Icarus 318 (2019) 188–194

Contents lists available at ScienceDirect

Icarus

journal homepage: www.elsevier.com/locate/icarus

Mineralogical mapping of the Kerwan quadrangle on Ceres

E. Palomba[a,e,*], A. Longobardo[a], M.C. De Sanctis[a], F.G. Carrozzo[a], A. Galiano[a,b], F. Zambon[a], A. Raponi[a], M. Ciarniello[a], K. Stephan[c], D.A. Williams[d], E. Ammannito[a,g], M.T. Capria[a,e], S. Fonte[a], M. Giardino[a], F. Tosi[a], C.A. Raymond[f], C.T. Russell[g]

[a] Istituto di Astrofisica e Planetologia Spaziali, INAF, via del fosso del Cavaliere, 100, 00133, Rome, Italy
[b] Università di Roma Tor Vergata, Department of Physics, via della ricerca scientifica, 1, 00133 Rome, Italy
[c] Institute of Planetary Research, German Aerospace Center (DLR), Rutherfordstrasse 2, d-12489 Berlin, Germany
[d] School of Earth & Space Exploration, Arizona State University, Tempe, AZ 85287-1404, USA
[e] Space Science Data Center (SSDC) - Agenzia Spaziale Italiana (ASI), Via del Politecnico snc, Edificio D, 00133 Roma, Italy
[f] Jet Propulsion Laboratory, Pasadena, CA 91109, USA
[g] Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90095-1567, USA

ARTICLE INFO

Article history:
Received 28 April 2017
Revised 11 July 2017
Accepted 25 July 2017
Available online 25 July 2017

ABSTRACT

The Ceres surface is globally composed of Mg-phyllosilicates, ammoniated clays, carbonates and dark components. To obtain a more detailed mineralogical and geological investigation, the dwarf planet surface has been divided into fifteen quadrangles. The aim of this work is to investigate the abundance of phyllosilicates and ammoniated clays in the Kerwan quadrangle, classified as Ac-H-7 and spanning from 22°S to 22°N in latitude and from 72°E to 144°E in longitude. Maps of band depth distribution at 2.7 µm and 3.1 µm have been performed and compared with a map of geometric albedo estimated at 1.2 µm. Phyllosilicates and ammoniated clays generally correlate in the Kerwan quadrangle, even if departure from this behavior is observed in the floor of Kerwan, Inamahari and Homsuk craters. The greatest abundance of ammoniated phyllosilicates is found in Rao and Kerwan ejecta, while Bonsu and Tafakula floors are the most depleted in volatile, as well as Inamahari and Dantu ejecta. Six bright spots are detected in the Kerwan quadrangle, and the one richest in carbonate is related to Dantu ejecta in the southeast region. Some younger features (such as Rao or Kerwan ejecta) show deeper band depths than older terrain, a contrast trend with respect to the entire Ceres surface. Since this correlation is observed in a few other places on other quadrangles but not on the entire Ceres surface, it is possible that recent impact events could have been masked this correlation.

1. Introduction

The Dawn/NASA mission began orbiting the dwarf planet Ceres in March 2015 (Russell and Raymond, 2011), taking visible images by means of the Framing Camera (FC) (Sierks et al., 2011) and hyperspectral images by the Visual and InfraRed spectrometer (VIR) (De Sanctis et al., 2011).

According to VIR observations, Ceres has an average reflectance at standard geometry (30° phase) of 0.03 at 0.55 µm (Ciarniello et al., 2017; Longobardo et al., 2017a), but includes many bright areas, the so-called bright spots or faculae (Stein et al., 2017; Palomba et al., 2017). In particular, Cerealia and Vinalia Faculae, placed on the dome and floor of the Occator crater, respectively, show an albedo larger than 0.2 (Stein et al., 2017; De Sanctis et al., 2016).

The primary Ceres surface compositional components are ammoniated phyllosilicates, phyllosilicates, Mg-carbonates and dark materials. The spectral features corresponding to such minerals are at 2.7 µm (related to phyllosilicates), 3.1 µm (due to NH_4), and the two carbonates absorption features centered at 3.4 µm and 3.9 µm (De Sanctis et al., 2015, 2016). Band depth distributions show that a correlation exists between ammoniated clays and phyllosilicates over Ceres (Ammannito et al., 2016).

Variation in the strength of phyllosilicates and ammoniated bands was also observed over Ceres surface, indicative of dissimilar abundances or differences in granulometry, probably connected to the age of features or terrains (Stephan et al., 2017b, c).

* Corresponding author.
E-mail address: ernesto.palomba@iaps.inaf.it (E. Palomba).

http://dx.doi.org/10.1016/j.icarus.2017.07.021

The features at 3.4 µm and 3.9 µm are deeper in some regions, related to a higher abundance of carbonates (De Sanctis et al., 2016) and their band centers are shifted toward longer wavelengths, indicating the occurrence of Na-carbonates (Carrozzo et al., 2017a).

Concerning the absorption at 3.4 µm, it is probably affected by carriers other than carbonates, e.g., in the Ernutet crater (52°N, 45°E). The observed excess of 3.4-µm band depth has been attributed to the presence of organics (De Sanctis et al., 2017).In order to obtain a more detailed geological and mineralogical description of Ceres, its surface has been divided into 15 quadrangles (Williams et al., 2017; McCord and Zambon, 2017): the two poles, four quadrangles relative to the Northern hemisphere, four quadrangles in the Southern hemisphere and five at equatorial latitudes. This work focuses on the mineralogical mapping of the Kerwan quadrangle (classified as Ac-H-7), spanning from latitude 22°S to 22°N and from longitude 72°E to 144°E. The name of the quadrangle is related to its greatest impact feature, the Kerwan crater, named after the Hopi spirit of the sprouting maize.

