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Spider-Ravine Models and Plant-like FeaturesP on Mars - Possible Geophysical andP Biogeophysical Modes of OriginP

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The Martian South Polar region of Mars is littered with crypto-organic structures, structures that look like trees and plants. They vary in shape, size and colour seasonally and some may disappear over winter.

A number of models for their origin are proposed and discussed:

(1) Dry venting of CO_2 gas and dust up joints.

(2) Head-ward erosion: Fluid derived from sub-surface layers is expelled up fissures eroding joints to create tributaries capped with mud-like material and/or ice.

(3) Modified Clathrate-hydrate model: Structures form as the outside of the flow chills.

(4) Hydrothermal-type sources, and

(5) Magma pressurizes overlying fluids, expelling mud-like material, hydrothermal fluids or basalt.

Some complex ‘spiders’ may revert to ravines in the summer.

The morphology of ‘spiders’ appears to be controlled by bedding and local jointing of the rocks; implying that expelled fluids are derived from within a few hundred metres of the Martian surface. Some spider-ravines modify, some destroy and others create crust in a dynamic near-surface process that mimics subduction zones. Ancient forms of these structures have had a more extensive coverage.

Some valley networks may be formed by similar processes.

We consider the possibility that organic material, microbes, or even simple plants might co-exist with these inorganic models.

Keywords: Mars, hydrothermal, water, organic, jointing

1.P IntroductionP

MGS imaging has revealed that the South Polar region of Mars is littered with structures that exhibit the convincing characteristic appearance of trees and plants (Fig. 1a-i; Fig. 2a-l).

The most common forms are fan, ravine and linear structures. Initially, we were extremely skeptical regards the claims being made for the occurrence of controversial bush and plant-like structures on Mars. However, after analyzing hundreds of images, we conclude that large numbers of such structures exist and are widely dispersed.

In general, we refer to a collection of differing structures as ‘spider-ravines’ except when discussing complex forms where we often use the word ‘spider’ as a generic name.

The structures are ‘Chameleon’ in appearance: varying seasonally in shape, size and colour. Some spiral or have complex branching patterns. Some varieties (see definitions p.xx) such as fans, one-armed bandits (structures with a single curved arm) and spiders even occur on polar ice.

Layers in the South Polar areas develop networks of unconnected gully-like depressions (reverse tributary structures) that appear to be enclosed creek systems that duplicate patterns one normally associates with erosion by surface wa-

Fig. 1a 151.62°W, 87.10°S. Fans (dark) with two directional orientations (top left). Spiders are pale albedo, typically with a mud-like core. The image is ~800 m across. Small pockmarked spots or hollows in the image are older or non-active - this is what the fans look like in ancient terrain (i.e. pockmarks or etched terrain). Several small light-coloured (raised) mounds in the middle and lower right of the image have one single (one-armed bandits) or two small rotating arms.

Fig. 1b Spiders – with branches (tubes) above ground. Some may have a ravine core, others have a mud-like core.

Fig. 1c Spider with a central mud-like core. Several legs display meandering patterns – normally attributed to flow of a liquid such as water. There is some jointing control of the branches (legs) in the bottom of the image.

Fig. 1d Linear (elongate) mounds infill the joints. Complex structures form from mud-like cores at the intersection of the joints. Scale ~1.5 km across.

Fig. 1e 291.44°W, 83.10°S. Three-dimensional Martian Boab-tree structures above plain level, surrounded by small spiders. The large objects are 200 to 400 m in diameter. Some arms spiral. Some have a hollow and others a solid core (pale albedo).

See "Spider-Ravine Definitions" on p.xx.

Fig. 1f 273.96°W, 86.96°S. Scale: Spiders are ~200 m across. Spring. Spiders with either a hollow or a mud-like core or plug. The dark linear areas are fans. The elongate areas of pale albedo are probably ice/snow. Ice/snow is deposited between spider branches.

ter - we are confident that these are created by spider-ravine forming processes. Spider-ravines tend to form only at latitudes greater than 65°S predominantly in the Southern Polar Regions – only in the area of maximum summer sunlight, typically below 0°C. The closest to the equator that recent spiders have so far been identified is 43°S – although this limitation might be a consequence of the resolution and number of the images available. However, the distribution may have been more extensive in the past.

The definitions on pp.xxx and xxx are based upon what is known to be possible under terrestrial conditions on Earth. When transplanting this knowledge to explain features on Mars or any other planetary body where the geologic and surface conditions and mechanisms differ both separately and in combination - even profoundly as in the case of Mars – there are limitations of the analogy. Conventions (names given to structures) do not imply a biological origin – they are only used to describe or clarify an object’s shape or appearance.

In this paper, we show that the majority of structures may be accounted for without invoking any organic ‘life on Mars’ theory hypothesis.

Although any biophysical/organic theory may be an explanation to account for any, some, or all of these features it can be founded only on the most tenuous grounds - amounting almost to supposition. Therefore, organic and other models are discussed for completeness and to note these alternative conclusions. Likewise, the analysis in this paper does not imply that all the structures are formed by the same mechanism, or are all necessarily of purely geophysical origin.

We argue that if a single or combination of geophysical model(s) can explain the majority of features and the varieties of structure - then any at-

Fig. 1g 284.38°W, 82.02°S. Scale 2.83 km across. Bush or Banyon Tree structures.

Fig. 1h Branch (creeper) forms of spiders adopting the joint pattern of the host rock. These look like normal creek systems when inverted. Scale: ~1.10 km across image.

Fig. 1i 69.94°W, 73.59°S. Spring. Scale: ~1.4 km wide. On the left: small joint controlled amoeba with a central core and numerous legs. On right: larger Amoeba shapes with a dark core and more complex tubes radiating from the large central core/ fissure. Dark albedo material is deposited over the branches. Note the small dark fans associated with the structures.

(All images courtesy of NASA/Malin)

tempt to seek a biological explanation is probably unnecessary.

If the structures were created by a single mechanism or by a single gas or fluid alone, due only to temperature and pressure changes, then it might be expected that the structures will show the same or similar patterns and sizes. On the contrary, they do not. The sheer variety of shape, size and distribution makes it virtually improbable that a single fluid or process could adequately account for more than a proportion of the structures.

These crypto-organic structures vary considerably in appearance from fan or linear, to complex forms (as in Fig. 1 a-i) and are the focus of this paper. Their characteristic form appears to depend closely on a combination of such factors as fluid composition and pressure, rock type, local climate and meteorological conditions. We will explain the main forms using a number of simple, but overlapping, models.

The most common structures that look plant-like are 'branch (creeper)' forms that resemble couch grass and sometimes look like raised forests in appearance (Fig. 2a), Banyon trees or bushes (Fig. 2b) and complex spiders which have a central plug or a central core in this winter image (Fig. 2c). Figure 2d is mid-summer and may show spiders reverting to ravines. Compare this to M0700604 (187.37°W, 73.69°S) where ravines have a rotated creek system and a central core with mud-like material covering the openings in the bottom of the ravines and developing tubes. Spiders form on platforms (Fig. 2e) with smaller spiders either side of larger ones. They tend to grow over each other. There are also unusual varieties with 'squid-like' and above

General DefinitionsP

- *Vent* – Where gas, fluid etc are expelled out of a joint, bedding plane, fissure or fault or other opening in the rock. The opening, hole or void, is termed a vent. If the vent is actively ejecting a fluid or some type then it is venting.
- *Fluid* – Anything that flows like a gas, dust, water-like substance, mud-like material, basalt etc.
- *Clay or Mud* – We typically mean very fine silt or clay mixed with ice (H_2O or CO_2 ice), but would include clathrate-hydrates in this definition.
- *Sand hill* – These are typically ridges of sand and/ or ice.
- *Platform* – a single, typically flat or raised, layer or bench. These are usually created by intergrowth of spiders, except in the instance where the layer is being formed by retreat (or defrosting) of a layer along bedding surfaces. These can extend for tens of kilometers in scale. Many spider platforms tend to avoid craters and certain rock types.
- *Terrace* – A group of stepped platforms or benches that are layered in a terrace pattern (with patterns like one sees in benches in a mine or layered rice paddies). These can extend for tens of kilometers in scale.
- *Canyon* – fissure than looks like it has been created by running water (it may not be the case).
- *Tributary* – Dendritic drainage type pattern that one sees on Mars that mirrors creeks on Earth. Reverse tributary and reverse drainage mean that the tributary pattern is adopting a branch shape (like a tree) with tributaries meeting at some focal point.
- *Grow* – form.
- *Macro-band* – beds or rock units, which vary from metre, to tens of metres, in thickness.
- *Branch, limb, leg, arm* etc - these are used interchangeably to describe the tube or mound of a spider that resembles these features of a plant or animal (the terminology does not imply a structure is either).

Fig. 2a 157.39°W, 76.57°S, Scale: 2.8 km across image. Terraces (forests) of branch (creeper) forms, confined to one rock type. Sand/ice/snow deposits fill gaps between spiders.

Fig. 2b 284.38°W, 82.02°S. Scale: 2.83 km across image. Bush shapes in M0804688 vent gas bubbles and dust/mud so are sometimes covered in a CO_2 fog. The Banyon Tree or bush form typically grows as a complex structure with interlocked branches, out from a central point.

Fig. 2c A spider in winter with a mud-like core.

Fig. 2d Spiders reverting to ravines. Compare this to M0700604 (187.37°W, 73.69°S) where ravines have a rotated creek system and a central core with mud-like material covering the openings in the bottom of the ravines, developing tubes.

Fig. 2e 265.49°W, 87.13°S. Scale: 2.4 km wide. Spring. Large complex spiders several hundred metres across surrounded by small ones. The spiders tend to follow the pattern of the underlying rock, which indicates that this platform is relatively thin, therefore may also be fairly young, supporting the observation that platforms may be created in a single season.

