SESSION NINE: COMPARATIVE PLANETOLOGY—THE MOON

S U R V I V A L

Star Date 725.35: Sea of Tranquility

You are part of a 7-person space crew originally scheduled to rendezvous with your mother ship, the ***WEF Neil Armstrong***, on the sunlit surface of the moon. About 04:07 Universal Lunar Time, a computer breakdown and fire in the nuclear-powered engine room of your small craft has made a departure launch impossible. One crewman is dead and the officer in charge, Capt. John R. Peterson, has ordered a complete evacuation of the ship for fear of a radiation leak which would prove fatal to the remaining occupants. Rescue from another ship is now impossible since all available space vehicles of the World Earth Fleet have been summoned to Ceres, a large asteroid, where a mining disaster, created by an unforeseen geyser eruption, occurred late yesterday evening.

Since survival depends on reaching Lunar Command Base Brown, some 200 miles (320 km) distant, only the most useful items must be chosen for the long trek ahead. Unfortunately, the ESL (Emergency Survival Locker) located next to the engine room has been completely destroyed except for 15 items. They have been hauled out, examined, and tested to confirm they are safe for use. The coolant pump in one of the Portable Life Support System units (the space suit backpack) has also been damaged, and there are no usable spares in working order.

Your job as crew is to pick out the six most important items of the 15 remaining and tell why you have chosen them for the trip. You are only allowed to take along six items because the other nine will be of little or no value to you on your journey. The 15 items are listed below:

1. box of matches
2. emergency food rations
3. 200 feet of nylon rope
4. white parachute silk
5. portable heating unit that attaches to a space suit
6. two conventional .45 caliber pistols
7. one case dehydrated milk in plastic pump containers
8. two 100-pound (Earth weight) tanks of oxygen
9. map of the constellations as seen from the moon
10. life raft
11. magnetic compass
12. 25 gallons of water in plastic pump containers
13. common signal flares
14. first aid kit containing injection needles
15. solar powered FM receiver-transmitter

Survival: Sea of Tranquility, cont.

Prioritize your items in the order of their importance, the most valuable item with respect to survival mentioned first. The item and reason are each worth one point apiece for a maximum of 12 points.

LIST YOUR CREW MEMBERS (NO LESS THAN THREE, AND NO MORE THAN SIX):

1. ____________________________________ 4. ____________________________________

2. ____________________________________ 5. ____________________________________

3. ____________________________________ 6. ____________________________________

1. Item_____________________________ Reason:

2. Item_____________________________ Reason:

3. Item_____________________________ Reason:

4. Item_____________________________ Reason:

5. Item_____________________________ Reason:

6. Item_____________________________ Reason:

THE MOON'S BASIC PROPERTIES

A. **Distance** of moon from the Earth
   1. Average: 238,857 miles / 384,440 km / Angular size: 31 min 05 sec
   2. Perigee: 221,463 miles / 356,445 km / Angular size: 33 min 30 sec
   3. Apogee: 252,710 miles / 406,737 km / Angular size: 29 min 31 sec

B. **Diameter** of the moon
   1. 2160 miles / 3471 km
   2. Geometric distance determination: Observe the angular diameter of the moon (what portion of a circle does the moon's diameter block) at the moon's distance from the Earth. Find the orbital circumference of the moon's orbit by using the circumference of a circle $2\pi r$, where r = the Earth-moon distance and $\pi = 3.1416$, multiplied by the part of that circle (its angular diameter) which the moon blocks.
   3. Trigonometric distance determination: Knowing the radius of the moon expressed as an angular diameter, and the moon's distance, will allow the radius of the moon to be calculated.

C. **Eccentricity** of the moon's orbit is 0.0549. The perigee and apogee distances can be calculated by this formula.
   1. Perigee: Average distance – (average distance x eccentricity)
   2. Apogee: Average distance + (average distance x eccentricity)

D. **Volume** of the moon: 1/49th (0.0204) that of the Earth's volume. This datum can be found by comparing the ratio of the cubes of the radii for the Earth and moon. The volume of a sphere equals $4/3\ \pi\ r^3$, but in a ratio the 4/3 and π will cancel each other and are not necessary.

E. **Mass** of the moon: 1/81.5 of Earth's mass
   1. Use Newton's derivation of Kepler's third law to determine the mass of the Earth. The resulting mass of the Earth will also include the mass of the moon in this calculation. Kepler—$p^2 = ka^3$; Newton—$(m_1 + m_2)p^2 = (4\pi^2/G)\ a^3$
   2. Determine the location of the barycenter. This will yield the distance from each body to the mass center of the Earth-moon system.
   3. The mass ratios are exactly the inverse of the distance ratios.

F. **Acceleration** at the lunar surface is approximately 1/6th that of Earth.
   1. Calculate the acceleration at the Earth's surface using Newton's universal law of gravitation. $F = G(m_1 + m_2)/r^2$; $F = m_2\ a$; substituting $a = Gm_1/r^2$ Relative ratios of accelerations can be compared between different bodies using this technique
   2. Set up a ratio of acceleration at the Earth's and moon's surfaces by using the universal law of gravitation. This can either be calculated in specific units or in ratios with the Earth's mass and radius equal to one.

G. **Density** of the moon: 3.33 gm/cm^3; Earth = 5.54 gm/cm^3. Since density is a ratio of mass per unit volume, the calculation follows without any further assistance.

OBSERVING THE MOON FROM EARTH

A. **Phases** of the moon equals the **synodic** period of the moon: **29.5**30589 days
   1. The moon emits no visible radiation, and thus, its brightness is a function entirely of reflected sunlight.
   2. A complete cycle of lunar phases takes on average **29.5**30587981 days which is a direct result of our calendrical month. The relationship is obvious—moon-moonth—month.
   3. Watching the moon's phases is analogous to observing the moon go through a day and night cycle. Since a sphere can have only 50 percent of its surface illuminated at any one time, the progression of lunar phases results from our changing view of the lighted hemisphere as we observe the moon revolving around the Earth.
   4. Another way of stating this concept is that we watch the moon going through its day and night cycle as orbits the Earth.
   5. Phase names are given below, assuming that the rising and setting times of the moon were occurring if day and night were of equal durations. Sunrise would transpire at 6 a.m. and sunset would happen at 6 p.m.

