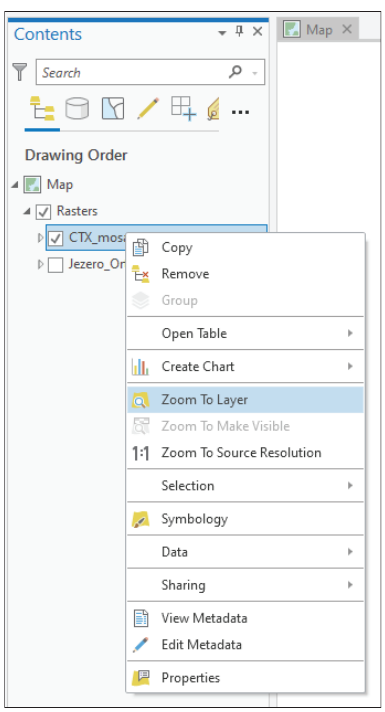


27. In the **Contents** pane, quickly collapse the **CTX_mosaic** and **Jezero_Orthomosaic.tif** by holding the control key and clicking on the small triangle next to the **CTX_mosaic** layer name. *(Note: the control+click also works to expand all layers in a list at once)*

28. In the **Contents** pane, uncheck the box next to the **Jezero_Orthomosaic.tif** layer to turn it off.

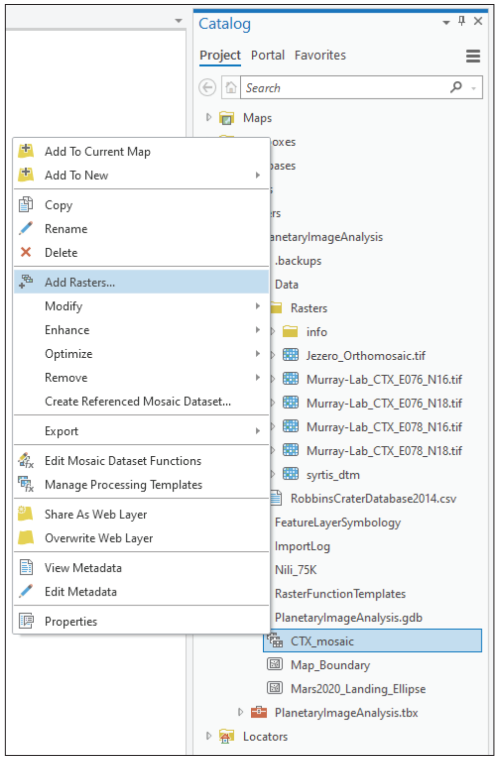
With the **Jezero_Orthomosaic.tif** layer turned off, all that should be visible in your map is the **CTX_mosaic** layer.

29. In the **Contents** pane, right click the **CTX_mosaic** layer and select **Zoom to Layer**. This will make sure you are in the correct place to view it.

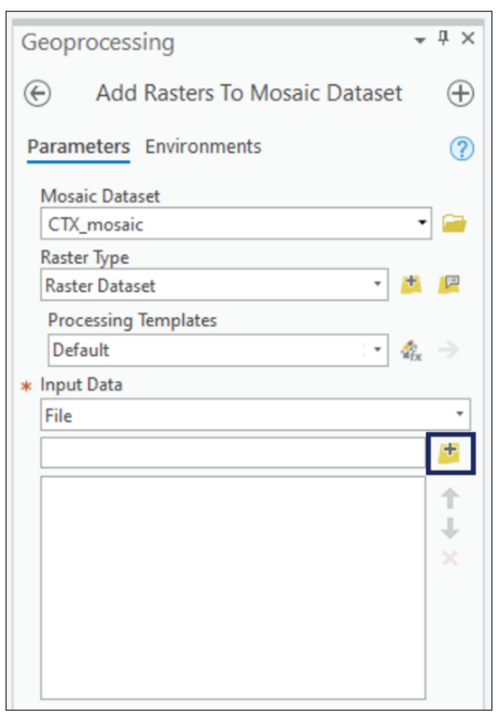


When you zoom to the **CTX_mosaic** layer, you will notice there are no images visible. This is because the **Create Mosaic Dataset** tool only creates an initial mosaic dataset file. The new mosaic dataset file is empty and must have images added to it.

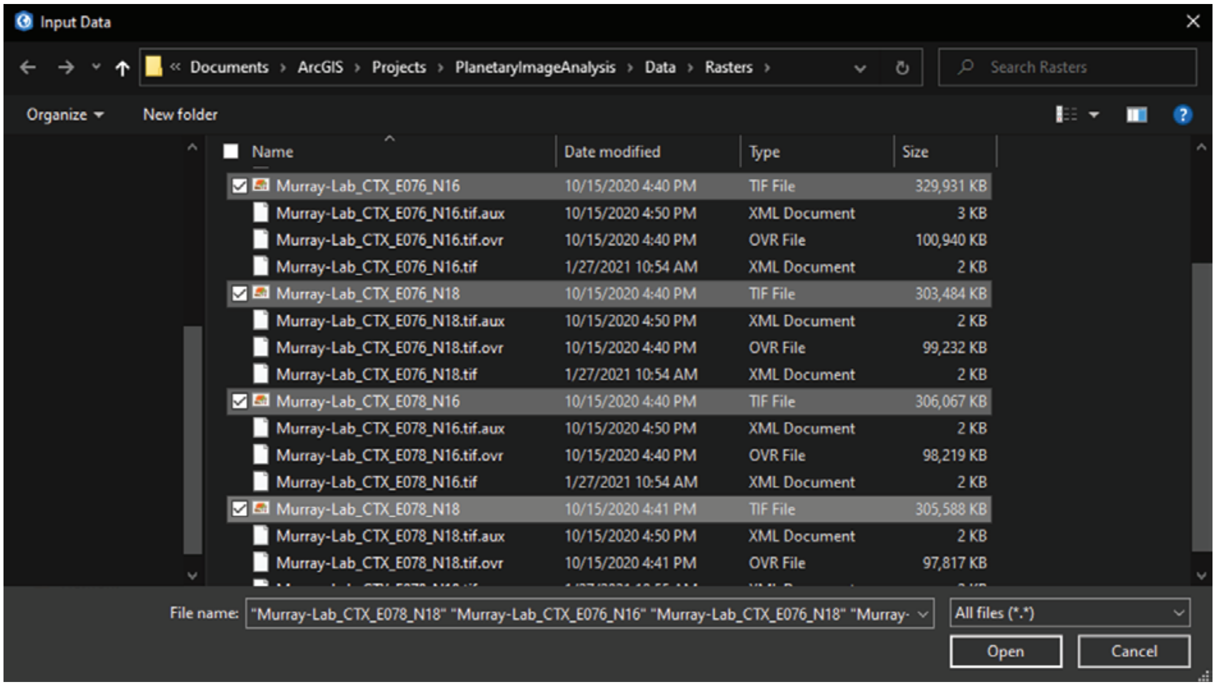
30. In the **Catalog** pane, right click the CTX_mosaic item in the **PlanetaryImageAnalysis_Exercise_2 geodatabase** and select **Add Rasters**.



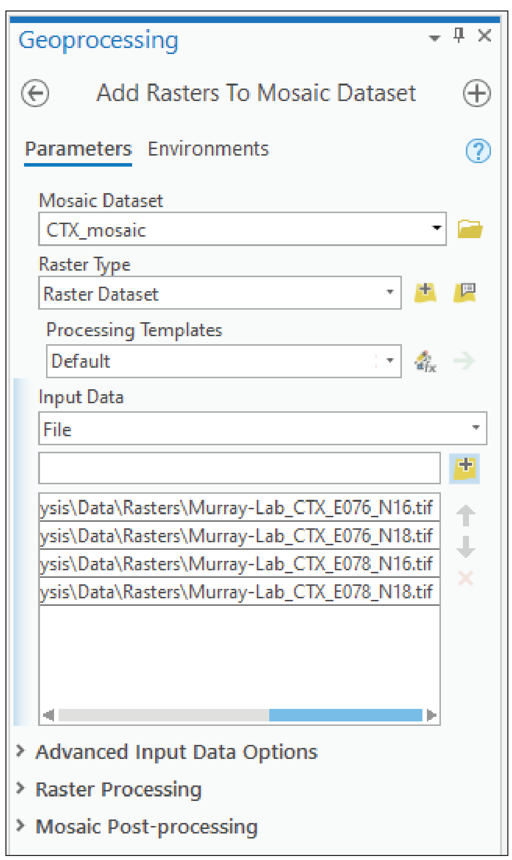
31. In the **Add Rasters To Mosaic Dataset** tool, leave the defaults unchanged and click on the small **Browse** icon under **Input Data**.



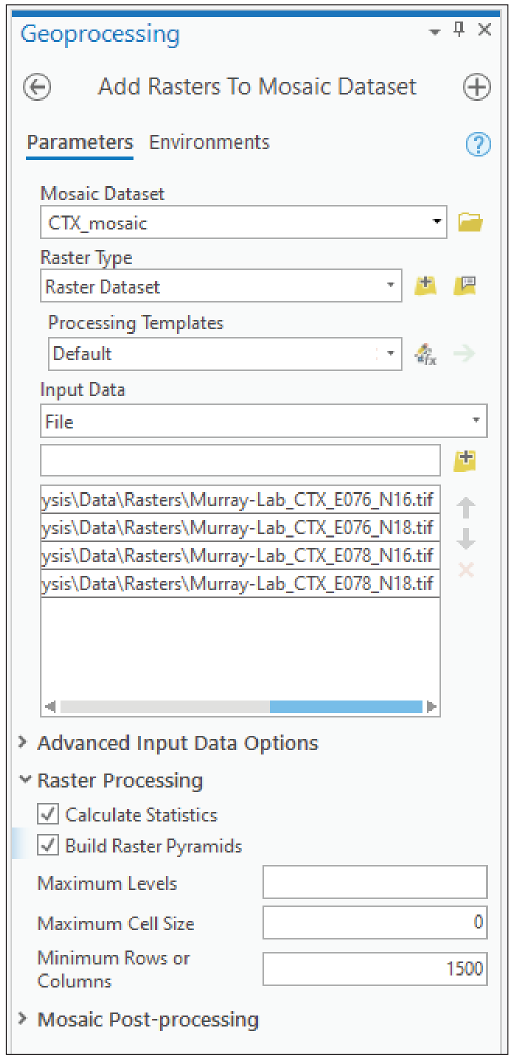
32. Navigate to **PlanetaryImageAnalysis\Data\Rasters** and select the <u>four</u> **Murray-Lab_CTX .tif** files (and only the **.tif** files). Use control+click to select multiple files at once. *(Note: You may have to change the display option from "File List (*.csv)" to "All files (*.*)" in the bottom right corner of the Input Data window.)*



33. Click **Open** to add these to the **Input Data** list.



34. In the **Add Rasters To Mosaic Dataset** tool, expand the **Raster Processing** section and check the boxes to **Calculate Statistics** and **Build Raster Pyramids**.



35. Click **Run** to add the CTX images to your mosaic dataset.

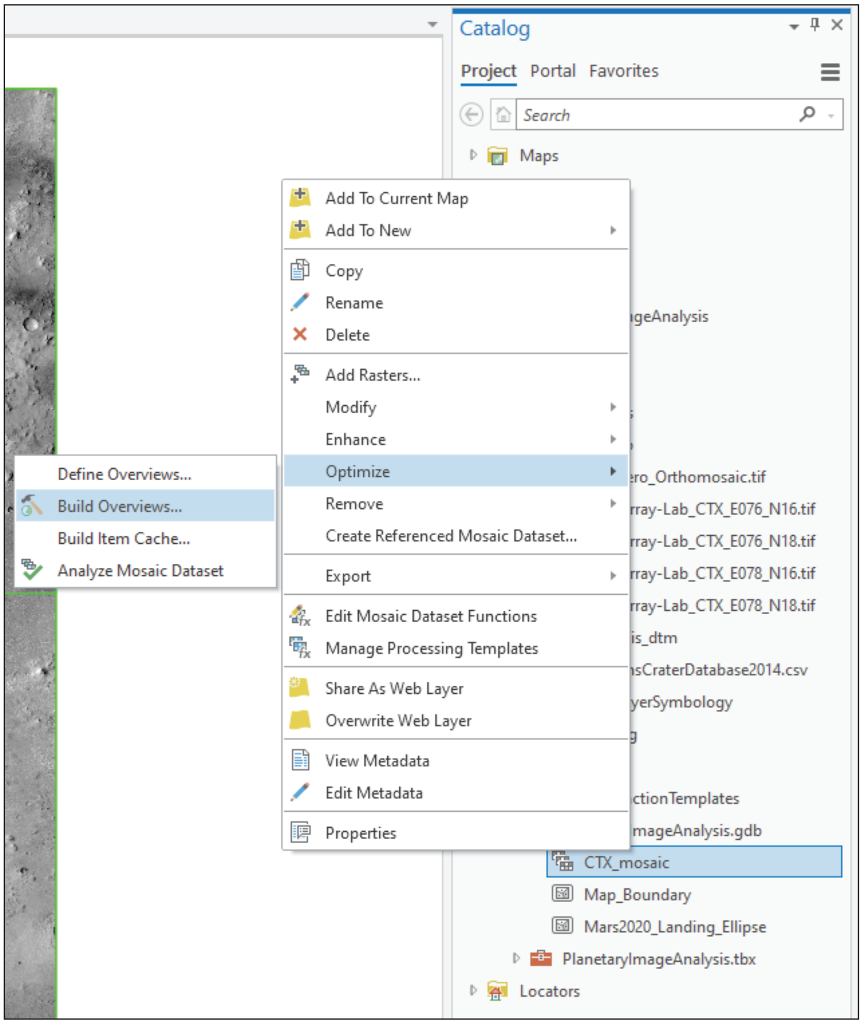
Once the **Add Rasters To Mosaic Dataset** tool has completed, you will see four small green boxes in your map window. These are the footprints of the CTX images you just added to the **CTX_mosaic** layer.

36. Use the scroll wheel of your mouse to zoom in to the four green footprints in your map window. As you zoom in you will eventually see the images appear within the footprints.

The images within your mosaic dataset are only displaying when you zoom in because you have not yet created overviews. **Overviews** are lower resolution versions of the image that will display when zoomed out. Using overviews improves the rendering speed of your map and is easier for your computer to display compared to the higher resolution images which have unnecessary levels of detail at those scales.

37. Click the **Catalog** tab located at the bottom of the **Add Rasters To Mosaic Dataset** Geoprocessing pane to return to the **Catalog** pane.

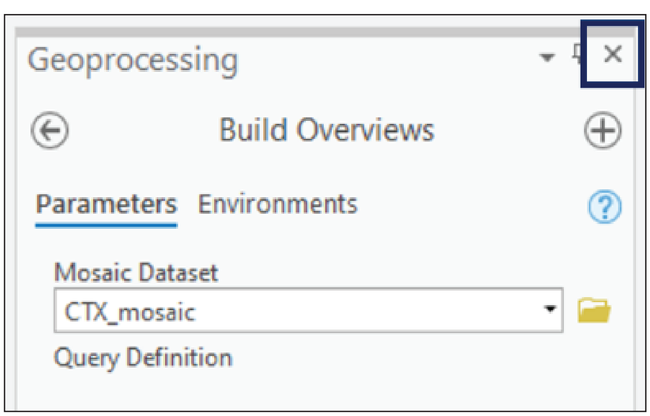
38. In the **Catalog** pane, right click the **CTX_mosaic** item in the **PlanetaryImageAnalysis_Exercise_2 geodatabase** and select **Optimize → Build Overviews**



39. In the **Build Overviews** tool pane, leave all defaults, and click **Run** to create the overviews for your mosaic dataset.

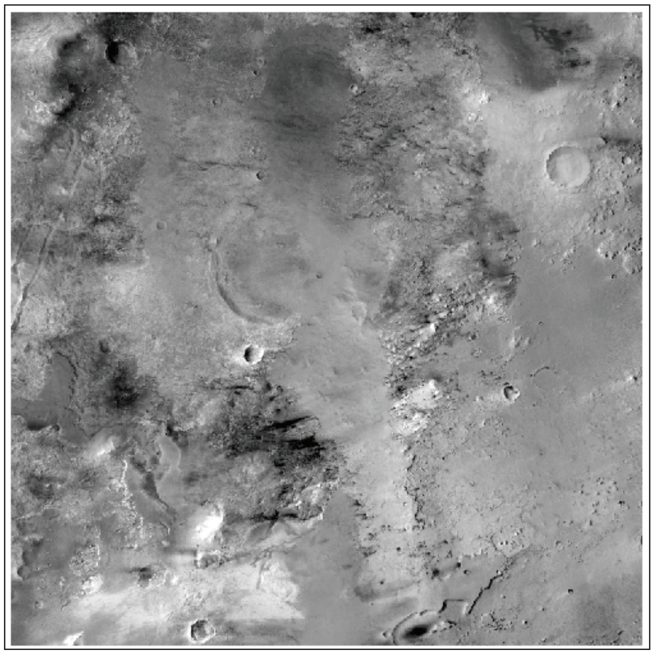
40. Once the **Build Overviews** tool is complete, zoom out in the **map** window. You should now be able to see the images in **CTX_mosaic** layer even when zoomed out.

41. Now that you have confirmed your overviews were successfully created, click on the small **x** in the upper right corner of the **Build Overviews** tool to close it and return to the **Catalog** pane.



42. In the **Contents** pane, click on the small triangle next to the **CTX_mosaic** layer to expand it. Then uncheck the **Footprint** box to turn the footprints off. Click on the small triangle next to the **CTX_mosaic** layer name again to collapse the layer details.

With the footprints turned off, all that should be visible now is a seamless mosaic of CTX images.



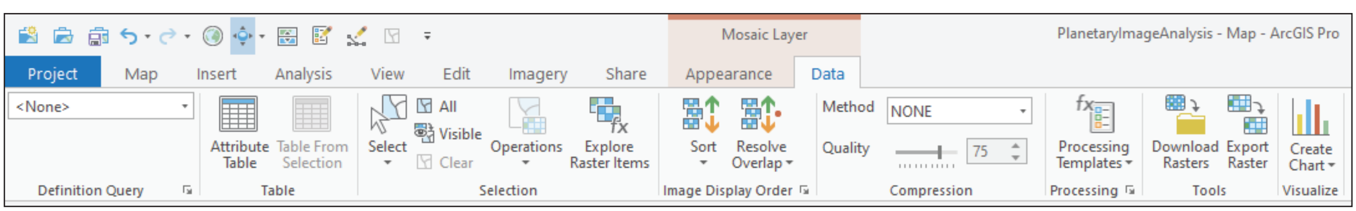
43. In the **Contents** pane, right click the **CTX_mosaic** layer and select **Zoom to Layer** to zoom back to its full extent.

One of the benefits of working with mosaic datasets is that you can quickly and easily work with many images as though they were one.

44. In the **Contents** pane, select the **CTX_mosaic** layer. This will activate the **Mosaic Layer** tabs in the menu bar.

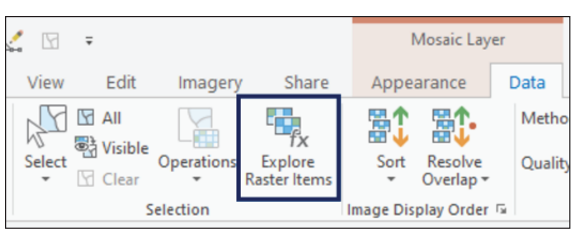
45. In the **Mosaic Layer Appearance** tab, experiment with the **Stretch**, **Brightness**, and **Contrast** as you did earlier. Note how this affects all the images in your mosaic dataset instead of just working with a single image. When you have finished, return the **Stretch** to **Percent Clip**, and the **Brightness** and **Contrast** to 0.

46. Click on the **Mosaic Layer Data** tab in the menu bar to explore the tools that are available for this type of data.

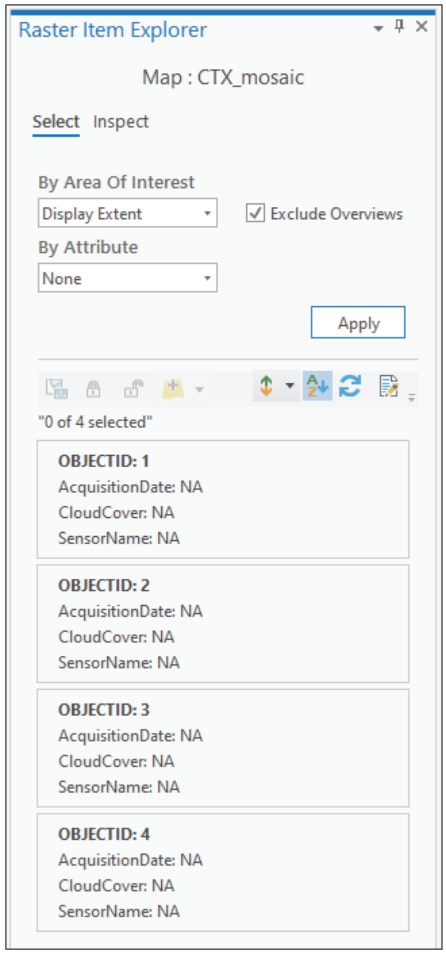


When working with a mosaic dataset, you may want to search for specific images within your collection. You can do this using the **Explore Raster Items** tool.

47. In the **Selection** section of the **Mosaic Layer Data** tab, click on the **Explore Raster Items** tool.

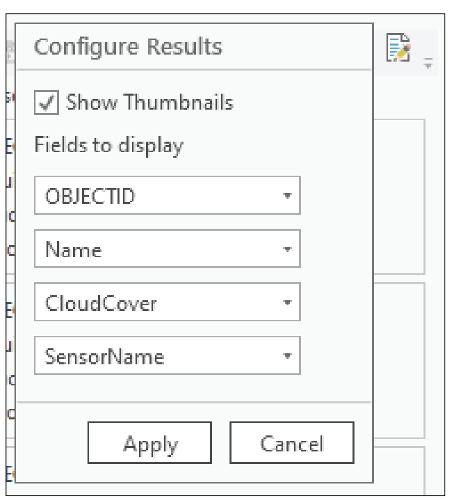


48. In the **Raster Item Explorer** pane, change the **By Area Of Interest** dropdown menu to **Display Extent**, and check the box to **Exclude Overviews**. Then click **Apply**. This will search for and display all the images that are included in the mosaic dataset, as long as they are within your current display. By checking the box to exclude overviews, the explorer will only return a list of the original images, and not the original images and each of their overviews.



The **Raster Item Explorer** list now contains the four original CTX images you added to the mosaic dataset.

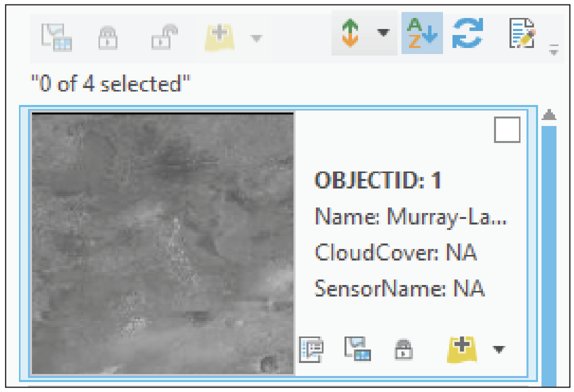
49. Click on the **Configure Results** icon in the toolbar at the top of the list and check the box to **Show Thumbnails**. In the second dropdown list, change the selection from **AcquisitionDate** to **Name**. Then click **Apply**.



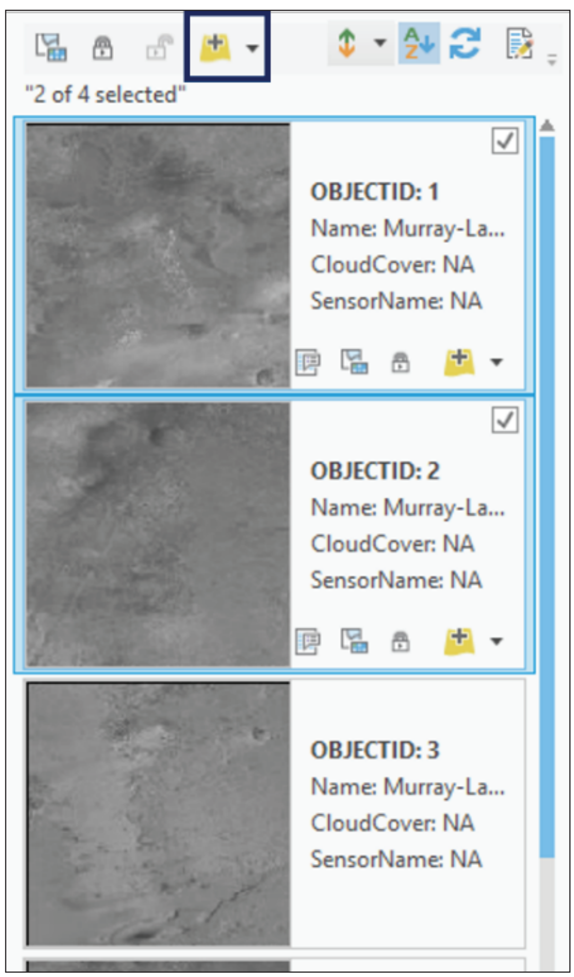
The individual CTX images in the **Raster Item Explorer** list are now shown with thumbnails and the file names. Configuring how the results are displayed can make it easier to explore your mosaic dataset items. If you were working with data that had other identifying information, you could use the **Configure Results** selections to show those as well.

From the **Raster Item Explorer** list, you can also add individual images to your map. This is often helpful if you have a large collection of images and only need to work with one or a few of them.

50. In the **Raster Item Explorer** list, hover over individual images to see the icons that appear.

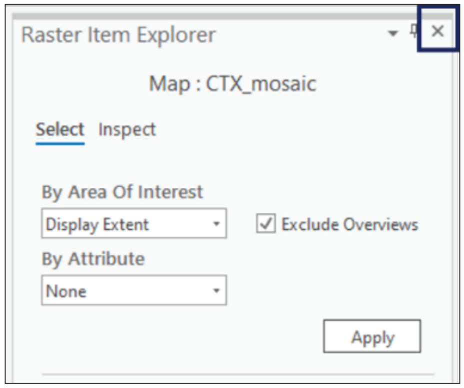


The **Add to Current Map** icon is available for each mosaic dataset item. You can click this icon to add any individual image to your map. To add multiple images to the map, check the box in the upper right corner of the mosaic dataset items you want to add, and then click the **Add to Current Map** icon in the toolbar at the top of the list.



For this exercise, you will be working with the whole mosaic dataset and do not need to add any individual images to the map.

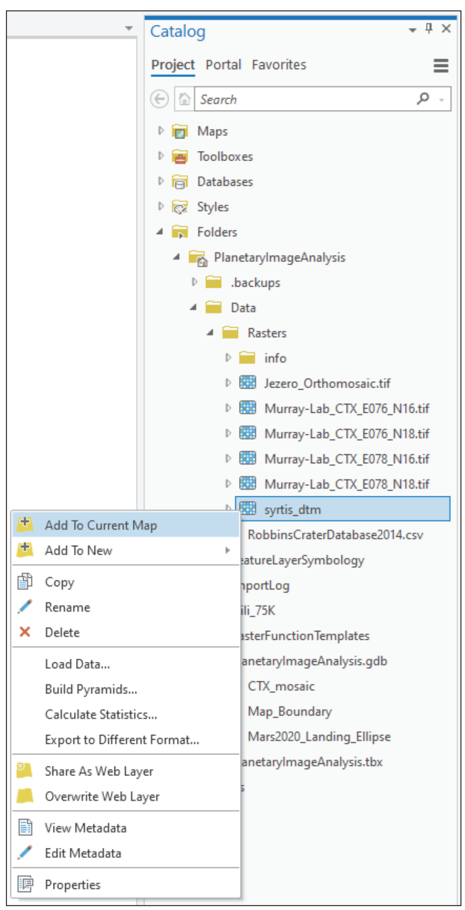
51. Click on the small **x** in the upper right corner of the **Raster Item Explorer** pane to close that tool and return to the **Catalog** pane.



Part 6: Modifying Symbology

Often in planetary science, you will work with Digital Elevation/Terrain Models (DEMs/DTMs). DTMs can provide valuable insight into a region and are frequently used for analyses such as the landing site suitability assessment you will complete in Exercise 4. For this analysis, you will use a subset of the Syrtis DTM, which uses a blend of the European Space Agency's High Resolution Stereo Camera (HRSC) and NASA's Mars Orbiter Laser Altimeter (MOLA) elevation data.

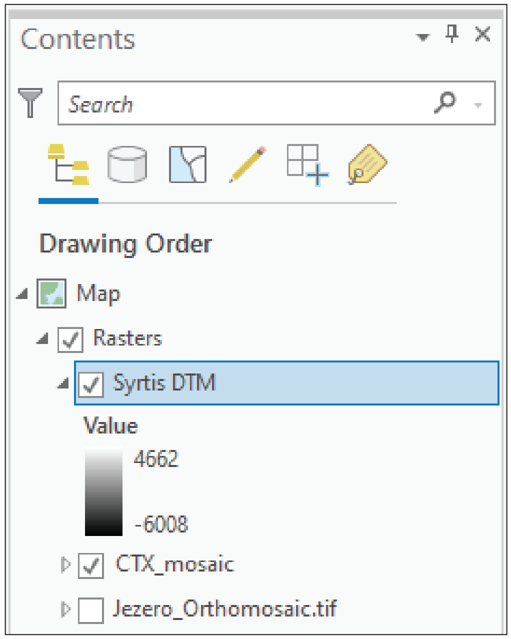
52. In the **Catalog** pane, right click on the **syrtis_dtm** raster (located under **Folders** → **PlanetaryImageAnalysis** → **Data** → **Rasters**) and select **Add to Current Map**.



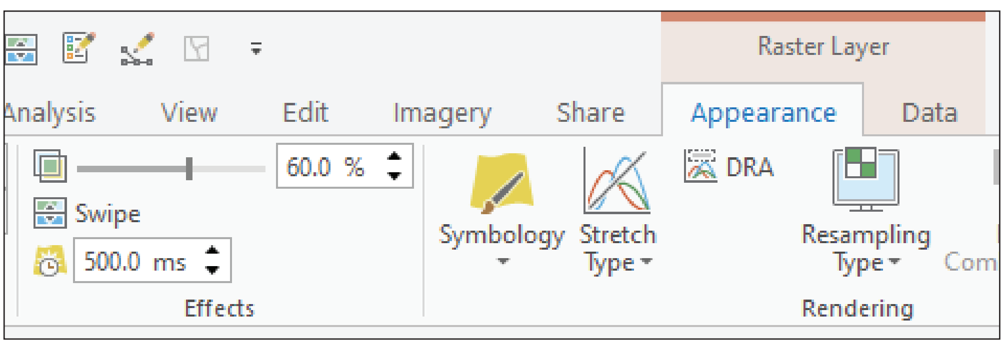
The **syrtis_dtm** will be added to your map as a new layer.

53. In the **Contents** pane, click on the **syrtis_dtm** layer you just added and hover over the name to enable editing. Rename this map layer to **Syrtis DTM** and press **enter** to apply the changes. Often datasets will come with names that are not intuitive. You can rename any map layer within the **Contents** pane for clarity (the "alias"), without changing the original file names. *(Note: When working in ArcGIS, actual file names can not include spaces. However, file aliases may include spaces)*

54. In the **Contents** pane, click on the **Syrtis DTM** layer and drag it into the **Rasters** group, on top of the **CTX_mosaic** layer.

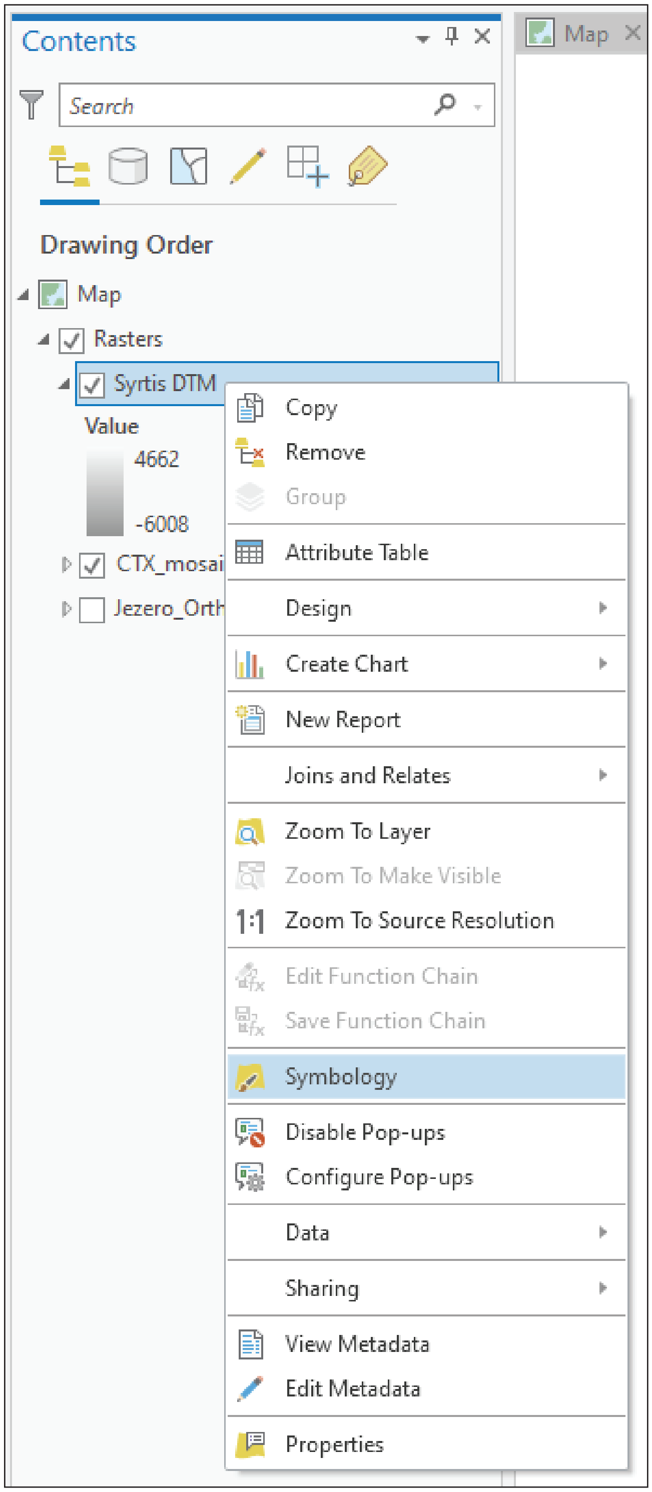


55. With the **Syrtis DTM** set to 0% transparency, the base images are not visible. In the **Effects** section of **the Raster Layer Appearance** tab, set the **Syrtis DTM** layer **transparency** to 60%



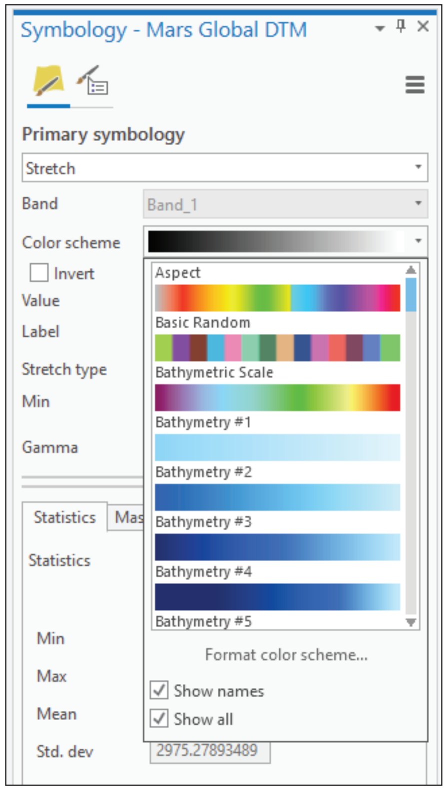
The **Syrtis DTM** layer is now transparent, and the underlying base imagery is visible. However, the current DTM symbology is set to grayscale and is not useful for visualization.

56. In the **Contents** pane, right click the **Syrtis DTM** layer and select **Symbology**.



This will open the **Symbology** pane. The **Symbology** pane is where you can change the symbol type, color, stretches, and many other options.

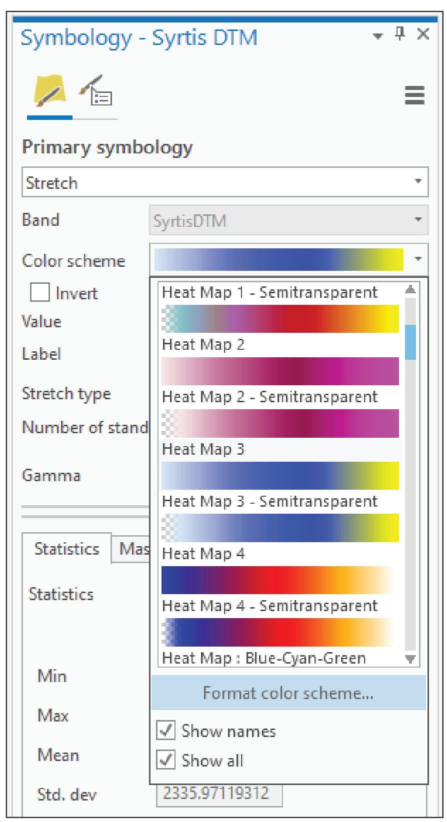
57. In the **Symbology** pane, open the **Color scheme** dropdown menu and check the boxes for **Show names** and **Show all**.



58. Scroll down through the available color schemes and select **Heat Map 3**.

This is a preset color scheme, but it can be further modified within the **Symbology** pane.

59. Open the **Color scheme** dropdown menu again and select **Format color scheme** at the bottom.



60. Explore the **Color Scheme Editor** options and change the color scheme to anything of your choosing. (Note: This is not the color scheme you will be using later, so do not worry about messing something up.)

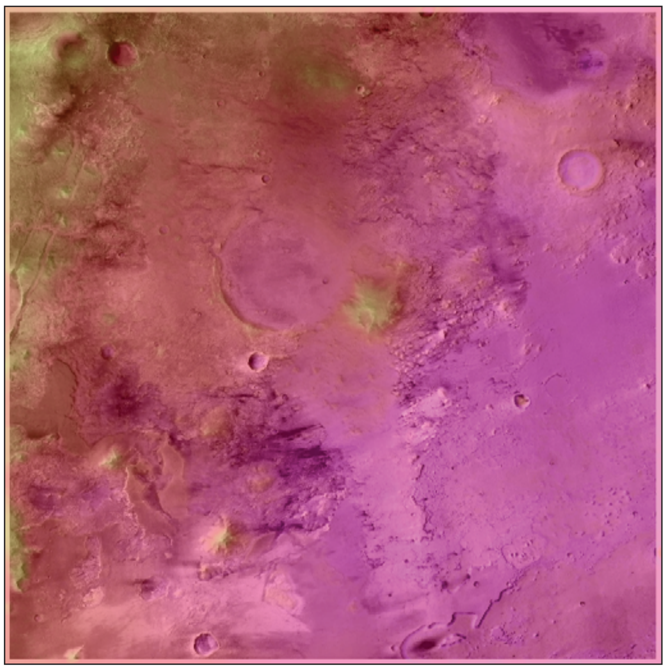
    A. Select different colors by selecting a pointer and changing the color in the Color dropdown box.

    B. Delete and add different color marker points by clicking the + and **x** in the upper right corner.

    C. Experiment with moving the pointers along the color ramp to change how the colors are distributed.

    D. Flip the color ramp so the order is reversed.

61. Once you have finished experimenting with the **Color Scheme Editor**, click **OK** to apply your changes. You should now see the new **Syrtis DTM** symbology displayed in the map.

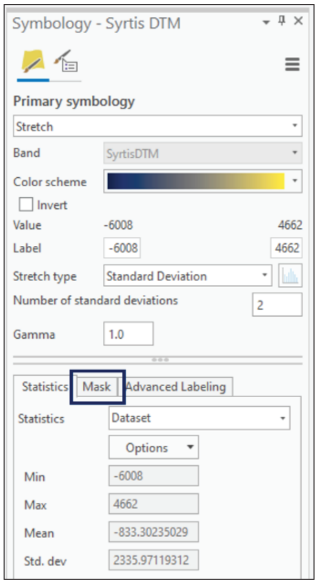


Note: Colors will vary dramatically depending on the changes you made.

Now that you have had a chance to experiment with making a custom color scheme, you will set the actual color scheme for your **Syrtis DTM** layer.

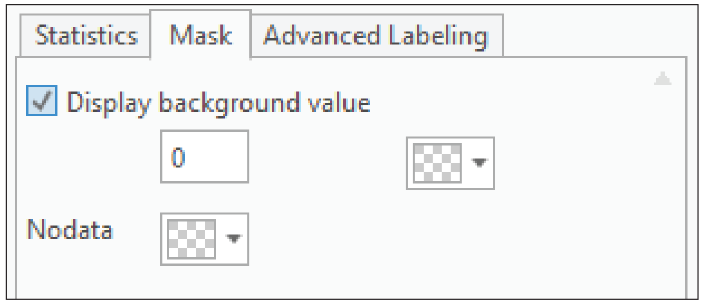
62. Open the **Color scheme** dropdown menu again and select **Cividis**.

*Colorblind-friendly color schemes: Many commonly used color schemes are not colorblind-friendly. For this tutorial, you will use the **Cividis** color scheme, which is a blue to yellow color ramp. If needed, feel free to choose a different color scheme which best suits your visual needs. If desired, you can use the **ColorBrewer Schemes (RGB**, red-green-blue**)** style to identify colorblind-friendly schemes. To do this, in the **Catalog** pane, click on the small triangle to expand the **Styles** section. Then right click the **ColorBrewer Schemes (RGB)** style and select **Manage** to open this style in the **Catalog view**. In the **Search Project** box (upper right), search for "**color blind**" to return a list of colorblind-friendly color schemes. You can then select the colorblind-friendly color scheme of your choice in the **Symbology** pane. When you have finished, click on the small **x** in the **Catalog view** tab to close it and return to your **map**.*



Helpful tip: Before exiting the ***Symbology*** *menu, take a moment to explore the* ***Mask*** *tab in the bottom section. Often, images have a black border or background that needs to be removed so they can be displayed top of other images. The* ***Symbology Mask*** *tab is where you can remove this background.*

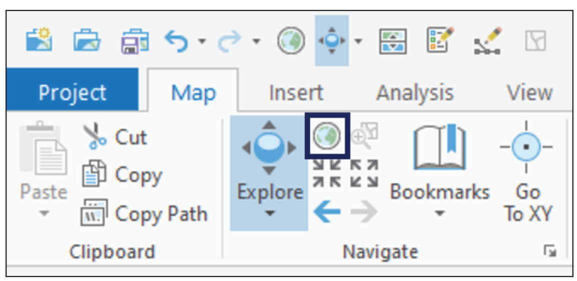
In future projects, if an image has a black background you wish to remove, check the ***Display background value*** *box in the* ***Symbology Mask*** *tab. This will set the background value to have no color.*



63. Click the small **x** in the upper right corner of the **Symbology** pane to close it and return to the **Catalog** pane.

The **Syrtis DTM** you added to the map covers a large region of Mars. At the current scale, you can only view a small portion of it.

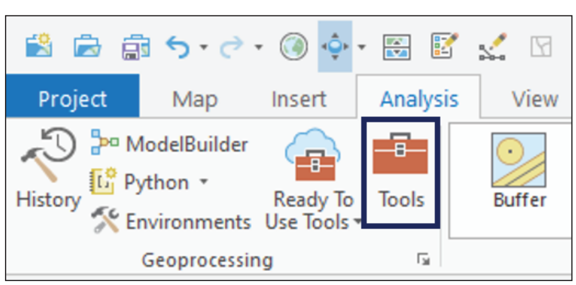
64. In the **Navigate** section of the **Map** tab, click on the small **globe icon** to zoom to the full extent of the data. (Note: since this is the most expansive dataset in your map, you could accomplish the same thing by right clicking the **Syrtis DTM** layer in the **Contents** pane and selecting **Zoom to Layer**)



Part 7: Working with Geoprocessing Tools

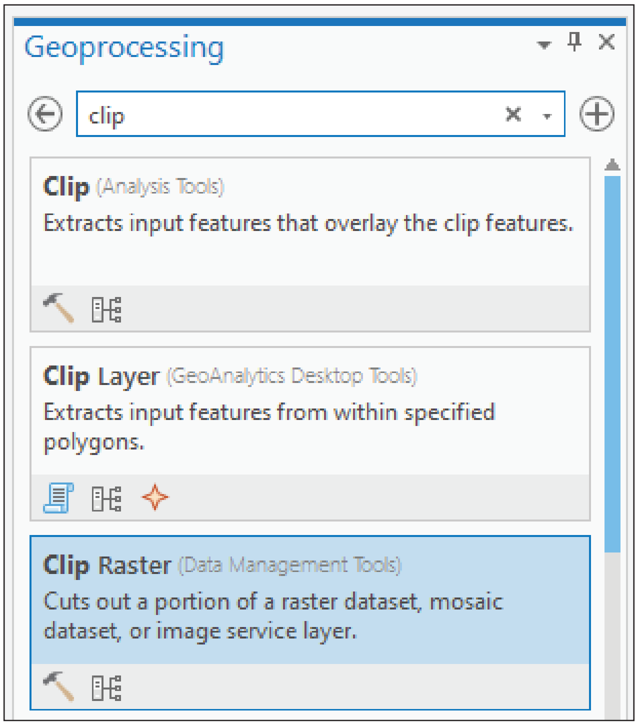
Now that you can view the full extent of the **Syrtis DTM**, it is clear that this is more data than you need to work with. For this activity, you will only be working within the region of the **CTX_mosaic** layer, which is substantially smaller than the **Syrtis DTM** dataset. Instead of trying to process the entire **Syrtis DTM**, you can clip this dataset to just the area where you will be working.

65. In the **Geoprocessing** section of the **Analysis** tab, click on the **Tools** icon to open the **Geoprocessing** pane.



The **Geoprocessing** pane contains many of the data processing and analysis tools that you may need when working in ArcGIS Pro. This pane contains three tabs: **Favorites**, **Toolboxes**, and **Portal**. Regardless of which tab you are in, you can always quickly search for a tool using the **Find Tools** search bar at the top of the **Geoprocessing** pane. The **Favorites** tab contains a list of any tools you have saved as a favorite, and a list of your most recently used tools. The **Toolboxes** tab contains a full list of all the geoprocessing tools that are available, and groups them by which toolbox they are in. In this tab, you can manually click through the different toolboxes to access any geoprocessing tool. This is also where you will find any custom toolboxes you may have installed (like the USGS Astrogeology Planetary Geologic Mapping Python toolbox). The **Portal** tab lists any geoprocessing tools that are available to you through your organization's web portal. In most cases, you will only use the search bar to find tools, since that is often the quickest and easiest way to access them.

66. In the **Geoprocessing** pane, search for **clip**. Click on the **Clip Raster** tool to open it.



67. In the **Clip Raster** tool, set the following inputs:

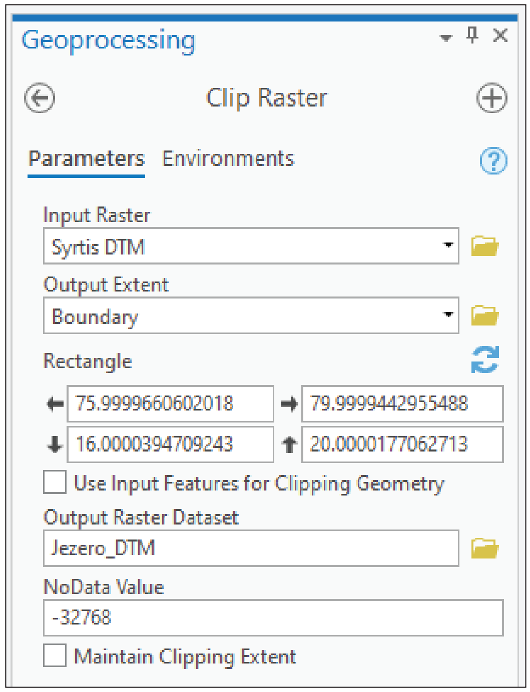
    Input Raster: **Syrtis DTM**

    Output Extent: **CTX_mosaic\Boundary**

    Use Input Features for Clipping Geometry: **Checked**

    Output Raster Dataset: **PlanetaryImageAnalysis_Exercise_2.gdb\Jezero_DTM**

    Leave all the other automatically populated settings (Rectangle boundaries, and NoData value)

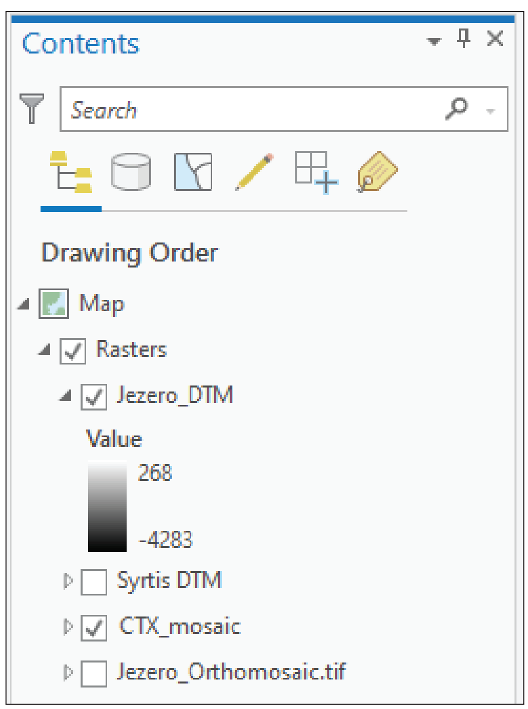


68. Click **Run** to clip the **Syrtis DTM** to your region of interest using the boundary of the **CTX_mosaic** layer as your guide.

When the **Clip Raster** tool is complete, the new **Jezero_DTM** layer will be automatically added to your map.

69. Click the small **x** in the upper right corner of the **Geoprocessing** pane to close it. Then, In the **Contents** pane, click on the small triangle next to the **Syrtis DTM** layer name to collapse the symbology, and uncheck the box next to **Syrtis DTM** map layer to turn it off.

70. In the **Contents** pane, click on the **Jezero_DTM** map layer and drag it into the **Rasters** group. Place the **Jezero_DTM** layer at the top of the **Rasters** group layers.



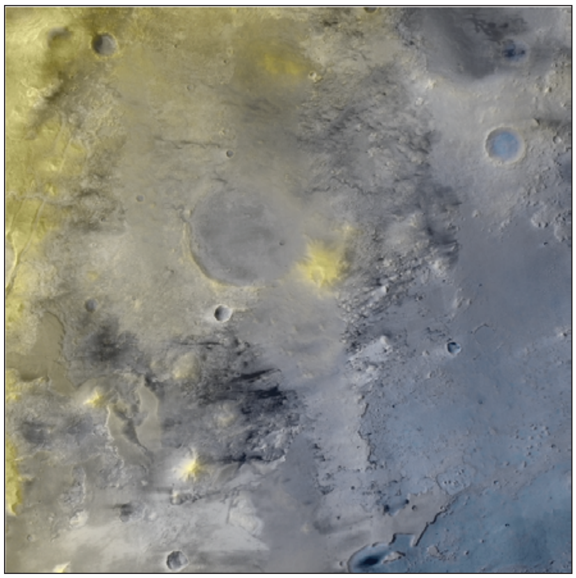
Now that you have the DTM clipped to your region of interest, you do not need to be zoomed out to the current extent.

71. In the **Contents** pane, right click the **Jezero_DTM** layer and select **Zoom to Layer**.

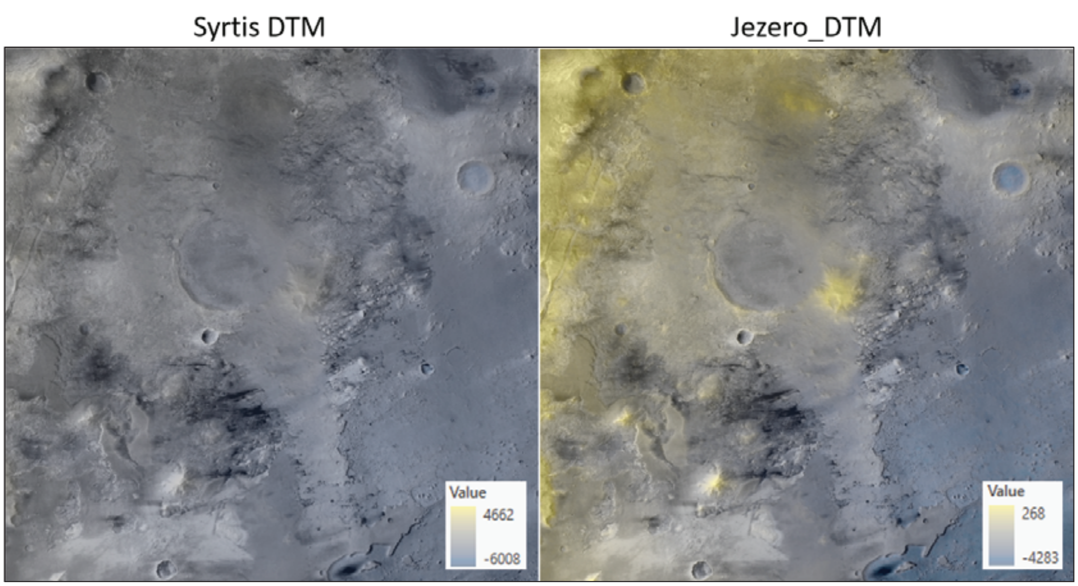
When you clipped the **Syrtis DTM**, the resulting map layer was automatically given the default grayscale symbology and 0% transparency. You will need to change these to improve the visualization of your data.

72. In the **Contents** pane, select the **Jezero_DTM** layer and then open the **Raster Layer Appearance** tab in the menu bar. In the **Effects** section of the **Raster Layer Appearance** tab, change the layer **transparency** to 60%.

73. In the **Contents** pane, right click the **Jezero_DTM** map layer and select **Symbology**. Change the **color scheme** to **Cividis** (or the same alternate color scheme as the one you chose earlier) and then close the **Symbology** pane (click the small **x** in the upper right corner).



You may notice the color distribution for the **Jezero_DTM** map layer is different than it was when you were viewing the **Syrtis DTM** map layer. This is because the color ramp is applied using the full range of pixel values in the map layer. The **Syrtis DTM** has a much larger range of elevation values (-6,008 to 4,662), that the color ramp must cover. With the **Jezero_DTM** clipped to your region of interest, you are working with a much smaller range of elevation values (-4,283 to 268), so the color ramp is compressed, and more detail is visible.

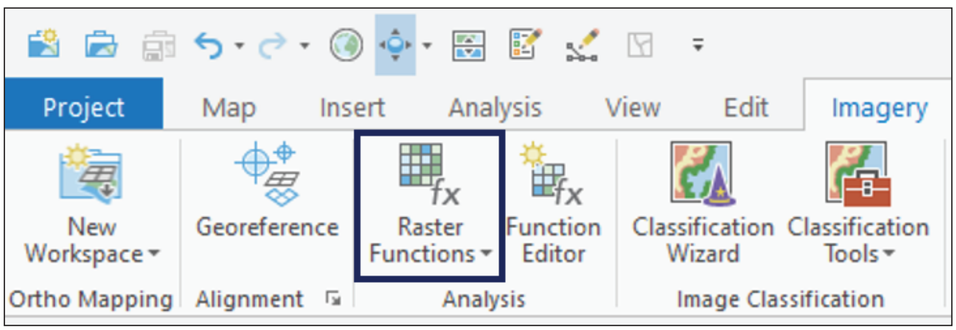


74. Take a minute to pan around and zoom in and out in this region. Turn the **DRA** (in the **Rendering** section of the **Raster Layer Appearance** tab) on and off and see how that changes the symbology of the DTM as you move around. When you have finished exploring, make sure **DRA** is turned back off and zoom back to the full extent of the **Jezero_DTM** layer (right click the **Jezero_DTM** layer in the **Contents** pane and select **Zoom to Layer**).

Part 8: Working with Raster Functions

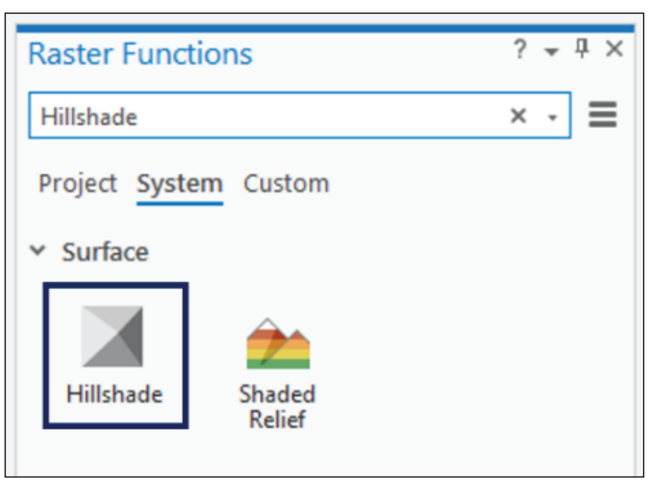
One way to work with raster data in ArcGIS Pro is with raster functions. Raster functions are tools that process your data on the fly, and only within the area you are viewing. Unlike geoprocessing tools, raster functions do not create a new data layer. Instead, they temporarily apply the process directly to the pixels of the original data layer. This makes raster functions extremely useful for quick analyses or experimenting with settings since they process only the data you are viewing and do not take up additional computer storage space. Raster function results can also be exported and saved as needed. In addition to single step analyses, raster functions can be chained together to create custom functions that can be saved and used again. You will experiment with all of these in the upcoming exercises.

75. In the **Catalog** pane, select the **Jezero_DTM** map layer. Then open the **Imagery** tab of the **menu bar**. In the **Analysis** section of the **Imagery** tab, click on the **Raster Functions** icon to open the **Raster Functions** pane.

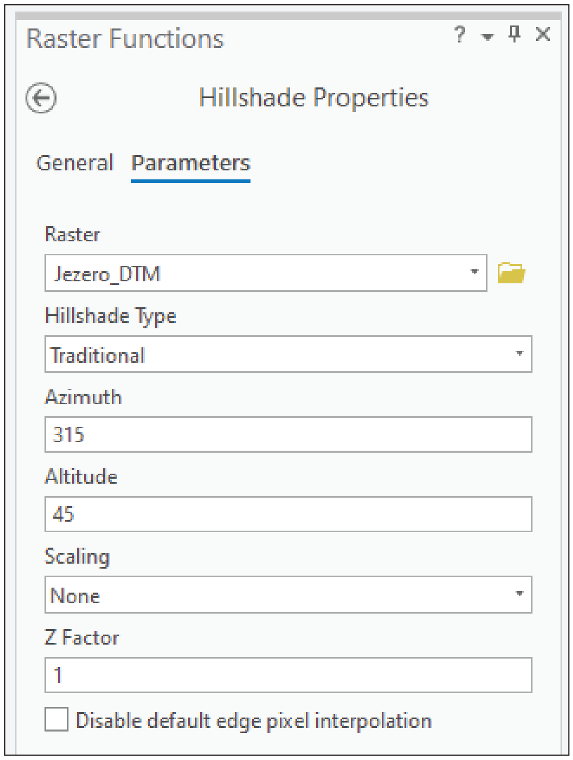


The **Raster Functions** pane has three tabs: **Project**, **System**, and **Custom**. The **Project** tab will show any custom raster functions that you have saved specifically within your current ArcGIS Pro project. The **System** tab lists all raster functions that come with the ArcGIS Pro software. The **Custom** tab lists all the custom raster functions that you have saved that are not tied to a specific ArcGIS Pro project. By default, the **System** tab will be open when you open the **Raster Functions** pane.

76. At the top of the **System** tab in the **Raster Functions** pane, search for **Hillshade**. Click on the **Hillshade** icon to open the **Hillshade** raster function.



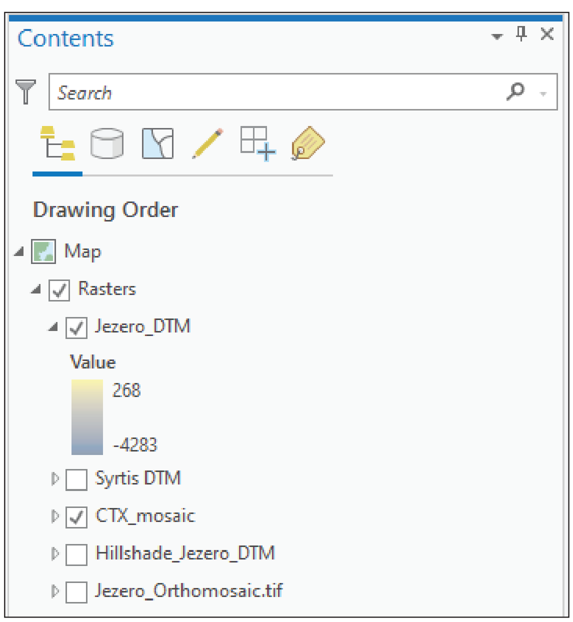
77. In the **Hillshade Raster Function** pane, set the Raster to **Jezero_DTM**. Leave all other default settings. Click **Create new Layer** at the bottom of the **Raster Function** pane to run your hillshade analysis.



When you run the raster function, the layer will be added to your map. The raster function will quickly process only the data within the current display extent, and only at the resolution you are currently viewing. If you move around the scene or zoom in or out, the raster function will reprocess the data and update the display as you move.

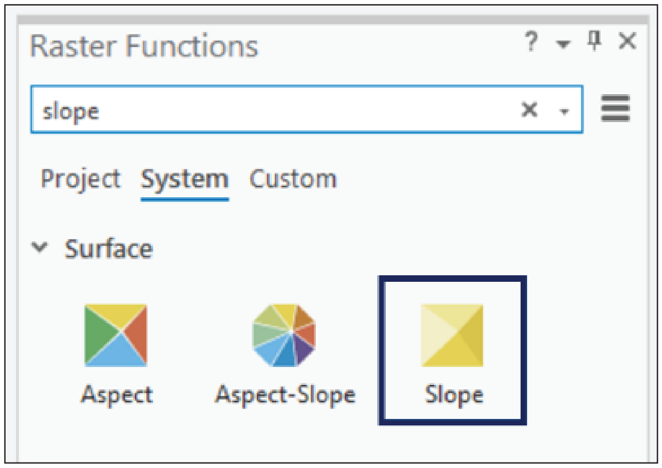
78. Take a minute to pan around the region and zoom in and out as you explore. Notice how the **Hillshade_Jezero_DTM** layer updates as you move. When you have finished exploring, return to the full extent of the **Jezero_DTM** layer (Zoom to the **Jezero_DTM** layer in the **Contents** pane)

79. In the **Contents** pane, click on the small triangle next to the **Hillshade_Jezero_DTM** layer to collapse the symbology. Then uncheck the box to turn the **Hillshade_Jezero_DTM** layer off. Click and drag that layer into the **Rasters** group, putting it below the **CTX_mosaic** layer.

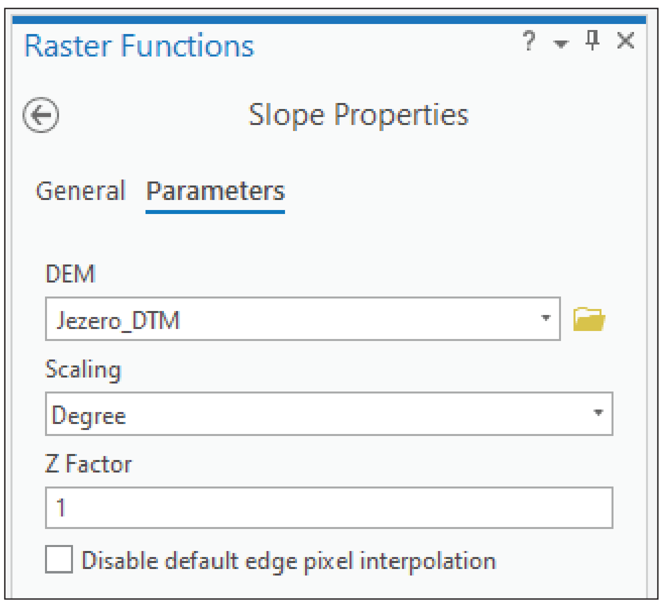


To complete the landing site assessment in the "Exercise 4" section of this tutorial, one piece of information you will need is the slope. You can quickly calculate the slope across your area of interest using raster functions.

80. In the **Raster Functions** pane, search for **slope**. Then click on the **Slope** raster function icon to open it.

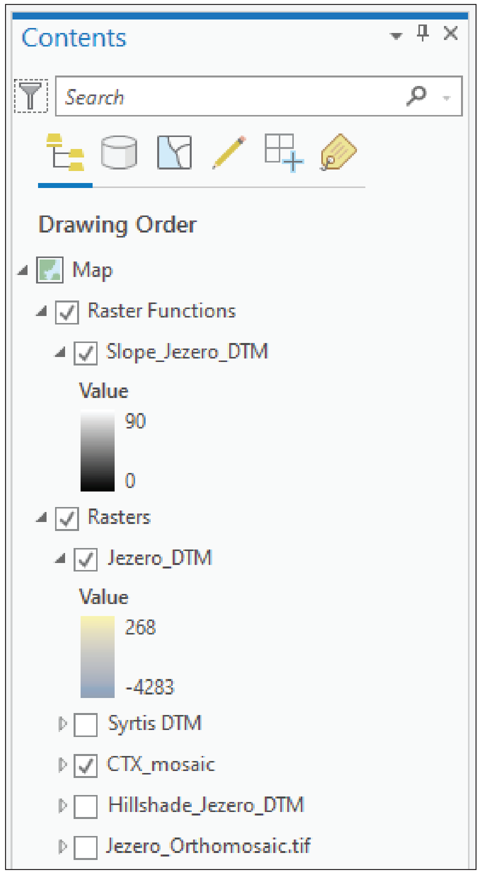


81. In the **Slope Raster Function** pane, set the DEM to **Jezero_DTM**. Leave all other default settings. Click **Create New Layer** at the bottom of the **Raster Function** pane to run your slope analysis.



The new **Slope_Jezero_DTM** layer will be added to your map. To begin, this layer will have the default black and white color ramp and 0% transparency, which is not ideal for your visualization purposes.

82. In the **Contents** pane, right click the **Map** name and select **New Group Layer**. Rename this layer **Raster Functions** and click and drag the new **Slope_Jezero_DTM** layer into it. Click on the small triangle next to the **Raster Functions** group to expand it and view the **Slope_Jezero_DTM** layer in the list.

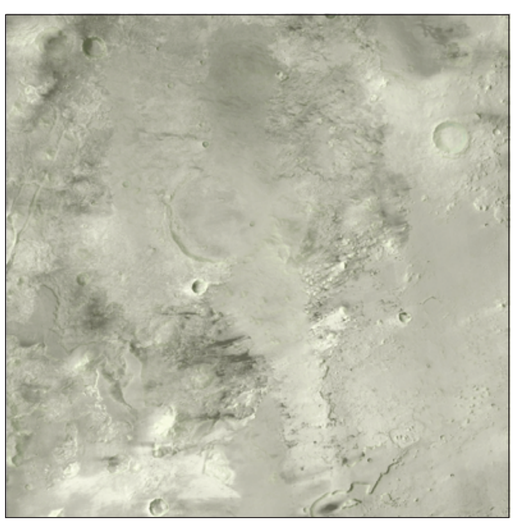


83. In the **Contents** pane, select the **Slope_Jezero_DTM** layer. Then change its transparency to **60%** in the **Raster Layer Appearance** tab.

84. In the **Contents** pane, right click the **Slope_Jezero_DTM** layer and select **Symbology** to open the Symbology pane. In the **Symbology** pane, change the **color scheme** to **Yellow-Green-Blue (Continuous)**. *(Note: This color scheme is very close to the end of the list.)*

85. In the **Contents** pane, uncheck the box next to the **Jezero_DTM** layer to turn it off.

With the **Jezero_DTM** layer turned off, and the new transparency and symbology for the **Slope_Jezero_DTM** layer, you are now looking at the slopes across the region of interest.



At first glance, the entire area appears to be one color. However, the slope color scheme covers from 0° to 90°, and despite the varied topography in this area, the majority of this area has slopes that are less than 30°, making them appear uniform.

When searching for appropriate landing sites, candidates are limited to slopes that are less than 15°, with slopes of 0° to 5° being ideal. With the current color ramp style symbology, it is difficult to discern what areas lie within these constraints.

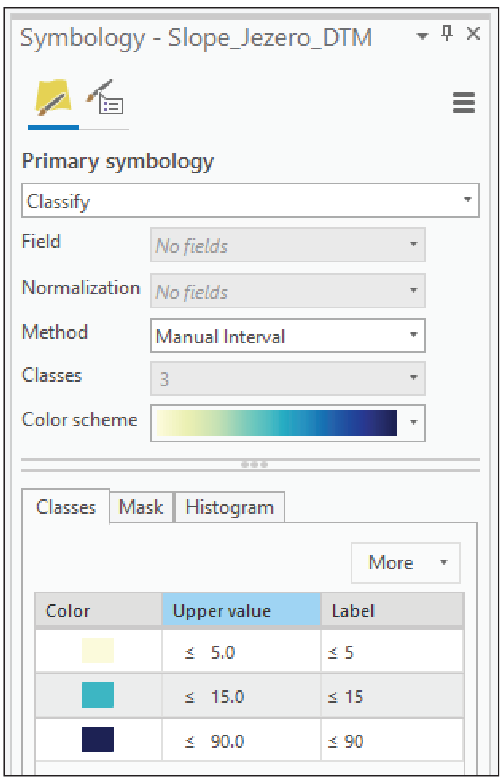
86. In the **Symbology** pane, change the **Primary symbology** type to **Classify**. When you select **Classify**, you will be prompted to compute the histogram for your dataset. Click **Yes** to compute the histogram.

