Unsupervised Classification of Submarine Landslides

J.A. Corter[1], P.L. Guth[2]

[1]Department of Oceanography, US Naval Academy
572C Holloway Rd, Annapolis MD 21402 USA
Email:jencorter@gmail.com

[2]Department of Oceanography, US Naval Academy
572C Holloway Rd, Annapolis MD 21402 USA
Telephone: 00-1-410-293-6560
Fax: 00-1-410-293-2137
Email: pguth@usna.edu

1. Introduction

A geomorphometric analysis of Crater Lake, Oregon and Lake Tahoe, California and Nevada, tested automatic classification of landforms. Landform classification is based largely on size, shape, orientation, and relief of an area (MacMillan et al. 2007). Also, since most landforms on earth's surface depend on adjacent bodies, it is difficult to separate one landform from another with definitive boundaries.

Cliffs and landslides, however, show a very definite border. We studied the Chaski landslide in Crater Lake, and the McKinney Bay landslide in Lake Tahoe (Figure 1). Both submarine landslides were both triggered by seismic activity, McKinney Bay Landslide by an earthquake about 15,000 years ago (Moore et al. 2006) and the Chaski landslide after failure in the caldera wall about 8,000 years ago (Bacon et al. 1997).

The results reported here represent part of a larger study to investigate differences between landforms in the two lakes and the surrounding terrain, and to investigate the use of a suite of geomorphometric terrain parameters for unsupervised terrain classification.

2. Methods

The bathymetric data for the lake basins were acquired from the USGS (Gardner and Dartnell 2001; USGS 2003). We also acquired DEMs for the land area around each lake from the National Elevation Dataset (Gesch et al. 2002) (Table 1). Since the lake data had different spacings, both were re-interpolated to make them comparable to the NED data with 1/3" spacing. Higher resolution data sets, with smaller data spacing, produce steeper average slopes and other terrain parameters (Guth, 1995).

	Crater Lake Bathymetry	**Crater Lake NED**	**Lake Tahoe Bathymetry**	**Lake Tahoe NED**
DEM horizontal spacing	2x2 m	1/3"x1/3" ~7.5x10.3 m	10x10 m	1/3"x1/3" ~8.0x10.3 m

Table 1. Horizontal DEM Resolution.