LUNAR PHASE	MOONRISE	MOONSET
New Moon	6:00 a.m./ 06:00	6:00 p.m./ 18:00
Waxing Crescent	9:00 a.m./ 09:00	9:00 p.m./ 21:00
First Quarter	Noon/ 12:00	Midnight/ 24:00
Waxing Gibbous	3:00 p.m./ 15:00	3:00 a.m./ 03:00
Full Moon	6:00 p.m./ 18:00	6:00 a.m./ 06:00
Waning Gibbous	9:00 p.m./ 21:00	9:00 a.m./ 09:00
Last (third) Quarter	Midnight/ 24:00	Noon/ 12:00
Waning Crescent	3:00 a.m./ 03:00	3:00 p.m./ 15:00

B. **Brightness** of the moon: Magnitude -12.6 when full.
   1. Approximately 400,000 full moons would be necessary to equal the illumination of the sun. Only 80,000 moons could be placed in the sky at any one time.
   2. Phase brightness relationship is not linear: A two-day old moon is only about $1/1000^{th}$ as bright as a full moon. A first quarter moon gives only $1/10^{th}$ the light of a full moon. This results from the
      a. The small surface area of the moon which is being lit by the sun.
      b. Obliqueness (shallow angle) of solar radiation striking the surface of the moon
      c. Shadow features from the projection of mountains and crater walls on the lunar surface
   3. **Albedo** or reflectivity of the lunar surface:
      a. Average albedo of moon: 0.07 or 7%
      b. Maximum reflectivity: 0.30 or 30%
      c. Minimum reflectivity: 0.02 or 2%
      d. Average reflectivity of Earth: 0.39 or 39%

C. **<u>Rotation/Revolution</u>** period of the moon**: 27.3**21662 days
  1. The moon rotates on its axis in the same period of time that it takes Luna to revolve around the Earth. Its revolution is synchronous with its rotation.
  2. If the moon did not rotate, we would observe both the near and the far sides of the moon during the course of one lunar revolution.

D. **<u>Why are the synodic and sidereal periods different</u>?** The difference between the sidereal and the synodic periods result from the Earth's orbital motion around the sun. After one lunar sidereal period (27.3 days), the Earth, moon, and sun are no longer in the same phase configuration because the Earth has revolved through approximately 1/12 (30 degrees) of its orbit around the sun. The moon must revolve an additional 30 degrees more to create a similar phase configuration among the three bodies. The time interval which allows the moon to sweep through this angle (2-1/6 days) results in the synodic (phase) period of the moon, 27-1/3 days + 2-1/6 days = 29-3/6 days = 29.5 days.

E. **<u>Librations</u>:** The motions of the moon and the Earth that allow an observer to see different portions of the moon's surface during the lunar sidereal period.
  1. **<u>Lunar librations</u>** allow the charting of 59 percent of the moon's surface even though only 50 percent of the moon is visible at any one time.
  2. **<u>Three different librations</u>:**
     a. <u>Libration in latitude</u>: Results from the 6.6-degree inclination of the moon's axis to its orbital plane. This allows us to look over and under the moon's poles.
     b. <u>Libration in longitude</u>: The elliptical orbital velocity of the moon varies due to its distance from Earth, but the rotation of the moon occurs at a uniform rate. This causes a wobbling effect when the rotation leads or lags behind the revolution of the moon allowing us to view about eight degrees beyond the western and eastern limbs.
     c. <u>Diurnal librations</u>: This results from the rotation of the Earth carrying the observer over an 8000-mile baseline. At moonrise, it is possible to see approximately one degree beyond the western limb, while at moonset it is possible to view about one degree beyond the eastern boundary of the moon.

F. **<u>Harvest moon</u>:** The full moon which occurs closest to the autumnal equinox. This phenomenon occurs in autumn over a period of several nights when the full or nearly full moon rises at approximately the same time. Although the moon travels about 13 degrees per day along its orbital path, this motion is not necessarily translated as perpendicular to the horizon. The angle which the orbit of the moon makes with the horizon, coupled with its daily orbital motion, determines the amount of delay in the next moonrise. In autumn the lunar orbital plane lies at the lowest angle to the plane of the horizon in mid to upper latitudes, allowing the altitude of the moon to remain nearly constant for several nights, thus causing the time of moonrise to change by only a small amount. Because in autumn the daily motion of the moon is almost concentric to the celestial equator, the moon appears to rise at nearly the same time for a period of three or four nights. The delay is about 25 minutes each evening for 40 degrees north latitude and as little as 10-15 minutes in Europe. The bright moonlight was and still is an aid to farmers harvesting their fall crops and was given the name of the harvest moon because of this situation.

G. **<u>Appearance of the Earth from the moon</u>:**
   1. The angular diameter of the Earth is two degrees and the Earth would appear 13.6 times larger than the moon appears from the Earth.
   2. Because of the Earth's high albedo (39 percent—5.6 times more than the moon), the Earth appears 5.6 x 13.6 or about 76 times brighter than the moon appears from Earth. Eighty full moons is a good approximation.

GEOLOGY OF THE MOON

A. **<u>Appearance</u>** of the full moon to the unaided eye or with binoculars is basically black and white with dark circular features spread across its northern hemisphere and lighter materials dominating its southern half. In the brighter areas of the moon, a preponderance of impact craters can be seen, some with ray systems (splash marks) that extend more than 1000 miles (1600 km) across its surface. The larger circular, darker areas, called seas or basins are the result of huge impacts by asteroid-sized objects that fractured the lunar crust allowing material at depth to rise to the surface and fill them over a period of hundreds of millions of years.
   1. **<u>Highlands</u>**/terra/uplands: Rougher, more reflective (brighter) area with albedos up to 30 percent. They are higher in elevation, crater saturated, and represent the oldest regions of the lunar surface.
   2. **<u>Maria</u>**/seas/lowlands: Most appear as dark circular features which indicate that they originated from large meteoritic impacts. Their elevations are lower than the highlands in which they are embedded. Their lower reflectivity is indicative of a difference in chemical composition from the highlands.
   3. **<u>Craters</u>:** Depressions made by smaller meteorites which formed impacts like Tycho and Copernicus. These can still be hundreds of miles in diameter.
   4. **<u>Rays</u>** are splash marks left in the regolith (soil) emanating from more recent impact features that have gardened (exposed) the materials under which they impacted. They were created by the debris from large crater excavations. Tycho is the best example of this phenomenon on the moon and can sometimes be seen with the unaided eye around the time of full moon.

B. <u>Six stages of lunar history</u>:
   1. **<u>Early solar system impact</u>** between the Earth and a Mars-sized object threw copious amounts of material into orbit around the Earth which quickly accreted to become the moon. The moon was probably molten throughout this era of its formation. The rocks that formed from this period are termed basalts.
   2. **<u>Differentiation</u>:** As cooling occurred, the denser minerals that formed either sank towards the center of the moon and melted, or if less dense, rose to the surface to form the lunar crust. Continuous meteoritic bombardment fractured these rocks causing them to become more reflective. They represent the highland material.
   3. **<u>Appearance of KREEP</u>** in the Imbrium basin and Oceanus Procellarum: Magma upwelling near many of the isolated peaks in this area was enriched in potassium (<u>K</u>), <u>R</u>are <u>E</u>arth <u>E</u>lements, and <u>p</u>hosphorus (P), as well as concentrations of radioactive elements which originated at depth. KREEP contrasts from mare basalts because of these chemical differences.

4. **<u>Impacts by major planetesimals</u>** (asteroids) about 3.85 billion years ago, triggered perhaps by disruptions in the asteroid belt, or objects thrown sunward by the outer planets, formed huge basins hundreds of miles in diameter and 50-100 miles (80-160 km) deep, mainly on the near side of the moon.
5. **<u>Inundation</u>** by magma from regions surrounding the basins 3.5-3.0 eons (billion years) ago filled the large circular craters made by the asteroidal impacts, including Oceanus Procellarum, which was not created by a large impact event. Fracturing of the basin perimeters and the release of pressure by their excavation of overlying layers allowed magma to generate from the heat of radioactive isotope decay and to work its way to the surface, filling the large basin craters. This material had higher concentrations of iron, magnesium, and titanium that flowed easily across the lunar surface.
6. **<u>Quiescence (dormancy)</u>:** Not much happens… There is some geological activity from within (very minor moonquakes), as well as from meteorite hits. Small meteorite impacts were recorded by Apollo seismometers indicating that the moon is essentially a dead world internally.

