Spatial Organization in the Landforms of Death Valley

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Death Valley, California, presents a classic site for the study of desert geomorphology in the Basin and Range province of North America. The harsh landscape reveals spectacular examples of faulted wineglass valleys, alluvial fans, shorelines of ancient lakes, weathering and erosion of brightly colored sediments, and a rich history of western frontierism and hardluck miners. A 25-kilometer trip from Badwater (~85 meters) to Telescope Peak (3,368 meters) traverses a diverse line of environments: from the evaporite salt polygons of the Devil’s Golf Course on the valley floor; through aromatic mesquite (Prosopis juliflora) thickets; up extensive aprons of coalesced alluvial fans dotted with hardy xerophytes (especially creosote bush, Larrea tridentata); up steep hillslopes shedding debris at rates on the order of meters per thousand years; finally into conifers (such as Pinus flexilis, P. longaeva) which tenaciously stabilize fossil periglacial landforms atop the Panamint Range.

In an attempt to bring meaning and organization to diverse landforms in this stark setting, we treat the geomorphology of Death Valley as a hierarchy of spatial scales (cf. Chorley 1972; Fenneman 1916), from the regional overview provided by satellite imagery at 1,000,000 meters to the intimate scrutiny of electron microscopy at 0.000 001 meter. We employ distance rather than area in our discussions, in accordance with the linear nature of fault lines, shorelines, and debris flows in Death Valley; and we use radiocarbon and potassium/argon radiometric clocks to measure time.

Process and Form

Different processes operate at different scales to organize landforms. Viewed as a morphotectonic entity at 1,000,000 meters, Death Valley is an incredibly active region of block and strike-slip faulting (Figure 1). This is in great contrast with neighboring provinces: the relatively stable Colorado Plateau to the east; the less active Mohave Desert to the south; and the Sierra Nevada batholith to the west.

Though still dominated by regional tectonism, satellite views at 10,000 to 100,000 meters begin to reveal a number of the elements that give Death Valley its own unique local character (Figure 2). Most striking are features such as major fault zones within a horst and graben setting, Death Valley’s salt playa at the terminus of the Owens and Amargosa drainages, and extensive flanking bajadas. Eastward tilting of the Panamint Range and active normal faulting along the Black Mountains creates the great west-to-east asymmetry of these elements: long and complex west-side fans contrast with short and simple east-side fans (cf. Hooke 1972) (Figure 2).

At 1,000 meters, regional tectonic interrelationships no longer occupy center stage. In contrast to fault zones on satellite imagery, single faults become evident on aerial photos (Figure 3A). Individual alluvial fans (Figure 3A), channel patterns, and playa types are resolved. Human effects are apparent as straight roads cut across bajadas and playas.

Scales of 10 meters to 100 meters reveal details of this weathering-limited landscape. Individual sand dunes, springs, debris flows, and hillslope features predominate (for example, Figure 4). Palaeolake features, such as wave-cut benches on Shoreline Butte, are distinguishable.

Landforms lose their character at meter and finer scales, but with the aid of magnifying tools microscopic units that compose individual landforms can be explored. Microfractures in rock minerals reveal tectonic
The Landforms of Death Valley

What distinguishes Death Valley from humid landscapes is the ubiquitous contrast of very stable land surfaces adjacent to constantly changing forms. As the observer zooms in, changes over time become more and more "catastrophic." If it were possible to revisit Death Valley 1 million years ago, its morpho-geotectonic appearance at 1,000,000 meters would have changed little. At the scale of 100 meters, a change in process can create a drastic change in form. In Death Valley, if gullyng starts, more exposure of bedrock generates more runoff; gullies continue to grow and permanently alter hillslope form. In contrast, in humid landscapes such as nearby coastal California, geomorphic changes tend to occur slowly; perturbations such as gullyng are repaired by creep and biogenic transport of colluvium, and hillslopes again converge toward a convex form. At the weathering scale of 1 meter to 0.000 001 meter, some surfaces revisited during the Quaternary have not changed at all except for more layers of rock varnish (Figure 5). In contrast, other rock surfaces are completely remade by salt weathering (Goudie and Day 1980). We speculate that catastrophe theory (Graf 1988) is most viable as a tool to interpret geomorphic change in drylands at more detailed scales.

