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GULLY FORM AND DEVELOPMENT ON KAROO SEDIMENTS IN CENTRAL ZIMBABWE: A PRELIMINARY SURVEY

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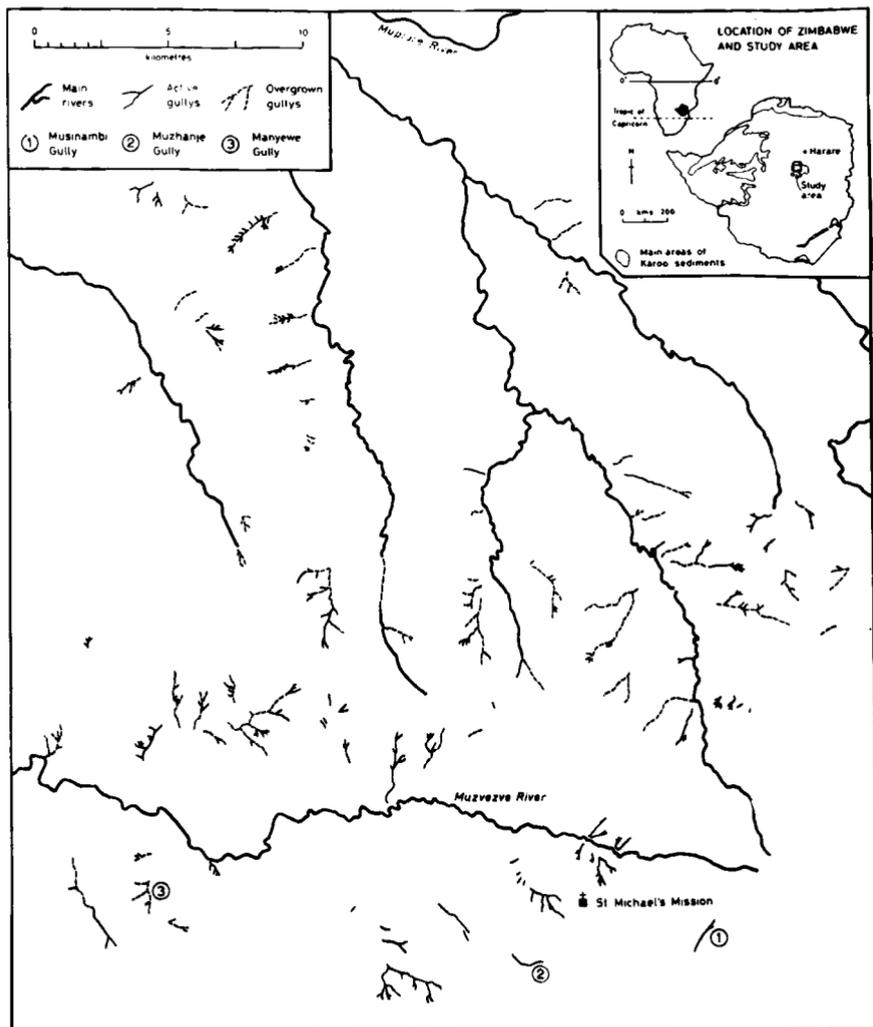
ABOUT ONE TENTH of Zimbabwe is characterized by sodic soils which are especially prone to sheetwash erosion and gullying associated with subsurface piping (Wendelaar, 1976). Although localized patches of sodic soil occur in poorly drained sites on granitic rocks, they are more widespread on Karoo sediments in the north-western, western and central parts of the country (see inset in Fig. 1). Previous research on these soils has been directed mainly at the dynamics of plant-habitat relationships, as a basis for devising suitable methods of reclamation (Dye, 1979; Dye and Walker, 1980), and at the definition of factors influencing the morphology and extension of headcuts (Stocking, 1977 and 1981). Consequently, a great deal is known already about the nature and current rates of erosion on sodic soils. However, very little basic geomorphological research has been carried out on the development and environmental significance of gully systems on the Karoo sediments or, more specifically, the fine sandy colluvium overlying these sediments.

The present exploratory study was carried out in an 'island' of Karoo sediments some 2 380 km² in area, which lies to the south of Harare (Fig. 1). The objectives of the exercise were, firstly, to determine the distribution of active and stabilized gully systems in this locality and, secondly, to evaluate the morphology and sedimentary sequence of selected gully systems. Although it would be unrealistic, at this stage, to propose an evolutionary model and chronological framework comparable with that described by Smith (1982) for large gullies in northern Nigeria, there are good prospects for doing so in the future. In addition, it would be desirable to link such research with the picture of late Quaternary environmental changes identified from recent investigations in Swaziland (Price-Williams *et al.*, 1982).

DISTRIBUTION OF GULLIES

Initial mapping of the gullies was carried out by detailed examination of 1:80 000 aerial photographs. This indicated that gully features are restricted to the western

Figure 1: DISTRIBUTION OF ACTIVE AND STABILIZED GULLIES ON KAROO SEDIMENTS IN CENTRAL ZIMBABWE



half of the area underlain by Karoo sediments (Fig. 1 inset). More detailed mapping of this western area was carried out using 1:50 000 topographical base maps and 1:25 000 aerial photographs taken in 1976. The results of the survey are presented in Figure 1.

A total of 116 gullies or gully segments (where active and stabilized channels were linked) were identified, of which 62 appear to be active and the remainder

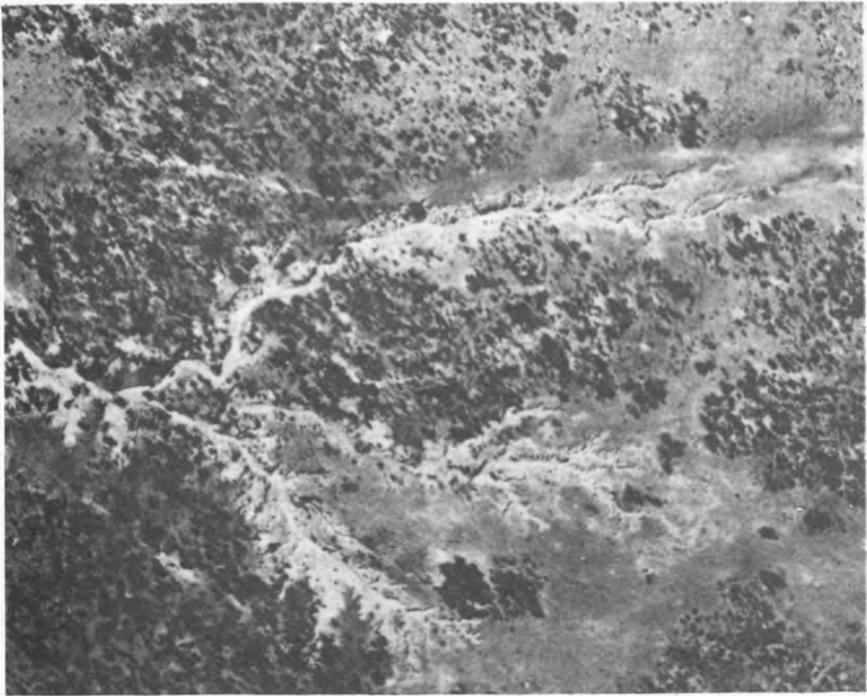
have the plan forms of gullies, but are overgrown with herbaceous and shrub vegetation. The total length of active gullies is 73 575 m giving an average length per gully of 1 187 m and a density of 70 m per km². Although there are fewer stabilized gullies, their total length is greater than that of the active systems giving an average length of 1 605 m per gully and a density of 83 m per km². The density of natural streams in this area, excluding the main rivers shown in Figure 1, is in the order of 425 m per km². Therefore, the gullies represent a significant extension of the overall drainage network.

