# Martian Spheroids: Statistical Comparisons with Terrestrial Hematite ('Moqui Balls') and Podetia of the Lichen *Dibaeis Baeomyces*

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*Journal of Astrobiology, Vol 7, 15-23, Published 7/14/2021*
*(Invited Commentary: "Is there Life on Mars?")*
*Editors-in-Chief: G. Bianciardi, R. del Gaudio, K. Wołowski*

**Abstract**

Statistical comparisons were made between the populations of Martian spheroids photographed by Opportunity and terrestrial Moqui balls and between the stalked Martian spheroids and reproductive podetia of the lichen *Dibaeis baeomyces*. Principal components analysis (PCA)based on various metrics suggested significant differences in statistical properties of the Martian spheroids compared with the Moqui balls but considerable similarities between the stalked spheroids and the lichen podetia. These preliminary results suggest that Moqui balls are not a good terrestrial analogue of the Martian spheroids and support the hypothesis that the stalked spheroids may represent the reproductive podetia of a lichen; albeit considerably strengthened via mineral deposition to survive the Martian environment.

**Key Words:** Mars, Martian spheroids, Moqui balls, Dibaeis baeomyces, Principal components analysis

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## 1. Martian Spheroids, Hematite Maqui Balls and *Dibaeis Baeomyces*

Among the more controversial features discussed in the papers by Joseph et al. (2021) and Joseph (2021) are the large numbers of Martian spheroids, a proportion of which appear to have distinct stalks, photographed by Opportunity in Eagle crater (e.g. Sols 28-97) and commonly referred to as 'blueberries' (Aubrey et al. 2007). Various hypotheses have been proposed to explain these structures including that they are iron-rich spheroids containing hematite gradually eroding from the rock and thus resembling the brownish-black 'Moqui balls' or 'marbles' composed of iron oxide and sandstone found in deserts in southern Utah (Wilkerson 2017).

In addition, the stalked spheroids resemble the reproductive 'podetia' of several terrestrial lichens including *Dibaeis baeomyces* (L. f.) Rambold & Hertel, a species also similar to *Icmadophila ericetorum* (L.) Zahlbr. species of the genus *Baeomyces*, and to some *Cladonia* species. The Martian spheroids occur both on the tops and sides of boulders and also on the ground emerging from the regolith between the boulders where they appear at their most abundant. Some appear to be bent over and some to have broken off the rock. Whether these structures result from an abiotic or a biotic process or a combination of the two remains to be established.

To help decide between these hypotheses, a statistical analysis of the relative similarity between Martian and terrestrial structures was carried out using a series of metrics and principal components analysis (PCA). Statistical approaches to comparing fossil-like features on rocks from Gale crater with putative terrestrial analogues have been published previously (Joseph et al. 2020, Rizzo et al. 2021).

## 2. Methods

There are two problems in attempting to quantify objects visible in Martian photographs. First, it is difficult to establish an absolute scale measure accurate enough to make absolute comparisons of features in different images. As a consequence, metrics were largely based on degree of variation such as the coefficient of variation (CV) which is a measure of variation independent of the mean, ratios of different measurements, and the degree of fit to different distributions; all of which do not depend on establishing an accurate scale. Second, there is a considerable problem of scale in panoramic photographs in which objects are at different distances from the camera and hence, subject to image distortion. Hence, only objects equidistant from the camera, e.g., across the foreground were analysed from the same photograph.

**In Study A**, three populations of Martian spheroids (N = 297-574) (Joseph 2021, Fig 26, 33, 35) were compared with three populations of terrestrial Moqui balls (N = 58-263, Joseph 2021, Figs 23, 25, 27). **In study B**, a total sample of 50 Martian spheroids with distinct stalks from seven images (Joseph 2021 Figs 1, 2, 4, 5, 12, 30, 31) were compared with samples of podetia of the terrestrial lichen *D. baeomyces* (Joseph 2021 Figs 3, 34, https://fr.wikipedia.org/wiki/Dibaeis, https://florafinder.org?LargePhotos/DB/Dibaeis_baeomyces-A1C5430AFB).

