



Life on Venus and the interplanetary transfer of biota from Earth

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Abstract Evidence and observations favoring the hypothesis that Venus is habitable, and the celestial mechanisms promoting the interplanetary transfer of life, are reviewed. Venus may have been contaminated with Earthly life early in its history via interplanetary transfer of microbe-laden bolide ejecta; and this seeding with life may have continued into the present via spacecraft and due to radiation pressure and galactic winds blowing microbial-laden dust ejected from the stratosphere via powerful solar winds, into the orbit and atmosphere of Venus. Venus may have had oceans and rivers early in its history until 750 mya, and, hypothetically, some of those species which, theoretically colonized the planet during that time, may have adapted and evolved when those oceans evaporated and temperatures rose. Venus may be inhabited by a variety of extremophiles which could flourish within the lower cloud layers, whereas others may dwell 10 m below the surface where temperature may be as low as 200 °C—which is within the tolerance level of some hyperthermophiles. Speculation as to the identity of mushroom-shaped specimens photographed on the surface of Venus by the Russian probe, Venera 13 support these hypotheses.

Keywords Venus · Extremophiles · Thermophiles · Atmosphere · Subsurface · Microorganisms · Solar winds · Radiation pressure · Galactic winds · Stratosphere · Fungi · Biotransfer · Lithopanspermia · Interplanetary transfer of life

1 Overview: hypothesis, observations, evidence

Observations and evidence for the possibility of life on the subsurface and clouds of Venus, and celestial mechanics promoting the transfer of life from Earth, are reviewed, and images of specimens resembling fungal mushroom-shaped organisms photographed by the Russian Space Probe Venera 13, on the surface of Venus are presented (Figs. 1–5) with the caveat that similarities in morphology are not proof of life.

A number of scientists have hypothesized that Earth may be seeding this solar system, including Venus, Mars, and the Moons of Jupiter and Saturn, with microbes buried within ejecta following impact by comets and meteors (Cockell 1999; Gladman et al. 1996; Melosh 2003; Mileikowsky et al. 2000a,b; Gao et al. 2014; Schulze-Makuch et al. 2004), and via microbes attached to space craft (Joseph 2018). Extremophiles attached to dust particles which are lofted into Earth's upper atmosphere and via powerful solar winds blown into space (Joseph and Schild 2010) may also be transported by radiation pressure and galactic winds into the atmosphere of Venus (Arrhenius 1908, 1918). Atmospheric contamination by Earthly life would account for data indicating microbes may be dwelling within and attached to particles in the lower cloud layers of Venus (Bullock 2018; Limaye et al. 2018; Grinspoon and Bullock 2007).

In support of the solar-galactic-wind microbe-laden-dust hypothesis is evidence of an interplanetary (Misconi and Weinberg 1978) circumsolar ring of dust (Krasnopolsky and Krysko 1979) which appears to follow (Leinert and Moster 2007) and to have possibly originated external to the orbit of Venus (Altobelli et al. 2003; Jones et al. 2013; Leinert and Moster 2007; Russell and Vaisberg 1983) and which

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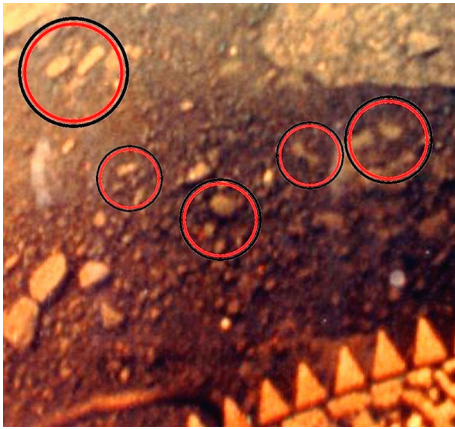


Fig. 1 Venera-13. Venus: Fungi-Mushroom-Lichen-shaped specimens. It must be stressed that morphology alone is not proof of life



Fig. 2 Venera-13. Venus: Fungi-Mushroom-lichen-shaped specimens

penetrates the planet's atmosphere (Carrillo-Sánchez et al. 2020). As to dust originating from Earth, it is probable that microbes may be adhering to some of these particles (Arrhenius 1908, 1918).

Cockell (1999) contends that atmospheric conditions at higher altitudes would freeze, but not necessarily kill microorganisms. As these organisms fall toward the surface they would encounter environments between the middle and lower cloud layers that are conducive to biological activity (Limaye et al. 2018). Moreover, the turbulence experienced may enhance the viability of some species (Gibson 2000; Gibson and Thomas 1995) including plankton which have been hypothesized to be dwelling in the clouds of Venus (Korolovskiy 2009; Schulze-Makuch et al. 2004).

The Venusian subsurface may also provide a livable habitat for photoautotrophic, lithobiontic, poikilohydric, and fungal hyperthermophiles which have evolved and adapted to these conditions. For example, temperatures at 10 m below the surface may range from 305 °C to 200 °C—which is within the tolerance level of some thermophiles (Baross and Deming 1983; Kato and Qureshi 1999). It is well estab-

Fig. 3 Venera-13. Venus: Fungi-Mushroom-lichen-shaped specimens. (Enlarged from Figs. 1, 2)



lished that extremophiles are “capable of living in extreme environments such as highly acidic or alkaline conditions, at high salt concentration, with no oxygen, extreme temperatures (as low as -20 °C and as high as 300 °C), at high concentrations of heavy metals and in high pressure environments” (Kato and Takai 2000).

Organisms deep beneath the surface may also have access to moisture drawn from subterranean sources before completely evaporating. In support of this hypothesis, when the Russian probe Venera 13 landed on Venus and in so doing blew away surrounding top soil, specimens resembling fungi were later photographed by Venera, as reported here (Figs. 1, 2, 3, 4, 5).

2 Terrestrial analogs: life in the clouds

Over 1800 different types of bacteria and other species thrive and flourish within the troposphere, the first layer of the Earth's atmosphere (Brodie et al. 2007). These denizens of the air include fungi and fungal spores, lichens, algae, protozoa, diatoms, plants, pollen, seeds, and invertebrates including insects, spiders, mites, and nematodes (Adhikari et al. 2006; Diehl 2013; Fröhlich-Nowoisky et al. 2009; Griffin 2004; Polymenakou 2012); many of which become

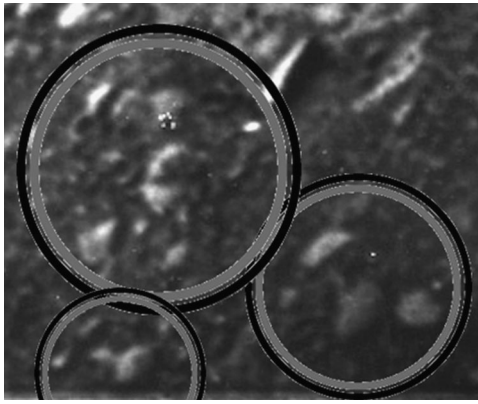


Fig. 4 Venera-13. Venus: Fungi-Mushroom-lichen-shaped specimens

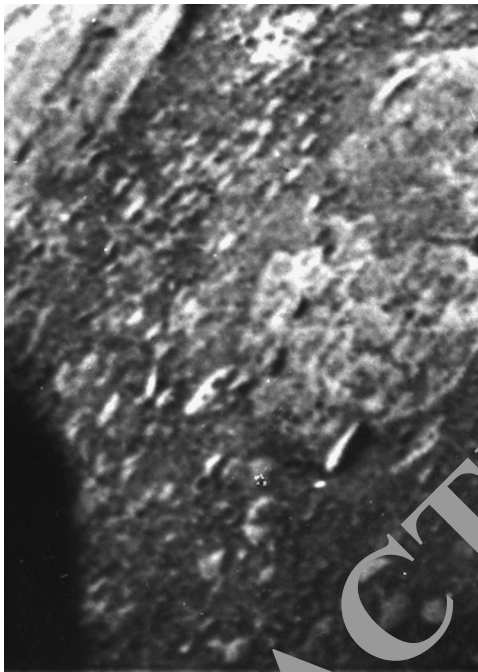


Fig. 5 Venera-13. Venus: Fungi-Mushroom-lichen-shaped specimens. (Enlarged from Figs. 2, 4)

attached to dust and other particles (Möhler et al. 2007; Sattler et al. 2001).