Integrating Process and Form with New Geomorphic Tools

A major difficulty in integrating the study of process and form in geomorphology is the inability to translate contemporary process measurements to landforms made in the past. This is well illustrated in Death Valley. In the late Wisconsin glacial period about 20,000 BP (radiocarbon years before present), a Yucca semidesert occupied the alluvial fans (Wells and Woodcock 1985) and, some 85 meters deep, Lake Manly filled Death Valley to sea level (Dorn 1988; Hooke 1972). About 10,000 to 13,000 BP, the lake dried up and sparse desert scrub species replaced more mesic vegetation. Geomorphic evidence of this climatic change is ubiquitous at several spatial scales, from alluvial fans (Figure 3B) to shorelines (Figure 3A) to talus flatirons (Figure 4B) and weathering phenomena (Figure 5).

Most of the age-determination techniques used to reconstruct geomorphic changes over time are based on dating materials found in a stratigraphic sequence, for example radiocarbon, thermoluminescence, and potassium/argon dating. These methods provide insights into changes in a vertical column at one site. However, if both spatial and temporal reconstruction of landscape change is desired, a key problem emerges: the inability...
to correlate in time spatially disjunct stratigraphic sequences.

New surface-exposure dating techniques such as cosmogenic isotopes and rock varnish have the potential to provide quantitative data to reconstruct landscape history from place to place (Dorn et al. 1991; Phillips et al. 1990). These methods permit the correlation of landform development with available paleoclimatic records (Hooke 1972; Wells and Woodcock 1985). For example, the pronounced shorelines at Mormon Point (Figure 3A) correlate with an early 180,000- to 130,000-year-old cycle of Lake Manly, and with a major glacial pulse in the nearby Sierra Nevada (Dorn 1988; Phillips et al. 1990). Similarly, the 13,000- to 14,000-year-old talus reliefs at Artist’s Drive (Figure 4B) correlate with a period when climate changed from semiarid to hyperarid (Hooke 1972; Wells and Woodcock 1985). The separation of talus from its sources at this time of climatic transition, creating the flailrons, is consistent with R. Gerson’s (1982) model.

Climatic geomorphology has established correlations between climate-environment and landform processes. However, it is an untenable jump, at this stage, to relate quantitative process studies with landforms developed in past climates. Still, correlating paleolandforms with paleoclimates is a vital ingredient in being able to link geomorphic processes with the vast number of fossil landforms beyond the reach of process geomorphology.

Summary

Three classic themes of geomorphology are stressed in this examination of Death Valley, an archetype of
Figure 3. Landform associations in oblique aerial photographs: A. Mormon Point displays shorelines of Pleistocene Lake Manly (large arrow), normal faulting (smallest arrows), and a tectonic turtleback (medium arrows). B. Hanaupah Canyon alluvial fan. Note the distributary patterns on the active Holocene section of the fan (lower left), and the differential development of rock varnish and desert pavement on the older sections of the fan.

Figure 4. Individual landforms seen from the ground: A. A mid-Holocene alluvial-fan deposit from Hanaupah Canyon fan. The “bar and channel” topography is gradually evolving into a smooth desert pavement. B. Talus flats near Artist’s Drive, radiocarbon dated by rock varnish to have formed about 13,000 to 14,000 years ago.

Figure 5. Two cycles of lamellate (L) and botryoidal (B) layers in rock varnish seen by a scanning electron microscope, collected from an alluvial unit of Hanaupah Canyon fan, about 170,000 years old (Figure 3B). Scale bar about 8 micrometers; line shows the boundary between varnish and rock. The corresponding x-ray analyses show the chemistry of the different layers. Botryoidal layers form in less alkaline, semiarid periods, while manganese-poor lamellate layers form during more alkaline, arid period (Dorn 1988).

dryland geomorphology. First, processes that operate at different spatial and temporal scales combine to organize the landforms of Death Valley in a distinctive pattern. Second, gradual rates of geomorphic change that characterize landforms of humid climates contrast with the extreme dichotomy of rates of landscape change in Death Valley; landforms have remained virtually unchanged for hundreds of thousands of years are adjacent to landscapes remade yesterday. Third, the difficulty of integrating process and form in geomorphology is nowhere better illustrated than in Death Valley, where the contemporary arid climate could not have produced humid landforms left fossilized today. In Death Valley we illustrate the potential for understanding the link between process and form by correlating, in time, fossil landforms with the paleoclimates that produced them.
Acknowledgments

Research on the geomorphology of Death Valley was made possible by grants from the National Geographic Society and National Science Foundation. We thank L. Cremis, D. Friend, S. Lichty, T. Liu, M. Pickup, and T. Wasklewicz for comments, D. Dorn for field assistance, and B. Trapido for graphical assistance.

References


GEOGRAPHICAL SNAPSHOTs OF NORTH AMERICA

Commemorating the 27th Congress of the International Geographical Union and Assembly

Edited by
Donald G. Janelle

THE GUILFORD PRESS
New York   London

1992