DISCONTINUOUS GULLIES ON THE VOLCANIC PLATEAU

R. J. Blong*

SUMMARY

A discontinuous gully in the Paritaniwha Valley, Mangakowhiriwhiri Catchment is described and changes in the gully with time are noted. The recognition of a black, humic layer as predating land development has made it possible to calculate rates of erosion and deposition for selected areas. Those factors described by other authors as encouraging surface water flow are mentioned and processes of gully development described. On relatively flat valley floors gullies originate where the slope is steepest or where vegetation is sparsest. Deposition of material at gully mouths steepens gradients and encourages gully extension down valley. Present evidence suggests that this has occurred in the Paritaniwha Valley and that gully extension will continue.

INTRODUCTION

Those gullies cut in the pumice deposits of the Volcanic Plateau are characterised by vertical headcuts and sidewalls, a rapidly decreasing depth down stream, and occasionally by fans at their lowers ends. The term 'discontinuous gullies' has been applied to similar phenomena in the arid south-west of the U.S.A. (Leopold and Miller, 1956, p.29; Leopold et. al., 1964, p.448).

Observations in the Tokoroa, Kinloch, Reporoa, Mangakino and West Taupo areas suggest that discontinuous gullies occur throughout wide areas of the pumice plateau. The Mangakowhiriwhiri Catchment (Fig. 1) in the Mangakino Basin has been selected for detailed comment as field studies of some gullies in this area span the last three years, although detailed work has been confined to the last few months. As observations will continue for a further period, this paper must be regarded as a preliminary report and the conclusions reached are by no means final.

---

* University of Waikato.

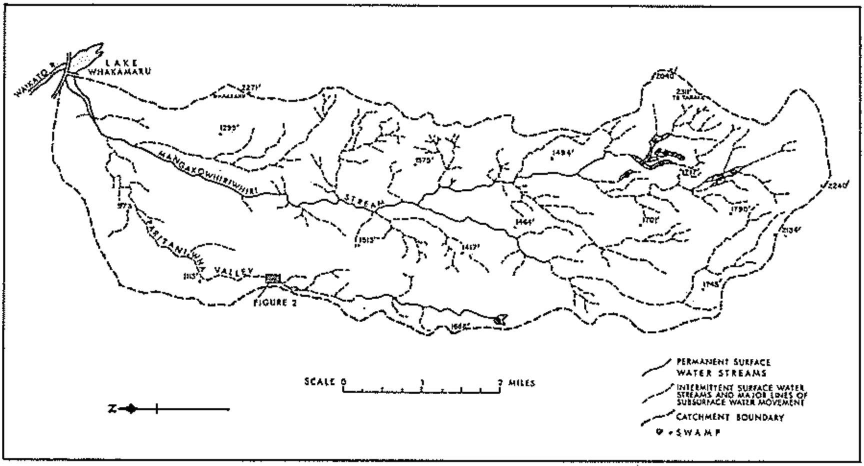


Fig. 1 — THE MANGAKOWHIRIWHIRI CATCHMENT — Perennial and Intermittent Streams.

MORPHOLOGY OF GULLIES

As a result of Pleistocene and Recent events, the Mangakowhiriwhiri Valley and its major tributaries consist of a series of ignimbrite gorges separated by basins infilled with pumice and other fluvial deposits. Where ignimbrite outcrops on valley floors, stream flow is on the surface; where deposition of pumice sands and gravels has deeply buried the ignimbrite bedrock, stream flow is underground and valley floors are broad, flat and generally dry.

Discontinuous gullies in the Mangakowhiriwhiri Catchment occur in three situations: (1) on flat, pumice-valley floors; (2) at the discordant junction of a tributary valley with a main valley; and (3) on lower colluvial hillslopes with ash and pumice mantles.