Kerwan is a 284-km diameter impact basin, the oldest definitive impact feature on Ceres' surface. The impact took place either 280 Ma ago (based on Asteroid Flux Model Age) or 1300 Ma ago (based on the Lunar-derived Model Age), defining the boundary between the Pre-Kerwanan and the Kerwanan period (Williams et al., 2017).

The geological map (Williams et al., 2017) describes a degraded and discontinuous rim of the Kerwan crater, characterized by isolated peaks, ridges or chains. It lacks a central peak, and the low depth-to-diameter ratio suggests a relaxation of the crater floor, probably from an impact into an ice-rich crust. In fact, in the crater floor and surrounding rim (especially in the east, south and west side), a smooth geological unit dominates. Smooth material is probably the volatile, ice-rich crust melted after the Kerwan impact, which was altered over time by space weathering and subsequent impacts.

Another geological unit on the Kerwan quadrangle is the "crater material", present inside and outside the impact craters Inamahari-Homshuk and surrounding the impact crater Dantu. It is a morphologically variable unit, with flat regions and hummocky areas, probably made of ejecta from Dantu and Inamahari-Homshuk craters, in addition to other large basins (Williams et al., 2017). Dantu is partially part of the Kerwan quadrangle (for the south and southeastern ejecta and the south part of crater floor), and because it overlies the northern Kerwan ejecta, it is stratigraphically younger, with an age of 77.7 ± 8.0 Ma (Lunar-derived Model Age) or 22.9 ± 2.3 Ma (Asteroid-Flux Model Age).

Cratered terrain is the geological unit widespread on Ceres' surface and also visible in the Kerwan quadrangle. Craters with all sizes and with various shapes are part of the unit. Some crater rims are well defined, while others are barely identifiable. Crater floors are shallow and covered by ejecta expelled by nearby craters. This unit is probably the ancient Ceres crust, dominated by dark material and, furthermore, made of salts, carbonates, water ice and ammoniated phyllosilicates, heavily and hydrothermally altered by subsequent impacts. The Lunar-derived Model suggests an age of 1.98 ± 0.27 Ga, while 0.55 ± 0.084 Ga is obtained with the Asteroid-Flux Model.

The main objective of this paper is to create maps of the hydroxylated and ammoniated compounds together with the reflectance value and discuss their distribution around the quadrangle. The most important geological features will be analyzed in term of these spectral parameters. The first two chapters describe the data and tools used in this analysis. The third chapter describe the mineralogical maps. The fourth chapter discuss the main geological features located in the Kerwan quadrangle. The fifth chapter gives the conclusions of this work.

2. Data

This work is focused on the analysis of spectra acquired from the Visible and InfraRed (VIR) mapping spectrometer (De Sanctis et al., 2011). VIR is characterized by one optical head and by two channels, the first one operating in the visible range (0.2–1 µm with a sampling of 1.8 nm) and the second one in the infrared (1–5 µm with a sampling of 9.5 nm) range. VIR provides 2D spatial images at different wavelengths, referred to as spectral cubes.

Reflectance (*I/F*) calibration, removal of artifacts (Carrozzo et al., 2016) and removal of the thermal contribution (Raponi, 2014) were applied to all the VIR datasets. Photometric correction described by Ciarniello et al. (2017) was also applied. A different approach to photometric correction is also applied and provides similar results (Longobardo et al., 2017a).

The Dawn mission on Ceres is divided into different phases, each one with its own spacecraft altitude and spatial resolution, i.e. Approach (700 down to 3400 m/pixel), Rotation Characterization (altitude ~13,000 km and resolution ~3400 m/pixel), Survey (altitude ~4400 km and resolution ~1100 m/pixel); High Altitude Mapping Orbit (HAMO—altitude ~1470 km and resolution 360–400 m/pixel); and Low Altitude Mapping Orbit (LAMO—altitude ~385 km and resolution 90–110 m/pixel) (Russell and Raymond, 2011). HAMO data were considered in this work as described in Frigeri et al. (2017).

3. Tools

The quadrangle is analyzed by mapping significant spectral parameters of Ceres spectra, i.e. reflectance at 1.2 µm and 30° phase angle and band depths at 2.7 µm and 3.1 µm (Frigeri et al., 2017). Other parameters were not considered for different reasons: band centers do not show variability inside the Kerwan quadrangle (Ammannito et al., 2016), whereas carbonate bands are observed only in a few locations (Carrozzo et al., 2017a).

4. Global maps

The maps of infrared geometric albedo, band depth at 2.7 µm and band depth at 3.1 µm are shown in Figs. 1, 2, and 3, respectively.

The general behavior on Ceres is a moderate correlation between the two band depths, being the Pearson coefficient (e.g. Palomba et al., 2015) about 0.3, in turn uncorrelated with albedo with a Pearson coefficient close to zero (Longobardo et al., 2017b). The Kerwan quadrangle shows a weak correlation between the 2.7 and 3.1 µm band depths, with a global Pearson coefficient of 0.191. However some exceptions which show a behavior closer to the average Ceres are present. One concerns the southeast Dantu crater area (i.e., the NE corner of the quadrangle), where albedo and band depth at 2.7 µm are both low, and the 3.1 µm band is deeper than its surrounding (Section 5). The cratered terrain on the western regions of the quadrangle shows instead an association between deep phyllosilicate band and low albedo: in these terrains, the ammoniated band depth is deep only below the equator, whereas it appears shallow at northern latitudes. The two bands always correlate in correspondence with craters, i.e. Kerwan (centered at 10°S 124°E), Rao (10°N 122°E), Inamahari (14°N 90°E), Bonsu (2°N 94°E), Tafakula (20°S 88°E). In particular, in the first three cases, the bands are deeper and associated with brighter areas and in the latter two, the bands are shallow and associated with dark areas.

