Unnamed skeletal soils

The rough stony country has been divided into two groups, on the basis of the geological formation on which they occur.

(a) That of the Devonian igneous country in the south.
(b That of the Cambrian diabase country in the north.

The significance of these associations in relation to agriculture and soil erosion is described in the relevant section later in the Bulletin.

VI. SOILS - CHEMICAL AND PHYSICAL CHARACTERISTICS

The chemical and physical properties have been studied both in the laboratory and in the field. So far as the soils of this survey are concerned, the chemical data are mainly of theoretical value, providing confirmation of the ideas concerning the pedogenesis of the soils which had been developed from their study in the field. The physical properties, however, are particularly important in a survey of this kind, where the main purpose is the study of the soils in relation to erosion. Structure and permeability are the physical properties which have been studied, for it is these which will determine the behaviour of a soil under conditions likely to cause erosion.

The complete analytical data are given in Appendix A, and extracts have been made to illustrate various points of interest which will be discussed below.

1. Mechanical Analysis

The data for mechanical analysis are self-explanatory and require little comment except for two minor points.

Table 10 - Comparison of fine sand silt content in Earlston and Koonda fine sandy loams formed on alluvial parent material derived from different sources

Earlston Fine Sandy Loam						**Koonda Fine Sandy Loam**					
Parent Material Derived from Igneous Rocks			**Parent Material Derived from Sedimentary Rocks**			**Parent Material Derived from Igneous Rocks**			**Parent Material Derived from Sedimentary Rocks**		
Depth (in)	**Fine Sand (%)**	**Silt (%)**	**Depth (in)**	**Fine Sand (%)**	**Silt (%)**	**Depth (in)**	**Fine Sand (%)**	**Silt (%)**	**Depth (in)**	**Fine Sand (%)**	**Silt (%)**
0-5	51.0	24.2	0-3	34.5	37.9	0-2	47.8	30.5	0-4	32.5	43.6
5-9	50.9	26.0	3-6	31.1	42.2	2-5	45.6	28.8	4-9	31.0	44.1
9-12	49.4	27.0	8-13	20.2	33.4	5-15	28.9	24.5	10-18	25.5	35.2
12-20	39.5	27.1	13-24	19.0	25.0	15-40	38.2	21.6	18-38	19.7	31.8
20-24	27.9	25.9	24-44	29.8	31.1	40-45	29.3	11.0	38-48	18.3	36.6
24-38	27.8	22.3	44-60	35.5	25.2	45-65	39.1	28.8			
39-60	35.2	22.4									

The Earlston and Koonda series have been formed on fine sandy alluvial parent materials which have been derived from two sources, in the south from the igneous rocks of the south-eastern mountains and in the central parishes from the Ordovician and Silurian sedimentary rocks of the central hills. No difference between the soils formed on the different alluvia was observable in the field, but the mechanical analyses indicate a slight difference in the proportions of fine sand and silt in soils from the different localities. These are given in Table 10.

The field textures of. all horizons of the Dookie, Major, and Cashel series of soils are lighter than mechanical analysis figures seem to indicate, which is a reflection of the good structure of the soils.

2. Reaction (pH)

The reaction of all surface soils is slightly acid, with the exception of the Major and Cashel series and unnamed Type A, which are alkaline. The distribution of surface and subsoil reactions for the more important groups of soils are shown in Table 11.

Table 11 - Distribution of the reaction 9pH) values for the major soil groups

Soil Group	Horizon	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	9.0-9.4
Red-brown earth	Surface (A$_1$)			6	4					
	Subsurface (A$_2$)		3	4	4	1				
	Subsoil (B)			1	2	6	3	5	4	10
Podsolized soils	Surface (A$_1$)		7	4	2					
	Subsurface (A$_2$)	2	5	3	5					
	Subsoil (B)	4	7	9	5	3	9	1	4	
Chocolate and black earths	Surface (A$_1$)						1	3		
	Subsoil (B)						1	2	10	2
Red loams	Surface (A$_1$)		1		1					
	Subsoil (B)			1	2	1			2	
Lowland self-mulching soils	Surface (A$_1$)			3				1		
	Subsoil (B)			1	1	2	2	3	2	2

3. Total Soluble Salts and Chlorides

All soil types show relatively low amounts of total soluble salts and chlorides, particularly in the upper horizons. The only possible exceptions to this general statement are the Upotipotpon, Cashel, and Major series. The parent material on which the Upotipotpon series has been developed is considered to have been deposited within an impeded drainage system which would be conducive to the accumulation of soluble salts. This is supported by the analytical data which show that in the Upotipotpon soils the total soluble salt content rises at depths below 18 in. to values between 0.2-0.3 per cent, a big proportion of which is chloride.

