ISSN: 0214-1744

BACKWEARING OF SLOPES - THE DEVELOPMENT OF AN IDEA

Backwearing of slopes - the development of an idea

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Resumen: Los modelos que describen el comportamiento de procesos tales como el retroceso de un escarpe, o de una ladera, hunden sus raíces en los cálculos geométricos de Osmod Fisher, así como en las ideas de Walter Penck en relación a la evolución de las laderas desde su base. La meteorización y erosión basal mantiene a las laderas en su máxima pendiente posible para ser estables, permitiendo así la posibilidad de una evolución "en retroceso" a largas escalas espaciales y temporales, tal y como propusieron Lester King y otros pioneros de la geomorfología. La existencia de un nivel resistente superior (caprock) magnifica los mecanismos de retroceso de las laderas. No obstante, estos niveles, no son esenciales para que la humedad descienda progresivamente ladera abajo dando lugar a que la meteorización y la erosión tengan lugar con mayor intensidad en su zona basal manteniendo y retroalimentando el proceso a lo largo del tiempo.

Palabras clave: Retroceso de escarpe, caprock, erosión basal, evolución del paisaje.

Abstract: The scarp retreat or backwearing model of slope behaviour has its roots in the geometrical deductions of Osmond Fisher, and the realisation due to Walther Penck and others that such slopes evolve from the base upwards. Basal weathering and erosion maintains slopes at the steepest inclination commensurate with stability and implies the possibility of long distance scarp retreat, as envisaged by Lester King and others. A caprock enhances the scarp retreat mechanism but is not essential, for moisture gravitates to lower levels ensuring that basal weathering and erosion exceeds that taking place at higher slope levels.

Keywords: scarp retreat, caprock, basal slope attack, landscape evolution.

1. Introduction

The scarp retreat hypothesis is the basis of a well-known and useful model of landscape evolution. It is commonly and rightly associated with the name of Lester King who first used the concept as the basis of landscape interpretation at the regional scale. But the idea has a much longer history.

C. R. Twidale (2007). Backwearing of slopes - The development of an idea. *Rev. C & G.*, 21 (1-2), 135-146.

2. Theoretical slope development

The suggestion that steep slopes may be worn back began with a geometrical consideration of the consequences of the disintegration of a chalk cliff by Osmond Fisher (1866), a reverend gentleman and a keen and prolific amateur geologist. He deduced that if there were no effective evacuation of debris from the base of the cliff, the weathering of a vertical face would result in the formation of a talus slope beneath which would develop a convex-upward bedrock surface. The cliff, though reduced in vertical extent because of the basal accumulation of talus, would continue to maintain its steep inclination as it was worn back (Figure 1). Fisher cited parallel scarp retreat again in his 1872 paper on glacial landforms (Fisher, 1872, p. 10). It was also the basis of Lawson's (1915) explanation of the piedmont angle, the sharp break of slope between hillslope and plain commonly developed in arid and semi-arid lands. Familiar with the faulted landscapes of southern California he suggested that the feature was simply the angle between juxtaposed fault blocks, and that the backing scarp was worn back with the inclination and the basal angle maintained (Figure 1b). No mechanism was suggested, but like Fisher he considered situations in which talus accumulated at the base of the slope.

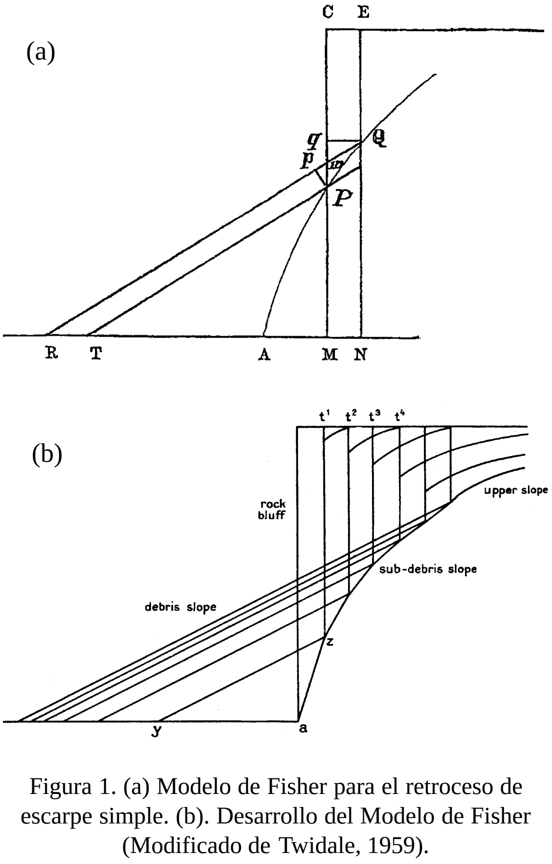

Figura 1. (a) Modelo de Fisher para el retroceso de escarpe simple. (b). Desarrollo del Modelo de Fisher (Modificado de Twidale, 1959).
Figure 1. (a) Fisher's (1866) simple scarp retreat diagram. (b) A development of Fisher's scheme (after Twidale, 1959).

