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The lunar-like mineralogy of the Martian Trojan asteroid (101429) 1998 VF$_{31}$

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1 Introduction

The so-called Martian Trojans are asteroids orbiting in the stability regions corresponding to the L4 and L5 Lagrangian points of Mars. Their existence is thought to date back to the early epochs of the solar system history. Out of the ten confirmed Martian Trojans, nine belong to L5 and only one belongs to L4. The asteroid (101429) 1998 VF$_{31}$ (VF31 hereafter) is the only one non-Eureka family Martian Trojan asteroid in L5.

2. Observations and data reduction

We have used X-SHOOTER on the European Southern Observatory Very Large Telescope to obtain new visible and near-infrared reflectance spectra of VF31. For this investigation we combined our visible spectrum with the near-infrared one from [1], kindly provided by A. Rivkin. As Rivkin's near-infrared spectrum was scaled to their visible one (Rivkin, A., private communication), which has a poor S/N, we rescaled it to match our visible spectrum, which is of better quality.

3 Searching for the best match

In order to find the mineralogy of the surface of VF31 we compared its spectrum to spectra of different solar system bodies. First we did a comparison with the average spectra of different taxonomic classes from DeMeo database [2]. We carried out curve matching using cost functions from [3]. The top five matches have spectral type X, S, Xk, T and Sr. Then we compared our spectrum to available spectra of asteroids from the Small Main-Belt Asteroid Spectroscopic Survey (SMASS).[1] We considered all asteroid spectra that cover the visible and the near-infrared region, (427 in total), and applied the same χ^2-ranking approach as before. The top six matches are: asteroids (250) Bettina (Xk), (20) Massalia (S), (110) Lydia (X), (69) Hesperia (X), (55) Pandora (X) and (32) Pomona (S). In our search for the best spectral matches we used the Tool for Asteroid Modelling - M4AST[2] with its option to compare with all spectra from the RELAB database. We found that the top χ^2-matches were reflectance spectra of Apollo lunar samples. For further analysis we decided to use instead a database of reflectance spectra of the lunar surface obtained from ground-based telescopes and available from the PDS Geoscience Node[3]. We used our χ^2-ranking approach for 359 database spectra. The top matches are from Aristarchus crater central peak and Censorinus crater. Continuing one step further, we compared the VF31 spectrum with all available meteorite spectra in RELAB. Interestingly enough, the top ranked one is that of a lunar meteorite breccia.

4 Global ranking of all analogues

We compared the VF31 spectrum with all the spectra together as to find its best analogue (asteroid, lunar surface or meteorite). In order to have a consistent criterion for comparing between spectra, we recompute the χ^2 values for a wavelength range common to all reflectance spectra (0.656–2.455 μm) and resample to the same number of data points (93). The results of the comparison are presented in Table 1. Fig. 1 shows our 3 best matches, one from each type of analogue. Our analysis shows that all the top χ^2-ranked spectra have approximately the same χ^2 value, so the shapes, the positions and the intensities of the individual spectral features are used for further analysis. In the first place, we observe that the overall shape of the VF31 spectrum is similar to that of S-type asteroids with their features, namely the reflectance maximum

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[1] http://smass.mit.edu/catalog.php

[2] http://spectre.imcce.fr/m4ast/index.php/index/home

[3] http://pds-geosciences.wustl.edu/missions/lunarspec/index.htm

around 0.75 μm and absorptions at $\sim$1 and $\sim$2 μm. The positions and intensities of the absorptions are nearly the same, but the intensity of the maximum is not, i.e. the S-type asteroids tend to have higher relative reflectance there than VF31. Even though the meteorite spectra represent better the maximum reflectance in the visible region and the overall slope, they poorly match the 1 and 2 μm features of the VF31 spectrum. Finally, the top ranked lunar surface spectra have the same overall slope and all the features presented in the VF31 spectrum which are on the same position and with the same intensities. From what we state above we conclude that the lunar surface spectra are the best matches among all analogues.

Table 1: The top χ^2 rankings from a combined set of asteroid, meteorite and lunar surface spectra.

Name	Type[a]	χ^2	Name	Type	χ^2
250 Bettina	Ast	0.097	Bokkeveld	Met	0.125
Censorinus	LS	0.111	Y-74659	Met	0.126
20 Massalia	Ast	0.113	32 Pomona	Ast	0.127
Aristarchus Pk.	LS	0.117	Tsarev	Met	0.127
Pervomaisky	Met	0.116	110 Lydia	Ast	0.127
Aristarchus Pk.	LS	0.119	30 Urania	Ast	0.128
Descartes Cr. 3	LS	0.121			

[a] Ast (Asteroid), Met (Meteorites), LS (Lunar surface)

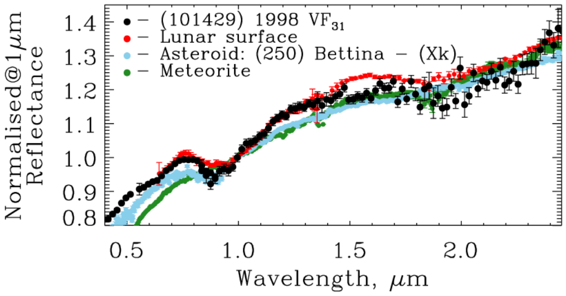

Figure 1: Our best matches from the combined set of Lunar surface, Meteorite and Asteroid spectra.

5. Mineralogy of the surface

The top ranked lunar surface spectra are all from crater features in lunar highlands. Their chemical composition is mainly anorthite, which is rare on the Earth, and different kind of magnesoferrous minerals, mainly pyroxene and olivine. The type of pyroxene present on the surface is responsible for the position of the 1 μm feature. Low-Ca pyroxene has an absorption at 0.93-0.95 μm and high-Ca pyroxene at 0.95-1.00 μm [4]. The presence of an olivine just broadens the absorption feature. The position of the 1 μm feature observed in the spectrum of VF31 indicates that it should contain low-Ca pyroxene while the presence of a weak 2 μm absorption tells us that there is a moderate abundance of magnesoferrous minerals. More information for the type of pyroxene can be obtained from the positions of the 1 and 2 μm features. In our case they are 0.935 and 2.015 μm which according to [5] show that it is a low-Ca pyroxene (orthopyroxene). The positions of these features puts VF31 in the high-Fe end of orthopyroxenes [6].

6 Conclusions

Our study shows that VF31 surface is probably dominated by an orthopyroxene. A previous study of the same asteroid [1] explains the red slope by adding iron. The similarity that we found with lunar spectra and especially that the best matches are craters from highlands, where orthopyroxene is dominantly iron-rich [6], can explain the red slope and the positions and intensity of the spectral features. In spite of all uncertainties, we can rule out the possibility that this object belongs to any class of primitive low albedo objects and its most likely origin is the inner solar system. To extend our analysis, we plan to assess the possible role of space weathering effects.

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