'Grange:' 'Crystalline/Carbonate' Rock Crystals or Evidence of Endolithic Lichens in Gale Crater, Mars?

Richard A. Armstrong
Dept. of Vision Sciences, Aston University, Birmingham B4 7ET, United Kingdom,

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ABSTRACT

An unusual specimen referred to as 'Grange' was photographed on Mars by the Curiosity rover on Sol 2217 close to the 'Inverness' drilling site at Gale crater. 'Grange' appears to be composed of a crystalline/carbonate resembling calcite and extends from a fissure onto the rock surface as a partially eroded oval object approximately 20 mm in diameter. 'Grange' possesses clusters of circular black surface features (BSF) which have been interpreted as embedded rock crystals but which also resemble the reproductive apothecia of terrestrial lichens. Quantitative morphological analysis showed that the BSF were dissimilar to black 'particles' adhering to the rock adjacent to 'Grange' and which may be regolith or small black crystals eroding from the rock. Comparison of the BSF with samples of apothecia of the crustose lichen *Porpidia macrocarpa f. macrocarpa* (DC.) Hertel & AJ Schwab and terrestrial rock crystals using Principal components analysis (PCA) indicated that both share some features with 'Grange' but overall, the lichen apothecia were more similar to the BSF. Hence, although a calcite-like structure with embedded crystals remains the more likely explanation for 'Grange', the data indicate that an endolithic lichen living within the crystalline structure, as in extreme habitats on Earth, is a plausible alternative interpretation. Future Mars missions should intensify the study of cracks and fissures in rocks, using drilling and sample collection, especially at sites which may have evidence of carbonate or crystalline-like deposits as they could harbour the first definitive evidence of life on Mars.

Key Words: Gale crater, 'Grange', Lichen, Apothecia, *Porpidia macrocarpa f. macrocarpa*, Calcite, Rock crystals, Principal components analysis (PCA)

*Corresponding Author: R.A.Armstrong@aston.ac.uk

1. Introduction

Whether there is or ever has been life on Mars remains highly contentious (Kaminskyj 2021; Weintraub 2018). Despite considerable evidence suggestive of current and past life (Bianciardi et al. 2014, 2015, 2021; Joseph et el. 2020, 2021; Rizzo & Cantasano 2009; Rizzo et al. 2020, 2021) including what may be lichens (Armstrong 2021a) and fossilized sponges and tube worms (Armstrong 2021b, 2022) it is the position of NASA (2015) and others, that Mars may have been habitable in the ancient past but is currently inhospitable to all but microbes well below the surface of the planet. Given this

prevailing belief in a lifeless or microbial-inhabited Mars, many scientists, therefore, instead focus their investigative efforts in the search for water, chemical biosignatures in soil and rock, geophysical alterations due to weathering, and gases in the atmosphere (Mumma et al. 2009' Trainer et al. 2019). One possible consequence of this more narrow focus and emphasis on geology, is a predisposition to misinterpret and failure to examine life-like forms which are dismissed as oddly shaped rocks or minerals when morphological evidence, including complex statistical comparative analysis, favors biology, including what may be algae, fungus and lichens (Armstrong 2021b, 2022; Rizzo 2020; Rizzo et al. 2021).

There has been speculation regarding whether lichens could survive successfully on Mars (Kuiper 1955; Armstrong 2017, 2019a,b). Lichens could withstand some aspects of the hostile environment especially if they live within relatively protected environments such as within the fissures and surface layers of rocks as in some terrestrial deserts and the dry valleys of Antarctica: 'endolithic lichens' (Friedmann 1977, 1984; Kappen & Friedmann 1983). An interesting terrestrial example of life in extreme environments is the endolithic desert lichen *Verrocaria rubrocinta* Breuss, which inhabits the 'caliche plates' exposed on the surface of the Sonoran desert (Garvie et al. 2008). Caliche is a sedimentary rock composed of hardened natural cement of calcium carbonate which binds to gravel, sand, clay, and silt often in arid or semiarid areas, also known as 'calcrete' (Dixon 2013). There is a distinct zonation within the calcrete: (1) an upper micrite layer composed of a microcrystalline form of calcite, (2) an algal layer with clusters of algal cells, and (3) a 'pseudomedulla' with fungal hyphae, the hyphae becoming less numerous with depth below the surface (Garvie et al. 2008). Calcite has been reported from Mars by the Phoenix lander, 3 – 5wt% of calcite and an alkaline soil being detected (Boynton et al. 2009).

A review of photographs uploaded by the Curiosity rover at Gale crater reveals many rocks with cracks and fissures filled with apparently light-colored deposits which resemble a crystalline carbonate such as calcite. An unusual object associated with these fissures, and referred to as 'Grange', was photographed by the Curiosity rover on Sol 2217 close to the 'Inverness' drilling site (Lakdawalla 2018). This unusual structure extends from a fissure onto the rock surface as a partially eroded object. The complete specimen comprising 'Grange' is shown in Fig 1. It shows an oval, crystalline-like object, approximately 20 mm in diameter, almost one half of which is missing, possibly the result of erosion by Martian winds. Various extensions of the object ramify over the surface of the rock especially in adjacent cracks and fissures.

A second, smaller structure is present above 'Grange' which also appears to be connected to the network of strands. Fig 2 shows the immediate surroundings of 'Grange' and shows numerous black 'particles' adhering to the rock surface which could be either regolith or small black crystals eroding from the rock.

A closer view of 'Grange' is shown in Fig 3 revealing clusters of distinct embedded circular black surface features (BSF), many forming linear clusters. The BSF have been interpreted as embedded crystals (Lakdawalla 2018) but they lack obvious crystalline features such as a 'faceted' shape with straight edges and flat surfaces. Nevertheless, the BSF of 'Grange' also resemble the reproductive 'lecideine-type' apothecia of many terrestrial crustose lichens (Armstrong 2017).

Lichen apothecia consist of two parts, the 'disc' and the 'margin'. Some apothecia consist of only a single 'proper' margin the same colour as the disc referred to as 'Lecideine' whereas others are also surrounded by a second 'thalline' margin the same colour as the thallus and referred to as 'Lecanorine'. Fig 4 shows the similarities between the clustering patterns of the apothecia of the common terrestrial rock lichen *Porpidia macrocarpa f. macrocarpa* (DC.) Hertel & AJ Schwab (Fig 4a) and the BSF (Fig 4b).