Headwalls from 2 ft to over 35 feet in height have been measured in the catchment while gullies vary in length from 20 feet to over 1 mile. Portions of a shallow gully, located on the floor of the Paritaniwha Valley have been selected for detailed description (Fig. 2). The sections described are considered representative in form, though not in size, of the discontinuous gullies in the catchment area.

The total length of the gully is approximately 1.3 miles. Towards its headward end the gully gradually changes in character, eventually becoming a typical ignimbrite valley with a bedrock floor and continuously-flowing surface water. (see Table 1). The valley floor into which the gully is incised has a slope of about 1°, and is composed of water-deposited pumice. Although in the deposits the individual beds vary markedly in thickness over quite small distances, the following profile reveals the general sequence. (Profile close to the gully mouth — Grid Reference NZMS 86, Sheet 84/8, 266645):

0 - 1½ inches — blackish-brown topsoil; poor structure, mainly loose grains, but sometimes a strong root mat; some signs of organic matter accumulation with a few humus-stained pumice blocks and lapilli (4-32 mm. diameter).

1½ - 4½ inches — pumice alluvium; light brown humus stains on outside surfaces of pumice blocks and alluvium; mainly sand and lapilli-sized material; lower boundary sharp.

4½ - 9½ inches — greasy black humic horizon with incorporated pumice lapilli and blocks.

9½ - 24 inches plus — dark brown humus-stained horizon becoming lighter with increasing depth; pumice and rhyolitic sand.

The black, humic layer rarely occurs at the surface but forms a useful marker bed usually at a depth of between 3 and 24 inches.

The floor of the valley is covered with loose deposits of pumice blocks, some of which are 10 inches in diameter, lapilli and sand. These deposits vary considerably in thickness, being entirely absent from some sections of the valley floor, but over two feet deep in parts such as the upslope side of those fences that cross the valley floor (Fig. 2).

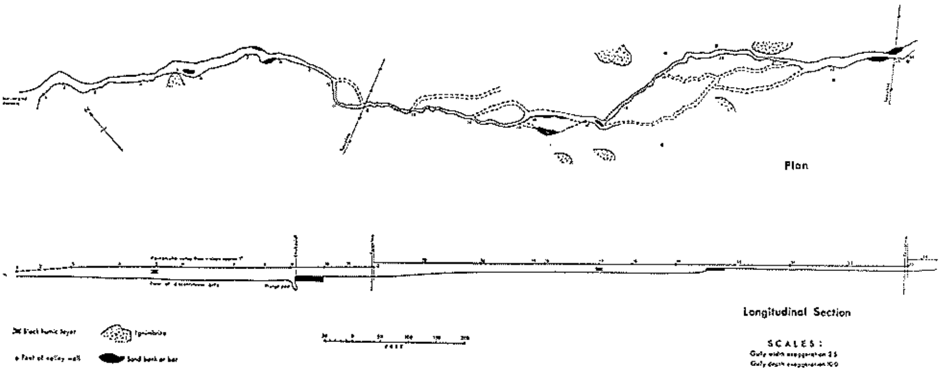


Fig. 2 — DISCONTINUOUS GULLY — Paritaniwha Valley.

TABLE 1 — Selected Discontinuous Gully Statistics

Location	Section 1 At Gully Mouth (see Figure 2)	Section 2 Near Headward end of Gully
Length of section of gully (ft)	1630	2560
Mean channel width (ft)	4.12	4.75
Mean channel depth (ft)	1.93	5.58
Mean cross-sectional area of channel (sq.ft)	6.3	28.3
Mean width of Paritaniwha Valley (ft) ...	74	66.5
Mean depth of black, humic layer (inches)	15.5	14.5

The gully is characterised by a very low-angled bed — lower than the one degree slope recorded for the valley floor. Knickpoints, or points along longitudinal profiles of channels or gullies at which the slope increases abruptly (Brush and Wolman, 1960, p.60), occur at a number of places on the gully floor, varying from several inches to over three feet in height. They are often formed on the black, humic horizon, and the base of this headwall is undermined and locally overdeepened. With increasing distance above each knickpoint, the gully increases in depth, but in places the black, humic layer may form the floor of the gully for considerable distances, though only 10 to 20 inches beneath the surface of the surrounding valley fill. The rest of the gully floor is composed of loose deposits of pumiceous sands.