Due to tropical storms, monsoons, and seasonal upwellings in columns of air (Dehel et al. 2008; Deleon-Rodriguez et al. 2013; Randel et al. 1998, 2010), microbes, spores, fungi, along with dust, dirt, water, methane, and other gases may be transported to the stratosphere (Griffin 2004; Imshenetsky et al. 1978). Many organisms eventually fall back to the surface where they may negatively impact (Griffin et al. 2007; Polymenakou 2012) or promote the growth and metabolic activity of other species (Jones et al. 2008).

Microorganisms and spores have been recovered at heights of 40 km (Soffen 1965), 61 km (Wainwright et al.

2010) and up to 77-km (Imshenetsky et al. 1978). These include *Mycobacterium* and *Micrococcus*, and fungi *Penicillium notatum*, *Circinella muscae*, and *Aspergillus niger*, 77-km above Earth's surface (Imshenetsky et al. 1978). These atmospheric fungi and microorganisms play a major role in organic compound degradation and the alteration and chemical composition of the atmosphere (Amato et al. 2007a,b; Ariya et al. 2002; Côté et al. 2008).

Clouds and wind are an effective transport mechanism for the dispersal of bacteria, virus particles, algae, protozoa, lichens, and fungi including those dwelling in soil and water and which may be transported by air thousands of miles across land and oceans (Prospero et al. 2003; Polymenakou 2012) or lofted into the stratosphere (Griffin 2004; Imshenetsky et al. 1978) where they may continue to thrive.

3 Atmospheric transfer of biota from Earth

How often or how much of this atmospheric biota is lofted into space, is unknown. However, under extreme conditions, and if solar winds strike with sufficient force, then water molecules, surface dust (Schroder and Smith 2008), along with air-borne bacteria, spores, fungi, lichens, algae, and other microbes may be ejected into space (Joseph and Schild 2000), where, as demonstrated experimentally, this biota may easily survive (Novikova et al. 2016; Setlow 2006; Horneck et al. 1994, 2002; Nicholson et al. 2000; Onofri et al. 2012; McLean and McLean 2010; Kawaguchi et al. 2013).

For example, between September 22–25, 1998, NASA's Ultraviolet Imager aboard the Polar spacecraft, detected and measured a series of coronal mass ejections and a powerful solar wind which created a shock wave that struck the magnetosphere with sufficient force to cause helium, hydrogen, oxygen, and other gases to gush from Earth's upper atmosphere into space (Moore and Horwitz 1998). When the CME struck on Sept. 24, the pressure jumped to 10 nanopascals, whereas normally the pressure is around 2 or 3 nanopascals. Thus it could be predicted that airborne microbes attached to dust particles were also swept from the stratosphere into space; and those survivors which were eventually deposited in the atmosphere and clouds of Venus may have begun to flourish and multiply.

As determined by Leinert and Moster (2007) interplanetary dust accumulates outside the orbit of Venus, and the dust ring is similar to that found along Earth's orbit. Krasnopolsky and Krysko (1979) based on data from the Venera 9 and 10 orbiters, observed a dust layer at heights of 100–700 km above the surface of Venus, and which had a ring formation. According to the data provided by Carrillo-Sánchez et al. (2020) these interplanetary dust particles are mass contributors to the atmosphere of Venus.

The Ulysses space probe was equipped with dust detectors and reported 374 impacts, beginning within the orbit

of Venus at 0.7 AU (Grün et al. 1992). At 2 AU Ulysses detected fluxes in the dust density “compatible with a population of interplanetary dust particles moving on low to moderately eccentric ($e = 0.1$ to 0.5) and low inclination ($i = 0$ deg to 30 deg) orbits” thereby indicating at least two dust particle populations in different orbital trajectories (Grün et al. 1992). It is not likely that those dust particles, with a radii smaller than 0.3 mm, detected between and within the orbits of Venus and Mars, originated from the outer solar system beyond Mars (Altobelli et al. 2005; Landgraf et al. 2000). Competition between gravitation and radiation pressure determines how deep dust can penetrate such that the smallest are believed to be filtered by radiation pressure before entering the inner solar system (Altobelli et al. 2005). Therefore, the smallest dust particles following or ringing Venus (Leinert and Moster 2007; Krasnopolsky and Krysko 1979), most likely originated within the orbits of Mars, Earth and Venus.

As determined by Leinert and Moster (2007) these inner planetary dust particles range in size from 0.1 mm to 0.001 mm. Most bacteria range from 0.002 to 0.0002 mm in diameter (Evans 2016), whereas fungal spores (e.g. *Penicillium*, *Cladosporium*, *Aspergillus*) range from 0.016 to 0.0036 in diameter (Reponen et al. 2001). And microbes in Earth’s upper atmosphere are often attached to particles of dust (Möhler et al. 2007; Sattler et al. 2001) which may range in size from 0.077 to 0.002 mm (Arimoto et al. 1997; Beltzer et al. 1988; Maring et al. 2000; Tegen and Lacis 2012).

Galactic winds and radiation pressure can propel dust particles at speeds ranging from 300 and $3,000$ km/sec (Chandrasekhar 1989; Heckman and Thompson 2017; Ishibashi and Fabian 2015; Murray et al. 2011; Working et al. 2018). According to the calculations of Nobel laureate (Arrhenius 1908, 1918) if microbes ranging in size from 0.002 – 0.0002 mm in diameter are attached to particles ranging from 0.02 – 0.002 mm in diameter, or if fungal spores ranging in size from 0.0036 to 0.0016 mm are attached to particles ranging from 0.0036 – 0.0016 mm in diameter, and “if we assume that the spore starts with zero velocity” and originate from Earth, then due to the sun’s gravity, galactic winds and radiation pressure, it would take “forty days” to travel from Earth to Venus and would then fall into the atmosphere of Venus with a velocity of approximately two kilometers per second.

As organisms which may survive the descent to the surface of Venus—especially during the planet’s early history—they may have also remained viable and may have evolved over time (Cockell 1999; Schulze-Makuch et al. 2004). In this regard, and as reported here, there are mushroom-shaped specimens on the surface of Venus; the source of which may be the lower clouds (Limaye et al. 2018) which in turn may have been seeded from microbe-laden interplanetary dust (Arrhenius 1908, 1918; Joseph and

Schild 2010), bolide particles originating on Earth (Cockell 1999; Gladman et al. 1996; Grinspoon and Bullock 2007; Melosh 1988; Schulze-Makuch et al. 2004) or contamination by space craft (Joseph 2018). However, due to the poor quality of the Venera 13 photos, it is unknown if these are in fact Venusian fungi or mushroom-shaped anomalies. One can only hypothesize and speculate.

