URGENT PROCESSING AND GEODETIC CONTROL OF LUNAR DATA. B. A. Archinal, L. R. Gaddis, R. L. Kirk, T. M. Hare, and M. R. Rosiek, U. S. Geological Survey, Astrogeology Team, 2255 N. Gemini Drive, Flagstaff, AZ 86001, USA, barchinal@usgs.gov.

Introduction: There is an urgent, time-critical need to begin tying together (geodetically controlling) all past and current lunar data, and to establish the cartographic foundation needed to make maximum use of future planned lunar data. Proper control of lunar data is ***required*** to properly support both lunar science and exploration, and at present we know of no plans within NASA to fund such work adequately. The utility of past and future lunar data will be severely hampered if they cannot be correlated/compared with each other or if the uncertainties in the positional accuracies are not well characterized. Since "required capabilities" and "technology developments" are on the primary list of issues for this workshop [1], it is clear that this issue is not only appropriate but critical to discuss and that strong recommendations must be made to address this problem. This white paper summarizes more detailed discussions that we have presented earlier [2].

The Need for Geodetic Control: The only way to connect/register/compare data with quantified precision and accuracy is to geodetically (usually photogrammetrically) process the data into controlled products. Otherwise the uncertainties in the comparison of data sets undermine their synergistic value. Users always want the best precision and accuracy possible and require that it be quantified. Such knowledge is critical for mineralogic, geologic, and scientific investigations and exploration purposes such as landing and landed operations. Controlling any single dataset provides many benefits including (a) the best method of removal of mosaic seams for qualitative work; (b) proper orthometric projection of data (registration of images to topography in order to make or match existing mosaics and maps), (c) registration of multispectral data, and (d) proper photometric correction of data. ***The value of such control increases exponentially when multiple datasets are considered, so it is essential that this work be planned for and done with new lunar data.*** Geodetic control adds substantial value to the data, especially relative to the cost of data collection. Furthermore, if one considers the cost of the loss of a mission (e.g. landing at incorrect coordinates), such costs are absolutely necessary and relatively insignificant.

Existing Lunar Control: The current best global geodetic information for the Moon is the just released Unified Lunar Control Network 2005, created by USGS under NASA Planetary Geology and Geophysics Program funding [3]. This network effectively controls the (750-nm 'basemap') images of the Clementine mission, and indirectly provides connections to Earth-based, *Apollo*, *Mariner 10*, and *Galileo* images of the Moon, in the lunar mean Earth/polar axis coordinate system tied to the lunar laser ranging (LLR) retroreflector sites. It provides the densest global 3D topographic model for the Moon, with accuracies of order several hundred meters or better horizontally and vertically. Work is underway to complete a global digital *Lunar Orbiter* mosaic of the Moon that will also be tied to this network [4]. However, additional value can be created by tying existing lunar data directly into this network (or a further improved version of it) so that the lunar science community is in the proper position to make maximum use of the new lunar data. These steps would be useful in the near term – before future mission results become available – both to significantly improve the accuracy of the network and to further improve knowledge globally of the Moon's topography, thus greatly benefiting the planning for near term orbital and landed missions. These steps are also necessary in the long term, in order to tie legacy datasets (including *Prospector* and *SMART-1*) rigorously together, so they can be compared among themselves and with future data.

Pressing Issues: Several major issues ***must be addressed now*** because lack of action now will have far-reaching consequences later, and because substantial technology development that requires long lead times and ramping up of capabilities is needed for the proper processing of coming data. These issues include:

Coordinate System Issues: Although the mean Earth/polar axis (ME) system has long been in use and is internationally recommended for lunar cartographic products [5], the principal axis system is also of value in dynamical studies (e.g. LLR and gravity field solutions). Confusion has arisen among various NASA components and international missions about which system to use for final products. In part at the urging of the authors, the *LRO* and *SELENE* missions have adopted the use of the ME system and have begun adopting other standards [6] in accordance with existing international standards [5]. However, more cooperation is needed to assure that common standards are adopted, particularly regarding details not yet addressed internationally. We strongly recommend that a Lunar Geodesy and Cartography Working Group (LGCWG), along the lines of the highly successful Mars GCWG, be established by NASA to facilitate such cooperation.

Technology Development Issues: Procedures, improved algorithms, and software are urgently required to: (a) photogrammetrically control line scanner, pixel-scanner, and push-frame cameras; (b) substantially improve cartographic production methods for automatic tie-pointing of overlapping image and other (e.g. altimetric) data by implementing algorithms from the image processing research community; and (c) develop complex multiple-partitioned matrix solution procedures for processing the coming extremely large datasets. The issue of controlling the various new types of cameras has already long been a critical one, since it applies to the very large datasets from Mars (e.g., MOC, THEMIS IR, HRSC, HiRISE, CTX, and MARCI). Except for some success by DLR and others in controlling large numbers of HRSC images, the software for routine production of cartographic quality products (i.e., deriving controlled solutions, topography from stereo, and mosaicking the results) from