The Cashel and Major series are considered to have been developed on areas where a high water-table has caused restricted drainage and prevented leaching; the total soluble salt contents for these soils support this view. The considerable difference between the salt content of the Cashel clay loam and the Dookie clay loam is indicated by the following figures:

Soil	Depth (in)	Total Soluble Salts (%)	Chloride (%)
Dookie clay loam	50-72	0.041	0.004
Cashel clay loam	54-78	1.130	0.115

Along the lower slopes of the south-eastern hills on soils of the Warrenbayne and Boho series small areas having high salt concentrations are found. Such areas are subject to erosion, the nature of which is discussed in a later section of the bulletin. Analyses of samples from one of the bare patches were made and the results are quoted below.

Depth (in)	Total Soluble Salts (%)	Chloride (%)
0-6	0.141	0.042
At 12	0.164	0.056
At 24	0.160	0.052

4. Nitrogen and Organic Carbon

The results are of little significance, the only feature worthy of comment being the generally lower values for surface soil of both nitrogen and organic carbon found in the red-brown earth soils in comparison with the podsolized soils, and also that the other major groups of soils have generally higher values than both of these groups.

Both nitrogen and organic carbon values of surface soils are dependent to a large extent on past history of land use and consequently the values are unsatisfactory other than to indicate the general level of the district. The mean values for all surface soils are 0.13 per cent nitrogen and 1.7 per cent organic carbon.

5. Phosphate (P_2O_5)

Some of the soils have been analysed for phosphate content and the results are given in the Appendix. The values are relatively low, being mostly under 0.05 per cent. The red-brown earths, red loams, and chocolate and black soils are somewhat higher, being of the order of 0.05 to 0.07 per cent.

6. Calcium Carbonate

Where this has not been determined separately the values for "loss on acid treatment" indicate the calcium carbonate content fairly well. The main point of interest is the contrast in the calcium carbonate content of the subsoils of the red-brown earths and podsolized soils.

7. Mineral Composition of the B Horizon Colloid

The analytical data and the derived data are given in Table 12. Because of the variability of free ferric oxide in these soils the silica-sesquioxide ratios do not afford such a good comparison of the nature of the colloids as does the silica-alumina ratio.

The tabulated values for the podsolized soils appear to conform with those for the grey-brown podsolic and the yellow and red podsolic soils in the United States; the actual values for the soils of the area appear to be midway between those of representative samples of the two American groups. This is shown by the following figures:

	Grey-Brown Podsolic Soils (USA)*	**Podsolized Soils (NE Victoria)**	**Red and Yellow Podsolic Soils (USA)†**
SiO_2/R_2O_3	2.15-2.63	1.65-2.63	1.33-1.53
SiO_2/Al_2O_3	2.87-3.40	1.98-3.19	1.78-1.90

*Brown and Thorp (1942). † Byers et al. (1935).

The other point of interest to be seen in Table 12 is the contrast between the colloids of the Dookie and Cashel clay loams formed on the same parent material. The Cashel clay loam formed under moist alkaline conditions tends to be montmorillonitic whereas the Dookie clay loam formed under strong leaching conditions with definite periods of desiccation tends ,toward, the kaolinitic type of colloid.

Table 12 - Composition of the colloids of the B Horizon and various soils*

Soil Series	**Depth (in)**	**SiO_2 (%)**	**$FeSO_3$ (%)**	**Al_2O_3 (%)**	**$SiO_2:Al_2O_3$**	**$SiO_2:R_2O_3$**
Warrenbayne	6-19	45.5	12.7	39.2	1.98	1.65
Boho	11-30	47.7	10.5	40.2	2.02	1.73
Earlston	8-13	51.7	8.5	33.0	2.67	2.31
Koonda	10-18	52.5	9.6	33.2	2.68	2.23
Gowangardie	6-15	53.3	8.0	33.6	2.7	2.34
Caniambo	6-10	55.6	10.0	29.7	3.19	2.63
Dookie	8-14	47.6	17.7	30.4	2.66	1.94
Cashel	6-20	56.6	13.7	23.0	4.19	3.04

*Analyses by J. T. Hutton.

8. Exchangeable Cations

The exchangeable metal cations for several profiles together with the percentage of the total which each of the metals constitutes are given in the appendix tables. These soils in common with many other Australian soils show a high ratio of exchangeable magnesium to calcium, particularly in the lower horizons, some of the profiles exhibiting this property to a marked degree. The Warrenbayne and Boho sandy loams and the Gowangardie loam are notable in this respect, the proportion of exchangeable calcium to the total being unusually low.

Some soils show a definite rise in the proportion of exchangeable sodium in the lower horizons and in all cases these soils are those which normally occur on the fiat country or are the lower members of the catenas in which they occur. Two of these profiles, the Upotipotpon clay and the Caniambo loam, are of special interest, the former because it has been suggested that crabhole development of soils is in part due to the properties of a solonetzic subsoil; while in the latter, the higher proportion of exchangeable sodium partly explains the readily dispersible nature of the subsoil which is one of the factors leading to the development of tunnelling erosion occurring extensively on that type.

The only other feature of interest is the high amount of exchangeable cations in all horizons of the Cashel clay loam in contrast to the other soils.