Fig. 2f 177.45°W, 76.88°S, Scale: 1.4 km across image, so objects are ~250 m across. Squid-like shapes are attached to the dark tuff (?) band (the flat body area may be dust/mud jets?). Five legged (unusual for geology) star fish or tree shapes. The mud-like layers are probably retreating, which allows fluids to become available so the structures can form.

ground tree shapes (Fig. 2f), which seem to be forming from mud-like layers. If these structures are eating up material from the layers, the layers should therefore be retreating or diminishing in size. One-armed bandits are like the squid but have a single tube which spirals out from the ice or mud-like layer. Spiders have mud-like cores. When spiders are overpressured they may burst their sides and form outflow patterns (Fig. 2g).

Terraces created by amoeba shaped structures (Fig. 2h) are very common and form dune-like structures. In many cases, one set of spiders or ravines seems to superimpose on another group (Fig. 2e,i). Figure 2j shows spiders with a central core having formed in the core and on the rim of an old crater. This is the typical pattern associated with craters. Figure 2k is black (dark albedo) ‘blob’ material creating fans and ravines in the bedding.

Although spider-ravines only seem to occur in Southern Polar Region, there are ancient spider forms, similar structures and platforms with textures with wider dispersal that suggest spiders may once have had wider dispersal (Fig. 2l).

The main controls on the spider-ravine structures are:

1. Bedding planes, local jointing pattern and small scale faulting of the host rocks - implying fluids are derived within a few hundred metres of the Martian surface (otherwise spider-ravines would be localized around large, regional faults - few are);

Fig. 2g Mud-like material forms a central pack. This image may also contain outflow channels formed by bursting of spider branches.

Fig. 2h 192.70°W, 77.90°S, Scale: 2.85 km across image. Spring. Amoeba shapes on a large terrace. Sand or ice tends to collect around/between the amoeba as they create a sand-like terrace.

Fig. 2i 224.26°W, 77.01°S, Scale: 2.6 km across. Ravines, each ~200 m in size, venting dust and basalt (or mud-like). The platform surface texture mimics large mud-cracks.

Fig. 2j 34.96°W, 77.47°S. Late Spring. Spiders, each ~200 m across, are in a large circle (lower right of image), so are venting up the side of an old impact crater. The largest one in the center has a mud-like (?) core. This follows the pattern of magma – but they mimic mud volcanoes.

Fig. 2k 304.68°W, 81.35°S. Scale: 1.42km wide x ~1.0 km high. The parent image shows folded beds and ravines/fans developing and undercutting in specific layers. The dark 'blob' material looks like a plant but may be CO_2 and other minerals venting.

Fig. 2l A spider from a non-polar area, Southern Hemisphere. The spider legs are fine and growth extends from one single limb, but tends to cross more randomly than other complex spiders (may be a result of resolution).

(All images courtesy of NASA/Malin)

2. The effect of summer heat evaporating CO_2 and saline minerals (the reaction helping volatalize H_2O-ice). It is difficult to get sufficient liquid lasting long enough to produce the structural changes to produce these structures at atmospheric pressure. To get liquid CO_2 and H_2O on Mars these materials have to form under a gas-tight lid and then be catastrophically released when they can exist briefly as liquids – or erode below a permafrost-type seal;
3. The effect of fluids and gases: (a) on creating expansive diapiric clay-like materials and (b) on the resultant spider, ravine, fan, bush and other shapes;
4. The pressure of venting fluids and gases: in some cases pressurized hydrothermal-type fluids, clathrate-hydrates or even magma may be involved; and
5. Whether the fluid-gas slurry is wet or dry, hot or cold.

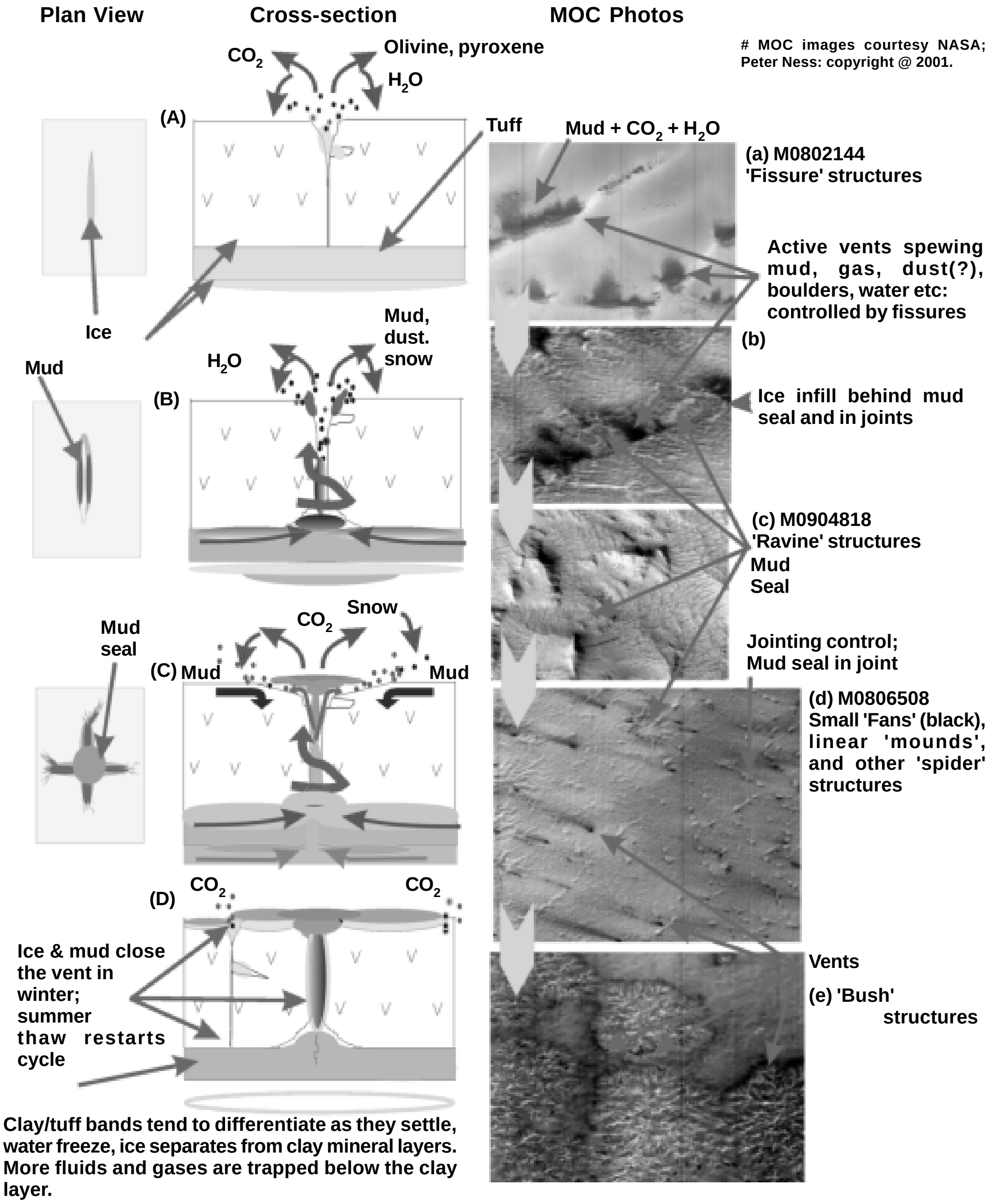
There are five main model variants with a slightly different fluid and genesis:

1. Dry venting (high or low pressure): CO_2 gas (and ice) erodes pyroxene, amphibole, olivine and feldspars from fissures,
2. Head-ward erosion: A system where clay-like minerals from tuff-like or sedimentary-like layers expands up cracks and fissures and erodes the structure. CO_2 and H_2O are often still the main fluids ejected (as gas or ice), especially in tributaries but saline minerals and expanding (diapiric) clays may be involved.
3. Modified clathrate-hydrate model: where the external margin of the flow chills to form a shell through which fluids flow. Extreme pressures may enable CO_2 and H_2O to combine as slurry forming clathrate-hydrates along with other minerals.
4. Hydrothermal-type: typically a system of high pressurize hydrothermal-type mud-like material (or very fine silt),
5. Basalt heat source: The case where basalt close to the surface causes the overlying fluids to expel mud-like material or is itself ejected (unlikely).

The fluids and resulting mineralogy and structures may differ but most physical processes and textures are similar.

2.P The Spider-Ravine Models

A model proposed by JPL (Jet Propulsion Labora-



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Clay/tuff bands tend to differentiate as they settle, water freeze, ice separates from clay mineral layers. More fluids and gases are trapped below the clay layer.

Fig 3. A stylized composite Spider Model: In reality, the fluids and gases rise up multiple joints or create their own crosscutting pathways up permafrost fractures.

(A) CO_2 dry venting near surface melts, pyroxene, olivine, feldspar grains fly off the rock due to pressure of escaping gas and thermal expansion.

(B) Ice on/in submerged clay-like material and in fissures/cavities melts, probably due to sublimation of mineral salts. Fluid/gas collects on top and may ooze back into fissure (if the system is sealed by permafrost).

(C) Hard-cap ice/mud seals the fissure opening. Fluids and gas erode the structure, cutting a swathe up joints. Pressurized gases gouge out the structure.

(D) In winter mud-like material and/or ice seal the vent. As spring arrives CO_2 evaporates, pressure and temperature build-up may allow water to condense below the seal and flow back into core, eroding the structure by head-ward erosion. The seal is broken at its weakest points – ends of branches and where head-ward erosion cuts up along joints – thus fluids vaporize.

(a) 215.54°W, 65.42°S, 2.84 km across image. Gas, dust, mud-like material are expelled. Mounds develop.

(b) 182.84°W, 86.91°S, M0801839. Image 1.06 km across. Mud-like (silt) seals block the exit of CO_2 and gas. Ice (?) helps create the seal.

(c) 128.49°W, 7.11°N, M0904818. Mud-like material (or lava) seal (some 300 m across) with small creek tributaries and fans. Ravines are around 250 m across.

(d) 63.12°W, 81.56°S. Scale 1 km across image. Spiders with mud-like core (200 m in size) controlled by jointing and linear mounds – this shows they are the same thing. Venting dark (fan-shape outline) material is blown by the wind.

(e) 284.38°W, 82.02°S. Scale 2.83 km across. Bush structures forming a platform, venting from the finger branches. Bushes are up to 400 m in diameter. Vents at the end of fingers (tubes) are typically 10-15 m in length; therefore if the structures ice up diurnally opening in the day a spider (or even a platform) could easily grow in a single season.

