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THE AUTHORS OF THE SEVERAL PAPERS ARE INDIVIDUALLY RESPONSIBLE FOR THE SOUNDNESS OF THE OPINIONS GIVEN AND FOR THE ACCURACY OF THE STATEMENTS MADE THEREIN.

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ART. I.—*The Measurement of Soil Structure.*

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[Read 9th March, 1939; issued separately, 1st March, 1940.]

Introduction.

It has long been recognized that soil in its natural state is different from the ground-up material which is analysed in the laboratory for its physical and chemical properties. The particles of sand, silt, clay, and organic matter into which this material may be separated are arranged in nature to form composite units, or aggregates. It is this arrangement which is called the "structure" of the soil. The mechanism by which the aggregates are formed presents a complex fundamental problem on which Russell's work (1934, 1938 i) is outstanding. We are not concerned here with this fundamental problem but rather with its practical outcome and with an attempt to find methods of measuring structure in the laboratory.

A soil of good structure contains a large percentage of aggregates of the order of $\frac{1}{2}$–1 mm. diameter or a little larger, and these aggregates are stable towards rain. Such a soil allows excess water to drain away rapidly, since the spaces between the aggregates are as large as those between grains of coarse sand. Surface run-off is therefore low, and the risk of erosion is accordingly small. Further, a good structured soil can be easily worked over a wide range of moisture content. A soil of poor structure, on the other hand, contains a big proportion of its fine fractions as individual particles. If there is more than a small amount of dispersed clay present, such soil is sticky when wet, and forms large, hard clods when dry. Such a soil is badly aerated during wet spells, since the spaces between the individual particles are small. It can be worked successfully only between narrow limits of moisture.

Poor-structured soils include not only those which easily become sticky because of their high content of dispersed clay, but also those which are liable to "pack" or set hard after heavy rain. Soils which pack are typically high in silt and fine sand, and low in clay. Their capacity for aggregation is therefore low, especially if organic matter is deficient. They are particularly dense, and since they possess few large pores they may be badly aerated in wet weather in spite of good underdrainage. When cultivated they become powdery, and are liable to erosion by both wind and water. Both roots and shoots may find difficulty in penetrating such hard soils, in contrast to the ease with which plants penetrate through good-structured soil.

It is clear from the foregoing discussion that the structure of soil is of great agricultural importance. There is an urgent need for the development of satisfactory methods of expressing structure in numerical terms, especially if we are to measure and compare the changes that take place under different systems of cultivation or cropping. Since about 1930 the measurement of structure has begun to receive the attention it deserves. Unfortunately a great deal of the most interesting work is available only in Russian; but Hénin (1938) and E. W. Russell (1938 ii) have recently prepared valuable summaries of the experimental methods that have been proposed. The technique of such work must always include some arbitrary rules, and it is to be hoped that workers in different countries will soon reach agreement as to some of these. Meanwhile, we have attempted to arrive at a standard procedure for the study of Australian soils, bearing in mind two important principles: firstly, that the laboratory measurements should give a good correlation with observations in the field; secondly, that the methods should be simple and rapid.

The samples for study were chosen as follows: Firstly, representative soils were taken from well known types with a good or bad agricultural reputation. Secondly, a few types were studied in detail in order to test the effect of differences in management or cropping.

Description of the Soils Studied.

KERIKERI CLAY LOAM.

A highly ferruginous soil from North Auckland, New Zealand. It is derived from basalt, is high in clay, and has an extremely good structure.

PENOLA (S.A.).

A black reclaimed swamp soil, neutral in reaction, high in clay and in organic matter and having a very good structure. Water applied to the surface soaks through with remarkable speed.

BERWICK (25 miles east of Melbourne).

(i) *Black Clay on Oligocene Basalt.*—Of excellent structure, very permeable, rich in organic matter, and non-erosive, although low in exchangeable calcium.

(ii) *Hallam Loam.*—Typical of the podzols found in southern Victoria on the colluvium from hills of Silurian mudstone. Very poor structure, silty, low in humus and colloids and tends to "pack."

TRENTHAM, VICTORIA.

Red loam—rather typical of the soils developed on basalt in the wetter parts of Victoria. A deep friable soil high in clay and having a good structure. This red loam and the black clay from Berwick are probably analogous to the red and black types formed on basalt in Tasmania as described by Stephens (1937).

WERRIBEE (South Central Victoria).

Samples were collected from the State Research Farm, where breeding and manurial experiments on cereals are carried out. The soils are derived from Pleistocene basalt.

(1) The "red" soil, denoted as "Werribee R," is a red-brown clay loam of pH 6, overlying red clay. This surface soil has a poor structure, and is difficult to work. In some winters the water lies on the surface for several days. This soil type is said to have deteriorated in structure since it was first cultivated about 50 years ago. Applications of gypsum at the rate of 1½ to 2 tons per acre cause striking improvements in wet seasons. For example, during the late autumn and winter of 1935 the land remained wet following a total fall of 5 inches of rain in April. Gypsum at the rate of 2 tons per acre applied to experimental oat plots so improved the aeration during the early growth of the plants that the treated plots yielded 51.6 cwt. of hay per acre, as compared to 37.6 cwt. for the untreated. Samples of this red soil were taken both from cultivated paddocks and from land that had been left under native grasses. A rather better type than the prevalent "red" soil was studied in certain green manurial trials which are also discussed later.

(2) The "black" soil, denoted as "Werribee B," occurs in patches up to 20 yards across in paddocks of predominantly red soil. This is a dark grey calcareous clay, of excellent structure. It does not get waterlogged, and is far more fertile than the red type, as may be seen in the spring from the far denser growth of cereals on the black soil.

WIMMERA (Victoria).

The soils are derived from unconsolidated quaternary sediments. Most of the samples were collected near Horsham.

(1) The "red" soil is a red-brown loam overlying red clay, with calcareous clay at a lower level. This type has a rather poor structure, and is inferior generally to the "black" soil, with which it alternates through the district. The sample used in this work, Wimmera R, was collected at Longerenong Agricultural College.

(2) The "black" soil of the Wimmera has become famous for its prolific crops of wheat. This type is a grey calcareous clay. In the natural state it occurs in the formation locally known as "crabholey," in which puffs or hummocks of calcareous self-mulching clay alternate with depressions which are non-calcareous and less clayey. When the land is levelled and cultivated the good structure of the puffs is extended over the whole formation. These soils were studied from three points of view: firstly, the comparison of virgin land with cultivated land; secondly, the comparison of different systems of cultivation of fallows; and thirdly, the association of structure with windblowing. This type is denoted as "Wimmera B," and the puffs and depressions in the crabhole complex as "Wimmera BP" and "Wimmera BD" respectively.

MERRIGUM, GOULBURN VALLEY (Northern Victoria).

This soil is a red-brown loam to sandy loam, neutral in reaction, lying over a clay subsoil, and derived from quaternary sediments. The district includes irrigated orchards and dry land that has formerly been heavily cropped with wheat. It is believed that the structure, which is poor, has deteriorated under cultivation.

RUTHERGLEN (North-eastern Victoria).

The soil of the State Farm at Rutherglen is a greyish-brown non-calcareous sandy loam containing ironstone gravel. The profile is intermediate between the red-brown earths of the Goulburn Valley and the podzolic soils in the wetter country to the south and east. The structure of this soil is very poor. It packs very easily, and its poor aeration during wet spells seriously limits the growth of wheat crops. The soil is particularly variable. The chief interest with this type is the possibility of improvement with vigorous pasture or with green manure.

DOOKIE (Northern Victoria).

A red, good-structured soil derived from metamorphic rocks occurs on a hillside, and a grey calcareous soil similar to the "black" soil of the Wimmera occurs in flat areas which were formerly swampy.

At Werribee, Dookie, and Merrigum, and in the Wimmera, the climate is on the dry side, and when wheat is grown the land is prepared by a year of bare fallow.

Measurement of Structure.

The methods of measuring structure may be classified into two groups, direct and indirect. The direct methods consist simply of separating the soil into fractions of different sizes on a set of sieves. This may be done in air or under water. From these analyses the respective percentages are obtained, either of the actual aggregates or of the water-stable aggregates of various sizes present in the soil at the time of sampling. We shall ignore the former figure, since it represents only a temporary phase of strueture which might be completely changed within 24 hours. The indirect methods consist of the measurement of specific physical properties which are thought to be correlated with soil structure. Pore space of the soil *in situ* is probably the most important of these properties.

Measurement of Water-Stable Aggregates.

It must first be decided what is the smallest aggregate that should be included in an analysis. Many Russian writers measure the material of diameter greater than 0.25mm., while others such as Baver and Rhoades (1932) prefer to include aggregates down to 0.05 mm. or less. These limits correspond roughly to what some workers have described as "macro-structure" and "micro-structure" respectively, and there is as yet no agreement as to their relative importance. Each is dealt with here in turn.

(A) MACRO-STRUCTURE. (Aggregates greater than 0.25 mm.)

The first method for measuring the water-stable aggregates in a soil is associated with Tiulin (1928). It consists simply of washing the soil on a set of sieves by moving them up and down in a bucket of water at a constant rate. Meyer and Rennenkampff's (1936) apparatus consists of a cylinder 40 cm. high in which is placed a set of sieves 9 cm. in diameter and ranging in mesh from 4 mm. to $\frac{1}{4}$ mm. holes. The cylinder is filled with tap-water from below, until the level of the 4 mm. sieve, on which the soil initially rests, is just exceeded. At this point the cylinder is emptied by a siphon, and the filling and emptying continue automatically. In the apparatus as published the sieves are fitted with rubber flanges which touch the walls of the cylinder. These flanges are troublesome to fit and work with and we have not used them in our work.

This apparatus seemed the most promising, and we have accordingly tried to standardize the technique. This has involved certain problems which can be discussed under the following headings :—

(i) Sampling in the field.
(ii) Sub-sampling.
(iii) Pretreatment methods.
(iv) Time and manner of washing.
(v) Expression of results.
(vi) Lower limit of sieves.

(i) *Sampling in the Field.*—This must involve the least possible damage to the natural structure. For this reason we used a sampling tool essentially similar in design to that proposed by Coile (1936). This removes a core 8.5 cm. deep and 442 c.c. in volume, without compaction or other interference, and this sample can also be used to determine the apparent specific gravity and the pore space.

(ii) *Sub-sampling.*—Because of the size of sieves (9 cm. diameter) the maximum sample allowable for any one test is 25 gm. If more is used, there is a risk that the finer aggregates may be retained through the filtering effect of the soil on each sieve. Because of this limitation and the nature of the material collected from the field it is difficult to get a true representative sub-sample. An attempt to improve on the ordinary sub-sampling method was made by using the composite sampling method quoted by Tsyganov (1935). The bulk sample was first separated into four fractions of the following sizes:—greater than 4 mm., 4–1 mm., 1–$\frac{1}{4}$ mm., and less than $\frac{1}{4}$ mm. From these fractions a sub-sample was constructed so that each of them was present in the same proportions as in the bulk sample. It was found on comparison of duplicate results obtained from both sampling methods that there was little difference in variability and we decided that the considerable work involved in the new sampling technique was not warranted. Russell, however (1938 ii) considers that this additional work is worth while.

At this point the problem arises of whether analysis should be done on the field-moist or air-dry material. Since structure is markedly influenced by wetting and drying it is essential to standardize this matter. Selected soils were therefore analysed in the Meyer apparatus before and after drying in the laboratory, and some of the results are given in Table I. It will be seen that the dried samples have a more stable structure than the fresh soils and also give more erratic results, as is shown by their higher co-efficient of variation. It seems better therefore to analyse the soil in the moist condition, on account of the higher reproducibility as well as the greater approximation to natural conditions.

TABLE I.—COMPARISON OF RESULTS FROM FIELD MOIST AND AIR DRY MATERIAL.

Figures represent the mean percentages of each fraction. Air dry figures are means of quadruplicates while the Field Moist are means of duplicates.

Soil Type.	Treatment.	Mean Percentages of Fractions.				Standard dev. of material < ¼ mm.
		> 4 mm.	4–1 mm.	1–¼ mm.	< ¼ mm.	
Werribee R ..	Field moist ..	0·2	6·3	16·8	76·9	4·8
	Air dry	12·4	17·7	31·3	38·8	9·1
Wimmera B ..	Field moist ..	0·4	0·7	42·5	56·5	3·4
	Air dry	0·6	5·6	52·6	40·7	7·7
Merrigum	Field moist ..	0·4	1·8	6·5	90·9	0·1
	Air dry	1·3	7·4	26·1	64·1	7·9

(iii) *Pretreatment of Sample.*—The soil may be either placed directly on the sieves or first brought to capillary saturation by moistening from below. Sokolovsky (1933) in a valuable practical review of the whole subject quotes figures to show the stabilizing influence of this capillary moistening. Our own figures confirm his findings (see Table II). We have adopted this method as a routine since it tends to give more nearly equal results for the same soil sampled at different moisture contents.

TABLE II.—COMPARISON OF ANALYSIS ON SOILS WITH AND WITHOUT PREVIOUS CAPILLARY SATURATION.

Soil Type.	Treatment.	Mean Percentages of Fractions.			
		> 4 mm.	4–1 mm.	1–¼ mm.	< ¼ mm.
Trentham Red Loam	Capillary soaked ..	12·0	28·0	36·4	25·8
	Flooded	10·5	14·9	39·2	35·2
Penola	Capillary soaked ..	5·3	53·8	29·0	11·8
	Flooded	2·8	43·6	28·4	17·6
Werribee R.2 ..	Capillary soaked ..	0·5	4·2	25·2	72·7
	Flooded	0·1	3·1	17·5	79·0
Wimmera B.12 ..	Capillary soaked ..	..	4·1	56·9	38·9
	Flooded	..	0·4	26·5	73·1

Another problem concerns the pretreatment of certain soil types such as the Werribee R and Wimmera BD, which become soft and plastic and remain on the 4 mm. sieve although there are obviously no true aggregates of that size in such soils. These soils were shaken with water for various times before being analysed in the Meyer apparatus. When this was done these lumps disintegrated giving a large increase of material less than

$\frac{1}{4}$ mm. diameter. If soils of good structure are subjected to the same treatment there is no appreciable increase of material less than $\frac{1}{4}$ mm. size but only an increase in the intermediate aggregates at the expense of the larger ones (see Table III).