Images were analyzed using ‘Image J' software developed by the National Institute of Health (NIH), Bethesda, USA (Syed et al. 2000; Girish & Vijayalakshmi 2004; Vicenzo et al. 2021). Each image was opened using the software and magnified to clearly reveal the objects of interest. Images were manipulated using brightness, contrast, sharpening, and edge detection to optimize the appearance of the objects and to establish their boundaries. In study A, a grid of squares was then superimposed over each image to establish a number of sample fields. Each of the Martian spheroids or Moqui balls with at least 50% of their area within a sample field was measured. The following data were obtained from each sample field: (1) total number of objects, (2) the maximum diameter of each object in arbitrary units, and (3) if damaged or eroded, whether there was evidence that the spheroid or Moqui ball was hollow. A number of metrics based on these data were obtained: (1) the degree of variation in diameter as measured by the CV, (2) the degree of skew of the size frequency distribution of diameters, (3) the ratio of the cumulative frequencies less than the mode to those greater than the mode, (4) the degree of fit of the size distributions to the log-normal distribution (Pollard 1977), often used to describe the size distributions of both biotic populations and abiotic structures (Hattis & Burmaster 1994, Limpert et al. 2001), (5) the degree of fit of the numbers of objects per sample field to the Poisson distribution to determine whether the distribution of the objects deviates from random and the variance/mean ratio as an index of dispersion (Armstrong 2007), and (6) the percentage of objects that appeared hollow.