(All images courtesy of NASA/Malin)

tory) suggests that defrosting of CO_2 on sand dunes forms dark spots when temperatures are just beginning to creep above -125 °C (148 K). This coincides with a springtime defrosting process on Mars. Both frozen water and carbon dioxide may be involved, though it is unclear as to whether one type of ice dominates. By summer all of the frost and thus all of the spots on the dunes have gone [1].

Although this may be an explanation for the smaller, dark or round spots, structures associated with the edge of the dunes form dark 'oil-like' or 'bush-like' structures and form seasonally. However, many structures cannot be formed in this way and are much more complex. Virtually all structures appear to be controlled by joints or bedding planes, many have a dark core and a pale rim, they occur in an open fissure, and are three-dimensional complex shapes, ravines, or other large structures (up to 1 km or more across) that look like plants or trees.

We suggest that the following processes may explain how the majority of the structures form (Fig. 3a is a much simplified, stylized composite of the staged processes). In reality the systems are much more complicated than shown: spider mounds (legs) often interconnect crossing each other.

2.1P Dry VentingP

(Condition – either no tuff-like or clay-like layer below, or few clay minerals involved)

This process occurs above ice sheets and over bedrock. As the Martian spring approaches, surface temperature and pressure changes allow CO_2 snow and ice in near surface vertical and horizontal joints, fissures, faults, or cavities, or large caverns within several hundred metres of the surface (but typically much closer) to sublime. The gases rise toward the surface. The process can lead to low or high pressure venting of fluids.

Pressure release from escape of degassing CO_2 from pores and sublimation of saline minerals (such as magnesite, gypsum, anhydrite) and ice (H_2O) may allow rock fragments and even boulders to be blasted from joints and fissures from exposed, outcropping surfaces. In fact – if it did not occur joints could not open up to allow venting. Slow moving gases and fine dust start to be expelled near the surface and build up extensive pressures as the temperature and confining pressures (below the ground) increase (Fig. 3A), allowing release of pressurized gas.

At the surface, a small mound of dust or mud-like material (depending on how much water is involved) may collect along with snow and ice. Any water quickly evaporates instantaneously. Below permafrost, water may last for some time. As spring progresses, fan-shaped tails develop from the central spot and branches often extend from these areas. These tails initially demonstrate strong directional elements, wherein many spots display one or more streaks of identical orientation and relative length [2] due to wind and jointing. Therefore, some of the dust may be blown away by the wind.

If the temperature is rising slowly around zero in Fig. 3C and certain salts are present, liquid water may exist for longer periods. Dissolved salts are likely in the Martian soil and may lower the sublimation point and reduce the equilibrium vapour pressure considerably [3]. Magnesium sulphate (Epsom salt) has a sublimation point of -35 °C and so could combine to form salts in the Martian soil. A solution of calcium sulphate would sublime at -55 °C; and a mixture of the two sublimes at only -63 °C [4] and could perhaps release CO_2 and H_2O gases leaving dehydrated mineral remnants and sulphate crystals.

Where little water is involved, the gases strip the grains from the wall of the joints as they escape, which opens the joints, so depressurizing the system. A small pile of coarse, angular and sub-rounded debris may be deposited at the edge of the vent (Fig. 3a,b). Finer dust may be blown away. Given time, the pile loses any moisture, compresses and flattens. Ice may form in or at the base of the pile. Being the same colour as the host rock only a small mound, if any, is observable.

The structures formed tend to be linear and irregular: they adopt the joint pattern of the host rock. Where joints or bedding planes are flat 'fan' shaped structures form out of the side of the hill. Where joints are sub-vertical or vertical, fissures develop. Given that pressures vary dramatically, this process may explain some linear mounds and most fan structures.

Dry venting may not require clay or salt minerals, or even water (H_2O) and could occur by venting of sublimed CO_2 alone. Due to the lower sublimation and boiling point of CO_2 one would expect a dry-ice/liquid/gas transition sequence to be able to generate significantly higher pressures than H_2O under Martian conditions.

However, if gas becomes trapped below the permafrost, pressure build-up may allow some conversion of gas to liquid. Permafrost has the ability to self-seal any fissures resulting from stress and needs thermal energy - geophysical or from kinetic input i.e.

Spider-Ravine DefinitionsP

- *Fan* – **A simple structure created when gas or fluid is expelled in a fan or wedge shape from a vent, fissure, fault, bedding plane. Both the eroded shape (if it is fan shaped) or the venting fluid or gas is termed a fan (Fig. 1a).**
- *One-armed bandit* – **These are single tubes that often form out of the edge of (ice) layers. They are often rotated or bifurcate at the end. Some have a small central pale mound and a single rotated arm (Fig. 1a).**
- *Complex Spider* (*or Spider*) – **These have a central core, or hollow, with 3 or 4 mounds (arms or legs) extending from that central point. These arms adopt fibonacci patterns and bifurcate in the same way as plants branch on earth. The arms are often rotated, typically in the same direction – but not always. These sometimes adopt an above ground, five-legged, star-fish shape (Fig. 1b,c,f).**
- *Linear* - **Elongate mounds, piles of material, or tubes that line up along joints over large areas. These are simple structures unlike more complex spiders, which tend to form from intersections of the joints (Fig. 1d).**
- *Mound* - **Mud, ice or other material that piles up to form a simple, above ground, rounded hump shape. Mounds may be created when material or debris ejected from a fissure or opening in the ground piles up over the opening in a rounded shape or from fans jetting into a mound pile. Sometimes fan shaped (as in the base of the M0906614 image). Not to be confused with branches of spiders which are sometimes called mounds (Fig. 1a,d).**
- *Martian Boab* – **Describes spiders raised above the ground level on a central mound. The shape mimics a Boab Tree but the limbs form down from the top and splay toward the ground (Fig. 1e).**
- *Tube* – **Elongate structures typically with a hollow core, usually above the ground and tending to taper-off or bifurcate toward the ends.**
- *Bushes* (*Banyon trees*) – **The term Banyon Tree was coined by Arthur C. Clarke. A structure where the tubes, mounds, branches or legs of a single spider are so complexly interwoven that it forms the shape of a finely limbed bush (Fig. 1g).**
- *Branch* (*creeper*) *Forms* – **A pattern of interlinked tubes or mounds that form the same bifurcation patterns as seen in bushes and trees on Earth. However, 'branch forms' are typically trellis shape or adopt patterns similar to creepers (such as couch or buffalo grass). These are similar to complex spiders but do not always stem from a single opening. They adopt the joint pattern over a wide area. Inverting the image, gives an overall shape identical to an ordinary creek system. Where they are formed exclusively by CO_2 and H_2O ice, once this sublimes, they also form a normal tributary system. Individual structures may cover areas >10 km^2 (Fig. 1h).**
- *Old Tree* – **Above ground structures that look like tree stumps in old forests. They are normally pale albedo (white) and seem to be mostly composed of ice. They may represent a seasonal change.**
- *Amoeba* – **Have a large dark albedo (black) central core, which may or may not be solid in appearance and legs that radiate out from the core. The shape is similar to a cockroach, with a large elongate central core and many small legs. These sometimes bifurcate. Amoebas tend to be related to and create linear elongate mounds (so may form dune-type patterns) (Fig. 1i).**
- *Ravine* – **An open reverse tributary structure, typically where creeks meet at a central or focal point and the structure appears to be self-enclosed. If it is open at one end and is more than 100 m or so deep it is a canyon. If there are no, or few, tributaries then it is typically a fissure. They may be rotated or elongate. When they are rotated, the large proportion in that area have the same rotation direction.**

impact - to depressurize. As it vents (at the surface) open systems may rapidly depressurize vaporizing any fluid. Thus, this model overlaps with the next.

2.2P Head-Ward Erosion ModelP

(Condition – tuff-like or clay-like layer in subsurface)[1]

Many 'spider-ravine' structures have a solid mud-like (or ice) core or plug (Fig. 1f; Fig. 2b,c; Fig. 3b,c). This may be either a pale or a dark albedo – which implies more than one type of material may be involved. A central core seems to be required to channel fluids in order to create many complex spiders. If the plug were not hard (like ice) then the structure may open up vertically as a fan or simple ravine/ fracture. The most likely material is that directly removed from the sides of the vent, but since it is often mud-like, some material may be sourced elsewhere.

Figure 4a,b,c,d,e, show a series of layers (macro-bands) exposed in cliffs. Most have ravine or spider structures associated either with, or above, the macro-band. Each photo has in excess of 100 m of macro-bands exposed, from which the fluid seems to be sourced.

2.3P The ProcessP

Where dark albedo (tuff-like) macro-bands occur below permafrost or a layer of strata (Fig. 4b,c,e), the sudden seasonal change in surface conditions may allow CO_2 and H_2O ice - in association with the saline minerals (i.e. gypsum, magnesite etc) within, on top of (and perhaps below) subsurface macro-band layers - to sublime (as shown in Fig. 3B). CO_2 and H_2O may occur directly above or below a clay-like layer as either ice or gas – or be part of it. Ice may be held as ice layers (or sheets) within, below, or above clay-like macro-bands.

As gas above or in these macro-bands tries to escape, the pressure build-up (below the perma-

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[1] Pressures seem to vary from atmospheric, up to, but not sufficient to shatter the surrounding rock (so less than ~150-200 psi). If they were higher, most spiders would form upwards - rather than cutting an infilled valley form.

Fig. 4a 184.39ºW, 86.67ºS, Scale: ~200 m across. Dark albedo layers in the top image are tuff-like bands that may have oozed material out of the bedding plane. It looks like plant matter but may be a CO_2 gas plume (?). It is unlikely that layers could 'grow' to form a uniform thickness. The collapse structure indicates the macro bands are retreating.

Fig. 4b 21.24ºW, 84.16ºS. Scale: 2.13 km across. Parallel tuff-like bands in the bottom image adopt negative relief creating ravines. Dark mud-like material has covered the bands above and below the venting mud-like layer. The image has captured a turbidity flow of ice/mud mix being ejected from a central vent (semi-circle structure due to the effect of gravity and the slope) like an avalanche.

