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Erosion of the slopes of gold-residue dams on the Transvaal highveld

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2015-01-19
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	3L39 E	4L34 S	Balmoral N	4L37 N	E	4L36 N	E	4L24 S	S	4L40 W
Mean kPa	(408)V 336	288	313	304	313	345	245	351	353	339
Std Deviation	130	95	125	60	93	104	68	96	100	101
Range	330	320	350	250	150	300	175	245	330	250
No. of Readings	14	8	8	6	6	10	11	10	8	8

V = average shear strength on vertical face of a benched slimes dam

Range = difference between highest and lowest reading

Table 3.2 Average Surface Shear Strength - kPa

V in 3L39 refers to readings taken on the vertical face of the benched slimes dam and is found to have a higher average value than the horizontal slope where ponding of rain water has reduced the surface shear strength.

The shear vane readings on individual dams varies widely but the overall average from dam to dam tends to be consistently in the 250 to 350 kPa range.

The results were then placed in frequency blocks of 50 kPa intervals to observe any outliers or any radical differences from the average.

From the comparison of the frequency observations and the average only one, 3L39 E, appeared to need adjustment for an outlier. This then gave an average of 408 kPa with a standard deviation of 60 kPa.

Overall the averaging system appears the best method for determining the shear strength value but with a check comparison with frequency blocks for observation of peaking and outliers.

3.4.4 SLOPE AND ANGLE MEASUREMENT

The slopes were chosen for differing aspects i.e. north, south, east or west facing to determine if aspect has any relationship with erosion. Similarly the slope of each dam was measured from the presumed water divide which in all cases was the top of the slope, to the toe of the slope of where a stilling pond was built. On 3L39 which is a benched slope the vertical and horizontal slopes were measured and a slope length determined. Similarly an inclinometer was used to measure the average slope angle. As the slope roughness would

distort the overall angle of the slope, a metre length of plank was used on which the inclinometer was placed and several readings taken in mid slope to determine the angle.

The results are shown in Table 3.3

	Slope Length (m)	Slope Angle (Deg)
3L39 E	34,3+	33,4° *
4L34 S	25,1	37,1°
Balmoral	23,0	32,2°
4L37 N	22,0	34,9°
4L37 E	42,0	35,8°
4L36 N	49,4	32,7°
4L36 E	25,7	31,0°
4L24 S	25,4	46,3°
4L40 S	25,4	24,7°
4L40 W	30,0	36,7°

Table 3.3 Slope and Angle measurements

* The average slope angle was calculated from the benching heights and widths, hence  bench angle

+ The average slope length includes vertical and horizontal measurements of each bench.

4.0 RESULTS AND PREDICTIONS OF EROSION

4.1 INTRODUCTION

This chapter, through statistical and regression analysis, tries to validate the use of the erosion tester E T C O M for use in a direct correlation with erosion on slimes dams slopes. There appears however to be no direct correlation with erosion, the reasons for which, will be discussed later. The chapter also describes much simpler methods of predicting erosion and a discussion as to the most effective combination of methods in the prediction.

4.2 E T C O M STATISTICAL ANALYSIS

In chapter 3 the field work described the process of taking readings on each plot in winter and summer throughout the period of one calendar year - April 1984 to March 1985. Appendix B gives the observations and frequency of these observations for winter and summer.

In a statistical analysis it is very easy to give a distorted view of the results unless all aspects are looked at closely. This is clearly seen by taking the average of the readings at the plot. This gives average values in winter ranging from 48 kPa to 156 kPa and in summer from 92 kPa to 260 kPa. However if individual readings are placed in intervals of 25 kPa as shown, a different picture appears. A block histogram tended to confuse the summer and winter readings so the graph representation of observations gives a clearer picture.

Of the ten winter readings, seven registered definite peaks in the range 50 to 74 kPa, one in the 100 to 124 kPa range, one in the 25 to 49 kPa range and one in the 75 to 99 kPa range.

In summer, the readings, tend to be more scattered and the peak although not as well defined spreads over two observation intervals in some cases.