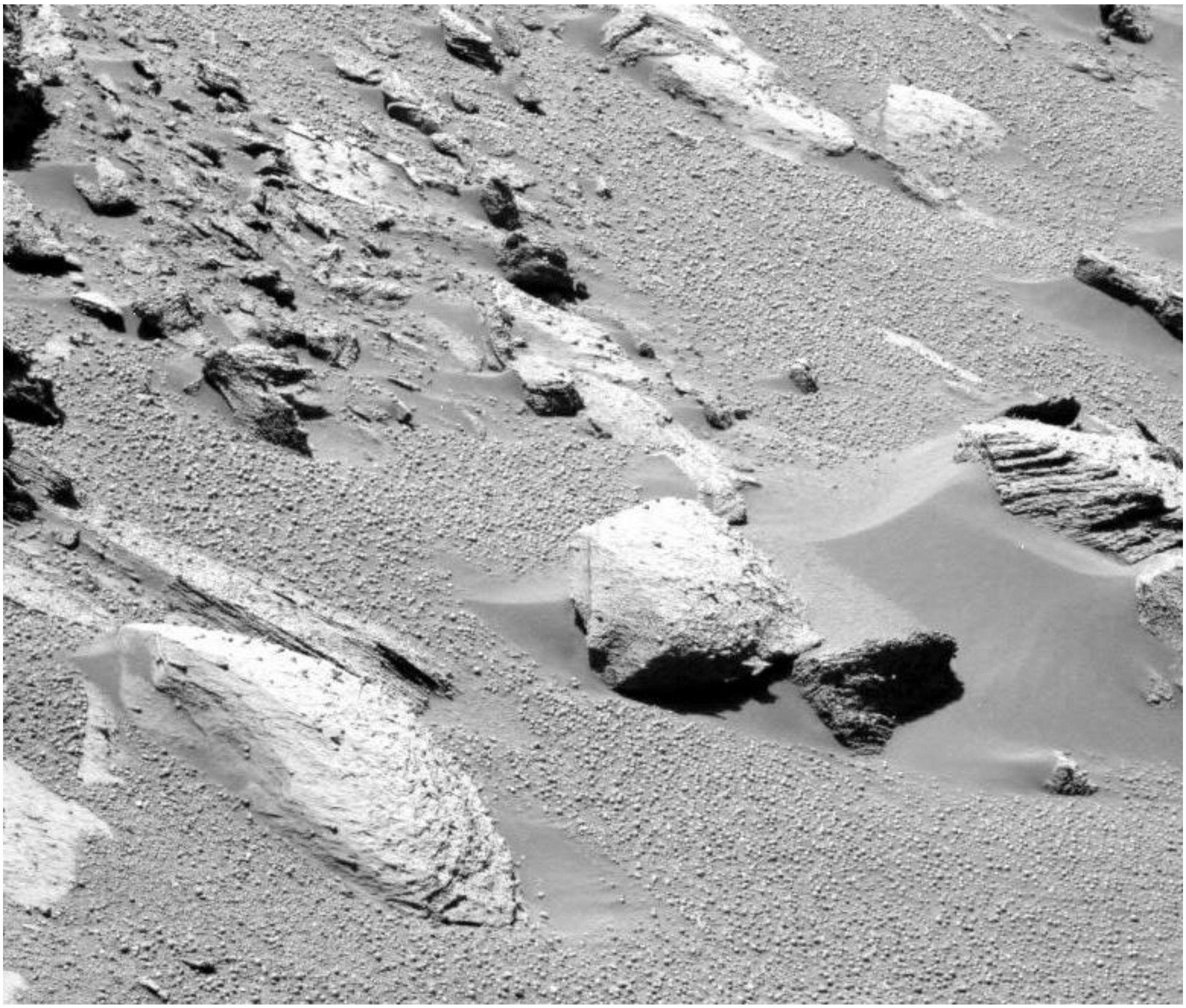

**Figure 1**. Large populations of Martian spheroids in Eagle crater (Opportunity, Sol 85, NASA/JPL – Caltech).

**Figure 2.** Stalked Martian spheroids (arrows) in Eagle crater (Opportunity, Sol 85, NASA/JPL - Caltech)

**In Study B**, the morphology of samples of the stalked Martian spheroids was compared with samples of podetia of the lichen *D. Baeomyces*. Seven samples of stalked spheroids were compared with a six samples of images of lichen podetia. Each object measured was chosen to have a clearly defined 'head' and 'stalk' and the following measurements made on each object using an arbitrary scale: (1) maximum width of the head (HW), (2) maximum length of the head (HL), (3) width of the stalk halfway down the tail (SW), and (4) the length of the stalk (SL). The following metrics were obtained from these data to define each object in each sample: (1) CV of HW, (2) CV of SL, (3) HW/HL, (4) SW/SL, and (5) HW/SL.

To study the similarities between the unstalked Martian spheroids and Moqui balls and between the stalked spheroids and podetia of the lichen *D. baeomyces*, the data were analysed using principal components analysis (PCA) (Armstrong & Hilton, 2011, Vicenzo et al. 2021). The analyses were carried out using the various categories of objects as variables and the various metrics as defining features. In a PCA scatter plot of the different populations, the distance between objects 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 (Pearson's 'r') were calculated between the values of each metric from each variable and the factor loadings of the population relative to the 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 objects along PC1. PCA is strongly affected by the specific images selected for analysis and the metrics used to define them. Hence, the results should be regarded as preliminary as addition of further images and of additional metrics could alter the stated conclusions.

## 3. Results

A PCA of the data from study A resulted in the extraction of two Principal components (PC's) accounting in total for 97% of the total variance (PC1 = 89%, PC2 = 8%) A plot of the three populations each of Martian spheroids and Moqui balls in relation to PC1 and PC2 is shown in Figure 3: (1) considerable variation in statistical properties within a group and (2) segregation of the Martian spheroids and Moqui balls. Correlations between factor loadings and the various metrics suggest that the CV of diameters was correlated with PC1 ($r = -0.83$, $P < 0.05$) while to the Poisson distribution ($r = 0.82$, $P < 0.05$) and the V/M ratio ($r = 0.94$, $P < 0.01$) are significantly correlated with PC2. Hence, the separation of the Martian spheroids and the Moqui balls is largely based on the significantly less variation in size and greater degree of clustering of the Martian spheroids.

A PCA of the data from study B resulted in the extraction of two Principal components (PC's) accounting in total for 93% of the total variance (PC1 = 87%, PC2 = 6%). A plot of the seven populations of Martian spheroids and six populations of the lichen *D. baeomyces* in relation to PC1 and PC2 is shown in Figure 4: (1) all populations of *D. baeomyces* cluster to the left of the plot together with five of the populations of Martian spheroids and (2) two populations of Martian spheroids are located some distance away from the main cluster. Correlations between factor loadings and the various metrics suggest that only the ratio SW/SL was significantly correlated with PC1 ($r = -0.61$, $P < 0.05$), suggesting some of the populations of Martian spheroids have longer tails relative to their widths than others and compared with all of the populations of *D. baeomyces* studied.