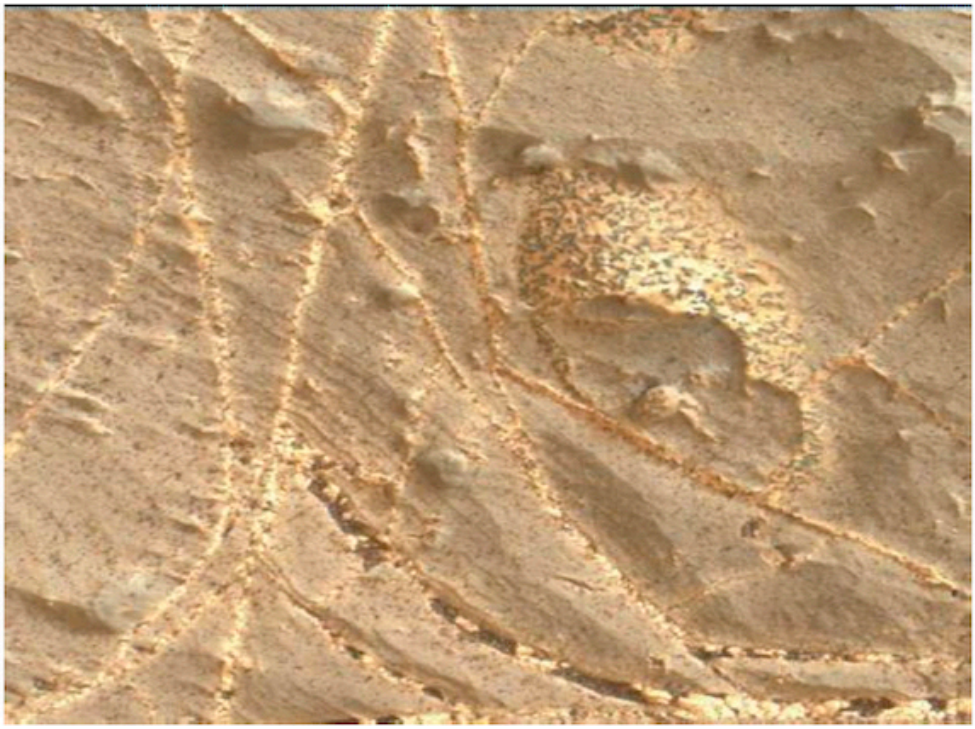


Figure 1. The unusual object ('Grange'), resembling a crystalline carbonate-like structure such as calcite, complete with its immediate surroundings photographed by Curiosity on sol 2217. It comprises an oval-shaped object with almost one half of the structure missing and various extensions ramifying over the surface especially in cracks and fissures (Image: 2217MH0007060000802993C00_DXXX) (NASA/JPL – Caltech).

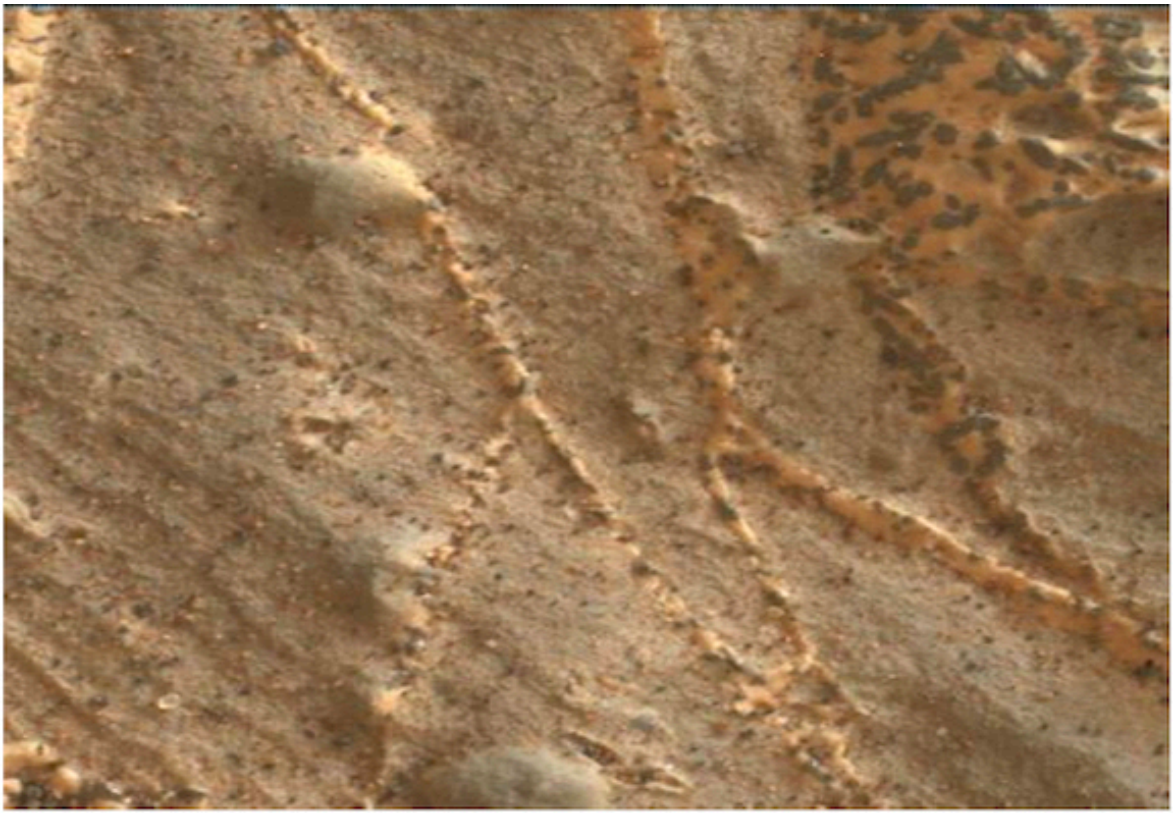


Figure 2. The surroundings of 'Grange' showing the black particles adhering to the rock surface (Image: 2217MH0007060000803020C00_DXXX) (NASA/JPL – Caltech).

