Proceedings of the Iowa Academy of Science

Volume 86 | Number | Article 5

1979

The Importance of Mass Movement and Piping in Badlands Slope Development

Robert R. Churchill
Middlebury College

Proc. Iowa Acad. Sci. 86(1): 10-14. 1979

The Importance of Mass Movement and Piping in Badlands Slope Development

ROBERT R. CHURCHILL

Department of Geography, Middlebury College, Middlebury, Vermont 05753

Field reconaissance study of a small drainage basin developed on the Chadron Formation (Oligocene) in the Big Badlands, South Dakota, revealed mass movement and piping to be dominant processes in hillslope development. While seasonal creep is undoubtedly a major factor in slope development, evidence of a wide variety of mass movement types is apparent. Piping and associated collapse features occur in mass movement debris as well as in materials *in situ* on the valley sides. Mass movement features and piped tributary channels show a marked preference for the northeast-facing valley side. As a result, northeast-facing valley-side slopes are complexly faceted in contrast to smooth and convexly rounded southwest-facing side slopes. Field evidence suggests that differences in surface morphology of opposing valley sides arise from aspect-induced differences in moisture budget.

INDEX DESCRIPTORS: piping, slope development, topoclimatic differential, Badlands, Chadron Formation, South Dakota.

Hillslopes developed on the Chadron Formation (Oligocene) in the Big Badlands, South Dakota, generally exhibit smooth, convexly rounded forms resembling haystacks in appearance. Wanless (1922) attributed the difference in topographic expression between these haystacks and the steeper, straight slopes developed on the overlying Brule Formation (Oligocene) to differences in relative amounts of calcareous cement. Although Wanless showed the Chadron sediments to be poorly cemented, he did not comment directly on the effects of weak cementation on geomorphic form and process. Schumm (1956) subsequently suggested that the rapidity with which Chadron sediments break down facilitates seasonal creep. Detailed field observations and measurements of slope erosion rates led Schumm to conclude that creep is in fact the dominant process in the development of Chadron hillslopes. Salisbury and Parson (1971) more recently noted the coincidental occurrence of piping and large scale mass movement features on the Chadron. They reported that hillslopes are modified by slumping and piping of slumped debris as well as by seasonal creep.

The purpose of this note is to add some further observations on the role of mass movement and piping in the denudation of hillslopes on the Chadron Formation and to offer preliminary ideas on factors which influence the relative contributions of these erosional processes.

METHOD OF STUDY

The observations reported here are based on field reconnaissance study of a small drainage basin located in Section 34, T. 3 S., R. 12 E., on the Heutmacher Table quadrangle, Pennington County. The drainage basin was mapped in the field with theodolite, and mass movement and piping features were examined and measured. Only major mass movement and piping features and only those tributary channels which are integrated with the trunk stream are shown on the map (Figure 1).

The drainage basin is developed entirely on the Chadron Formation (see Figure 2). A channel-sandstone, cobble-conglomerate sequence about 25 cm thick crops out at the head of the valley producing a marked knickpoint in the longitudinal profile of the trunk stream. A fresh-water limestone unit varying from 75 cm to 1 m in thickness crops out high on both valley walls and forms a second, slightly lower knickpoint in the headward reach of the trunk stream. Elsewhere, the basin is developed predominantly on buff to brown mudstones. Apparent local dip of these sediments is 1.5° to the southeast (S. 41° E.) which corresponds well with the regional dip of the Chadron (see Clark, 1937).

