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BASE-LEVEL CONTROL OF EROSION SURFACES

H. F. Garner

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Several recent papers dealing with mountain regions (Dresch, 1958; Garner, 1959; Cotton, 1960; Garner, 1963; and Mackin, 1959) raise the issue of base level control of elevated erosion surfaces. In a personal communication to Cotton (1960, p. 477) at that writer's request, L. C. King states, "Re base level, I have never abandoned this concept, which places a limit upon downward erosion either by running water or by mass movement, and if it does not appear stated in my own work that is just because I have accepted the concept and have not seen any reason to discuss it further, understanding that there are two kinds, local and general."

It is certainly true that the control of erosion surfaces by base level has gone unquestioned in the literature for many decades. But elevated erosion surfaces have been noted and cited by literally scores of authors as evidence of the grading of a land surface to some regional strand and the subsequent elevation of said surface. If alternative interpretations are possible they should certainly be noted, for they bear on major geomorphic concepts and have influenced tectonic evaluations of the nature of orogenesis and epiorogenesis. The problem has two major aspects, (1) the nature of any control mechanism and (2) the character of alternative reference datums, if any.

The control of one phenomenon by another necessitates some form of interaction. If one may regard the marine strand as approximating the location of regional base level at any one time, then the interaction in question is necessarily between the surface of erosion and the strand. The latter is usually and unrealistically regarded as fixed. For the moment, I will regard this as a provisionally tolerable fiction, for it is not the various theories of erosion surface genesis but rather the mode of datum control that is in question here.

As noted by King (in Cotton, 1960) base level places rather specific downward limits on fluvial erosion. Gravity, of course, shows no similarly abrupt response to this limit and submarine mass movements are well documented by Shepard (1963) and many others. Nevertheless, excepting marine oscillation, there is little direct interaction between terrestrial surfaces of erosion and marine water bodies. And submarine mass movements can hardly be considered as affecting more than the margins of the erosion surfaces in question. Therefore, because essentially all surfaces of erosion display evidence of the influence of running water and it is the consensus that fluvial agents are of primary importance in their formation, running water is here acknowledged as the principal agent of interaction through which base level may exert influences on subaerial erosion surfaces.

Establishing that there is **some** fluvial interaction between base level and land surfaces is no new thing and does not, in itself, estab-

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lish that the interaction is effective geologically, i.e. that base level can actually be claimed to have controlled the gradation of an erosion surface during its development. Two dimensions of activity are involved, space and time. And at the outset, it is freely admitted that given an infinite amount of time a given agent can act effectively across any space to which it has access. To those who subscribe to base level control without reservations, it is apparently not so obvious that fluvial agents do not have equal access to all land surfaces under all environments. Some are spatially limited.

The fact that gravity alone could, in theory, cause all land surfaces to slope toward ultimate low points on the earth's surface is beside the point. Base level would not be involved. And the fact that an infinite amount of time is not available (geologically) for the development of any regional erosion surface has long been recognized. But the fact that regionally extensive erosion surfaces do exist proves that **sufficient** time was periodically available for their development, whether they are base-level controlled or not. It is not the specific purpose of this paper to determine the probability of occurrence of one or another of the various types of erosion surfaces. Rather, the writer will try to demonstrate that spatial restrictions on fluvial action necessarily vary the degree to which a given type of erosion surface can respond to regional base level in the limited available time for surfaces so influenced. Temporal restrictions are therefore also important and together with spatial restrictions are potentially capable of reducing regional base level influences over certain types of erosion surfaces to insignificance.

Three distinct degrees of spatial and temporal limitation are imposed on fluvial activity by the three principal theories of regional erosion surface genesis.

According to the Peneplanation Theory of Davis (1902) a peneplain is the product of perennial rivers flowing to regional base level. Fluvial interaction between the developing surface and base level is constant, equal in temporal duration to the humid environment responsible for the flow, and spatially competent across tremendous distances. Free admission of the probable interruption of the formative processes by epirogenic adjustments, orogenic movements, glacio-eustatic shifts or climate changes does not change one relationship. A peneplain, if developed, would involve maximum fluvial interaction with base level and, therefore, maximum base level control to the extent that said control exists.

The Pediplanation Theory of King (1953) advances the idea that most extensive erosion surfaces are pediplains, products of semiaridity, and therefore reflect intermittent fluvial erosion. In at least some instances — possibly the majority — flow reaches base level every wet season. Fluvial interaction is, however, discontinuous and in many regions runoff endures for as little as a third to a half of each year as long as the environment persists. In comparison with humid conditions, semiarid fluviation shows a distinctly reduced temporal inter-

