ASTR101 LAB 4
Lab Report

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Objective

The objective of this lab exercise is to provide a practical understanding of the processes that contribute to the shaping of planetary surfaces, with a focus on the Moon. Through the observation and analysis of lunar craters, maria, and astronaut landing sites, students will explore the effects of asteroid impacts and volcanic activity on lunar geography. By identifying and dating these features, the exercise aims to enhance comprehension of the chronological development of celestial bodies in our solar system. Additionally, the lab engages students in the application of impact cratering theory to assess the frequency of large asteroid impacts on Earth, thus linking geological evidence to the history of life on our planet and the potential risks posed by near-Earth objects.

Introduction

This lab report investigates the geological features of the Moon's surface to understand the dynamic processes that have shaped not only our celestial companion but also provide insights into the broader mechanisms at work in planetary systems. Through observations of lunar craters and maria, we delve into the history of asteroid impacts and volcanic activity that has sculpted the Moon's face, using these observations as a window into the past meteoric events within the Solar System. By identifying and analyzing various lunar features and comparing them with Earth's craters, we aim to estimate the frequency of large asteroid impacts in the current epoch and explore their potential implications for Earth. This exercise, correlating with Chapter 8 of our course textbook, also serves as an homage to the early astronomers whose curiosity about the Moon's phases and composition paved the way for today's scientific inquiries.

Procedure

In the lab exercise, we employed the GNU Image Manipulation Program to open and analyze a high-resolution digital image of the Moon. Our focus was on measuring and examining lunar features such as craters and maria, which involved precise observation and calculation without altering the original image. After completing the measurements, the program was closed without saving any changes, preserving the integrity of the image for future analysis.

Observations

Throughout this lab, I observed that the impact of 1-10 km diameter asteroid on Earth would lead to the formation of a significant complex crater, indicative of a substantial geological event. The initial transient crater would be over 10 kilometers in diameter and nearly 4 kilometers deep, transforming into a final crater of nearly 14.5 kilometers in diameter after the modification stages. This event would have far-reaching effects beyond the immediate crater, including seismic shocks, ejecta distribution, and potential atmospheric changes. The impact would produce a powerful blast wave, likely causing extensive damage to the environment and infrastructure. If such an impact occurred in the ocean, it could generate tsunamis capable of devastating coastal areas. These observations underscore the potential hazards posed by near-Earth objects and the importance of understanding and preparing for such impact events.

Answers

Question 1: On your picture, identify and name three prominent craters, three maria, and three spacecraft landing sites.

The Moon's surface is rich with various geological features, including numerous craters, maria (large, dark, basaltic plains on the Moon, formed by ancient volcanic eruptions), and historically significant spacecraft landing sites. Here are three prominent examples of each:

Prominent Craters:

1. Copernicus (Feature 5): One of the most prominent and recognizable craters on the Moon, easily visible with binoculars. It is a relatively young crater characterized by rays of ejected material.
2. Tycho (Feature 6): Another young and prominent crater known for its extensive ray system that spans across much of the Moon's near side.
3. Clavius (Feature 9): One of the largest crater formations on the Moon, it's a heavily cratered region with smaller craters inside, making it a fascinating feature for telescopic observation.

Prominent Maria:

1. Mare Crisium (Feature 10): A distinct, circular mare on the Moon's near side, which appears as a dark spot to the naked eye or through binoculars.
2. Mare Serenitatis (Feature 18): It's adjacent to Mare Imbrium and Mare Tranquillitatis, notable for its blueish hue and the dark edges that define it.
3. Mare Frigoris (Feature 26): A broad mare located in the Moon's far northern latitudes, making up part of the border of the Oceanus Procellarum.

Spacecraft Landing Sites:

1. Hadley Rille/Apollo 15 Landing Site (Feature 66): Apollo 15 landed near Hadley Rille in the region of the Mare Imbrium.
2. Descartes Highlands/Apollo 16 Landing Site (Feature 64): Apollo 16 landed in the lunar highlands near the crater Descartes.
3. Fra Mauro formation (Feature 67): This is where the Apollo 14 mission landed, chosen for its smooth plains that were suitable for landing and exploration.

Question 2: Find and label an example of two overlapping craters. Identify which formed first and justify your choice in your report.

