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High-resolution atlas of Rhea derived from Cassini-ISS images

Th. Roatsch [a,*], E. Kersten [a], M. Wählisch [a], A. Hoffmeister [a], K.-D. Matz [a], F. Scholten [a], R. Wagner [a], T. Denk [b], G. Neukum [b], C.C. Porco [c]

[a] *Institute of Planetary Research, German Aerospace Center (DLR), Berlin, Germany*
[b] *Remote Sensing of the Earth and Planets, Freie Universität Berlin, Germany*
[c] *CICLOPS/Space Science Institute, Boulder, CO, USA*

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A B S T R A C T

The Cassini Imaging Science Subsystem (ISS) acquired 370 high-resolution images (< 500 m/pixel) of Rhea during two close flybys and 9 non-targeted flybys between 2004 and 2010. We combined these images with lower-resolution Cassini images and others taken by the Voyager cameras to produce a high-resolution semi-controlled mosaic of Rhea. This global mosaic is the baseline for a high-resolution Rhea atlas. The nomenclature used in this atlas was proposed by the Cassini imaging team and approved by the International Astronomical Union (IAU). The atlas is available to the public through the Imaging Team's website 〈http://ciclops.org/maps〉 and the Planetary Data System 〈http://pds.jpl.nasa.gov〉. This atlas completes the series of the atlases of the Saturnian medium-sized satellites Mimas, Enceladus, Tethys, Dione, Rhea, and Iapetus.

1. Introduction

The Cassini spacecraft started its tour through the Saturnian system in July 2004. The Imaging Science Subsystem 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. Rhea was imaged by the Cassini spacecraft during eleven flybys, two targeted and nine non-targeted flybys (Table 1). A targeted flyby is one where the orbiter's trajectory has been designed to pass through a specified aimpoint (latitude, longitude, and altitude) at closest approach in order to use the satellite's gravitational influence to produce a desired change in the trajectory (Wolf, 2002). The images taken during these flybys allowed us to create a global mosaic of Rhea with a spatial resolution of 32 pixel/degree (about 417 m/pixel in case of $R=764.1$ km). To date, the Cassini ISS has not yet imaged the northern high latitude regions (> 79°) because they are shrouded in seasonal darkness and will not be illuminated by the Sun until later in the decade during the second Cassini extended mission. Fortunately, the Voyager camera was able to take the 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 done to produce the high-resolution map and the atlas. Two tiles of the atlas are shown. A brief overview of future work is given in Section 4.

2. Data processing

2.1. Image processing

The image processing chain is the same as it was used for the generation of the high-resolution Dione mosaic (Roatsch et al., 2008a). At the time of this writing, a total of 4386 images of Rhea

Table 1
Cassini flybys at Rhea during the nominal and first extended mission (2004–2010), (t) means targeted flyby and (nt) means non-targeted flyby.

Target	Date	Orbit	Distance (km)	Phase angle (degree)	Relative velocity (km/s)
Rhea (t)	26 November 2005	18	503.6	87	7.3
Rhea (nt)	21 March 2006	22	82,000.5	137	5.3
Rhea (nt)	28 June 2007	47	104,384.5	105	10.7
Rhea(nt)	30 August 2007	49	5727.2	46	6.7
Rhea (nt)	16 November 2007	52	91,621.1	150	9.3
Rhea (nt)	2 February 2009	102	98,806.5	82	10.5
Rhea (nt)	13 October 2009	119	40,380.3	82	9.0
Rhea (nt)	21 November 2009	121	24,359.6	58	8.7
Rhea (t)	2 March 2010	127	100.9	87	8.6
Rhea (nt)	3 June 2010	132	69,355.8	102	8.0
Rhea (nt)	18 June 2010	133	120,515.3	109	10.7

* Corresponding author. Tel.: +49 30 67055339.
E-mail address: Thomas.Roatsch@dlr.de (Th. Roatsch).