Three general observations can be made regarding the distribution of the gullies. Firstly, although active gullies occur throughout the area they are especially common in the upper reaches of the Muzveze River. Here gully density is around 237 m per km² — over five times that for active gullies elsewhere in the study area. Secondly, stabilized gullies are prevalent in the lower reaches of the river along with the gullies draining into the northward flowing tributaries of the Mupfure River. Thirdly, there are several gullies where the lower portions of the incised channels are now vegetated and stabilized but where the upper portions are still devoid of plant cover and apparently actively eroding. The reasons for these differences are not known as yet but may relate to variations in the nature of the Karoo sediments and rejuvenation of the major river systems.

Human factors may also be involved in determining the occurrence of these gullies since, with one major exception, all the gullies are located within the Mhondoro and Ngezi Communal Lands. The gullies are thus located in areas used for peasant agriculture and are generally absent from the adjacent commercial farmlands. On a national level there is certainly more widespread and severe erosion in the Communal Lands due, in part, to the population pressures and poor conservation methods (Whitlow, 1987). However, in this area general observations on aerial photographs suggest that there is a poor spatial coincidence of gullies and human factors such as settlement density and extent of croplands, a fact demonstrated previously by Stocking (1978a) for the St Michael's Mission area. Nevertheless, as discussed later, the concentration of runoff along tracks and old plough furrows can have localized effects on the form and enlargement of gullies.

Generally, the active gullies in this area are 'Type 3 gullies' as defined by Imeson and Kwaad (1980); that is, they have U-shaped cross-sections, are formed in colluvial or weathered materials and are characterized by subsurface piping due to the influence of high levels of exchange sodium. Although the gullies are typically dendritic in form (Plate 1), at least three other types are present. Firstly, at least 7 of the 62 active gullies have a compound form (Plate 2; Ireland *et al.*, 1939). This gully form is believed to represent an advanced stage in the degradation of a dendritic system whereby tunnelling between adjacent headcuts results in the formation of residual ridges and the opening out of the gullies as

Plate 1: DENDRITIC GULLY SYSTEM 1:12 500



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channels coalesce. Secondly, there are ten distinctly linear gullies (Plate 3), these being relatively narrow channels with very few lateral headcuts (Ireland *et al.*, 1939). Thirdly, there are three examples of broad, shallow gullies with distinctive bulbous forms (Plate 4). In a detailed study of headcuts on dendritic gully systems Stocking (1978b) recognized five major plan forms (pointed, rounded, notched, digitate and bulbous), these being related to the processes of subsurface and overland flow affecting the headcuts. Similarly, at the scale of the gully system as a whole, the variations in a plan form are likely to reflect dominant processes as well as the nature and depth of the unconsolidated materials within which the gullies are formed. Further field observations are required to verify these points.

CROSS-SECTIONAL FORMS OF GULLIES

The examination of cross-sectional forms and associated sediments along the length of a gully can reveal evidence of infilling and trenching (e.g. Womack and Schumm, 1977; Hannam, 1983). Reconnaissance surveys were undertaken on

Plate 2: COMPOUND GULLY SYSTEM 1:12 500

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two active gullies and one stabilized gully in the south of the study area, the local names for these sites being indicated in Figure 1. Gullies were chosen in this locality primarily because of the availability of 1:25 000 scale false colour imagery taken as part of an FAO/UNDP programme in May 1986. Field maps based on 15× enlargements of this imagery were drawn up prior to fieldwork and proved invaluable in the selection and location of cross-sections for surveying. Five other active gullies were examined briefly to ensure that the surveyed features were typical of the gullies in the area.

Manyewe Gully: This was selected as an example of a stabilized gully, now choked with sediment, in the lower Muzveze basin. The outline plan of the gully (Fig. 2) defines the junction between the relatively flat gully floor covered in dense herbaceous vegetation, a vivid red colour on the false colour imagery, and the adjacent sparsely-wooded degraded slopes. The gully system is 2 810 m in length, up to 6 m in depth and, using the basal width of the infilled floor, between 6 and 42 m wide. The former headcuts have a distinct broad lobate form and are distinguished on the ground mainly through contrasts in vegetation rather than

Plate 3: LINEAR GULLY SYSTEM 1:12 500

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clear breaks in slope. For example, the fringes of the gully floor are characterized by a narrow (3–8 m) zone of stunted, frosted shrubs, mainly *Terminalia sericea* and *Colophospermum mopane* (Fig. 2).

Three morphological units could be identified in this stabilized gully — these being degraded slopes, a sheetwash zone and the gully floor. The degraded slopes, lowered through processes of sheetwash and rilling, were characterized by a dry miombo woodland dominated by *Brachystegia* spp., very similar to that in areas surrounding the gully. The upper margins of these slopes were poorly defined, but generally convex in form. Slope angles (see sections 1–5 in Fig. 2) were generally between 8° and 12° along the main gully, although locally much greater. Extensive areas of bare ground are exposed beneath the discontinuous tree canopy, and numerous calcareous nodules 1–2 cm in diameter occur on these denuded surfaces. The bases of these degraded slopes are sometimes marked by a clear break in slope with the lower sheetwash zone. More commonly, however, deposition of sheetwash material gives rise to a gradual change in slope on rather hummocky ground.

