Websites for Rare Earth Course 2018

http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_plate_reconstruction_blakey.html

The above site has a visualization of the tectonic plate history of the earth.

This is a NASA site which describes the formation of the moon (below):

https://sservi.nasa.gov/articles/nasa-scientist-jen-heldmann-describes-how-the-earths-moon-was-formed/

A second, more complex version of moon formation, from "Sky and Telescope" magazine

http://www.skyandtelescope.com/astronomy-news/when-and-how-did-the-moon-form/

Scientific American article : Without the Moon, would there be life on earth?

The ocean tides mirror life itself. Their ebb and flow pay homage to the cyclic nature of the cosmos along even the most secluded seashores. But is life itself also ultimately a fluke of the tides?

If so, life may ultimately owe its origins to our serendipitously large moon. The sun and wind also drive the ocean's oscillations, but it is the moon's gravitational tug that is responsible for the lion's share of this predictable tidal flux.

Our current Earth–moon system, according to the prevailing theory of lunar formation, reflects our solar system's early game of planetary billiards, when colliding planetary embryos created entirely new versions of themselves—in the case of our own planet, a disproportionately large natural satellite in close orbit.

It all started some 4.5 billion years ago when, as theory has it, our nascent Earth was blindsided by a Mars-size planetary embryo, believed to have spun Earth into its initial fast rotation of roughly 12 hours per day. The molten mantle thrown into orbit after the catastrophic lunar-forming impact quickly coalesced into our moon. Within a few thousand years, Earth cooled to an object with a molten surface and a steam atmosphere. Life emerged some 700 million years later, or about 3.8 billion years ago.

But four billion years ago a cooling Earth already had an ocean, but remained barren. The moon was perhaps half as distant as it is now, and as a result, the ocean tides were much more extreme.

At an average distance of 235,000 miles (380,000 kilometers), the moon is currently receding from Earth at a rate of 1.5 inches (3.8 centimeters) per year. As it does, Earth's own spin rate is slowing. And, in the process, roughly 10^{20} joules of gravitational energy is shed into the oceans annually.*

Over the eons, all that energy has had an evolutionary impact.

"The oceans' tidal flow helps transport heat from the equator to the poles," says Bruce Bills, a geodynamicist at the NASA Jet Propulsion Laboratory in Pasadena, Calif. "Without the lunar tides, it's conceivable that climate oscillations from the ice age to the interglacial would be less extreme than they are. Such glaciations caused migrations of animal and plant species that probably helped speed up speciation."

Bills also points out that such tidal heat transfer could have also mitigated climate fluctuations. The problem in determining which "tidal forcing" scenario is correct, he says, is that climate researchers currently lack data spanning extremely long timescales. Even so, Peter Raimondi, an ecologist at the University of California, Santa Cruz, says the tools of evolution are also driven by the tides' influence on these intertidal regions.

"In a rocky intertidal area," Raimondi says, "it's very clear there are strong evolutionary pressures brought on by a changing environment over a short spatial scale. Without our moon, our marine environment would be much less rich in terms of species diversity."

But is the influence of the lunar tides actually responsible for life itself?

If life originated around deep ocean hydrothermal vents (so-called black smokers), then the lunar tides played a minor role, if any, says James Cowen, a biogeochemical oceanographer at the University of Hawaii at Manoa. If, however, life originated in tidal waters, he says, then tidal cycles could have played a major role.
*CORRECTION (4/23/09): An earlier version stated that three terawatts (3 TW) are shed into the oceans annually; 3 TW is the measure of the power dissipated continually.

Both DNA and RNA—the messengers of life as we know it—almost certainly were selected and evolved from a large diverse group of protonucleic acid molecules. But for DNA and RNA to evolve from this group of protonucleic acid structures, first they had to be able to replicate. That involved organizing their copying via cyclic assembly and dissociation.

"A lot of origin-of-life reactions involve getting rid of water," says Kevin Zahnle, a planetary scientist at the NASA Ames Research Center at Moffett Field, Calif. "So you look for means to concentrate your solutions. One way to do that is to throw water up on a hot rock, then have the waters recede and evaporate."

Molecular biologist Richard Lathe of Pieta Research, a biotech consultancy in Edinburgh, Scotland, contends that some 3.9 billion years ago, fast tidal cycling caused by the influence of our moon enabled the formation of precursor nucleic acids.

Lathe says that a 12-hour Earth day would have produced high tides "a little faster than every six hours."

He believes these lunar tides would have moved many miles inland, beyond the crashing waves driven by the sun or surface winds, and onto a vast, flat sandscape. Today, this sort of ocean cycling pervades the sandy flats surrounding France's famed tidal island of Mont-Saint-Michel, abutting the English Channel.

In the early Earth environment, Lathe notes that such fast lunar tidal oscillations would result in the highly saline low-tide environment that protonucleic acid fragments would have needed to associate and assemble complementary molecular strands.