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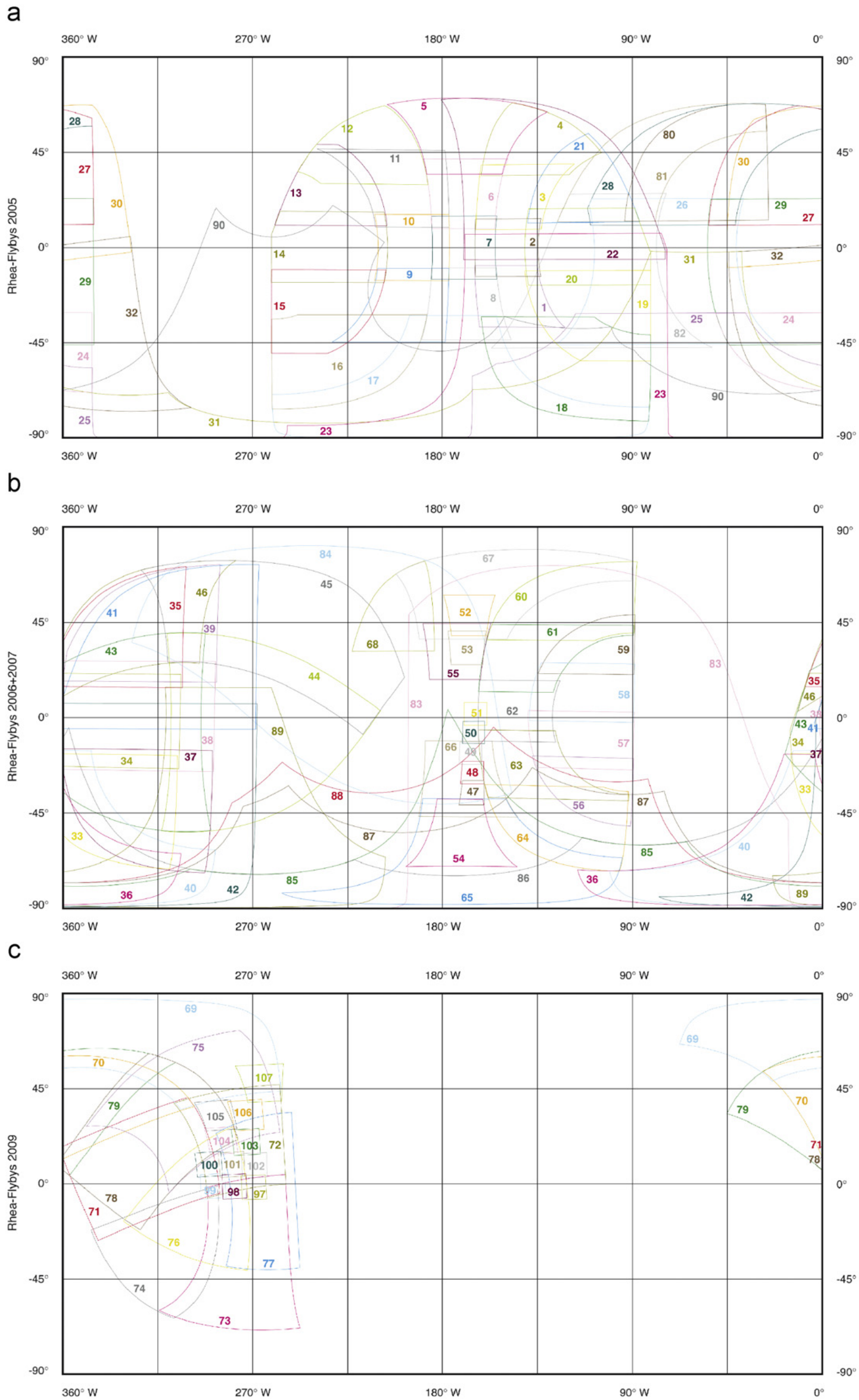

Fig. 1. (a) Global mosaic showing the location of the Cassini ISS images taken in 2005 (see Table 2). Mosaic is in Simple Cylindrical projection with latitude=0°, longitude=180°W at the center. (b) Global mosaic showing the location of the Cassini ISS images taken in 2006 and 2007 (see Table 2). Mosaic is in Simple Cylindrical projection with latitude=0°, longitude=180°W at the center. (c) Global mosaic showing the location of the Cassini ISS images taken in 2009 (see Table 2). Mosaic is in Simple Cylindrical projection with latitude=0°, longitude=180°W at the center.