C. <u>Chemical composition of the moon as a whole</u>:

1. **<u>No water</u>** was found in lunar rocks which allowed them to look fresher than any terrestrial rocks. Most terrestrial basalts have between 1-2 percent water in them. Returned Apollo samples have been kept in a dry nitrogen environment to preserve their freshness.
2. **<u>Water</u>** has been discovered near the poles of the moon in craters where sunlight cannot reach. The polar regions would be the most likely areas for lunar settlements.
3. **<u>No new elements were discovered</u>**, but three new minerals that had not originated on Earth were discerned.
4. **<u>Only igneous basaltic rocks were seen</u>** on the moon. These were rocks solidified from a liquid state.
   a. <u>Sedimentary rocks</u> can only form in the presence of water (crystallization) or through deposition which involves water.
   b. <u>Metamorphic rocks</u> (formed through heat, pressure, or both) may have been absent because they eventually change back into their igneous origins over billions of years.
5. **<u>Refractory rocks</u>** (rocks that melt and boil at high temperatures) **<u>are more common on the moon than on the Earth</u>.** The moon, probably as a whole was heated to a much higher temperature during its formation, boiling off the volatiles (low melt, low boil) minerals. The lower gravitational attraction of the moon would have aided this process, allowing these materials in a gaseous state to escape more easily.
6. **<u>Basic rock types</u>:**
   a. <u>Maria basalts</u>: density equals 3.2 gm/cm^3. Solidified at 1500^{o}C (2700 F). Olivine [(Mg, Fe)SiO_4] and Pyroxene (CaFeMg Si_2O_6) were most common.

   b. <u>Highland basalts</u>: density equals 3.0 gm/cm^3. Solidified at 2000^{o}C (3600 F). Anorthosites, igneous rocks formed at great depth, are almost totally Calcium Plagioclase ($CaAl_2Si_2O_8$).

D. **Regolith:** A term for the lunar soil. Found only on the surface of the moon.

1. Lunar samples were returned to Earth from six Apollo landing sites (383 kg, 846 pounds/ 2000+ samples) and from three Russian automated Luna vehicles (310 gm, 10.9 oz.), including one core sample 160 cm (5.3 ft.) long.
2. **No water or organics** were discovered in the lunar regolith samples.
3. Formed from the bombardment of meteorites which **gardened** the regolith. Impacts debris mixed the surface soil to great distances, so that any individual sample contained lunar materials from hundreds of kilometers away from the collection site.
4. Depth: 10 cm-20 m (4 in.-66 ft.).
    a. Thickest deposits found in the Fra Mauro region (Apollo 14), 8.5 m (30 ft.).
    b. Maria (seas): 1-4 m (3.3-13.1 ft.) on average.
    c. Youngest (thinnest): Crater Tycho, 10 cm (4 in.).
5. **Regolith contains breccias**, rocks that were formed from the solidification of fragments of many different types of rocks heated during impact events and cemented together while still in a liquid (plastic) state.
6. **Glass beads** were also found in several locations. The most famous example was the orange soil discovered by astronaut, Harrison Schmitt, during the Apollo 17 mission. The beads were created by the rapid cooling of rock fragments melted during an impact event or more likely, magma from a volcanic vent forcibly sprayed under high pressure into the "air."

E. **Lunar Interior**

1. **The moon is a differentiated body.** Its rock becomes denser with depth due to compositional changes (heavier elements) which resulted from cooling and compression from overlying layers.
    a. Crust: 60 km (40 mi.) in depth. Ca (calcium) and Al (aluminum) rich rocks.
    b. Mantle: 60-800 km (40-500 mi.). Rich in Olivine [(Mg, Fe) SiO_4]
    c. Lithosphere: solid portion of moon—surface to 800 km (500 mi.) in depth
    d. Deep Interior: There is speculation that it is still hot and perhaps partially molten or at least plastic (flexible) in the deep lunar interior. A remnant magnetic field may indicate a small iron core. The low density of the moon, 3.33 gm/cm^3, indicates that if a core does exist, it must be very small.
2. **Mascons:** Mass concentrations in the lunar maria pointed to a difference in composition with depth, as well as a thick rigid crust. Had the crust not been rigid, the mascons would have sunk into the moon's mantle and probably remelted. No mascons were discovered in Oceanus Procellarum, the largest mare on the moon, indicating that the lava overcoating is shallow.
3. **Seismically the moon is quiet** compared to the Earth. Lunar seismic events number about 3000/year compared to hundreds of thousands of tremors for Earth. The average lunar seismic event releases as much energy as a firecracker and is probably due to a small meteorite impact.

F. <u>Topographical features</u>:

1. **<u>Highlands</u>:** The more reflective (lighter) original crust of the moon. The highlands are composed of essentially anorthositic rocks with high concentrations of Al and Ca (aluminum and calcium). The higher reflectivity is caused by the anorthositic rock being internally crushed (fractured) by meteoric impacts. Think of the increase in brightness of safety glass in a cracked car window. Uncrushed anorthosite is brown-grey in color.
   a. **<u>Saturated with large meteorite craters</u>** in the diameter range of 30-60 km (20-35 mi.). which exhibit terracing, central peaks, and lava flooding of their crater floors. At least 300,000 craters one km (0.6 mi.) or greater in diameter exist in the highlands.
      1) **<u>Determining impact or volcanic origins of craters</u>:** Impact craters always have crater walls which are higher than the surrounding terrain and crater floors which are lower than their surrounding terrain. Volcanic craters have walls which are at the same level of the surrounding landscape and crater floors that are lower. Crater floors and walls which are higher than their surrounding terrain represent more traditional mountainous volcanic features.
      2) **<u>During the formation of a large meteorite crater, the ground acts as a liquid</u>:** The meteorite vaporizes the surface at the point of impact and pulverizes the area near the impact zone, blowing out the crater in the process.
   b. **<u>Central Peaks</u>** probably result from the <u>rebound</u> of the compressed rock after the vaporization of the parent body. Another way of thinking about central peaks is to consider them the central portion of a splash frozen in the rock. Other less accepted theories target volcanism or the inward push of the crater walls when they slump. See below.
   c. **<u>Terracing</u>** results from the slumping (collapsing) of material along weak fracture zones concentric with the impact basin or crater. Terracing results from seismic shock waves frozen into the crater's structure upon its formation, similar to ripples after a rock is thrown into water.
   d. **<u>Lava flooding</u>** of the crater floors could be the result of localized ground melting or volcanism generated by the released heat from friction at the time of impact. Lava flooding also resulted from the extensive flows that filled the huge impact basins between 3.0-3.5 billion years ago.
   e. <u>Features surrounding large impact sites</u>:
      1) **<u>Secondary impact craters</u>** result from debris thrown from the primary crater. Secondary craters are often associated in groups and found over considerable distances from the primary impact site.
      2) **<u>Arcuate (bowed or curved) crater chains</u>** created from large clumps of surface material flung beyond the crater (Copernicus/Tycho). Think of the curtains of water which are thrown outward by impact of a rock into water.

