1995/27383

N95-33804

USE OF TOPSAR DIGITAL ELEVATION DATA TO DETERMINE THE 3-DIMENSIONAL SHAPE OF AN ALLUVIAL FAN

Tom G. Farr
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA

Landforms in arid regions record the interplay between tectonic forces and climate. Alluvial fans are a common landform in desert regions where the rate of uplift is greater than weathering or sedimentation (Bull, 1991; Bull and McFadden, 1977). Changes in uplift rate or climatic conditions can lead to isolation of the currently forming fan surface through entrenchment and construction of another fan either further from the mountain front (decreased uplift or increased runoff) or closer to the mountain front (increased uplift or decreased runoff). Thus, many alluvial fans are made up of a mosaic of fan units of different age, some older than 1 million years. For this reason, determination of the stages of fan evolution can lead to a history of uplift and runoff.

In an attempt to separate the effects of tectonic (uplift) and climatic (weathering, runoff, sedimentation) processes on the shapes of alluvial fan units, a modified conic equation developed by Troeh (1965) was fitted to TOPSAR digital topographic data for the Trail Canyon alluvial fan in Death Valley, California. This allows parameters for the apex position, slope, and radial curvature to be compared with unit age.

Troeh's (1965) equation is given as:

$$Z = P + S\sqrt{(X - X_0)^2 + (Y - Y_0)^2} + L\{(X - X_0)^2 + (Y - Y_0)^2\}$$

where Z is the height at position X, Y; X_0, Y_0, and P are the coordinates of the cone apex; S is the slope at the apex; and L is the radial curvature. Note that the term containing L adds a radial curvature to the simple right-circular cone described by the rest of the equation.

Troeh (1965) accomplished his work with topographic contour maps. With the advent of modern digital computers and digital elevation models, his approach can now be taken further and used to compare the topographic attributes of many alluvial fans or individual fan units with their age, drainage basin size, relief, lithology, uplift rates, etc. Further, the original extent and volume may be estimated for fan units of which only remnants are exposed. The topographic signature of individual fan units will help in regional correlation of fan surfaces of similar age.

A variety of techniques have been used over the years to map the relative ages of alluvial fan surfaces in arid regions. Since suitable material for numerical age determination is scarce in these environments, the actual depositional history of few fans has been determined. Exceptions include the fans on the west side of Silver Lake (Wells et al., 1987) and on the west side of the Owens Valley (Gillespie, 1982). In addition, tentative age assignments for major units on the fans along the west side of Death Valley, mapped by Hunt and Mabey (1966), have been made by Dorn (1988). These studies indicate that major pulses of fan aggradation are related to climatic changes that occur either during or at the close of major glaciations when rainfall and weathering processes are most conducive to the formation of debris flows and fluvial activity.

In order to characterize topographically the alluvial fan units mapped by Hunt and Mabey (1966), sufficient resolution is required to discriminate the individual units and sufficient coverage is required to provide enough points for a meaningful fit. Typical units, as mapped by Hunt and Mabey (1966) and by other students of alluvial fans (e.g. Hooke, 1972) are tens of m wide and cover in aggregate, at least in the case of the Trail Canyon fan, an area of several square km. Another requirement on the data to be used for 3-dimensional fitting is that the vertical errors in the data are smaller than the signal on the alluvial fans. On the Trail Canyon fan, relief differences between fan units are generally less than 5 m, while dissection within units typically ranges between 1 and 2 m.

There are several sources of digital topographic data that could be used for measurements of desert piedmont shapes. The most widely available data that most closely satisfy the above requirements are the U.S. Geological Survey's 7.5' Digital Elevation Models (DEM). The horizontal resolution (pixel size) of these data is 30 m and the vertical accuracy ranges between 7 and 15 m. These DEMs, however, are not available for large areas, including Death Valley. For this study, data from the NASA/JPL TOPSAR was used (Zebker et al., 1992; Evans et al., 1992). The spatial resolution of the TOPSAR data for Trail Canyon is 20 m. Analysis of TOPSAR data in control areas indicates that statistical errors in height are in the 1 m range, while systematic effects due to aircraft motion are in the 1-2 m range. Performance is best in areas of low relief and degrades slightly in the far range, as the signal to noise ratio decreases.