Fig. 4c Alternate dark albedo tuff-like bands undercut ice layers.

Fig. 4d A pitted texture with remnant tubes and ravines. Our interpretation is that large fans created trough-cross bedded (TCB) terraces (see Fig. 8). This image (and the others) may represent the same TCB units etched or eroded by the process of retreat – caused by the growth of tubes and ravines related to specific (dark albedo) layers.

Fig. 4e 10.06ºW, 79.85ºS Spring. 1.42 km wide. Fans (dark) and small spiders form along the banding.

(All images courtesy of NASA/Malin)

frost) may allow fluid to condense on minerals (the escaping sublimating gas may tend to cool the area as it takes heat away from the surroundings). Macro-bands would absorb the fluid. Where clay bands exist they would expand to many times their original volume, so may turn to slurry. Fluid expansion may increase pressures and sheer stress may enable joints to slightly open. Material derived from macro-bands would ooze (as a slurry-gas mix) or be forced up intersections of fissures and fractures under hydrostatic pressure to the surface, creating complex structures (Fig. 3C). The alternative is that minerals sublime and CO_2 gas is expelled, so as the clay-like layer opens up more gas or fluid is expelled.

If the macro-band acts as a clay-like material, it may result in diapiric expansion helping pressurize the CO_2 gases and water slurry above, forcing it to be expelled upward. A mud-gas slurry could then be splattered or ejected at the surface (as in Fig. 3a). Where a lot of fluid is involved, (small) mud-like volcanoes or mounds may form in the core of the vent [5] from which the gases are expelled outward (as in Fig. 1e; Fig. 2b).

Central cones may collapse under their own weight and form mud-like puddles, which would harden rapidly, forming a hard central cap. The mechanism is shown in Fig. 3A - D and in images 3a - d and the central plug in Fig. 2b,c.

As CO_2 is degassed, it rises up the vent and along with mud-like material, water and other fluids swirls up to the surface in a turbulent, rotating slurry (CO_2 plus dust could possibly create the same effect). Spiralling may be due to Coriolis force (unlikely) or to the angle and pressure of the fluid movement causing angular deflection[2] but it has been suggested that it might also indicate an organic origin [6]. As fluids escape the surface vent, water and CO_2 revert to gas or to snow depending on the temperature of the venting fluids. The mud-like material may harden and form a mud-cake in the core, or slide/flow back down the sides of the vent and harden.

A mushroom-shaped plug (or a slightly sunken concave plug) forms to cap the vent at an early stage - most spiders form from a central hard-cap (plug) core. The plug must harden to create a cemented, impermeable mud or icepack; otherwise, it would be blown out by the next expulsion of pressurized fluid. The gases and fluids then cut a new path up joints. Depending on the fluid type the plug may vary from mud to pure ice (CO_2 + H_2O).

Where the system is fully blocked, pressure may build up below the central mud-like plug allowing the condensing of acid water or brines – or subliming of ice in joints – which may encourage erosion of joint patterns. Gas, other fluids and mud-like material would then be expelled up the joints, out the sides of the central plug, eroding the structure further and creating tributaries.

Fluids may also ooze as a turbidity flow back toward the central vent, down joints eroding small tributaries - or at the ends of the structure. This explains the poor creek definition in close up images of the tributary erosion patterns.

As the system vents mud-like material and gas, the ice and/or mud sticks to the side of the mud-like cap – but also to the side of the eroded fissures (or ravines) enclosing them. Mud-like material is often deposited on top of, or in conjunction with, pale albedo (white) material that looks like ice. A large proportion of the flow is probably CO_2 so as the fluid is expelled the edge may chill allowing the tube to close (to form CO_2 + H_2O ice) around the vent and to infill the fissure. Unless pressurized sufficiently, ice is unable to covert to liquid (water) so the tube may remain open.

Any pyroxene, amphibole, feldspar, magnesite or anhydrite minerals vented with CO_2 and H_2O may revert to dust and be blown away or deposited in the mound. Piles of mud-like material (or ice) on the edge of the fissures may slide back into and infill joints. When temperatures drop (daily or seasonally), fluids (?) or gas trapped in and on the edge of the vent and its tributaries turn to ice sealing the vent. As temperatures rise, pressures inside the vent increase restarting the system.

Below the permafrost seal, any subsurface clay-like layer may harden, becoming impermeable. Fluids and mud-like material in the vent and tributaries ice up. Snow, ice and mud-like material close off and seal the fissures. The mounds on the surface settle (harden like permafrost); the structure stops forming.

By late summer, the mound appears to be dormant. It either disappears and becomes a ravine with ice or mud blocking the core, or remains as a dark mound. Thus, the branches may be capped with pure ice at one extreme, may be comprised of other material (mud, silicates etc), or may be a mix of the two. In the extreme example, where CO_2 and H_2O ice are the main components involved, the central plug could be almost totally composed of ice (as in Fig. 2d[3]). In this case, the spiders would become ravines in the summer – providing a direct link between the two structures.

Snow and ice may be deposited onto the area over winter or it may remain dormant. However, as temperatures rise next spring the gases below the surface are again pressurized, re-starting the cycle. Where an enclosed mound still exists (mounds composed only of CO_2 and H_2O may melt in summer), these may break through at the weakest points – usually at intersections of joints or ends of the branches (as in Fig. 3D,e). A branch could form along a joint or bedding plane via a chilled margin of mud-like minerals and CO_2 ice as the fluids are vented (as either a hollow tube or tributary with a mound). The more complex spider (branch, bush, amoeba) forms may tend to form this way.

The system may vary from high mud to low mud components and high to low water (H_2O) or CO_2 content. Material removed from the expanding hole is deposited on the surface. It slides back into the hole, where it may be held in place by snow or ice until it solidifies. Some tributaries may be blocked by ice rather than mud-like material (silt). The amount of clay-like mineral would diminish rapidly away from the central vent, so the system may revert towards the dry CO_2 ice-gas venting pattern.

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[2] Due to the fluid being angularly deflected each time it encounters a surface.

[3] See http://www.msss.com/moc_gallery/m13_m18/images/M16/M1600550, Courtesy of Nick Hoffman. This may be the most common process that occurs.

2.4P Hydrothermal ModelsP (Hot or Cold Emplacement)P

The term 'hydrothermal' implies hot fluids (typically 100-250°C) but, on Mars a wide range of hydrothermal-type fluids may even be involved.

2.4.1 Modified Clathrate-hydrate Model

Where pressures are sufficient [7[4], 8 and 9] a clathrate-hydrate fluid may be expelled as slurry.

Clathrates of CO_2 and H_2O could theoretically occur at the Martian poles (at depth) as the most common ice we would expect to find, especially underground where the pressure of overlying rock forces CO_2 molecules into the lattice [10 and 11[5]]. These conditions may not be possible both below the Martian polar caps and in the lithosphere, given low Martian geothermal gradients.

Where ice forms around the edge of venting streams of gas, complex patterns may form. When a spider branch is blocked and broken a jet of gas spurts out. Where the gas is chilled, ice forms on the outside of the vent and forms a tube structure in a similar way to the formation of mud tubes (in some respects, similar to the toothpaste structures in pillow basalts but with a hollow core). The tube narrows to a taper because pressure drops off with distance.

If a tube becomes blocked or pressures are sufficient then a branch will burst. A new one may form from the new jet of fluid (gas/ice). The branches could form above ground and would simply follow and chill the edge of the flow. If one branch crosses another, it will cut into it bursting the second. If the branch intersected is blocked with ice or other material the perpetrator may erode through or flow over the top. Thus, this process explains three-dimensional structures or those that seem to defy gravity and explains many structures that look plant-like.

This mechanism could occur in the each of the low temperature models, provided CO_2 was the dominant fluid involved and water content was low (or else tubes would close off).

It has been proposed [12 and 13] that subsurface gas channels of CO_2 flowing at high velocities beneath sections of ice explain some of the fan-shaped spider structures at the Martian South Pole. This is realistic so would fit this and other cold emplacement models. Below ice sheets the gas pressures might build up to such extremes that ice volcanoes may form and the ice may be fractured. Gases below the ice sheet would be ejected outwards along bedding planes and reach the surface up fissures and cracks in surrounding rocks.

Therefore, the models above probably coexist and overlap to some extent.

2.4.2 Normal Hydrothermal model

(Condition – fluids and gas may build up below the tuff-like/clay-like layers)

In some cases, either an expanding clay-like (tuff-like) macro-band below the sub-surface may absorb so much water and gas that it becomes weakened, or pressurized fluids below this macro-band exert so much pressure they may force their way through to the surface. Fluids and CO_2 trapped under pressure may be normal meteoric, hydrothermal-type fluids, clathrate-hydrates – or just gas. If they penetrate and breach the weakened layers, they should be vented as a mud-like slurry plus gas at sufficient pressure to gouge out a vent. Where water seeps down, mud layers[6] may absorb so much water and gas that they act like slurry.

Pressure release may allow fluids below the mud-like material to expand and ice to sublime. The trapped fluid is under pressure. It breaches the layer, or forces it to the surface where the jet of fluid and gas gouges channels. As the fluid gets near the surface, gases may evaporate so minerals and ice may be deposited, typically at or near the vent.

Once the initial pressurized gas-water bubble below has escaped, the system gradually slows to a trickle (except where highly pressurized). The mud-like material may lose its fluidity and clog up the system. As temperatures decrease ice forms in and on the mud and the clay-like band rejoins (ices over) and becomes impermeable and rigid.

If pressures are high and hydrothermal-type fluids are involved 'crack and fill' may dominate, forcing joints to open and to erode the structures. At the extremes, the structure may culminate with open

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[4] Work done by Wiley (1998) shows that the critical pressure of CO_2 is about 1,070 pounds per square inch (psi) and the critical tempreature is about 31 degrees C, so CO_2 is in a supercritical state at temperatures between 32 degrees C and 49 degrees C and pressures of between 1,070 and 3,500 psi.

[5] If CO_2 is heated to 31.1 °C and subjected to pressures greater than 72.8 atmospheres, it converts into a "supercritical" clathrate-hydrate form.

