Chasing the Lost Oceans of Venus

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David Grinspoon

Is it deranged to build a good part of a career studying something that may or may not have been? I study the oceans of Venus. Maybe it's the scientific equivalent of an artist who emphasizes negative space—focusing on something that is believed to have existed but is no longer there. And yet I believe. True confession: I've even dreamed about them (Fig. 2.1).

I imagine them timeless, vast and deep, covering most of the planet except where mountains—conical volcanoes and steep rims of giant craters—jut skyward. I picture foaming waves lapping the eroding shores of those scattered highlands, blowing in warm breezes, sometimes raging into terrible storms but completely untroubled by tides.

There's no moon to raise the tides and perhaps no early trauma of a moon-forming collision,[1] without which—all else being equal[2]—Venus may have retained more water but left more of it buried in its less-distressed mantle.

Call me crazy. I've studied them my whole adult life and yet I've never seen them. Maybe I'm better off than a particle physicist who spends her life chasing some strange, charmed anti-gluon that turns out to not even have been a good idea. Or perhaps not much more pathetic than a geophysicist who focuses on Earth's core that nobody has ever seen except in a couple of Hollywood mistakes. But, at least indirectly, we know the core is there. It gives its lurking presence away, like a fetus in the womb, in the attenuation patterns of seismic waves, which allow us to see the core. We can sense its presence indirectly in the Earth's gravitational and magnetic fields.

I would argue that in a similarly indirect sense we can also sense the oceans of Venus. Only it's worse because they are long gone, like the scientists on all those tissue-sample TV shows, we are seeking forensic evidence that is mostly vanished from the scene (Fig. 2.2).

I have friends who study extinct creatures or disappeared civilizations, but they can go and dig up evidence without risking instant death in 900° superpressurized air. In fact we simply can't go look for ourselves[3] so we have to send machines, and we haven't been able to send very many, though not for lack of trying.

So we don't yet know, but in the meantime we've been able to gather some pretty strong circumstantial evidence. The data are still loose enough to allow for a contrarian "Venus was always dry" opinion, but most scientists who have looked at all the evidence and how it fits into what we've learned about the entire solar system believe that almost surely Venus started out as a watery, more Earthlike place—a planet with warm, liquid water oceans (Fig. 2.3).

What were they like? I see them alternately dappled with sunlight and dulled with thick cloud. When the sun does break through it is much closer than on Earth and therefore looks huge, twice as large as what we are used to. But it is also unnaturally pale as the young sun was markedly dimmer. When the clouds scatter, the full sun is 40 % less bright than what we see on Earth today.

That dim Sun[4] is the reason why young Venus, despite her proximity to our star, should have been able to host oceans for eons. Stars like ours start out cooler. As they age, they fuse Hydrogen into Helium, and they gradually brighten. At some point, and we don't yet know when, the warming sun crossed a threshold so that Venus could no longer hold her oceans. More sunlight heated the surface waters, causing evaporation, which fed water vapor into the air. Water vapor is itself a strong "greenhouse gas", so this caused young Venus to heat up further, which caused still more evaporation, and so on. Evaporation causes more greenhouse heating causes more evaporation. A positive feedback. Thus was initiated the runaway greenhouse.

[1]Or maybe several big hits that, when the plasma and dust cleared, cancelled out and left her spinning retrograde and slow.

[2]Was it? Give me 5 billion dollars and 10 years, then ask me again…

[3]For now.

[4]No not a typo for a Chinese brunch treat.

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Fig. 2.1 A primordial ocean washes across a battered crater rim, as volcanoes in the distance strive to dominate what will eventually become their realm. Any early seas on Venus would have eventually become acidic, boiling into a carbon dioxide sky. The continent of Ishtar Terra rises at left (Painting ©Michael Carroll)

Runaway here refers to the fact that such a feedback loop is unstoppable. Once it started, the fate of those oceans would have been sealed. But it also applies in its other sense, for those oceans did run away—left home for good. When in the form of an ocean, water is gathered tight to a planet and largely protected from solar radiation. But once it enters the air as steam it is vulnerable to the sun's ultraviolet, and the H_2O is split.