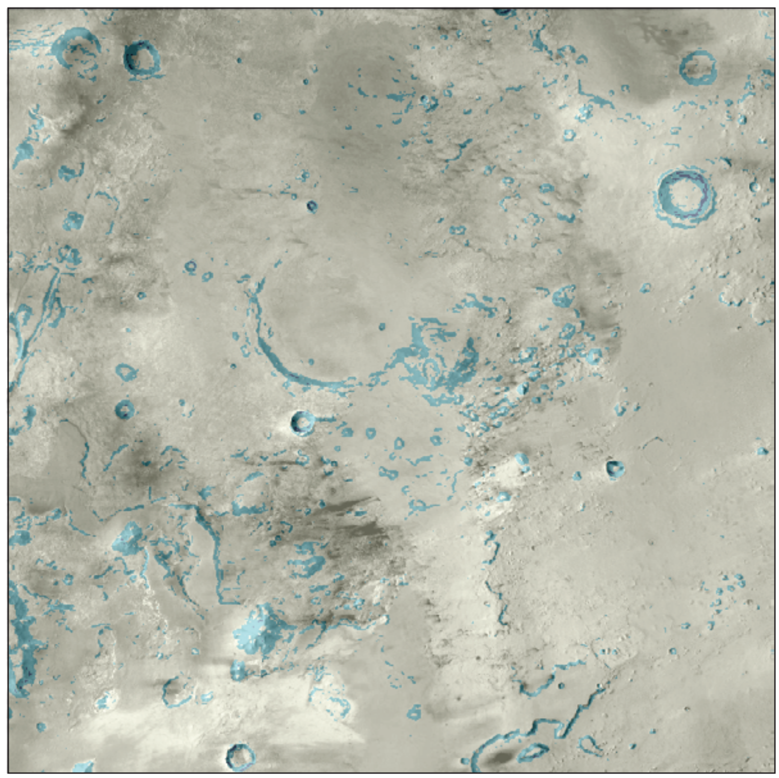
Once the histogram has been calculated, the **Slope_Jezero_DTM** layer symbology will change in the **Contents** and **Symbology** panes.

87. In the **Symbology** pane, change the number of **Classes** to **3**. Then change the **Color scheme** back to **Yellow-Green-Blue (Continuous)** (it reverts to a default color scheme when you change the **Primary symbology** style).

The **Slope_Jezero_DTM** layer now shows three slope classes in pale yellow, teal, and dark blue. However, the groupings for these classes have been automatically generated and don't yet match the cutoffs for landing site selection.

88. In the **Classes** tab at the bottom of the **Symbology** pane, click and hover over the numbers in the **Upper value** column to update them. For the first class, set the upper value to 5. For the second, set the upper value to 15. For the third class, set the upper value to 90. Press **enter** to apply your changes to each value.





With these changes applied, the **Slope_Jezero_DTM** layer now shows the areas that are acceptable for landing site selection in pale yellow, with areas that have marginally acceptable slopes (5-15°) in teal and unacceptable slopes (>15°) in dark blue.

Summary

In this exercise you learned the basics of working with rasters in ArcGIS Pro, beginning with adding raster data to a map project and modifying its display properties and symbology. In situations where you are working with many rasters, it is often helpful to put your data into a mosaic dataset. Here you learned how to create, add rasters to, and work with a mosaic dataset using a collection of CTX images over Jezero crater and Nili Planum, Mars. You then learned how to use both geoprocessing tools and raster functions to process and analyze a set of raster data in this region.

To Prepare for the Next Exercise

If you wish to start with a fresh GIS project for Exercise 3, click the **x** in the upper right corner of your ArcGIS Pro window to close it. Alternatively, if you prefer to continue working in this GIS project, complete the following steps before moving on to Exercise 3: In the **Contents** pane uncheck the box for the **Slope_Jezero_DTM** map layer to turn it off. Then click on the small triangle next to the **Raster Functions** group layer to collapse it. Click on the small **x**'s in the upper right corners of the **Symbology** and **Raster Functions** panes so all that remains open in that area is the **Catalog** pane.

Exercise 3: Working with Vectors

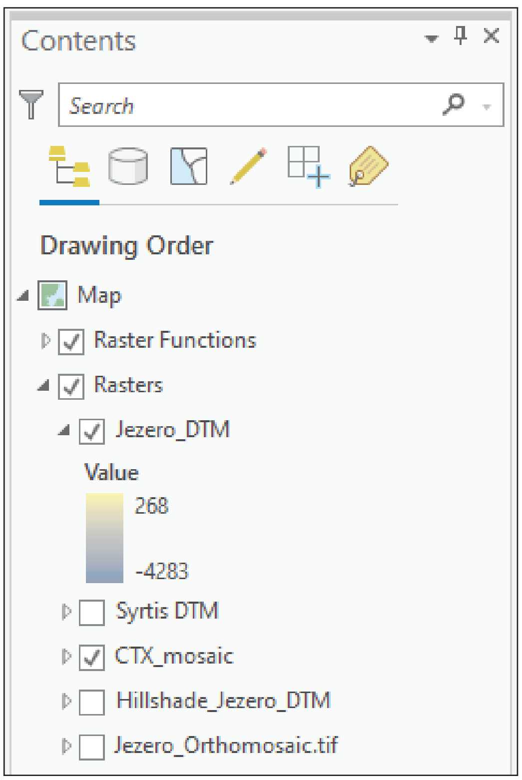
In Exercise 2 you learned how to work with raster data in ArcGIS Pro. Rasters commonly serve as the base imagery and additional datasets when performing analyses or creating a geologic map. In this exercise, you will learn how to create and work with **vector data**. Vector data is made of **points**, **lines**, and **polygons**, and is typically used to represent discrete features on the surface of a planetary body. **Points** are often used to indicate the presence of small features like cones, domes, or small craters. **Lines** are commonly used to represent geologic contacts and structures like faults and folds. **Polygons** are typically used to represent geologic units, surficial deposits, and the boundaries of large craters.

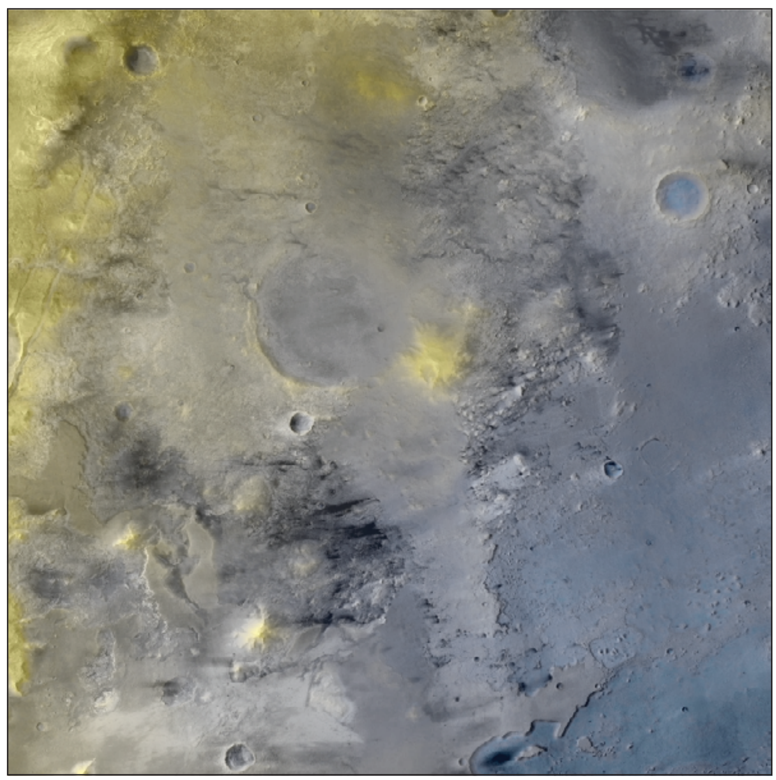
If you wish to continue working with the GIS project from Exercise 2: (**PlanetaryImageAnalysis_Exercise_2.aprx**) skip to step 2. If you prefer to start with a fresh GIS project, begin with step 1 below:

1. In your Windows File Explorer, navigate to the **PlanetaryImageAnalysis\Exercise_3** folder and double click the **PlanetaryImageAnalysis_Exercise_3** project file (.**aprx**) to open it in ArcGIS Pro.

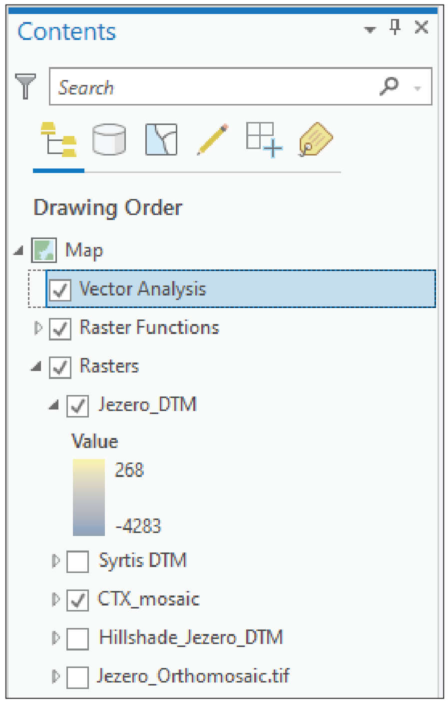
The **PlanetaryImageAnalysis_Exercise_3** project will open in ArcGIS Pro. Data has already been added to the map, and all map layers are listed in the **Contents** pane.

2. Begin by checking your map layers in the **Contents** pane. All layers should be turned off except the **CTX_mosaic** and **Jezero_DTM** layers. If you are not currently zoomed to the extent of the **Jezero_DTM** and **CTX_mosaic** layers (they have the same extent), right click one of those layers in the **Contents** pane and select **Zoom to Layer**.





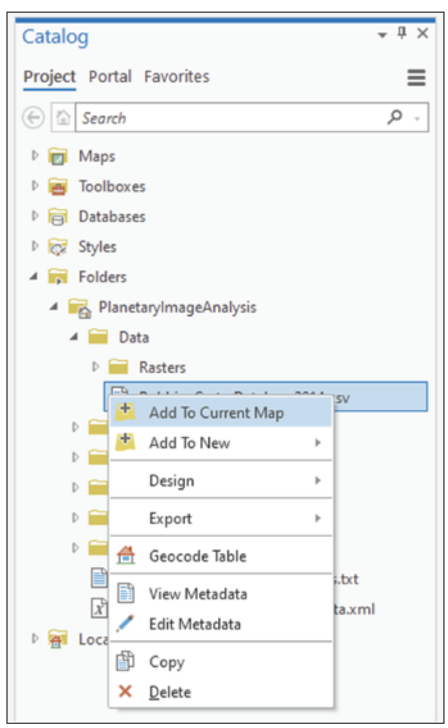
3. In the **Contents** pane, right click **Map** and create a **New Group Layer**. Rename the new group **Vector Analysis**. All the map layers that you create in this exercise will be put into this group layer.



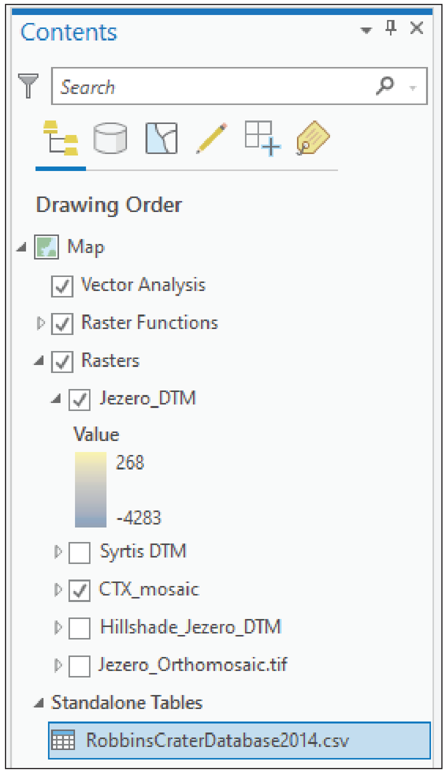
Part 1: Creating Point Features From an Existing Database

When creating new features in a map, you can draw them manually or import features from an existing database. In this section, you will begin by importing crater locations from an existing, previously-published database. The database is already included for you in the tutorial materials, but the original database and associated information is available from the USGS Astropedia Data Repository.

4. In the **Catalog** pane, expand the **Folders** → **PlanetaryImageAnalysis** → **Data** section. Then right click the **RobbinsCraterDatabase2014.csv** file and select **Add to Current Map**.

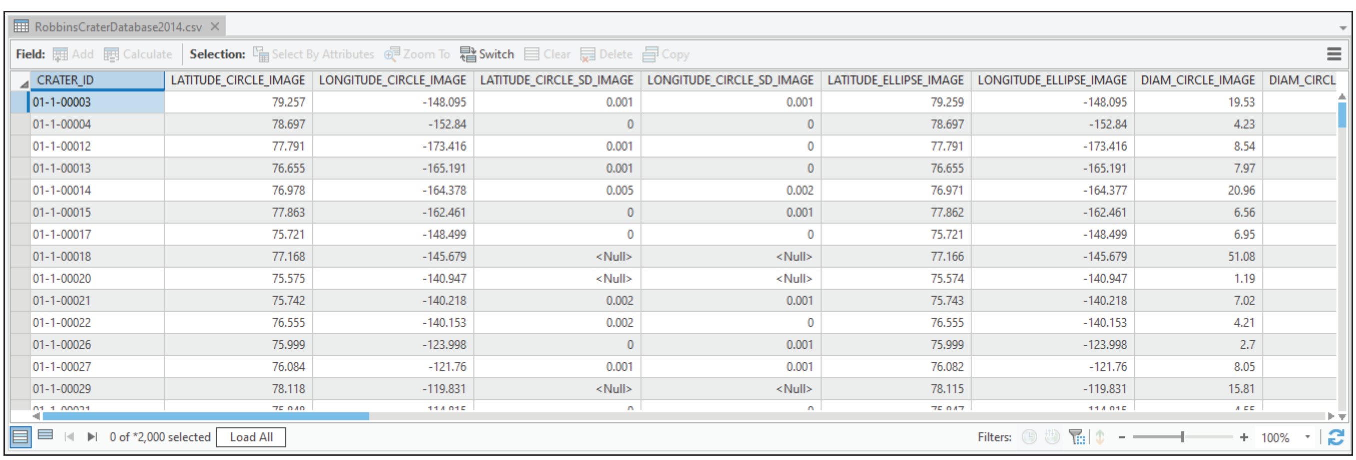


This crater database exists as a **.csv** file, which is added to your map as a standalone table. When a database is added to the map as a table, the features are not yet displayed on the map.



5. Before adding the crater features to your map, it is always good practice to view the table first. In the **Contents** pane, right click the **RobbinsCraterDatabase2014.csv** table and select **Open**.

The table will open as a tab at the bottom of your map window. If desired, you can always pull the tab out from the main ArcGIS Pro window and view it somewhere else on your screen. *(Note: You can also do this with the **Contents**, **Catalog**, and other panes, and any maps.)*

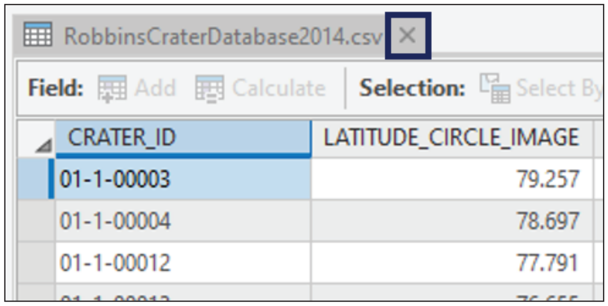


CRATER_ID	LATITUDE_CIRCLE_IMAGE	LONGITUDE_CIRCLE_IMAGE	LATITUDE_CIRCLE_SD_IMAGE	LONGITUDE_CIRCLE_SD_IMAGE	LATITUDE_ELLIPSE_IMAGE	LONGITUDE_ELLIPSE_IMAGE	DIAM_CIRCLE_IMAGE	DIAM_CIRCL
01-1-00003	79.257	-148.095	0.001	0.001	79.259	-148.095	19.53	
01-1-00004	78.697	-152.84	0	0	78.697	-152.84	4.23	
01-1-00012	77.791	-173.416	0.001	0	77.791	-173.416	8.54	
01-1-00013	76.655	-165.191	0.001	0	76.655	-165.191	7.97	
01-1-00014	76.978	-164.378	0.005	0.002	76.971	-164.377	20.96	
01-1-00015	77.863	-162.461	0	0.001	77.862	-162.461	6.56	
01-1-00017	75.721	-148.499	0	0	75.721	-148.499	6.95	
01-1-00018	77.168	-145.679	<Null>	<Null>	77.166	-145.679	51.08	
01-1-00020	75.575	-140.947	<Null>	<Null>	75.574	-140.947	1.19	
01-1-00021	75.742	-140.218	0.002	0.001	75.743	-140.218	7.02	
01-1-00022	76.555	-140.153	0.002	0	76.555	-140.153	4.21	
01-1-00026	75.999	-123.998	0	0.001	75.999	-123.998	2.7	
01-1-00027	76.084	-121.76	0.001	0.001	76.082	-121.76	8.05	
01-1-00029	78.118	-119.831	<Null>	<Null>	78.115	-119.831	15.81	

6. Take a minute to scroll through the crater database and explore its contents. As you scroll down, you will notice there are several thousand individual craters included in this database. Scroll across to observe the information that is included for each.

The Robbins crater database contains several pieces of information for each crater and can be used for a number of analyses. For this exercise you will only use the basic latitude, longitude, and diameter information.

7. Click on the small **x** in the tab at the top of the **RobbinsCraterDatabase.csv** table to close it.



8. To display the craters from the database, in the **Contents** pane, right click the **RobbinsCraterDatabase2014.csv** table and select **Display XY Data**. This will open the **Display XY Data** window, where you will input the parameters to create a new point feature class based on the contents of the database.

9. Input the following parameters in the Display XY Data window:

   Input Table: **RobbinsCraterDatabase2014.csv**

   Output Feature Class: **PlanetaryImageAnalysis_Exercise_3.gdb\Craters_Robbins2014**

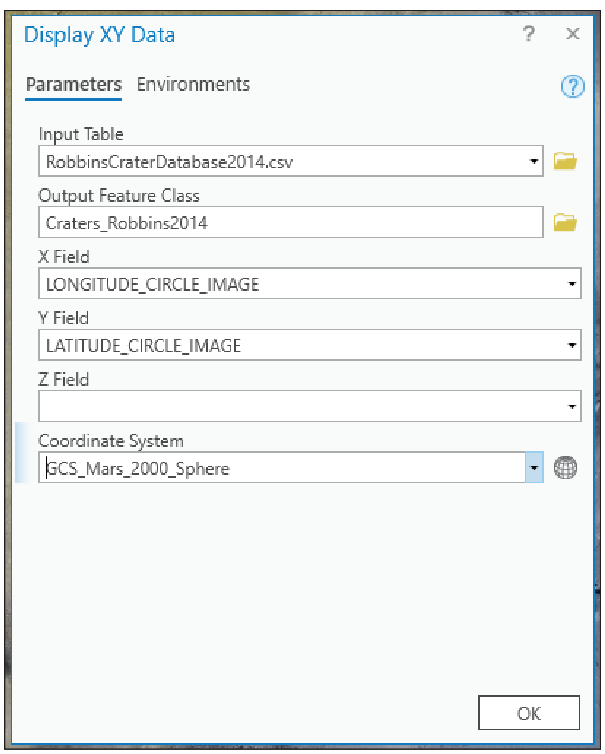
   X Field: **LONGITUDE_CIRCLE_IMAGE**

   Y Field: **LATIDUDE_CIRCLE_IMAGE**

   Z Field: *[leave blank]*

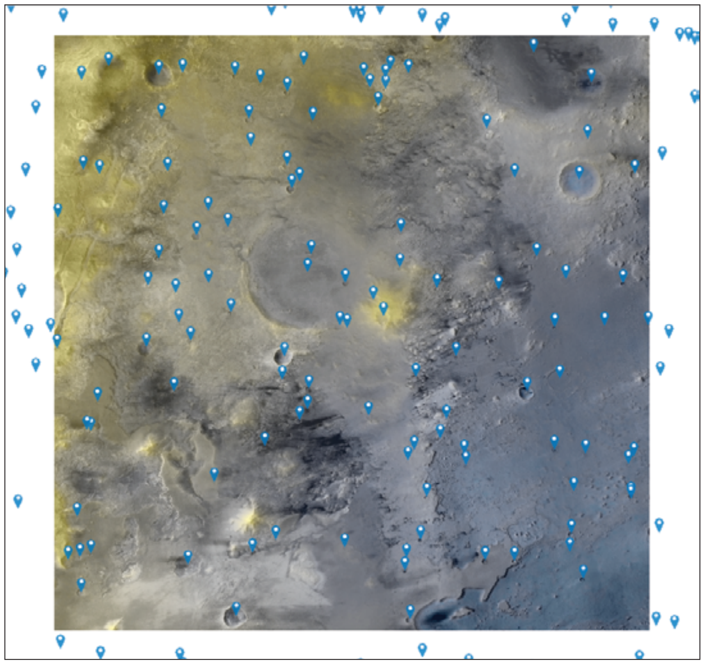
Note: When you are assigning the X and Y field inputs, you are selecting the database columns that will be used to locate each crater on the map.

10. In the **Display XY Data** window, click on the **Coordinate System** dropdown menu and select the **Jezero_DTM** layer. This will automatically populate the selection for **Coordinate System** using the projection from the **Jezero_DTM** layer.

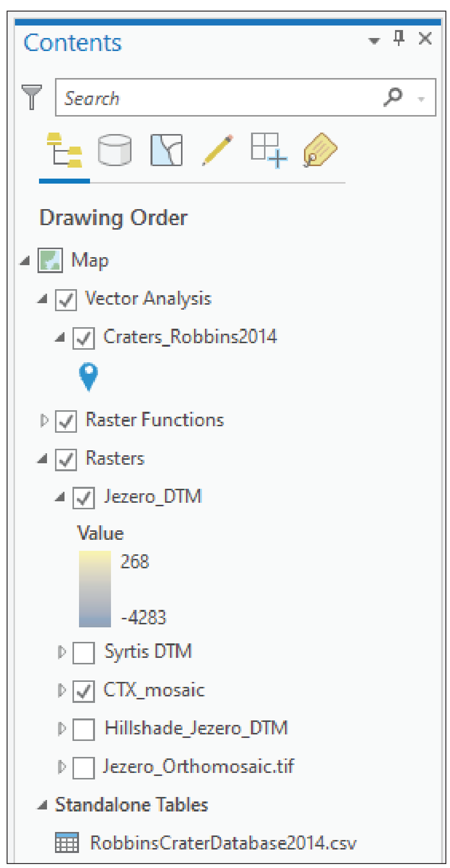


11. In the **Display XY Data** window, press **OK** to create the new **Craters_Robbins2014** feature class.

The new **Craters_Robbins2014** feature class will be added to your map.



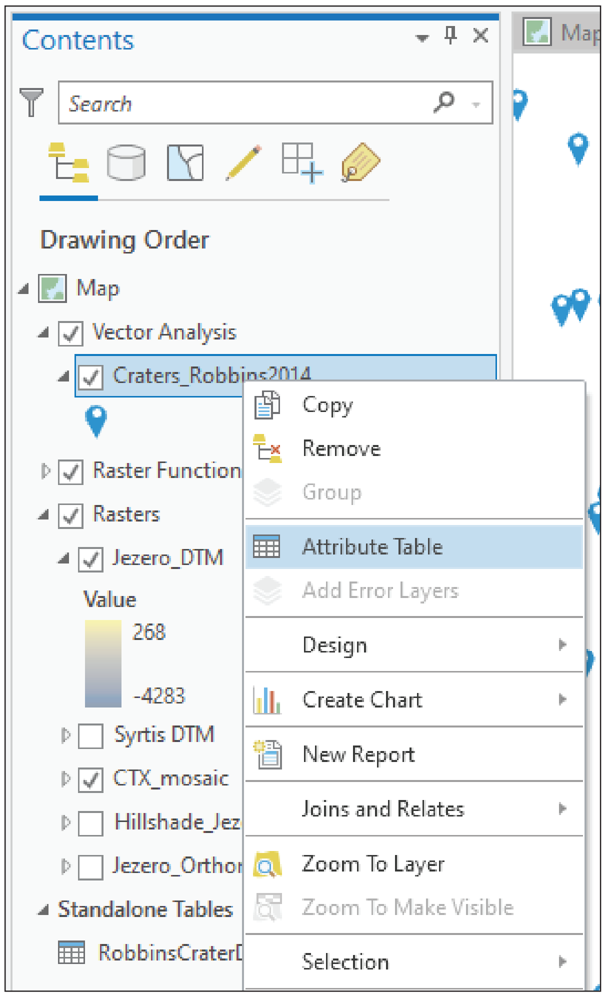
12. In the **Contents** pane, click and drag the **Craters_Robbins2014** layer into the **Vector Analysis** group layer. Then click on the triangle to expand the **Vector Analysis** group layer so the **Craters_Robbins2014** map layer is visible.



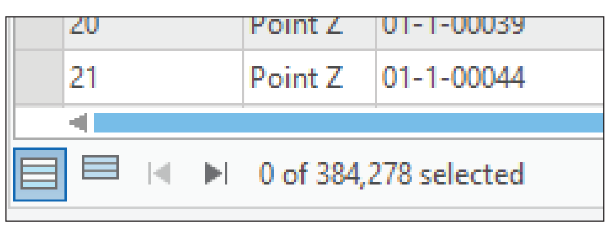
13. In the **Contents** pane, check the box to turn on the **Syrtis DTM** layer. Then right click the **Syrtis DTM** layer and select **Zoom to Layer**. Take a minute to zoom in and out and pan around to explore the crater database within this area *(Note: Data points will fall outside the Syrtis DTM region because the crater database covers the entirety of Mars)*. When you have finished, uncheck the box to turn off the **Syrtis DTM** layer and zoom back to the full extent of the **CTX_mosaic** or **Jezero_DTM** layer (your region of interest).

Before beginning to work with the **Craters_Robbins2014** feature class, it is best to see how it compares to your region of interest. There may be more information than is necessary for your analysis.

14. In the **Contents** pane, right click the **Craters_Robbins2014** layer and select **Attribute Table**.

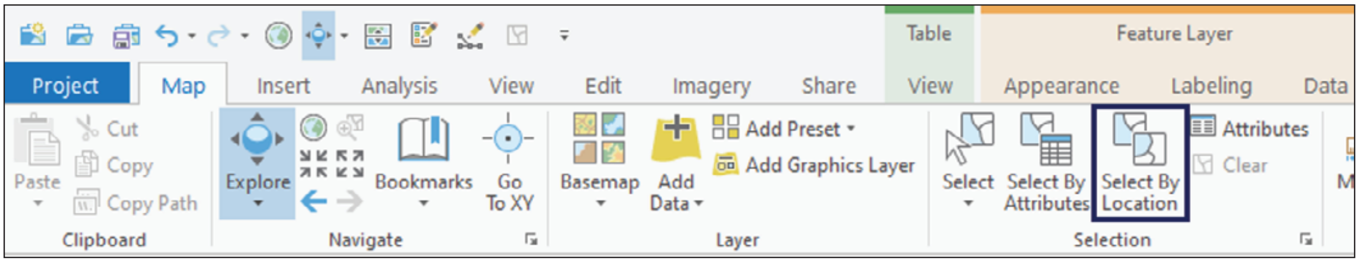


This will open the attribute table for the **Craters_Robbins2014** feature class. At the bottom of the table, you will see number of entries that are currently selected out of the total number of entries in the feature class.



To see how many of 384,278 craters fall within your region of interest, you will use a selection tool.

15. In the **Selection** section of the **Map** tab, click on the **Select by Location** icon.



The **Select by Location** tool allows you to select all the features within the **Craters_Robbins2014** feature class that are located within your area of interest.

16. In the **Select by Location** window, set the following parameters:

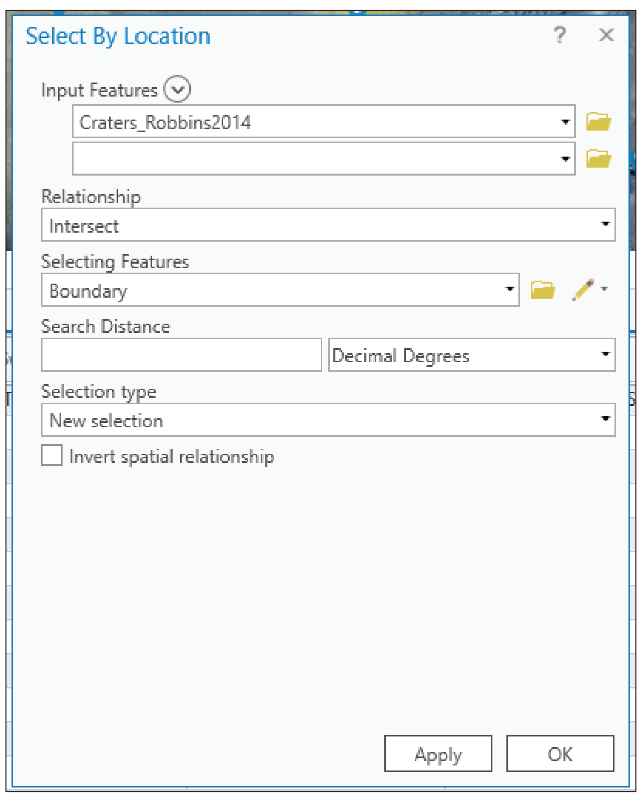
Input Features: **Craters_Robbins2014**

Relationship: **Intersect**

Selecting Features: **CTX_mosaic\Boundary**

Search Distance: *[leave blank]*

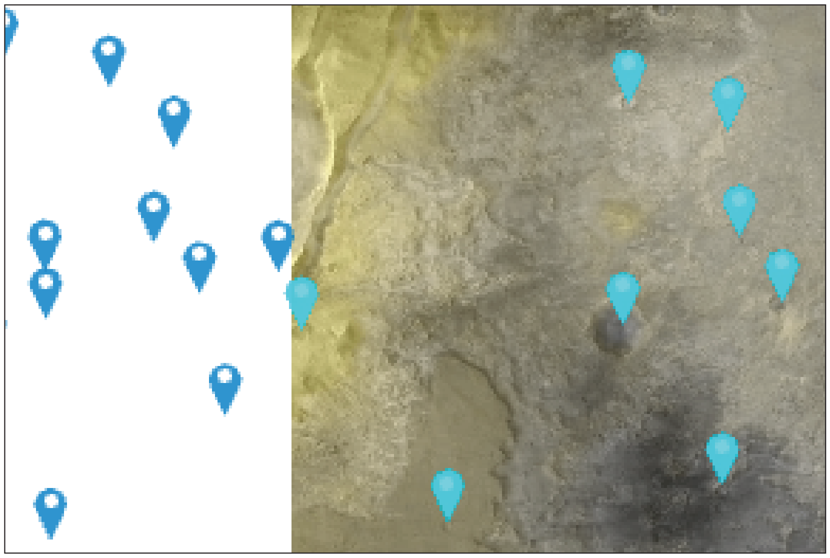
Selection type: **New selection**



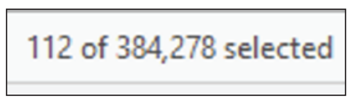
This will select only the crater points which are located within the boundary of the **CTX_mosaic** map layer.

17. Click **OK** to run the **Select by Location** tool.

After the Select by Location tool is complete, the crater points located within the boundary of the **CTX_mosaic** layer will be highlighted. Crater points located outside the **CTX_mosaic** layer boundary will not be highlighted.

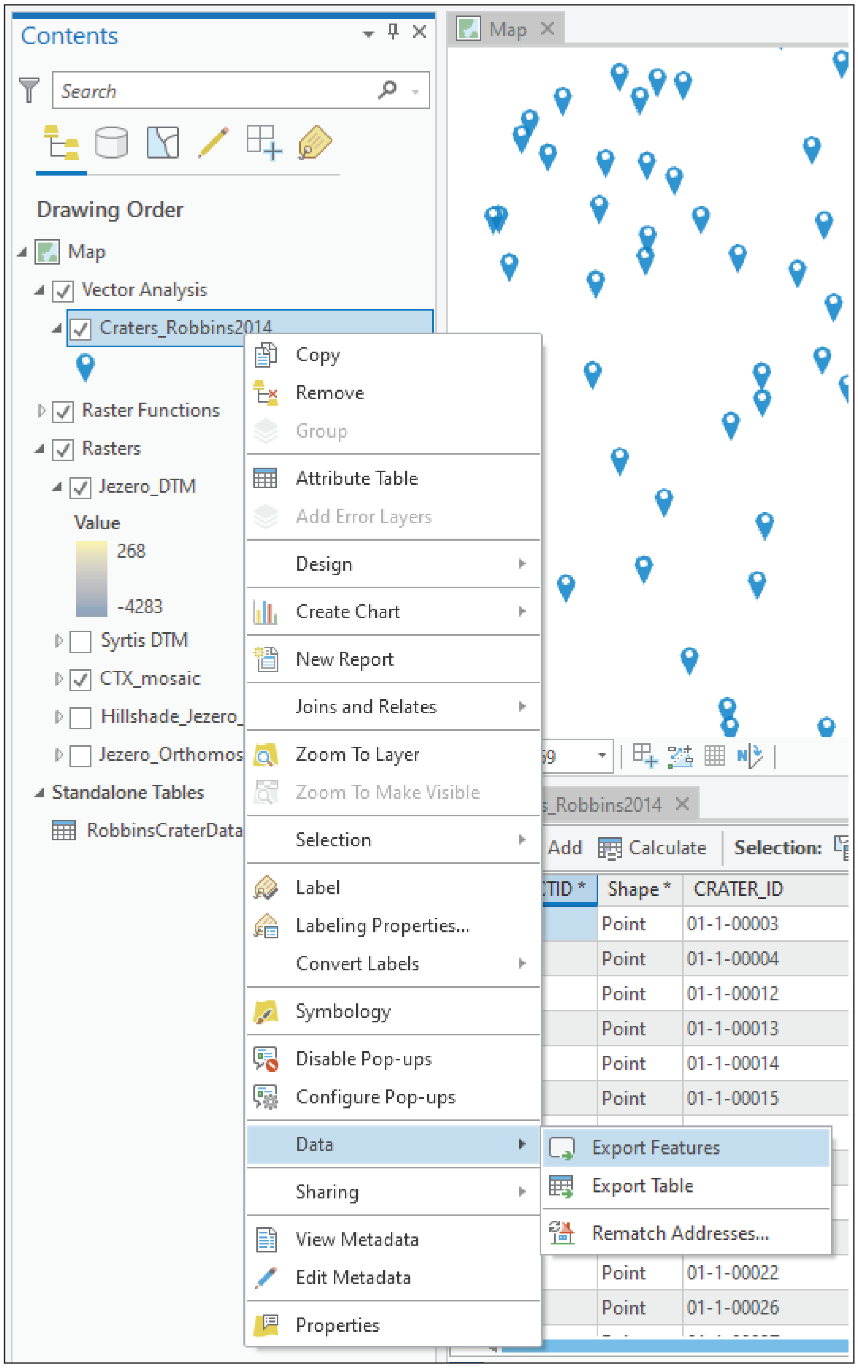


In the **Craters_Robbins2014** attribute table, the number of selected features is listed in the bottom left corner.



This is a global crater database which documents 384,278 individual craters that are greater than or equal to (≥) 3 kilometers (km) in diameter and covers the entire surface of Mars. The **Select by Location** results indicate that only 112 of those craters lie within your area of interest. Therefore, before beginning to work with this feature class, it will be best to clip it to your area of interest. This will reduce the computational and storage needs for your analyses going forward.

18. In the **Contents** pane, right click the **Craters_Robbins2014** layer and select **Data → Export Features**.



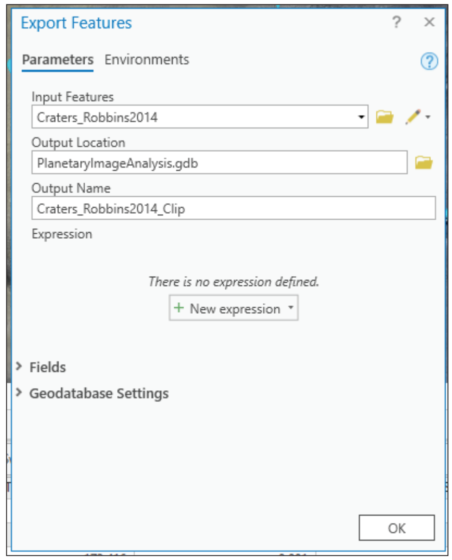
The **Export Features** tool with either export all the features in a feature class (if no features are selected), or only the selected features. This is a quick way to create a new dataset which includes only the craters you selected by location.

19. In the **Export Features** tool window, set the following parameters:

    Input Features: **Craters_Robbins2014**

    Output Location: **PlanetaryImageAnalysis_Exercise_3.gdb**

    Output Name: **Craters_Robbins2014_Clip**

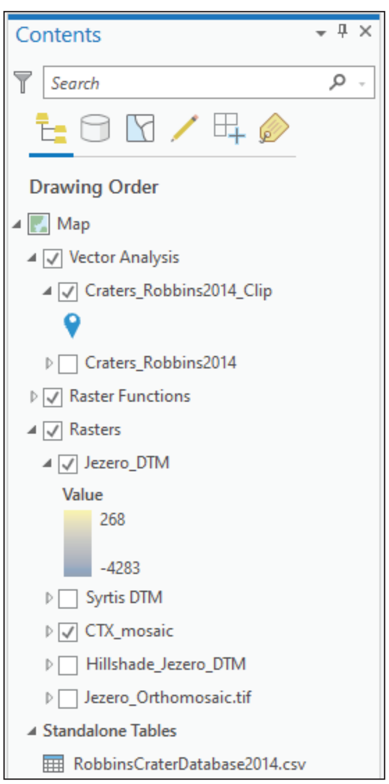


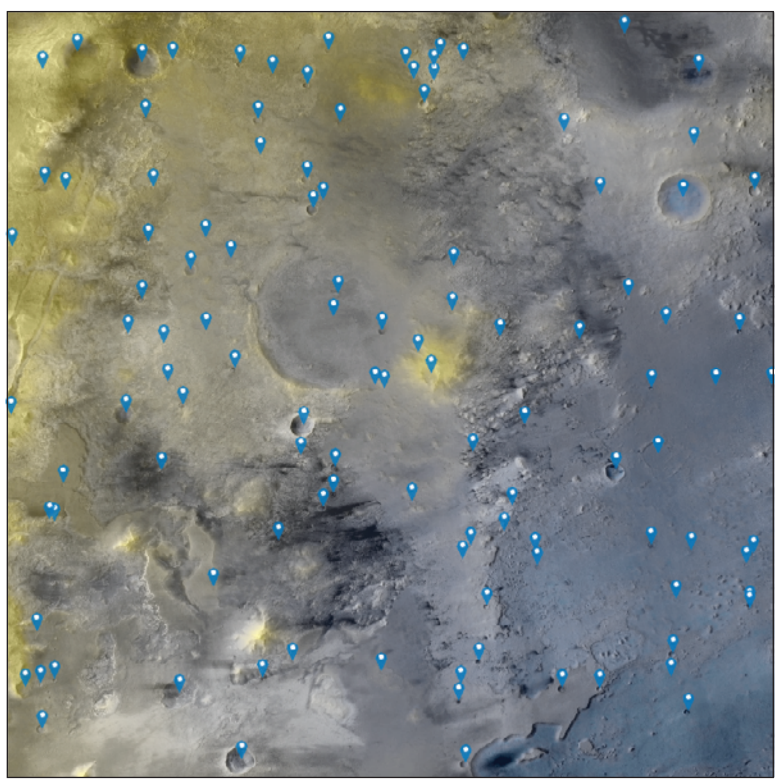
20. Click **OK** to run the **Export Features** tool.

When the **Export Features** tool is complete, the new **Craters_Robbins2014_Clip** layer will be added to your map.

21. In the **Selection** section of the **Map** tab, click the **Clear** icon to clear the selection. Then click the small **x** in the tab for the **Craters_Robbins2014** attribute table to close it and return to the full map view.

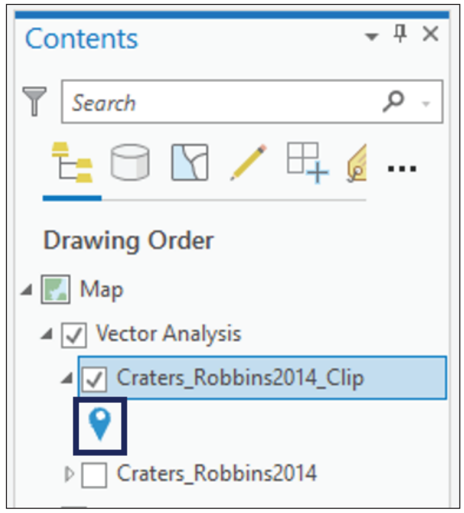
22. In the **Contents** pane, click and drag the **Craters_Robbins2014_Clip** layer to the top of the **Vector Analysis** group. Then click the small triangle next to the global **Craters_Robbins2014** layer to collapse it and uncheck the box to hide this layer. You should now only be viewing the clipped crater points.



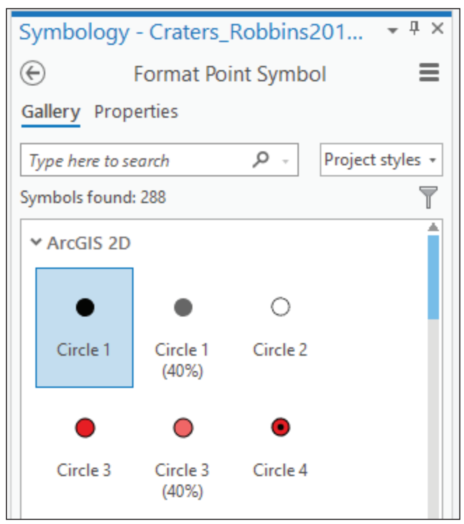


In planetary science, point features typically use circular point symbols, rather than the location markers that are currently used for the **Craters_Robbins2014_Clip** layer.

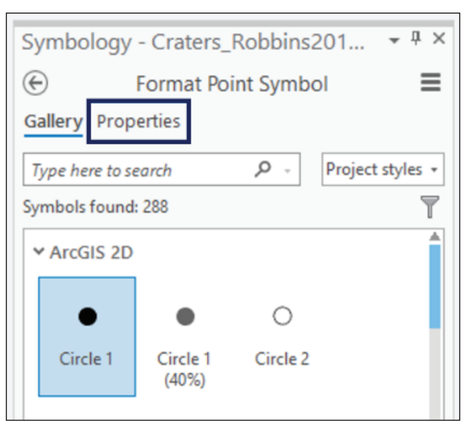
23. In the **Contents** pane, click on the **Craters_Robbins2014_Clip** symbol to open the **Format Point Symbol** pane.



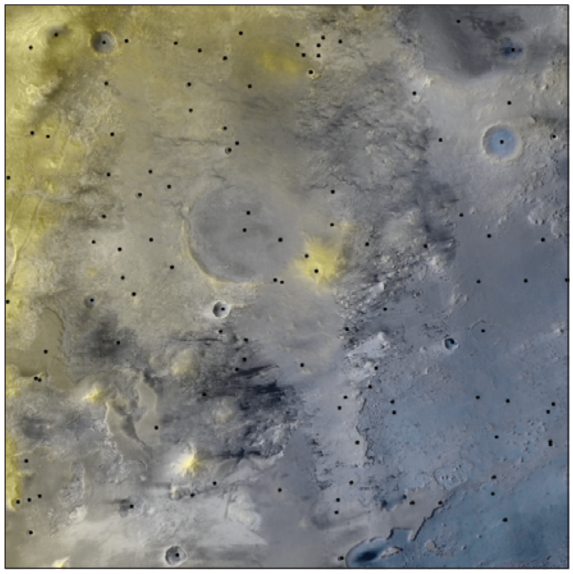
24. In the **Gallery** tab of the **Format Point Symbol** pane, select the **Circle 1** symbol. You will see the symbols update on your map.



25. In the **Format Point Symbol** pane, click on the **Properties** tab.



26. In the **Properties** tab of the **Format Point Symbol** pane, set the **Size** to **4 pt** and click **Apply**. Then click the small **x** in the upper right corner of the **Format Point Symbol** pane to close it.

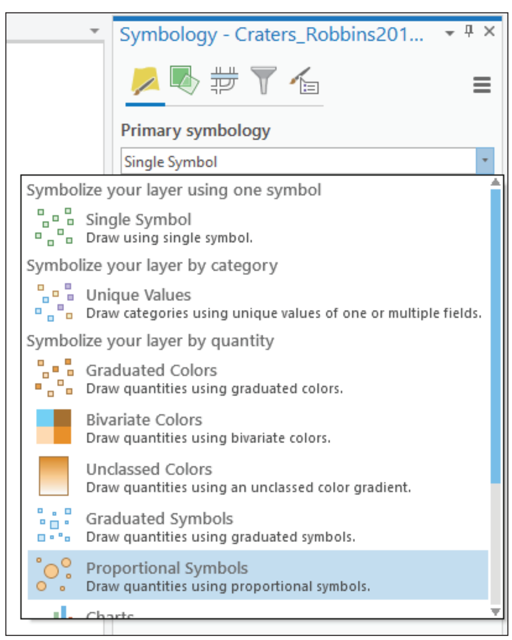


Part 2: Creating Polygons From Points

The database you used to create the **Craters_Robbins2014_Clip** layer represents each crater using a point feature. However, geologic maps often represent the rims of larger craters using polygons to make them easier to identify. In this section, you will use the point features from the **Craters_Robbins2014_Clip** to automatically draw polygons for each crater. There are two ways you can complete this task.

Method 1: Proportional Symbology

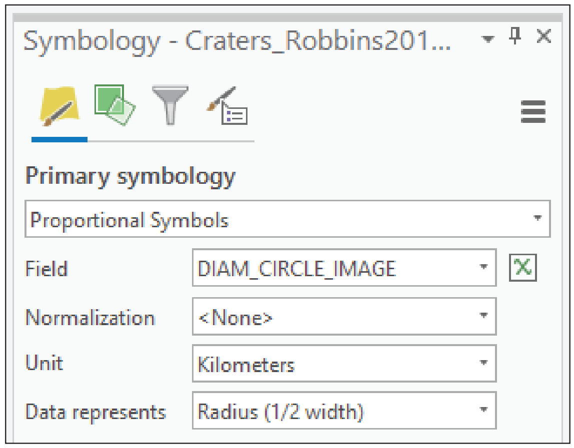
27. In the **Contents** pane, right click the **Craters_Robbins2014_Clip** layer and select **Symbology** to open the **Symbology** pane. In the **Symbology** pane, change the **Primary symbology** to **Proportional Symbols.**



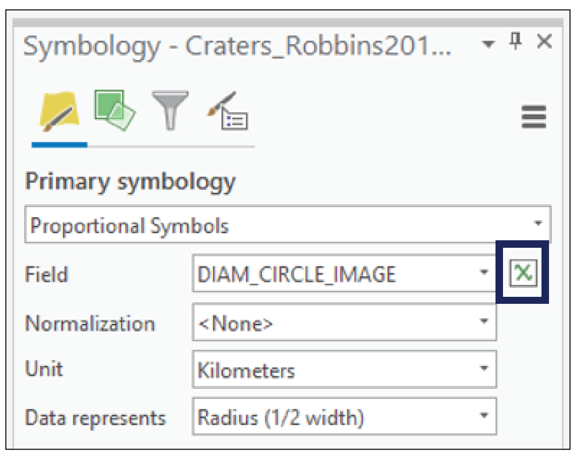
Proportional symbols allow you to vary the size of the symbol based on one of its attributes. Here, you will vary the size of the symbol based on the crater size itself.

28. In the **Symbology** pane, change the **Field** to **DIAM_CIRCLE_IMAGE** and set the **Unit** to **kilometers**. Change the **Data represents** setting to **Radius (1/2 width).**

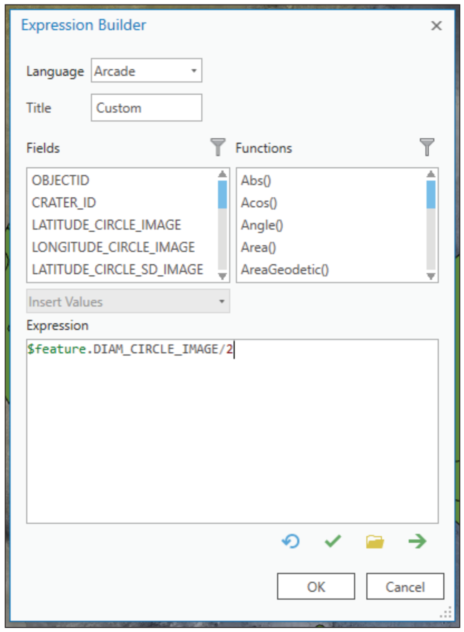
The symbology is now varying the size of the symbol using the **DIAM_CIRCLE_IMAGE** value. However, in the symbology settings, this number represents the radius of the symbol, rather than the diameter, which is the value that is represented in the **DIAM_CIRCLE_IMAGE** attribute.



29. To adjust the **Field** value to represent the crater radius instead of the diameter, in the **Symbology** pane, click on the **Expression** icon next to the **Field** dropdown menu.



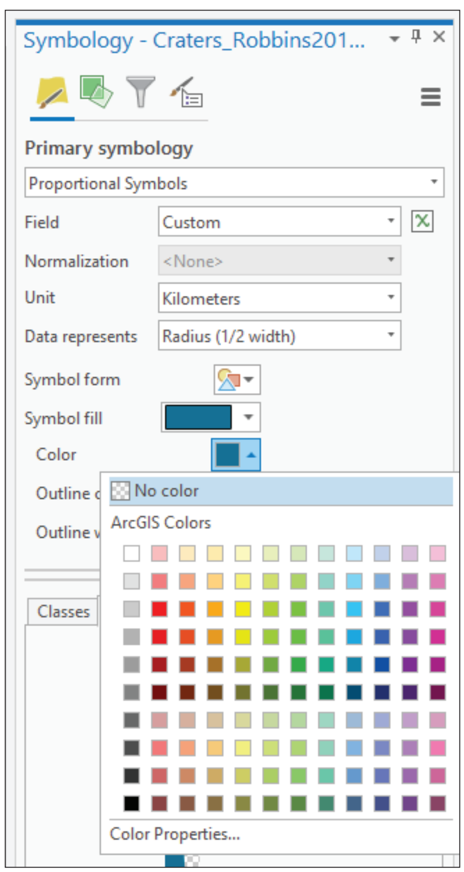
30. In the **Expression Builder** window, add **/2** to the end of the text in the **Expression** box. This will divide the diameter value by 2, which will result in a correct radius.



31. Click **OK** to apply this change.

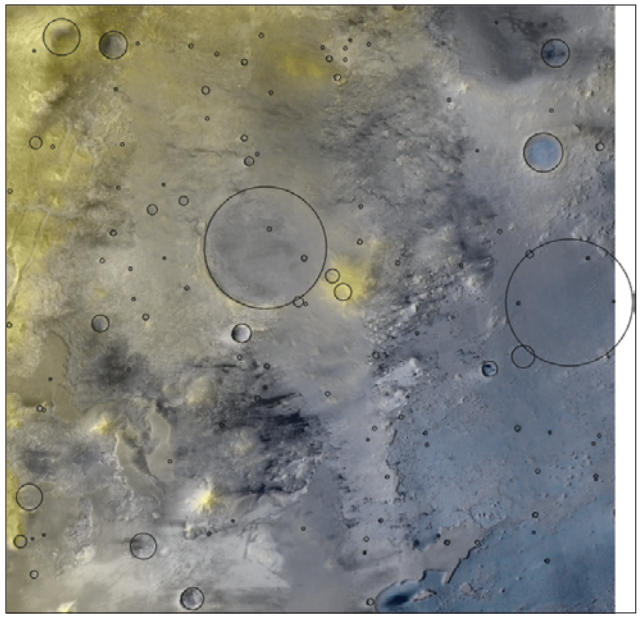
The radius of each circle is now representative of the actual crater radius and should roughly line up with the observable crater rim. However, the point symbols are currently opaque and contain color, making it difficult to compare them to the base imagery and DTM.

32. To make your crater outlines easier to see, in the **Symbology** pane, change the **Color** (fill color) to **No color**.



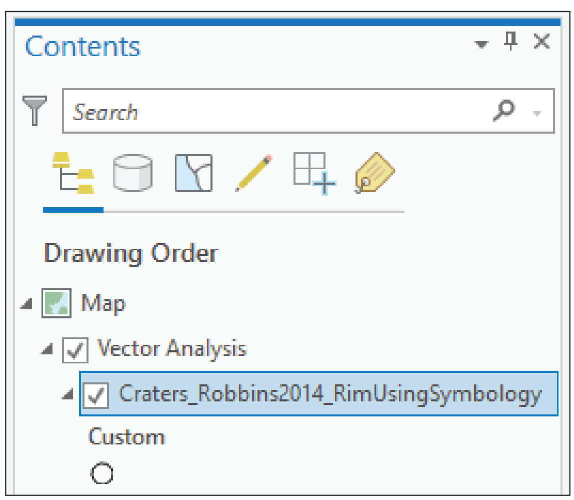
33. Click on the small **x** in the upper right corner of the **Symbology** pane to close it.

Your map now shows approximate crater boundaries using just the layer symbology.



34. Take a moment to explore your map and see how the crater symbology compares to the observable crater rim. When you have finished, return to the full extent of the **Jezero_DTM**/**CTX_mosaic**/**Craters_Robbins2014_Clip** layers (**Contents** pane → right click and **Zoom to Layer** on any of those layers—they all have the same extent).

35. In the **Contents** pane, click and hover over the name for the **Craters_Robbins2014_Clip** layer to select the layer name. Rename this layer **Craters_Robbins2014_RimUsingSymbology**. This will help you distinguish it from the results from the next method, buffering.

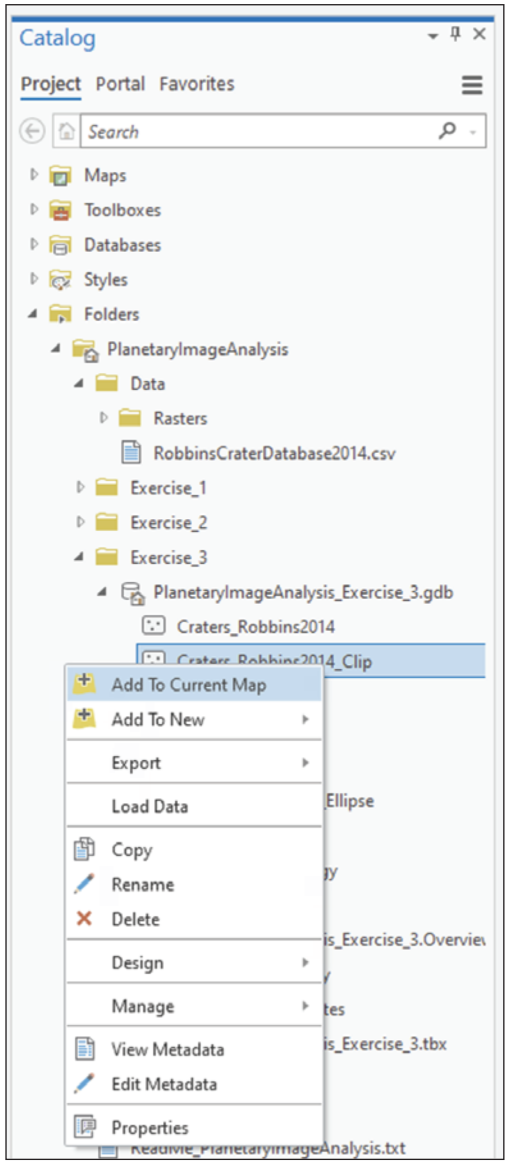


Method 2: Buffering

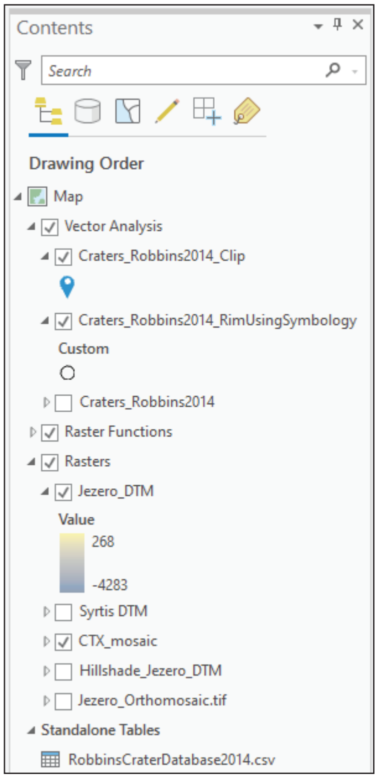
The second method to create polygons from points is by buffering. Buffering draws a polygon around a point, keeping a consistent distance (the buffer) from that point. The points contained in the crater database can be buffered by their radius to create polygons.

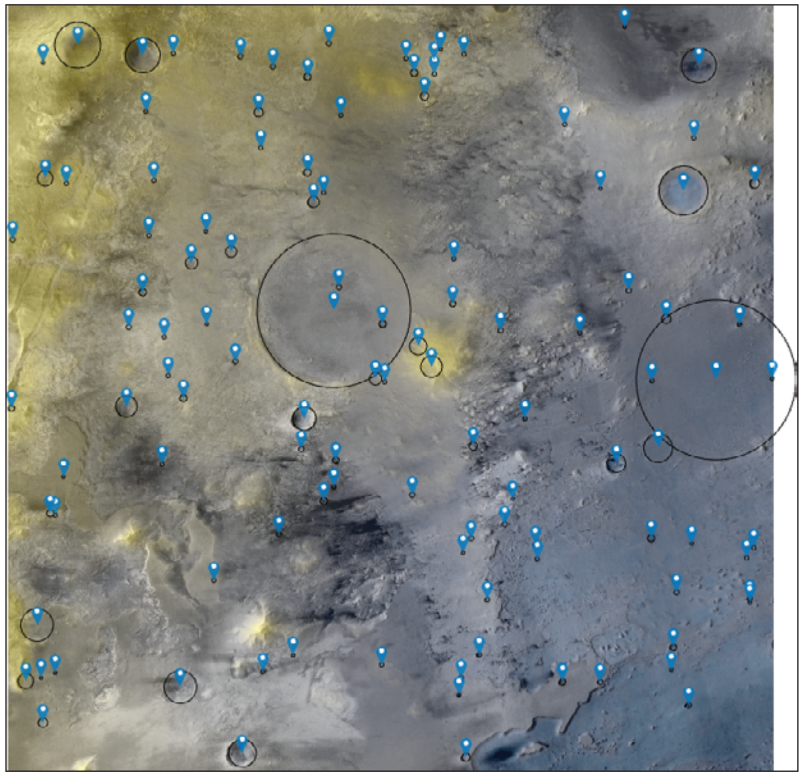
You will compare this result to the results of the first method (**Craters_Robbins2014_RimUsingSymbology**), so you will first need to add a new copy of the crater points to the map.

36. In the **Catalog** pane, right click the **Craters_Robbins2014_Clip** layer (located in **Folders** → **Exercise_3\ PlanetaryImageAnalysis_Exercise_3.gdb**) and select **Add to Current Map**. *(Note: If you don't see the **Craters_ Robbins2014_Clip** feature class listed in the geodatabase, right click the **PlanetaryImageAnalysis.gdb** and select **Refresh** for this new feature class to show up.)* After it is added to the map, in the **Contents** pane, click and drag the new **Craters_Robbins2014_Clip** layer into the **Vector Analysis** group.



You should now have both the **Craters_Robbins2014_RimUsingSymbology** and the new **Craters_Robbins2014_Clip** layers displayed in your map.

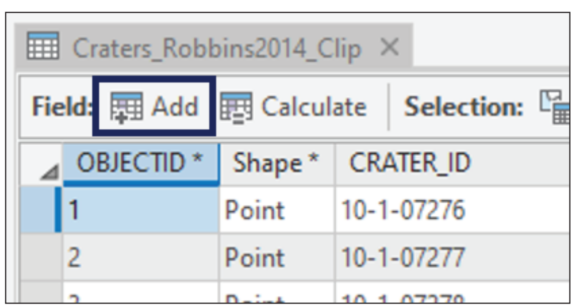




You will use the crater radius to create the buffer for each point. However, as you observed earlier, the database currently only contains the crater diameters. To buffer by the crater radius, you will first need to add a new field to the **Craters_Robbins2014_Clip Attribute Table** and calculate the radius for each crater.

37. In the **Contents** pane, right click the **Craters_Robbins2014_Clip** layer and select **Attribute Table**.

38. In the Attribute Table, click on the Add Field button.



A new table will open with all the Fields that are included in the **Craters_Robbins2014_Clip Attribute Table**.

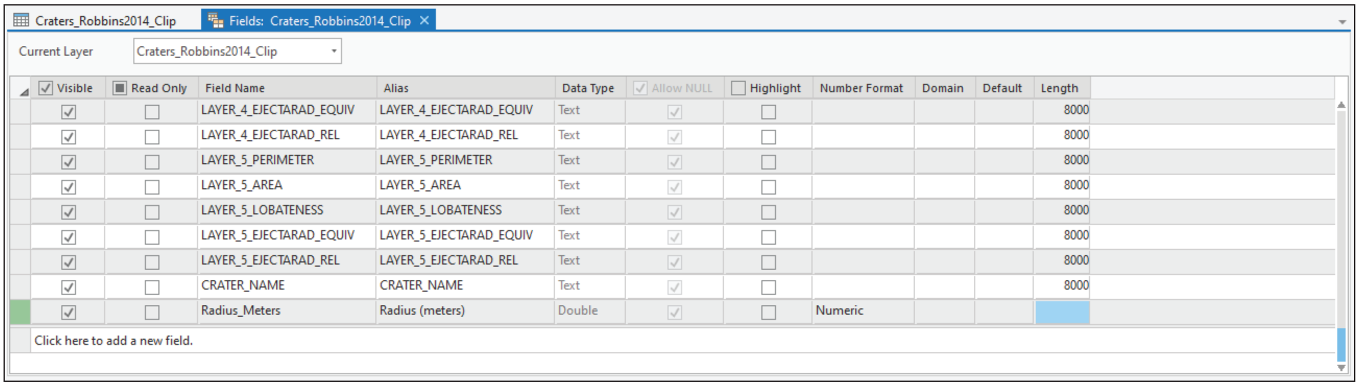
39. At the bottom of the **Fields: Craters_Robbins2014_Clip** table, enter the following:

Field Name: **Radius_Meters** (field names may not have spaces)

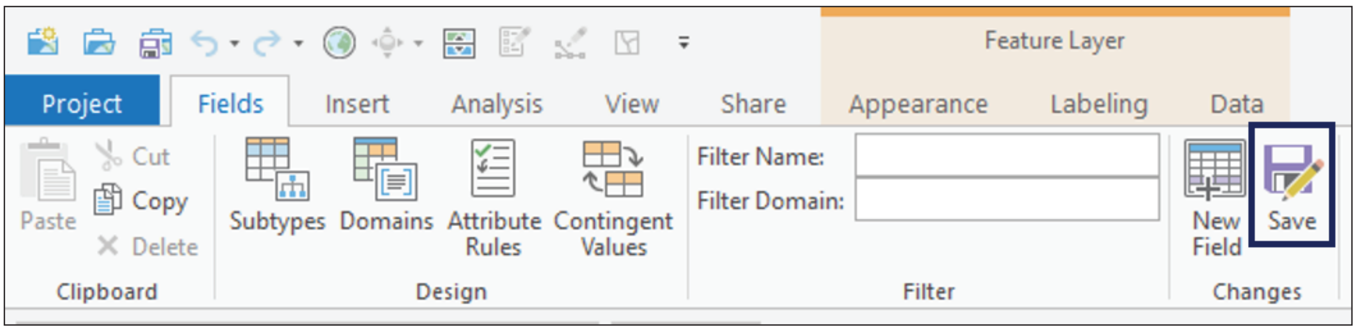
Alias: **Radius (meters)** (this is the display name, and may have spaces)

Data Type: **Double**

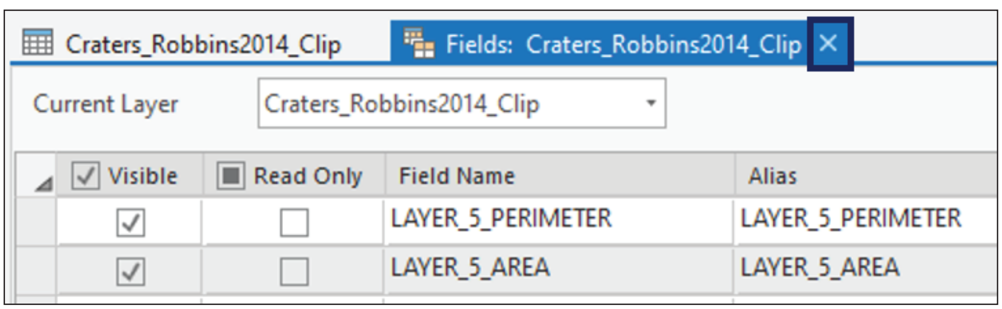
Number Format: **Numeric** (leave all defaults in the Number Format window and click **OK**)



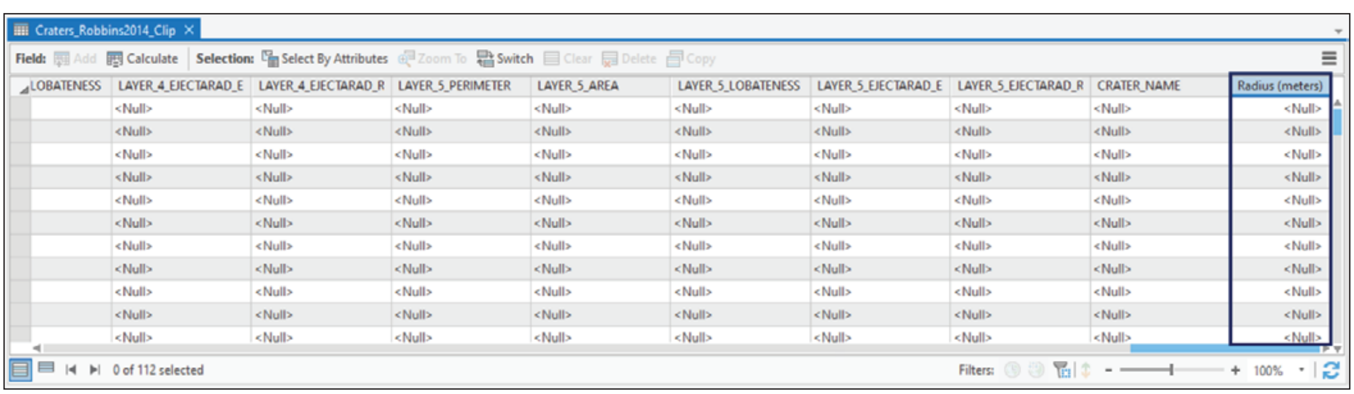
40. In the **Changes** section of the **Fields** tab, click the **Save** icon to save this new field.



41. Click the small **x** in the **Fields: Craters_Robbins2014_Clip** table tab to close the field editor and return to the **Attribute Table**.

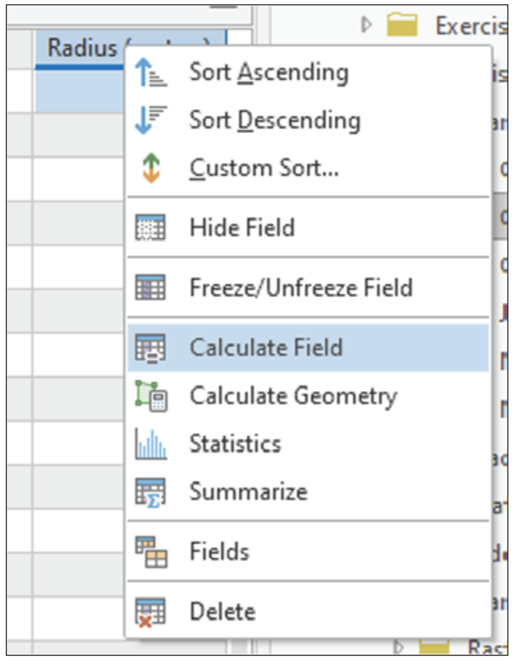


42. In the **Attribute Table**, scroll all the way to the right to view the new **Radius (meters)** field.



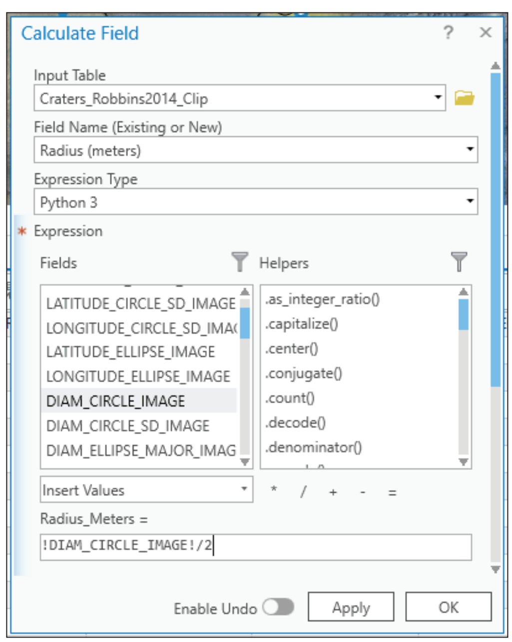
The **Radius (meters)** field was just added to the **Attribute Table** and does not yet contain any values. Before buffering, you must calculate the radius for each crater in the table.