9. Structure and Infiltration Capacity

One of the main difficulties in making a general assessment of the physical properties of a soil type is that they depend largely on the past history of land use of the test area and also to some extent on the time of the year when the study is made. For a full statement of the physical properties of the soils, tests should be made for each type at different times of the year on areas representing all possible kinds of previous land use. This could not be done as a part of the present survey, but some investigations have been made, to indicate broadly the difference between those soil types which normally occur in situations rendering them liable to erosion damage.

(a) Soil Structure

The superiority of the soils in the vicinity of Dookie, with respect to their friability and ease of cultivation, in comparison with other soils of the district, has long been recognized. This superiority is demonstrated numerically by the figures given in Table 13 for the percentage aggregation of these soils.

Table 13 - Percentage aggregation (water-stable aggregates > 0.25 mm) of certain soil types which have never been cultivated and also after cultivation for many years

	Dookie Clay Loam (%)	**Cashel Clay Loam (%)**	**Gowangardie Loam (%)**	**Caniambo Loam (%)**
Never cultivated *(a)*	78.2	61.6	67.0	58.2
Cultivated many years *(b)*	55.6	41.0	28.4	19.5
Ratio *a/b*	1.4	1.5	2.4	3.0

These figures indicate that not only do the Dookie and Cashel soils have a better natural structure than the Gowangardie and Caniambo soils, but also they have a much more stable structure under cultivation, shown by the ratio *a/b*. The values for the Cashel clay loam are not a true reflection of its real structure, for it is a self-mulching soil and much of the material <0-25 mm consists of small aggregates which recombine into larger ones on drying. In this respect they have similar properties to the Wimmera soils as indicated by Downes and Leeper (1939). The most interesting and important difference between the two sets of soils is that of structural stability; the Dookie and Cashel types have shown little deterioration under cultivation, but the Gowangardie and Caniambo types have deteriorated to an alarming extent.

(b) Infiltration Capacity

It was hoped that comparative values for infiltration capacity of the different soil types could be obtained so that some assessment could be made of their relative abilities to absorb rainfall of various intensities. Except for a general indication this has not been possible because the values for any one soil type vary so greatly from paddock to paddock depending on previous history of usage, the differences often being greater than those for two different soil types. A further difficulty was that all the work was done during the summer following an extraordinarily long dry period and consequently other factors which could not be considered normal apparently became operative.

Table 14 - Infiltration capacity (points/hour) for different time intervals on the Dookie clay loam and the Gowangardie and Caniambo loams

		5 min	**15 min**	**1 hour**
Uncultivated (under pasture)	Dookie clay loam	2060	1590	830
	Gowangardie loam	540	550	590
	Caniambo loam	810	800	670
Cultivated	Dookie clay loam*	810	800	670
	Gowangardie loam*	210	150	120
	Caniambo loam†	460	310	210

*Under stubble.
†Under fallow.

The results of the infiltration tests are given in Table 14 which indicates the amounts infiltrated in points per hour for each of the time intervals. The results are the means of six tests run concurrently on each area, and consequently the anomalous behaviour of the Gowangardie and Caniambo loams under pasture, in which there is an increase of infiltration capacity with time, can be assumed to be real. Some of the other tests showed similar trends after one hour; such behaviour can only be explained in terms of the unusual dryness of the soil at the time of the tests. This dryness may have produced two factors tending to hinder infiltration at first, namely the large amount of soil air which would be trapped by the water and/or the development of a surface crust which is difficult to wet and more impermeable than usual but ameliorates after being wetted for one or two hours. The only test showing the normal decrease of infiltration rate with time was that on the Caniambo loam fallowed area.

In spite of the anomalies of these results they do show the distinct superiority of the Dookie clay loam when compared with either the Gowangardie or Caniambo loams, and also indicate the more serious deterioration of the physical condition of the latter soils after some years of cultivation.

The results in Table 14 have been given in points per hour so that they may be studied in conjunction with the figures for probability of high intensity rainfall given in Table 2. However, in doing so, it should be remembered that the figures in Table 15 are higher than the real infiltration capacity of the soil because with this method of measurement (Plate 3, Fig. 1) there is some lateral spread of the water infiltrated below the depth to which the containing cylinder has been sunk into the ground.

It was because such static measurements of infiltration capacity were not considered really satisfactory that an attempt was made to measure it under dynamic conditions. For this purpose an iron frame 4 feet long and 6 inches wide was driven into the soil and 2,000 cc. of water was delivered at the up slope, at a known rate. The amount of run-off and the time taken for the water to reach the outlet were measured, thus enabling the calculation of the amount absorbed and the average initial velocity of flow. The average time to deliver 2,000 cc. was 75 seconds. The minimum intensity of rainfall represented by this treatment is calculated on the assumption that all the water could be placed in that time over the whole area enclosed by the iron frame, but it is actually greater, because the water is being added to a small area at one end of the frame. Using the above assumption such a delivery rate represents a minimum intensity of 36 points per minute, a very much larger intensity than would be expected to occur in reality.