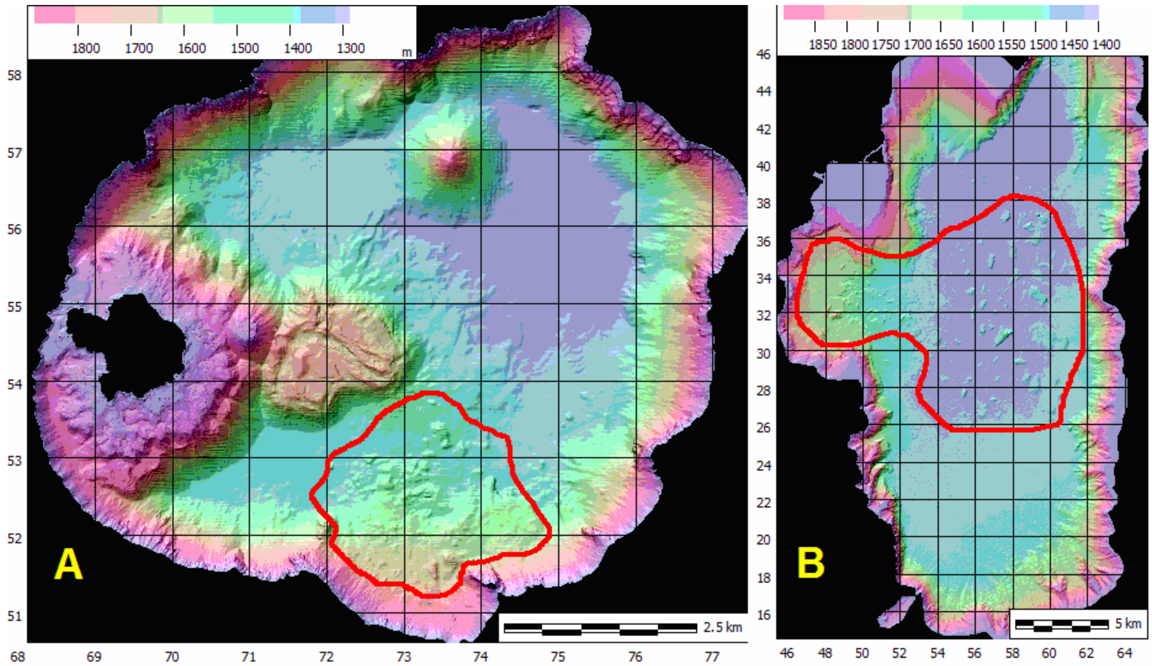


Figure 1. Crater Lake (A) and Lake Tahoe (B) bathymetry. Submarine landslide areas outlined in red.

To test the effect of re-interpolating the DEM on terrain statistics, we compared the 2 m and 1/3 arc second DEMs for Crater Lake (Figure 2). Elevation and slope distributions are essentially identical, however, the average slope versus elevation graph show the 1/3 arc second data to have a slightly less steep average slope.

The digital elevation model (DEM) of each lake was analyzed in MICRODEM (Guth 2007) in blocks of 25 by 25 grid postings, or about 250 m by 250 m. For each block the program computed 30 parameters. These regions are small enough, and we compute a sufficient number of them, that they can be considered random sampling areas. These parameters were then normalized in terms of standard deviations away from the mean, so that all parameters covered essentially the same range in n-dimensional space and would contribute equally to the results. An ISODATA algorithm (Edberg 2003) created clusters.

From the 30 parameters, we selected 17 for detailed analysis. We ran the ISODATA algorithm for every combination of 5 normalized parameters. Each set of five parameters were ranked by calculating the percent of landslide points classified in a single cluster, as well as percent of the cluster that is a part of the landslide. The best combination for grouping the two landslides were average elevation, elevation relief, elevation skewness, slope kurtosis, and profile curvature standard deviation. Full descriptions of all 30 parameters, with references, can be found in MICRODEM's help file (Guth 2007).