The hydrogen drifts off into space and the oxygen chases after it or stays behind to react with minerals, forming rusty rocks and leaving Venus an empty nest, permanently stripped of its potentially life-giving waters.

We don't know when this departure occurred, or how long it took, but we're pretty sure it did happen. Today Venus is drier than Arizona in June. Much. It is ridiculously parched. The tiny trace of water vapor left in the air is about 100,000 times less than the water found on Earth's surface. (although we don't know how much water is trapped inside Earth's interior and even less about any water trapped inside Venus…)

And we see convincing evidence of the watery exodus: like the shoes of refugees forced to leave in a hurry, we see the signs of a thorough evacuation of hydrogen which left behind a strong residue of deuterium—the more massive variant of hydrogen which has a harder time packing up and leaving. The huge build-up of this heavy hydrogen tells us that most of the water has escaped. Not when, or how much, just most.

The loss of water completed an irreversible and dramatic shift in climate. Do not let this happen to your planet! Rocky water worlds like Earth have a built-in thermostat that regulates climate over the long run, keeping it in the range of liquid water (which we carbon-in-water creatures pretty much demand as a minimum condition of residency). If it gets too cold then volcanic CO_2 builds up in the atmosphere, eventually warming the planet. If it gets too hot then the rate at which water dissolves CO_2 and "weathers" silicate rock into carbonate rock increases, drawing down the CO_2 content and cooling the planet. This mechanism has worked over the ages to keep Earth's climate more or less in line. It probably functioned on Early Venus as well. But once the last surface water was lost to the brightening sun, there was no efficient way to make carbonate rocks swiftly enough to counter the runaway warming. At this point the thermostat of Venus broke completely and the thermometer pegged in the red zone- where it has remained ever since (Fig. 2.4).

There are other reasons to believe in the lost seas. Aside from the hydrogenous evidence of mass escape there is our growing understanding of how the planets were made and what the planets were like near the beginning. Many lines of evidence conspire to suggest that Venus and Earth were formed much more alike and evolved in different directions. At times we have entertained theories suggesting that Venus and Earth formed very differently, that somehow materials in the planet-forming nebula segregated themselves and Earth ended up with 100,000 times as much water. But we now understand that planet formation was a violent and random process. The planets accreted in a gathering of material from small to large- from dust to pebbles to boulders and finally

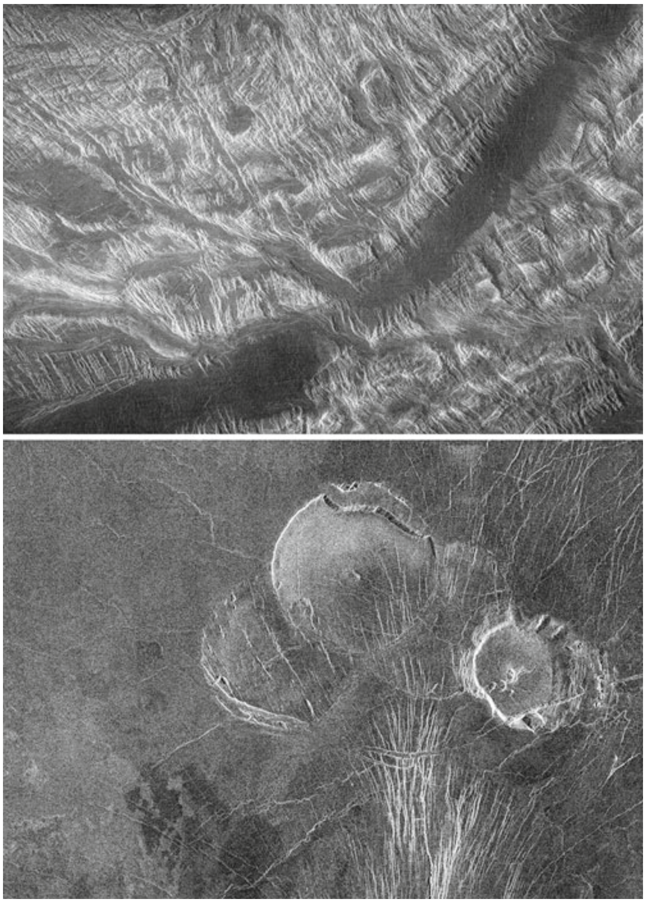

Fig. 2.2 The restless surface of Venus has obliterated geological records of ancient seas. (*top*) Tectonic faults and uplifted crust blanket Ovda Regio, whose surface may be only a few 100 millions years old geologically. (*below*) Volcanic mountains, lava flows, and associated fractures cover nearly 90 % of the Venusian surface (Magellan photos courtesy NASA/JPL)