3) **Hummocky (lumpy) landforms** can be found in the immediate area of the impact. They are formed by clots of matter thrown from a crater.
4) **Rays:** Long bright linear streaks radiating from a crater. They are similar to the long splash marks that result when a rock is thrown into water. Lunar rays were created by the exposure (gardening) of subsurface materials from debris thrown away from the crater. The surfaces of moons without atmospheres or tectonic processes darken with age because of less reflective micrometeorites falling to their surfaces. Rays are indicative of a more recent impact event.

2. **Maria:** They are the dark, circular, and relatively smooth plains on the lunar surface. They were inundated by massive basaltic lava flows which occurred between 3.5-3.0 billion years ago.
    a. **Basins were formed about 3.85 billion years ago** during a possible disruption in the asteroid belt or from cometary type objects being thrown into the inner solar system initially from the planets Uranus and Neptune and then Jupiter and Saturn.
    b. **Meteorites 50-100 km (30-60 mi.) in diameter** created most of the basins which were hundreds of km in diameter and as deep as 50 km (30 mi.) with fractures/faults (weak zones) several hundred km (100+ mi.) in depth.
    c. **Melting of rocks at depth** resulted from the release of pressure from the excavation of overlying layers and the heat generated from the decay of radioactive isotopes. The increased pressure from the (expanding) melted rock forced huge amounts of magma to more towards the surface along these fault zones, filling the basins with layer upon lay of lava over a timescale of approximately 500 million years.
    d. **Wrinkles** on the surface of the maria represent some of the last of these lava flows. They can be seen in areas where the sun angle is very low.
    e. **Low crater counts on the surface of the maria** indicates little external activity (meteorite impacts) on the surface of the moon since the last period of lava inundation three billion years ago.
3. **Straight rilles/Linear channels** are often observed to cut through other geological features such as large craters. Straight rilles are **graben faults**, areas of a surface longer than they are wide that have collapsed along faults (weak) zones located on either side of the collapse. Straight rilles can be formed when:
    a. **An area of the lunar crust shrinks** due to the cooling of magma and lava.
    b. **Localized regions of uplift occur** where volcanic intrusions of magma have raised up and put pressure on the surface. The pressure is released by generating more surface area through the creation of a graben fault.
4. **Straight Wall, a thrust fault**—a fault in which the hanging wall has been raised relative to the footwall (*Dictionary of Geological Terms*). The Straight Wall is located along the eastern flank of Mare Nubium, and it is the best example of a fault which resulted from the motion of material perpendicular (up or down) along

a zone of fracture. Telescopically, it is easily seen when the moon is at eight days.

   a. Hanging Wall: The mass of rock above a fault plane.
   b. Footwall: The mass of rock beneath a fault plane.

5. **Sinuous rilles—wavy or river like troughs** formed in the lunar crust resulting from the above or below surface flow of lava or magma.
   a. **Underground:** They are often **delineated by collapse features** on the surface which look like crater chains, but unlike meteorite impacts, their crater walls are even with the surrounding terrain. The Huygens and Hadley rilles are excellent examples of this type of feature.
   b. **Above ground—they have river like features**, but are smoother. Their flow paths are down slope and their origins often occur in locations where volcanic craters are present in sink areas which were once magma reservoirs.
6. **Domes—low rounded hills**, several thousand feet in altitude generally found around the perimeters of maria. The observation of small craters at their summits is indicative of these features being volcanic in nature.

G. **Lunar far side and near side compared:** There are distinct differences between the lunar near side and the far side of the moon.

1. **Lack of maria on the far side:** This region of the moon was not struck by the large number of asteroidal type objects which formed the basins on the near side of the moon.
2. **The crust on the far side of the moon is thicker** by about 40 km (25 mi.) than on the hemisphere of the moon which faces Earth. The total crust thickness on the far side is about 100 km (60 mi.). This may have been the result of near side bombardments which lofted crustal material to the far side of the moon or a massive strike on the far side which thickened the crust and lofted materials to the near side to form the basins.
3. **Orientale Basin** is the only major impact feature on the lunar far side. A portion of the basin is visible on the near side. It is likely the most recent basin to be formed on the lunar surface, possibly occurring when the far side lunar crust was thickened after the near side impacts or when cooling had deepened the lithosphere (solid layer) of the moon. In the Orientale basin, volcanic activity was more localized in regions within the basin floor. Seismic shocks waves buckled the rock at the time of impact, producing concentric terracing around the crater which can be plainly seen today.

H. Processes, current and past, which have brought change to the lunar surface:

1. **Crater impact and blanketing from ejecta:** Past process for the most part… Today there are very few meteorites hitting the lunar surface, but in the period of heavy bombardment (ended 3.85 billion years ago), the formation of basins and craters threw ejecta from the impact sites to all regions of the moon bringing abrupt and lasting changes to the moon's surface.
2. **Antipodal seismic disturbances:** Past process… Seismic waves produced after large impacts were focused into regions opposite to the impact zones creating jumbled and chaotic surface terrain.

3. **Basin regions flooded by magma/lava:** Past process… KREEP flowed in the Imbrium Basin and Fra Mauro formation (Apollo 14) very early in the history of the moon. This epoch was minor compared to the massive flooding of the basins after the epoch of heavy bombardment. The basins filled with lava from 3.5-3.0 billion years ago.
4. **Slumping or mass wasting:** Past Process… These were areas of collapse along fracture/fault zones concentric with large craters and in areas of upward magmatic motion or crust shrinkage (graben faults).
5. **Micrometeorite impacts:** Dominates change in the present. Sand grained-sized objects and smaller bits and pieces of material slowly erode the moon's surface through collision with the its surface.
6. **Temperature differentiation between day and night:** Dominates change in the present. A 500-degree F (275-degree C) difference in temperature between day and night causes surface materials to expand and contract, eventually fracturing rocks and causing their breakage.
7. **Gravity:** Dominates change in the present. As fracturing, breakage, slumping, or impacts occur, gravity pulls material from a higher to a lower elevation.
8. **Solar wind:** Dominates change in the present. The moon is exposed directly to the solar wind except when it is going through the Earth's magnetotail. Apollo experiments (aluminum window shade) show that about 120 million hydrogen protons, 6 million helium nuclei, and 15,000 neons atoms impact the lunar surface per cm^2 per second. Over eons of time this bombardment gradually weakens and pulverizes rock. The erosion of lunar soil to the depth of 1 mm takes tens of millions of years. Neil Armstrong's footprints, from the first human to walk upon the moon, will be visible on the lunar surface for at least 100 million years.

