Using Impact Craters to Investigate Subsurface Water on Mars

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Working with Excel – a quick refresher

PART 1: USING FORMULAS (should take ~20 minutes)

1. Start Microsoft Excel.
2. Prepare the Spreadsheet. What you should see when you start the program is a sheet with cells – lots of columns and rows. The rows (along the left side of the spreadsheet) should have numbers (1, 2, 3…), the columns (top of the spreadsheet) should have letters (A, B, C…). If the column headings are numbers instead of letters, please go to Tools and select "Options" or "Preferences" (which you see will depend upon what version of Excel you are using). You then want to select the "General" tab, and on this sheet you want to make sure that "R1C1" is **not** selected (i.e., there should be no check mark in the box beside it). Once you have turned off the check mark, click on "Okay" to close the window and implement the change.
3. Enter some Data. For the first part of this exercise you will be working with the area data collected by the class. In cell A1, type the words "Area, km^2" and then, in the cells below this, type in the numerical data which follows; the first number goes into cell A2, the next one in cell A3, etc. down to cell Axx. If you like, use the *bold* and *center text* options to make the heading and data easier to read.
4. The data you collected involved (1) making a measurement of an area in Canvas, which returned the number of pixels enclosed, (2) knowing the area per pixel when the pixel's resolution is 75 m, and (3) asking Canvas to convert the number of pixels to an area in km^2. This wasn't too tedious to do with one calculation, and might not even be that tedious if you had to do it ten times. What about 100 times? 1000 times? At some point, you're going to get pretty tired of manually performing the same calculation over and over again. That's where Excel comes in handy!
5. Writing an Excel Formula. Let's begin by converting each area in km^2 back to number of pixels. In cell B1 type "Area, pixels." Next, in cell B2, you're going to write a formula to do the calculation that converts from km^2 to pixels for you. Recalling that 1 pixel = 0.005625 km^2, you will need to use an equation of the form:

   $$\text{Area in km}^2 * (1 \text{ pixel} / 0.005625 \text{ km}^2) = \text{answer in pixels}$$

   To do this in Excel, type the following formula into cell B2 then hit return:

   = A2/0.005625 (be sure to check your answer!)

   Alternatively, you could have typed =, then clicked once on cell A2, then entered the rest of the equation /0.005625.

   Now, you don't want to have to type the same formula in for every calculation. Fortunately, there's a faster way to do this. Click once on cell B2 and you'll see that the cell is surrounded by a dark line with a small box in the bottom right corner. Click on the small box and drag it down so that you have selected cells B2 through Bxx (where xx is the same as the last row in column A which has data in it), then let go. What happens? If you click on one of the cells, say B6 and look in the toolbar near the top, you'll see that the formula entered in the cell is =A6/0.005625, which is what you wanted! [You can also do this by selecting B2, choosing copy, highlighting B3-B11, then hitting enter.]

6. Rounding to the Nearest Integer. Now you have recovered what the number of pixels was for each area you calculated in class… or have you? How many of you originally obtained a value which was not an integer – i.e., were you able in Canvas to measure **part** of a pixel? Nope. So, we need to round the answer you just obtained to the nearest integer value. To learn how to do this, find the help box in the upper right hand corner of the screen and then type in what it is you want to learn to do (in this case "rounding numbers"). Read the Excel help describing how to do this, and try writing a formula in cell C2 (extended through cell Cxx) to do this – be sure to give your new column a label, and ask for help if you get stuck… but using the help functions available in Excel and Word will prove a more effective strategy for learning how to use the capabilities of these two programs in the long run.

7. Average and Standard Deviation. Now that you have integer values, you may notice that the values range quite a bit – even though everyone looked at the same feature, you didn't all come up with the same answer. One thing you might want to do, therefore, is determine the arithmetic mean (i.e., average) and standard deviation (sigma, i.e., one measure of how much scatter is there in the range of values). In cell E2 type "Average" and in cell E3 type "Standard Deviation." In cell F2 type the formula "=AVERAGE(**range**)" and then hit return – where for **range** you drag over the cells C2 to Cxx to let it know what values to use when calculating the average. Does your answer make sense? [NOTE: If you decided you wanted a round number instead, you can do this too – take a stab at doing it or ask me how!] To calculate the Standard Deviation, in cell F3 type the formula "=STDEV(**range**)".