3. Landscape and inselberg development

Jutson (1914) linked genetically the Old and New plateaux of the southwest of Western Australia. He interpreted the latter as the plain exposed after the stripping of the widely developed Mesozoic lateritic regolith. Though he did not use the term he interpreted the New Plateau as an etch plain (see Mabbutt, 1961, Twidale, 2002). The mode of stripping clearly involved the recession of scarps capped by a duricrust (see Jutson's diagrams on pp. 143, 144, 154, and 156 of his 1914 Bulletin 61, and pp. 97, 224, 236, and 239 of Bulletin 95, published in 1934 and 1950). He also drew attention to the importance of basal slope attack, both generally and in the local context, citing locations where the cliffs bordering lake depressions on the eastern shore were undermined and worn back as a result of basal slope erosion by wind-driven waves (Figure 2). Evidently he did not recognise a link between the lake depression and the adjacent slope.

Working in Mozambique, Holmes (1918) cited scarp retreat in relation to the formation of some types of inselberg. Like Jutson he considered incised valleys bordered by bluffs, of which he wrote: 'the escarpment slopes would be worn back and intensified by localized attack at their base, and that the escarpments themselves would be eaten away laterally, until only isolated remnants remained'(Holmes, 1918, p. 93).

Also in relation to inselbergs but in a Libyan Desert landscape developed in flat-lying sedimentary sequences that include caprock-forming resistant beds, Peel (1941, p. 21) remarked that the undercutting of the bluffs bordering plateaux, and most notably evidenced in huge shelters or alcoves, would result in recession of the slopes. In broader view he mentions that the 'inward retreat'of scarps

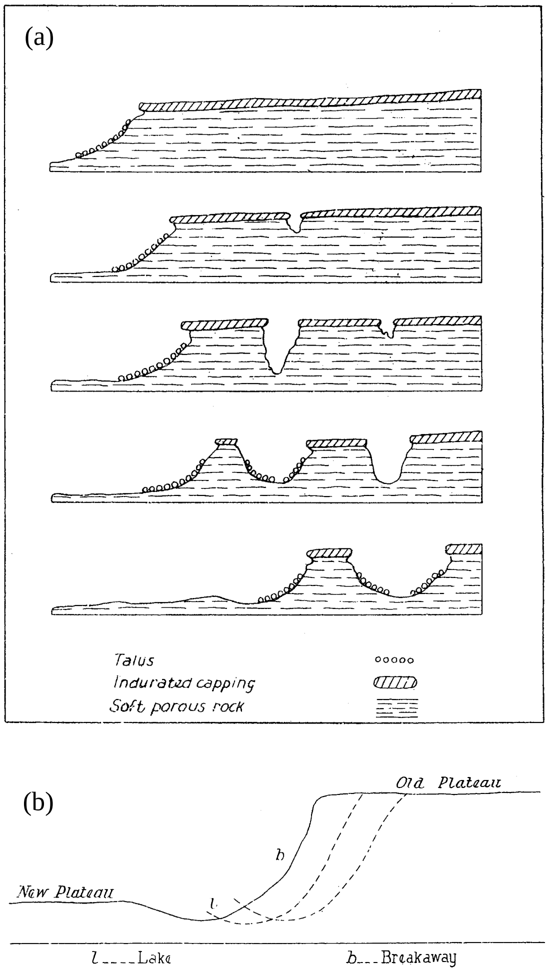

Figura 2. Modelo de Retroceso de escarpe de Jutson (a) en laderas protegidas por estratos resistentes –caprocks- y (b) en una ladera cercana a la orilla de un lago (Modificado de Jutson, 1914).

Figure 2. Scarp recession according to Jutson (a) in a caprock setting, and (b) on the lee shore of a lake (after Jutson, 1914).

eventually results in the formation of ‘conical remnants’.

It was against this background that King, rebelling against the Davisian theory espoused by his mentor, C.A. Cotton (see Twidale, 1992), conceived his scarp retreat model of landscape evolution (King, 1942, 1953, 1957). Travelling in southern Africa in landscapes based in flat-lying basalts and sediments he noted that, in any given area of common structure, regardless of the degree of dissection - whether the remnants were plateaux, mesas or buttes - hillslope form and inclination were so similar as to be practically identical (Figure 3). That his observations were real and not imagined was demonstrated by painstaking measurements of slope angles (Fair, 1947, 1948). He thought scarp retreat was the favoured mode of landscape development wherever there was a sufficient relief amplitude (see below) and in all climates save those dominated by wind or glacier ice. The basal slope left behind by scarp recession was the pediment. He considered scarp retreat and pedimentation to be the fundamental mechanism of landscape development through the ages, and suggested that pediplains, formed by the coalescence of pediments occupied huge areas in the landscapes of southern Africa (King, 1953).

In the opinion of some, it was unfortunate that King linked slope behaviour with pediments, for the latter are fringing forms (Twidale, 1983) and even the type examples of pediplains cited by King are manifestly rolling and dominated by convexities rather than the concave profiles typical of pediments. But scarp retreat is more common than many would allow, simply because of processes that Holmes and Peel appreciated but that King underestimated.