5. Main features

In what follows we introduce the main geological features located in Kerwan, starting with the large and ancient crater who

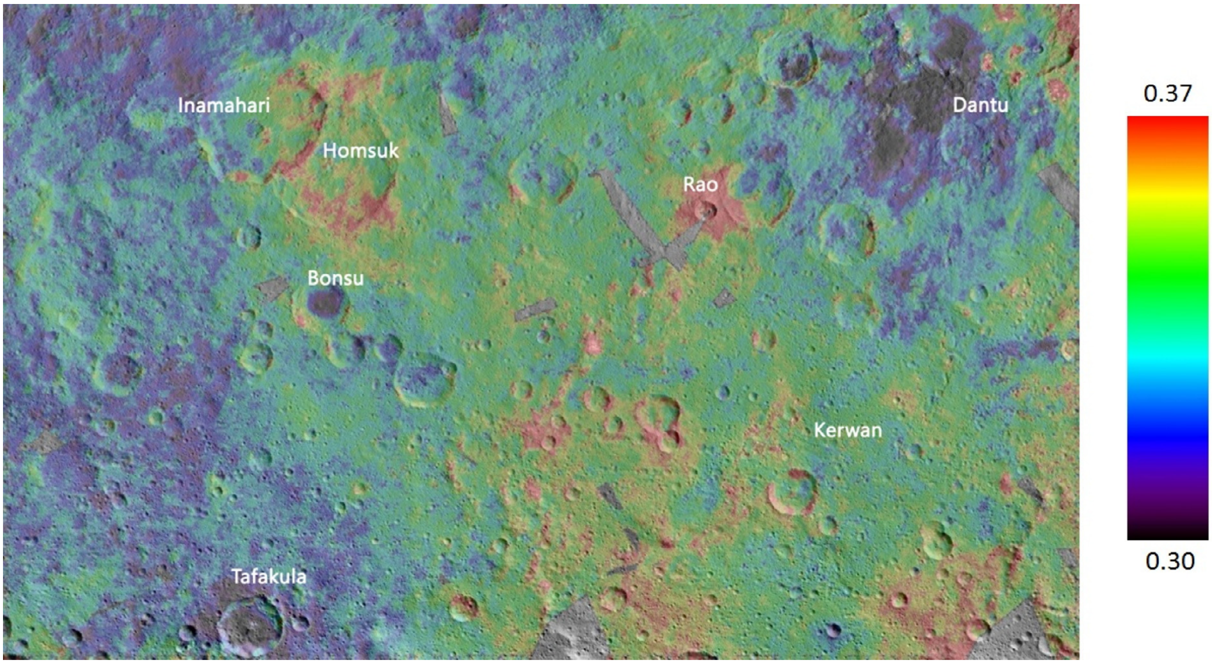

Fig. 1. Geometric albedo map at 1.2 µm of the Kerwan quadrangle, superimposed on the Framing Camera (FC) mosaic.

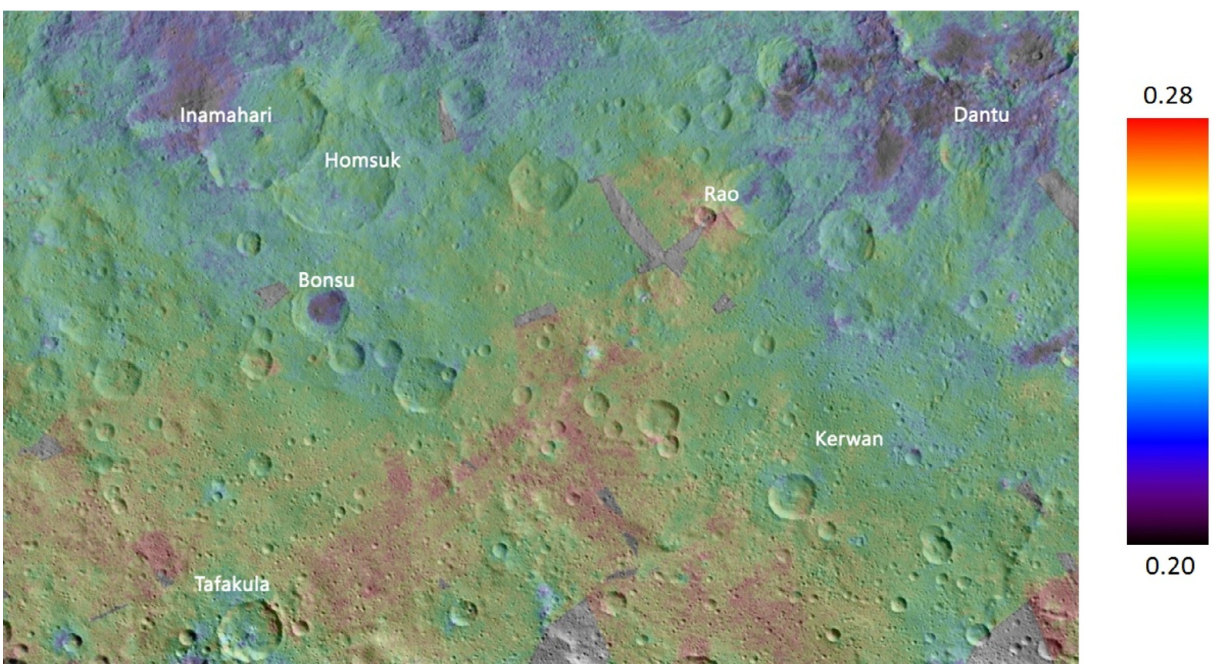

Fig. 2. Band depth at 2.7 µm of the Kerwan quadrangle, superimposed on the Framing Camera (FC) mosaic.

give its name to the entire Quadrangle. The portion of Dantu falling inside this quadrangle will be discussed, together with other small craters and the six bright spots present here.

