GIS-BASED ANALYSIS OF SECONDARY CRATERS AS STRATIGRAPHIC MARKERS, MARS. R. A. Nava[1,2] and J. A. Skinner, Jr.[1], [1]Geography Department, Northern Arizona University, Flagstaff, AZ, 86011; [2]Astrogeology Science Center, U. S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001 (rnava@usgs.gov).

Introduction: The pervasive occurrence of secondary large crater clusters (LCCs) across the Martian northern plains elevates their potential utility as stratigraphic markers [1]. Martian surfaces are generally delineated into discrete packages based on morphological, compositional, and/or temporal characteristics, the latter of which are derived not only from crosscutting relationships between geologic units and tectonic features, but also from assessing the size and density of impact craters of any given surface [1]. However, present workflows for the temporal subdivision of Martian geologic terrains are not straightforward, particularly when attempting to use the full array of current dataset resolutions.

To assist stratigraphic analyses in specific conjunction with Mars geologic mapping, we are in the process of developing a GIS-based computer program that uses LCCs to identify source craters. So far, we have encountered moderate successes for the application and refinement of the tool [1-2]. Our method intends to establish a systematic and repeatable approach of stratigraphic studies that uses the spatial distribution and crosscutting relationships of LCCs. The goal is to avoid many of the interpretive errors that often plague stratigraphic analyses using crater density assessments. We define LCCs as clusters containing $\geq$10 individual craters $\geq$300 m in diameter and are $\geq$20 km in length. Herein, we (1) outline the overarching technical aspects of the approach, (2) summarize our recent developmental successes, (3) detail the step-wise GIS-based methods, (4) present anticipated packaging and distribution tactics, and (5) discuss ongoing application to geologic mapping of Mars.

Technical Approach: The program is written in the Visual Basic .NET computer language and works as a plug-in for the Environmental Systems Research Institute™ (ESRI) ArcGIS® software package. Three main tools are made available from toolbars within the ArcMap® graphical user interface. Each tool performs different functions: (1) clustering and directional distribution analyses of point features, (2) ejecta trajectory computation from elliptical features, and (3) intersection of ejecta trajectories, and clustering and centroid analyses for trajectory intersections [1-2]. Program parameters are entered into each form, and passed to the underlying code for execution. Control parameters can be dynamically changed to examine multiple ejection-trajectory-impact scenarios. The user is able to manipulate clustering analysis thresholds, eccentricity of crater distributions, and ejection velocities, among other variables.

GIS-based Method: Given a vector point file, the complete set of spatial analysis steps outlined below is executed in sequence, using the output of each operation as input for the next.

Step one. Clusters are identified from point data using nearest neighbor analysis. The program selects only those craters within a user-specified distance from their nearest neighbor (e.g. $\leq$4000 km) and buffers them to create circular polygons around each crater. Clusters are completely enclosed, and identified, after resulting circles are merged together as single polygons (clusters). Points in each cluster inherit the cluster's unique ID when spatially intersected with the merged polygon features and become input for subsequent operations.

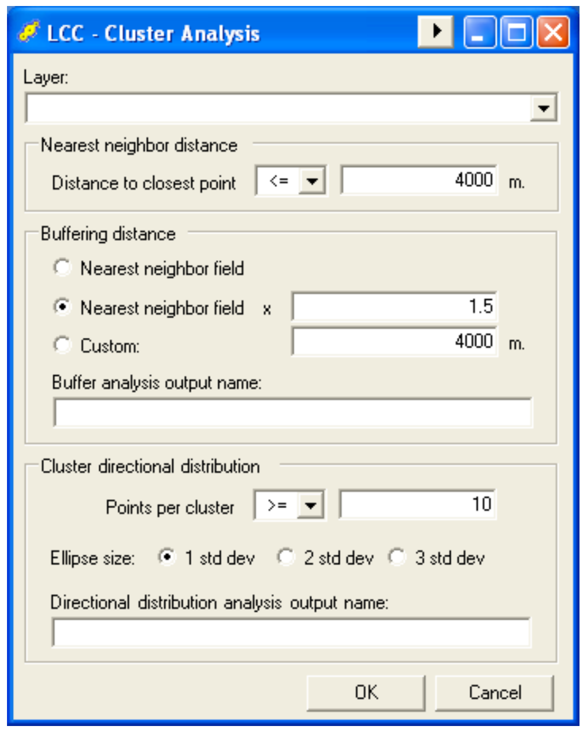

Figure 1. User interface for the cluster analysis tool, which assembles multiple core ArcGIS geoprocessing tools.

Step two. Each cluster's directional distribution is calculated by statistically fitting an ellipse to the point data contained within the cluster. The ellipse size covers an area of one standard deviation (optionally, the program allows for 2 or 3 standard deviations to be selected, see Fig. 1). Attributes regarding location, length, eccentricity, and azimuth are linked to each elliptical polygon and stored in tabular form.