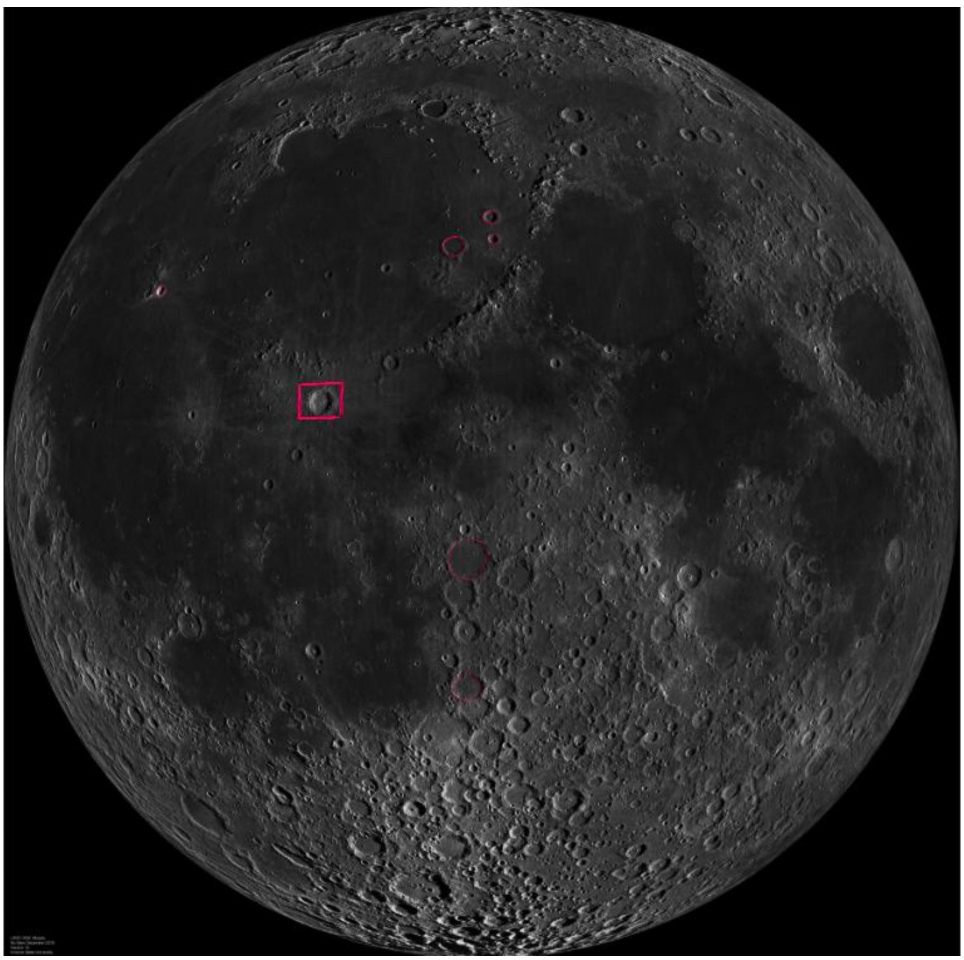
Overlapping craters are quite common on the Moon due to its history of bombardment by meteoroids and asteroids. Among the listed features, Theophilus, Cyrillus, and Catharina (feature number 8) are a famous trio of overlapping craters.

In this trio, Cyrillus is the oldest crater, as it has been significantly degraded and is overlapped by Theophilus, which is relatively younger and has a more defined structure with a central peak and terraced walls. Theophilus overlaps Cyrillus, and its sharp, well-defined features suggest it is the younger of the two. Catharina is the most degraded and oldest of the three, with Cyrillus superimposed on its northeastern rim and Theophilus sitting atop the northwestern rim of Cyrillus. Thus, Catharina formed first, followed by Cyrillus, and then Theophilus.

Question 3: In the digital image, find a crater created more recently than a mare. Find one that formed before a mare. Mark these on your printed image and explain your reasoning in your report.

To identify a crater on the Moon that is more recent than a mare, look for one with a ray system, which indicates it's relatively young due to the lack of space weathering. Tycho (feature number 6) is an excellent example; its extensive ray system overlays the surrounding mare, showing it's younger.
For a crater older than a mare, find one that's been flooded by mare basalt. Craters at the edge of Mare Serenitatis (feature number 18) are partially covered by basalt, meaning they predate the mare.

Question 4: Find and label some lighter colored craters, and streaks or patches of lighter colored material around a crater.



Question 5: Determine the scale of the digital image in km per pixel. The GIMP display window shows the diameter of the Moon in pixels. The actual diameter of the Moon is 3476 Km. Divide the actual size in km by the size in pixels to obtain the scale in km per pixel.

$$\text{Scale in km or pixel} = \frac{\text{diameter in pixels}}{\text{actual diameter in km}} = \frac{10000\ px}{3476\ km} = 2.877\,\frac{px}{km}$$

Question 6: Next, measure the sizes of a large and a small crater on the digital image. Use the scale you calculated in Question 5 to determine the actual size of the large and the small craters in km.