5.1. Kerwan

Kerwan (10.77°S, 123.99°E), at 284 km in diameter, is the largest identifiable impact crater on the dwarf planet Ceres. It has a highly discontinuous, polygonal, degraded rim and contains a 'smooth' unit that both fills the basin floor and surrounds the degraded rim to the west, south, and east. The crater morphology suggests that it has undergone viscous relaxation (Bland et al., 2016), which, along with crater counts, suggests a very advanced age, >280 Ma (Asteroid-Derived Chronology Model, ADM) or >1.3 Ga (Lunar-Derived Chronology Model, LDM: Williams et al., 2017). There is no evidence that the smooth unit was produced by cryovolcanism, such that the leading hypothesis is that it formed by impact-induced melting of an ancient ice-rich cerean crust (Williams et al., 2017).

The Kerwan crater reaches the lowest topography level of the quadrangle. It is the oldest impact basin on Ceres (Williams et al., 2017) and is located in the large depression Vendimia Planitia, which includes also the impact crater Dantu (Stephan et al., 2017c). Because the Vendimia Planitia impact excavated very deep material (Marchi et al., 2016), the material present in the Kerwan crater could indicate the composition of Ceres' subsurface.

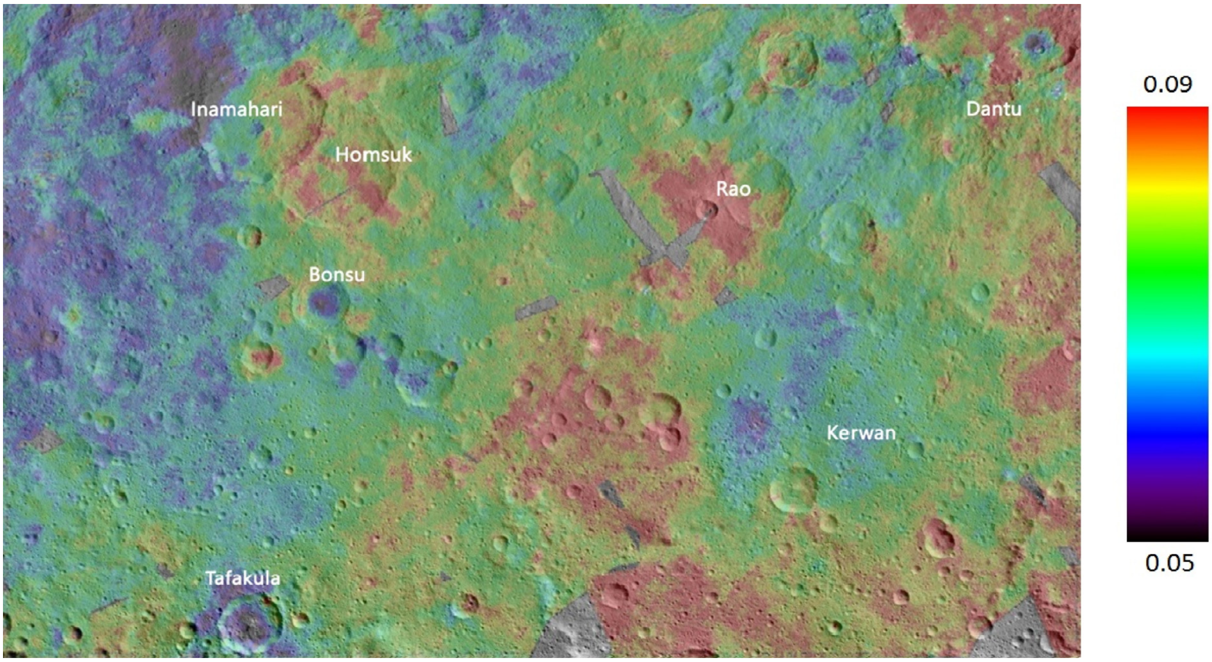

Fig. 3. Band depth at 3.1 µm of the Kerwan quadrangle, superimposed on the Framing Camera (FC) mosaic.

5.2. Dantu

Dantu is a large crater (126 km in diameter) with a complex shape and a variegated morphology including central pit, pit terrains, fractures and a ring of ridges (Williams et al., 2017). According to Lunar Derived Model Age, it formed 111+−39 Ma ago (Kneissl et al., 2016) by means of an impact and a subsequent disruptive collapse. Dantu lies in a low lying topographic terrain, the Vendimia Planitia, and ejecta of this region probably excavated material existing deeper within Ceres's crust than usual (Ammannito et al., 2016). The Vendimia Planitia, which contains both the Kerwan quadrangle and Dantu crater is the brightest Ceres region: it is about 10% brighter than the average Ceres (Ciarniello et al., 2017). This region could be brighter because of a relation with Kerwan and Dantu impact events and any subsequent geologic activity (Marchi et al., 2016).

5.3. Rao

Rao is a 12-km diameter rayed impact crater located at 8.1°N, 119.01°E. Its bluish rays are distinctive in FC color ratio images, and crater counts of its eject blanket suggest a very young age, 34 Ma (ADM) or 33 Ma (LDM). Rao is moderately degraded and transitions between simple to complex craters, and is superposed on ejecta materials from both Kerwan and Dantu craters (Williams et al., 2017).

