THE PROSPECT OF GULLY GRAVURE ON RECLAIMED HILLSLOPES

by

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and

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Abstract. Hillslope development and evolution are the products of process-sequences. One such sequence is gully gravure, a mode of development requiring coarse-textured material overlying fine-textured material. Rill or gully processes erode through the coarse material into the fine material. The coarse material falls into and accumulates in the channel entrapping fine material. The permeability and porosity of the channel-fill is reduced, and runoff is deflected toward the periphery of the deposit. Thus, the loci of erosion shifts laterally along the hillsides. The sequence is completed by channel-filling with additional coarse material from the channel sides. A new surface of coarse material is created at a lower elevation as a result of lateral planation. Field studies near Tucson, Arizona and Denver, Colorado, indicate that gully gravure may occur on reclaimed hillslopes. Previous research suggests that gully gravure results in landscape stability, maintenance of adjusted hillslope angles, and low rates of denudation and sediment delivery, which are fundamental objectives of reclamation.

Additional Key Words: Hillslope Erosion, Hillslope Evolution, Rock Fragment Surface Cover

Introduction

Both natural and reclaimed hillslopes are subject to various geomorphic processes, such as geochemical and pedochemical weathering, mass-movement, erosion, and deposition. The assemblage of processes in a particular environmental setting controls hillslope development and evolution. Each process has been examined in detail by earth scientists in order to understand its mechanics and rates of operation. Infrequently, however, do we consider sequences of processes that may be collectively responsible for hillslope characteristics. Through sequencing, one process prepares the surface for the next process and usually contributes certain attributes to the final form. It is the purpose of this report to describe the process-sequence known as " gully gravure" and suggest, based upon field examples, that this process-sequence may be occurring on reclaimed hillslopes.

The Gully Gravure Process-Sequence

Gully gravure is the term used by Bryan (1940) to describe the process-sequence depicted in the idealized diagram of Figure 1. In profile, the initial stage (A) consists of a nearly planar surface of coarse-textured, erosion-resistant geologic material overlying a fine-textured, less-resistant material. During the second stage (B), the surface is incised by rill or gully processes. In stage (C), coarse material falls by simple gravity processes and accumulates in the channels because flow energies are insufficient to transport it downslope. Weathering processes influence the rate of material