43. In the **Attribute Table**, right click the top of the **Radius (meters)** field and select **Calculate Field**.



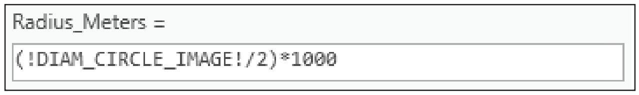
This will open the **Calculate Field** tool. The **Calculate Field** tool can be used to apply a calculation or constant numeric value or text string to all items or selected items in a feature class. If no items are selected in the **Attribute Table**, the tool will be applied to all items. If specific items are selected in the **Attribute Table**, the tool will only be applied to the selected items. You need to calculate the radius for every point in the feature class. Therefore, you did not need to select specific items in the **Attribute Table**.

44. In the **Calculate Field** tool, leave the default values for the **Input Table**, **Field Name**, and **Expression Type**. Under **Expression**, double click on **DIAM_CIRCLE_IMAGE**. You will see it automatically appear in the **Radius =** text box below. Then add **/2** to the end of the text string in the **Radius =** box.

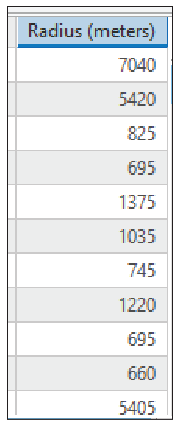


This calculation will take the value that is contained in the **DIAM_CIRCLE_IMAGE** field and divide it by 2 to calculate the **Radius** for each crater. However, the original database records the crater diameters in kilometers. To accurately display using a buffer, the radius needs to be calculated in meters.

45. Modify the text in the **Radius** = box to read **(!DIAM_CIRCLE_IMAGE!/2)*1000** This will multiply the radius by 1000 to convert it from kilometers to meters.



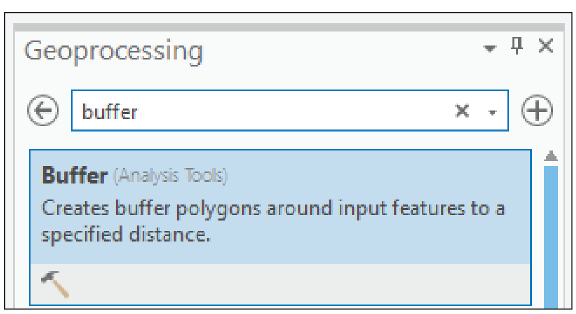
46. Click **OK** to run the calculation and return to the **Attribute Table**. Once the calculation is complete, values will be visible in the **Radius** field.



47. Click on the small **x** in the **Attribute Table** tab to close it and return to the map.

48. In the **Geoprocessing** section of the **Analysis** tab, click on the **Tools** icon to open the **Geoprocessing** pane.

49. In the **Geoprocessing** pane, search for **Buffer**. Click on the **Buffer** tool to open it.



50. In the Buffer tool, set the following parameters:

    Input Features: **Craters_Robbins2014_Clip**

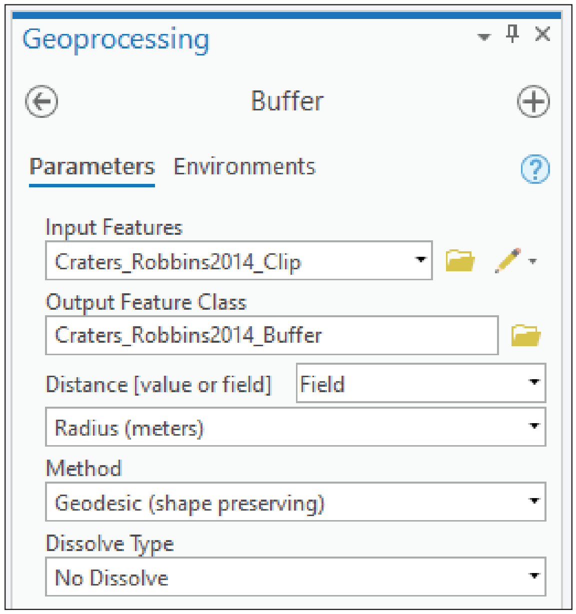
    Output Feature Class: **PlanetaryImageAnalysis_Exercise_3.gdb\Craters_Robbins2014_Buffer**

    Distance: **Field**

    Method: **Geodesic (shape preserving)**

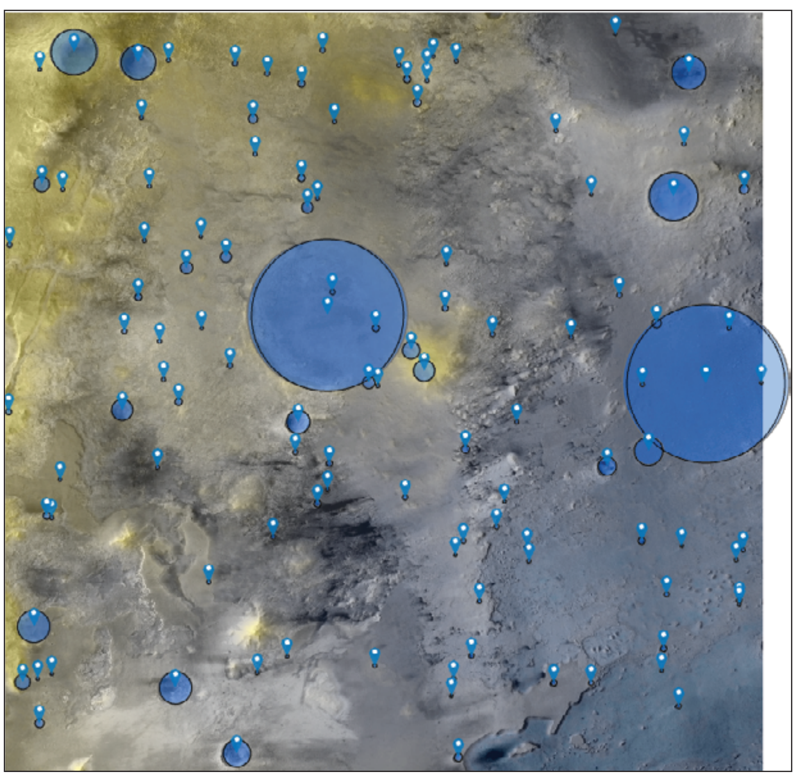
    Dissolve Type: **No Dissolve**

51. In the blank dropdown menu below **Distance [value or field]**, select the new **Radius (meters)** field.



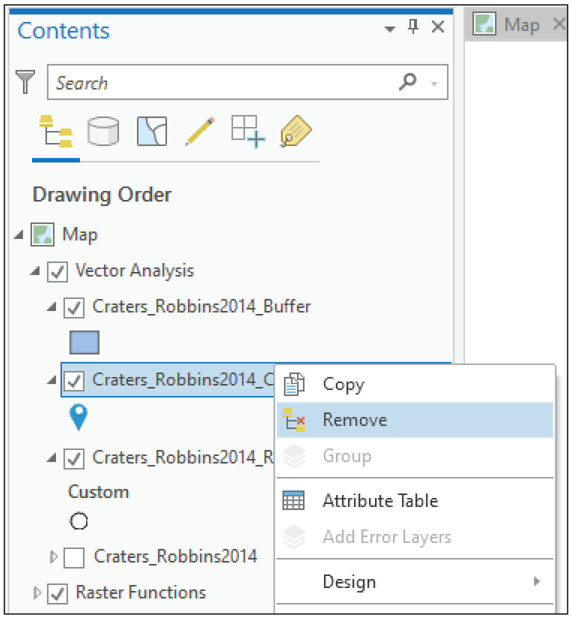
52. Click **Run** to create the new **Craters_Robbins2014_Buffer** feature class.

When the **Buffer** tool is complete, the new **Craters_Robbins2014_Buffer** feature class will be added to the map.



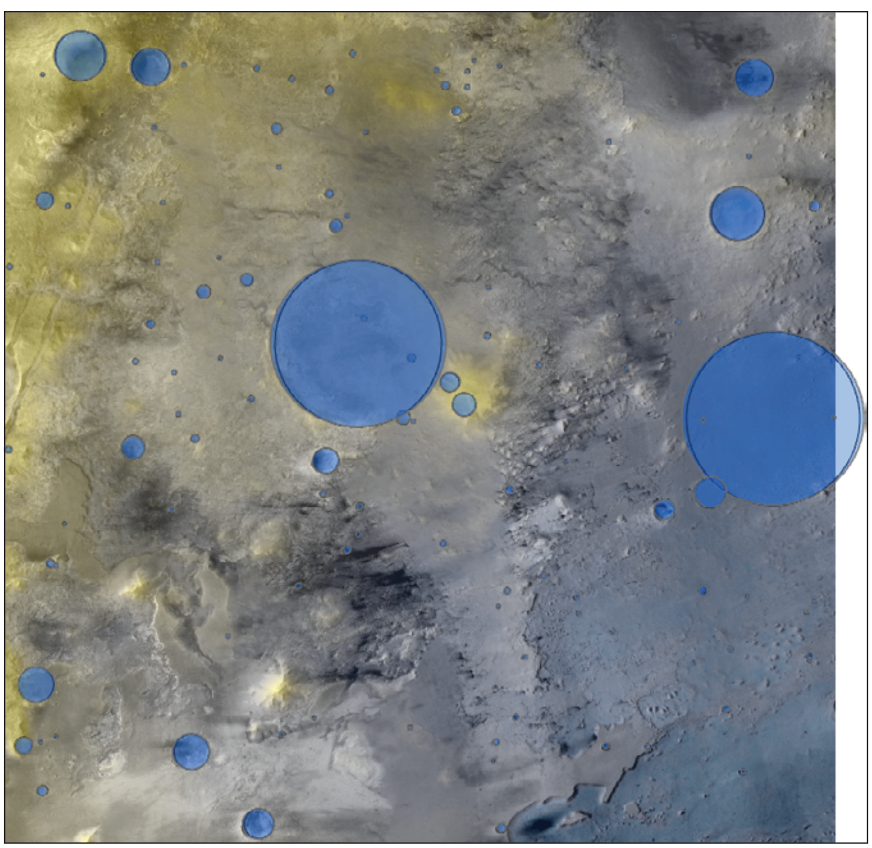
53. Click the small **x** in the upper right corner of the **Buffer** tool to exit the **Geoprocessing** pane.

54. In the **Contents** pane, click on the **Craters_Robbins2014_Buffer** layer and drag it into the **Vector Analysis** group. Then right click the **Craters_Robbins2014_Clip** layer and select **Remove** to remove it from the map.



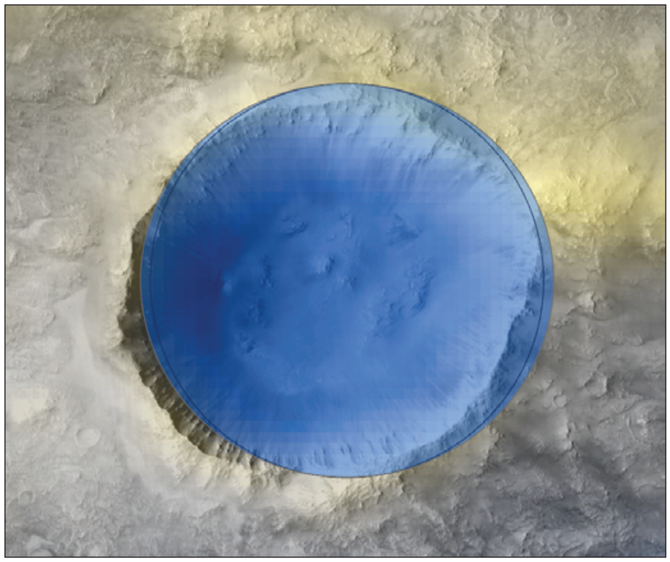
Note: Removing a layer from your map does not delete it. It is still available in the ***Catalog*** *pane.*

The map now contains layers which represent approximate crater diameters through two different methods (proportional symbology and buffering).



55. Take a minute to zoom and pan around the map and explore these two layers. Compare the approximate crater boundaries with the observable crater rims using the CTX base image (**CTX_mosaic**) and the DTM (**Jezero_DTM**). You may want to turn **DRA** on for the DTM layer (select the **Jezero_DTM** layer in the **Contents** pane, and turn **DRA** on in the **Raster Layer Appearance** tab) to make subtle variations in the topography easier to see as you zoom in. When you have finished, zoom back to the full extent of the **CTX_mosaic** or **Jezero_DTM** layer (they have the same extent), and if you turned on **DRA** for the **Jezero_DTM** layer, make sure it is turned back off.

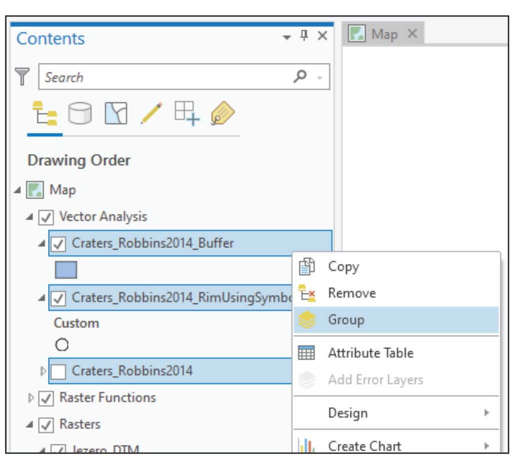
In your exploration, you should see that the approximate crater boundaries do not line up exactly with the observable crater rims:



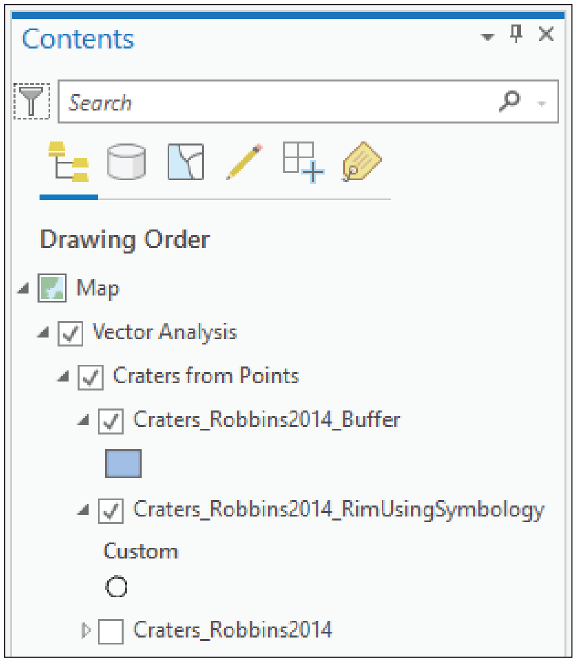
This is because both methods—proportional symbology and buffering—only provide an approximation for these features. Depending on your needs, the approximate methods may be enough for your analysis. However, crater rims are not always perfectly circular. These approximations also rely on the location of a point symbol that may or may not be in the exact center of the crater, which can result in a crater rim that may be the correct size and shape but is offset. Because of these challenges, crater rims are more accurately represented by manually drawn features.

It is common for GIS projects to contain many layers, which can make it difficult to keep track of your datasets and features. Grouping and collapsing map layers within the **Contents** pane is not necessary. However, it can help you and any collaborators keep better track of your map layers and be able to view all the most important layers and symbologies at once. The crater layers you created in this exercise will not be used in the upcoming activities. To keep them available, but without cluttering up the **Contents** pane, you can group them and quickly hide their details.

56. In the **Contents** pane, select the **Craters_Robbins2014_Buffer**, **Craters_Robbins2014_RimUsingSymbology**, and **Craters_Robbins2014** layers (control+click to select multiple layers). Then right click one of the selected layers and select **Group**. This will create a new subgroup within the **Vector Analysis** group that contains the three selected layers.

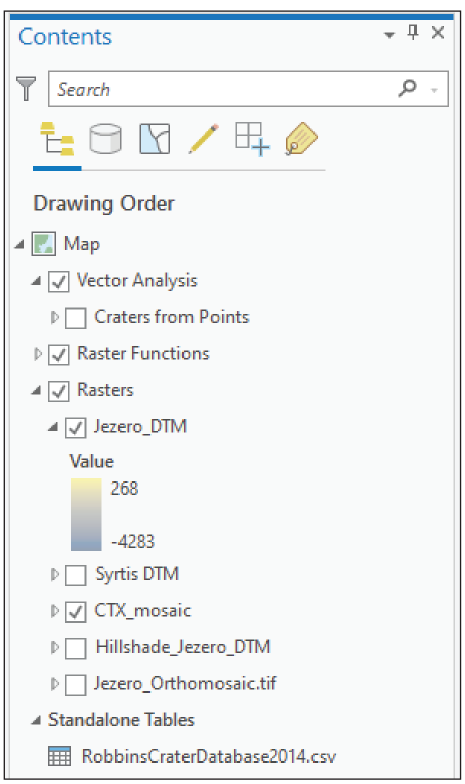


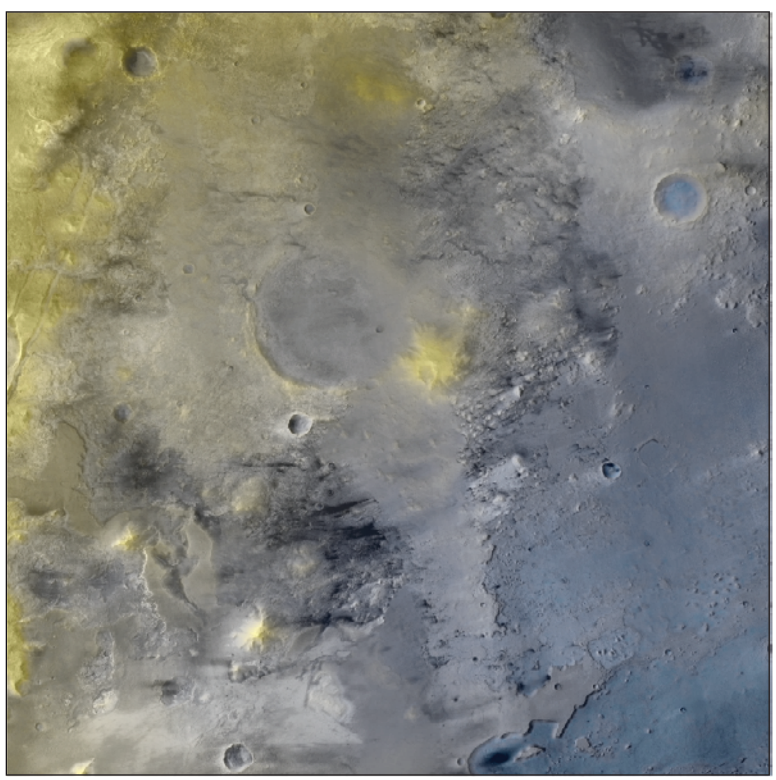
57. In the **Contents** pane, click and hover over the **New Group Layer** to activate and edit the group layer name. Rename this group layer **Craters from Points**. Press **enter** to apply the name change.



By grouping these layers, you can now quickly turn all of them on or off with one click.

58. In the **Contents** pane, uncheck the box next to the **Craters from Points** group to turn off all layers contained within that group. Then click on the small triangle next to the **Craters from Points** group to collapse it.



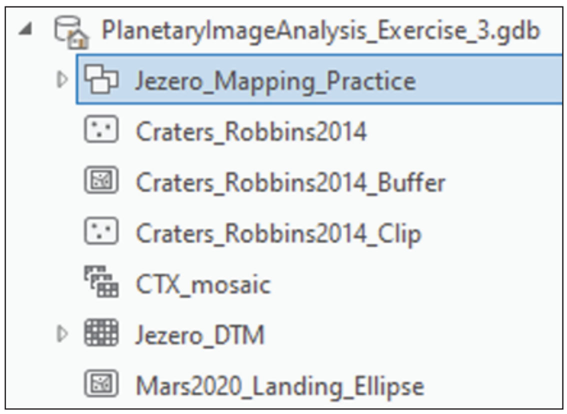


Part 3: Drawing Map Features (Points, Lines, and Polygons)

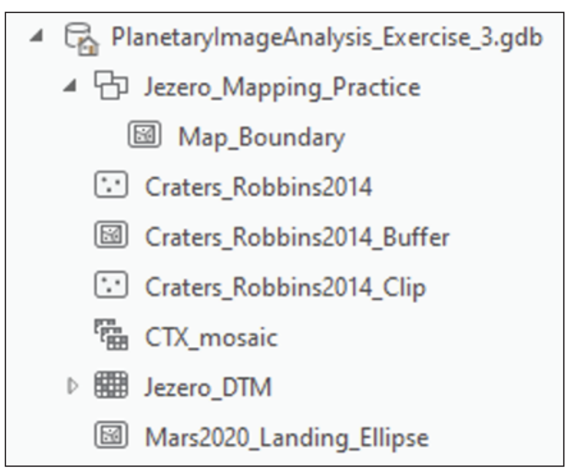
Features in a map are represented using a combination of points, lines, and polygons. These features are drawn manually, and like the crater data you worked with earlier, they are stored in a feature class within your project geodatabase. Each feature class may only contain one type of feature (point, line, or polygon). However, different kinds of features may be contained within a feature class as long as the feature type is consistent. For example, a linear feature class may be used to identify anything that can be marked with a line. In planetary geologic mapping, it is typical to group mapping features into the following feature classes: geologic contacts (lines), geologic units (polygons), location features (points; small craters, cones, and other small features of note), surface features (polygons; coatings of dust or other surface textures), and linear features (lines; faults, folds, graben, ridges, channels, and scarps). To become familiar with creating and editing features, you will use a linear feature class to place geologic contacts within your area of interest.

When creating a geologic map, all point, line, and polygon **feature classes** are grouped into a **feature dataset**. A feature dataset is a collection of related feature classes that all use the same coordinate system. Although it is not a requirement to group feature classes into feature datasets, this is a necessary step to enable certain functions like checking topologies—a critical step in map creation.

The **Jezero_Mapping_Practice feature dataset** has already been created and is listed under the **PlanetaryImageAnalysis_Exercise_3 geodatabase**.

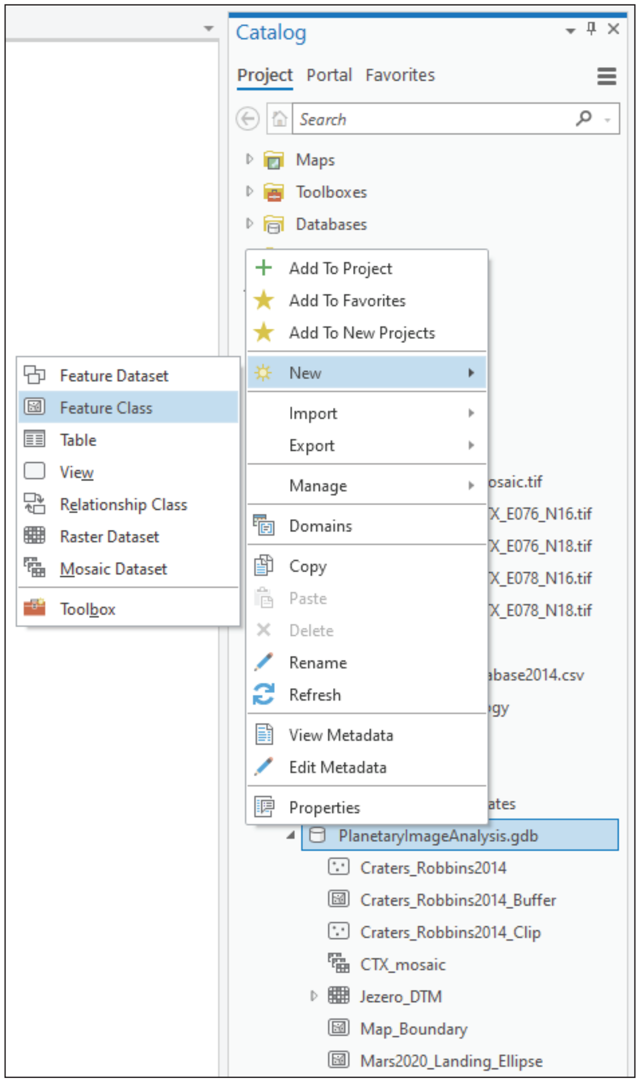


59. In the **Catalog** pane, click on the small triangle next to the **Jezero_Mapping_Practice** feature dataset to expand it and view its contents



The **Jezero_Mapping_Practice** feature dataset currently only contains the **Map Boundary** feature class. All feature classes that you create for mapping will be added to this **feature dataset**.

60. In the **Catalog** pane, right click the **Jezero_Mapping_Practice feature dataset** in the **PlanetaryImageAnalysis_Exercise_3.gdb** (**Folders → PlanetaryImageAnalysis\Exercise_3**) and select **New → Feature Class**.



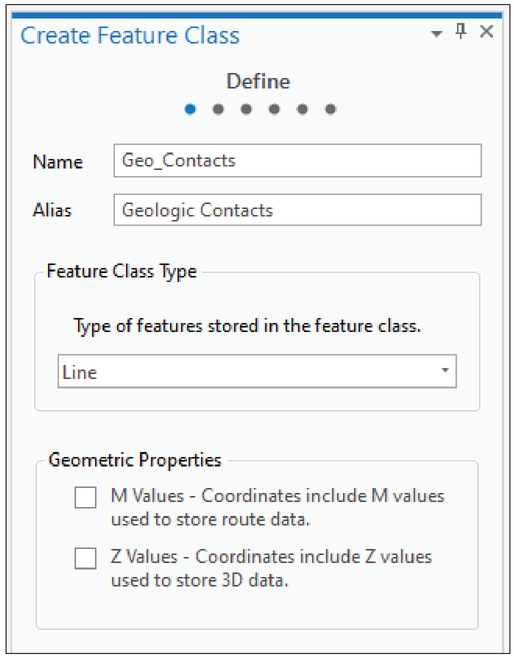
61. In the **Create Feature Class** pane set the following parameters:

Name: **Geo_Contacts**

Alias: **Geologic Contacts**

Feature Class Type: **Line**

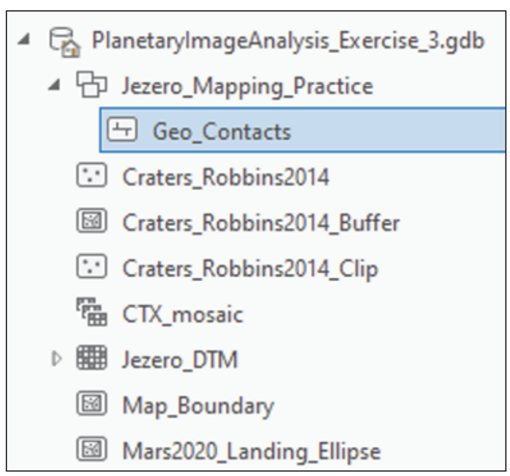
Geometric Properties: **uncheck both boxes** (M and Z values are not needed for geologic contacts)



Depending on what you need, you may click the **Next** button to move through the remaining steps in the **Create Feature Class** tool. In the remaining steps you can change the fields of the attribute table, the spatial reference (coordinate system), tolerance, resolution, and storage options. However, for the **Geologic Contacts** feature class you are creating today, the default settings are appropriate.

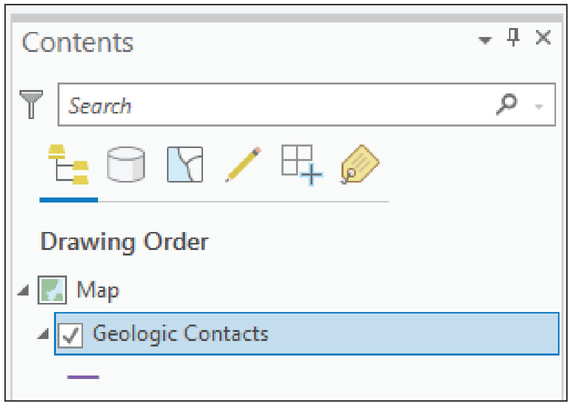
62. In the **Create Feature Class** tool, click **Finish** to create the **Geologic Contacts** feature class. Then, click on the small **x** in the upper right corner of the **Create Feature Class** tool to close it and return to the **Catalog** pane.

The **Geo_Contacts** feature class has been added to the **Jezero_Mapping_Practice feature dataset** in the **PlanetaryImageAnalysis_Exercise_3 geodatabase** and is now visible in the **Catalog** pane.

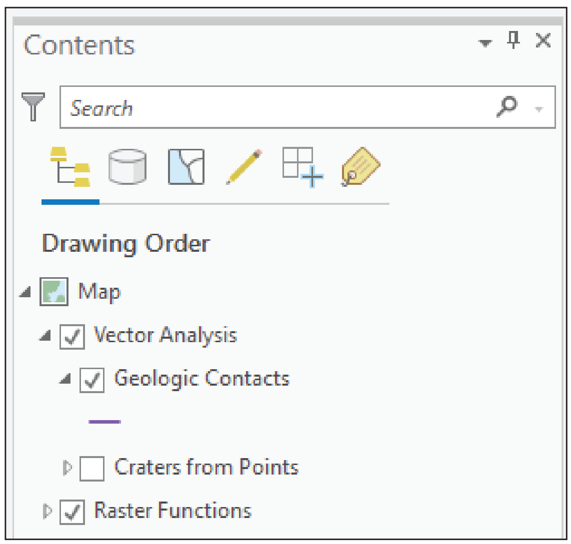


63. In the **Catalog** pane, right click the new **Geo_Contacts** feature class (**Folders → PlanetaryImageAnalysis\Exercise_3\PlanetaryImageAnalysis_Exercise_3.gdb\Jezero_Mapping_Practice**) and select **Add to Current Map**.

The **Geo_Contacts** feature class will be added to the map as a new layer. When you created the feature class, you set the **Alias** (display name) to **Geologic Contacts**, which is how the feature class will be listed in the **Contents** pane. Whenever you update the name of a map layer in the **Contents** pane, you are updating its **Alias**.

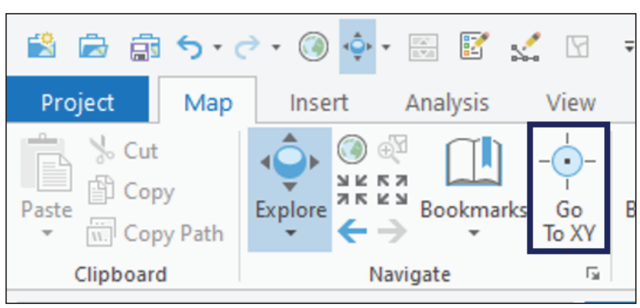


64. In the **Contents** pane, click and drag the **Geologic Contacts** layer into the **Vector Analysis** group.

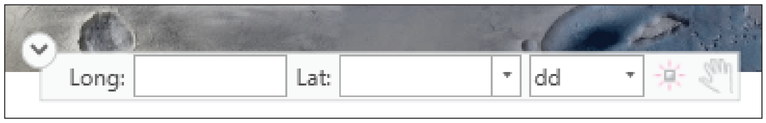


The **Geologic Contacts** feature class has been created, but it does not yet contain any features.

65. In the **Navigate** section of the **Map** tab, click on the **Go To XY** icon to enter a location of interest.



A small window will appear at the bottom of the map with input boxes for the latitude and longitude.

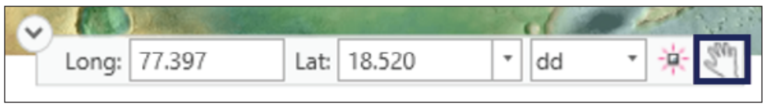


66. In the Go To XY window, input the following coordinates:

    Long: **77.397**

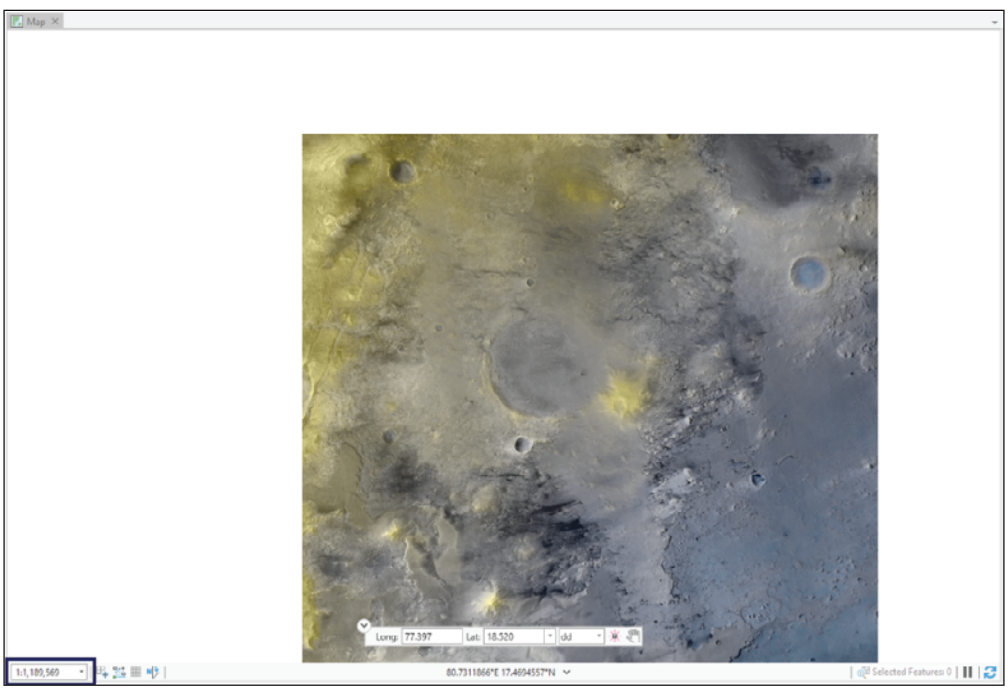
    Lat: **18.520**

67. Leave the third box set to dd (decimal degrees) and click the **Pan to Location** icon to center the map on the specified coordinates.



The map will re-center on the specified coordinates, but it will not zoom in or out.

68. To zoom in on the mapping area, locate the **scale** window in the bottom left corner of the map.



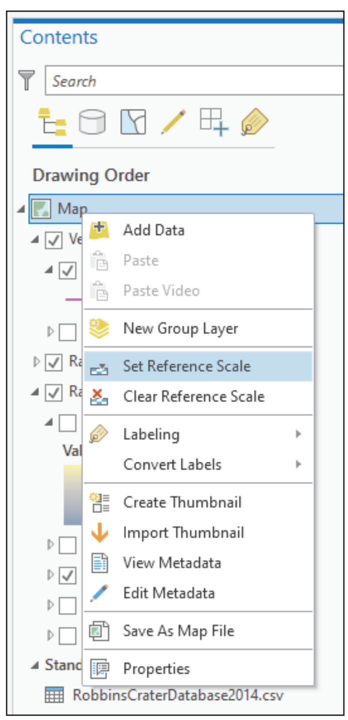
69. Click on the **scale** window to activate the text and enter **1:75000**. Press **enter** to set the scale.

The map will zoom in to the coordinates on which it was centered (77.397°E., 18.520°N.), to a scale of 1:75,000. Alternatively, you could have set the scale first, and use the **Go To XY** tool to pan to the location after zooming in.

70. The **Go To XY** tool does not need to remain open while you are mapping. In the **Navigate** section of the **Map** tab, click on the **Go to XY** icon again to turn this tool off.

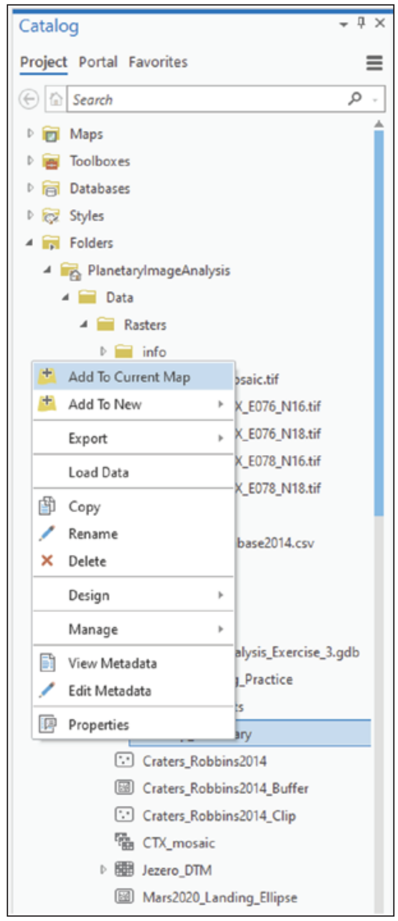
You will be creating a 1:75,000 scale map of this northwest region of Jezero crater. When mapping, it is often helpful to set the **reference scale** of your map. All features (for example, symbols and annotations) are drawn according to the reference scale, so this allows you to see how they will appear in your final map product.

71. First, check the **scale** window in the bottom left corner of the map and confirm that you are viewing your map at **1:75,000**. Then, in the **Contents** pane, right click the **Map** title and select **Set Reference Scale**.



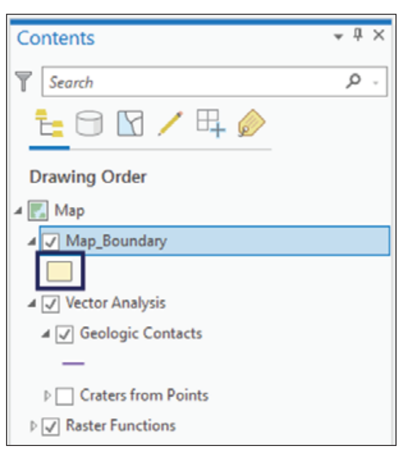
The **reference scale** will be set to the current map view, which is **1:75,000** and your desired map scale. All map features will now be drawn as they will appear at this final printed scale, even as you zoom in and out.

72. In the **Catalog** pane, locate the **Map_Boundary** feature class which is contained in the **Jezero_Mapping_Practice** feature dataset in the **PlanetaryImageAnalysis_Exercise_3 geodatabase** (**Folders → PlanetaryImageAnalysis\Exercise_3**). Right click on the **Map_Boundary** feature class and select **Add to Current Map**.

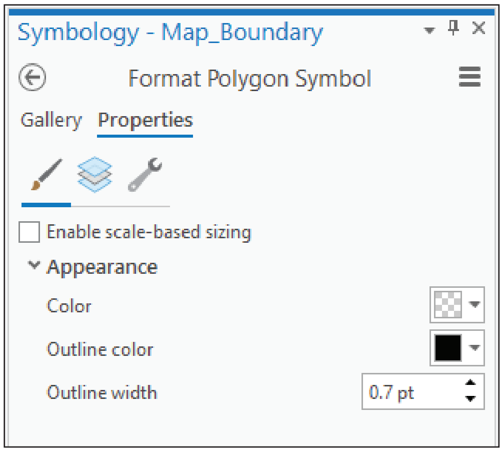


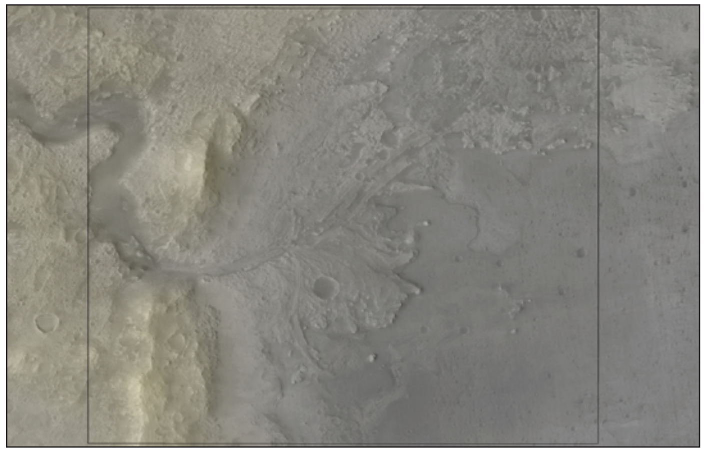
The **Map_Boundary** feature class will be added to the map as a new layer.

73. In the **Contents** pane, click on the symbol listed under the **Map_Boundary** layer to open the **Format Polygon Symbol** pane.



74. In the **Format Polygon Symbol** pane, change the **Color** to **No Color**, and the **Outline color** to **Black**. Then press **Apply** to update the **Map_Boundary** symbol.





75. Click the small **x** in the upper right corner of the **Format Polygon Symbol** pane to close it and return to the **Catalog** pane.

The area within the **Map_Boundary** polygon contains several different geologic units. If desired, you can view the USGS map of Jezero crater and Nili Planum by Sun and Stack (2020) and experiment with their interactive map to explore the geology within this region. Other planetary and interactive maps and resources can be found on the USGS Planetary Geologic Mapping Program website. For this exercise, you will create a simplified 1:75,000 scale map with only three units: the crater floor, depositional fan, and surrounding plains.

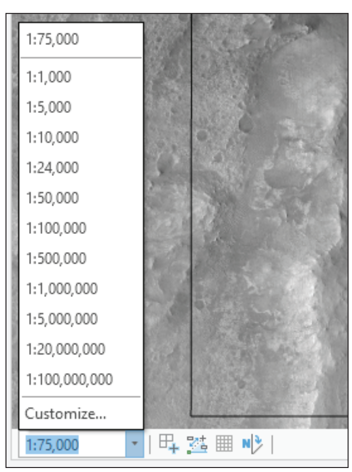
The current map display has both the CTX basemap (**CTX_mosaic**) and the DTM (**Jezero_DTM**) turned on. When mapping, you may want to view the DTM occasionally, but map features should be drawn with only the CTX basemap (**CTX_mosaic**) turned on. Additional datasets like the DTM are supplemental.

76. In the **Contents** pane, uncheck the box for the **Jezero_DTM** layer to turn it off.

As you draw your map features, you may turn the **Jezero_DTM** layer on and off as needed by checking or unchecking its box in the **Contents** pane. It may also be helpful to have **DRA** turned on (located in the **Raster Layer Appearance** tab) for the DTM to help distinguish smaller terrain details.

You will be creating a 1:75,000 scale map of this area. Standard planetary geologic mapping protocols call for map features to be drawn while viewing the area at ¼ of the map scale (as noted on page 14 of the 2022 Planetary Geologic Mapping Protocol). For a 1:75,000 scale map that means you should draw all features while viewing the area at 1:18,750 scale. This results in map features that contain an appropriate level of detail for the scale at which they are meant to be viewed. Although you may be able to view additional details at higher resolutions, drawing map features while zoomed in beyond this limit results in too much detail for the resulting map scale.

77. In the bottom left corner of the map window, click on the small triangle in the scale box to open it.

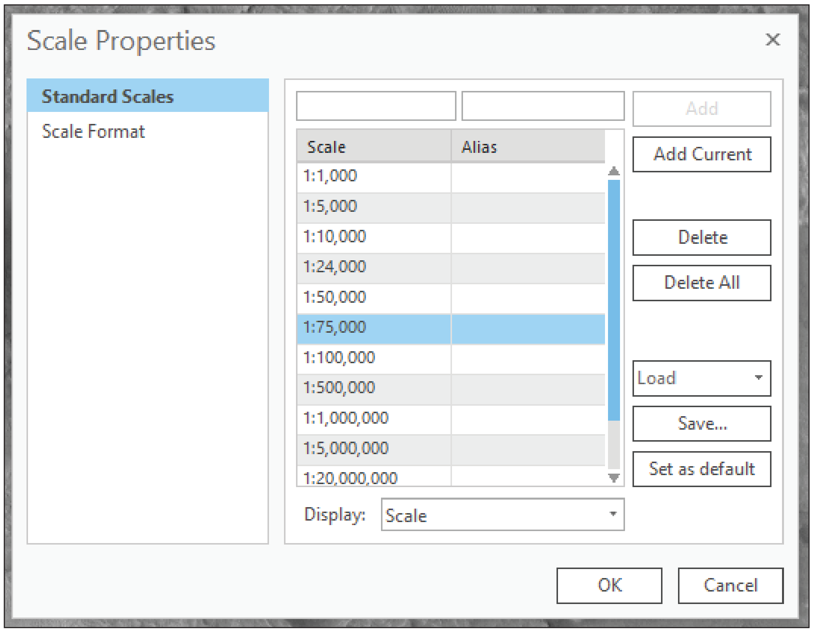


78. Select **Customize** at the bottom of the **scale** menu.

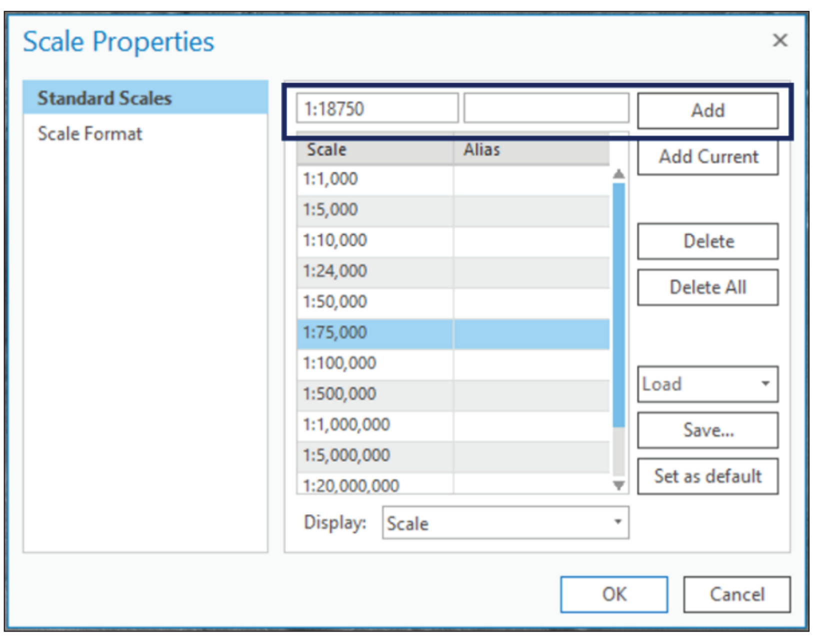
This will open the **Scale Properties** tool where you can customize the options that will be displayed in the pop out scale window. When mapping, you will often switch between the printed map scale (1:75,000) and the digital map scale. The digital map scale is the scale at which features will be drawn. In this case, the digital map scale is 1:18,750. Therefore, it is helpful to add both of these to the quick list of scale options.

79. You are currently viewing the map at the printed map scale of 1:75,000. In the **Scale Properties** window, click **Add Current** to add the printed map scale (1:75,000) to the list.

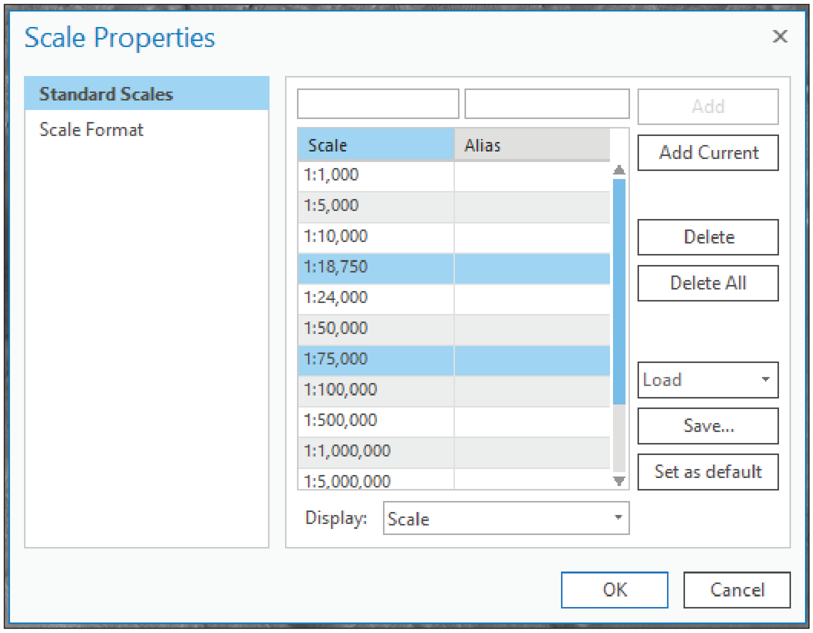
The printed map scale of 1:75,000 has been added to the list of scale options.



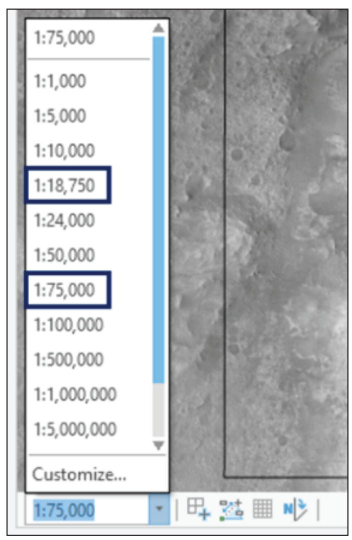
80. In the **Scale Properties** window, there are two blank boxes at the top. Enter **1:18750** in the left (Scale) box. Then press **Add** to add this scale to the list of options.



1:75,000 and 1:18,750 have been added to the scale options and both are now visible in the **Scale Properties** list.



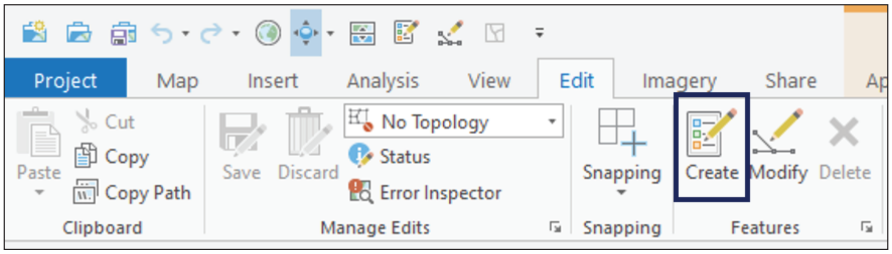
81. Click **OK** to exit the **Scale Properties** tool. Then open the **scale** pop out menu in the bottom left corner of the map to observe the updated options. You will see the 1:18,750 and 1:75,000 scales now listed.



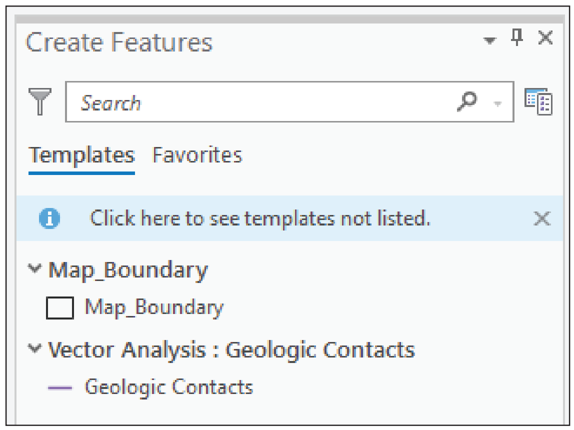
While mapping, you can quickly switch between the printed (1:75,000) and digital (1:18,750) map scales by clicking on them in the **scale** pop out menu. Using the 1:18,750 option when viewing the map will also prevent you from accidentally zooming in too far and drawing map features at an inappropriate resolution.

You will begin mapping by adding linear features to the **Geologic Contacts** feature class. In previous steps, you added this feature class to the map, but it does not yet contain any objects.

82. In the **Contents** pane, select the **Geologic Contacts** layer. Then, in the **Features** section of the **Edit** tab, click on the **Create** icon.



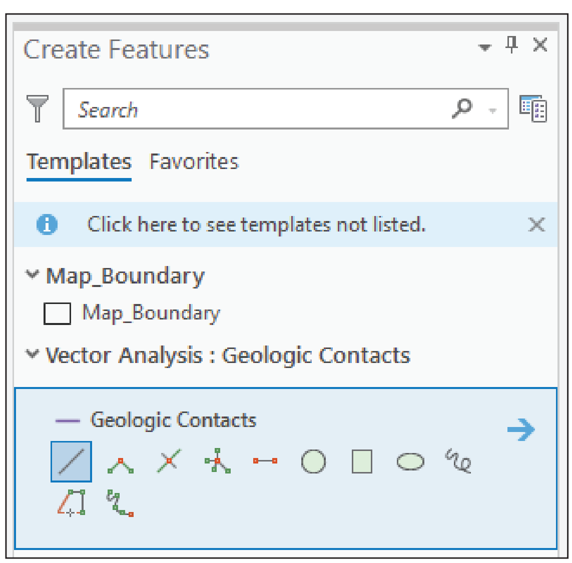
This will open the **Create Features** pane. The **Templates** tab will list all the feature classes that are currently available for editing.



83. In the **Create Features** pane, click on the **Geologic Contacts** feature class to begin editing it.

> *Note to ArcMap users: In ArcGIS Pro, you no longer need to start (or stop) a separate editing session. Instead, by accessing the tools in the **Edit** tab, you are automatically entering the editing mode. You do, however, still need to save the edits you make within this tab.*

With the **Geologic Contacts** feature class selected, several drawing options will appear in the **Create Features** pane.



In geologic mapping, the most frequently used options for drawing linear features are:

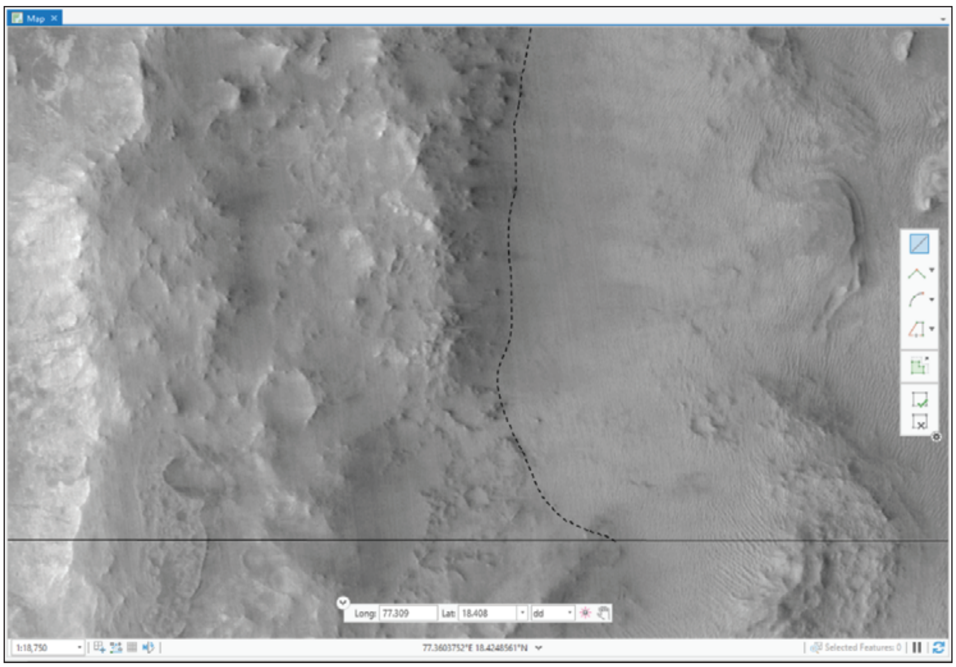
Line (default selection): Click to manually place individual points (vertices) along the line.

Stream : Automatically places vertices along a line by tracking the position of your pointer. This setting is ideal for those working with a digitizing tablet or touchscreen.

During this exercise, you will experiment with both the **Line** and **Stream** options.

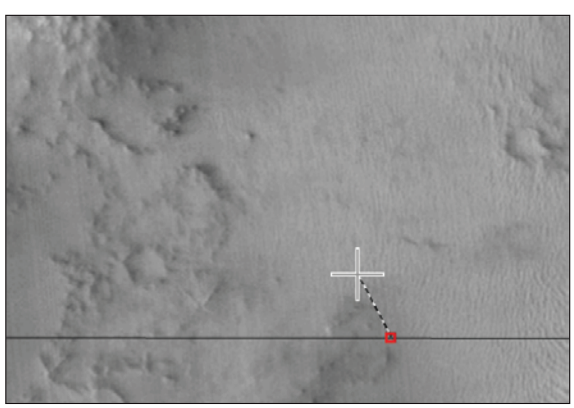
84. In the **Navigate** section of the **Map** tab, click on the **Go To XY** tool to open it. Enter the coordinates **77.309 (Long.)** and **18.408 (Lat.)** and click the **Pan to Location** icon to center the map on this location. Then use the **scale** pop out menu to select and zoom to the **1:18,750** scale.

This location is where the geologic contact between the crater rim/plains materials and the crater floor materials (dashed line below) intersects the **Map_Boundary**. You may need to zoom in and out to orient yourself within the map area and get context. The coordinates you entered in the **Go To XY** tool will remain, and you can return to this location by clicking the **Pan to Location** icon again and selecting **1:18,750** in the scale pop out menu.

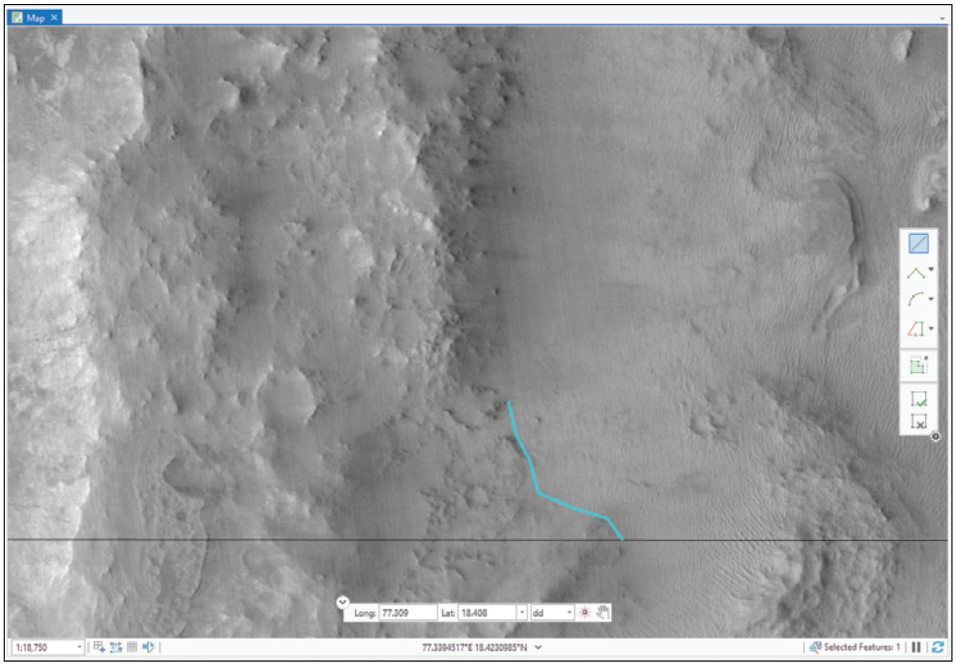


85. To begin drawing, in the **Create Features** pane, confirm the **Line** option is selected under **Geologic Contacts**.

86. In the map window, click to place the southernmost vertex marking the boundary between the crater rim/plains materials and the crater floor materials. Once you click, a dashed line will appear between the placed vertex and your pointer. This shows you what the line will look like as you click to place additional vertices.

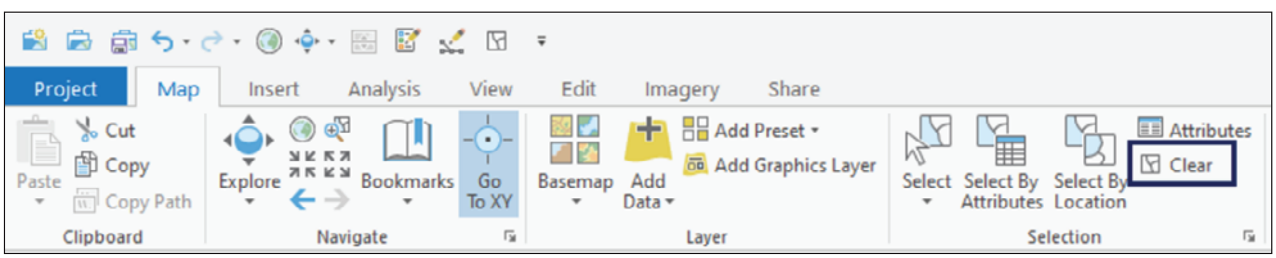


87. Click to place 3 or 4 more vertices along the boundary between the crater rim/plains materials and the crater floor materials (do not go beyond the current display of the map). Then double click to place one final vertex and finish drawing this line.



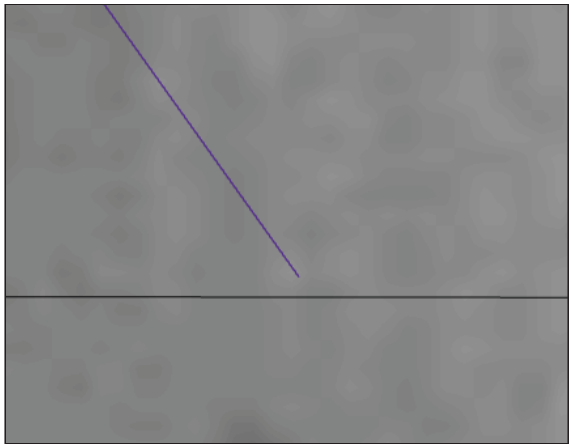
When you double click to finish drawing a feature, it will be highlighted in bright blue (see above).

88. In the **Selection** section of the **Map** tab, click **Clear** to deselect all features.



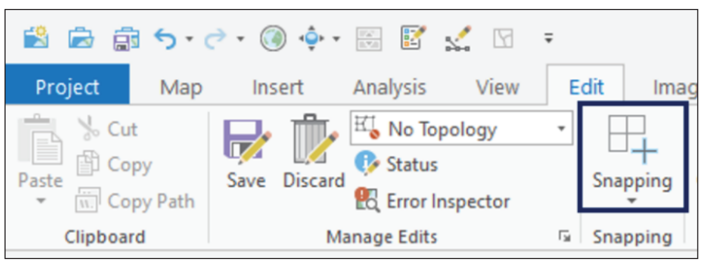
89. Use the scroll wheel of your mouse to zoom in to the first (southernmost) vertex you placed.

Tip: ***Tip:*** *When in editing mode, you can not click and drag the map to pan. Clicking on the map will begin to place a new feature. Instead, click and drag using the* ***middle button or scroll wheel*** *of your mouse, or* ***press and hold the "C" key*** *while left clicking and dragging. If you accidentally click in the map and begin creating a new feature, you can cancel that drawing action by right clicking in the map and selecting* ***Cancel****.*

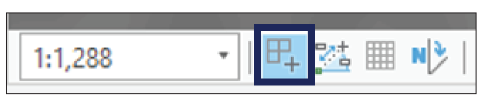


When drawing geologic contacts, it is imperative that there are no gaps like the one shown above. In subsequent mapping stages, you will use the geologic contacts to create polygon features representing each geologic unit. If there are gaps between the geologic contacts, the tool will view those as one contiguous unit and the resulting polygons will not be correct. To prevent this issue, it is best to turn on **Snapping** while drawing your geologic contacts. **Snapping** will automatically place vertices on top of another feature if it is close by.

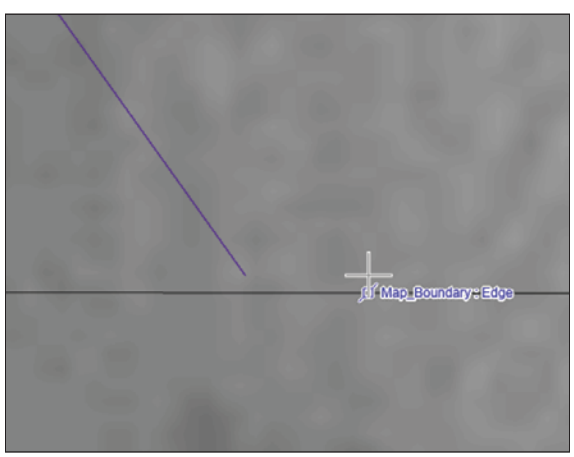
90. In the **Snapping** section of the **Edit** tab, click on the **Snapping** icon to turn **Snapping** on.



When **Snapping** is on, this icon will be highlighted in blue. An additional small **Snapping** icon is also available in the bottom left corner of the map window, next to the **scale** pop out menu. You can also quickly turn Snapping on and off using this icon.



91. With **Snapping** on, hover over and around the **Map_Boundary** and note how the vertex is placed.

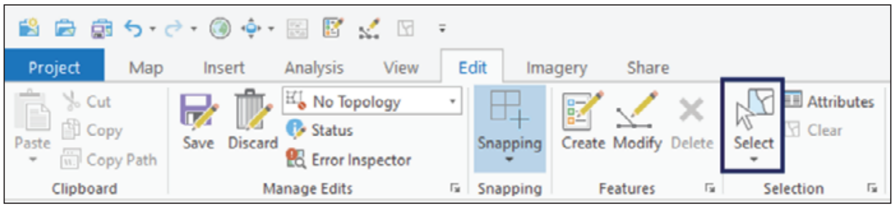


With **Snapping** on, the vertex will be pulled to the nearby feature—in this case, the **Map_Boundary**—as long as it is within a specified distance. As you map, there are times where you may or may not want to have **Snapping** on. You can quickly turn **Snapping** on and off using the small **Snapping** icon in the lower left corner of the map.

92. In the **Go To XY** tool, click on the **Pan to Location** icon again and select **1:18,750** in the scale pop out menu to return to the appropriate mapping scale.

Since the first line was drawn without **Snapping** on, you will need to edit the first vertex so it intersects the **Map_Boundary**.

93. In the Selection section of the Edit tab, click on the **Select** icon.

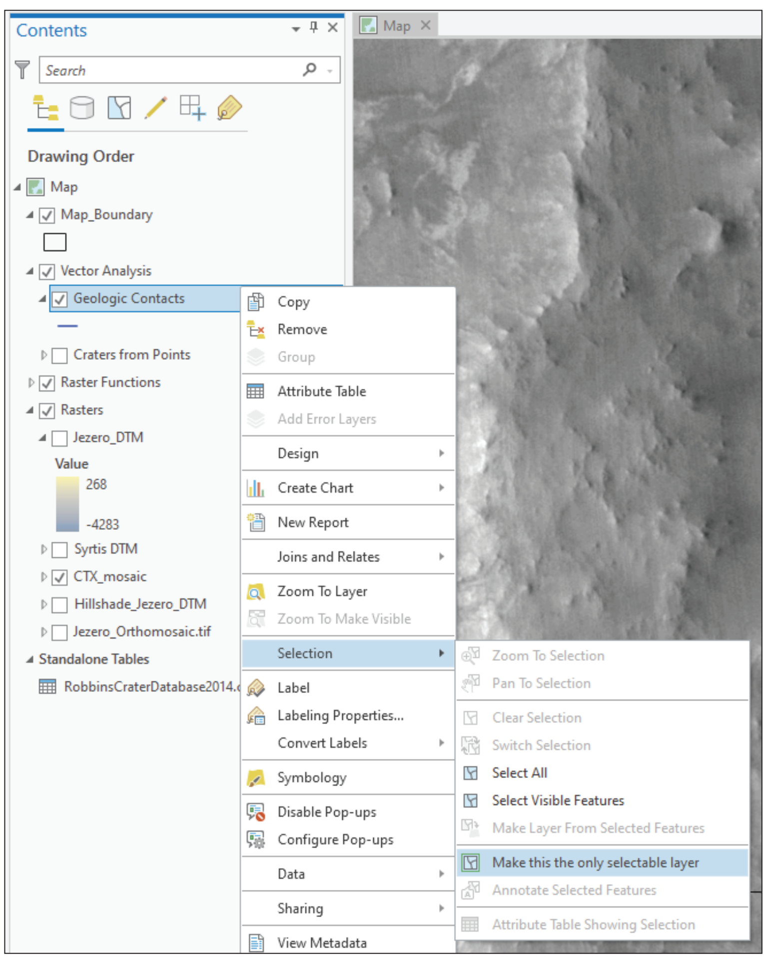


The **Select** icon will be highlighted in blue when it is turned on.

94. In the map, click on the line you drew earlier to select it.

When you click on the **Geologic Contact**, you will notice the **Map_Boundary** is highlighted in blue, instead of the **Geologic Contact**. This is because both feature classes are available and selectable in the map. You can click on the **select feature** icon in the map to change the selection. However, it is easiest to change the **Map_Boundary** layer so it is not selectable. This will prevent this issue going forward.

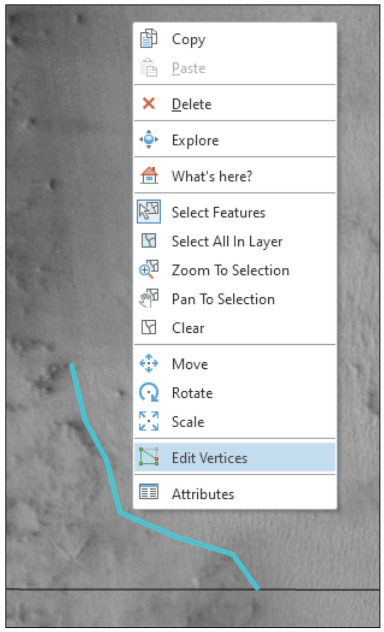
95. In the **Contents** pane, right click the **Geologic Contacts** layer and select **Selection → Make this the only selectable layer**.



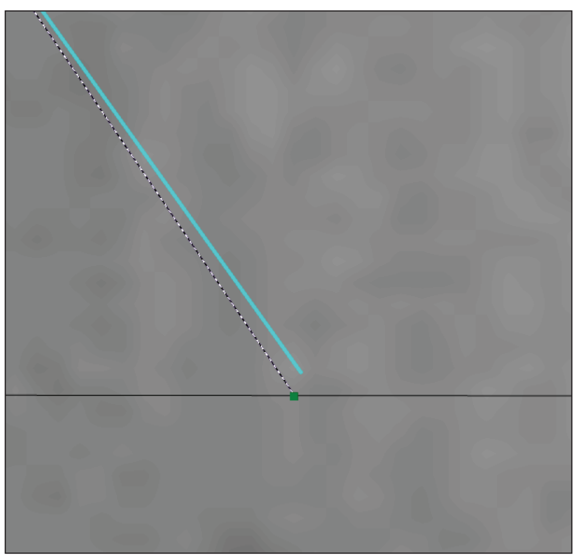
96. In the map, click on the **Geologic Contact** feature you drew earlier to select it.