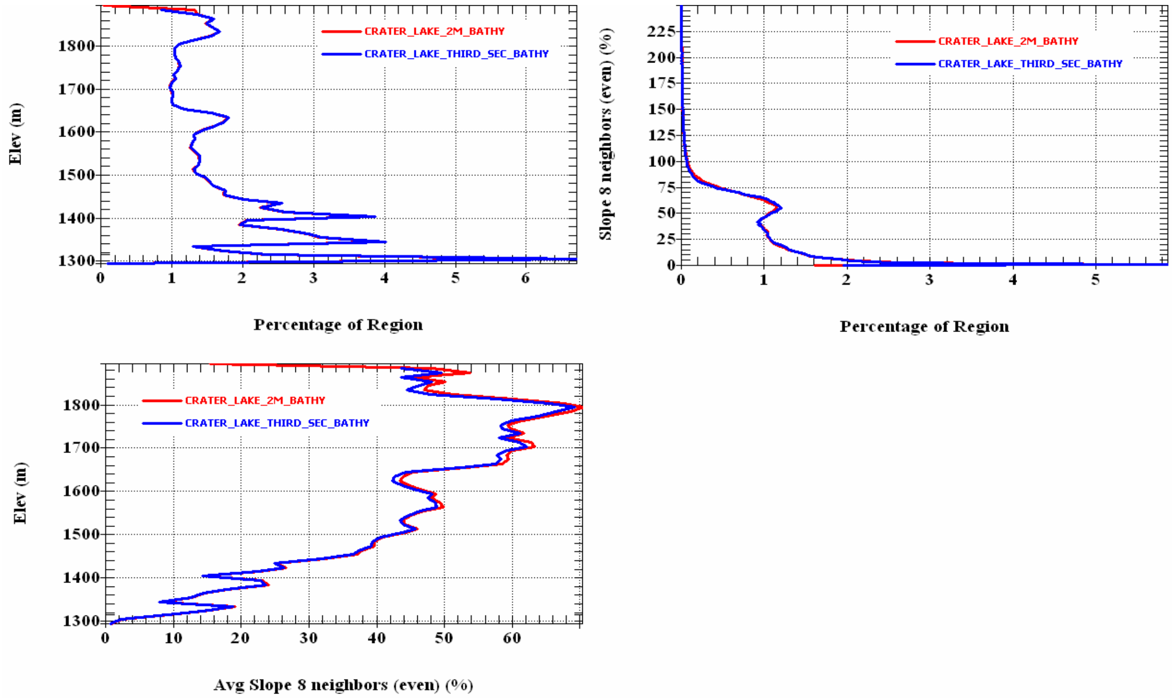


Figure 2. Effect of re-interpolated the Crater Lake bathymetric model from 2 m to 1/3 arc second.

3. Results

Because of the difficulty in visualizing results in four dimensional space, we created two dimensional graphs showing the values of each pair of parameters for each analysis region. The set of graphs (Figure 3) shows each cluster in a different color. Figures 4 shows the major cluster groupings in Crater Lake, and Table 2 shows the statistics for the clusters. Cluster 2 includes all points in the Chaski landslide, but only about 10% of the lake bottom points in the class and only about 4% of the points in the class. For Lake Tahoe, the classification placed 92% of the landslide points in the same cluster.

The method used to classify submarine landslides showed marginal success in exclusively separating the landslide from other terrain. In both lakes, greater than 90% of the landslide points were placed together in the same cluster. However, in both cases, the method also placed many points not in the landslide in the same cluster as the landslide points.

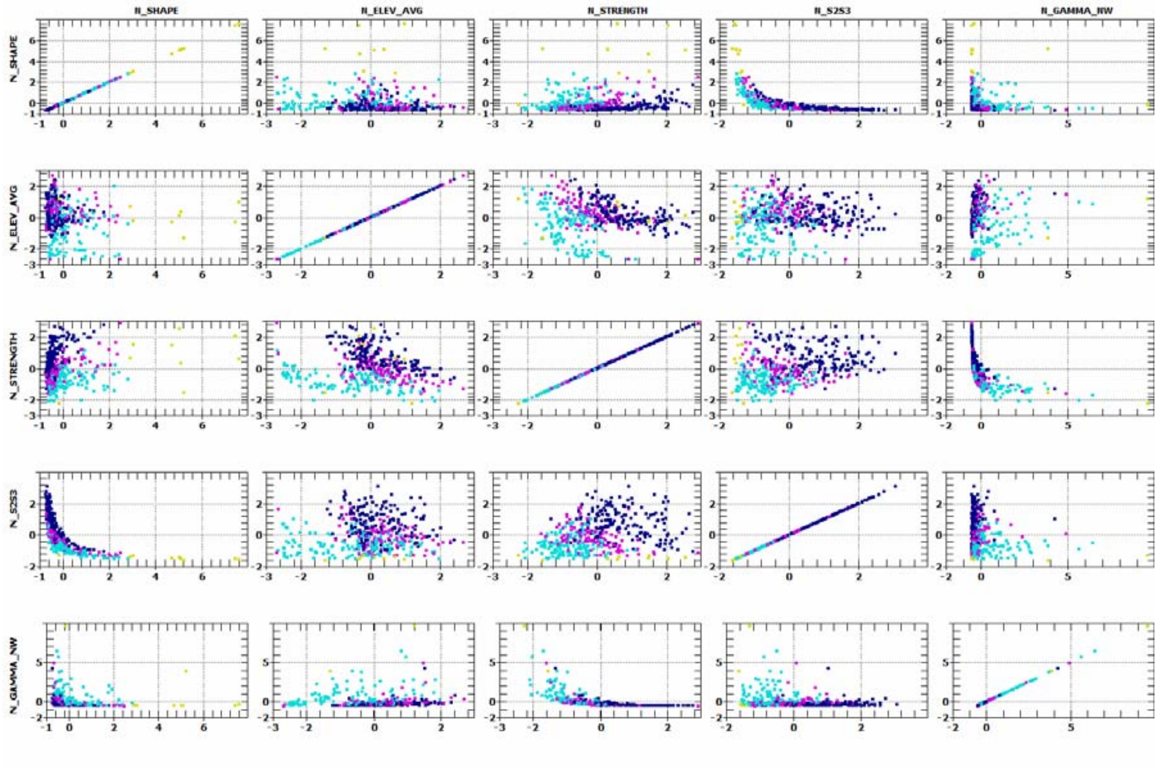


Figure 3. Two dimensional graphs of parameters for Crater Lake, colored by cluster.

