```
PDS_VERSION_ID       = PDS3
RECORD_TYPE          = STREAM
SPACECRAFT_NAME      = "CLEMENTINE 1"
TARGET_NAME          = "MOON"
OBJECT               = TEXT
 INTERCHANGE_FORMAT = ASCII
 PUBLICATION_DATE   = 1997-07-01
 NOTE               = "THE CLEMENTINE BASEMAP MOSAIC"
END_OBJECT           = TEXT
END
```

THE CLEMENTINE BASEMAP MOSAIC

by

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INTRODUCTION

The Clementine Basemap Mosaic of Earth's Moon is a radiometrically and geometrically controlled, photometrically modeled global Mosaicked Digital Image Model [Batson, 1987; Batson, 1990] compiled using more than 43,000 images from the 750 nanometer filter observations from the Ultraviolet/Visible camera onboard the Clementine Spacecraft. The basemap mosaic is mapped in the Sinusoidal Equal-Area Projection [Snyder, J.P, 1982] (see the 'dsmap.cat' file in the 'catalog' directory for more information on the Sinusoidal projection) at a resolution of 100 meters per pixel requiring approximately 10 gigabytes of digital storage.

The basemap is partitioned into 14 geographic zones with each zone contained on a single CD volume. Twelve zones, each 30 degrees wide in longitude and ranging from 70 degrees north to 70 degrees south, make up the mid-latitude regions (CD volumes 2-13). The two polar zones cover 360 degrees of longitude from 70 degrees latitude to the pole (CD volumes 1 and 14). The polar regions additionally contain orthographic projection maps centered at the poles. A 15-th volume contains reduced-resolution planetwide coverage at .5, 2.5, and 12.5 km/pixels. Backplane data files for emission, incidence, and phase angle values are also present on volume 15.

The geographic zones are further divided into "tiles". Each tile covers ~7 degrees of latitude and ~6 degrees of longitude at the equatorial regions to larger longitude coverage at higher latitudes (longitude convergence at the poles allows more longitude coverage of each tile at the higher latitudes with approximately the same file size). Tiles are stored as image files of approximately 2000 pixels on a side. Pixels are 16-bit signed integers. The table shown below summarizes the contents of each CD volume.

CD GEOGRAPHIC COVERAGES

CD Volume	Latitude Range	Longitude Range
cl_3001	70 N to 90 N	0 to 360
cl_3002	70 S to 70 N	0 to 30
cl_3003	70 S to 70 N	30 to 60
cl_3004	70 S to 70 N	60 to 90
cl_3005	70 S to 70 N	90 to 120
cl_3006	70 S to 70 N	120 to 150
cl_3007	70 S to 70 N	150 to 180
cl_3008	70 S to 70 N	180 to 210
cl_3009	70 S to 70 N	210 to 240
cl_3010	70 S to 70 N	240 to 270
cl_3011	70 S to 70 N	270 to 300
cl_3012	70 S to 70 N	300 to 330
cl_3013	70 S to 70 N	330 to 360
cl_3014	90 S to 70 S	0 to 360
cl_3015	(reduced resolution global coverage)	

The CD volume set contains ancillary data files that support the basemap mosaic. These files include browse images stored in a 'JPEG' format, 'HTML' documents that support a web browser interface to the CDs, index files ('imgindx.tab' and 'srcindx.tab') that tabulate the contents of the CD volume set, and documentation files that describe the archive collection. For more information on the contents and organization of the CD volume set refer to the "Files, Directories, and Disk Contents" section of this document. Additionally, the 15-th volume holds special image arrays containing information about the illumination and viewing geometry. A file exists each for the solar illumination angle, emission angle, and the phase angle at 2.5 kilometers per pixel.

Using a web browser, such as Netscape or M/S Internet Explorer, open the 'index.htm' file located in the 'root' directory of each CD. The html document will direct you to other informational documents and the image browser for rapidly viewing the image collection.

Software tools for viewing and accessing of the image collection are available through the Planetary Data System's (PDS) internet services. Refer to the 'aareadme.txt' located in the 'root' for more information on these tools. NASAView provides an image display capability for viewing images stored in a PDS format [JPL, 1992]. NASAView is soon to be operational on Macintosh, Windows-95, and UNIX platforms. The MapMaker system enables users to generate seamless image maps for any latitude-longitude region at a variety of scales and map projections. For more information on the MapMaker system, contact the PDS Imaging Node.

CLEMENTINE MISSION

The Clementine Mission [Nozette et al., 1994], officially designated as the Deep Space Program Science Experiment (DSPSE), is the first in a planned series of technology demonstrations jointly sponsored by the Ballistic Missile Defense Organization (BMDO) and the National Aeronautics and Space Administration (NASA). Clementine was launched on 1994-01-25 aboard a Titan IIG rocket from Vandenburg Air Force Base in California. The mission included two months of systematic lunar mapping (1994-02-26 through 1994-04-

21), which was to have been followed by a flyby of the near-Earth asteroid Geographos (1994-08-31). An onboard software error, combined with improbable hardware conditions, on 1994-05-07 led to accidental spin-up of the spacecraft and loss of attitude control gas. This precluded the flyby of Geographos. The spacecraft itself was affectionately known as Clementine since, as in the song of the same name, it would be 'lost and gone forever' after completing its short mission.

Clementine's primary objective was qualification of light weight imaging sensors and component technologies (including a star tracker, inertial measurement unit, reaction wheel, nickel hydrogen battery, and solar panel) for the next generation of Department of Defense spacecraft. DSPSE represented a new class of small, low cost, and highly capable spacecraft that fully embraced emerging lightweight technologies to enable a series of long-duration deep space missions. A second objective was the return of data about the Moon and Geographos to the international civilian scientific community. For more information on the Clementine Mission refer to the 'mission.cat' file located in the 'catalog' directory.