In some places subsidiary channels meet the main gully (Fig. 2). These are shallower and indefinite in form, and decrease rapidly in depth away from the main gully and end usually in a pile of loose pumice sand deposits. They may rejoin the major gully, forming an alternative channel.

Down valley from the gully, the floor of the valley widens and an extremely low-angle fan has spread outward from the gully mouth (Figs. 3 and 4). A number of very shallow channels cross the fan radiating from the mouth of the gully, but the common characteristics of the gully trench are no longer present.

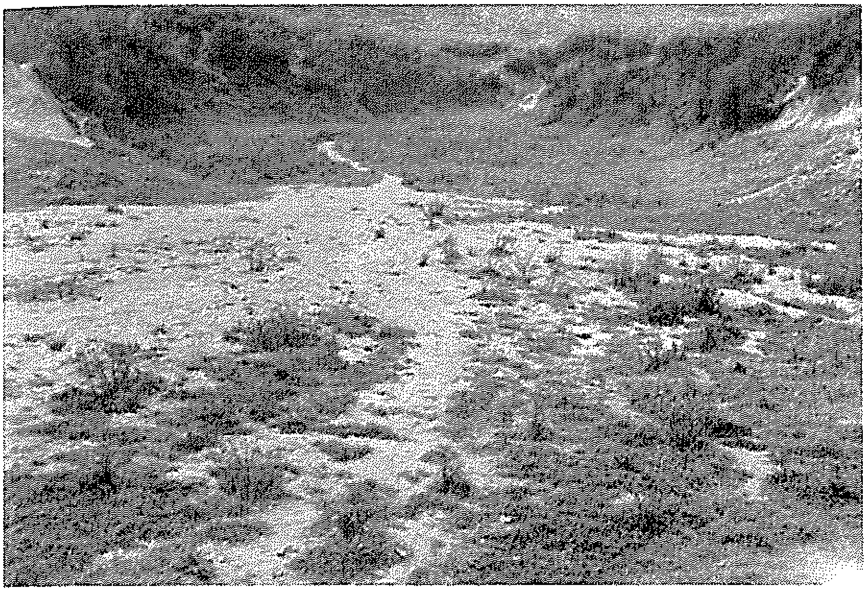


Fig. 3 — DISCONTINUOUS GULLY MOUTH May 1965.

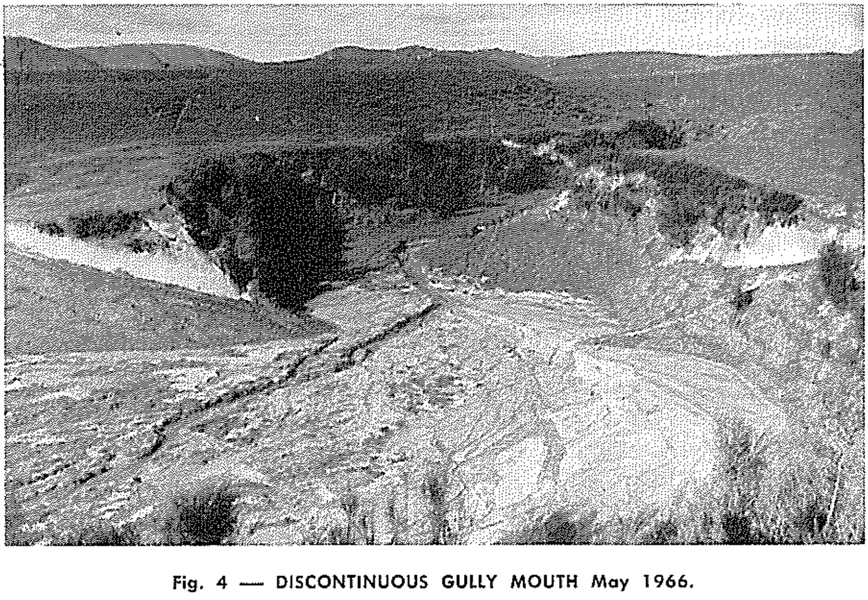


Fig. 4 — DISCONTINUOUS GULLY MOUTH May 1966.