I. Differentiating old and new lunar formations.

1. **Angularity indicates newness**, highly rounded and blanketed features are considered old.
2. **Crater counts:** The greater the number of craters per unit area, the longer (older) the surface of the moon has been exposed to the space environment. Fewer craters indicate a newer area modified by some older process, such as lava inundation. The concept is analogous to icing over a flaw in a cake. The surface icing now represents the time from when the icing was applied to the present. As an example, maria show fewer and smaller craters as compared to the highlands because they were covered by lava between 3-3.5 billion years ago. Low crater counts over this long period of time show that not much has happened to the lunar surface during the last three billion years.
3. **Crater overlap:** In regions of high impact, such as the highlands, craters are deformed by other near and direct impacts from other meteorites. The crater which shows the least overlap or no overlap is generally judged, in a relative sense, to be the youngest impact feature.
4. **Straight rilles/Sinuous rilles** postdate regions over which they transect (cross).
5. **High albedo areas** usually indicate a newer, fresher gardened surface, since the moon darkens with age as it accumulates darker micrometeorites in its orbit around the Earth and the sun.

6. **<u>Ray systems</u>:** Splash marks made by meteorite impacts on the moon's surface throw debris away from the crater. Impact of this material overlaps older features and gardens the moon's surface exposing fresher material with a higher reflectivity (albedo).

NOTES

MOON WORD LIST

1. **Accretion:** The coming together of smaller pieces to build a larger body.
2. **Albedo:** The reflectivity of an astronomical body.
3. **Blanketing:** The covering of older formations from the debris ejected by a meteorite impact.
4. **Breccias:** A United Nations rock… Many different types of rock cemented together by partial melting from the heat released from a large meteoritic impact.
5. **Central Peak:** A mountain found in the center of some large meteorite impact craters. It is similar to the rebound effect of a splash when a rock is thrown into water.
6. **Collision-Accretion:** The theory which details that the moon was formed from the debris flung into orbit around the Earth after a Mars-sized impact or near collision which occurred in the very early history of the solar system.
7. **Core:** The densest, most central part of a differentiated body.
8. **Crater:** The depression remaining from the aftermath of a meteoritic impact or a volcanic eruption.
9. **Crater Overlap:** A form of relative impact dating that examines the manner in which craters have been deformed through the impact of other meteorites on top or near them.
10. **Curst:** The least dense uppermost layer of a differentiated object.
11. **Dark Side:** The misconception for the far side of the moon. This word should not be used in describing the hemisphere of the moon which is not visible from Earth because information abounds from this region of the moon and far side also goes through a day and night cycle just like the near side.
12. **Density:** The mass of an object divided by its volume.
13. **Differentiation:** The process of separation of materials (minerals) of different densities which results as a body cools.
14. **Dome:** A term used for a small volcano on an object's surface.
15. **Far Side:** The hemisphere of the moon which cannot be seen from Earth.
16. **Fault:** A large, weak linear region in the structure of the crust which allows for motion if enough pressure is exerted upon it.
17. **Fracture:** A weak zone or crack (large or small) in rock strata where faulting may occur.
18. **Gardening:** The churning or overturning of lunar soil usually through the debris ejected from a meteorite impact.
19. **Glass Beads:** Rapidly cooled volcanic ejecta usually spayed from a fissure (weak zone) under high pressure.
20. **Harvest Moon:** The full moon closest to the autumnal equinox.
21. **Highlands**/terra/uplands: The more reflective, older, crater saturated surface of the moon's two general regions.
22. **Igneous:** Rocks that solidified from a melted state.
23. **KREEP:** A differentiated igneous rock composed of higher concentrations of Potassium (chemical symbol "K"), Rare Earth Elements, and Phosphorous, as well as radioactive isotopes. KREEP was melted at depth and forced to the surface prior to the major period of inundation of the moon's basins.
24. **Lava:** Molten rock that flows on the surface of an object.
25. **Libration:** Cyclical gyrations of the moon that allow an observer to see cumulatively more than half of the lunar surface over the course of a lunar revolution.

26. **<u>Lithosphere</u>:** The solid portion of an astronomical body. In the case of the moon, it includes the crust and the mantle.
27. **<u>Mafic</u>:** A dark igneous rock composed of one or more ferromagnesian (iron/magnesium) minerals. In a differentiated object, rocks become more mafic with depth.
28. **<u>Magma</u>:** The term used for molten rock which is present beneath the surface of a body.
29. **<u>Mantle</u>:** The layer of a body between the crust and the core. It usually contains more mafic minerals, in particular containing magnesium (Mg) and iron (Fe).
30. **<u>Mare</u>**/lowlands/basins; plural, maria: The large, circular features on the moon. Most were excavated by huge meteoritic impacts followed by inundation by lava.
31. **<u>Mascons</u>:** Mass concentrations resulting from the upwelling of denser rock from depth after the huge impacts which created the basins.
32. **<u>Mass</u>:** Quantity of material which an object contains.
33. **<u>Mass Wasting</u>:** The collapse of a formation resulting from little or no water being involved. In the case of the moon, no water was involved.
34. **<u>Metamorphic Rocks</u>:** Rocks whose crystalline structure has been changed due to heat, pressure or both agents acting together.
35. **<u>Meteorite</u>:** A natural object from outer space that strikes a larger body.
36. **<u>Micrometeorite</u>:** A sand grain or smaller sized object which strikes a larger body.
37. **<u>Moon</u>:** The official name for Earth’s nearest neighbor in space.
38. **<u>Moonquake</u>:** A seismic event on the moon that results from slippage along a fault or the impact of a meteorite upon the lunar surface.
39. **<u>Normal Fault</u>:** A fault in which the mass of rock above the fault plane has been depressed, relative to the mass of rock below the fault plane.
40. **<u>Phase Period</u>:** The time it takes for the moon to go through a complete series of shapes, starting and ending with the new moon (29.5 days).
41. **<u>Rays</u>:** The gardening effects created when large strands of debris have been thrown from crater impacts and have turned over the soil in which they have landed.
42. **<u>Refractory</u>:** Chemicals with high melt and high boil temperatures. Silicates, most surface rocks of Earth, are refractory materials.
43. **<u>Regolith</u>:** The lunar soil composed of crushed rock from meteorite impacts and other eroding phenomena occurring on the moon’s surface.
44. **<u>Reverse Fault</u>:** A weak zone along which the hanging wall (higher elevation) has been raised relatively to the footwall (lower elevation).
45. **<u>Secondary Crater</u>:** Smaller meteoritic impacts which result from the ejecta thrown from the excavation of a larger meteorite crater.
46. **<u>Sinuous Rille</u>:** A river like collapse feature created on or beneath the lunar surface from the flow or lava or magma.
47. **<u>Seismology</u>:** The study of the internal structure of the Earth from the vibrations created by earthquakes, i.e., in the case of the moon, moonquakes, which arise from the slippage along fault lines or the impact of meteorites.
48. **<u>Sidereal Period</u>:** The time it takes for the moon to complete one revolution around the Earth.
49. **<u>Slumping</u>:** A form of mass wasting that occurs when material slides downward along a fracture or fault zone.
50. **<u>Solar Wind</u>:** Mainly protons and the nuclei of helium atoms, as well as electrons which flow away from the sun along lines of solar magnetic force.

