USING LARGE CRATER CLUSTERS TO IDENTIFY POTENTIAL SOURCE CRATERS ON MARS: TECHNICAL METHODS AND SCIENCE APPLICATIONS. J. A. Skinner, Jr. and R. A. Nava, Astrogeology Science Center, U. S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001 (jskinner@usgs.gov).

Introduction: The majority of crater clusters on Mars are interpreted to have resulted from either the breakup of weak, stony meteoroids within the atmosphere or the high-velocity ejection of large blocks from the surface as secondary debris from primary impacts [1-5]. The two processes, however, produce unique cluster characteristics, the former resulting in "small clusters" consisting of tens-of-meter diameter (and smaller) craters distributed over a range of a few hundred meters, and the latter producing "large clusters" consisting of hundreds-of-meter diameter craters distributed over tens of kilometers [6-7]. Previous workers have identified the chief parameters that control ejection and distribution of large clusters [1-7]. However, despite their numerous occurrences [6] and obvious cross cutting relationships in multiple geologic units [7], there has been no satisfactory effort to use large clusters as temporal markers [8-9]. Herein, we present the final technical methods behind a recently developed program that uses large crater clusters (LCCs) to identify potential source craters and summarize ongoing program applications for selected regions of Mars.

Technical Methods: The GIS-based program uses the density and orientation of individual craters within LCCs (as vector points) to identify potential source craters through a series of cluster identification and ejection modeling analyses. These operations are intended to establish a systematic, repeatable, and testable means to analyze the spatial distribution of LCCs, with particular regard to cross-cutting relationships with geologic units and landforms.

Program Mechanics. The Large Crater Cluster Analysis Program is written in Visual Basic .NET and works as a plug-in for the Environmental Systems Research Institute (ESRI) ArcGIS 9.3 software package. Three main operations are accessible from the program's graphical user interface: (1) clustering and directional distribution analyses of point features, (2) ejection trajectory computation from statistical ellipses, and (3) intersection of ejection trajectories and centroid analyses (see [8-9] for developmental specifics). Given a vector point file that represents the individual craters within clusters of interest (**Fig. 1**), the program performs the above operations in sequence, using the output of each operation as input for the next. Changeable parameters include near distance thresholds (for determination of statistical neighborhoods), buffer distance as a factor of near distance thresholds (for determination of statistical clusters), trajectory distance (for determination of maximum distance from primary), and ejection speed (for determination of distance and Coriolis effects). The program can incorporate unique IDs for trajectory analysis for cases where clusters are pre-determined by the user (via image analysis). Plausible ejecta trajectory solutions account for geodesic measurements on an ellipsoid by implementing Vicenty's direct and indirect formulae [11].

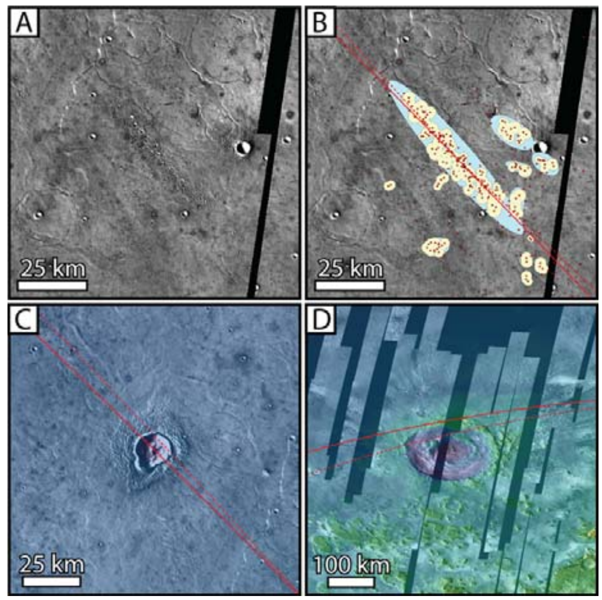

Figure 1. Example analysis of large crater cluster in Utopia Planitia. (A) THEMIS daytime IR mosaic centered at 26.6°N, 118.1°E. (B) Mapped craters from 0.5 to 1.0 km diameter (red points), cluster statistics using buffered (1.5x) nearest neighbor of 2 km (yellow circles), and resultant trajectories (dashed line accounts for Coriolis effect). (C) Closest potential source impact (D=14 km). (D) Lyot crater (D=212 km), located ~4000 km to WNW of crater cluster.

Performance reporting. Systematically changing input parameters provides a means to not only test operational effectiveness but also guide subsequent iterations in search of source craters. The program automatically generates a performance report for each operation, including time and date stamps, input layer names, operation status and sub-analysis steps, and resultant statistics (sub-populations, quartiles, ranges, means, and standard deviations). Statistics provide specific information regarding optimal thresholds that can be used to filter data on subsequent iterations. For example, the intersection of ejection trajectories operation provides a ranking table for the sites that have the highest potential for being source regions for the input crater clusters (based on the number of intersections used to calculate the centroid).

