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High-resolution Enceladus atlas derived from Cassini-ISS images

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Abstract

The Cassini Imaging Science Subsystem (ISS) acquired 377 high-resolution images (<1 km/pixel) during three close flybys of Enceladus in 2005 [Porco, C.C., et al., 2006. Cassini observes the active south pole of Enceladus. Science 311, 1393–1401.]. We combined these images with lower resolution Cassini images and four others taken by Voyager cameras to produce a high-resolution global controlled mosaic of Enceladus. This global mosaic is the baseline for a high-resolution Enceladus atlas that consists of 15 tiles mapped at a scale of 1:500,000. The nomenclature used in this atlas was proposed by the Cassini imaging team and was approved by the International Astronomical Union (IAU). The whole atlas is available to the public through the Imaging Team's website (http://ciclops.org/maps).

Keywords: Cassini; Icy satellites; Planetary mapping; Saturnian system

1. Introduction

The Cassini spacecraft started its tour through the Saturnian system in July 2004. The Imaging Science Subsystem (ISS) onboard the orbiter consists of a high-resolution narrow-angle camera (NAC) with a focal length of 2000 mm and a wide-angle camera (WAC) with a focal length of 200 mm (Porco et al., 2004). One of the main objectives of the Cassini mission is to investigate the icy Saturnian satellites. Enceladus, the second innermost of the medium sized satellites, was imaged by the Cassini spacecraft during three close flybys (Table 1, Porco et al., 2006). The images taken during these flybys together with lower resolution frames allowed us to create a global mosaic of Enceladus with a spatial resolution of about 110 m/pixel. Unfortunately, the Cassini ISS has not yet imaged the northern high latitude regions (>67°) because they are shrouded in seasonal darkness and will not be illuminated by the Sun until later in the decade when the Cassini extended mission begins. Fortunately, the Voyager camera was able to take images from these regions during its flyby in the early 1980s. We thus used Voyager images to fill the north polar gaps in the global mosaic.

Details of the image processing will be described in Section 2. Section 3 summarizes the high-level cartographic work that produced our high-resolution atlas, which consists of 15 maps of the different regions of Enceladus. Three examples of these maps are shown. A brief overview of future work is given in Section 4.

2. Data processing

2.1. Image processing

The image data returned from the spacecraft are distributed to the Cassini imaging team in VICAR (Video Image Communication and Retrieval) format (http://www-mipl.jpl.nasa.gov/external/vicar.html). The first step of the image processing is the radiometric calibration of the images using the ISS Team's CISSCAL computer program

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Table 1
Cassini Enceladus flybys in 2005

Flyby date	Flyby distance (km)
17 February 2005	1263.5
9 March 2005	501.8
14 July 2005	173.0

(Porco et al., 2004). Next, the specific subset of images that will be used to construct the global basemap is selected. At the time of this writing, a total of 2353 images of Enceladus are available. This total data set contains images obtained through a variety of different ISS color filters and at spatial resolutions ranging from 3 m/pixel up to 14 km/pixel. For our mosaic, we selected only those images taken with the filters CL1, CL2 or GRN, as