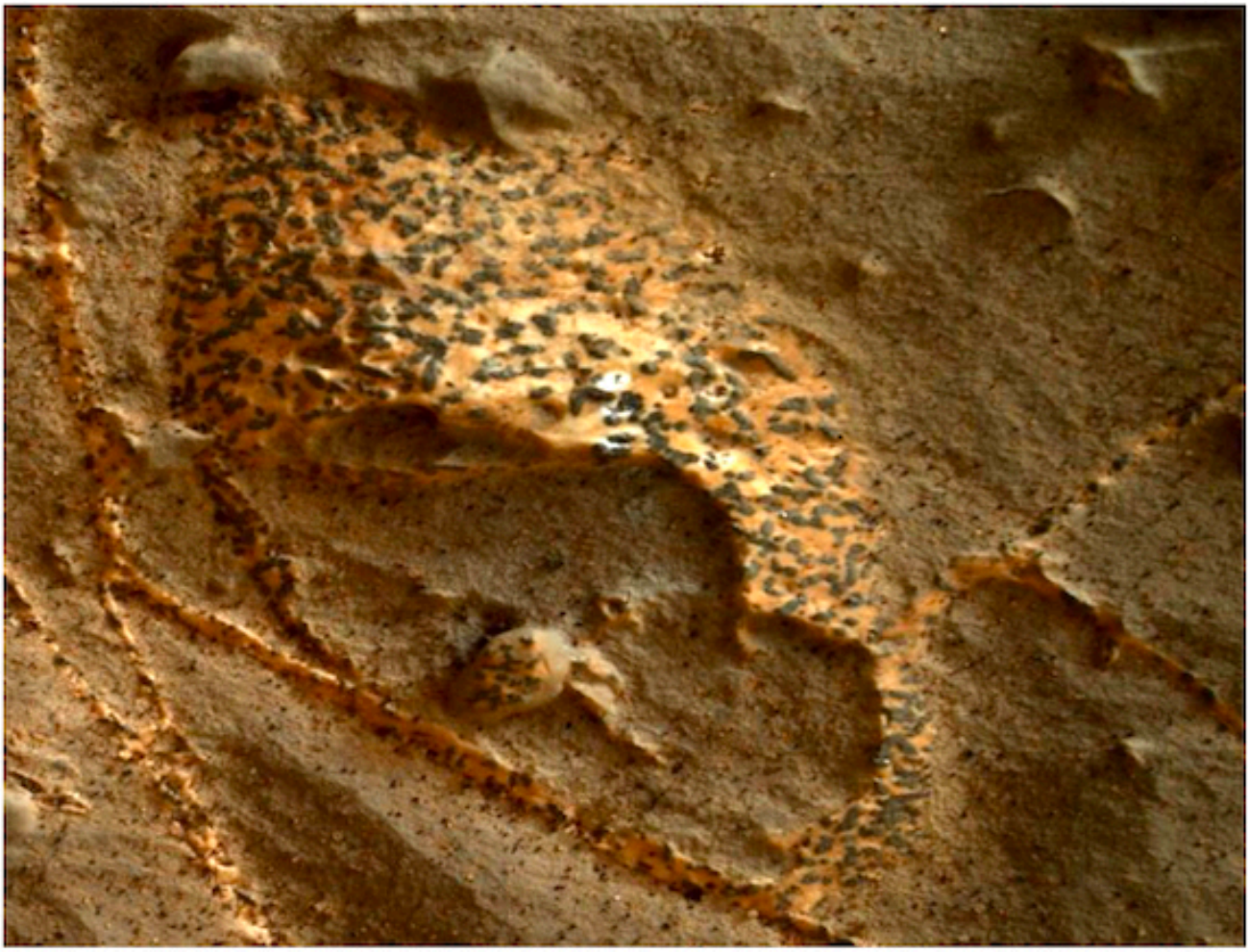


Figure 3. Close-up view of part of 'Grange' showing the clusters of black surface features (BSF) scattered over the surface (Image: 2217MH0007060000803018C00_DXXX) (NASA/JPL – Caltech).

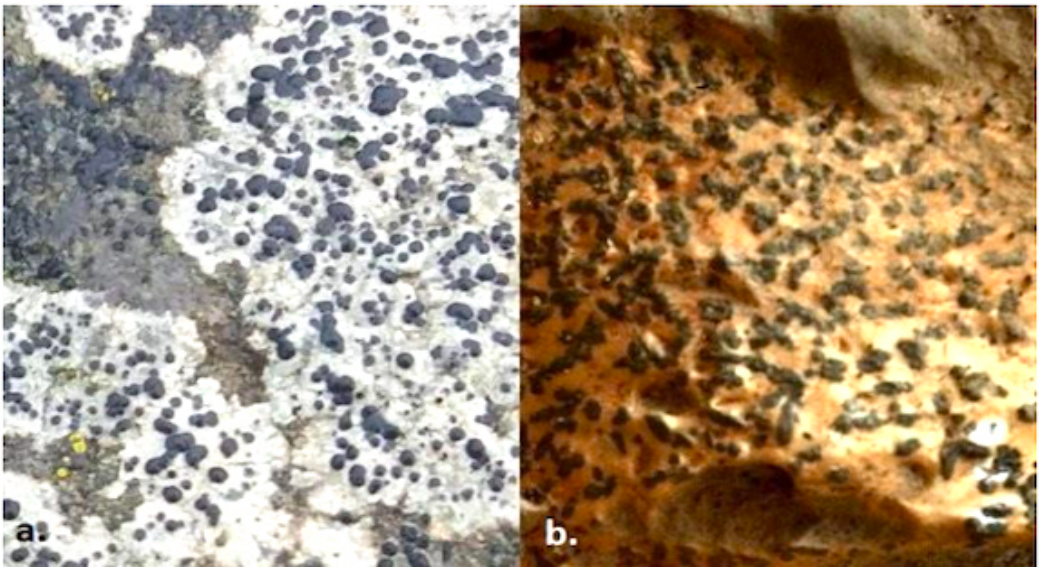


Figure 4. Clustering of the BSF on the surface of: (a) thalli of the terrestrial crustose lichen *Porpidia macrocarpa f. macrocarpa* and (b) 'Grange' Note the similarity of the clusters of the BSF to the reproductive black apothecia on the surface of the lichen thallus (Image 4a: 2217MH0007060000803018C00_DXXX) (NASA/JPL – Caltech).