In support of the spacecraft-Earth-to-Venus-transfer-of-life scenario is evidence that viable fungi and bacteria not only survived heat-treatment sterilization of spacecraft (Lévesque et al. 2014; Venkateswaran et al. 2012; Puleo et al. 1977) but may have survived the journey from Earth to Mars, as successive photos taken months apart depict what appears to be masses of fungal-bacterial organisms growing on the NASA’s Mars rovers’ Curiosity and Opportunity (Joseph 2018; Joseph et al. 2019). There is also evidence (but no proof) that fungi, lichens, algae and microbes may have, at different times in our planet’s history, colonized the surface of Mars (De Vera 2017; Joseph 2014, 2016; Joseph et al. 2019; Krupa 2017; Levin and Straat 2016; Noffke 2015; Rabb 2018; Rizov and Cantasano 2009, 2016; Roffman 2019; Rüger and Farmer 2016; Small 2015). These putative Martian organisms include mushroom- and lichen-shaped specimens similar to those reported here (Figs. 1–4). In fact, the Martian specimens resembling “puff balls” emerged from beneath the surface and dramatically increased in size over a period of three days (Joseph et al. 2019); observations which may indicate the rovers are stimulating the growth of these specimens, or they are the source. Hence, probes from Earth may have also transported innumerable microbes to Venus.

Similarities in morphology are not proof of life, and there is no definitive proof of life on Mars or Venus. Moreover, several scientists have taken issue with the findings of Joseph et al. (2019) and questioned if fungi and lichens could flourish on the Red Planet (Armstrong 2019a,b; Kidron 2019). On the other hand, simulation studies have shown that these and other species can survive in a Mars-like environment (De Vera et al. 2014, 2019; De la Torre Noetzel et al. 2017; Onofri et al. 2012, 2019; Pacelli et al. 2016; Sanchez et al. 2012; Schuerger et al. 2017; Selbman et al. 2015; Zakharova et al. 2014).

Life-simulation studies conducted with Venus-like environments also supports the possibility of life (Seckbach et al. 1970). Moreover, many scientists have argued that a variety of terrestrial life forms could survive on or below the surface and especially within the cloud layers (Cockell 1999; Grinspoon and Bullock 2007; Ksanfomality 2013; Limaye et al. 2018; Schulze-Makuch et al. 2004). Thus there is reason to suspect that biota already adapted to life in the clouds of Earth, and which survived a journey to Venus, may flourish and multiply.

4 Transfer of life by spacecraft

Several space craft and balloons have passed through the atmosphere and crashed or landed on Venus (Marov et al. 1998). Since all attempts to completely sterilize space craft have failed (La Duc et al. 2014; Venkateswaran et al. 2012; Puleo et al. 1977), these vehicles were likely transporting billions of microorganisms to Venus—beginning with the Venera 3 Soviet probe on March 1, 1966, followed by the Venera 5 and 6 in May of 1969 and Venera 7 (12/15/70), Venera 8 (7/22/1972), Venera 9 (10/22/1975), and two Pioneer Space craft in 1978, as well as probes from the European Space Agency and Japan (Marov et al. 1998).

As based on published studies on survival following heat treatment sterilization of spacecraft and equipment, at a minimum, billions of organisms, or their spores, per spacecraft, were likely transported to Venus (as well as Mars). For example, immediately after sterilization, 350 to 500 distinct colonies (on average) consisting of millions of organisms, including fungi, were found per square meter on the outer surfaces of the Viking Landers, rovers, and other spacecraft (La Duc et al. 2014; Venkateswaran et al. 2012; Puleo et al. 1977). As to species which were not or could not be cultured, and those masses of fungi and bacteria growing within the equipment's interior, the number of survivors is unknown. Many of the survivors of these failed attempts at sterilization, including fungi, can also survive long duration exposure to space (Novikova et al. 2016; Setlow 2006; Horneck et al. 1994, 2002; Nicholson et al. 2000; Onofri et al. 2012; McLean and McLean 2010; Kawaguchi et al. 2011), well in excess of the four months it takes a spacecraft to reach Venus (Marov et al. 1998). Moreover, after clean room sterilization, and prior to launch, these crafts and much of this equipment was then exposed to the biota-laden external environment.

Following the explosion of the space shuttle Columbia, during its reentry from space and subsequent crash in 2003, viable organisms, including the nematode, *Caenorhabditis elegans* (Szewczyk et al. 2005) and *Microbispora sp* (McLean et al. 2007) survived. Likewise, it can be predicted that spaceships crashing on Venus (or Mars) would still be laden with viable microorganisms.

5 Bolide ejection and spores: transfer of life from Earth to Venus

Microbe-laden debris ejected into space following terrestrial impact by asteroids, comets, and meteors, may have repeatedly transferred life from Earth to Venus, Mars and the moons of Saturn and Jupiter. Likewise, life-bearing debris from other worlds, in the form of dust, meteors, asteroids or comets, including those originating from outside this solar

system, may have delivered and may continue to transport viable microorganisms to Earth and other planets and their moons (Arrhenius 1908; Joseph and Schild 2010; Wickramasinghe et al. 2018). In addition to meteors, ejecta in the form of comets may be playing a significant role in the wider context of the interstellar transport of life (Hoyle and Wickramasinghe 1978; Joseph and Wickramasinghe 2010; Wickramasinghe et al. 2018).

Many species of microbe have evolved the ability to survive a violent hypervelocity impact, shock pressures of 100 GPa, and extreme acceleration and ejection into space including the vacuum and frigid temperatures of an interstellar environment; the cosmic rays, gamma rays, UV rays, and ionizing radiation they would encounter; and the descent through the atmosphere and the crash landing onto the surface of a planet (Burchell et al. 2004; Horneck et al. 2001a, 2001b; Horneck et al. 1994; Masopust et al. 2001; Nicholson et al. 2000, 2012; Mitchell and Ellis 1971).

It is reasonable to assume that Venus and Mars, beginning in the early asteroid-comet-meteor bombardment phase 3.8 bya (Cocke 1999; Gladman et al. 1996) may have been repeatedly and continually seeded with life from Earth, attached to meteor ejecta, and more recently, via space craft. In the early history of Mars, Earth and Venus, these planets may have repeatedly exchanged life—the ultimate source of which is as yet unknown.

When a meteor, asteroid, or comet, strikes this planet, the surface area of ejecta may be heated to temperatures in excess of 100 °C upon impact (Artemieva and Ivanov 2004; Fritz et al. 2005), which is well within the tolerance range of thermophiles (Baross and Deming 1983; Kato and Qureshi 1999; Stetter 2006). Moreover, because the ejecta-surface is acting as a heat shield, the interior may never be heated above 100 °C (Burchell et al. 2004; Horneck et al. 2002). Spores can survive post shock temperatures of over 250 °C (Horneck et al. 2002). Thus, innumerable microbes may remain viable despite violent impact-induced ejection into space.

