Astronomy Cast Episode 221 for Monday, February 21, 2011: Geomorphology

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Fraser: Welcome to Astronomy Cast, our weekly facts-based journey through the cosmos, where we help you understand not only what we know, but *how* we know what we know. My name is Fraser Cain, I'm the publisher of *Universe Today*, and with me is Dr. Pamela Gay, a professor at Southern Illinois University Edwardsville. Hi, Pamela, how are you doing?

Pamela: I'm doing well. How are you doing, Fraser?

Fraser: Good. Finally warming up a little...

Pamela: Good.

Fraser: Ready to come out of the Canadian deep- freeze for another summer... Alright, when we look around our planet, we see a huge variety of landforms: mountains, valleys, plateaus and more. Continents rise and fall over the eons providing geologists with a history of the planet's evolution. The study of these changes is known as "geomorphology," and the lessons we learn here on Earth apply to the other planets in the solar system. Well, I think, as always, our specific interest is that we're going really want to talk about how this all applies to the solar system because there's these lessons that go back and forth: things we learn in the solar system apply back to Earth, and on Earth back to the solar system. And it sets our imagination for extra-solar planets, but let's kind of go back to the basics and really understand: what is geomorphology?

Pamela: It's basically a really long, fun-to-say word that means the surface of a planet isn't flat due to a variety of processes, ranging from tectonic processes (this is the plates that make up the surface of the planet moving around), to aeolian processes (things getting blown about by the wind), and fluvial processes (which basically means stuff that's been affected by liquids, like water). You also get Imbrian processes, which is volcanism. So all of these different things, basically earth, wind and fire (if you consider volcanism fire) -- they have an effect on the shape of the surface of the planet. We don't have perfect spheres, and where we deviate from that perfect sphere -- that's geomorphology.

Fraser: And so we're talking about when we look at a mountain, or we look at an ocean, or we look at, you know, as I said, a plateau or a valley, or things like that, each one of those had a history that happened over time, and there are processes going on. So you sort of quickly mentioned a bunch of the processes. Can you give us some concrete examples, maybe?

Pamela: Mountains are perhaps as concrete an example as you can get, especially if they're made of granite -- just to be "punny." So, when you see a mountain, those mountains are typically formed by two different processes. You either have a volcanic mountain, which means that there was a hole in the Earth's crust, and up out of the hole rose magma that eventually broke through the surface and built up and built up and built up and built up, forming that large hill/mountain, that deviation from the sphere that you see on the horizon. Now, most mountains, however, things like the Alps, the Rockies, these are formed where two plates, two pieces of the surface of the earth have collided together and have, in the collision, folded up, sort of like when two cars have the misfortune of running into each other -- their hoods crinkle up. Well, this is the exact same thing as that crinkled hood; it's just a crinkled plate on the surface of the planet Earth.

Fraser: And some of these processes...I guess there's the processes that build things up, and then there's the ones that wear them down.

Pamela: Right, and the things that wear things down are, primarily on the surface of the earth: the wind slowly wearing away at the surface, rain slowly eating away at the surface, rivers flowing across the surface and cutting into it...so this is where the aeolian, and the fluvial, the air and water processes, cut into the surface and change its shape.

Fraser: And I guess where this is really interesting to us is that when you take this concept mostly developed to understand Earth's changes, and then you apply it to the other objects in the solar system, then the rules get different. I mean, we look at the moon: the moon has no air, the moon has no water, the morphology of the moon is driven in a very different way.

Pamela: Right, so on the moon, I wouldn't say that something was mostly eroded due to water or air, but rather on the moon, we still have things wearing away at the surface. The astronauts' footprints aren't actually permanent. They're just permanent on the scales of nations and civilization. Over time, the slow pitting of the surface of the moon by micrometeorites will eat away at small features. Over time, you'll also get rather dramatic feature changes when the moon gets hit with asteroids, with comets, with basically rocks bigger than micrometeorites.

Fraser: And so the primary... so what's both building up the landscape and tearing it back down again is purely just impacts.

Pamela: Exactly, and this is the way it is today, but in the past, the moon did have volcanism, and this is something that's kind of hard to think about. We don't think of the moon as being geologically active in the same way that we see Iceland and Hawaii and Indonesia as geologically active, but if you pore over the high-resolution the images of the moon that are coming down from the lunar reconnaissance orbiter and the other orbiting missions --

Pamela: Kaguya, Chandrayaan -- these missions are revealing shield volcanoes, the same sorts of things that we see on the surface of our planets. They once were active on the moon. Lava tubes existed on the moon; the mare, that's just dried lava, or solidified, I guess, is a better word. So our moon, while currently very, very dead, in the past did have an active history.

Fraser: And then let's compare that to some other world, like maybe Enceladus.