Tests were made on a variety of slopes on the Dookie clay loam but the beginning of the winter rain prevented a comparable series being made on the Gowangardie loam. A few tests were made on the Gowangardie loam at an early stage of the investigation and from these results it is possible to make some comparison between it and the Dookie clay loam. Table 15 shows the infiltration values for the first run and the means of subsequent runs on the covered and bared areas for each soil.

Table 15 - Amounts of water infiltrated by each of two soils types from a total of 2,000 cc. poured over the surface

		Covered (cc.)	**Bared (cc.)**
Dookie clay loam	1st run *(a)*	1080	520
	Subsequent runs *(b)*	720	250
	Ratio *a/b*	1.5	2.0
Gowangardie loam	1st run *(a)*	940	470
	Subsequent runs *(b)*	480	180
	Ratio *a/b*	2.0	2.6

The ratio *a/b* in each case indicates the decrease in infiltration capacity in runs subsequent to the first and shows the superiority of the Dookie clay loam in this respect as well as in the total amount infiltrated. The terms "covered" and "bared" refer to two conditions under which the infiltration was measured. Pairs of tests were made side by side, with the dry grass vegetative cover retained on one but removed on the other, and the above terms refer to those conditions respectively. Each test consisted of adding 1,000 cc. at the standard rate on each of five occasions as soon after each other as possible, and it was found that the infiltration for runs subsequent to the first remained relatively constant. The means of these values have been used for the calculation of the ratio of the infiltration covered/bared, a useful figure for comparing results of tests made under a variety of minor soil differences.

The tests on the Dookie clay loam reveal some interesting trends with regard to infiltration in relation to slope.

Table 16 - Percentages of total water absorbed by Dookie clay loam for both covered and bared conditions tested on various slopes

Slope	**0-6° (%)**	**6°-12° (%)**	**>12° (%)**
Covered *(c)*	40	31	26
Bared *(b)*	13	12	16
Mean of *c/b* cvalues	3.7	3.2	2.1

Table 16 indicates the decrease in infiltration with an increase of slope for the areas on which vegetative cover had been retained, but for the bared soils there has been a reasonably constant infiltration for all slopes. Because of this, the values of the ratios of covered/bared for infiltration can be used to indicate the trend better, for they are the means of the ratios computed for Individual pairs of tests and consequently eliminate the effect of minor soil structural changes from place to place. These figures indicate a much larger difference between slopes of 6°-12° and >12° than between those of 0-6° and 6°-12o, which is only to be expected.

VII. SOIL EROSION

It has already been demonstrated that the climatic conditions in this area are conducive to erosion if the land is not managed carefully. The alternate wet and dry nature of the seasonal climate and the possibility of dry seasons which prevent the production of adequate vegetative cover to protect the land from the summer and autumn rains, constitute a menace to the land which the farmer has not realized until considerable damage has been done. The equilibrium between vegetation, soil, climate, and animal which existed prior to settlement has been upset, and during the past 70 years no conscious attempt has been made to establish a new equilibrium.

An opportunity to set up a new equilibrium having a higher productive capacity than the original set of conditions was presented after the clearing of the forest, for the country grew a relatively good pasture cover in place of the trees. However, ignorance of the climatic variability and the real productive capacity of the land gave rise to an unduly optimistic system of land husbandry. Excessive grazing and extensive cultivation of areas unsuited to such treatment has lead to the present condition of the area which is indicated by the maps, showing the nature and extent of the damage due to soil erosion.

Since erosion on the area is mainly due to the agency of water it is reasonable to assume that the damage will be confined to the hills and land adjacent to them. The flat country, apart from a few minor exceptions, is undamaged, but practically the whole of the hill country has been affected by erosion to some degree. Figure 9, showing. the parts of the area which have suffered erosion damage, is virtually art indication of the hill country and. the flatter land adjacent to it. The most badly eroded country is in the 41% to the south of the Broken River and the least affected hill country is that in the south-eastern part of the area. The fact that the south-eastern hills are least affected is strange because the slopes are steep and the soils are erodible. Possibly the stony appearance and the steep slopes led landholders to assess the stocking rate more truly than in other parts of the area and consequently a better vegetative cover has been maintained on them.

Before specifically discussing the erosion of the area it is important that the objectives of soil erosion maps and mapping be defined. Soil erosion in not a suitable subject for mapping unless the ultimate objective is some programme of soil conservation; consequently it is essential that any mapping of erosion should be done with this end in view. This means that fine distinctions between erosion classes on the basis of the amounts of topsoil lost are no longer of primary interest, but that broader categories which indicate the present state of soil erosion on an area and the ease or difficulty with which It can be reclaimed are the basic concepts. From this arises a utilitarian conception of mapping, the result of which is the production of a map that indicates to the soil conservation worker those areas requiring the following treatment:

1. Little or no attention at present.
2. Immediate attention to prevent further damage which may relegate, that land to an even lower category.
3. Major conservation and reclamation work which may have to continue for a long period and for which adequate methods may not yet have been devised.