TABLE III.—COMPARISON OF THE EFFECT OF VARIOUS TIMES OF SHAKING DIFFERENT SOIL TYPES.

Soil.	Treatment.	> 4 mm.	4–1 mm.	1–$\frac{1}{4}$ mm.	< $\frac{1}{4}$ mm.	Percentage disaggregation.
Kerikeri (N.Z.) Clay	Not shaken ..	30·8	47·3	13·8	8·0	8·3
	30 minutes shaken	12·6	62·1	17·6	7·9	8·2
Hallam loam ..	Not shaken ..	74·6	10·8	4·9	9·5	10·5
	5 minutes shaken	51·8	15·4	7·2	25·4	28·2
	30 minutes shaken	10·2	15·4	8·2	65·4	73·0
Penola	Not shaken ..	9·0	41·5	26·5	22·4	22·9
	30 minutes shaken	1·0	44·8	27·8	25·2	25·7
Wimmera B (puff) Grassland	Not shaken ..	14·5	37·1	24·2	23·3	25·4
	5 minutes shaken	1·5	31·4	37·2	30·0	32·7
	30 minutes shaken	0·9	31·4	35·2	32·4	35·3
Wimmera B (depression) Grassland	Not shaken ..	27·2	22·6	19·1	31·0	37·3
	5 minutes shaken	6·4	14·3	29·8	49·5	59·5
	30 minutes shaken	0·7	6·6	31·1	61·5	74·0
Merrigum (pasture)	Not shaken ..	57·5	8·8	2·3	31·4	32·0
	5 minutes shaken	16·8	18·6	14·2	50·6	51·4
	30 minutes shaken	8·8	15·8	13·9	61·6	62·5

(iv) *Time and Manner of Washing.*—The soil is washed on the sieves until the outflowing water is completely clear. This usually takes about 20 minutes but may take longer for some soils. Extra washing beyond this stage has no effect on the result. Neither does the long washing appear to disperse the soil more than when done by Tiulin's method. In fact, in spite of the purity of tapwater in Melbourne, those differences that do occur are in the opposite direction to that expected, probably because of the more vigorous swirl of the water in Tiulin's method.

After washing is completed the sieves are separated and dried in an oven at 105°C. and the material from each sieve is weighed after coming to equilibrium with atmospheric humidity. By means of an air-damped rapid balance these weighings can be accomplished in a short time.

After weighing, the material is retained for estimating the amount of coarse sand greater than $\frac{1}{4}$ mm. diameter which must be allowed for in calculating the degree of aggregation of the soil.

(v) *Expression of Results.*—We found that the percentage of "dust"—that is, material less than $\frac{1}{4}$ mm.—was a satisfactory figure by which these results could be expressed. For soils having large amounts of coarse sand the "dust" figures require adjusting as may be shown by the figures in Table IV. From this table it may be seen that the percentage of "dust" calculated in the normal way gives a false impression, making the soil appear better than it is in actual fact. It is preferable to think in terms of the percentage of material less than $\frac{1}{4}$ mm. in the soil which is shown in the Meyer apparatus to be aggregated. The best expression for such a soil is probably the percentage "disaggregation" which is "dust" $\times \dfrac{100}{100 - \text{coarse sand}}$.

TABLE IV.—TYPICAL FIGURES FOR A RUTHERGLEN SOIL.

Weight of Soil.	Weight of C. Sand.	Weight of material < $\frac{1}{4}$ mm. in Soil.	Total weight of aggregates > $\frac{1}{4}$ mm.	Meyer fraction < $\frac{1}{4}$ mm.	Percentage "dust".	Percentage disaggregation.
22·24	3·86	18·38	6·18	16·06	72·2	87·4
20·94	4·71	16·23	6·51	14·43	68·9	88·9

(vi) *Lower Limit of Sieves.*—Attempts to include a $\frac{1}{8}$ mm. sieve in the set were unsuccessful owing to the fact that a sieve of that mesh creates considerable resistance to the passage of water which in turn causes serious variability of results.

Summarized Procedure for Meyer Analysis.

(*a*) Samples are taken from the field by the constant-volume sampler.

(*b*) After other tests, to be described later, have been made on the sample it can be sub-sampled in the ordinary manner, the sub-samples being of the order of 20–25 gm.

(*c*) Sub-samples are placed on a filter paper resting in a petri dish of water and allowed to soak in this capillary fashion.

(*d*) Sub-samples are introduced into the Meyer apparatus and there allowed to wash until the outflowing water is clear.

(*e*) Sieves are removed, separated and dried in the oven at 105°C.

(*f*) Material from each sieve is weighed separately after standing in air. This material is retained and dispersed.

(*g*) All material from sieves is decanted for sand. This sand is passed through sieve of $\frac{1}{4}$ mm. mesh and the coarse sand weighed.

(*h*) Percentage of "disaggregation" is calculated.

(B) Micro-structure.

Sieves cannot be used for determining aggregates below $\frac{1}{4}$ mm. diameter (see p. 8) and one must therefore rely on Stokes's Law connecting the size of a small particle with its rate of fall through a liquid. Bouyoucos (1935) has used a sensitive hydrometer to give a quick method of measuring the material remaining in suspension after a given time. Cole and Edlefsen (1935) designed a special sedimentation tube in an endeavour to obtain similar results gravimetrically, but we have found that their method is cumbersome and has no advantage over Bouyoucos's method.

Bouyoucos's hydrometer was designed originally for use in mechanical analysis of soil but it has not been widely adopted for this purpose, possibly because his tables for the relation between time of settling, hydrometer reading and particle size do not agree with Stokes' Law. Wintermyer et al. (1931) of the U.S. Bureau of Public Roads, have given this matter some consideration and have made several corrections which can be applied to the hydrometer reading. This has greatly increased the usefulness of the hydrometer.

We have used the hydrometer for measuring the microstructure in nineteen soils. A sample of 50 gm. of each soil was moistened in capillary fashion and placed in a tall cylinder with a litre of water. The soils were first mixed by gently inverting the cylinders six times by hand and the resistance to mechanical disturbance was further tested by taking hydrometer readings after end-over-end mechanical shakings for intervals of 5, 15, 30 and 60 minutes. In every case hydrometer readings were taken after standing for about half a minute and for two minutes.

Sizes corresponding to these approximate intervals are .07 mm. and .035 mm. diameter respectively. Assuming the specific gravity of the aggregates to be 1.93, the exact times of settling required for the measurement of these sizes can be calculated using the Bureau of Public Roads corrections. (The above figure of 1.93 is calculated from the value of 1.50 for the apparent density of an aggregate in air. Naturally it is not a universal figure.)

Analyses of the soils for percentages of sand greater than these two sizes were also made and the percentage disaggregation of the soils calculated for each treatment. From the collection of results in Table V it appears that the best indication of the relative structural merits of the soils is shown by the figure for 0.07 mm. particles after 15 minutes shaking. The size .07 mm. rather than .035 mm. diameter is chosen because it is considered that .035 mm. particles are much too small to be of use in forming a good structure. Fifteen minutes shaking seems to be the optimum amount of treatment necessary to show differences between good soils such as Wimmera BP1 and bad soils such as Werribee R. Any longer time seems to be equally drastic to all types.

Table V.—Showing Percentage Disaggregation of Material < 0.07 mm. and 0.035mm. Diameter Respectively as Measured by the Soil Hydrometer after Various Times of Shaking.

Soil.	Percentage disaggregation of material < 0·07 mm. diameter.				Percentage disaggregation of material < 0·035 mm. diameter.			
	No shaking	5 min.	15 min.	30 min.	No shaking.	5 min.	15 min.	30 min.
Wimmera BP1—native grassland	6	18	27	39	5	14	22	33
Wimmera BD3—native grassland	21	41	52	68	16	38	47	67
Trentham red loam—under forest	5	14	22	31	3	10	17	25
Penola black clay	2	8	16	22	3	8	13	20
Werribee R1—native grassland	7	28	43	58	7	28	43	55
Werribee R3—cultivated 30 years	18	45	60	66	16	40	58	63

The procedure for measurement of structure with the hydrometer may be summarized thus:—

(*a*) A sub-sample of 50 gm. is moistened in a capillary fashion and placed in a cylinder.

(*b*) The cylinder is then filled up with water to the litre mark.

(*c*) It is shaken end-over-end mechanically for 15 minutes.

(*d*) It is shaken by hand two or three times to mix before putting aside to settle.

(*e*) The hydrometer is read after ½ minute settling, this time being corrected for temperature according to Wintermyer's tables.

(*f*) The percentage of sand greater than .07 mm. diameter is estimated by settling and decantation.

(*g*) The percentage of disaggregation is calculated.

The rapidity of this test is a strong point in its favour.

Apparent Specific Gravity and Pore Space as Indications of Structure.

The total pore-space may be divided into two classes, capillary and non-capillary. Capillary pore-space is that within the aggregates themselves and is a measure of the water-holding capacity of the soil. Non-capillary pore-space is that which exists between the aggregates and this indicates the degree of aeration and drainage of the soil. A soil in which both these figures are high combines the drought-resistance of clay with the good aeration of coarse sand. Non-capillary pore-space is the more important in our investigations; it must necessarily be high in a well-aggregated soil in which the aggregates have the dimensions of coarse sand.

The apparent specific gravity of soil in the field may be used for calculating the total pore-space. Capillary pore-space depends on texture and so remains nearly constant for any one soil type; thus on the one soil, changes of apparent specific gravity represent changes of non-capillary pore space. Naturally one could not expect differences in apparent specific gravity to be correlated with differences between one soil type and another.

We have recorded the apparent specific gravity as simply the weight of the amount of oven-dry soil present in the field sample, divided by its volume (442 c.c.). The total pore-space may be calculated from this if the true specific gravity of the soil material is known. For most soils, it may be estimated approximately assuming a specific gravity of 2.65. The correct measurement of capillary pore-space is particularly difficult, and the problems involved have been fully discussed by Russell (1938 ii).

Apparent specific gravity is a valuable figure, easily and quickly measured, the figures for any one treatment of a particular soil type having a co-efficient of variation of approximately 3–5 per cent.

Crumb Strength as an Indication of Structure.

Several workers have measured crumb strength and have considered it as an indication of the structure of soil. Nikiforoff (1938) suggests that ideal structure combines low cohesion between aggregates with high cohesion within individual aggregates, from which it follows that structure may be estimated from the crushing strength of crumbs. According to Russell's (1934) theory of the nature of crumbs, sandy crumbs should be softer than those consisting almost entirely of clay.

Various pieces of apparatus have been used for measuring this crushing strength. The principle of the apparatus that we have designed is as follows:—A weight which just extends a spring balance to its maximum reading is gradually lowered on to the upper of two long strips of wooden board hinged at one end. The aggregate (2–3 mm. in diameter) is placed between the boards at the end distant from the hinge. On each board is a metal contact, that on the lower one being a flat strip of brass and that on the upper one an adjustable screw. These contacts are situated at the crushing end of the boards quite close to the point where the aggregate is placed.

Since measurements are only to be comparative and not absolute an arbitrary standard of crushing through a distance equal to half the diameter of the aggregate was adopted. The upper contact can be adjusted to suit this condition so that it makes contact when the aggregate has been crushed through

1–1½ mm. The two contacts are connected to an electric circuit in which there is a "buzzer." The force required for such crushing is determined by subtracting the actual reading at the sound of the "buzzer" from the maximum reading on the scale. To facilitate the procedure the scale and weight are lowered by a small windlass.

It was thought that crushing strength would be influenced by the relative humidity with which the soil is in equilibrium but exhaustive tests have shown that there are no significant differences within the range from 35 per cent. to 98 per cent. In some cases slight increases were noticed at 10 per cent. From the series of results given in Table VI it may be seen that there is no correlation between the crushing strength of aggregates and the structure of the soil. It is unreasonable to expect any correlation, since the factors contributing toward crumb strength are so complicated.

TABLE VI.—SHOWING PERCENTAGE DISAGGREGATION OF PARTICLES < 0.25 MM. DIAMETER AND CRUSHING STRENGTH OF UNWASHED AGGREGATES (2–3 MM. DIAMETER) OF 4 SOILS.

—	Percentage disaggregation.	Crushing Strength.	
	Mean of 4 samples.	Mean of 20 samples.	Coefficient of variation.
		gms.	
Werribee R1—native grassland	26	360	70
Werribee R2—cultivated	91	1,250	60
Merrigum 1—permanent pasture	32	330	61
Wimmera BP4—native grassland	25	1,210	50

General Discussion.

The first purpose of this investigation is to obtain some numerical expression which indicates the desirability of the structure of the soil under test. In order to show the extent to which this has been achieved Table VII has been compiled showing the values obtained for several soils by three of the tests described in the preceding section, together with the percentage of organic carbon (representing about 58 per cent. of the total organic matter) as found by the rapid approximate method of Tiurin (1931). The several samples have been classified into four groups in order of merit. The basis for this division (which at best must naturally be somewhat arbitrary) is the local reputation or the farmer's opinion or description of the behaviour of the particular soils.

The percentage disaggregation as determined both for material less than 0.25 mm. and 0.07 mm. diameter, gives a good correlation with field behaviour, as shown in figs. 1 and 2. It appears that these two proposed methods will be distinctly useful in further work on soil structure.