Table 2
Cassini images used for the mosaic

Image number in Fig. 1	Image name	Resolution (km/pixel)	Center latitude (°)	Center longitude (West) (°)
1	N1484519630	2.184	5.24	85.37
2	N1484532352	1.444	7.24	90.78
3	N1487299402	0.177	42.07	295.58
4	N1487299578	0.170	18.99	263.86
5	N1487299765	0.163	−0.76	243.61
6	N1487299918	0.156	−23.93	250.00
7	N1487300107	0.148	−12.47	281.07
8	N1487300285	0.141	5.28	309.06
9	N1487300482	0.133	20.90	331.94
10	N1487300648	0.126	−6.54	335.74
11	N1487300854	0.118	−22.62	313.85
12	N1487301032	0.111	−39.37	286.38
13	N1487301209	0.104	−47.51	257.24
14	N1487301386	0.097	−60.21	299.94
15	N1487301590	0.088	−42.85	324.25
16	N1487302209	0.064	2.40	288.95
17	N1489034080	0.860	−0.45	157.15
18	N1489039292	0.559	1.28	173.85
19	N1489047359	0.188	−38.29	248.69
20	N1489047533	0.180	−39.14	202.65
21	N1489047708	0.173	−35.00	157.63
22	N1489047867	0.167	3.13	156.62
23	N1489048050	0.159	−0.32	192.31
24	N1489048222	0.152	−3.41	224.71
25	N1489048394	0.146	−5.77	255.47
26	N1489048550	0.139	24.59	258.65
27	N1489048724	0.132	26.31	224.88
28	N1489048898	0.125	28.43	193.25
29	N1489049072	0.118	30.93	161.39
30	N1489049404	0.105	53.43	196.82
31	N1489049580	0.098	50.97	237.40
32	N1489049756	0.091	45.20	264.82
33	N1489087177	0.991	0.48	130.16
34	N1500051528	0.617	−43.64	169.92
35	N1500056680	0.349	−72.47	147.16
36	N1500060756	0.147	−4.06	199.58
37	N1500060887	0.141	−14.13	174.12
38	N1500061010	0.135	−38.04	166.70
39	N1500061132	0.129	−61.99	154.72
40	N1500061253	0.123	−84.38	95.17
41	N1500061390	0.116	−68.34	295.81
42	N1500061512	0.110	−63.25	220.27
43	N1500061634	0.104	−42.39	200.67
44	N1500061771	0.097	−29.96	219.25
45	N1500061892	0.091	−45.46	233.84
46	N1500068930	0.250	15.39	21.60
47	N1500069083	0.257	36.78	340.68
48	N1500069258	0.266	82.81	341.29
49	N1536530570	0.386	46.15	277.22
50	W1487299765	1.616	1.43	315.99
51	N1490643112	8.800	−0.22	74.90

these images show comparable albedo contrasts among different Enceladus terrains. Fifty Cassini NAC images, one Cassini WAC image (Table 2), and four Voyager high-resolution images were used to produce a 40 pixel/deg global mosaic. Fig. 1 shows the location of the individual Cassini images. The resolution of the selected Cassini images varies between 0.064 and 8.8 km/pixel. The resolutions of the Voyager images C4398347, C4400044, C4400412, C4400432 are 8.8, 1.85, 1.0, and 1.0 km/pixel, respectively.

The next step of the processing chain is to map project the images to the proper scale and map projection type—a process that requires detailed information about the global shape of Enceladus. The inner Saturnian satellites are best described by tri-axial ellipsoids as derived from ISS images by Thomas et al. (2007). The latest radii for Enceladus are 256.6, 251.4, and 248.3 km. However, to facilitate comparison and interpretation of the maps, ellipsoids were used only for the calculation of the ray intersection points, while the map projection itself was