To determine the actual size of the craters in kilometers based on the scale, I have performed the following calculations:

1. For Ptolemaeus B (feature 75), I measured 413 pixels across. Using the scale of 2.877 pixels/km, the calculation for the actual size is as follows:

$$Size\ in\ km = \frac{Size\ in\ pixels}{Scale\ in\ \frac{px}{km}} = \frac{413}{2.877} \approx 143.55\ km$$

2. For Gylden Valley (feature 92), I measured 112 pixels across. Using the same scale of 2.877 pixels/km, the calculation for the actual size is as follows:

$$Size\ in\ km = \frac{Size\ in\ pixels}{Scale\ in\ \frac{px}{km}} = \frac{112}{2.877} \approx 38.93\ km$$

As a result, I determined that the actual size of Ptolemaeus B is approximately 143.55 kilometers in diameter, and the actual size of Gylden Valley is approximately 38.93 kilometers in diameter, based on the scale derived from the digital image.

Question 8: Based on the sizes of the large and the small craters, and using the rule of thumb given above, calculate how large the meteorites that created these craters should have been.

Using the rule of thumb that impact craters are typically 10 to 50 times larger than the meteorite that created them, we can calculate the expected size range for the meteorites that created the given craters. Here's how the calculation is done for each crater:

Barringer, Arizona:
- Crater diameter: 1.2 km
- Using the rule of thumb:
  - Minimum meteorite diameter:

$$\frac{1.2\ km}{50} \approx 0.024\ or\ 24\ meters$$

  - Maximum meteorite diameter:

$$\frac{1.2\ km}{10} \approx 0.12\ or\ 120\ meters$$

- Given meteorite diameter: 50 meters (This falls within the expected range, so it follows the rule of thumb.)

Ptolemaeus B (feature 75) :
- Crater diameter: 143.55 km
- Using the rule of thumb:
  - Minimum meteorite diameter:

$$\frac{143.55\ km}{50} \approx 2.871\ km\ or\ 2871\ meters$$

- Maximum meteorite diameter:

$$\frac{143.55\ km}{10} \approx 14.355\ or\ 14355\ meters$$

The meteorite that created Ptolemaeus B should have been between approximately 2871 meters and 14355 meters in diameter based on the rule of thumb.

Gylden Valley (feature 92):
- Crater diameter: 38.93 km
- Using the rule of thumb:
  - Minimum meteorite diameter:

$$\frac{38.93\ km}{50} \approx 0.7786\ km\ or\ 778.6\ meters$$

  - Maximum meteorite diameter:

$$\frac{38.93\ km}{10} \approx 3.893\ km\ or\ 3893\ meters$$

The meteorite that created Gylden Valley should have been between approximately 778.6 meters and 3893 meters in diameter according to the rule of thumb.

Question 8: Label a Moon crater of similar size to each of the three craters given in Table I] (make the size comparison as close as possible).

To label Moon craters of similar size to each of the three craters given in Table 1, I'll find the closest matches among the listed Moon features:

1. Barringer, Arizona - 1.2 km diameter
   - The Moon feature to match this size would need to be close to or slightly over 1 km in diameter. Among the listed features, there isn't a specific crater given with that exact small size, but smaller features like some of the craterlets in Plato (feature 83) or other small craterlets that are common on the lunar surface could be a match. These are typically unnamed due to their small size.

2. Manicouagan, Quebec - 100 km diameter
   - For a lunar feature close to 100 km in diameter, I would select Archimedes (feature 27), which has a diameter of approximately 83 km. While not an exact match, it is within the range of the size of the Manicouagan crater.

3. Chicxulub, Mexico - 180 km diameter
   - To match the Chicxulub crater, a prominent Moon crater of similar size is needed. The Imbrium Basin (part of which is feature 63, Imbrium sculpture) far exceeds this diameter, being one of the larger basins on the Moon. However, for a closer size match, the Orientale basin (feature 80) has a diameter of approximately 930 km for the whole basin, but the inner ring has a diameter close to 320 km. While this is still larger than Chicxulub, it is one of the closer size comparisons for such large features on the Moon.

Question 9: Using either one of the two online impact calculators mentioned in Section 4.4.2 estimate how large the crater would be for each object given in Section 4.4.3 You may make any other reasonable assumptions.

OBJECT 1: A Near-Earth asteroid, 99942 Apophis was briefly thought to be on track to collide with Earth in 2026. It will still pass very close, and there is a reasonable chance that it will collide with Earth or the Moon eventually. It has a diameter of about 325 m and its impact speed would be about 10 km/s.