   Putting these data together, if someone asked you what the size of the rough white area was, your answer (based on the number of measurements which were made) would be something of the form "31351 +/- 3657 pixels." Statistically, this in essence says that there is a 67% certainty that the true area lies within the range 27694 to 35008 pixels. This 3657 value is called the "one sigma error," and if you wanted to state the answer with more certainty you could have to give the "mean +/- 2*sigma" and say that you are 95% confident that the true area falls in the range 31351 +/- 7314 pixels, or 24037 to 38665 pixels; we'll leave the details for now, but when you fulfill PAC 4 you'll learn all about the mathematical basis for this uncertainty technique. If you wanted to know the area in km^2, you could do this conversion as well and tell them the area is "176 +/- 21 km^2" (1 sigma). You could also just find the average and standard deviation for the original km^2 values directly – do you get the same thing? Check *later*, but the answer should be yes! Remember—an answer with error bars that doesn't tell you whether the error bars are 1 sigma, 2 sigma, etc. is not very useful, because you don't know what the error bars mean!

PART 2: GRAPHING, CURVE FITTING, & IMPORTING A SPREADSHEET INTO WORD

8. Close the spreadsheet you've been working on and open a new one. As before, check to make sure that the columns are labeled as A, B, C and make them so if they don't come up that way. For the example which follows, you are given depth and diameter information for a number of impact craters on Mars. It has been shown by many scientists that these features follow a power law of the general form $d = kD^z$, where d is the crater depth (in **km**), D is the crater diameter (in **km**), k is a constant and z is an exponent that generally falls between zero and one.

Given pairs of data in the form (diameter, depth) for 20 Martian impact craters below, you will plot the data, fit a power law curve to it to determine k and z, and will then export this graph into Microsoft Word. The data, acquired using Mars Orbiter Laser Altimetry (MOLA) measurements from Mars Global Surveyor (to learn more about the mission and instruments, see http://mars.jpl.nasa.gov/mgs/), are:

diameter	**depth**		**diameter**	**depth**
7.7	0.3		25	0.5
10	0.8		27	0.8
10	0.3		32	1.2
14	0.25		32	1.2
18	0.4		32	1.9
18	0.8		35	0.6
20	0.7		41	1
20	0.5		41	1.4
23	0.7		47	0.3
24	0.5		71	1

Enter these values into **two** columns in Excel (diameter, depth).

9. Graphing in Excel. Now that you've got the data entered, it's time to graph it. In your spreadsheet, drag over the data and headings in both columns to select these as the data you wish to plot. Then, on the Excel toolbar, find the icon that looks like a little graph (with yellow, red and blue histogram bars on it) and click on it once to indicate that you wish to construct a graph. A Graph Wizard will pop up to help you draw the graph. First, you need to pick the Chart Type – you want an XY (Scatterplot), and of the various forms of scatterplot available (shown at right in the Wizard window) you want to select the one that plots the data only – no lines. Once you have done this, click Next.

   Second, the Graph Wizard asks you to let it know what data to use in the graph; you already did this by selecting the data prior to choosing the Graph option, so there are already data values filled in… just click Next again.

   Third, you have the option to set a range of parameters for the graph – do you want gridlines, should the points all be labeled, etc. – but for today simply enter a descriptive title for the graph, an X axis label that says "Diameter (km)" and a Y axis label which says "Depth (km)." Once you have done this, click Next again.

   Fourth, in the final window of the Graph Wizard, indicate that you want to plot the graph as an object in the current sheet, then click Finish and your graph will show up. You can select it and drag it around, resize it, even delete it if you have made a mistake and need to start again. If you were to save this Excel spreadsheet, your graph would be saved with it.