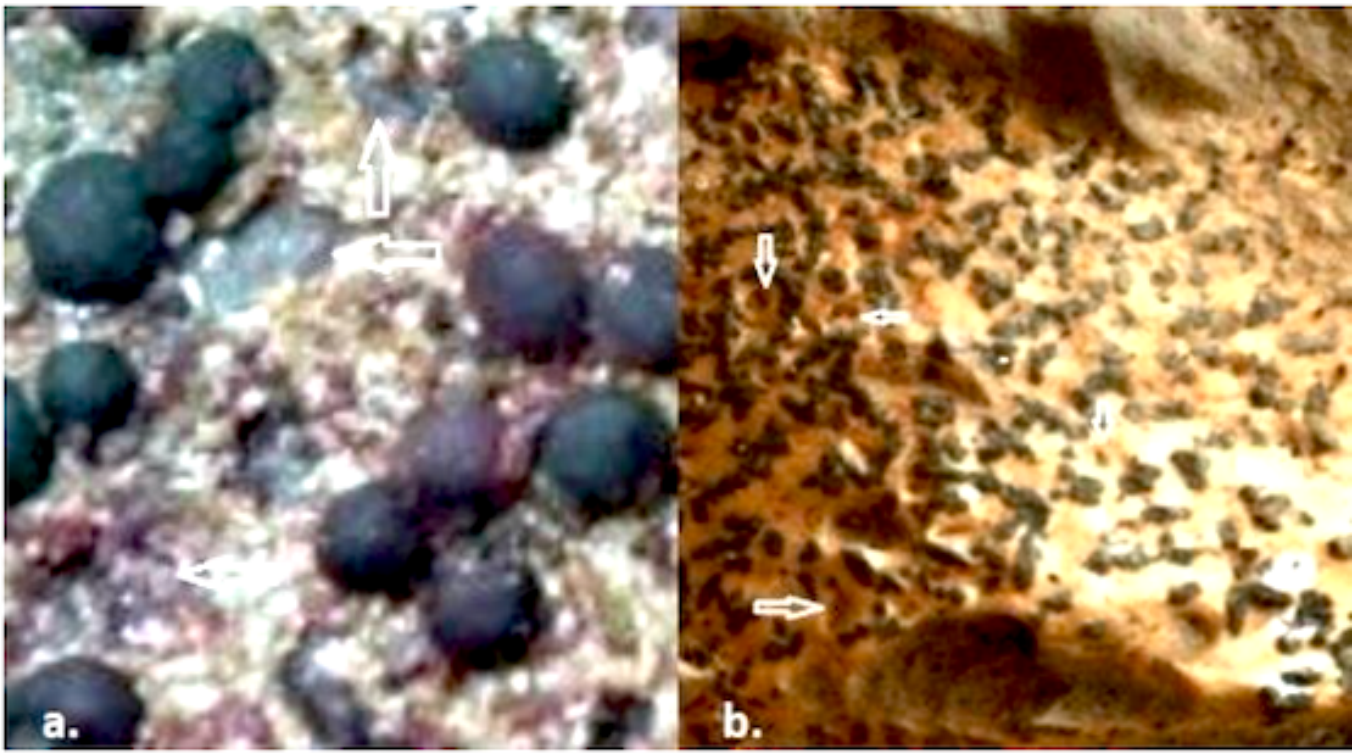


Figure 5. 'Pitting' on the surface of: (a) thalli of the terrestrial crustose lichen *Porpidia macrocarpa f. macrocarpa* and (b) 'Grange'. The surface pitting of the terrestrial lichen may be the result of mature apothecia breaking off the thallus. Note the similarity to the pits on the surface of 'Grange' (Image 4a: 2217MH0007060000803018C00_DXXX) (NASA/JPL – Caltech).

Table 1. Details of photographs analysed

Image	*Features*	*Origin*
'Grange'	Possible calcite with embedded black surface features (BSF)	(NASA/JPL – Caltech).
PM1 - PM6	Terrestrial crustose lichens with black apothecia	R.A.Armstrong (Personal lichen archive)
CC1	Calcite, Willemite, Franklinite,	Franklin-Ogensdorf Mineralogical Society, Incorporated. Trotter Dump, Franklin, NJ
CC2	Calcite, Willemite, Franklinite, Minor Sphalerite	Franklin-Ogdensburg Mineralogical Society, Incorporated. Sterling Hill Mine, NJ
CC3	Small black crystals in calcite	mindat.org
CC4	Small black crystals in calcite	CanStockPhoto.com (cap52113560)
CC5	Babingtonite crystals in calcite	Lane Brothers Quarry, Hampden County, MA
CC6	Porphyritic rock with large phenocrysts	Kaiser Science

In addition, Figure 5a shows various 'pits' on the surface of the lichen which may result when mature apothecia become detached from the thallus Similar pits are also present on 'Grange' (Fig 5b). The similarity between the BSF of 'Grange' and terrestrial black crystals, such as Willemite and Franklinite embedded within calcite are shown in Figure 6, some of which also display clustering and in some cases, linear clusters of crystals similar to 'Grange'.

The rationale of this study was as follows: (1) in the most extreme environments on Earth, lichens often live endolithically within cracks, fissures, and the surface layers of the rock, (2) in some terrestrial deserts, the 'callitriche plates' may harbor endolithic lichens, (3) there is likely to be calcite and other crystalline carbonate deposits on Mars, and (4) 'Grange' appears to be such a structure and to exhibit apothecia-like features, i.e., the BSF, on its surface. Hence, a quantitative morphological investigation was made as to the degree of similarity of the BSF with: (1) apothecia of P. macrocarpa f. macrocarpa (DC.) Hertel & AJ Schwab and (2) examples of terrestrial rock with embedded black crystals. First, the BSF of 'Grange' were compared with the black 'particles' adhering to the adjacent rock surface to determine whether they could have a common origin. Second, using Principal components analysis (PCA), the morphological features of the BSF were compared with examples of lichen apothecia and black rock crystals.

2. Methods

2.1 Photographs

Details of the photographs included in the study are summarized in Table 1. The photographs of 'Grange' were taken by Curiosity on sol 2217 (November 2018) near the attempted drill site 'Inverness', a region of hard, gray Jura and part of Vera Rubin Ridge (Lakdawalla 2018). This photograph was compared with six thalli (PM1-6) of the terrestrial lichen P. macrocarpa f. macrocarpa taken in north Wales, UK (Armstrong 1974) which has clustered black apothecia similar to the BSF of 'Grange'. Both 'Grange' and the terrestrial lichens were compared with six photographs of terrestrial rocks with embedded black crystals (CC1-6). Online searches were used to select an initial sample of photographs using various search terms, e.g., 'black rock crystals', 'black crystals embedded in calcite', 'black crystals in rock', 'Franklinite', and 'Babingtonite'. Photographs were then selected from this initial sample for study which most resembled the BSF, i.e., exhibited individual and clustered rounded black crystals which were distributed over the surface of the rock (Fig 6).

2.2 Image analysis

The various features, viz. BSF of 'Grange', lichen apothecia, and rock crystals were analyzed using 'Image J' software developed by the National Institute of Health (NIH), Bethesda, USA (Syed et al. 2000; Girish &Vijayalakshmi 2004) which has been used in previous studies of Martian features (Rizzo et al. 2021; Armstrong 2021a, 2021b). Although an approximate scale measure for 'Grange' can be obtained from the 'motor count' associated with the photograph (Rizzo et al. 2021), this is not accurate enough to make detailed comparative measurements among photographs. Hence, basic measurements were made in pixels. A grid of squares, each square with a dimension approximately 6 x the mean diameter of the BSF, apothecia, or crystals was overlain over each image to establish a number of sample fields. The following data were then obtained from each sample field: (1) the number of clusters of the features (BSF/crystals/ apothecia) per field, (2) the number of individuals making up each cluster, and (3) the dimension ('greatest diameter') of each feature making up each cluster. Similar sample fields were located adjacent to 'Grange' to study the black 'particles' adhering to the rock surface.