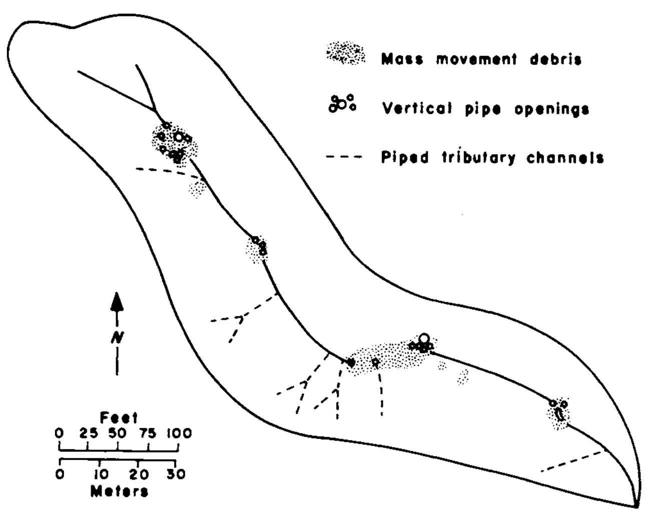

Fig. 1. *Map of the study basin showing the integrated drainage network and major piping and mass movement features.*

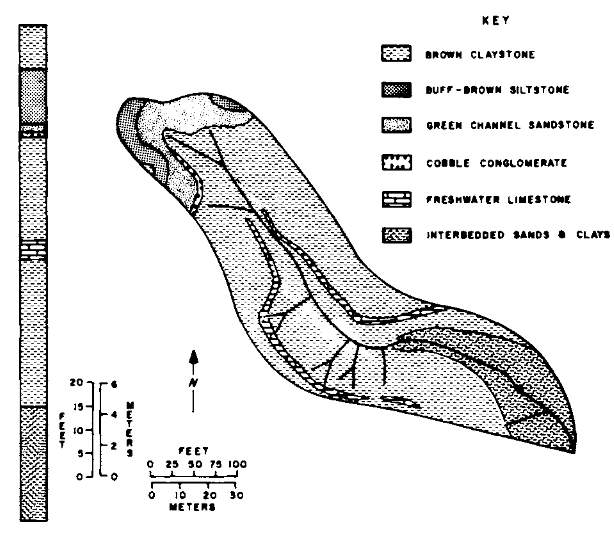

Fig. 2. *Sketch map of surface geology and composite geologic column for the study basin.*