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Table 2
Cassini images used for the Rhea mosaic. Resolution, center latitude and center longitude were calculated using reconstructed SPICE kernels.

Image number	Image name	Resolution (km/pixel)	Center latitude (degree)	Center longitude (WEST/degree)	Exposure time (ms)
01	N1511729588	0.348	−22.3	149.1	80.0
02	N1511729463	0.353	−0.1	150.6	80.0
03	N1511729338	0.359	22.9	147.9	80.0
04	N1511729097	0.372	54.6	128.1	80.0
05	N1511728958	0.377	55.5	168.5	80.0
06	N1511728833	0.381	24.2	170.1	80.0
07	N1511728708	0.386	−0.1	170.0	80.0
08	N1511728581	0.392	−25.3	169.7	80.0
09	N1511728440	0.399	−25.8	195.0	80.0
10	N1511728315	0.404	0.0	192.7	80.0
11	N1511728175	0.411	26.2	195.6	80.0
12	N1511728035	0.419	51.7	226.9	80.0
13	N1511727899	0.425	27.9	244.9	80.0
14	N1511727774	0.430	0.1	230.3	80.0
15	N1511727641	0.437	−28.3	251.5	80.0
16	N1511727503	0.443	−55.4	241.4	80.0
17	N1511727361	0.448	−56.3	176.6	80.0
18	N1511727217	0.456	−57.7	114.8	80.0
19	N1511727079	0.462	−29.8	102.9	80.0
20	N1511726954	0.466	0.2	116.6	80.0
21	N1511726828	0.474	31.7	94.2	80.0
22	N1511719101	0.823	26.8	134.1	70.0
23	N1511718003	0.875	−28.1	130.7	70.0
24	N1490875063	0.828	−0.3	75.8	80.0
25	N1490875006	0.828	−0.3	75.6	80.0
26	N1490874834	0.829	−9.4	74.6	80.0
27	N1490874718	0.830	−0.3	74.6	80.0
28	N1490874664	0.831	47.9	76.1	80.0
29	N1490874782	0.832	−9.4	8.8	80.0
30	N1484584831	0.924	−7.2	56.9	80.0
31	N1484585173	0.925	−39.0	79.1	80.0
32	N1484584650	0.928	−32.9	333.8	80.0
33	N1521610148	0.561	−42.5	324.3	100.0
34	N1521609952	0.562	−1.0	350.7	100.0
35	N1521609757	0.566	38.8	331.2	100.0
36	N1521609128	0.575	−43.1	26.9	100.0
37	N1521605631	0.645	0.9	18.1	150.0
38	N1521605436	0.651	1.0	332.2	150.0
39	N1521605243	0.654	0.9	16.8	150.0
40	N1521604645	0.670	−46.1	14.0	150.0
41	N1521598440	0.849	28.4	326.5	150.0
42	N1521598221	0.856	−27.0	325.7	150.0
43	N1534495416	0.977	−6.1	333.9	50.0
44	N1534495259	0.978	−6.6	269.5	50.0
45	N1534495104	0.978	53.3	240.2	50.0
46	N1534494958	0.979	52.6	5.6	50.0
47	N1567132880	0.116	−35.0	166.0	70.0
48	N1567133038	0.122	−25.7	166.0	70.0
49	N1567133301	0.132	−16.6	166.9	70.0
50	N1567133359	0.134	−7.0	165.5	70.0
51	N1567133515	0.140	1.8	164.6	70.0
52	N1567134219	0.168	47.4	167.7	70.0
53	N1567134455	0.177	32.6	168.6	70.0
54	N1567135595	0.223	−50.9	171.9	70.0
55	N1567137512	0.298	30.3	174.1	70.0
56	N1567138407	0.333	1.2	178.5	70.0
57	N1567138558	0.342	−10.1	117.3	70.0
58	N1567138714	0.348	11.6	115.1	70.0
59	N1567138871	0.352	1.2	179.3	70.0
60	N1567139044	0.362	56.4	108.7	70.0
61	N1567139201	0.366	26.9	143.7	70.0
62	N1567139356	0.372	3.2	147.7	70.0
63	N1567139513	0.379	−20.9	144.7	70.0
64	N1567139669	0.388	−53.0	112.2	70.0
65	N1567139841	0.394	−62.8	162.9	70.0
66	N1567139998	0.398	−27.1	172.0	70.0
67	N1567140466	0.419	61.5	163.9	70.0
68	N1567140637	0.425	53.4	214.0	70.0
69	N1612266198	0.597	68.4	292.4	120.0
70	N1612266305	0.597	22.9	265.1	120.0
71	N1612266440	0.599	9.5	318.7	120.0
72	N1612266547	0.599	22.2	270.5	120.0
73	N1612266682	0.601	−23.6	265.3	120.0
74	N1612266789	0.601	20.0	265.5	120.0