Mars data and planned lunar image data simply does not exist. The problem is difficult to overstate given the expected 2-3 orders of magnitude increase in lunar data, and the extremely complex *LRO* cameras. No algorithm currently exists for photogrammetrically controlling extremely wide angle, push-frame cameras, such as the *LRO* WAC and MARCI. Furthermore, millions to tens of millions of points will be required for tying together single datasets in the future, far exceeding human capabilities to make such measurements manually as has been done in the past. Automatic methods of placing, measuring, quality control, and accuracy assessment of image tie points show great promise (e.g. for HRSC processing) and are under development by many groups (including USGS and NASA Ames) but substantially more work is required to make these algorithms and software robust and capable of processing thousands of extremely large images reliably without extensive human oversight. Even should appropriate camera models be generated and capabilities developed to measure millions of tie points, the least square solution algorithms needed to process the data will have to handle orders of magnitude more data than the largest geodetic/photogrammetric solutions ever performed with terrestrial datasets.

Data Volume Issues: It is well known that ***any one of the coming lunar missions is likely to return data volumes several times more than all previous planetary missions combined***. See Figure 1 – *a logarithmic plot* – for a comparison of estimates of what data volumes will be returned from upcoming missions. For example, *the* LRO *NAC image set could be about 1600 times the size of the entire* Clementine *UVVIS dataset!* Obviously, the necessary tools to process, control, mosaic, distribute, and archive such datasets to the PDS will require a massive investment if the data are to be made available and used to any meaningful degree.

International Collaboration: Although there is a significant level of international collaboration between various NASA components and foreign space agencies on lunar missions, much more could and should be done. We are concerned that the excellent example of the *Mars Express* mission is not being followed, where NASA funded various U.S. co-investigators so they could assist (e.g., with the particularly successful HRSC camera built by DLR). It is likely that the HRSC data would be much more difficult or impossible to use routinely by U. S. investigators if this cooperation had not occurred. Such an example should be followed in offering to foreign space agencies and missions the opportunity to have U. S. investigators participate, providing advice in particular on standards for coordinate systems, processing algorithms and techniques, data archiving (including ancillary data in the JPL NAIF SPICE format), and final product creation. The time to begin such activities is fast becoming too late as the international missions progress (or, in the case of *SMART-1*, are already completed) but even a belated start would be invaluable in terms of providing feedback to those missions, as well as to NASA, on the work needed to begin the production of data products. An early start on collaboration with a particular foreign space agency could open the door for other such collaborative efforts in the future.

Specific Recommendations for Lunar Data Processing: The following steps urgently need to be taken over the next few years to process existing and planned lunar data: 1) Begin development of the tools described above and establish a "LGCWG" and international mission Co-I or Participating Scientist programs. 2) Begin/continue to process available mission data to improve coordinate system definitions and facilitate comparison and ties to future datasets. 3) As data are released from upcoming missions, begin tying the datasets together and performing initial geodetic control and mosaicking, starting with the *LRO* mission (thereby at least processing the U.S. data first) and proceeding to the *Chandrayaan-1*, *SELENE*, and *Chang'E-1* missions. 4) Due to the higher expected relative accuracy and density of the LOLA dataset, once a final LOLA solution is accomplished and reconciled (or even combined) with the altimeter data from other missions, perform final control solutions to properly tie all the datasets together in a final reference frame, tied absolutely to the LLR retroreflector sites. 5) During this entire time, proceed with landing site mapping using high resolution Apollo, LO, and future mission datasets. 6) Process the eventual stereo datasets from *Chandrayaan-1* and/or *SELENE* to densify the altimeter data and complete a global 5-10 m resolution lunar topographic model. To our knowledge, none of these steps are currently planned or funded by NASA.

In summary, we strongly recommend that collaboration be increased and that a small fraction of the total cost of a given mission or instrument be allocated to processing and controlling the collected data so they can be utilized effectively.

References: [1] https://www.infonetic.com/tis/lea/. [2] Archinal, B. A., et al. (2006), response to NASA "Request for Information (RFI): Developing a Strategy for Future Exploration of the Moon and Beyond"; Kirk, R. L., et al. (2006) Int. Arch. Photogram. Rem. Sen. & Spatial Inf. Sci., XXXVI, Part 4, Goa. (Copies of both available on request). [3] Archinal, B. A., et al. (2006). U. S. Geological Survey Open-File Report 2006-1367, http://*pubs.usgs.gov/of/2006/1367/*; Archinal, B. A., et al. (2007) LPS, XXXVIII, 1904. [4] http://astrogeology.usgs.gov/Projects/LunarOrbiterDigitization/; Weller, L., et al. (2007) LPS, XXXVIII, 2092. [5] Seidelmann, P. K., et al., (2002), Cel. Mech. Dyn. Ast., 82, 83. [6] *LRO* Project White Paper (2006), A Standardized Lunar Coordinate System for the *Lunar Reconnaissance Orbiter*, August 23; Matsumoto, Koji, pers. comm. (2006).

Figure 1: Expected data volumes of Mars (red) and lunar (blue) missions (and a reflection of data complexity). **Note this is a logarithmic plot!** Units on left are 1, 10, 100, and 1000 Tbytes.