This approach is all the more reasonable when the temporary nature of a soil erosion map is considered, as it is merely an assessment of the condition of an area at some specified time and liable to constant change in improvement or degeneration. Having adopted this utilitarian concept of erosion mapping, the best way to define the erosion classes is on the basis of their effect on land use, for this gives the necessary subdivisions with respect to conservation and reclamation that are desired. The finished soil erosion map should indicate the distribution of the various kinds of erosion and, for each kind, the degree in accordance with the above classification, along with an indication of any unusual forms of erosion.

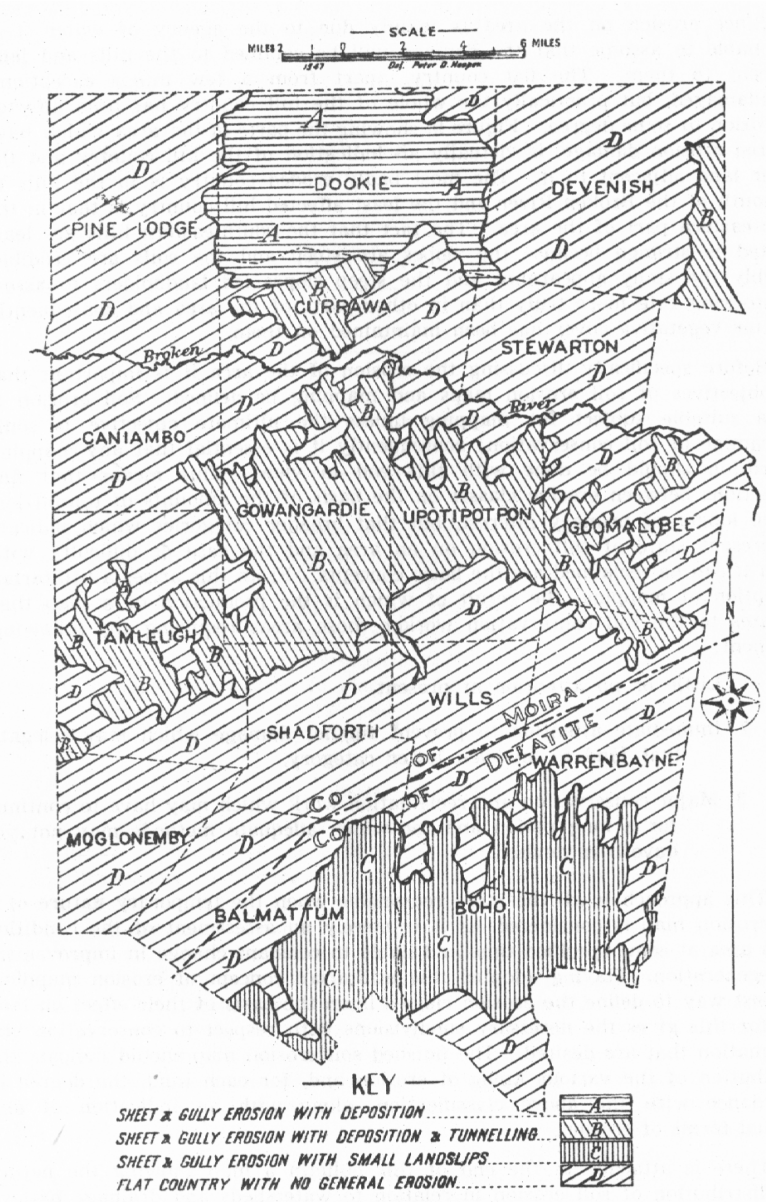
There is attached at the end of this bulletin a map showing the nature and distribution of soil erosion in relation to watersheds and drainage pattern and also topography for the tour parishes surveyed in detail. The classification used for compiling the maps described in detail below is virtually the same as that used on a previous erosion survey In South Australia (Taylor and Stephens .1943; Stephens *et al.* 1945).

1. Erosion Classes

(a) *Sheet* Erosion

Class 1 - This class of erosion is represented by those areas of land on which there has been no appreciable effect on production due to erosion. On pasture land there is a good even sward with few or no bare patches and on cultivated land there is usually an even depth of surface soil and an absence of any kind of gullying except those which are definitely attributable to excessive run-off further up the watershed.

Fig 9 - Map showing the occurrence of soil erosion in the sixteen parishes



Class 2 - This class of erosion is represented by those areas of land on which erosion is evident but only to the extent that reclamation can be achieved by relatively simple control measures and perhaps some change in the cultural and grazing policy. There are definite signs of loss of production as shown by numerous bare patches in the pastures or relatively thin cover; on the cultivated land there is an unevenness in the depth of surface soil. In some places small patches of subsoil may show after ploughing or there are definite signs of weak spots in the crop.