51. **Straight Rille:** A linear depression which results from the collapse of a block of material found along parallel faults.
52. **Straight Wall/ Rupes Recta:** The best example of a fault on the lunar surface. It occurs on the edge of Mare Nubium. It is considered to be a thrust or reverse fault.
53. **Synodic Period:** The phase period of the moon, from new moon to the next new moon, 29.5 days on the average.
54. **Tectonic:** Pertaining to the deformation of geological structural features in the Earth's crust.
55. **Terracing:** The slumping (sliding down) of material along the concentric fracture zones of large meteorite craters.
56. **Thrust Fault:** A weak zone along which the hanging wall (higher elevation) has been raised relatively to the footwall (lower elevation). The fault is characterized by a low angle of inclination.
57. **Volatiles:** Chemicals with low boil and melt temperature. Water is a volatile.
58. **Volume:** The amount of space which an object contains.
59. **Wrinkles:** The final ridges of lava that helped to inundate the maria.

NOTES

CAN YOU ANSWER THE FOLLOWING QUESTIONS/STATEMENTS ABOUT THE MOON?

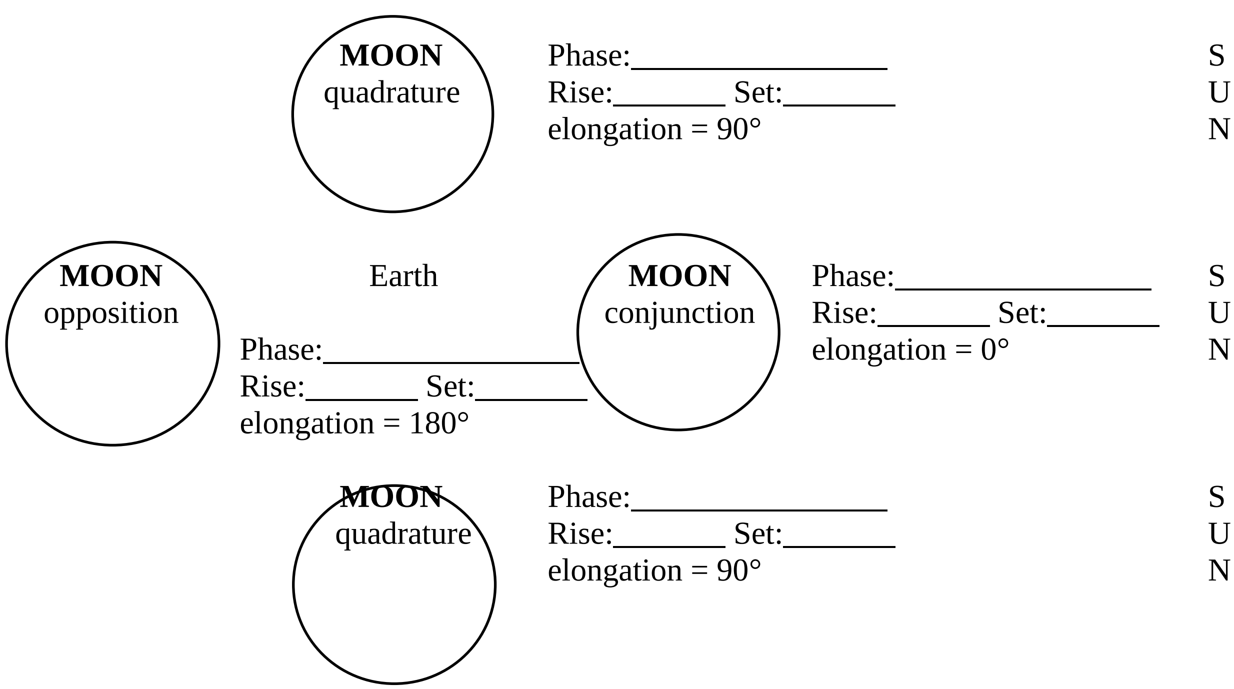
BASIC INFORMATION

1. Give an accounting of some of the vital characteristics of the moon.

   a. diameter .... ____________________
   b. average distance from Earth .... ____________________
   c. mass, as compared to Earth's mass .... ____________________
   d. volume, as compared to Earth's volume .... ____________________
   e. density .... ____________________
   f. period of revolution (sidereal) .... ____________________
   g. period of rotation .... ____________________
   h. period of phase change (synodic) .... ____________________
   i. lowest temperature/highest temperature .... ____________________
   j. possesses an atmosphere (yes or no) .... ____________________
   k. possesses water (yes or no) .... ____________________
   l. possesses gravity (yes or no) .... ____________________

PHASES OF THE MOON

2. List the correct name for the lunar phase which would correspond to the four basic elongations of the moon which are given below. Also, give the rising and setting times of the moon for each case. The elongation represents the angular separation of the moon from the sun in the sky. The phase period of the moon, also called the synodic period, represents the amount of time that it takes the moon to complete a day and night cycle.



3.The _______________ period equals the time it takes the moon to make one complete revolution around the Earth. Its period equals _______________ days.

4. The _______________ period equals the time it takes for the moon to cycle through a complete a series of phases. One lunar phase period occurs every _______________ days.

5. The phase period of the moon is different from its revolutionary period because the Earth
____
____
____

6. Because the moon keeps its same hemisphere pointed towards the Earth at all times, the moon makes one complete _______________ in the same period of time that it takes it to orbit the Earth. These two periods are said to be _______________.

7. The "dark side" of the moon really indicates the hemisphere of the moon which cannot be _______________ from Earth and represents a misconception. The term used by astronomers to delineate this hemisphere is the _______________ side, since the dark side of the moon implies that this region of the moon does not receive any sunlight or we know nothing about it. The far side of the moon is completely in the light of the sun at ____________________ (phase of moon as seen from Earth).

8. On the lunar surface, the period between two successive sunrises would take _______________ days.

FORMATION OF THE MOON: Accretion, Collision-Accretion, Fission, Capture

9. The _______________ theory claims that the moon was once a part of the Earth and that it broke away early in the history of our planet. The Pacific Ocean basin was once thought to be the region where this origin occurred. Its density and volume are consistent with the moon's density and volume. However, geologists now know that the Pacific Ocean basin could not have been the source of the moon's formation because of a crustal process called ____________________.

10. One problem with the above theory is that when a secondary body of the same density as its primary approaches its primary to within 2.44 times the radius of the primary, the secondary body will ____________________. This region is called the _______________ limit. If this is the manner in which the moon was formed, the time period in which the moon could have been within this limit would have had to have been very LONG/SHORT (circle one).

11. If the moon formed by the capture of smaller particles which were orbiting the Earth as the Earth formed, then the _______________ theory is the correct one.

12. If the moon was formed in some unknown distant location in the solar system, then the Earth must have ________________ the moon. This is unlikely since the motion of the moon would have had to have been counterclockwise after the capture occurred.

13. A variant of all three theories is that early in Earth's early history a large Mars-sized object ________________ with our world, catapulting large quantities of debris into Earth orbit which ________________ (came together) to form the moon.

14. In the above hypothesis, some astronomers feel that two objects were formed. The smaller body impacted onto the far side of the moon creating a thicker ________________ and the dark ________________ on the near side.