Meteors at least ten kilometers across will also punch a hole in the atmosphere before striking the planet (Van Den Bergh 1989) and will eject tons of dust, rocks, and boulders (Beech et al. 2018; Gladman et al. 1996; Melosh 2003) through that hole into space (Van Den Bergh 1989), along with any adhering microbes, fungi, algae, and lichens (Gladman et al. 1996; Melosh 2003; Mileikowsky et al. 2000a,b) before air can rush back in to completely fill the gap (Van Den Bergh 1989). Thus, following the initial impact, ejected debris and adhering organisms would not be subject to extreme heating as they pass through the atmosphere. There are currently 200 known terrestrial impact craters (Earth Impact Database 2019), and this planet may have been struck thousands of times (Melosh 1989), resulting in the ejection of millions of rocks, boulders and tons of debris into

space (Beech et al. 2018; Gladman et al. 1996; Melosh 1989, 2003; Van Den Bergh 1989). Many scientists have argued that some of this debris and any adhering microbes likely landed on Mars and Venus (Beech et al. 2018; Gladman et al. 1996; Melosh 2003; Davies 2007; Fajardo-Cavazos et al. 2007; Hara et al. 2010; Schulze-Makuch et al. 2005). Given that microbes can survive the shock of a violent impact and hyper velocity launch ejecting them into space (Mastrapaa et al. 2001; Burchell et al. 2001, 2004; Nicholson et al. 2000, 2012; Hazael et al. 2017; Horneck et al. 2008), as well as the descent to the surface of a planet (Burchell et al. 2001; Horneck et al. 2002; McLean and McLean 2010), the interplanetary transfer of viable microorganisms, via bolides, within our Solar System, is overwhelmingly likely (Mileikowsky et al. 2000a,b; Beech et al. 2018), beginning, possibly, soon after life appeared on Earth over 3.8 bya. Over the course of the last 550 million years there have been a total of 97 major impacts, leaving craters at least 5 kilometers across (Earth Impact Database 2019), and it's been estimated that in consequence, approximately "10¹³ kg of potentially life-bearing matter has been ejected from Earth's surface into the inner solar system" (Beech et al. 2018) during this time frame. Consider, for example, the Chicxulub crater, formed approximately 66 Mya, which has a 150 km diameter (Alvarez et al. 1980). It's been estimated, given an 25 km/s impactor velocity, that up to 5.5 × 10¹² kg of debris may have been ejected into space (Beech et al. 2018), along with unknown volumes of water, and perhaps millions of trillions of organisms buried within this ejecta. According to calculations by Beech et al. (2018), given an impact velocity greater than 23 km/s, this microbial-laden ejecta could have entered the orbits of and intercepted Venus, Mars and other planets and moons within a few weeks or months.

Studies have demonstrated that bolide ejecta provides nutrients that can sustain trillions of microorganisms, including algae and fungi, perhaps for thousands of years Mautner (1997, 2002). However, ejecta may orbit in space for millions of years before impacting another planet (Gladman et al. 1996; Melosh 2003). Microbes and fungi, however, are well adapted to survive life in space for even tens of millions of years; accomplished via the formation of spores. Cano and Borucki (1997) have reported that spores, embedded in amber may remain viable for 25- to 40-million-years, whereas Vreeland et al. (2000) have reanimated 250 million-year-old halotolerant bacterium from a primary salt crystal.

Specifically in the absence of water, nutrients, or under extreme life-neutralizing conditions, microbes and fungi may instantly react by forming a highly mineralized enclosure consisting of heat or cold shock proteins which wrap around their DNA and which alters the chemical and enzymatic reactivity of its genome making it nearly impermeable to harm (Setlow and Setlow 1995; Marquis and Shin 2006; Sunde et al. 2009). "In the dormant stage a spore

has no metabolism and resists cycles of extreme heat and cold, extreme desiccation including vacuum, UV and ionizing radiation, oxidizing agents and corrosive chemicals" (Nicholson et al. 2000). Space experiments and the Long Duration Exposure Facility Mission have shown that bacteria and fungal spores can easily survive the vacuum of space and constant exposure to solar, UV, and cosmic radiation with just minimal protection (Horneck 1993; Horneck et al. 1995; Mitchell and Ellis 1971). Moreover, survival rates increase significantly from 30% to 70% if coated with dust, or embedded in salt or sugar crystals (Horneck et al. 1994). Spores buried beneath the surface of ejecta could easily survive in space for millions of years. Although the full spectrum of UV rays are deadly against spores, a direct hit is unlikely, even if unprotected while traveling through space. A few meters of surface material provides a significant degree of protection for those buried deep inside (Horneck et al. 2002). Although high-energy radiation or particles which strike a meteorite on Earth may create secondary radiation, studies have shown that as the thickness of surrounding material increases beyond 30 cm, the dose rate and lethal effects of heavy ions, including secondary radiation, depreciates significantly (Horneck et al. 2002).

It's been estimated that because microbes and spores are so small that even when bombarded with photons and deadly gamma and UV radiation, they can drift in space for up to a million years before being struck (Horneck et al. 2002). If shielded by 2 meters of meteorite, even after 25 million years in space, a substantial number of spores would survive (Horneck et al. 2002). *B. subtilis* spores can even survive a direct hit (Horneck et al. 2002).

Further, many species form colonies with those in the outer layers creating a protective crust, which blocks out radiation and protects those in the inner layers from the hazards of space (Nicholson et al. 2000). Therefore, even if dwelling just beneath the surface of ejecta, colonies of living microbes provide their own protection.

Of the 60,556 meteorites so far documented, 227 originated on Mars, and 360 are from the Moon (Meteoritical Bulletin Database 2019). Meteors from Venus have not yet been identified. However, given the estimated 1000 impact craters detected by the Magellan spacecraft (Schaber et al. 1992) clearly Venus has been repeatedly impacted by meteors which survived descent through the atmosphere without vaporization.

It can be predicted, depending on size, that the surface of ejecta from Earth, would be subject to extremely high temperatures for only a few seconds upon striking the atmosphere of Venus. And if the bolide fragments or explodes, it could be predicted that it may shed spores into the Venusian cloud layers. A variety of organisms remain viable even following atmospheric explosions (Szewczyk et al. 2005), and despite reentry speeds of up 9700 km h⁻¹ (McLean

et al. 2006), and high velocity impact onto a planet's surface (Burchell et al. 2001; Horneck et al. 2002; McLean and McLean 2010). Therefore, microbial-infested bolides from Earth could have repeatedly contaminated Venus throughout its history. And those survivors which could adapt, would likely go forth, multiply, and then evolve.

6 Can life survive on Venus? Terrestrial analogs

It has been argued that a variety of terrestrial organisms could tolerate the high temperatures and dwell in the atmosphere of Venus (Clarke et al. 2013; Cockell 1999; Grinspoon and Bullock 2007; Konesky 2009). These include thermophilic phototrophs (Arrhenius 1918; Cockell 1999), algae (Seckbach and Libby 1970) and acidophilic microbes (Schulze-Makuch et al. 2004). Sagan and Morowitz (1967) have hypothesized that even complex multi-cellular organisms swim between the thick layers of clouds.

Venus, at ground level has a temperature of 465 °C (Avduevsky et al. 1971), with a surface atmospheric pressure of 9.5 MPa (Bougher et al. 1997; Donahue and Russell 1997). Although there are trace amount of H₂O and water vapors, the atmosphere is 96.5% CO₂, 3.5% nitrogen, and subject to a high sulfur cycle due to active volcanism (Donahue and Hodges 1992; Barstow et al. 2012).

Several terrestrial species, such as algae and *Cyanidium caldarium* can survive environments which are 100% CO₂ (Seckbach and Libby 1970; Seckbach et al. 1970). *Chlorella* will continue to grow at 0.6 atm and can survive CO₂ at 1 atm, (Pirt and Pirt 1980). The biological activity of some species of fungi and archaea is inhibited by the presence of oxygen and increases with increased levels of carbon dioxide (Lenhart et al. 2012). Therefore, the high levels of CO₂ in the atmosphere of Venus would not preclude colonization by a variety of microorganisms and fungi.