Pamela: Well, in Enceladus, here we have an icy body that is as close to a perfect circle -- a perfect sphere -- as you can get, and this is because all those crater impacts it's definitely had in the past. It's part of the solar system -- it's been hit. They've all been filled in by ice. It's thought that cracks in the surface, geyser holes in the surface caused this little moon to basically spray out liquid that freezes on a regular basis. Some of this escapes and fills in Saturn's rings, but much of it falls back to the surface just constantly refreshing that surface with fresh, shiny ice.

Fraser: So, and then let's go for another one, right? Like, what's happening on Venus? Venus has an atmosphere, right? So you can have air working, but no water.

Pamela: And this is where you start to get differences between...not all planets are made the same. Venus and Mars are in many ways very similar to the Earth. They have both had volcanoes, they both have had (at one point or another) atmospheres that have caused liquid that falls through the skies, most likely water on Mars, and nastier things involving hydrochloric acid on Venus. Don't want to be there! But both these planets have slightly different gravities -- much less on mars, slightly different on Venus -- and neither of these two planets has the same active plate tectonics that we have here on the Earth. The surface of our planet is made from a series of plates that are colliding, that are going over and under one another, that are basically being reformed in different places as they're consumed in others. This constant moving of the plates causes the ring of fire with its earthquakes all around Alaska and Japan and Indonesia and South America. Those sorts of events don't occur on Mars or Venus. With Venus, it's a big enough planet that it hasn't cooled off. It's close enough to the sun that it's going to take it a little bit longer to cool off anyways, and the way it releases heat instead of through the constant shifting of the plates in steady of volcanism is it appears to undergo periodic spastic eruptions. There's evidence that at one point in the past, pretty much all of Venus was resurfaced through one wild go of volcanism, so that's not some place you want to experience that sort of active surface geology.

Fraser: So it's almost like it held in the heat until it finally just gave, and the whole surface was just volcanoes.

Pamela: Right, so think of it as the worst volcanic nightmare you've ever had, basically.

Fraser: So then what's wearing down the surface of Venus, though?

Pamela: So on Venus you do have rain, it's more acidic; it's a greenhouse effect, so you do have...

Fraser: You have sulfuric acid raining down, right?

Pamela: Right. All of these nasty hydrocarbons are causing all sorts of nasty chemicals to literally rain from the sky, and those affect the surface. You also have cratering, and we don't actually know if there's ongoing volcanism on Venus. This is one of those constant questions that we just don't have an answer for, but hopefully as we get better at building spacecraft that can withstand the high heat and the not-particularly-friendly chemical attributes of Venus, we'll be able to start putting a network of detectors down to sort out: is the surface still active today?

Fraser: And then you've got Mars, as you said, as the comparison. It also doesn't have plate tectonics, but the tallest volcanoes in the whole solar system are located on Mars.

Pamela: This is where gravity comes into play. We see similar extremes going to the Moon. Here on the Earth, if you try to build a mountain too big, gravity pulls it down. Everest is about as big as you can do to the properties of dirt, rocks, soil and gravity combined. Everest is about the biggest mountain you can get on the planet Earth, but on Mars, where there's a lot less gravity, it's possible to build things a whole lot higher. Thus we have Olympus Mons. Now, here on Earth at the same time, if you try to dig too big a hole, the sides will start slumping, and...well, on the Moon, things like the Aitkin Basin -- these are much deeper than any canyon, or ravine, or pit found on the surface of our planet, and that's because on the Moon you have much less gravity there as well. So when we look at Mars, we're seeing a surface that doesn't have the same gravitational effects, so we see valleys that are deeper, we see volcanoes that are higher, and all of this is what happens when you have, at least temporarily in your past, the same rain that we experience on the Earth, thus you had the cutting of the canyons and the riverbeds found all over the planet, and you have volcanism that's able to build the largest volcanoes in the entire solar system.

Fraser: Yeah, I know that if you look at some of the photographs of the Martian surface, you see clearly what were ancient riverbeds, but I guess a lot of this stuff happened a long, long time ago, so it's definitely not recent.

Pamela: Right, so here we're starting to look at events that happened several hundred -- not hundred. Here we're starting to look at events that happened several billion years ago, and we're still trying to figure out how did all the water get to Mars? What triggered these active periods of water on the surface? These are questions that are still being answered, but we're able to figure out "when" the water was by looking at the craters. We can assume a pretty standard rate of rocks hitting planets over the course of the evolution of our solar system. There was a much higher rate of impacts in the much distant past. There is a period called the Age of Heavy Bombardment, and today things still get hit, but not that often, and so when you look at something, you count up all the craters, and you look at your table of how quickly craters have built up over time, and you can figure out...you can work your way backwards mathematically to figure out "OK, this particular riverbed has on the surface of it this many craters per square mile, that tells you the age. This other one has a whole lot more craters, that means it's older; this other one has a lot fewer craters, that means it's younger," and what we find is there's a certain minimum age that we're finding these things out, which is a few billion years old.