4. Mechanism involved in scarp recession

Some piedmonts are drained and eroded by streams that have regressed into the scarp foot zone or that have emerged from the upland. Basal attack by rivers was cited by Johnson (1932) in explanation of the piedmont angle. Some rivers debouching from uplands are diverted along the hill front but only to a limited extent: most such rivers divaricate (Blackwelder, 1931) or adopt a distributary habit on leaving the upland ramparts and flow toward the centre of the local drainage basin. Many short stream sectors aligned parallel to the upland front (Figure 4) have eroded scarp foot depressions in the moat of weathered bedrock commonly found there (e.g. Clarke, 1936). But similar depressions are formed also where no stream has penetrated and where none is generated, as for instance at the base of isolated inselbergs.

Such scarp foot depressions (Bergfussniederungen, dépressions annulaires: see Thorbecke,

Figura 3. Meseta erosionada mostrando laderas de similar geometría y pendiente asociadas a la propia meseta, mesas y cerros testigos, Cuenca de Carnarvon, Australia occidental. Estos relieves tabulares se desarrollan a favor de estratos horizontales cretácicos discordantes sobre materiales cristalinos del Arcaico que afloran en la base de las laderas y constituyen una superficie exhumada en la llanura circundante a los relieves (K.H. Wyrwoll).

Figure 3. Dissected plateau with slopes of similar form and inclination associated with plateau, mesa and butte, northern Carnarvon Basin, Western Australia. The plateau forms are developed in flat-lying Cretaceous strata which rest unconformably on Archaean crystalline rocks that are exposed as an exhumed surface in the present plain (K.H. Wyrwoll).

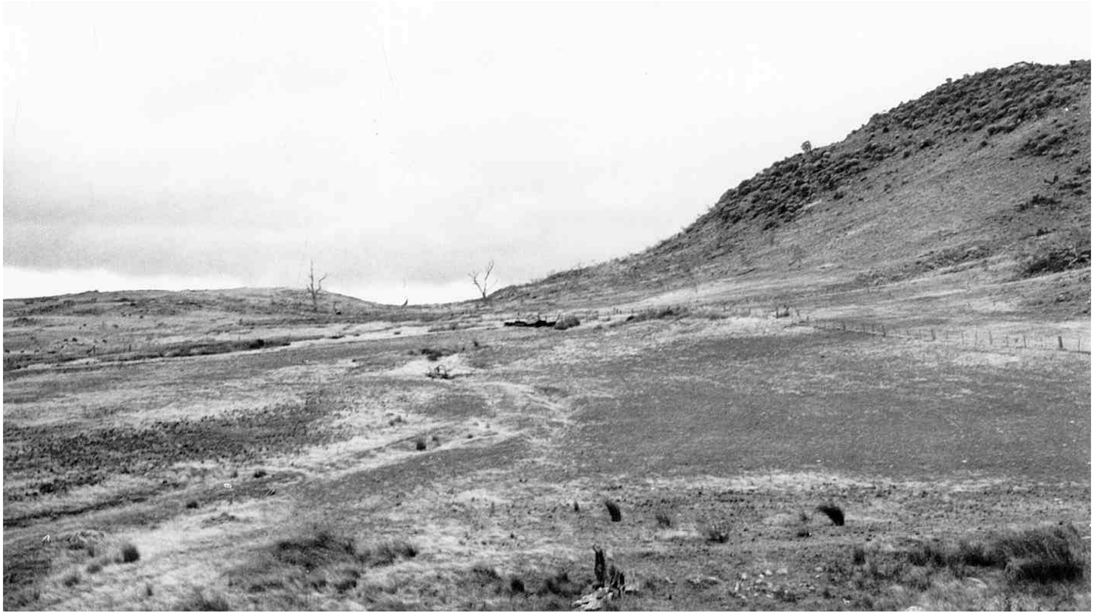

Figura 4. Depresión de piedemonte drenada por un arroyo asociado a un escarpe de falla. Lofty Range Mountains Orientales, Sur de Australia.

Figure 4. A piedmont depression drained by a stream river and associated with fault scarp, eastern Mt Lofty Ranges, South Australia.