Numerous species of prokaryotes and eukaryotes easily survive pressures of 3.5 MPa at a depth of 950 m beneath the sea, including elephant seals and sperm whales; whereas microbes such as obligate barophiles and *Shewanella* and *Moritella* (Deming et al. 1992; Kato 1999; Kato et al. 1998a,b, 2010; Robb et al. 2007) flourish within the Mariana trench at a depth of 10,898 m (108 Mpa).

Terrestrial microbes and communities of hyperthermophiles have also been discovered up to 3.5 km below ground (Biddle et al. 2008; Chivian et al. 2008; Doerfert 2009; Moser et al. 2005; Gohn et al. 2008). *Bacillus infernus*, have been discovered thriving at depths of 2700 meters where the weight and pressure is 300 x that of the surface (Boone et al. 1995). Genomic analysis of the bacterium, *Desulforudis audaxviator*—discovered 2.8 km beneath the surface—indicates this species metabolizes minerals in place of sunlight and “is capable of an independent

life-style well suited to long-term isolation from the photosphere deep within Earth's crust” (Chivian et al. 2008). Species similar to these may also thrive at great depths or just beneath the surface of Venus, despite the high temperatures.

Some species of hyperthermophiles continue to grow at a temperature of 122 °C (Robb et al. 2007), and have been discovered thriving adjacent to 400 °C thermal vents (Stetter 2006)—the most resilient of which include *Pyrococcus furiosus* (Baross and Deming 1983) and *Methanopyrus kandleri* (Kurr et al. 1991). However, there are no known terrestrial species which can survive direct exposure to temperatures above 300 °C (Kato and Qureshi 1999; Kato and Takai 2000).

Based on data from Earth, unless any hypothetical Venusian organisms have evolved heat-related adaptive features enabling them to survive surface temperatures of 465 °C, then the most likely habitats are the clouds or beneath the ground where subsurface temperatures may be significantly cooler—as is the case on Earth (Davis and Schubert 1981; Smerdon et al. 2004; Temeemi and Harris 2001).

7 Venusian water vapors and habitability

In addition to atmospheric water vapors (Donahue and Hodges 1992; Barstow et al. 2012)—which could sustain life dwelling in the clouds of Venus—the atmosphere contains high levels of deuterium with a deuterium-to-hydrogen ratio which is approximately 150 times that of terrestrial water (Donahue and Russell 1997). The D/H ratio indicates that Venus at one time had rivers and shallow oceans (Donahue et al. 1997), thereby making early Venus habitable (Way et al. 2016; Way and Del Genio 2019). What became of this water is unknown.

The D/H ratio leaves open the possibility there are tremendous reservoirs of water buried deep beneath the surface, and which, like terrestrial underground water under high temperature, arid surface conditions (Al-Sanad and Ismael 1992), may seep upward only to evaporate. Hence, subsurface water evaporation may account for the trace amounts of cloud-water and contribute to the D/H ratio.

Therefore, Venus may have had lakes and oceans for billions of years—making it more conducive to life (Kasting 1988; Colin and Kasting 1992; Donahue and Russell 1997; Way et al. 2016; Way and Del Genio 2019)—which then may have slowly evaporated over the following years, the remainder possibly remaining deep beneath the soil. Hence, early in its history Venus could have become home to Earthly archae, bacteria, and fungi which may have evolved, or migrated to the clouds or beneath the soil. As summed up by Cockell (1999), the possible “existence of hot surface oceans on Venus may have favored the successful evolution or transfer of early life.”

On the surface of Venus there is no evidence of water vapor. Given that sea water will completely evaporate at 420 °C it is not likely there is any surface water. The only source of moisture would be deep beneath the surface or within the clouds. Any species which colonized the surface of Venus early in its history, and in order to survive under present day conditions, would have had to evolve as temperatures rose and surface water was lost (Schulze-Makuch et al. 2004); or they would have had to migrate to the clouds or beneath the surface.

However, even present day organisms transferred from Earth may remain viable. Cockell (1999) has argued: “Neither the pressure (9.5 MPa) nor the high carbon dioxide concentrations (97%) represent a critical constraint to the evolution of life on the surface or in the atmosphere. The most significant constraints to life on the surface are the lack of liquid water and the temperature (464 °C). In the lower and middle cloud layers of Venus, temperatures drop and water availability increases, generating a more biologically favorable environment. However, acidity and the problem of osmoregulation in hygroscopic sulfuric acid clouds become extreme and probably life-limiting. If it is assumed that these constraints can be overcome, considerations on the survival of acidophilic sulfate-reducing chemoautotrophs suspended as aerosols in such an environment show that Venus does come close to possessing a habitable niche.”

In support of Cockell’s (1999) argument is evidence indicating that microbes may have colonized the cloud layers of Venus (Limaye et al. 2018), and the observations, presented in this report, of mushroom-shaped surface features the latter of which are similar to those observed on Mars (Dass 2017; Joseph 2016; Joseph et al. 2019). Moreover, Grinspoon (1993, 1997) and Grinspoon and Bullock (2007), have argued that bright radar surface signatures may be evidence that living organisms have colonized portions of the Venusian surface.

8 Life in the clouds of Venus

In 1967, Sagan and Morowitz (1967) presented a scenario where multi-cellular organisms, up to 4 cm in diameter may dwell in the upper Venusian atmosphere and metabolize and generate hydrogen as propellants and a means of floatation. At this writing, the only evidence remotely suggestive of multi-cellular organisms have been photographed at ground level (Sanfomality 2013 and as reported here).

Venus has three cloud layers which circle the planet at an altitude of 48–68 km and which are composed of H₂SO₄ aerosols, with an acid concentration ranging from 98% in the lower atmosphere to 81% in the upper atmosphere (Bougher et al. 1997; Donahue and Russell 1997). The clouds of Venus also contain high levels of deuterium and trace amounts

of water (Donahue and Hodges 1992; Barstow et al. 2012) which could sustain life.

According to Limaye et al. (2018): “The lower cloud layer of Venus (47.5–50.5 km)” provides “favorable conditions for microbial life, including moderate temperatures and pressures (~60 °C and 1 atm), and the presence of micron-sized sulfuric acid aerosols,” which could sustain sulfate-reducing microbes.

Konesky (2009) argues in favor of the life-cloud hypothesis, and states “there exists a habitable region in the atmosphere, centered at approximately 50 km, where the temperature ranges from 30 to 80 °C and the pressure is one bar.” He’s suggested that organisms similar to plankton may dwell in the upper atmosphere. Likewise, Schulze-Makuch et al. (2004) hypothesized that Venusian clouds, 48 to 65 km above the surface, could harbor aeroplankton (which metabolize sulphur), and acidophilic microbes who employ sulfur allotropes as photo-protective pigments which enable them to engage in photosynthesis.

The upper cloud layers of Venus are subject to wind speeds of up to 355 km/h (100 meters a second) and then increase to more than 700 km/h in the lower layers (Blamont et al. 1986). Although increasing turbulence can have an inhibitory influence on the growth and metabolism of a variety of species, the opposite is true of phytoplankton and diatoms. Turbulence can increase photosynthetic activity (Gibson 2000; Gibson and Thomas 1995; Thomas et al. 1995), thus supporting the plankton hypotheses of Konesky (2009) and Schulze-Makuch et al. (2004).