15. The moon probably formed through the ________________ of debris in Earth orbit, early in the history of the solar system or through the ________________ of another large object with the Earth which threw debris into orbit which ________________ to form our natural satellite. Regardless of which hypothesis is correct, ________________ played a central role in the formation of our moon.

CHRONOLOGY OF MAJOR LUNAR EVENTS

16. A casual inspection of the full moon with the unaided eye reveals light and dark regions referred to as ________________ and ________________, respectively. These features reveal a major epoch in the geologic history of the moon.

17. In the beginning, probably the entire moon was molten after it accreted. The moon began to cool, and the rock crystals which formed either moved towards the surface or sank, depending upon the ________________ of the minerals. This process of separation is known as ______________________.

18. As the planets and their satellites swept up the remaining solar system debris, cratering dwindled, and the entire surface of the moon looked basically like the ________________ do today. Near the end of the heavy bombardment, some major catastrophic event took place in the solar system. It may possibly have been the breakup of the ________________ belt, which released a large number of bodies into the solar system or Uranus and Neptune which perturbed ________________ bodies into the inner solar system. This occurred about ________________ billion years ago.

19. These major impacts on the moon began the formation of the lunar ________________ which are hundreds of miles in diameter and 50 to 100 miles deep. After their creation, several hundred million years elapsed during which nothing much happened. Then ________________ from warmer, denser regions underneath the crust gradually began to seep from the basin fractures created by these huge impacts. Afterwards, for a period of several hundred million years, these depressions were actively being filled with ________________. The igneous material which covered the basins, layer upon layer, was denser because chemically it contained larger quantities of ________________, titanium, and magnesium. These darker regions today are known as the ________________.

20. For the past ONE/TWO/THREE (circle one) billion years, since the inundation of the basins, the moon has for all geological purposes been a ________________ world.

21. This can be confirmed by visual observation from Earth because the maria are relatively crater ________________ (amount of cratering) indicating that since their formation billions of years ago
____
(Hint: See the next question below if you are having difficulty with the above question.)

22. The number of craters which a region contains is an indication of its relative ________________ in comparison to other locations surrounding an area which may have had more or less impacts. Fewer craters indicate that the area is ________________ in comparison to another location which may have more craters.

APPEARANCE AND GEOLOGY OF THE MOON

23. The moon when viewed with the unaided eye appears to have dark areas. These darker regions are called ________________ after the Latin word for ________________. Circle the correct words which apply to the darker regions of the moon—older, newer, flatter, rougher, denser, less dense.

24. The regions of the moon's surface which appear brighter are termed the lunar _____________. The words not circled in the last statement apply to these regions of the lunar surface.

25. ________________ is another word for the reflectivity of an astronomical body. The reflectivity of the moon's surface is HIGH/LOW (circle one). The various shades of gray on the moon are similar to a ____.

26. The moon appears bright in the nighttime sky because the sky is so much ________________ in contrast to the moon.

27. All of the rocks on the moon are mainly composed of varying combinations of the elements, ________________ and ________________. Smaller amounts of other atoms and compounds create the characteristics which allow one to differentiate whether these rocks belong to maria or highland varieties.

28. The highland rocks which originally composed the entire surface of the moon have more ________________ and ________________. These materials contain less massive atoms than those which are contained in the denser lowland rocks which have more ________________, ________________, and ________________ within them.

29. The Earth and moon probably received an equal pounding from meteorites throughout their respective histories. Yet the Earth appears almost totally devoid of these blemishes, while the moon does not. State three processes which have caused the Earth to evolve more rapidly than the moon.

a. ____
b. ____
c. ____

30. The surface of the moon changes very slowly when compared to the Earth, yet over eons of time (billions of years) even very slow amounts of change become easily discernable. State three processes that would be actively modifying the lunar surface at present.

a. ____
b. ____
c. ____

31. As the moon ages, the albedo of the lunar soil becomes HIGHER/LOWER (circle one) as it sweeps up dust in its orbit around the Earth. This is also common with other satellites in the solar system and is an indicator of younger versus older terrain.

32. When a large meteorite crater is formed, clumps of debris fan out and churn up the soil, sometimes at great distances from the impact site. This debris exposes fresher material under the surface soil, sometimes in elongated streaks called _______________. Any crater possessing these elongated streaks indicates that this feature is NEWER/OLDER (circle one) than the craters which are around it and devoid of this feature.

33. The far side of the moon possesses a thicker _______________ which may be attributable to debris thrown into this area from the major impacts which formed the _______________ on the near side.

34. The major lunar features visible to Earth observers without a telescope, but virtually absent on the far side of the moon are the _______________.

35. Since the bulk density of the moon is similar to the moon's surface density, as well as the surface density of the Earth, it seems reasonable to suspect that the moon does not possess any significant _______________.

36. Magnetic fields are usually associated with bodies that are rotating rapidly and possess a liquid core of iron or some other conducting medium. The moon WOULD/WOULD NOT (circle one) be expected to possess a magnetic field.

37. All of the samples that have been returned from Apollo mission are IGNEOUS/SEDIMENTARY/METAMORPHIC rocks (circle one).

38. The lithosphere of a body represents that part of an object which is in the ________________ phase (physical state). On Earth, a layer called the **asth________________** occurs below the lithosphere when temperatures are high enough to allow the material to deform or flow slowly. This region is still not considered to be liquid. On Earth, the continents float and move around on this portion of the upper mantle.

39. The moon's lithosphere is THIN/DEEP/VERY DEEP (circle one). Because of this situation, active volcanism WOULD/WOULD NOT (circle one) be expected to be occurring on the lunar surface at the present time.

40. Prior to the human conquest of the moon, an ingenious series of vehicles were sent to the moon to learn more about its properties. _________________ spacecraft hard-landed during the early to mid-60's. Later, soft-landing ________________ spacecraft investigated the lunar environment at specific locations, while ______________________ circled the moon to photograph its surface for prospective landing sites.

41. It was absolutely necessary to send satellite orbiters and landers to the moon prior to the Apollo missions. Telescopes on Earth could not resolve lunar detail clearly enough because of ________________ turbulence. Remember the series of slides, taken from Earth and from lunar orbit, which detailed the morphology (form and structure) of the crater Copernicus.

CRATERING

42. When a large meteorite strikes the surface of a planet or a satellite, the target area reacts much like a SOLID/LIQUID/GAS (circle one). During the deceleration of the meteorite, a tremendous amount of heat is released which causes most of the impacting body to be __________________.

43. A large meteorite produces a crater in which the walls of the crater are HIGHER/LOWER (circle one) than the surrounding terrain, and the floor of the crater is HIGHER/LOWER (circle one) than the land around it. This is one way of distinguishing an impact crater from one formed through the process of __________________.

44. In a traditional volcanic mountain, the crater walls are HIGHER/LOWER (circle one) than the surrounding terrain, while the crater floor is HIGHER/LOWER (circle one) than the land around it. In a volcanic pit crater, the crater walls are LOWER/EVEN/HIGHER (circle one) than the surrounding landscape while the pit is LOWER/EVEN/HIGHER (circle one) than the land around it.