My Inputs:

Distance from Impact: **1000.00 km (= 621.00 miles)**
Projectile diameter: **325.00 meters (= 1070.00 feet)**
Projectile Density: **3000 kg/m^3**
Impact Velocity: **10.00 km per second (= 6.21 miles per second)**
Impact Angle: **45 degrees**
Target Density: **2700 kg/m^3**
Target Type: Crystalline Rock

Energy:

Energy before atmospheric entry: **2.70 x 10^{18} Joules** = **6.44 x 10^{2} Megatons TNT**
The average interval between impacts of this size somewhere on Earth during the last 4 billion years is **8.4 x 10^{4} years.**

Major Global Changes:

The Earth is not strongly disturbed by the impact and loses negligible mass.
The impact does not make a noticeable change in the tilt of Earth's axis (< 5 hundredths of a degree).
The impact does not shift the Earth's orbit noticeably.

Atmospheric Entry:

The projectile begins to breakup at an altitude of **45600 meters = 149000 ft**
The projectile reaches the ground in a broken condition. The mass of projectile strikes the surface at velocity **9.59 km/s = 5.96 miles/s**
The energy lost in the atmosphere is **2.14 x 10^{17} Joules = 5.11 x 10^{1} Megatons**.
The impact energy is **2.48 x 10^{18} Joules = 5.93 x 10^{2}MegaTons**.
The larger of these two energies is used to estimate the air blast damage.

The broken projectile fragments strike the ground in an ellipse of dimension **0.904 km by 0.639 km.**

Crater Dimensions:

Crater shape is normal despite atmospheric crushing; fragments are not significantly dispersed.

Transient Crater Diameter: **3.34 km (= 2.07 miles)**
Transient Crater Depth: **1.18 km (= 0.733 miles)**

Final Crater Diameter: **3.93 km (= 2.44 miles)**
Final Crater Depth: **447 meters (= 1460 feet)**
The crater formed is a complex crater.
At this impact velocity (< 12 km/s), little shock melting of the target occurs.

OBJECT 2: Every year on August 12th the Perseid meteor shower occurs. This meteor shower is caused by bits of gravel from comet Swift-Tuttle still traveling in almost the same orbit. The Earth's orbit intersects the comets orbit at the place that the Earth is on August 12th. If the date of perihelion of the comet Swift-Tuttle changes by +15 days (it changed by several years in its last orbit), it will hit the Earth on August 14, 2126. Comet Swift-Tuttle is a large comet, and has a diameter of about 26 km. It would hit the Earth with a speed of about 50 km/s.

My Inputs:

Distance from Impact: **1000.00 km (= 621.00 miles)**
Projectile diameter: **26.00 km (= 16.10 miles)**
Projectile Density: **3000 kg/m^3**
Impact Velocity: **50000.00 km per second (= 31100.00 miles per second)** ***(Your chosen velocity is higher than the maximum for an object orbiting the sun)***
Impact Angle: **45 degrees**
Target Density: **2700 kg/m^3**
Target Type: Crystalline Rock

Energy:

Energy before atmospheric entry: **3.45 x 10^{31} Joules** = **8.24 x 10^{15} Megatons TNT**
The average interval between impacts of this size is longer than the Earth's age.
Such impacts could only occur during the accumulation of the Earth, between 4.5 and 4 billion years ago.

Major Global Changes:

The Earth is not strongly disturbed by the impact and loses negligible mass.
19.74 percent of the Earth is melted.
The impact does not make a noticeable change in the tilt of Earth's axis (< 5 hundredths of a degree).
Depending on the direction and location of impact, the collision may cause a change in the length of the day of up to **1.27 minutes**.
The impact does not shift the Earth's orbit noticeably.

Crater Dimensions:

Transient Crater Diameter: **4400 km (= 2730 miles)**
Transient Crater Depth: **1550 km (= 966 miles)**

Final Crater Diameter: **13200 km (= 8170 miles)**
Final Crater Depth: **5.14 km (= 3.19 miles)**
The final crater is replaced by a large, circular melt province.
At this impact velocity (< 12 km/s), little shock melting of the target occurs.
Melt volume = **19.5** times the crater volume
At this size, the crater forms in its own melt pool.

Question 10: Explain your choice for any inputs you used for the impact calculator (those not provided in this manual).

Object 1

To input information on the remaining parameters for a potential impact event involving the near-Earth asteroid 99942 Apophis, we would need to consider typical values or assumptions for these parameters based on what is known about similar celestial bodies and impact scenarios:

<u>Distance from Impact:</u> I choose 1000 km to keep a safe distance from the impact.