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Table 2 (*continued*)

Image number	Image name	Resolution (km/pixel)	Center latitude (degree)	Center longitude (WEST/degree)	Exposure time (ms)
75	N1612262022	0.622	39.6	294.0	120.0
76	N1612261932	0.624	48.5	262.6	120.0
77	N1612261825	0.627	5.4	256.4	120.0
78	N1612261585	0.632	25.6	316.4	120.0
79	N1612261454	0.634	51.0	262.3	120.0
80	N1490887028	0.870	−0.4	115.9	100.0
81	N1490886974	0.871	52.7	116.4	100.0
82	N1490887144	0.872	−9.0	114.9	100.0
83	N1519488890	2.038	−2.0	116.3	70.0
84	N1576624267	3.224	63.4	144.0	70.0
85	N1532332269	1.004	−49.8	216.2	460.0
86	N1532332188	1.004	−52.0	305.9	460.0
87	N1558977185	1.080	−78.5	73.0	90.0
88	N1558983473	1.147	−69.4	146.8	80.0
89	N1516211242	1.154	−31.9	259.7	60.0
90	N1501608806	1.372	−51.6	302.0	80.0
91	C3495255	0.637	70.6	311.0	480.0
92	C3495257	0.643	58.5	44.1	480.0
93	C3495259	0.649	73.6	88.0	480.0
94	C3495301	0.656	36.3	65.5	480.0
95	C3495303	0.662	56.1	90.7	480.0
96	C3495236	4.444	68.5	62.3	1440.0
97	N1637518901	0.147	−1.5	270.0	70.0
98	N1637519058	0.148	−1.2	279.2	70.0
99	N1637519176	0.148	−1.1	289.3	70.0
100	N1637519283	0.149	9.4	291.1	70.0
101	N1637519392	0.151	9.2	280.4	70.0
102	N1637519501	0.152	8.8	269.8	70.0
103	N1637519610	0.154	19.8	273.5	70.0
104	N1637519768	0.156	20.4	284.9	70.0
105	N1637519875	0.159	32.2	287.0	70.0
106	N1637519986	0.161	32.2	273.1	70.0
107	N1637520093	0.164	47.1	265.9	70.0

All ISS images were taken by the NAC using clear filters. All Voyager images were taken by the NAC using clear filter except for C3495236, which is a WAC image taken with orange filter.