45. Many larger lunar impact craters display a mountain in the middle of the formation known as a ____________________. These features may be the result of the slumping (collapse without water) of the crater walls, the rebound or splash effect which may occur after impact, or simply local __________________ caused as an aftermath of impact due to the tremendous amounts of heat released during the crater formation process.

46. Fractures (faults or weak zones) within the walls of a crater often cause the walls to collapse in a step like configuration which is known as ________________.

47. Many larger meteorite craters display smooth floors which may be the result of **v**________________ which occurred after impact or the melting of surface rocks from the heat released during impact.

48. Smaller impact features which surround a larger crater are often the result of objects which have been thrown from the crater during its formation. These are called ________________ craters.

49. Any feature which overlaps, intrudes, or is contained within another formation can be said to be YOUNGER/OLDER (circle one) than the other structure.

50. Younger craters appear to have __________________ boundaries, while older craters have become more __________________ during eons of bombardment and lunar weathering.

51. _________________ rilles probably acted like lunar rivers during the time period after the great bombardment of asteroidal-sized meteorites. However, one apparent difference was that these rilles carried _________________ rather than water. These features may reveal themselves as a series of _________________ chains if the rilles were underground and sections of the tube collapsed.

52. _________________ rilles are graben faults which may have been caused by upward pressure, caused by magmatic movement and doming, or the shrinking and cracking of large expanses of lava during cooling. In the former case they represent a mechanism by which crustal tensions are released through the creation of more surface area.

NOTES

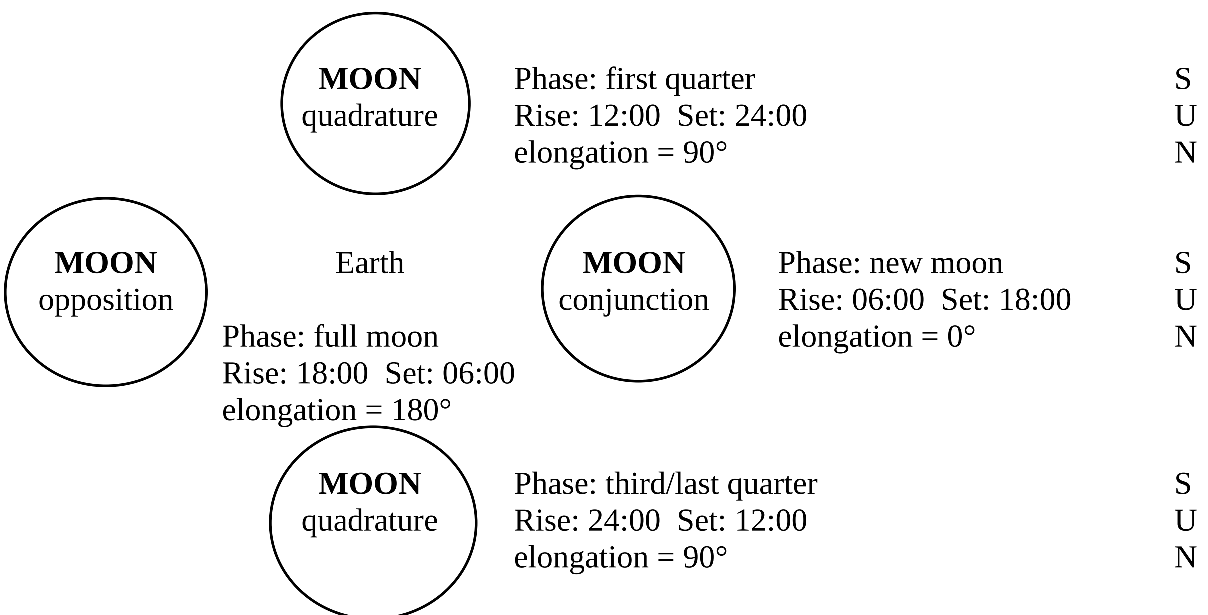
ANSWERS TO SESSION NINE QUESTIONS

BASIC INFORMATION

1. a. approximately 2000 miles (actually 2160 miles or 3476 km)
   b. approximately 250,000 miles (actually 239,000 miles or 384,000 km)
   c. $^{1}/_{81}$ that of Earth
   d. $^{1}/_{50}$ that of Earth
   e. 0.62 that of Earth or 3.33 $^{gm}/_{cm^3}$
   f. 27.3 days
   g. 27.3 days
   h. 29.5 days
   i. approximately -250° F to +250° F (actual range -279° F to +212° F or -173° C to 100° C)
   j. no atmosphere
   k. yes. A small but still significant amount of frozen water exists near the lunar poles.
   l. yes ($^{1}/_{6}$th Earth's gravitational pull)

PHASES OF THE MOON

2.



3. sidereal, 27.3
4. synodic, 29.5
5. is revolving around the sun. After one revolution of the moon around the Earth, the Earth has moved through $^{1}/_{12}$th of its orbit around the sun. The alignment of Earth, moon, and sun is not the same, and an additional $2^{1}/_{6}$ days is needed to achieve the same configuration and repeat the same phase.
6. rotation, synchronous
7. observed, far, new moon
8. 29.5 days or one synodic period

FORMATION OF THE MOON

9. fission, continental drift
10. break apart, Roche, SHORT
11. accretion or cocreation
12. captured
13. collided, accreted
14. crust, maria
15. accretion, collision, accretion, accretion

CHRONOLOGY OF MAJOR LUNAR EVENTS

16. highlands (terrae, uplands), lowlands (seas, basins, maria)
17. density, differentiation or crustal differentiation
18. highlands, asteroid, cometary, 3.9
19. basins, magma, lava, iron, maria
20. THREE, dead
21. free, not much has been happening to the surface of the moon since this time.
22. age, younger

APPEARANCE AND GEOLOGY OF THE MOON

23. maria, sea, newer, flatter, denser
24. highlands or terrae
25. albedo, LOW, a macadamized roadway
26. darker
27. oxygen, silicon
28. calcium, aluminum, iron, magnesium, titanium
29. a. continental drift: surface of Earth is reprocessed
    b. erosion: water and wind reduce the elevation of objects
    c. weathering: chemical changes induced by air or water and mechanical changes created by expansion and contraction
30. a. Cratering and blanketing and bombardment by micrometeorites
    b. Mechanical weathering: expansion and contraction due to diurnal temperature changes
    c. Bombardment by solar wind particles
31. LOWER
32. rays, NEWER
33. crust, basins (seas)
34. seas (The Orientale Basin on the lunar far side was never flooded by lava.)
35. core
36. WOULD NOT
37. IGNEOUS
38. solid, asthenosphere
39. VERY DEEP (about 600 miles or 1000 km), WOULD NOT
40. Ranger, Surveyor, Lunar Orbiters
41. atmospheric (seeing)

CRATERING

42. LIQUID, vaporized
43. HIGHER, LOWER, volcanism
44. HIGHER, HIGHER, EVEN, LOWER
45. central peak, volcanism
46. terracing
47. volcanism
48. secondary
49. YOUNGER
50. sharper, rounded
51. sinuous, lava, crater
52. straight

January 12, 2018

NOTES