The Basemap mosaic was created using the Clementine EDR Image Archive [Eliason, et al., 1995] produced by the Clementine mission. The EDR (Engineering Data Record) data are raw images and they contain the inherent properties of unprocessed and uncorrected data. The Clementine EDR Image Archive contains more than 1.9 million images acquired during active mission operations. For information on how to obtain this archive contact the PDS Imaging Node or visit their world wide web site at the URL: http://pdsimage.jpl.nasa.gov/PDS.

ULTRAVIOLET/VISIBLE CAMERA (UVVIS)

The Ultraviolet/Visible Camera (UVVIS) [Kordas, et al., 1995] has a catadioptic telescope using fused silica lenses focused onto a metachrome-coated charge couple device (CCD) imager. Active wavelength response is limited on the short wavelength end by the transmission of fused silica and the optical blur of the lens. Wavelength response on the long end is limited by the response of the CCD. Six spectral bands can be selected from a filter wheel assembly allowing observations in the 415, 750, 900, 950, 1000nm wavelengths. An additional broad band filter was available on the filter wheel. For more information on the UVVIS camera refer to the 'uvviscat.cat' file in the 'catalog' directory.

LUNAR ORBIT SUMMARY

The Clementine spacecraft maintained a polar orbit during the systematic mapping of the surface of the Moon. Mapping of virtually 100% of the lunar surface was done in two lunar days (two Earth months). In order to obtain full coverage during these two months, the required image overlap for the UVVIS and NIR cameras was ~15% in the down track and ~10% in the cross track directions. This required that the inclination of the orbit at 90 degrees plus-or-minus 1 degree with reference to the lunar equator and that the periselene of the lunar orbit be maintained at an altitude of 425 plus-or-minus 25 km. To provide the necessary cross-track separation for the alternating imaging strips to cover the entire surface of the moon, the orbital period was approximately 5 hours, during which the moon rotated approximately 2.7 degrees beneath the spacecraft. Images were taken and recorded only in the region of periselene, leaving sufficient time to replay the data to Earth.

The best data for lunar mineral mapping is obtained if the solar phase angle is less than 30 degrees. The solar phase angle is defined as the angle between the vector to the Sun and the vector to the spacecraft from a point on the Moon's surface. To maximize the time period in which the solar phase angle is less than 30 degrees the plane of the lunar orbit should contain the Moon-Sun line half way through the two-month lunar mapping period. Therefore, insertion into the lunar orbit was selected so that, as the Moon-Sun line changes with Earth's motion about the Sun, the Moon-Sun line will initially close on the orbital plane, and then lie in the orbital plane half-way through the mapping mission. The angle between the Moon-Sun line and the orbital plane was close (less than 5 degrees) for approximately five weeks before becoming zero. The table shown below contains a list of Clementine's orbital parameters. For more information on the Lunar orbit refer to the 'mission.cat' file located in the 'catalog' directory.

Clementine Orbital Parameters

Orbital Period:	4.970 hr < P < 5.003 hr
Altitude of Periselene:	401 km < radius < 451 km
Eccentricity:	0.35821 < e < 0.37567
Right Ascension:	-3 deg < Omega < +3deg(referred J2000)
Inclination:	89 deg < i < 91 deg
Argument of Periselene:	-28.4 deg < w < -27.9 deg (1st month)
	29.6 deg < w < 29.2 deg (2nd month)

GEOMETRIC ACCURACY

The Clementine Basemap Mosaic is the result of an exhaustive Lunar cartography project based on data processing of the Clementine EDR image collection. Systematic calibration and processing enable global, full-resolution scientific analysis of the Clementine Datasets. The basemap mosaic significantly improves the geometric control of the moon from previous maps and ground control points. Based on best effort measurements of the spacecraft orbit and pointing, UVVIS geometric distortions, and time tags for each observation, the SPICE [Acton, 1996] data alone provides positional accuracy better than 1 kilometer over most of the Moon. With residuals primarily small random pointing errors, then the accuracy approaching the UVVIS scale becomes achievable.

The goal of the basemap is for 95% of the Moon (excluding the oblique observation gap fills) to be better than 0.5 km/pixel absolute positional accuracy and to adjust the camera angles so that all frames match neighboring frames to within an accuracy of 2 pixels. To achieve these goals we required camera alignment and pointing data accurate to a few hundredths of a degree. We determined the absolute alignment of the UVVIS with respect to spacecraft-fixed axes (A and B Star Tracker Camera quaternions) by analyzing a major subset of the over 17,000 images of Vega, over 6,000 images of the Southern Cross and a few hundred images of the Pleiades, taken during the approach to the Moon and throughout the lunar mapping mission phase. Multiple star images within a single picture were used to determine the UVVIS focal length and optical distortion parameter values.

Approximately 265,000 match points were collected at the USGS from ~43,000 UVVIS images providing global coverage. About 80% of these points were collected via autonomous procedures, whereas the 20% required the more time consuming but highly accurate pattern-recognition capability of the human eye-brain. We also developed streamlined procedures for the supervised collection of match points. The new procedures saved several person-years of effort and represents new capabilities useful with other planetary datasets. The automated success rate exceeded 90% along each spacecraft orbit track, where the overlap regions of successive images are highly correlated, but failed when the overlap regions is narrow and/or nearly featureless. ('Failure' is defined as less than 3 points per image with correlation coefficients grater than 0.85; thus, many good match points were rejected because we could not be certain that the matches were valid without verification.) Across-track matching was more difficult due to changes in scale and illumination angle, but a fair success rate (~60%) was nevertheless achieved via the use of 'window-shaping' (local geometric reprojections). The oblique gap-fill images were the most difficult to match, and required substantial human intervention. Matching the polar regions was time-consuming because each frame overlaps many other frames. Most match points were found to a precision of 0.2 pixels.