Photo: M. J. Selby.

CHANGES WITH TIME

Between December 1963 and July 1966, the gully described above underwent changes as summarized in Table 2.

TABLE 2 — Changes with Time

Date	Gully Length	Position of Gully Mouth	Total Burial of Fence 200ft. Down Valley From Gully Mouth	Water Flow in Gully
December 1963	Number of short channels on valley floor — none measured (Blong, 1964, p.24)	200ft. up valley from fenceline — no depositional fan evident	16 inches	None - apparently surface water flow occurs only 3-4 days/year (Blong, 1965, p.83)
18 January 1965	Gully with mouth at G.R. 266645, 420ft. in length	Same — depositional fan now developed (Fig. 3)	28 - 6 inches Very recent	None - although flow continuous 2 miles up valley from gully mouth
11 May 1965	—*	Same	—*	None
11 May 1966	Not measured but obviously much longer than in January 1965	Smaller channel developed toward fence-line (Fig. 4)	—*	Strong surface flow
27 July 1966	1.3 miles — short channels observed in December 1963 had coalesced	Same	32 inches	Strong surface flow - apparently continuous since January, 1966

* Observations not recorded.

Between May, 1965 and May, 1966, the gully lengthened rapidly, coalescing with other short gullies and forming a continuous channel with a length of 1.3 miles. Surface water flow, previously an aperiodic and infrequent occurrence, became continuous. The cause of the change in flow characteristics is not known, but it appears that normal subsurface water flow has been diverted to the surface following the blockage of a subsurface water course. This diversion may have resulted from natural changes, or as a result of road re-alignment activities higher up the valley. While the change to continuous surface water flow has undoubtedly hastened gully development, the morphological changes which have taken place would apparently have occurred even if surface flow had remained aperiodic and infrequent. Observations on gully development from other parts of the catchment support this view.

RATES OF EROSION AND DEPOSITION

Rough measurements of rates of erosion and deposition have been attempted (Tables 1 and 3). Although these calculations may not be entirely accurate, they provide a rough value for recent erosion and deposition in two selected areas.

Land development in the portion of the Paritaniwha Valley under consideration began approximately 15 years ago. Field evidence from a number of parts of the Mangakowhiriwhiri catchment indicates that when fence posts dating from the time of original development were placed in the ground, the black, humic layer (Fig. 2) was at, or very close to, the surface. In Section 1 (Table 1) the black humic layer is found at a mean depth of 15.5 inches, but discing at the time of development may have caused some mixing — a mean depth of only 13 inches has been allowed in calculating the total amount of deposition (Table 3). Field evidence shows that material deposited on the black, humic layer does not thin noticeably toward the valley sides.

TABLE 3 — Measures of Erosion and Deposition*

	Section 1	Section 2
Mean depth of material deposited (inches) ...	13	12
Total volume of gully in section (cu. yards) ...	378	2690
Volume of gully per foot gully length (cu.ft) ... (Also cross-sectional area)	6.3	28.3
Volume of material deposited in section above black, humic layer — see text — (cu. yards)	4822	6315
Volume of material deposited above black, humic layer/foot gully length (cu. yards) ...	3.0	2.5
Annual rate of deposition — last 15 years (inches)	0.87	0.8
Deposition/foot valley length/year — last 15 years (cu. ft)	5.4	4.5

* Figures have been rounded.