1,000 mile planetesimals smashed together to make planets. As the planet chunks grew larger, so did the force of their gravitational attraction to each other. This made the final phases chaotic indeed. Collisions were fast and furious and the even more frequent near-misses flung near-planets into wild orbits, setting them up for further collisions or for getting tossed out to the nether regions of the solar system.

It was a hot mess; everything was smashed, melted, vaporized, steamed, churned and mixed together, over and over again. It seems likely that the materials that composed the inner planets were fairly well mixed. In order to somehow form Venus so much drier than Earth they would have to be extremely, absurdly, well unmixed.

You can even, if you'll indulge me, look at it in thermodynamic terms. Say what? I mean in terms of entropy- you know, the second law: it all runs downhill—no matter how many times you clean your room you'll have to do it again. Nature mixes things together. It doesn't randomly make dramatic differences between neighboring spaces- it erases them. So unless some tremendously efficient process dried Venus out completely then it must have started with more water, perhaps even an Earth's oceans worth of water- perhaps ten times this much.

We have also learned that water is common in the solar system (in the whole universe, actually). In most places it's not liquid but any reasonable source material for Earth would have been water-rich—some combination of rocky stuff with water chemically bound in hydrous minerals or icy interlopers from the outer solar system. We also see plenty of signs that Mars, our other neighbor, started out drenched in water, though he too had trouble holding it for different reasons. The planets started out wet, and they were drenched by the same scattershot rain of planet pieces.

So, yes, I don't think I'm delusional, but I do believe in the lost oceans of Venus. And believing is seeing. I see them filling the lowland basins on either side of the great continent-sized upland of Aphrodite Terra. This, I admit is complete fantasy as it doesn't seem likely that Venus has maintained her shape over the billions of years it might have been since she lost her oceanic look. Look at Earth- mountain ranges come and go, riding the slow currents of plate tectonics, moved by the churning heat engine of Earth's interior. In fact it seems quite possible that it is Earth's oceans that enable plate tectonics on Earth. Absent their lubricating effect on crustal motions and mantle flows, Earth's smooth interior engine might seize up. Some model results suggest that if you dry out Earth to Venusian extremes then instead of plate tectonics you get a more constipated type of behavior with bursts of tectonic and volcanic activity separated by 100s of millions of years of relative inactivity. But either way, it seems that Venus has to lose as much heat as Earth and thus, over the long term, probably moves around. We can tell approximately how old the Venusian surface is by counting the craters left from random asteroid and comet impacts. The surface averages less than 1 billion years. The older craters have been covered up by volcanic flows or broken up by Venus-quakes. So what are the chances that the same places where we find highlands and lowlands were the oceans and continents of a Venusian water-world? That depends on how recently Venus could have lost its water. For those of us studying the history of Venus and trying to place our lost oceans accurately in this chronology, the timescales are vexing. We have a pretty good story of how Venus went from ocean to steam, lost hydrogen to space and ended up permanently stuck in a horribly hot and dry condition. But whether the last trickle of water there flowed more than 3 billion years ago, or only a billion years, depends on factors that we still have trouble estimating, like how cloudy the early atmosphere was. We need more data, and better models, to know exactly when the oceans were lost (Fig. 2.5).