[6] Assumes a permafrost surface seal.

fissure trellis, square joint controlled vein patterns. Montmorillinite[7] clays form in rhyolitic at less than 150°C within 400 m of the surface at Wairakei, in New Zealand[8] [14]. In the deeper zones, water contains higher concentrations of CO_2 making it acidic but near the surface CO_2 is lost from the system and the water becomes alkaline. This corresponds with the observation that some of the rock associations near some spiders may be rhyolitic.

On Mars, fluids would have low H_2O content. Mars lacks surface water (due to atmospheric pressure) to form mud-like puddles so CO_2 may be dominant as a lubricant.

2.4.3 Magma or Basalt Heat Source

(Condition – proximal magma source)

Some of the Martian tuff-like bands shown in Fig. 4 could equally be mafic-igneous sills being emplaced along horizontal bedding planes[9]. A volcano with no ash may only display its root structure and a small vortex or cone. Thus – in some cases - the clay-like layers below the surface may be sills, the mud-like plug could be basalt, the mud and boulders that are jetted could be magma and there may be little or no water present.

This type of model has immediate attraction. However, most tuff-like bands are probably not sills (e.g. Fig. 4a,c,d; Fig. 5a,b).

The problems with magma as a source fluid are:

1. Volcanic eruptions never follow seasonal patterns (except by pure coincidence) and imply that Mars is highly active geologically [15].
2. The pale (white) material in fissures overlain by the plug in Fig. 3b,e and in fissures (Fig. 5c, or in M1102650) may be ice.
3. Spider-ravines are controlled by local, rather than regional structures (Fig. 1d; Fig. 5d). Fluids derived from more than a few kilometres depth would tend to follow regional structures. Therefore, the source must be shallow.
4. Most spider branches eject or seem to be composed of ice or snow (Fig. 5e).
5. Most spiders form on elevated platforms – basalt would flow into lowland areas.
6. If the magma is close to the surface and interacts with ice or water – as with 'rootless cones' [16] an explosive reaction may occur. Lava moving through tubes may mix with, and cause, water ice to flash to steam [17]. When the steam pressure exceeds the pressure of the lava above it, there is a "phreatomagmatic" — or groundwater and magma explosion.
7. Confining pressures and release of hot gases tends to smash the rock leading to relationships that follow simple, linear (M0980481), angular patterns.

Therefore, if magma is involved, one or more of the models described above must also be correct in order to form complex spiders. This does not mean magma is not a source; it simply may not be the major fluid involved.

The alternative is that hydrothermal-type fluids are pressurized by slowly cooling magma from below rather than by pressurized meteoric water. These fluids may saturate the base of the tuff-like and basalt layers causing them to weather to smectite.

3.P DiscussionP

3.1P The Age of the Spider-RavinesP

We have described a number of processes that allow for rapid creation of the spider-ravine structures and rapid erosion to occur. In some areas large and small (young?) spiders coexist, and overgrow - implying either the conditions have existed stably for a long time or several phases occur in a season.

To see physical seasonal change of 2 to 5 m growth, or more (up to 10 or 20 m), on each structure (Fig. 3e) in an image suggests most structures develop within a single season. That growth rate is expected for a plant or animal but is rather unusual in geology - especially for Mars.

3.2P Mound, Ravine and Pitted TerrainsP

Some structures have positive relief with a mound structure on the surface (most spiders – e.g. boab, banyon trees, branch shapes and bushes), while others form a depression (ravines) or are open at the surface (partly enclosed or open fissures).

Ravines may form in three ways: Firstly, from dry venting excavating a fissure or joint. Secondly, when fluid from submerged macro-bands is expelled from the vent (Fig. 2i) - rock or ice fragments and boulders may be stripped from the walls of the fissure and jetted into the air. This would tend to stop the mud-cap forming and may result in an open fan or ravine. The third way is by retreat of the spider's ice

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[7] Montmorillinite has the chemical formula: $(Al, Mg)_8.(Si_4O_{10})_3.(OH)_{10}.12H_2O$ [8] which forms the same structure as vermiculite $Mg_3.(Si, Al)_4. (OH)_2.4.5H_2O.[Mg]_{0.35}$, in which Mg represents an exchangeable ion in the structure. Montmorillinite is typically derived from pyrophyllite (talc). Alternatives are beidellite with the formula: $(SiAl)_8.Al_4O_{20}.(OH)_4$ [8].

[8] This may be a little too Earth-like for Mars, so the reactions may need modifying.

[9] Horizontal jointing and bedding may be a common feature on Mars.

Fig. 5a 230.26°W, 77.48°S. Scale: 2.12 km across. Mudslides – in thick tuff-like beds implies saturation by a liquid e.g. water.

Fig. 5b Layers forming terraces.

Fig. 5c Ice or snow are deposited in the edge of the fissure.

Fig. 5d Local joint patterns control.

Fig. 5e Local joints and fissures control spider growth. The pale albedo (white) tubes are old spiders partly eroded by outflow channels where fluids have burst the spider. Note the plug in the fissure with vents either side.

Fig. 5f 321.84°W, 87.00°S. Scale: 1.42 km across image. Rock type and local joints control the location and shape of the objects.

Fig. 5g 215.54°W, 65.42°S. Scale: <1 km wide. Spring. Fissures/faults with dust and mud-like material being jetted.

Fig. 5h 290.05°W, 80.78°S. 2.4 km wide. Late winter. Fans and ravines adopt the bedding planes. Cross cutting faults are avoided.

Fig. 5i 268.57°W, 87.00°S. Scale: 2.85 km across. Three-dimensional views showing terrace layering. Gas and fluids expelled take the shortest path to the surface – up any joint or crack (in cliff).

(All images courtesy of NASA/Malin)

mound in the summer (Fig. 2d) with re-growth of new tubes next season. Most large or interlinked ravines are identical in structure to tributary creek systems created by normal water-flow on earth – except they are often self-enclosed.

When the material removed from the fissure is deposited at the surface and joints to form mud-like mounds (rather than dust, which is blown away), the result is an elongate or complex mound shape that follows a reverse mini-creek or tributary pattern, often with a central core. Where mud-like material is involved, it may still form on the tops of the rims of snow above or below ice or snow (Fig. 5c). Mud-like material (and/or ice) may ooze down the side and simply block fissures.

On Earth, we do not get blocked fissures with mounds because erosion and weathering by rain, wind and surface water occurs too fast. We do see similar erosion patterns present in carbonate rocks (such as limestone) but erosion is often controlled by weak carbonic acid. so pitted or karstic weathering is more common and less well defined. Chemical weathering of primary rocks and the formation of carbonates may not be in abundance on Mars [18]. Several images that we looked at had pitted terrain with at least one sunken cave but these may have other causes (e.g. M1401676 at 179.37°W, 11.21°N).

One possible mechanism to create these structures is where minerals in the rock are preferably removed during degassing. The reader should compare the texture at the bottom of M1401676 with that at the bottom of M0705318 which is a Southern Polar image where ice is retreating with CO_2 and dust being expelled along bedding planes creating a pitted or etched terrain due to the near-surface retreat of ice.

4.P Rock Type and Joint PatternsP

Ravines, fans and one-armed bandits are often bedding controlled. Ravines tend to occur in or above tuff-like macro-bands, or are formed by spider mounds retreating in summer. Most spiders have joint pattern (Fig. 5d,f), fissure, fault (Fig. 5e,g) rock type (Fig. 5f,h,i), and bedding planar control (Fig. 5h).

Complex spiders, bushes and some branches seem to dominate in Mg-Fe rich rocks such as basalt. Branches tend to prefer flat terrain and the joint pattern seems to be the major control. In some cases (Fig. 5i), the fluids open up joints and spiders form raised platforms. Elongate tubes tend to form in association with rhyolite-like rocks, on the inside perimeter of craters, along the edge of raised spider platforms, or on cliff edges of retreating ice ridges or terraces (which look rather like large sand dunes). This may represent another form of the near-surface crustal retreat – the Martian process whereby crust is destroyed.

Each layer of rocks has a different jointing pattern, so to escape via a joint a fluid has to be derived near the surface. Jointing differs depending on the rock type, so it would be unusual for joints to continue down through the next layer. Therefore, the bulk of CO_2 is either trapped by widespread impermeable barriers and is only released when pressure builds up sufficiently. Then it is preferably removed from near surface ice (leaving an enriched H_2O ice sheet). Alternatively, it is derived from weathering of tuff-like beds and the base of basic rock types within the first few hundred metres of the surface.

4.1P Seasonal ChangesP

The spider-ravines seem to change size seasonally with growth tending to occur in the spring and summer months.

Most spider structures are sealed from the Martian atmosphere in winter, so as spring and then summer approaches, pressure build-up may sometimes lead to condensation of gases and subliming of ice inside the fully sealed tubes with water seeping back to the source and eroding the structure[10]. With most spiders, a slow moving water–mud mix would take between 20 minutes and 50 hours to return to the vent or vortex from which it came – but as soon as a breach occurred the water would revert to gas or to ice. This can only happen in a fully enclosed, pressurized tube (e.g. below permafrost). Pressures would otherwise be far too low.

If a vent is fully enclosed, pressure and temperature build-up may increase sufficiently to sublime any ice. Rather than water from one small tributary subliming, there may be a sudden torrent of all tributaries subliming at once - with the combination leading to internal head-ward erosion of the structure, along joints. Once the structure is open, fluids rapidly vaporize.

Since, the temperatures and pressures would not normally allow water ice to melt the majority of erosion must be caused by jetted gas, ice, dust and mud-like material; with only a small amount caused by erosion by fluids during or between venting episodes – and as this would be CO_2 gassed it would act like ignimbrite-type flow.