The most significant figures are those showing gully volume and volume of deposition per foot of channel length. The depth of the black humic layer is similar in each section of valley floor considered; as valley widths are similar (Table 1), rates of deposition and volume of deposition per foot of valley length per year are similar for each section. However, channel volumes are markedly different, because the depths of the gully vary from section to section (Tables 1 and 3).

The figures quoted do not include material deposited down valley from the present gully mouth, and undoubtedly the major part of deposition in the last few years has taken place in this area. At a fence 200 feet down valley from the gully mouth, at least 32 inches aggradation has taken place in the last 15 years; 16 inches of this deposition occurred between December, 1963 and July, 1966 (Table 2).

In 1956, the mouth of the Mangakowhiriwhiri Stream was dammed to form a sub-lake adjacent to the main Lake Whakamaru. Between 1956 and 1965 an estimated 186,000 cubic yards of material was deposited in this sub-lake. While this amount of aggradation may seem large, data included in Table 3 indicates that it probably represents only a fraction of the total volume of material deposited on valley floors (particularly tributary valley floors) throughout the catchment.

DEVELOPMENT OF DISCONTINUOUS GULLIES

Although surface water run-off is undoubtedly the most important single agent of discontinuous gully development on the Volcanic Plateau, individual gullies may owe much of their present morphology to other agents such as subsurface water movement, frost action, and stock trampling· The general importance of each agent is discussed below.

Numerous factors which may encourage surface water flow over pumice soils have been reported:

(1) Short duration, high intensity rainfalls (Robertson, 1963; Blong, 1965, p.83).

(2) Resistance to wetting of pumice soils when unsaturated (Packard, 1957, p.287; Glass and Drost, 1962, p.119).

(3) Organic matter accumulation in the upper horizons of pumice soils (Dixon and Jackman, 1954, pp.20-21; Jackman, 1964, p.451, p.463).

(4) Soil compaction as a result of consolidation by heavy machinery and stock (Packard, 1957, p.284; Campbell, 1965: p.9).

Combinations of these factors promote low soil infiltration rates under pasture (Campbell, 1965, p.9) and considerable surface run-off.

Where aperiodic surface water flow occurs, discontinuous gully development proceeds by knickpoint retreat and plunge-pool erosion. Provided that the knickpoint has a resistance to shear stress greater than the stress induced by the water flow, and provided that the flow is sufficient to transport eroded material from the base of the headcut, the knickpoint will retreat upstream maintaining a vertical face (Leopold, et. al., 1964, pp.442-443). Although the pumice deposits are not cohesive enough to maintain a vertical headcut against the stress provided by surface water flow, knickpoints with a vertical face are present because of the cohesive strength of the greasy, black, humic layer. Knickpoints, maintained in the black, humic layer, retreat headwards by plunge pool erosion of the underlying pumice deposits and consequent collapse of the superficial layers.

As Leopold and Miller (1956, p.30) have pointed out, plunge pool erosion tends to deepen channels more quickly than it tends to widen them. Many of the small gullies observed in the Mangakowhiriwhiri Catchment exhibit this characteristic, but the depth of larger gullies may be controlled by more resistant underlying beds of ignimbrite and weathered ash. In most cases the plunge pool erodes to a depth greater than the general depth of the gully just down slope from the knickpoint and plunge pool (Fig. 2). Thus, the flat channel bed down stream from each plunge pool is a slope of deposition.* In some cases more than 12 inches of loose pumice and sand deposits may overlie the undisturbed pumice deposits that form the base of channel erosion.