Science Application: The program provides an opportunity to assess whether large-scale crater clusters have stratigraphic application beyond inclusion (or exclusion) in crater size-frequency plots. The ability to place non-contiguous geologic terrains within a common temporal framework can test and (where necessary) refine the current Martian time-stratigraphic scheme. To address these issues, we must first evaluate the accuracy of the program, note its limitations, and define a best approach. Below, we summarize ongoing scientific tests, which focus on investigating (1) the accuracy of the program using secondary fields with a known source, (2) the characteristics of a large crater cluster field within the Martian northern plains, (3) the utility of other secondary impact-related landforms (i.e., catenae and rays) on source crater identification, and (4) the potential correlation of clusters within two non-contiguous geologic map regions.

For initial control and calibration, we used the locations of >22,000 secondaries interpreted to have been sourced from Zunil crater [10]. Though Zunil secondaries are "small crater clusters," the "known" source region is critical for program evaluation. Mapped points served as input for multiple iterations to test the effect of program variables as well as potential differences between human and automated cluster identification processes [8]. Using optimized parameters from performance reports, the program used 16,053 secondaries located at least 1500 m apart to identify 345 statistical cluster ellipses (each with ≥10 craters). Ellipses with inverse flattening ≤1.4 and major axis length ≥7500 m were extended 90° in either direction. An intersection of these modeled ejecta paths resulted in a potential source located 1.6 km from Zunil's true center. In addition, the program found that at least 8 clusters are not spatially associated with Zunil and perhaps source from a region >1400 km to the west-northwest. These efforts demonstrate that the program works as expected on youthful, source known, small crater clusters.

The above parameters establish a testable baseline for application to other regions of Mars where the source crater is unknown. We have used these to test a dense field of LCCs within southwestern Utopia Planitia, which can be considered representative LCCs due to their ellipticity, area, and density of component craters. Their range of orientation lends credence to a hypothesis that the Utopia LCCs represent down-range relicts of Lyot crater (D=212 km), which is located >4000 km to the west. We identified ~65 unique LCCs within the region, based on crater density and cluster orientation, and assigned each unique IDs for use in the LCC analysis program. To date, we have successfully tracked several LCCs to potential source craters (**Fig. 1**), including several to Lyot crater. We are validating these results and examining variance in density and orientation with distance from potential sources.

Though the LCC analysis program is intended to track clusters of impact craters with individual diameters >300 m (for regional to global use with THEMIS mosaics), there may be legitimacy for the inclusion of other secondary impact crater-related landforms (catenae, rays, and herringbone patterns). We are using the secondary features located within Acidalia Planitia as a means to examine not only their utility in tracking source craters but also their potential to provide some verification of impact models. A comparison of the shape, density, and orientation of secondary impact-related landforms has the potential to shed light on size-velocity distributions [2-3], physical properties of target material [5], and relationships between primary and secondary crater diameters [6-7].

One of the chief goals of the LCC analysis program was the use of LCCs as stratigraphic markers. Though the full realization of this goal may not be possible without expanded application and analysis of program performance, we are investigating the potential utility of using LCC populations located within two regions currently funded for geologic mapping: Nili Fossae and Libya Montes. Both regions (1) are defined by six MTM quadrangles, (2) are located around Isidis Planitia, (3) contain a swath of highland, intermediate, and lowland plains units, and (4) have complete coverage in THEMIS daytime and nighttime IR images.

Availability: The Large Crater Cluster (LCC) Analysis Program executable and associated help documentation is currently available for download from either PIGWAD (http://webgic.wr.usgs.gov) or ESRI ArcScripts (http://arcscripts.esri.com). The program will automatically launch Setup Wizard for installation and a "LCC Analysis Tools" toolbar can be opened and docked in ArcGIS.

References: [1] Hartmann, W.K. (1969) *Icarus*, *10*, 201-213. [2] Holsapple, K.A. and Schmidt, R.M. (1982) *JGR*, *87*, 1849-1870. [3] Vickery, A.M. (1986) *Icarus*, *67*, 224-236. [4] Melosh, H.J. (1987), *Impact cratering: A geologic process.* 245 pp. [5] Vickery, A.M. (1987) *GRL*, *14*, 726-729. [6] Hartmann, W.K., and Engel, S. (1994) *LPS XXV*, Abstract 511-512. [7] Popova, O.P., et al. (2007), *Icarus*, *190*, 50-73. [8] Nava, R.A. and Skinner, J.A., Jr. (2009) *AGU Fall Suppl.*, P23A-1243. [9] Nava, R.A. and Skinner, J.A., Jr. (2010) *LPS XLI*, Abstract #2699. [10] Preblich, B.S. et al. (2007) *JGR*, *112*. [11] Vincenty, T. (1975) *Survey Review XXIII*, 176.