Fraser: And so, what does the study of geomorphology...how would a scientist use that? You just explained one example, right? Where you count craters and that tells you how old a structure is. What are some other ways that you would use geomorphology to try and answer some questions about the planet that you're studying?

Pamela: I think one of the most interesting case studies of using geomorphology to understand something is the surface of the moon Titan. This little world happily orbiting Saturn has an extremely thick atmosphere that's very rich in methane, and when we sent the Huygens probe descending through this atmosphere, the probe was able to take images of river deltas, of shorelines, and we were able to piece together that there's definitely liquid on that surface. Now, the thing is Titan's really tiny, and the way we were seeing the deltas cut, the way we were seeing the shorelines cut, if it was water on the surface, well first of all water would have frozen, it's really cold on Titan, but even if Titan was warm enough, water 's ability to cut through soil is such that you really wouldn't see the same shapes that we're seeing. And by looking at "well, I see how that set of deltas formed, I can use radar to figure out the elevation changes from one place to the other," and you can use all of this to say, "Yeah, I'm pretty certain that it's methane -- liquid methane cutting up the surface of that planet. So by combining the properties of the rocks that make up Titan, the ability of liquid methane to eat through soils, the gravity at the surface of Titan, we were able to build theoretical models that matched what was actually observed, and that's just kind of neat to think about.

Fraser: And it tells you sort of what else to look for...

Pamela: Right, and we can extend this across the solar system, so when we look at Io, and we see its massive volcanism, that tells us something about the temperatures inside that moon. This is a moon of Jupiter, and so we're able to get a sense of "what are the forces that are changing this surface?" And when we start to compare surface to surface to surface, moving across the solar system, we can also start to figure out "well, *this* part of the solar system had *this* type of bombardment going on; *this* part of the solar system had *this* type of bombardment going on." Now, there aren't a lot of variations that we know of. One of the problems that we run into is you can't really say "this crater was formed exactly during this point in history" unless you go and you pick up a rock and you date it in a lab, and we've only been able to go and pick rocks up off the surface of the Moon. We're hoping to be able to go and pick up rocks off the surface of Mars, and this will allow us to tie the surfaces together.

Fraser: But you've got a bit, right? You can count craters within craters.

Pamela: Right. At the same time, it's just making sure we understand that what we're saying is true of Mercury and true of Mars isn't the exact same "time true" because you can kind of imagine that there's that possibility that you had during Year A -- I don't know I'm going to make up numbers -- during the Year A you had 20 impacts a year at Mercury, and during the Year B you had 20 impacts a year at Mars, and they both proceeded to have fewer and fewer in subsequent years in the exact same way, where a certain number of years later instead of having twenty they had ten, but that certain number of years later had a different starting point, so we don't know if the rates at which impacts have slowed down has the exact same "zero point," the exact same "this many this year, this many this year" from planet to planet to planet, and this is why we want to go pick up rocks.

Fraser: Right, if the inner planets might have been hit for longer harder than the outer planets, and if you were near Jupiter you got an extra beating later, so it just depends.

Pamela: And comets melt as they come into the inner part of the solar system, so maybe you have that affecting things -- there's a lot of things that we're still trying to figure out. And at a certain level, geomorphology is all about curiosity because let's face it, volcanoes and impact craters are both just really cool! And so what we're really studying is the explosive nature and the being-hit-really-hard nature of different planet surfaces, and that's just a "we want to" kind of science.

Fraser: But I think what you're driving at though, is it's a real impetus for us to actually get some boots on the ground on some of those other worlds -- that if we could actually drop a probe down that has the kind of laboratory on it that can date things, then that's the really big piece of the puzzle that right now we really don't have, except for the Moon. We really don't know how old the rocks are on Venus, or Mercury or the surface of Mars and that is a huge gap in the knowledge.

Pamela: And while I'm kind of not going to say we should ever land people on the surface of Venus because I like most humans...

Fraser: Robots! Robots!

Pamela: Right, getting robots that are capable of then blasting at least part of their body back into space and sending something back to earth...this is where the Mars Sample Return discussions come in. The idea of landing...the crude idea is to actually land a probe down that does its digging, does its laboratory science, and then land something side by side, and that side by side spacecraft is the one that has the parts necessary to return rocks back to earth. It's a kind of scary mission for [missing audio]. We don't really have the ability to land things side by side right now. We sort of have the ability to land things within very large landing ellipses, and if you want two robots to be able to interact with one another, we need to get those landing ellipses much, much smaller, but this is why we fund research and development, as well as science.

Fraser: And there's one whole class of erosion that happens here on Earth that just doesn't happen that we know of anywhere else, which is biological impact.

Pamela: Right.