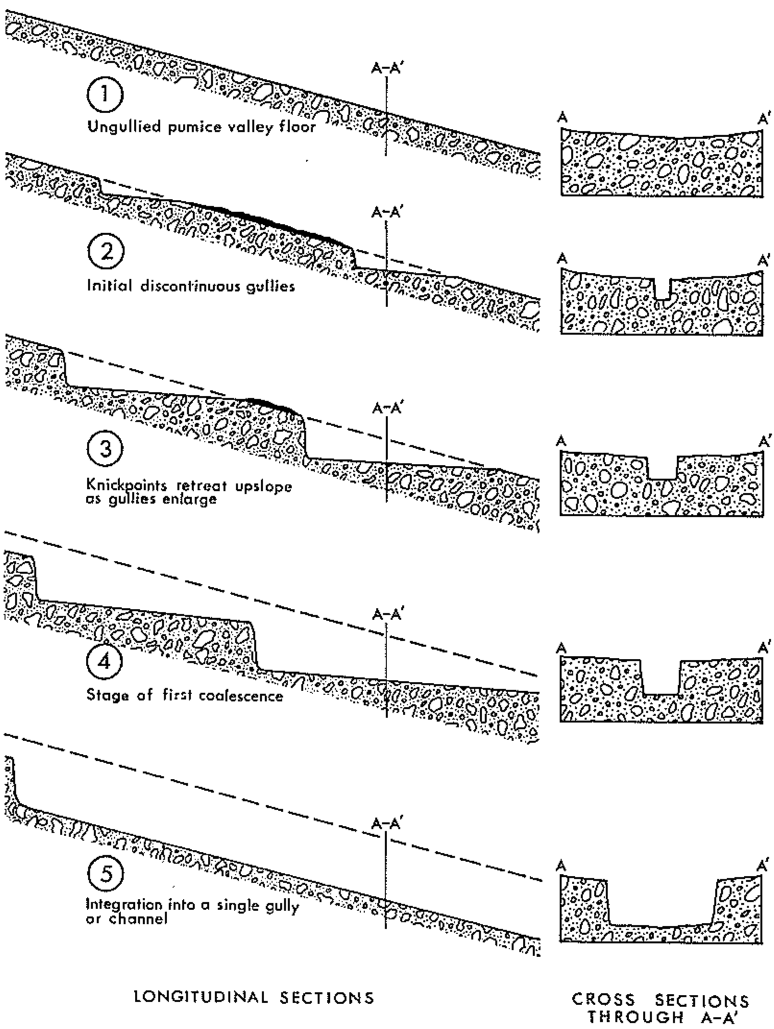
As each knickpoint retreats upstream, coalescence of gullies occurs until integration into a single gully takes place (Fig. 5). Stage 2 in Fig. 5 shows that stage of gully development which existed in the Paritaniwha Valley in 1963, while the July 1966 situation is represented in Stage 4. The cohesive strength of the black, humic layer suggests that it may be some time before complete integration of the discontinuous gullies (Stage 5) takes place.

Beyond the mouths of discontinuous gullies, bed losses apparently cause rapid decrease of competence and water flow ceases almost immediately. Consequently the load of pumice blocks, lapilli and sand is deposited as a broad, low-angled fan just beyond the channel mouth (Fig. 3). Continuous surface water flow across the fan at the gully mouth in the Paritaniwha Valley has made this example atypical. Although flow is confined largely to shallow channels across the fan (Fig. 4), most of the load is carried further down the valley. Until early 1966 most deposition took place on a small area of valley floor less than 400 yards in length, and most of this in the 100 yards adjacent to the channel mouth. Now that surface water flow in the gully is continuous, deposition takes place over nearly two miles of valley floor·

In some gullies water reaches the headwall via subsurface courses. Water that percolates through the pumice soils, moves along definite subsurface channels forming natural pipes. Pipes may form at several levels in a vertical headcut but the largest occur in the pumice layers at their contact with the underlying finer-textured ash or ignimbrite bedrock. As natural pipes enlarge the overlying material is undermined and collapse ensues. Material thus deposited on the gully floor is subsequently removed by aperiodic surface water flow (Blong, 1965, pp.88-89). In many gullies it is difficult to ascertain whether surface water or subsurface water is the agent more active in promoting gully development.

---

* Leopold et. al. (1964, pp.449-451) describe this slope in more detail and give consideration to changes with time.