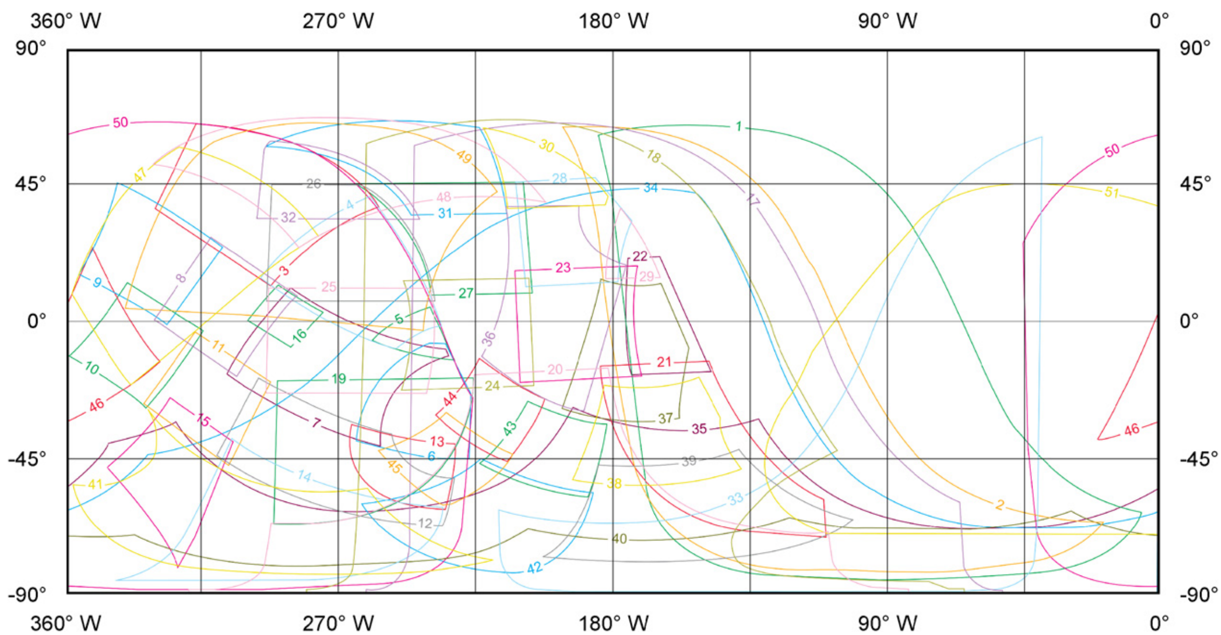

Fig. 1. Global mosaic showing the location of the Cassini ISS images (see Table 2). Mosaic is in simple cylindrical projection with latitude = 0°, longitude = 180° in the center.

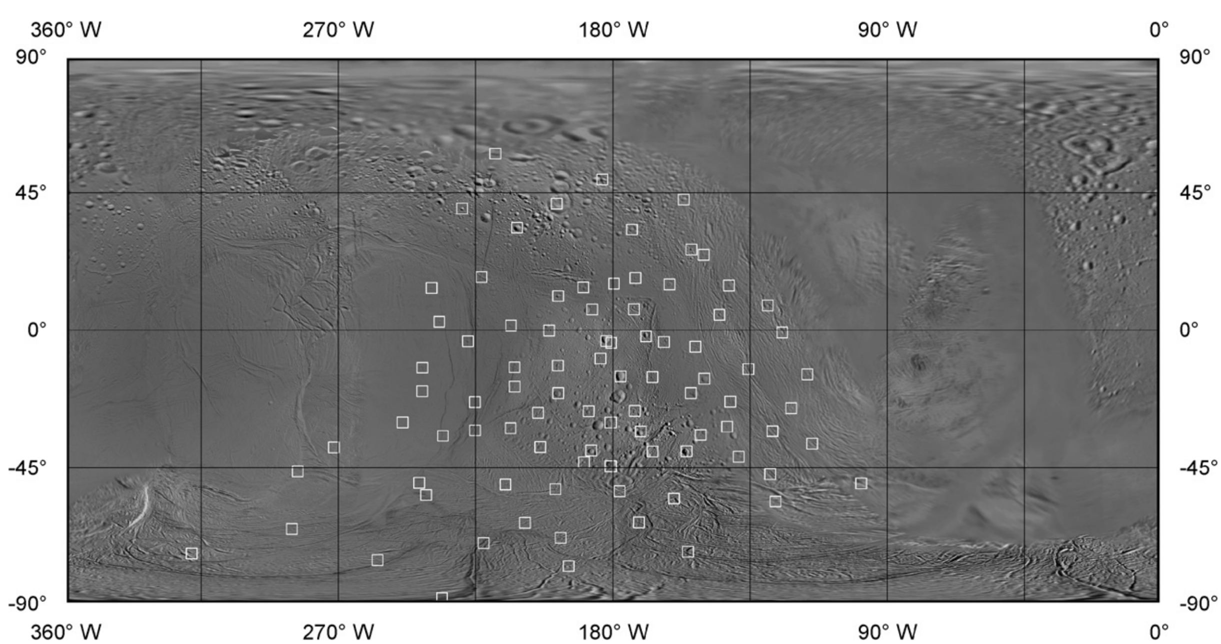

Fig. 2. Global mosaic showing the location of the control points. Mosaic is in simple cylindrical projection with latitude = 0°, longitude = 180° in the center.

done onto a sphere with the mean radius (252.1 km) (Thomas et al., 2007). The Cassini orbit and attitude data used for the calculation of the surface intersection points are provided as SPICE kernels (http://naif.jpl.nasa.gov) and were improved using a limb-fitting technique (Roatsch et al., 2006). We chose an equidistant map projection as map projection type. The coordinate system adopted by the Cassini mission for satellite mapping is the IAU "planetographic" system, consisting of planetographic latitude and positive West longitude. But because a spherical reference surface is used for map projections of the satellites, planetographic and planetocentric latitudes are numerically equal. The Hapke photometric model (Hapke, 1993) was applied to adjust the brightness of each map pixel so that it represents the reflectance that would be observed at the nadir at 30° phase angle. Imaging data viewed at incidence and emission angles greater than 80° were omitted from the map. After photometric correction, mosaicking was the final step of the image processing (Roatsch et al., 2006).