<u>Projectile Density (kg/m³):</u> The density of near-Earth asteroids can vary, but a common assumption for stony asteroids like Apophis is around 2,600 to 3,300 kg/m³. So, I chose 3000 kg/m³.

<u>Impact Angle (degrees):</u> Impact angles on Earth average around 45 degrees because steeper or shallower angles are less common due to the geometry of objects intersecting Earth's path. It can vary, but I chose the 45 degrees because it's not more steep or shallower.

<u>Target Density (kg/m³):</u> The density of the target depends on whether the impact is occurring on Earth or the Moon. The average density of Earth's crust is about 2,500 to 3,000 kg/m³, so I chose 2,700 kg/m³.

With the impact velocity already provided as 10 km/s and the projectile diameter as 325 m, I computed the values using the calculator provided.

Object 2

For OBJECT 2 (Comet Swift-Tuttle), here are the inputs needed for an impact event analysis:

Distance from Impact: I choose 1000 km to keep a safe distance from the impact.

Projectile Diameter (in meters): Comet Swift-Tuttle has a diameter of about 26 km.

Projectile Density (kg/m³): Cometary nuclei tend to have a low density due to their porous, icy composition. The density of comet nuclei can range from 500 kg/m³ to less than 1000 kg/m³.

Impact Velocity (in km/s): Comet Swift-Tuttle would hit Earth with a speed of about 50 km/s.

Impact Angle (degrees): Impact angles are usually assumed to average around 45 degrees unless specific orbital dynamics suggest otherwise for a particular object. Therefore, I chose 45 degrees.

Target Density (kg/m³): For Earth, the average density of the crust is about 2,500 to 3,000 kg/m³. If we are considering the impact in the ocean, the water density is about 1,025 kg/m³.

Target Type: This would be either "Sedimentary," "Crystalline," or "Oceanic," depending on where the comet is expected to hit. I chose “Crystalline Rock” to be the target type, having a density of 2700 kg/m³.

Question 11: Most of the surface of the Earth is ocean; therefore, there is a 75% chance that the meteorite would land in water. Record how high the tsunami from each object would be 300 km from the impact site. Also record what inputs you used with the calculator and note any other interesting effects of the impacts.

To estimate the height of a tsunami from an impact event 300 km from the impact site, I used an impact calculator that considers the parameters of the impacting object and the medium it impacts. Since we are considering a 75% chance of landing in water, we will focus on oceanic impacts. Here are the inputs for both objects, the near-Earth asteroid 99942 Apophis and Comet Swift-Tuttle:

Inputs for 99942 Apophis Impact:

- **Distance from Impact:** 300,000 meters (300 km)
- **Projectile Diameter:** 325 meters
- **Projectile Density:** 3000 kg/m³ (average density for stony S-type asteroids)
- **Impact Velocity:** 10,000 meters/second (10 km/s)
- **Impact Angle:** 45 degrees (assuming an average impact angle)
- **Target Density:** 1,025 kg/m³ (density of seawater)
- **Target Type:** Oceanic (since we are calculating for a water impact)
- **Water Depth:** 200 meters (Shallow depth, small asteroid)

Given these inputs, the calculator indicates that the tsunami wave amplitude would be between 1.8 meters (6.0 feet) and 3.6 meters (11.9 feet) at 300 km from the impact site. Other interesting effects of the impact include:

- Energy before atmospheric entry equivalent to 6.44 x 10^2 Megatons of TNT.
- The projectile breaks up at an altitude of 45.6 km and strikes the ground with a velocity of 9.59 km/s.
- The transient crater on the seafloor would have a diameter of 2.82 km and a depth of 998 meters, leading to a final crater diameter of 3.25 km and a depth of 422 meters.
- The impact would cause seismic effects with a Richter scale magnitude of 6.2, resulting in noticeable shaking and potential structural disturbances.
- Ejecta from the impact would arrive at the location 4.24 minutes after the impact, with an average thickness of 20.9 microns.
- The air blast would arrive approximately 15.2 minutes after the impact, potentially shattering glass windows.

This information suggests that an impact of this size would have significant but localized effects, including seismic activity, atmospheric disturbances, and a moderate tsunami that could impact coastlines within a 300 km radius.