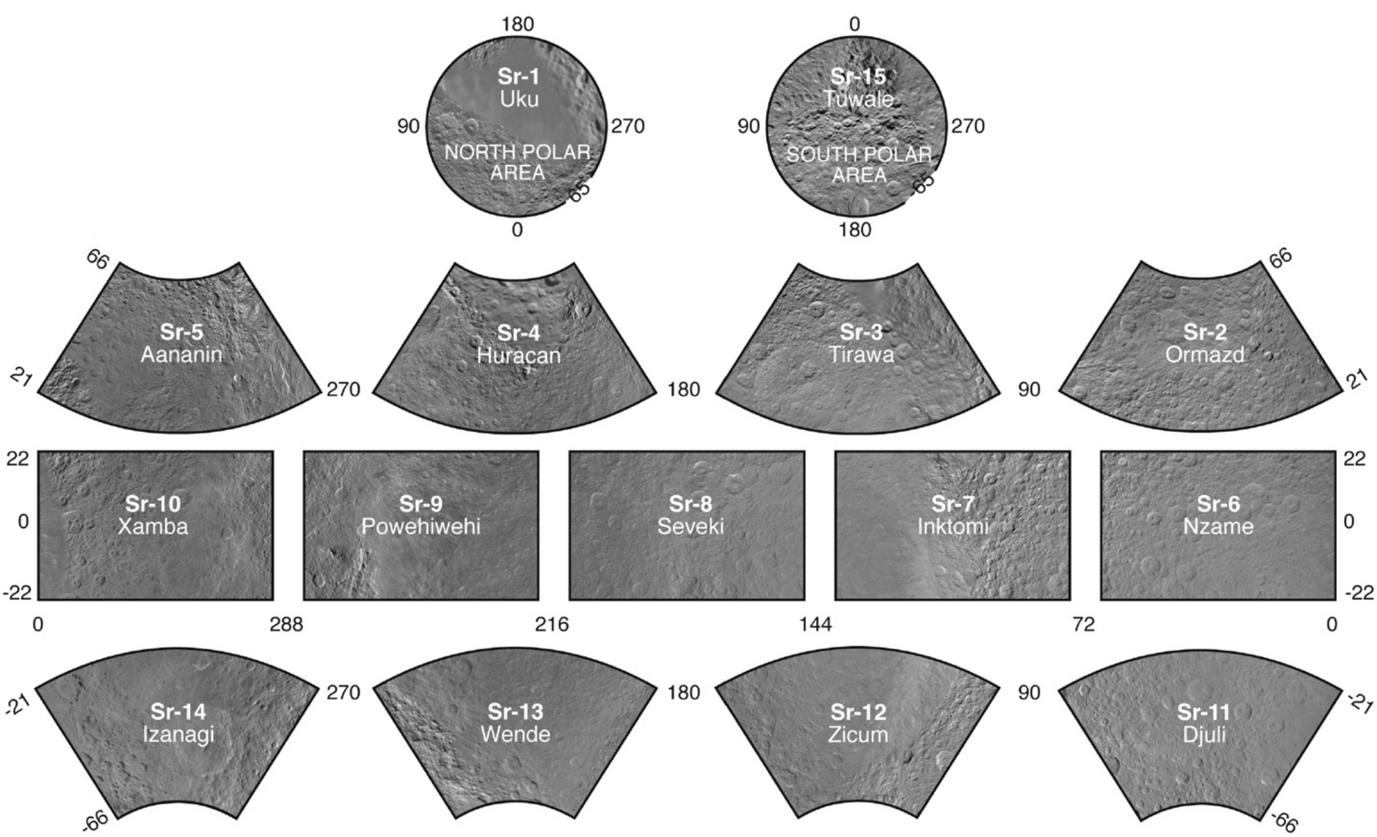

Fig. 2. 15 tiles of the atlas, the quadrangle scheme filled with the Rhea mosaic.