5.4. Bonsu

Bonsu is a 31-km diameter impact crater (1.74°N, 93.21°E) superimposed on the ejecta blankets of paired craters Inamahari and Homshuk. The Bonsu crater has a smooth floor unit surrounding its central peak. The smooth unit in Bonsu is interpreted as an accumulation of low-albedo impact melt or cryovolcanic material (Williams et al., 2017).

5.5. Tafakula

The Tafakula crater (19.82°S, 88.59°E) is 34 km in diameter, located in the ancient cratered terrain of the Kerwan quadrangle. It is noted for a low albedo crater floor of (~0.08–0.09) surrounding its central peak. There is a WSW-ESE-trending groove SE of Tafakula, part of which corresponds to the location of the bright ray from the Occator crater that crosses the Kerwan quadrangle (Williams et al., 2017).

5.6. Inamahari and Homshuk

The paired impact craters Inamahari (68-km diameter, 14.13°N, 89.22°E) and Homshuk (70-km diameter, 11.23°N, 94.06°E) are superposed on the ancient cratered terrain in the northwestern part of the Kerwan quadrangle. Their ejecta blankets are mapped as distinctive crater material, but are superposed by younger units. Inamahari and Homshuk have polygonal rims, and Inamahari has a visible central peak. The structure of the rims suggests that Inamahari superposes Homshuk (Williams et al., 2017).

5.7. Bright spots

In the Kerwan quadrangle, six bright spots (BS) have been detected (Fig. 4), using a "relative" criterion procedure as well explained in Palomba et al. (2014). Five of them are features associated with crater features, such as crater rims and crater walls, whereas only one is related to ejecta. In particular, two bright spots correspond to crater rim and ejecta southeast of the Dantu crater: the BS related to Dantu crater rim (B21) is at 17°N, 135°E, while the BS of Dantu ejecta (B22) is located at 15°N, 142°E (Palomba et al., 2017). The other BS are: the crater rim of Rao (B26, located at 6.5°N, 121.5°E), the youngest feature in the Kerwan quadrangle; the crater wall (B29, at 2.5°N, 137.5°E) and crater rim (B31, at 2.5°S, 135.5°E) of unnamed features near the Kerwan crater; the rim of a crater close to Tafakula (B41, located at 20.5°S, 85°E) (Palomba et al., 2017).

6. Discussion

In Kerwan, we observe an increase in band depths of both ammoniated phyllosilicates and Mg-phyllosilicates. This is a behavior opposite to young craters, which are instead characterized by band