Fraser: We have trees and plants and animals tearing the landscape apart.

Pamela: Mining.

Fraser: Yeah -- humans mining! Right?

Pamela: Yeah, it's really amazing to fly over the continental United States (and I'm using this as a primary example because in flying over Europe, I haven't seen pit mining the same way I see in the United States). You'll be flying across the country, and if you've ever done "Moon Zoo" or any other surface morphology project for Citizen Science [missing audio]. As you're looking through these images you start seeing things like "graben," which are straight lines across the surface that are created by two faults, or a fault where part of the land along the fault gets raised up, and part of it collapses down into these long, linear features -- and you can see these as you're flying across the country. And you can see the dried up shorelines of ancient oceans, and you can see mountains and volcanoes, but then you see the granite quarries, you see the pit mines, you see the mountains that have had their tops removed to get at coal, and you start to realize that human beings, especially when you start looking at some of the giant mines that exist in...I think it's South Africa that has the really big pit mine. As you start to look at these images, you realize that human beings can have just as consequential -- I'm not going to say damaging, but just as consequential impact on the landscape as a volcano can.

Fraser: I guess the last thing we want to talk about is we've really seen what happens here in the solar system, but when you kind of apply the fundamentals of geomorphology, but then consider the universe as a whole, does this help guide our search for extra-solar planets at all? Or does it help us recognize features of those planets? I know it's hard to see them, but...

Pamela: Right now, we're not quite there yet. We're starting to get to the stage where we can spot "hot spots" in gaseous planets by looking in the infrared light, but in terms of being able to do more than say, "well, this planet has both light and dark albedo feature, both areas that are highly reflective and not highly reflective"...we're a long ways from being able to say, "Ah, volcanoes on another planet," unless we're doing spectroscopy of their atmosphere. But what's interesting is as we start to look at all the crazy places that planets put themselves in this universe, there's planets out there that have to have unimagined features on their surface because of the weird tidal effects, the weird scrunching that they're experiencing due to orbits that take them just way too close to their parent star. So if you can imagine taking something the size of Earth and putting it on an orbit much, much smaller than Mercury's that's even a little bit elliptical, the difference in the gravity it experiences at its closest point and at its furthest point is going to have radical effects that's going to make what's happening on Io look like just pretty afternoon sparklers. So we can imagine that there's things out there that we can't even imagine.

Fraser: Look at worlds like Iapetus. It has that huge, strange wall on it, right -- The Seam. Or the strange...on Europa, what look like sliding sheets of ice running across the surface. I mean, that's a combination of water with tidal lock heating and, well Iapetus was possibly...it got hit -- struck really hard -- and then almost reformed. When you just consider that there's powerful volcanoes, tremendous tidal forces, impacts, and then super winds, and things wearing things back down again, it's just a whole other class of possibilities. It would be great if we could see some of those worlds, and we only get a glimpse of them. You'll have these artists that do these illustrations of what it could look like on one of these worlds that's really tidally locked to its star, things like that. The point is that as we discover these worlds, we'll try to make some guesses on what the geomorphology is going to be like, but unfortunately, actually getting the evidence is a lot harder.

And you're in fact bringing up things that we'd ignored earlier in this show: things like super winds, super tornadoes. What was recently experienced in the south of America, down in Alabama in particular, the 300 some odd earthquakes in just a 48-hour period, these caused "tiger stripes" across the surface of the planet that were visible from satellite maps. These are some of the most amazing images because you can actually see just stripe after stripe after stripe all running roughly parallel to each other caused by these tornadoes. Now you can imagine a planet that is in a situation where it has a different type of star, it's in a different location compared to its star, and has much greater temperature extremes, and thus has much more powerful tornadoes that don't just tear paths of destruction, but actually gouge paths of destruction across the surface of the planet.

Fraser: Yeah, and you can imagine things in our own ancient history, like you've got...there was a time when the whole Earth was covered with ice. Then you've got to imagine, what's the geomorphology there? Scraping away the undersurface...You can imagine worlds that are all water, that have no surface land at all.

Pamela: But then you have geomorphology under the surface -- not under the surface, under the water.

Fraser: You could have underwater currents that are pushing...there's just so many possibilities, and each one is both interesting in what stories it tells you about the planet. It can also tell you what you might expect to see in other worlds as well. It's really exciting.

Pamela: And if you like to look out windows of airplanes, learning geology can both enrich and destroy this experience for you, sort of like learning vectors and playing pool: once you've learned vectors, you can play pool much better, but then you can't stop calculating vectors. Once you start learning geomorphology, as you fly across the continents looking out your window, you're able to go, "Ah, graben...ah, scarp... " and identify the features.

Fraser: Tiger stripes, yeah. Oh, hurricane damage! Exactly. Cool. Well, thanks a lot, Pamela.

Pamela: It's been my pleasure, Fraser.