9 Radiation and UV absorption

Schulze-Makuch et al. (2004) have argued “that the cloud deck of the Venusian atmosphere may provide a plausible refuge for microbial life.... Here we make the argument that such an organism may utilize sulfur allotropes present in the Venusian atmosphere, particularly S₈, as a UV sunscreen, as an energy-converting pigment, or as a means for converting UV light to lower frequencies that can be used for photosynthesis. Thus, life could exist today in the clouds of Venus.”

Fungi, lichens, and prokaryotes can survive long-term exposure to gamma, and solar UV radiation and remain viable (Horneck et al. 2002; McLean and McLean 2010; Nicholson et al. 2000; Novikova et al. 2016; Onofri et al. 2012; Satoh et al. 2011; Tugay et al. 2006; Sancho et al. 2007; Raggio et al. 2011). A variety of terrestrial species thrive in and are attracted to highly radioactive environments (Beckett et al. 2008; Dadachova et al. 2007; Tugay et al. 2006; Wember and Zhdanova 2001), including fungi, lichens and numerous species of microbe. UV rays would have no detrimental effects on these species.

Vesper et al. (2008) and Novikova et al. (2016), Novikova (2009) reported that fungi are invigorated and grow rapidly

within the International Space Station as a consequence of the heightened radiation levels. Fungi also flourish on the outskirts and along the walls of the highly radioactive Chernobyl nuclear power plant (Dighton et al. 2008; Zhdanova et al. 2004). Fungi (Wember and Zhdanova 2001; Zhdanova et al. 2004) and radiation-tolerant bacteria (Moseley and Mattingly 1971; Ito et al. 1983) will seek out and grow towards sources of radiation which serve as an energy source for metabolism (Dighton et al. 2008; Tugay et al. 2006). These organisms can easily repair radiation-damaged DNA due to a redundancy of genes with repair functions (White et al. 1999).

Ground and low cloud level radiation may not be nearly as intense as first believed as an unknown UV absorber has been detected in the cloud layers (Krasnopolsky 2017; Markiewicz et al. 2014; Rossi et al. 2015); thus making Venus more hospitable to life (Limaye et al. 2018). Although it's possible that sulfur dioxide and iron chloride are acting as UV absorbers, the albedo, between 330 and 500 nm, and the refraction index between 1.07 and 1.7 (Laven 2008), and the spatial and temporal changes in contrasts (Markiewicz et al. 2014; Rossi et al. 2015), may be evidence that microbial populations, attached to particles in the lower cloud layers of Venus (Limaye et al. 2018), are waxing and waning in biomass.

Specifically, as based on observations from spacecraft and terrestrial telescopes, it is likely that the clouds of Venus' have a high density of micron-sized particles (Hansen and Hovenier 1974; Knollenberg and Hunten 1980). Although a variety of absorbing mechanisms have been proposed (reviewed by Limaye et al. 2018), if these particles originated in space and are from Earth, or if they are comprised of sulfuric acid or other substances elevated from the surface, is unknown (Pérez-Hoyos et al. 2017). Regardless of their source or composition, it is not likely that these particles, alone, are acting as UV absorbers since their numbers are insufficient and incompatible with Venera 14 observations (Krasnopolsky 2017; Limaye et al. 2018). The refraction indices also exceed the values expected from sulfuric acid cloud particles except in the presence of FeCl₃ (Markiewicz et al. 2014), the latter of which may be contributing to cloud condensation nuclei.

Grinspoon (1993, 1997) proposed that the “unknown ultraviolet absorber” may be a photosynthetic pigment and the “terrestrial” photosynthetic, acid-resistant organisms are metabolizing and engaging in phototrophic and chemotrophic activities involving sulfur and iron within the Venusian clouds. Grinspoon and Bullock (2007), have also argued that irregularly shaped cloud particles may be living organisms. Another possibility is that living organisms are attached to and feeding on these particles.

To adequately account for the amount of UV rays absorbed, the biota dwelling in the clouds of Venus would have

to be massive in numbers. According to the calculations of Bullock (2018): “If microbes grow to represent one tenth of the aerosol mass, the total biomass in Venus' clouds would be 3.6 billion tonnes, or about the biomass of the Earth's oceans.”

Certainly a biomass of this magnitude would absorb a significant amount of UV rays; and this position, and Bullock's calculations, are supported by Limaye et al. (2018) who have argued: “for Venus' lower clouds, the mass loading estimates ($\sim 0.1\text{--}100\text{ mg m}^{-3}$) are comparable to the upper biomass value for terrestrial biological aerosols ($\sim 44\text{ mg m}^{-3}$), while the particle size regime ($\leq 8\text{ }\mu\text{m}$) opens the possibility that the clouds may similarly harbor suspensions of single cells or aggregated microbial communities. In theory, the 2- and 8- μm -sized particles (modes 2' and 3) could harbor a maximum of 10^9 and 10^{10} cells.”

The possibility of iron- and sulfur-centered metabolism in these clouds, coupled with particle and biomass density as estimated by Bullock (2018) and Limaye et al. (2018), may account for the spectral refraction anomalies observed in polarized and unpolarized light. UV rays are being absorbed and metabolized by Venusian organisms.

If the cloud layers of Venus harbor biology, then we would expect they would exhibit spectral signatures similar to terrestrial clouds. As pointed out by Limaye et al. (2018) data from the Galileo, Pioneer, Messenger and Akatsuki space probes “are tantalizingly similar to the absorption properties of terrestrial biological molecules.”

10 Speculations: Venusian atmospheric organisms

Limaye et al. (2018) also propose that microorganisms similar to *A. ferrooxidans* may dwell in the clouds of Venus as “this bacterium thrives at extremely low pH values (pH 1 to 2), fixes both CO₂ and nitrogen gas from the atmosphere (Valdes et al. 2008), and obtains its energy for growth from the oxidation of hydrogen, ferrous iron, elemental sulfur, or partially oxidized sulfur compounds.” Other candidates include chemolithoautotrophic and acidophilic γ -proteobacterium, both of which thrive under low pH and anaerobic conditions and at temperatures of 50–60 °C, and oxidize elemental sulfur and using Fe₃⁺ as a terminal electron acceptor. Likewise, green sulfur bacteria and archaeal *Stygiolobus* oxidize elemental sulfur to yield sulfuric acid under acidic and anaerobic conditions.

Therefore, if the analyses of Bullock (2018) and Limaye et al. (2018) are correct, then species similar to *Stygiolobus*, green sulfur bacteria, sulfate-reducing bacteria, and *A. ferrooxidans*, and a biomass equal to that found in the oceans of Earth, may be thriving within the clouds of Venus. Bullock (2018) and Limaye and colleagues (2018) also point

out that cloud-based microbial populations would have to be replenished on relatively fast timescales. According to the calculations of Bullock (2018): “The residence time of mode 3 ($r = 3.6 \mu\text{m}$) aerosols in Venus’ lower cloud is about 2 days. The rate equation shows that if the microbial lifetime is shorter than this, a steady state population can exist within the aerosols.” That is, as microbes reproduce they replace those which fall to the surface and can transfer between aerosol, otherwise they must be replenished from the surface or from space.