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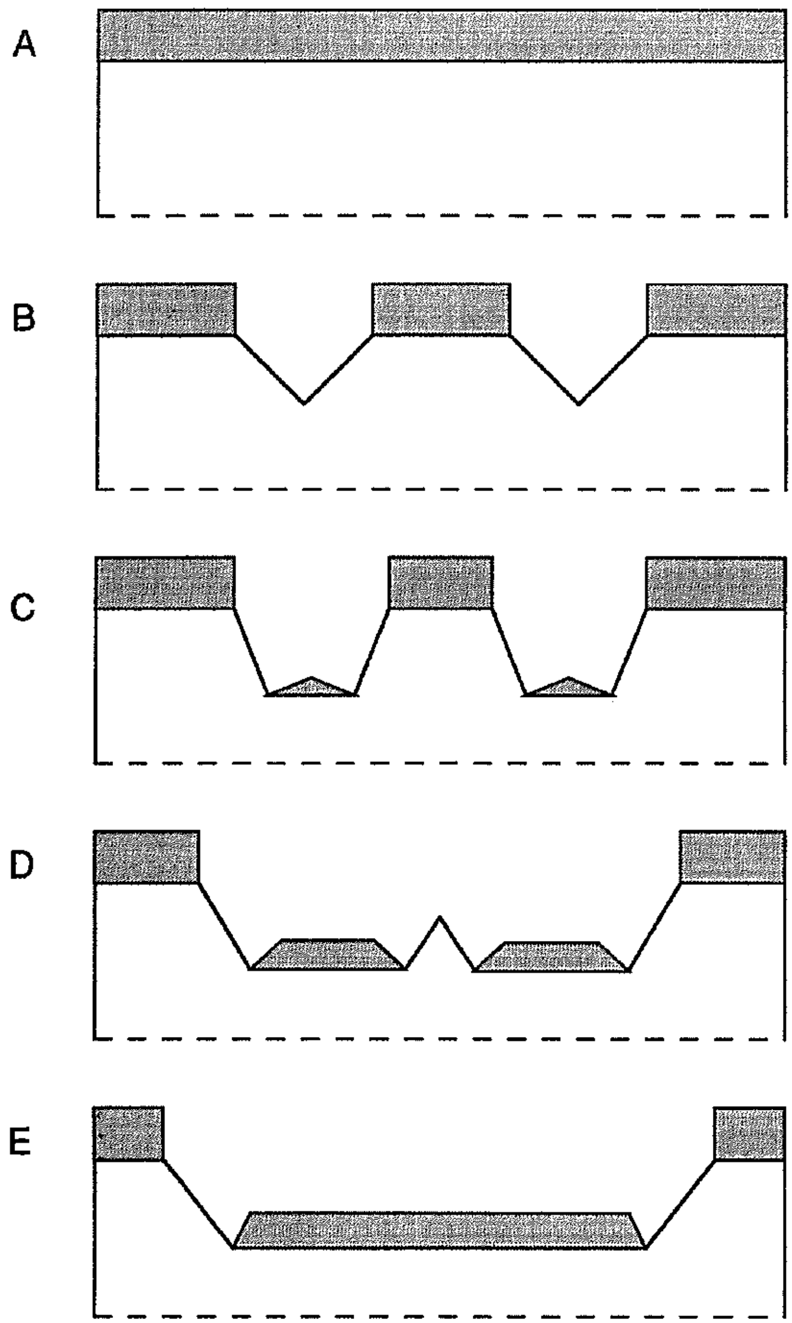

Figure 1: The sequence of gully gravure processes; (A) initial stage of coarse material overlying finer material; (B) incisement of surface by rills and gullys; (C) accumulation of coarse material from above in the incisement; (D) lateral shifting of rills and gullys and continued accumulation of coarse material; (E) lateral planation and formation of a new surface veneered by coarse material.

released from the overlying cap and hence the rate of accumulation in the channels. The coarse channel-fill entraps interstitial fine-textured materials produced by weathering, or wind and water erosion. The permeability and porosity of the channel-fill are reduced, and runoff is deflected toward the periphery of the deposit. As suggested in stage (D), the loci of erosion shift laterally along the hillslope, exploiting the weakness of the fine material. The sequence is completed by the filling of the newly enlarged channel with additional coarse material from the sides of the channel. A new surface of coarse material is created at a lower elevation as a result of lateral planation on the hillside, as shown in stage (E).

A few characteristics of hillslopes experiencing gully gravure are especially noteworthy. First, there seems to be a limit to the depth of incision that can occur before sufficient coarse material accumulates to deflect the flow and erosion toward the periphery of the channel-fill. Second, a topographic inversion takes place between stages (B) and (C), wherein the former channel becomes elevated due to the accumulation of coarse material. Third, in map view, the surface may appear as alternating stripes of coarse and fine materials. Last, surfaces composed of coarse rock fragments, as found in many places, could be products of gully gravure.

Gully gravure has not been widely documented because many hillslopes do not possess the requisite geologic configuration and hillslope processes commonly operate at slow, nearly-imperceptible, rates. Nevertheless, in addition to Bryan (1940), Mills (1981), Twidale and Campbell (1986), possibly Whitney and Harrington (1993), and Osterkamp and Toy (1994) found evidence of gully gravure at various scales and in various environmental settings.