The USGS match points were sent to RAND corporation for analytical triangulations. Using these match points, control points from the Apollo region, and the latest NAIF/SPICE information, RAND determined improved camera orientation angles for the global set of UVVIS images. A constant lunar radius of 1737.4 kilometers was assumed, a significant source of error near the oblique gap fills. The analytical triangulation is a least-squares formulation designed to adjust the latitude and longitude of the control points and the camera orientation angles to best fit the match points. The triangulation was first computed on 'packets' of match points (each covering ~1/8-th of the Moon), then checked and rechecked at the USGS via plots and test mosaics to fix and add match points as needed. The final (global) analytical triangulation required solving ~660,000 normal equations. The mean error is less than 1 pixel. This is by far the largest analytical triangulation ever applied to a planetary body other than Earth. The results fully define the planimetric geometry of the basemap, to which future systematic products will be tied.

RADIOMETRIC UNITS

The Clementine basemap mosaic was assembled from the 750 nanometer (filter "B") imaging. The 900 nanometer (filter "C") imaging (normalized to match the 750 band) was used to fill gaps where there was missing 750 coverage. Photometric processing normalized data to an emission angle of zero degrees and a solar illumination angle of 30 degrees. Radiometric normalization coefficients for Clementine imaging were developed by Dr. Carle Peters (Brown University) based on laboratory spectra from Apollo 16 landing site soils returned to Earth. The Clementine EDR frame 'lub1845i.295' was used to define the radiometric normalization coefficients for the 750nm data. The image sub-area: 51-61 (sample) x 86-117 (line) relative to the upper left pixel addressed at 0,0 was selected as the control area assuming the soils were representative of the returned Apollo 16 landing site soils. For the spectral range of the 750 nanometer filter, laboratory observations gave .1868 fractional reflectance (18.68% reflectance at 30 degrees illumination, 0 degrees emission). To convert from counts/millisecond (Rraw column in table below) normalized to 30 degrees incidence and 0 degrees emission (Rclem) to fractional reflectance (Rlab) the coefficient (AvgCr(l)) is applied. The table shown below lists the normalization coefficients (AvgCr(l)) of each UVVIS filter . The AVGCr(l) coefficients convert counts/millisecond camera output to fractional reflectance.

		Photometric Angles								
Filter	Frame	EM	IN	PH	Rraw	Cphot	Rclem	Rlab	Cr(l)	AvgCr(l)
A	lua1850i.295	2.34	26.79	28.62	5.60	0.960	5.378	.114	.0213	
A	lua1851i.295	2.36	26.79	28.61	5.56	0.960	5.338	.114	.0214	.0214
B	lub1845i.295	2.28	26.79	28.67	15.84	0.961	15.230	.187	.0122	
B	lub1846i.295	2.29	26.79	28.66	15.84	0.961	15.227	.187	.0122	.0122
C	luc1842i.295	2.24	26.79	28.72	19.42	0.962	18.686	.199	.0106	
C	luc1843i.295	2.25	26.79	28.71	19.47	0.962	18.733	.199	.0106	.0106
D	lud1838i.295	2.20	26.79	28.78	19.55	0.963	18.830	.204	.0108	
D	lud1839i.295	2.21	26.79	28.77	19.58	0.963	18.859	.204	.0108	.0108
E	lue1835i.295	2.18	26.79	28.82	9.02	0.964	8.698	.210	.0242	
E	lue1836i.295	2.19	26.79	28.81	9.00	0.964	8.681	.210	.0242	.0242

To convert the 16-bit integer values found in the image arrays of the basemap mosaic to fractional reflectance an offset and scaling factor need to be applied as shown:

```
FRACTIONAL_REFLECTANCE = (SCALING_FACTOR * DN) + OFFSET
where: DN = 16-bit pixel value of basemap image array.
       SCALING_FACTOR = 1.2028247E-04
       OFFSET = -9.0128981E-04
```

DATA PROCESSING

The Integrated Software for Imaging Spectrometers (ISIS) processing system, developed by the U.S. Geological Survey, was used to generate the basemap mosaic. Processing within ISIS includes radiometric and geometric correction, spectral registration, photometric normalization, and image mosaicking. Radiometric correction applies 'flat fielding', dark current subtraction, non-linearity correction, and conversion to radiometric units. Geometric transformations tie each raw image with a ground control network and convert from raw image coordinates to the Sinusoidal Equal-Area projection. Photometric normalization is applied to balance brightness variations due to illumination differences among the images in a mosaic. Images are then mosaicked together to form a global map of continuous image coverage for the entire planet.

The basemap mosaic was processed in five stages or "levels." All corrections made during these stages have some degree of uncertainty; the processing sequence was designed to process from corrections with highest probability of accuracy to those with the lowest. The first level of processing, level 0, prepares the data for processing by ISIS. The raw images are converted to ISIS format and ancillary data such as viewing geometry are added to the labels of the image file. Level 1 processing applies radiometric corrections and removes artifacts from the image. Level 2 performs geometric processing to remove optical distortions and to convert the image geometry to a standard map projection. Level 3 performs photometric processing for normalizing the sun-viewing geometry of an image scene. Level 4 performs mosaicking of individual images to create global or regional views for the planet surface.

Level 0

The Level 0 processing step prepares the raw image data and associated meta-data for processing by the ISIS system. Level 0 processing consists of two program steps. The first step reads the format of the raw image and converts it to an ISIS file. Additionally this step will extract the meta-data from the input image labels for inclusion into the ISIS label. The meta-data may contain information such as the instrument operating modes, temperature of the camera focal plane, UTC time of observation, and other information necessary to rectify an image. The second step extracts navigation and pointing data ("SPICE" kernel data) for inclusion into the ISIS file.

Level 1

The next level of processing, Level 1, performs radiometric correction and data clean-up on an image. Level 1 consists of a series of programs to correct or remove image artifacts such as 1) camera shading inherent in imaging systems, 2) artifacts caused by minute dust specks located in the optical path, 3) microphonic noise introduced by operation of other instruments on the spacecraft during image observations, and 4) data drop-outs and spikes due to missing or bad data from malfunctioning detectors or missing telemetry data. Level 1 processing results in an "ideal" image that would have been recorded by a camera system with perfect radiometric properties (although in practice residual artifacts and camera shading remain). The density number (DN) values of a radiometrically corrected image are proportional to the brightness of the scene.