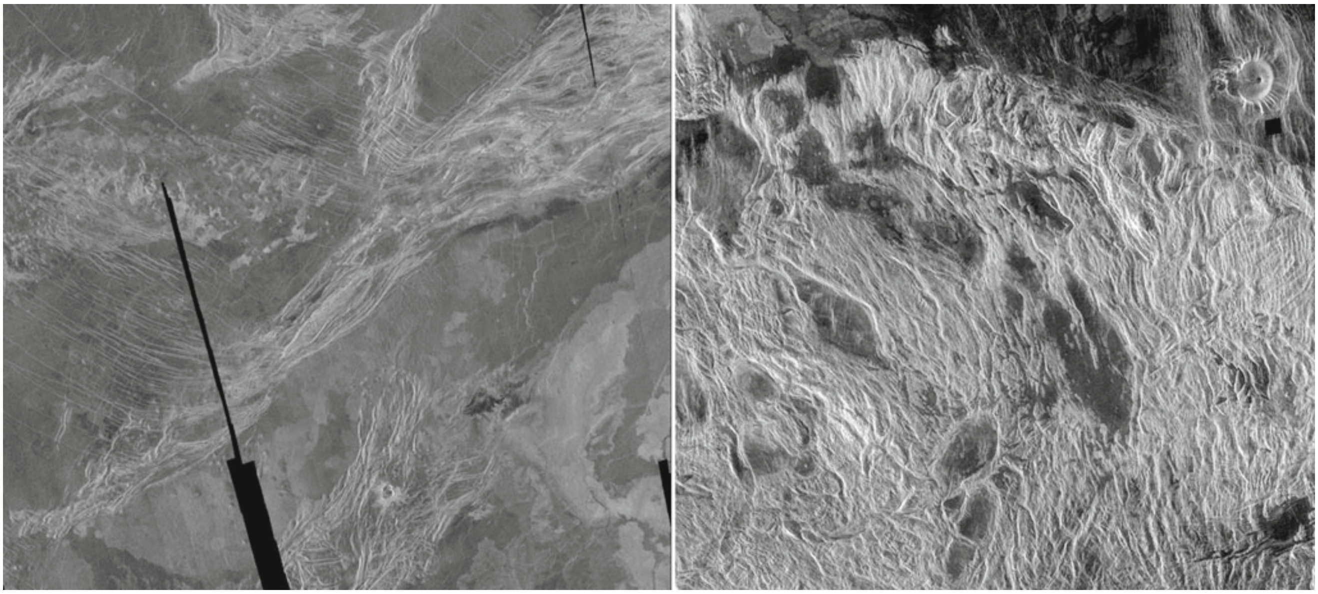

Fig. 2.3 Infrared studies of Venus' highland plateaus have detected the kind of heat signature often associated with granite. Granitic rock on Earth forms in the presence of plate tectonics and oceans. *Left*: Ridges and lava flows cut across Lavinia Regio. *Right*: The highland area Alpha Regio is 1,300 km across (Courtesy NASA/JPL/Magellan project)

Fig. 2.4 Some researchers suggest that Venus has always been a desert world. Today, Venus is thousands of times drier than the most parched regions of Earth (© Michael Carroll)

And, by the way, in my vision those seas are teeming with life?[5] No, seriously—why not? There is a lot we still don't know about the origin of life on Earth but it happened quickly once the remnants from planetary formation ended their deathly pummeling of the planets around 4 billion years ago. This suggests that it might have happened easily or inevitably on planets with the right conditions. Everything we suspect about what those right conditions probably also existed at the same time on Venus.

[5] Hey this is my dream. If you don't like it, start your own.