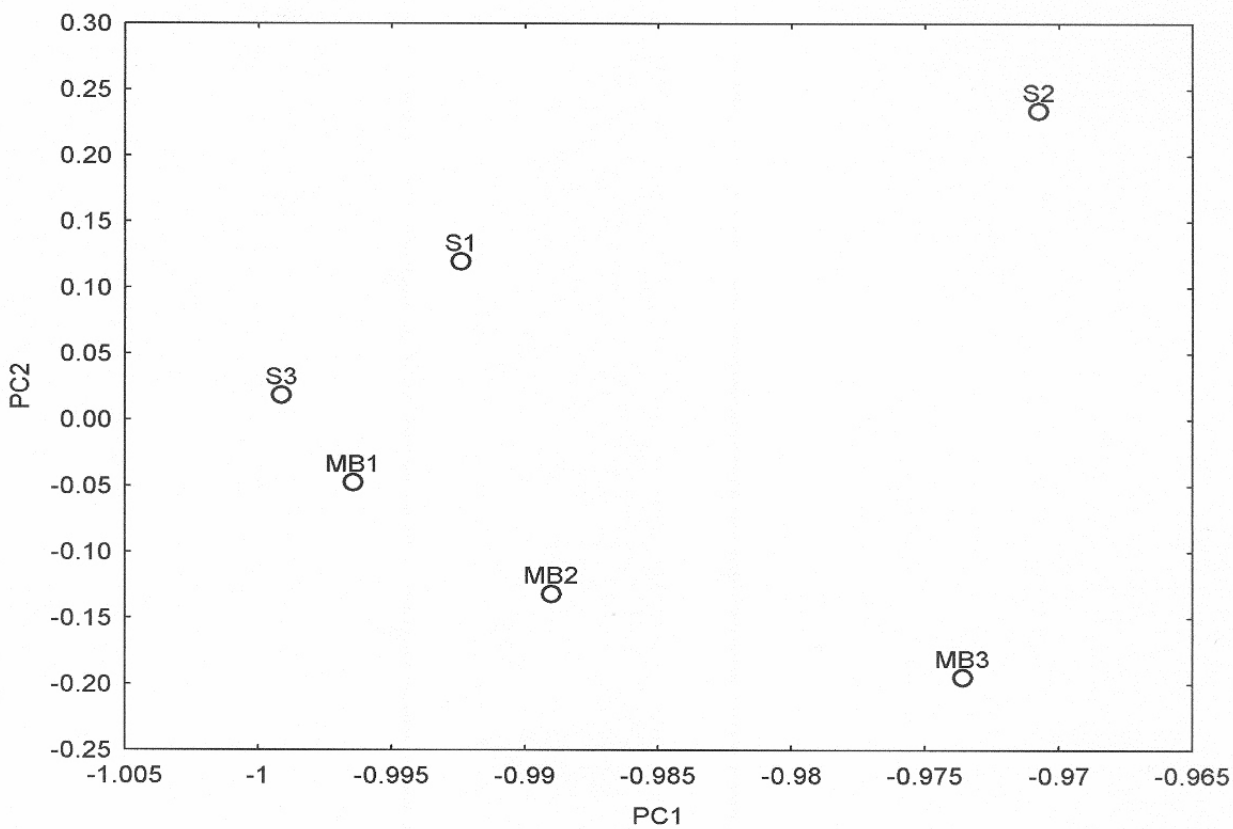


**Figure 3.** Study A**:** Principal components analysis (PCA) of three populations of Martian spheroids (S1-S3) and three populations of terrestrial Moqui balls (MB1-MB3): A plot of PC1 versus PC2.