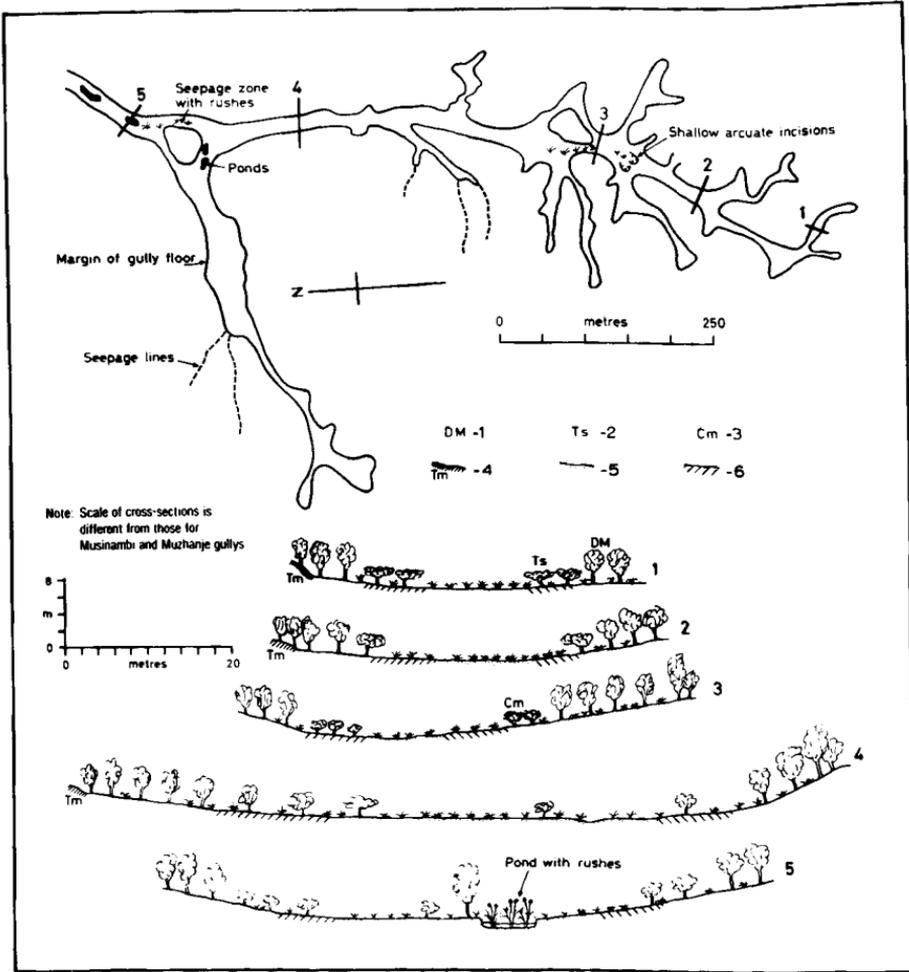
Plate 4: BULBOUS GULLY SYSTEM 1:12 500

Reproduced by courtesy of the Surveyor-General of Zimbabwe

The sheetwash zone is defined mainly because of its distinctive shrub vegetation and via the thin veneer of sediments that mantle its surface. This zone is an area through which sediment is transported from the steeper adjacent slopes to the low angled surfaces (under 4°) on the margins of the gully floor. However, since the grass cover is still very sparse in this zone it is unable to prevent overland flow from removing the unconsolidated surface materials during heavy rainstorms. The gully floor is relatively flat, with dense plant cover and localized strips of rushes (sections 3 and 5, Fig. 2) marking possible seepage lines. Shallow depressions in the gully floor between sections 2 and 3, for example, may have been caused through livestock trampling. However, elongated pools in the lower parts of the gully suggest that subsurface erosion may be undermining the infill sediments. An entrenched section just above the junction with the main stream indicates that the gully infill is at least 1,6 m deep. The exposure consists of intercalated coarse to fine sandy materials and humic horizons, generally well defined and 2–8 cm in thickness.

If the interpretation of this channel as a former, now-stabilized gully is correct,

Figure 2: MORPHOLOGY OF MANYEWE GULLY



Key to symbols used to identify features on gully cross-sections

- | | |
|--------------------------------|------------------------------------|
| dry miombo woodland | 4 termite mound |
| 2 <i>Terminalia sericea</i> | 5 poorly stratified channel infill |
| 3 <i>Colophospermum mopane</i> | 6 sheetwash zone |

it has some interesting clues to offer on the duration and stages of stabilization of gully systems. Certainly, it would appear that it has taken a long time for infilling and lowering of the formerly steep gully banks to occur if one compares the form of Manyewe Gully with that of Muzhanje Gully described below. Since there are good prospects for finding datable organic-rich horizons in the gully infills, it may be possible to establish the period(s) when active sedimentation began in these gully systems.

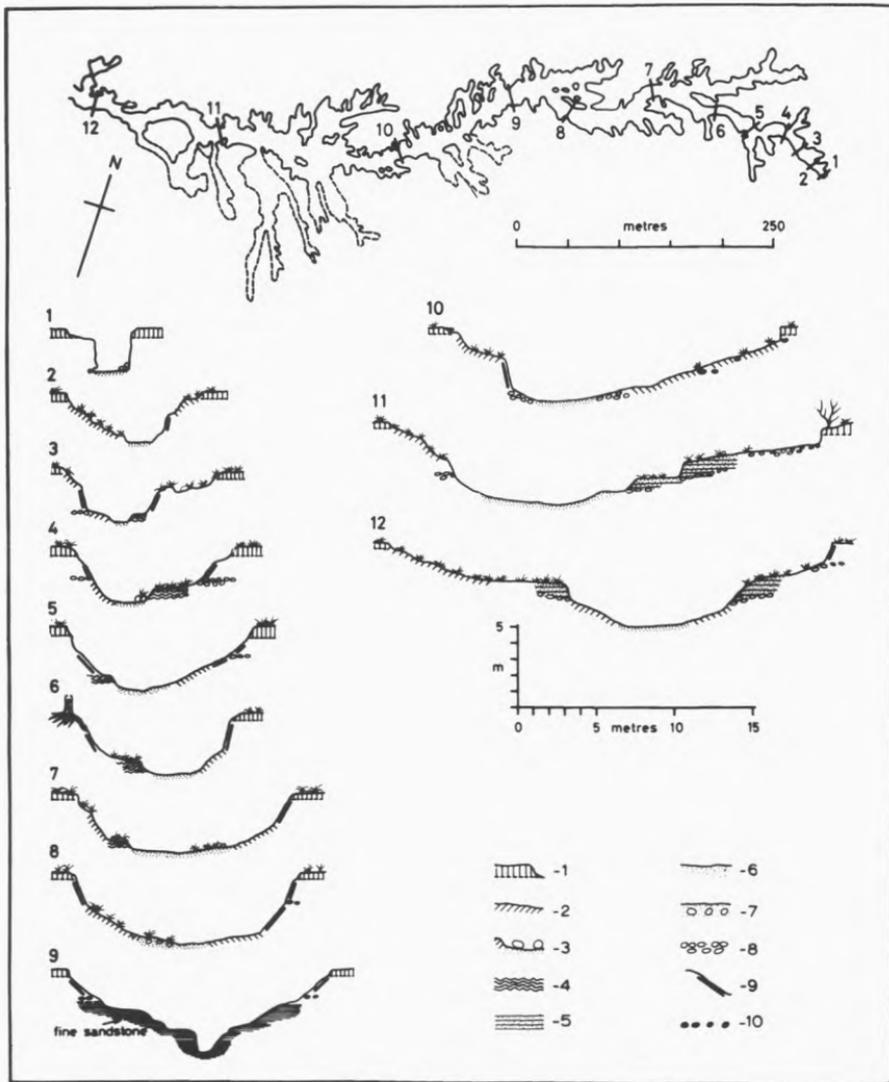
Muzhanje Gully: This was selected as a relatively simple example of a deep, active gully system. Twelve cross-sections were surveyed in the upper reaches of this gully over a length of 720 m, with more general observations being made in the remaining 630 m of the channel (Fig. 3).