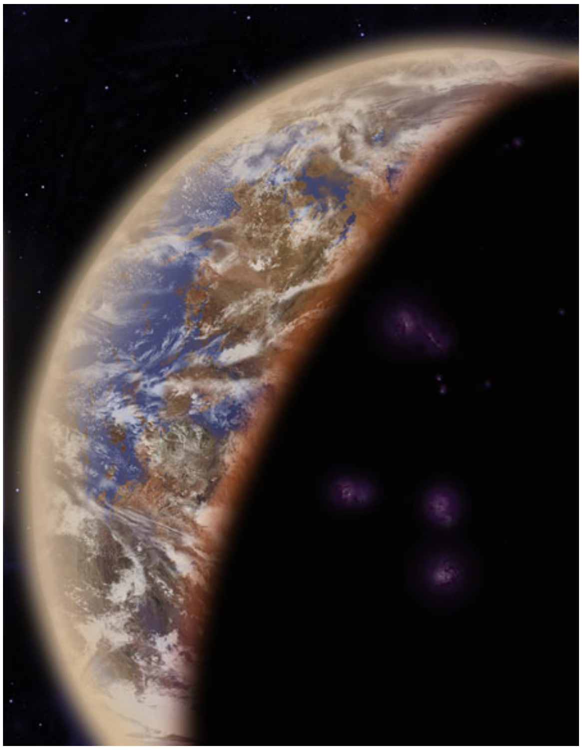

Fig. 2.5 Dying planet: The Venusian ocean is close to the boiling point, held to the surface by skyrocketing humidity. At the terminator near the center of the image, the land mass that will become Tellus Tesera looms out of the darkness. Stretching across the lower portion of the view sprawls the infant continent of Aphrodite Terra, with mountains twisting across Ovda Regio. Fierce lightning flickers across the night side (©Michael Carroll)

Oceans? Check.

Fresh rocky surface? Check.

Volcanic vents on the ocean floor? Lightning? Plenty of organic matter falling from space and forming on the surface? Check. Check. Check.

Earth's oceans were already brimming with primitive critters a couple 100 million years after the great bombardment slowed to an occasional fusillade, and nothing we know about Venus suggests it should have been significantly different.

And also consider this—rocks can get knocked between worlds in large impact events. This we know. We find meteorites from Mars in Antarctica. Such events happened with much greater frequency when the worlds were young. Venus, Earth and Mars were all flinging bits of themselves on each other. And we know that simple life forms like bacteria are very, very hard to kill off and would surely survive an interplanetary trip inside of rocks. So if life formed on any one of these worlds it could have naturally spread to any other, if it landed in a place where it could survive. The early oceans of Venus, Earth and Mars were not isolated and if any of them were populated, chances are they all were. Wait—we KNOW that one of them was populated, so… so, yes lets paint that early Venusian ocean teeming with bacteria and who knows what else.

What happened to that life after the surface dried up and heated up to the point where organic matter cannot be? Just maybe it moved to the sky. This is the opposite of what we suspect about Mars, where when the surface dried the life perhaps moved underground. Today in a sense the clouds are the oceans of Venus—a thick, globally encircling aqueous layer that covers the planet 30 miles up in the sky. Some of us have speculated that there may even be a niche for some kind of cloud-based life up there today. A long shot, perhaps, but remember that we still don't really have a scientific clue about the evolution of life elsewhere so it's important in astrobiology to remain open to exotic ideas.[6]

Perhaps life on Venus today is too much of a stretch. I don't know, but I think that while we explore the planet for all of the other good reasons—to understand how Earthlike planets work and test our climate models—we should at least look. And whether or not Venus is inhabited today, I think there is a very good case to make for creatures that once enjoyed the moonless nights there and swam endless days under that alien sky.

And what color was that sky? Nobody knows (heck we don't even know if the early Earth was a Titanian organic hazy orange, a steamy, cloudy white or a nice blue marble) so I'm going to go with blue, flecked with white. Today Venus is densely clouded- a bright pearl from the outside but a dull red on the surface. I'm betting that the permanently cloudy visage of Venus we see today is not new but not ancient either, that it arose with those same planetary transformations that doomed its once heaving, brackish ocean.

My first introduction to the idea of oceans of Venus came in the 5th grade when I read Isaac Asimov's juvenile sci-fi book *Lucky Starr and the Oceans of Venus*, which featured humans living in giant submarine domed cities which protected them from a global ocean populated with various exotic creatures, some menacing and some harmless (and some just enigmatic, like the telepathic frogs…) (Fig. 2.6).

At the time this was written in the 1950s, this was a scientifically reasonable view of Venus. Historically, the idea of oceans on Venus precedes the space age by centuries. In fact, before the time of spacecraft everyone "knew" Venus had oceans. Of course she did- she's the same size as Earth, a little bit closer to the sun, possessing a thick atmosphere and covered with clouds. It seemed reasonable to imagine her as a slightly warmer and more tropical Earth. After World War II, with the benefit of radar technology developed for the war, the first radio astronomy observations of Venus started

[6]Without, of course, keeping our minds so open that our brains fall out.