Cluster	n	Landslide	Lake Floor	Surrounding Land
1	2347	0	21	2321
2	2629	91	848	1781
3	193	0	66	130
4	1892	0	152	1744
5	10	0	4	7
7	5	0	0	5
9	4	0	0	4
11	2	0	2	0
13	1	0	0	1
15	1	0	0	1

Table 2. Cluster composition

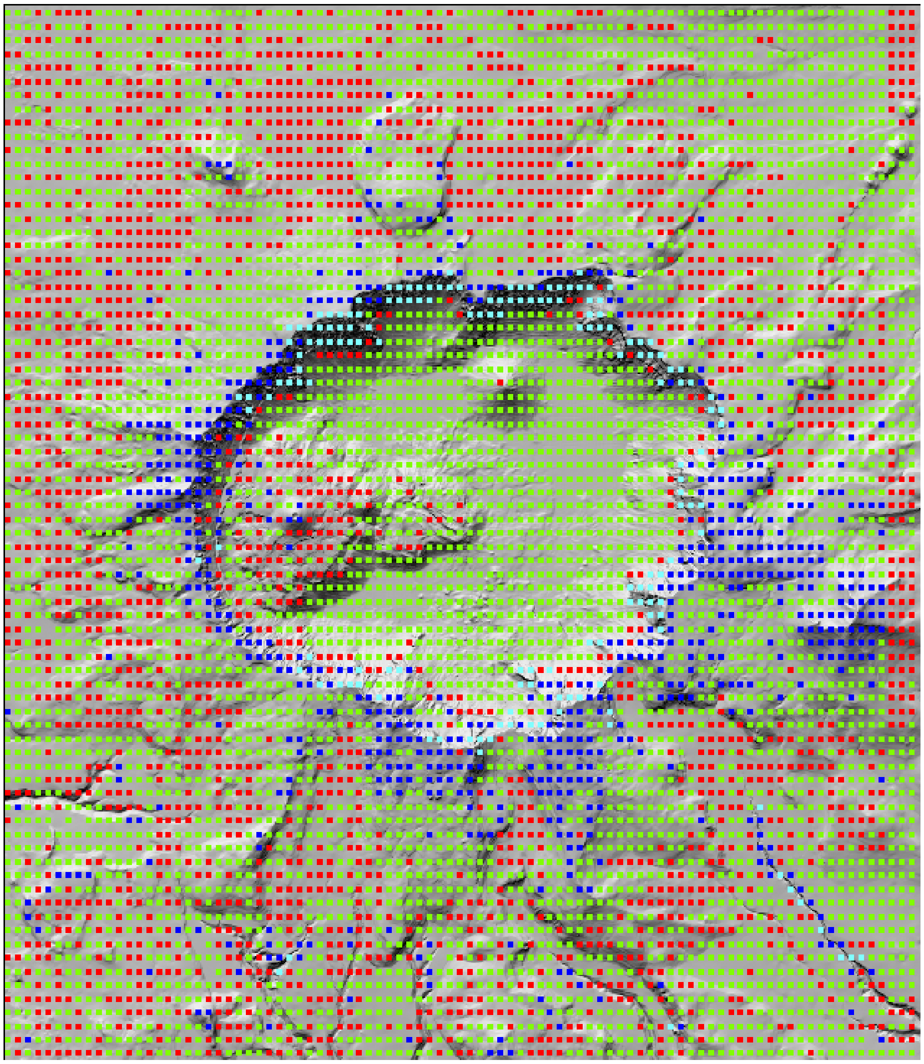
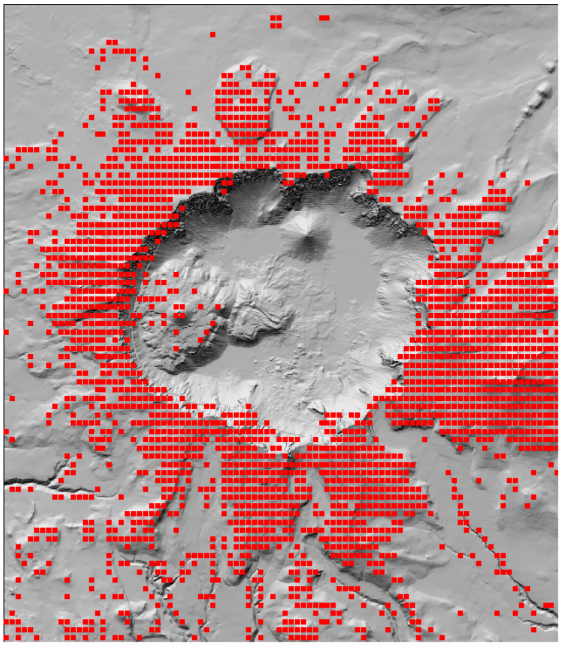
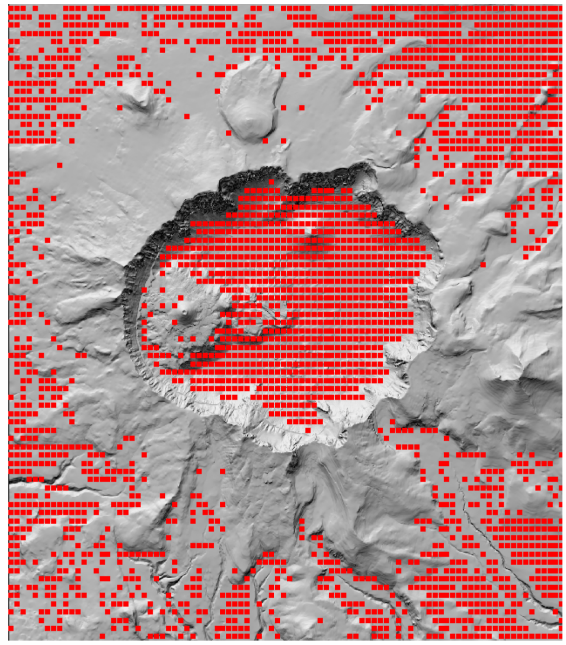