The gully is incised in a gently sloping valley floor (Plate 5), with generally well-defined, somewhat irregular margins due to the existence of numerous small lateral headcuts. Coalescence of active headcuts in the past has left a series of residual ridges and knolls (Fig. 3), between sections 8 and 10, for example. There are also several large subsidence hollows, over 2 m in diameter, near the gully upstream of section 8 and these emerge as pipes at various levels in the walls of the gully below section 7. Downstream of section 9 several shallow lateral gullies drain into the main channel, but these are well vegetated and have poorly defined margins.

This incised channel is eroded into deep colluvium within which there are clearly developed discontinuous stonelines. Stocking (1978c) interpreted these as lag gravels buried by colluvium which is up to 3,5 m deep in this particular gully. The upper 1 m of the colluvium forms a distinct layer that probably originated from sheetwash erosion (Fig. 3), but this origin requires further study.

Six profiles were surveyed within 120 m of the headcut on the basis that these would show evidence of more recent (last 200 years) gully extension. The headcut itself is 2,8 m deep and 2,2 m wide with a 'square' plan form. A shallow, discontinuous channel drains into the headcut and most of the surface horizon above the incision has been stripped away (Plate 5). At the base of the headcut there is evidence of lateral undercutting associated with piping (Fig. 3). The sections directly below the headcut are essentially U-shaped with a flat floor covered in recently deposited sediments. Differential erosion of the friable sheetwash material and localized mass movements have resulted in irregular hummocky and stepped gully walls, with the steeper banks (over 40°) being characterized by fluting. There is a terrace-like feature some 0,8 m above the present floor in this upper reach of the gully (Plate 6). It is composed of poorly stratified sediments which could have been produced from materials derived from sidewall erosion rather than movement down the channel. It suggests a recent phase of localized entrenchment of the gully of up to 1,5 m into infill deposits that extend 0,5–0,7 m below the present gully floor.

Figure 3· MORPHOLOGY OF MUZHANJE GULLY



Key to symbols used to identify features on gully cross-sections

- | | |
|-------------------------------|----------------------------------|
| 1 suspected sheetwash | 6 channel infill |
| 2 loose surface material | 7 infill with siliceous boulders |
| 3 slump blocks | 8 siliceous gravels and boulders |
| 4 poorly stratified sediments | 9 fluted gully bank |
| 5 well-stratified sediments | 10 pipe outlets |

Plate 5: MAIN HEADCUT ON MUZHANJE GULLY WITH HANDLE OF SPADE MARKING THE SUSPECTED SHEETWASH HORIZON



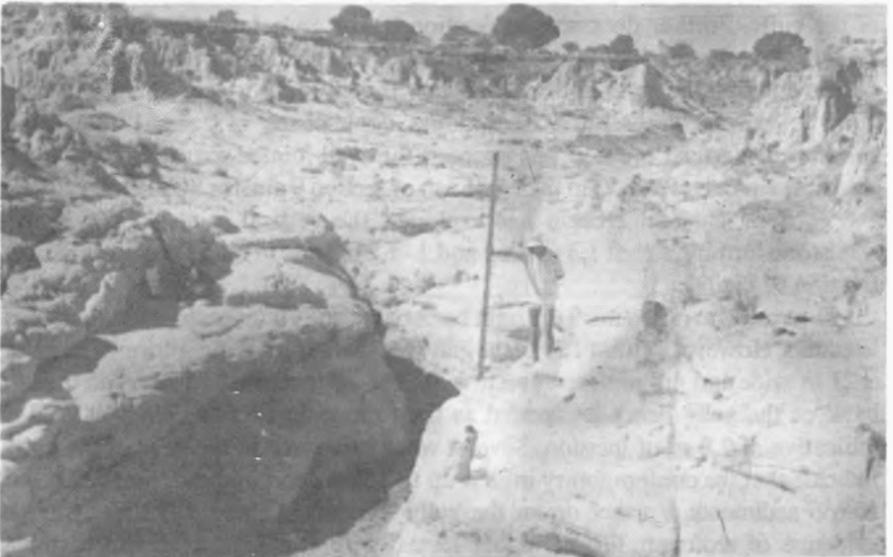
Below the junction of a major right-bank tributary, the main gully widens appreciably to about 13,5 m at section 7, but does not exhibit a comparable increase in depth (Fig. 3). There is still evidence of a terrace feature in this portion of the gully. Further downstream (section 8) the gully increases to a width of 14,4 m and a depth of 4,4 m and the banks are strongly fluted with numerous pipe outlets entering the gully about 2 m below the ground surface. This part of the gully is extremely dissected due to the coalescence of several right-bank tributaries. Vertical incision has exposed the well-jointed, partially weathered Karoo sediments (Plate 7) in the basal 3 m of section 9 and for 80 m either side of this section. Channel erosion has exploited the vertical joints in the Karoo sandstone forming a cleft 1,3 m deep and 1–1,2 m wide in the base of the channel (section 9, Fig. 3).

Downstream of section 9 the right bank of the gully is indented with numerous headcuts. However, within 120 m the gully regains a more regular form. The gully is 21 m wide and 4,8 m deep at section 10, the distinct break in slope on the left bank of the gully being interpreted as the former floor of the channel, and is indicative of 2,8 m of incision. Several wells excavated in the base of the gully indicate that the contemporary infill is up to 1,2 m deep, and overlies weathered Karoo sediments. Further down the gully (sections 11 and 12) there is clear evidence of sediment fills at higher levels, with stratified sediments forming

Plate 6: FLUTED VERTICAL BANK AND RESIDUAL BENCH BELOW SECTION 6, LOOKING UPSTREAM



Plate 7: EXPOSED KAROO BEDS AT SECTION 9, LOOKING UPSTREAM



distinctive benches between 2,2 and 2,8 m above the present gully floor (Plate 8). These sediments comprise intercalated humic and mineral horizons which are generally underlain by a coarse gravel layer of mainly siliceous nodules. These terraces seem to have been produced as a result of deposition in a broad, flat channel with localized fans from lateral gullies. Below section 12 the gully has near vertical walls up to 8 m deep and a very flat floor, this form being typical of the lower reaches of gullies in this area. However, remnants of the infill terraces persist, sometimes on both sides of the channel, for some distance below section 12.