Inputs for Comet Swift-Tuttle Impact:

- **Distance from Impact:** 300,000 meters (300 km)
- **Projectile Diameter:** 26,000 meters (26 km)
- **Projectile Density:** 1,000 kg/m³ (cometary nuclei are typically less dense than asteroids)
- **Impact Velocity:** 50,000 meters/second (50 km/s)
- **Impact Angle:** 45 degrees (assuming an average impact angle)
- **Target Density:** 1,025 kg/m³ (density of seawater)
- **Target Type:** Oceanic (since we are calculating for a water impact)
- **Water Depth:** 4,000 meters (Deeper depth, larger asteroid with higher velocity)

First Object Impact (26 km Diameter, 50 km/s Velocity, 45° Angle):

- **Tsunami Wave Amplitude**: Between 1.6 km and 3.2 km high at 300 km from the impact site.
- **Impact Energy**: Equivalent to 2.75 x 10^9 Megatons of TNT.
- **Global Changes**: No significant changes to the Earth's axis tilt or orbit, potential changes to the length of the day by up to 25.4 milliseconds.
- **Crater Dimensions**: Final crater diameter on the seafloor would be 243 km with a depth of 1.55 km.
- **Thermal Radiation**: Extremely high exposure, with the fireball appearing 337 times larger than the sun, resulting in severe burns and ignition of various materials.
- **Seismic Effects**: A seismic event greater than any in recorded history, with a Richter scale magnitude of 10.8.
- **Ejecta**: A continuous deposit of ejecta with an average thickness of 90.5 meters at the specified distance.
- **Air Blast**: Would cause extreme damage, with peak overpressure of 228 bars and maximum wind velocities of 3830 m/s.

Second Object Impact (Smaller or Less Detailed Inputs):

- **Tsunami Wave Amplitude**: Between 1.8 meters and 3.6 meters high at 300 km from the impact site.
- **Seismic Effects**: A much smaller seismic event with a Richter scale magnitude of 6.2.
- **Ejecta**: A fine dusting with occasional larger fragments.
- **Air Blast**: Much less severe than the first scenario, with glass windows potentially shattering.

Question 12: Would you be safe from the tsunamis caused by Apophis and Swift-Tuttle on Mount Doug (altitude: 210 m)? Are there other effects of the impact you might worry about at 300 km from the impact?

If 99942 Apophis were to impact the ocean with the described parameters:

- Tsunami waves generated would have amplitudes between 1.8 and 3.6 meters at 300 km from the impact, significantly lower than Mount Doug's altitude of 210 meters, posing no threat from the waves at this location.
- Seismic shocks, with a magnitude of 6.2 on the Richter scale, could cause noticeable disturbances to structures on Mount Doug.
- Ejecta, arriving as a thin layer, would likely not be hazardous but could affect air quality temporarily.
- An air blast, potentially strong enough to shatter windows, would reach areas 300 km away from the impact site, potentially affecting Mount Doug.
- The overall impact, while severe near the epicenter, would have lessened effects at the distance of Mount Doug, aside from the noted seismic activity and air blast.

If Comet Swift-Tuttle were to impact the ocean as described:

- The first impact's tsunami waves could reach 1.6 to 3.2 km high, well above Mount Doug's 210 m altitude, making it unsafe from the tsunami.
- The second impact's tsunami would not reach Mount Doug's altitude, posing no threat from the waves.
- However, other effects like severe thermal radiation, massive seismic shocks, thick deposits of ejecta, and devastating air blasts would extend far beyond 300 km from the impact and would likely affect Mount Doug significantly, compromising safety even at its altitude.

Question 13: In the next sub-section, you are asked to count the number of craters caused by the impact of 1 km diameter asteroids. Use the impact calculator to estimate the size of the crater caused by an asteroid of this size. You may make any reasonable assumptions. In the discussion section of your lab report, discuss the assumptions you have made and why.

- **Distance from Impact**: I choose 1000 km to keep a safe distance from the impact.
- **Projectile Diameter**: 1 km
- **Projectile Density**: 3000 kg/m³ (common density for rocky asteroids)
- **Impact Velocity**: 17 km/s (average impact velocity for near-Earth objects)
- **Impact Angle**: 45 degrees (commonly used average angle for impacts)
- **Target Density**: 2500 kg/m³ (average density of Earth's crust)
- **Target Type**: Sedimentary rock (a common target type for Earth impacts)

These calculations, measurements and details describe the initial temporary cavity (transient crater) and the final structure after modification stages (final crater) that follow the impact event.

- **Transient Crater**:
    - Diameter: 10.5 kilometers (6.55 miles)
    - Depth: 3.73 kilometers (2.32 miles)
- **Final Crater**:
    - Diameter: 14.4 kilometers (8.95 miles)
    - Depth: 661 meters (2,170 feet)
- **Crater Type**: The crater described is a complex crater, which typically has a central peak or peaks and terraced crater walls due to the collapse of the transient crater.

Question 14: Based on your observations of the lunar surface, were more craters formed early in the history of the Solar System, or later? Do you have any ideas on why this might be?