2.2. Least-squares adjustment of attitude data

A 3-D control net was set up to correct errors in the nominal camera pointing data. Here, we applied least-squares adjustment techniques (Giese et al., 2006).

Table 3
Images used for the least-squares adjustment of attitude data

Image name	Resolution (km/pixel)	Center latitude (°)	Center longitude (West) (°)
N1489029762	1.16	−0.49	145.41
N1489034080	0.86	−0.45	157.15
N1489039292	0.56	1.28	173.85
N1489047533	0.18	−39.14	202.65
N1500041648	1.22	−36.26	142.41
N1500051528	0.62	−43.64	169.92
N1500056680	0.35	−72.47	147.16
N1500056947	0.34	−28.26	154.94
N1500057234	0.32	−13.42	198.46
N1500057514	0.31	−50.81	244.17
N1516171253	0.93	0.00	243.62

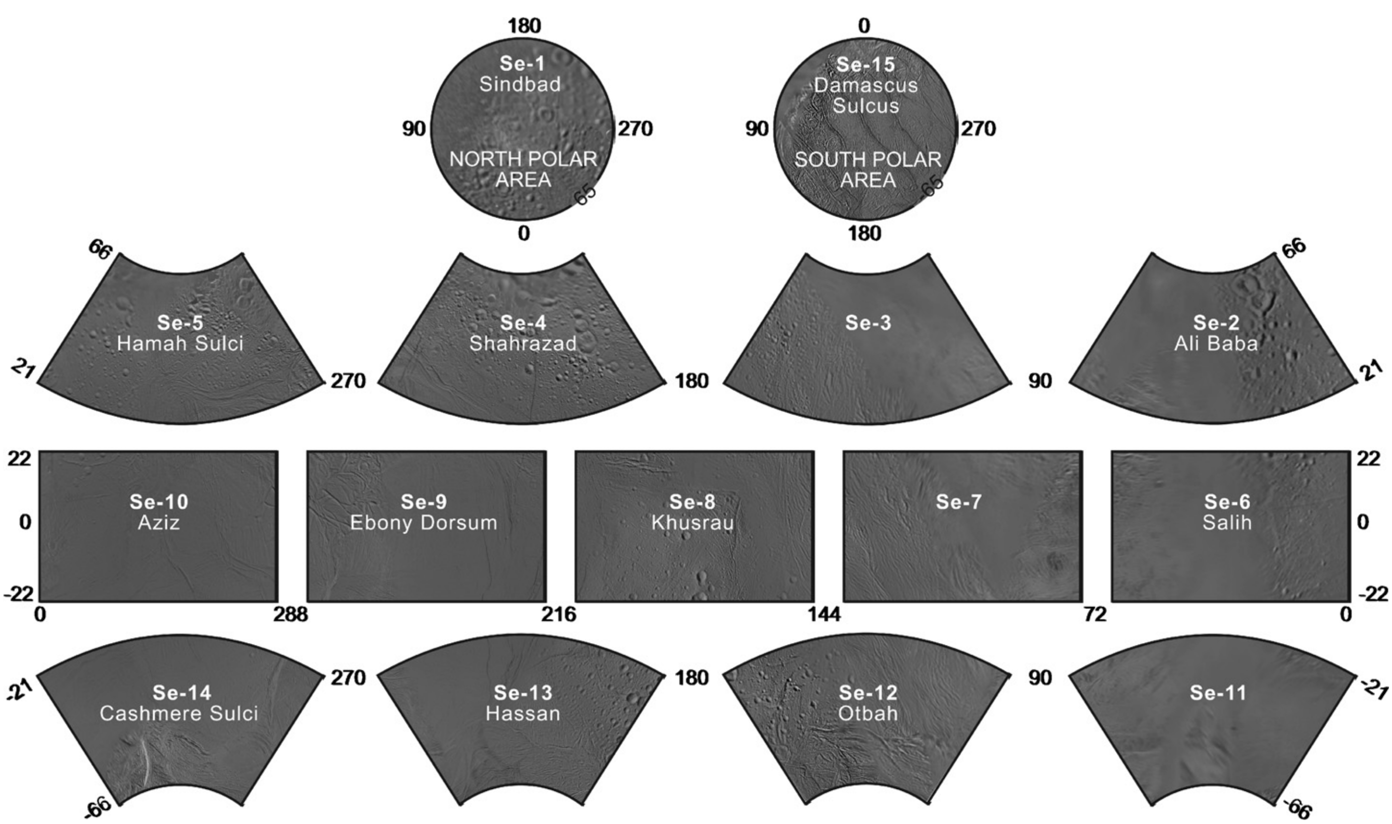

Fig. 3. Quadrangle scheme filled with the 15 Enceladus tiles.

The image coordinates of 88 control points (Fig. 2) collected in 11 NAC images (Table 3) were applied as observational data in the adjustment, and the ground coordinates of the control points and the camera pointing angles were treated as unknowns. The spacecraft orbit was fixed during the calculations. In result, we obtained improved camera pointing angles and a 3-D control net with average 1σ errors of 736, 335, 608 m for the x, y, z coordinates, respectively. Unfortunately, the control points are not equally distributed over Enceladus' surface due to missing stereo data around the prime meridian (Fig. 2).

The improved pointing data were used to calculate a medium-resolution, controlled mosaic. Finally, the high-resolution mosaic calculated as described in Section 2.1 was registered on the controlled mosaic to improve its global accuracy and feature definition.