4.2P Temperature-Pressure ChangesP

Recent temperature data [19] show that at 60° S latitude the temperature varies between 0 °C and 10 °C (data are between longitudes 250° and 300° – e.g. late summer[11]). North of 60° S latitude, spiders do not seem to form in great numbers. This seems to coincide with the 0 °C line. We suspect that as more free water becomes available the spider tubes close off and block. Many spiders disappear in mid summer when the ice in tubes retreats to a central core (the mushroom shaped plug). At 75°S temperatures vary between –10 °C and -20 °C (data are between longitudes 280° and 300° – e.g. autumn). Darker soil may raise these temperatures slightly at ground level. Perhaps the highest surface temperature recorded on Mars was 27 °C (300 K), but in equatorial rather than polar regions [20]. The highest temperature recorded in early summer (at latitude 65 °S) was 240° K, not far off zero Celsius [21]. Hence, it may

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[10] Structures must be capable of withstanding high pressures or this process cannot occur.

[11] These are solar longitudes which are equal to the season. There are four seasons, so 250° to 300° is roughly summer.

be possible for water ice and or snow to be involved in the process of spider formation to some degree.

During summer months spider tubes may become blocked (by ice/snow/mud etc). When the tube is closed it may pressurize sufficiently and gas may revert to liquid water plus pressurized CO_2 (and/or clathrate). Any sudden change in pressure may have a dramatic effect. Spiders (1-2%) may burst their sides and develop outflow channels, which appear to be eroded by a fluid, possibly a turbidity flow of CO_2 and water. Where a lot of liquid is trapped, outflow channels may create structures that look like ancient rivers. The subsequent erosion may allow submerged layers to be exposed and these may subsequently retreat (as in Fig. 6).

4.3P The Spiral PatternP

Where gases are venting and temperatures drop, the gas may convert to snow or ice. As it moves up the tube, it spirals. The flow may be turbulent (most fluid or gas flow on Mars probably is) and this may cause it to expel outwards in a fan shape. At the vent opening it may snake (flick) back and forth due to the angular deflection of the spinning fluid and the interaction of the fluids on the surfaces encountered (rather than as a result of the Coriolis force), or in the weak Martian wind (a bit like when one lets a pressurized hose loose), eroding a curved path.

In order to spiral, a fluid would need to be mostly gas or a carbonated slurry of mud – so it must be low density - ruling magma out as a source. In the absence of a stronger torque, Coriolis force (being less than 40% of that on Earth) would have little or no effect on the shape of the spiders [22[12]].

The fluid must have the capacity to chill and set rapidly on exposure to the Martian atmosphere in order to retain the spiral structure and form complex branching forms. Viscous fluids (basalt, thick mud) would result in either a dome or a large concave mud-like puddle. Therefore, the fluids must be mostly CO_2 gas plus H_2O.

Fig. 6 Ancient river like structures may have formed by layer retreat on the edge of an outflow channel.

4.4P Snow, Frost and IceP

Excess CO_2 may exist either as layers of dry ice in the pole caps and polar permafrost, or as liquid CO_2 under high pressure, deep in the crust [10]. On escape from the vents, given temperatures at and below their triple points, CO_2 and H_2O should both turn to snow, ice, or frost. These may build up on the edges of or just above the rim of the fissure (Fig. 5c).

4.5P FluidsP

The spiders are controlled by the bedding and local

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[12] "The water in a sink might make a rotation in a few seconds and so have a rotation rate ten thousand times higher than that of the Earth. It should not be surprising, therefore, to learn that the Coriolis force is orders of magnitude smaller than any of the forces involved. …….it plays no role in determining the direction of rotation of a draining sink anymore than it does the direction of a spinning CD. …………….The rotation of the Earth does influence the direction of rotation of large weather systems and large vortices in the oceans, for these are very long-lived phenomena and so allow the very weak Coriolis force to produce a significant effect with time." [22].

joint pattern of the host rock which rules out the mantle as a source of the CO_2 and other fluids. Most fluid must have a near surface origin, so clathrate-hydrate could only account for those spiders where pressures were able to build up sufficiently between various horizontal layers of polar cap.

Where hydrothermal-type fluids are involved, they may pass through tuff-like layers, rhyolites or basalts and react with pyrite (FeS_2) and Fe^{2+} in those rocks – which may in-turn react with carbonates and silicates releasing CO_2, MgO and perhaps even some SiO_2 resulting in expansive clay-like minerals and even sulphides or sulphates.

Therefore, $MgSO_3$ (magnesite), anhydrite and gypsum may exist in the subsurface along with CO_2 – implying saline rather than fresh fluids. Magnesium sulphate may make up 30% of Mars' soil by itself [4]. Some of this may be associated with spider mounds and fans[13].

5.P Spider-Ravine DistributionP

There are numerous types of platforms and terraces. In most cases, complex spiders are related to creation of crust (however, some amoeba may be near-surface crustal destroying). The photos listed below show platforms, terraces and other related formations that are intimately related to spiders around the South Polar regions[14]: which may either mean the spiders are creating them or they somehow give a favourable environment to spiders, or the same processes create both:

1. Examples of terraces and spider formations on the South Pole: M0904866, M0904888, M1103239, M1104199, M1301769, M1302161, M1401631 etc[15],
2. Example of gullies and spider formations on the South Pole: M1600989, M0803864, M0802124, M1103105, M1103968, M1003203, M0900004, and
3. Examples of possible fluid channels on the South Pole: M0703526, M0302709, M0706139, M1003462, M1001461, M0903898, M0306499, M0305102, etc.

Accumulation of spiders and bushes (Fig. 7a) may also lead to the creation of multi-layered raised platforms or benches (Fig. 7b,c), which are widespread and very common in South Polar regions. Fans can also create crust – especially over ice. This is near-surface crustal growth – so some spiders destroy, while others create, regions. Some spider-related terrain may form the dune-type patterns. Textures in M0902218 (191.91°W, 81.84°S) and M0903139 from Southern Polar Regions, or from M1401568 (43.49°S, 347.87°W) - may display this type of feature.

Computer simulations demonstrate that the tilt angle of Mars fluctuates over a 100 million year period between 10 and 50 degrees with respect to a line perpendicular to the plane of its orbit. The axial tilt of Mars has a direct effect on atmospheric pressure and surface temperature; and the latter plays a significant role in the appearance and disappearance of polar ice caps on Mars [23]. The axial tilt may impact on the location of polar ice caps and associated structures, such as complex spiders. Ancient spider activity (see below) and associated platforms and terraces (which is quite extensive) may reflect polar wandering.

Complex spiders only seem to be active near Southern Polar Regions where the climate is more stable - only within an area of total daylight in the Martian summer. Therefore, constant sunlight and temperature may be necessary for their formation.

Numerous remnant textures attributed to formation of ancient spider, ravine (M0806317) and other less complex structures (with similar modes of formation) have been identified in the North Polar Regions, near the equator and throughout the Southern Hemisphere. Remnant platforms/terraces of overprinted spiders/ravines exist at lower latitudes (Fig. 7d)[16]. Away from the poles near surface CO_2 ice and H_2O ice from ancient structures should have evaporated[17] leaving creek structures that do not go anywhere or join at a central point as with ravines (Fig. 7e).

Figure 7f from the North Polar Regions (36.67°W, 76.82°N) has ancient structures virtually identical to old-tree spider shapes from M0808054 in the Southern Polar Regions (192.70°W, 77.90°S). Linear tube structures that follow joint patterns also exist at differing latitudes (Fig. 8a, Southern Polar area; Fig. 8b, lower latitudes).

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[13] Given the lack of carbonates observed on Mars and that Fe_2S (pyrite) H_2S is usually present in geothermal fields, carbonates may be less stable so much of the Ca^{2+} and Mg^{2+} would probably revert to $MgSO_3$ (magnesite) or $CaSO_4$ (anhydrite – the most likely form) or $CaSO_4 .2H_2O$ (gypsum) and siderite ($FeCO_3$) – or other minerals of similar form (mostly anhydrites) may also be ejected along with CO_2.

[14] These will just be listed, as sufficient 'type' examples are included in the figures and can be viewed at www.martianspiders.com or www.marsglobalsurveyor.com where the reader can input the image number and be directed to the corresponding MSSS web page.

[15] As well as: M1401621, M0905569, M0903715, M0906356, M0903484, M1401848, M0902066, M0806582, M0805723, M0901547, M1401708, M1301816, M1401682, M1401838, M0805965, etc.

[16] Note - the original image M1601033 also has remnant fan deposits (the dark streaks).

[17] Therefore, remnant pale albedo (white) material in ancient spiders and ravines not in latitudes away from the poles (Fig. 7e, f) may be one or more of the following minerals: magnesite, gypsum, salt, talc etc - as well as - or in preference to H_2O and/or CO_2 ice.

Fig. 7a Amoeba and spiders form complex inter-growth patterns.

Fig. 7b 178.98°W, 75.63°S. 2.8 km wide. Spring. A raised platform created by spiders, with tubes forming on the edges. Spider platforms tend to avoid depressions or bend around craters. There seems to be a crater on the left side of the platform (due to the curve).

Fig. 7c 7.81°W, 75.63°S, The spider terrace is some 1.42 km across and over 50 m thick. This shows that spiders create a large thickness of vertically stacked spider terraces. The terraces are undercut. The curved shape may be due to avoidance of an old crater.

Fig. 7d 77.78°W, 59.91°S. Scale: 1.41 km wide. An ancient spider terrace, with a honeycomb texture of overprints. The texture where two holes are aligned (like a pair of eyes) is common – each is an opposing vent from an old spider. The parent image has craters impacted onto the platform.

Fig. 7e 132.79°W, 31.61°N. Scale: 1.6 km wide. Old terrace of ravines/ spiders from the equator. They have pale albedo infill as with spiders. The creeks are not inter-linked and seem to join at a central point - as with ravines or spiders.

Fig. 7f 36.67°W, 76.82°N. Compare this platform comprised of old-tree (stump) shapes from the North Pole, with M0808054 (192.70°W, 77.90°S), from the South Pole. Both have almost identical texture. Scale: ~2.8 km.