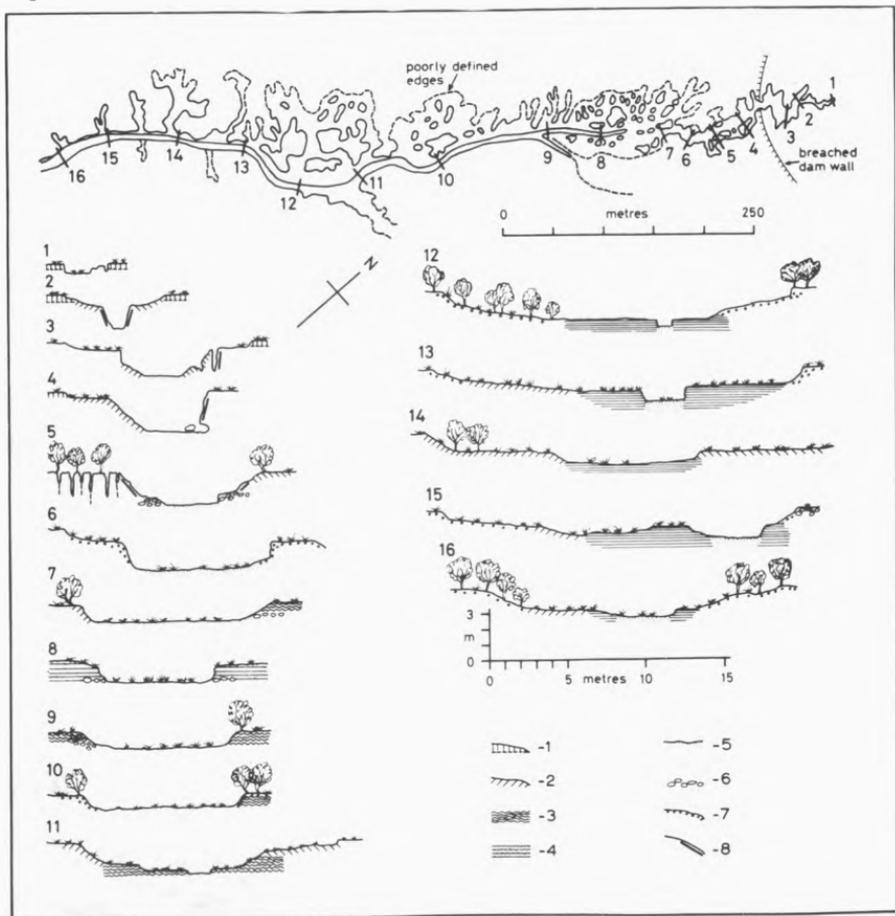
Musinambi Gully: This was selected as an atypical gully system with distinctive badland erosion along its right banks, giving rise to an asymmetric cross-sectional and plan form (Fig. 4). The gully is also noteworthy because relatively recent headward extension has breached a dam. The area surrounding the gully is used mainly for grazing but the extensive network of ridges and furrows to the north-west of the gully indicate that cultivation was more widespread in the past (see Fig. 5A–E). The furrows may, in fact, have contributed towards the erosion of the right bank of the gully through concentration of surface and subsurface runoff.

Sixteen cross-sections were surveyed along this gully as shown in Figure 4. For discussion purposes these can be divided into three groups, these being a zone of

Plate 8: STRATIFIED INFILL IN LOWER REACHES OF MUZHANJE GULLY



Figure 4: MORPHOLOGY OF MUSINAMBI GULLY



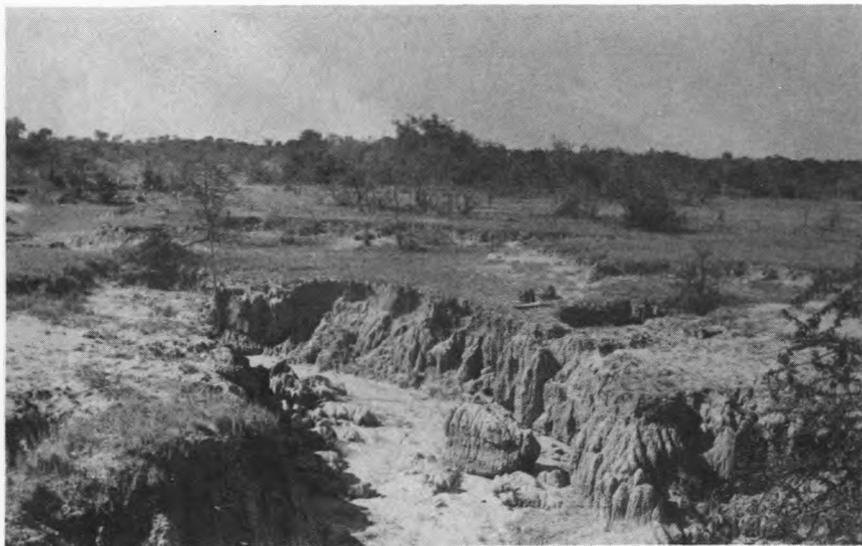
Key to symbols used to identify features on gully cross-sections

- | | |
|-------------------------------|----------------------------------|
| 1 sheetwash | 5 channel infill |
| 2 loose surface material | 6 siliceous gravels and boulders |
| 3 poorly stratified sediments | 7 surface nodules |
| 4 well-stratified sediments | 8 fluted gully bank |

incision (sections 1–6), a zone of deposition (sections 7–10) and zone of entrenched infill (sections 11–16). Below section 5 the cross-section surveys were restricted to the inner portion of the gully because of badland erosion extending 30–80 m back from the main axis of the gully. Wherever possible the sections were located where intact remnants of the former ground surface existed, avoiding severely eroded banks. A series of photographs was selected to demonstrate variations in morphology and infill sediments in this gully (Plates 9–12).