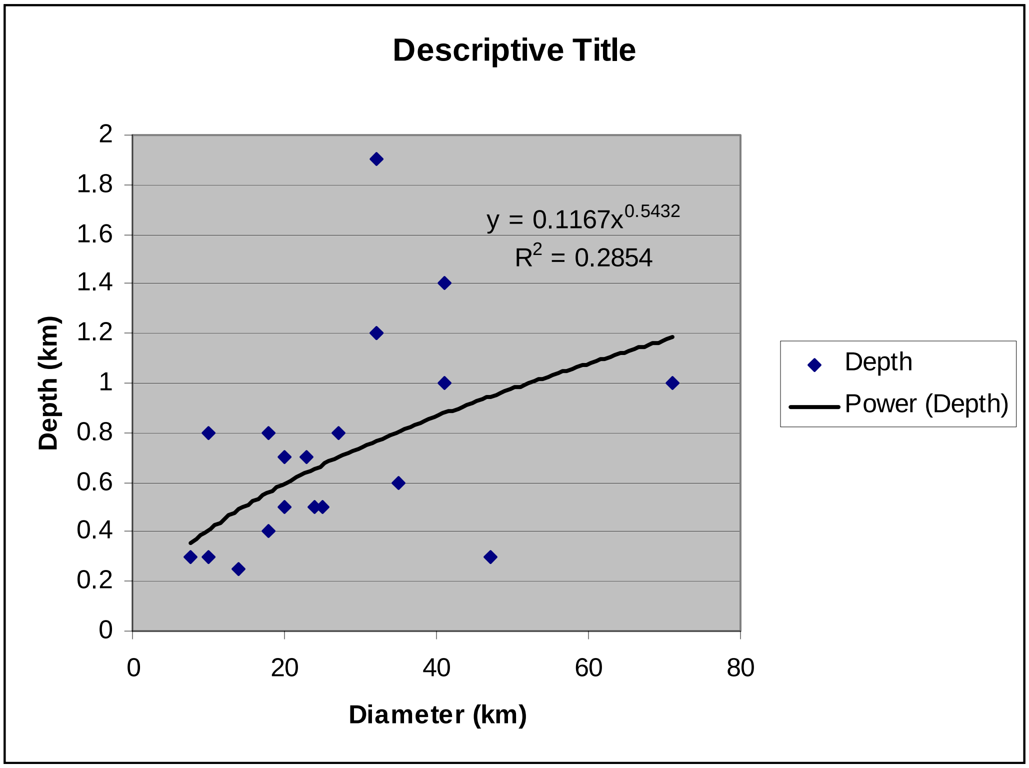
10. Fitting the Data (Adding a Trendline). Now that you have a graph of the data, you are in good shape for evaluating the k and z values for the power fit. To do this, select the graph by clicking on it once (the **whole** graph area will be selected, not just the area with the data), then look at the Excel Toolbar under "Chart." Select the option called "add trendline" and select "Power" to indicate that you want a Power Law fit. Before clicking on "okay" to add the line however, select the "Options" tag and check "Display Equation on Chart" and "Display R-squared value on Chart." Then click okay. Your graph now has a best-fit power law line drawn, and you should see that $y = 0.1167x^{0.5432}$. Remembering that in this case y

is the depth and x is the diameter, you have learned that k = 0.1167 and z = 0.5432. Now that you have this equation, if someone gave you a diameter *in kilometers* and asked what the depth should be *in kilometers*, you can use the equation to tell them!

You should also note, however, that the R^2 value listed is ~0.28. This is not a statistics exercise, but R^2 values for fits range from zero to one, with zero meaning the line's fit is so poor it is completely meaningless and one meaning that all the data fall exactly on the best fit line. In most branches of science, you want your R^2 value to be 0.9-0.95 or higher to have confidence about the usefulness and precision of your fit; clearly this is not the case in this instance! In part this stems from the fact that you have only 20 values – but fortuitously, the law you have derived is extremely close to the depth-to-diameter equation derived thus far for the planet as a whole using millions of craters, so we will take advantage of this good fortune and continue to use it for now. If, however, all you had was the 20 data points I gave you and no other information, you would have to conclude that, if someone gives you an impact crater diameter, you really can't say a whole lot about the real depth.