3. Enceladus map tiles

The Enceladus atlas was produced in a scale of 1:500,000 and consists of 15 tiles that conform to the quadrangle scheme proposed by Greeley and Batson (1990) and Kirk (1997, 1998, 2002, 2003) for large satellites (Fig. 3). A map scale of 1:500,000 guarantees a mapping at the highest available Cassini resolution and results in an acceptable printing scale for the hardcopy map of 4.5 pixel/mm. The individual tiles were extracted from the global mosaic and reprojected, coordinate grids were superposed as graphic vectors and the resulting composites were converted to the common PDF-format using software that was originally developed for Mars maps, the Planetary Image Mapper (PIMap) (Gehrke et al., 2006). The equatorial part of the map ($-22°$ to $22°$ latitude) is in Mercator projection onto a secant cylinder using standard parallels at $-13°$ and $13°$ latitude. The regions between the equator region and the poles ($-66°$ to $-21°$ and $21°$ to $66°$ latitude) are projected in Lambert conic projection with two standard parallels at $-30°$ and $-58°$ (or $30°$ and $58°$, respectively). The poles are projected in stereographic projection ($-90°$ to $-65°$ latitude and $65°$ to $90°$ latitude). The Mercator maps are $72°$ in longitude dimension, the Lambert maps $90°$, and the poles $360°$. The individual tiles overlap in the North–South direction by one degree, however, no overlapping region is