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was available. This data set contains images obtained through a variety of different ISS color filters and at spatial resolutions ranging from 6.5 m/pixel up to 170 km/pixel. For our mosaic, we selected only those images taken with the filters CL1 and CL2, as these images show comparable albedo contrasts among different terrains. Fig. 1 shows the location of the individual Cassini images. The resolutions of the selected Cassini images are given in Table 2.

The Cassini orbit and attitude data used for the calculation of the surface intersection points are provided as SPICE kernels 〈http://naïf.jpl.nasa.gov〉 and were improved using a limb-fitting technique (Roatsch et al., 2006). It was not possible to improve the attitude data using least-squares adjustment as it was possible for the Enceladus mosaic (Roatsch et al., 2008b) due to insufficient stereo data of Rhea.

As the medium-sized Saturnian satellites are best described by tri-axial ellipsoids as derived from ISS images by Thomas et al. (2007), an ellipsoid with the axes 766.9, 762.4, and 763.0 km was used for the calculation of the ray intersection points during the geometric correction process. However, to facilitate the comparison and interpretation of the mosaic, the projection itself was done onto a sphere with a mean radius of 764.1 km.

2.2. Coordinate system

The coordinate system adopted by the Cassini mission for satellite mapping is the IAU "planetographic" system consisting of planetographic latitude and positive West longitude. The ephemeris position of the prime meridian of Rhea as defined by Davies and Katayama (1983) and adopted by the IAU cartography working group as standard (Seidelmann et al., 2007) is defined by the crater Tore (located at 340° West). A longitude shift to keep this definition (see Roatsch et al., 2008a, 2009 for description) was not necessary for the Rhea mosaic.

3. Rhea map tiles

The Rhea atlas was produced at a scale of 1:1,500,000 and consists of 15 tiles that conform to the quadrangle scheme proposed by Greeley and Batson (1990) and Kirk et al. (1998) for large satellites (Fig. 2). This atlas is a great improvement compared to the Voyager-based atlas at a scale of 1:5,000,000 (Roatsch et al., 2006). The same 15 tiles scheme was also used for the Enceladus, Tethys, and Dione atlases (Roatsch et al., 2008a, b, 2009). A map scale of 1:1,500,000 guarantees mapping at the highest available Cassini resolution and results in an acceptable printing scale of 3.6 pixel/mm for the hardcopy map. The individual tiles were extracted from the global mosaic and reprojected. The equatorial part of the map (−22° to 22° latitude) is in Mercator projection, the regions between the equator and the poles (−66° to −21° and 21° to 66° latitude) are projected in Lambert conic with two standard parallels, and the poles (−65° to