<u>Class 3</u> - This class includes the definitely bad land, the subsoil has been uncovered in many places and in certain soil types excessive amounts of stone occur in the surface. On pasture land the fodder plants have deteriorated and their place has been taken by poor quality ephemeral species, if there is any vegetative cover at all.

The meanings of these three sheet erosion classes can be summarized briefly in the following way: Class 1 is represented by those areas of land on which there has been no serious erosion and consequent loss of production; Class 3 land has already become unproductive or at least it will need to be removed from production if its final reclamation is to be successful; and Class 2 is represented by all stages between these two classes, such areas being in need of soil conservation treatment to prevent further deterioration.

(b) Gully Erosion

Class 4 - This class refers to small gullies which can be easily and safely crossed by agricultural implements and consequently have not impaired the efficiency of the farmer in the management of the paddock. These gullies are usually associated with sheet erosion approaching or of Class 2 type, and the damage caused by them is often concealed from the casual observer for they can be ploughed over and apparently eliminated. The elimination is only apparent, however, for they scour again during the next heavy summer rain.

Class 5 - This class refers to gullies which cannot be crossed by agricultural implements and as a consequence they subdivide the paddocks, often to such an extent that these become useless for arable agriculture. The Class 5 gully represents the final development of Class 4 gullies which are allowed to go unchecked, or sometimes they are the result of enlargement of natural watercourses due to excessive run-off from sheet-eroded watersheds.

With both these classes of erosion other symbols are used with the class number on the map to denote special meanings. Where either of these classes of gully occur frequently, that is at intervals of less than 5 chains apart, they are denoted by the symbols 4F and 5F; and where the gullies have apparently become stabilized they are denoted by the symbols $\bar{4}$ and $\bar{5}$. The symbol 5V refers to the deep steep-sided gullies which would require considerable earth movement if they are to be graded and filled subsequent to the treatment and prevention of excessive run-off from the watersheds. The symbol 5T is used to denote a special form of erosion known as tunnelling, since the ultimate development of this form of erosion gives gullies of the Class 5 type.

(c) Deposition

Class 6 - This represents deposition which has had no deleterious effect on production, in fact in some places it may have improved the land by virtue of the accumulation of fertile topsoil and animal manure.

Class 7 - This represents deposition which has had an effect on production, the deposited material being rock, gravel, or raw sand debris.

Classes of wind erosion are not important. During the, summer months there is a certain amount of dust blown up from fallow paddocks, but the frequency and intensity of such occurrences do not at the present time constitute a danger. This of course does not imply that such occurrences cannot be more frequent, and consequently any form of land management which can reduce them is preferable to continued neglect. However, in view of the nature of the soils and climate it seems unlikely that wind erosion can ever be a major problem or cause damage on anything like the same scale as water erosion in this area.

2. Discussion of Erosion

When examining the soil erosion map it should be realized that the boundary lines do not strictly delineate areas of one class of erosion from another, but merely areas in which one or other of the classes predominates.

The general map of the sixteen parishes (Fig. 9) indicates those parts of the area which have been damaged by erosion. There are some isolated cases of damage in areas not included within these boundaries but they are negligible. The map indicates four main areas which have been damaged and these areas correspond with specific topographic regions:

1. The Dookie and Currawa hills which have suffered sheet and gully erosion and also deposition (Plate 3, Fig. 2; Plate 4).
2. The Goorambat hills, which are just a small portion of a fairly large area of hill country to the cast of the survey boundary, have suffered sheet and gully erosion along with deposition.
3. The Gowangardie-Upotipotpon hills, which have suffered more damage than any other part of the area, the damage being of all kinds including tunnelling, the incidence of which is widespread and severe (Plate 1, Fig. 2).

4. The south-eastern hills where erosion has not been severe. Some sheet erosion and landslips have occurred and in some places severe gullying. There are a few examples of severe sheet and gully erosion on the lower slopes which have been induced by high salinity.

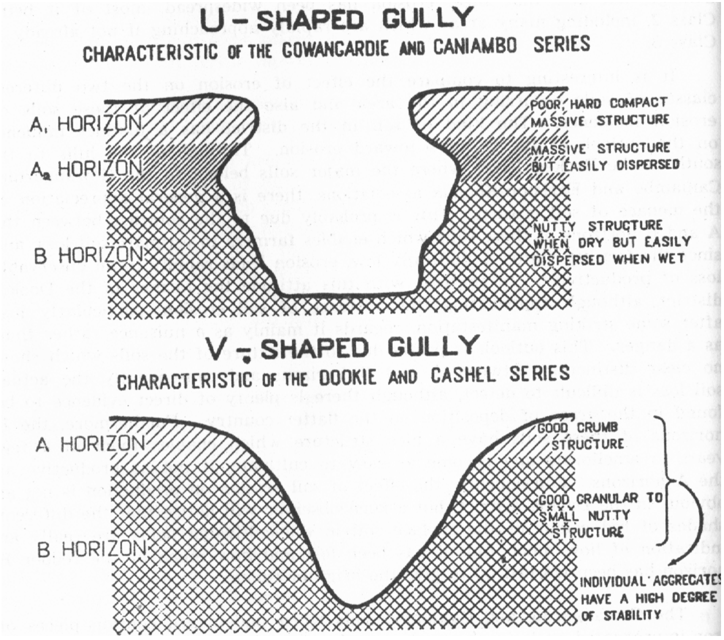
The map of the four parishes surveyed in detail shows the erosion damage at the time of the survey and constitutes a basis for the soil conservation worker to plan soil conservation on each individual farm within a specific catchment area. Such a map indicates not only the centres of bad erosion damage, but also that sheet erosion has been widespread, most of it being Class 2, including many areas which are rapidly approaching if not already in Class.3.