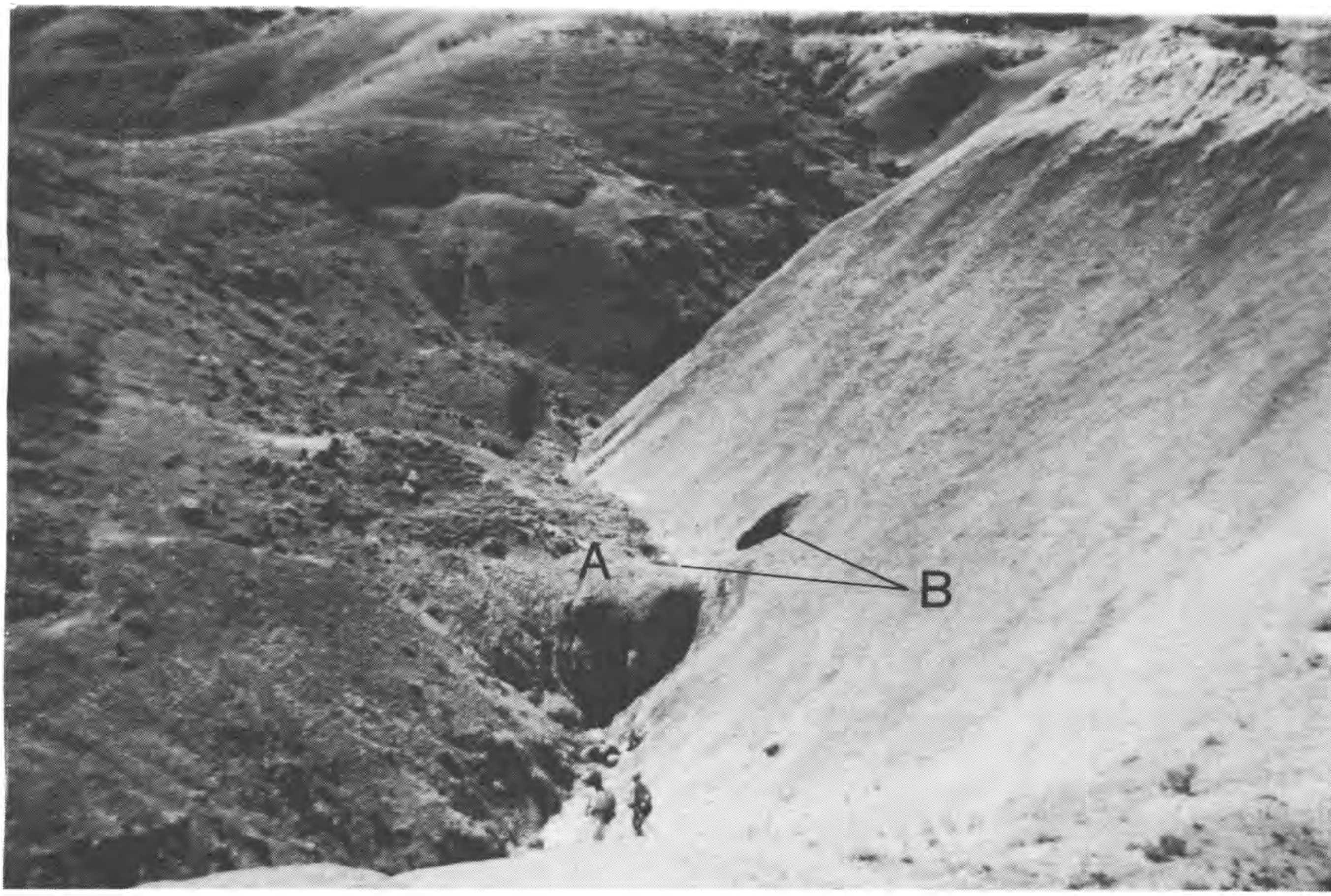

Fig. 3. View up-valley from just downstream of largest debris block obstruction (for reference, see Fig. 1). Survey team in foreground provides scale. A) shows the nearly flat upper surface of the large block of debris which occupies the valley bottom. B) illustrates two large, vertical pipe openings which drain the upper surface of the block and adjacent valley wall.

OBSERVATIONS AND DISCUSSION

The most striking topographic features in the basin are several large blocks of debris which occupy the valley bottom (see Figure 1). The largest of these blocks, pictured in Figure 3, is nearly 22 m long and rises 4.9 m above the channel floor. Lack of lithologic continuity with the adjacent valley walls clearly indicates that these blocks are not *in situ*, but the source of the blocks and exact nature of emplacement are obscure. In most cases, evidence of large scale failure is not well preserved on adjacent valley walls. Two of the blocks, however, exhibit intact bedding inclined steeply toward the right valley wall, suggestive of rotational slumping.

All of these debris blocks have been modified by piping, the development of subterranean conduits or pipes by aqueous removal of clastic materials (Mears, 1968). The pipes observed in association with the debris blocks are of two general types: 1) lateral pipes which maintain the stream channel through the base of the debris accumulations; and 2) steeply inclined, nearly vertical pipes which drain the flat upper surfaces of the blocks and adjacent valley sides to the underlying stream channel.

The upstream and downstream orifices of the lateral pipes vary in diameter from 36 cm to over 1 m. These lateral pipes must have originated in one of two ways (Salisbury and Parson, 1971): either the debris blocks moved into their present positions slowly enough that the channel could be maintained, or the blocks acted as dams until sufficient head was attained to cause lateral seepage of water through the base of the debris blocks. It is difficult to establish which of these explanations applies without knowing the nature of the movement responsible for emplacement of the blocks. However, a piped channel maintained through a collapsed portion of the roof of one of the blocks (Figure 4) testifies to the efficacy of the piping process and suggests that lateral conduits may develop quite rapidly in disturbed materials.