There are a few cases in which the field rating disagrees with laboratory analysis. Two grassland soils from Werribee, which

TABLE VII.—SHOWING PERCENTAGE DISSAGGREGATION AS DETERMINED BOTH BY THE MEYER APPARATUS AND ALSO HYDROMETER METHOD ALONG WITH PERCENTAGE ORGANIC CARBON, APPARENT SPECIFIC GRAVITY.

Soil and Treatment.	Percentage disaggregation.		Apparent Specific Gravity.	Organic Carbon.
	< ·25 mm.	< ·07 mm.		
Group I.—First Class Structure.				
Kerikeri clay	8	..	..	4·23
Penola black clay	23	16	..	5·35
Berwick black clay—under permanent pasture	5	18	0·80	4·10
Dookie red loam—under cultivation	33	51	..	1·71
Trentham red loam—virgin forest soil	31	22	..	1·16
Wimmera BP4—native grassland	25	24	1·13	1·50
Merrigum 2—lucerne for many years, then 4 years sown pasture	32	..	1·24	1·94
Merrigum 1—natural pasture—greatly improved—much subterranean clover	32	67	1·24	2·14
Group II.—Good Structure.				
Merrigum 7—untouched native grassland	46	..	1·34	2·18
Werribee R4—native grassland	27	..	1·26	1·63
Werribee R1—native grassland	26	43	1·18	2·09
Rutherglen 3—under subterranean clover for 8 years, then cropped year before sampling	47	..	..	1·75
Werribee B—long cultivated soil, bare fallow	53	..	0·95	2·22
Wimmera BP1—native grassland	41	27	1·18	0·49
Wimmera BD3—native grassland	54	52	1·48	0·73
Wimmera BD6—native grassland	37	52	1·55	1·49
Wimmera B15—cultivated rough fallow	68	..	1·03	0·90
Wimmera BD16—native grassland	25	..	1·29	2·12
Wimmera B18—paddock which had just been cultivated for first time	45	..	..	1·12
Dookie black clay—long cultivated bare fallow	60	62	..	..
Group III.—Rather Poor Structure.				
Wimmera R8—native grassland	61	63	1·65	1·43
Wimmera R19—red patch occurring among black—native grassland	72	..	1·59	1·45
Wycheproof—from "red plains" country in Southern Mallee—native grassland	67	..	1·50	1·13
Wycheproof—from "buloke" country in Southern Mallee—native grassland	60	..	1·57	..
Group IV.—Bad Structure.				
Merrigum 4—orchard soil—much cultivated	96	..	1·34	1·26
Merrigum 5—orchard soil—much cultivated	96	71	1·46	1·41
Merrigum 6—wheat-fallow rotation for many years	91	64	..	1·21
Merrigum 8—cultivated for many years—reverted to native pasture in the last 2 years	82	..	1·67	1·30
Merrigum 9—cultivated for many years—reverted to native pasture in the last 2 years	88	66	1·66	1·46
Werribee R2—cultivated for many years	91	60	1·34	1·34
Werribee R3—long cultivated—treated with gypsum, three years previously	87	57	..	1·39
Rutherglen III. } cultivated for many years—various green manurial treatments	88	..	1·35	0·70
Rutherglen V. }	87	..	1·33	0·96
Rutherglen VIII. }	87	..	1·33	0·97
Rutherglen X. }	90	..	1·35	0·63
Rutherglen 4—much cultivated paddock	69	..	1·35	1·04
Rutherglen 6—much cultivated paddock—said to be "worn out"	73	..	1·42	0·70

are placed in group II, appear by Meyer's method (fig. 1) to be better than they are. This effect is due to the way in which roots hold the particles together; when thse soils are shaken with water as in the hydrometer method the discrepancy disappears (fig. 2). Again, Merrigum 1, a soil which has never been ploughed, seems very good in the field but gives a poor figure after shaking (fig. 2). This may be due to the softness of the crumbs, and suggests that the soil deteriorates quickly under cultivation.

CORRELATION BETWEEN AGRICULTURAL REPUTATION AND PERCENTAGE DISAGGREGATION (MEYER APPARATUS)

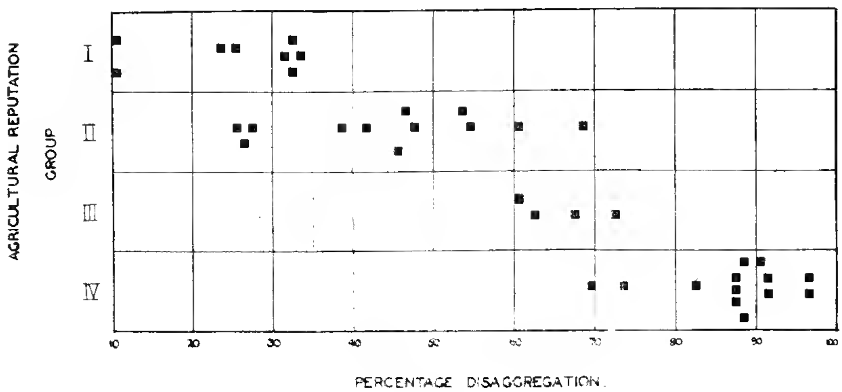

Fig. 1.

CORRELATION BETWEEN AGRICULTURAL REPUTATION AND PERCENTAGE DISAGGREGATION (HYDROMETER METHOD)

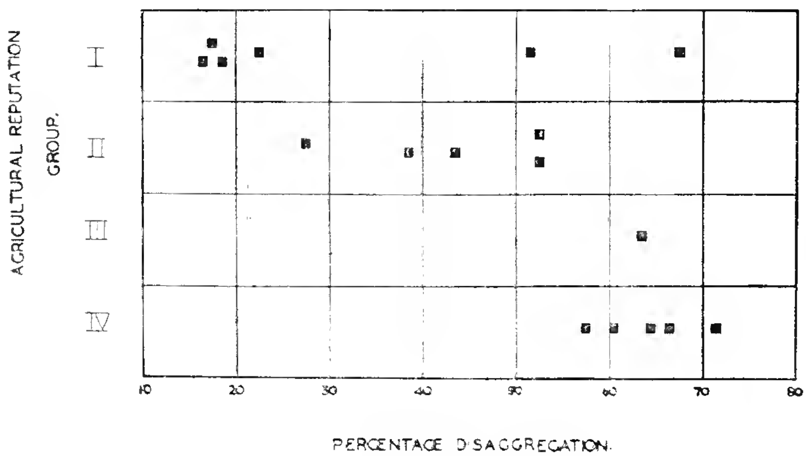

Fig. 2.

From the above discussion it seems to follow that for proper comparison of grassland soils with one another it is desirable to include a shaking treatment in order to form a judgment on the relative merits of such soils after a few years of cultivation.

The results obtained from the Meyer apparatus after various times of shaking and those obtained from the hydrometer method which involves shaking treatment, given in Tables III and VII respectively, form a reasonably sound basis by which the soil types may be classified. A soil having a low percentage disaggregation which alters very little after shaking has a very good structure. The amount of alteration on shaking is probably more important from the practical point of view than the initial percentage disaggregation for it represents what structure that soil may develop when subjected to agricultural practices. On this basis the soil types studied may be placed in order of merit as follows:—

Kerikeri clay loam
Penola black clay
Berwick black basaltic loam
Wimmera B "puff"
Trentham and Dookie red loams
Werribee R
Wimmera B "depression"
Merrigum.

Comparison of Structure Within Types.

Probably the most useful application of the measurement of structure is to show up the effects of various treatments on one soil type. Many workers both in Russia and America emphasize the damage to structure caused by cultivation. Bradfield (1937) likened cultivation to a surgical operation, meaning that it should be done only if absolutely necessary—it may do immediate good but in itself is bad. Cultivation is essential for the growing of crops, but a long succession of crop and fallow, without a period under pasture, is undesirable. The red soil at Werribee and certain types in the Goulburn Valley have deteriorated physically under cultivation. In the case of the Werribee soils it is said by some old residents that the deterioration is not only in physical condition but also in crop yields. The "black" soils of the Wimmera with a better natural structure than the two types already mentioned do not seem to have suffered at all.

From Table VIII it may be seen that each cultivated soil shows a greater percentage disaggregation than the respective uncultivated soil. Most of the cultivated soils studied have been farmed on a crop-fallow rotation and it can be seen from the table that they contain less organic matter than the uncultivated soils and in general have a higher specific gravity, except immediately after cultivation.

It is interesting to see how the application of gypsum to the cultivated Werribee soil only brings the density of the soil down to that of native grassland and has apparently little effect on the percentage disaggregation. The differences however were probably more marked two years earlier. Meyer's method is, of course, not suitable for soils which owe their virtue to flocculation by soluble salts.

TABLE VIII.—SHOWING THE DIFFERENCE IN STRUCTURE OF CULTIVATED AND UNCULTIVATED LAND.

Soil.	Treatment.	Percentage disaggregation. Meyer.	Percentage Organic Carbon.	Apparent Specific Gravity.
Merrigum 1 and 2	Improved pasture ..	32	2·04	1·24
,, 7 ..	Virgin pasture ..	46	2·18	1·34
,, 4 and 5	Orchard—much cultivated	96	1·33	1·40
Werribee R 1 and 4	Native grassland ..	26	2·09	1·18
,, R 2 ..	30 years cultivated ..	91	1·34	1·34
,, R 3 ..	30 years cultivated, treated with gypsum 2 years previously	87	1·15	1·15
Wimmera B ..	Native grassland ..	25	1·50	1·13
,, B ..	Wheat stubble, August, 1938	44	..	1·07
,, B ..	Under wheat crop, August, 1938	58	..	0·99

The high specific gravity of some cultivated soils is due to the reduction of aggregates to finer particles which block up the non-capillary pore spaces. This effect of cultivation is not shown on Wimmera soils for it seems that such fine particles have the capacity to regenerate into aggregates of reasonable size within a short space of time. Investigations on plots at Longerenong under crop and fallow have shown that while under crop and not being cultivated the soil tends to regenerate its structure as shown by the results in Table IX. This is not the case with other soils such as Werribee and Merrigum types for on these soils the effect of cultivation is cumulative and the structure gets worse from year to year unless the land is allowed to revert to pasture for a few years.

The effect of pasture on the regeneration of structure has been described by various Russian workers. The beneficial effect of pasture on structure is due to two factors. Firstly, the chemically stabilizing effect of the rapidly decomposing organic matter according to Geltzer (1934). Secondly, besides any such chemical effect there is the mechanical effect of roots holding particles together which would otherwise have passed through a sieve. The relative importance of these two factors is as yet undetermined. Some of our figures also show the good effect of pasture. The Merrigum soil under pasture, a prominent component of which is subterranean clover, can be compared with an orchard soil which has been constantly cultivated for many years. During the last few years weeds in the orchard have been encouraged in the winter and ploughed under during the spring in order that the increased organic matter might improve the soil both from the point of view of working and irrigating. The orchard soils seen just after a good cultivation gave a good impression and the subsequent poor results given by a Meyer analysis were rather surprising. The results were justified, however, for inspection of the orchard later in the year showed it to be badly

Table IX.—Showing Regeneration of Structure of Wimmera Black Soils During a Period of 12 Months and also the Differences in Structure of Non-fallow Compared with Various Fallow Practices.

—	Percentage Disaggregation (Meyer Apparatus).			
	Last cultivated June, 1938—prior to sowing.		Last cultivated June, 1937—prior to sowing.	
		Standard Error.		Standard Error.
Summer fallow ..	52·2	2·1	39·9	1·7
Winter fallow ..	50·3	2·1	43·4	1·9
Late fallow ..	49·2	2·1	..	..
Non-fallow ..	39·9	1·4	..	..

packed in spite of the green manurial crop which is ploughed in every year. The reason for green manuring orchard soils at Merrigum was to overcome the effects of bad structure. It is quite likely that green manuring although it cannot regenerate the structure of a soil having so much cultivation, does prevent any further deterioration. Our methods are not refined enough to measure such differences as green manuring may bring about on these soils.

Green Manurial Trials.

Structure analyses were done in conjunction with dynamometer trials on green manurial fields at Werribee in 1937 and 1938 and at Rutherglen in 1938. The plots were first laid down in order to compare the relative merits of the rotations: (*a*) wheat or oats alternating with a year of bare fallow; (*b*) wheat or oats alternating with a green crop sown in autumn and fed off in late spring; (*c*) the same as (*b*) with the green crop ploughed in during late spring. The results with Meyer's method on Werribee samples in 1937 showed that the "fed off" plots were slightly better than the "ploughed in" which in turn were better than those with the crop-fallow rotation. The records of the dynamometer also showed that the fallowed plots were the most refractory. In 1938 however the results were completely at random probably because the plots were very uneven both from the point of view of soil type and topography. At Rutherglen in 1938 samples taken from the green manurial field showed no differences among treatments. The soil in this field is too variable for such a test to succeed.

Windblowing of Soil.

The possibility that the "black" land of the Wimmera might be liable to blowing is suggested by its resemblance to certain areas in the North-American wheat belt which have suffered severely in recent years. Hopkins (1935) has pointed out that soils high in organic matter and lime have blown in past years in America. The Wimmera "Black" soil which is considered to be the best of the Victorian wheat belt has blown in previous years. It seems, however, that a certain set of conditions are required before anything of a serious nature occurs. It is only after a heavy fall of rain in the summer time followed by strong winds that the blowing occurs for then the top layer is disintegrated into small particles which dry quickly, before any regeneration can take place, into a light powdery layer. The blow can be prevented by working this thin layer into the soil as soon as possible after the rain; it is then able to regenerate its structure. We have examined drifts of blown soil and paddocks that have been blown and have found that as regards soil structure one paddock is no more likely to blow than any other. It is obvious that the fineness of the natural structure is connected with the problem, for the crumbs of the Wimmera soils are very small. According to Hénin (1936) this property is to be expected of calcareous soils.