Now that the **Geologic Contacts** layer is the only selectable layer, the feature will be selected and highlighted in blue.

97. In the map, right click on the selected feature and select **Edit Vertices**.



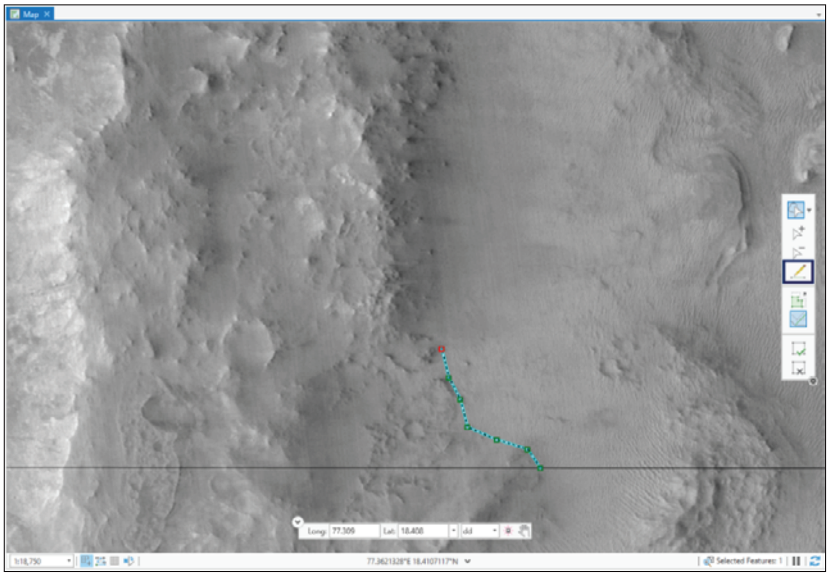
98. Zoom in to the southernmost vertex. Then click and drag the southernmost vertex so it snaps to the **Map_Boundary**.



When editing vertices, the dashed line shows the updated feature. The initial blue line also remains. This allows you to see what the updated feature will look like compared to how it was before editing.

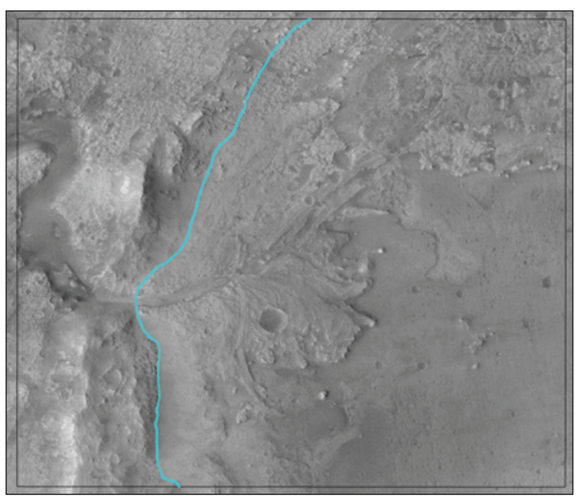
99. With the southernmost vertex now snapped to the **Map_Boundary**, use the scale pop out menu to return to **1:18,750** scale.

100. Along the right side of the map is the **Edit Vertices** toolbar. Click on the **Continue Feature** icon to continue drawing this feature.



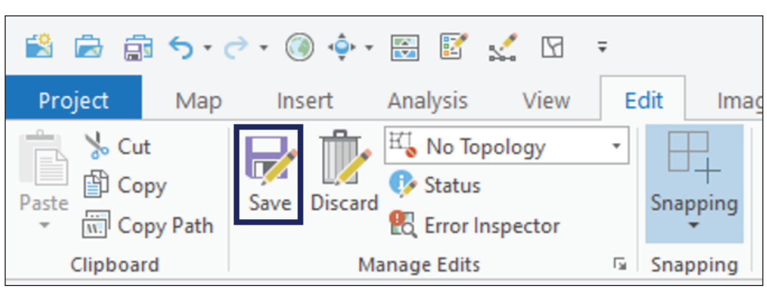
The **Continue Feature** editing mode will continue drawing the feature from the red endpoint vertex.

101. Use the **Continue Feature** editing mode to draw and extend the **Geologic Contact** between the crater rim/plains materials and the crater floor. Double click to place the final vertex on the northern **Map_Boundary**. To pan as you draw, click and drag using the **middle button or scroll wheel** of your mouse, or **press and hold the "C" key** while left clicking and dragging. If you accidentally click in the map and begin creating a new feature, you can cancel that drawing action by right clicking in the map and selecting **Cancel**. Remember to not zoom in beyond the **1:18,750** scale while drawing.



When editing and creating features, you must save your work. This is separate from saving your overall map project.

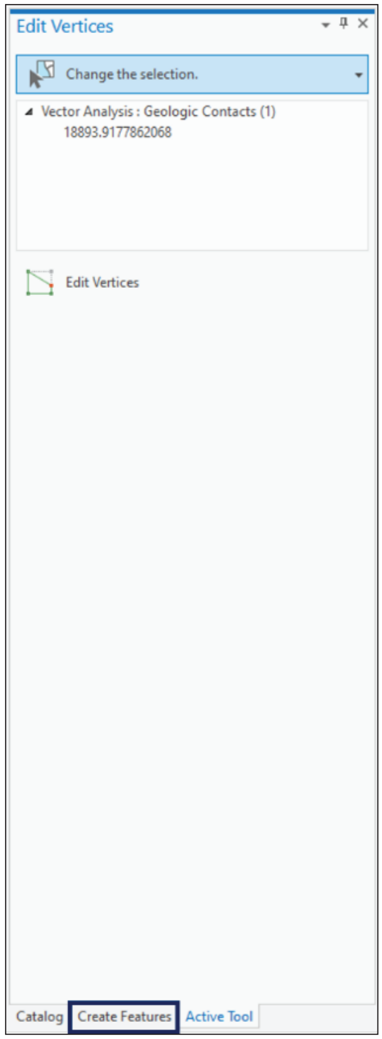
102. In the **Manage Edits** section of the **Edit** tab, click **Save**. Click **Yes** to save all edits.



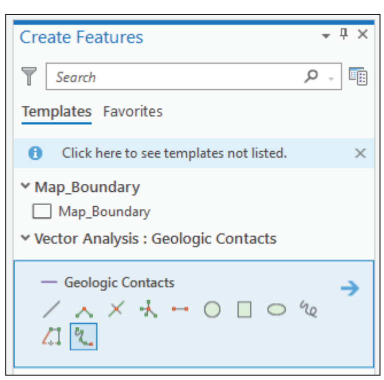
If you try to save your map project without saving your edits, you will be automatically prompted to save your edits before saving the overall map project.

Now that you have finished editing the geologic contact between the crater rim/plains materials and the crater floor, you can return to the Create Features pane.

103. To return to the **Create Features** pane, click on the **Create Features** tab at the bottom of the **Edit Vertices** (**Active Tool**) pane.



104. In the **Create Features** pane, select the **Geologic Contacts** feature class to continue adding features to it. Then select the **Stream** option.



To draw the second geologic contact you will use and experiment with the **Stream** mode. The streaming mode is ideal for those who are working with a digitizing tablet or a touchscreen but can be used with a mouse as well. (Alternate option: If you find the streaming mode does not work well with your computer setup, right click in the map area while still drawing the feature and select **Cancel**. Then change to the **Line** mode in the **Create Features** pane and draw the geologic contact as you did in the previous steps.

105. For the second geologic contact, use the **Stream** method to mark the approximate boundary of the fan-shaped feature located on the crater floor (dashed line in image below):

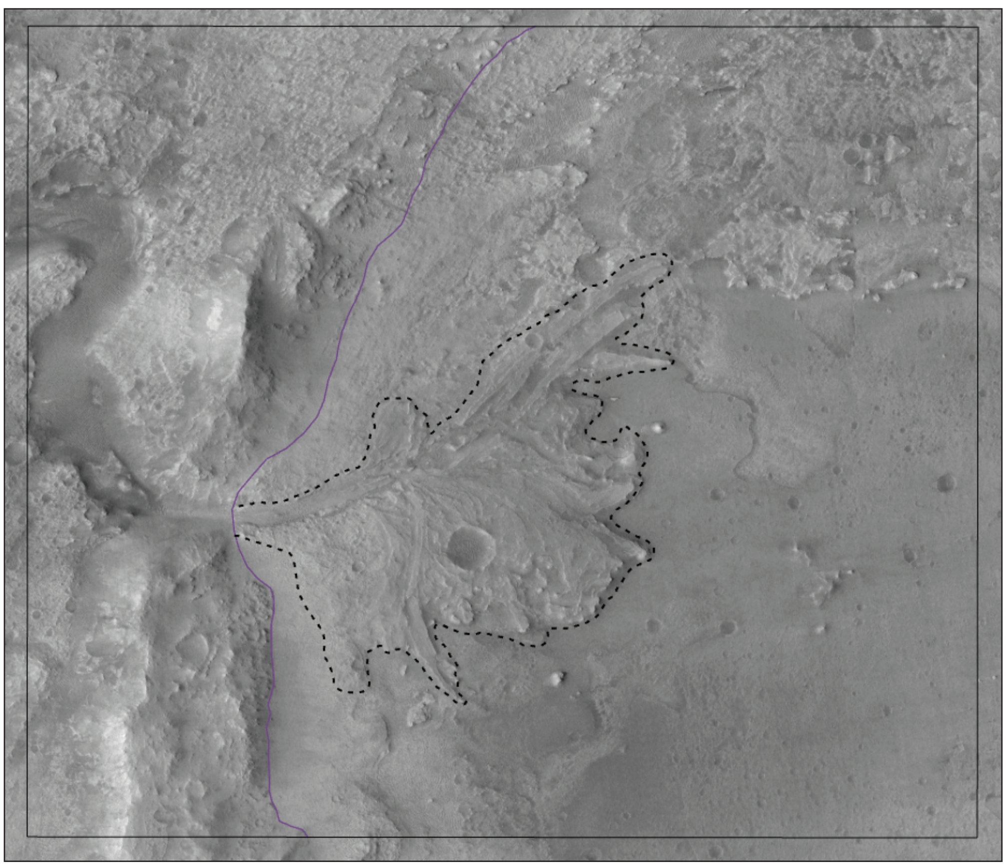
    A. Use the **scale** pop out menu to zoom in to the appropriate digital mapping scale (**1:18,750**)

    B. Pan around the area by clicking with the middle mouse button or holding the **C** key while left clicking and dragging the map.

    C. When drawing features in **Stream** mode, click once to begin drawing the feature. Vertices will be automatically created following the path of the cursor until you double click to finish drawing.

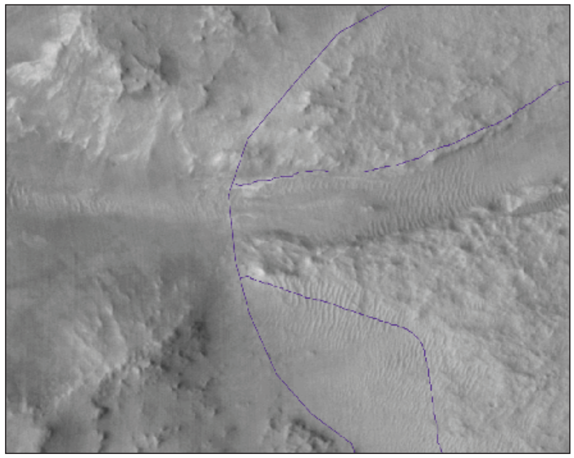
    D. To pause the drawing of vertices (for example, if you need to move your cursor off the path of the boundary or pan the map to another area), press and hold the **C** key. The vertices will begin drawing again as soon as you let go of the **C** key.

    E. As you practiced earlier, the beginning and ending vertices should be snapped to their abutting feature—in this case, this is the geologic contact you drew in the previous steps.



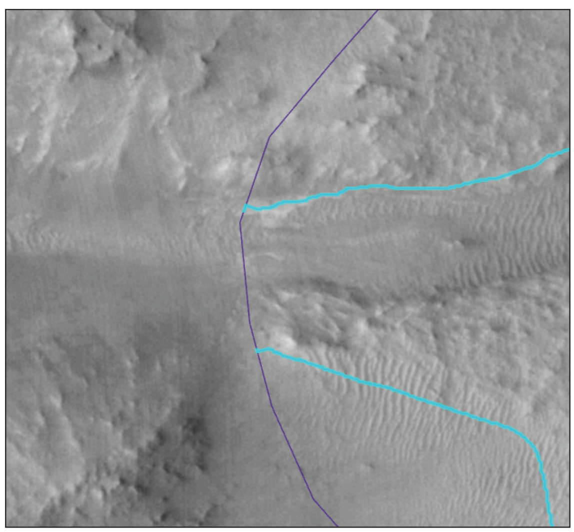
Now that the fan boundary is complete, you have finished drawing the **Geologic Contacts** for your map. After drawing features, it is typical to need to clean up vertices and make edits to those features.

106. Zoom in to the area of your map where the geologic contacts intersect. This should be on the east side of the fan.



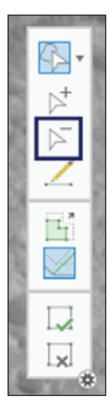
When drawing the fan boundary, you snapped the beginning and ending vertices to the existing geologic contact, so there are no gaps between the features. However, snapping features during streaming mode can result in additional, unnecessary, and often inaccurate vertices which need to be edited.

107. In the **Selection** section of the **Edit** tab, click on the **Select** icon. Then click on the fan boundary to select it.

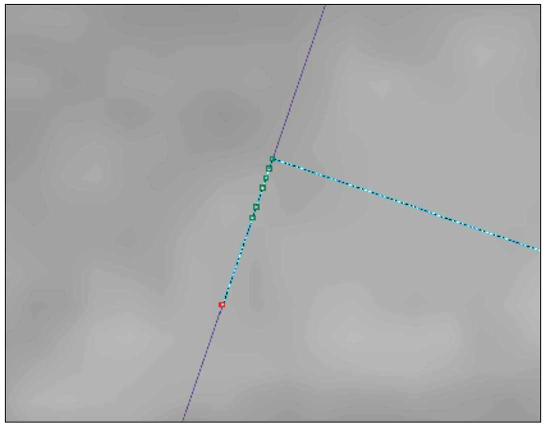


108. Right click the selected feature and choose **Edit Vertices**.

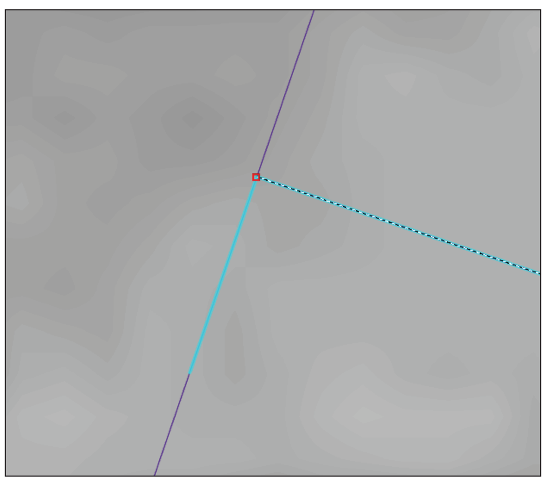
109. Click on the **Delete** icon in the **Edit Vertices** toolbar that is displayed along the right edge of the map.



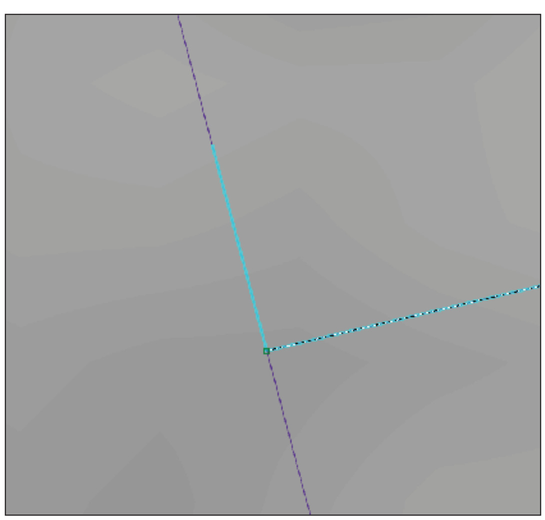
110. Zoom in to each end of the fan boundary feature and check the vertices. Snapping during Stream mode will often result in excess vertices that need to be removed like the ones shown here:



111. With the **Delete** tool selected, click on each erroneous vertex to delete it. Like before, the dashed line will update to show the current feature, while the highlighted blue line will remain for comparison.

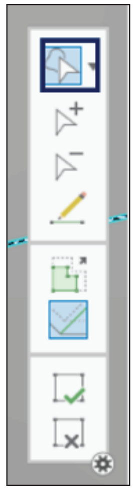


112. Check the other end of the fan boundary and remove any unnecessary vertices.

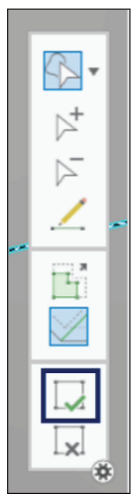


113. Pan through the rest of the fan boundary feature and check for any other vertices that need to be deleted or moved. Use the middle button of your mouse or press and hold the C key while clicking and dragging the map to pan.

   A. To move a vertex (but not delete it), use the **Select** tool at the top of the **Edit Vertices** toolbar. Then click on the vertex you wish to move and drag it to the desired location.



114. When you have finished editing the vertices, click on the **Finish** icon in the **Edit Vertices** toolbar.

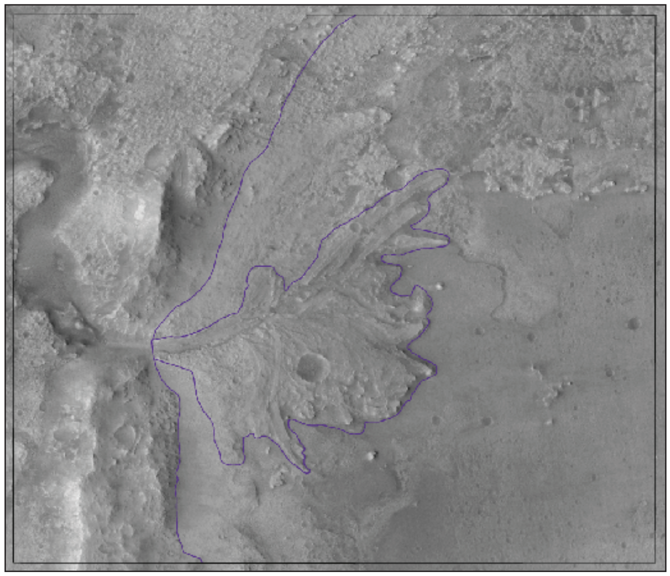


115. In the **Manage Edits** section of the **Edit** tab, click **Save** to save the edits you made to the **Geologic Contacts** feature class. Click **Yes** to save all edits.

116. Click the small **x** in the upper right corner of the **Edit Vertices** pane to close it. Click the small **x** in the upper right corner of the **Create Features** pane to close that as well.

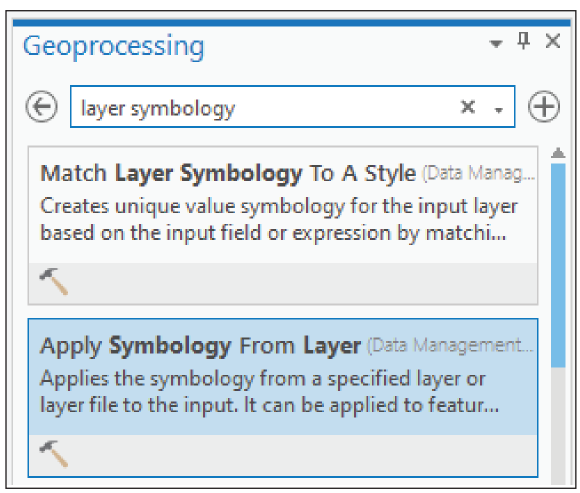
117. In the **Selection** section of the **Edit** tab, click **Clear** to de-select all features.

118. In the **Contents** pane, right click the **Map_Boundary** layer and select **Zoom to Layer** to observe the full extent of the map area.

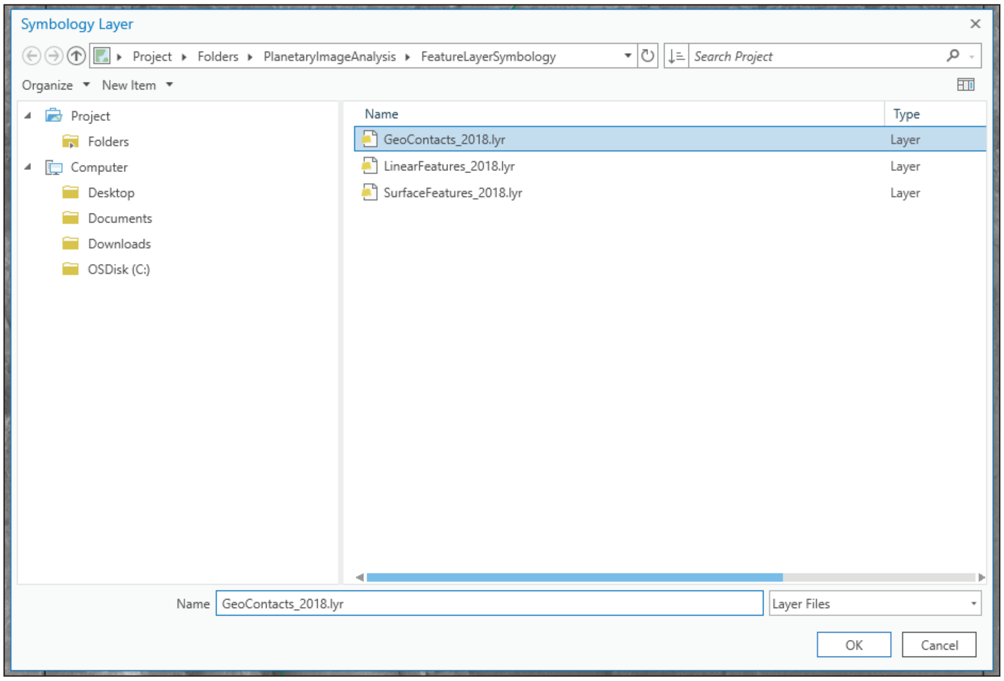


When the **Geologic Contacts** features were created, they were assigned a default symbology. When mapping, you can update the symbology manually through the **Symbology** pane, but it is typical to apply standard symbologies to your features using a pre-existing set of symbols. These are contained in a **layer file** (**.lyr**).

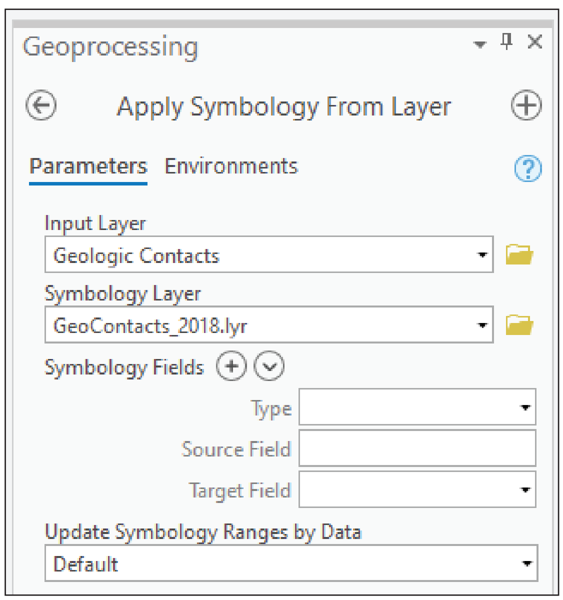
119. In the **Contents** pane, select the **Geologic Contacts** layer. Then in the **Geoprocessing** section of the **Analysis** tab, click on the **Tools** icon to open the **Geoprocessing** pane. In the **Geoprocessing** pane, search for **layer symbology**. Then click on the **Apply Symbology From Layer** tool to open it.



120. In the **Apply Symbology From Layer** tool, set the **Input Layer** to **Geologic Contacts**. Then click on the **Open** icon for the **Symbology Layer** and navigate to the **PlanetaryImageAnalysis\Exercise_3\FeatureLayerSymbology** folder. Select the **GeoContacts_2018.lyr** file and click **OK**.

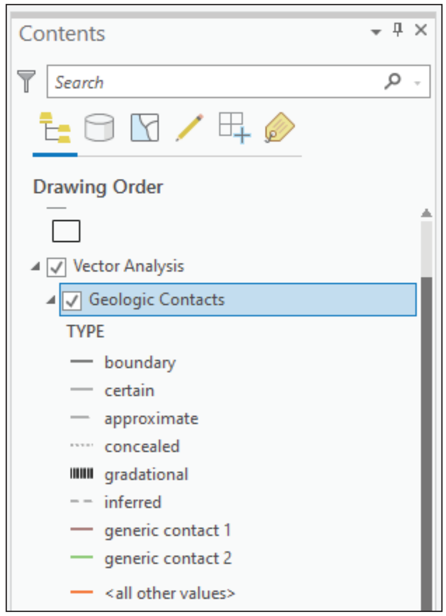


121. In the **Apply Symbology From Layer** tool, leave all other defaults and click **Run**.



122. Click on the small **x** in the upper right corner of the **Apply Symbology From Layer** tool to close it and return to the **Catalog** pane.

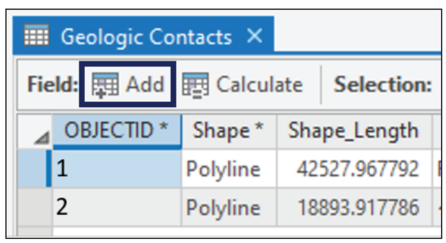
In the **Contents** pane, you will see the **Geologic Contacts** layer symbology has been updated to reflect the new schema.



The Geologic Contacts feature class symbology has been updated, but the boundaries you created do not yet have types assigned to them.

123. In the **Contents** pane, right click the **Geologic Contacts** layer and select **Attribute Table.**

124. In the **Geologic Contacts Attribute Table**, click on the **Add Field** icon to open the field editor.



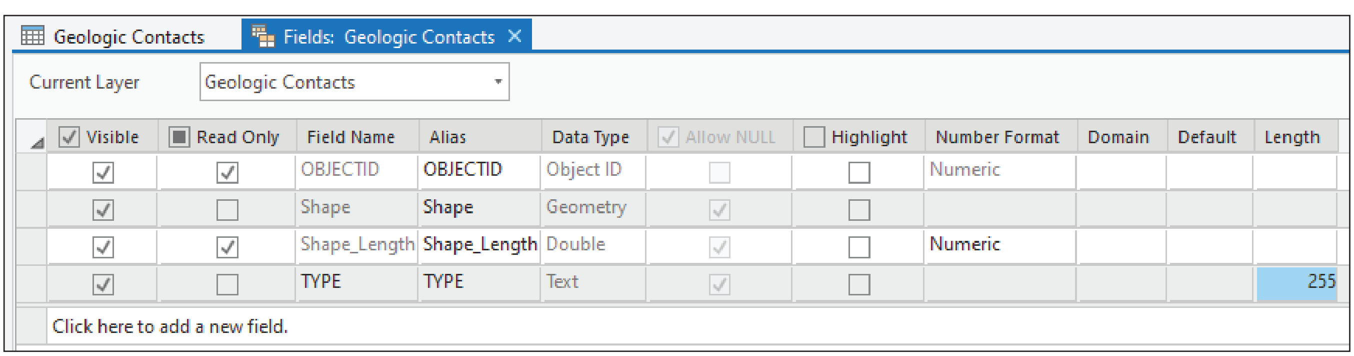
125. In the **Fields: Geologic Contacts** tab create a new field with the following parameters:

Field Name: **TYPE** (The field name must match what is listed in the **Contents** pane at the top of the layer symbology)

Alias: **TYPE**

Data Type: **Text**

Length: **255**

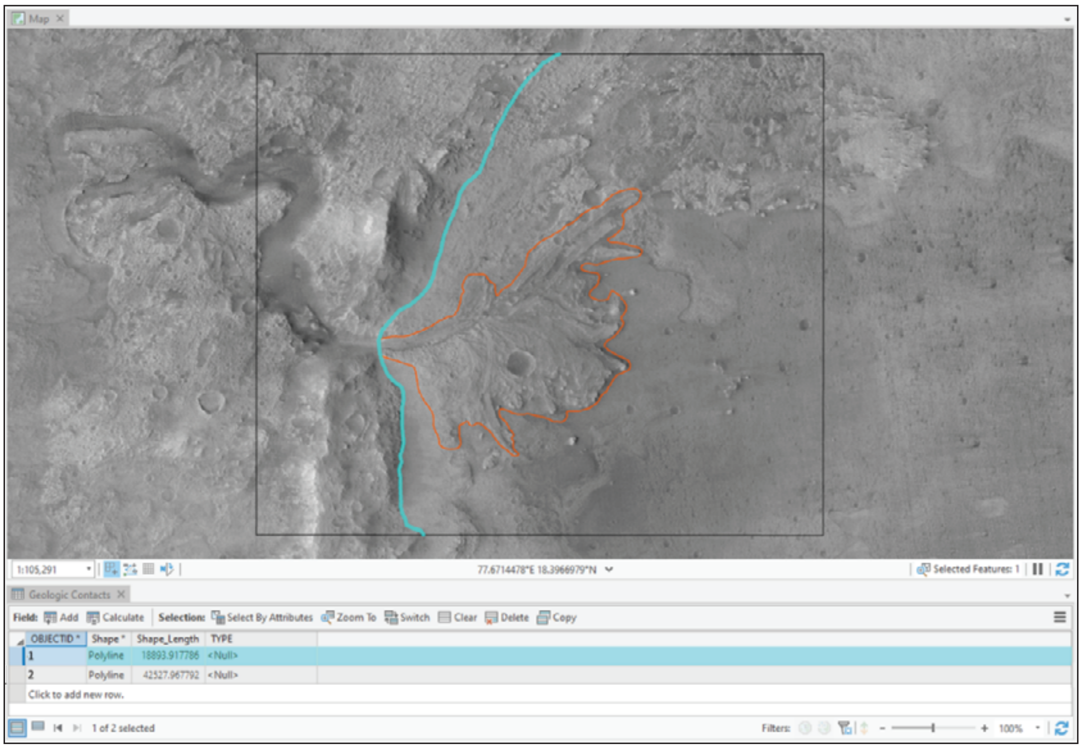


126. Press **enter** to finalize your entry. Then, in the **Changes** section of the **Fields** tab, click **Save** to save your edits.

127. Click on the small **x** in the **Fields: Geologic Contacts** tab to close the field editor and return to the **Geologic Contacts Attribute Table**.

When a new field has been added to the **Geologic Contacts Attribute Table**. In the new **TYPE** field, all values are set to <Null> and contain no data. This new **TYPE** field is where you will assign boundary types. The boundary types that are entered should match those that are displayed in the **Geologic Contacts** layer symbology.

128. In the **Geologic Contacts Attribute Table**, click on the box to the left of the first row to highlight that object. The feature will also be highlighted in the map.



129. For the boundary between the crater rim/plains materials and the crater floor, click in the **TYPE** field and enter **approximate**. Press **enter** to finalize this entry. For the fan boundary, set the **TYPE** to **certain** and press **enter** to finalize this entry.

130. In the **Geologic Contacts Attribute Table** toolbar, click on the **Clear** icon to clear the selection. Then, in the **Manage Edits** section of the **Edit** tab, click on the **Save** icon to save the updates to the **Attribute Table**. Click **Yes** to save all edits. Once your edits have been saved, click on the small **x** in the **Geologic Contacts Attribute Table** tab to close it and return to the full map view.

When you return to the map, you will see the updated **Geologic Contacts**, which now reflect the boundary types that were assigned.

You have finished drawing the **Geologic Contacts** for your simplified map of northwest Jezero crater. In addition to drawing linear features, you can also create point- or polygon-based features. The process is similar to the one you just followed to create the **Geologic Contacts** linear features. Since feature classes can only contain one type of shape (points, lines, or polygons) point and polygon features must be contained in their own feature classes.

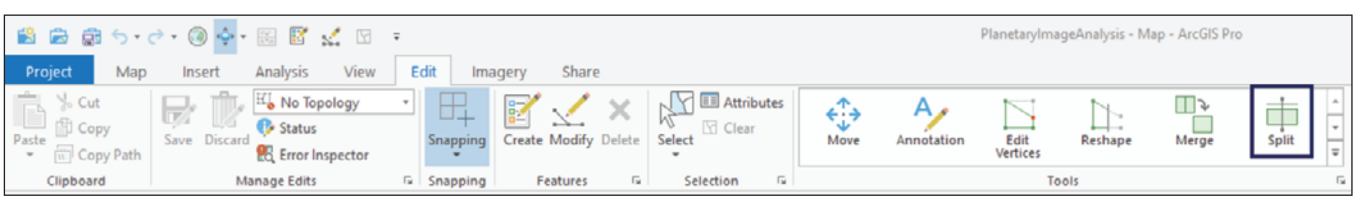
Part 4: Creating Polygons From Linear Features

In the previous section, you created the **Geologic Contacts** for a simplified map of northwest Jezero crater, Mars. The **Geologic Contacts** feature class identifies the boundaries for three units: The crater rim/plains materials, crater floor, and depositional fan. These **Geologic Contacts** can now be used to create the polygons which will represent each geologic unit.

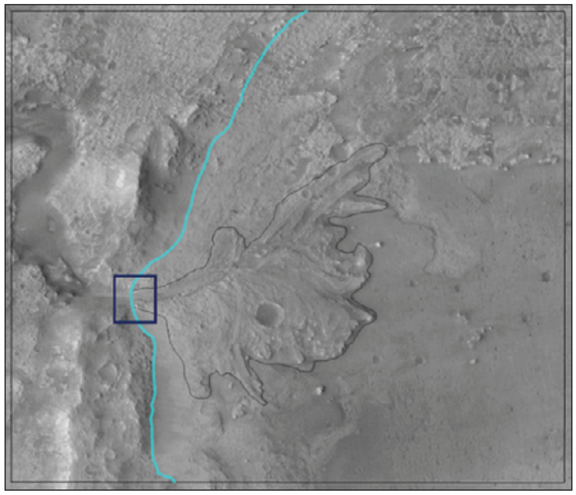
Before using the **Geologic Contacts** feature class to create polygons, there are few steps that must be taken to prepare the data. There are two locations in your map (black arrows) where features intersect:

The **Features to Polygon** geoprocessing tool will use the **Geologic Contacts** and **Map_Boundary** feature classes to create polygons. However, to properly build the polygons, the tool requires that all linear input features (the **Geologic Contacts**) must be split at any point that they intersect so each polygon boundary is distinct. If the lines are not split, the tool can not properly identify the polygon boundaries and they will be combined.

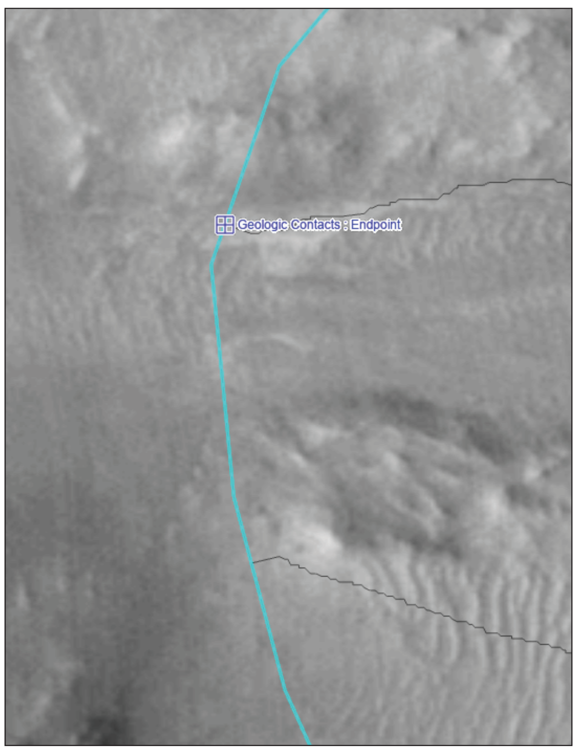
131. In the **Tools** section of the **Edit** tab, click on the **Split** icon.



132. In the map, click on the unit boundary between the crater rim/plains materials, and the crater floor to select it. Then zoom to the region where this boundary intersects the boundary of the fan unit (blue box in the image below).



133. In the map, use your cursor to hover over one of the points where these two boundaries intersect. With **Snapping** on, the cursor will snap to the features. When you are at the location where the two features intersect, the cursor will display **Geologic Contacts: Endpoint**.

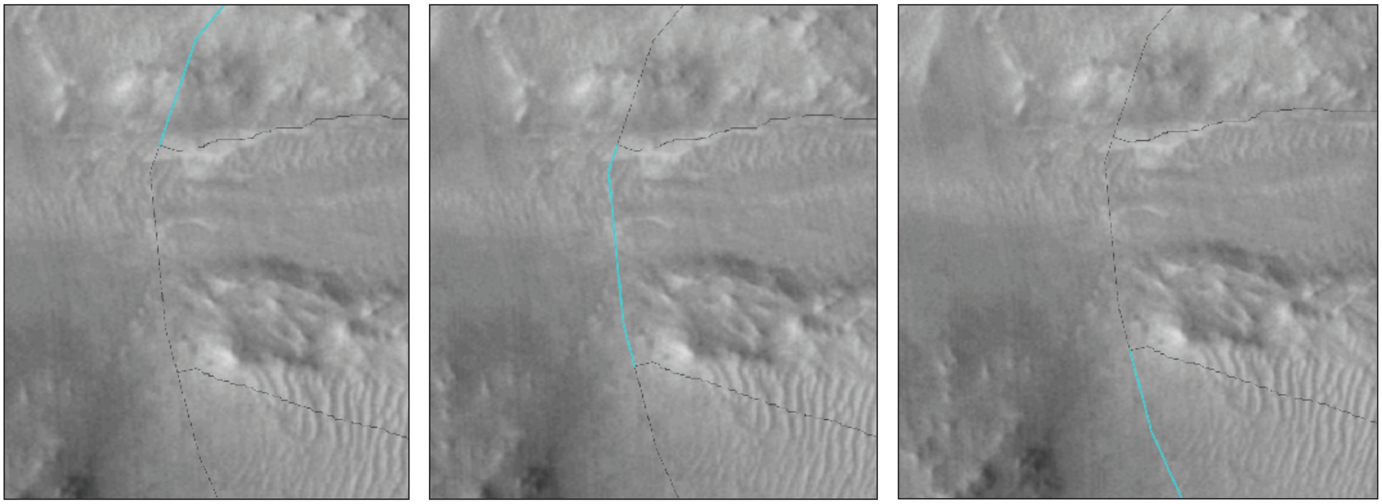


134. In the map, click once on the point of intersection to split the line at that location. You should see one portion of the split line flash to indicate it has been separated into a new, distinct line.

135. In the map, move along the selected boundary and repeat the previous step to split it at the second point where it intersects with the fan boundary.

136. In the **Selection** section of the **Edit** tab, click on the **Clear** icon to clear the selection. Then click on the **Select** icon to enable it.

137. In the map, click on the different sections of the boundary line you just split to confirm that they have been separated. There should now be three distinct sections:



138. In the **Selection** section of the **Edit** tab, click **Clear** to clear the current feature selection.

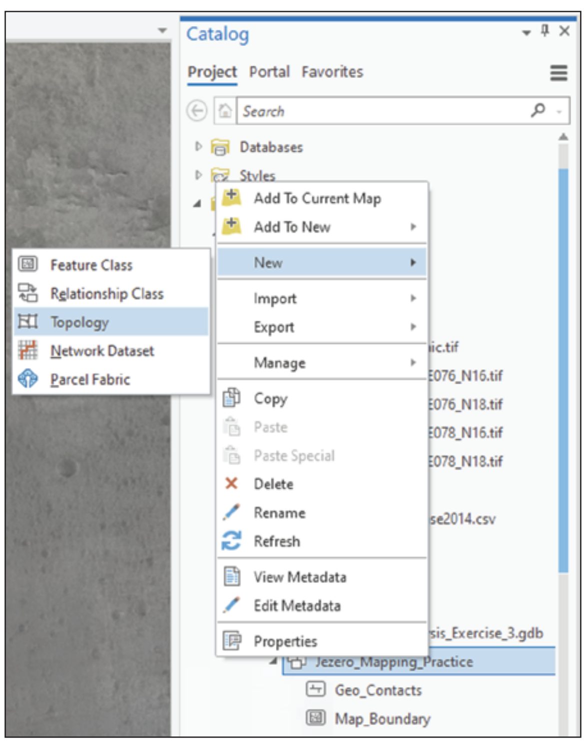
139. In the **Manage Edits** section of the **Edit** tab, click on the **Save** icon to save the changes to this feature class. Click **Yes** to save all edits.

140. Click on the small **x** in the upper right corner of the **Modify Features** pane to close it.

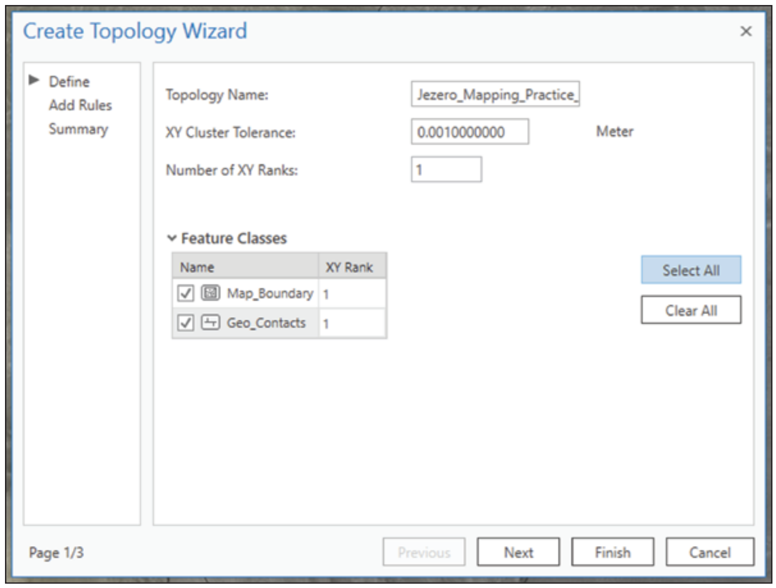
141. In the **Contents** pane, right click the **Map_Boundary** layer and select **Zoom to Layer** to return to the full extent of your map.

With the **Geologic Contacts** split, you can now build polygons for the geologic units. However, before building the geologic unit polygons, it is best to complete a topology check. A topology check makes sure there are no fundamental errors in the geologic contacts that could cause problems when you create the unit polygons.

142. In the **Catalog** pane, right click the **Jezero_Mapping_Practice** feature dataset in the **PlanetaryImageAnalysis_ Exercise_3.gdb** (**Folders → PlanetaryImageAnalysis\Exercise_3**) and select **New → Topology**



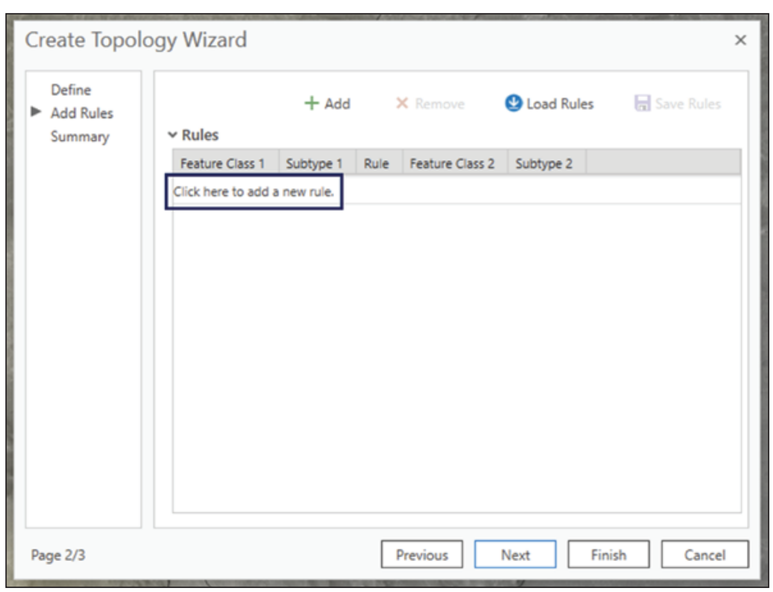
143. In the first step of the **Create Topology Wizard** tool, you will select which feature classes you want to include. All feature classes that exist in the feature dataset are listed under Feature Classes. Click **Select All** to select all feature classes that are available, and then click **Next** at the bottom of the **Create Topology Wizard** tool to move to the next step.



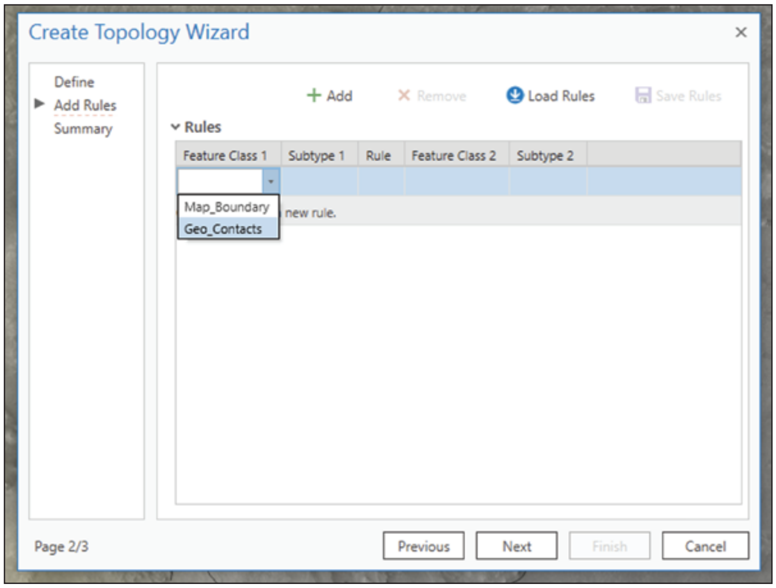
Here, you will add the rules against which your map features will be checked. There are five fundamental rules for geologic contacts. A geologic contact must not:

1. Overlap with other lines,
2. Overlap with itself,
3. Intersect with other lines,
4. Intersect with itself,
5. Dead end ("dangle").

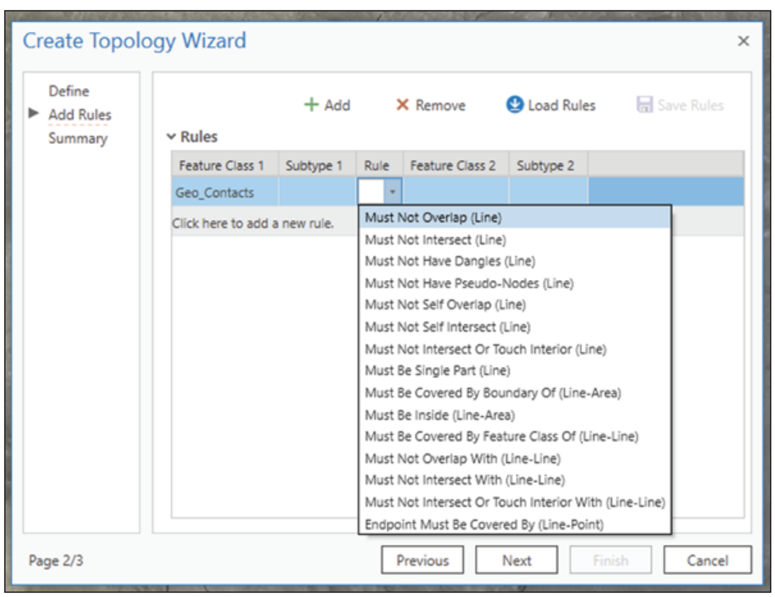
144. In the **Add Rules** tab of the **Create Topology Wizard** tool, click on the table to add a new rule.



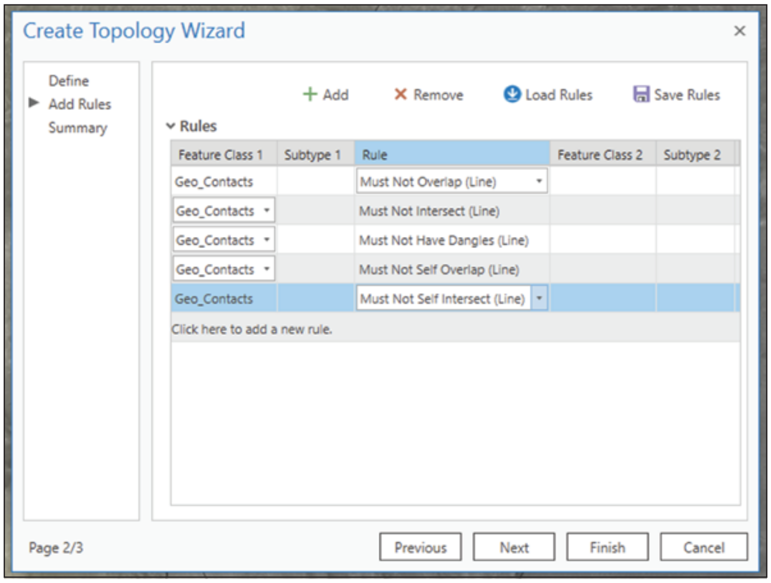
145. In the **Create Topology Wizard** tool, click on the dropdown menu under **Feature Class 1** and select **Geo_Contacts**.



146. In the **Create Topology Wizard** tool, click on the empty box under **Rule** to open a dropdown menu. Then select **Must Not Overlap (Line)**.

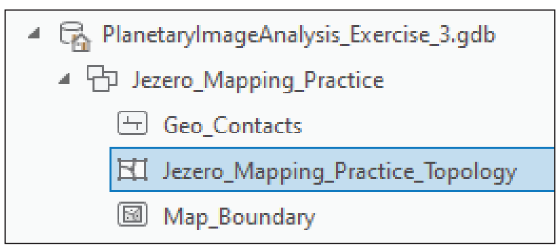


147. Repeat the previous steps to add four more rules to the table, checking the **Geo_Contacts** Feature Class: **Must Not Intersect (Line)**, **Must Not Have Dangles (Line)**, **Must Not Self Overlap (Line)**, and **Must Not Self Intersect (Line)**.

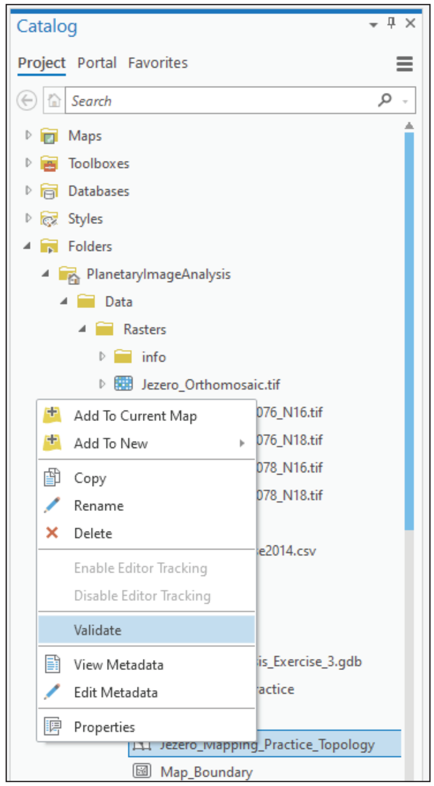


148. Click **Finish** to run the topology check.

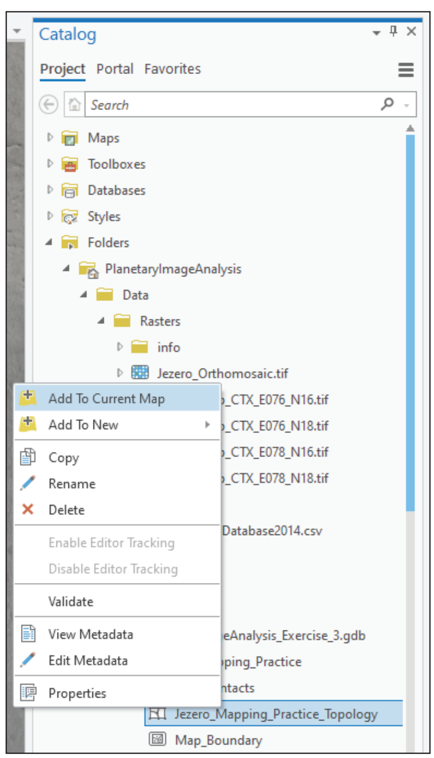
149. After the topology check is complete, the topology file will be added to the **Jezero_Mapping_Practice** feature dataset. In the **Catalog** pane, click the small triangle next to the **Jezero_Mapping_Practice** feature dataset to re-expand it (it automatically collapsed when the topology file was added) and view its contents.



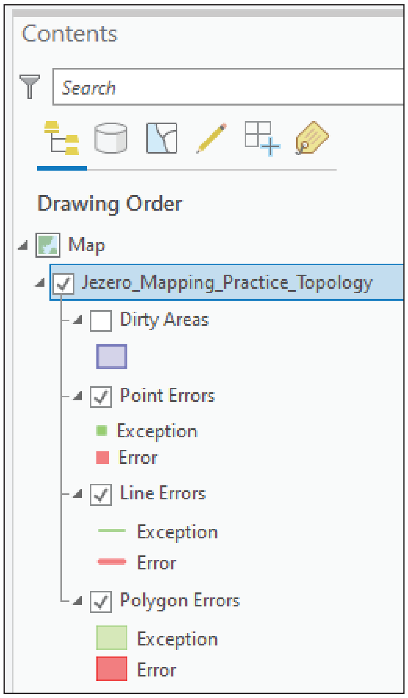
150. Before viewing the topology results, they should be validated. In the **Catalog** pane, right click the **Jezero_Mapping_Practice_Topology** item and select **Validate**.



151. Once the validation is complete, in the **Catalog** pane, right click the **Jezero_Mapping_Practice_Topology** item and select **Add to Current Map**.

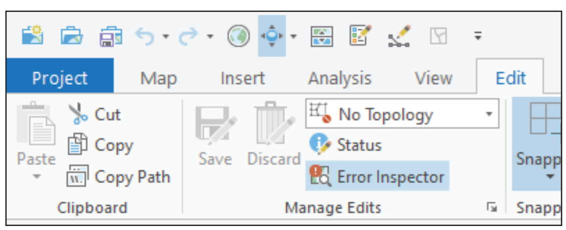


The topology results will be added to your map and will be listed in the Contents pane as a new map layer.

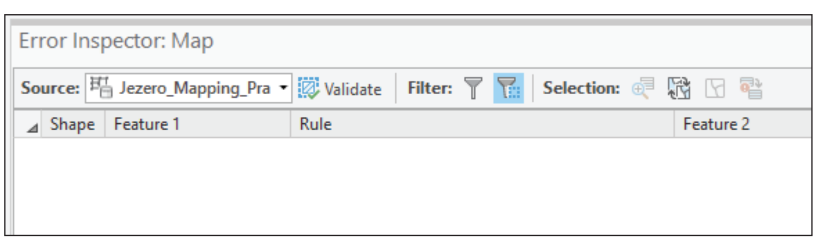


The topology results enable you to see if there are any areas of your map that violate the 5 rules you entered in the previous steps. If you have followed the instructions closely, you should see two red point errors in your map: one at the top, and one at the bottom (see the image above). Before moving on to create the geologic unit polygons, all topology errors must be reviewed and fixed as necessary.

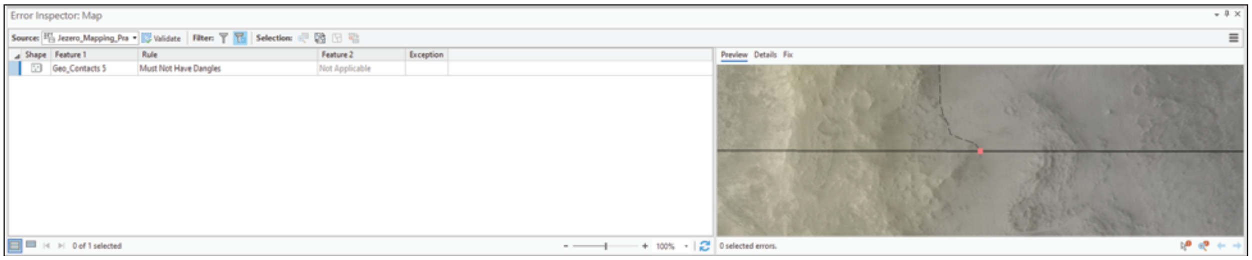
152. In the **Manage Edits** section of the **Edit** tab, click on the **Error Inspector** icon.



The **Error Inspector** will open in the bottom half of the window. By default, the **Jezero_Mapping_Practice_Topology** layer should be selected as the **Source** in the upper left corner of the **Error Inspector**.

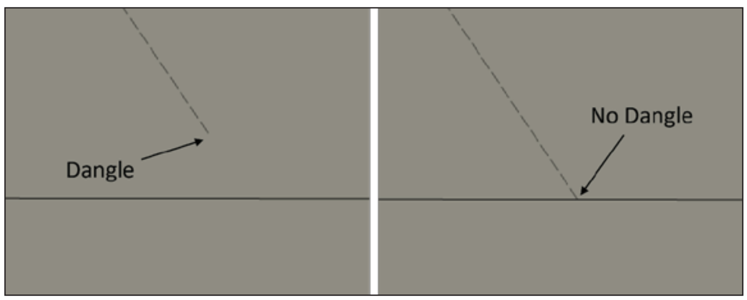


153. There are no features currently selected, so initially the **Error Inspector** table will appear empty. Pan through your map and click on the point error located on the southern edge of the map boundary to select it. Once the point error is selected, it will appear in the Error Inspector.



The **Error Inspector** will list the reason for the error under the **Rule** column. The rule that is listed here is the rule that is violated at this location. According to the topology check, the point at the southern map boundary violates the "Must Not Have Dangles" rule. You will use this information check and, if necessary, revise the linework at this location.

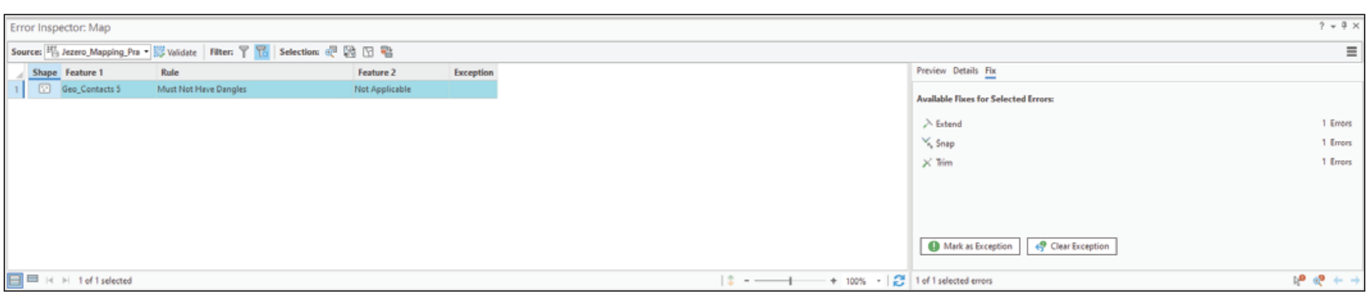
154. In the **Map** window, zoom in extremely close (approximately [~] 1:100 scale) to the location of this point error. Once you are zoomed in, in the **Contents** pane, uncheck the box next to the **Jezero_Mapping_Practice_Topology** layer to turn it off. This will allow you to check that the geologic contact and the map boundary connect at this location. Since you drew your contacts with snapping on, you should not have a dangle at this location, and the contact should appear like the "No Dangle" example shown below:



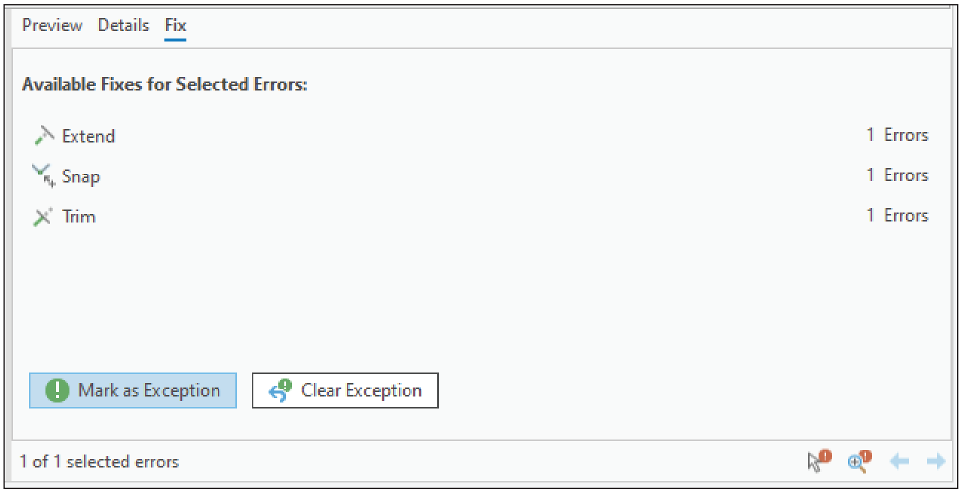
Note: If you do have a dangle at this location, use the Edit Vertices tool in the Tools section of the Edit tab to fix it before moving on.

If the **Geologic Contact** feature is touching the **Map Boundary** at this location, it is drawn correctly and is not an error. Instead, this location has been marked as an error because the topology tool was only checking the **Geologic Contacts** feature class and did not take into account the **Map Boundary** layer. However, the **Map Boundary** layer will also be used when you build the polygons for the geologic units. If you do not have a dangle at this location, this topology error should be marked as an exception before you move on to check any others.

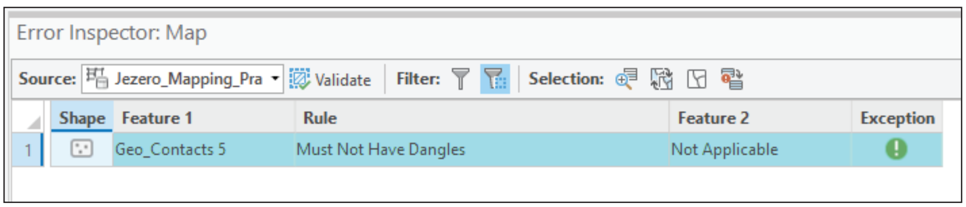
155. In the **Contents** pane, check the small box next to the **Jezero_Mapping_Practice_Topology** layer to turn it back on. Then, in the **Map** window, click on the point error at this location to make sure it is selected. In the **Error Inspector** pane, click on the point error to select it and then click on the **Fix** tab (located at the top of the **Preview** window) to view the available fixes for this feature.



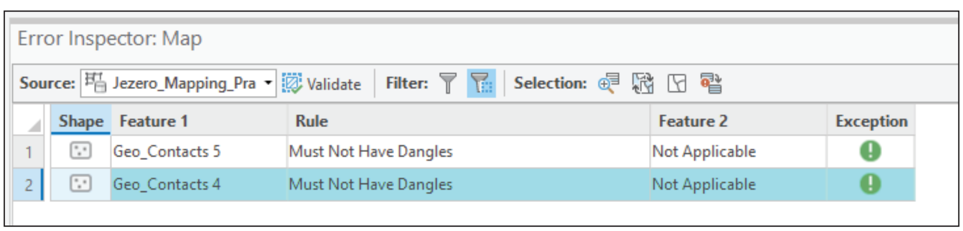
156. Since this location is not a true dangle, it does not need to be fixed, and instead should be marked as an exception. In the Fix tab of the **Error Inspector**, click on the **Mark as Exception** button.



You will see the **Error Inspector** table update to show this point error is now marked as an exception.



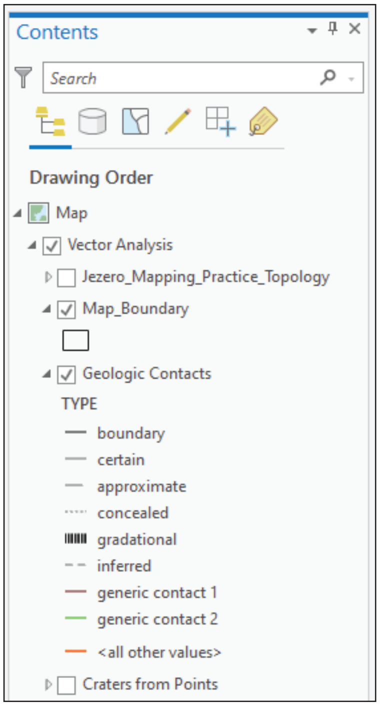
157. In the **Map** window, pan and zoom to view the point error on the northern edge of the **Map Boundary**. Then repeat the steps to check if this location is a true dangle. After checking the error, remedy any potential dangles (if necessary) and mark the error as an exception.



Note: If there are any other errors highlighted in your topology results, you will need to review and fix them (this is often done using the edit vertices tool) before moving on to the next step.

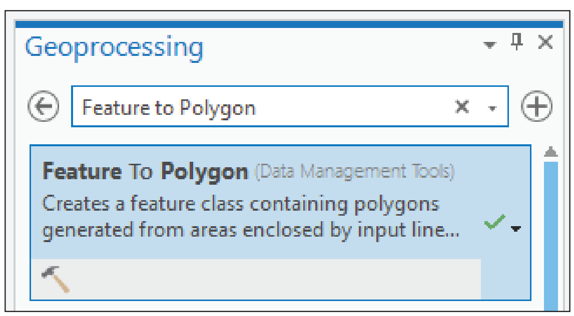
158. Once you have finished checking (and fixing, if necessary) all topology errors, in the **Manage Edits** section of the **Edit** tab, click the **Save** icon (if possible—if you did not make any changes to your map, this icon may not be active) and click **Yes** to save all edits. Then, in the **Selection** section of the **Edit** tab, click the **Clear** icon to deselect any topology features.

159. Click on the small **x** in the upper right corner of the **Error Inspector** to close it. Then, in the **Contents** pane, right click the **Map Boundary** layer and select **Zoom To Layer**. In the **Contents** pane, uncheck the box next to the **Jezero_Mapping_Practice_Topology** layer to turn it off, then click on the small arrow to collapse it. Drag the **Jezero_Mapping_Practice_Topology** layer to the top of the **Vector Analysis** group.



Now that you have checked topologies and fixed any errors, you are ready to create the polygons for your geologic units using the **Geologic Contacts** and **Map Boundary** features.

160. In the **Geoprocessing** section of the **Analysis** tab, click on the **Tools** icon to view the **Geoprocessing** pane. In the **Geoprocessing** pane, search for **Feature to Polygon**, and click on the **Feature to Polygon** tool to open it.



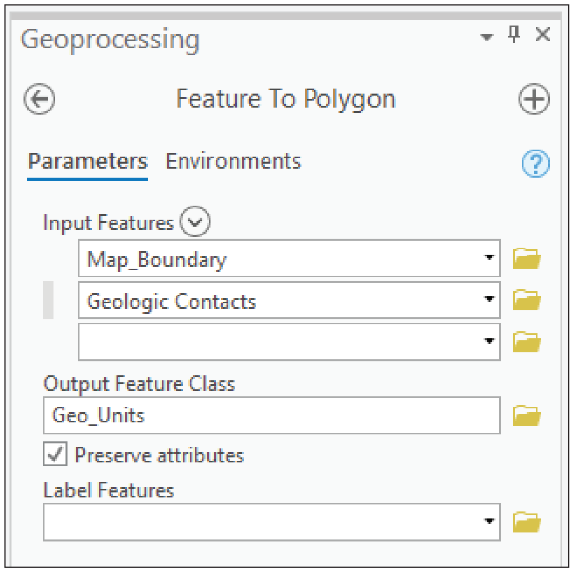
161. In the Feature to Polygon tool, set the following parameters:

Input Features: **Map_Boundary**, **Geologic Contacts**

Output Feature Class: **PlanetaryImageAnalysis_Exercise_3.gdb\Jezero_Mapping_Practice\Geo_Units**

Preserve attributes: **leave checked**

Label Features: <leave blank>

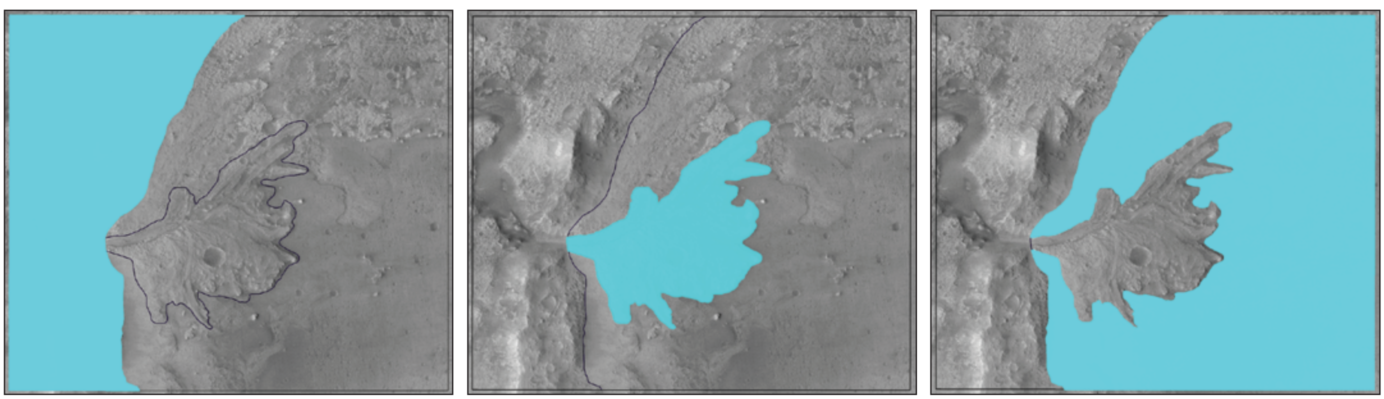


162. Click **Run** to create the **Geo_Units** polygon feature class.

When the **Feature to Polygon** tool is complete, the new **Geo_Units** feature class will be added to the map as a new layer.