Field Evidence

Osterkamp and Toy (1994) examined hillslope development on two road cuts and one borrow pit southeast of Tucson, Arizona. At these sites sand, gravel, and cobbles cap mid-Pleistocene lacustrine beds. The hillslope surfaces are extensively rilled with coarse material accumulating in the channels. Excavation of cross-sections through the rills revealed sharp textural contrasts between the channel-fill and the lacustrine material adjacent to and beneath the channel. Especially interesting was the wide, roughly horizontal contact along the base of the channel fill, shown in Figure 2. This indicates lateral planation rather than further incision by erosion processes. In some places, topographic inversion appeared to be in progress. The field evidence was analogous to stages (C) and (D) of Figure 1.

Hillslope development at certain locations within the "mesa and butte" topography of the Colorado Piedmont south of Denver, Colorado, also suggests the operation of gully gravure. The hillslopes in this area are products of a complex geomorphic history as portrayed diagrammatically in Figure 3. In profile, the geology consists of horizontal strata of conglomerates or rhyolite overlying sandstones, siltstones, and shales, shown in stage (A) of Figure 3. Erosion by fluvial processes is primarily responsible for the characteristic flat-topped mesas and buttes with steep sideslopes. Colluvial deposits at various places on these sideslopes attest to debris flows following formation of the mesas and buttes, as indicated in stage B (fig. 3). These deposits were incised by fluvial erosion and probably debris avalanches during a high-intensity precipitation event of June 16, 1965, indicated by stage C (fig. 3). Gravitational processes caused both coarse- and fine-textured colluvium to fall into the channels. Fluvial processes since that time have evacuated much of the fine material leaving the very coarse material to accumulate in the channel. Some clasts of this channel-fill approach a mean diameter of 3 meters. This coarse debris deflects flow toward the periphery of the channel resulting in nearly-vertical channel banks in various places. The current cross-section topography is reminiscent of stage C in Figure 1. If this interpretation is correct, then stages D and E of Figure 1 may follow.