Deterioration and Regeneration.

It is obvious from the above discussion that structure is by no means a permanent property of the soil, but changes take place in some soils in the course of a few days and in others over a period of years.

By deterioration of structure we mean that the aggregates are breaking down into smaller particles thus blocking the pore spaces, or else the aggregates are losing their capacity to remain as separate individuals and are gradually merging into one another to form a compact mass, thus giving the same effect.

Pot Tests on Werribee Soils.

This experiment was designed in the first place in order to check some surprising Russian work by Chizhevsky and Kolobova (1935), comparing the growth of a crop on soils composed of aggregates of various sizes. These were obtained from the red and black soils from Werribee already described (p.). The experiment was inconclusive as regards the relative growth of plants, but as a study of the effect of weathering on aggregates from good and bad soil types it is of interest. The soils were collected from the mulch of a fallowed field and air-dried, after which each type was sieved into fractions of the following sizes, greater than 12 mm., 12–5 mm., 5–2 mm., 2–½ mm., and less than ½ mm. diameter. The four smallest fractions were placed in pots, 9 inches in diameter and 30 inches deep, which had been sunk into the ground. Duplicate pots of each fraction (making the total number sixteen) were arranged in the formation of a randomized square. Oats were sown and harvested and with the exception of a general superiority of the yields of the black over the red no conclusive results were obtained. It was decided to leave the pots to stand for twelve months exposed to the weather and then determine the condition of the structure in the top 4 inches and compare this with the analyses done on the original materials. The results in Table X show that all fractions of the black soil have regenerated their structure to a certain extent while the red fractions have not changed significantly. The reason for the slight increase of the material greater than 4 mm. is due to the refractory nature of the clods caused by "packing." This material cannot be called genuine aggregates as in the case of Kerikeri and some other soils, for it becomes paste-like on the sieves and requires slight mechanical action to remove it. On breaking down it passes entirely through the sieves and merely increases the percentage of material less than ¼ mm.

Table X.—Showing Structure Analyses of Various Fractions of Werribee Red and Black Soils Before and After 14 Months Weathering.

——	Fraction.	Year.	> 4 mm.	4–1 mm.	1–¼ mm.	< ¼ mm.
Werribee Red ..	12–5 mm. ..	1937 1938	1·9 7·3	3·8 4·0	12·5 13·0	80·8 75·7
	5–2 mm. ..	1937 1938	2·0 8·1	9·4 4·3	11·9 8·4	76·7 79·2
	2–½ mm. ..	1937 1938	.. 3·5	5·3 2·1	21·5 12·4	73·2 82·0
	< ½ mm. ..	1937 1938	.. 1·8	.. ..	8·1 6·2	91·9 92·0
Werribee Black ..	12–5 mm. ..	1937 1938	10·1 6·7	11·3 19·6	27·7 35·9	50·9 37·7
	5–2 mm. ..	1937 1938	8·2 19·9	33·7 24·8	25·4 13·6	32·6 31·8
	2–½ mm. ..	1937 1938	.. 4·5	7·1 13·2	43·8 46·7	49·1 35·7
	< ½ mm. ..	1937 1938	.. 33·2	.. 2·3	30·6 22·9	69·4 42·6

Longerenong Plots.

The regeneration of structure has already been referred to in reference to the results from Longerenong as given in Table IX. The results show that there are no differences in structure caused by different fallowing systems commonly used in the Wimmera. They do, however, show that after cultivation the percentage disaggregation is higher than at the end of the period during which the soil is under crop and stubble, thus showing that regeneration has taken place. It is only on such soils as these and the Werribee black type that constant cultivation can be carried on without after a few years encountering the difficulties attributable to bad structure. On other soils which do not show this regeneration such as Werribee red, Merrigum and Rutherglen, cultivation for a few years should be rotated with pasture for another period of years the length of which is as yet undetermined.

Summary.

Two methods of measuring the water-stable aggregates of soils are studied in detail and the correlation of these methods with field behaviour is discussed.

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ART. II.—*A Study of the Granulation of Some Commercially Milled Victorian Flours.*

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[Read 13th April, 1939; issued separately, 1st March, 1940.]

Introduction.

When samples of flour from different flour mills in Victoria became available in 1936, it seemed an opportune time to record their granulation, especially since no general survey had been made of the granulation of wheat flour milled in Victoria. The Victorian Millowners' Association supplied the samples and a grant which made this work possible.

Wheat flour is a microscopic system containing particles of wheat endosperm ranging in diameter from 0.1μ to about 200μ. The particles are composed of starch granules of different sizes—accounting for about 75 to 90 per cent. of the total weight, a protein material called gluten—usually 8 to 20 per cent. and a small amount of cell wall. The starch granules are present in two forms—free and imbedded in the protein material. The protein is present in the aggregates of protein and starch granules. The number and size of the flour particles depend to a large extent on the milling operation.

The granulation of flour is important to both the miller and the baker. The miller is desirous of producing the flour as economically as possible, while at the same time retaining a high quality. He knows that the finer the milling products, the greater the cost of production, since more power is required for the reduction process, and fine flour requires a greater dressing or sieving surface because small particles are more difficult to dress. Quality may be affected by the heavy roller-pressure used in producing fine flours since this pressure is accompanied by elevated temperatures.

The baker judges flour to some extent by the " feel " of it and he considers the texture of the flour to be correlated with certain characteristics exhibited by the flour in the bakehouse. He is interested in the amount of water which must be used in making a dough, in the rate at which the dough develops and in the rate of gas production. It has been shown by Gründer (1935) that the fineness of a flour is related to both the rate at which water reacts with the flour when it is made into a dough and to the rate of gas production in the dough. Thus fine grinding may compensate to some extent for a low diastatic activity in the flour.

On the other hand, the same worker has shown that the elasticity and stability of the gluten are impaired by very fine grinding.

Two procedures are in general use by the miller for judging the fineness of flour. The first one is to feel the flour between the fingers. Variations between flours of very different granulation can be detected in this way but no record can be made of such variation except to describe the flour as "soft, medium, hard, smooth, gritty, &c." The "feel" of a flour is greatly influenced by the sharpness of the particles, not only by the size. Thus the final judgment is a composite of two characteristics, the shape and the size of the particles. It is obviously not possible to differentiate between them in the description of the "feel" of a flour.

The second method for judging fineness is to sift a sample of flour through a bolting cloth of known mesh size and note the proportion retained on the sieve. That this may be misleading has been shown by several workers among whom are Shollenberger and Coleman (1926). They found that flour which had been ground several times and was undoubtedly made finer by the process, sifted through a certain sized mesh less readily than did the same flour which was ground only once. Markley (1934) also found that the sieving method of estimating granulation is very inefficient. Thus neither of these methods, feeling it or sieving it, gives the miller or baker a satisfactory estimate of the granulation of flour.

Measurement of Granulation.

Methods for the estimation of the granulation of a powdered material such as flour may be divided into two groups—direct and indirect.

I. Direct Methods of Measurement.

The direct methods of measurement are of two kinds.

(*a*) *Sieve Analysis.*—Gründer (1932) pointed out that this method is only of use for particles of 60μ diameter or over. Inasmuch as the largest starch granules in Victorian flours are about 40μ in diameter and the finest mesh of bolting cloth has an opening of about 60μ, there can be no differentiation in size of starch granules by this method. In addition to the free starch granules all aggregates of starch and protein below 60μ in diameter would be free to pass through the finest mesh of silk bolting cloth.

By representing Markley's (1934) results for a commercial patent flour graphically, as in fig. 1, it is evident that up to 84 per cent. of such a flour is composed of particles having an equivalent diameter of 60μ or less and therefore a sieve having openings of 60μ diameter can differentiate only 16 per cent. of the total weight under theoretical conditions. Markley actually found, by determining the granulation of flours of varying degrees of fineness by sieving and by sedimentation, that very much less than the expected amount is passed through a sieve, as the particles passing a fine mesh are all considerably smaller than the finest mesh through which they have passed.

Gründer (1937) found that a flour sifted so as to be retained on an 150μ mesh opening and to pass a 200μ mesh, may be made up of particles of which only 20 per cent. are greater than 150μ diameter.

Several workers have contributed observations on the sifting of flour. Shollenberger and Coleman (1926) found that finely ground flour bolted more slowly than coarsely ground flour. Van der Lee (1928) considered that the rubbing of the flour on the silk sieves generated electrical forces which were partially responsible for the abnormalities encountered in sifting flour. Micka and Vrana (1930) thought that the temperature and moisture content of both the flour and air, the load on the sieves and their motion as well as the time of sifting, all affected the results of a sifting test for granulation.

(*b*) *Microscopic Measurement.*—By this method particles of angular shape are difficult to measure and small numbers of measurements are inaccurate. The method is also very time-consuming.

II. INDIRECT METHODS OF MEASUREMENT.

The indirect methods of measurement are those involving sedimentation in a gas or liquid. Sedimentation by means of an elutriator is not practical for small quantities of material.

Sedimentation in liquids may be carried out according to several modifications. They are all based on Stokes' Law of falling spheres in liquids, which is—

$$V = \frac{2}{9} g\, r^2 \frac{(D_1 - D_2)}{\eta}$$

V being the velocity of fall; g, the gravity constant; r, the radius of the sphere; D_1, the density of the sphere; D_2, the density of the liquid which is in lyophobic relation to the particle and η, the absolute viscosity of the liquid.

In any one system, the radius of the largest particle being deposited at a given time is in inverse ratio to that time since—

$$V = \frac{h}{t}$$

h, being the height of fall and t, the time of fall.

Therefore $\frac{h}{t} = \frac{2}{9} g\, r^2 \frac{(D_1 - D_2)}{\eta}$

The results are commonly represented graphically by plotting the percentage deposited against the time.

(*a*) *Odén's Method of Weighing* (1916).—This method has been applied to flour by Markley (1934). He used a mixture of carbon tetrachloride and cleaner's naptha as the liquid in which to suspend the flour particles. One pan of an automatic balance was suspended in a dilute suspension of the flour and the increase in weight of the pan noted as the particles settled out. Markley obtained his data as accumulation curves. One way of interpreting such curves is to draw tangents to the curves at successive time intervals. The points where these tangents intersect the percentage deposited axis represent the amount of material in the system with radii larger than those defined by the time points used. This method of interpretation is slow. Markley used a method of calculation from the data collected in which q represents the quantity of particles of radius greater than that defined by the corresponding time t from the percentage deposited value P.

$$q_2 - q_1 = t_2 \left(\frac{P_2 - P_1}{t_2 - t_1} - \frac{P_3 - P_2}{t_3 - t_2} \right).$$

(*b*) *Sterckx Method* (1935).—By measuring the height of the sediment accumulated in a vertical cylinder at successive intervals of time, Sterckx has developed a method for flour mill control work. It is quick and does not require special skill for its use. Unfortunately, it cannot be interpreted in terms of absolute size of particles. Also it disregards the finer particles since the height of the column of sediment is proportional to the weight, only during the early part of the sedimentation.

(*c*) *Pipette Method.*—This method is another variant of the Odén technique. Instead of weighing the sediment as it settles out, samples are pipetted off from a suspension at a known depth and time. The amount of flour in the aliquot is then determined. Gründer (1932) applied this method to wheat and rye flours. He suspended 10 grams of flour in 535 ml. of diethyl phthalate. 10 ml. samples were taken at known depths and times after the sample had been vigorously agitated.

He encountered some difficulty with the entrapped air after shaking due to the high viscosity of the diethyl phthalate. The suspended material in each pipetted sample was filtered off into a fritted glass crucible having pore openings of 5 to 10μ, washed with ether to remove the diethyl phthalate, dried at 40–50°C. and weighed. The percentage in suspension at each given time was calculated and the difference between those values and 100 is the amount that had settled out. For a given time and depth the largest particle to settle out can be calculated from Stokes' law and such values for diameters are plotted against the corresponding percentage of material settled out. To determine the amount of flour in a certain size range it is only necessary to consult the graphical representation of results.

The high viscosity of the solution used, causing entrapping of air seems at first to be the main disadvantage of this method.

(*d*) *Turbidity Measurement.*—Because the pipette method is slow, Gründer and Sauer (1937) developed a quicker method for plant control work, in which the turbidity of a suspension could be observed with a photoelectric cell. This method depends on the relation between light absorption and size of particle. They found that for the range studied (about 70μ to 200μ diameter) in the system of wheat flour in diethyl phthalate, the light absorption was practically independent of the size of particle. However, apparently measurements were not made for particles of low diameter and in fact these workers neglect the sedimentation of particles of less than 30μ diameter. They state that about 80 per cent. of the flour is made of granules which are about 40μ in diameter.

In Australian flour it is desirable to measure a greater range of sizes than Gründer and Sauer did by means of the photoelectirc cell method.

(*e*) *Separation of Flour Constituents on Basis of Density.*—Gründer (1934) has separated wheat and rye flour into their component particles by means of mixing them with solutions having different densities. For this purpose he used varying amounts of xylol, carbon tetrachloride and dichlorethylene to obtain densities ranging from 1.42 to 1.60. By centrifuging the flour with a solution of density 1.46 to 1.48, the flour was separated into two fractions. The floating material consisted of bran particles and practically all of the protein containing particles. The sediment consisted of almost pure starch with a trace of impurities such as sand, &c. These two fractions were further subdivided by repeating the centrifuging with liquid mixtures of other densities. This method of separation does not give information on the particle size but it might be used as an indication of the degree of grinding since very fine grinding will liberate more starch, which will in turn be separated by this method.

(*f*) *Surface Area by Witte's Method* (1936).—Information as to the surface area of a powder is an indication of its fineness. Witte mixed small amounts of flour with coal dust in definite proportions and noting the percentages of black and white in the mixture by means of a Leukometer, a number proportional to the surface area of the flour can be obtained The method is relatively quick to carry out but it has the disadvantage of masking any unusual mixture of fine and coarse particles such as would be revealed by a sedimentation curve.