Table 4.1 shows the peaks for winter and summer for the ten plots.

Plot	Peak kPa	
	Winter	Summer
3L39 N	75 - 99	100 - 124
4L34 S	5 - 74	75 - 99
Balmoral N	50 - 74	75 - 99
4L37 N	50 - 74	100 - 124
4L37 E	50 - 74	150 - 174
4L36 N	100 - 124	100 - 149
4L36 E	25 - 49	50 - 74
4L24 S	50 - 74	100 - 124
4L40 S	50 - 74	50 - 74
4L40 W	50 - 74	50 - 99

Table 4.1 Peak E T C O M Readings

Table 4.2 and 4.3 shows the 95% confidence limit based on the average of the individual plots. In a Normal or Gaussian distribution one would expect the 95% confidence limit at approximately 1,96 standard deviations. All except 4L36 N summer reading and 4L40 S winter readings are above 2 standard deviations. 4L36 N has a large standard deviation therefore indicating a wide scatter and this is shown in Appendix B.6 4L40 is the only one to be similar to a Normal distribution.

	3L39		4L34		Balmoral		4L37N		4L37E	
	Summer	Winter	S	W	S	W	S	W	S	W
$\bar{x}$ kPa	178,5	96	136	68	188	117	183	68	168	59
S	69,8	27,4	58	29,2	55,5	83,6	73,4	17,9	65,9	18
	% OF OBSERVATIONS WITHIN RANGE									
$\bar{x} \pm S$)	66,6	66,6	60,4	66,7	41,7	70,8	54,2	66,0	62,5	50,0
$\bar{x} \pm 2S$) Range	89,5	93,3	91,7	93,7	75,0	87,5	81,3	93,6	75,0	81,2
$\bar{x} \pm 3S$)	95,8	100	93,8	100	89,6	88,5	100	97,9	95,8	97,9
95% Confidence Limit A	2,87	2,25	3+	2,21	3+	3+	2,73	2,33	3+	2,83
$\bar{x} \pm$ A.S)										

A = multiplication factor applied to S

x = mean E T C O M reading

S = standard deviation

Table 4.2 95% CONFIDENCE LIMITS FOR SUMMER AND WINTER AVERAGE ETCOM READINGS

	4L36N		4L36E		4L24S		4L40S		4L40W	
	Summer	Winter	S	W	S	W	S	W	S	W
$\bar{x}$ kPa	261	156	164	86	108	61	92	52	92	48
S	113,3	75,5	102,7	83	21,2	17,6	26,1	14,9	37,0	17,1
	% OF OBSERVATIONS WITHIN RANGE									
$\bar{x} \pm S$)	37,2	66,7	50,0	85,4	41,7	62,5	43,8	70,8	60,0	43,8
$\bar{x} \pm 2S$) Range	97,6	89,6	85,4	91,7	70,8	87,5	91,7	97,9	93,3	85,4
$\bar{x} \pm 3S$)	100	93,8	100	95,8	85,4	97,9	95,8	100	100	97,9
95% Confidence Limit A ($\bar{x} \pm A.S.$)	1,96	3+	2,66	3+	3+	2,73	3+	1,89	2,25	2,77

A = multiplication factor applied to S

x = mean E T C O M reading

S = standard deviation

Table 4.3 95% CONFIDENCE LIMITS FOR SUMMER AND WINTER AVERAGE ETCOM READINGS

The E T C O M readings were then plotted versus erosion. As previously discussed the average results of erosion rates were taken as depicting the true picture. Two variations were analysed to see if there was any trend :

(1) Average E T C O M versus average erosion Fig. 4.1

(2) Peak E T C O M versus average erosion Fig. 4.2

The E T C O M readings in Fig. 4.1 showing average values are higher than the peak values shown on Fig. 4.2. The reason for this being that the scatter of values is over a wide range tending to put the average higher than the peak value. This can clearly be shown in the Appendix graphs B.1 - B.10.