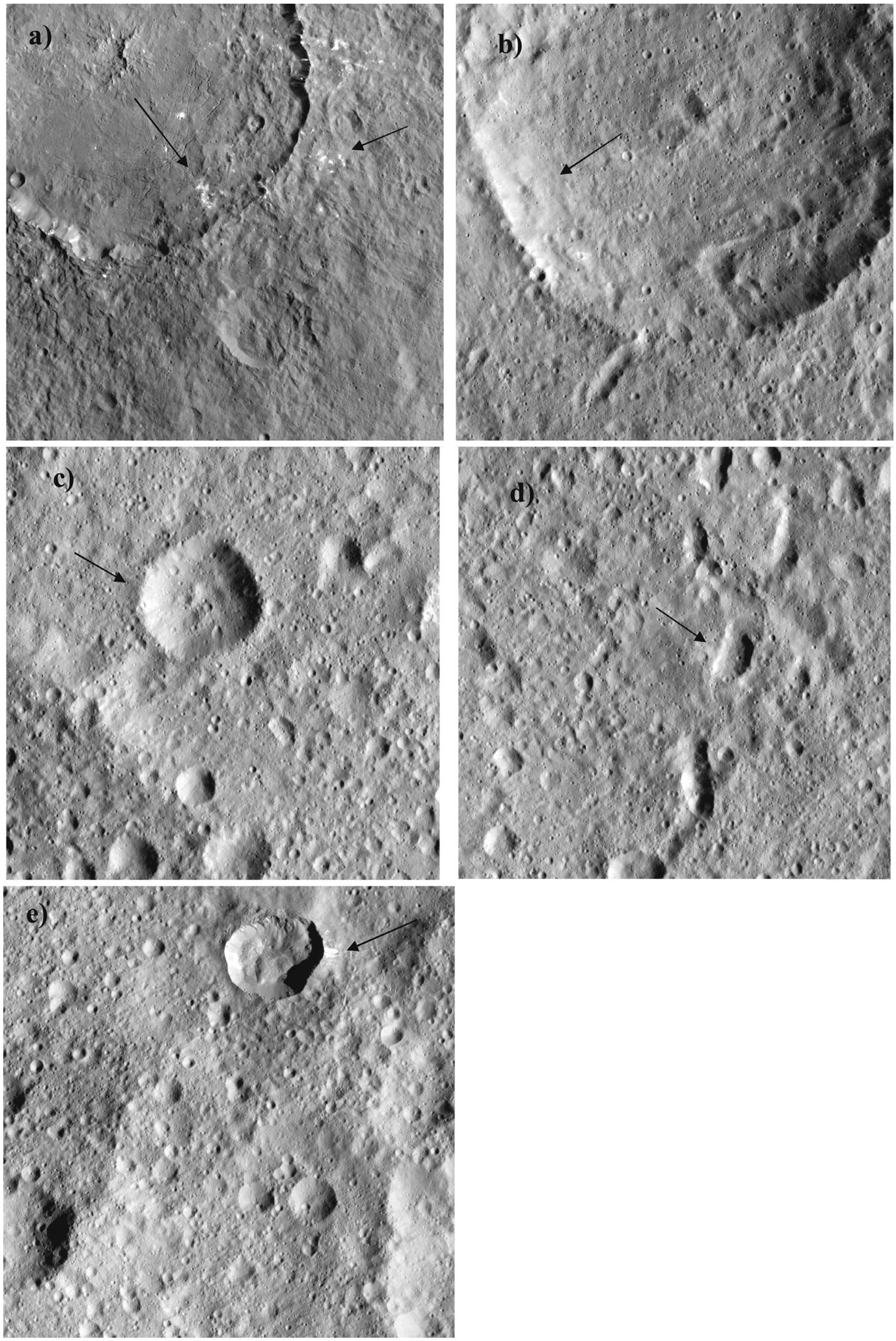

Fig. 4. Images acquired by FC of Kerwan BS associated to (a) rim and ejecta of Dantu crater, (b) crater rim of Rao, (c) crater wall of unnamed feature near Kerwan feature (B29), (d) crater rim of unnamed feature near Kerwan crater (B31), (e) rim of a crater close to Tafakula (B41).

depths' shallowing (e.g., Stephan et al., 2017a). In addition, as seen in other equatorial quadrangles (Carrozzo et al., 2017b; Longobardo et al., 2017b), an association between deeper bands and lower topography level arises. This may reflect a vertical gradient of ammoniated phyllosilicates abundance. Relative to the Kerwan quadrangle, Dantu crater shows a high 3.1-µm band depth and a low 2.7-µm band depth. The behavior of the two bands show a stronger correlation than the average Kerwan quadrangle but weaker that the average Ceres (Pearson coefficient = 0.212 vs 0.191 vs 0.3, respectively): in the Dantu crater floor, higher and lower values of the two band depths tend to correspond. The distinct differences with the rest of the quadrangle are due to the fact that Dantu belongs to a different geological unit and should be related to the Dantu quadrangle (Stephan et al., 2017c) rather than the Kerwan quadrangle.

A detailed analysis of this crater is indeed found in Stephan et al. (2017c). Here, we observe a very variegated distribution inside the crater, with lower band depths corresponding to the youngest, small impact features (e.g., the Centeotl crater) or to the occurrence of bright spots hosting carbonates. Both behaviors are common to the rest of the Ceres surface (Stephan et al., 2017b; Palomba et al., 2017). The floor and the rayed impact ejecta of Rao have a higher reflectance than the terrain of Kerwan quadrangle, as well as an increasing 3.1-µm band depth, indicative of an elevated abundance of ammoniated phyllosilicates. The strength of the 2.7-µm band is stronger in the rim and in the ejecta closer to the crater. Moving away from the crater, the 2.7-µm band depth in the Rao ejecta decreases, suggesting a lower quantity of Mg-phyllosilicates.

The Bonsu crater has a smooth floor unit surrounding its central peak, which has a slightly lower albedo (∼0.09) than the other units in the quadrangle (∼0.09–0.1). The floor is characterized by a very low albedo and shallow 3.1 µm band depth, while rims are brighter and richer in ammoniated phyllosilicates. Bonsu results in a low level of Mg-phyllosilicates, especially in the floor, where band depth values are minimal. Tafakula is a very dark crater; the geometric albedo of ejecta, crater floor, rim and part of the crater wall are particularly low. The band depth relative to NH_4-phyllosilicates follows a similar trend, suggesting a lower abundance of ammoniated phyllosilicates, especially in the floor and ejecta. The strength of the 2.7-µm band is moderate and comparable in all craters, reaching minimal values in the central peak. The NE side of the Tafakula crater is, instead, characterized by a greater abundance of Mg-phyllosilicates. A very small portion of the south rim of Inamahari shows an enhanced 3.4 µm band that has been interpreted as due to the presence of organic material (De Sanctis et al., 2017). Inamahari has a moderate albedo on the crater floor, darker in the west side and brighter in the east. In particular, crater rim and ejecta on the east side of Inamahari reach high values of geometric albedo and cross the floor of the Homsuk crater, which is characterized by a lower albedo. The rim and ejecta of Homsuk are brighter than the surrounding terrain. The abundance of Mg-phyllosilicates is reduced in the paired craters: a particular depletion is observed on the west side of Inamahari, in its northern and southern crater rim, and in the central peak. A lower abundance of phyllosilicates is also observed in the central part of Homsuk's floor.

Similarly, the ammoniated phyllosilicates are more abundant in the eastern part of the Inamahari crater, in the floor, walls, rims and ejecta. Rims, walls and ejecta of the west side are depleted in ammoniated phyllosilicates, as well as in the central peak. Localized regions in the Homsuk floor are richer in ammoniated phyllosilicates, while its rim and ejecta are more depleted.

A strong correlation (Pearson coefficient = 0.707) between 2.7 and 3.1-µm band depth is observed for the six BS (Fig. 5). The band depth is larger in the BS of Dantu's crater rim with respect to the other BS observed in the Kerwan quadrangle, suggesting a more elevated abundance of phyllosilicates. The BS of Dantu ejecta is characterized by a lower abundance of ammoniated phyllosilicates and Mg-phyllosilicates. Bright spots in Kerwan quadrangles are, in general, more abundant in ammoniated phyllosilicates with respect to the Ceres average (green rhombus) and poorer in Mg-phyllosilicates. The photometrically corrected reflectance (estimated at 1.2 µm with a phase angle of 30°) of Dantu's crater rim is the highest of Kerwan BS's, and it is almost 1.5 times the albedo of Dantu ejecta, the darkest Bright Spot and about 1.6 times the albedo of mean Ceres surface (Fig. 6). The low abundance of phyllosilicates in the Dantu ejecta is in agreement with younger features, but the low albedo suggests a mixing of young material with