Experimental.

In carrying out determinations of the particle size of flours milled in Victoria, a modification of the Robinson (1922) pipette method as applied to soils was used. The flour was suspended in a mixture of two parts benzene and one part of carbon tetrachloride by weight. This mixture has a fairly constant viscosity which is low enough so as not to entrap air. The viscosity and density of the solution were determined for the temperature at which the sedimentation took place. It was possible to follow the sedimentation to a point where only 5 per cent. or less remained in suspension.

25 grams of air-dry flour were placed in a thick glass bottle and 200 ml. of benzene carbon tetrachloride mixture were added. The stoppered bottles were shaken for three hours. Then the contents were poured into a cylinder $2\frac{1}{2}$ inches in diameter, having a capacity of 1,250 ml. and the volume made up to 1,200 ml. at 15°C.

20 ml. aliquots were withdrawn at varying times and depths after the suspension had been thoroughly mixed. The aliquots were placed in small tared florence flasks, the liquid distilled off on a water bath and the flasks and contents dried and weighed. Sedimentations were carried out in duplicate in a constant temperature cupboard at 15°C.

The average density of the finest and coarsest samples of flour was determined by placing a known amount of the flour in a pycnometer and filling the pycnometer with the benzene-carbon tetrachloride mixture of known density. The volume of the flour could then be determined and its density calculated. The average density was found to be 1.476 ± 0.006.

Knowing the average density of the flour particles and the density and viscosity of the liquid, by means of Stokes' law, the equivalent radii of the flour particles were calculated corresponding to different falling velocities.

From the percentage in suspension, the percentage deposited may be calculated and plotted against the corresponding equivalent radius of particle. The curves No. 55, 31, 27, and 58 in fig. 1 were obtained in this way.

Knowing the radii and having summation sedimentation curves as in fig. 1 for each sample, the surface area exhibited by 1 gram of each flour may be calculated. In Table I. the surface area of 1 gram of flour is tabulated for each flour examined. Instead of recording the surface area as square centimeters per gram of flour, one may construct summation curves (fig. 2) based on surface area instead of on weight. Such a representation emphasizes the extraordinary influence which the small granules have on the total surface area.

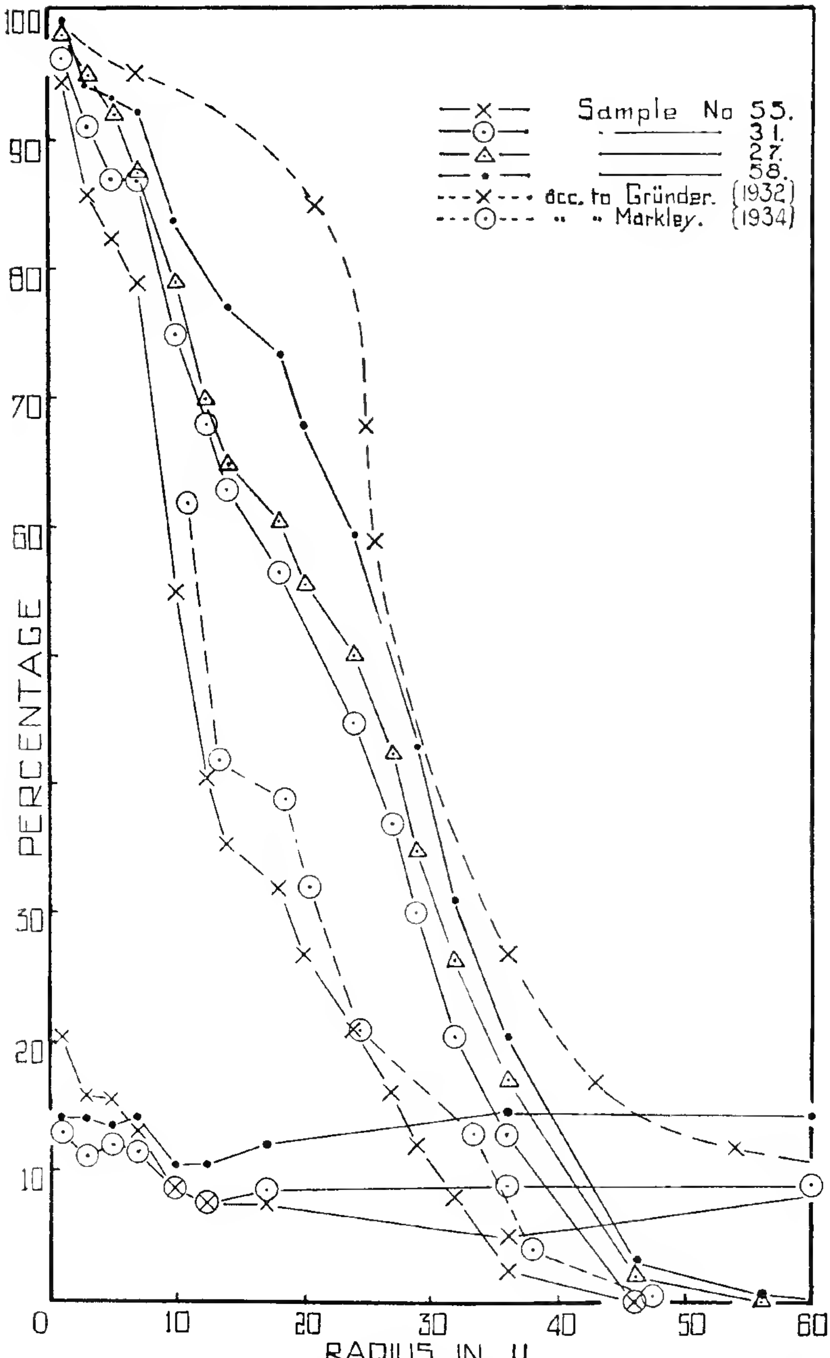

Fig. 1.—Summation curves illustrating the granulation of six samples of flour and the corresponding protein content of different size fractions for three of the samples.

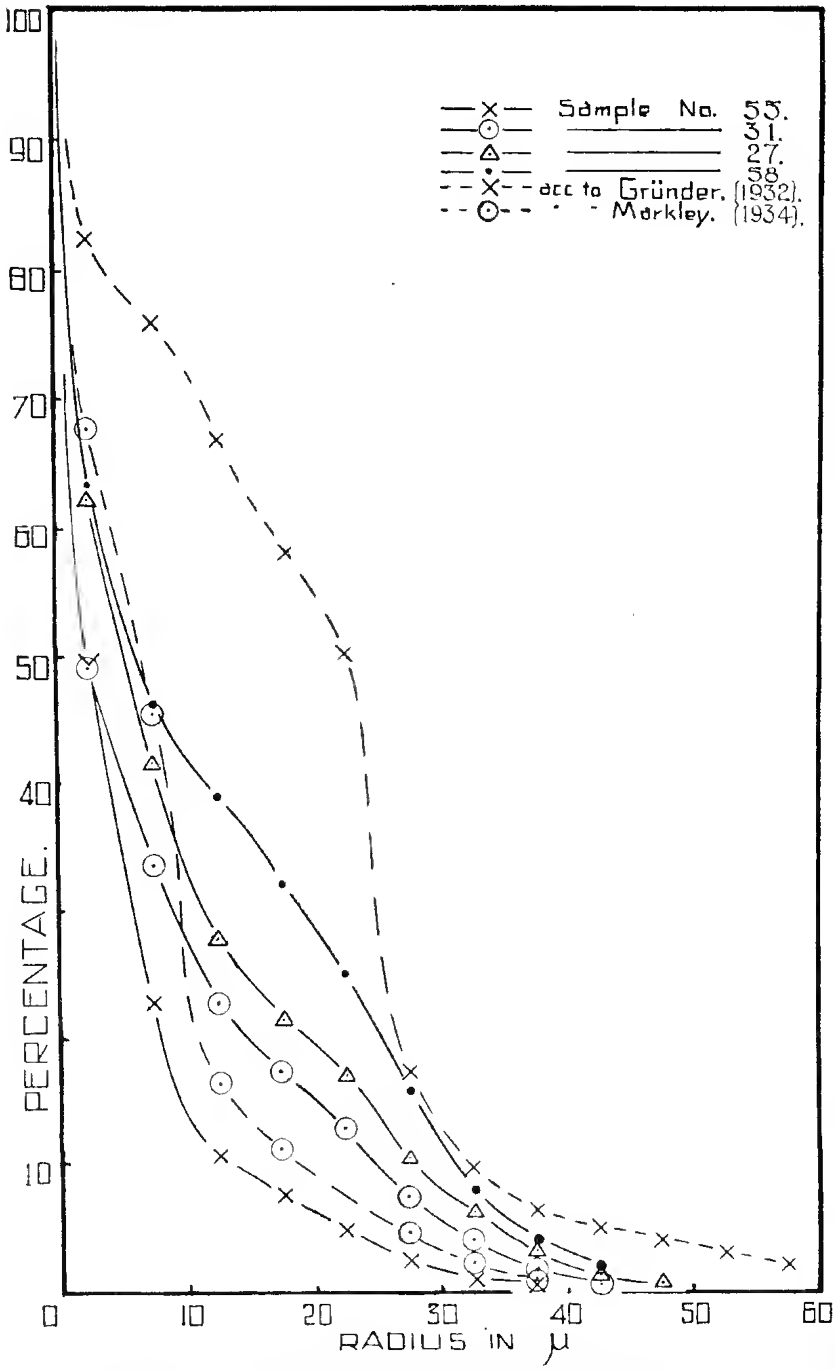

FIG. 2.—Summation curves illustrating the percentage distribution of the surface area in relation to the radius of particle for six samples of flour.

The nitrogen content of the 20 ml. aliquots was determined by the Kjeldahl method for three flours. The protein values (N x 5.7) obtained for a finely ground flour of low protein content (No. 55), a coarsely ground flour of high protein content (No. 58), and a moderately coarse flour of low protein content (No. 31) are shown together with their granulation curves in fig. 1.

A description of the flour as to the constituent wheats used, protein eontent, surface area per gram, and the percentage by weight above 20μ radius are given in Table I.

Discussion.

Fig. 1 gives a series of six summation curves. Three of them are for Victorian flours, one for a Canadian flour, and two from the literature for eomparison. The three curves given for the Victorian flours represent the finest (No. 55) and coarsest (No. 27) flours in the collection of twenty-three samples as well as one (No. 31) of moderately coarse granulation. The Canadian flour (No. 58) was milled in Canada from Manitoba hard wheat and was imported into Australia for use in comparative baking tests. One curve represents graphically the results as published by Markley (1934) for a patent flour of commercial origin milled in America from hard spring wheat, and the remaining curve, the granulation of a wheat flour of usual commercial superfine quality in Germany according to Gründer (1932).

It is readily seen that all the flours from Victoria are finer than the Canadian flour represented in fig. 1, but the sample examined by Markley lies within the range covered by the Vietorian samples. The interpretation of the curves as to size of particle is very dependent on the specific gravity of the flour. Markley does not indicate what value he used for the density of the flour. Gründer does give this value as 1.4000 in one paper (1932) and as 1.458 in another (1935). In still another place (1934) he indicates a method of separation of flour into two portions with a solution whose specific gravity was 1.46 to 1.48, such that 64 per eent. of the flour is in the floating portion and 36 per cent. in the heavier fraction, the latter being mainly free starch granules.

It is to be expeeted that Gründer's results will differ from those obtained in this investigation, since he was working with flours milled under different conditions and he was using a different density value for the flour with which he worked. The main difference between the granulation curve for a commercial flour obtained by Gründer (1932) and that obtained by Markley (1934), as well as those obtained in this investigation, lies in that portion of the eurve for the particles of low radii,. i.e., below

30μ radius. An explanation of the probable reasons for the difference in the two types of granulation curves will be given elsewhere.

Taking the percentage with radius above 20μ as an indication of the relative coarseness of the flour (see Table I.), 65 per cent. of the Victorian samples are made up of particles in which 40 per cent. or less are above 20μ radius. The remaining 35 per cent. of these Victorian flours contain 40 to 55 per cent. of their total weight as particles of radius greater than 20μ. 68 per cent. of the Canadian sample is made up of particles of greater than 20μ radius.

The percentage of protein in the suspended material rises slightly as the sedimentation progresses with the finely ground flour, but it remains more nearly constant in the coarsely ground flour (see fig. 1). This alteration in protein content of the suspended material indicates that fine grinding allows of the liberation of more of the starch from the protein material, at the same time particles of higher than average protein content are freed, and these remain in suspension longer because of their slightly lower density. It is evident that the use of an average value for density of the flour particles over the whole range of sedimentation will not lead to very serious error in interpretation of the sedimentation curves.

The curve showing the relation between the equivalent radius and the summation of the surface area of the particles (fig. 2) is a better indication of the fineness of a flour than the curve showing the summation weight or sedimentation curve in relation to the radii of the particles as in fig. 1. For certain purposes such as comparing the fineness of different flours, the surface area of 1 gram of flour in square centimetres is very useful. Such values from Table I. for the 22 samples of Victorian flour were used in compiling the frequency data in Table II. The values for surface area per gram of flour give a normal frequency distribution.

Theoretically, in forming a dough by addition of water, intimate contact between flour particles and water should be achieved in less time in a finely ground flour than in a coarsely ground one. Likewise, the contact between added dough improvers, yeast, &c., and the flour would be more readily established in finely ground flour. Gründer (1935) has furnished experimental proof of the correlation between fineness of a flour and both the dough developing time and the rate at which carbon dioxide is generated in the dough. By the use of the Brabender fermentograph and farinograph apparatus he was able to show that as the surface area of a given flour increased, so the carbon dioxide produced increased and the dough developing time shortened. In controlling the quality and uniformity of his product, this is of direct use to the flour miller. The control of granulation may be achieved either by mixing flours of known granulation or by controlling the grinding and dressing of the flour from a given blend of wheats.