In both graphs there is a general tendency for increasing E T C O M readings with increasing erosion. This is the reverse of what one might expect, as high penetration pressures would infer a harder crusting or consolidation of the outer surface and hence a lowering of the rate of erosion.

The procedure of reading E T C O M as it impinges on the dry surface is not representative of the way erosion is initiated or procedes. The predominant characteristic of erosion is that caused by the shearing effect of parallel surface flow, dislodging and transporting particles down slope. Flow over the surface happens when the slimes becomes saturated and no more infiltration can take place whereas E T C O M is used on a partially saturated slope where capillary action may have a significant effect in binding the surface. This may account for the consistent peaking in winter where little rain falls and the capillary effect is greater. In summer the greater scatter may be by cyclical heating and drying caused by intense

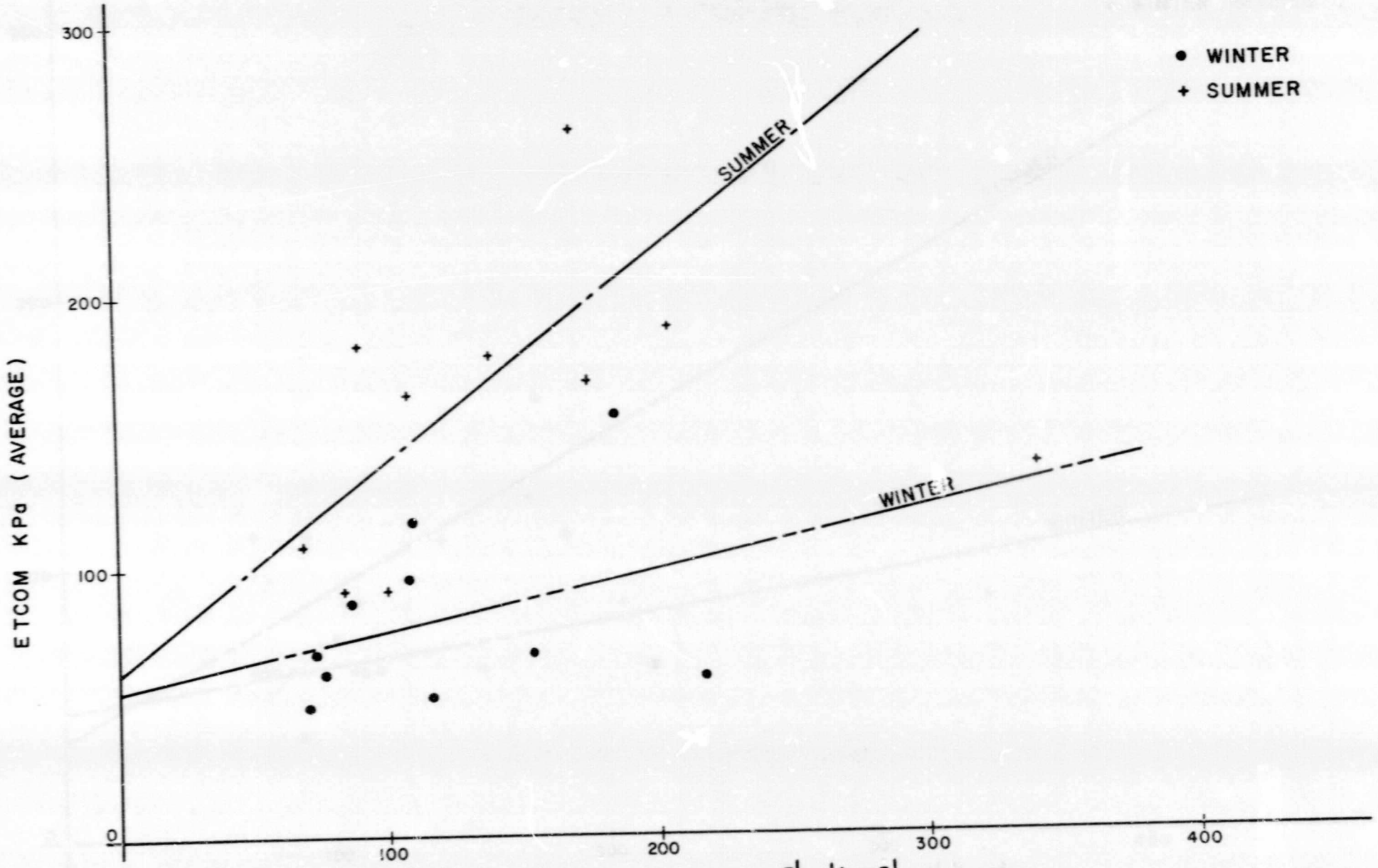


FIG. 4.1 CORRELATION BETWEEN AVERAGE ETCOM EROSION INDEX AND RESIDUE LOSS BY EROSION

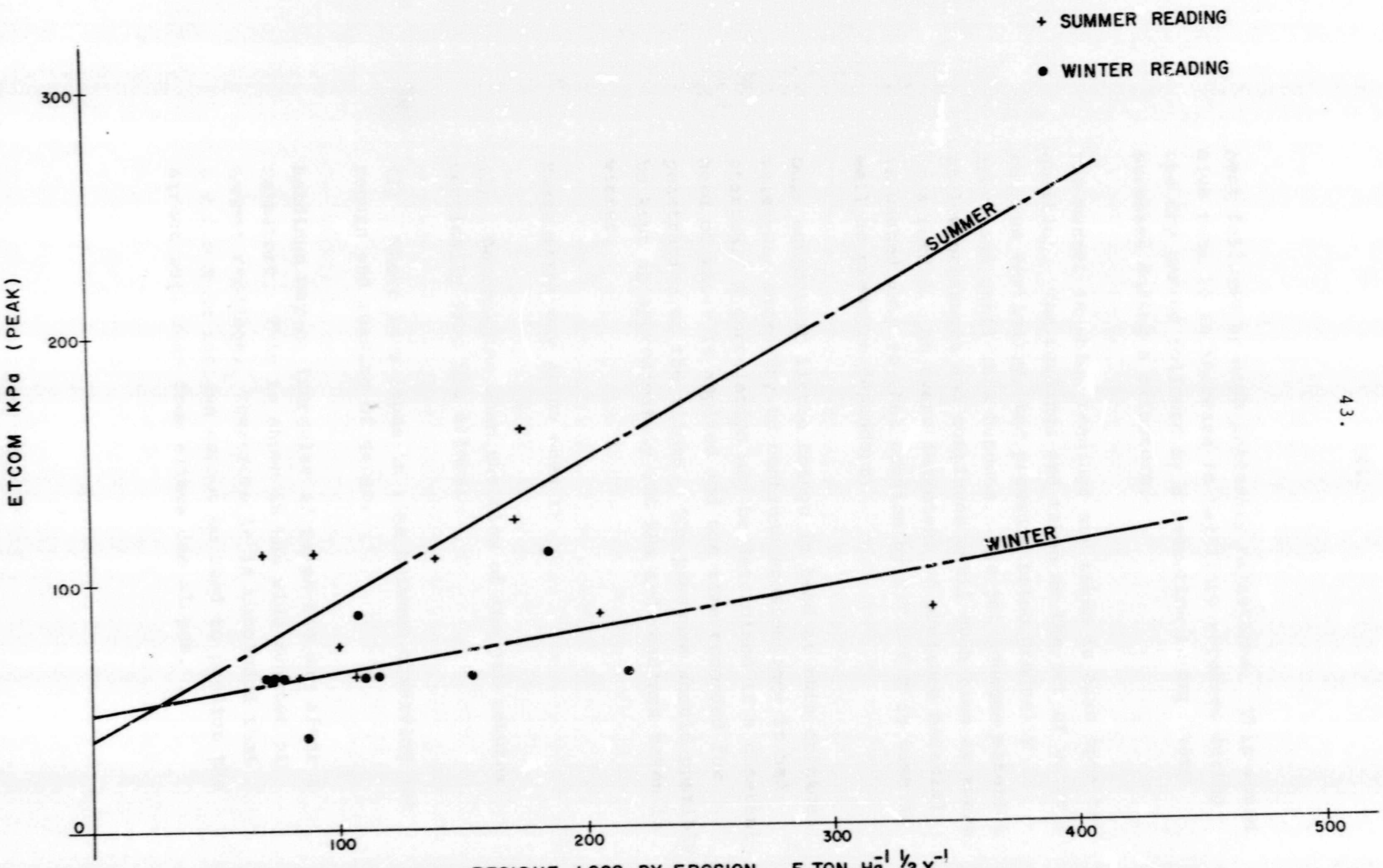


FIG. 4.2

CORRELATION BETWEEN PEAK ETCOM EROSION INDEX AND RESIDUE LOSS BY EROSION

heat followed by high intensity rainstorms. This would give rise to an increase in capillary stresses during the dry period followed by a reduction in capillary stresses during a rainstorm.

The manner in which readings are taken is also open to question. The readings are taken as the jet of water returns vertically, the pressure being gradually increased until this happens. The jet loosens material at low pressures and continues until such time as there is a return. At every increment of pressure material is washed away so that erosion by E T C O M is time as well as pressure dependent.