163. Click the small **x** in the upper right corner of the **Feature To Polygon** tool to close it.

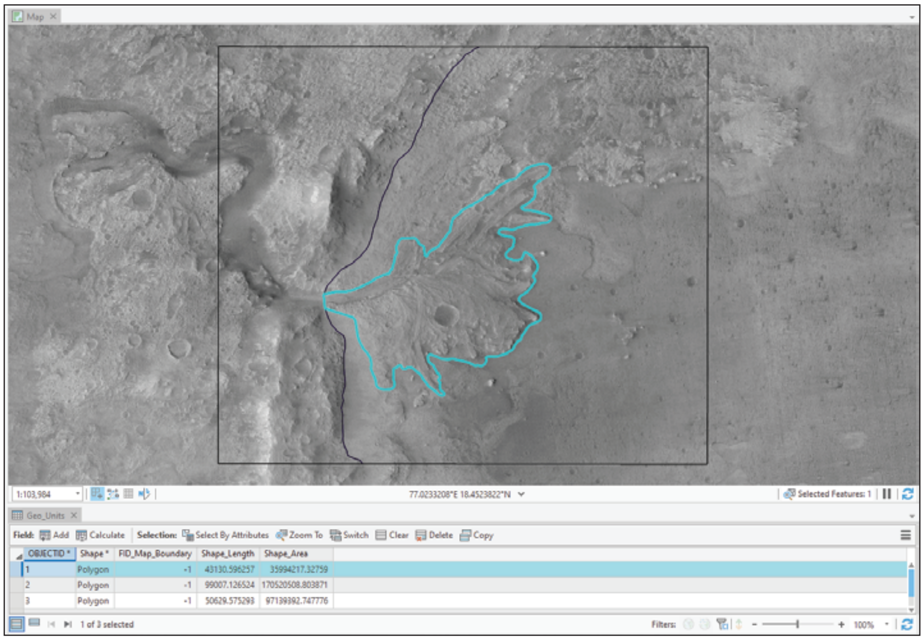
164. In the map, click inside each of the different geologic units to explore the new **Geo_Units** layer. Confirm that there are three separate units, and they are the correct size, shape, and location.



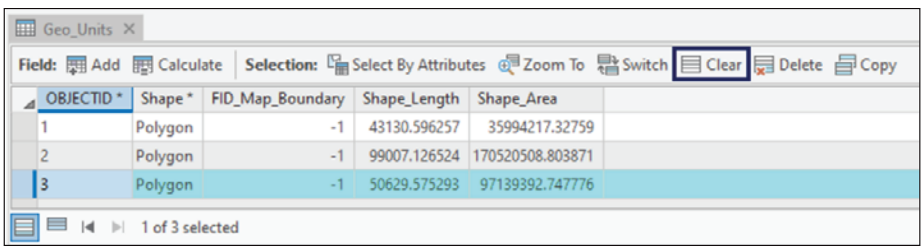
165. In the **Contents** pane, right click on the **Geo_Units** layer and select **Attribute Table** to open it.

The **Geo_Units Attribute Table** contains three polygons.

166. In the **Attribute Table**, click on the gray box to the left of each row to select it. When an object is selected in the **Attribute Table**, it will also be highlighted on the map.

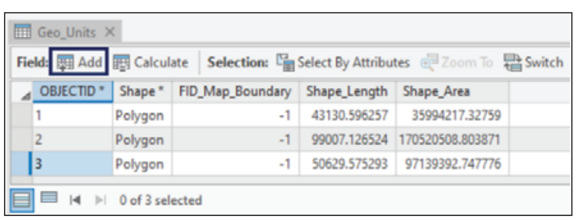


167. After you have explored each polygon, click on the **Clear** icon in the **Attribute Table** toolbar to clear the selection.

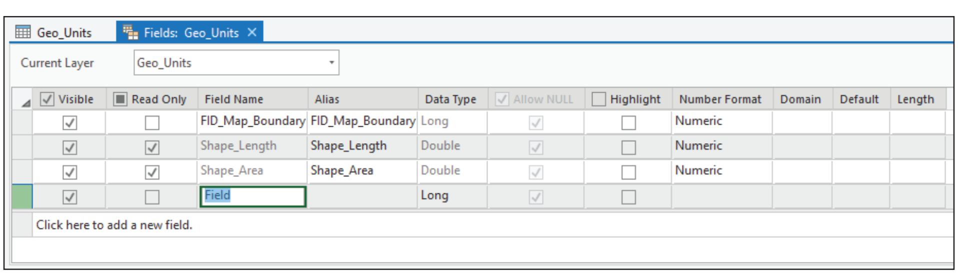


Polygons have been created for the geologic units (**Geo_Units**), but the **Attribute Table** does not yet contain a field in which you may assign geologic units to them.

168. In the **Geo_Units Attribute Table**, click on the **Add Field** icon.



This will open the **Geo_Units Attribute Table** Field editor in a new tab.



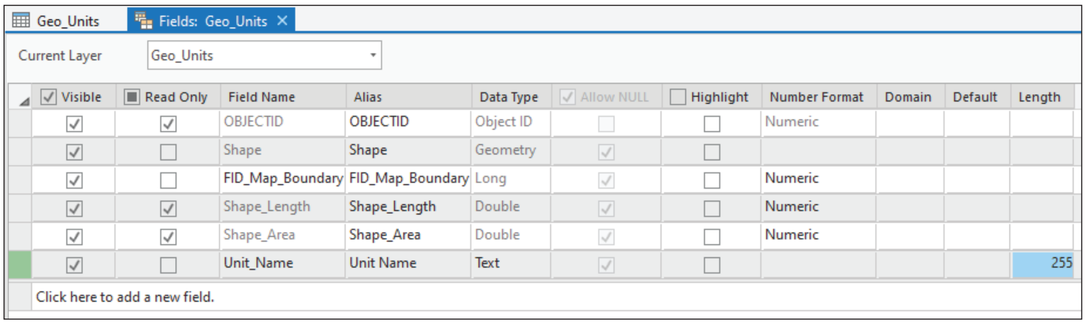
169. In the **Fields: Geo_Units** table, enter the following:

Field Name: **Unit_Name**

Alias: **Unit Name**

Data Type: **Text**

Length: **255**

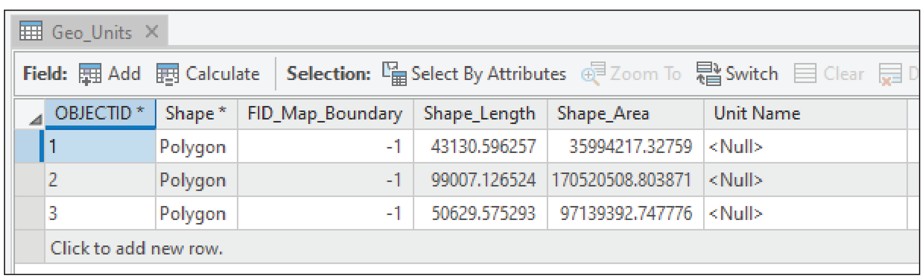


Visible	Read Only	Field Name	Alias	Data Type	Allow NULL	Highlight	Number Format	Domain	Default	Length
☑	☑	OBJECTID	OBJECTID	Object ID	☐	☐	Numeric			
☑	☐	Shape	Shape	Geometry	☑	☐				
☑	☐	FID_Map_Boundary	FID_Map_Boundary	Long	☑	☐	Numeric			
☑	☑	Shape_Length	Shape_Length	Double	☑	☐	Numeric			
☑	☑	Shape_Area	Shape_Area	Double	☑	☐	Numeric			
☑	☐	Unit_Name	Unit Name	Text	☑	☐				255

170. Press **enter** to finalize the new field entry. Then, in the **Changes** section of the **Fields** tab, click the **Save** icon to save this new field.

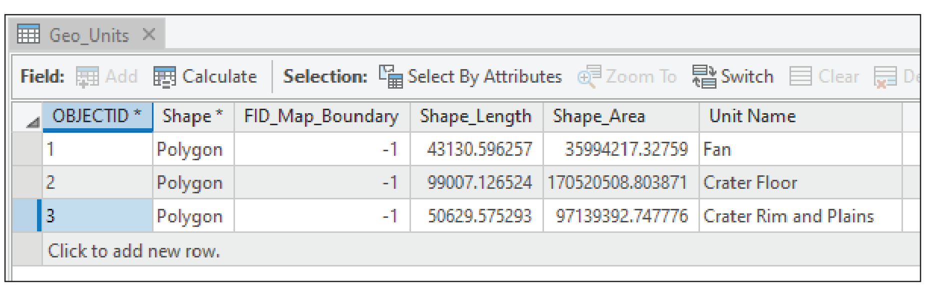
171. Click on the small **x** in the **Fields: Geo_Units** tab to close it and return to the **Geo_Units Attribute Table**.

The **Geo_Units Attribute Table** will automatically update to include the new **Unit Name** field.



OBJECTID *	Shape *	FID_Map_Boundary	Shape_Length	Shape_Area	Unit Name
1	Polygon	-1	43130.596257	35994217.32759	<Null>
2	Polygon	-1	99007.126524	170520508.803871	<Null>
3	Polygon	-1	50629.575293	97139392.747776	<Null>

172. To assign a **Unit Name** to each polygon, click and hover over the <Null> **Unit Name** value for each row to select the text. Once the text has been selected, type the new **Unit Name** and press **enter** to apply the change. Enter the new unit name for each of the three polygons: Crater Rim and Plains, Crater Floor, and Fan



OBJECTID *	Shape *	FID_Map_Boundary	Shape_Length	Shape_Area	Unit Name
1	Polygon	-1	43130.596257	35994217.32759	Fan
2	Polygon	-1	99007.126524	170520508.803871	Crater Floor
3	Polygon	-1	50629.575293	97139392.747776	Crater Rim and Plains

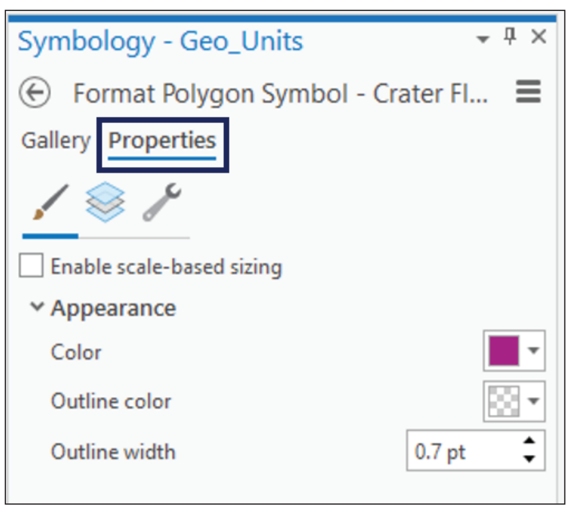
Now that the polygons have unit names, the symbology can be updated to reflect these units.

173. Click on the small **x** in the **Geo_Units Attribute Table** tab to close it.

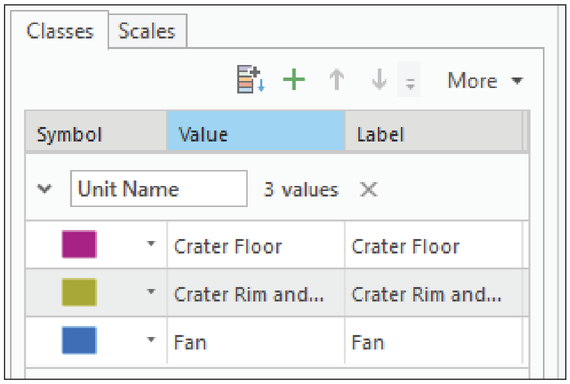
174. In the **Contents** pane, right click the **Geo_Units** layer and select **Symbology**.

175. In the **Symbology** pane, change the **Primary symbology** to **Unique Values**. Then set **Field 1** to **Unit Name**.

176. In the **Classes** tab of the **Symbology** pane, click on the colored symbol box for the **Crater Floor** unit to open the **Format Polygon Symbol** options. Then click on the **Properties** tab to switch to the manual symbol options. Set the **Color** to **Cattleya Orchid**, and the **Outline Color** to **No Color**. Then click **Apply** to update the symbol.



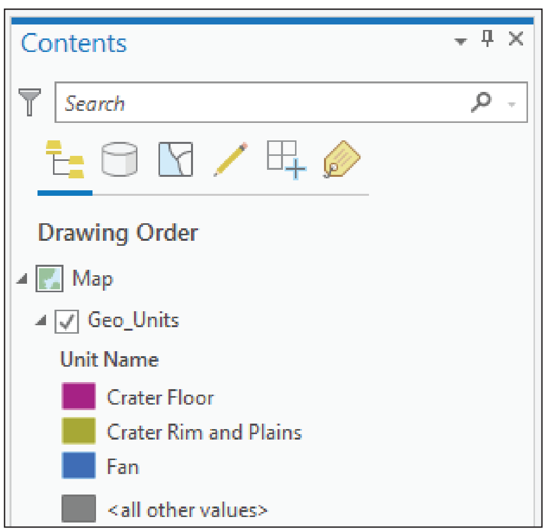
177. Click on the back arrow in the upper left of the **Format Polygon Symbol** pane to return to the **Symbology** pane. Then repeat the above steps to update the **Color** and **Outline Color** for the Crater Rim and Plains (**Olivenite Green**/**No Color**) and Fan (**Cretan Blue**/**No Color**) units.



Unit colors are meaningful and typically help indicate the rock type and (or) origin of the unit. See the USGS Planetary Mapping Guidelines for more information. The colors used in this exercise are adapted from the interactive version of the USGS map of Jezero crater and Nili Planum, Mars (Sun and Stack, 2020).

178. Click on the small **x** in the upper right corner of the **Symbology** pane to close it.

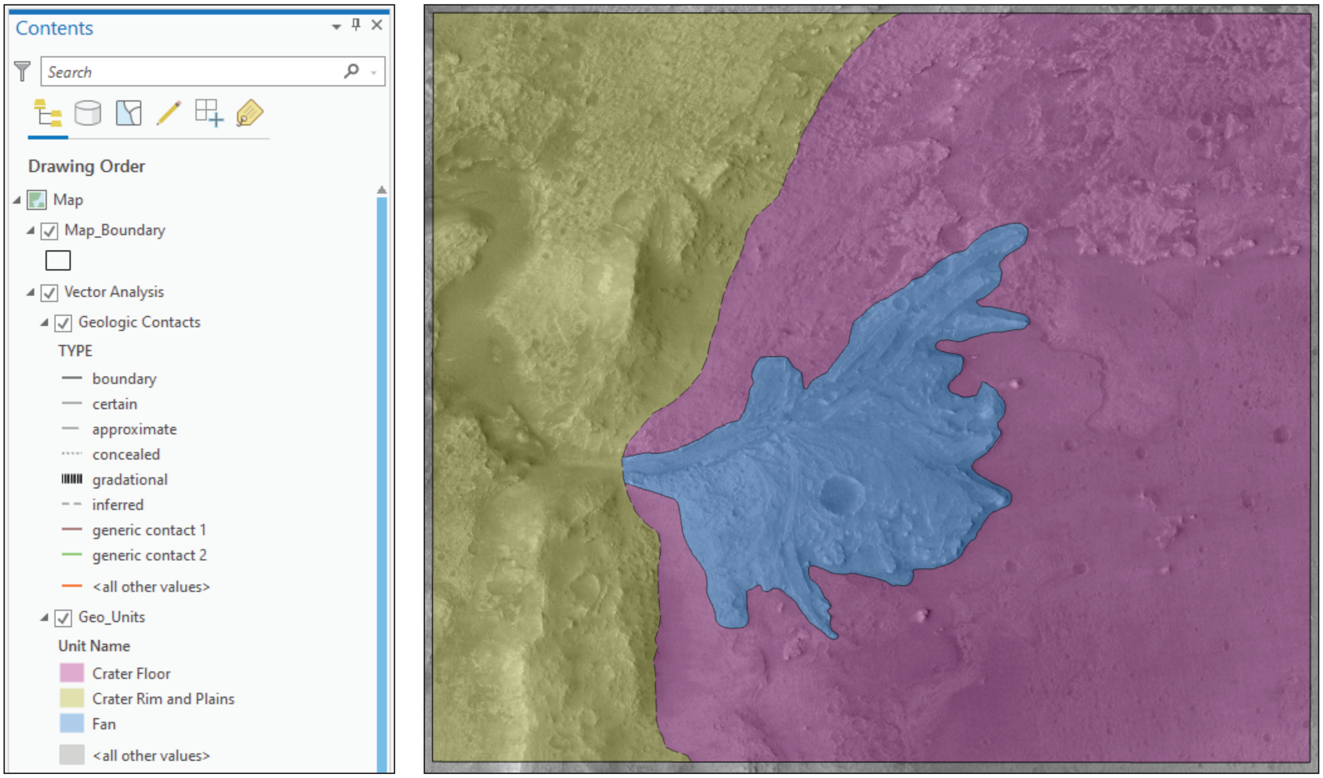
As you edited the **Geo_Unit** symbols, the map and **Contents** pane automatically update to reflect these changes.



Now that you have created the polygons for the geologic units and applied the symbology, you can view this layer on top of the base imagery.

179. In the **Contents** pane, select the **Geo_Units** layer. Then, in the **Effects** section of the **Feature Layer Appearance** tab, set the **transparency** to **70%**.

180. In the **Contents** pane, click on the **Geo_Units** layer and drag it into the **Vector Analysis** group, placing it below the **Geologic Contacts** layer. This will allow the **Geologic Contacts** to be visible since they will now be drawn on top of the **Geo_Units** layer.



Summary

Through this exercise you explored the basic process of planetary geologic mapping and learned how to import, create, and work with vector data in ArcGIS Pro. You imported a Martian crater database, an existing point-based dataset, and used those data to create polygons representing crater rims within your map area through two different methods: symbology, and buffering. You also learned how to create and add features to a new feature class by drawing geologic contacts for the three generalized geologic units within your map area. You then learned how to complete a topology check before creating geologic unit polygons. You also learned how to create polygons from linear features and used the geologic contacts feature class to create polygons for each geologic unit. In addition to creating and editing features, you also learned how to edit attribute tables to assign contact types and unit names, and how to update symbologies to reflect those new attributes both manually and through the use of symbology layer files. These processes represent the basic process for planetary geologic mapping. Several planetary geologic mapping tools are available through the Planetary Geologic Mapping Program website, including the Planetary Geologic Mapping (PGM) Toolbox. The PGM Toolbox includes several tools which help automate steps in the mapping process and help to check your work for errors before proceeding. Additional guidelines for planetary geologic mapping can be found in the USGS Astrogeology Planetary Mapping Guidelines.

To Prepare for the Next Exercise

If you wish to start with a fresh GIS project for Exercise 4, click the **x** in the upper right corner of your ArcGIS Pro window to close it. Alternatively, if you prefer to continue working in this GIS project, complete the following steps before moving on to Exercise 4: In the **Contents** pane, click on the small triangle next to the **Vector Analysis** group to collapse it and uncheck the box for the group to turn off all layers within it. You should end with only the base CTX imagery (**CTX_mosaic**) displayed. Then, in the **Contents** pane, right click the **CTX_mosaic** layer and select **Zoom to Layer** to view the full extent of your region of interest.

Exercise 4: Analyzing Data for Threshold Criteria (Landing Site Selection)

In planetary science, GIS is often used to conduct analyses and interpret data to better understand planetary bodies. One such analysis is selecting suitable sites for landed missions like NASA's Mars Science Laboratory (MSL) rover (Curiosity) which landed in Gale crater on August 6, 2012, and the Mars 2020 rover (Perseverance) which landed in Jezero crater on February 18, 2021. Landing site selection must consider several factors such as the elevation, slope, and rockiness of an area. These factors, along with many others, are assessed to identify regions where a spacecraft may land safely. In this exercise, you will conduct a simplified landing site assessment in the Jezero crater and Nili Planum region using two different methods: geoprocessing tools, and raster functions.

As you learned in Exercise 2, raster functions differ from geoprocessing tools because they apply the function directly to the pixels of the input data and show the result as a temporary data layer. This decreases the amount of computer storage space that is needed to complete an analysis. Raster functions also only complete the analysis for the pixels you are currently viewing (those within the current display extent) and only at the scale which they are being viewed. This makes raster functions particularly useful for quick analyses and experimentation. Additionally, raster functions may be strung together to create custom raster functions, which can be saved and used later by you and those with whom you share the custom raster function.

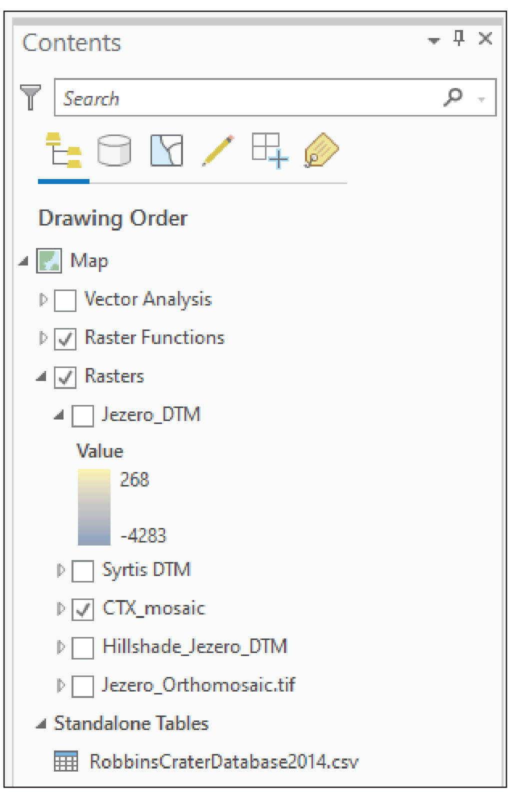
Part 1: Analysis with Geoprocessing Tools

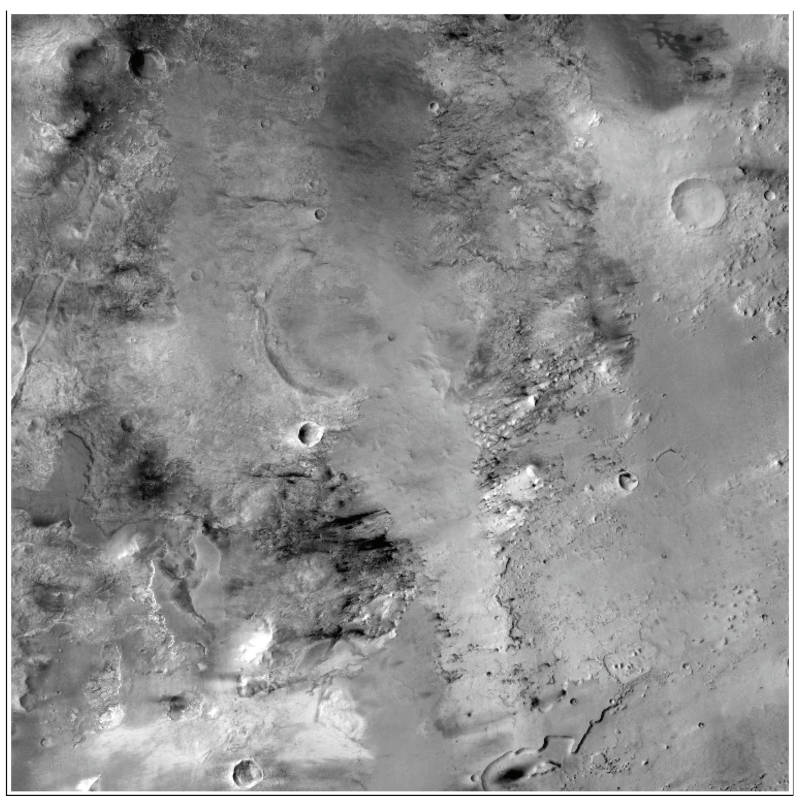
If you wish to continue working with the GIS project from Exercise 3 (**PlanetaryImageAnalysis_Exercise_3.aprx**) skip to step 2. If you prefer to start with a fresh GIS project, begin with step 1 below:

1. In your Windows File Explorer, navigate to the **PlanetaryImageAnalysis\Exercise_4** folder and double click the **PlanetaryImageAnalysis_Exercise_4** project file (**.aprx**) to open it in ArcGIS Pro.

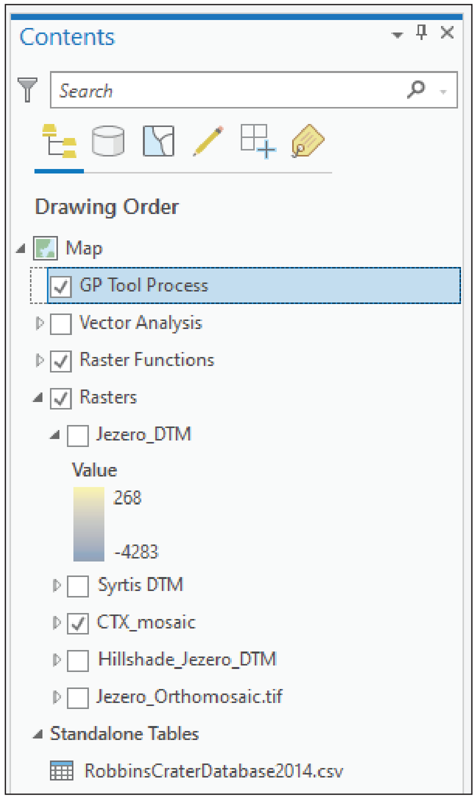
The **PlanetaryImageAnalysis_Exercise_4** project will open in ArcGIS Pro. Data has already been added to the map, and all map layers are listed in the **Contents** pane.

2. Begin by checking your map layers in the **Contents** pane. All layers should be turned off except the **CTX_mosaic** layer. If you are not currently zoomed to the extent of the **CTX_mosaic** layer, right click it in the **Contents** pane and select **Zoom to Layer**.



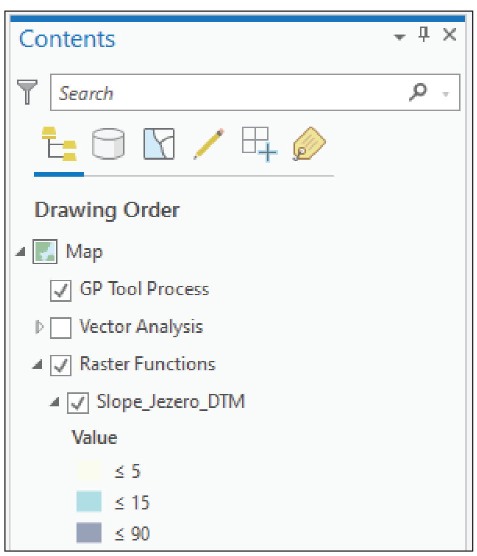


3. In the **Contents** pane, right click **Map** and select **New Group Layer**. Then click on this **New Group Layer** and hover to rename it. Rename this group layer **GP Tool Process** and press **enter** to finalize the new group layer name.



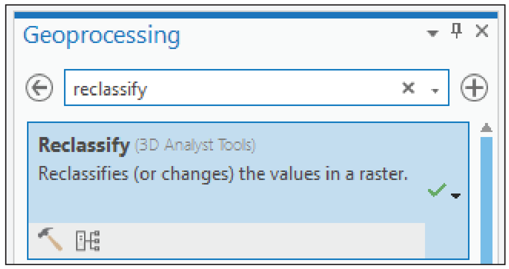
All outputs which are created in this section will be placed in this new group layer.

4. In the **Contents** pane, click on the small triangle next to the **Raster Functions** group to expand it. Then check the box for the **Slope_Jezero_DTM** raster function layer you created in Exercise 2 to turn it back on.



Although the **Slope_Jezero_DTM** layer was created using a raster function, it can still be used as an input layer for a geoprocessing tool the same way you would input any other raster layer. Alternatively, this slope analysis layer could have been created using the **Slope** geoprocessing tool. Since you already created it using the raster function, you will use the raster function layer as the input for the next step.

5. In the **Geoprocessing** section of the **Analysis** tab, click on the **Tools** icon to open the **Geoprocessing** pane. Then search for the **Reclassify** tool and click to open it.

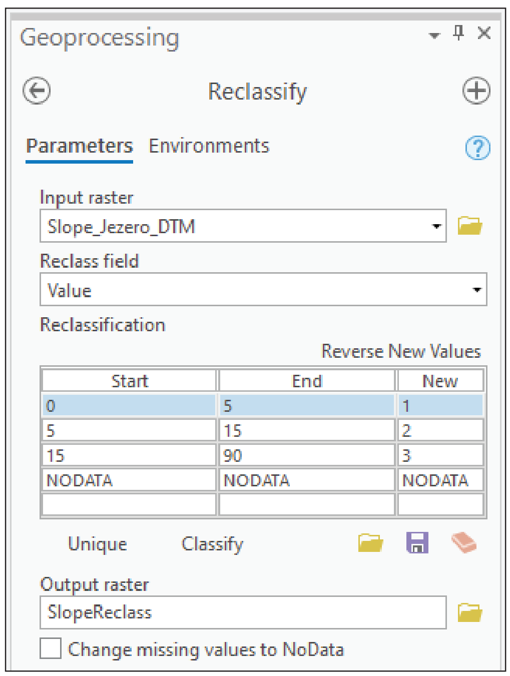


6. In the **Reclassify** tool pane, set the following inputs:

   Input raster: **Slope_Jezero_DTM**

   Output raster: **PlanetaryImageAnalysis_Exercise_4.gdb\SlopeReclass**

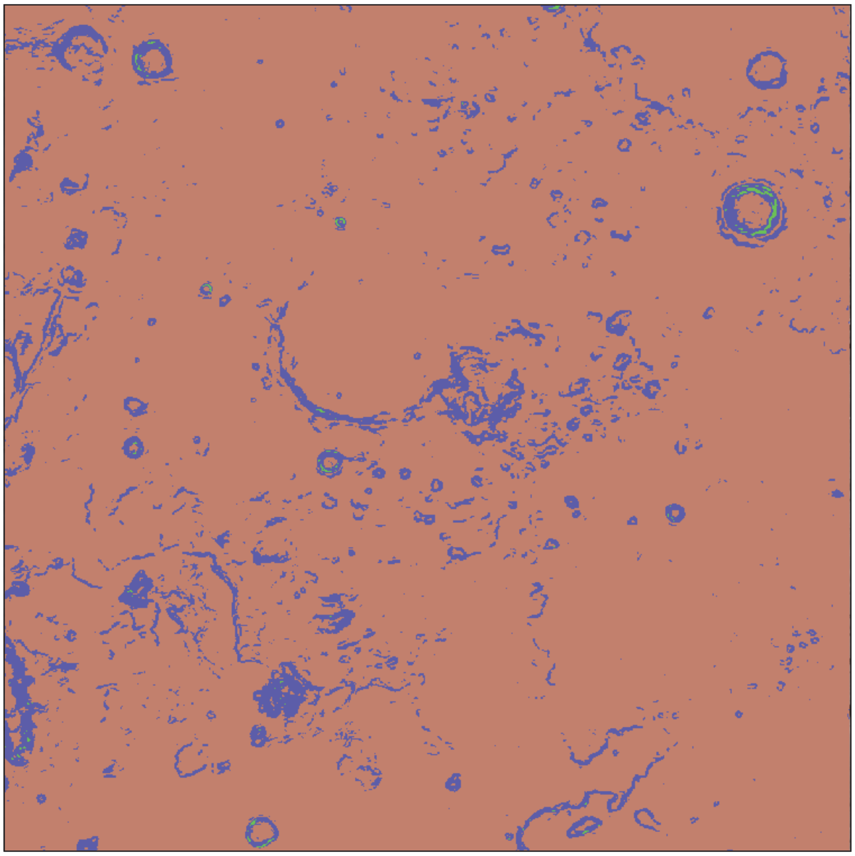
   Leave all other default values.



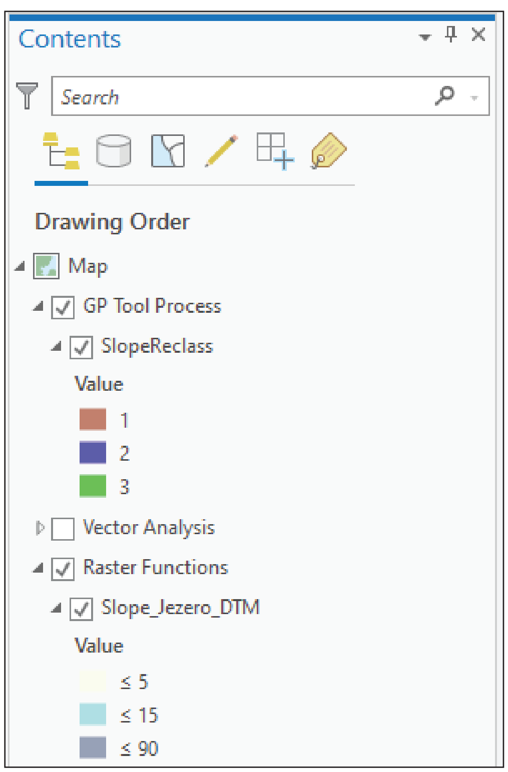
In Exercise 2, you set the **Slope_Jezero_DTM** layer symbology to classes. Because the classes have already been defined, they will automatically be used as the **Reclassification** boundaries for the **Reclassify** tool. If needed, you could alter those boundaries before running the tool. For this analysis, these boundaries are already set to what you need.

7. Click **Run** to run the **Reclassify** tool.

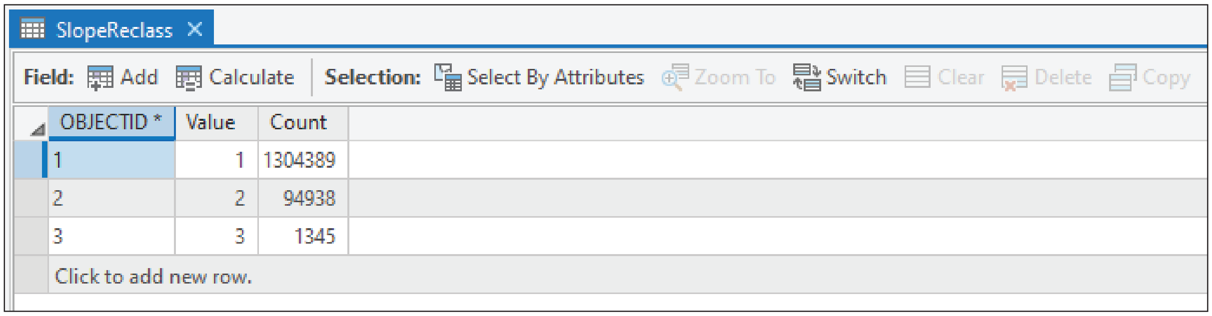
The **Reclassify** tool output (**SlopeReclass**) will be added to the map as a new layer.



8. In the **Contents** pane, click on the **SlopeReclass** layer and drag it into the new **GP Tool Process** group. Then click on the small triangle to expand the **GP Tool Process** group and view its contents.



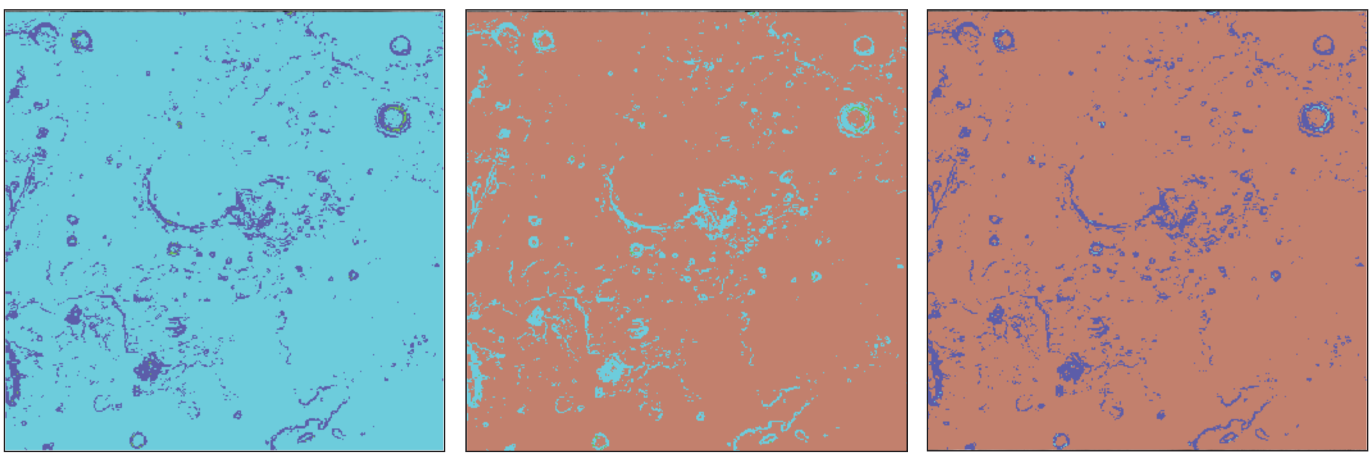
9. Take a moment to explore the output from the **Reclassify** tool. In the **Contents** pane, right click the **SlopeReclass** layer and select **Attribute Table** to view the new dataset.



OBJECTID *	Value	Count
1	1	1304389
2	2	94938
3	3	1345
Click to add new row.		

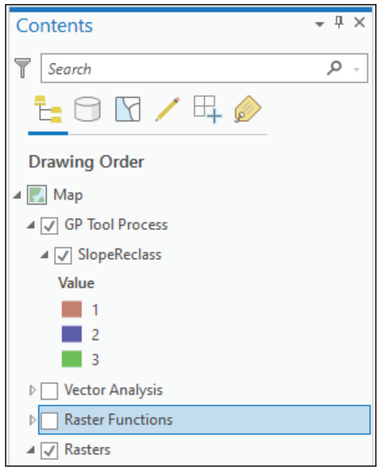
The **Slope_Jezero_DTM** layer displays slope values from 0° to 90°. The **Reclassify** tool grouped those values into three classes. The new classes have the values 1 (0°–5° slopes), 2 (5°–15° slopes), and 3 (slopes that are greater than [>] 15°). Through the reclassification process, the actual slope angles do not persist—instead, they are grouped into the three new classes. In the **Attribute Table,** you can view how many pixels are in each class. Class 1 (0°–5° slopes) are slopes that are gentle enough to be acceptable for a landing site. This class has the most pixels within the map area, followed by class 2 (non-ideal 5°–15° slopes) and class 3 (slopes that are >15° and are unacceptable for landing site selection).

10. In the **SlopeReclass Attribute Table**, click on the small box to the left of each object to select it and view the corresponding areas on the map.



11. Once you are done exploring the new **SlopeReclass Attribute Table**, click on the **Clear** icon in the **SlopeReclass Attribute Table** tool bar to clear the selection, the click on the small **x** in the **SlopeReclass Attribute Table** tab to close it and return to the full map view.

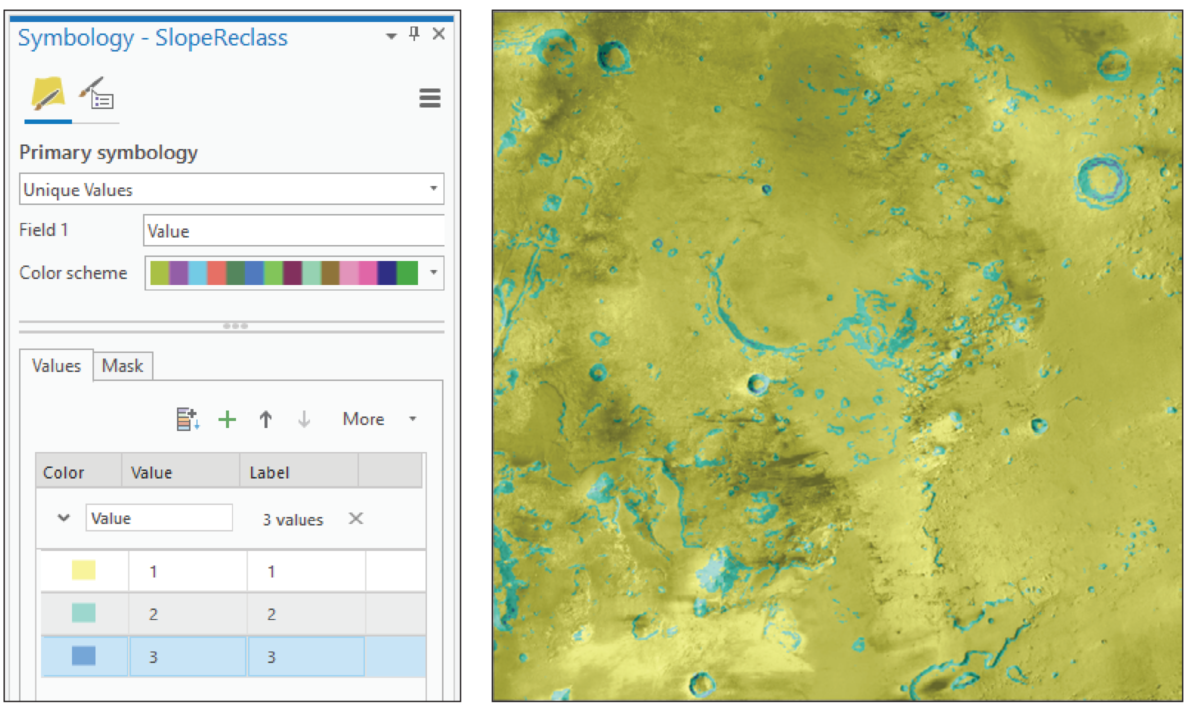
12. In the **Contents** pane, uncheck the box for the **Raster Functions** group layer to turn it off and click on the small triangle to collapse it. You do not need to view this group for the remainder of the geoprocessing tool analysis. You will return to it in part 2 for the raster function analysis.



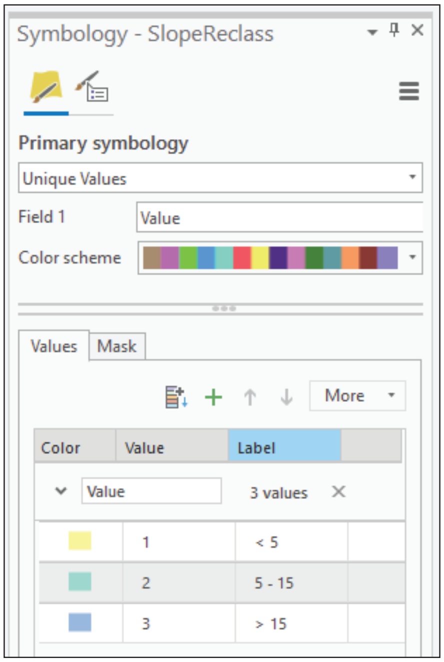
The new **SlopeReclass** layer is currently opaque and does not allow you to view the underlying CTX imagery (**CTX_mosaic**).

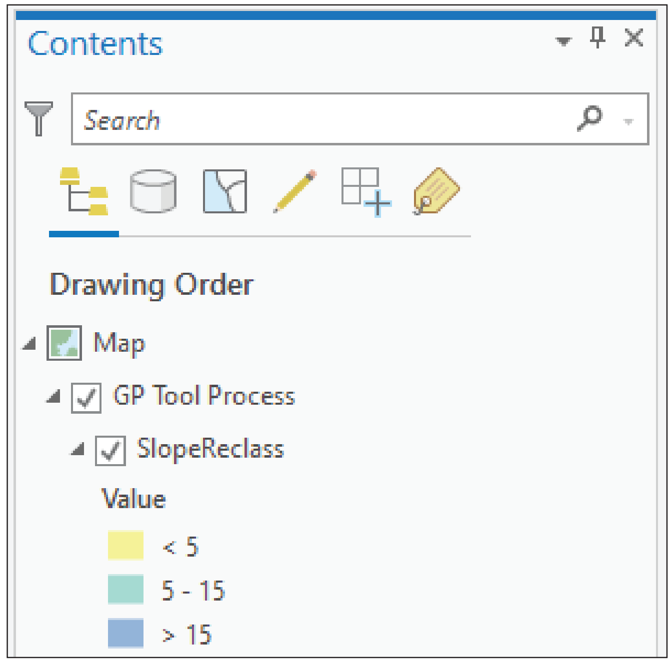
13. In the **Contents** pane, click on the **SlopeReclass** layer to select it. Then in the **Effects** section of the **Raster Layer Appearance** tab, set the **transparency** to **60%.**

14. In the **Contents** pane, right click the **SlopeReclass** layer and select **Symbology** to update the colors for each class. In the **Values** table of the **Symbology** pane (the lower portion of the **Symbology** pane), click on each small colored box to set the colors for the classes. The new colors should be set to **Solar Yellow** (class 1), **Tourmaline Green** (class 2), and **Ultra Blue** (class 3). As you change the colors, you will see them update in the **Contents** pane **SlopeReclass** layer symbology and in the map itself.



15. In the **Values** tab of the **Symbology** pane, click on the text in the Label column to update each class label. New class labels should be **< 5** for class 1, **5 – 15** for class 2, and **> 15** for class 3. Press **enter** to apply each new label. As you update the labels, you will see them change in the **Contents** pane **SlopeReclass** layer symbology.





16. Once you have finished updating the **SlopeReclass** layer symbology, click on the small **x** in the upper right corner of the **Symbology** pane to close it and return to the **Geoprocessing** pane.

In the **Geoprocessing** pane, the **Reclassify** tool will still be open from your earlier analysis. You will run the **Reclassify** tool a second time, using the **Jezero_DTM** layer as the input. This second **Reclassify** analysis will identify areas that are above and below the elevation threshold for a safe landing site.

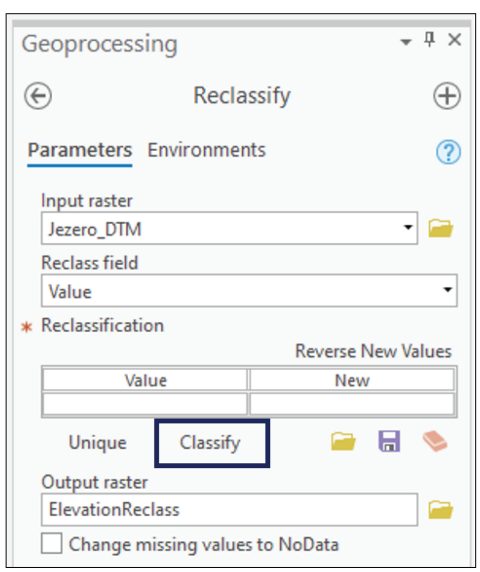
17. In the **Reclassify** tool pane, set the following inputs:

    Input raster: **Jezero_DTM**

    Reclass field: **Value**

    Output raster: **PlanetaryImageAnalysis_Exercise_4.gdb\ElevationReclass**

18. When you changed the **Input Raster**, the **Reclassification** options reset to a blank table. To set the **Reclassification** options, click on **Classify**, located below the table. Then set the **Number of classes** to **2** and click **OK**.

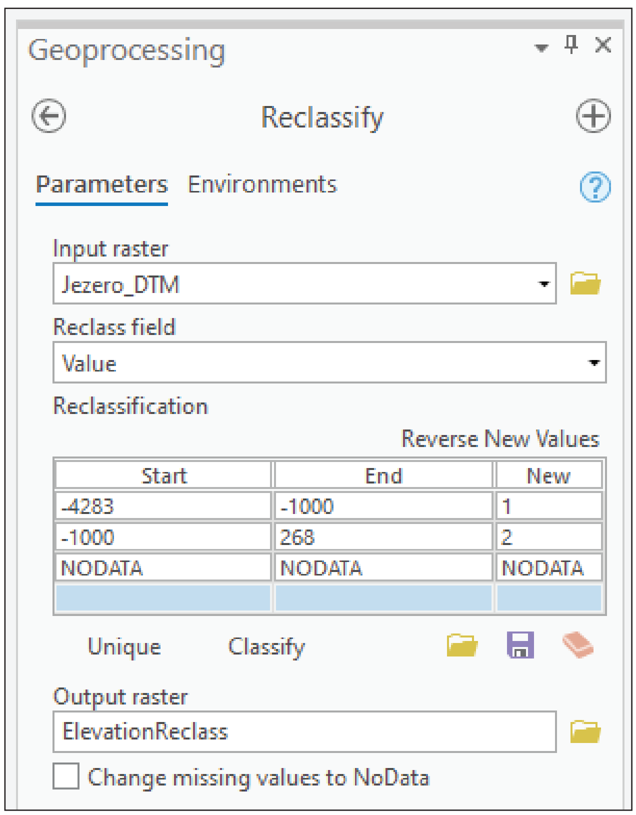


19. The new classes will be assigned default values. Click in the table and edit the **Start** and **End** values to set the following inputs:

    Reclassification:

Start	End	New
-4283	-1000	1
-1000	268	2
NODATA	NODATA	NODATA

Earlier, when you ran the **Reclassify** tool on the **Slope_Jezero_DTM** layer, classes had already been established through the symbology. No classes have been identified for the **Jezero_DTM** layer so the initial **Reclassification** table was empty. The values you have entered here are based on the elevation range within your region of interest (the 268-m maximum and the -4,283-m minimum elevation values can be found in the **Contents** pane under the **Jezero_DTM** layer symbology). For landing sites, acceptable locations must be located at elevations that are -1,000 m or lower (the new class 1) to provide enough atmosphere for aerobraking. All elevations that lie above -1,000 m are unacceptable and will be separated into class 2.

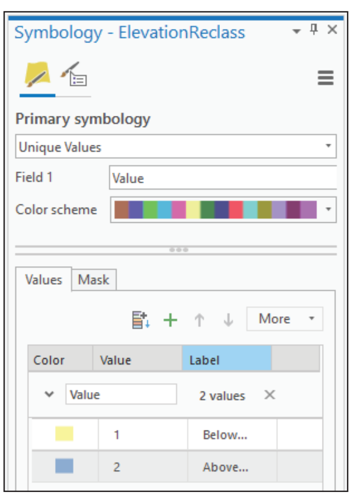


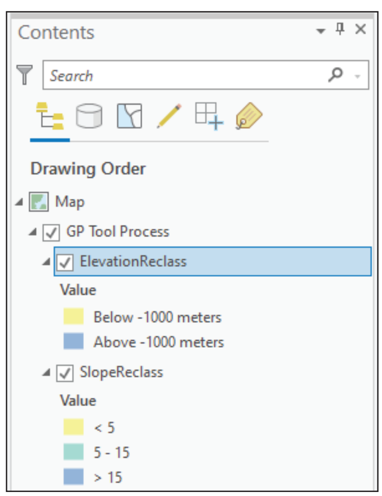
20. In the **Reclassify** tool pane, click **Run** to create the new **ElevationReclass** layer.

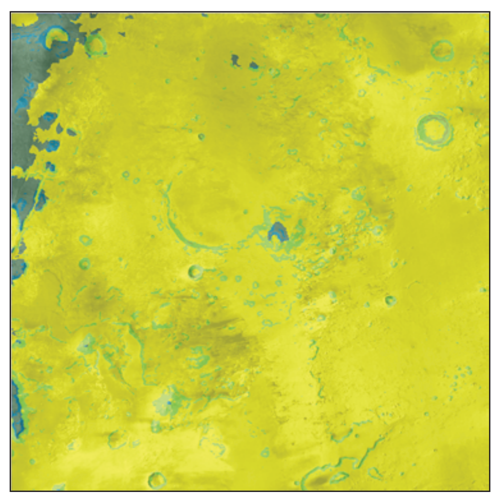
    The **ElevationReclass** dataset will be added to the map as a new layer.

21. In the **Contents** pane, click on the **ElevationReclass** layer and drag it into the **GP Tool Process** group. Then, in the **Contents** pane click on the **ElevationReclass** layer to select it and change the **transparency** to **60%** (located in the **Raster Layer Appearance** tab).

22. In the **Contents** pane, right click the **ElevationReclass** layer and select **Symbology** to update the colors for each class. In the **Values** table of the **Symbology** pane, click on each small colored box to set the colors for the classes. The new colors should be set to **Solar Yellow** (class 1) and **Ultra Blue** (class 2). Then, in the **Values** tab of the **Symbology** pane, change the class **Labels** to **Below -1000 meters** (class 1), and **Above -1000 meters** (class 2). When you have finished, click on the small **x** in the upper right corner of the **Symbology** pane to close it and return to the **Geoprocessing** pane.

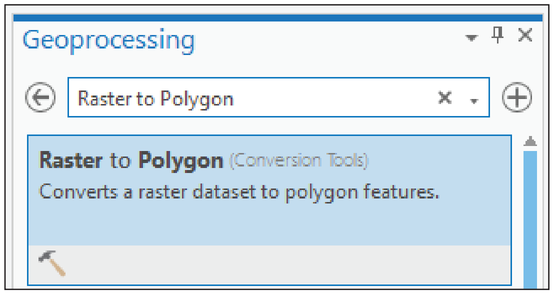






So far, you have identified the areas with acceptable slopes (<5°) and elevation (below -1,000 m). However, these datasets need to be combined. To combine them and continue with the subsequent analysis steps, these results must first be converted to polygons.

23. In the upper left corner of the **Geoprocessing** pane, click on the **back arrow** to return to the **Geoprocessing** tool menu. Then search for **Raster to Polygon** and click on the **Raster to Polygon** tool to open it.



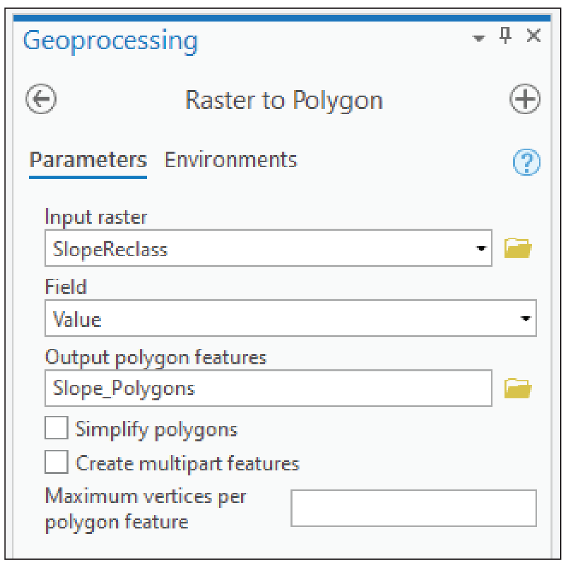
24. In the **Raster to Polygon** tool, set the following parameters:

    Input raster: **SlopeReclass**

    Field: **Value**

    Output polygon features: **PlanetaryImageAnalysis_Exercise_4.gdb\Slope_Polygons**

    Uncheck the box for Simplify polygons.



25. Click **Run** to create the **Slope_Polygons** layer.

The **Slope_Polygons** will be added to the map as a new layer. Next, repeat the process to create polygons for the **ElevationReclass** layer.

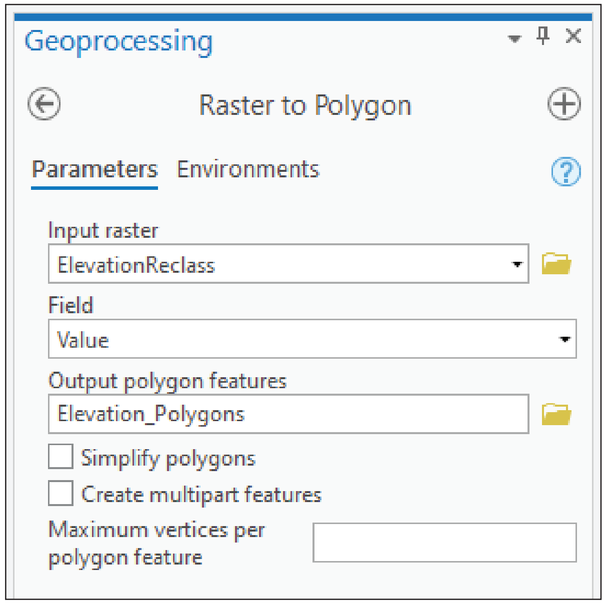
26. In the **Raster to Polygon** tool, set the following parameters:

    Input raster: **ElevationReclass**

    Field: **Value**

    Output polygon features: **PlanetaryImageAnalysis_Exercise_4.gdb\Elevation_Polygons**

    Uncheck the box for Simplify polygons.



27. Click **Run** to create the **Elevation_Polygons** layer.

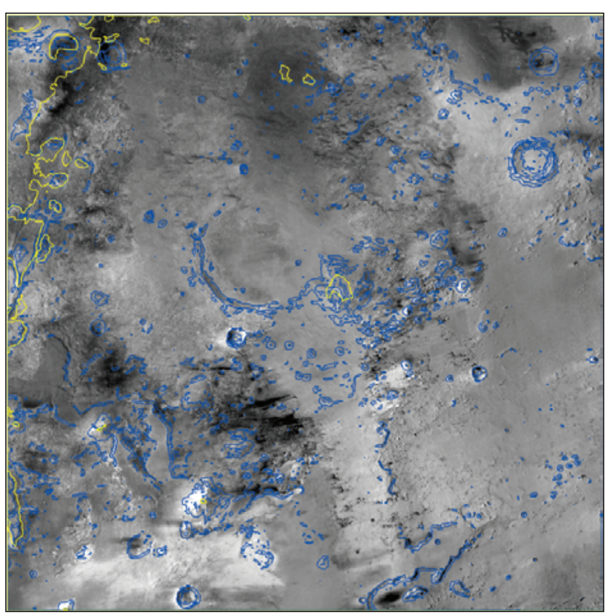
Both the **Slope_Polygons** and **Elevation_Polygons** layers have been added to your map.

28. In the **Contents** pane, click and drag and **Slope_Polygons** and **Elevation_Polygons** to the top of the **GP Tool Process** group. Then, in the **Contents** pane, click on the symbol box for the **Elevation_Polygons** layer to open the **Format Polygon Symbol** pane. In the **Properties** tab of the **Format Polygon Symbol** pane, change the **Color** to **No Color** and the **Outline color** to **Solar Yellow**. Leave the default line thickness of 0.7. Click **Apply** to update the **Elevation_ Polygons** symbol.

29. In the **Contents** pane, click on the symbol box for the **Slope_Polygons** layer to open the **Format Polygon Symbol** pane. In the **Properties** tab of the **Format Polygon Symbol** pane, change the **Color** to **No Color** and the **Outline color** to **Ultra Blue**. Leave the default line thickness of 0.7. Click **Apply** to update the **Slope_Polygons** symbol. Then click on the small **x** in the upper right corner of the **Symbology** pane to close it and return to the **Geoprocessing** pane.

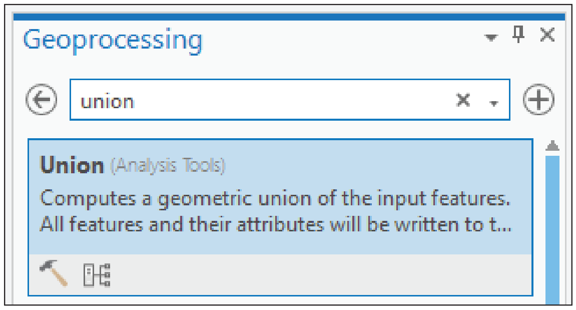
30. In the **Contents** pane, uncheck the boxes for the **ElevationReclass** and **SlopeReclass** layers to turn them off.

Your map now shows the polygon boundaries for the **Elevation_Polygons** (yellow) and **Slope_Polygons** (blue) layers.



Now that you have converted the slope and elevation analyses to polygons, these outputs can be combined to find areas that meet both the slope and elevation criteria for an acceptable landing site. There are several different data overlay options in ArcGIS Pro. For the purposes of this analysis, you will use the **Union** tool.

31. In the upper left corner of the **Geoprocessing** pane, click on the **back arrow** to return to the **Geoprocessing** tools menu. Search for **Union** and click on the **Union** tool to open it.

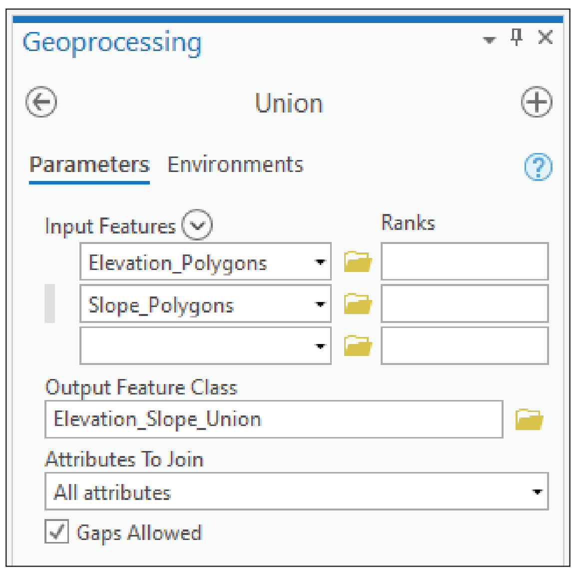


32. In the **Union** tool, set the following parameters:

    Input Features: **Elevation_Polygons** and **Slope_Polygons**

    Output Feature Class: **PlanetaryImageAnalysis_Exercise_4.gdb\Elevation_Slope_Union**

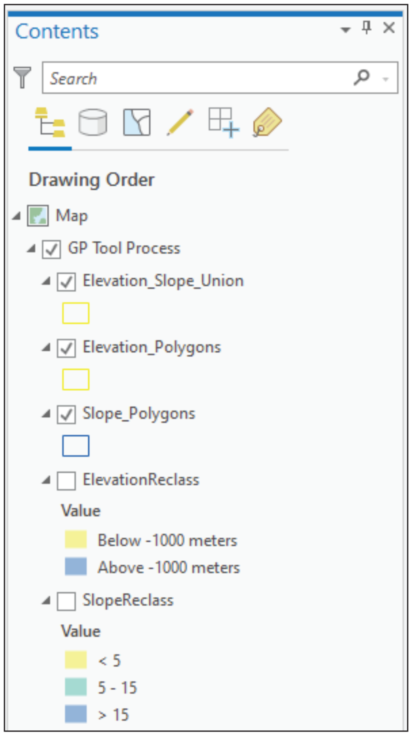
    Attributes To Join: **All attributes**

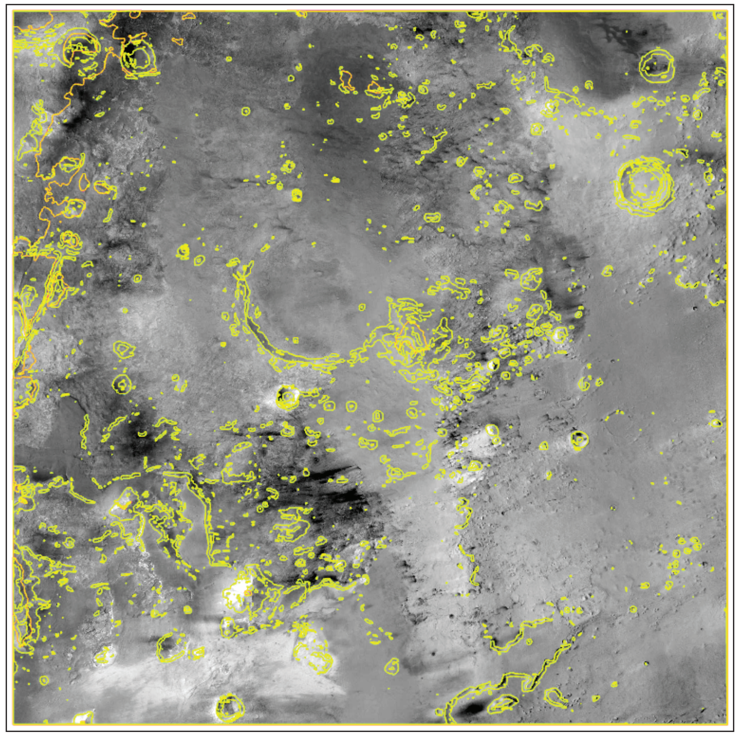


33. Click **Run** to create the **Elevation_Slope_Union** dataset.

The **Elevation_Slope_Union** dataset will be added to the map as a new layer. This dataset combines the results from both the **Elevation_Polygons** and **Slope_Polygons** layers and can be used to identify areas which meet both the elevation and slope criteria for an acceptable landing site.

34. In the **Contents** pane, uncheck the boxes for the **Elevation_Polygons** and **Slope_Polygons** layers to turn them off. Then click and drag the **Elevation_Slope_Union** to the top of the **GP Tool Process** group. Click on the symbol for the **Elevation_Slope_Union** layer and change the **Outline color** to **Solar Yellow** and click **Apply** to update the symbol. Once the symbology has been updated, click on the small **x** in the upper right corner of the **Symbology** pane to close it and return to the **Geoprocessing** pane.



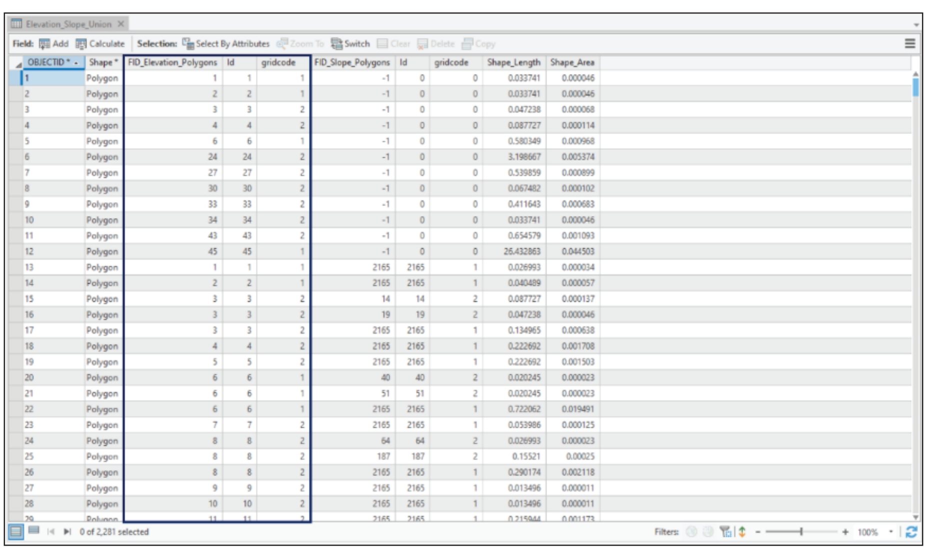


35. In the **Contents** pane, right click on the **Elevation_Slope_Union** layer and select **Attribute Table** to open it and explore the data that resulted from the **Union** tool.

The **Elevation_Slope_Union** layer contains a combination of the **Elevation_Polygons** and **Slope_Polygons** attributes. You can see both of those features represented in the **Attribute Table**. The **gridcode** fields are the class values that were assigned in the reclassification steps you completed earlier.

36. Explore the **gridcode** values that exist in the **Elevation_Slope_Union Attribute Table** by right clicking the top of each **gridcode** column and selecting **Sort Ascending**. This will allow you to easily identify the maximum and minimum values for these fields and confirm that the data was combined correctly.

There are two **gridcode** columns in the **Elevation_Slope_Union Attribute Table**: one for the **Elevation_Polygons**, and one for the **Slope_Polygons**. These two sets of polygons were combined in the order that you entered them in the **Union** tool. Here, the **Elevation_Polygons** were set as the first input to the **Union** tool, and the **Elevation_Polygons** attributes are listed first in the resulting **Attribute Table**.