TABLE I.

Sample No.	Mill.	Percentage above 20μ radius.	Surface area in cm^2 per gram of Flour.	Percentage Protein on dry basis.	Description of Sample.
58	N	68·9	1,504	14·1	Manitoba hard wheat
27	C_2	55·6	1,705	16·3	"Strong" flour
34	H	53·0	1,949	8·9	"Dundee" and "Baringa" wheat from South Riverina, N.S.W., and "Ghurka," "Ranee," and "Waratah" from Rutherglen and Wangaratta
23	B_2	48·0	2,023	8·5	"Ghurka" from Rupanyup District
31	E	52·0	2,065	9·1	"Dundee" wheat from Charlton District
22	B_2	41·0	2,135	11·4	Blend of Mallee wheats
32	F	47·0	2,147	9·4	"Ford," "Baringa," and "Dundee" wheat from N.S.W. (41 per cent.); 1934–35 wheat from Waaia District (mixed) (17 per cent.); 1935–36 wheat from Katamatite and Waaia Districts (mixed) (42 per cent.)
28	D	41·5	2,148	9·7	Wheat from Riverina and Victorian Wimmera Districts
29	D	41·5	2,230	9·7	,, ,, ,, ,, ,,
26	C_3	39·5	2,256	11·3	"Medium" strength flour
36	J	39·0	2,284	10·8	"Ranee 4H" wheat with small amounts of "Free Gallipoli" and others. Wheat from 3 seasons—⅓ 1933–34, Millewa District; ⅓ 1934–35, Walpeup District, and ⅓ 1935–36, Millewa District
24	C_1	40·0	2,292	11·1	
25	C_3	37·0	2,300	9·6	"Weak" flour
35	I	39·0	2,313	9·9	Mainly "Ranee" and "Ghurka" with mixture of premium wheats (no Gallipoli used) from Northern and Mallee Districts
30	E	35·0	2,350	10·0	50 per cent. from Charlton District, 30 per cent. from Stations north of Charlton, and 20 per cent. from Stations on Ultima Line
38	L	36·8	2,358	9·8	
21	B_1	38·0	2,359	12·5	Blend of specially selected "strong" North-west Mallee and Riverina wheats
37	K	37·0	2,363	10·8	
20	B_1	35·5	2,367	11·1	Selected Victorian wheat of f.a.q., quality
33	G	30·5	2,567	9·7	Mixed varieties grown in Wycheproof, Murrayville and Donald Districts
54	C_1	32·5	2,590	10·3	"Strong" flour
53	C_1	29.0	2,682	12·4	"Extra strong" flour
55	C_1	26·7	2,784	8·7	"Weak" flour
	Mean of Victorian Samples ..	39·7 ± 9·7	2,284 ± 242	10·5 ± 1·6	

Of the samples of Victorian flour examined, the surface area per gram of the finest sample (No. 55) is 63 per cent. greater than that of the coarsest sample (No. 27). These two samples differ widely in their protein content, the coarsest sample being higher. In contrast, two samples (No. 55 and 23) having an almost identical protein content differ in their granulation such that the finer (No. 55) has a surface area 35 per cent. greater than that of the coarser sample. In considering all the samples examined there is a significant correlation of —0.538 between protein content and granulation.

TABLE II.

Area in sq. cm. per gram of Flour.	Frequency.
1,700–1,899	1
1,900–2,099	3
2,100–2,299	7
2,300–2,499	7
2,500–2,699	3
2,700–2,999	1

With differences in surface area per gram of the magnitude indicated in Table I., one might expect that such differences would be reflected in the bakery and no doubt those differences which do exist are partially bound up in the flour granulation.

For wheat of a given quality for a given purpose, it seems probable that there is an optimum granulation, just as there is an optimum diastatic capacity, protein content, &c. As yet very little is known about connecting the granulation of a flour with its properties except for the work of Gründer on flour milled in Germany.

It is to be expected that wheat of different varieties, grown in different places, may yield a flour of varying granulation when milled in different flour mills. If, however, the wheats from various sources were milled under uniform, set conditions, the granulation of the flour might be an indication of certain characteristics of the wheat from which it is made. Cutler and Brinson (1935) have found that by grinding whole wheat under uniform conditions, the resulting granulation is an indication of the class to which the wheat belongs, soft, medium, or hard, and the granulation number determined by them is correlated with the percentage of starchiness—a high proportion of fine particles being positively correlated with a high percentage of starchiness.

Further work carried out by Fifield (1934) of the United States of America Department of Agriculture indicates that the granulation number is correlated with the protein content of the grain and to a certain extent with the locality where it was grown.

Now the grinding of whole wheat meal is a different process from the grinding of wheat into white flour, but if there are inherent properties in the wheat kernel which affect the granulation number, one would expect that there would be some evidence of those properties exhibited in the grinding of wheat into flour.

If the setting of the rollers in the flour mills and the dressing processes were similar in the different mills, the flour produced might be expected to reflect that uniformity in production by varying in granulation according to the wheat used. As the granulation of the flours examined does not reflect such an indication of quality as the protein content, one can only conclude that the granulation of the commercial flours examined is almost solely the result of the varying opinions of the flour millers as to what constitutes a desirable granulation superimposed on the inherent properties of the particular blend of wheat which they have at hand for milling.

One must also infer that it is very unwise to draw any conclusions as to the quality of a flour from the " feel " of it for the granulation of these commercial flours in Victoria show no relation to one of the common measures of quality, namely the protein content.

It is of interest to note that certain Victorian flour mills tend to produce a flour of fairly uniform granulation irrespective of the protein content of the flour. This is true of samples from mills B_1, B_2, and D. (Table I.).

Other mills, E and C, produce flours of varying granulation and with different protein content, there being no relation between the protein content and the granulation of the products of the individual mill.

Since this paper was read the authors have learned of the work on Flour Granularity carried out by D. W. Kent-Jones, E. G. Richardson and R. C. Spalding, which was reported in the *Journal of the Society of Chemical Industry*, Vol. 58, pp. 261-267, August, 1939.

Summary.

The difficulties and inaccuracies encountered in estimating the granulation of flour particles by feeling the flour between the fingers and by sieving have been enumerated.

Other methods for the measurement of flour granulation have been discussed. The sedimentation method used in this investigation has been described and the results obtained when it was applied to 22 samples of commercial Victorian flour and one of Canadian flour are described.

It has been pointed out that there is a low but significant correlation in these commercial flours between quality as revealed by their protein content and granulation.

Because of the differences in both the blending of the original wheats and in the milling practice followed by the various millers, it is to be expected that the granulation of the samples will not be closely related to such a quality estimate as that furnished by protein.

Acknowledgments.

The authors are indebted to Professor W. J. Young and Professor S. M. Wadham for their interest and assistance throughout the work, and to the Victorian Millowners' Association which provided the samples and a grant for one of us. (I.W.D.).

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Art. III.—*The Biology of the Silverfish,* Ctenolepisma longicaudata *Esch. with Particular Reference to its Feeding Habits.*

By EDER LINDSAY, B.Agr.Sc.

[Read 13th April, 1939; issued separately, 1st March, 1940.]

Contents.

I. Introduction.

Ctenolepisma longicaudata was first described by Escherich in 1905 from material collected in South Africa. It has, since been found in Palestine, Seychelles, and the New Hebrides, and the first record from Australia was made by Silvestri in 1908 from material of the 1905 Hamburg expedition. It is widely distributed in Australia and collections have been received from all the coastal regions, as far north as Cairns, and as far inland as Broken Hill. During the last fifteen to twenty years it has become a household pest of economic importance, and in 1935 investigations into its control were undertaken by the Commonwealth Council for Scientific and Industrial Research. The work carried out at the School of Agriculture of the Melbourne University started as an inquiry into the attack upon wallpapers; but the control measures which were evolved necessitated the study of the insect's biology with particular reference to the reasons for its food preferences, and the extent to which it is affected by climatic conditions.

II. Experimental Methods.

Silverfish have a long life cycle. They reach sexual maturity in two to three years, and continue to grow for about five years longer, moulting three to five times each year. As it was necessary to use adults for the feeding tests, insects were collected in various buildings, mainly at night, and stocks of these were held in lots of one hundred in 200 cc. glass beakers, and were fed on tissue paper, gummed paper, artificial silk, and ground whole wheat and yeast. The beakers were kept in a cupboard in which a high humidity was maintained by open tubes of water, since previous tests had shown that in dry conditions, as, for example, in open containers on the bench, the insects died within one month. These conditions proved satisfactory for reproduction and growth. Cotton-wool was provided as a nidus for egg laying and facilitated the collection and removal of the eggs. Nymphs were reared on the same food as the adults.

In the tests on the food preferences the materials to be compared were subjected to the attack of twenty to forty silverfish held in a Petri dish containing two pieces of each material. As soon as the attack showed, the edible materials were removed, so that the silverfish were confined on the remaining pieces under semi-starvation conditions. In this way, any variation in the feeding stage of the various individuals was eliminated, and the tests were sufficiently rigorous to ensure that the materials would be attacked if at all edible. The pieces were folded so that the insects had easy access to all the materials. The whole series was duplicated. All were held in closed tins with tubes of water and kept at 24°C. for the two to three months of the test.

In the tests on wallpapers, the insects were confined on the surface of the sample by pushing the piece to the bottom of a 1-inch glass vial. Three silverfish were used on each sample. The tests were duplicated and the results were confirmed by subjecting selected samples pasted on glass to the attack of eighty silverfish. A section of these samples is shown in pl. II, fig. 2.

III. Feeding Habits.

Observations during the past three years have shown that silverfish, even the 2nd instar nymphs, range far in search of food, and include both animal and plant remains in their diet, as well as materials of economic importance such as paper and artificial silk. They are easily disturbed and are seldom observed eating; but at various times, they have been found indoors feeding on a variety of materials including bread crumbs, a dead moth, a piece of dried grass, and a fragment of the thorax of a beetle in which the muscles were still fresh.

1. Crop Contents.

Further information about the nature of the substances which are included in the normal diet, was obtained from an examination of the crop contents of more than sixty insects which were collected in various buildings.

The origin of the large fragments could be determined from their structure, and some of the stages of decomposition were identified by comparison with the crop contents of silverfish which had been given a diet of grass, paper, wool, cotton or artificial silk. The staining reaction of the fragments was tested with Iodine, Sudan III, Phloroglucin and Hydrochloric acid, Herzeberg's stain, and Lieberman's reagent. Herzeberg's stain was particularly useful for showing the presence of cellulose derivatives even after the structure of the plant cells had been completely destroyed.

Usually the crop contained material from one source only. Evidently the silverfish made a large meal from any edible material which it discovered. Insects collected indoors had frequently been feeding on plant tissue a short time previously. Many fragments found in the crops were so large that the epidermis and the cortical and vascular tissue could still be distinguished (pl. II, fig. 1B). The epidermis with stomata and hairs, and the vascular tissue with thickened and pitted walls were easily recognized. In many cases the cells still contained chloroplastids, and even after these had been broken down, the green colour of the chlorophyll persisted in the crop for some time. Many other groups of cells with various kinds of thickening could not be identified.

The fragments in many crops resembled those found among plant debris. Sand grains and pollen grains (pl. II, fig. 1A), Protococcus in both active and resting stages, and fungal spores and hyphae could be recognized (pl. II, fig. 1C). In some cases the hyphae were still living, and in one case the spores of *Ustilago hordei* were identified.

Four of the crops examined were almost completely filled with starch grains. One of these insects had been collected from a decaying tree, but the source of the starch could not be located.

Insect remains form part of the diet, and frequently setae, pieces of chitin (pl. II, figs. 1D and F), scales and tracheae were found in the crop. Animal hairs were found in only two of the crops.

In view of the varied nature of the crop contents it was interesting to see to what extent the dust of the room was a potential source of food. The dust was collected with a vacuum cleaner from behind the skirting boards and window frames of two lecture rooms. On examination the following materials were found; crumbs, small cellulose fibres, both single and in masses, woody fragments, insect legs, feelers, and claws, fragments of leaves and dried grass, string and sawdust. Even dust, it would seem, provides a varied diet for the insects.

2. Range of Materials Attacked.

To find the range of substances the silverfish would eat, various materials were subjected to the attack of groups of five insects for two months, no food other than the material under investigation being provided.

Artificial silk and cotton fabrics were readily eaten. Wool fabrics were generally not damaged, although occasionally a few fibres were found in the crop. Wool felt, flannel, carpet, fur felt, and natural silk were not damaged.

Attack on materials which were otherwise unpalatable, could be encouraged by smearing them with a palatable mixture of sweetened flour paste. In the course of the removal of this layer some of the fibres of the material were eaten, and occasionally the attack extended deep enough to damage the fabric. The unpalatable material, e.g., wool, silk, or sawdust was slowly digested. In the crop the fibres of wool were broken transversely into short lengths, the epidermal sheath flaked off, and the cortical cells frayed at the ends of the fragments. The cortical cells were apparently digested, for few were found in the hind intestine, though short lengths of the undigested fibres were sometimes found there.

3. Food Requirements of Adults and Nymphs.

Although the silverfish is normally an active feeder it can survive long periods without food. An experiment was made with twenty adult insects in separate containers (1-inch glass tubes). The first died after 21 days, and the others followed at intervals, the last three living 252, 276, and 307 days respectively.

A diet of cellulose alone was sufficient to support a longer life. The death rates of twenty adults fed only with filter paper were noted and in this case the last three insects lived 449, 576, and 636 days respectively.