The steeply inclined pipes which drain the surfaces of the blocks and adjacent valley sides (see Figure 3) range from less than 2 cm to more than 2 m in diameter, the mode being from 5 cm to 8 cm. Vertical pipes are often clustered in their occurrence, clusters of pipes occurring near the contact between the debris block and the adjacent valley wall (see Figure 1). Clausen's (1969) explanation of similar occurrences in Wyoming appears to be applicable here: a zone of higher permeability exists at the debris-bedrock contact which favors concentration and downward movement of runoff. As water saturates this permeable zone during runoff periods, sediment is sapped first at the outlet and then progressively toward the surface of the debris blocks until a pipe is formed.

While piping of debris blocks is an indirect consequence of large scale mass movement, piping occurs elsewhere in the basin independently of mass movement. A few pipe outlets were observed near the base of the valley walls which appear to drain pipes developed in

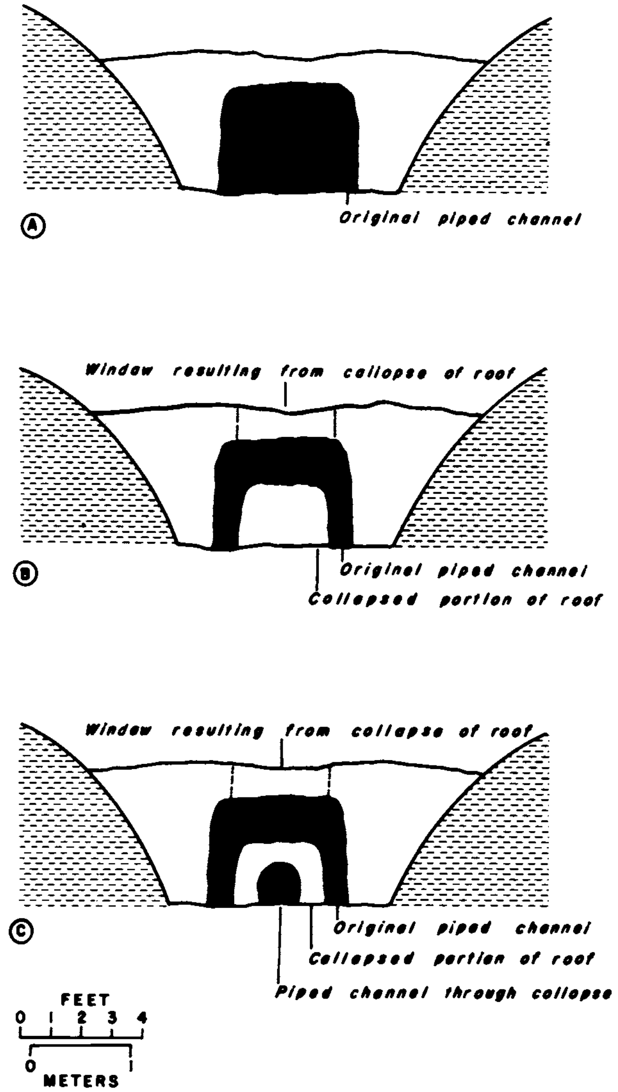

Fig. 4. *Inferred sequential development of piping through block of debris occupying valley floor: A) cross-sectional view showing the original piped channel; B) growth of pipe has resulted in collapse of a portion of the roof; C) collapsed portion of the roof has been piped although original piped channel is unobstructed on both sides of the collapse feature.*