Elevation_Slope_Union

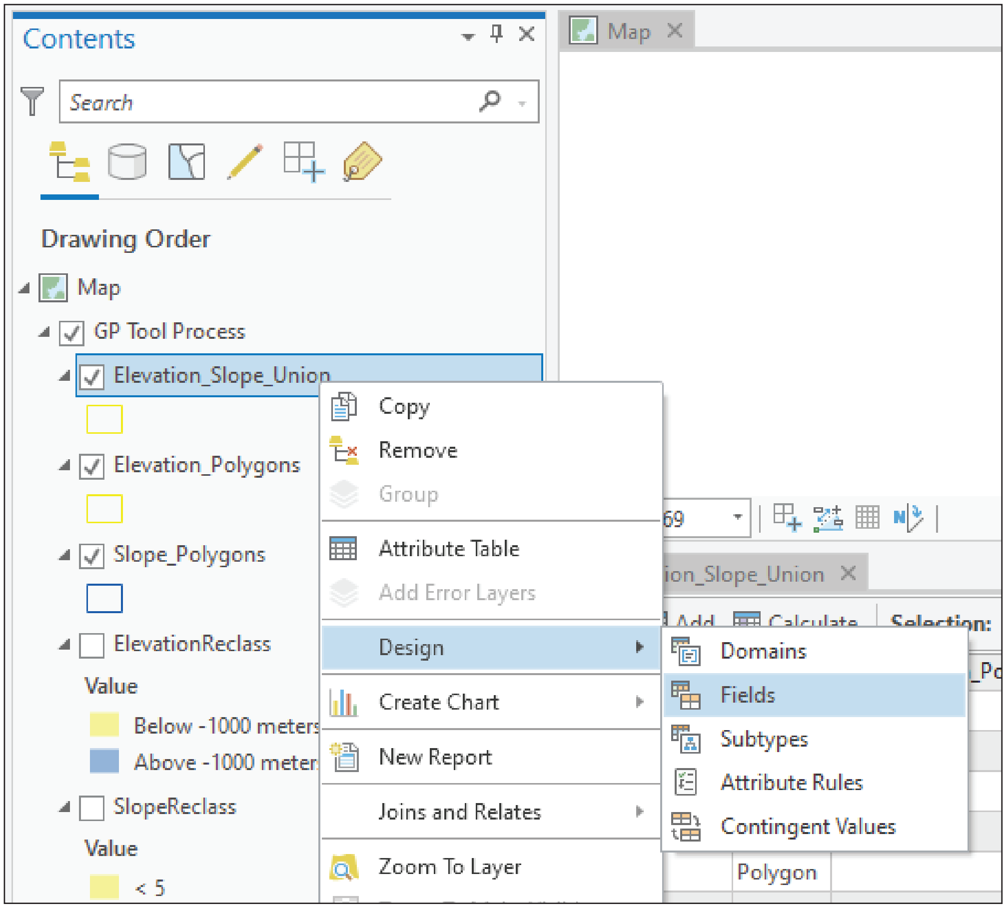
Field: Add Calculate Selection: Select By Attributes Zoom To Switch Clear Delete Copy

OBJECTID *	Shape *	FID_Elevation_Polygons	Id	gridcode	FID_Slope_Polygons	Id	gridcode	Shape_Length	Shape_Area
1	Polygon	1	1	1	-1	0	0	0.033741	0.000046
2	Polygon	2	2	1	-1	0	0	0.033741	0.000046
3	Polygon	3	3	2	-1	0	0	0.047238	0.000068
4	Polygon	4	4	2	-1	0	0	0.087727	0.000114
5	Polygon	6	6	1	-1	0	0	0.580349	0.000968
6	Polygon	24	24	2	-1	0	0	3.198667	0.005374
7	Polygon	27	27	2	-1	0	0	0.539859	0.000899
8	Polygon	30	30	2	-1	0	0	0.067482	0.000102
9	Polygon	33	33	2	-1	0	0	0.411643	0.000683
10	Polygon	34	34	2	-1	0	0	0.033741	0.000046
11	Polygon	43	43	2	-1	0	0	0.654579	0.001093
12	Polygon	45	45	1	-1	0	0	26.432863	0.044503
13	Polygon	1	1	1	2165	2165	1	0.026993	0.000034
14	Polygon	2	2	1	2165	2165	1	0.040489	0.000057
15	Polygon	3	3	2	14	14	2	0.087727	0.000137
16	Polygon	3	3	2	19	19	2	0.047238	0.000046
17	Polygon	3	3	2	2165	2165	1	0.134965	0.000638
18	Polygon	4	4	2	2165	2165	1	0.222692	0.001708
19	Polygon	5	5	2	2165	2165	1	0.222692	0.001503
20	Polygon	6	6	1	40	40	2	0.020245	0.000023
21	Polygon	6	6	1	51	51	2	0.020245	0.000023
22	Polygon	6	6	1	2165	2165	1	0.722062	0.019491
23	Polygon	7	7	2	2165	2165	1	0.053986	0.000125
24	Polygon	8	8	2	64	64	2	0.026993	0.000023
25	Polygon	8	8	2	187	187	2	0.15521	0.00025
26	Polygon	8	8	2	2165	2165	1	0.290174	0.002118
27	Polygon	9	9	2	2165	2165	1	0.013496	0.000011
28	Polygon	10	10	2	2165	2165	1	0.013496	0.000011
29	Polygon	11	11	2	2165	2165	1	0.215944	0.001173

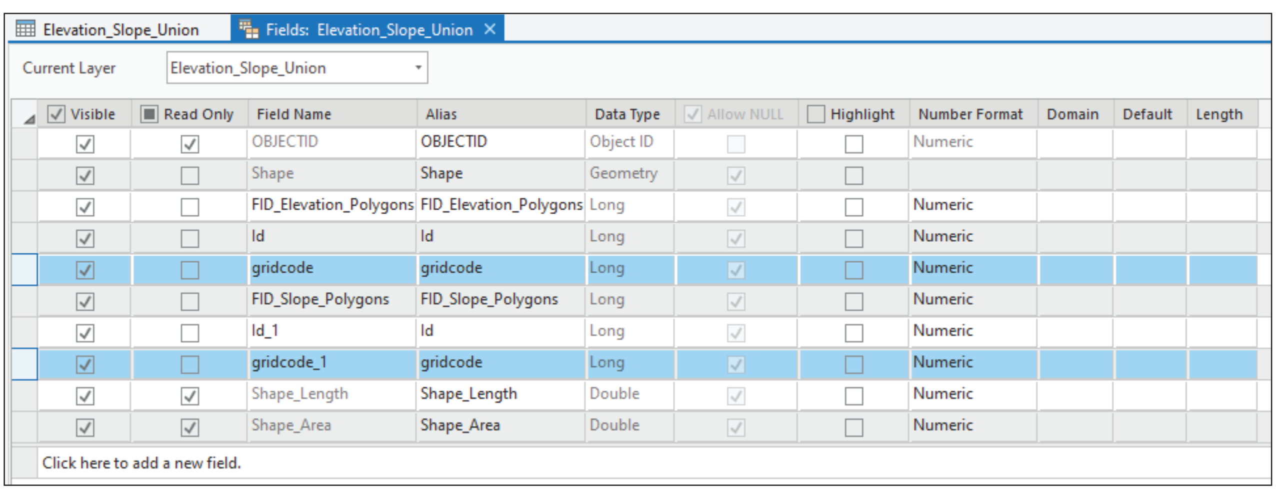
0 of 2,281 selected Filters: 100%

These **Attribute Table** fields can be renamed for better clarity in the upcoming steps.

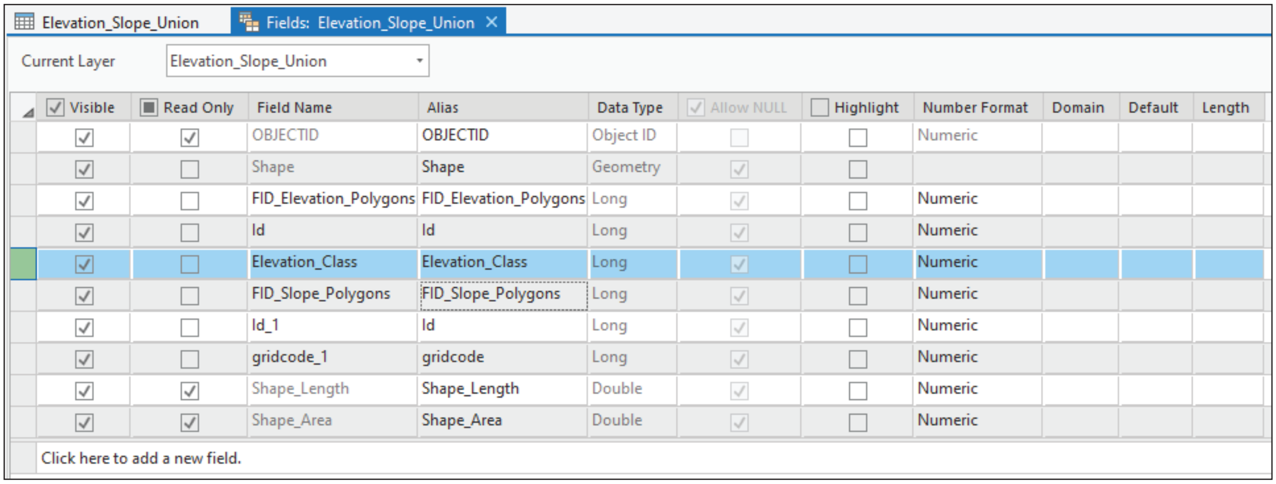
37. In the **Contents** pane, right click on the **Elevation_Slope_Union** and select **Design** → **Fields** to open the **Fields: Elevation_Slope_Union** editing tab.



In the **Fields: Elevation_Slope_Union** editing tab, you will see two fields with the **Alias** of **gridcode**. However, the formal **Field Names** are **gridcode** and **gridcode_1**.

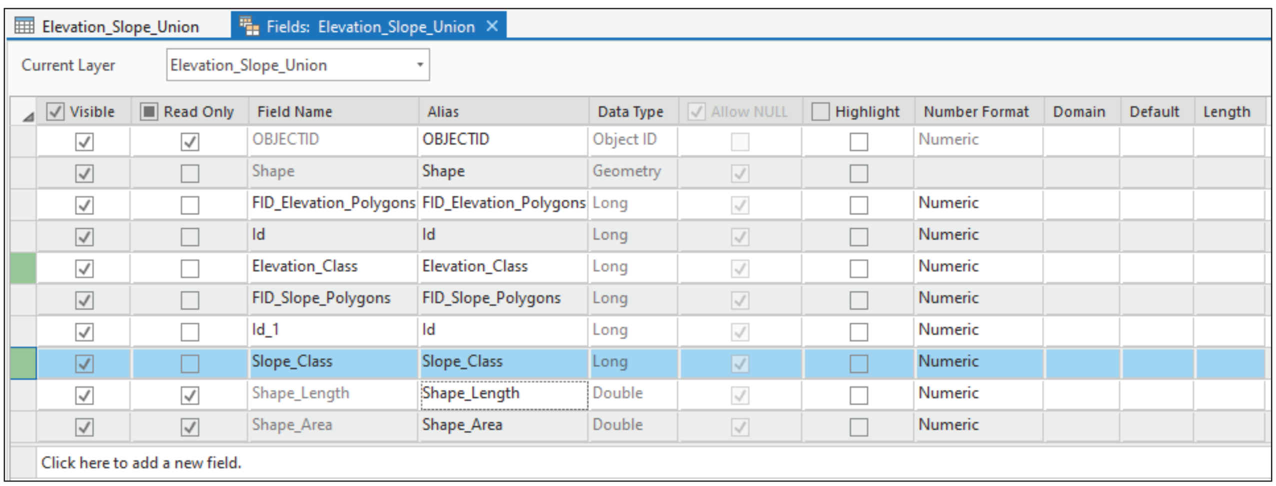


38. In the **Fields: Elevation_Slope_Union** editing tab, Click and hover over the **Field Name** for **gridcode** to activate and edit the text. Change this **Field Name** and the **Alias** to **Elevation_Class** and press **enter** to apply the changes.



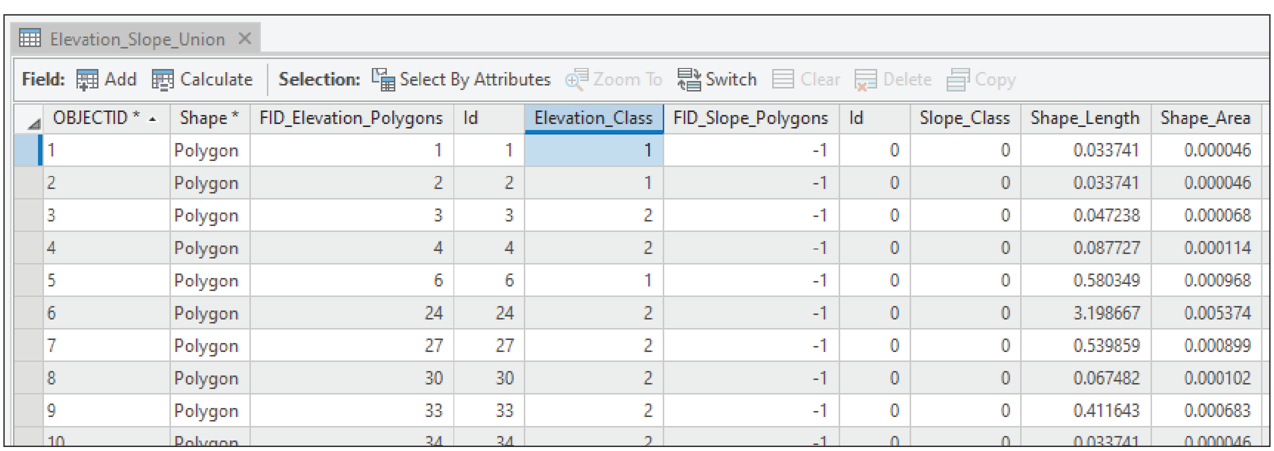
Visible	Read Only	Field Name	Alias	Data Type	Allow NULL	Highlight	Number Format	Domain	Default	Length
✓	✓	OBJECTID	OBJECTID	Object ID			Numeric			
✓		Shape	Shape	Geometry	✓					
✓		FID_Elevation_Polygons	FID_Elevation_Polygons	Long	✓		Numeric			
✓		Id	Id	Long	✓		Numeric			
✓		Elevation_Class	Elevation_Class	Long	✓		Numeric			
✓		FID_Slope_Polygons	FID_Slope_Polygons	Long	✓		Numeric			
✓		Id_1	Id	Long	✓		Numeric			
✓		gridcode_1	gridcode	Long	✓		Numeric			
✓	✓	Shape_Length	Shape_Length	Double	✓		Numeric			
✓	✓	Shape_Area	Shape_Area	Double	✓		Numeric			

39. In the **Fields: Elevation_Slope_Union** editing tab, Click and hover over the **Field Name** for **gridcode_1** to activate and edit the text. Change this **Field Name** and the **Alias** to **Slope_Class** and press **enter** to apply the changes.



Visible	Read Only	Field Name	Alias	Data Type	Allow NULL	Highlight	Number Format	Domain	Default	Length
✓	✓	OBJECTID	OBJECTID	Object ID			Numeric			
✓		Shape	Shape	Geometry	✓					
✓		FID_Elevation_Polygons	FID_Elevation_Polygons	Long	✓		Numeric			
✓		Id	Id	Long	✓		Numeric			
✓		Elevation_Class	Elevation_Class	Long	✓		Numeric			
✓		FID_Slope_Polygons	FID_Slope_Polygons	Long	✓		Numeric			
✓		Id_1	Id	Long	✓		Numeric			
✓		Slope_Class	Slope_Class	Long	✓		Numeric			
✓	✓	Shape_Length	Shape_Length	Double	✓		Numeric			
✓	✓	Shape_Area	Shape_Area	Double	✓		Numeric			

40. In the **Changes** section of the **Fields** tab, click on the **Save** icon to save these changes. Then click on the small **x** in the **Fields: Elevation_Slope_Union** tab to close it and return to the **Elevation_Slope_Union Attribute Table**.



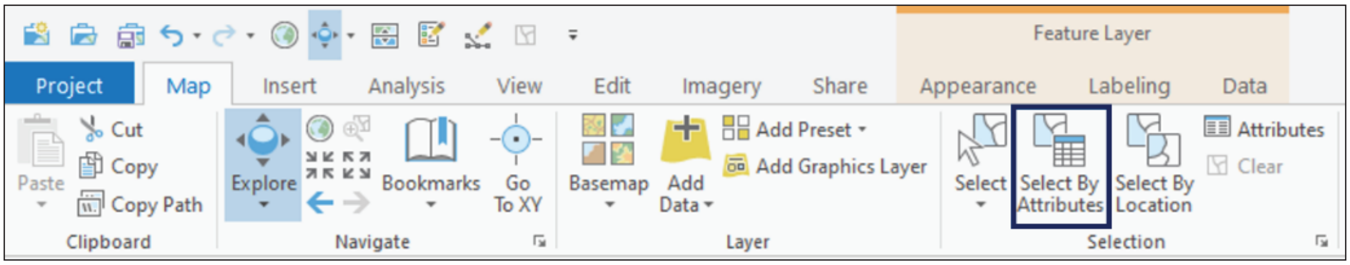
OBJECTID *	Shape *	FID_Elevation_Polygons	Id	Elevation_Class	FID_Slope_Polygons	Id	Slope_Class	Shape_Length	Shape_Area
1	Polygon	1	1	1	-1	0	0	0.033741	0.000046
2	Polygon	2	2	1	-1	0	0	0.033741	0.000046
3	Polygon	3	3	2	-1	0	0	0.047238	0.000068
4	Polygon	4	4	2	-1	0	0	0.087727	0.000114
5	Polygon	6	6	1	-1	0	0	0.580349	0.000968
6	Polygon	24	24	2	-1	0	0	3.198667	0.005374
7	Polygon	27	27	2	-1	0	0	0.539859	0.000899
8	Polygon	30	30	2	-1	0	0	0.067482	0.000102
9	Polygon	33	33	2	-1	0	0	0.411643	0.000683
10	Polygon	34	34	2	-1	0	0	0.033741	0.000046

The **Attribute Table** field names have been updated to reflect your changes.

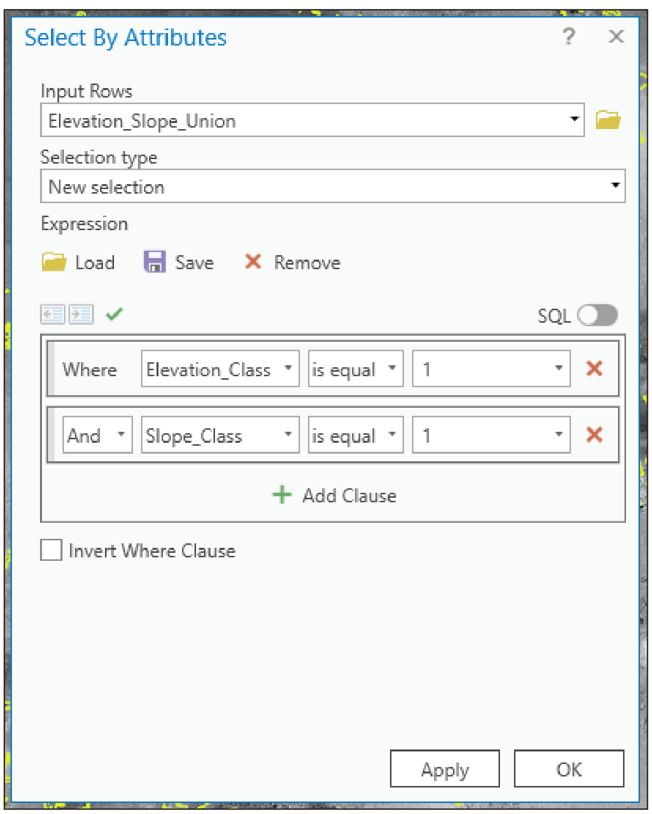
41. Click on the small **x** in the **Elevation_Slope_Union Attribute Table** tab to close it and return to the full map view.

When you created the **SlopeReclass** and **ElevationReclass** datasets a class value of **1** was used to identify areas that met the landing site criteria. All other classes represent areas that do not meet the landing site criteria. With these datasets combined into the **Elevation_Slope_Union** dataset, you may now search for areas which have a value of **1** for both the **Elevation_Class** and **Slope_Class**.

42. In the **Contents** pane, click on the **Elevation_Slope_Union** layer to select it. Then, in the **Selection** section of the **Map** tab, click on the **Select By Attributes** icon.

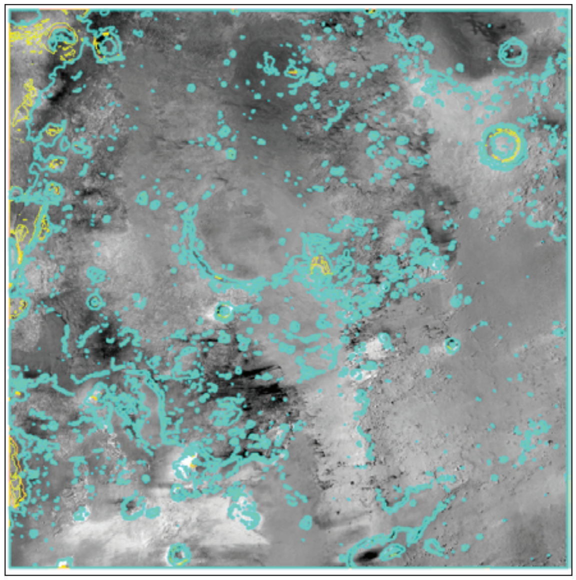


43. In the **Select By Attributes** window, confirm the **Input Rows** is set to the **Elevation_Slope_Union** layer, and the **Selection type** is **New Selection**. Use the dropdown menu to define the first search as Where **Elevation_Class is equal to 1**. Then click the **Add Clause** icon and add a second clause to **And Slope_Class is equal to 1**.



44. Click **OK** to run the **Select By Attributes** tool.

The **Select By Attributes** tool will select only areas of the **Elevation_Slope_Union** layer which have both an **Elevation_Class** and **Slope_Class** of **1**. These areas satisfy both the elevation and slope requirements for landing site selection. All other areas are either too steep, too high, or both.



45. In the **Contents** pane, right click the **Elevation_Slope_Union** layer and select **Data → Export Features**.

As you learned in Exercise 3, the **Export Features** tool will output only the features that are currently selected in a layer, or all the features in the layer if none are currently selected.

46. In the Export Features tool, set the following parameters:

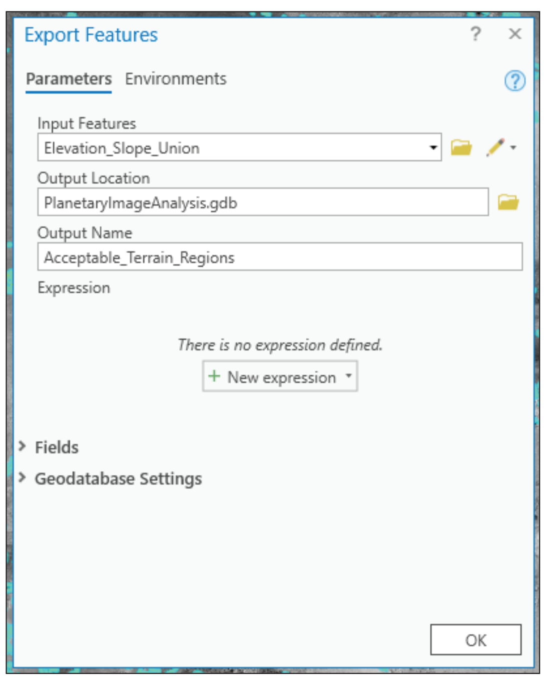
Input Features: **Elevation_Slope_Union**

Output Location: **PlanetaryImageAnalysis_Exercise_4.gdb**

Output Name: **Acceptable_Terrain_Regions**

Leave all other defaults.

*(Note: As an alternative to the previous **Select By Attribute** step, you can also build the expression to select and export only the features which have an **Elevation_Class** and **Slope_Class** value of **1** in the **Export Features** tool itself.)*



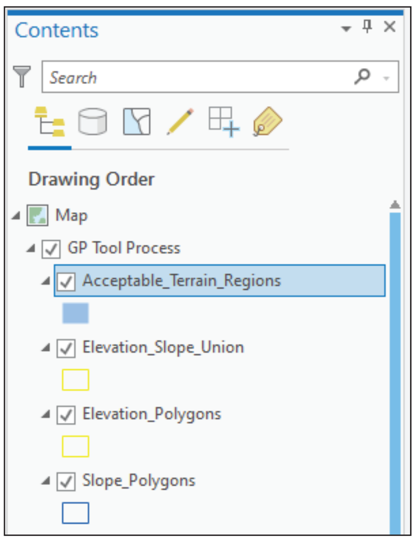
47. Click **OK** to export the selected features and create the **Acceptable_Terrain_Regions** layer.

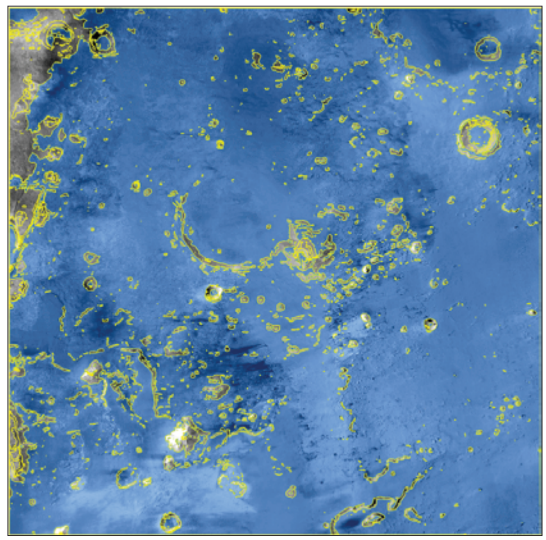
The **Acceptable_Terrain_Regions** features will be added to the map as a new layer.

48. In the **Selection** section of the **Map** tab, click on the **Clear** icon to clear the selection. Then, in the **Contents** pane, click and drag and **Acceptable_Terrain_Regions** layer into the top of the **GP Tool Process** group.

49. In the **Contents** pane, click on the symbol for the **Acceptable_Terrain_Regions** layer to open the **Format Polygon Symbol** pane. In the **Properties** tab of the **Format Polygon Symbol** pane, change the **Color** to **Cretan Blue** and the **Outline color** to **No Color** and click **Apply**. Then click on the small **x** in the upper right corner of the **Symbology** pane to close it and return to the **Geoprocessing** pane.

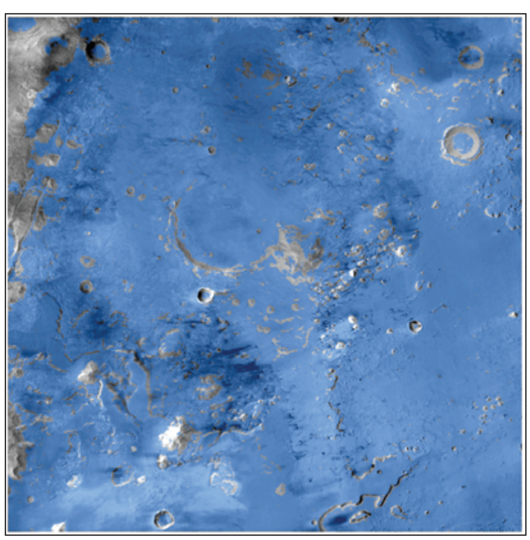
50. In the **Contents** pane, click on the **Acceptable_Terrain_Regions** layer to select it. Then set the **transparency** to **60%** (in the **Raster Layer Appearance** tab)



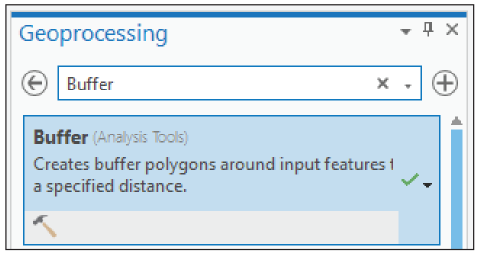


51. Take a minute to explore the **Acceptable_Terrain_Regions** layer relative to the **Elevation_Polygons** and **Slope_Polygons**. Zoom and pan through your map while turning layers on and off to see how these layers compare. When you have finished, turn off the **Elevation_Slope_Union**, **Elevation_Polygons**, and **Slope_Polygons** layers and return to the full extent of your area of interest (**Zoom to Layer** in the **Contents** pane). The only layers that should be visible when you continue are the **CTX_mosaic** and the **Acceptable_Terrain_Regions** layers. All other layers should be off.

The **Acceptable_Terrain_Regions** layer shows areas that meet both the elevation and slope criteria for landing site selection. The next step in the process is to identify areas within this layer which are large enough to accommodate a 12-km-diameter landing ellipse.



52. In the upper left corner of the **Geoprocessing** pane, click on the **back arrow** to return to the **Geoprocessing** tools menu. Then search for **Buffer** and click on the **Buffer** tool to open it.



53. In the **Buffer** tool, set the following parameters:

Input Features: **Acceptable_Terrain_Regions**

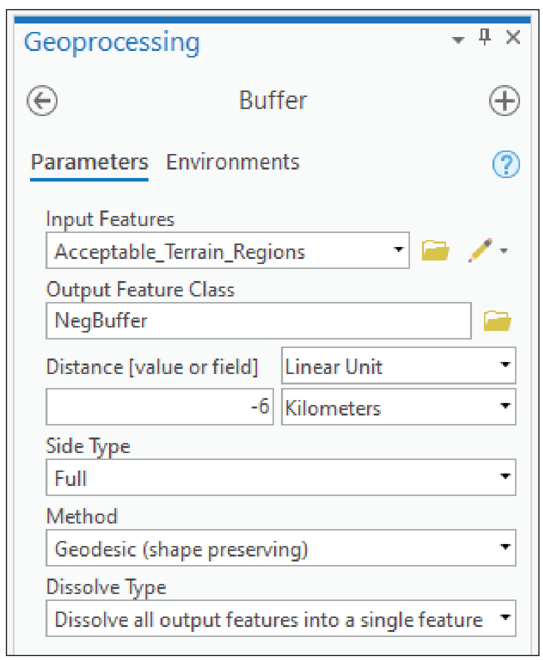
Output Feature Class: **PlanetaryImageAnalysis_Exercise_4.gdb\NegBuffer**

Distance: **Linear Unit**, **-6 Kilometers**

Side Type: **Full**

Method: **Geodesic (shape preserving)**

Dissolve Type: **Dissolve all output features into a single feature**



By setting the **Distance** value to -6 km, the **Buffer** tool will remove all areas that are within 6 km of the polygon boundary. Typical landing ellipses for Mars have a 6-km radius, and the entire landing ellipse must have suitable terrain. Any areas of the **Acceptable_Terrain_Regions** polygon that are within 6 km of the polygon boundary will not have acceptable terrain for a landing ellipse throughout an entire landing ellipse and should therefore be removed from consideration.

54. Click **Run** to complete the **Buffer** tool and create the **NegBuffer** layer.

The **NegBuffer** result will be added to your map as a new layer. However, the **Buffer** tool must be run once more to encompass all the areas that can fit a landing ellipse.

55. In the **Buffer** tool, set the following parameters:

Input Features: **NegBuffer**

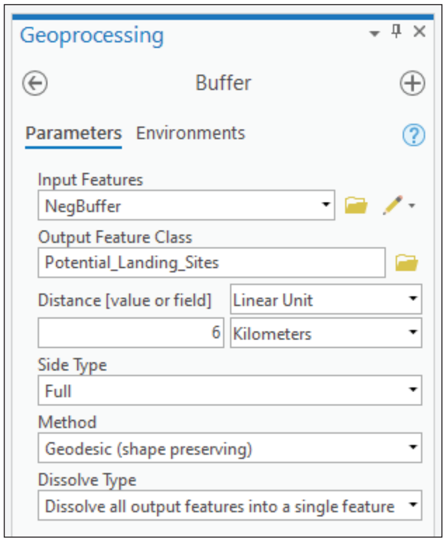
Output Feature Class: **PlanetaryImageAnalysis_Exercise_4.gdb\Potential_Landing_Sites**

Distance: **Linear Unit, 6 Kilometers** (this time you are running it with a positive 6 km distance)

Side Type: **Full**

Method: **Geodesic (shape preserving)**

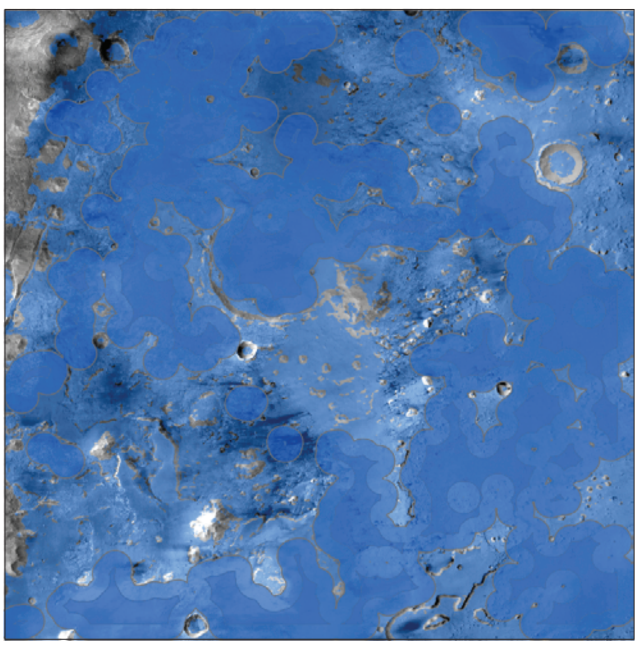
Dissolve Type: **Dissolve all output features into a single feature**



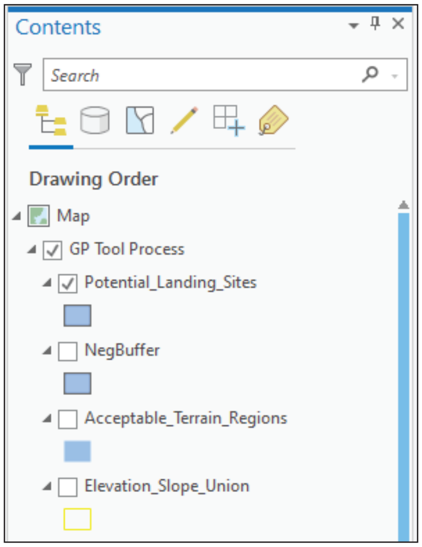
The previous buffering step removed areas that were too small to fit a 12-km diameter landing ellipse. However, the 6 km must be added back on to the remaining regions to result in a polygon that has all the possible landing site options.

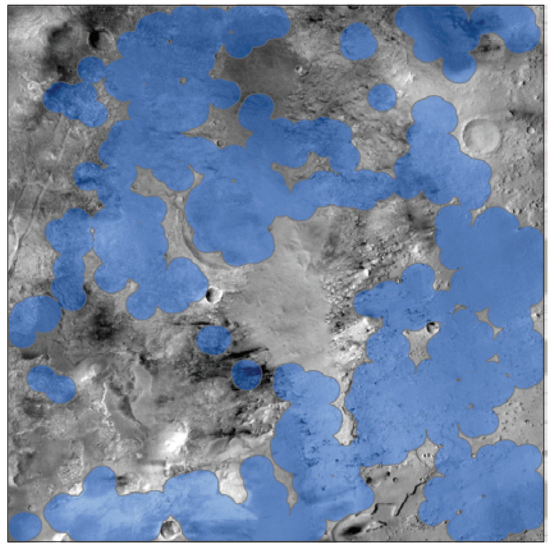
56. In the **Buffer** tool, click **Run** to create the **Potential_Landing_Sites** dataset.

The **Potential_Landing_Sites** result will be added to your map as a new layer.



57. In the **Contents** pane, click on the **Potential_Landing_Sites** and **NegBuffer** layers and drag them into the top of the **GP Tool Process** group. Then uncheck the box for the **NegBuffer** and **Acceptable_Terrain_Regions** layers to turn them off.



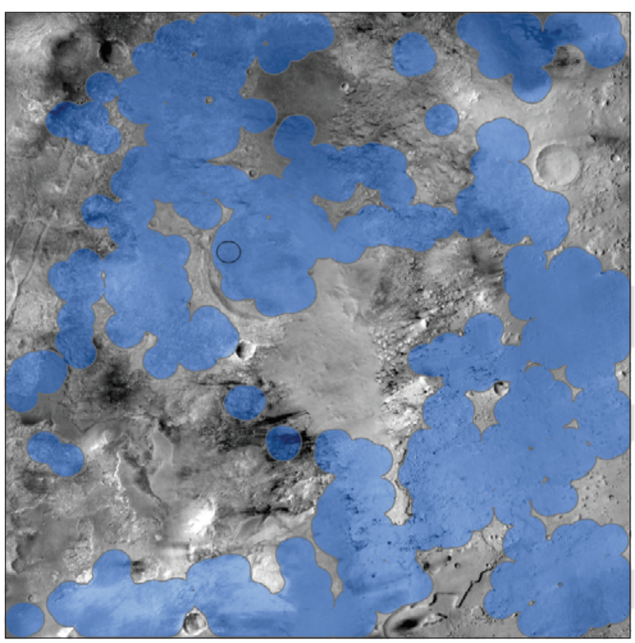


The **Potential_Landing_Sites** layer contains the areas around Jezero crater that meet the slope and elevation criteria for a safe landing site and are also large enough to hold a 12-km diameter landing ellipse.

58. Click on the small **x** in the upper right corner of the **Buffer** tool to close the **Geoprocessing** pane and return to the **Catalog** pane.

59. In the **Catalog** pane, right click on the **Mars2020_Landing_Ellipse** feature (located in **Folders → PlanetaryImageAnalysis\Exercise_4\PlanetaryImageAnalysis_Exercise_4.gdb**) and select **Add To Current Map**.

60. In the **Contents** pane, click on the **Mars2020_Landing_Ellipse** symbol to open the **Format Polygon Symbol** tool. In the **Properties** tab of the **Format Polygon Symbol** pane, change the **Color** to **No Color** and the **Outline color** to **Black**. Then click **Apply** to update the symbol and click on the small **x** in the upper right corner of the **Symbology** pane to close it.



61. Take a minute to explore your map and analysis results and see how they compare to the final landing site for the Mars 2020 rover in Jezero crater.

62. When you have finished exploring the landing site assessment results, in the **Contents** pane, uncheck the box and click on the small triangle next to the **GP Tool Process** group to collapse it and turn those layers off. Then uncheck the box for the **Mars2020_Landing_Ellipse** layer to turn it off. Your map should now only show the **CTX_mosaic** layer. Return to the full extent of the **CTX_mosaic** layer (**Contents** pane → **Zoom to Layer**) before beginning the next section.

Part 2: Analysis with Raster Functions

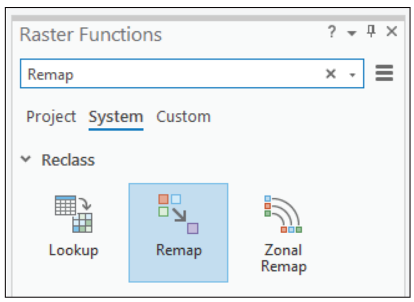
In the previous steps, you completed a landing site assessment using geoprocessing tools. Here, you will repeat this assessment, but this time you will use raster functions and create a custom raster function. Once the assessment is complete, you can compare the outputs.

63. In the **Contents** pane, click on the small triangle to expand the **Raster Functions** group layer you created earlier. All outputs from this section will be placed in this group. Check the box to turn the **Raster Functions** group on.

In Exercise 2, you created the **Slope_Jezero_DTM** layer using a raster function. That layer should still be turned on and now visible in your map. *(Note: If you unchecked the box to turn the **Slope_Jezero_DTM** layer off earlier, check it now to turn it back on.)*

64. In the **Contents** pane, click on the **Slope_Jezero_DTM** layer to select it. Then, in the **Analysis** section of the **Imagery** tab, click on the **Raster Functions** icon to open the **Raster Functions** pane.

65. In the **Raster Functions** pane, search for **Remap**. Then click on the **Remap** icon to open the **Remap** raster function.



66. In the **Remap** raster function pane, set the following parameters:

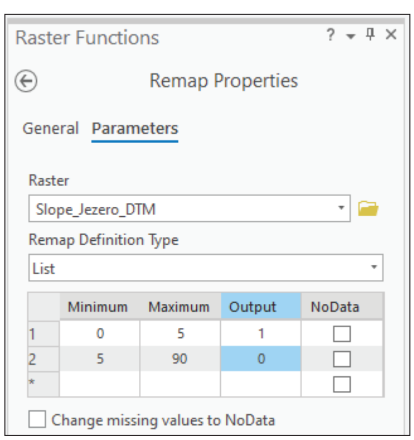
Raster: **Slope_Jezero_DTM**

Remap Definition Type: **List**

Table entries: Row **1 = 0 – 5, output 1**

Row 2 = **5 – 90, output 0**

(Note: To delete row 3 of the table, hover over the 3 and click the x that appears.)



67. In the **Remap** raster function, click **Create new layer** to run the analysis.

The **Remap_Slope_Jezero_DTM** result will be added to your map as a new layer.

68. In the **Raster Functions** pane, click on the **Remap** icon again to reopen the tool. Then set the following parameters:

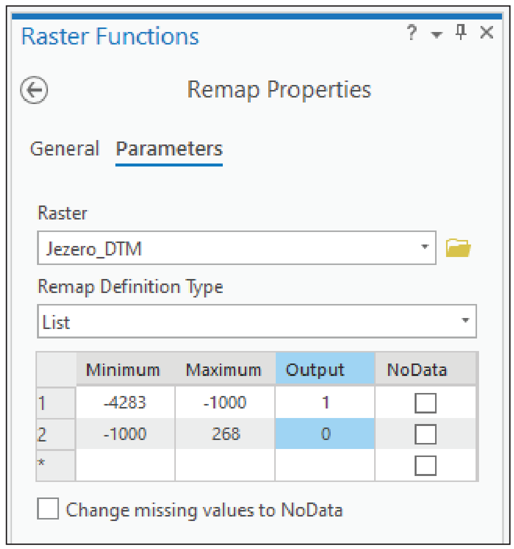
Raster: **Jezero_DTM**

Remap Definition Type: **List**

Table entries: Row 1 = **-4283 to -1000, output 1**

Row 2 = **-1000 to 268, output 0**

*(Note: to create a new row, click in the **Minimum** value box in the * row and begin typing)*



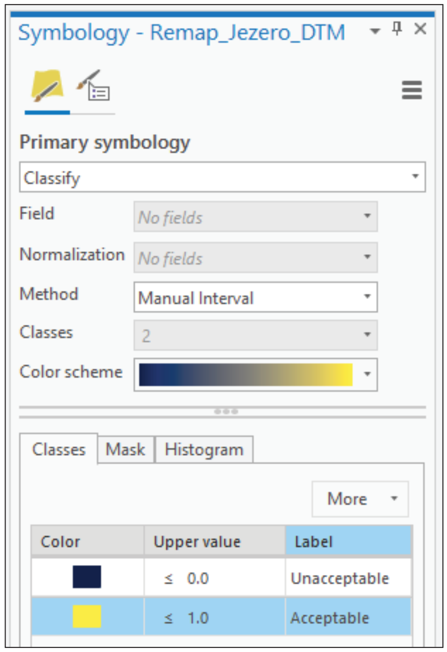
69. In the **Remap** raster function, click **Create new layer** to run the analysis.

The **Remap_Jezero_DTM** result will be added to your map as a new layer.

70. In the **Contents** pane, click and drag the **Remap_Jezero_DTM** and **Remap_Slope_Jezero_DTM** layers into the top pf the **Raster Functions** group. Uncheck the box next to the **Slope_Jezero_DTM** layer to turn it off.

71. In the **Contents** pane, right click on the **Remap_Jezero_DTM** layer and select **Symbology** to open the **Symbology** pane. Set the **Primary Symbology** to **Classify** and select the **Cividis** color scheme *(Note: you may need to check the boxes to **Show names** in the **Color scheme** dropdown menu).*

72. In the **Classes** tab of the **Symbology** pane, set **the Upper value** for the second (yellow) class to **1**. Then change the **Label** for the first (blue) class to **Unacceptable**, and the second (yellow) class to **Acceptable**.



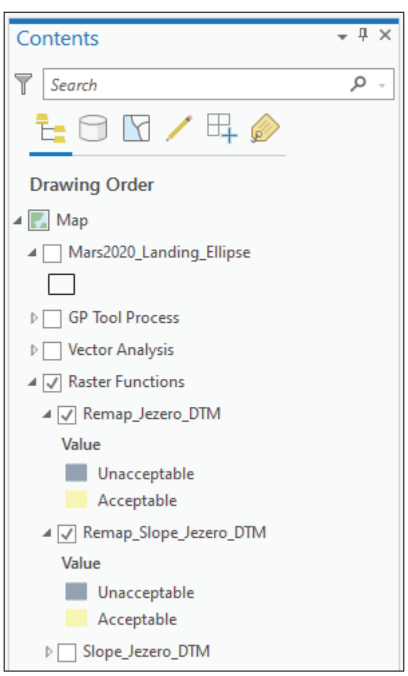
73. In the **Effects** section of the **Raster Layer Appearance** tab, set the **transparency** to **60%**.

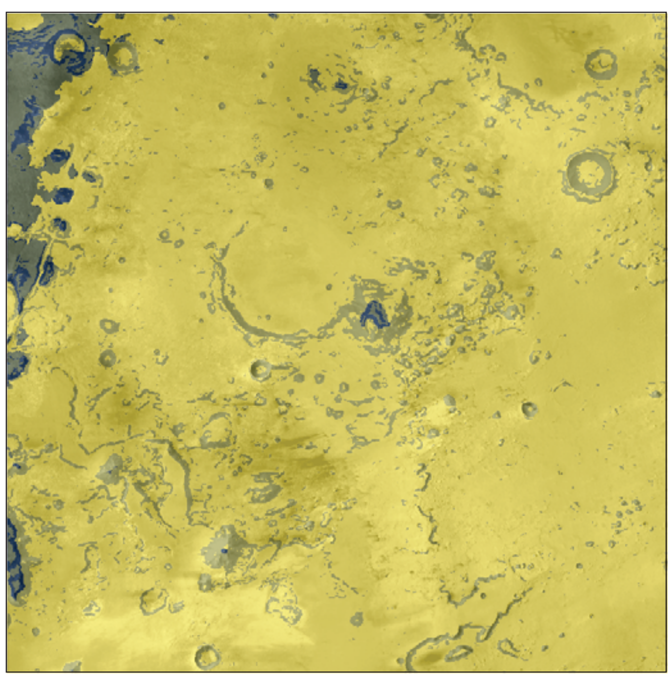
Now that you have formatted the symbology and display properties of the **Remap_Jezero_DTM** layer, you will repeat these steps to format the **Remap_Slope_Jezero_DTM** layer.

74. In the **Contents** pane, click on the **Remap_Slope_Jezero_DTM** layer to select it. When you select this new layer, the **Symbology** pane will automatically update to display the options and current settings for the selected layer.

75. In the **Symbology** pane, Set the **Primary Symbology** to **Classify** and select the **Cividis** color scheme. Then, in the **Classes** tab of the **Symbology** pane, change the **Label** for the first (blue) class to **Unacceptable**, and the second (yellow) class to **Acceptable**. Then click on the small **x** in the upper right corner of the **Symbology** pane to close it and return to the **Raster Functions** pane.

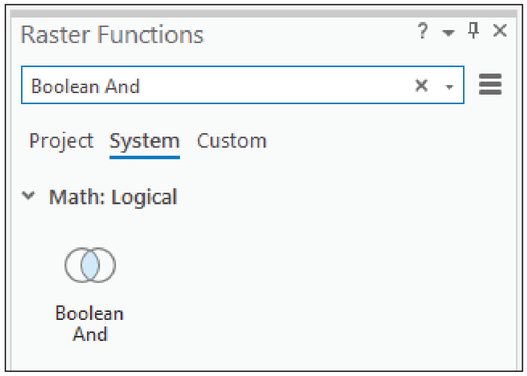
76. In the **Effects** section of the **Raster Layer Appearance** tab, set the **transparency** to **60%.**





You now have two layers which represent the areas with acceptable slopes (**Remap_Slope_Jezero_DTM**) and acceptable elevations (**Remap_Jezero_DTM**) for a landing site. The next step is to combine these layers and find areas which have both acceptable slopes and acceptable elevations.

77. In the **Raster Functions** pane, search for **Boolean And**. Then click on the **Boolean And** icon to open the raster function.

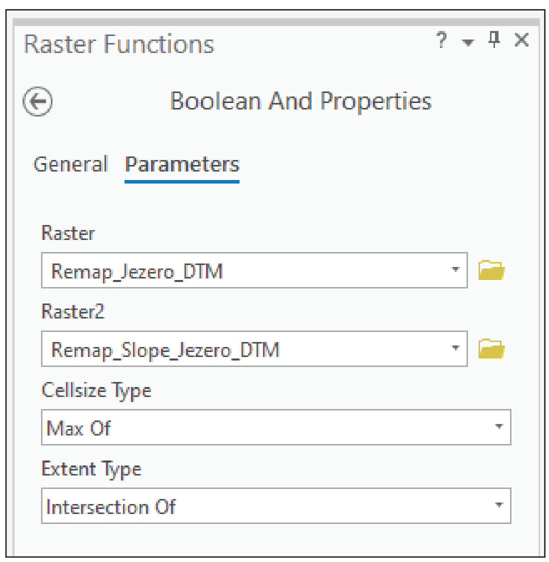


78. In the **Boolean And** raster function, set the following parameters:

    Raster: **Remap_Jezero_DTM**

    Raster2: **Remap_Slope_Jezero_DTM**

    Leave other defaults.

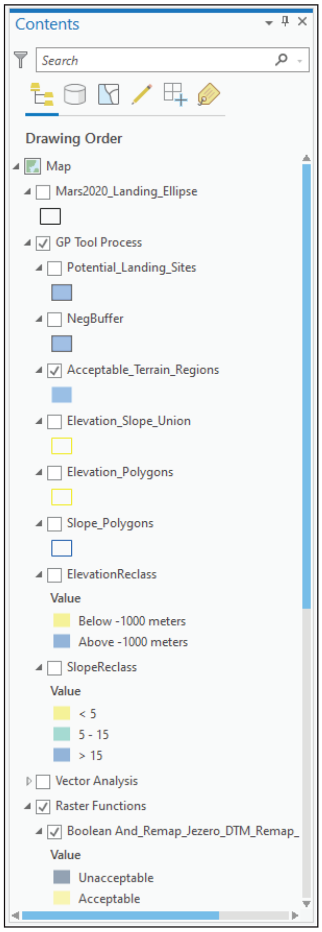


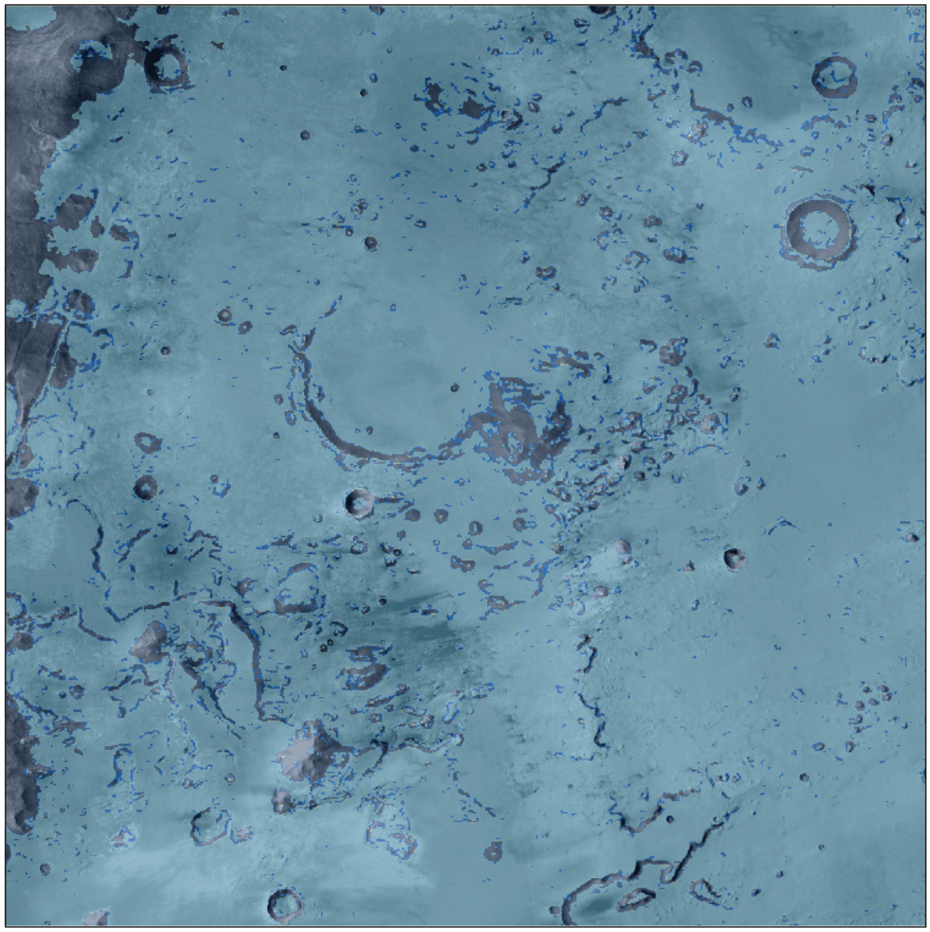
79. In the **Boolean And** raster function, click **Create new layer** to run the analysis.

When the raster function is complete, the new **Boolean_And_Remap_Jezero_DTM_Remap_Slope_Jezero_DTM** layer will be added to your map. The **Boolean And** raster function identifies areas which have a value of 1 (acceptable terrain) in both input rasters.

80. In the **Contents** pane, click and drag the **Boolean_And_Remap_Jezero_DTM_Remap_Slope_Jezero_DTM** layer into the top of the **Raster Functions** group. Then right click on the layer name and select **Symbology**. Format the **Symbology** following the same process as you did for the **Remap_Jezero_DTM** and **Remap_Slope_Jezero_DTM** layers and set the **transparency** to **60%.**

81. In the **Contents** pane, uncheck the boxes for the **Remap_Jezero_DTM** and **Remap_Slope_Jezero_DTM** layers to turn them off. Then click on the small triangle to expand the **GP Tool Process** group and check the box to turn it on. In the **GP Tool Process** group, turn off the **Potential_Landing_Sites** layer and turn the **Acceptable_Terrain_Regions** layer on.





82. Take a moment to compare these two layers. In the **Contents** pane, click on the **Acceptable_Terrain_Regions** layer to select it. Then in the **Effects** section of the **Feature Layer Appearance** tab, click on the **Swipe** icon. With the **Swipe** tool enabled, click near the top of your map and drag the pointer down to swipe the **Acceptable_Terrain_Regions** on and off. *(Note: The **Swipe** tool will work on whichever layer is currently selected in the **Contents** pane.)*

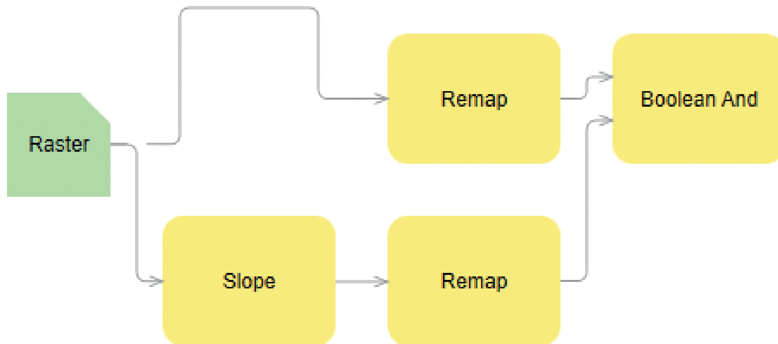
*Note: The next step in the landing site assessment (buffering) begins working with vector data, which is not what raster functions are used for. To continue the landing site assessment from this point, you would use the **Raster to Polygon** geoprocessing tool to turn this raster function output into a polygon feature class. However, you can use raster functions (or your own custom raster function that you will create in the next section) to identify regions with acceptable terrain and quickly complete the first half of the analysis.*

Part 3: Create a Custom Raster Function

Your map now contains two layers showing all the areas that meet both the elevation and slope requirements for a landing site. However, one (**Acceptable_Terrain_Regions**) was created using only geoprocessing tools, and the other (**Boolean_And_Remap_Jezero_DTM_Remap_Slope_Jezero_DTM**) was created using only raster functions. The raster function steps you took to get to this point may be saved and used to create a custom raster function which can be used at any time to quickly complete this analysis in only one step.

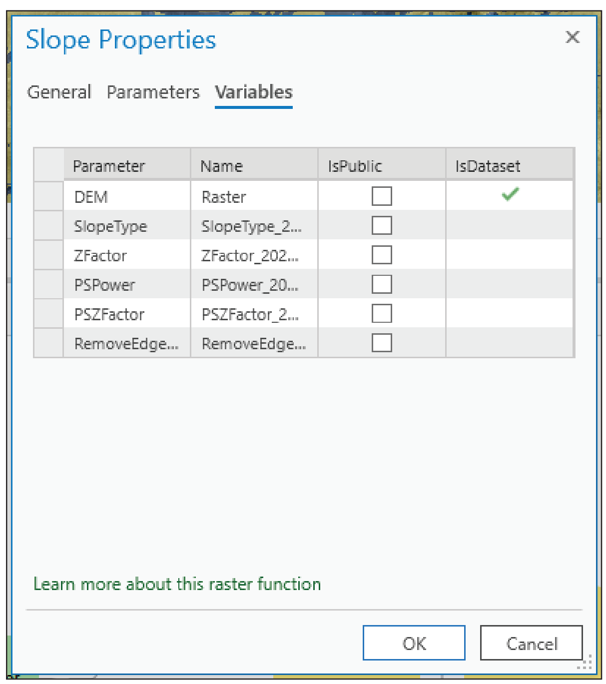
83. In the **Contents** pane, uncheck the box for the **GP Tool Process** group and collapse the group. Then right click the **Boolean_And_Remap_Jezero_DTM_Remap_Slope_Jezero_DTM** layer and select **Save Function Chain**.

This will open the **Raster Function Template** tab, which shows all the raster function steps you took to get to this point in your analysis. Here, you can view and edit the processing steps, and save this process as a custom raster function. Settings and thresholds for individual steps in the process (like **Remap**) can be changed by double clicking on the function boxes. For now, you will keep those settings the same, but they can be changed even after the custom raster function is saved. More information on working in the **Raster Function Template** is available from Esri here.



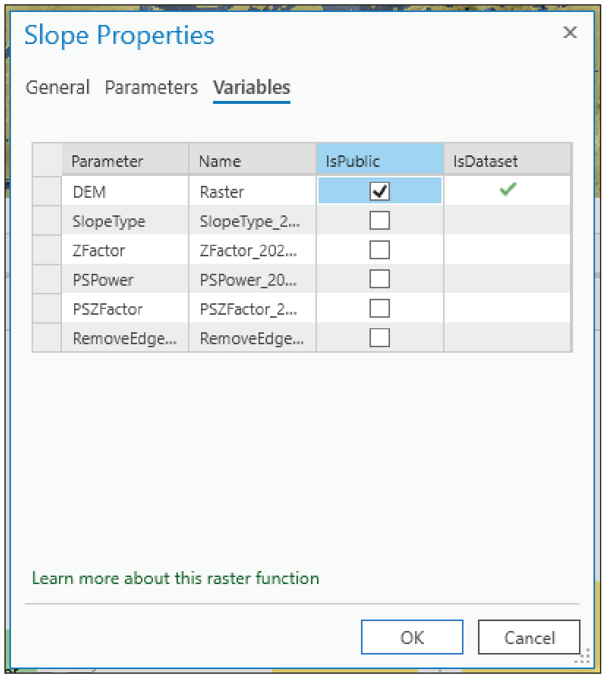
When saving a custom raster function, you will often want to make certain inputs and settings available to the user. In this example, you will need to make the starting raster dataset (the DTM) available to the user to set their own input raster.

84. In the **Raster Function Template**, double click on the **Slope** box to open the options for this step. Then switch to the **Variables** tab in the **Slope Properties** window.



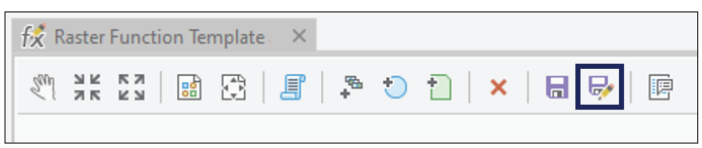
The **Variables** tab is where you may define which parameters are visible to the user (**IsPublic**) as inputs.

85. In the **Variables** tab of the **Slope Properties** window, check the box for the **DEM** Parameter. This will allow the user to input the DEM of their choice when running the custom raster function. Then click **OK** to exit the **Slope Properties** window.



Since the same DEM feeds into both branches of the custom raster function, you only need to make one of these inputs public. If you were making a custom raster function which relied on additional data inputs, you would need to make those public as well.

86. In the **Raster Function Template** toolbar, click on the **Save As** icon to save a new custom raster function.



87. In the Save As window, set the following parameters:

Name: **Landing Site Terrain Assessment**

Category: **Custom**

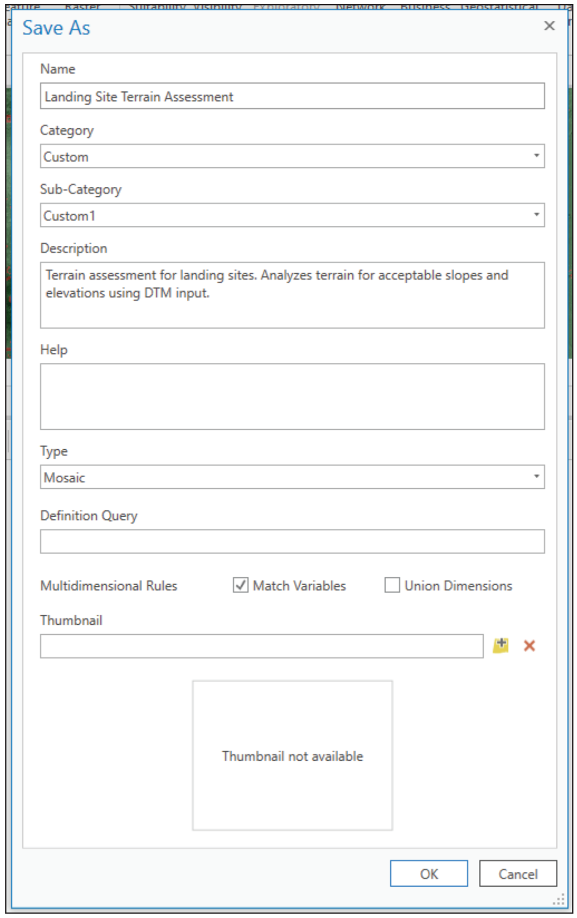
Selecting Custom will make your custom function available in any ArcGIS Pro project, not just the current project.

Sub-Category: **Custom1**

You can create your own categories within your custom raster function menu. This is the default setting.

Description: **Terrain assessment for landing sites. Analyzes terrain for acceptable slopes and eleva tions using DTM input.**

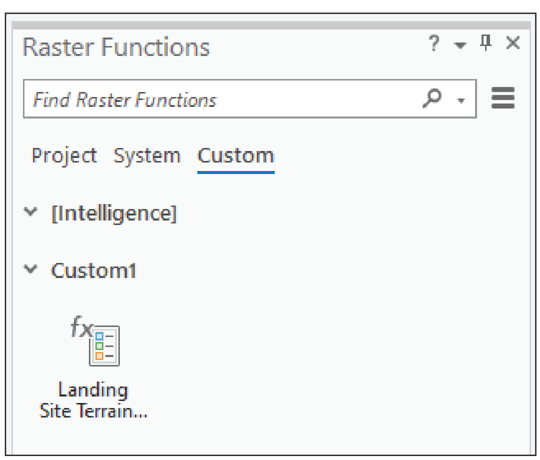
Leave all other defaults.



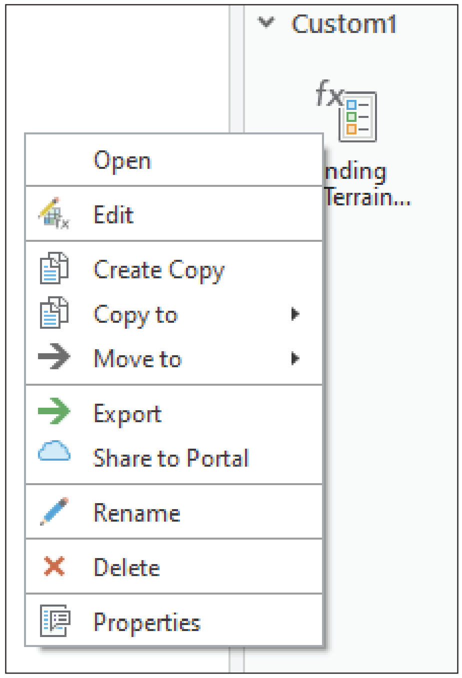
88. Click **OK** to save your custom raster function. Then click on the small **x** in the **Raster Function Template** tab (now named **Landing Site Terrain Assessment.rft.xml**) to close it.

When you save your custom raster function, it will be automatically added to the **Raster Functions** menu, under the **Custom** tab, and the **Raster Functions** pane will open to the **Custom** tab to view it.

89. In the **Raster Functions** pane, clear the previous search by clicking on the small **x** in the right end of the search bar. You will then see the new custom **Landing Site Terrain Assessment** raster function listed.

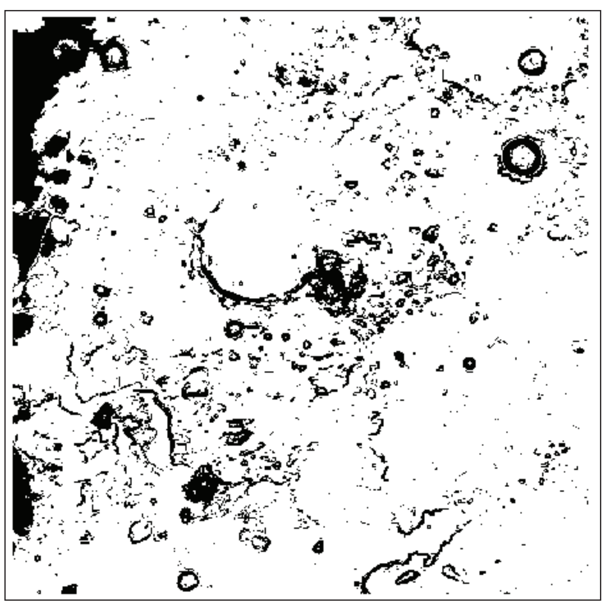


From here, you can run, edit, export, and share your custom raster function.

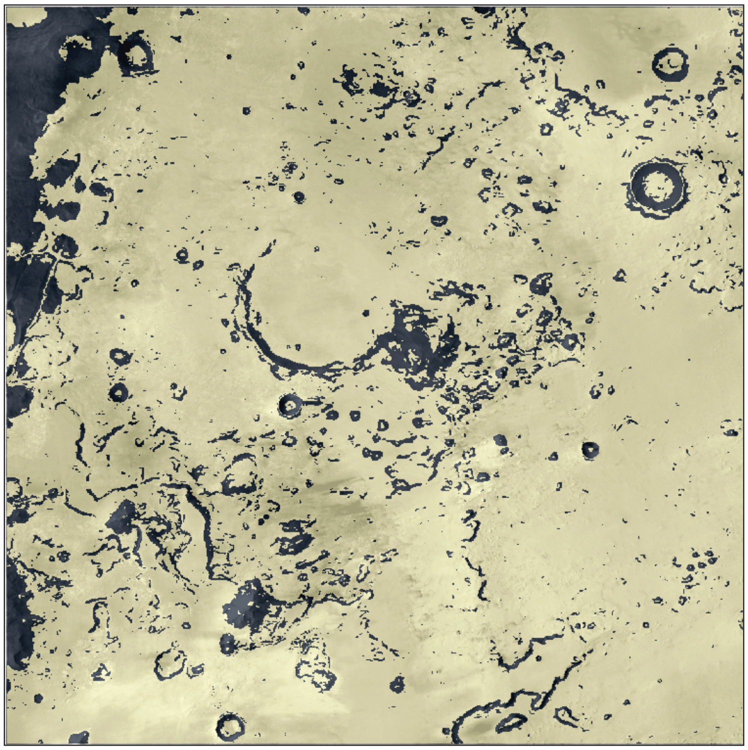


90. To test the new **Landing Site Terrain Assessment** function, click on the icon to open it. Then set the input **Raster** to **Jezero_DTM** and click **Create new layer**.

With one click, the new **Landing Site Terrain Assessment** function will run all the same steps you took to create the **Boolean_And_Remap_Jezero_DTM_Remap_Slope_Jezero_DTM** layer, and that new output will be added to your map as the **Landing Site Terrain Assessment_Jezero_DTM** layer.



91. In the **Contents** pane, click and drag the **Landing Site Terrain Assessment_Jezero_DTM** layer into the top of the **Raster Functions** group. Then, with the **Landing Site Terrain Assessment_Jezero_DTM** layer selected, turn on the **Swipe** tool (in the **Effects** section of the **Raster Layer Appearance** tab) and compare this new custom raster function output to the **Boolean_And_Remap_Jezero_DTM_Remap_Slope_Jezero_DTM** layer, which you produced through individual raster function steps. You may also want to set the **transparency** of this new **Landing Site Terrain Assessment_Jezero_DTM** layer to **60%** for easier comparison.



You now have your own custom raster function which can be used at any time to quickly and easily complete a slope and elevation landing site terrain assessment. You can also share this custom function with others. Custom raster functions can be particularly helpful to streamline and automate analyses or processes which you do frequently. Through sharing, custom raster functions can also be used to ensure that multiple people are using the same methods and settings in their processing steps.

92. In the **Contents** pane, uncheck the box for the **Raster Functions** group turn these layers off and click on the small triangle to collapse the group. Your map should once again show only the **CTX_mosaic** layer.

Part 4: Landing Site Assessment with a Custom Raster Function

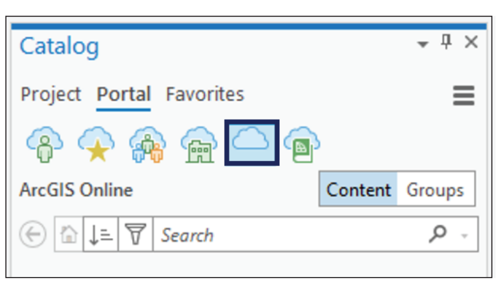
In the previous section you created a custom raster function which will complete a landing site assessment and identify areas with acceptable slopes and elevations. In this activity, you will use that custom raster function to quickly complete a larger scale landing site assessment for Mars.

93. In the **Contents** pane, right click **Map** and select **New Group Layer**. Name this new group layer **Landing Site Assessment**.

To complete the landing site assessment, you will work with a larger dataset than just the region around Jezero crater.