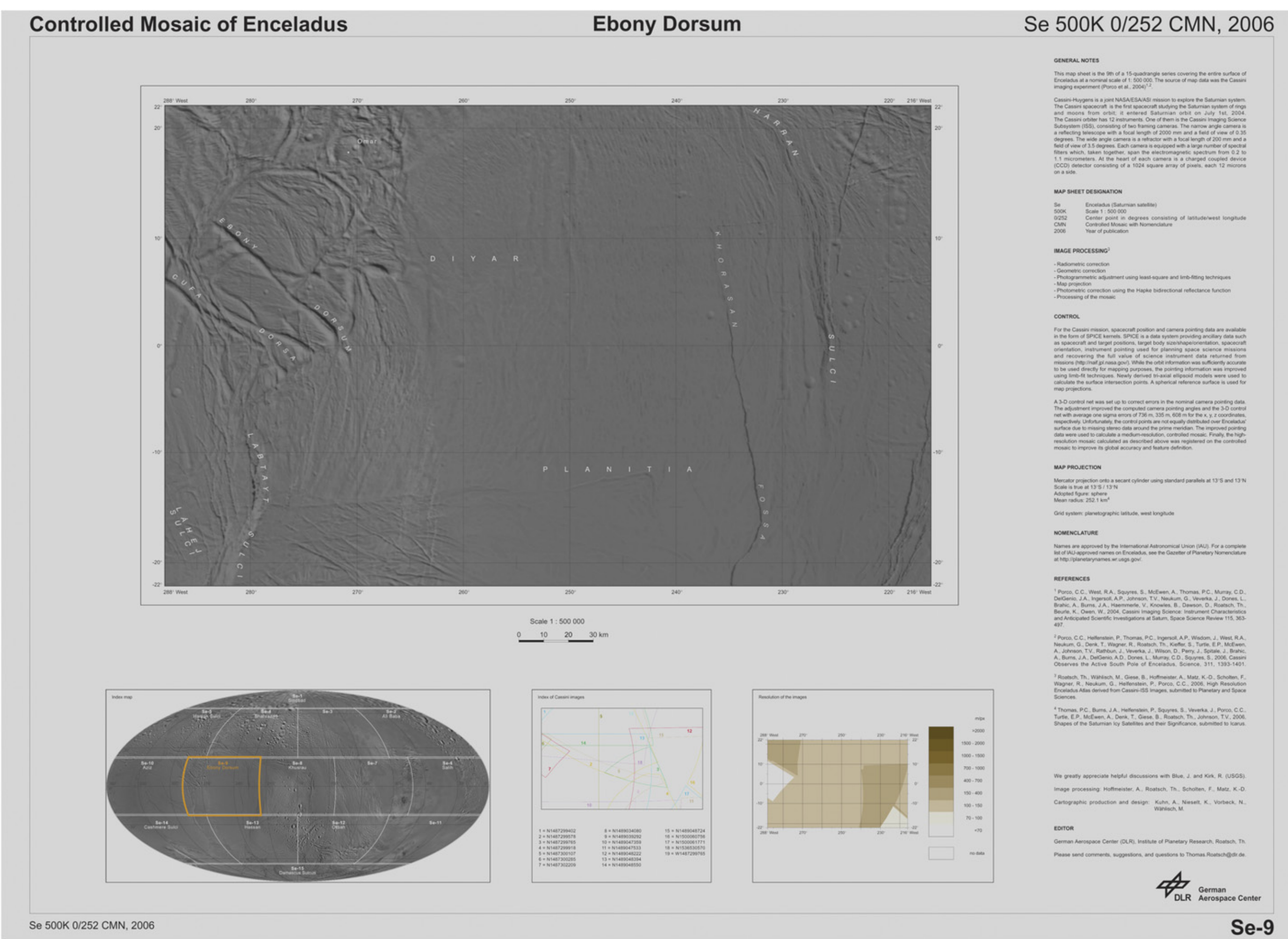

Fig. 4. Enceladus map sheet 09: Ebony Dorsum.

present in the East–West direction (see Fig. 3). We have produced the maps using the same scaling factors in overlapping regions at the matching parallels $\pm 21.34^\circ$ and $\pm 65.19^\circ$ latitude, 1.0461 and 1.0484, respectively (Snyder, 1987). Using this quadrangle scheme in the 1:500,000 scale for Enceladus, we get the printed maps in the same user-friendly size of 1050 mm width by 750 mm height. We also added resolution maps and index maps for every individual tile, showing the image resolution, the image numbers and the location of the images for every map, respectively. Three map examples in different projections are shown in Figs. 4–6.

The Cassini imaging team proposed 38 names for geological features, in addition to the 22 features already named by the Voyager team that are used in the maps. By international agreement, the features must be named after people or locations in the medieval Middle Eastern literary epic "The Thousand and One Nights". The locations and dimensions of all previously known features were measured again on the basis of the Cassini data and were corrected when necessary. Table 4 shows a comparison of the locations measured on the basis of the Voyager data and the Cassini data for three craters. The nomenclature proposed by the Cassini-ISS team was approved by the IAU (http://planetarynames.wr.usgs.gov/).

The entire Enceladus atlas consisting of 15 map tiles will is available to the public through the Imaging Team's website (http://ciclops.org/maps). The map tiles are also archived as standard products in the Planetary Data System (PDS) (http://pds.jpl.nasa.gov/).

4. Future work

The Cassini spacecraft will continue its imaging campaign through the Saturnian system. The next close flyby of Enceladus is scheduled for March 2008. Additional flyby opportunities are currently under investigation for the extended Cassini mission, which is expected to last until 2010. These upcoming flybys will help to replace the low-resolution parts of this atlas with higher resolution image data and to enlarge the control point coverage. The northern part of Enceladus will be illuminated during the extended mission providing an opportunity to obtain high-resolution Cassini coverage of high northern latitudes.

