EROSION ON LUNAR HIGHLAND SLOPES: IMPLICATIONS FOR
PLANETARY LANDFORM ANALYSIS. R. A. Young, Department of Geolog-
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The established ages of the major lunar maria and detailed
measurements of equilibrium and saturation cratering effects
place finite limits on regolith thicknesses and production rates.
These limits also define and demonstrate the effect of impact
gardening on mare flows and volcanic landforms (1). Some speci-
fic effects of the documented postmare impact flux on highland
slopes have been discussed by Young (2). One concept that should
be emphasized is the contrast between gardening of younger hori-
zontal mare surfaces and the effect of the equivalent flux on
nearby highland slopes mantled with thicker regolith. The pre-
dictable consequences of downslope ballistic transport on high-
land slopes can help to explain some anomalous lunar landforms
which are crucial to the interpretation of lunar geology, parti-
cularly the later stages of mare volcanism and associated tec-
tonism. The natural tendency to view lunar features from a ter-
restrial perspective may have tended to obscure important infor-
matIon preserved in lunar landforms.

As described by Young (2) the effect of downslope ballistic
sedimentation on lunar highland slopes produces a uniform "con-
veyor belt" type of downslope transport which is independent of
slope length. This relatively uniform movement of the surface
layer is especially characteristic of slopes during postmare
time when large impacts have been few, and saturation cratering
has progressed only to craters from 100m to 200m in diameter.
Slow uniform downslope ballistic transport must be the dominant
mode of slope erosion, because the regular debris aprons formed
at the bases of slopes adjacent to the younger maria do not exhib-
it many irregular "talus cones" or distinct landslide features.
Other processes, such as thermal creep, are assumed to be of les-
ser significance. The uniformity and efficiency of the process
is attested to by the relatively smooth, regular appearance of
lunar slopes and debris aprons as compared to the adjacent cra-
tered mare surfaces. However, numerous young craters are clearly
visible on enlarged photos of highland slopes, indicating that
craters do not "obliterate" themselves on slopes as a result of
the slumping and seismic effects that must accompany impact.

Studies of the genesis of mare ridges, the most widespread
lunar (Martian and Mercurian?) features that continued to develop
following the cessation of larger scale extrusive volcanism, have
not produced a clear consensus among geologists (3,4,5,6,7,8,9).
The ridges are closely associated with adjacent and colinear
faults and graben structures that in many cases would be consid-
ered predominantly tensional features, especially those near ba-
sin margins like those in eastern and southern Mare Serenitatis.
It seems likely that near-surface intrusions and extrusions have
occurred along portions of many ridges (5,6) producing both broad
arching and smaller scale extrusive features that have partially
obscured adjacent craters. However, the abrupt and distinctive
morphologic change along ridge segments that cross the lower por-
tions of highland slopes has resulted in attempts to invoke com-
pression and thrust faulting as the major or dominant cause of
mare ridge development. Certainly compressive stresses are

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likely to have existed in the central portions of subsided mare basins (3). This could have produced reverse faults of limited magnitude but is unlikely to have resulted in true thrust faulting of large magnitude (9).

Morphologic transitions along typical mare ridges on highland slopes, such as Dorsa Aldrovandi in Mare Serenitatis, are common in places where other geologic evidence clearly indicates tensional faulting, subsidence and late stage mare volcanism as being most compatible with the regional geology. The widespread evidence of subsidence and tensional faulting along mare margins is also compatible with evidence for late stage flooding of the centers of these subsiding mare basins from marginal vents. The existence of deep seated fractures along mare basin margins is predictable, as well as observable, in partially filled basins such as Mare Orientale.

Careful consideration of the gross effects of downslope ballistic transport across slope irregularities suggests that extrusive volcanism along fractures that intersect highland slopes is compatible with the observed morphological changes along ridges intersecting these slopes (Fig. 1). The greater flux of large objects during the early mare basin filling episodes would create some large-scale random slumping of highland material out onto the mare fill across the location of marginal fracture zones. Some deep seated circumferential fractures would intersect highland slopes, merely by coincidence. These circumstances would create conditions for late stage volcanism along fractures similar to the relationships shown on Fig. 1. Where lavas were extruded along fractures intersecting the lower segments of highland slopes fissure eruptions could have an initial form as depicted on Fig. 1a.

The long-term effect of downslope ballistic transport moves material down all slope segments and produces slow net erosion of all summit areas. However, one of the unique aspects of ballistic transport is that uniform transport (flux) conditions exist at all points on smooth slopes for each discrete crater size class. For each crater of a given size moving material downslope toward A (Fig. 1) from both sides, an equivalent impact at A will throw material out of the depression, back onto the slopes. This has the effect of slowing the filling of the linear depression by comparison with a simple gravitational mass wasting model. For larger craters (>20-100m) each impact at A will throw a significant amount of material over ridge B where it will eventually continue down slope C. Thus a quazi-equilibrium will be achieved so that moderate sized impacts (>10m) will result in the maintenance of a slowly filling depression by ejection of significant amounts of material over ridge B.

For slow rates of uniform downslope ballistic transport on thick regoliths the amount of material contributed to such a depression from the long highland slope (D) and the shorter slope on ridge B would be similar. However, initially, impacts into the thick highland regolith would be more effective than equivalent impacts into the solid lavas at B.

This morphologic form is transitional and will ultimately disappear as the cumulative flux increases through time. Preservation of such features merely attests to the slow uniform
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FIGURE 1: a. Initial condition after eruption of lavas at B. X,Y,Z illustrate effect of large impacts. b. Enlarged view of ridge B at later time showing effect of smaller impacts (m,n,o,p) c. Dorsa Aldrovandi in Mare Serenitatis showing highland area (h).