Step three. Plausible ejecta trajectory vectors are extended from the center of each ellipse by implementation of Vincenty's inverse and direct formulae for the solution of geodesics on the ellipsoid [2]. New coordinate points on the geodesic are calculated at increasing distances from the center of each cluster using the ellipse center location and azimuth. In order to account for the planet's rotation, the longitudinal component of each newly computed coordinate pair is shifted by applying standard formulae for ballistics of ejecta on a spinning surface [3]. Formulae iterations run in both directions beginning the center of each ellipse until reaching a user-defined distance threshold. At the end of the routine, computed coordinate points are connected to form continuous line vectors.

Step four. Finally, the program intersects geodesic lines resulting form step three, computes clusters of intersections by applying the nearest neighbor analysis routine used in step one, and generates a new vector point file from the mean location of intersection clusters that meet a user-specified density. The number and density of geodesic line intersections, along with the computed centroid, model the potential parent crater locations where LCCs could have originated.

Recent Successes: To control and calibrate the program, we used the spatial locations of >22,000 secondaries (mapped using THEMIS VIS images) interpreted to have been sourced from Zunil, a 10.1-km-diameter, Late Amazonian-age crater located in Elysium Planitia, Mars. Mapped points served as input for multiple program iterations, each of which calculated and displayed the effects that different cluster characteristics, ejection velocities, and angular rotations have on the modeled location of the parent crater. We also estimated variance in the modeled parent crater location based on human and automated cluster identification (Fig. 2). Results indicate: (1) optimized parameters identify the source as a point located 1.6 kilometers from Zunil's center; (2) distance between modeled source location and Zunil's center decreases with increasing cluster ellipticity; (3) human- and auto-identified cluster analyses identify comparable source locations but use contrasting parameters; (4) inclusion of ejection velocities and the Coriolis effect has varying effects on accurately correlating modeled and actual source location; and (5) some mapped secondaries do not appear to source from Zunil crater.

There are some notable differences between the controlling parameters employed in the above calibration exercises and those expected for full-scale application of the tool to lowland and lowland-marginal surfaces. For example, our circum-Zunil efforts relied upon secondary craters that generally do not fit within the envelope of what we consider LCCs. In addition, we used THEMIS VIS images, rather than the more

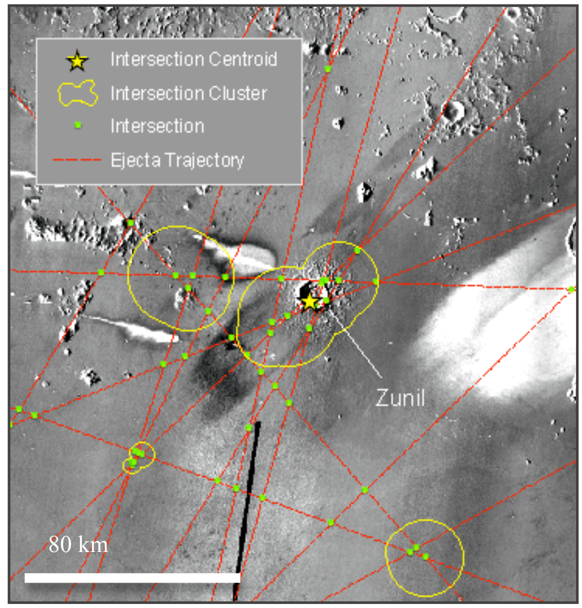

Figure 2. One of several program iteration models with the majority of the resulting trajectory intersections about Zunil.

continuous THEMIS IR images expected for widespread utility in the northern plains. We are currently assessing the analytical effect that datasets and crater clustering has on the results. Nevertheless, these results are encouraging in regard to the tool's ability to resolve source craters and provide confidence to the technical method.

Packaging and Distribution: We are planning to make the tool available as an ArcGIS® ArcMap plug-in by the time of LPSC. It will be packaged as an executable and uploaded to PIGWAD, the ESRI-Support website, and the ESRI Resource Center.

Ongoing Application: A fundamental "next step" to our methods is the use of the tool to model ejection-trajectory-impact scenarios for the regions circumferential to Utopia. We are using THEMIS daytime IR mosaics (100 m/px) constructed for three Mars Transverse Mercator (MTM)-based quadrangle sets that are regions currently allocated for geologic mapping. These regions collectively contain Noachian to Amazonian highland, highland-lowland transitional, and lowland plains, providing a large stratigraphic swath of analyzable surfaces. As this process is ongoing, we will present a status report of its successes and failures at LPSC.

References: [1] Nava, R.A. et al. (2009) LPSC XL, Abstract #2530. [2] Nava AGU abstract. [3] Vincenty, T. (1975), Survey Review XXIII, 176. [4] Dobrovolskis, A. (1981), Icarus 47, 203-219.