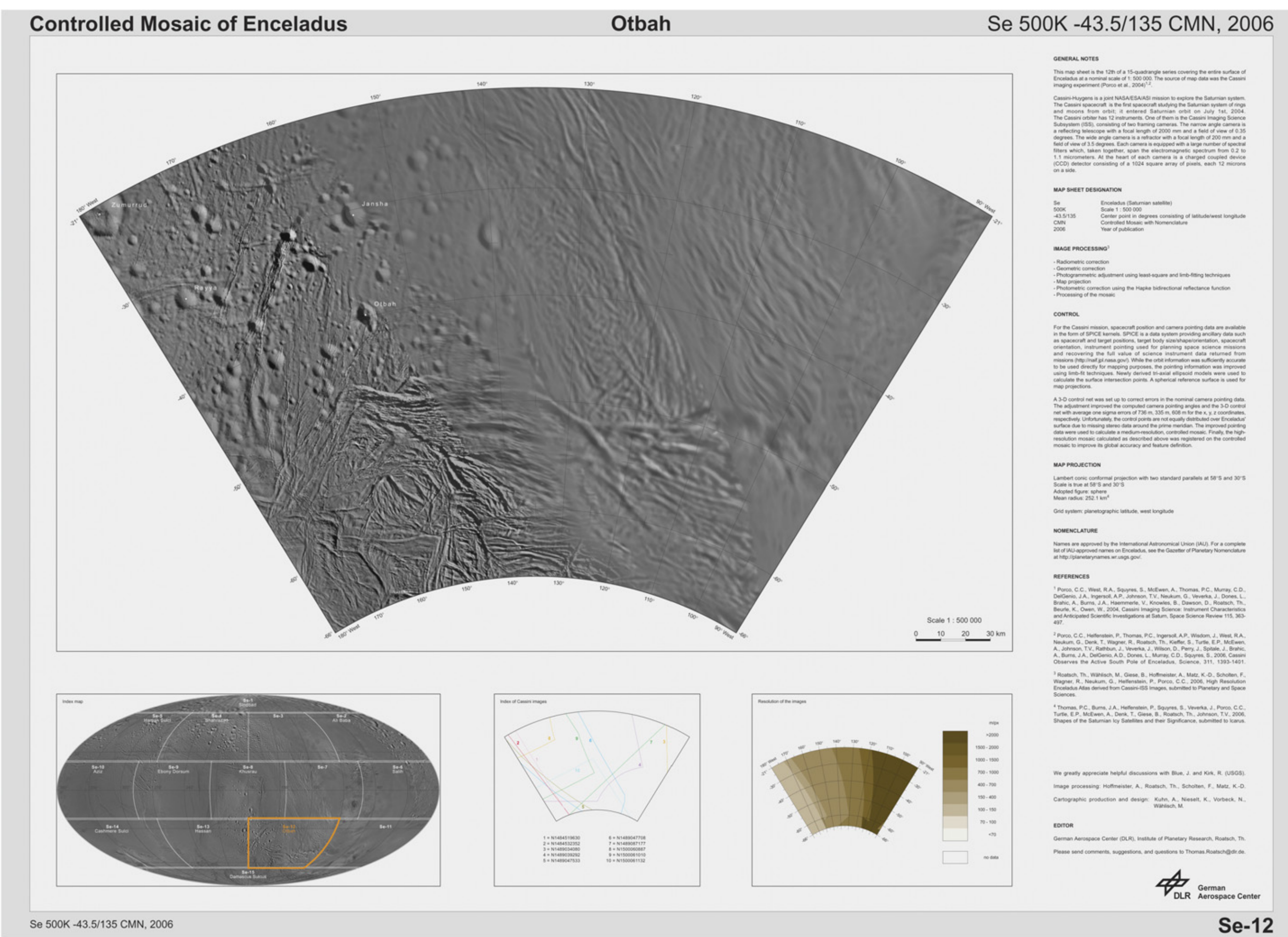

Fig. 5. Enceladus map sheet 12: Obtah.