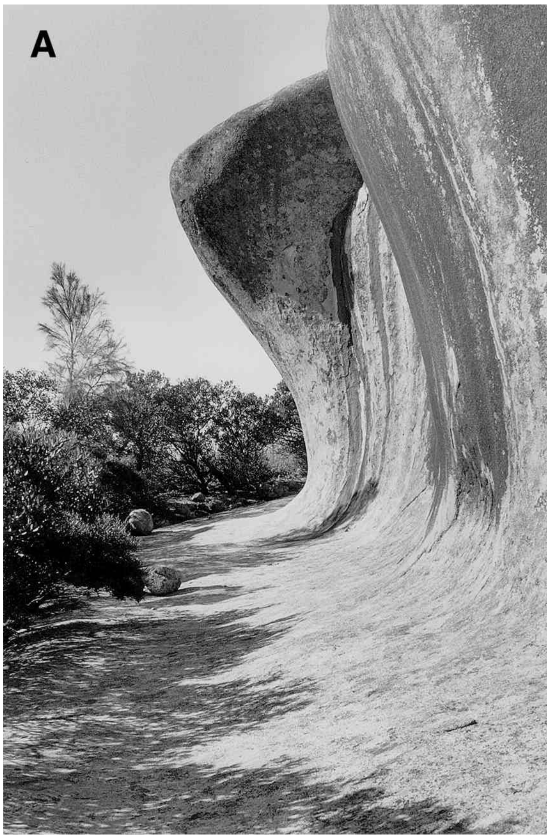

Figura 5. (a) Ladera ensanchada en la base de Ucontitchie Hill, un bornhart granítico al suroeste de Wudinna, Norte de la Península de Eyre, Sur de Australia. (b) Socave (o alcoba) en la base de un cantil en areniscas, Lesotho, Sudáfrica. (c) Meteorización e indentación basal en bloques graníticos. Devil's Marbles, Territorios del Norte, Australia.
Figure 5. (a) Flared slope at the base of Ucontitchie Hill, a granite bornhardt southwest of Wudinna, northern Eyre Peninsula, South Australia. (b) Alcove at base of sandstone bluff, Lesotho, southern Africa. (c) Basal fretting and indentation on granite boulders, Devil's Marbles, Northern Territory, Australia.

1927, Clayton, 1956, Dumanowski, 1960, Mabbutt, 1965, Bocquier et al., 1977, Twidale, 1983) are caused by scarp foot weathering by water washed or seeping from the backing uplands. Where there are no streams the lowering of the surface may be attributed to subsurface flushing of fines (Ruxton, 1958) or volume decrease consequent on alteration and evacuation of salts in solution (e.g. Trendall, 1962), in both instances followed by compaction and surface subsidence. Scarp foot weathering is attested by flared or concave slopes (Twidale, 1962, Twidale and Bourne, 1998) and by other evidence of preferential scarp foot weathering and erosion in alcoves and basal fretting (Figure 5). It is largely responsible for the piedmont angle (Twidale, 1967, 1978, Twidale and Bourne, 1998) and also accounts for the lake depressions that so interested Jutson (Figure 2b).

Thus basal slope attack, with or without river action, is commonplace. It is also crucial to the scarp retreat process. Given a faceted slope, such erosion, localised in gullies or generally in the form of mass movements of material, extends upslope where the surficial debris is unbuttressed and either slides or is washed to the bottom of the slope and beyond. This wave of erosion extends upslope from the foot of the slope (W. Penck, 1953, p. 112, *in* Bremer, 1983) and eventually reaches the base of the bluff (Figure 6). This site is already weathered because the detritus of the debris slope that laps on to the bedrock at the base of the bluff holds moisture. Weathering is evidenced by a kaolinised zone in rocks, such as granite, or by numerous solution hollows in chemically reactive rocks, such as limestone (Figures 5b and 7). Also, the debris may be of low permeability, causing some of the water seeping through the bedrock that forms the bluff to emerge at its base, sapping the bedrock. Caverns, shelters, or tafoni frequently are developed there, undermining the bluff and causing it to collapse.

In this way scarps are worn back with only minor and temporary variations in slope inclination and detailed morphology (Twidale and Milnes, 1983). Thus, even where material is evacuated from the base of the slope, a substantial relief amplitude is maintained as slope development extends from the base of the slope upwards. Basal attack ensures that slopes are maintained at or near the maximum inclination commensurate with stability. Oversteepening causes collapse of the upper slope, deposition of detritus on the slope below, and thus its reduction in inclination and a return to stability.

The dominance of basal weathering and erosion is also evident where rivers have incised their valleys in sequences of uniform lithology, for slope form varies according to the position of the river –