[NOTE: As a quick exercise, change one of the depths or diameters in your spreadsheet – not only does the graph update itself, but so does the line fit you did… see how the equation and R^2 values alter?]

11. <u>Excel to Word</u>. Now that you have a nice diagram, let's say that you want to incorporate it into Microsoft Word to use as part of a report. Start up Microsoft Word, then make Excel active again. In Excel, again select the **whole** graph area by clicking on it once, then under Edit (on the Toolbar) select Copy. Next, make Word active and, under Edit, select Paste. This will place the graph in Word where you have the cursor located; if the graph is larger or smaller than you want, resize it in Excel before copying it into Word. The result might look something like the graph below:



Note that if you wanted to copy some cells from Excel to Word you could do the same thing – select the cells you want to copy, then copy them in Excel, switch to Word, and select Paste.

Now you've learned a bit about Excel. It takes some practice to learn how to design effective spreadsheets and to perform calculations efficiently, but practice will help. So, with that in mind, the homework for this week will have you employ the skills you've learned in Canvas and Excel to address an intriguing question – if there is water at shallow depth beneath the surface of Mars, how deeply buried is it? The characteristics of impact crater ejecta (the stuff thrown out of the crater when the meteorite hit the ground) can provide some insight…

Research Project

Now that you have learned a bit about Excel, you are ready to tackle your research project.

The possibility of life on Mars has become quite an exciting topic recently, and renewed interest in this important issue has coincided with a major NASA initiative to return to our solar system's fourth planet to conduct new scientific research—as you know there is a lot of activity at Mars right now! Understanding the past/present hydrological cycle on Mars is an essential component of the ongoing and proposed missions as the presence of water is thought to be one of the key factors necessary to promote life. For your project, you will examine a peculiar form of impact crater called a *rampart crater* (see Fig 1, below) in order to assess the depth to a possible subsurface volatile (i.e., water) layer. While rampart craters occur all over the Martian surface, you will restrict your analysis in the first part of the project to a portion of Xanthe Terra (Figure 2) where there are numerous, well-preserved examples that you can study. [Note: there are alternative interpretations for how rampart craters form. For this assignment we will assume that the rampart crater ejecta morphologies are due to the presence of water as this is the strongest hypothesis at present, but keep an open mind -- studies using new data are a great example of "scientific understanding in flux"!]

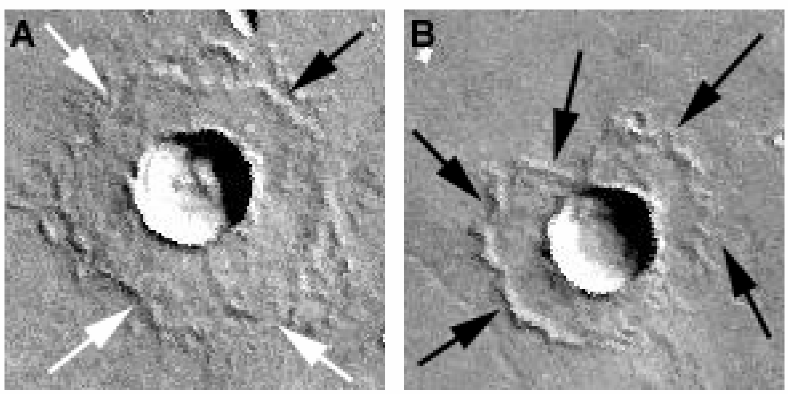
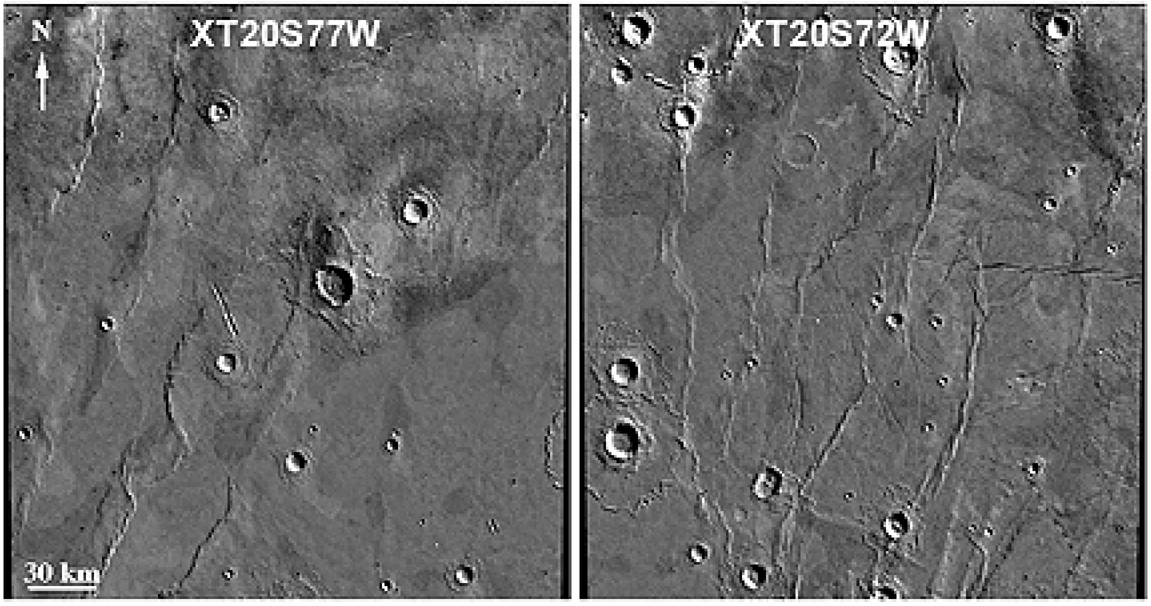