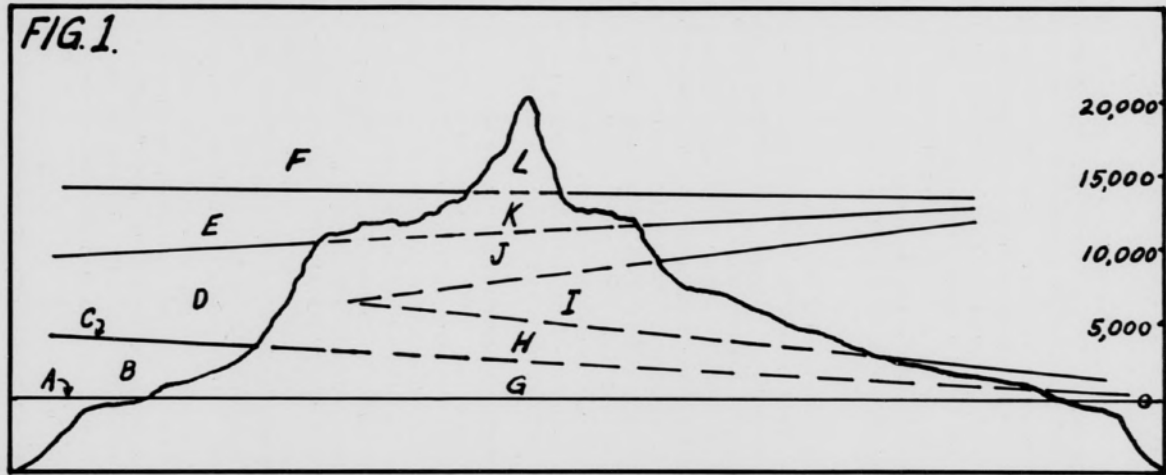
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action between any resulting erosion surface and regional base level. Clearly, spatial continuity also suffers as annual runoff dwindles. But it must be noted that, given **sufficient** time, a semiarid erosion surface should respond to any existing regional base level controls.

The Planation-Aggradation Theory of Quinn (1957) proposes that many extensive erosion surfaces are a response to arid erosion processes imposed in desert environments. In such instances, fluvial activity is ephemeral. In "wetter" deserts (those with 5-10 inches of annual rainfall) an entire year's precipitation may fall in a few minutes and flow continues for only a few hours because of intense evaporation and infiltration. In "dry" deserts (those with less than 5 inches of annual rainfall) such as the Sahara, Atacama and Nubian, rain may fall only every few years or every few decades and then not everywhere. Fluvial activity is therefore reduced below that of humidity and semiaridity by a factor of several hundred to several thousand.

Arid runoff is limited to the area occupied by the arid environment for the most part. Indeed, it is usually restricted to a small part of the environmental area at any one time. And a specific geographic point may endure droughts of hundreds of years (Garner, 1959, p. 1356). Even where the environmental margins extend to base level, runoff rarely attains this potential goal (Gignoux, 1955, p. 3). In such instances fluvial interaction with regional base level is minor. In combination with mass movement over a very long period, coastal desert erosion surfaces might develop slopes toward regional base level. They could incline toward inland deflation depressions with equal ease. But where the arid region is inland (as many are) ephemeral fluvial interaction with base level is, to all intents and purposes, nonexistent. Where there is no interaction there can be little control.

Lest it be suggested that the writer has argued himself into a corner, it is necessary to answer the obvious question, "What replaces regional base level as a leveling datum for widespread arid erosion surfaces?" The answer would seem to be climatic zonation. The present moisture zonation is both geographic and topographic in nature and closely reflects a corresponding atmospherically stratified moisture zonation keyed to latitude. Along most of the world's coasts poleward from a few degrees either side of the equator there are two 30-40-degree-wide belts characterized by low-level coastal dryness. These belts reflect the adiabatic gap between sea level evaporation and minimum precipitation elevation and their vertical effectiveness ranges from a few inches to several thousand feet. The height of the corresponding water-deficient atmospheric zone and the intensity of related land dryness is a function of several factors including ocean surface temperature and prevailing wind (Garner, 1959, p. 1353). Because they fringe the strand and have great potential temporal duration, resulting arid erosion surfaces are at least potentially capable of undercutting and displacing all erosion surfaces developed at higher levels. They are frequently confused for elevated wave-cut marine terraces (Fig. 1).



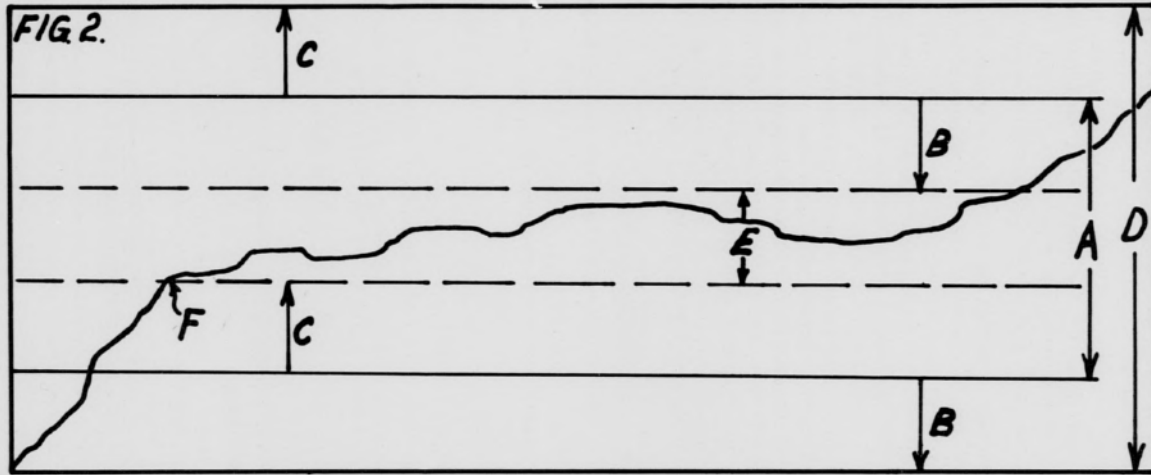
Text Figure 1. Continental atmospheric moisture zonation and climate belts; (A) Sea level — evaporation surface, (B) Adiabatic gap — undersaturated air, (C) Minimum precipitation elevation, (D) near-saturated air — triggered precipitation, (E) Moisture depleted air, (F) Frost zone, (G) Coastal Deserts, (H) Sémiarid steppes, (I) Humid uplands, (J) Semiarid transition, (K) Desert plateaus, (L) Frigid peaks, (Elevations are in feet.) In this instance the sea to the left is assumed to be cold, that to the right warm.