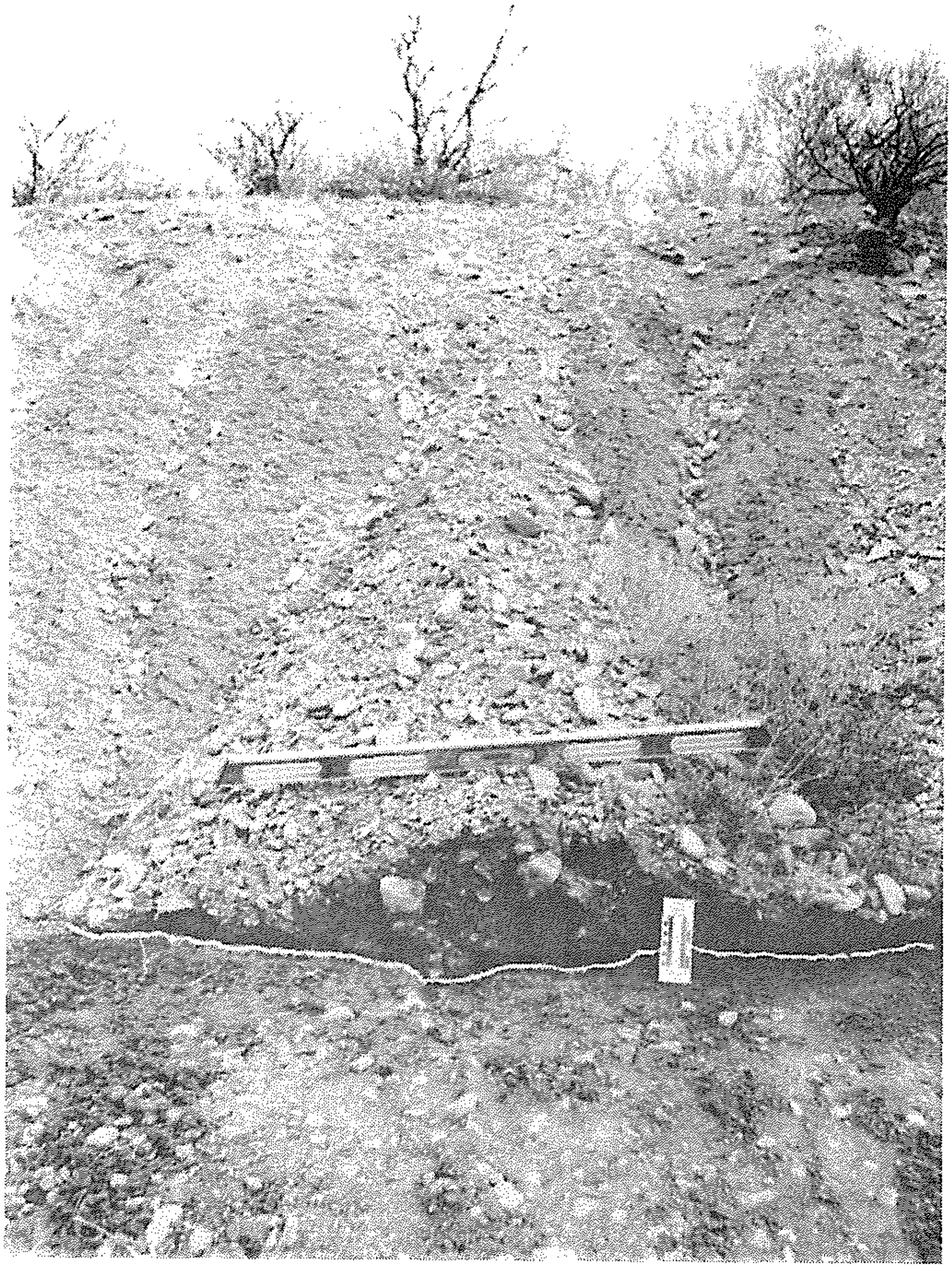

Figure 2: Photograph of rill partially filled with coarse material from above. The white line marks the contact between the coarse material and the underlying fine material. This field site, near Tucson, Arizona, is representative of stage D in Figure 1.