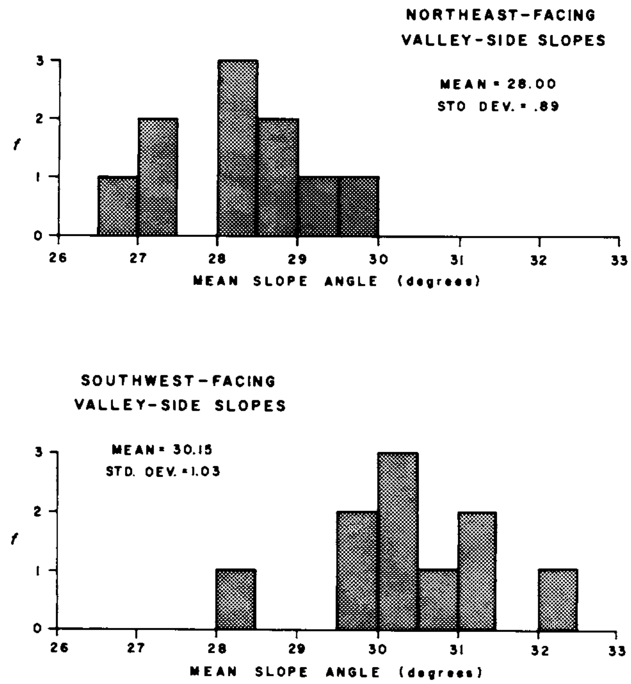

Fig. 5. *Frequency distributions of mean slope angles for northeast-facing valley-side slopes versus southwest-facing side slopes.*

bedrock at appreciable depths below the surface. The difficulty of tracing these pipes in the time available precluded an investigation of their role in geomorphic development.

In addition, piping is particularly apparent along the tributary channels which occupy the valley side. Throughout most of their courses, these tributaries maintain open channels, but the channels frequently disappear below the surface reappearing a short distance downslope. These tributary channels were likely initiated by shallow piping.

The sequential development of open channels via the piping process was described by Fletcher *et al.* (1954) who argued that pipes develop where relatively permeable surface materials overlie less permeable subsurface materials. Downward movement of water is retarded upon reaching the impermeable subsurface materials. Given a sufficient hydraulic gradient and some outlet for flow, lateral throughflow commences at the contact between the permeable layer and the impermeable subsurface layer. This throughflow becomes concentrated along preferred courses, and if the materials affected are erodible, pipes are initiated. Once initiated, pipes grow progressively until their ceilings collapse.

Although subsequent workers have modified this model for environmental conditions of their particular study sites (e.g., Parker, 1963; Jones, 1971), the general principles appear applicable on the Chadron slopes. The rapid dissolution of weak cements and the appreciable shrink-swell clay content of the Chadron sediments are conducive to the formation of a mantle of loose clay aggregates (popcorn) upon desiccation. Rain falling after a period of desiccation is readily infiltrated into this highly permeable popcorn surface, but water is limited in its downward movement by the relatively impermeable, subsurface materials which seal quite rapidly when wet (Schumm, 1956). Consequently, water moves down gradient as throughflow leading to the initiation of pipes. Schumm in fact noted the emergence of throughflow at the base of hillslopes during his infiltration experiments. Whether or not piping is wholly responsible for the initiation of tributary channels, there can be little doubt that piping is a primary factor in their development.

Both piping and mass movement then are important processes in the development of valley-side slopes. The role of mass movement is evidenced not only by the large blocks of debris which occupy the valley bottom but also by numerous, smaller mass movement features which occur on the valley sides. Piping contributes to the disintegration of mass movement debris, and piped tributary channels attest to the more direct role of piping in slope development. Several compelling lines of evidence suggest that the degree of activity of both of these processes — mass movement and piping — is related to aspect of valley side exposure.

The greater frequency of piped tributaries on the northeast-facing valley side is readily apparent on the map (Figure 1). In addition, mass movement scars and mudflow lobes ranging from several cm to 2 m across occur on the northeast-facing valley wall and impart multifaceted forms to valley-side slope profiles. In contrast, the smooth, convexly rounded side slopes of the southwest-facing valley wall show little evidence of similar mass movements. These morphologic differences between opposing valley sides are apparent in Figure 3.