Fig. 2.6 Literature is rife with Venusian monsters on land and sea (©Michael Carroll)

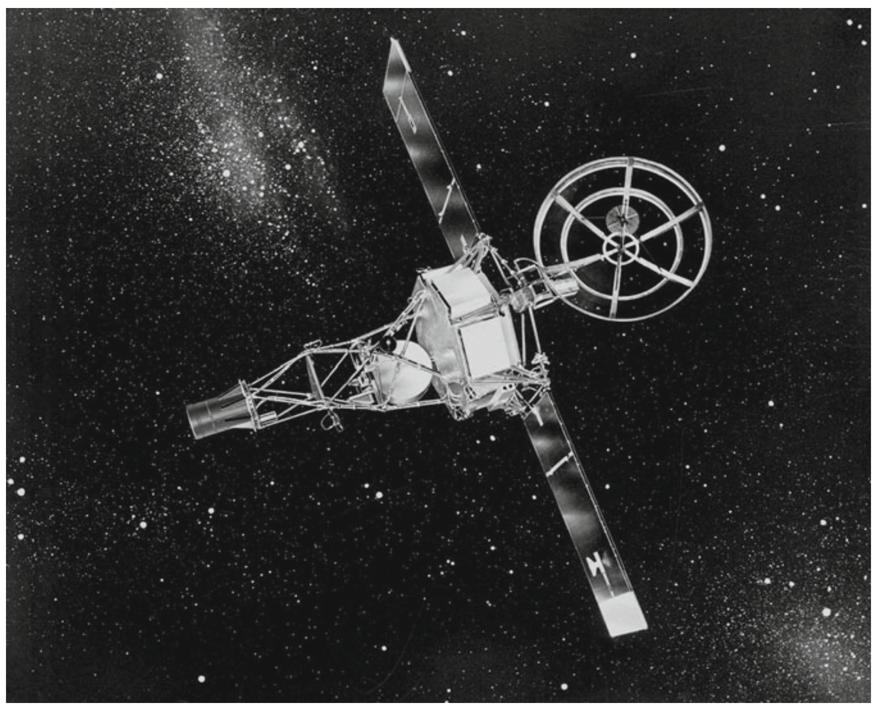

Fig. 2.7 Mariner 2, the first successful interplanetary craft, flew by Venus in 1962. To the left of the wing-like solar panels is the octagonal instrument box (the "bus"), and just to its left is the circular "microwave radiometer" which essentially took the temperature of the planet (Courtesy of NASA/JPL-Caltech)

dropping some hints that all might not be wet and warm in paradise. Speculation on the source of the "anomalous microwave radiation" included several possibilities, including that it might be revealing an extremely hot surface. The first ever successful spacecraft sent from Earth to another planet was Mariner 2 to Venus, launched in August 1962. The most important experiment on Mariner 2 was a "microwave radiometer" designed to find the source of the strange radiation. In the first scientific result ever achieved by interplanetary spacecraft exploration, Mariner 2 showed that the signal was indeed coming from a surface far too hot to support liquid water. We learned then that Venus on the surface is not at all like Earth, that it is absurdly hot and dry (Fig. 2.7).

We've come a long way in the first 50 years of space exploration, but the dramatic questions posed by Mariner 2's first exploration, "How did these 'twins' become so different from one another?" and "What happened to the lost oceans of Venus?" still remain with us.

And as we learn more about the vulnerability of our own planet to climate change, we will have all the more reason to test our knowledge and abilities on a nearby sister world where familiar climate processes have produced a completely alien environment. As we embark on an era of discovering planets that are more and more earthlike in various ways, and as we attempt to reconstruct their stories-the need to more fully understand the planet next door will make this next stage of exploration unavoidable and inevitable. We will soon return to Venus, with orbiters, balloons, probes and landers, and we'll finally solve the mystery of the lost ocean.

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