Because of the very strong downdrafts and updrafts (e.g. Blamont et al. 1986), the powerful winds of Venus may be continually transferring and recycling biomass to and from the surface to the atmosphere, and from the upper cloud layers to the lower layers. Conversely, if via galactic winds microbes and microbe-laden dust are expelled from the upper atmosphere of Earth (Joseph and Schild 2010) into the path of Venus, they would continually contaminate the upper atmosphere and descend from the upper to lower cloud layers where they may flourish, reproduce, and perhaps evolve, only to be eventually deposited on the surface. Conversely, those dwelling on or just beneath the surface would be lofted back into the Venusian atmosphere via strong updrafts. Life would continually be recycled from clouds to the surface and from the surface (or subsurface) back to the clouds, and replenished by organisms from Earth.

11 Life beneath the subsurface

Venera 13 landed in the Beta-Phoebe region at medium elevations in the upland rolling plains province, an area described as a “stony desert” with loose soil, compacted sand, pebbles, and rocks similar to terrestrial tholeiitic basalts which make up much of Earth’s ocean crust (Surkov et al. 1983). The Venusian basalts were found to contain high levels of potassium and covered with soil and soil patches (Florensky et al. 1983; Surkov et al. 1983). Garvin et al. (1984) likened the area to the bedrock at Snake River Plain, in Idaho, USA, and noted that many large and small rocks were partly buried beneath the sandy soil.

On Earth, endolithic microorganisms flourish in hyper-arid rocky deserts and extreme environmental conditions by colonizing the interior or the undersides of rocks including those just beneath the surface (Weirzchos 2012; Pointing and Belnap 2012); conditions which allow photosynthesis, and within which water molecules may be trapped. However, in the absence of water these organisms are able to “reversibly activate metabolism” until moisture becomes available (Harel et al. 2004). Generally, these hot desert micro-habitats are dominated by fungi, lichens, cyanobacteria, mosses and heterotrophic bacteria (Pointing and Belnap 2012).

The surface temperature of Venus, as determined by Venera 7, was 747 K/473.85 °C for the first 50 seconds after landing and to have a constant temperature of 739 K °/465.85 °C (Avduesvesky et al. 1971). Basalt has high thermal insulating properties (Eppelbaum et al. 2014; Mostafa et al. 2004) such that temperatures beneath these rocks would be much cooler. Temperatures beneath the Venusian soil are unknown.

In hot and arid climates, temperatures 1 m to 10 m beneath the surface are significantly cooler than surface temperatures (Davis and Schubert 1981; Smerdon et al. 2004; Al-Temeemi and Harris 2001). At these shallow depths, and due to these more temperate subsurface vs. higher surface temperatures, microorganisms are able to engage in considerable metabolic activity (Blum et al. 2002; Buchanan and King 1992; Kaiser and Hagemeyer 1993). Investigators have found a considerable biomass of microorganisms and fungi up to 15 cm beneath the subsurface (Dobbins et al. 1992; Fierer et al. 2012; Cocker et al. 2000; Krumholz 2000) even in arid high temperature environments (Weirzchos 2012; Pointing and Belnap 2012; Steven et al. 2013; Mueller et al. 2013).

Because of its density, soil is an excellent modulator of heat such that soil temperatures decrease at a rate exponential to soil depth until reaching 10 m; below which thermal conductivity is fairly uniform (Davis and Schubert 1981; Smerdon et al. 2004; Al-Temeemi and Harris 2001). In high temperature environments, heat transfer reduction from the surface to the subsurface can be as much as 57% (Al-Temeemi and Harris 2001); i.e. 43% of surface temperature.

Kuwait is located in a dry desert region and is characterized by high temperature extremes and intense solar radiation with a mean air temperature ranging from 37 °C to 45 °C during the summer months of June through August (Al-Temeemi and Harris 2001). There is little precipitation and soil water content is 2% (Al-Sanad and Ismael 1992; Al-Temeemi and Harris 2001). However, it is much cooler beneath the surface and temperatures steadily decrease with depth. For example, Al-Temeemi and Harris (2001) established that if the average surface air temperature is 41 °C, the subsurface temperature, at a depth of 1 m, reaches a maximum of 36 °C, whereas at a depth of 10 m the subsurface temperature is a constant 27 °C; i.e. a reduction of 12.2% and 34.2% respectively.

Al-Temeemi and Harris (2001), also determined that when compared to atmospheric temperatures the comparative decline is even more pronounced due to subterranean cooling. They concluded there are “significant temperature drops below-ground when air temperatures are at their highest.”

These findings support the likelihood that subsurface temperatures on Venus are much cooler than the surface

and may be habitable for a variety of microorganisms. Hypothetically these may include photoautotrophic, lithobiontic, poikilohydric, and fungal hyperthermophiles which have evolved and adapted to the Venusian environment. Specifically, by applying to Venus the 12.2% and 34.2% reductions in subsurface temperatures as determined by Al-Temeemi and Harris (2001) then, at a depth of 1 m temperatures will have fallen by 56.6 °C yielding a temperature of 407.4 °C, followed by a reduction of 158.7 °C and thus a subsurface temperature of 305.3 °C at 10 m. However, given the reduction value of 57% (Al-Temeemi and Harris 2001), temperatures 10 m beneath the surface might fall to 200 °C—well within the limit for the hardest hyper-thermophiles on Earth (Kato and Takei 2000). However, although some species may survive at this temperature, there would likely be little or no biological activity—according to terrestrial standards. On the other hand, because basalt has high thermal insulating properties (Eppelbaum et al. 2014; Mostafa et al. 2004), temperatures beneath these rocks could be much cooler.

The hyper-arid, waterless surface of Venus may also draw moisture and water up from the subterranean depths, just as occurs on Earth and the deserts of Kuwait (Al-Sanad and Ismael 1992). If so, then any organisms living 10 m below ground may be continually supplied with water as it rises to the surface and completely evaporates.

12 Speculations: fungi and mushroom-shaped specimens on the subsurface of Venus?

Specimens resembling fungi have been observed on the surface of Venus as reported here (Figs. 1, 2, 3, 4, 5). Unfortunately, because of the poor quality of the Venera 13 photos, positive identification is impossible, and one can only speculate and propose hypotheticals based on morphological similarities to terrestrial mushrooms.

Specifically, upon examining panoramic color images from the 1982 Soviet Venera 13 mission—reprocessed by NASA—five well defined specimens with caps and stalks which resemble the classic terrestrial mushroom were observed (Figs. 1, 4). These specimens protrude approximately 2 to 3 cm from the surface, and the caps are approximately 3 to 4 cm in diameter. Several smaller, less defined specimens with caps and what may be stalks appear to the far left of the center and which are bordered by additional specimens which form a crescent of mushroom-shapes (Figs. 2, 5).

Examination of the original black and white Venera 13 photos—which provides a 180 degree view—reveals a third well defined specimen at the bottom left (three in total, Fig. 4). Clusters of additional poorly defined specimens are observed to the upper left (Figs. 2, 5).

Therefore, five well defined specimens and numerous smaller surface structures which resemble classic terrestrial

mushrooms have been observed on the surface of Venus. There is no known geological or weathering process on Earth which can sculpt mushroom-like shapes from rocks. However, it must be stressed that similarities in morphology are not proof of life.

These Venusian specimens may have been uncovered from beneath the surface when Venera 13 landed and blew away top soil, rocks, and dust surrounding the landing site. Garvin (1981) reports that due to surface winds and turbulence, clouds of dust were recorded by the Venera 13 crafts for up to 30 seconds after impact and which persisted for up to 7 minutes.