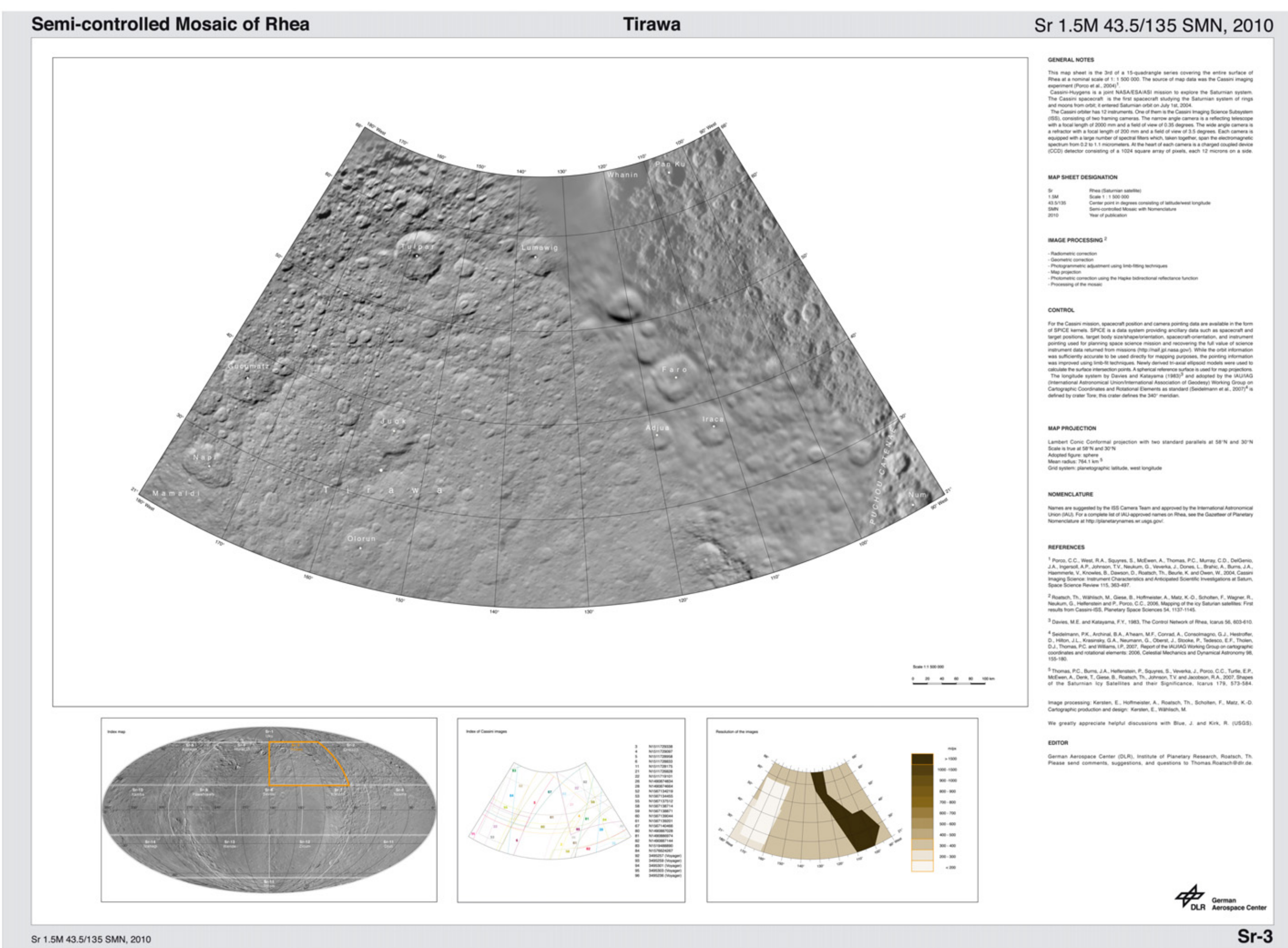

Fig. 3. Rhea map sheet 03: Tirawa.