It is interesting to compare the effect of erosion on the two different classes of soils occurring in the area and also the effect of these soils on erosion incidence. The kind of soil in the district has a distinct influence on the outlook of the farmers toward erosion. Throughout the hills to the south of the Broken River where the major soils belong to the Gowangardie-Caniambo and Earlston-Koonda associations, there is a general appreciation of the menace of soil erosion. This is probably due to the contrast between the A and B horizons of these soils which enables farmers to estimate soil loss, and since the fertility status is naturally low, erosion leads rapidly to an observable lost of productivity. In contrast with this attitude the farmer in the Dookie district, although appreciating the existence of soil erosion, particularly just after some striking manifestation, regards it mainly as a nuisance rather than as a danger. This outlook is partly due to the nature of the soils which show no clear distinction between A and B horizons and consequently the actual soil loss is difficult to detect, although there is plenty of direct evidence to be found in the areas of deposition on the flatter country. Furthermore, the B horizons of these soils have a nice structure which enables them in a few years to ameliorate and become as easy to cultivate, if not as productive as the A horizons. Consequently the effect of soil erosion on production is not as obvious in the Dookie district, but a keen observer will notice that the different shades of red colour of the surface soil in the cultivated fields are really an Indication of how much topsoil has been lost and how much of the redder B horizon has been worked up to give the brighter colour.

The Gowangardie and Caniambo soils when undamaged contain pieces of iron-impregnated rock in the surface soil. After erosion, when much of the fine earth portion of the soil has been removed, the stone remains until ultimately on badly eroded areas, such as those associated with tunnelling, the soil surface may be covered by a mantle of stones. These soil series have a kind of defence mechanism against sheet erosion in that they can develop a hard, impermeable crust on the surface due to the beating action of raindrops. Such areas seem to be protected against further sheet erosion once this hard crust has become covered with lichens. Although such a mechanism may prevent further sheet erosion of that particular area, it has also reduced the productivity to zero and the fact that it is so impermeable constitutes a danger to land lower down the watershed by virtue of the excessive run-off.

The Dookie and Cashel soils, because of their good structure giving aggregates of larger dimensions than in the Gowangardie and Caniambo soils, appear to be resistant to erosion up to a certain limit; however, under certain conditions when the water flow reaches a velocity which enables aggregates of such a size to be carried, these soils erode as readily as any others. This may account for the more erratic incidence of erosion in the Dookie district when compared with the even and universal distribution in the Gowangardie area. Erosion in the Dookie district apparently occurs on those occasions when the soils are in a certain condition, making them more liable to the effects of water movement. It is probable that the areas showing bad erosion have damaged as a result of a heavy rain when the paddocks were in fallow or at a time when there was practically no vegetative cover on the hills to hinder run-off. In spite of this relative immunity except on special occasions, the erosion where it has occurred has been so bad that definite conservation methods are generally required to forestall such events in the future.

Fig 10 - Cross section of typical U-shaped and V-shaped gullies



The shape of the cross section of the eroding gully is influenced by the soil type in which it is found, and those on the Dookie and Cashel soils are V-shaped while those on the Gowangardie and Caniambo are U-shaped (Fig. 10). This difference is due to the relative structural properties of the A and B horizons in each of the two kinds of soils. In the Dookie and Cashel soils there is no big-difference in the physical properties of the A and B horizons, but in the Gowangardie and Caniambo soils the A horizon is hard and compact and more difficult to erode than the B horizon, which has a small nutty structure when dry, but is easily dispersed on wetting.

The relatively less erodible A horizon in the Gowangardie-Caniambo soils prevents the gully broadening at the top at a rate comparable with the deepening, in fact the broadening process takes place by undercutting the bank and subsequent collapse of the unsupported A horizon.

There are some unusual forms of erosion occurring in the area which require special mention.