Dunn noted that little change in head at this critical value was necessary to continue erosion once it had started. A correlation may be determined if a constant head of water is applied and the time recorded for penetration of the slimes. The pressure should possibly be kept at approximately 100 kPa and readings taken in winter.

Human error may arise when :-

(1) Determining when the flow of the jet returns vertically from the slimes;

(2) There is a lapse in time between observing jet return and reading of gauge.

Readings may be irregular if taken the day after a rainstorm. This is shown in the wide scatter of summer readings. Therefore it is concluded that E T C O M on its own cannot be used to predict the direct soil loss from slimes dam slopes.

4.3 PREDICTION BY U S L E AND 'L' 'S' 'T' GRAPHS

4.3.1 EROSION RESULTS

Dunn showed good correlation between shear vane strength and surface shear stress and hence a direct correlation with erosion. It was with this in mind that if it was possible to measure the shear strength as close to the surface as possible then a correlation may result between shear and erosion. This resulted in the use of the 'TORVANE' which was mentioned in chapter 3. With this and the results of measurement of slope and grading analysis it will be shown that it is possible to predict, with certain boundary conditions, the erosion on steep slopes.

From the average readings of the retreat on the plots and determination of the dry density from the samples taken, the rate of the erosion for summer, winter and the total for the year has been computed in tons per hectare per half year. The dry densities average around the 1500 kg/m^3 except for Balmoral which is still in use. Slimes are still being pumped into this dam, hence the higher bulk density. All the other slimes dams are out of commission. Table 4.4 shows the characteristics of the individual slopes. The average erosion was taken at the end of winter and the average total reading at the end of summer. The averages were then subtracted to give the soil loss over the summer months.

The soil loss was then divided by the average rainfall of the three gauges. Table 3.0.

From the results shown it is clearly seen that erosion in winter is only slightly less overall than in summer.

	3L39 East	4L34 South	Balmoral North	4L37 North	4L37 East	4L36 North	4L36 East	4L24 South	4L40 South	4L40 West
Bulk Density	1661	1820	2075	1667	1667	1687	1687	1608	1527	1527
Dry Density	1426	1658	1781	1550	1550	1563	1563	1424	1416	1416
Winter T/Ha/½y	108	154	110	74	217	186	87	77	116	72
Summer T/Ha/½y	140	342	206	91	176	172	109	70	84	61
Total T/Ha/y	248	496	316	165	393	358	196	147	200	133
Winter T $Ha^{-1}{}_{mm}{}^{-1}{}_{½y}{}^{-1}$	2,12	3,02	2,16	1,45	4,25	3,64	1,71	1,51	2,27	1,41
Summer T $Ha^{-1}{}_{mm}{}^{-1}{}_{½y}{}^{-1}$	0,32	0,77	0,47	0,21	0,40	0,39	0,25	0,16	0,19	0,14
Total T $Ha^{-1}{}_{mm}{}^{-1}{}_{y}{}^{-1}$	0,50	1,00	0,64	0,33	0,80	0,72	0,40	0,30	0,40	0,27
L m	34,3	25,1	23	22	42	49,4	25,7	25,4	25,4	30
S %	66*	75,6	63	70	72	64	60	105	46	75
τ kPa	(408)+ 336	288	313	304	313	345	245	351	353	336
$Uc = \frac{D60}{D10}$	20,8	7,0	8,0	9,7	9,7	14,7	14,7	1,4	8,3	8,3