A few examples[18] are given below that may support the concept that spiders and similar structures were once distributed more widely over other parts of the planet. This may be due to ice caps moving with changes in axial tilt:

- Ancient spider trees and ravines in M1600875 at 76.82°N (36.67°W), and remnant (etched) ravine structures in ice and possible one armed bandits on the edge of ice layers and other remnant features at the North Pole in M1700869 at 85.79°N (148.01°W). Terraces and other features on the North Pole may imply that spiders were once active there: M1500634, M1501020 (303.29°W, 70.9°N), M1600505, M1600874, M1600875, M1801854.
- Terraces with similar modes of formation in equatorial regions between 10°N and 10°S. M0904818 at 7°N (128°W) has an extensive platform or reworked (over printed) ravines and fans. This should be compared with M1701003 (44.78°W, 47.98°S).
- M1801807 at 5.30°S (221.75°W) is an example of extensive terraces and tubes formed by a similar mode of formation.
- Large etched terraces with ancient spiders exposed in cliffs and in craters in M1600734 at 35.32°S, (17.96°W)[19].
- Etched platforms, ancient spiders, tubes, dunes in M1701031 at 42.90°S, (154.25°W); Etched spider platforms, old rotated spiders covered with sand and meandering canyons partly covered by mud-like (spider-related) tubes in M1401568 – also at 43°S, (358°W). The fluid channels in this image are rather unique and may even have been eroded/ created by spiders (?).
- Etched spider platforms in M1801713 at 49.50°S, (2.60°W).
- Fluid channels (see footnote[20]).

Further examples for comparison are the lower latitude Noachis Pits and Noachian formations of spiders near Terby Crater (~27°S, ~285°W) with the Southern Polar spider platforms:

- Noachian: M1491277, M1500964, M1801039,

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[18] For purposes of brevity only a subset has been provided. North is listed first to make it easier for the reader to visualize the north-south dispersal, which is more important at this stage.

[19] The material in the craters is very interesting.

[20] Examples of fluid channels from the MSSS web site can be seen at: http://barsoom.msss.com/mars_images/moc/june2000/. Interested researchers can compare these to the possible polar fluid channels to form their own opinion.

Fig. 8a Polar linear mounds in joints and faults.

Fig. 8b Linear mounds at lower latitudes.

Fig. 8c 107.95ºW, 86.16ºS. Scale: ~1 km wide. Spring. Large fans from the South Pole forming terraces of alternate dark and light coloured material.

Fig. 8d (left), 8e (middle) and 8f (right) 62.08°W, 3.74°S. Each ~1.74 km wide. Late spring. Trough-cross bedded (TCB) terraces of light and dark material have formed from venting of material (possibly clathrates or ice and eroded bedrock minerals) via faults. The beds are not folded; it is the same rock unit in a continuous sequence.

M1801490, M1101304 (355ºW, 48ºS), M1100268 (356ºW, 47ºS), M0900539

- Southern Polar: M1103219, M1103956, M0904839, M1301769

6.P Other ModelsP

6.1P Genesis of Similar StructuresP

Large terraces can be formed by fans, provided the pressures are sufficient and the fans are large so overlap occurs. For instance, Fig. 8c comprises layers of large sub-horizontal fans on the Southern Polar icecap. Pseudo-sedimentary ‘trough-cross bedded’ (TCB) deposits (Fig. 8d-f[21]) that are further north (non-polar), may form when high-pressure jets expel fluids from faults or fissures. In this case, the fluid has expelled fans of material to create horizontal layers of alternating dark and light albedo material. One explanation of the alternate banding is gravity separation of minerals in a rotating fluid where minerals have a density contrast. However, the Southern Polar cap fans are similarly layered. The fluids could be clathrate-hydrates or derived from alternate layers of ice and bedrock that have differentially been removed from the subsurface. This is a process of near surface creation of crust – so considerable destruction of layers must occur at depth, which may lead to normal faulting (concentric) as the source material from below is removed[22]. Thus, the process with Fig. 8c,d,e,f may create TCB layers. Platforms and terraces can also be created by spiders (Fig. 7a,b,c). These same layers may be destroyed by formation of (Fig. 4) tubes, ravines and spiders. Thus, Mars has a dynamic process of continual creation and destruction of near surface crust.

Large fanned sand hills that look like inverted river systems (Fig. 8g, Southern Polar ice cap, Fig. 8h, 60ºS) or those with enclosed tube feeders that vent in a shape like a delta (Fig. 8i) most likely form in a similar process to spiders. There is little venting, either since most fluid flow is below the surface, because the structure forms when sand or ice is draped onto the moist toe of a dune, or because venting at the toe is via a series of small fans.

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[21] There is a possibility that the platform in Fig. 6c may also formed the same way, rather than from amoeba.

[22] If a terrace of spiders is built up over an ice sheet then other rocks could then form on top of the spider terrace. Subliming ice would enable H_2O, CO_2 and clay-like layers to build up and be expelled. A void must exist below the ground surface equivalent to the amount of material removed. Therefore, faults may be slip along the top of the submerged layer - so displacement may be proportional to the volume of ice and clay-like layers removed from the sub-surface.

Fig. 8g Sand hills forming alluvial fans that adopt reverse drainage patterns at the South Pole. These form by growth at the toes and also down the middle of the ridge.

Fig. 8h The same pattern at 60ºS. The fluid seems to be expelled at the top or along the ends.

Fig. 8i A variant with long feeder tubes (if the sand/ice cover was melted we would see an open canyon). Note the slight meander of tubes and the way the fans have formed ridges – so this may be growth rather than retreat. The small spots in the dune toe may be small fans and the gray albedo on the left is probably dust or gas.

Tubes also form on the edge of craters, in association with dark areas (‘blobs’), or on the edges of cliffs in polar areas due to retreat of the icecap in the summer months.

The terraces of Fig. 9a show spiders forming as layers shrink rather than biological growth of layers. Compare this image to Fig. 4a and b. Both represent near-surface crustal retreat – hence destruction of layers. Figure 9b is another area of contention. The dark ‘blotches’ are forming above ground in permafrost cracks next to other spider areas, yet the areas do not seem to overlap. Either the source fluid has depleted on the left, the rock type differs, or growth follows a front (like a fire). Figure 9c and d could be explained away as cryptic CO$_2$ frost, but Fig. 9c seems to be forming above the ground (which can be confirmed by inverting the image). Figure 9e is probably the most convincing as organic – there are starfish-shaped, serrated and other unusual spider structures in this image[23]. There is most probably water within metres of the surface. This area has complex spiders on a raised platform, so it is probably an area of accretion with a platform forming.

Figure 9f looks rather like the root system of a plant – but the low temperature geophysical models have no problems explaining this structure. It is a series of layers that have faulted along the bedding, with movement breaking spider tubes apart (those at the top), while others have formed etching away at the layer’s base in the opposite direction.

6.2P Regards Life on MarsP

If features exist that cannot easily be explained by geology, then some structures might have an organic origin. The reverse assumption is that if a single geologic model may explain everything, then there is no reason to invoke organic life form models.

A number of geologic models were investigated to explain the various forms of ‘plant or animal’ like structures from Mars. Literally hundreds of photos and a large number of different structures were examined. Following this, relationships to geology were established.

Few geologic models, with the exception of those discussed, cover the apparent seasonal changes in the appearance of the structures.

The main spider-ravine variants were systematically analyzed from the perspective of both a geophysical process and a biological model. We looked for and found that the bulk of the structures are controlled by geological structures. Then we looked for evidence that would contradict a geophysical origin – structures that would simply not occur or exist in nature. Structures above the ground do not prove an organic origin. They can often be explained by geology. The structure that would prove an organic model would be a fibonacci one (see below). The other structures are coils, spirals or loops of branches. These are common in vines and many species of plants on Earth (but typically only at the small scale). So far, we have not found this pattern replicated – although some branches curl back on themselves in a less convincing fashion.

We have problems with the inorganic models in the following areas:

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[23] The larger image has what seems to be either a water-like fluid which we have interpreted as ice on the surface.

Fig. 9a Terraces in retreat. Spider tubes form perpendicular at the base of layers.

Fig. 9b The dark albedo (black 'blob') material on the right forms bush-shapes with feeders being permafrost fractures. The area on the left either represents different underlying rock or subsurface depletion of source fluid from layers.

Fig. 9c 305.18°W, 81.67°S. Scale: 700 m, Late spring. Black (dark albedo) frost or bushes (?). It looks like cryptic CO_2, but the branches are very fine and the object is three-dimensional.

Fig. 9d A similar object, which may be cryptic CO_2 growing along cracks in the ice.

Fig. 9e 179.29°W, 75.77°S. Scale 2.2 km across image. A platform with rotated and pitted forms in mud-like material at the South Pole. The vent (hole) on the left has burst. Note the small-rotated starfish shape above this. The serrated and pitted textures are hard to explain geologically. On the right side is a mud volcano. A serrated spiral form exists in the top right side of the image. The sponge shapes are probably small vents. There may be water near the surface.

Fig. 9f Spiders that look much like a plant root system. The top layer slid down to the left breaking the original spider branches (on the top of the layer) – the reader can rejoin them. There are also spider tubes growing from the layer at the base of the bedding plane etching the planar fault.

1. Few models explain where the CO_2 comes from.
2. Inorganic models do not adequately explain why some of the spider-ravines rotate (although we have tried).
3. The sheer variety, size and shape of the structures severely stretches the limits even to these geophysical models, which are quite robust[24].
4. The reverse tributary pattern (bush shape) follows that of plants and is rarely found in nature (although we have provided an explanation).
5. Spiders should follow cracks in craters or be confined to the rim or the very core but they often cover the whole crater.
6. The length of time it takes the spider-ravines to form is typical of plant activity rather than geology. Most of Mars has apparently undergone little change over the last two or three billion years yet 'spider' and 'bush' structures form in perhaps a single season, which is quite remarkable[25].
7. Some layers are in retreat (subliming) while only metres away complex spiders are forming, so two different processes occur at similar temperatures – one layer destroying the second layer building.
8. The seasonal growth pattern: Spider branches seem to gradually disappear in winter (wither away?)[26]. Some areas may become unsuitable for

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[24] The reader should compare the different spider formations in M0900384, M0906352, M0900570, M0807706, M0807008, M0902066, M0804821, M0803864, M0802620, M0802193, M0805688, M0805994, M0901352, M0901488, M0901567, M0903312, M1003736 (358.70°W, 70.91°S), M1102665, M1103105, M1103107, M1301113, M1104140, M1301816, M1301827, M1401682, M0302709, M0706139, M1003462, M1001461, M0903898, M0305102, M0204761, M0905128, M0906313, M1600550, M0702750, M0703883, M0901100, and M1202005.