It is unknown if these are mushroom-shaped rocks, fossils, or living organisms that have evolved and had been growing beneath the surface where temperatures would be cooler and which may provide access to any underground moisture drawn toward the surface. One can only speculate and propose hypotheticals. Based on terrestrial standards, if alive, they would have been obliterated almost instantly upon exposure to surface conditions. However, the number and density of these specimens also increase with increasing distance from the lander (Figs. 2, 4), suggesting those closer in proximity were destroyed by the sudden turbulence of the craft's landing. This leaves three explanations: they are mushroom-shaped rocks, they are fossilized organisms, or they have evolved into hyper-extremophiles perfectly adapted to the Venusian surface/subsurface environment.

It must be emphasized this author does not claim to have discovered fossilized or current life on Venus but is speculating and proposing hypotheticals. However, several of these specimens are similar to what may be fungal-lichen organisms growing on Mars (see Joseph et al. 2019) as well as on Earth, which supports the interplanetary transfer hypothesis. Hypothetically, if the specimens observed on Venus are fossils, or organisms which evolved and adapted, this supports the possibility that fungi, in general, may be hyper-extremophiles, capable of colonizing Mars, Venus, and the harshest of alien environments.

The author's observations and interpretation of these mushroom-shaped specimens are supported by the findings of Ksanfomality (2013). Based on examination of NASA-enhanced panoramic images from the 1982 Soviet Venera 13 mission, Ksanfomality (2013) observed what he believed to be two fungal shaped objects at a distance of 15 to 20 cm from the buffer of the landing module. Ksanfomality (2013) has estimated these specimens to be elevated 3 cm above the surface and to have a diameter of approximately 8 cm. These do not have mushroom-shapes and are to the far (90°) right of the specimens observed by this author and cannot be observed in Figs. 1–5.

13 Photosynthesis, water, hydrocarbons, anaerobic respiration

It is unknown if the fungal and mushroom-shaped specimens reported here are fossils, living organism, or mushroom-shaped rocks which may have been uncovered when the Venera-13 landed on the surface. One can only speculate. If fossils, then they may be relics from a time when Venus had oceans, rivers, and a less extreme environment.

It has been suggested that Venus may have had liquid water on the surface and provided a habitable environment for billions of years (Grinspoon and Bullock 2007; Way et al. 2016; Way and Del Genio 2019). Way and Del Genio (2019), based on the results from four simulations, determined that Venus “may have had enough condensable water on its surface for a shallow ocean...” and “would have been able to maintain stable temperatures—from a low of 20 °C (68 °F) to a high of 50 °C (122 °F)—for about three billion years” i.e. until about 750 mya. The finding of Donahue and colleagues (Donahue et al. 1982; Donahue and Hodges 1992)—based on comparisons of atmospheric deuterium/hydrogen ratios with Earth—support those contentions.

On Earth, in this general time frame, a variety of prokaryotes and eukaryotes had evolved. Between 600 to 800 mya, this biota included acritarchs, protozoa, ediacarans, amoebozoans, cercozoans, plankton, algae, coccoid and filamentous cyanobacteria, and fungi (Butterfield 2005a,b; Bottjer et al. 2006; Narbonne 2005; Narbonne and Gehling 2003; Shen et al. 2008). Hypothetically, if Venus was also habitable and wet at this time, then similar species may have also evolved. If this view is correct, then as surface water evaporated and temperatures rose, survivors may have adapted, evolved, migrated beneath the surface, and/or via the powerful winds of Venus (Blamont et al. 1986), were lifted to the clouds (Cockell 1999; Schulze-Makuch et al. 2004; Grinspoon and Bullock 2007; Limaye et al. 2018).

It is unknown if there is water beneath the Venusian surface. Budisa and Schulze-Makuch (2014) have hypothesized that in the absence of water and high concentration of carbon dioxide, that life on Venus may be sustained by “supercritical fluids” which “have different properties compared to regular fluids and could play a role as life-sustaining solvents on other worlds... One location where CO₂ should occur in the supercritical state is in the near-subsurface of Venus.”

Although the amount of light reaching the surface is only approximately 70% of that of Earth (within 0.5–9 klx), Venusian organisms, dwelling in the clouds, or beneath the surface, could derive energy from photosynthesis. Some terrestrial prokaryotes, as a solvent, utilize hydrogen sulfide, H₂S as the electron donor, whereas some autotrophic prokaryotes living beneath the surface engage in chemosynthesis instead of photosynthesis (Durvasula and Rao 2018; Gerday and Glansdorff 2007).

The atmosphere of Venus is 96.5% CO₂, 3.5% nitrogen, and due to active volcanism, subject to a high sulfur cycle (Donahue and Hodges 1992; Barstow et al. 2012). Seckbach and Libby (1970) in an experiment designed to mimic the Venusian environment, grew algae in pure CO₂, at elevated temperature and in an acidic medium, and reported these specimens continued to thrive.

A variety of anaerobic species survive and flourish in anoxic, high CO₂, environments (Kelly et al. 2001; Holliger et al. 1998; Emerson et al. 2016) such as *Shewanella*—a gram-negative, proteobacteria (Fredrickson et al. 2008; Hunt et al. 2010). In the absence of oxygen, anaerobes utilize substances such as sulphate (SO₄²⁻), nitrate (NO₃), or sulphur (S), as terminal electron acceptors to convert energy into adenosine triphosphate (ATP) which is conserved and utilized when performing energy-requiring processes (Grein et al. 2013; Kelly et al. 2001; Richter et al. 2012; Holliger et al. 1998). Some eukaryotic species which normally respire oxygen (e.g. some arctic dwarf shrubs), can survive high levels of CO₂, under hypoxic conditions, with no indication of damage (Lee and Phoenix 2013).

The metabolic activity of some eukaryotic fungi and anaerobic bacteria is inhibited by oxygen and amplified with increased levels of CO₂ (Lenhart et al. 2012). Given the high sulfur cycle, a variety of sulfate reducing anaerobic organisms (e.g. from the sulfur *molybdoenzyme* family) could adapt to the Venusian environment as they utilize sulfur compounds for sulfur metabolism to obtain energy (Grein et al. 2013).

So far, hydrocarbons have not been detected in the atmosphere (Plummer 1969); and without this evidence any possibility of life on Venus must be viewed with caution.

On Earth, fungi and microorganisms dwelling in clouds, and on the surface/subsurface, have a major role in organic compound degradation (Amato et al. 2007a,b; Ariya et al. 2002; Côté et al. 2008); and they play the same role in regard to hydrocarbons (Aydin et al. 2017; Heider et al. 1998). It is possible that the lack of evidence for Venusian hydrocarbons is due to rapid mineralization and consumption, serving as an energy source for Venusian organisms; similar to what occurs on Earth. A variety of microorganisms, including ferric iron-reducing, sulfate-reducing, and anaerobic hydrocarbon degrading bacteria (Heider et al. 1998) as well as anaerobic fungi (Aydin et al. 2017), catabolize hydrocarbon compounds. These species might be well adapted for life beneath the surface or within the clouds of Venus.

14 Conclusions

Venus may have been contaminated with Earthly life early in its history, and that seeding with life may have continued into the present via microbial-laden debris, dust, and

spacecraft. Venus may have had oceans and rivers until as recently as 750 mya, and, hypothetically, species which colonized the planet may have adapted and evolved when those oceans evaporated and temperatures rose. However, Venus may still provide a habitable environment for a variety of hyperextremophiles including fungi which might be continually arriving from Earth.

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