(Modified after Leopold & Miller, 1956, p.31)

Fig. 5 — STAGES OF GULLY DEVELOPMENT.

Stock trampling along gully sides seems to be an important factor in aiding the widening of gullies, particularly near fence-lines. Frost action, whereby thin layers of material are removed from the gully walls, may also be important in widening gullies, particularly in those gullies where the action of surface and sub-surface water is no longer of great importance.

Although the processes by which discontinuous gullies develop seem quite clear the origin of some gullies appears to be more complicated. In those cases where a headwall already exists, as at the mouth of a tributary valley whose junction with the main valley is discordant, the explanation is quite simple. Retreat of the headwall begins as a result of overland flow of water, or perhaps following natural pipe development. Once gullying has begun, retreat of the headwall is continued by undermining and surface collapse. However, where discontinuous gullies have been initiated on the relatively flat valley floors (Fig. 2), no headwall or knick-point exists, and the above explanation is not satisfactory. Aggradation occurs at various points on the valley floor as a result of ephemeral discharge (aperiodic surface water flow). Continued aggradation steepens portions of the valley fill, until oversteepening reduces the stability of some parts of the valley floor, and gullying begins (Schumm and Hadley, 1957, pp.168-169; cf. Terzaghi, 1950, p.104 ff.; Strahler, 1956, p.577). If a given discharge is not sufficient to initiate gullying, gullying may begin with either greater discharge, or with steepening of the valley floor by additional deposition.

Although only fragmentary evidence is as yet available to support the assumption, it appears that discontinuous gullies develop in those portions of the Paritaniwha Valley floor where the gradient is steepest. With aperiodic surface water flow, a critical discharge is likely to occur more readily on the steeper portions of the valley floor and gullying begins at these points; headward retreat taking place in the manner already described.

In some cases critical discharge occurs first where frictional resistance of the ground surface is lowest and flow velocity thus greatest, i.e. in those areas where vegetation has been removed. Some evidence suggests that discontinuous gullies develop along stock tracks, and that the morphology of the gully (in particular its width and direction) may result, at least in part, from the original character of the stock tracks.

A great deal of pumice material is deposited just beyond the mouths of some discontinuous gullies, and these portions of the valley floor are thus steepened. As gullies are most easily initiated on steeper portions of the valley floor, further gullies may develop down valley from the initial starting point. No definite evidence is available but it seems that this down-valley extension of the gully system has taken place in the Paritaniwha Valley. Furthermore, with shallow channels already cut in the fan surface (Fig. 4) it seems highly likely that this process will continue.

Thus discontinuous gullies that occur on the lower colluvial hillslopes are irregular in appearance, but they result from the processes already described. Slopes are steeper (as with the flat floors of the smaller tributary valleys) and thus lower discharges can initiate trenching. Although the colluvial ash and pumice beds of the lower hillslopes are less homogeneous than the valley floor deposits, gully morphology and the sequence of development closely resemble that described in Fig. 3. On these colluvial hillslopes, however, the black humic layer has a less important role in gully morphology and development.

CONCLUSIONS

The general conditions favouring pumice gully erosion have been described by a number of authors (Glass, 1965; Vine, 1965; Thomson, 1965; Campbell, 1965; Selby, 1966). Land development, compaction, organic matter buildup, increased run-off and decreased infiltration have all been cited as factors influencing the increase in pumice gully erosion. Knickpoint retreat, undermining and collapse, sometimes in association with natural pipe development, are important processes by which headward gully erosion takes place.

Discontinuous gullies are characterised by a vertical headwall, steep sidewalls, a channel bed of very low gradient, and frequently a low-angled fan down valley from the gully mouth. It is suggested that for a given discharge gullying begins either where the slope is steepest or where vegetation is sparsest. Gullying begins at a number of points, but eventually the channels coalesce as knickpoints retreat headwards to form a continuous gully. Deposition of material at the gully mouth steepens the valley floor and a new gully may be formed. There is some evidence that gullying has already occurred and will continue to occur in the Paritaniwha Valley.