Level 2

Producing the Clementine Basemap Mosaic required geometric processing to be performed on the individual images that make up the basemap. The individual images are geometrically transformed from spacecraft camera orientation to a common map coordinate system of a specific resolution. Before geometric transformation, images must first be geometrically "matched" to each other to establish relative geometric control among the images and then the image set must be "tied" to a ground control net to establish absolute ground truth. The process of matching images and tying the image set to ground truth minimizes the spatial misregistration along image boundaries.

Level 2 performs geometric processing which includes correcting camera distortions as well as transformation from image coordinates to map coordinates. All geometric transformations are made simultaneously so that an image is resampled only once and resolution loss is minimal. The image transformation is based on the original viewing geometry of the observation (including the optical distortion model of the camera), relative position of the target, and the mathematical definition of the map projection.

Level 3

Photometric normalization is applied to images that make up the basemap in order to balance the brightness levels among the images that were acquired under different lighting conditions. To illustrate, consider two images of the same area on the planet where one image was acquired with the sun directly overhead and the second with the sun lower to the horizon. The image with the higher sun angle would be significantly brighter than the image with the low sun angle. Photometric normalization of the two images would cause them to be adjusted to the same brightness level.

Radiometrically calibrated spacecraft images measure the brightness of a scene under specific angles of illumination, emission, and phase. For an object without an optically significant atmosphere, this brightness is controlled by two basic classes of information: 1) the intrinsic properties of the surface materials, including composition, grain size, roughness, and porosity; and 2) variations in brightness due to the local topography of the surface. Photometric normalization is effective only to the extent that all geometric parameters can be modeled. The local topography is not included in the model (i.e. the planetary surface is thought of as a smooth sphere). However, illumination geometry at each pixel certainly depends on local topography; unless the topographic slope within a pixel is accurately known and compensated, the photometric correction cannot be perfect.

Level 4

Compilation of an accurate digital mosaic of the individual images is the final stage in the construction of the basemap. The basemap is created by first generating a blank (or null) image that represents the regional or global image map of the Moon. The individual images are then mosaicked into the initially blank image map. The order in which individual images are placed into the mosaic is an important consideration. Because images are mosaicked one on top of the other, images that get laid down first are overwritten in the area of overlap with subsequent images that are added to the mosaic. It is preferable to first lay down images that have the lowest data quality or resolution followed by images with highest quality. In this way the areas of image overlap contain the highest quality images.

FILES, DIRECTORIES, AND DISK CONTENTS
=====================================

The files on CD volume set are organized starting at the root or 'parent' directory. Below the parent directory is a directory tree containing data, documentation, and index files. In the table below directory names are indicated by brackets (<...>), upper-case letters indicate an actual directory or file name, and lower-case letters indicate the general form of a set of directory or file names.

```
DIRECTORY/FILE           CONTENTS
-------------------      ------------------------------------------

<root>
|
|-AAREADME.TXT           The file you are reading (ASCII Text).
|
|
|-INDEX.HTM              Hypertext Markup Language(HTML) file
|                        as a user interface to files on this CD.
|
|-ERRATA.TXT             Description of known anomalies and errors
|                        present on the volume set(optional file).
|
|-VOLDESC.CAT            A description of the contents of this
|                        CD volume in a format readable by
|                        both humans and computers.
|
|-<CATALOG>              Catalog Directory
|  |
|  |-CATINFO.TXT         Describes Contents of the Catalog directory
|  |
|  |-DATASET.CAT         Clementine Basemap Mosaic description
|  |
|  |-DSMAP.CAT           Map Projection description
|  |
|  |-INSTHOST.CAT        Clementine Spacecraft description
|  |
|  |-MISSION.CAT         Clementine Mission description
|  |
|  |-PERSON.CAT          Contributors to Clementine Basemap
|  |
|  |-REFS.CAT            References for Clementine Basemap
|  |
|  |-UVISCAT.CAT         UVVIS Camera description
|
|-<DOCUMENT>             Documentation Directory. The files in this
|  |                     directory provide detailed information
|  |                     regarding the Clementine Basemap Mosaic.
|  |
|  |-DOCINFO.TXT         Description of files in the DOCUMENT
|  |                     directory.
|  |
|  |-VOLINFO.TXT         Documentation regarding the
```

```
|   |                   contents of this CD Volume Set.
|   |
|   |-VOLINFO.DOC       Microsoft Word V6.0A version of VOLINFO.TXT
|   |
|   |-VOLINFO.PDF       Adobe-Acrobat Portable Format (PDF)
|   |                   version of VOLINFO.TXT
|   |
|   |-VOLINFO.HTM       HTML document for VOLINFO.TXT
|   |
|   |-VOLINFO.LBL       PDS Label file describing the VOLINFO
|   |                   documents.
|
|-<INDEX>               Directory for the image index files.
|   |
|   |-INDXINFO.TXT      Description of files in <INDEX> directory.
|   |
|   |-IMGINDX.TAB       Image Index table.
|   |
|   |-IMGINDX.LBL       PDS label for IMGINDX.TAB.
|   |
|   |-SRCINDX.TAB       Table of source images used in the
|   |                   production of the Clementine Basemap.
|   |
|   |-SRCINDX.LBL       PDS Label for SRCINDX.LBL
|
|
|-<tssl_nly>            Data directory name where;
|   |
|   |                           (For this Basemap CD Volume Set)
|   |                       t = B (Clementine Basemap Mosaic)
|   |                         = E (Emission angle backplane)
|   |                         = I (Incidence angle backplane)
|   |                         = P (Phase angle backplane)
|   |
|   |                           (For future CD Volumes)
|   |                         = U (UVVIS Cube)
|   |                         = N (NIR Cube)
|   |                         = L (LWIR Image Data)
|   |                         = H (Hi-res Image Data)
|   |
|   |                       s = (Resolution - km/pixel)
|   |                         = A   (.004 km/pixel-future mapping)
|   |                         = B-D (For future mapping as needed)
|   |                         = E   (.02 km/pixel - future mapping)
|   |                         = F-H (For future mapping as needed)
|   |                         = I   (.1 km/pixel)
|   |                         = J   (.15 km/pixel)
|   |                         = K-L (For future mapping as needed)
|   |                         = M   (.5 km/pixel)
|   |                         = N-P (For future mapping as needed)
|   |                         = Q   (2.5 km/pixel)
|   |                         = R-T (For future mapping as needed)
|   |                         = U   (12.5 km/pixel)
|   |                         = V-Z (For future mapping as needed)
|   |
|   |                       sl = Southernmost Latitude
|   |                       nl = Northernmost Latitude
|   |
|   |                       y = N (Positive latitude)
|   |                         = S (Negative latitude)
```

```
|   |                          = <none> (Not used for full latitude
|   |                                    coverage. i.e. -90 to 90)
|   |
|   |                    The following data directories exist on
|   |                    Volume 1
|   |                    <BI70_90N> <POLAR>
|   |
|   |                    The following data directories exist on
|   |                    Volumes 2-13
|   |                    <BI70_35S> <BI35_00S> <BI00_35N> <BI35_70N>
|   |
|   |                    The following data directories exist on
|   |                    Volume 14
|   |                    <BI90_70S> <POLAR>
|   |
|   |                    The following data directories exist on
|   |                    Volume 15
|   |                    <BM90_90> <BQ90_90> <BU90_90> <EQ90_90>
|   |                    <IQ90_90> <PQ90_90> <POLAR>
|   |
|   |
|   |-<tsppymmm.xxx>     Data filenames where;
|
|                      t = (Same as directory description above)
|                      s = (Same as directory description above)
|                     pp = (00-90) Center latitude of Image File.
|                          (Two digit truncated integer)
|                      y = N (North Latitude)
|                          S (South Latitude)
|                    mmm = (000-360) Center longitude of Image.
|                          (Three digit truncated integer)
|                    xxx = IMG (PDS Labeled Image File)
|                        = LAB  (ISIS Detached Label File)
|                        = JPG (JPEG "small", "medium", and "large"
|                              Browse Images) <BROWSE> Directory
|                              Tree only)
|                        = HTM (<BROWSE> Directory Tree only)
|
|-<POLAR>                Data directory for polar region
|   |                    Orthographic products.
|   |
|   |-<tsppymmm.xxx>     Data filenames as described above.
|
|
|-<BROWSE>               Directory tree containing "Browse" (reduced
|   |                    resolution) JPEG images for each image data
|   |                    product on the CD. The directory structure
|   |                    below <BROWSE> is identical to
|   |                    the Data directory structure at the <root>
|   |                    level with <SMALL>, <MEDIUM>, and <LARGE>
|   |                    directories added.
|   |
|   |-BROWINFO.TXT       Description of <BROWSE> content.
|   |
|   |-BRWSGRP.HTM        Graphics (map)-based HTML interface to CD
|   |                    data (Accessed by INDEX.HTM file).
|   |
|   |-BRWSTXT.HTM        Text (ASCII)-based HTML interface to CD
|   |                    data (Accessed by INDEX.HTM file).
|   |
```

```
|   |-<SMALL>
|   |-<MEDIUM>
|   |-<LARGE>             Directories containing "small", "medium",
                          and "large" sized JPEG images for each
                          product. These images are primarily used by
                          the HTML documents on the CD. The directory
                          structure below the <SMALL>, <MEDIUM>, and
                          <LARGE> directories are identical to the
                          directory structure at the <root> level.
                          "small" images are ~60x60 pixels
                          "medium" images are ~400x400 pixels
                          "large" images are ~1000x1000 pixels
```