While less revealing than a detailed analysis of profile form, a comparison of 20 mean slope angles taken at 10 different points along the valley show the southwest-facing slopes to be slightly but consistently steeper than the northeast-facing slopes (see Figure 5); the average difference in mean slope angles is 2.15°. Assuming the slope angles are distributed log normally (Speight, 1971), a paired difference test indicates that this difference would arise less than 5 percent of the time by chance alone.

Possible explanations for morphological differences of opposing valley sides include: 1) rightward deflection of the intermittent basal stream due to Coriolis force (Gabriel *et al.*, 1957); 2) homoclinal shifting i.e., downdip migration of the stream (Thornbury, 1969); and 3) disparate topoclimates on opposing valley walls owing to differential receipt of direct solar radiation (Kennedy, 1976). While the ability of Coriolis force to divert streamflow is a moot issue in general (Carson and Kirkby, 1972), Coriolis force is at best a subservient factor in the case at hand in that the left valley wall is steeper than the right wall. Homoclinal shifting is unlikely in that the valley trend subparallels the apparent dip of the Chadron sediments.

The morphologic differences between opposing valley sides seem most plausibly related to aspect-induced topoclimatic differences. This contention is supported by an interesting observation. A moderate rainfall event occurred just prior to the field investigation. At the outset of the study, the southwest-facing valley side was completely mantled by loose clay aggregates or popcorn, whereas popcorn existed only near the crest of the northeast-facing valley side, although popcorn did develop more fully on the northeast-facing slopes during the period of study. These observations suggest that the southwest-facing valley side, which receives greater direct solar radiation, desiccates much more rapidly than the opposing northeast-facing valley side. A comparatively high moisture environment on the northeast-facing valley side is also suggested by the markedly greater occurrence of shrubs; in contrast, the southwest-facing valley side is nearly devoid of vegetation (see Figure 3).

Aspect-induced differences in moisture budgets offer a working hypothesis for observed differences in opposing valley-side slope morphology. Southwest-facing slopes generally experience comparatively drier conditions and undergo frequent episodes of wetting and drying conducive to seasonal creep. Northeast-facing valley sides maintain higher moisture levels over longer periods of time and are, consequently, more susceptible to slope failure and the development of shallow piped tirbutaries, particularly during the spring wet season when storms follow one another in relatively rapid succession. The presence of greater amounts of mass movement debris on northeast-facing slopes in itself may be conducive to the formation of piped tributaries, but pipes developed in bedrock demonstrate that the presence of comminuted debris is not a necessary condition for the initiation of piping. The preferential occurrence of piped tributaries is probably more a function of moisture budget than of mass movement activity. Because southwest-facing slopes desiccate more rapidly, they will have higher infiltration capacities at the outset of any precipitation event. Northeast-facing slopes, with high antecedent moisture levels by comparison, will have lower infiltration capacities such that throughflow will commence more rapidly and occur more frequently and in greater volume.

Greater susceptibility to rapid mass movement and fluvial erosion associated with piped tributaries results in more rapid reduction of the northeast-facing valley side than on opposing southwest-facing slopes. More rapid denudation might be supposed to produce basal debris accumulations capable of displacing the channel toward the southwest-facing valley side. Under such circumstances, the steeper southwest-facing side slopes might be explained, at least in part, as a function of preferential stream corrasion (Bass, 1929; Walker, 1948; Hadley, 1961). However, the gradient of the main channel, which averages 4.3°, is likely too steep to facilitate protracted debris accumulation necessary for channel displacement (Melton, 1960; also see Emery, 1947). Moreover, there is little physical evidence to suggest channel displacement and preferential corrasion; in cases where debris has imposed on the channel, the common response of the stream has been to pipe through the obstruction.