+ ( ) shear strength of vertical face only

* slope calculated from benching widths and heights

mm Millimetre of rainfall

Table 4.4 CHARACTERISTICS OF SLIMES DAM SLOPES

In four out of the ten plots erosion was more in winter than in the summer. The overall average for the ten plots in summer was 149 T/ha and winter 120 T/ha giving an overall average winter erosion which is 80% of the overall average summer erosion.

Reasons for this result may be :-

(1) Wind in winter may play a substantial part in the removal of soil.

(2) Through a decrease in surface moisture the effect of capillary action may be decreased and combined with the wind, particles are loosened and transported. This is substantiated by the lower E T C O M readings in winter in comparison to summer readings.

(3) Silting around the pegs occurred in some cases in summer. This may reduce the overall measured rate of erosion.

(4) The intense heat tended to increase the oxidation process of the slimes and together with consolidation through rainsplash produced a harder "crusting" which would need a higher intensity of rain to penetrate. Hudson[10] in his calculation for soil loss in Zimbabwe only took into account rainstorms with intensities of 25mm/hr or more as necessary to start and prolong erosion.

In the graphs for length, slope, shear strength versus the residue loss the 'x' axis has been chosen in all cases for the residue loss. Although this tends to be against convention, as the residue loss is seen to be a function of slope, length and shear strength, it was depicted in the way shown to give prominence to the rate of residue loss.

In all the graphs the zero point for the axes has been suppressed deliberately for two reasons :

1. No results of residue loss were obtained below 100 ton/ha/year.

2. The data at this stage tends to be limited and only shows a small "window" of results.

Outside the results obtained,and until more data has been collected, it is deemed inappropriate to speculate on the trend of the graphs below 100T/ha/year.

4.3.2 LENGTH AND SLOPE ANGLE

The length and slope angle were plotted separately against erosion and then combined using the U S L E equation : (Fig. 4.5).

$$LS = \sqrt{\frac{L}{100}} \quad (0,136 + 0,097S + 0,0139S^2)$$

The results show a linear relationship in the length of slope / erosion Fig plot 4.3 with two outliers which are 4L34 and Balmoral. This may be the result of higher bulk densities. E T C O M readings Appendix B.2 and B.3 show that in summer the definite peak observation is lower (75 - 99 kPa) suggesting a softer crusting than normal, which would then be more prone to erosion by water.

The plot of slope angle / erosion also show a linear relationship but takes a steepening curve for slimes dams 4L24, 4L40 W and 4L37 N which have angles of 46° 37° and 35° respectively. Fig. 4.4 The relationship shows that rate of erosion becomes almost constant for all slope angles once slope exceeds about 35° and

approaches a value of 150 T/ha/y.

This shows that there is a critical angle beyond which erosion does not occur in a linear relationship with slope angle. This angle appears to be between 35° and 37°.

The shape of the slope may be explained by the fact that, as the slope angle increases towards ninety degrees, residue loss must decrease due to a reduction of the impacting and dislodging effect of rain drops. At the same time, as the slope increases the residue loss must increase due to the shearing effect of the rainwater flow across the surface. Therefore of double branched function as shown in Fig. 4.4 may be expected.