IMAGE FILE ORGANIZATION

The image files are stored in a PDS compliant format. An Image file contains an label area (header) at the beginning of the file followed by the image data. The number of bytes of the label area is a multiple of the number of bytes that make up an image line (number of samples * 2 bytes/pixel). The image label area contains ASCII text data that contains information about the image file (see Image Labels section below). The label area can be viewed with a simple ASCII editor on most computer systems.

Pixel Storage Order

The Clementine basemap mosaic is stored as image files with 16-bit signed integer pixels. The storage order of the pixels is "most significant byte order first". This is the storage order for UNIX/Sun and Macintosh systems. For other systems such as IBM-compatible PC and VAX systems, the high and low order bytes of the pixels will need to be swapped before the data can be used.

Image Labels

The label area of a image file contains descriptive information about the image. The label consists of keyword statements that conform to version 3 of the Object Description Language (ODL) developed by NASA's PDS project. There are three types of ODL statements within a label: structural statements, keyword assignment statements, and pointer statements.

Structural statements provide a shell around keyword assignment statements to delineate which data object the assignment statements are describing. The structural statements are:

```
1) OBJECT = object_name
2) END_OBJECT
3) END
```

The OBJECT statement begins the description of a particular data object and the END_OBJECT statement signals the end of the object's description. All keyword assignment statements between an OBJECT and its corresponding END_OBJECT statement describe the particular object named in the OBJECT statement. The END statement terminates a label. A keyword assignment statement contains the name of an attribute and the value of that attribute. Keyword assignment statements are described in more detail in Appendix B of this document. These statements have the following format:

```
name = value
```

Values of keyword assignment statements can be numeric values, literals, and text strings.

Pointer statements are a special class of keyword assignment statements. These pointers are expressed in the ODL using the following notation:

```
^object_name = location
```

If the object is in the same file as the label, the location of the object is given as an integer representing the starting record number of the object, measured from the beginning of the file. The first label record in a file is record 1. Pointers are useful for describing the location of individual components of a data object. Pointer statements are also used for pointing to data or label information stored in separate files. An example of a detached label (i.e., label information stored in a separate file) is shown below: By convention, detached labels are found in the LABEL directory.

```
^STRUCTURE = 'logical_file_name'
```

The value of 'logical_file_name' is the name of the detached label file containing the description.