Section 1 (Fig. 4) is at the head of the gully where there is a broad rounded headcut some 0,8 m deep. Subsurface piping is evident at the base of the fine sandy A-horizon and appears to be a major cause of headcut enlargement. Some 30 m downstream of this there is an incision 1,4 m deep and 1,7 m wide, with near vertical, fluted walls (section 2, Fig. 4), giving rise to a clear gully-in-gully form (Plate 9). The subsoil material which has been incised is pale grey-brown in colour with localized iron mottling and a distinctive prismatic structure, typical of the weathered Karoo sediments. Below the inner gully headcut the channel widens rapidly to about 6 m and at section 4, below the breached dam, is nearly 2,5 m deep. Deep vertical clefts and pipe outlets up to 0,35 m in diameter, along with loose fresh debris and blocks of soil on the gully floor, show that there is very active erosion, mainly subsurface in nature, in this reach of the gully. Small (under 0,1 m diameter) holes are present up to 35 m away from the outer gully banks and

Plate 9: GULLY-IN-GULLY FORM OF THE UPPER REACHES OF MUSINAMBI GULLY



indicate the existence of an extensive pipe network. Subsurface tunnelling could well have caused the breaching of the dam wall between sections 3 and 4 (Fig. 4).

Sections 5 and 6 represent a more advanced stage of widening of the gully. Massive siliceous nodules at the base of the gully at section 5 form distinctive steps in the gully wall and have inhibited basal widening. However, erosion of materials overlying the nodules has given rise to lower angled ($45\text{--}50^\circ$) slopes, with numerous deep vertical clefts on the left bank and rounded cavities providing evidence of active subsurface erosion. There is still some sign of the gully-in-gully form at section 6 (Fig. 4), with the inner channel being nearly 9,5 m wide and 1,8 m in depth. Stripping away of the surface soil has exposed material packed with calcareous nodules, 1–2 cm in diameter, which in section display a series of concentric rings, suggesting gradual accretion in a weathered substrate. There is still loose, fresh sediment on the gully floor at this site, but now with a sparse cover of stoloniferous grasses.

Sections 7–10 represent a zone of deposition within the inner gully system which itself is incised into infill sediments (Fig. 4). The channel is rectangular in section and about 7,5–12 m wide and about 1 m in depth, with a well-grassed flat floor (Plate 10). Either side of the gully the surface soil has been removed completely giving rise to a series of residual knolls and ridges, especially on the

Plate 10: CHANNEL INFILL IN MIDDLE REACH OF MUSINAMBI GULLY
LOOKING DOWNSTREAM WITH C. FIRTH AT POSITION OF
SECTION 7



right bank. Some of the materials in the exposed walls of the inner gully are poorly stratified, but of limited lateral extent, while sediments at section 8 are clearly bedded. This suggests that the present channel has been incised into a former gully infill and now the gully is being filled itself, a hypothesis supported by observations in the remaining sections of the gully.

The third reach of the gully, the zone of entrenchment, is in the order of 1.5–2 m in depth, up to 23 m wide and very irregular in cross-sectional form (Fig. 4). There is a well-defined trench about 1 m deep and up to 3 m wide in the gully floor (Plate 11), beginning with a narrow, vertical headcut at section 12 and extending for some 80 m down the centre of the infilled channel. The trench becomes progressively shallower downstream of section 13 until it eventually disappears. The remaining sections, 14–16, show signs of successive reworking of infill sediments which has left a very hummocky channel floor. The entrenched sediments were clearly stratified (Plate 12) with several thin humic bands separated by fine, convoluted layers of fine sandy clays indicative, perhaps, of gradual accretion of material. Shallow, elongated troughs upstream of the present headcut at section 11, for example, suggest that there is an element of subsurface erosion taking place within the infilled gully floor. The main cause of headward migration of the trench appears, however, to be overland flow.