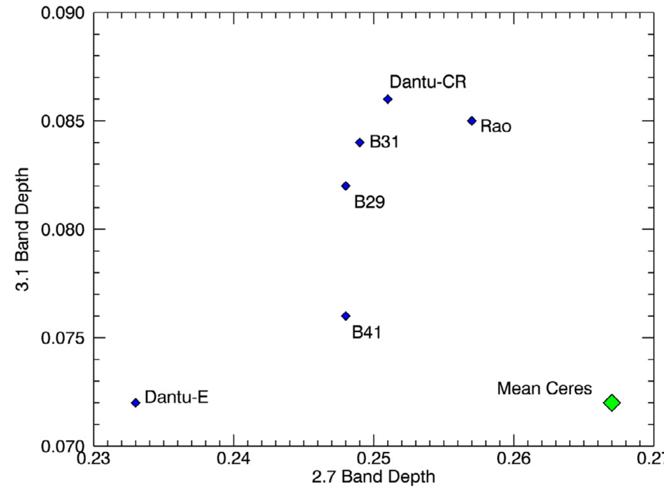

Fig. 5. Scatterplot of 2.7-µm band depth vs 3.1-µm band depth for the six BS (blue rhombus) detected in the Kerwan quadrangle (Palomba et al., 2017) and Mean Ceres (green rhombus). A strong correlation is observed (Pearson coefficient = 0.707) and the BS related to Dantu crater rim (Dantu-CR) is the richest in phyllosilicates, while the BS connected to Dantu ejecta (Dantu-E) is the most depleted. The BS of Rao's crater rim is also characterized by a high abundance of NH_4- and Mg- phyllosilicates, as its floor and ejecta. Kerwan BS, are in general, more depleted in Mg-phyllosilicates with respect to Ceres surface and richer in ammoniated minerals. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

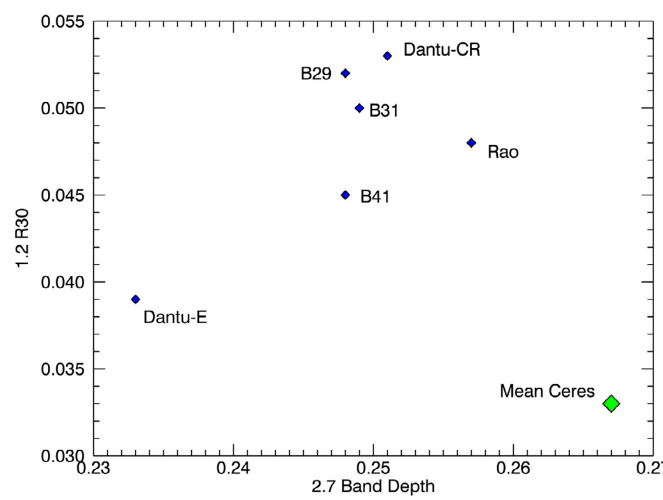

Fig. 6. Scatterplot of 2.7-µm band depth vs photometrically corrected albedo (evaluated at 1.2 µm with a phase angle of 30°). The BS of Dantu's crater rim is the brightest one in the Kerwan quadrangle, while the BS of Dantu ejecta is the darkest one. Value relative to the average Ceres surface is also plotted (green rhombus). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

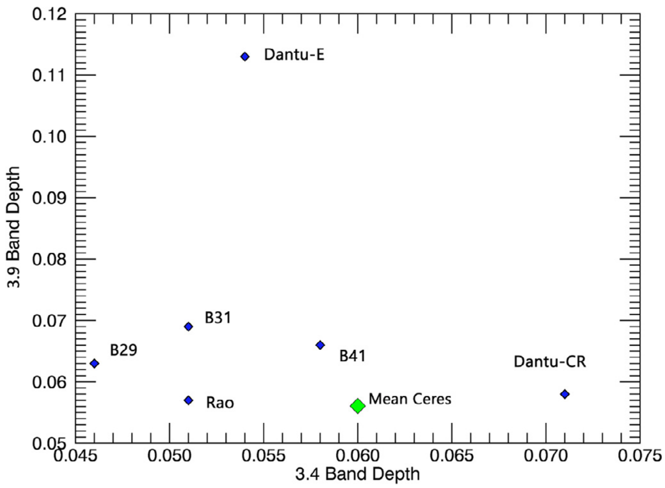

Fig. 7. 3.4 vs 3.9 µm band depth scatterplot. The BS of Dantu ejecta presents the highest abundance of carbonates among the BS of Kerwan quadrangle, while Rao is the poorest one, with a 4.0 µm band depth value very similar to the mean Ceres surface (green rhombus). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the ancient and darker terrain of the Kerwan quadrangle. The BS of the Dantu ejecta (B22) is recognized as a peculiar BS by Palomba et al. (2017) for the deep 3.9-µm absorption band, related to carbonates. Most of Kerwan BS are characterized by a 3.9 µm band depth very similar to the Mean Ceres, while the absorption band in Dantu ejecta is 2 times deeper than Ceres surface. The position of band center, located at 3.97 um, suggests a Ca-Mg carbonate composition (Palomba et al., 2017). It is, furthermore, the richest in carbonate BS of the Kerwan quadrangle (Fig. 7). The reflectance, the 2.7 and 3.1 µm band depths of the other BS have intermediate values between Dantu ejecta and Dantu's crater rim, except for Rao. Rao is the youngest crater on the Kerwan quadrangle, but it is also one of the richest in phyllosilicates. The BS corresponding to Rao's crater rim has, therefore, a high albedo and elevated abundance of ammoniated and Mg-phyllosilicates. It is also, the BS of the Kerwan quadrangle with the lowest abundance of carbonates (Fig. 7).