SUMMARY

Mass movement and piping are dominant processes in the denudation of badlands hillslopes developed on the Chadron Formation. Seasonal creep, whose importance has been well established, is supplemented by other types of mass movement occurring on a wide range of scales. Piping has three distinct modes of occurrence: it occurs on large blocks of debris which occupy the valley floor and contributes to their disintegration; it occurs along the courses of tributary channels which occupy the valley wall and is likely instrumental in their initiation and development; and it occurs at depth in bedrock where its net effect is not certainly known.

Piped tributary channels and mass movement features demonstrate a marked preference for the slightly less steep northeast-facing valley side apparently resulting in observed morphological differences between opposing valley sides. Differences in process activity and side slope morphology are ostensibly attributable to topoclimatic differential, particularly moisture budget.

Fuller understanding of the geomorphic importance of aspect-induced differences in moisture budget, however, awaits the results of a more detailed investigation currently in progress.

REFERENCES

BASS, N.W., 1929, The geology of Cowley County, Kansas: Kansas Geol. Survey Bull. 12, p. 17-23.

CARSON, M.A., and KIRKBY, M.J., 1972, Hillslope form and process: London, Cambridge Univ. Press, p. 385-386.

CLARK, J., 1937, The stratigraphy and paleontology of the Chadron Formation in the Big Badlands of South Dakota: Ann. Carnegie Mus., v. 25, p. 261-350.

CLAUSEN, E.N., 1969, Evolution of caves in badland debris: Proc. No. Dakota Acad. Sci., v. 23, p. 56-64.

EMERY, K.O., 1947, Asymmetrical valleys of San Diego County, California: Bull. So. Calif. Acad. Sci., v. 46, p. 61-71.

FLETCHER, J.E., HARRIS, K., PETERSON, H.B., and CHANDLER, V.N., 1954, Piping: Trans. Am. Geophys. Union, v. 35, p. 258-262.

GABRIEL, V.G., BROCKMAN, L., and HABER, D.F., 1957, Influence of Coriolis force on river profiles: World Oil, v. 145, no. 4, p. 89.

HADLEY, R. F., 1961, Some effects of microclimate on slope morphology and drainage basin development: U.S. Geol. Survey Prof. Paper 424-B, p. B32-B34.

JONES, A., 1971, Soil piping and stream channel initiation: Water Resources Res., v. 7, p. 602-610.

KENNEDY, B.A., 1976, Valley-side slopes and climate *in* Derbyshire, Edward (ed.), Geomorphology and Climate: London, John Wiley and Sons, Inc., p. 171-201.

MEARS, B., Jr., 1968, Piping, *in* Fairbridge, R.W. (ed.), Encyclopedia of geomorphology: New York, Reinhold Book Corp., p. 849-850.

MELTON, M.A., 1960, Intravalley variation in slope angles related to microclimate and erosional development: Bull. Geol. Soc. America, v. 71, p. 133-144.

PARKER, G.G., 1963, Piping, a geomorphic agent in landform development of the drylands: Internat. Assoc. Sci. Hydrology Pub. No. 65 (*Assemblée Générale de Berkeley de l'uggi*), p. 103-113.

SALISBURY, N.E., and PARSON, C.G., 1971, Piping and related mass-movement in the Big Badlands of South Dakota (abs.): Proc. Assoc. Am. Geog., v. 3, p. 194.

SCHUMM, S.A., 1956, The role of creep and rainwash on the retreat of badland slopes: Am. Jour. Sci., v. 254, p. 693-706.

SPEIGHT, J.G., 1971, Log-normality of slope distributions: Zeitschr. Geomorph., v. 15, p. 290-311.

THORNBURY, W.D., 1969, Principles of geomorphology: New York, John Wiley and Sons, Inc., p. 111.

WALKER, E.H., 1948, Differential erosion on slopes of northern and southern exposure in western Wyoming (abs.): Bull. Geol. Soc. Am., v. 59, p. 1360.

WANLESS, H.R., 1922, Lithology of the White River sediments: Proc. Am. Philos. Soc., v. 61, p. 184-203.