(a) *Tunnelling.*-This form of subsoil erosion occurring on the Gowangardie and Caniambo soils has already been fully described in a previous publication (Downes 1946) and consequently only a brief summary will be given here. Under certain conditions on these soils, large amounts of the clay subsoil are removed, and as a result long tunnels are formed beneath the surface soil. These tunnels ultimately collapse to form gullies but only when they have become so wide that the surface soil is unable to support itself as a rigid layer across such a wide span. The formation of tunnels follows the deterioration of vegetative cover which causes the structure and permeability of the surface soils to degenerate, thus preventing infiltration and producing over most of the area a big increase in water run-off. Much of this run-off water collects in local depressions, old stump holes, or rabbit scrapes to give an increased infiltration on these parts of the area. This increased infiltration at isolated places enables a differential scouring of the subsoil to form tunnels.

(b) Gully Erosion in Swamps.-In at least two parts of the area there occurs extensive gully erosion in flat flooded for a portion of the year ditches have been cut through them In fact the grade on the land is greater than would be suspected and consequently the resulting stream has developed active cutting tendencies. The result has been extensive "fingering" or headward erosion back into the flat area. In one area this has been controlled by means of a concrete check dam across the gully, and on each side of this dam, earth wing banks extend out for a few chains to prevent water cutting around the dam when the water level is high.

(c) Erosion Induced by High Salinity.-Around the edges of the hills in the south-eastern part of the area are several examples of erosion caused by excessive concentrations of salt (Plate 5). These areas are in the 25-inch rainfall region and it may seem surprising that such concentrations could be developed. Such occurrences,

however, are not uncommon in relatively high rainfall country for they have been reported by Holmes *et al*. 1939) in the Berwick district of Victoria, Which has a comparable rainfall, and also by Teakle in parts of Western Australia.* It can be presumed that the salt is of cyclic origin, brought in by rain from the sea, but the reason for its concentration at certain places is not clear. The concentration of drainage may be the, result of one of two factors; firstly clearing of the trees on the slopes has allowed uneven infiltration and perhaps greater water movement than previously, or secondly some structural feature of the igneous mass may cause this concentration of drainage rather than a much wider distribution of seepage waters having a lower salt concentration which could be used by the vegetation. The increase of salinity in these places is followed by a replacement of the natural grasses by more salt-tolerant species such as barley grass (*Hordeum leporinum*) and ultimately by the elimination of all vegetation. The sodium-saturated soil is easily dispersed and consequently erosion proceeds rapidly, the severe sheet erosion ultimately turning to bad gully erosion.

From the general account of the erosion on the area and the description of. special forms, it is apparent that the development and execution of a plan of soil conservation on this area will be a big task, requiring the solution of a number of problems. The work on soil conservation at Dookie College is already having some effect in arresting soil erosion, but even with contour furrowing (Plate 6), the most common form of control measure, there remains much to be done in the determination of optimum spacing and/or vertical interval between the furrows. The recovery under a system of contour furrowing alone is relatively slow, since the cover obtained consists mainly of ephemeral species, and it seems therefore that although contour furrowing is most successful in preventing excessive run-off, something more should be done in an attempt to establish better pasture cover on the hills at the same time. Some such technique as this must be devised if the rehabilitation of the eroded country in the parishes of Gowangardie and Upotipotpon is to be achieved, for it is the hills themselves which have suffered most damage in that area. Associated with the problem is the prevention and control of tunnelling erosion. Although on the basis of the hypothesis of tunnel development, put forward in a previous publication, it is possible to make suggestions about possible control measures, there is no doubt that experimental work will be needed to devise the best method.

In the agricultural areas the use of broad base terraces and a widening of the rotation should achieve success provided the upper sections of the catchment units are treated to prevent excessive run-off. Erosion due to salinity is not really a serious problem either in size of area affected or in numbers of occurrences, but its ultimate development gives rise to such complete destruction of an area that it should be controlled if possible.

The fundamental necessity for successful soil conservation is not merely rehabilitation of the damaged areas but the development of systems of use under which there is an equilibrium between the soil, climate, man, animal, at as high a level of production as possible. This will constitute greatest problem of all since it is inescapably dependent on the mental attitude of the farming community toward the land and its use.

VIII. WATERSHEDS AND DRAINAGE PATTERN

The fundamental problem facing the soil conservation worker in an area object to water erosion is the determination of the origin of the excessive water movement and its control. It has been amply demonstrated that control by suitable treatment of the catchment areas to prevent excessive run-off, is better than control at the place of damage. Consequently a knowledge of the watershed units of an area is essential if effective soil conservation work is to be achieved.

The map of the four parishes showing the stream pattern and major watershed units has been compiled from a study of the aerial photographs and field observations. The value of such a map lies in the delineation of the area into units which can be treated separately for soil conservation, and consequently it indicates to the soil conservation worker a number of separate problems. Furthermore, when this map is used in conjunction with the soil erosion map, it enables him to decide which are the most urgent problems and also the size of the project necessary for a satisfactory solution, since watershed units must be treated as a whole.

On either side of the Broken River there are main watersheds running in an east-west direction and these enable the drainage system of the area to be divided into three major units (Fig. 11).

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* Private communication