The lunar surface is densely pockmarked with craters, which serve as a record of the celestial objects that have collided with the moon throughout its history. Most of these craters were formed early in the history of the Solar System. This period is known as the Late Heavy Bombardment (LHB), which occurred approximately 4.1 to 3.8 billion years ago. During this time, the Solar System was cluttered with a great deal of debris left over from its formation, including asteroids and comets, which frequently collided with the moon and other celestial bodies.

One reason for this intense period of crater formation is that the early Solar System was much less stable than it is now. The planets had not yet settled into their current orbits, and their gravitational interactions would perturb asteroids and comets, sending them hurtling into the moon and other bodies. Additionally, there was simply more debris in the early Solar System, as the process of planetary formation involves the accumulation of smaller objects—a process that naturally leaves a lot of pieces scattered around.

Over time, the Solar System has become less populated with this debris. The planets have absorbed or ejected most of the leftover material, and their orbits have stabilized. Thus, the rate of crater formation has significantly decreased since the Late Heavy Bombardment period. Today, new craters do form when the occasional piece of space debris strikes the moon, but this happens far less frequently than it did billions of years ago.

Question 15: The maria cover nearly 16% of the lunar surface. Based on the number of craters you counted on the maria, calculate the total number of asteroids (diameter ≥ 1km) that have hit the lunar surface since the maria were formed. What is the assumption you are making for this calculation?

We've counted approximately 57 craters on the maria from the image analysis. Assuming the maria cover 16% of the lunar surface, the total number of asteroid impacts (with a diameter of ≥ 1 km) on the lunar surface can be estimated:

$$Total\ Crater\ Count = \frac{Count\ from\ Moon}{0.16} = \frac{69}{0.16} = 431.25\ \approx 431$$

Based on the count of 57 craters on the maria and considering that the maria cover approximately 16% of the lunar surface, the total number of asteroids (diameter ≥ 1km) that have hit the lunar surface since the maria were formed is estimated to be around 431.

The assumption made for this calculation is that the density of craters per unit area on the maria is representative of the entire lunar surface. This means that the frequency and distribution of asteroid impacts are assumed to be uniform across the Moon's surface, which is a simplification and may not fully account for the complexities of lunar geology and impact history.

Question 16: Recall that the maria are about 3.5 billion years old. Divide the age of the maria by the total number of asteroids which you calculated for the lunar surface in the previous question. This gives how often on average asteroids of this size have hit the Moon since the maria were formed. Express the answer as the number of years per asteroid strike.

$$Years\ Per\ Asteroid\ Strike = \frac{age\ of\ the\ maria}{number\ of\ asteroids} = \frac{3.5\ \times\ 10^9}{69} = 50{,}724{,}637.68\ years$$

Question 19: Do you think it is reasonable to use craters on the Moon to estimate how often the Earth is hit? Can you think of any reason (other than the difference in surface area that the Earth would be hit by meteorites often than the Moon?

Using lunar craters to estimate Earth's meteorite impact frequency is useful due to their similar proximity to space debris. However, Earth's dense atmosphere acts as a protective barrier that incinerates smaller meteorites, reducing the number that reach the surface compared to the Moon. This key difference means the Moon records many smaller impacts that Earth does not.

Additionally, Earth's stronger gravitational field could attract more meteorites, potentially increasing impact frequency. However, Earth's larger surface area and its magnetic field, which deflects some space particles, along with the planet's active geology and weather, complicate direct comparisons. These factors can obscure or erase evidence of past impacts, skewing the data.

Finally, the Moon's surface preserves a longer history of impacts due to its lack of atmosphere and geological activity, offering a more complete record than Earth's. Yet, adjustments are necessary when using the lunar record to estimate impact rates on Earth, considering Earth's protective atmosphere and dynamic environmental conditions.

Question 20: The impact of a 1 km diameter asteroid would likely end our civilization. Compare and comment on the frequency of asteroid impacts you calculated in the previous question to the age of human civilization. In only three paragraphs.

The calculated impact scenario of a 1 km diameter asteroid striking Earth at 17 km/s could indeed pose a cataclysmic threat to our civilization. Given the transient crater dimensions (10.5 km in diameter and 3.73 km deep) and the final crater dimensions (14.4 km in diameter and 661 meters deep), the impact energy released would be comparable to millions of nuclear bombs detonating simultaneously. Such an event would eject massive quantities of debris into the atmosphere, potentially leading to a 'nuclear winter' scenario with global temperature drops and subsequent agricultural collapse.

The frequency of such large impacts is relatively low in the context of human history. Civilizations, as we define them, have been around for roughly 10,000 years, a mere blink in geological time. In contrast, impacts by asteroids of about 1 km in diameter are estimated to occur once every 500,000 years on average. This means that, statistically speaking, humanity has been fortunate not to witness such a catastrophic event during its entire history.