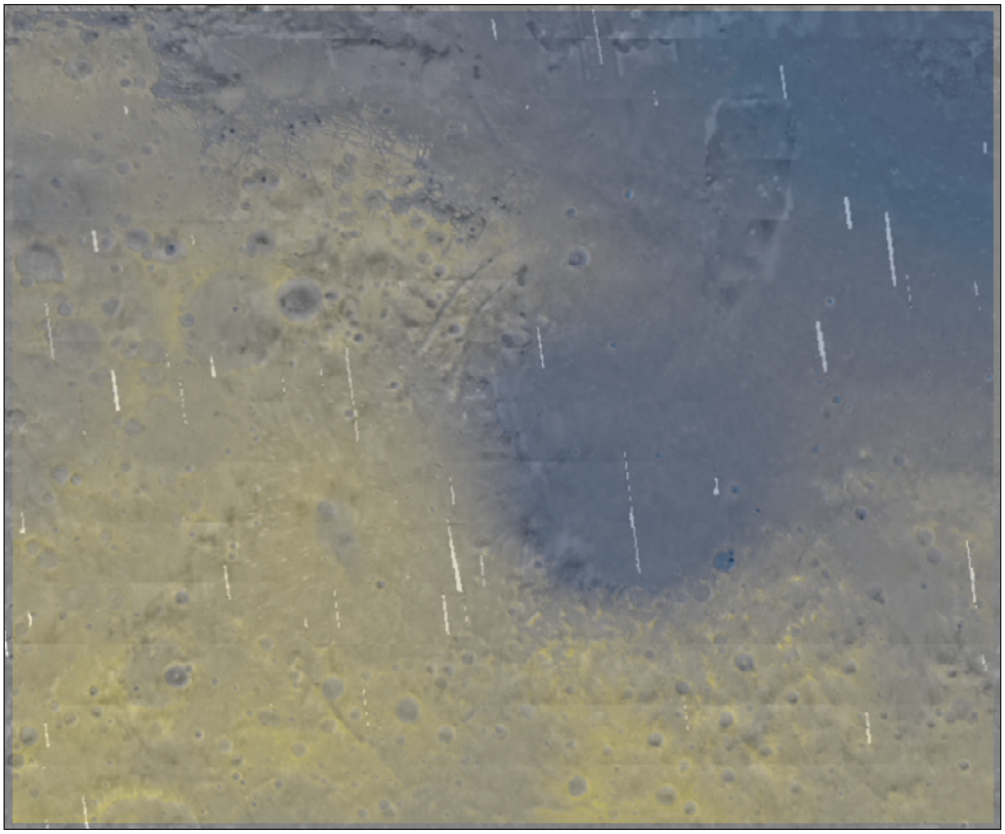
94. In the **Contents** pane, uncheck the box for the **CTX_mosaic** layer to turn it off. Then check the box to turn the **Syrtis DTM** layer on. Then, in the **Contents** pane, right click the **Syrtis DTM** layer and select **Zoom to Layer**.

95. At the bottom of the **Raster Functions** pane, click on the **Catalog** tab to return to the **Catalog** pane. Then switch to the **Portal** tab of the **Catalog** pane and click on the **ArcGIS Online** icon to search the entire ArcGIS Online portal.



The only required input to your custom **Landing Site Terrain Assessment** raster function is the DTM, but it is often helpful to have base imagery for additional context. A global mosaic of CTX imagery is available from the California Institute of Technology (Caltech) through the ArcGIS Online portal and can be added directly to your map.

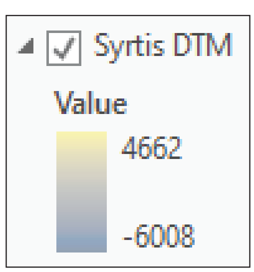
96. In the **Portal** tab of the **Catalog** pane, search the **ArcGIS Online** portal for **Mars CTX**. In the search results, right click the **Mars CTX (beta01) Image Mosaic** Tile Layer (owner: esri_astro, credit: NASA, JPL, MSSS, Caltech Murray Lab, Esri) and select **Add to Current Map**. Once the layer has been added to your map, in the **Contents** pane, click and drag it into the **Rasters** group, putting it just below the **Syrtis DTM** layer.



The Caltech Mars CTX (beta01) Image Mosaic is one of several Mars global datasets which are available for use through the ArcGIS Online portal. Also available are the Mars HiRISE Image Mosaic, the Mars HRSC-MOLA Terrain (elevation layer), the Mars HRSC-MOLA Colorized Shaded Relief, and the Mars MDIM 2.1 Colorized Global Image Mosaic datasets. These datasets are freely available for anyone to view and use in their GIS projects.

97. At the bottom of the **Catalog** pane, click on the **Raster Functions** tab to return to the **Raster Functions** pane.

The custom **Landing Site Terrain Assessment** raster function was created from the processing steps used in the analysis of the Jezero region. Before running this custom raster function on a broader Mars dataset, you must first update the maximum and minimum elevation values to reflect all the elevations which are present in the study area. These values can be identified by looking in the **Contents** pane at the **Syrtis DTM** symbology. *(Note: you may have to expand the **Syrtis DTM** layer in the **Contents** pane to view the symbology details.)*

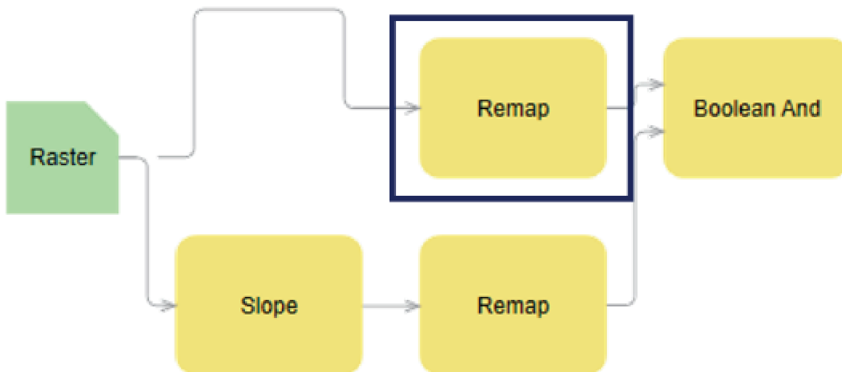


For this analysis, you could update the maximum and minimum elevation values to match only those that are present in the **Syrtis DTM** region. However, to make the custom raster function more versatile for future use, you will instead update the elevations to encompass all of Mars (-8,324 m to 21,078 m).

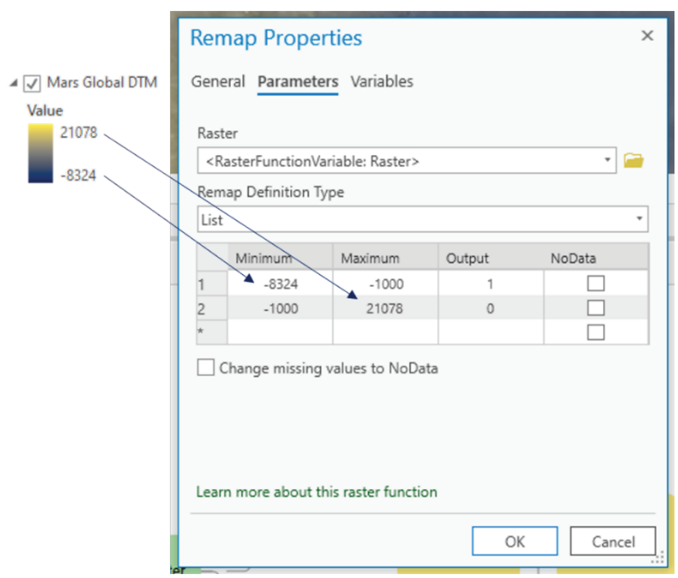
98. In the **Custom** tab of the **Raster Functions** pane, right click the **Landing Site Terrain Assessment** icon and select **Edit**. This will open the **Raster Function Template**.

The **Landing Site Terrain Assessment** function contains two **Remap** steps: one for slope, and one for elevation.

99. In the **Raster Function Template**, double click on the **Remap** block which has the **Raster** as a direct input. This is the elevation Remap step.



100. In the **Remap Properties** window, update the **Minimum** and **Maximum** elevation values to reflect the minimum and maximum elevation values on Mars (see example Mars Global DTM values in the image below). Then click **OK** to close the **Remap Properties** window.

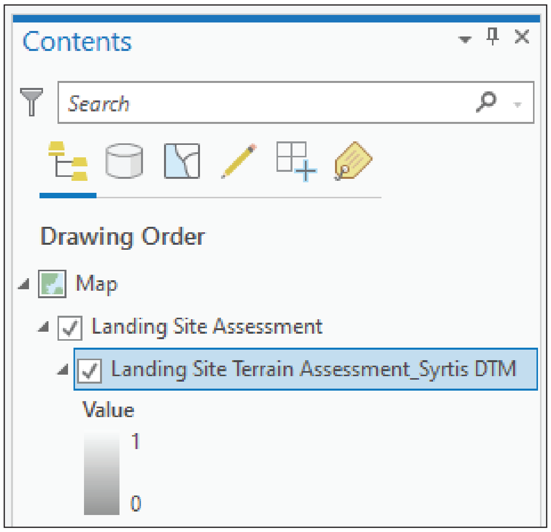


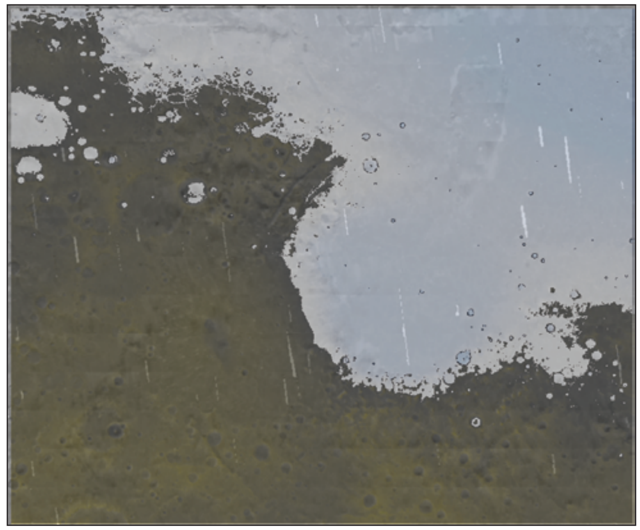
101. In the **Raster Function Template** toolbar, click on the **Save** icon to update the custom raster function. Then click on the small **x** in the **Raster Function Template** tab to close it and return to the full map view.

Now that you have updated the elevation values in the custom raster function, it can be used for any location on Mars, or all of Mars.

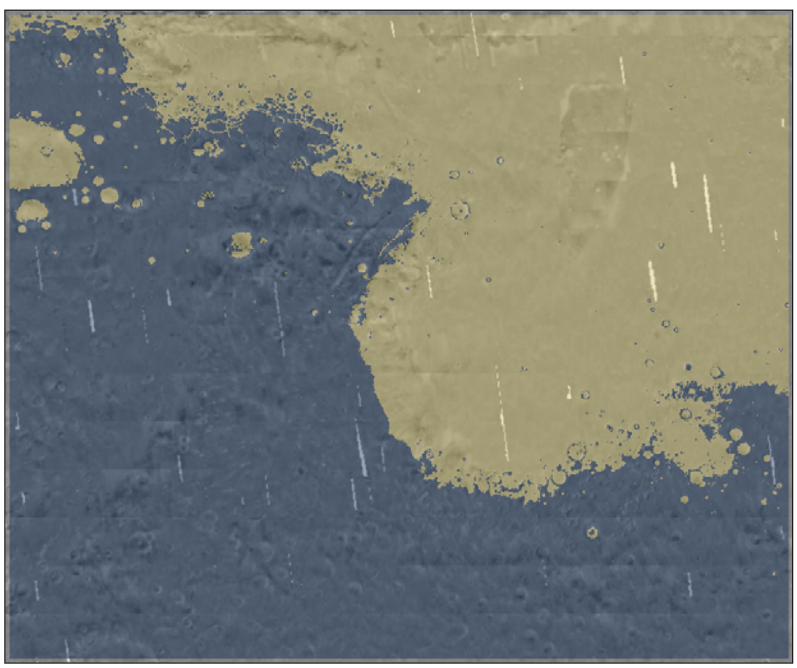
102. In the **Custom** tab of the **Raster Functions** menu, click on the **Landing Site Terrain Assessment** icon to open the custom raster function. Set the input **Raster** to the **Syrtis DTM** and click **Create new layer** to run the analysis.

103. In the **Contents** pane, click and drag the new **Landing Site Terrain Assessment_Syrtis DTM** layer into the **Landing Site Assessment** group. Then click on the small triangle to expand and view the contents of the **Landing Site Assessment** group. Select the new **Landing Site Terrain Assessment_Syrtis DTM** layer and set the **transparency** to **60%**.





104. In the **Contents** pane, right click the **Landing Site Terrain Assessment_Syrtis DTM** layer and select **Symbology**. In the **Symbology** pane, set the **Color scheme** to **Cividis**. Then click on the small **x** in the upper right corner of the **Symbology** pane to close it. In the **Contents** pane, uncheck the box for the **Syrtis DTM** to turn the layer off.



Your map now contains an assessment of slopes and elevations across the whole Syrtis region and has identified areas that have both slopes between 0°–5° and elevations of -1,000 m or lower. These areas are highlighted in yellow.

105. Take a minute to zoom and pan through your map and explore the outputs from your custom **Landing Site Terrain Assessment** raster function.

As you explore the map, remember that raster functions process data on the fly, and the results will update every time you move the map and (or) zoom, so the raster function is only processing the pixels you are currently viewing.

Summary

In this exercise you learned how to complete a multi-step analysis in ArcGIS Pro using two different methods: geoprocessing tools, and raster functions. Geoprocessing tools and raster functions can both be used for analysis but work in different ways. Geoprocessing tools analyze datasets and put the resulting product into new data layers. These new data are saved on your computer. Raster functions apply an analysis directly to the pixels of a dataset, but those shown within the current view and only at the current scale. Raster functions produce temporary map layers instead of creating new permanent files. You also learned how to string several raster functions together to create and save a custom raster function. These custom raster functions can be used later by you and others with whom you share them. Once your custom landing site assessment raster function was created, you then used it to quickly complete a large-scale landing site assessment for the Syrtis region of Mars. This example landing site assessment activity follows the same basic techniques that you would use to conduct data analyses of all types.

To Prepare for the Next Exercise:

If you wish to start with a fresh GIS project for Exercise 5, click the **x** in the upper right corner of your ArcGIS Pro window to close it. Alternatively, if you prefer to continue working in this GIS project, complete the following steps before moving on to Exercise 5: Click on the small **x** in the upper right corner of the **Raster Functions** pane to close it. Then, in the **Contents** pane, uncheck the boxes for the **Landing Site Assessment** group, and the **Mars CTX (beta01) Image Mosaic** to turn those layers off. Click on the small triangle next to the **Landing Site Assessment** group to collapse it. Then check the box to turn the **CTX_mosaic** layer back on and zoom to the extent of the **CTX_mosaic** layer.

Exercise 5: Creating Map Layouts and Products

When working in a GIS, you may need to present your findings or final map products in a layout form. Map layouts typically include objects like a legend, scale bar, title, and north arrow, and may also include multiple maps or variations of the same map. This exercise will introduce you to the basics of creating map layouts and GIS products in ArcGIS Pro. To learn more about the requirements for planetary maps published through the USGS, see the USGS Astrogeology Planetary Mapping Guidelines.

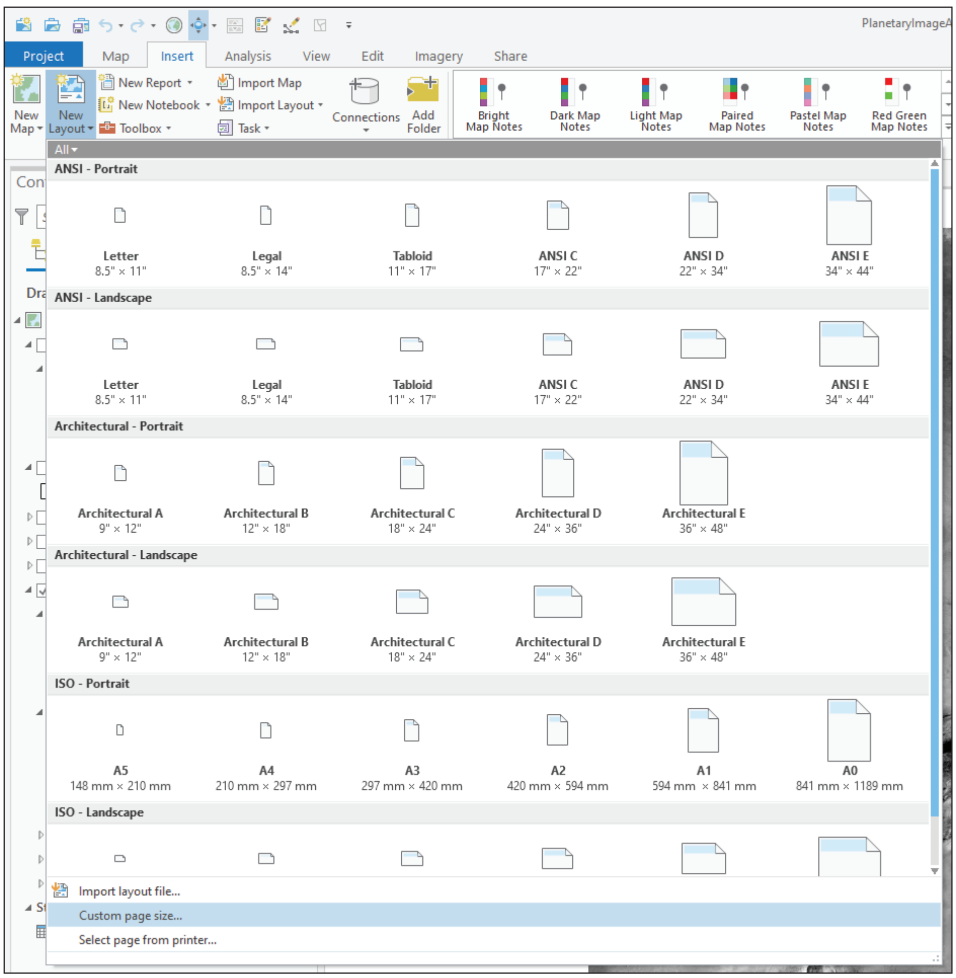
If you wish to continue working with the GIS project from Exercise 4 (**PlanetaryImageAnalysis_Exercise_4.aprx**) skip to step 2. If you prefer to start with a fresh GIS project, begin with step 1 below:

1. In your Windows File Explorer, navigate to the **PlanetaryImageAnalysis\Exercise_5** folder and double click the **PlanetaryImageAnalysis_Exercise_5** project file (**.aprx**) to open it in ArcGIS Pro.

The **PlanetaryImageAnalysis_Exercise_5** project will open in ArcGIS Pro. Data has already been added to the map, and all map layers are listed in the **Contents** pane.

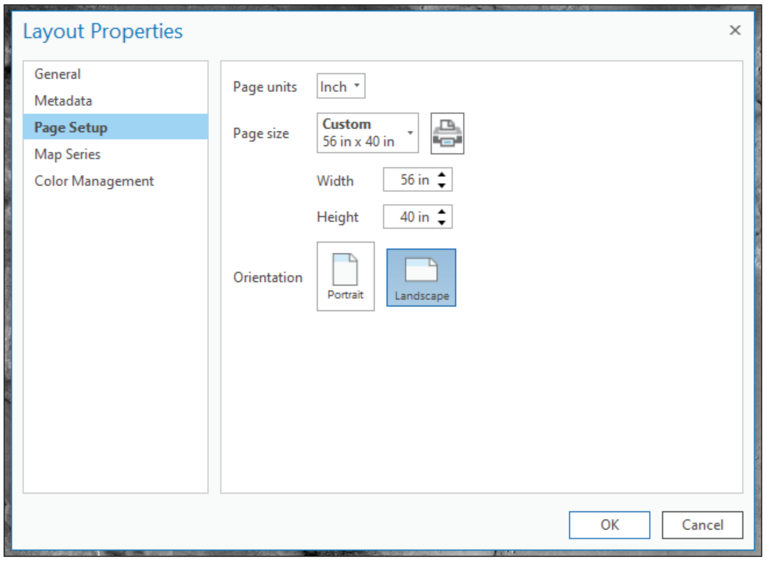
Part 1: Creating a New Map Layout

2. In the **Project** section of the **Insert** tab, click on the **New Layout** icon and then select the **Custom page size** option.



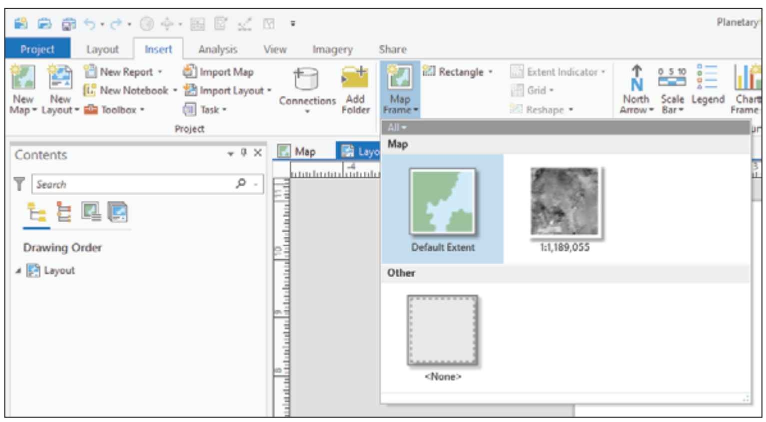
USGS Scientific Investigation Maps (SIMs) are limited to 40″×56″. For this exercise, you will create a map layout with these dimensions.

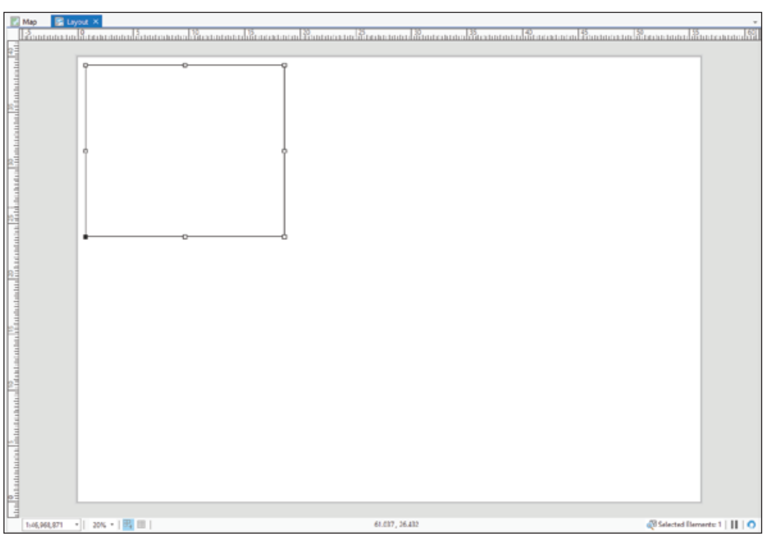
3. In the **Layout Properties** window, set the **Width** to **56 in**, and the **Height** to **40 in**. Then click **OK** to create the new Layout.



A new blank map layout will be added to your ArcGIS Pro project. You will add maps to the layout using **Map Frames**.

4. In the **Map Frames** section of the **Insert** tab, click on the **Map Frame** icon and select the **Default Extent** option. Then, click and drag to draw a box in the **Layout** to create this new **Map Frame**.

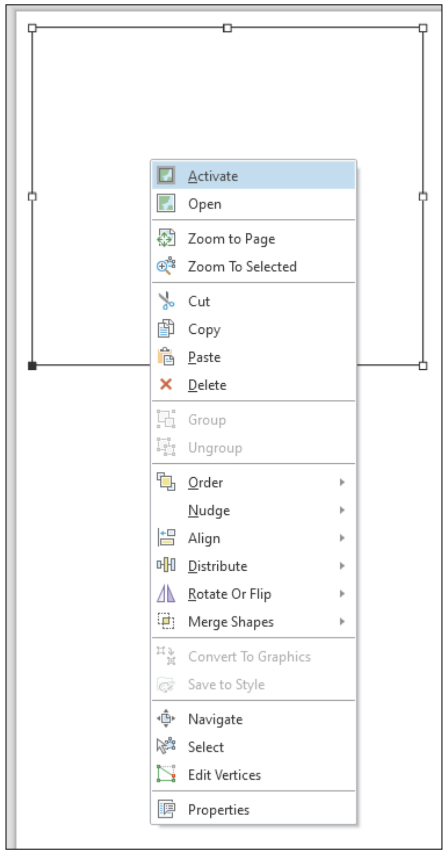




The new **Map Frame** has been added to the map. However, no map is visible within the **Map Frame** box.

Part 2: Working with Map Frames

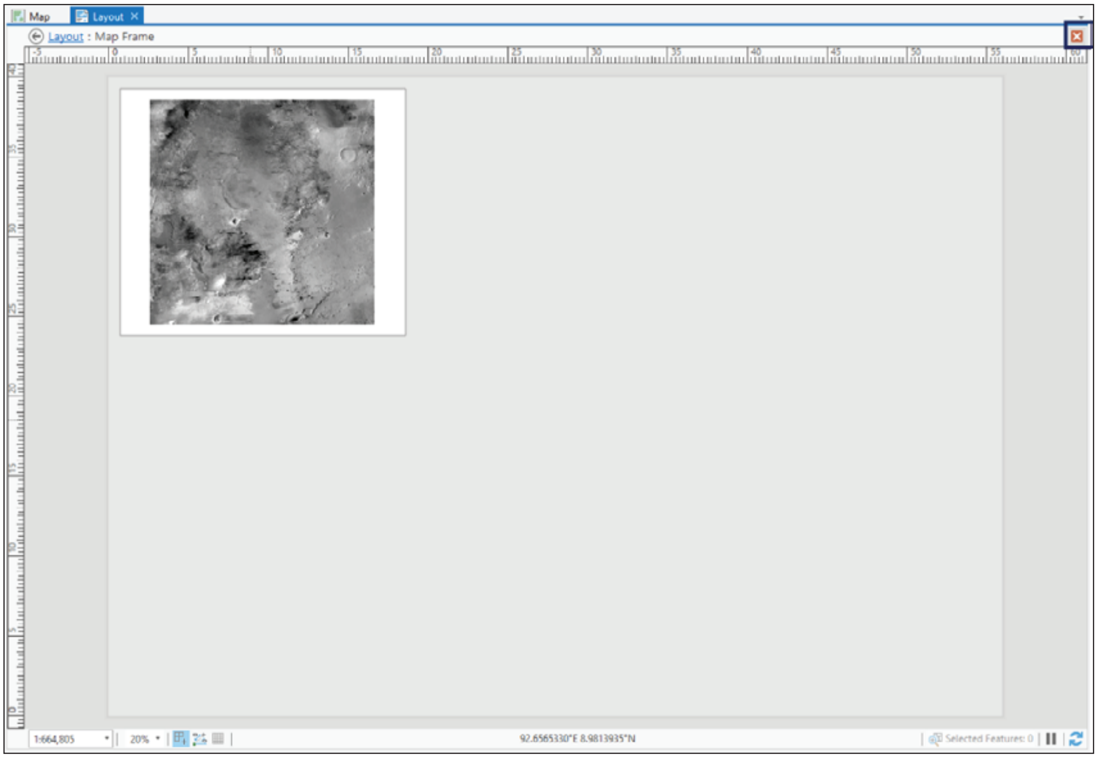
5. Right click inside the **Map Frame** and select **Activate**.



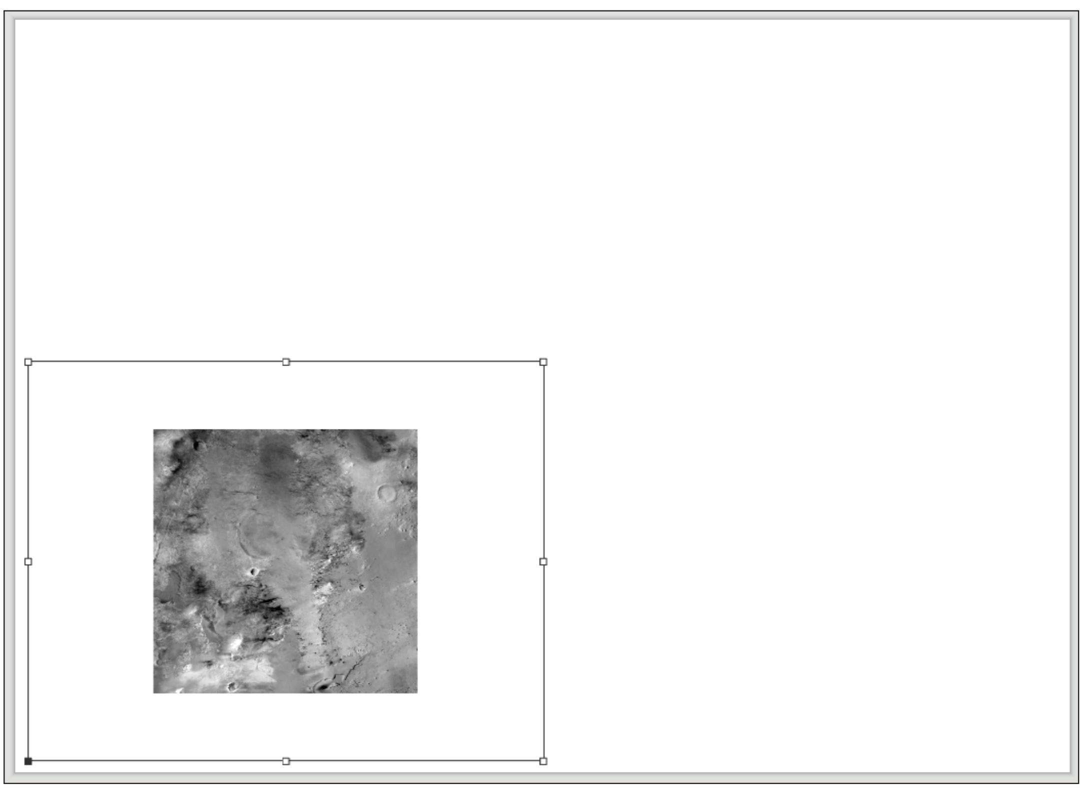
By activating the **Map Frame**, you can now zoom and pan to adjust the display within the frame. This **Map Frame** acts as a miniature version of the **Map** display and can be manipulated in a similar manner as the **Map** itself.

6. With the **Map Frame** now activated, in the **Contents** pane, right click the **CTX_mosaic** layer and select **Zoom to Layer**. You will see the active **Map Frame** update to display the full extent of the **CTX_mosaic** layer.

7. To deactivate the **Map Frame**, click on the small red **x** in the upper right corner of the **Layout** view.



8. In the **Layout**, click once on the **Map Frame** to display the resizing handles. Then click and drag one corner to resize the **Map Frame** so it takes up the top left quarter of the **Layout**. Once you have resized the **Map Frame**, click inside the **Map Frame** boundary and drag the entire frame to relocate it to the bottom left corner of the layout.

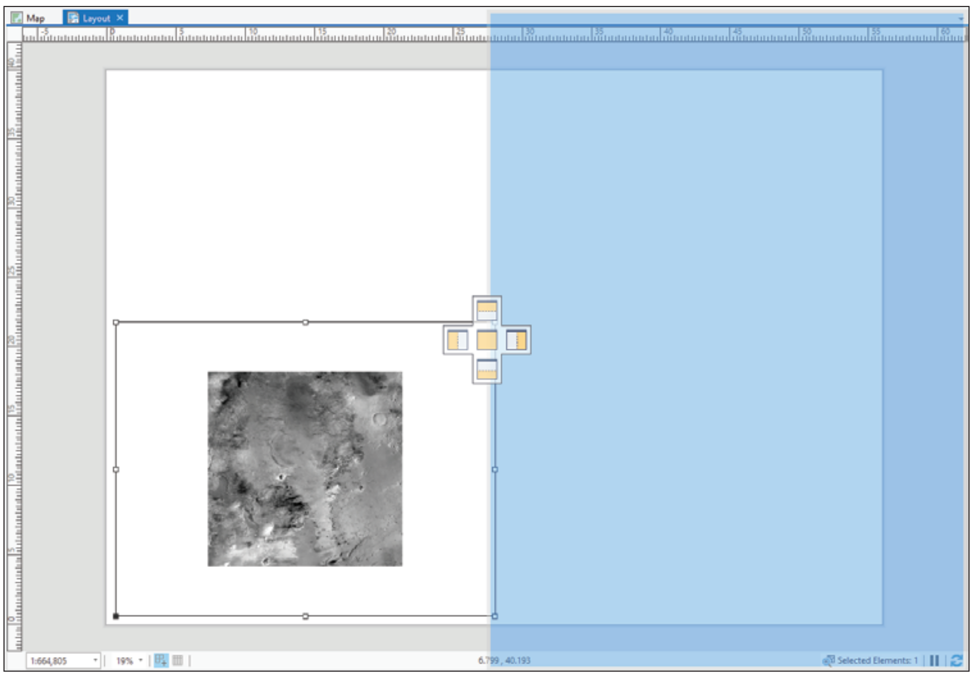


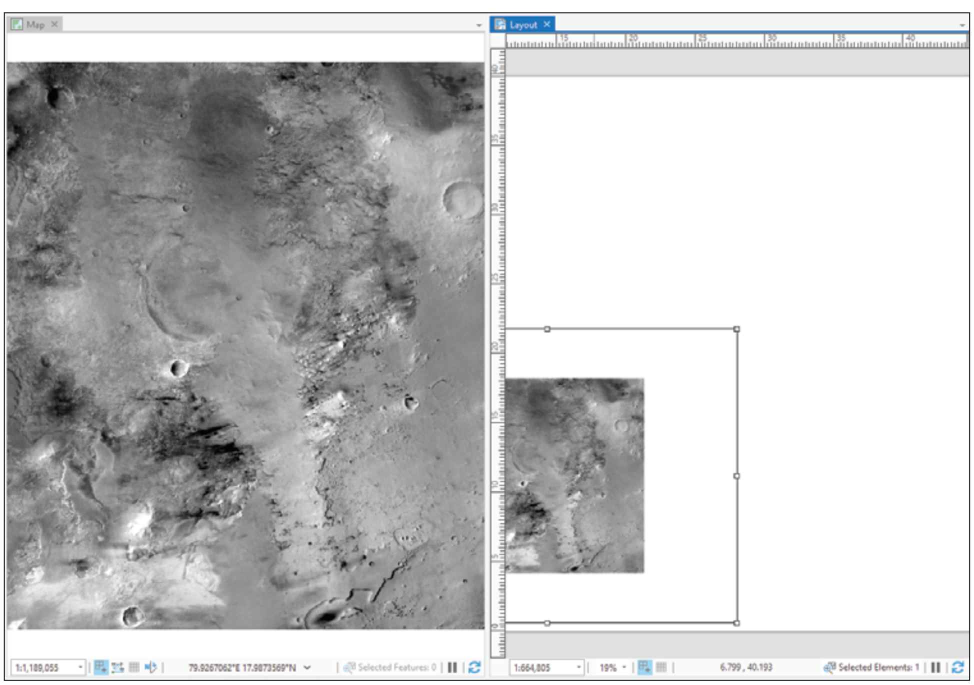
When you resize a **Map Frame**, the map displayed within its boundaries does not change in scale or location. Resizing a **Map Frame** will only show more or less of the map itself. To change the view within the **Map Frame**, you must first reactivate the **Map Frame**. Once the **Map Frame** has been activated, you may zoom and pan to make adjustments.

Part 3: Modifying Map Layers

The new **Layout** is displayed in the center of the ArcGIS Pro workspace as a new tab. Your **Map** is also displayed in this space as a tab, and you can switch back and forth between them. Like other components in ArcGIS Pro, you can also pull these tabs out from these locations and display them side by side, or as their own separate windows.

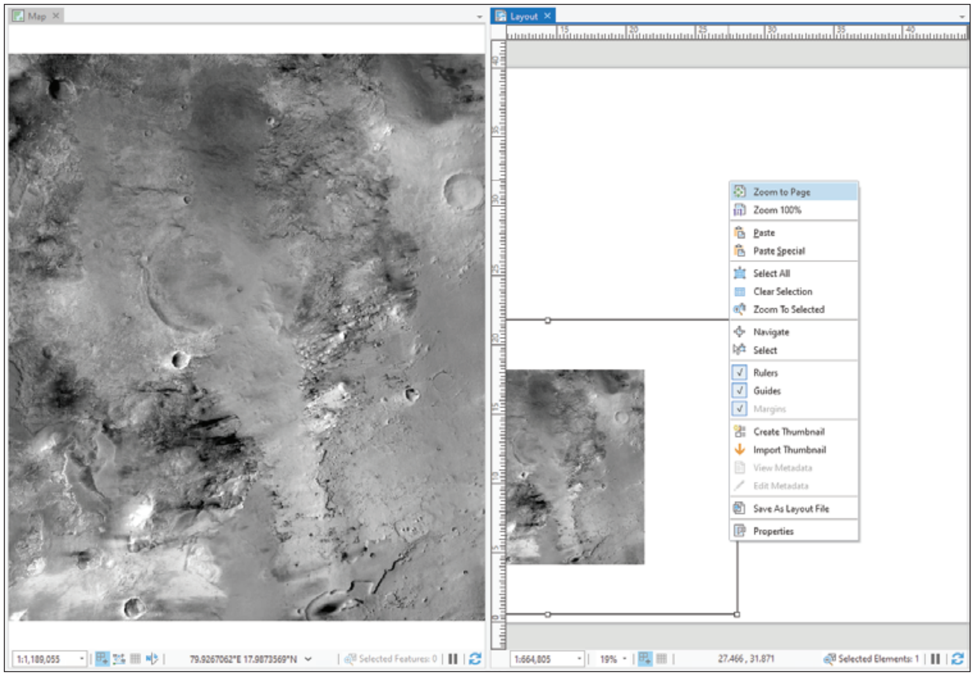
9. Click on the **Layout** tab and drag it away from its current location. Move your cursor around the main workspace until you see the docking options. Use the docking option on the right side of the main workspace to place the Layout and the Map side by side.





Viewing the **Layout** and **Map** together (either docked side by side, or with the **Layout** pulled into its own window) can make it easier to manipulate layers in your **Map**, while watching how that changes your **Layout**.

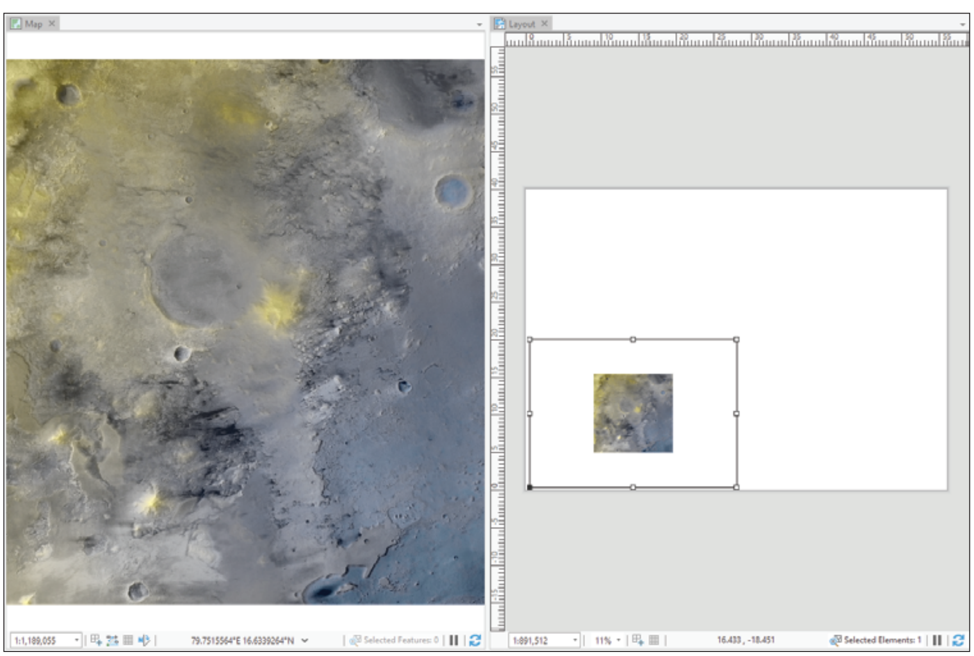
10. In the **Layout**, right click anywhere in the page and select **Zoom to Page**. This will reset the **Layout** view, so the entire page is visible.



Currently, the **Layout** tab is highlighted in blue, which indicates it is the active tab. You can switch between activating the **Map** and the **Layout** by clicking on their tabs or within their respective windows.

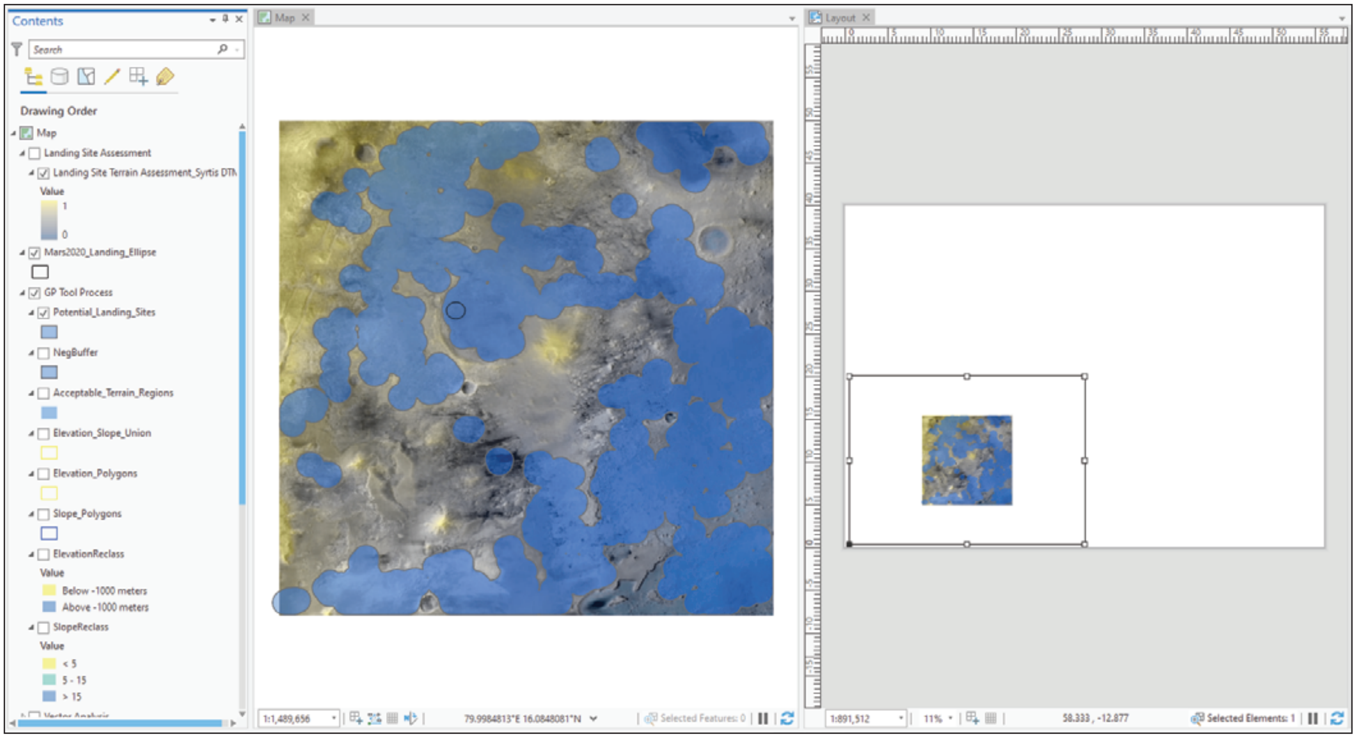
11. Click between the **Map** and the **Layout** tabs to observe how changing the active tab affects the tabs in the **Menu Bar** and the layers listed in the **Contents** pane. End with the **Map** tab activated.

12. With the **Map** tab activated, in the **Contents** pane, Check the box for the **Jezero_DTM** to turn the layer on. Observe how this affects the **Map Frame** in the **Layout** view.

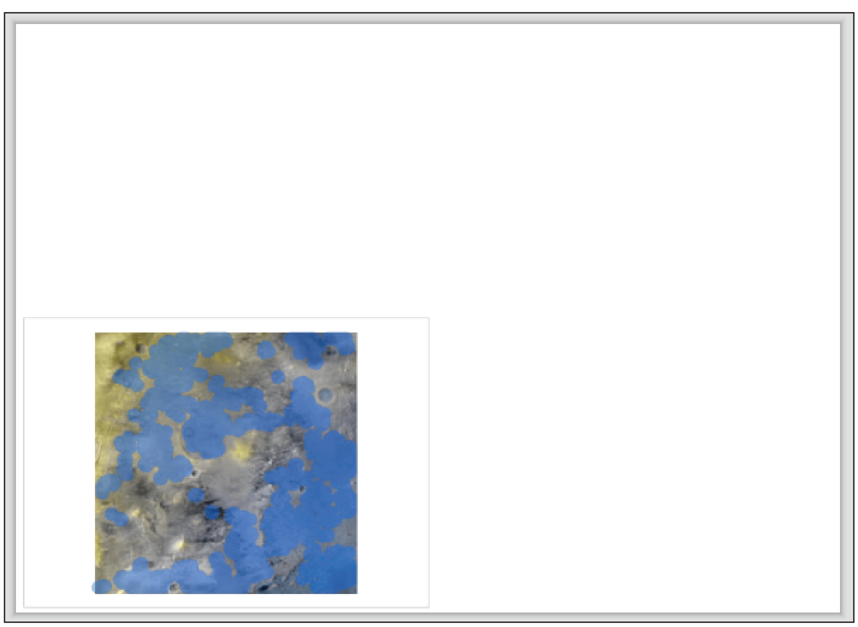


Each **Map Frame** is connected directly to a **Map**. Any changes that occur in the map (for example: changing visible layers), will also be seen in the **Map Frame**.

13. In the **Contents** pane, Check the box to turn on the **Mars2020_Landing_Ellipse**. Then expand the **GP Tool Process** group and check the box to turn the group on. The **Acceptable_Terrain_Regions** layer was left on and will automatically display when the group is made visible again. Uncheck the box for the **Acceptable_Terrain_Regions** to hide that layer and turn on the **Potential_Landing_Sites** layer instead. Then right click the **Jezero_DTM** layer and select **Zoom to Layer** so you can see the whole map area now that you are working in the side-by-side view.



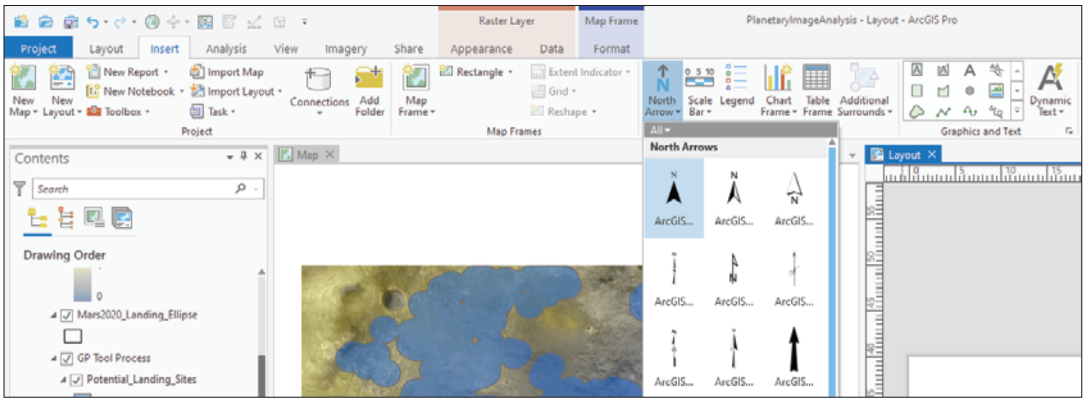
14. In the **Layout**, right click the **Map Frame** and select **Activate**. Then, in the **Contents** pane, right click the **Jezero_ DTM** layer and **Zoom to Layer** to fill the active **Map Frame**. Then click on the small red **x** box in the upper right corner of the **Layout** view to close the active **Map Frame**.

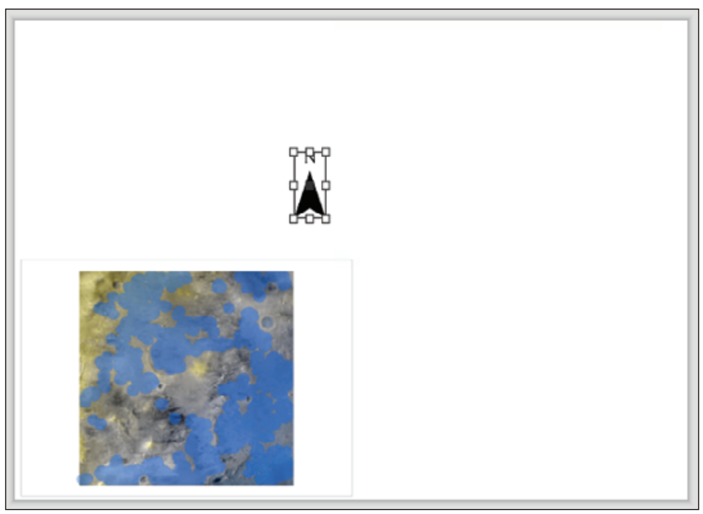


Part 4: Adding Map Features

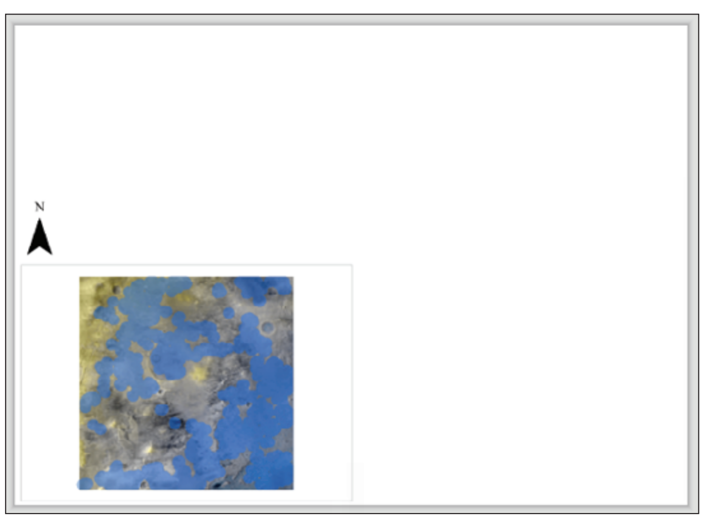
For a map to effectively convey information, it must contain a north arrow, scale bar, and legend. These features may all be added using the **Insert** tab.

15. Confirm that you have the **Layout** view selected. Then, in the **Map Surrounds** section of the **Insert** tab, click on the **North Arrow** icon to open the dropdown menu. Click on **the ArcGIS North 1** arrow style to add it to the map **Layout**. When the crosshairs appear, click and drag in the map **Layout** to draw a box and place the **north arrow**.

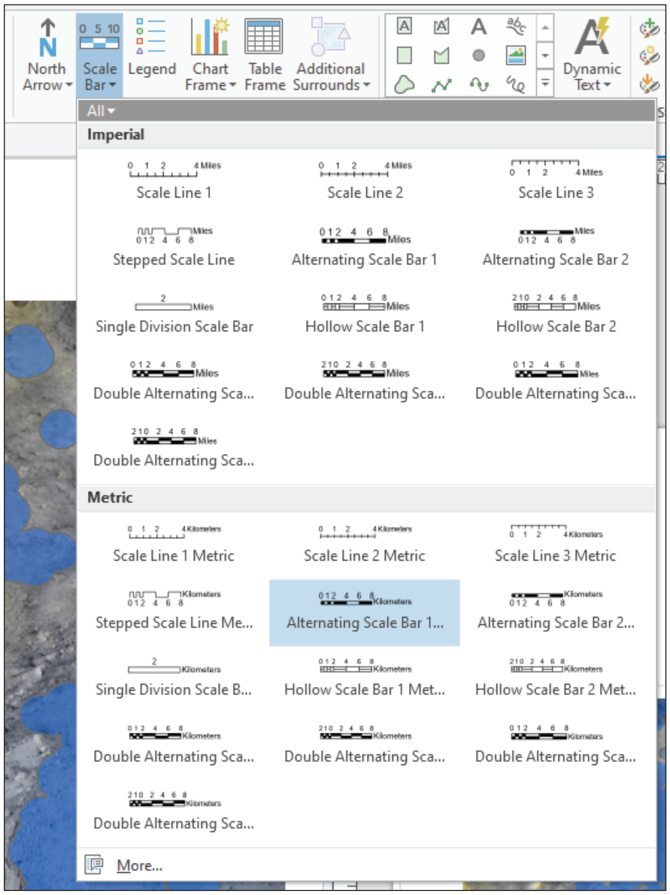


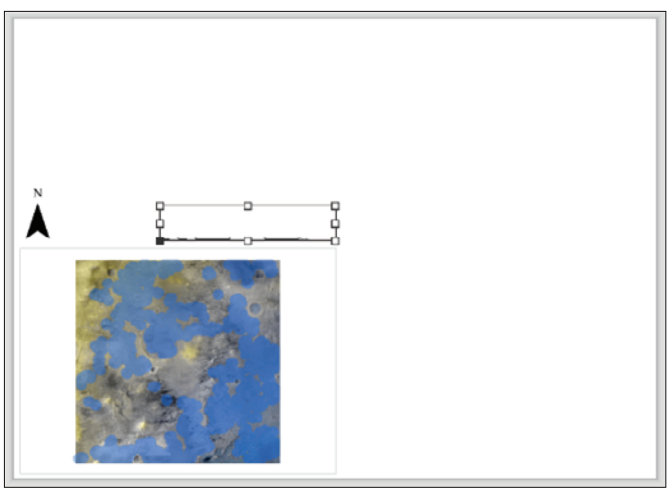


16. In the map **Layout**, use the handles to resize the **north arrow**. Then click and drag it to create the following result:



17. In the **Map Surrounds** section of the **Insert** tab, click on the **Scale Bar** dropdown menu to view the scale bar format options. Select the **Metric Alternating Scale Bar 1** format. When the crosshairs appear, click once in the **Layout** place the scale bar.





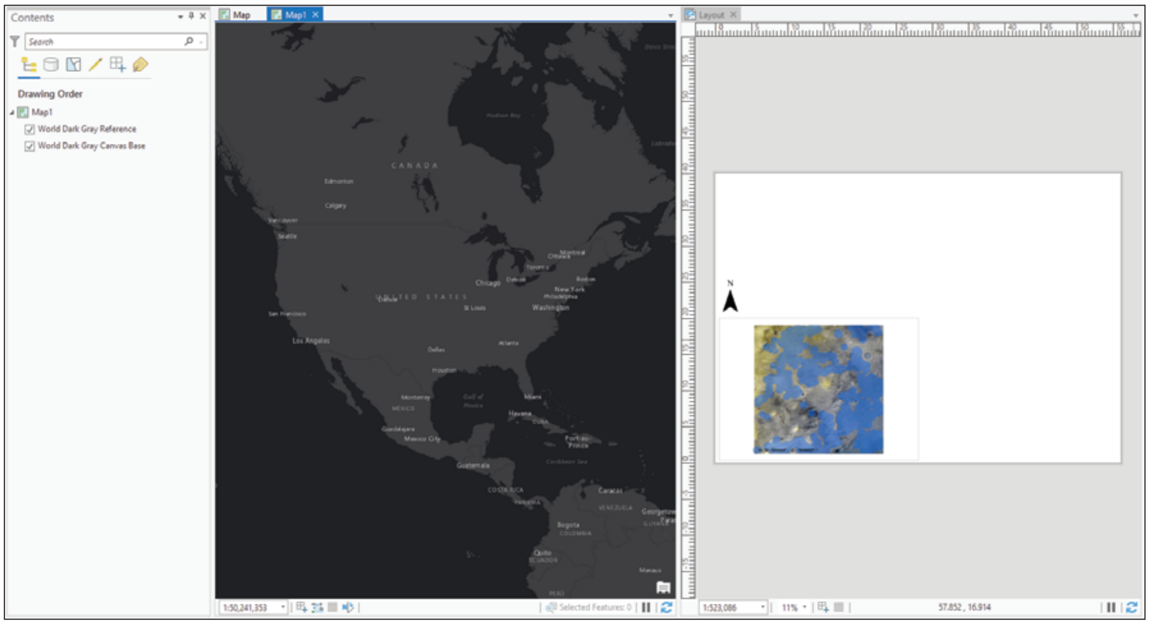
Scale bars are tied to one specific **Map Frame** contained in your layout. If you zoom in or out in the **Map Frame**, the **scale bar** will automatically update to reflect the new scale at which the **Map Frame** is being viewed. **Scale bars** will also automatically update as they themselves are resized.

18. Click and drag the **scale bar** into the bottom left corner of the **Map Frame**. Then use the handles to resize it until it is 100 km long. For this step, you may need to zoom in to the **Layout** view to see more detail. When you have finished, right click in the **Layout** page and select **Zoom to Page** to return to the current full-page view.

Part 5: Displaying Multiple Combinations of Data

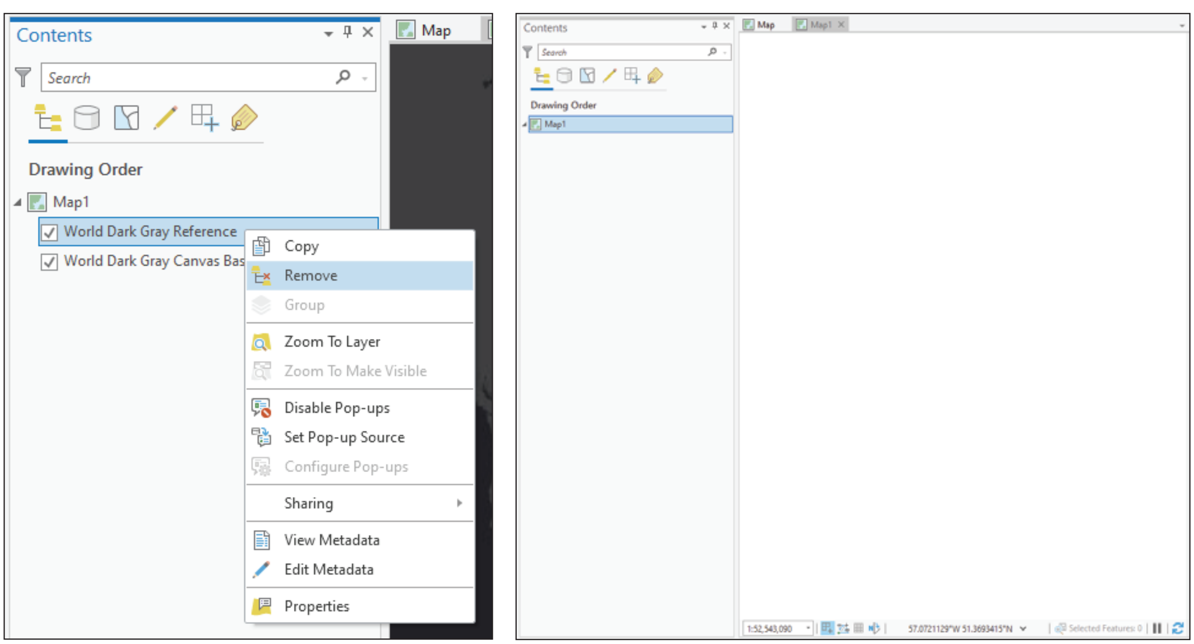
When creating a **Layout**, you can include multiple **Map Frames** to show data at various scales, or entirely different datasets. If a **Layout** includes multiple **Map Frames** that reference the same **Map**, you can only display the same data with a different extent. As you turn layers on/off in that **Map**, it will update both **Map Frames**. To display a different combination of data, you must reference a different **Map**. For this **Layout**, you will also include a global map to provide context for your study area. To have a **Map Frame** show this global context map, you must first create a new map within the ArcGIS Pro project.

19. Click in the **Map** to activate that tab. Then, in the **Project** section of the **Insert** tab, click on the **New Map** icon to create a new map. The new map (**Map1**) will be added as a second tab in the map window and the **Contents** pane will update to display the contents of this new map.

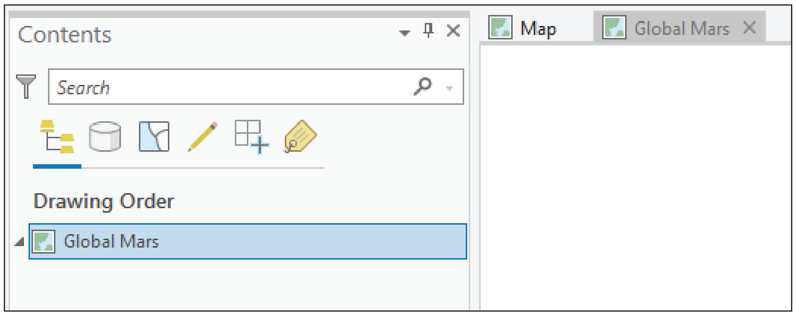


Because ArcGIS Pro is not specific to planetary science, all new maps open with Earth-based base maps by default.

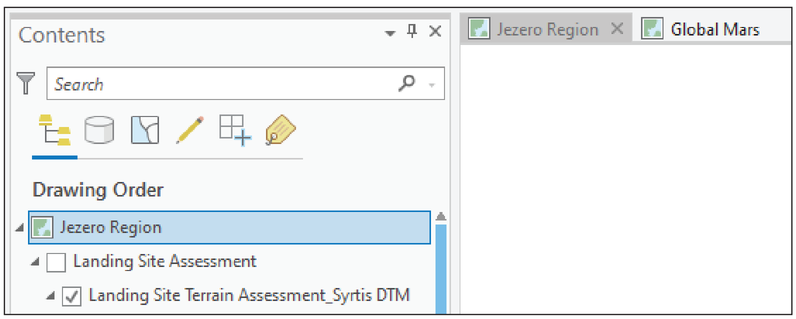
20. In the **Map1 Contents** pane, right click each of the existing basemap layers and select **Remove** to remove them from your map. You should end with an empty map and no map layers listed in the **Map1 Contents** pane.



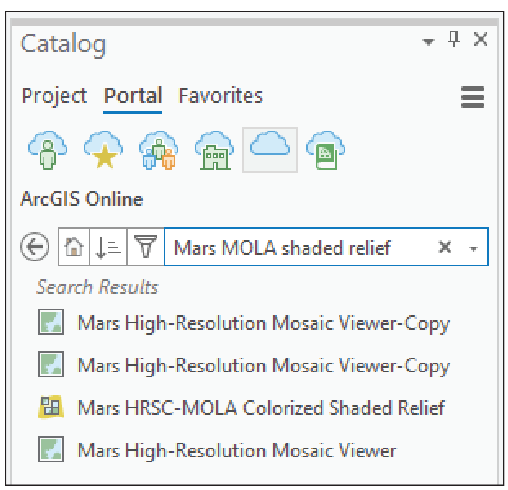
21. In the **Contents** pane, click on **Map1** and hover to activate the text. Rename **Map1** to **Global Mars**. Press **enter** to apply this change. You will also see the map tab update to reflect the new map name.



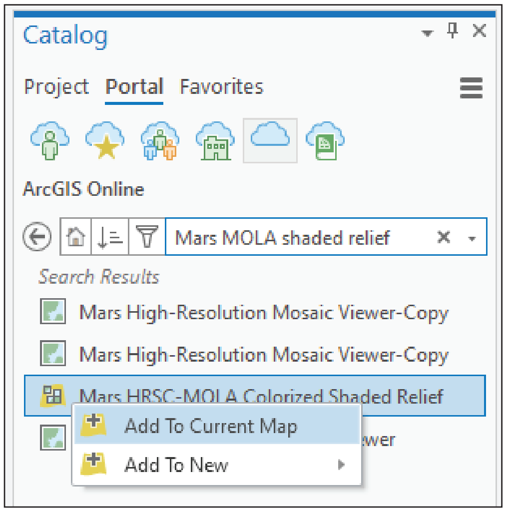
22. Click on the **Map** tab to return to your original map. Then, in the **Contents** pane, click and hover over **Map** to activate the text. Change the map name to **Jezero Region** and press **enter** to apply the change.



23. Click on the **Global Mars** map tab to switch to work in this new map. Then, in the **Catalog** pane, switch to the **ArcGIS Online** section of the **Portal** tab and search for Mars MOLA shaded relief.

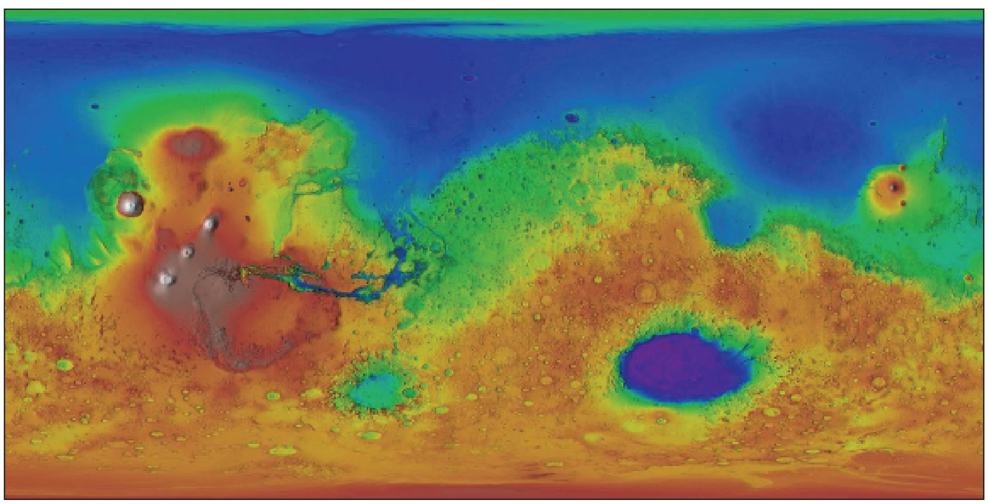


24. In the search results, right click on the **Mars HRSC-MOLA Colorized Shaded Relief** tile layer and select **Add To Current Map**.



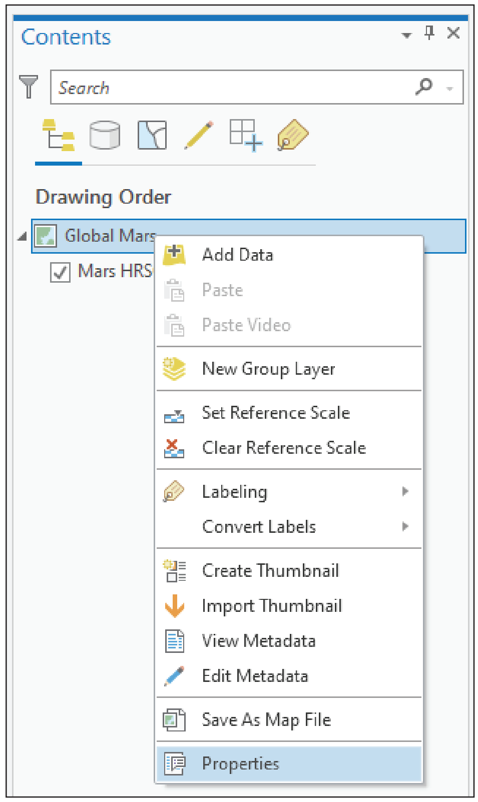
The **Mars HRSC-MOLA Colorized Shaded Relief** dataset will be added to the **Global Mars** map as a new layer.

25. In the **Contents** pane of the **Global Mars** map, right click on the **Mars HRSC-MOLA Colorized Shaded Relief** layer and select **Zoom to Layer** to view the full extent of this dataset.

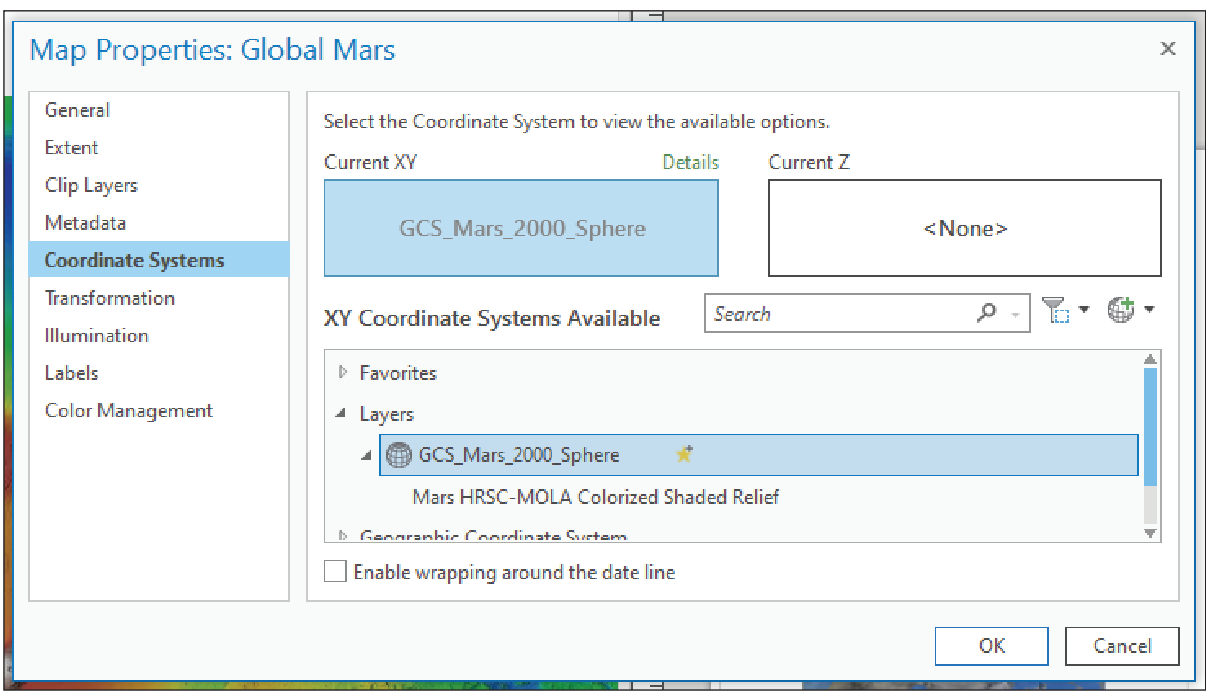


Since the original new map was automatically assigned Earth-based base maps, it is important to confirm that the coordinate system of the **Global Mars** map itself was updated when this new data is added.

26. In the **Contents** pane of the **Global Mars** map, right click on the **Global Mars** map name and select **Properties**.