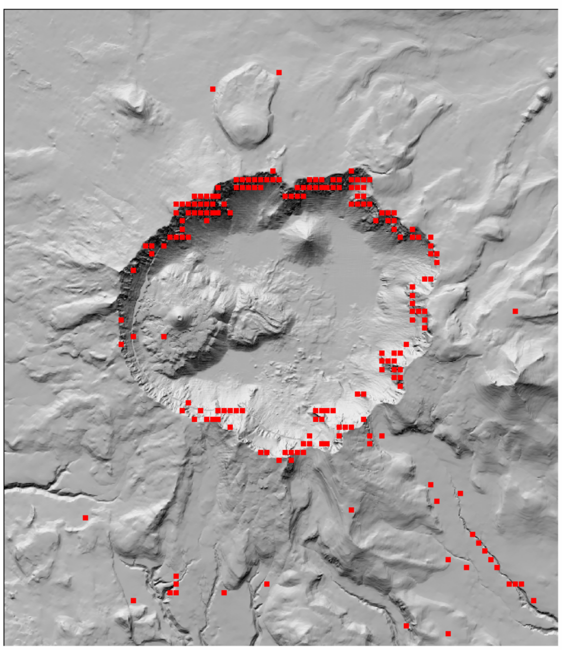
Figure 4. Map of Crater Lake color coded by cluster assignment using average elevation, elevation relief, elevation skewness, slope kurtosis, and profile curvature standard deviation. Cluster 1 (intermediate slopes) Cluster 2 (flat areas), Cluster 3 (steep margins), and Cluster 4 (lower slopes). All of the landslide is in cluster 2.