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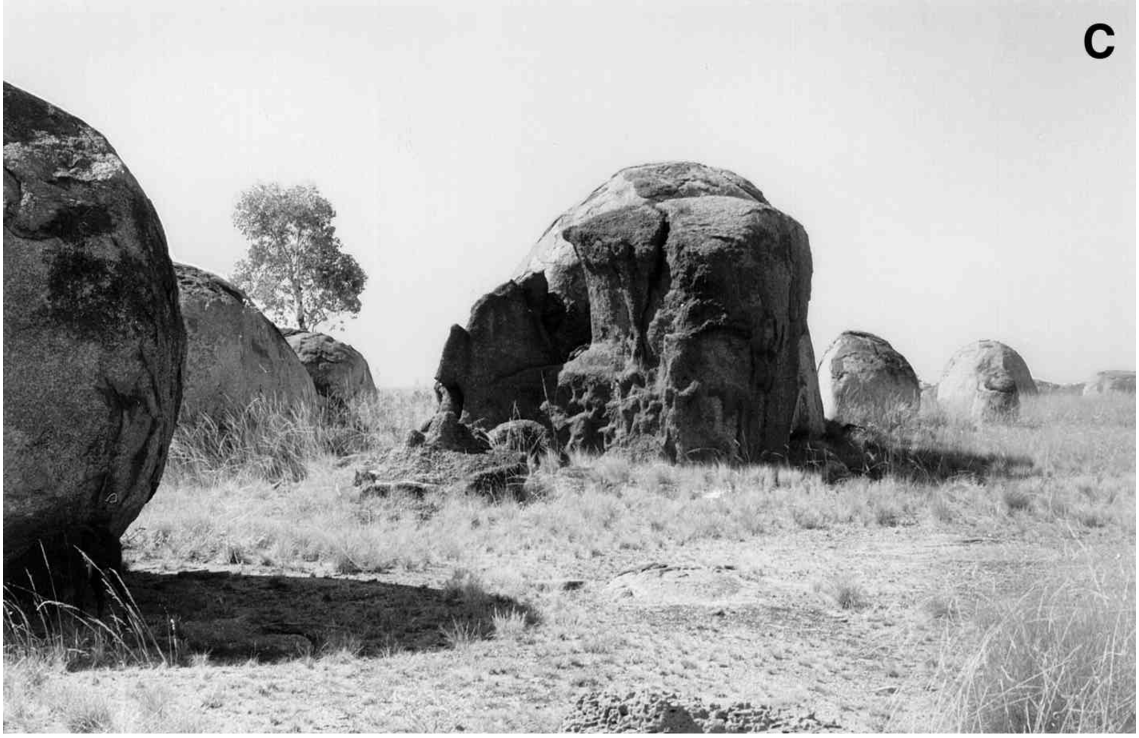
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the major agent of erosion and transportation – vis-à-vis the slopes. The lower River Murray has incised a gorge in flat-lying Miocene limestone. Where the outside of a river curve impinges on the limestone a cliff is formed as a result of undercutting. As Crickmay (1932, p. 186) remarked, erosion is confined to drainage lines, and on the inside of the meanders basal attack is nil. On the contrary a slip-off slope has formed with the upper slope reduced by weathering either to a low remnant cliff or to a convex graded upper slope. As the river meanders sweep downstream so the morphology of the bounding slopes has changed in time (Tate, 1884, Twidale, 1964, 2000).

Thus the presence of a caprock is conducive, but is not essential, to the wearing back of slopes: as Tricart (1957) pointed out, whatever the structure, a dominance of basal slope attack leads to scarp recession. Where stream incision is slight and the streams are close to baselevel, and particularly where the local bedrock is weak, little kinetic

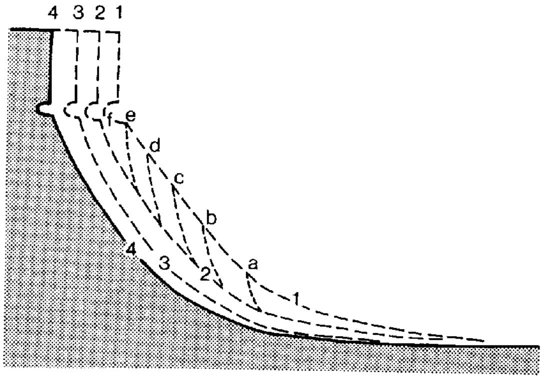


Figura 6. Estados evolutivos del retroceso de un escarpe (1-4) producidos por sucesivas fases (a-f) de erosión de la pendiente de coluvionamiento iniciada en la parte basal de la ladera y propagándose pendiente arriba (Twidale y Milnes, 1983).
Figure 6. Suggested stages in scarp retreat (1-4) caused by successive phases (a-f) of erosion of the debris slope initiated at its foot and extending up the incline (Twidale and Milnes, 1983).