Having bonded in pairs at low tide, these newly formed molecular strands would then dissociate at high tide, when salt concentrations were reduced, providing what Lathe terms a self-replicating system. Lathe believes that DNA would ultimately have arisen from such protonucleic acids.

If the lunar tides were a crucial part of evolution on our own planet, what of other ocean-bearing terrestrial planets without benefit of a significant nearby lunar neighbor? Would their prospects for life be diminished due to lack of tides?

"Odds of nucleic acids forming on Earth without the lunar tides would be much lower," Lathe says. By this accounting, he says that Mars, with its two puny moons, Deimos and Phobos, could not have formed life.

Within our own solar system, the moons of Jupiter have turned the idea of tidal influence on its head. On Jupiter's icy moon Europa, tidal heating, caused by the flexing of the satellite under the gravitational pull of the giant planet, is believed to maintain a large liquid water ocean below its frozen surface.

"Europa must have big tides, so it's my favorite for microbial life," says Max Bernstein, an astrochemist and program scientist at NASA Headquarters in Washington, D.C. "Europa is considered by many as the best place to find life in the solar system."

But even with strong tides, any evolutionary ambitions of microbes on Europa would soon be stymied by their harsh habitat. That is one reason why so much time and energy still goes into unraveling the mystery of life's origins on our own planet.

Our disproportionately large nearby moon certainly gave Earth an early tidal nudge. But unlike Venus and Mars, our moon's gravitational influence also helped ensure that Earth's spin axis and climate remained stable over long timescales. That's arguably just as important as our oceans' tidal ebb and flow.

Still, as Bruce Lieberman, a paleobiologist at the University of Kansas in Lawrence, points out: "I suspect that eventually life would have made land without the tides. But the lineages that ultimately gave rise to humans were at first intertidal."

Another website on the effect of the moon on evolution

https://futurism.com/the-moons-role-in-evolution-2/

Here is a great site with visualizations of how present life on earth is dependent upon and uses the tides.

http://www.math.nus.edu.sg/aslaksen/gem-projects/hm/0102-1-phase/TIDESONLIFE.htm

And yet another, with graphics:
https://www.space.com/29047-how-moon-formed-earth-collision-theory.html,

Initial text from the above website on the moon’s formation:
The formation of the moon has long remained a mystery, but new studies support the theory that the moon was formed from debris left from a collision between the newborn Earth and a Mars-size rock, with a veneer of meteorites coating both afterward.
Earth was born about 4.5 billion years ago, and scientists think the moon arose a short time later. The leading explanation for the moon's origin, known as the Giant Impact Hypothesis, was first proposed in the 1970s. It suggests the moon resulted from the collision of two protoplanets, or embryonic worlds. One of those was the just-forming Earth, and the other was a Mars-size object called Theia. The moon then coalesced from the debris.
The long-standing challenges this scenario faces are rooted in the chemistry of the moon. Most of the models of the giant-impact theory often say that more than 60 percent of the moon should be made of material from Theia. The problem is that most bodies in the solar system have unique chemical makeups, and Earth, Theia and therefore the moon should as well. However, rock samples from the moon reveal that it is puzzlingly more similar to Earth than such models would predict when it comes to versions of elements called isotopes. (Each isotope of an element has different numbers of neutrons.) [Evolution of the Moon: A Visual Timeline (Gallery)]

Burgess Shale insights:
http://burgess-shale.rom.on.ca/en/,

From Scientific American, Shannon Hall , July 2017

But just how essential is plate tectonics for life? Hints can be found from our own planet's history. Around 2.5 billion years ago the sun was so cold that Earth's liquid oceans should have been frozen in a snowball-like state—only they were not. Scientists think plate tectonics, which acts as a global thermostat, might have been our savior by creating volcanoes that spewed carbon dioxide into the atmosphere, helping it to retain more heat. Then, as the sun grew brighter and hotter, rainfall scrubbed the carbon dioxide from the atmosphere and plate tectonics later subducted it into the Earth's mantle (the layer of hot rock above the core), locking it away. It is this cycle, which acts on million-year timescales, that helps keep Earth's temperature stable enough to support life.

Yet Earth's example does not prove plate tectonics is a *requirement* for life. Planets can, after all, be geologically active without plate tectonics. Just take a look at Mars, which boasts the largest volcano in the solar system. Still, that volcano no longer rumbles to life. In fact, most solar system planets (and even dwarf planets and moons) that were once geologically active are now quiet. Without plate tectonics, volcanism declines rapidly (with some notable nontectonic exceptions such as Jupiter's Io and Saturn's Enceladus). As such, Mars's numerous but extinct volcanoes do not have the ability to belch carbon dioxide into the atmosphere, leaving the Red Planet quite chilly today. Such examples suggest plate tectonics—particularly long-lasting plate tectonics—is the best method of regulating a planet's temperature and is therefore a useful ingredient in the cocktail of life.