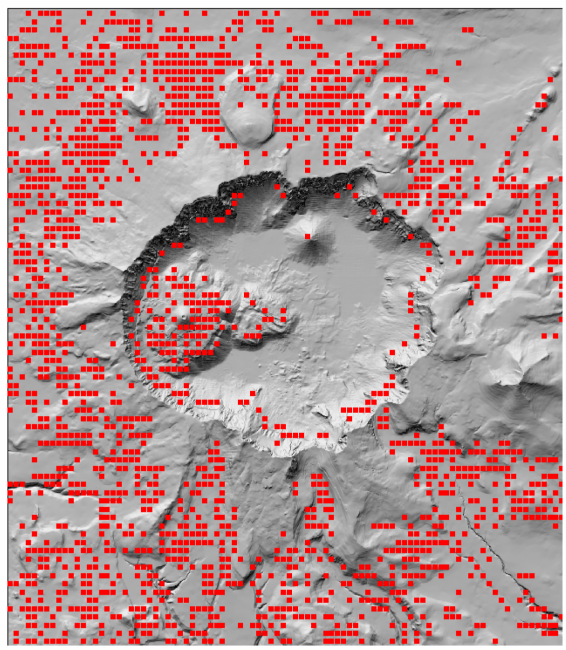
Cluster 1--intermediate slopes



Cluster 2--flat areas



Cluster 3--steep margins



Cluster 4--lower slopes

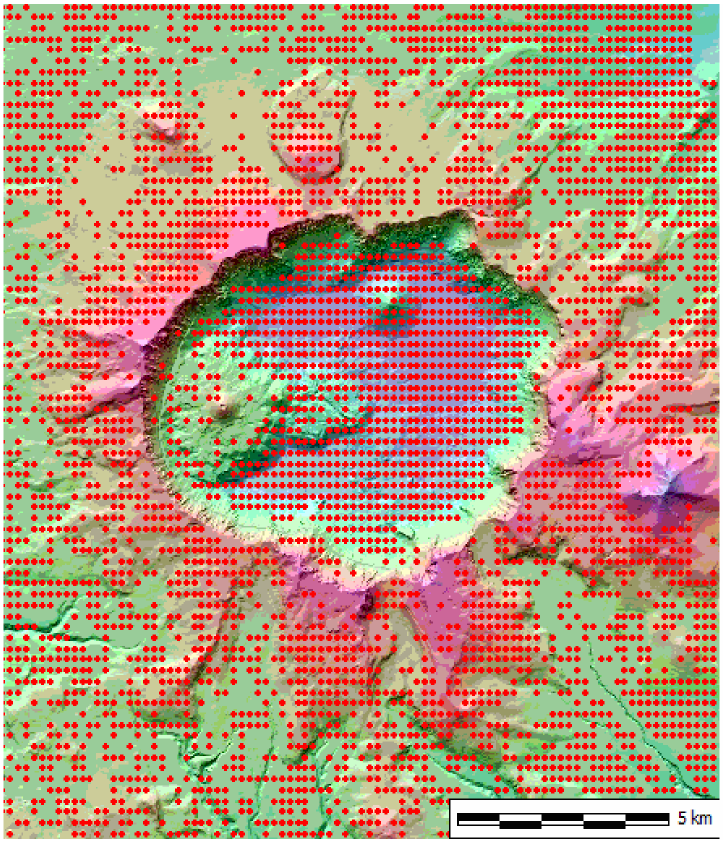


Figure 4. Map of Crater Lake the placement of cluster 2. 100% of the mask area was placed in cluster 2.

4. Conclusion

Unsupervised classification does a good job categorizing terrain and finds the steep slopes, gentle lake bottoms, and the transitional areas between them. It does a less good job segregating the landslides, because the landslide shares many similarities with other flat areas.