The keyword statements in the label are packed into the fixed-length records that make up the keyword label area. Each keyword statement is terminated by a carriage-return and line-feed character sequence. An example of a Clementine Basemap image label is shown below. Descriptions of the keywords used in the basemap label are found in Appendix A.

```
          Example PDS Label for Clementine Basemap Image files
          ====================================================

PDS_VERSION_ID                  = PDS3

/*          FILE FORMAT AND LENGTH */

RECORD_TYPE                     = FIXED_LENGTH
RECORD_BYTES                    = 4140
FILE_RECORDS                    = 2128
LABEL_RECORDS                   = 1
INTERCHANGE_FORMAT              = BINARY

/*          POINTERS TO START RECORDS OF OBJECTS IN FILE */

^IMAGE                          = 2

/*          IMAGE DESCRIPTION */

DATA_SET_ID                     = "CLEM1-L-U-5-DIM-BASEMAP-V1.0"
PRODUCT_ID                      = "BI66N337"
PRODUCER_INSTITUTION_NAME       = "UNITED STATES GEOLOGICAL SURVEY"
PRODUCT_TYPE                    = MDIM
MISSION_NAME                    = "DEEP SPACE PROGRAM SCIENCE
```

```
EXPERIMENT"
SPACECRAFT_NAME                = "CLEMENTINE 1"
INSTRUMENT_NAME                = "ULTRAVIOLET/VISIBLE CAMERA"
INSTRUMENT_ID                  = "UVVIS"
TARGET_NAME                    = "MOON"
FILTER_NAME                    = "B"
CENTER_FILTER_WAVELENGTH       = 750.0000
BANDWIDTH                      = 10.0000
START_TIME                     = "N/A"
STOP_TIME                      = "N/A"
SPACECRAFT_CLOCK_START_COUNT   = "N/A"
SPACECRAFT_CLOCK_STOP_COUNT    = "N/A"
PRODUCT_CREATION_TIME          = 1997-06-09T12:56:11
NOTE                           = "LUNAR BASEMAP MOSAIC"

/*          DESCRIPTION OF OBJECTS CONTAINED IN FILE */

OBJECT                         = IMAGE
  BANDS                        = 1
  BAND_STORAGE_TYPE            = BAND_SEQUENTIAL
  BAND_NAME                    = "N/A"
  LINES                        = 2127
  LINE_SAMPLES                 = 2070
  SAMPLE_TYPE                  = MSB_INTEGER
  SAMPLE_BITS                  = 16
  SAMPLE_BIT_MASK              = 2#1111111111111111#
  OFFSET                       = -9.0128981E-04
  SCALING_FACTOR               = 1.2028247E-04
  VALID_MINIMUM                = -32752
  NULL                         = -32768
  LOW_REPR_SATURATION          = -32767
  LOW_INSTR_SATURATION         = -32766
  HIGH_INSTR_SATURATION        = -32765
  HIGH_REPR_SATURATION         = -32764
  MINIMUM                      = 430
  MAXIMUM                      = 6137
  CHECKSUM                     = 593477699
END_OBJECT                     = IMAGE

OBJECT                         = IMAGE_MAP_PROJECTION
  ^DATA_SET_MAP_PROJECTION     = "DSMAP.CAT"
  COORDINATE_SYSTEM_TYPE       = "BODY-FIXED ROTATING"
  COORDINATE_SYSTEM_NAME       = "PLANETOGRAPHIC"
  MAP_PROJECTION_TYPE          = "SINUSOIDAL"
  MAP_RESOLUTION               = 303.2334900
  MAP_SCALE                    = 0.1000000
  MAXIMUM_LATITUDE             = 70.0000000
  MINIMUM_LATITUDE             = 62.9868011
  EASTERNMOST_LONGITUDE        = 345.0291138
  WESTERNMOST_LONGITUDE        = 330.0000000
  LINE_PROJECTION_OFFSET       = 21227.3452970
  SAMPLE_PROJECTION_OFFSET     = 2066.9105015
  A_AXIS_RADIUS                = 1737.4000000
  B_AXIS_RADIUS                = 1737.4000000
  C_AXIS_RADIUS                = 1737.4000000
  FIRST_STANDARD_PARALLEL      = "N/A"
  SECOND_STANDARD_PARALLEL     = "N/A"
  POSITIVE_LONGITUDE_DIRECTION = EAST
  CENTER_LATITUDE              = 0.0
  CENTER_LONGITUDE             = 345.0000000
```

```
  REFERENCE_LATITUDE           = "N/A"
  REFERENCE_LONGITUDE          = "N/A"
  LINE_FIRST_PIXEL             = 1
  SAMPLE_FIRST_PIXEL           = 1
  LINE_LAST_PIXEL              = 2127
  SAMPLE_LAST_PIXEL            = 2070
  MAP_PROJECTION_ROTATION      = 0.0000000
  VERTICAL_FRAMELET_OFFSET     = "N/A"
  HORIZONTAL_FRAMELET_OFFSET   = "N/A"
END_OBJECT                     = IMAGE_MAP_PROJECTION
END
```

INDEX FILES

Each CD volume in the Clementine basemap mosaic contains an image index file ('imgindx.tab') with catalog information about the entire basemap. The image index file and it's associated PDS label file ('imgindx.lbl') are located in the 'index' directory. The catalog information in the index table includes the file names, CD volumes, and mapping parameter information. An additional source file index table ('srcindx.tab' and corresponding PDS label 'srcindx.lbl')contains information about the EDR image collection used to assemble the basemap. This file contains an entry for each EDR image that was used in the basemap. Information in this file includes the improved camera pointing data (c-matrix) derived from tying to the geometric control network established by the Rand Corporation. For more information on the contents of the index files refer to the label files.

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APPENDIX A - KEYWORD ASSIGNMENTS

This section defines the keywords used in the image label area of the Clementine basemap mosaic.

PDS_VERSION_ID = PDS3
This dataset conforms to version 3 of the PDS standards.

RECORD_TYPE = FIXED_LENGTH
This keyword defines the record structure of the file as fixed-length record files.