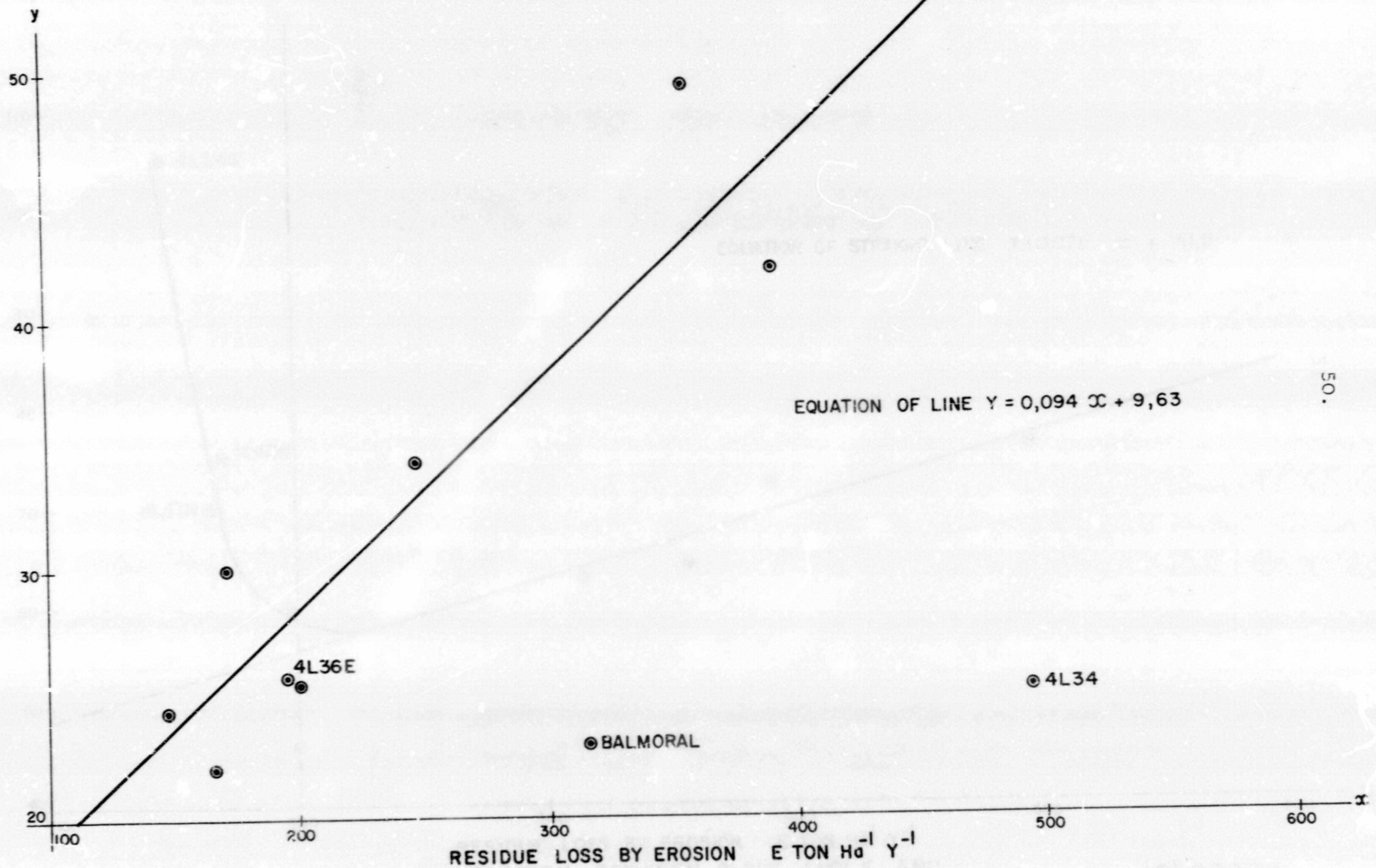


FIG. 4.3

CORRELATION BETWEEN SLOPE LENGTH AND RESIDUE LOSS BY EROSION

Author Dorren Douglas Ian
Name of thesis Erosion Of The Slopes Of Gold-residue Dams On The Transvaal Highveld. 1986

PUBLISHER:
University of the Witwatersrand, Johannesburg
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