Plate 11: ENTRENCHED INFILL IN LOWER REACH OF MUSINAMBI GULLY, LOOKING UPSTREAM TOWARDS HEADCUT AT SECTION 12



Plate 12: STRATIFIED SEDIMENTS IN ALLUVIAL INFILL NEAR SECTION 12



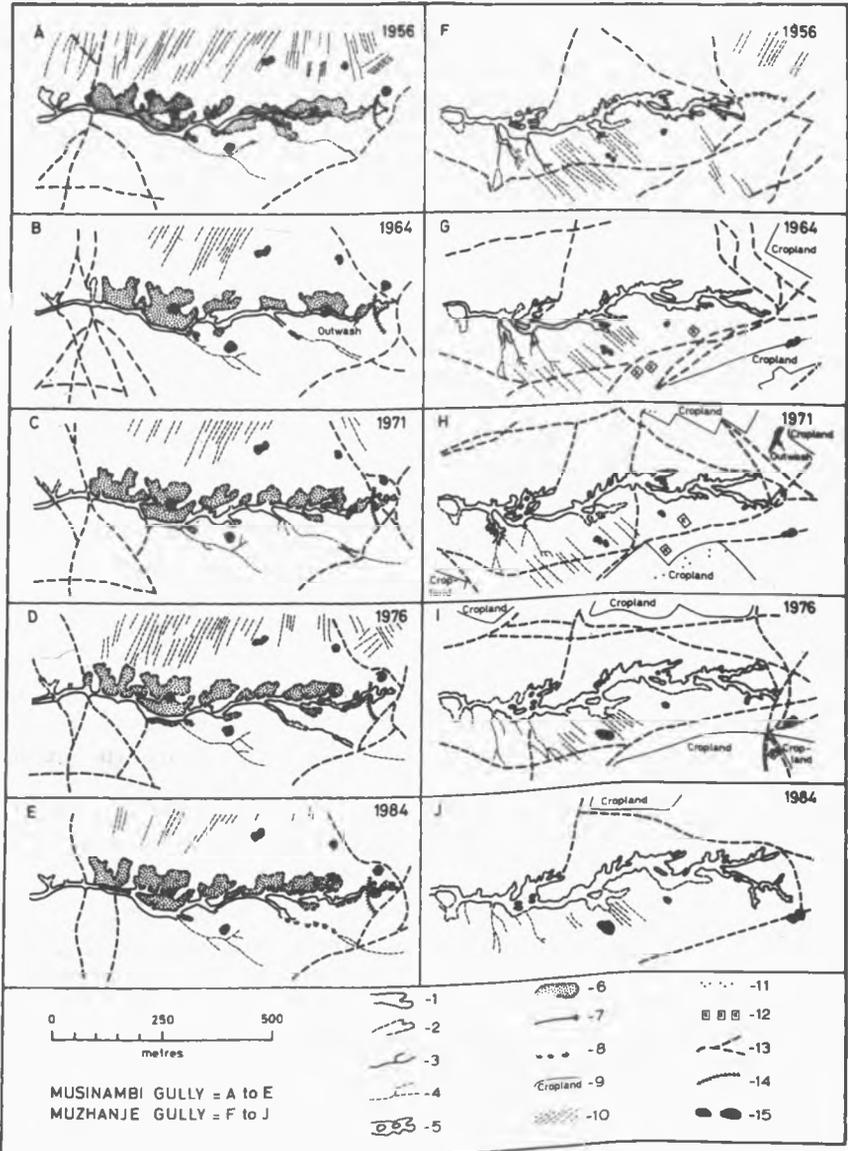
EXTENSION OF ACTIVE GULLIES

Considerable research has been conducted on the rates and processes of gully headcut extension in the Ngezi area. Stocking (1981), who monitored the St Michael's Mission gullies, has shown that headcut extension is a function of drainage area above each incision, precipitation amount, antecedent precipitation and the height of headcut. However, he noted that the order and significance of these variables alters between different headcuts and if the time-scale is changed. In contrast, there has been limited study of the ways in which the plan forms of gullies alter through time, information which is complementary to an analysis of the cross-sectional forms within gully systems. Apart from the false colour imagery referred to earlier, five different dates of panchromatic photographs were available for examination of Musinambi and Muzhanje Gullies as shown in the detailed map sequence in Figure 5. Changes in these two gullies since 1956 are discussed separately.

Musinambi Gully: This gully, as noted earlier, is characterized by a sequence of incision and infill and widespread badland erosion along its right bank. The 1956 photographs show that there was localized degradation along the left bank of the gully (Fig. 5A), but this is not visible on later photographs. This is because the ground surface is obscured by dense thickets of thorn shrubs, mainly *Acacia* and *Combretum* spp., which make it difficult to determine the margins of the badland erosion precisely. This also applies, to a lesser extent, to the right bank where over 14 000 m² of degraded patches were mapped on the 1956 photographs (Fig. 5A). Over the period 1956–84 these patches extended and coalesced, increasing the area to some 16 200 m² by 1984 (Fig. 5A–E). During this time there was gradual extension of flat-floored tributary channels into the badlands. The ground draining into these badlands is crossed by numerous old cultivation furrows which probably concentrated runoff (surface and subsurface) into the gully system, and thus aided the extension of badland topography.

Data on the three main incisions in Musinambi Gully, based on the measurements using 8× enlargements of the original 1:25 000 photographs, are summarized in Table I. Headcut 1 represents the incision above the dam wall, which had been breached by 1956 but had not been subjected to gullying upstream of the breach. Consequently, the estimated 6.5 m advancement of this shallow headcut between 1956 and 1964 probably took place towards the end of this period, the material excavated from above the dam wall forming a small outwash fan below the breach (Fig. 5B). Over the period 1956–86 this headcut extended 43.9 m, being especially active in the two very wet seasons during 1984–6, with an average rate of extension of nearly 1.5 m per year; this is a much slower rate of advancement than the other two incisions (Table I). The main incision in the gully, Headcut 2, was not visible on the 1956 and 1964

Figure 5: PLAN FORM CHANGES IN MUSINAMBI GULLY AND MUZHANJE GULLY, 1956-1984.



Key to symbols used to identify features on
gully cross-sections in Figure 5

- | | |
|----------------------------------|----------------------------|
| 1 well-defined gully margin | 9 boundary of croplands |
| 2 poorly defined gully margin | 10 old cultivation furrows |
| 3 shallow channel | 11 homesteads |
| 4 seepage line along old channel | 12 kraals (cattle pens) |
| 5 residual surfaces within gully | 13 main tracks |
| 6 badlands dissection | 14 former dam wall |
| 7 entrenched gully infill | 15 large clumps of trees |
| 8 seepage zone | |

photographs, possibly because of the clogging of the channel by sediment eroded from the breached dam. Between 1971 and 1986, this headcut advanced 76,9 m at an average rate of 5,1 m per year, being most active in the 1984–6 period of heavier rains. The fact that this headcut is nearly twice the height of Headcut 1 and more prone to the effects of undercutting partially accounts for the differences in the rates of advancement of the upper incisions (Stocking, 1981).

The trench in the lower part of the gully system is a result of upstream migration of a very active headcut or knick point. This was visible in the stream channel below Musinambi Gully in 1971, entering the lower reaches of the gully by 1976 (Fig. 5D). Since 1971 the headcut has advanced some 311 m up the gully at an average rate of 19,4 m per year, nearly four times the rate of the main headcut (Headcut 2). This higher rate of headcut advancement is probably the product of two factors. Firstly, the infill sediments are very poorly consolidated and thus more easily eroded than the surface colluvium and weathered Karoo. Secondly, the headcut in the infill sediments advances owing to channel flow rather than piping. Once a vertical headcut has formed in such infill it is likely to move upstream very quickly. Consequently, even the stabilized gullies could be affected by renewed erosion in the future.

Muzhanje Gully: The changes in plan form of this gully are shown in Figure 5F–J and details on the gully margins and the two main headcuts in the upper part of the gully are summarized in Tables II and III, respectively.

As in the case of Musinambi Gully, there is evidence of old cultivation furrows within close proximity of the gully. These may well have assisted in the formation of lateral headcuts along the left bank in the lower reaches of Muzhanje Gully (Fig. 5F and G), but these headcuts are now stabilized and barely visible on the aerial photographs. More crucial in terms of runoff and erosion has been the gradual encroachment of ploughed fields into the valley bottom and the associated restriction of tracks along the margins of the gully during the 1960s and

Table 1
INCISIONS IN MUSINAMBI GULLY

Period	Headcut 1		Headcut 2		Lower trench	
	Total headward extension (m)	Rate of extension (m/year)	Total headward extension (m)	Rate of extension (m/year)	Total headward extension (m)	Rate of extension (m/year)
From 1956 to 1964	6.5	0.8	—	—	—	—
From 1964 to 1971	17.8	2.5	—	—	—	—
From 1971 to 1976	1.6	0.3	16.2	3.2	70.0	14.0
From 1976 to 1984	9.7	1.2	42.2	5.3	180.0	22.5
From 1984 to 1986*	8.3	4.1	18.5	9.2	61.0 †	20.3
TOTALS/MEAN	43.9	1.5	76.9	5.1	311.0	19.4

* Data derived from Figure 3.

† Period of three years: 1984 to 1987.

Table II
CHANGES IN BANK LENGTHS OF MUZHANJE GULLY

Year	Right bank			Left bank		
	Main gully axis (m)	Estimated length of gully margin (m)	Ratio of length of main gully axis to gully margin	Estimated length of gully margin (m)	Ratio of length of main gully axis to gully margin	Estimated length of gully margin (m)
1956	738	1388	1:1.88	920	1:1.25	
1964	780	1635	1:2.10	943	1:1.21	
1971	796	1898	1:2.38	991	1:1.24	
1976	809	1661	1:2.05	1034	1:1.28	
1984	839	2070	1:2.47	1098	1:1.31	
INCREASE 1956-84	101	682	0.59*	178	0.06*	

* Increase in the sinuosity ratio.