The results of the conic fits to individual units on the Trail Canyon fan show that the fan has changed shape over time. The causes of these changes may be climatic, tectonic, or a combination of the two. The fits show that older units are flatter at the cone apex and have less radial curvature, that the two younger units are entrenched into the fan head, and the youngest unit is depositing at the toe of the fan. These data can be used to make inferences about the processes that have formed and modified Trail Canyon fan. In particular, the similarity of the fan-unit shapes is probably a reflection of a consistent tectonic uplift rate since the deposition of the oldest unit.

In order to make more far-reaching conclusions, additional studies of other fans in Death Valley and in other desert basins need to be undertaken. Fan shapes need to be correlated to drainage-basin size, relief, lithology, etc. in order to separate the effects of climate and tectonic uplift. Comparing basins subjected to similar uplift rates, but with different basin geometries and lithologies will help isolate the climatic variable. Whereas, comparing basins with similar regional climate, and presumably paleoclimate, but with different uplift rates will help isolate the tectonic variable. In this way, comparative analysis of the three-dimensional shapes of alluvial fan units may be used in combination with field observations, aerial-photographic analyses, and remote sensing (Farr and Gillespie, 1984; Gillespie et al., 1984; Gillespie et al., 1986) for more precise mapping and regional correlation of alluvial fan units.

Acknowledgments

The research described in this report was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References

Bull, W.B., 1991, *Geomorphic Responses to Climatic Change*, Oxford Univ. Press, New York, 326 pp.

Bull, W.B., L.D. McFadden, 1977, Tectonic geomorphology north and south of the Garlock Fault, California, in *Geomorphology in Arid Regions*, D.O. Doehring, ed., Proc. 8th Annual Geomorphology Symposium, SUNY Binghamton, p. 115-137.

Dorn, R.I., 1988, A rock-varnish interpretation of alluvial-fan development in Death Valley, California, National Geog. Res., v. 4, p. 56-73.

Evans, D.L., T.G. Farr, H.A. Zebker, J.J. van Zyl, P.J. Mouginis-Mark, 1992, Radar interferometry studies of the Earth's topography, Eos Trans. AGU, v. 73, p. 553-558.

Farr, T.G., A.R. Gillespie, 1984, Measurement of micro-relief on alluvial fans and its relation to age, lithology, and radar response, Geological Society of America Abs. with Prog., v. 16, p. 506.

Gillespie, A.R., 1982, Quaternary Glaciation and Tectonism in the Southeastern Sierra Nevada, Inyo County, California, unpublished PhD thesis, California Institute of Technology, Pasadena, CA, 695 pp.

Gillespie, A.R., E. Abbott, G. Hoover, 1986, Spectral basis for relative dating of granitic alluvial fans, Owens Valley, California, Geol. Soc. Amer. Abs. with Prog., v. 18, p. 614.

Gillespie, A.R., A.B. Kahle, F.D. Palluconi, 1984, Mapping alluvial fans in Death Valley, California, using multichannel thermal infrared images, Geophys. Res. Let., v. 11, p. 1153-1156.

Hooke, R. LeB., 1972, Geomorphic evidence for late-Wisconsin and Holocene tectonic deformation, Death Valley, California, Geol. Soc. Amer. Bull., v. 83, p. 2073-2098.

Hunt, C.B., D.R. Mabey, 1966, Stratigraphy and structure, Death Valley, California, U.S. Geol. Surv. Prof. Paper 494-A, 162 pp.

Troeh, F.R., 1965, Landform equations fitted to contour maps, Amer. Jour. Sci., v. 263, p. 616-627.

Wells, S.G., L.D. McFadden, J.C. Dohrenwend, 1987, Influence of late Quaternary climatic changes on geomorphic and pedogenic processes on a desert piedmont, eastern Mojave Desert, California, Quat. Res., v. 27, p. 130-146.

Zebker, H.A., S.N. Madsen, J. Martin, K.B. Wheeler, T. Miller, Y. Lou, G. Alberti, S. Vetrella, A. Cucci, 1992, The TOPSAR interferometric radar topographic mapping instrument, IEEE Trans. Geosci. Rem. Sens., v. 30, p. 933-940.