2.3 Metrics

Eight metrics were obtained from the above measurements to quantify the various features. All metrics were based on ratios of different measurements, the degree of variation among measurements, and the degree of fit to statistical distributions and therefore, do not depend on establishing an accurate scale measure (Armstrong 2021a,b). The metrics compared included: (1) percent frequency of clustering, i.e., the total number of features (BSF/crystals/apothecia) per field which occur in distinct clusters rather than as individuals (%FC), (2) the degree of variation in feature diameter (Dvar-CV) measured as the coefficient of variation (CV) which accounts for the effects of any differences among means, (3) the mean number of individual features present in each cluster (N/C), (4) variation in cluster size, measured as the CV (Cvar- CV), (5) the degree to which the distribution of N/C departs from a Poisson distribution (KS-N/C) and is a test of the hypothesis that the clustering pattern is random, (6) the degree to which the total number of individual features per field were randomly distributed over the surface by fitting the Poisson distribution (P-KS) (Armstrong 2013), (7) the variance-mean ratio (V/M) of the number of features per field as an index of 'dispersion'(V/M = 1 for a random distribution, >1 for a clustered distribution and <1 for a uniform or even distribution) (Armstrong 2022), and (8) the degree to which the size frequency distribution of feature diameter was described by a log-normal distribution (LN-KS) which often fits the distribution of the ages and sizes of populations of biological organisms (Hattis & Burmaster 1994: Limpert et al. 2001).

2.4 Statistical analysis

Statistical analyses were carried out using Statistica Software, Statsoft Inc., Tulsa, OK, USA). First, mean dimension of the 'particles' on the rock surface adjacent to 'Grange' was compared with the BSF of 'Grange' by an unpaired 't' test and the frequency distributions of the dimensions were compared using a chi-square (X^2) contingency table test. Second, to study the similarities between the BSF of 'Grange', lichen apothecia, and rock crystals, the data were analysed using an Q-type principal components analysis (PCA) (Rizzo et al. 2021; Armstrong 2021a,b). 'Grange', the lichens, and rocks were used as the variables and the various metrics as defining features (cases).

In a PCA scatter plot, the distance between variables reflects their relative similarity or dissimilarity based on the defining metrics. To correlate the location of population on a PC axis with the specific metrics, correlations (non- parametric Spearman's 'rs') were calculated between the values of each metric from each variable and their factor loadings relative to PC1 and PC2. For example, a significant correlation between a specific metric and PC1 would identify that feature as particularly important in determining the separation of the different populations of surface features along PC1.

3. Results

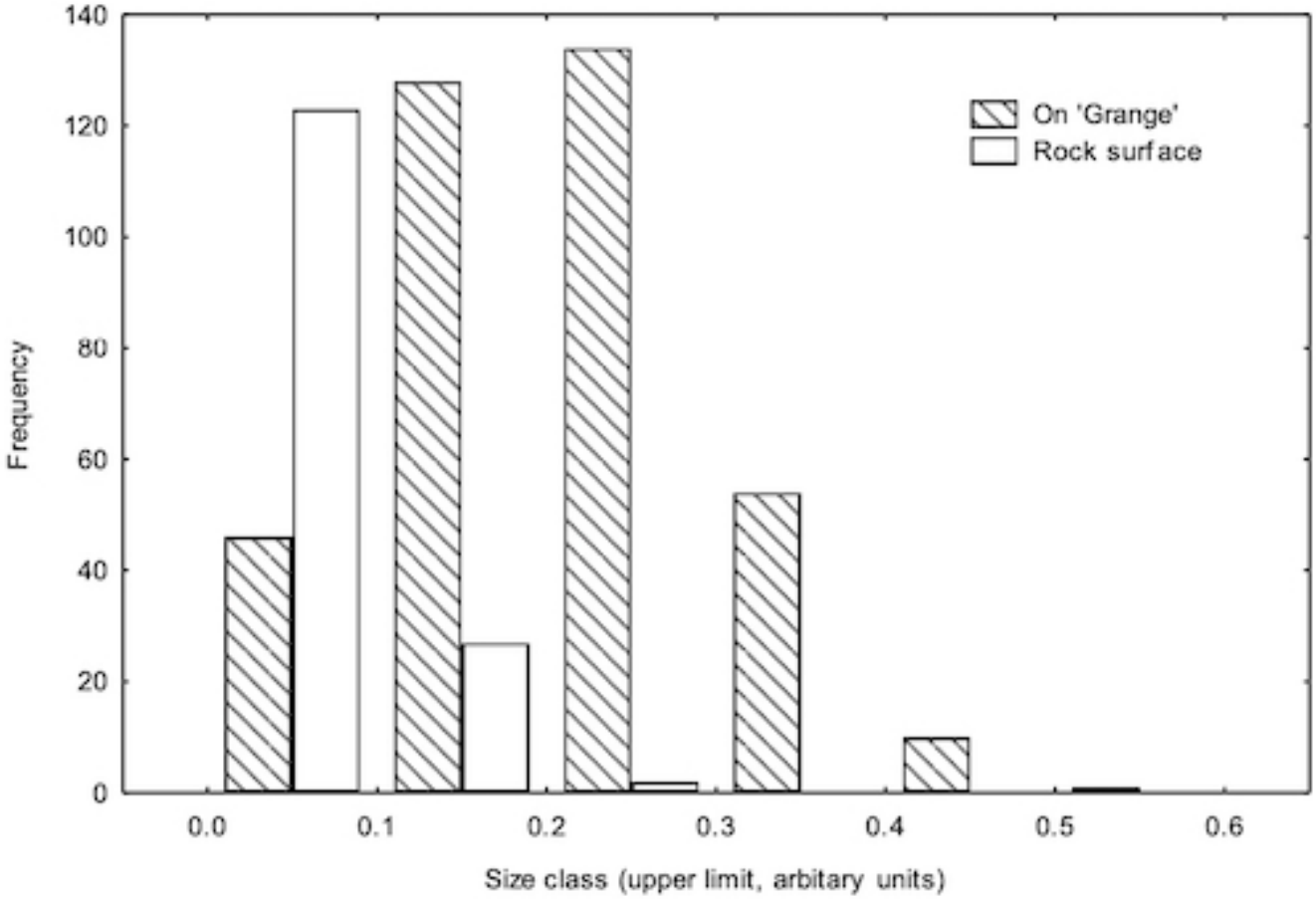
A comparison of the 'particles' adhering to the adjacent rock surface with the BSF on the surface of 'Grange' is shown in Table 2. The mean dimension of the BSF was significantly greater compared with the particles on the rock surface ($t = 17.42$, $P < 0.001$). The size frequency distribution of the BSF and particles (Fig 7) were also significantly different ($X^2 = 244.46$, $P < 0.001$), the majority of rock particles being in the smallest size classes while those of 'Grange' had a significantly larger range of size. Moreover, the 'shape' of the distribution was different, that of particles on the rock surface having a significant degree of skew and kurtosis while the BSF of 'Grange' exhibited no significant degree of skew or kurtosis.