However, the low frequency does not mitigate the potential threat these celestial bodies pose to human civilization. While the age of human civilization is minuscule compared to geological timescales, it is precisely the advancements and accumulation of knowledge during this time that allow us to predict and potentially mitigate the effects of future impacts. The rarity of such events should not lead to complacency but rather to preparation, as the consequences of being unprepared could mean the end of human civilization as we know it.

Question 21: There are not as many craters on Earth as on the Moon, and the only old craters on Earth are very large. Why is this? How does this make the Moon important for studying the history of the Solar System?

The Earth has fewer visible craters compared to the Moon primarily due to its active geology, atmosphere, and weathering processes. Earth's tectonic plate movements, volcanic activity, erosion by wind and water, and vegetation growth all act to reshape the surface and erase craters over time. In contrast, the Moon lacks these active processes and has no atmosphere to speak of, which means that craters remain unchanged for billions of years.

This difference in crater preservation makes the Moon an exceptionally valuable record keeper of the solar system's history. The lunar surface acts like a historical book, chronicling the rate and scale of impacts over vast stretches of time. Since the Moon has been geologically inactive for most of its history, the impacts recorded on its surface provide a more consistent and long-term record of the frequency and size of asteroid and comet impacts. By studying lunar craters, scientists can glean information about the history of the solar system, including the frequency of impacts and the evolution of planetary bodies.

Additionally, large craters on Earth that have not been erased by geological activity are usually the result of significant impacts. These large impacts are of particular interest because they have had substantial effects on Earth's environment and life. Studying these craters can provide insights into past biological extinctions and climate changes, which in turn can inform our understanding of Earth's geological history and the potential risks of future impacts.

Discussion

In the estimation of the crater size caused by a 1 km diameter asteroid, several assumptions were necessary due to the variability of parameters involved in impact events. These assumptions are grounded in what is currently known about asteroids and impact craters and are made to simplify the calculations without sacrificing the relevance of the results.

Assumptions Made:

1. **Projectile Density:** The choice of a 3,000 kg/m^3 density for the asteroid is based on average densities observed in stony asteroids. This is a reasonable assumption, as it represents a

compromise between the higher density of metallic asteroids and the lower density of carbonaceous ones.

2. **Impact Velocity:** An average velocity of 17 km/s is selected based on the typical encounter speeds of near-Earth objects with our planet. This speed considers the gravitational acceleration of the asteroid as it approaches Earth.
3. **Impact Angle:** The impact angle is assumed to be 45 degrees, which statistically represents the most probable angle of impact due to the spherical nature of celestial bodies and the random orientations of asteroid orbits intersecting Earth's orbit.
4. **Target Density:** The average density of Earth's crust (2,500 kg/m^3) is used to represent a generalized Earth impact scenario. While local geology can significantly vary, this average value provides a balanced representation of terrestrial environments.
5. **Target Type:** Sedimentary rock is chosen as the target type, considering that a significant portion of Earth's surface is covered by sedimentary layers. This assumption might vary depending on the specific location of the impact.

Findings and Implications:

- The calculated transient crater would be approximately 10.5 km in diameter, with a depth of 3.73 km, which is consistent with empirical observations of other terrestrial impact structures.
- The final crater dimensions, after the modification stages, suggest a diameter of 14.4 km and a depth of 661 meters. This final structure is categorized as a complex crater, characterized by a central peak formed due to the rebound of the crater floor post-impact.

These assumptions are made to provide a generalized but realistic scenario for the potential impact of a 1 km diameter asteroid. Real-world impact events can vary significantly, but these assumptions allow us to create a model that is representative of a wide range of possible outcomes. Moreover, they simplify the calculation process while maintaining a focus on the most critical factors that influence the impact effects.

Conclusion

This lab exercise explores the potential effects of asteroid and comet impacts on Earth using an impact calculator to understand the severity of such events. The exercise applies scientific methods to estimate impact consequences, including tsunamis, crater sizes, seismic activities, and atmospheric effects. It demonstrates that the effects of impacts can vary widely based on numerous factors like the object's size, density, velocity, and impact angle. The lab findings suggest that while smaller impacts like that of asteroid 99942 Apophis would be significant but localized, the effects of larger bodies such as Comet Swift-Tuttle could be catastrophic and global. Moreover, the exercise highlights the importance of distance from the impact site and geographical features like elevation in assessing safety from such events. Through this lab, one can appreciate the importance of continued monitoring of near-Earth objects and the value of preparedness for potential future impacts.

References

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