RECORD_BYTES = xxxx
Record length in bytes for fixed-length records (number of samples *2)

FILE_RECORDS = xxxx
Total number of fixed-length records contained in the file

LABEL_RECORDS = x
Number of fixed-length label records in the file

INTERCHANGE_FORMAT = BINARY
Data are organized as BINARY values

^IMAGE = x
Pointer to the first record that contains image data. (The first record in the file is designated as record 1.)

DATA_SET_ID = "CLEM1-L-U-5-DIM-BASEMAP-V1.0"
The PDS defined data set identifier for the Clementine basemap mosaic

PRODUCT_ID = "BI66N337"
Unique product identifier for this image file. This value is the same
as the file name. (Format described in the "FILES, DIRECTORIES, AND DISK CONTENTS" section above.)

PRODUCER_INSTITUTION_NAME = "UNITED STATES GEOLOGICAL SURVEY"
Identifies the producer organization of this data product.

PRODUCT_TYPE = MDIM
This keyword identifies the image product as a Mosaicked Digital Image Model (MDIM).

MISSION_NAME = "DEEP SPACE PROGRAM SCIENCE EXPERIMENT"
The keyword identifies the product name of the mission. (This is the
official name of the Clementine Mission.)

SPACECRAFT_NAME = "CLEMENTINE 1"
Name of the spacecraft that acquired the data.

INSTRUMENT_NAME = "ULTRAVIOLET/VISIBLE CAMERA"
Name of the instrument that acquired the image data.

INSTRUMENT_ID = "UVVIS"
Abbreviated name of the instrument that acquired the image data.

TARGET_NAME = "MOON"
Target of the data product.

FILTER_NAME = "B"
Virtually all images that make up the Clementine base map mosaic were acquired using the filter "B". Filter "C" images were used when filter "B" data were not available.

CENTER_FILTER_WAVELENGTH = 750.0000
The center filter wavelength of filter "B" is 750 nanometers.

```
BANDWIDTH                        = 10.0000
The bandwidth of the filter "B" is 10 nanometers.

START_TIME                       = "N/A"
STOP_TIME                        = "N/A"
SPACECRAFT_CLOCK_START_COUNT     = "N/A"
SPACECRAFT_CLOCK_STOP_COUNT      = "N/A"
Start_Time, Stop_Time, and clock counts are not applicable (N/A)
for this data product but are required keywords.

PRODUCT_CREATION_TIME            = 1997-06-09T12:56:11
Time at which the image product was produced.

NOTE                             = "LUNAR BASEMAP MOSAIC"
Note field always says LUNAR BASEMAP MOSAIC.

OBJECT                           = IMAGE
BANDS                          = 1
There is only one spectral band in the basemap mosaic.

BAND_STORAGE_TYPE              = BAND_SEQUENTIAL
Storage order is band sequential

BAND_NAME                      = "N/A"
Band name keyword is not applicable.

LINES                          = xxxx
Number of lines (rows) in image array

LINE_SAMPLES                   = xxxx
Number of samples (columns) in image array.

SAMPLE_TYPE                    = MSB_INTEGER
Data are stored in "Most Significant Byte" order first format. This
is the storage order of Sun workstations and Macintosh computers.
Other systems, such as IBM/PC compatible computes and DEC/VAX
systems will need to reverse the byte order of the 16-bit pixels
before the data can be used.


SAMPLE_BITS                    = 16
There are 16 bits per sample (2 bytes)

SAMPLE_BIT_MASK                = 2#1111111111111111#
This keyword indicates all bits within a 16-bit word are used in
the expression of the value.

OFFSET                         = -9.0128981E-04
SCALING_FACTOR                 = 1.2028247E-04
The OFFSET and SCALING_FACTOR keywords contain values used to
convert the 16-bit integer pixel value to radiometric units.

FRACTIONAL_REFLECTANCE = (PIXEL* SCALING_FACTOR) + OFFSET

VALID_MINIMUM                  = -32752
Lowest valid value that can be stored in pixel (always -32752).

NULL                           = -32768
Value of empty pixels or missing data (always -32768).
```

```
LOW_REPR_SATURATION          = -32767
Value of pixel if processing caused a low-end value pixel to go
outside  dynamic range of a 16-bit signed integer (always -32767).

LOW_INSTR_SATURATION         = -32766
Value if pixel was low-end saturated (always -32766). For example,
if the bias of the camera was set so that low DN values could not
be stored in the pixel.

HIGH_INSTR_SATURATION        = -32765
Value of pixel if processing caused a high-end value pixel to go
outside dynamic range of a 16-bit signed integer (always -32765).

HIGH_REPR_SATURATION         = -32764
Value if pixel was high-end saturated (always -32764). For example,
if the scene was too bright for the image to record at the pixel
value became saturated.

MINIMUM                      = xxxx
Minimum value in image array.

MAXIMUM                      = xxxx
Maximum value in image array.

CHECKSUM                     = xxxxxxxx
Sum of all bytes in the image object. Used to validate that an
image
file was properly stored on the media.

END_OBJECT                     = IMAGE

OBJECT                         = IMAGE_MAP_PROJECTION
^DATA_SET_MAP_PROJECTION     = "DSMAP.CAT"
Name of file containing additional information about the map
projection.
DSMAP.CAT is located in the 'catalog' directory.

COORDINATE_SYSTEM_TYPE       = "BODY-FIXED ROTATING"
COORDINATE_SYSTEM_NAME       = "PLANETOGRAPHIC"
Coordinate system used in the map projection.

MAP_PROJECTION_TYPE          = "SINUSOIDAL"
Name of map projection.

MAP_RESOLUTION               = xxx.xxxxx
Map resolution (pixels per degree) at the reference point of the
projection.

MAP_SCALE                    = x.xxxxxx
Map scale (kilometers per pixel) at the reference point of the
projection.

MAXIMUM_LATITUDE             = xx.xxxxxxx
Maximum latitude of the image file

MINIMUM_LATITUDE             = xx.xxxxxxx
Minimum latitude of the image file.

EASTERNMOST_LONGITUDE        = xxx.xxxxxxx
Easternmost longitude of the image file.
```

```
WESTERNMOST_LONGITUDE        = xxx.xxxxxxx
Westernmost longitude of the image file

LINE_PROJECTION_OFFSET       = xxxxx.xxxxxxx
SAMPLE_PROJECTION_OFFSET     = xxxxx.xxxxxxx
Projection offsets are used to define the relationship between line
and sample of the image array and the latitude and longitude
coordinate on the surface of the planet. See 'dsmap.cat' file
located in the 'catalog' directory for information on these
keywords.

A_AXIS_RADIUS                = 1737.4000000
B_AXIS_RADIUS                = 1737.4000000
C_AXIS_RADIUS                = 1737.4000000
Three axis radius of the Moon used in the derivation of the map
products that make up the basemap mosaic.

FIRST_STANDARD_PARALLEL      = "N/A"
SECOND_STANDARD_PARALLEL     = "N/A"
Standard parallels of map, not used in this sinusoidal equal-area
projection.

POSITIVE_LONGITUDE_DIRECTION = EAST
The Moon coordinate system uses a positive longitude direction of
east. Longitude values increase in the eastern direction.

CENTER_LATITUDE              = 0.0
Center latitude of the map projection.

CENTER_LONGITUDE             = xxxx.xxxx
Center longitude of the map projection.

REFERENCE_LATITUDE           = "N/A"
REFERENCE_LONGITUDE          = "N/A"
Reference latitude and longitudes are not used in the sinusoidal
equal-area projection.

LINE_FIRST_PIXEL             = 1
SAMPLE_FIRST_PIXEL           = 1
The first pixel (upper left) in the image array is defined as line
1, sample 1.

LINE_LAST_PIXEL              = xxxx
SAMPLE_LAST_PIXEL            = xxxx
The last pixel (lower right) in the image arrays is defined by
these keywords.

MAP_PROJECTION_ROTATION      = 0.0000000
Map projection rotation always 0 for the Clementine Basemap Mosaic.

VERTICAL_FRAMELET_OFFSET     = "N/A"
HORIZONTAL_FRAMELET_OFFSET   = "N/A"
These keywords are not applicable for the sinusoidal equal-area
projection.

END_OBJECT                     = IMAGE_MAP_PROJECTION
END
```