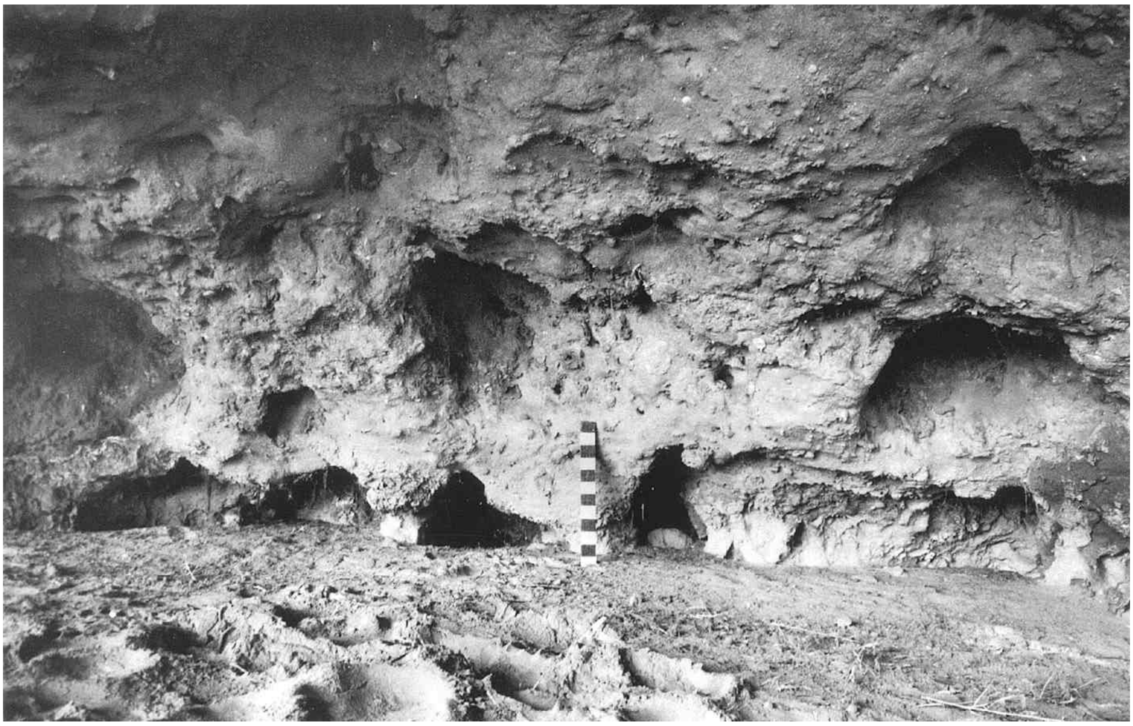


Figura 7. Socaves de disolución protegidas en la base de un cantil calcáreo. Garganta del Río Murria cerca de Walkers Flat, Sur de Australia.
Figure 7. Solution alcoves at back of shelter at base of limestone bluff, River Murray gorge near Walkers Flat, South Australia.

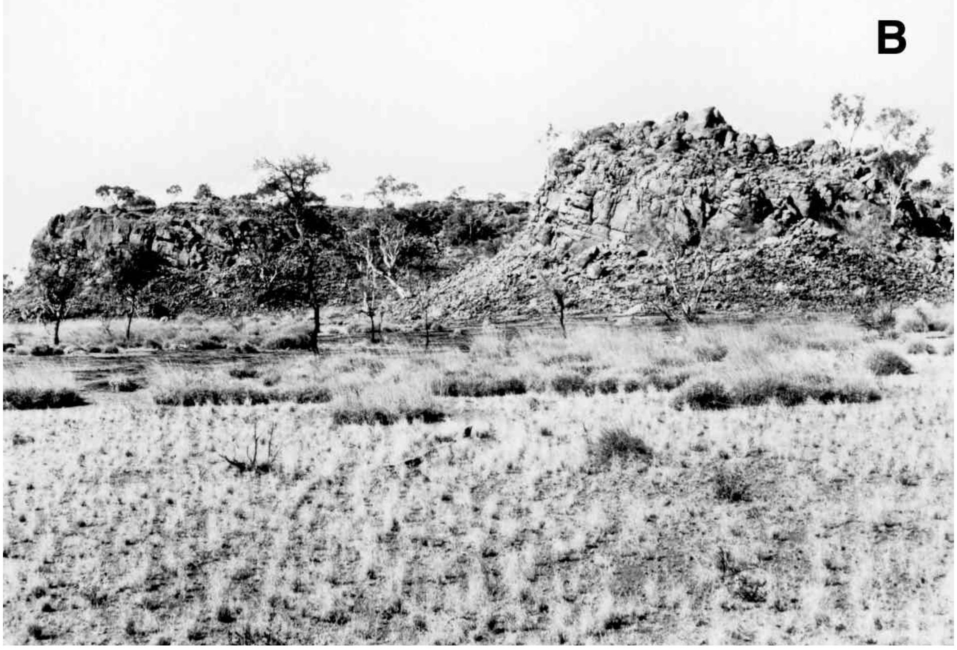


Figura 8. (a) Ladera facetada desarrollada en una meseta basáltica. Drakensberg meridional, Calvinia, Provincia del Cabo Occidental, Sudáfrica. Nótese la erosión linear de la pendiente de coluvionamiento. (b) Ladera facetada sobre granitos. Sur de Isa Highlands, Noroeste de Queensland, Australia.

Figure 8. (a) Faceted slope developed on basalt-capped plateau, southern Drakensberg, near Calvinia, Western Cape Province, Republic of South Africa. Note gullying of debris slope. (b) Faceted slope in granite, southern Isa Highlands, northwest Queensland, Australia.