The metrics for 'Grange' (GR), the lichen thalli (PM1-6), and the rocks with embedded crystals (CC1-6) are shown in Table 3. The data indicate: (1) %FC of the BSF of 'Grange' was outside the range exhibited by the lichen apothecia and rock crystals, (2) Dvar-CV of 'Grange' was within the range of both

the lichens and crystals, (3) N/C of 'Grange' was outside the range of both lichens and crystals, but closer to the range of the lichens, (4) Cvar-CV of 'Grange' was within the range of both lichens and crystals, (5) KS-N/C of 'Grange' was within the range of both lichens and crystals, but closer to the range of the lichens, (6) P-KS of 'Grange' was within the range of both lichens and crystals, (7) the V/M of the BSF was outside the range of both lichens and crystals, being more evenly distributed over the surface of 'Grange', and (8) LN-KS of 'Grange' was within the range of the crystals but outside the range of the lichens. In addition, the distribution of N/C deviated significantly from a Poisson distribution in the majority of cases, indicating clustering was non-random. The distribution of features over the surface was random in 'Grange' and in 3/6 of each of the lichen thalli and rock crystals. The size distribution of the various features also deviated from log-normal in all cases.

Figure 6. Examples of terrestrial black crystals embedded in calcite: (a) Calcite with Willlemite, and Franklinite, (Franklin-Ogdensburg Mineralogical Society, Incorporated; Trotter Dump, Franklin, NJ) and (b) Calcite with Willemite, Franklinite, and minor Sphalerite (Franklin-Ogdensburg Mineralogical Society, Incorporated; Sterling Hill Mine, NJ) Images: Creative Commons Attribution.

Table 2. Comparison of the dimensions of the black surface features (BSF) of 'Grange' with adjacent 'particles' adhering to the rock surface.



A PCA of the data in Table 2 resulted in the extraction of two Principal components (PC) accounting in total for 98% of the total variance. A plot of these features in relation to PC1 and PC2 is shown in Fig 8 which shows: (1) 'Grange' is located towards the top of the plot, (2) none of the lichen thalli or rocks with crystals are located immediately adjacent to 'Grange', the closest being a single lichen thallus (MP3) and one of the rock samples (CC5), and (3) overall, the lichen apothecia were more similar to the BSF of 'Grange' than the black crystals.

Correlations between factor loadings and the various metrics are shown in Table 4. The data indicate that the separation of 'Grange' from the rock crystals and lichens was largely based on the frequency of clustering and the mean number of features per cluster and to a lesser extent on the degree of variation in the number of features per cluster, variation in feature diameter, or the distribution of features per cluster. By contrast, the fit of the distribution of the number of surface features per field to a Poisson distribution, the V/M ratio, and the fit of the size distributions of diameters to a log-normal distribution played little role in differentiating between the different features.

Table 3. Comparative morphological analysis of the patterns of black surface features (BSF) on various specimens (SP) including the Martian feature 'Grange' (GR), apothecia of six terrestrial lichens *Porpidia macrocarpa f. macrocarpa* (PM1-6), and six rocks with black crystals (CC1-6) (* indicates significant deviation from fitted distribution; see text for explanation of metrics).

SP	*Metrics*							
	%FC	*Dvar-CV)*	*N/C*	*KS-N/C*	*Cvar-CV)*	*P-KS*	*V/M*	*LN-KS*
'GR'	95	38	3.5	0.14*	71	0.11	0.61	0.13*
PM1	69	50	1.7	0.18*	58	0.13	1.82	0.19*
PM2	72	44	1.9	0.15*	100	0.21*	3.59	0.23*
PM3	82	35	2.4	0.09	71	0.11	1.70	0.26*
PM4	79	50	2.1	0.12*	63	0.36*	3.87	0.25*
PM5	78	40	2.1	0.13*	65	0.23*	2.34	0.21*
PM6	73	43	1.8	0.17*	60	0.18	1.12	0.25*
CC1	54	45	1.5	0.22*	60	0.09	2.0	0.12*
CC2	79	51	2.2	0.12	64	0.25*	2.58	0.10*
CC3	66	42	1.56	0.21*	67	0.25*	2.37	0.12*
CC4	55	49	1.51	0.22*	58	0.19*	2.56	0.12*
CC5	73	34	2.08	0.19*	79	0.20	2.20	0.15*
CC6	80	43	2.20	0.11	70	0.17	1.43	0.12*

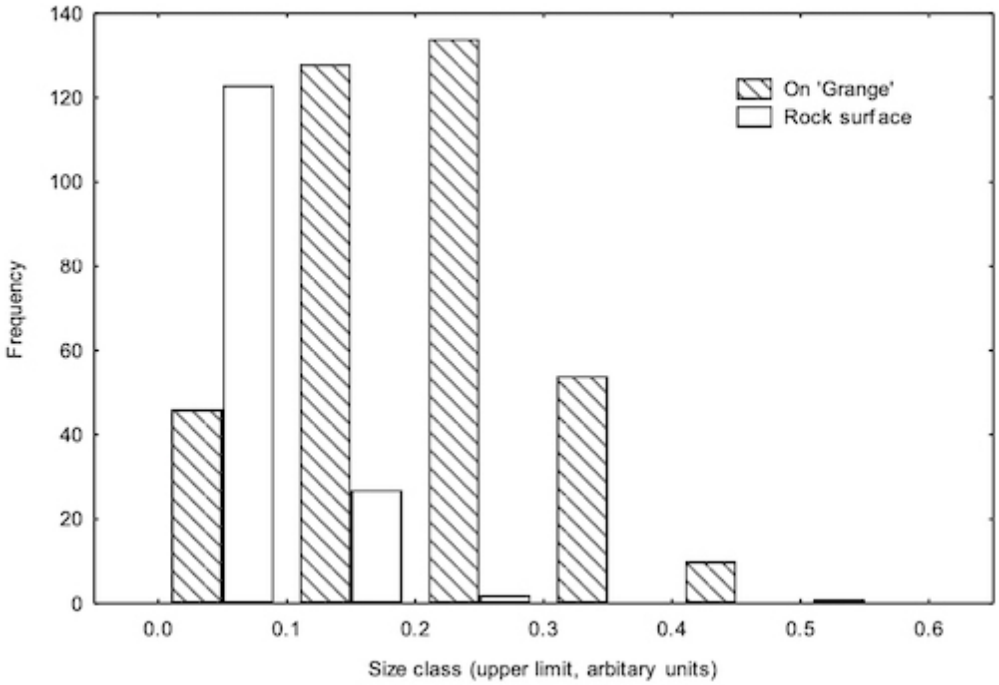


Figure 7. Comparison of the frequency distribution of size of the individual black surface features (BSF) on the surface of 'Grange' with black 'particles' adhering to the adjacent rock surface.