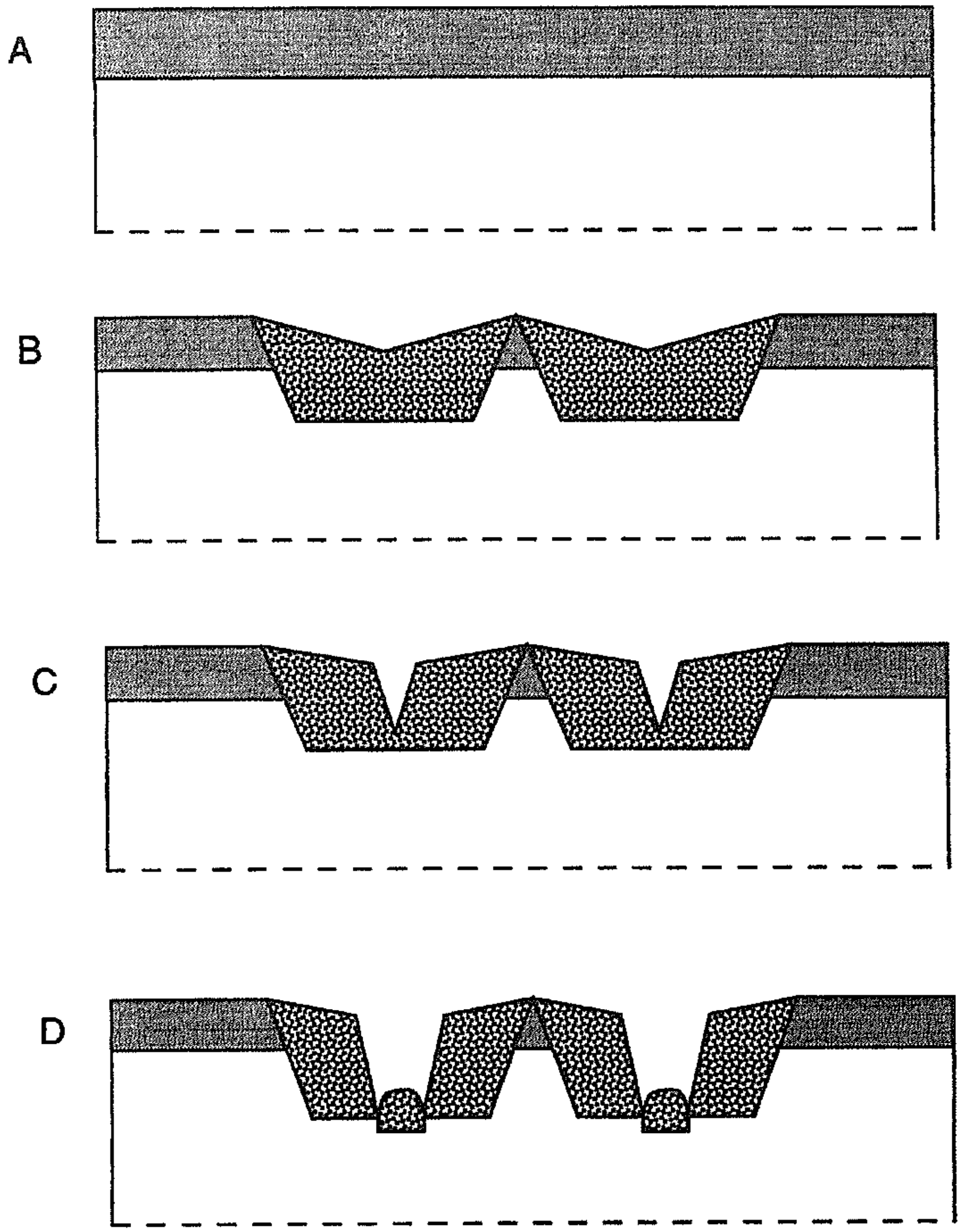

Figure 3: Diagram representing a sequence of hillslope-development processes near Denver, Colorado; (A) horizontal resistant rocks overlying less resistant rocks, forming a mesa-type topography; (B) erosion of sideslopes and filling of gullys with coarse colluvium; (C) fluvial incisement of colluvium; (D) fluvial sorting and additional accumulation of the coarse colluvium, thereby providing the potential for continuing gully-gravure processes.

An implication of this interpretation is that the source of channel-fill in gully gravure need not be a discrete capping layer of coarse materials envisioned by Bryan (1940) and others. A heterogeneous mixture of particle sizes, as occurs in a colluvial deposit or a waste-rock (spoil) disposal site, will suffice. Consequently, gully gravure on reclaimed hillslopes is a distinct possibility.

Conclusion

Osterkamp and Toy (1994) concluded that gully gravure yields general landscape stability, maintenance of adjusted hillslope angles, and low rates of denudation and sediment delivery. These conditions are fundamental objectives of hillslope reclamation. Such surfaces provide stable platforms for revegetation and support eventual land uses.

There is reason to suspect that gully gravure may be occurring on some reclaimed hillslopes. This would be fortuitous because the accumulation of coarse channel-fill limits the depth of incision by fluvial erosion and the development of a coarse surface veneer may reduce soil loss by as much as 99% (Osterkamp and Toy, 1994). Although it would not be prudent to rely upon gully gravure to produce stable hillslopes from waste rock disposal sites because specific geologic conditions and lengthy time periods are required, this process-sequence provides one mechanism that controls the extent of fluvial erosion and drives hillslope development toward stable configurations in many cases.

To be sure, gully gravure is only one mode of hillslope development and evolution. It is, however, a most interesting prospect within the context of disturbed-land reclamation and one deserving of careful scrutiny and verification. Toward this end, we solicit your assistance. If there is evidence of gully gravure on the reclaimed hillslopes with which you are familiar, please bring this to our attention.

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