A second geographically correlative atmospheric zone overlies the low-level dry zone and is characterized by adiabatically or pressure-front triggered precipitation in appreciable amounts. Precipitation climbs to a maximum within this second zone and where it reaches the humid climatic level it is bordered above and below by semiarid transition zones in many cases. To the extent that they actually occur, humid peneplanation and semiarid pedimentation are dependent on the environments represented in this zone. Any resulting erosion surfaces could only widen at the expense of landscapes developed inland at higher levels and would, in turn, be subject to sapping from below by arid planation processes keyed to coastal deserts. Such intermediate-elevation moist zones are very broad on continental flanks facing warm seas. On opposing continental flanks the moist atmospheric zone is thin or absent and correlative land climates are narrow or lacking (Fig. 1).

A third geographically correlative atmospheric zone reflects water-depleted air which has risen through the zone of adiabatic and pressure-front triggered precipitation. Elevated, inland arid regions are the result. The Tibetan and Andean plateaus coincide with this elevated dry zone and in the latter area the vertical span is some 3,000-4,000 feet. Within this zone arid erosion surfaces are environmentally delimited with respect to topography and land elevation. Developing erosion surfaces necessarily grade to local base levels which become progressively more obscure with time. The resulting topographic product of arid planation-aggradation processes naturally exhibits some relief as a reflection of the composite local base-level controls—detailed studies of most erosion surfaces show similar relief features (Fig. 1).

At least the arid planation processes are closely tied to an atmospheric zone a few thousand feet "thick" and not to a single horizon (e.g. base level). Though the water-deficient atmosphere zones, like the others and base level, are subject to some vertical fluctuation, long-term planation can be effected within the interval of zonal overlap determined by mean zonal fluctuation (Fig. 2). The planation process can thereby continue within a permanently arid interval so long as the atmospheric zone is not displaced either upward or downward more than fifty per cent. The arid erosion surface itself could probably survive periodic zonal displacements in excess of fifty per cent so long as the average protracted environment at the elevation of the erosion surface was arid. In this manner, though the controlling zone fluctuates, the leveling datum for the elevated arid erosion surface remains fixed at the base of the interval which remains dominantly arid. The temporal weakness of ephemeral arid fluviation is therefore probably compensated by long-term stability of the erosional datum. Widespread planation at one general elevated level is therefore more than possible.

It should be noted that regardless of what each of the three major environments accomplishes in terms of long-term erosion, each is sufficiently distinct to cause a contrasting terrain configuration.



Text Figure 2. High-level arid atmospheric zonation and gradation datum; (A) Mean position of moisture depleted air zone, (B) Maximum zonal depression. (C) Maximum zonal elevation, (D) Vertical scope of long-term zonal oscillation, (E) Residual, permanently or dominantly arid zone of protracted planation, (F) Regional slope change keyed to long-term climate zone boundary position.

Therefore, a transition from an area dominated by one type to that dominated by another should be characterized by at least a change in regional slope. The most pronounced slope changes of this type should occur between zones of greatest environmental contrast where there is the least fluvial interaction. The slope breaks at the heads of mountain piedmonts and those at the margins of elevated mountain plateaus are probably of this type and the higher type can hardly be said to grade to regional base level under such circumstances (Fig. 2).

The issue of the relative merits of the various erosion theories is not yet resolved. Each has its backers. But the spectre of intermittent climate change threatens each and the oscillating-base-level and graded-stream hobgoblins linger in the background ready to haunt any who wish to invoke them. Nevertheless, one relation is evident from the preceding discussion. Base level control, to the extent to which it occurs and for those erosion surfaces to which it applies, is a mixed blessing. Surfaces subject to it can readily have their reference datums changed, particularly in orogenic belts. Surfaces keyed to zonal atmospheric conditions may be more stable than previously believed and it is possible that the true erosional datums for intermediate and low-level planation processes are also zonally established rather than tied to an admittedly fluctuating base level **horizon**.

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