Our approach to clustering, using regional parameters computed over discrete areas differs from most others. For instance, Bolongaro-Crevanna et al. (2004) used point classification (peaks, pits, ridges, etc.) to form their clusters. Adediran et al. (2004) used slope and aspect in multiple directions as input to an ISODATA clustering. Bue and Stepinski (2006) used elevation, slope, and several drainage-derived statistics to classify terrain on Mars. Iwahasi and Pike (2007) used slope gradient, local convexity, and surface texture in an image processing based procedure. Micallef et al. (2007) classified a submarine landslide using ridge characteristics and moment statistics, but divided the landslide into different regions rather than differentiating it from adjacent terrain. There is no agreement on what parameters to use for terrain clustering for classification, or the procedures to use, and we will continue research on these techniques. Our goal is to create a system for classifying terrain using an atlas of terrain parameters computed from the Shuttle Radar Topography Mission, which provides an abundance of possible combinations.

5. References

Adediran A.O., Parcharidis I., Poscolieri M., and Pavlopoulos K., 2004, Computer-assisted discrimination of morphological units on north-central Crete (Greece) by applying multivariate statistics to local relief gradients: *Geomorpholog,y* 58 (1-4): 357-370.

Bacon, C. R., Mastin, L. G., Scott, K. M., and Nathenson, M., 1997, Volcano and earthquake hazards in the Crater Lake Region, Oregon: USGS Open-File Report, 97-487, 37p.

Bolongaro-Crevanna, A., Rodríguez, V.T., Sorani, V., Frame, D., and Ortiz, M.A., 2004, Geomorphometric analysis for characterizing landforms in Morelos State, Mexico, *Geomorpholog*y, 67(3-4), 407-422.

Bue, B.D., and Stepinksi, T.T., 2006, Automated classification of landforms on Mars: *Computers & Geosciences*, 32(.6), 604-614.

Edberg, F., 2003, *feStats* - "Plug-in" Multivariate Statistics Components: http://home.teleport.com/~fedberg/statspage.htm, last accessed 30 March 2007.

Gardner, J.V., and Dartnell, P., 2001, 2000 Multibeam sonar survey of Crater Lake, Oregon: Data, GIS, images, and movies: U.S. Geological Survey Digital Data Series DDS-72, CD-ROM; also available online at http://wrgis.wr.usgs.gov/dds/dds-72/site/data.htm, last accessed 30 Marchl 2007.

Gesch, D.B., Oimoen, M., Greenlee, S., Nelson, C., Steuck, M., and Tyler, D., 2002. The national elevation dataset: *Photogrammetric Engineering & Remote Sensing*, 68(1):5-11.

Guth, P.L., 1995, Slope and aspect calculations on gridded digital elevation models: Examples from a geomorphometric toolbox for personal computers*: Zeitschrift fuer Geomorphologie N.F. Supplementband*, 101:31-52.

Guth, P.L., 2001, Quantifying terrain fabric in digital elevation models, in Ehlen, J., and Harmon, R.S., (eds), *The environmental legacy of military operations*, Geological Society of America Reviews in Engineering Geology , vol., 14, chapter 3, p.13-25.

Guth, P.L., 2007, MICRODEM home page: http://www.usna.edu/Users/oceano/pguth/website/microdem.htm, last accessed 30 March 2007.

Iwahasi, J., and Pike, R., J., 2007, Automated classifications of topography from DEMs by an unsupervised nested means algorithm and a three-part geometric signature: *Geomorphology*, doi:10.1016/j.geomorph.2006.09.012, in press.

MacMillan, R.A., and Shary, P.A., 2007, Landforms and landform elements in geomorphometry, In Hengl, T., Reuter, H.I. (eds), *Geomorphometry: concepts, software, applications*. Office for Official Publications of the European Communities, Luxembourg, EUR 22670 EN, p.173-194.

Micallef, A., Berndt, C., Masson, D.G., and Stow, D.A.V., 2007, A technique for the morphological characterization of submarine landscapes as exemplified by debris flows of the Storegga Slide: *Journal of Geophysical Research*, vol.112, F02001, doi: 10.1029/2006JF000505.

Moore, J. G., Schweickert, R.A., Robinson, J.E., Lahren, M.M., Kitts, C.A., 2006, Tsunami-generated boulder ridges in Lake Tahoe, California-Nevada: *Geology*, 34(11), 965-968.

USGS, 2003, Lake Tahoe bathymetry: http://tahoe.usgs.gov/bath.html, last accessed 30 March 2007.