APPENDIX B - GEOMETRIC DEFINITION OF A PIXEL

The purpose here is to describe the spatial or geometric definition of a pixel used in the generation and utilization of the digital image products. A broad range of factors enters into this question. For example, is a pixel to be conceived of as a point or as an area? The point definition would be most convenient, for instance, when dealing with coordinate grid overlays. This results in an odd number of pixels across a map that has an even number of spatial increments. For changing scales (for instance by even powers of 2) this definition becomes a problem. In this case it makes more sense to treat a pixel as a finite area. Then an even number of pixels covers an even number of spatial increments and decreasing/increasing scales by a power of 2 becomes trivial. However, grids now fall between pixels, at least in a mathematical sense. Their treatment in the generation of hardcopy therefore becomes an issue.

It was decided that the area concept of a pixel was the better choice; we would have to live with the asymmetries introduced in things like cartographic grids. There are various solutions: (1) use two pixels for the width of a grid line, (2) stagger grid pixels back-and-forth across the mathematical position, (3) use a convention whereby grid lines are systematically drawn offset from their mathematical position.

The next issue is the conversion between integer coordinates and real coordinates of the pixel mesh. We adopt the convention that pixels are numbered (or named if you like) beginning in the upper left corner with line 1, sample 1 (pixel 1,1); lines increase downward; samples increase to the right. (Even this is not a universal standard; some astronomical systems begin, perhaps more logically, in the lower left corner.) There are three reasonable possibilities for aligning a real, or floating point, coordinate system with the pixel mesh: the coordinate 1.0, 1.0 could be the upper left, the center, or the lower right of pixel 1,1. The convention historically used for geometric calibration files (reseau positions) and also used in the Multimission Image Processing Laboratory at the Jet Propulsion Laboratory, is that the center of the pixel is defined as its location in real coordinates. In other words, the real coordinates of the center of pixel 1,1 are 1.0, 1.0. The top left corner of the pixel is .5, .5 and the bottom right corner is 1.49999...,1.499999. The bottom and right edge of a pixel is the mathematically open boundary. This is the standard adopted in the image products.

Cartographic conventions must also be defined. The map projection representation of a pixel is mathematically open at the increasing (right and lower) boundaries, and mathematically closed at its left and upper boundaries. An exception occurs at the physical limits of the projection; the lower boundary of the lowest pixel is closed to include the limit of the projection (e. g. the south pole). The figure below shows the coordinates of Pixel 1,1.

```
              Coordinates of Pixel 1,1

      longitude  180.0         179.00001
                   |               |
      latitude     |               |   line
         90.0  -- ----------------- -- .5
                   |               |
                   |               |
                   |               |
                   |               |
                   |       +       |
                   |   (1.0,1.0)   |
                   |               |
                   |               |
                   |               |
      89.00001 -- ----------------- -- 1.49999
                   |               |
                   |               |
         sample  .5            1.49999
```

Finally, we must select a convention for drawing grid lines for various cartographic coordinates on planetary images and maps. The convention used for the image products is that a grid line is drawn in the pixels that contain its floating point value until the open boundary is reached and then an exception is made so that the outer range of latitude and longitude will always appear on the image. This means, in the example given above, a 10 degree grid would start on pixel 1 and be drawn on every tenth pixel (11,21,31,...) until the open boundary is reached. Then the line would be drawn on the pixel previous to the open boundary (line 180 instead of line 181, or sample 360 instead of 361).

To summarize, the conventions are:

1) Pixels are treated as areas, not as points.

2) The integer coordinates begin with 1,1 (read "line 1, sample 1") for the upper-left-most pixel; lines increase downward; samples increase to the right.

3) Integer and floating point image coordinates are the same at the center of a pixel.

4) Grids will be drawn in the pixels that contain the floating point location of the grid lines except for open boundaries, which will be drawn to the left or above the open boundary.