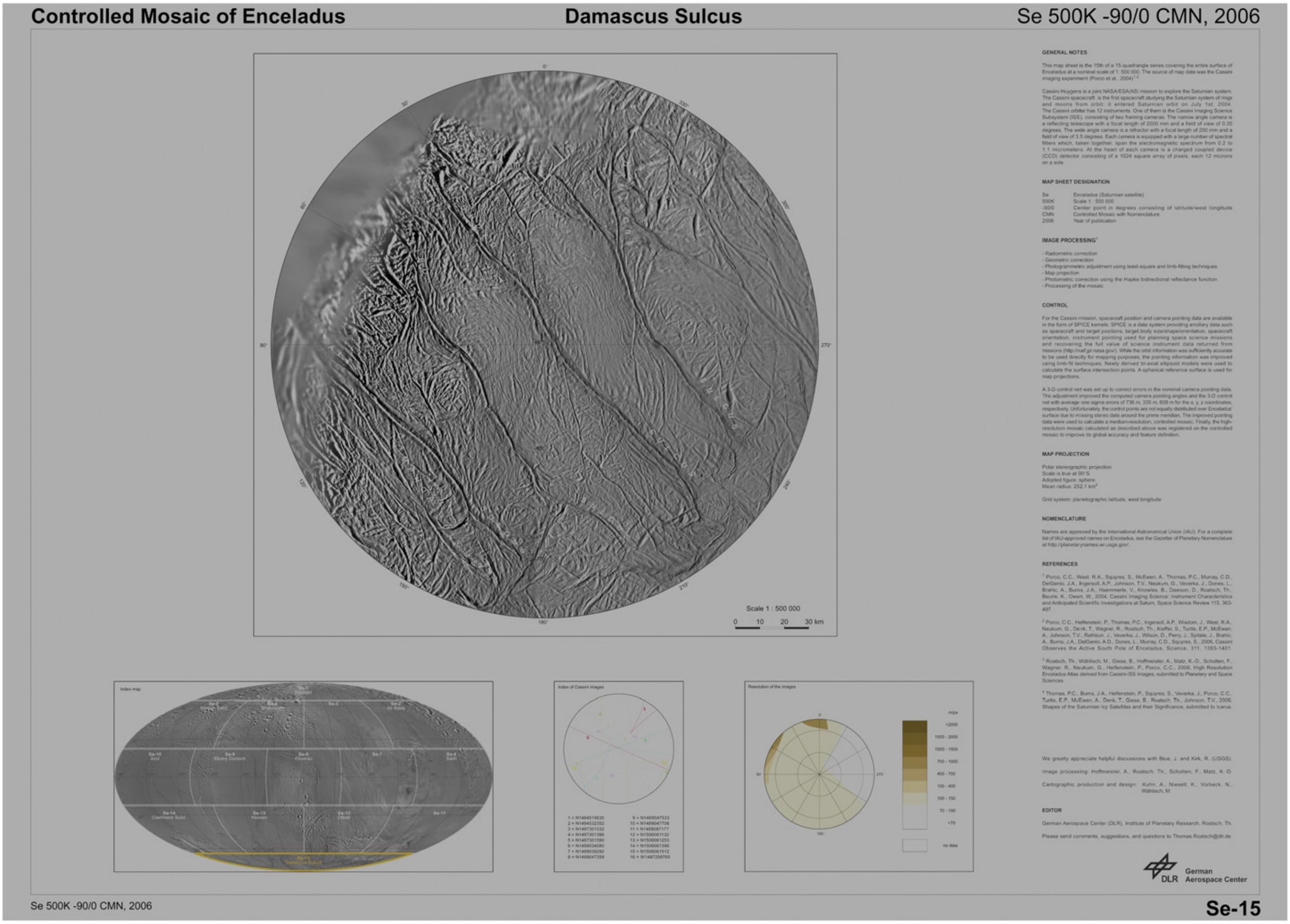

Fig. 6. Enceladus map sheet 15: Damascus Sulcus.

Table 4
Comparison of Voyager and Cassini crater location

Crater name	Voyager		Cassini	
	Latitude (°)	Longitude (West) (°)	Latitude (°)	Longitude (West) (°)
Shahrazad	48.2	195.1	46.8	197.6
Dunyazad	42.6	196.5	41.7	197.8
Dalilah	52.9	246.4	52.0	244.8

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