A more adequate diet is necessary for the nymphs. Four groups each of twenty newly hatched nymphs were kept on various diets. The first group was given no food and eighteen survived the first ecdysis, but died early in the second stadium. The second group was given paper and flour. Eighteen of these insects survived the second ecdysis but died during the third stadium. The remaining two in both groups ate the dead bodies and cast skins of the others, and survived to the fifth instar. The third group was given paper, flour and casein. Most of them survived until the fourth and fifth instars, and only one of the dead bodies was eaten. The fourth group was given ground wheat and yeast in addition. Apparently this made an adequate diet, for on this the nymphs have been reared for eighteen months.

On the inadequate diets the food reserves were depleted by metabolism and ecdysis. The fat content of adults starved, or fed with cellulose, was reduced from 20 per cent. to 7 per cent. Normal silverfish contain 9 per cent. nitrogen. The cast skins, which weigh 5 per cent. of the dry weight of the body, contain 6 per cent. fat and 11 per cent. nitrogen, so that, with each cast skin 1 per cent. of the fat and 6 per cent. of the nitrogen of the body is lost. (These analyses were very kindly carried out by Mr. G. Ampt, of the Chemistry Department of the Melbourne University.)

4. Taste.

Silverfish are sensitive to the taste of certain substances even when these form only a small part of a mixture. Their behaviour suggests that the labial palps are the organs most sensitive to taste, the sense being probably located in the small papillae which occur on both sides of the tip (fig. 1c).

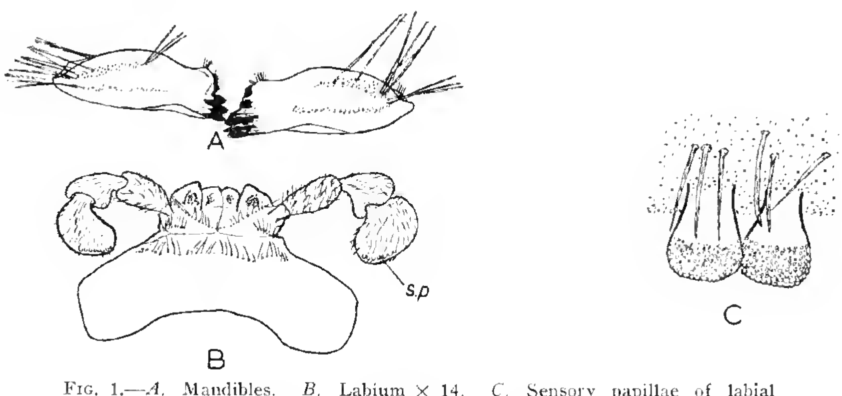

Fig. 1.—*A.* Mandibles. *B.* Labium × 14. *C.* Sensory papillae of labial palp × 300. *s.p.* sensory papillae.

The action of the mouth appendages during feeding was watched on silverfish confined in an optical cell $3\frac{1}{2}$ inches square and $\frac{1}{2}$ inch deep. The ventral side of the head was observed by means of a tilted mirror. Small heaps of powdered materials, viz., flour, ground sugar, casein, fine chalk, and crystallized sugar were placed about $\frac{1}{4}$ inch from the edge. As the silverfish under observation moved about, it came into contact with the powder. This was touched first by the antennae, then by the maxillary palps, and then by the labial palps. The antennae and maxillary palps seemed to behave in the same way towards all the powders; but the labial palps immediately "scooped" the palatable powder, ground sugar, towards the mouth. The other powders were frequently touched by the labial palps, but the flour and casein were only occasionally pushed into the mouth. No attempt was made to eat the chalk or the crystallized sugar. The grains of the latter were probably too large.

The scooping action of the labial palps is characteristic; the expanded terminal segments act as "shovels" and push the material towards the maxillae (fig. 1B).

The labial palps are able to detect the palatability of the material before it is eaten. This sensitivity may be assisted by fluid from the mouth, for on some of the wallpaper mixtures (see below) there was a "water mark" of concentrated colour around the teeth marks and on certain parts of the undamaged surface. The "water mark" showed only on mixtures containing dextrin, and tests with droplets of water showed that only in these mixtures is the pigment held in such a way that a water mark will remain.

On a hard surface such as that of wallpaper, the mandibles (fig. 1A) are worked with a scraping movement. The mandible on the left side, which lies ventral to that on the right side, takes a wide sweep and scrapes towards the centre. These scrapings are then gathered by the right mandible, and, together with the small amount it accumulates itself, are pushed into the mouth. The scraping marks of the teeth can be clearly seen at the edge of the damaged parts (pl. I, fig. 2).

On a fibrous surface such as that of textiles and paper, the laciniae tease and lift the material towards the mandibles which chew through the connecting strands (pl. I, figs. 3 and 4). The pieces of fabric removed in this way are sometimes so large that the mesh can still be seen on the fragments in the crop.

Owing to this sensitive taste different kinds of such goods as wallpaper, writing paper, and artificial silk are attacked to different extents.

Wallpaper:—The effect of the different ingredients in wallpaper was tested on more than 9,000 sample mixtures.

The palatable materials in wallpaper are the various sizes mixed with the pigment and filler. The sizes used are starch, dextrin, casein, gum and glue. Only the mixtures containing starch and dextrin were extensively attacked, the colour being removed from the surface of the paper before the paper itself was eaten (pl. II, figs. 2 and 3). The mixtures containing casein were eaten to a small extent, and as the insects did not continue feeding around the areas first attacked, only small areas of colour were removed. The mixtures containing gum and glue were not attacked unless the paper beneath was exposed at a scratch, and then the colour was removed as the paper was eaten.

All the sizes, even the apparently unpalatable gums and glues, were readily eaten when dissolved and dried into a thin layer on the surface of paper, so it is rather difficult to understand why the colour mixtures containing gum and glue proved so unpalatable.

Black, yellow, red and blue mixtures were tested, but the nature of the pigment had little effect on the extent of attack, except, perhaps, that it was rather slower on the black and yellow mixtures. The addition of filler lowered the percentage of size in the mixture and decreased the palatability.

It was interesting to watch the behaviour of a silverfish presented with pieces of both palatable and unpalatable wallpaper. The insect was held in a petri dish, and during its wanderings it walked over the surface of the unpalatable wallpaper several times. Then it touched the palatable wallpaper and immediately started to feed continuing for three hours, with only eight pauses of one to two minutes each. During the next hour it moved about the dish, walking over both the papers. Every time it walked over the palatable colour it took a few bites, but only twice did its jaws move when it was in contact with the unpalatable wallpaper, and even then no marks were made on the surface.

The paste used for fixing the papers to the walls was readily eaten when exposed at joins, but did not influence the attack on the surface. It had been thought at the outset of the investigation, that this paste attracted the silverfish to the wallpaper.

Writing, Printing and Wrapping Papers:—It was frequently noticed that only some of the sheets in a pile of papers suffered extensive damage; but that subsequently, all were readily eaten when the silverfish were confined on the papers. This localized attack could not be attributed to the position, for adjacent pieces of similar paper were attacked to different extents. Rather, it seemed that once the silverfish had made an attack, they tended to continue feeding there, with the result that the damage was concentrated in a few particular places.

The extent of attack was determined also by the nature of the paper. A wide range of papers, paper boards and paper pulps was tested. Mechanical pulp was not attacked, Kraft and Esparto pulps were slightly attacked, but bleached and unbleached sulphite pulps were readily eaten. A consideration of the nature of the pulps in the tested papers showed that all the papers which were readily eaten consisted of 100 per cent. chemical pulp, the degree of attack depending on the finish and fillers used. The papers only slightly attacked, including "writing" paper, newsprint, and other printing papers, contained mechanical as well as chemical pulp.

This unpalatability of the mechanical pulp influenced the attack on the surface of wallpaper. The papers used in the tests contained 100 per cent., 52 per cent. and 45 per cent. chemical pulp respectively. The rubbings on the paper containing 100 per cent. chemical pulp showed more extensive damage than those on the other two papers. Large areas of colour were completely removed as the paper beneath was eaten. On the other two papers small bites were distributed over the surface of the colour, and were more extensive on the paper containing the greater amount of chemical pulp.

It seemed remarkable that this small difference in the amount of mechanical pulp in the paper should have such an effect on the attack on the surface, and further tests were made on papers containing mechanical pulp. These were obtained through the courtesy of the Forest Products Division of the Commonwealth Council for Scientific and Industrial Research and the Australian Paper Manufacturers and comprise:—

(A) 100 per cent. bleached sulphite pulp.
(B) 100 per cent. chemical pulp from Eucalyptus wood.
(C) 80 per cent. bleached sulphite—20 per cent. mechanical (6 per cent. clay and rosin).
(D) 75 per cent. unbleached sulphite—25 per cent. mechanical.
(E) 52 per cent. sulphite—48 per cent. mechanical. (6.4 per cent. ash.)
(F) 45 per cent. sulphite—55 per cent. mechanical. (11.4 per cent. ash.)
(G) 30 per cent. sulphite—70 per cent. mechanical. (Newsprint.)

The papers were dipped in methylene blue so that any slight surface attack could be detected as the more deeply stained fibres on the surface were removed. Comparison with uncoloured samples showed that the methylene blue did not affect the attack. During the first ten days, papers A and B containing 100 per cent. chemical pulp were readily eaten, and after 30 days papers C and D containing 20 and 25 per cent. mechanical pulp showed some attack; but the papers with more than 48 per cent. mechanical pulp were not attacked even after 90 days. In each case the papers were removed from the test as soon as the attack was seen.

As mentioned above, it had been noticed that the composition of the paper affected the extent of attack on the surface coating. This observation was confirmed by coating the papers A to G with a palatable gum which was dyed crimson to facilitate observations. The gum was readily eaten off the papers of chemical pulp and the attack extended to the paper. But the gum on the papers of mechanical pulp was much less eaten, and even after 90 days very little attack occurred on the gum coating on paper F and the newsprint.

As no commercial papers containing between 25 per cent. and 45 per cent. mechanical pulp were available, sample papers were made from weighed quantities of mechanical and bleached sulphite pulp and the final composition of the papers was checked by counting the fibres under the microscope using the method described by Gaff, 1935. The papers thus prepared contained 64, 33, 30, and 23 per cent. mechanical pulp. Of these, the paper with 23 per cent. mechanical pulp was well eaten, the papers with 30 and 33 per cent. were slightly eaten, but no attack was made on the papers with 64 per cent. mechanical pulp even after four months.

It was concluded from these experiments that:—

1. Papers containing 100 per cent. chemical pulp—sulphite, bleached and unbleached—are readily eaten.
2. The presence of even 20 per cent. mechanical pulp greatly reduces the attack.
3. Papers containing 45 per cent. or more mechanical pulp are not damaged.

The Cause of the Unpalatability of Mechanical Pulp.—An attempt was made to find the cause of the unpalatability of the mechanical pulp. In the preparation of mechanical pulp, the wood, mainly spruce and hemlock, is rubbed into small fragments. In the preparation of chemical pulp the substances which impregnate the walls of the wood fibres are removed, and the cellulose itself is partly decomposed. Thus the fibres of the chemical pulp are different from those of the mechanical pulp, both in chemical composition and physical texture, and probably both these factors contribute in determining the palatability of the pulp. In the Kraft process the chemical action is not carried so far, and some of the unpalatable properties of the mechanical pulp still remain.

Very little is known about the chemical nature of the materials which impregnate the cellulose walls of a wood fibre, but various materials have been isolated from the mechanical pulp extracts, and an attempt was made to find the effect of these materials on the palatability of the pulp.

First the mechanical pulp was extracted successively with ether, alcohol, hot water and 5 per cent. sodium hydroxide. Other samples of the pulp were extracted separately with the above solvents and 3 per cent. sulphuric acid. "Bond" paper was soaked in these extracts for 24 hours and then subjected to the attack of silverfish. It was found that all the papers were readily eaten except those impregnated with the ether extract, which delayed the attack for three months. The materials extracted were decomposed by exposing the impregnated paper to sunlight for two weeks. The extract was bright yellow. It could be decolourized by charcoal or barium sulphate, but the colourless extract did not render the paper unpalatable.

The effects of various chemicals associated with the resins and fats of wood were also tested by impregnating the Bond paper with solutions of the substances in carbon tetrachloride. Oleic and linoleic acids proved ineffective, but abietic acid prevented attack for one month. Samples of wood extracts, lariciresinol, sitosterol, matairesinol, and a benzene-alcohol extract of paper pulp resin were kindly supplied by Dr. R. D. Haworth of the University of Newcastle-on-Tyne. Three per cent. solutions in acetone were used. Both lariciresinol and matairesinol prevented the attack on paper; but both caused the paper to turn a light brown, and both made it slightly sticky.

It was thought that the physical texture of the mechanical pulp might contribute to its unpalatability, and an attempt was made to test this by preparing papers from the mechanical pulp after it had been extracted with water, acid, alcohol and ether, as in the above tests. Some difficulty was experienced in making paper from the mechanical pulp because it would not hold together, and it was hard to see if any attack occurred on the surface. Certainly the attack, if any, was very slight.

The state of the cellulose itself also affected the palatability of the paper. Spruce wood pulp is high in hemicelluloses which are readily degraded during the chemical pulping. Further, as prepared for the "Bond" paper, the pulp has a large percentage of fragmental fibres produced during the beating, and both factors probably contribute to the palatability of this type of paper. In contrast to this, the pulp for filter paper (which is not readily eaten) is prepared from rag cellulose low in hemicelluloses, and so treated that all the degraded celluloses are removed leaving only the resistant α-cellulose. Duplicating paper (d.c. 48, from Thomas Tait) which also is not readily eaten contains a high percentage of Esparto fibres. These fibres are low in hemicelluloses, and, since they are only lightly lignified the treatment is so mild that little degraded cellulose is produced. The pulp is beaten for only a short time. It would seem therefore that this pulp, too, is not easily digestible.