[25] The following photos appear to show spiders in different stages of formation: M0900528, M0900452, M0808054, M0806175, M0805962, M0901716, M0904068, M1003668, implying different ages of spiders. The reader needs to be aware that geology can provide the same effect. Not all joints will open simultaneously. In both cases, there will be a peak time where the numbers of new entrants will decline.

[26] Complete spiders under frost: M0806508 (Ls 232), M0806477 (Ls 232), M0803818 (Ls 226), M0901372 (Ls 238), M0901714 (Ls 239), M0903302 (Ls 243), M0903642 (Ls 244), M1401708 (Ls 340), M1003372 (Ls 272), M0200791 (Ls 151 perhaps the first spider photo), M0903813 (Ls 244), Gradually disappearing (withering?) spiders: M1003215 (Ls 271), M1003277 (Ls 271), M1102603 (Ls 285), M1102620 (Ls 285), M1002538 (Ls 267), M1103109 (Ls 287), M1103219 (287W), etc).

spiders or this pattern may be temperature coincident. The CO_2 ice may start to crumble as the temperature drops, reverts to cryptic CO_2 form, or the structure settles and closes itself off as mud-cake ices up. This could be solved by imaging the same spider formations at different times in a season.

The following discussion is highly speculative.

7.P The Organic ModelP

The spiders are controversial because they have shapes that we would expect to see from organic life forms - yet also have strong geologic relationships. A simple, effective way to determine the difference does not exist. Therefore, the various organic models must be adequately addressed. The only solution is painstaking search for clues to see if geophysical, biological, or a combination explains everything. However, if some of the complex structures have an organic relationship there must be subtle indicators in the atmosphere.

The polar areas are more hospitable as they have more constant temperatures in summer so a better chance for water to exist (as in M0805688, Fig. 9e) within a few metres of the surface. In other areas, extreme temperature changes make life less likely.

The main problems with the organic models are:

- Photos showing one side of a spider blown out with snow or ice vented suggest a hollow structure (which we can explain geologically).
- The photos showing the side of the structure has 'blown' out and fluids have created an ignimbrite-type erosion gouge (a geophysical process).
- Most structures are in joints, fissures or have bedding plane relationships (e.g. follow tuff-like beds) so are clearly structurally controlled by geology.

Leonardo of Pisa, better known as Fibonacci (1170-1250), invented mathematical equations that are invariably represented by most plants on earth, in shells, some animals and even in brain neurons - but are rarely seen in inorganic relationships. Inorganic phenomena typically do not follow these numbers: 1,2,3,5,8,13,21,34,55,89,144.... Fibonacci branching normally does not occur inorganically because each number is based on the two previous numbers in the sequence. Some plants form by the sequence 1, 1, 2 (1+1), 3 (2+1), 5 (2+3), 8 (3+5), ...etcetera - which is difficult for inorganic processes to mimic [24 and 25].

Some spiders may follow a fibonacci pattern (Fig. 10a-d). Unfortunately, after 1,2,3,5 the relationship was sometimes lost due to poor definition of pixel size. However, the fibonacci-type relationship is widespread over entire platforms of complex branched spiders. Three types of spiders: bush forms, tree shapes, and some branch forms may fit this relationship, but further work is required to validate these statements. Hence, the bifurcation pattern is a very good reason to support the organic model (at least in its coexistent biogeophysical form).

However, in the same images there were also some exceptions. In addition, some ravine structures also seemed to fit the pattern and these almost certainly have a geologic origin as the creeks are dendritic. There is no way for ravines to work out how to branch by adding the number of previous tributaries. They can approximate this, but only by chance - except where biologically formed spiders revert to ravines in late summer. It may be possible for natural creek tributary structures as implied by the 'head-ward erosion process' to sometimes adopt the same branching structures as plants, due to the jointing patterns – again only by chance.

Fibonacci branching can be counted as a percentage of the total number of branches seen. It is unlikely that inorganic features would follow fibonacci patterns in large numbers by chance, so by taking large numbers of sample photos one could calculate the odds against chance of these being a coincidence. This provides a way to prove whether they are organic or not by just using the MOC images. One can take pictures of the same area and use this to make pictures with a continually smaller resolution. If one checked ~10,000 bifurcations one would then know whether spiders were organic.

8.P The Co-Existent,P Biogeophysical ModelP

Plants or simple life forms could co-exist with the geophysical models, which may be required as a means of accessing nutrients being ejected from vents.

Where mud is involved in the formation of the central spider plug maghemite may form at the surface. If bacteria are involved and oxygen levels of source rocks are low (as predicted) then it could be converted to magnetite.

Mileikowsky [26], estimates that, on average, roughly 150 kg of 'hospitable' ejecta from Earth

Fig. 10a 194.74°W, 76.92°S. Complex branching spiders, each around 800 m wide.

Fig. 10b The same branch image showing the fibonacci-type pattern outlined.

Fig. 10c 262.65°W, 85.80°S. Inter-growing spiders, 700 m across, with mud-like core; untouched. The reader should try to fit the fibonacci pattern. Note the similarity of the Fig. 8i toe area to the branch ends.

Fig. 10d 262.65°W, 85.80°S, A different spider shape (800 m across) from the same area with fibonacci-type pattern outlined.

rocks reach Mars each year. Approximately, 7% of hitchhiking microbes can be expected to survive the journey. The chances of survival and colonization would be enhanced if hitchhiking microbes were lucky enough to land in a warm, moist, spot on Mars [27]. The spider-ravines are extremely widespread, so the chances of an Earth microbe landing on an active vent and surviving, cannot be ruled out.

Work on hydrocarbon seeps [28] in the Gulf of Mexico shows that bacteria may subsist by gaining energy from compounds including methane and hydrogen sulphide – one of the gases that could be released from spider-ravine vents. Gas hydrates may also collect in the hydrothermal-type system, and could also supply organisms with their nourishment. Therefore, if the source of the fluids related to spider-ravines is hydrothermal then this further advances the case that bacteria and other more complex organisms, or even plants, could form either in the subsurface or at the spider-ravine vent.

The Martian Polar Regions have thick-layered sequences, presumed to consist of silicates and ice. CO_2 seasonal and residual frosts occur throughout summer. The North Polar Region comprises H_2O with the South Polar cap being mainly CO_2. The South Residual cap has distinctive collapse and possibly ablational topography, with polygonal depressions suggestive of thermal contraction cracks [29]. Clathrates of CO_2 and H_2O could theoretically occur at the Martian poles (at depth) as the most common ice we would expect to find, especially underground where the pressure of overlying rock forces CO_2 molecules into the lattice [10]. CO_2 must either reside in the regolith as extensive carbonate deposits or in the polar caps as ice or clathrate [11] or trapped and pressurized below clay-rich horizons. Hypothetically, these could be a source of sustenance or may be the cause of the fluids – especially in Polar Regions.

“The fact that the spots mainly appear in the polar region suggests that a long period of sunlight is necessary for the features to form. On Earth, the closest known analog to such biology is a mid-ice photosynthetic bacterial grouping uncovered in Antarctica” [30].

Spiders provide moisture, sustenance and perhaps even a heat source. Therefore, in order to survive on Mars organisms may require the geological structures and processes to occur.

9.P ConclusionP

While an organic model may be valid, it has a largely psychological attraction and is not required to explain most structures.

Yet, if life did form on Mars 4.3 billion years ago in a less harsh environment then, it would seem quite reasonable to assume that it would survive even the most extreme climatic events, therefore in all probability it should still exist.

That does not imply organic life does not exist on Mars, rather that if it did then a co-existent biogeophysical relationship would certainly exist – so these structures would be the best, first place to look for life on Mars.

If life does not exist at the surface but still does at depth, then it should be preserved in remnant spider mounds or in the mud-like layers of Mars. There is absolutely no way that bacterial life could exist at depth yet not be dragged to the surface by the fluids that help create the mounds.

The fan, ravine, linear, fissure, and many of the less complex branch, bush and spider forms most definitely have a geologic origin. The complex patterns could be formed by the geologic models, which are very robust – but it is less likely. Even with our skepticism of the organic models, we have difficulty with some of the complex spiders (some boab or banyon trees and those in Fig. 9e,f) forming by geophysical processes.

We have argued that some near-surface landforms are in the process of growth or creation (complex spiders, trough-cross bedded deposits) while others are associated to destruction or retreat (squid, tubes on cliffs, and some areas of pitted surface caused by fans). Thus, Mars seems to have a dynamic process of recycling of its near surface crust (of CO_2 perhaps), which rivals subduction zones on Earth. The fact that it is still operating after some 4.5 billion years suggests that it either is in equilibrium or follows a pattern. We think the following accurately describes the dynamic processes on Mars:

- In most cases, complex spiders tend to create platforms and terraces and hence crust (including some dunes). Some amoeba modify or etch terrain.
- The one-armed bandits, some spider-tubes and 'squid' form on the edge of clay-like layers. They destroy crust, so layers retreat.
- The trough cross-bedded layers and large fans tend to create terraces - so at depth layers (probably submerged ice and mud-layers) must be destroyed.
- The fans typically etch crust, digging out holes or pitted terrain - they may destroy or create terrain depending on the fluid. Ravines may do either.
- Many tuff-like layers and terraces are being destroyed by layer retreat.
- Black (dark albedo) 'blob' material and tubes that occur on the edge of layered cliffs (of ice and or sand) or edges of spider platforms in Southern Polar Regions is crustal destroying. The cliffs are in retreat.
- Large alluvial fan shaped sand-like ridges form as fluid oozes out the end of along the top or ends of the ridge – so they form crust.
- Where CO_2 alone is emitted as a gas, it tends to be related to destruction of crust and pitted terrain.

We have supplied sufficient information for the reader to make an informed judgment. The simplest explanation is often the best. The structures may be explained by the geologic processes described above. However, that does not mean the models are correct. The structures would appear to fit an inorganic origin but do not prohibit life on Mars.

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