4. Discussion

The BSF of 'Grange' could be 'particles' of regolith or small black crystals similar to those adhering to the adjacent rock surface. There were significant differences in the mean dimension and frequency distributions of size of the 'particles' adhering to the rock surface adjacent to 'Grange' compared with the BSF. Dust devils were recorded near the site on sol 2215 and could be responsible for the particulate matter on the rock surface and the BSF. Hence, it is possible that larger-sized particles were selectively retained by 'Grange' due to the more complex microtopography of its surface compared with the bare rock. Nevertheless, this explanation would appear unlikely as: (1) smaller particles were not retained on the surface of 'Grange' and (2) on some parts of 'Grange', the BSF appear to be been eroded or removed altogether leaving distinct pits and it is unlikely that a dust devil would create sufficient force in the thin atmosphere to embed larger-sized BSF. In addition, if the dark particles adjacent to 'Grange' are mineral inclusions or crystals eroding from the rock, it is unlikely that those in association with 'Grange' would differ significantly. Hence, the BSF of 'Grange' are distinct from the particles adhering to the adjacent rock surface.

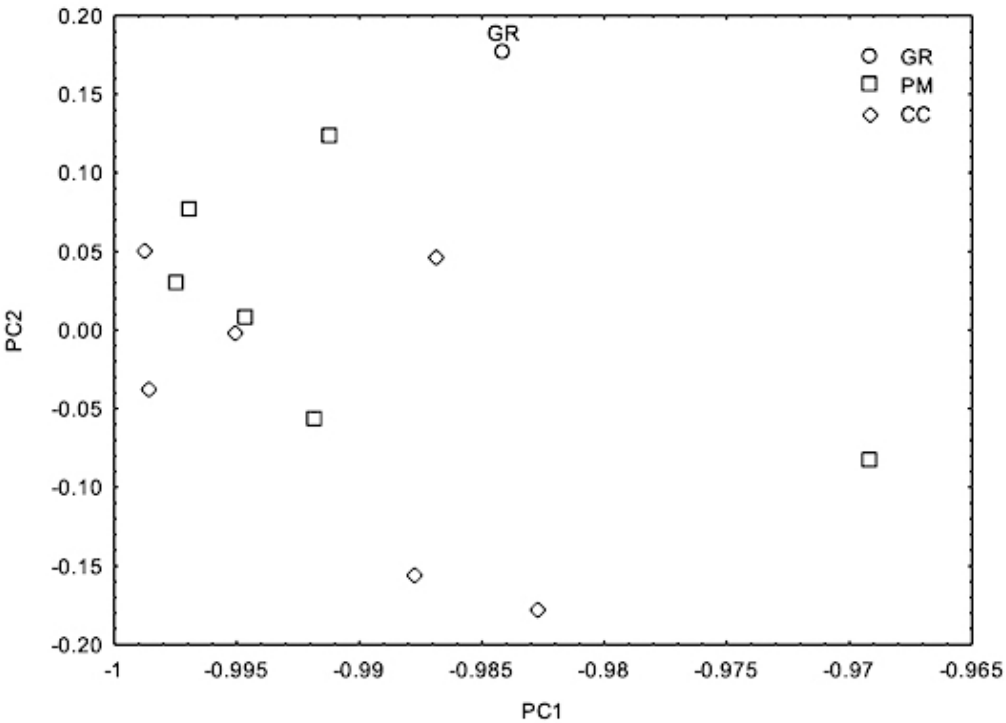


Figure 8. Q-type Principal components analysis (PCA) of the patterns of black surface features (BSF) on the Martian feature 'Grange' (GR), apothecia of six thalli of the terrestrial lichen *Porpidia macrocarpa f. macrocarpa*.) (PM), and six rocks with embedded black crystals (CC): A plot of PC1 versus PC2.

The PCA shows that neither the lichen apothecia nor the terrestrial black crystals were a perfect analogue of the BSF. On the PCA plot, the rocks CC5 and CC6, the former with crystals of 'Babingtonite', are located closest to 'Grange', the crystals of CC5 being rounded and often clustered in linear sequences resembling those of 'Grange'. The other rocks have crystals with less affinity to 'Grange' often exhibiting a less even distribution over the surface, a lower frequency of clustering, and of mean number per cluster. As a group, the lichen apothecia appear to have more affinity to 'Grange'

compared with the rock crystals most notably in the degree of clustering, the distribution per cluster, and the more even distribution of apothecia over the surface. Additional apothecia-like structures have been observed on Mars, e.g. Opportunity rover on sols 1166 and 2147 (R.A. Armstrong, unpublished). Furthermore, there is evidence that apothecia of terrestrial lichens such as the foliose species *Xanthoparmelia conspersa* (Ehrh. ex Ach.) Hale, develop and grow over time (Armstrong and Bradwell 2011) and the shape of the size class frequency distribution of the BSF (Fig 7) is consistent with this suggestion.

If 'Grange' is a lichen, then it is growing as an endolithic organism within the crystalline structure as in extreme environments on Earth such as in some deserts (Garvie et al. 2008) and in Antarctica (Friedmann 1977). Early remote sensing instruments did not suggest the presence of carbonates on Mars (Bibring et al. 2006; Catling 1999). Nevertheless, carbonates, and especially calcite, would be expected as liquid water was likely to be present early in the life of the planet and carbon dioxide is the most abundant constituent of the thin atmosphere (Stalport et al. 2005). The first successful identification of a strong infra-red spectral signature originating from surface carbonates at a local level (<10Km2) was by the MRO-CRISM team (Ehlmann et al. 2008). A local deposit in Nili Fossae was dominated by a single mineral phase associated with olivine rock, the dominant mineral being magnesite, suggesting the formation of carbonates from aqueous alteration of olivine and other igneous minerals. In addition, deposits of calcite were detected by the Phoenix Lander (Boynton et al. 2009) and outcrops rich in magnesium and iron carbonate (16-34 weight%) in the Columbia Hills within Gusev crater (Morris et al. 2010). Hence, it is possible that 'Grange' is a calcite deposit and, as in extreme environments on Earth, could represent a possible substrate for endolithic organisms.