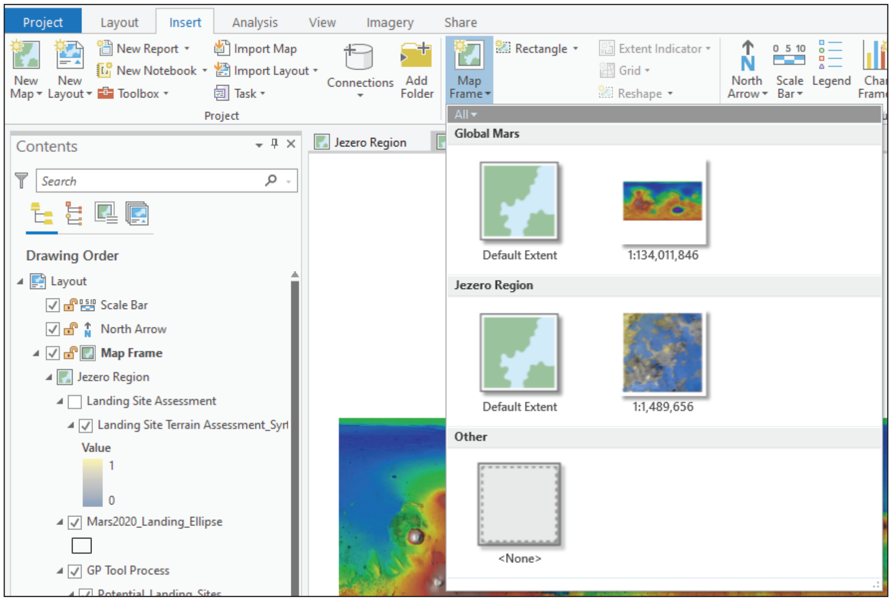


27. In the **Map Properties: Global Mars** window, select the **Coordinate Systems** tab (down the left side of the window), and confirm that the coordinate system has updated to **GCS_Mars_2000_Sphere**. Then click **OK** to exit the **Map Properties** window.



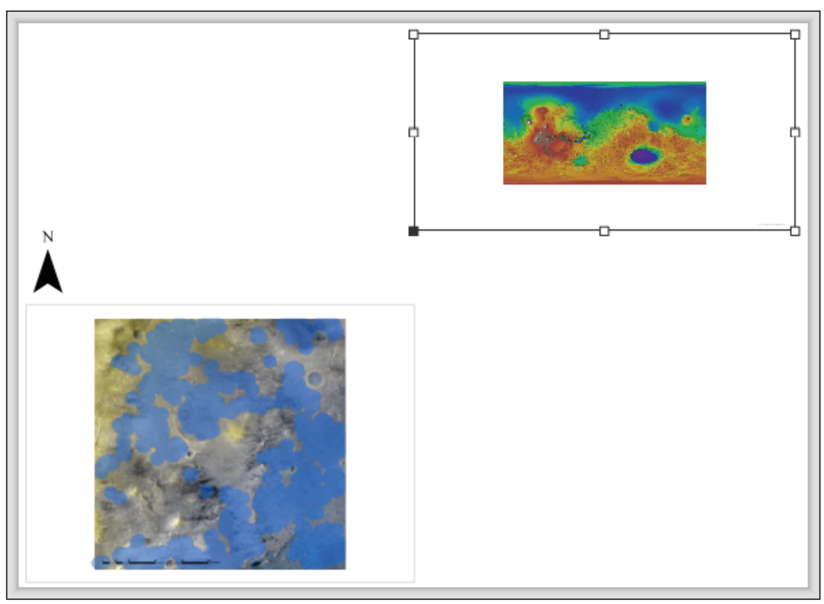
Now that you have created the **Global Mars** map, you can add **Map Frames** to the **Layout** to display it.

28. Click in the **Layout** window to activate it. Then, in the **Map Frames** section of the **Insert** tab, click on the **Map Frame** icon to open the dropdown menu and observe the available options.

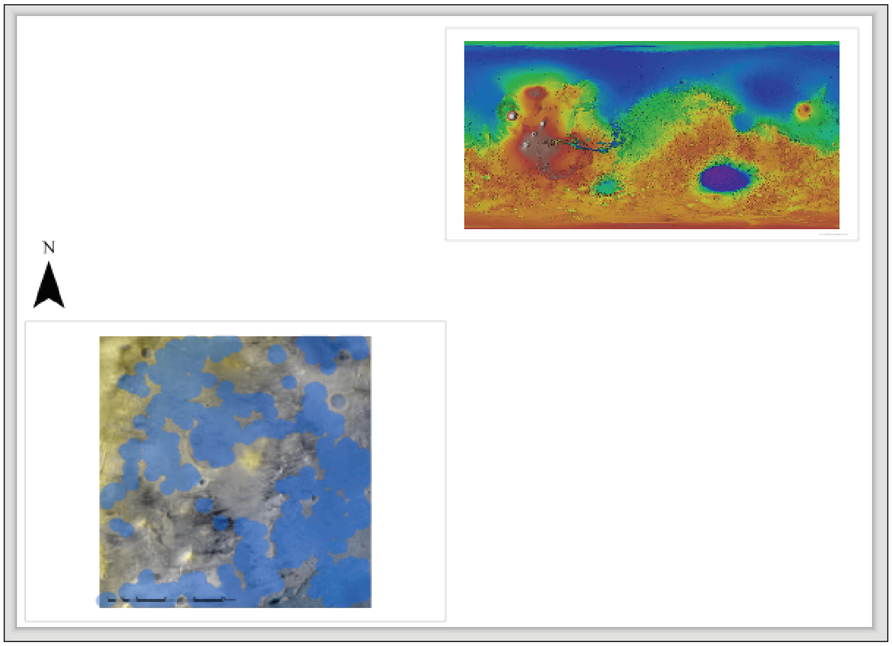


The **Map Frame** options now display the updated map names (**Global Mars** and **Jezero Region**) and have both maps available as **Map Frame** data sources.

29. In the **Map Frame** options, select the **Global Mars Default Extent** option. Then draw a box to place it in the upper right corner of your **Layout**.



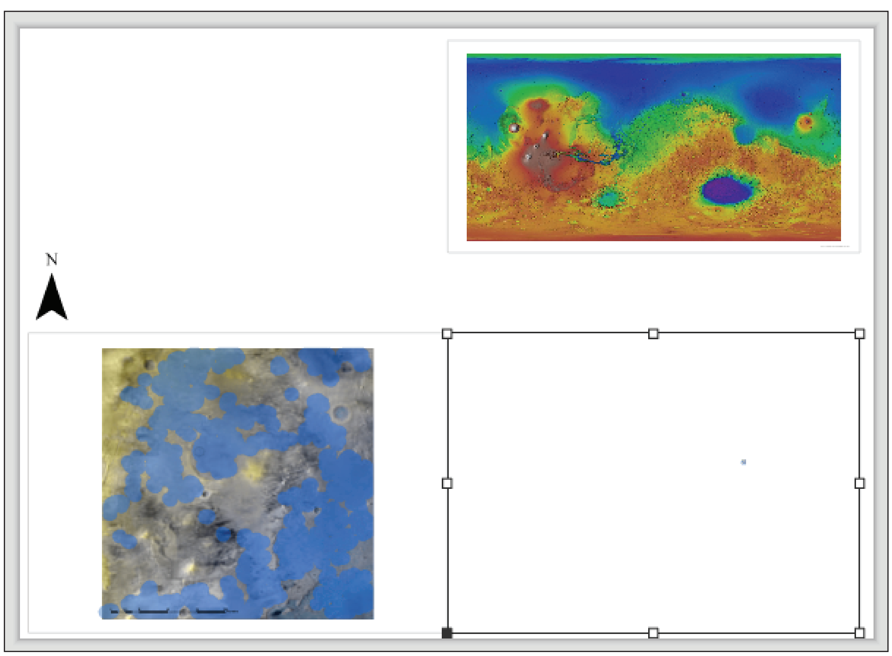
30. Right click in the new **Map Frame** and select **Activate**. Then, with the **Map Frame** activated, in the **Contents** pane, right click on the **Mars HRSC-MOLA Colorized Shaded Relief** layer and select **Zoom to Layer** to resize the data and fill the new **Map Frame**. Exit the active **Map Frame** by clicking on the small red **x** in the upper right corner of the **Layout**.



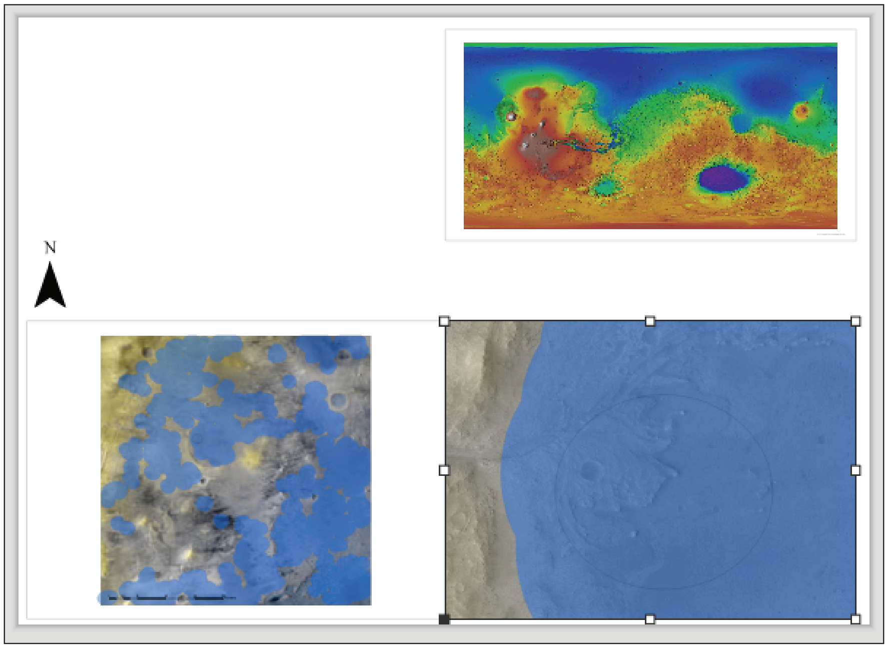
Part 6: Displaying the Same Data at Different Scales

The **Layout** now includes a landing site assessment map (lower left), and a global context map (upper right). You will add a third **Map Frame** to show a detailed view of the landing site assessment results in the area around the final Mars 2020 landing site.

31. In the **Map Frames** section of the **Insert** tab, click on the **Map Frame** icon and select the **Jezero Region Default Extent** option. Then draw a box for this new **Map Frame** in the lower right corner of the **Layout**.



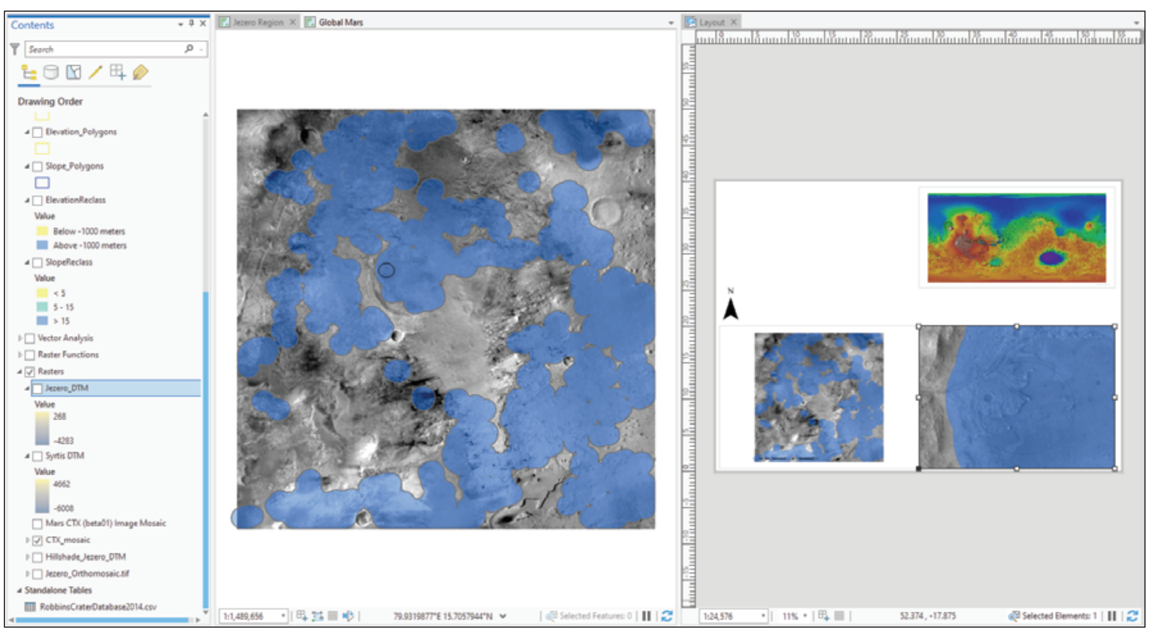
32. Right click in the new **Map Frame** and select **Activate**. Then use the scroll wheel of your mouse to zoom in to the **Mars2020_Landing_Ellipse** and surrounding area. Once you have zoomed to this area, exit the active **Map Frame** by clicking on the small red **x** in the upper right corner of the **Layout**.



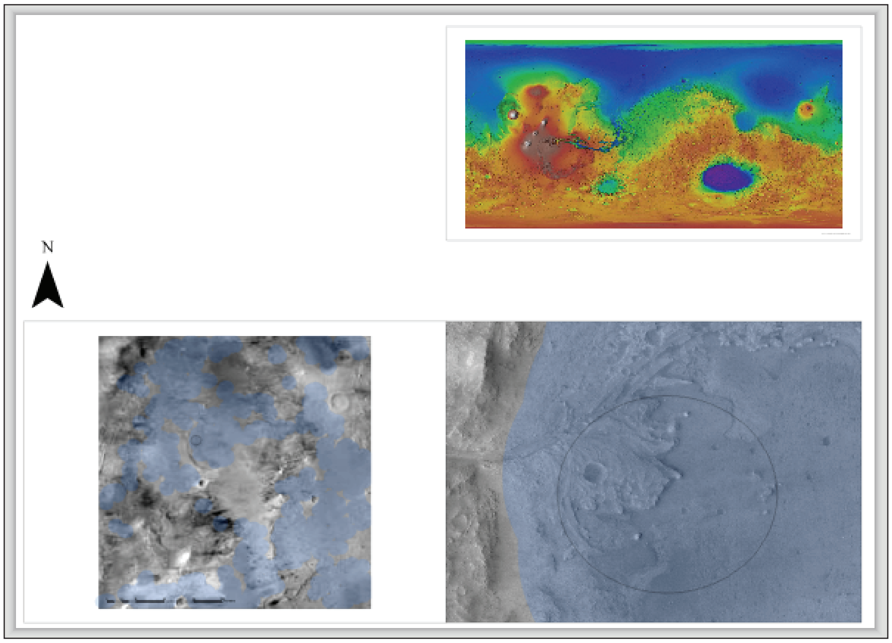
Part 7: Making Changes to Existing Map Frames

With all three **Map Frames** added, you may find that you wish to change some of the layer display properties to improve the look of your **Layout**. At any time, you can turn map layers on and off and change the symbology and those changes will be automatically reflected in the **Layout**.

33. Click on the **Jezero Region** map tab to activate it. Then, in the **Contents** pane, uncheck the box to turn off the **Jezero_DTM** layer. Observe how this change is automatically reflected in the **Layout**.

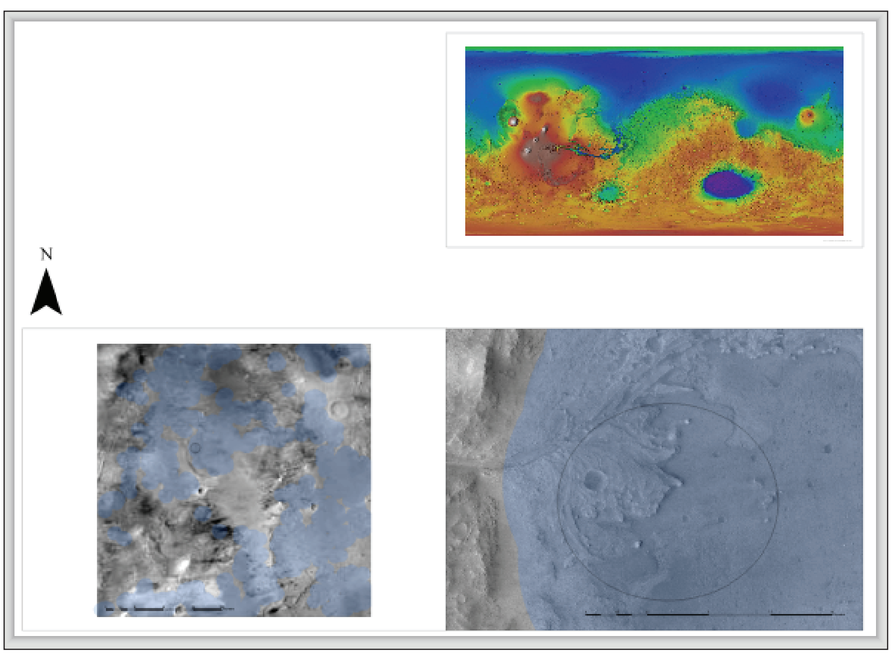


34. In the **Contents** pane of the **Jezero Region** map, select the **Potential_Landing_Sites** layer, and set its **transparency** to **60%** (in the **Feature Layer Appearance** tab). Then, in the **Contents** pane, click on the symbol for the **Mars2020_Landing_Ellipse** layer to open the **Format Polygon Symbol** pane. Switch to the **Properties** tab of the **Format Polygon Symbol** pane and change the **Outline width** to **1.5 pt** and click **Apply**. Then click on the small **x** in the upper right corner to exit the **Format Polygon Symbol** pane.



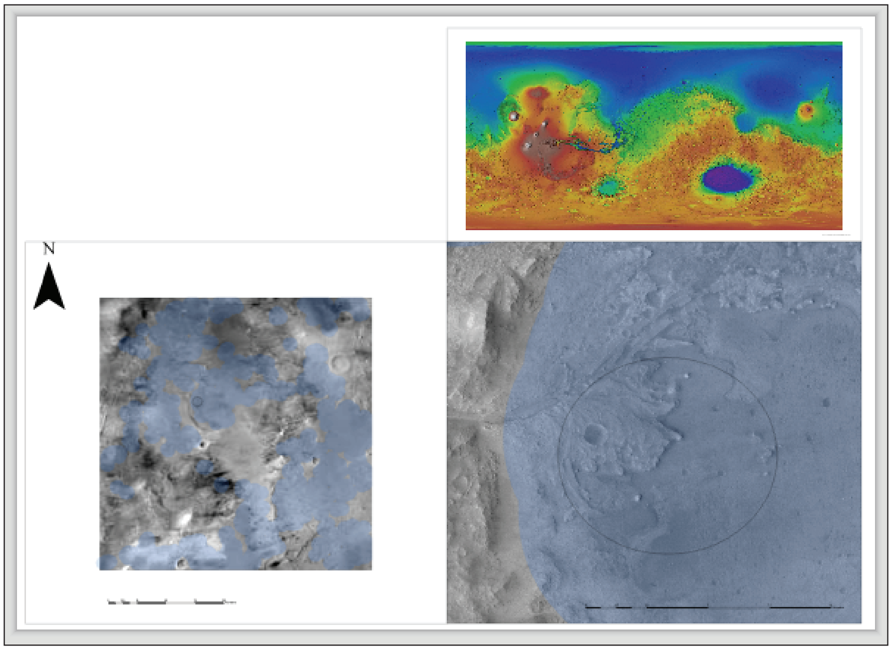
With the map displays updated, you can now return to the **Layout** and continue adding elements. The detailed landing site **Map Frame** is at a different scale than the other landing site assessment frame and should have its own scale bar.

35. Click in the **Layout** to activate it. Then click on the detailed landing site **Map Frame** (bottom right corner) to select it. (Note: When placing a scale bar, it will automatically tie to whichever **Map Frame** was last selected, so it is best practice to select the **Map Frame** you want before placing the scale bar.) In the **Map Surrounds** section of the **Insert** tab, click on the **Scale Bar** dropdown menu to open the options and select the **Metric Alternating Scale Bar 1**. Then click once in the **Layout** to place the scale bar, then use the handles to resize it to 10-km-long and drag it to the bottom right corner of the lower right **Map Frame**. (Note: Like before, you may need to zoom in to see more detail when you are resizing the scale bar. When you have finished, right click in the **Layout** page and select **Zoom to Page** to return to the full view.) You should end with this **Layout** result:

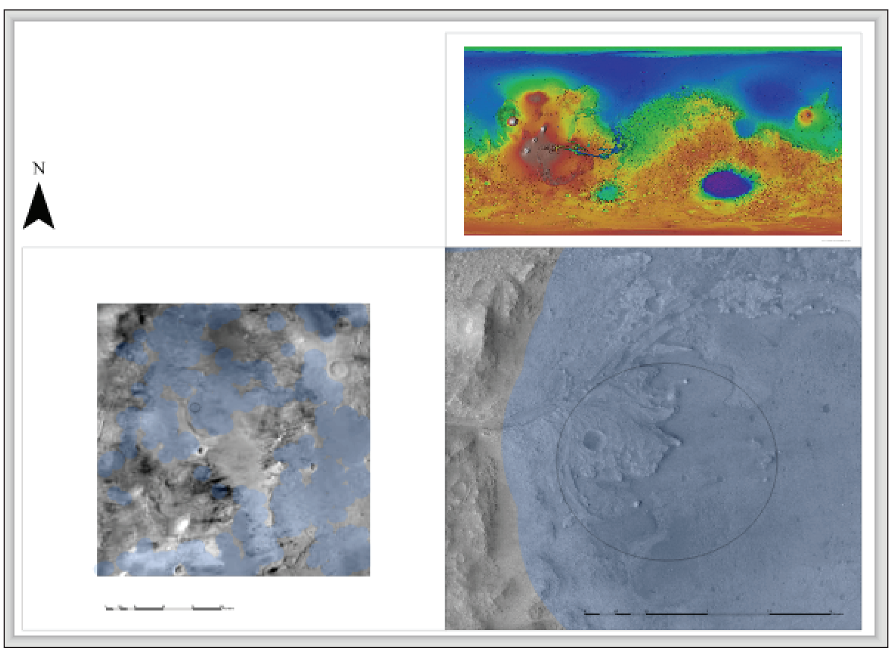


With all the **Map Frames** placed in the **Layout**, you may find you wish to adjust their locations or sizes to better fit the **Layout** space.

36. In the **Layout**, click on the lower left **Map Frame** to select it. Then use the handles to drag the top boundary up to the bottom of the upper left (global map) **Map Frame**. Repeat this step for the lower right **Map Frame**.

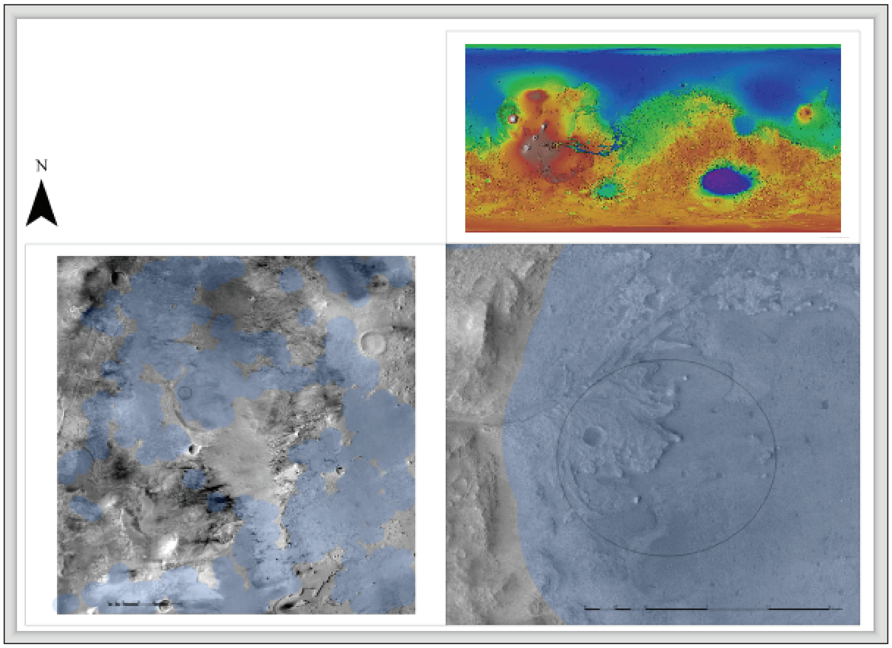


37. In the **Layout**, click and drag the **North Arrow** to move it to the blank space in the upper left corner.



Now that the **Map Frames** are their final desired sizes, you may need to adjust the maps displayed within their boundaries.

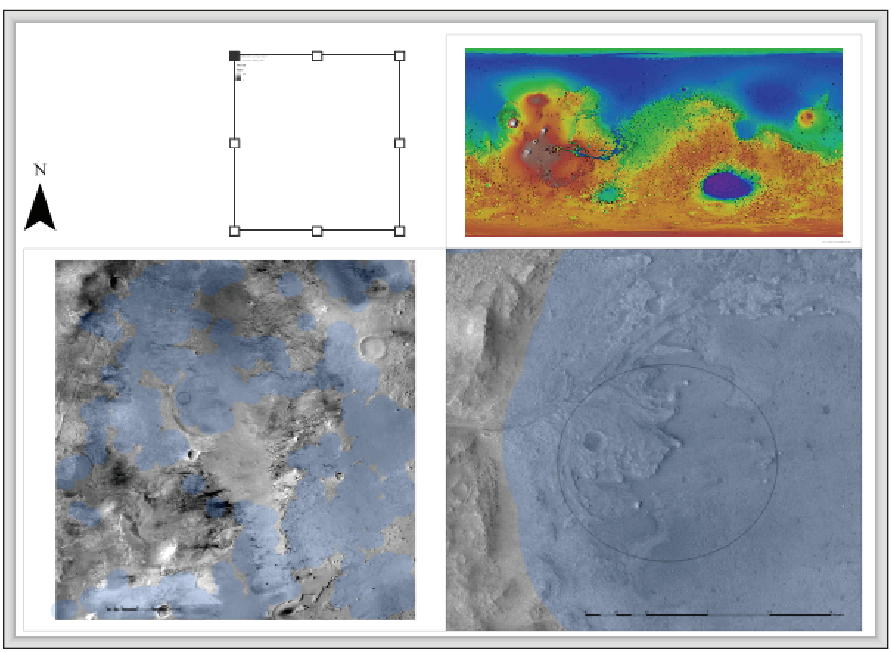
38. Right click on the lower left **Map Frame** and select **Activate**. Then, in the **Contents** pane, right click on the **Potential_Landing_Sites** layer and select **Zoom to Layer** to fill the **Map Frame**. When you have finished, click on the small red **x** in the upper right corner of the **Layout** to exit the active **Map Frame**. Then zoom in to this **Map Frame** to observe how this change affected the **scale bar**. When you have finished, return to the full **Layout** extent (**Zoom to Page**).



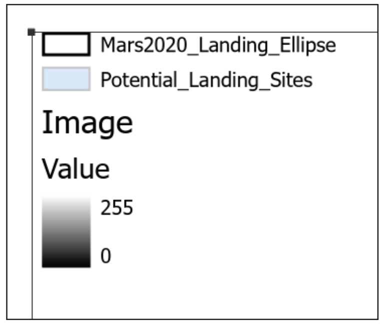
Part 8: Adding and Editing a Title and Map Legend

In addition to **scale bars** and a **north arrow**, effective maps also include a **Legend**.

39. In the **Map Surrounds** section of the **Insert** tab, click on the **Legend** icon. Then, in the **Layout**, click and drag to draw a box and place the **Legend**.

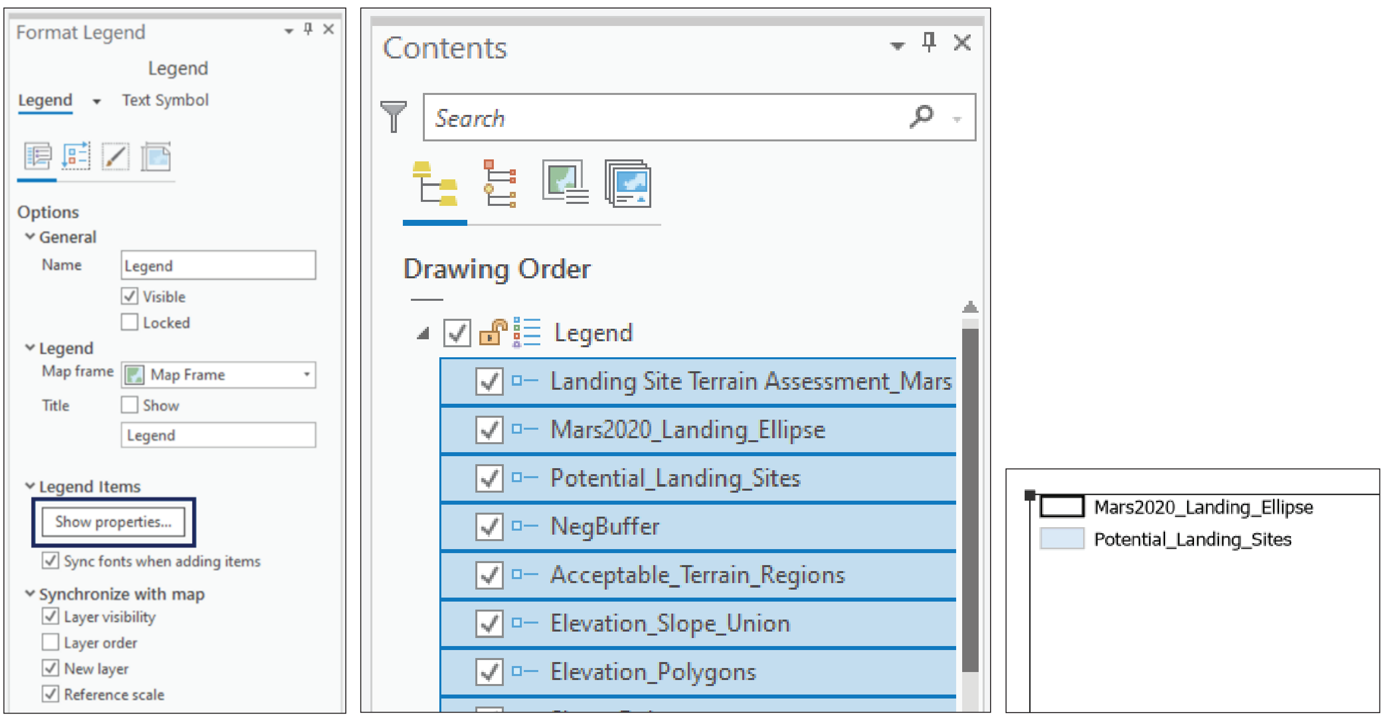


40. In the **Layout**, zoom in to view the **Legend**.

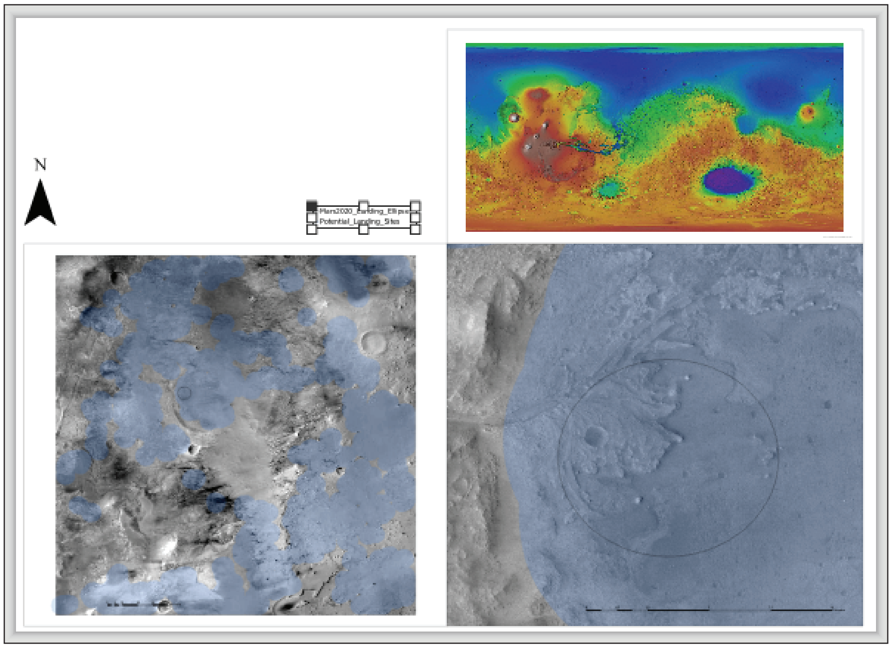


Often, the default configuration for the **Legend** will include items you do not want listed, like the Image pixel values shown above.

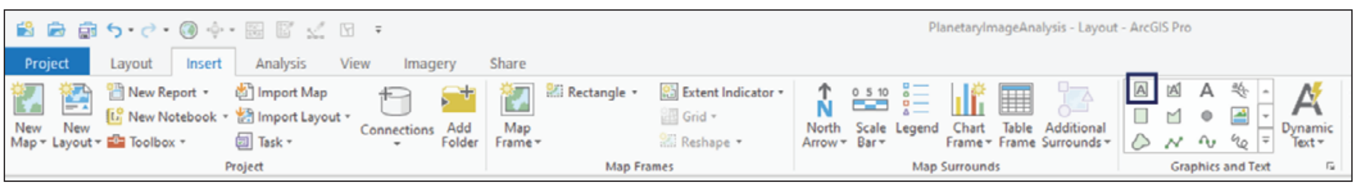
41. In the **Layout**, double click in the **Legend** box to open the **Format Legend** pane. Then, under **Legend Items**, click on the **Show Properties…** button. The **Legend Items** will then be listed in the **Contents** pane. In the **Contents** pane under **Legend**, uncheck the box for the **Image** to remove it from the **Legend**.

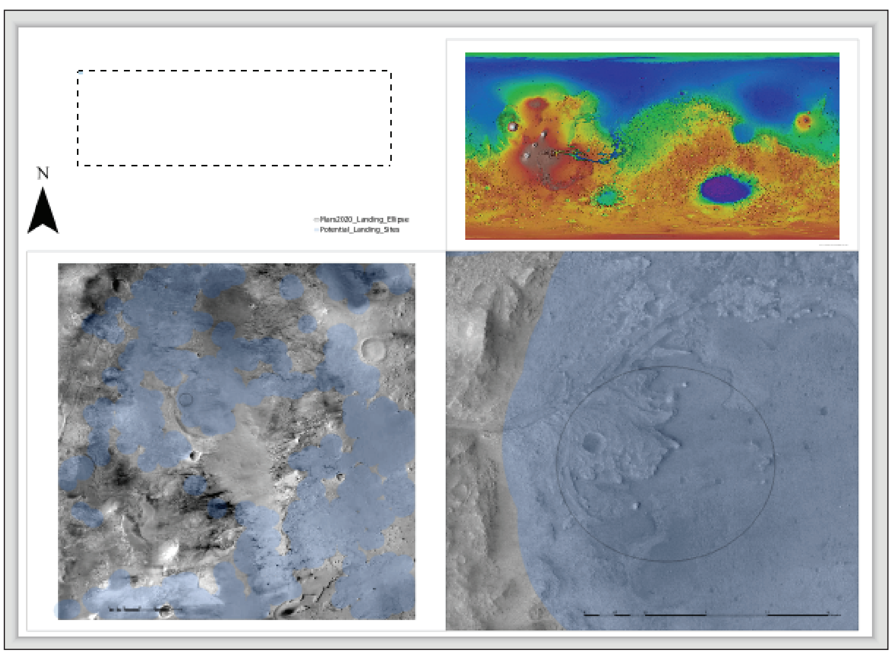


42. In the upper left corner of the **Legend Item** pane, click on the **back arrow** to return to the **Format Legend** pane. Then click on the **Text Symbol** tab and expand the **Appearance** section. Set the **Size** to **36 pt** and click **Apply** to update the **Legend** font. When you have finished, click on the small **x** in the upper right corner of the **Format Legend** pane to close it. Then, in the **Layout** use the handles on the **Legend** box to resize it to fit the new font size and return to the full-page extent (**Zoom to Page**). Click and drag to place the **Legend** in the bottom right corner of the open space.

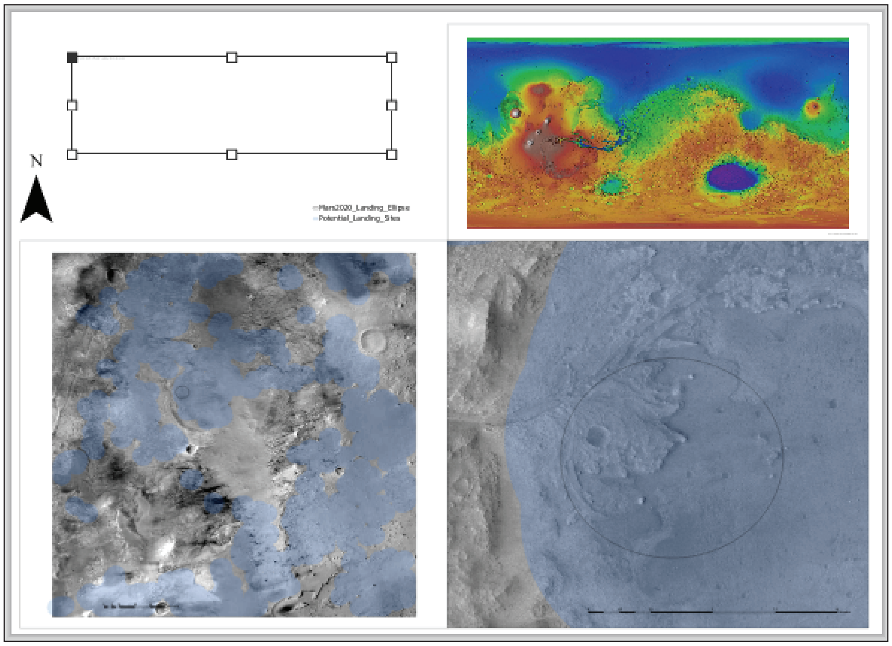


43. To add a title to the **Layout**, in the **Graphics and Text** section of the **Insert** tab, click on the **Rectangle text** icon. Then click and drag in the **Layout** to draw a box for the title.



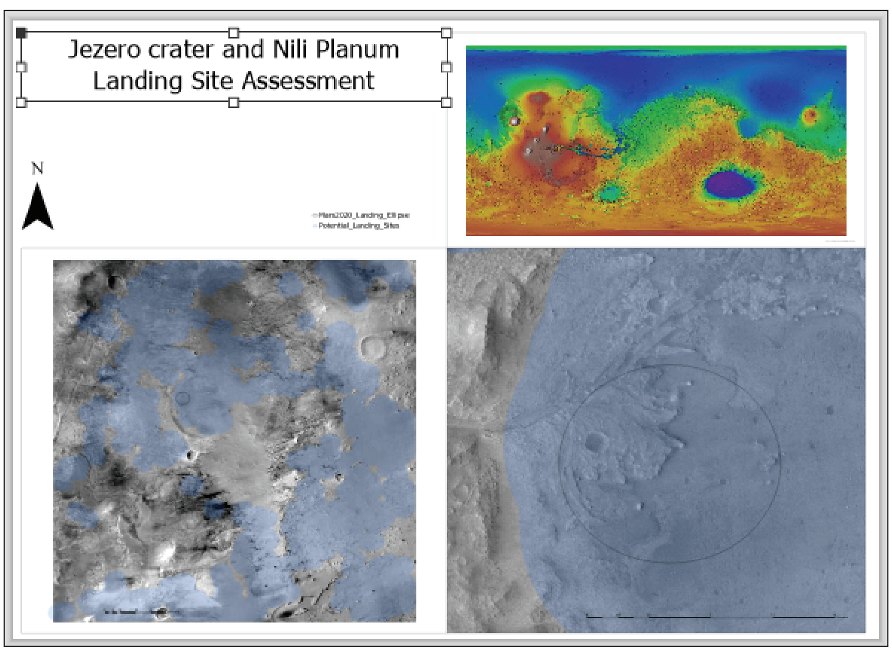


44. In the **Layout**, use the scroll wheel of your mouse to zoom in so the text is visible. Then, enter **Jezero crater and Nili Planum Landing Site Assessment** for the title, then click outside the text box to apply this change. Right click in the **Layout** and **Zoom to Page** to view the full extent of the **Layout**.



The default text setting has a font size that is too small for your **Layout**.

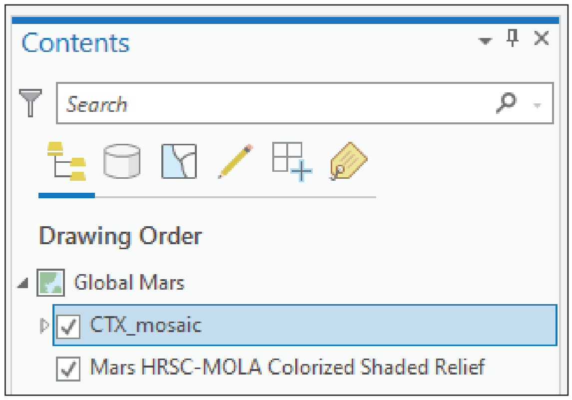
45. To edit the text, double click on the text box. This will open the **Format Text** pane. In the **Format Text** pane, switch to the **Text Symbol** tab and change the **Size** to **120 pt**. Expand the **Position** section and change the **Horizontal Alignment** to **Centered**. Then click **Apply** to update the font. When you are done, click on the small **x** in the upper right corner of the **Format Text** pane to close it. Return to the **Layout** and use the handles to resize the text box to fit in the blank space in the upper right corner of the **Layout**.



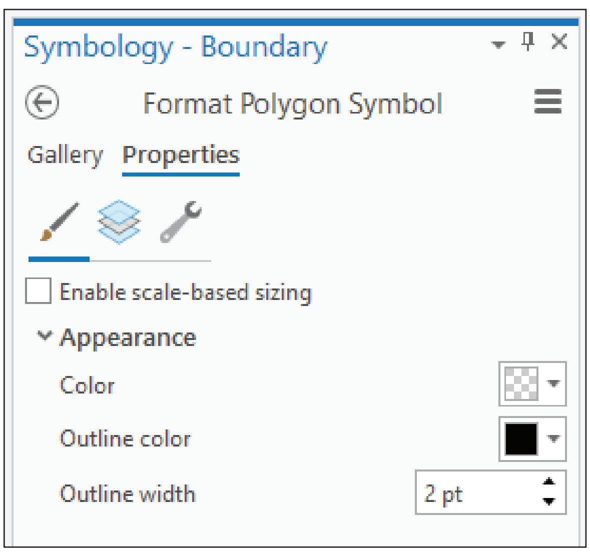
Part 9: Adding a Location Box to the Context Map

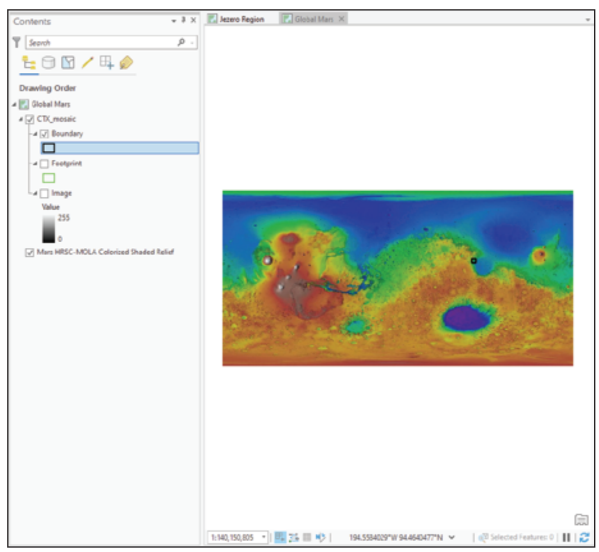
The final component to add to your **Layout** is a context box to show the location of the study area on the global map. The box can be drawn manually using the drawing tools in the **Graphics and Text** section of the **Insert** tab. However, in this example you can also use the boundary box from the **CTX_mosaic** layer since that marks the full extent of the study area and will provide the most accuracy.

46. Click on the **Jezero Region** map to activate it. Then, in the **Contents** pane right click the **CTX_mosaic** layer and select **Copy**. Switch to the **Global Mars** map tab. In the **Contents** pane, right click on the **Global Mars** map title and select **Paste** to paste this layer to the global map.

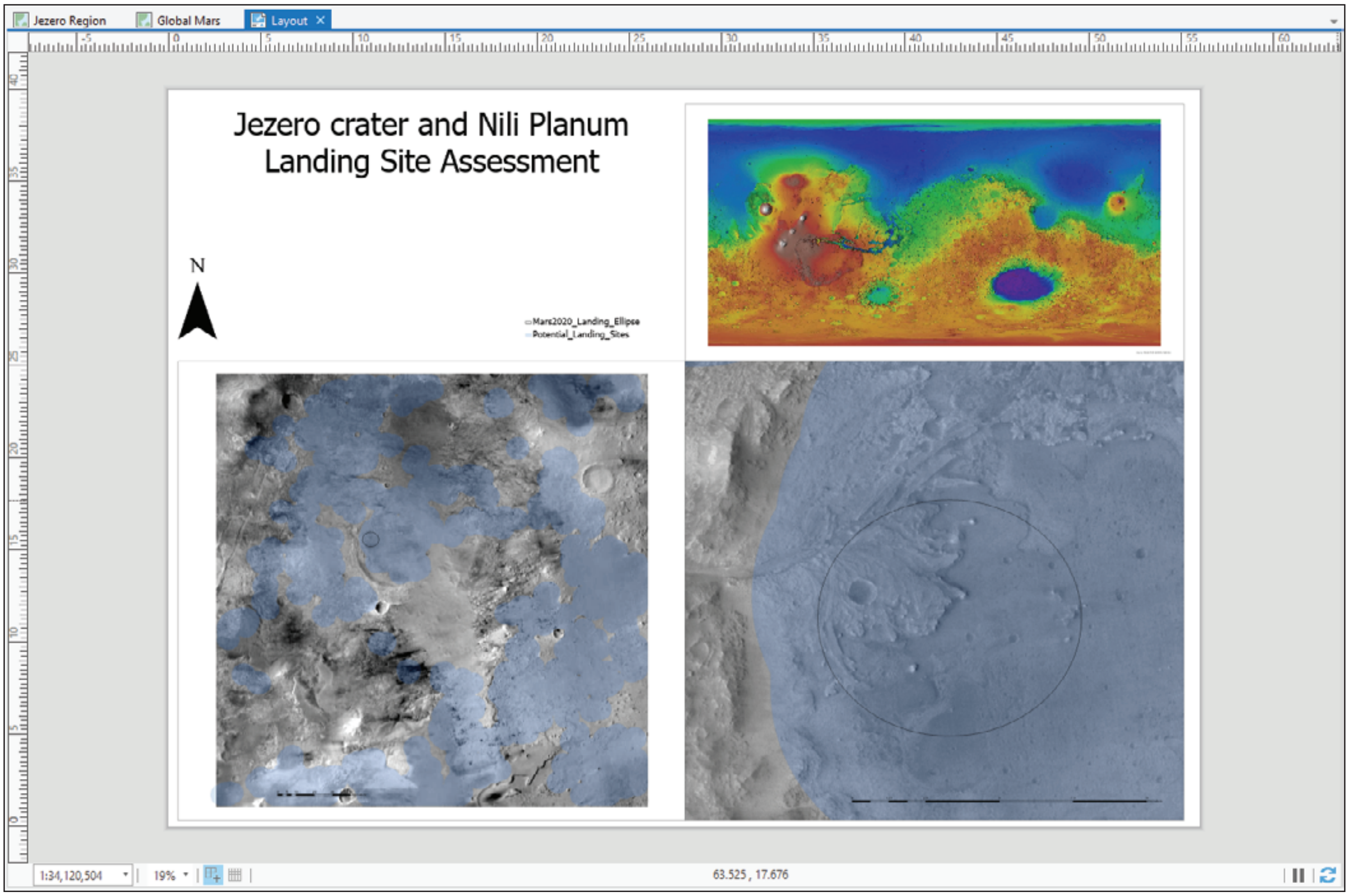


47. In the **Contents** pane for the **Global Mars** map, click on the small triangle to expand the **CTX_mosaic** layer. Then uncheck the box to turn the **Image** off and check the box to turn the **Boundary** on. Click on the **Boundary** symbol to open the **Format Polygon Symbol** pane. Switch to the **Properties** tab of **the Format Polygon Symbol** pane and change the **Outline color** to **Black** and the **Outline width** to **2 pt**. Click **Apply** to update the symbology. Then click on the small **x** in the upper right corner of the **Format Polygon Symbol** pane to close it.





48. Your **Layout** is now complete. Click and drag the **Layout** tab back to join the **Jezero Region** and **Global Mars** tabs so you can get a full screen view.



Summary

In this exercise you learned how to create and edit a basic map **Layout** in ArcGIS Pro, including adding a **North Arrow**, **Legend**, **Map Title**, and multiple **Map Frames** with **Scale Bars**. While creating a **Layout** for your Jezero crater and Nili Planum landing site assessment results you learned how to manipulate the map layers and display options which are then reflected in the map **Layout**. You also learned how to use **Map Frames** to display different combinations of datasets in the same layout by creating additional **Maps** within your ArcGIS Pro project. There are many additional options and capabilities for creating **Layouts** beyond those which you explored in this activity. For additional guidance on planetary geologic mapping and formatting your map products, see the USGS Astrogeology Planetary Mapping Guidelines.

Appendix 1: Additional Resources

Cornell University Library GIS

The Cornell University Library provides a variety of Geographic Information System (GIS) support services. This website will help you access GIS software and learn how to use it, find geospatial data, connect with GIS user groups, and get help when you need it.

Cornell University Spacecraft Planetary Image Facility (SPIF)

The Spacecraft Planetary Image Facility (SPIF) at Cornell University provides research support by assisting students and planetary scientists in their research, and by providing outreach services and educational support throughout the Central New York region and beyond.

Esri Corporation GIS Dictionary

Terms related to specific GIS operations, cartography, and Esri technology.

Esri Corporation GIS Bibliography

A broad and searchable collection of GIS literature from early GIS to present day.

Mapping and Planetary Spatial Infrastructure Team (MAPSIT)

Focuses on the use, functionality, and availability of planetary data. MAPSIT is comprised of members of the planetary science community and actively solicits input from the community to report to the National Aeronautics and Space Administration (NASA) as requested.

NASA EarthData: Geographic Information Systems (GIS)

An overview of GIS topics from NASA's EarthData program, including tools and tutorials and links to datasets.

Tennessee Tech Sedimentary Research Group GIS Tutorials

Includes multiple tutorials for planetary geologic mapping in ArcGIS Pro.

USGS (U.S. Geological Survey) Astrogeology Science Center Glossary of Terms

Terms related to planetary science, remote sensing, and data processing.

USGS Astrogeology Science Center MRCTR Lab

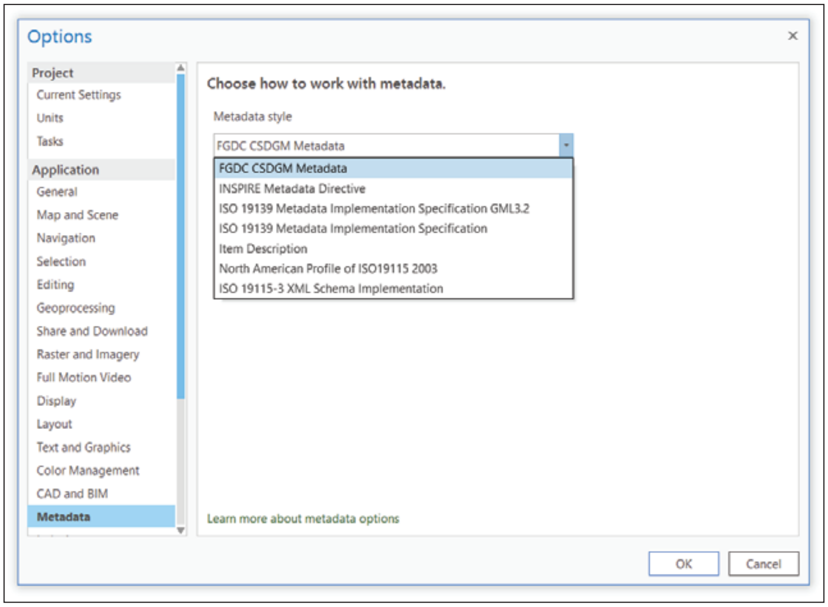
The USGS Astrogeology Mapping, Remote-sensing, Cartography, Technology, and Research (MRCTR, pronounced "Mercator") GIS Lab provides web-based resources aimed at the planetary research community. The lab supports GIS graphical, statistical, and spatial tools for analyses of planetary data, including the distribution of planetary GIS tutorials, tools, programs, and information. USGS maintains planetary GIS databases consisting of peer-reviewed digital geologic maps, feature maps, topography, and remote-sensing data under the scientific oversight of the NASA Geologic Mapping Subcommittee (GEMS). The lab also supports and encourages geospatial open standards. This website includes GIS tools, tutorials, and data.

USGS Planetary Geologic Mapping GIS Hub

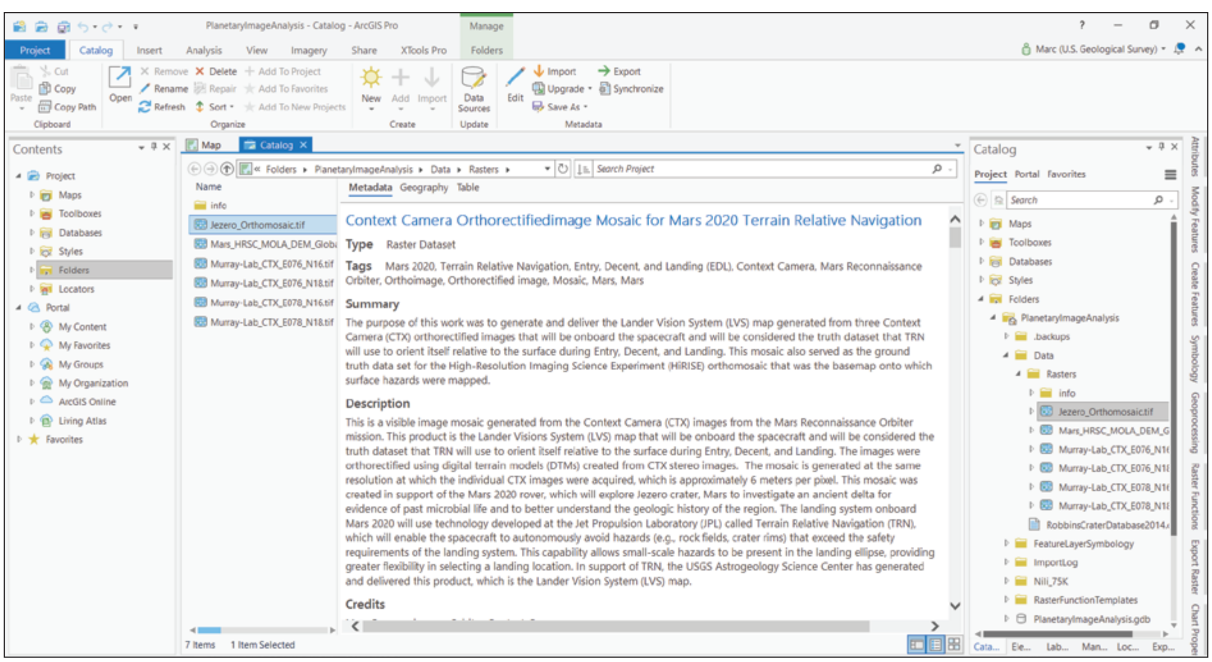
Website with links to USGS datasets and GIS tools.

Appendix 2: Metadata

By default, ArcGIS Pro uses its own Item Description metadata profile (ArcGIS Pro Help/Metadata), which can be translated into a variety of standards, but users can select a specific metadata standard in the **Options** window, accessed through the **Project** menu. U.S. Federal data catalogs require either Federal Geographic Data Committee (FGDC) Content Standard for Digital Geospatial Metadata (CSDGM) or ISO 19115-3 compliant metadata. To make changes to these fields (**Edit**, **Import** or **Update**) users must navigate to the source dataset through the Project tab of the Catalog inset window, and select **Edit Metadata**.

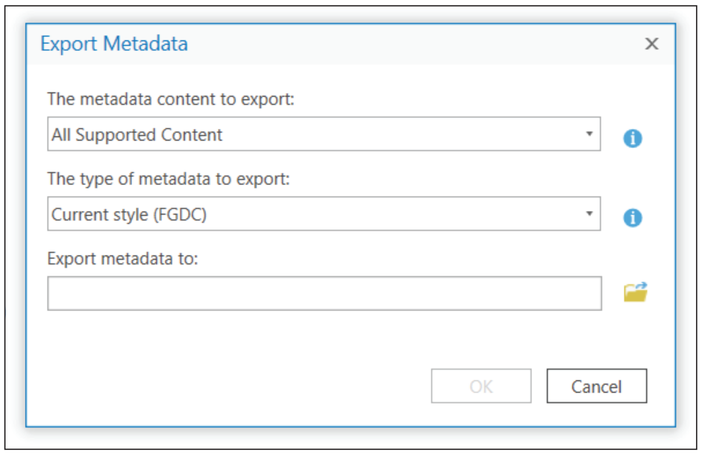


Many common image formats, like the GeoTIFF's in this tutorial, have their core metadata encoded directly into the file, but may also include supplemental metadata in a separate (sidecar) file. These files usually have the same base name and a different extension (for example, *.xml, or *.json), and are read automatically by ArcGIS. These files may contain more robust metadata. Raw image formats may also include a detached label containing essential geospatial metadata (*.lbl). Because metadata is often included in a separate, supplemental file, it is important to include all relevant files when copying or sharing images.

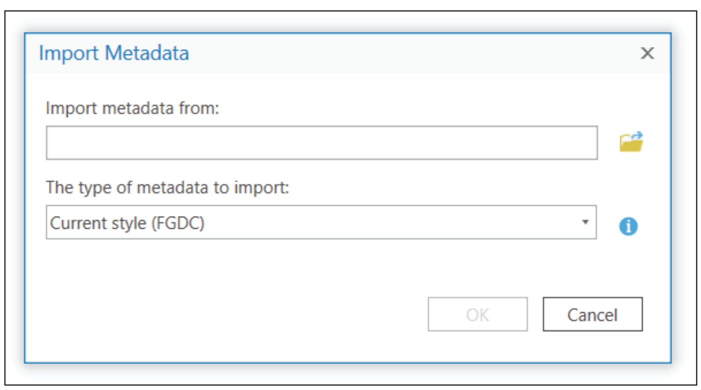


For data to be released for community or public use it is important that it is described as thoroughly as possible. One way to do this is to create an entire metadata record completely within ArcGIS Pro. For metadata requiring augmentation, users can capture machine-readable geospatial and schema information, which is time consuming to produce by hand, and augment it in other metadata editing applications that support that profile. Examples of this are the USGS Metadata Wizard (FGDC) and the MdEditor (FGDC, ISO), among others. While in **Catalog** view, the **Manage** menu provides access to **Import** and **Export** tools to work with metadata outside of ArcGIS Pro.

Export Metadata can also exclude potentially sensitive information or machine names, so be sure to check your metadata thoroughly before exporting.



Metadata can be imported from external files or datasets with the **Import Metadata** tool.

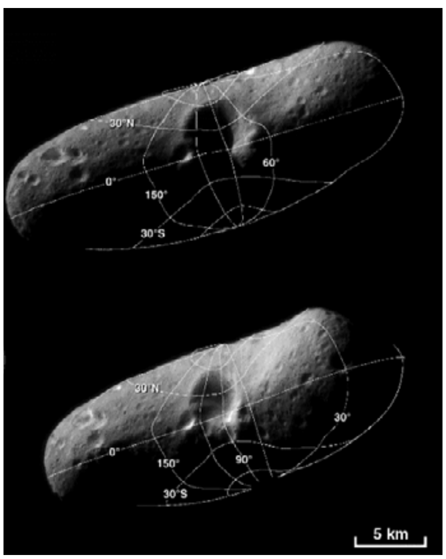


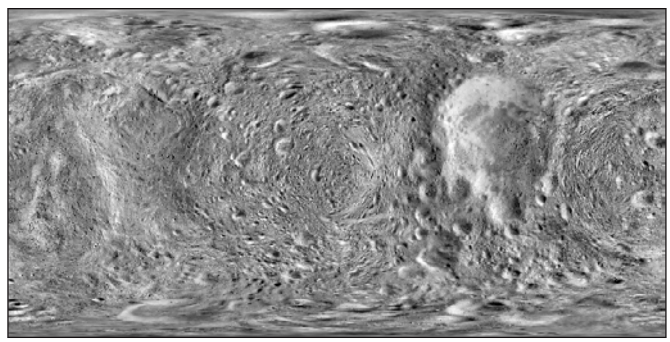
Appendix 3: Map Projections

Planetary researchers will encounter some quirks in planetary mapping, including the need to support positive west longitudes and geocentric (planetocentric) latitudes. Also, you may discover that many planetary bodies are defined as triaxial ellipsoids (using three radius values: sub-planetary equatorial, along-orbit equatorial, and polar axes). Fortunately, specifically defined to support planetary mapping, the International Astronomical Union (IAU) also commonly defines a best-fit mean radius. This simplifies the definition for the body to use a **single spherical radius**. Although, using a perfect sphere rather than an ellipsoid can increase surface distortions, it also greatly increases useability across different mapping applications. Spherical definitions are also often defined for very irregularly shaped bodies like asteroids or comets. To learn more about how the size of planetary bodies are defined, you can read more from the IAU Working Group on Cartographic Coordinates and Rotational Elements (WGCCRE, https://astrogeology.usgs.gov/groups/iau-wgccre).

When irregular bodies are not defined using a best-fit sphere, allowing for a simple map projection, ArcGIS Pro might not be able to suit your mapping needs. Fortunately, there are three-dimensional (3D)-enabled mapping applications being developed. For example, the interactive Small Body Mapping Tool (SBMT), created at Johns Hopkins University Applied Physics Laboratory, allow data, like the asteroid Eros, to be displayed within a 3D environment. For more see: http://sbmt.jhuapl.edu/.

The irregular shape of the asteroid Eros demonstrates how more typical map projections, meant to be used with ellipsoid or spherical bodies, will quickly break down. Once projected to a simple cylindrical (or other map projection) the data can be used in ArcGIS Pro. Note the original wavy grid-lines on the left will be snapped straight in simple cylindrical, often grossly distorting the image data underneath.





"Map of Eros." Map of the asteroid 433 Eros created by Phil Stooke using images acquired by the NEAR Shoemaker spacecraft in 2000. U.S. Geological Survey, and Phil Stooke, University of Western Ontario, https://www.planetary.org/space-images/map-of-eros.

In the planetary community, most printed maps have been based on conformal projections (angle preserving): Mercator for low latitudes, polar stereographic for high latitudes, Lambert conformal conic for intermediate latitudes at small scales, and transverse Mercator for large-scale maps. However, for modern digital products there is a trend to use very simple map projections to increase usability across mapping applications (also called data interoperability). Thus, we will often find global data sets released using the simple cylindrical map projection (also known as plate carrée, equidistant cylindrical, or equirectangular). Simple cylindrical uses an X,Y Cartesian plane in meters. You may also find data released in geographic/geocentric which is really the same global rectangular shape as defined by simple cylindrical map projection, but it is defined in degrees. Because polar regions are grossly distorted in a simple cylindrical or using a degree-based projection, high-latitude products are also commonly released in a polar stereographic (meters) map projection for latitude ranges from ±~60° to 90°.

Without an additional plug-in (not yet available), ArcGIS Pro will not be able to display positive west longitudes. When using a recommended spherical radius, geocentric and geographic latitudes are the same. Use caution when using an ellipse defined using geocentric latitudes in ArcGIS Pro (or really any GIS application). Most applications will assume the data is defined using a geographic latitude system.

Loading Images Without a Projection Defined

While less common these days, users may find that a data set has no projection defined (or is not recognized by ArcGIS Pro). There are some steps one can take to still use the data, though caution should be taken. Let's walk through a couple methods to define the needed geo-registration and map projection.

The recommended method is to execute this formatting outside of ArcGIS Pro using the free U.S. Geological Survey (USGS) Geospatial Data Abstraction Library (GDAL) utilities. As these utilities are now built-into ArcGIS Pro (as Python routines) we will show how they can also be used to accomplish this within ArcGIS Pro.

Method 1: Geospatial Data Abstraction Library (GDAL) Utilities

GDAL is a powerful library and is bundled with several useful utilities for any GIS user with data needs. GDAL has support for 100+ raster and 50+ vector-based formats. As a library, GDAL is also used in many GIS applications including ArcGIS Pro. For this task, we will use GDAL's utility application *gdal_translate.*

GDAL utilities will require installation on your system outside of ArcGIS Pro. The easiest method to install GDAL utilities is within an Anaconda or Miniconda environment (supported on many different operating systems). Anaconda is a method to install independent working environments. It is often related to support Python-based environments but offers many other non-Python environments). To install Miniconda (a light-weight Anaconda installation, visit https://docs.conda.io/en/latest/miniconda.html). Once Miniconda is installed, open a Miniconda terminal and type:

```
conda create -n gdal
conda activate gdal
conda install -c conda-forge gdal
```

To run any GDAL utility simply open a Miniconda terminal and "conda activate gdal".

Now download an example image for Mars which does not have a map projection. https://www.mars.asu.edu/data/mola_color/large/mola_color_N00_060.png (from the Arizona State University [ASU] website: https://www.mars.asu.edu/data/mola_color/). This MOLA colorhillshade has the longitude range of 60 to 90° and latitude range of 0 to 30°.

We can either export this definition from ArcGIS Pro or simply create a new projection file with "Mars 200 Sphere" defined as.

File: Mars_2000_Sphere.prj

```
GEOGCS["Mars_2000_(Sphere)",DATUM["Mars_2000_(Sphere)",SPHEROID["Mars_2000_(Sp
here)",3396190.0,0.0]],PRIMEM["Reference_Meridian",0.0],UNIT["Degree",0.017453
2925199433],AUTHORITY["Esri",104971]]
```

Now let's open our newly created Anaconda gdal environment and run:

```
gdal_translate -a_ullr 60 30 90 0 -a_srs "Mars_2000_Sphere.prj"
  -of GTIFF mola_color_N00_060.png mola_color_N00_060_ register.tif
```

So, what is this command doing? First, we are defining the extent in degrees using -a_ullr (upper left lon/lat and lower right lon/lat). Again, the longitude range for this image being 60 to 90° and latitude range of 0 to 30°. -a_srs loads the Mars 2000 Sphere definition. This can be a file or a string. Here we are using degrees (not a true map projection in meters). To define this same image in simple cylindrical projection, the -a_ullr would need to be defined in X, Y coordinates in meters. Lastly, as GeoTIFF is the default output format, "-of GTIFF" is optional.

Method 2: Using Geospatial Data Abstraction Library (GDAL) Inside ArcGIS Pro

While the GDAL library is used by ArcGIS Pro, the utility applications like *gdal_translate* are not included in the ArcGIS Pro installation. However, the utilities can also be accessed using Python calls. For available Python-wrapped GDAL utilities visit: https://gdal.org/python/osgeo.gdal-module.html#TranslateOptions.

From ArcGIS Pro's Python window, type or copy and paste the following code. Note the path to the input and output file will need to be modified. Note the use of "\\" which helps with directory paths across all operating systems.

```
from osgeo import gdal
src_ds = gdal.Open('C:\\GIS\\Mars\\test\\mola_color_N00_060.png')
out_fn = 'C:\\GIS\\Mars\\test\\mola_color_N00_060_register.tif'
out_srs = ('GEOGCS["Mars_2000_(Sphere)",'
           'DATUM["Mars_2000_(Sphere)",'
           'SPHEROID["Mars_2000_(Sphere)",3396190.0,0.0]],'
           'PRIMEM["Reference_Meridian",0.0],'
           'UNIT["Degree",0.0174532925199433],'
           'AUTHORITY["Esri",104971]]')
out_ds = gdal.Translate(out_fn, src_ds,
         outputBounds = [60,30,90,0],
         outputSRS = out_srs)
```

The above Python will run exactly the same as the command-line utility shown above. Note the use of single quotes and double quotes in the Mars 2000 Sphere definition. Here we are using a multiple line string, but this can be pushed together as a one line (as shown above). For example.

```
out_srs =
'GEOGCS["Mars_2000_(Sphere)",DATUM["Mars_2000_(Sphere)",SPHEROID
["Mars_2000_(Sphere)",3396190.0,0.0]],PRIMEM["Reference_Meridian",0.0],
UNIT["Degree",0.0174532925199433],AUTHORITY["Esri",104971]]'
```

Tip: to run multiple lines of code within the ArcGIS Pro Python window, use the combination of Control and enter buttons to run.

Map Projection Resources

There are many good resources available that allow you to dive further into map projections from both Esri and the mapping community. A few examples are listed below:

- Detailed coordinate system and projection information for ArcGIS Pro
- Geographic versus projected coordinate systems
- Choosing the right projection
- Video: Introduction to coordinate systems and map projections
- Story Map: Map projections
- Esri ArcGIS blog post on the Mercator projection
- USGS page of map projection posters and publications
- Fundamental Frameworks in Planetary Mapping: A Review (Hargitai and others, 2019)

Reference Cited

Hargitai, H., Willner, K., and Hare, T.M., 2019, Fundamental frameworks in planetary mapping—A review, *in* Hargitai, ed., Planetary Cartography and GIS, Part I—The basics: Springer, p. 75–101, accessed MM DD, YYYY, at https://doi.org/10.1007/978-3-319-62849-3_4. [Also available at https://www.researchgate.net/publication/331289441_Fundamental_Frameworks_in_Planetary_Mapping_A_Review.]

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