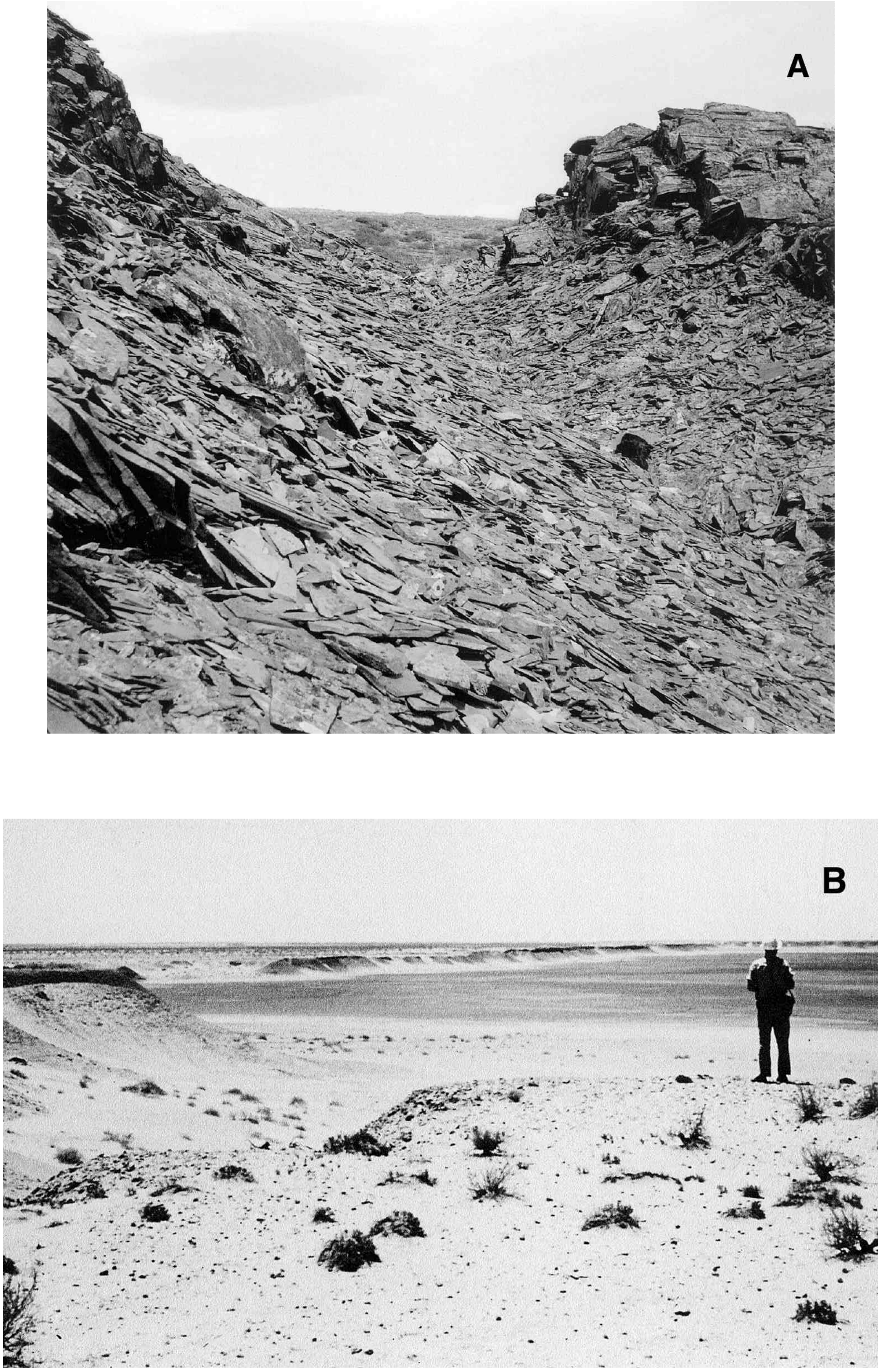
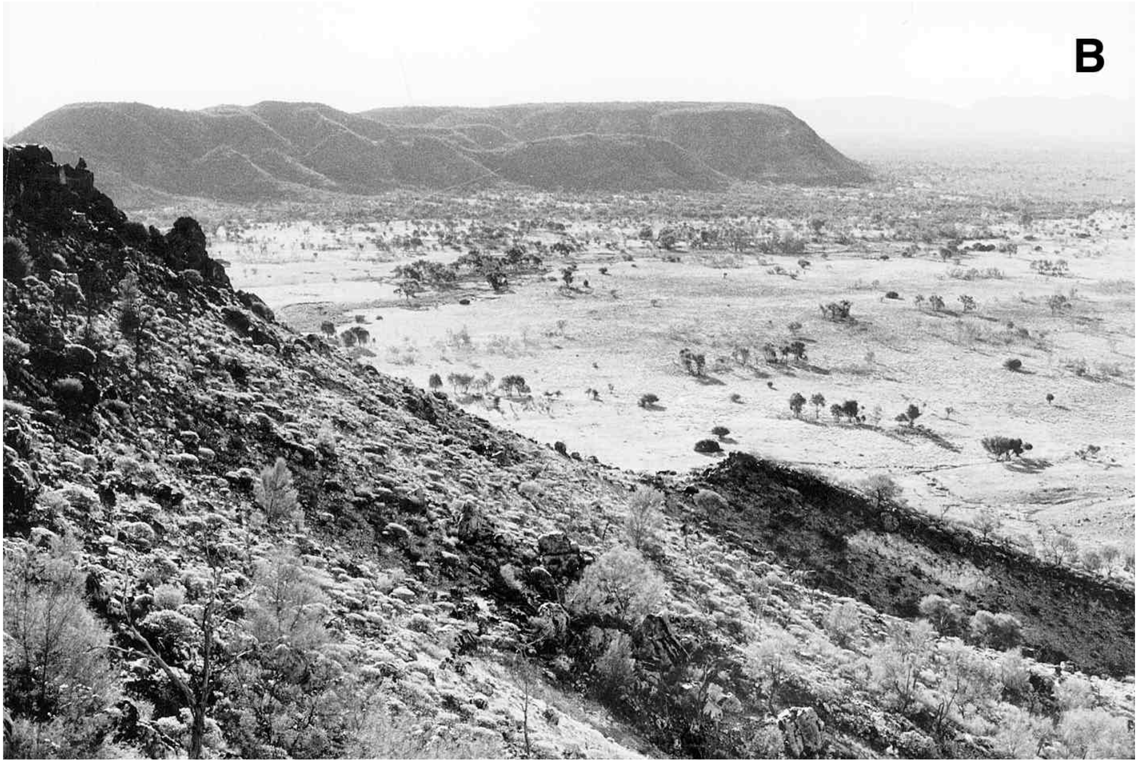