7. Conclusions

In this paper, we presented the distribution maps of the 1.2 µm albedo and the band depths of the OH and the ammoniated clay features at 2.7 µm and at 3.1 µm, respectively, for the Kerwan quadrangle. The abundance of ammoniated clays is well correlated with the phyllosilicates, a common behavior observed on Ceres, even if exceptions are observed in the floor of the Kerwan, Inamahari and Homshuk craters. The regions richest with ammoniated phyllosilicates are Kerwan ejecta and Rao. It is instead observed as a volatile depletion on most of the crater floors (Tatakula, Bonsu and an unnamed crater at the western latitudes). In some cases (Inamahari and Dantu), ejecta also show lower band depth. A possible explanation is that thermal energy associated with impact-generating crater features would have caused release of volatile materials and hence crater floors are now depleted in volatiles. Difference in grain size could also explain this band depth difference between young and old craters (Stephan et al., 2017b, c).

Six bright spots are detected in this quadrangle, one of which is located on the southeast Dantu ejecta (B22), which is among the richest in carbonates.

Generally, a moderate correlation between geology and mineralogy is observed, with younger terrains (Kerwan ejecta) showing larger band depths than the older ones. This correlation is even observed in a few other places on other quadrangles (e.g. Longobardo et al, 2017b; Carrozzo et al., 2017b) but it is not common to the entire Ceres surface. According also to conclusions of other works in this special issue (e.g. Stephan et al. 2017b; Carrozzo et al., 2017b; Stephan et al., 2017c), we suggest that the correlation of geology and mineralogy is generally observed, but the occurring of recent events could have been masked this correlation.

Acknowledgments

VIR is funded by the Italian Space Agency–ASI and was developed under the leadership of INAF-Istituto di Astrofisica e Planetologia Spaziali, Rome, Italy. The instrument was built by Selex-Galileo, Florence, Italy. The authors acknowledge the support of the Dawn Science, Instrument, and Operations Teams. This work was supported by ASI and NASA.

Sharon Uy (UCLA, USA) is thanked for the manuscript revision.

References

Ammannito, E., et al., 2016. Distribution of phyllosilicates on the surface of Ceres. Science 353, 6303.
Bland, M.T., et al., 2016. Composition and structure of the shallow subsurface of Ceres revealed by crater morphology. Nat. Geosci. 9, 538–542.
Carrozzo, F.G., et al., 2016. Artifacts reduction in VIR/Dawn data. Rev. Sci. Instrum. 87 (12), 124501.
Carrozzo, F.G., et al., 2017a. Nature, formation and distribution of Carbonates on Ceres. Sci. Adv. in press.
Carrozzo, F.G., et al., 2017b. The Mineralogy of the Nawish Quadrangle of Ceres, this issue.
Ciarniello, M., et al., 2017. Spectrophotometric properties of dwarf planet Ceres from the VIR spectrometer on board the Dawn mission. Astron. Astrophys. 598 14 pp.
De Sanctis, M.C., et al., 2011. The VIR spectrometer. Space Sci. Rev. 163, 329–369.
De Sanctis, M.C., et al., 2015. Ammoniated phyllosilicates with a likely outer Solar System origin on (1) Ceres. Nature 528, 241–244.
De Sanctis, M.C., et al., 2016. Bright carbonate deposits as evidence of aqueous alteration on (1) Ceres. Nature 536, 54–57.
De Sanctis, M.C., et al., 2017. Ac-H-11 Sintana and Ac-H-12 Toharu quadrangles: Assessing the large and small scale heterogeneities of Ceres' surface, in press.
Frigeri, A. et al., 2017. The spectral parameter maps of Ceres from NASA/DAWN VIR data, this issue.
Kneissl, T., et al. (2016), Geologic Mapping of the Ac-H-3 Dantu Quadrangle of Ceres from NASA's Dawn Mission, 47th Lunar and Planetary Science Conference, 1967.
Longobardo, A., et al., 2017a. Photometry of Ceres and Occator faculae as inferred by VIR/Dawn data, submitted to Icarus.
Longobardo, A., et al., 2017b. Mineralogy of the Occator Quadrangle, this issue.
Marchi, S., et al., 2016. The missing large impact craters on Ceres. Nat. Commun. 7, 12257.
McCord, T.B., Zambon, F., 2017. The Surface Composition of Ceres from the Dawn Mission, this issue.
Palomba, E., et al., 2014. Composition and mineralogy of dark material units on Vesta. Icarus 240, 58–72.
Palomba, E., et al., 2015. Detection of new olivine-rich locations on Vesta. Icarus 258, 120–134.
Palomba, E., et al., 2017. Compositional differences among Bright Spots on the Ceres surface. Icarus in press.
Raponi, A., 2014. Spectrophotometric analysis of cometary nuclei from in situ observations Ph.D. thesis. Università degli studi di Roma Tor Vergata.
Russell, C.T., Raymond, C.A., 2011. The Dawn mission to Vesta and Ceres. Space Sci. Rev. 163 (1), 3–23.
Sierks, H., et al., 2011. The Dawn Framing Camera. Space Sci. Rev. 163, 263–327.
Stein, N., et al., 2017. Characteristics, formation, and evolution of faculae (Bright Spots) on Ceres. Icarus in press.
Stephan, K., et al., 2017a. An investigation of the bluish material on Ceres. Geophys. Res. Lett. 44 (4), 1660–1668.
Stephan, K., et al., 2017b. Spectral investigation of quadrangle AC-H 3 of the dwarf planet Ceres – The region of impact crater Dantu, this issue.
Stephan, K., et al., 2017c. Ceres' craters – Relationships between surface composition and geology, this issue.
Williams, D.A., et al., 2017. The geology of the Kerwan quadrangle of dwarf planet Ceres: investigating Ceres' oldest impact basin. Icarus in press.