Table 4. Correlations (Spearman's rank correlation, rs) between the first two principal components (PC) and the measured metrics (see text for explanation), * indicates significant correlations with the PC.

				Metrics				
PC	*%FC*	*Dvar-CV)*	*N/C*	*KS-N/C*	*Cvar-CV)*	*P-KS*	*V/M*	*LN-KS*
PC1	-0.15	-0.06	0.07	0.21	0.67*	-0.23	0.28	0.05
PC2	0.92*	-0.62*	0.83*	-0.70	0.14	0.06	-0.47	0.26

Against this hypothesis, an endolithic lichen on Mars would be subjected to physiological challenges considerably beyond those present on Earth (Armstrong 2017, 2019a, 2019b). Some hold to the view that Mars is an arid, barren, and rocky planet unprotected from UV light and cosmic rays (Cockell & Raven 2004), whereas others have provided data indicative of significant amounts of water below the surface and sequestered in surface and subsurface glaciers and in the poles (Orosei et al. 2018; Dundas et al. 2018).

It has also been hypothesized that lichens would have evolved and adapted to these conditions and may be protected by surface level magnetic radiation and dark pigmentation (Joseph et el. 2021). For

example, in Antarctic despite high light intensity, only approximately 1% of the light reaches the lichen zone inside rocks, and the harmful UV are screened out by a dark-pigmented fungal layer (Armstrong 2017, 2019a, 2019b). Perhaps the same would apply to Mars.

The radiation assessment detector (RAD) on Curiosity monitors the natural radiation levels on the surface of Mars which might not only be deadly to surface dwelling lichens, and these sources include (1) galactic cosmic rays and (2) energetic solar particles (NASA, accessed 2022). During the first 10 months of the Curiosity mission, nearly all radiation affecting Gale crater was attributable to cosmic rays. Variations in levels were interpreted as seasonal effects, differences in shielding provided by the atmosphere and it has been hypothesized that significant decreases on certain days ('Forbusch decreases') may have resulted from the extra shielding provided by interplanetary coronal mass ejections from the sun. Hence, the radiation environment on the surface fluctuates, protective electromagnetic radiation has been detected as the surface, and may not be as inimitable to life as currently thought. Mars also experiences temperature extremes, ranging from below 0 to over 20 degrees centigrade, has a thin atmosphere composed mainly of CO^2 with trace quantities of nitrogen, argon, oxygen, and carbon monoxide (Nier & McElroy 1977; Trainer, et al. (2019).

Lichens thrive in cold and hot deserts and lichens may use the same metabolic functions to survive on Mars. In Antarctica, CO^2 exchange takes place very slowly through a relatively thick surface crust (Kappen & Friedmann 1983) and this could presumably also take place within 'Grange'. The main source of nitrogen for terrestrial endolithic lichens is abiotically fixed nitrogen by atmospheric electric discharge, the fixed nitrogen then being conveyed to the rock by atmospheric precipitation. However, there are only trace amounts of nitrogen gas in the Martian atmosphere (Nier & McElroy 1977). One possibility is that cyanobacteria in the rocks can fix sufficient nitrogen from the trace levels available to supply small populations of endolithic lichens.

Another potential concern is whether there is sufficient oxygen to support aerobic respiration. However, the presence of oxygen in the Martian atmosphere has been repeatedly detected, including seasonal variations (Trainer et al. (2019) that correspond to seasonal variations on Earth (Joseph et al. 2020). There is also evidence to suggest that at certain times Mars may support a liquid environment with sufficient dissolved oxygen in the form of salt solutions to support respiration, which may also explain the highly oxidized phase in Martian rocks (Stamenkovic et al. 2018).

Nevertheless, the combination of a very dry and often cold desert-like environmental conditions on Mars is significantly more extreme for lichens than any on Earth, including the dry valleys of Antarctica, and potentially too harsh for significant photosynthetic activity unless additional adaptations are present (Kidron 2019). For example, it has been documented that Thalli of *Xanthoria elegans* (Link) Th. Fr. exposed to space and simulated Martian conditions on the International Space Station (ISS) over 559 days (Brandt et al. 2014, 2016) exhibited considerable resistance with post-exposure activity at 50-80% of normal in the alga and 60-90% in the fungus (Brandt et al. 2014). Although a degree of desiccation-induced breakdown of cell integrity was also observed it was less severe under Martian conditions. In addition, dehydrated Antarctic crypto-endolithic communities and colonies of rock inhabiting black fungi were exposed to simulated Martian conditions for 18 months at the ISS (Onofri et al. 2015), less than 10% of the colonies proliferated but 60% of cells and rock communities remained intact. In addition, there are indications of lichen-like (Joseph et el. 2020), algal-like (Rizzo & Cantasano 2009; Bianciardi et al. 2014, 2015, 2021; Rizzo et al. 2020, 2021), and fungal-like (Joseph et al. 2021) features on the surface of Mars but to date, no definitive proof of their actual presence.

In addition, despite the low temperatures, Lichens living within carbonate-type deposits on Mars may be able to flourish just as they as in the dry valleys of Antarctica. Nevertheless, the lack of a continual supply of surface water would be a significant problem. However, at certain times, water ice on

the surface of Mars may melt and penetrate the rock fissures, the lichens remaining in a dehydrated condition during long intervening periods.

Lichen-like forms have been repeatedly observed on Mars (Joseph et al. 2020, 2021). Hence, 'Grange' could be evidence supporting the presence of an extremophile lichen similar to those found on Earth albeit highly adapted to the more extreme environments of Mars.

6. Conclusion

Quantitative morphological analysis suggests that the BSF of 'Grange' are distinct from the black 'particles' adhering to the adjacent rock and therefore not likely to be regolith. Although a crystalline/ carbonate-like' structure, possibly of calcite with embedded larger black crystals, remains the most likely explanation of 'Grange', the data also suggest that an endolithic lichen is a plausible alternative interpretation. If a lichen is present, it would be subjected to very considerable additional physiological challenges to survive on Mars compared with Earth. Future Mars missions should intensify the study, including drilling and sample collection, of the cracks and fissures in the rocks and especially those which contain crystalline carbonate-like deposits as they could harbor the first definitive evidence of life on Mars.

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