Sliding Plates

The latest study seems to contradict some previous investigations of whether or not exoplanets might shake like Earth. In 2007 planetary scientist Diana Valencia, then at Harvard University, concluded that super-Earths (rocky planets larger than ours) are so likely to host plate tectonics, it is practically inevitable. Because planets more massive than Earth would retain significantly more internal heat from their initial formation, and because heat drives plate tectonics (via the conveyor belt of sinking and rising rock within the mantle), plate activity should be prolonged on such planets. The trouble is that Valencia's study (and many studies that came later) analyzed only one parameter: a planet's size. Unterborn's study is among the first to address plate tectonics based on a planet's composition.

To carry out this analysis, Unterborn and his colleagues needed to determine what an exoplanet's chemical composition might look like. Although astronomers can currently decipher the elements within an exoplanet's atmosphere, there is no way to peer deep into an exoplanet's rocky interior—yet. So Unterborn and his team turned toward the planets' host stars. Because the stars and their planets are built from the same swirling disk of dust and gas, they tend to be made of the same stuff. The researchers looked at nearly 1,500 stars (including 123 stars observed with the Kepler space telescope that astronomers know have orbiting exoplanets) and then used computer models to discover how rocks of these varying compositions would react to the high interior temperatures and pressures formed in a planet.

Once they had an idea of what an exoplanet's mantle and crust might look like, geochemically speaking, the scientists were able to determine whether that exoplanet's crust would be dense enough to sink into the mantle, just as Earth's oceanic plates do at places like the Cascadia subduction zone—North America's 1,000-kilometer-long chain of volcanoes built as one plate takes a deep dive beneath another. Making the calculation involved rigorous modeling: As pressures and temperatures mount during a plate's descent, atoms in the plate undergo a reorganization that makes the plate denser. Should the plate remain denser than the surrounding mantle then the plate would continue to sink. If that is the case, plate tectonics might thrive for billions of years. But if it does not and the plate stalls, then plate tectonics would shut down, crippling life's chances.

The results paint a rather depressing result as far as habitability is concerned: At least two thirds of the simulated planets build a crust that is too buoyant to sink. “If subduction were to happen, and [the plate] were to go down, it would just pop back up,” Unterborn says. “It’s like trying to push an inner tube underwater.” If these plates are on the move, they might crash into each other and crumple upward to form mountain chains as tall as the Himalayas, Unterborn says. But one plate will never subduct below another to remove excess carbon dioxide or form the volcanoes that spew more carbon dioxide into the atmosphere. As such, the planet will not be able to regulate its own temperature and will easily escalate into a world that resembles a snowball or a sauna.

The New Field of Exogeology

The results highlight that a planet’s habitability cannot be defined only by the Goldilocks zone—that sweet spot in a planetary system where a planet’s orbital distance from its star keeps it neither too hot nor too cold. Nor can density alone determine what counts as an “Earth-like” planet. “Density is not destiny when it comes to planets,” Unterborn says. “The Earth is much more than a one-Earth mass, one-Earth radius planet” in the sun’s habitable zone. Just think back 2.5 billion years: Earth would not have been considered habitable to alien astronomers unless they took its geology into account.

Bradford Foley, a geologist at The Pennsylvania State University who was not involved in the study, agrees with the paper’s ultimate point—that the majority of rocky exoplanets likely cannot host plate tectonics—but he argues that finer details, such as the exact percentage of those planets, cannot yet be pinned down. “I would take everything beyond the big-picture view with a grain of salt because there are uncertainties wrapped up in there that are subject to change as more studies come out,” he says.

One of those uncertainties, Foley notes, is geologists still argue over how plate tectonics ignited on Earth and what continues to drive it today. The issue is that even if a plate is dense enough to sink into the mantle, the lithosphere—the strong and rigid outer shell of the planet—has to crack first. But what causes the lithosphere to crack is hotly debated in the field. Unterborn sidestepped this complication by looking for planets that might be able to undergo plate tectonics for billions of years—should it begin in the first place. Foley agrees that it is a clever workaround, and Unterborn argues that it is more interesting from a scientific point of view because we are more likely to find life where it has evolved over billions of years. But the assumption plate tectonics magically begins does show that even the proper elemental cocktail does not guarantee a shifting and rumbling surface. Still, Unterborn argues it does maximize our chances of finding plate tectonics and therefore life.

Unterborn views the work as a step forward in a new field—one where geology meets astronomy in a discipline one might call exogeology—that began just 10 years ago with Valencia’s paper. Just last week Foley, Unterborn and colleagues submitted a proposal to the NASA Astrobiology Institute to further assess how materials of different compositions react under high pressures and temperatures. Whereas Unterborn’s study was based on theoretical calculations, the new team would like to synthesize these rocks in the lab and physically subject them to those conditions. That would allow them to paint a more accurate picture and even explore how changing the composition might crack the lithosphere—the other important criterion for kick-starting plate tectonics. “I think it’s definitely the future,” Unterborn says. “I'm glad to be at the forefront of it.”

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Recent Articles

Website for the Kepler 90 planetary system: https://apod.nasa.gov/apod/ap171218.html,