Table III
INCISIONS IN MUZHANJE GULLY

Period	Headcut 1 Main gully		Headcut 2 Right bank tributary	
	Total headward extension (m)	Rate of extension (m/year)	Total headward extension (m)	Rate of extension (m/year)
From 1956 to 1964	42.2	5.3	22.8	2.8
From 1964 to 1971	16.2	2.3	26.0	3.7
From 1971 to 1976	13.0	2.6	9.8	1.9
From 1976 to 1984	29.2	3.7	26.0	3.2
From 1984 to 1986*	5.5	2.8	1.9	1.0
TOTALS/MEAN	106.1	3.5	86.5	2.9

* Data derived from Figure 3.

1970s (Fig. 5G, H and I). Extension of croplands at the expense of grazing areas certainly contributed towards growing pressures upon and accelerated degradation of valley sites in the Communal Lands during these years (Cleghorn, 1966; Whitlow, 1979). As a result of this erosion, peasant farmers since Independence (1980) have been persuaded to abandon fields close to gullies as shown here for Muzhanje Gully (Fig. 5J). This may slow down but is unlikely to prevent further growth of this gully.

It was not always easy to determine the exact position of the gully margins even on aerial photo enlargements. This was partly because of small trees and shrubs growing along the edges of the gully and partly because of degradation of the banks by livestock. Consequently, the configurations of plan forms of the gully between 1956 and 1984 (Fig. 5F–J) are approximations. Changes in gully margin over this 28-year period are given in Table II. The poorly defined, generally stabilized lateral gullies along the lower reaches of the left bank were excluded from these measurements since consistent identification of the margins of these channels was not practicable. A sinuosity ratio (SR) based on comparing the length of the main axis of the gully against gully margin provides an index of the irregularities of the right and left banks. The greater this SR value, the more indented the gully bank.

The left bank, allowing for the exclusion of the stabilized tributary gullies mentioned earlier, is more regular than the opposite bank with relatively low SR values between 1,21 and 1,31 (Table II). Over the 1956–84 period the left bank increased in length by only 178 m, mainly owing to the development and extension of two tributary gullies in the upper reaches of the main channel. The lower of these tributary gullies was poorly defined on the 1976 and 1984 aerial photographs (Fig. 5I and J) owing to the excessive trampling by cattle.

In contrast, the right bank is much more sinuous with SR ratios between 1,88 and 2,47. This is mainly because of the occurrence of three large tributary gullies and numerous smaller lateral headcuts along this bank. The gully margin increased in length by 682 m over the period 1956–84 with the extension of these side channels, and the resulting increased irregularity of the margin is shown by an increase of 0,59 in the SR value. The slight decrease in the length of the right bank in 1976 can be attributed to coalescence of headcuts, leaving isolated ridges and knolls within the main gully (Fig. 5I).

Over the 30-year period, 1956–1986, the main channel (Headcut 1 in Table III) advanced 106,1 m at an average rate of 3,5 m per year, the highest rate of extension being recorded during the first eight years of this period. The large right-bank gully, Headcut 2, increased in length by 86,5 m over the same 30-year period at an average rate of 2,9 m per year. Both headcuts were under 3,0 m in height and affected by basal piping, hence the slightly faster rate of extension of Headcut 1 is likely to be a function of receiving greater volumes of runoff than Headcut 2

according to the relationships defined by Stocking (1981). When these rates of advancement are compared with the equivalent feature in Musinambi Gully (Headcut 2), they are significantly lower. However, the Musinambi gully has a headcut of 1.4 m in height and a catchment area above the headcut nearly twice that of the Muzhanje features — hence the greater runoff entering this shallower incision explains the higher rate of extension. This view is supported by Stocking's (1981) equations which highlight the role of drainage basin area as a key variable accounting for differences in advancement of headcuts.

CONCLUSION

As indicated at the beginning of this article, it would be premature to formulate a general model on the development of gullies on the Karoo sediments in central Zimbabwe. Nevertheless, this reconnaissance study has shown that there are interesting possibilities for further research on these gullies, particularly in terms of evaluating hypotheses on episodic erosion (e.g. Womack and Schumm, 1977) and rates of gully growth (e.g. Graf, 1977). This preliminary survey has also provided some useful information concerning the distribution, morphology and enlargement of gullies in this part of Zimbabwe.

Mapping of gullies shows that these features are restricted almost entirely to the western area of the Karoo sediments in the central part of the country. This appears to be related to differences in mineralogy of the Karoo sediments rather than to the fact that this western area is used for peasant agriculture (Stocking, 1978a). The gullied areas are characterized by sodic soils produced by weathering of plagioclase feldspars and poor drainage (Wendelaar, 1976). The eastern area of Karoo sediments has more leached fersiallitic soils which are erodible and rarely subject to piping (Thompson and Purves, 1978). Both active and stabilized gullies were identified in the Mhondoro-Ngezi area, these constituting just over one quarter the length of the total drainage network. Whilst active gullies were mainly dendritic in form, linear, compound and bulbous gullies were also recorded. The reasons for these differences are not yet known.

The three gullies chosen for field observations differ markedly in their plan and cross-sectional forms. As an apparently stabilized, infilled channel, Manyewe Gully has a broad flat floor and low-angled banks. Musinambi Gully is a shallow gully with pronounced badland erosion along one bank and a gully-in-gully form due to repeated phases of incision and sedimentation. The deeper and longer Muzhanje Gully is more typical of the gullies in the area, with a more complex cross-sectional form and clear evidence of cut and fill sequences. Field observation of several other gullies in this locality indicates that this pattern of infilling and entrenchment is common, but very little is known, as yet, about the factors influencing these processes.

Enlargement of the two active gullies was examined by means of aerial photography for six different dates since 1956. In the case of Musinambi Gully, the photos reveal gradual coalescence of areas of badland and differential extension of headcuts, dependent on factors such as headcut height and sediment type. Subsurface piping and concentration of runoff from old cultivation furrows and tracks affected both this gully and Muzhanje Gully. This latter gully is asymmetric in form in so far as the right bank has numerous active lateral headcuts while the left bank is characterized by several stabilized headcuts. The rates of headward extension on these two active gullies are comparable to those reported elsewhere (e.g. Gregory and Walling, 1973), but the reasons for differences in rates of extension over the period 1956–86 have not been established. It is likely, however, that these variations are a result of rainfall fluctuations although the paucity of gauging stations in this part of the country would make it difficult to verify this possibility.

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