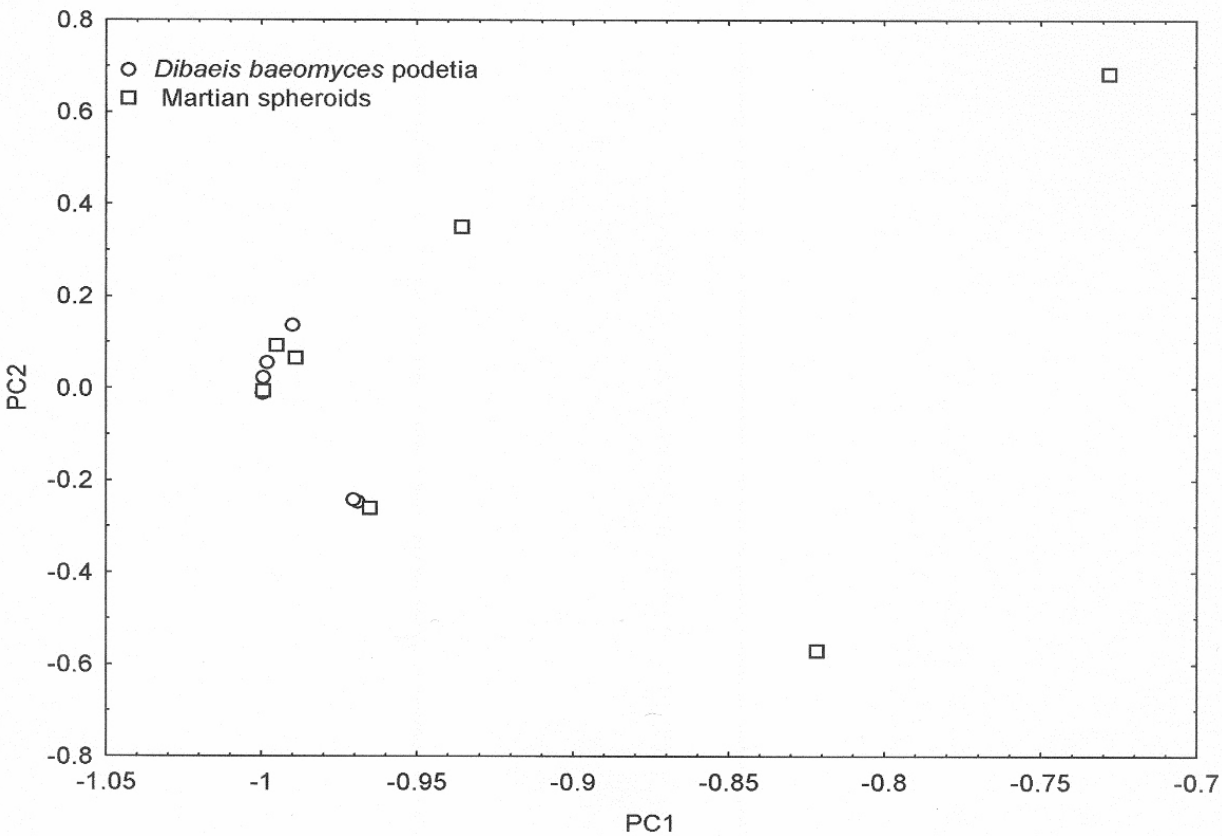


**Figure 4.** Study B: Principal components analysis (PCA) of seven populations of stalked Martian spheroids and six populations of podetia of the terrestrial lichen *Dibaeis baeomyces*: A plot of PC1 versus PC2

## 4. Discussion

The statistical analysis of the Martian spheroids and terrestrial Moqui balls suggest significant differences between the spheroids and the Moqui balls, especially in size variation and in degree of clustering. In addition, the Moqui balls comprise rounded or elliptical unstalked objects which are often bilobed and with a distinct seam or rim around the circumference. By contrast, the Martian spheroids appear to be small compact unlobed spheres, a proportion of which appear to have distinct stalks especially when located on rocks. Hence, these data question whether terrestrial Moqui balls should be regarded as a good terrestrial analogue of the Martian spheroids.

There is a close statistical relationship among aspects of the morphology of 5/7 populations of the stalked Martian spheroids and podetia of the terrestrial lichen *D. baeomyces*. In the remaining two populations, the spheroids appear to have longer stalks relative to their diameters. There could be considerable variation in the morphology of the 'stalked' spheroids at different sites, those with longer stalks relative to their widths being more vulnerable to damage by Martian winds and dust storms and may explain the bent and damaged specimens observed in some images.

On Earth, the algal partner of *D. baeomyces* is the green alga *Coccomyxa* Schmidl., and the lichen colonizes unstable soil, loose sand, and dry clay in full sun, disturbed ground being preferred. The species is a lichenized member of the Ascomycota and the apothecia containing the asci and spores are 1 - 4 mm on podetia up to 6 mm long, similar to many of the relative dimensions to the Martian spheroids. If these Martian structures are evidence of a *Dibaeis*-type lichen, then the primary crustose thallus is not particularly visible but may exist in crevices in the rocks, be endolithic, or be present underground. In some of the photographs published by Joseph et al. (2019, 2021), traces of a primary thallus and perhaps accumulations of fungal hyphae may be present in association with the spheroids. By contrast with terrestrial *D. baeomyces*, the Martian spheroids appear to be extremely resistant and long-lived structures.

If the stalked Martian spheroids are lichen podetia, then the evolutionary processes on Mars may have resulted in considerable strengthening of these structures by mineral deposition to withstand the harsh environment of the planet (Armstrong 2019). Terrestrial lichens are well known to accumulate minerals and heavy metals to high concentrations (Richardson 1995), an observation consistent with this hypothesis.

## 5. Conclusions

This preliminary analysis of the statistical comparisons among populations suggests similarities between the stalked Martian spheroids and lichen podetia but differences when compared with Moqui balls. Hence, Moqui balls may not be a good analogue of the Martian spheroids. By contrast, the data support the hypothesis of Joseph et al. (2021) that the stalked spheroids may represent the result of a biotic process resulting in a lichen-like structure, albeit considerably modified by abiotic chemical processes.

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