Discontinuous gullies have been found to occur in three local environments in the Mangakowhiriwhiri Catchment: (1) at the junction of a discordant tributary with a main valley; (2) on certain areas of flat valley floors; and (3) on lower colluvial hillslopes. The identification of these local environments in which discontinuous gully erosion occurs, and the recognition of those processes that initiate gullying, should make it feasible to predict those areas in which future erosion of this type will probably occur.

The present paper gives results of a preliminary study only. Further work on pumice gully erosion will continue at the University of Waikato.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to Mr M. J. Selby, University of Waikato, for critically reading the manuscript, and to Mr and Mrs J. A. Wilkinson of Marotiri for their unfailingly generous hospitality.

REFERENCES

Blong, R. J. 1964: Some aspects of valley morphology in the Mangakino Basin. **Auckland Student Geographer,** Vol. 1(1), p.20-6.

Blong, R. J. 1965: Subsurface water as a geomorphic agent with special reference to the Mangakowhiriwhiri Catchment. **Auckland Student Geographer,** Vol.1(2), pp.82-95.

Brush, L. M.; M. G. Wolman 1960: Knickpoint behaviour in noncohesive material: a laboratory study. **Bull. Geol. Soc. Am.,** Vol. 71, pp. 59-74.

Campbell, D. A. 1965: "After me the deluge" — pumice lands threatened. **Soil and Water,** Vol. 1(3), pp.8-10.

Dixon, J. K.; R. H. Jackman 1954: Some chemical aspects of pumice soils (a summary). **N.Z. Soc. Soil Science Proc. 1st Conf.,** pp.19-21.

Glass, A. N. 1965: Pumice land conservation problems. **11th N.Z. Science Congress,** unpublished manuscript.

Glass, A. N.; H. Drost 1962: Pumice ash soils: conservation problems and suggested hydrological investigations. **Hydrology and Land Management,** pp.117-24, S.C.R.C.C., Wellington.

Jackman, R. H. 1964: Accumulation of organic matter in some New Zealand soils under permanent pasture; I. Patterns of change in organic carbon, nitrogen, sulphur and phosporus. **N.Z. J. Agric. Res.,** Vol. 7(4), pp.445-71.

Leopold, L. B.; J. P. Miller 1956: Ephemeral streams — hydraulic factors and their relation to the drainage net. **U.S.G.S. Prof. Paper,** 282-A.

Leopold, L. B.; M. G. Wolman; J. P. Miller 1964: **Fluvial processes in geomorphology.** Freeman, San Francisco, 522p.

Packard, R. G. 1957: Some physical properties of Taupo pumice soils of New Zealand. **Soil Science,** Vol. 83(4), pp.273-89.

Robertson, N. G. 1963: The frequency of high intensity rainfalls in New Zealand. **N.Z. Meteorological Service,** Misc. Pub. 118.

Schumm, S. A.; R. F. Hadley 1957: Arroyos and the semi-arid cycle of erosion **Am. J. Sci.,** Vol. 255, p.161-74.

Selby, M. J. 1966: Soil erosion on the pumice lands of the central North Island. **N.Z. Geographer** (in press).

Strahler, A. N. 1956: Quantitative slope analysis. **Bull. Geol. Soc. Am.,** Vol. 67, pp.571-96.

Terzaghi, K. 1950: Mechanisms of landslides. In **Application of geology to engineering practice. Geol. Soc. Am.,** Berkley Volume. pp.83-123.

Thomson, J. L. 1965: The Volcanic Plateau and the erosion problem. **N.Z. Ass. Soil Conservators' Biennial Conf.,** Taihape, unpublished manuscript.

Vine, R. 1965: Pumice land erosion. (3 parts), **N.Z. Farmer,** March 11, pp.1-4; March 25, pp.10-1; April 8, pp.8-9.