Figure 1: Craters from Xanthe Terra, Mars. [A] This crater **might** be considered a rampart crater, but if so only just. The crater itself is surrounded by a blanket of ejecta, and in some places (black arrows) there is a hint of a raised rim at the edge of the ejecta blanket, while in many others no rampart is apparent (white arrows). [B] This crater is **definitely** a rampart crater. The ejecta blanket surrounding the crater is smooth and flat, and at the outer edge of the ejecta is a clear rampart (raised rim)(black arrows).



<u>Figure 2</u>: Portion of Xanthe Terra, Mars which you will study during this assignment.

In preparation for the project you determined that the relationship between the depth of an impact crater (d) and its diameter (D), *both in kilometers*, is given by the power law

$$d = 0.1167\ D^{0.5432}$$

Using this relationship, if you are able to measure the diameter of an impact crater you can predict how deep a hole the impact excavated when it formed.

During the impact process, one aspect of the target material which may be quite important is the presence or absence of a volatile phase such as water in the target material. Analog experiments and numerical models predict that the presence of a volatile phase will cause the ejecta thrown out of the crater to be deposited as a ground-hugging blanket (or blankets) of wet material, much like the "sploosh" pattern you would expect if you threw a rock into a soupy mud puddle. The resulting lobate ejecta pattern with a distinctive rampart (lip) at the outer edge is unique. This ejecta pattern is quite different than the ballistic emplacement which otherwise should occur in Mars' relatively thin atmosphere. As an interesting note, *if* the hypothesis for the formation of rampart craters is correct *and* water is the volatile phase involved, experiments suggest that **liquid** water must be present: even at the high pressures associated with an impact event, the experiments suggest that the melting point of ice is only reached locally, implying that insufficient volatiles would exist to mobilize the ejecta material. Since crater excavation depth is related to crater diameter, crater diameter in combination with ejecta morphology can be used to constrain the depth to the volatile-rich layer. Your assignment for the first part of your project is to try and answer the following question: what is the depth to the volatile rich layer beneath the surface of Xanthe Terra?

Locate the two TIFF images entitled XT20S72W.tif and XT20S77W.tif (Xanthe Terra, centered at 20°S, 72°W and at 20°S, 77°W). These Viking images fit side by side (see Figure 2). For each image, the spatial resolution is 235 m/pixel. North is up in each case. Then, employing an image processing program and Excel, ***use the population of craters in the Xanthe Terra region, to analyze whether or not water was ever present beneath this region, and if so at what depth(s)***.