Figura 9. (a) Laderas facetadas sobre pizarras fisibles alteradas mecánicamente por gelifracción, cerca de el lago Nov (Schefferville) Península del Labrador, Canadá. (b) Acantilado protegido por una gypscreta en la orilla occidental del Lago Eyre situado en el árido interior de Australia meridional.

Figure 9. (a) Faceted slope in fissile shale shattered by gelifraction, near Knob Lake (Schefferville) central Labrador, Canada. (b) Cliff capped by gypcrete, on the western shore of Lake Eyre, in the arid interior of South Australia.

Figura 10. (a) Ladera facetada en Chewings Range cerca de Alice Springs, Territorios del Norte, mostrando erosión linear y pendientes de coluvionamiento franjeadas a favor de niveles de gravas más cementados. Las franjas se encuentran protegidas por niveles de gravas procedentes de la meteorización del escarpe superior. (b) Franjas desarrolladas a favor niveles de gravas más resistentes en las laderas de Ooraminna Range, en el sureste de Alice Springs, Territorio del Norte. El relieve en mesa que se observa en esta foto se desarrolla a favor de capas resistentes silicificadas correspondientes a depósitos lacustres miocenos.

Figure 10. (a) Faceted slope on Chewings Range, near Alice Springs, Northern Territory, showing gullied and ribbed debris slope developed through gully gravure. The ribs are capped and protected by gravel derived from the weathering of the bluff. Some of the gullies carry talus. (b) Gravel-capped rib on slope of Ooraminna Range, southeast of Alice Springs, Northern Territory. The mesa in the middle distance is capped by Miocene lacustrine siliceous beds.



energy is generated by water flow. As a result, slope recession is slight whereas upper slopes may be weathered and worn down by compaction, wash and mass movements as rapidly or more rapidly than slopes are worn back.

Recession is not confined to flat-lying sequences or to sedimentary terrains. The slope elements and processes cited above in respect of the scarp retreat model are well evidenced in elements of fold mountain belts, and in basaltic and granitic terrains (Figure 8). Backwearing is evident in cold lands (e.g. Twidale, 1959) where frost action and summer melt cause rapid slope development and also in deserts where wind transport and deposition are dominant but where, as pointed out by Peel, water-related weathering and erosion, past and present, have helped shape the landscape (Figure 9).

5. Significance

Scarp recession is a major mechanism and component of landscape development. Where it is dominant land surfaces that pre-date stream incision persist much longer than they do in areas where, for whatever reason, slope lowering has been dominant. Moreover, the scarp retreat mechanism subsumes two secondary mechanisms that retard slope recession. First, where gully gravure (Bryan, 1940, Twidale and Campbell, 1986) is active, the loci of stream incision (gullying) changes along the slope so that instead of deep incision, slopes become armored by coarse debris which retards erosion and recession (Figure 10). Second, continued scarp retreat causes the area of the initial surface gradually to be reduced, so that the volume of water passing over the bounding cliff is decreased and the rate of recession again is diminished (Twidale, 1978).

6. Conclusion

The author spent a year in the mid-fifties in central Labrador at the McGill Subarctic Research Station. Like my colleagues I earned my keep employed as a meteorological observer and went into the field looking at slopes as weather and opportunity offered. The meteorological duties involved shift work. Usually (though not always) the night shift was the most uneventful and one could read or even write between observations. About 5 o'clock one morning I sat in a chair thinking about the local slopes I had seen and letting my mind wander over possibilities: how had faceted slopes evolved? I drew a cliff in section, assumed it was weathered and that the detritus fell to the base. There were no streams to evacuate the debris. I pursued sequential stages and found that the geometry was such that the cliff was not only undermined and maintained its steepness, but was worn back parallel to itself (Figure 1b). A faceted slope evolved, as appeared to have occurred in the dissected folded sediments of the Labrador Trough (Twidale, 1959). Eureka! My self-congratulatory glow lasted only a short while, however, for one of the few books I had with me was Baulig's '*Essais de Géomorphologie*' (1950) and on opening it, there was the essence of 'my'diagram! It had been anticipated not only by Fisher but also by such workers as Lawson (1915), Lehmann (1933) and Wood (1942).

Convergence of thought is not unknown but whereas my doodling was of no consequence, Fisher's geometrical deduction of almost a century earlier led to a geomorphological concept that is fundamental to the understanding of landscapes and not only in caprock structural settings. Backwearing is far more prevalent than even King imagined.

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