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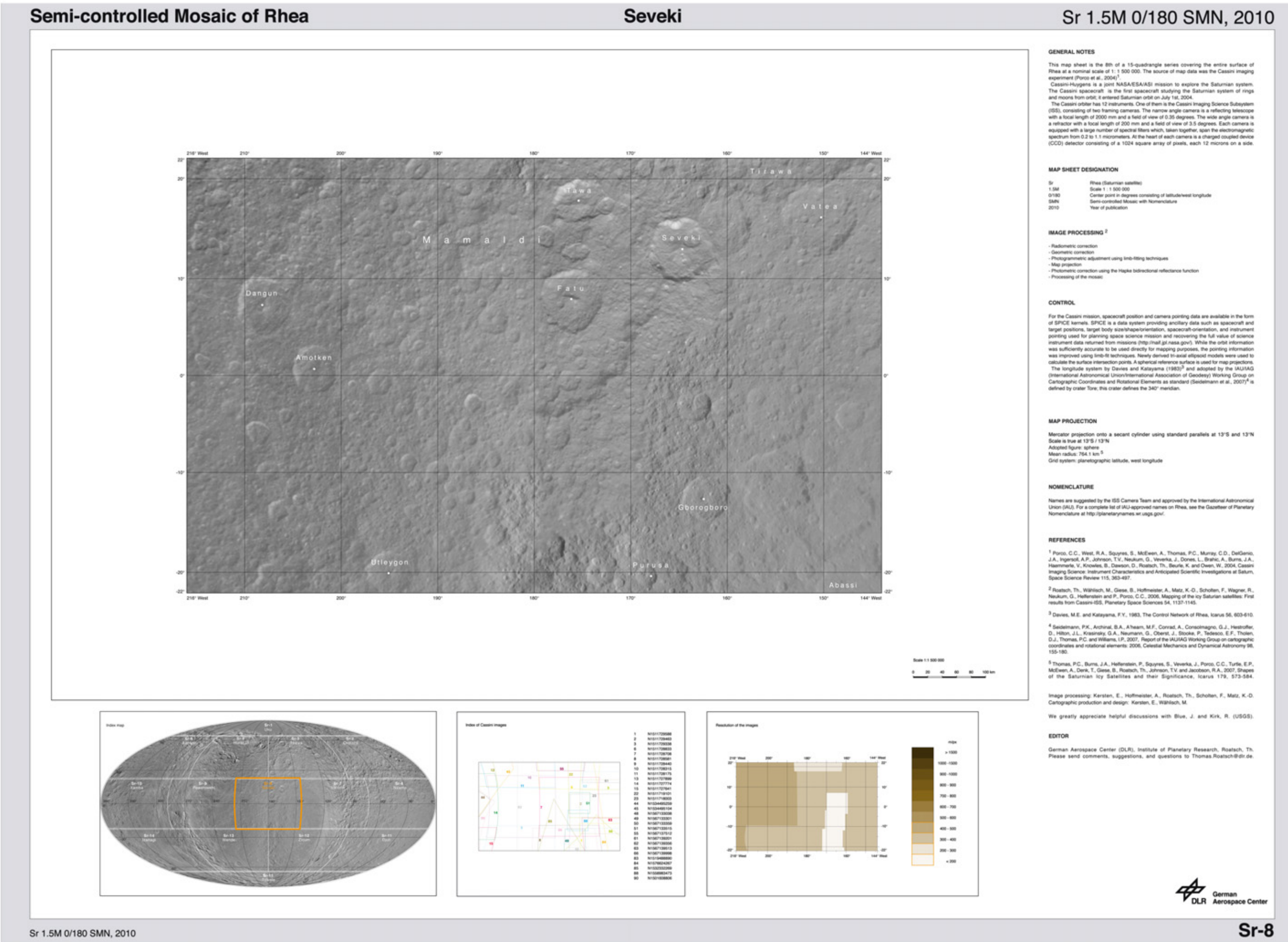

Fig. 4. Rhea map sheet 08: Seveki.

−90° and 65° to 90° latitude) are projected in Stereographic projection. Using this quadrangle scheme, we get the printed maps in the user-friendly size of 1200 mm width by 870 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. Two tiles of the atlas using different projections are shown in Figs. 3 and 4.

The Cassini imaging team proposed 93 names for geological features which were approved by the IAU 〈http://planetarynames.wr.usgs.gov/〉. According to IAU, the features must be named using characters and places from creation myths selected from various cultures around the world; Asian names are emphasized. Also, based on improved imaging from Cassini, the IAU working group changed two of 49 approved names derived during the Voyager mission. The transcription and the descriptor terms of Kun Lun Chasma and Pu Chou Chasma were changed to Kunlun Linea and Puchou Catenae, respectively. Locations and dimensions of all features were measured on the basis of the Cassini data and Voyager-based measurements were corrected if necessary.

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

4. Future work

The first extended Cassini mission ended in 2010. Cassini is now operating in the second extended mission until 2017. The northern part of Rhea will be illuminated during this extended mission providing an opportunity to obtain high-resolution Cassini coverage of high northern latitudes. Upcoming flybys will help to replace some of the low-resolution parts of the atlas with higher resolution image data.

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