Even though the silverfish will eat and digest any kind of cellulose, particularly if it is made palatable by mixing, for example, starch paste with sawdust, or large amounts of chemical pulp with the mechanical pulp, it is understandable that the attack should be more pronounced on the celluloses which are the most easily digestible.

Deterrent Sprays:—Since it is not possible in practice to eliminate the attractive materials from the wallpaper, an attempt was made to find some deterrent which could be sprayed on the surface. The 69 substances selected for the tests were derivatives of phenol, cresol, and salicylic acid, and salts of barium, mercury, tin and antimony (see Appendix). Water, methylated spirits, and a petroleum fraction "White Spirits" were used as solvents with several concentrations of each substance. The protection to both wallpaper and "Bond" paper was tested.

The appearance of the attack on some of the wallpapers suggested that areas were left uncovered as the spray dried. The distribution of the spray was tested by the reaction of ferric chloride on papers sprayed with salicylic acid, and by spraying with methylene blue. It seemed that the spray covered the surface, but did not penetrate far, so that underlying unimpregnated colour and paper fibres were readily exposed. An attempt was made to reduce the surface tension of the alcohol and water solutions by the addition of cetyl alcohol, but the deterrent action of the sprays made in this way did not last longer than before. Finally a 1 per cent. solution of tricresylphosphate in White Spirits, and a half saturated solution of Tartar emetic in water were selected. Both protected the surface for nine months. A small amount of damage occurred on the Tartar emetic sprayed paper, but the insects died. The insects made no attempt to eat the paper sprayed with tricresylphosphate. Apparently they detected its unpalatability without biting the surface.

Adhesives:—Twenty-four commercial adhesives were tested in thin layers spread on "Bond" paper. The pastes, gums, dextrin, casein, and cellulose adhesives were all readily eaten off the surface of the paper. The glues were less readily eaten, the attack occurring only on the edges. Only two adhesives, a gum and a glue, were not attacked, and it is probable that the preservative in these acted as the deterrent.

Tricresylphosphate and Tartar emetic were added to a starch paste and a gum. Attack on the paste was prevented by 4 per cent. of the tricresylphosphate, and 5 per cent. of the tartar emetic (both per cent. weight of flour). Attack on the gum was prevented by 1 per cent. Tartar emetic and 2.5 per cent. tricresylphosphate (by weight). With lower concentrations of the deterrents the paper was eaten, and at still lower concentrations the adhesive itself was eaten off the surface of the paper.

Artificial Silk:—Artificial silk is very readily eaten (pl. 1, figs. 3 and 4), but treatment with certain materials for fire proofing and water proofing rendered the silk so unpalatable that it was eaten only by starved insects. When this treated silk was smeared with a palatable mixture of sweetened flour paste, the paste and the silk underneath were readily eaten, and the attack extended to the surrounding strands. The tricresylphosphate spray rendered the untreated silk so unpalatable that, when soiled in the same way, the paste was eaten from between the strands of the material with very little damage to the strands themselves.

Poison Baits:—The taste sensitivity of the silverfish was important also in the preparation of poison baits. These baits were developed by the Division of Economic Entomology of the Commonwealth Council for Scientific and Industrial Research (Jr. C.S.I.R., 1939, p. 85).

5. Digestion and Absorption.

The Process of Digestion:—The digestive tract is simple (fig. 2). The large thin-walled crop extends to the third abdominal segment—more than half the length of the body. A pair of large salivary glands which lie around the anterior end of the crop, open on the hypopharynx, and may be the source of the small amount of fluid which moistens the food during chewing. The food is moved about slowly in the crop (peristalsis is not strong) and is further broken down by the teeth of the gizzard. It would seem that some chemical decomposition also takes place in the crop as the material which passes into the mid-intestine is very finely divided. There is no evidence that any secretion occurs in the crop and, possibly, digestive fluids pass forward from the mid-intestine.

The semi-fluid mass passes from the gizzard into the mid-intestine. In the anterior region of the mid-intestine, the material lies in the sacculi, but in the posterior region it is held within a well-marked peritrophic membrane. Presumably this membrane is secreted by all the cells of the mid-intestine, for no special secreting cells and "press" (Wigglesworth, 1929), could be seen in the stained sections.

The hind intestine is lengthened by an anterior, dorsal, loop before it joins the rectum. The epithelium of the hind intestine is deeply folded, and the walls of the rectum are thrown into six well-marked longitudinal folds, and two rows of papillae surround the anus. This increased surface of the proctodeum is presumably concerned with the extraction of water from the faeces which are nearly dry when extruded.

The rate of digestion of paper was observed. A starved insect was given access to the paper for two hours. Within twelve hours some of the paper had passed into the mid-intestine, and an examination after 48 hours showed that all the fibres in the crop had been completely destroyed. Residual material first appeared in the hind intestine 24 hours after feeding and faeces were passed until the fifth day. With more indigestible material, e.g., insect remains and wool, faecal pellets continued to be expelled at intervals for seventeen days.

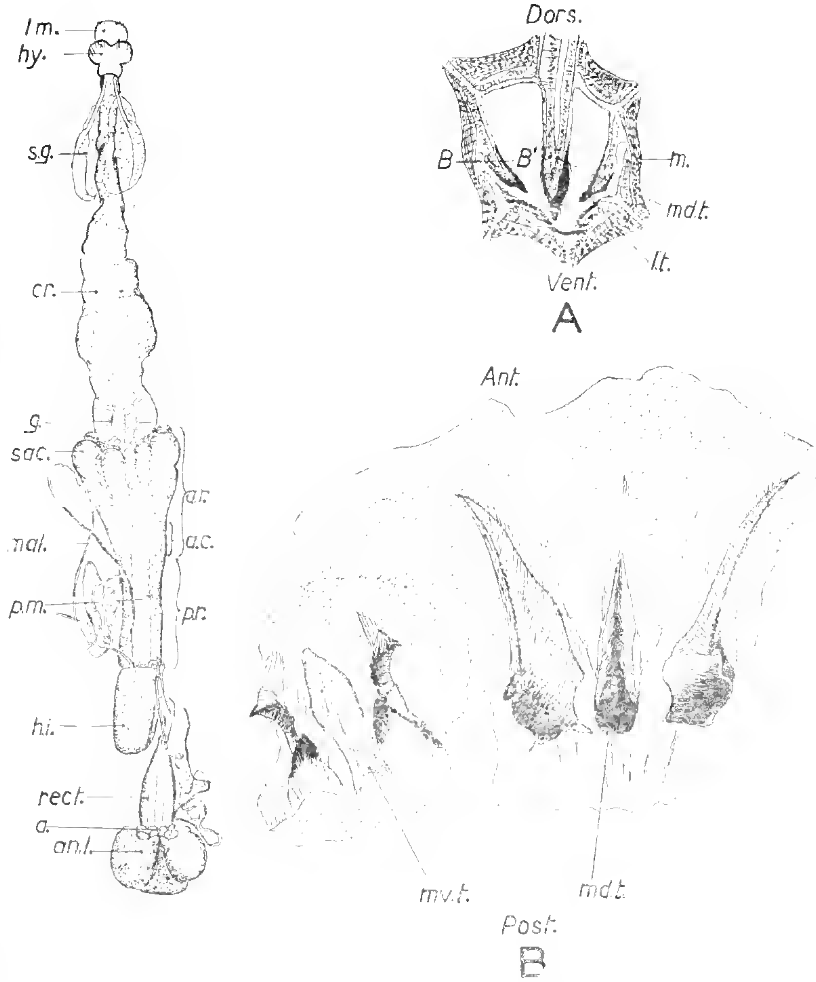

FIG. 2.—Alimentary canal and crop; *A*. Transverse section of crop and *B*. Crop opened on one side B-B[1]; *a*. anus; *an.l.* anal lobes; *cr.* crop; *g.* gizzard; *hy.* hypopharynx; *h.i.* hind intestine; *im.* labrum; *l.t.* lateral tooth; *m.* muscle; *md.t.* mid dorsal tooth; and *mv.t.* mid ventral tooth of gizzard; *mal.* malpighian tubule; *a.r.* anterior region; *p.r.* posterior region and *a.c.* absorbing cells of mid intestine; *p.m.* peritrophic membrane; *rect.* rectum; *sac.* sacculi; *s.g.* salivary glands.

Cellulose Digesting Bacteria:—Insects feeding on cellulose usually depend on the lower organisms in their intestine to assist in the digestion of the cellulose, and it was found that cellulose digesting bacteria could be readily cultivated from the contents of the crops of silverfish.

Thirty ccs. of Winogradsky's medium (1929), after sterilization, were mixed with the expressed contents of one crop. A piece of filter paper was half immersed in the liquid, and kept at 24°C. for one week. The paper at the water level became brownish, and below the water very gelatinous. When examined under the microscope the fibres had the "chewed" appearance typical of the action of these bacteria. There were many cocci and bacilli both on the surface and inside the fibre. The paper in the uninoculated salt medium was unchanged.

Fungal hyphae, which were frequently found growing in the crop also may aid in digestion.

The pH of the Alimentary Canal:—An attempt was made to measure the pH of the contents and cells of the alimentary canal by feeding the silverfish on paper dyed with indicators. Although conditions were not suitable for determining the depth of colour of the indicator, the change in colour could be seen, and, by using a range of indicators, the pH of the region determined. The indicators used were:—2, 4 dinitrophenol, phenol red, naphtholphthalein, tropoeolin 000, cresol red, brom-thymol-blue, brom-cresol-green, methyl red, para-nitrophenol, brom-cresol-purple, meta-nitrophenol, and thymol blue. The colour of the indicator was noted in a rapidly dissected insect. There was no disagreement in the results from any of the indicators.

The pH of the crop was always the same as that of the food. The pH of the anterior region of the mid-intestine was difficult to see, owing to the thick walls, the fluid nature of the contents, and the rapid entrance of food from the crop. It appeared to be between 4.8 and 5.4. The pH of the posterior region of the mid-intestine was between 6.4 and 7.0. The pH of the hind intestine was lower, between 2.6 and 3.8, possibly owing to acid excretory products.

Several of the indicators, viz., meta-nitrophenol, para-nitro-naphtholphthalein, tropoeolin 000, cresol red, and brom-cresol-green, were absorbed in the cells of the anterior part of the mid-intestine in apparently the acid form, but they no longer responded to pH changes.

Several of the indicators, viz., meta-nitrophenol, para-nitrophenol and methyl red, were found to be unsuitable because they were changed in the intestine and no longer indicated pH, or because their colour change was indefinite under these conditions.

The indicators were fed to the silverfish also on casein and sugar, and it was found that the nature of these foods did not affect the pH of the alimentary canal.

Redox Potential:—Using the same methods as above, the indicators, o-chlorophenol–indophenol, toluylene blue and methylene blue were fed to the insects.

Ortho-chlorophenol-indophenol was decolourized in all parts of the alimentary canal. Toluylene blue was present in the oxidized form in the crop and mid-intestine, where it could still be decolourized by sodium sulphite. Methylene blue was present throughout the alimentary canal in the oxidized form.

The Distribution of Certain Dyes:—These indicators and other dyes stained other parts of the body as well as the mid-intestine. When absorbed in these tissues the methylene blue could still be decolourized with hot sodium sulphite, but the toluylene blue could not be decolourized and no conclusions could be drawn about the Redox potential of these parts.

The methylene blue was absorbed by the mid-intestine, appearing in the cells of the anterior region within 24 hours, and in those of the posterior region on the fifth day. In each case the cells appeared to be filled with blue globules which were larger in the anterior region than in the posterior region of the mid-intestine. The crystals of excretory material in the faeces stained blue, and within four days the methylene blue appeared in the malpighian tubules located in indefinite patches of cells along their length. By the twelfth day the methylene blue coloured the immature eggs, the yellow cells of the ovarioles, and the edges of the fat bodies.

Sudan III was fed to the insects on ground wheat. Part was readily absorbed by the cells of the mid-intestine. Three days after feeding, red globules appeared in the cells of the malpighian tubules; the fat bodies were coloured a deep pink; the immature eggs, and the material inside the dilated portion of the vasa differentia were coloured pink; the accessory glands of the female were coloured red. In one female the eggs had passed into the calyx. The contents were coloured pink, but it is not known whether the dye penetrated the chorion, or whether the egg stained before this had formed. The colour persisted in the ovarioles for about twenty days, and even after 85 days the cells of the mid-intestine and the fluid in the crop still remained red, though, by this time, none of the other organs retained any Sudan III.

The appearance of the dyes absorbed in the mid-intestine was different in the cells of the posterior half from those in the anterior half. Two more regions in the anterior half (fig. 2) were distinguished by the appearance of the absorbed toluylene blue and Sudan III. These latter differences could not be correlated with any structural differences in the sections stained with Heidenhain's haematoxylin, and their particular function in digestion is not known.

A number of other red dyes were also tested in order that the form of the alimentary canal could be photographed through the semi-transparent chitin of the nymph. Magenta, carmine, and aniline red were all readily eaten, but were not absorbed in the mid-intestine, being merely concentrated in the faeces. Eosin and orange G. proved toxic.

IV. The Life History.

The first observations on the life history of the silverfish were made by J. W. Raff in 1933. The life cycle extends over several years. The nymphs develop with very little change in form. Sexual maturity is reached in 2½ to 3 years and the adults continue to grow, moult, and lay eggs for at least three years longer.

1. The Egg.

Eggs are laid in lots of from two to twenty. In normal conditions they are pushed by the long ovipositor about 2 mm. into a crevice and so are rarely seen. Some have been found under the edge of a piece of pasted paper, and in a crack in a wooden drawer. They are oval and measure 1.15 × 0.83 mm. (average of 15). When first laid they are cream coloured and smooth, but after three days the chorion darkens to a yellow and shows shallow reticulated markings.

The young insect bursts the shell with a small ridge on the frons, the hatching organ (fig. 3). This is shed with the first exuviae. The crop pulsates vigorously during hatching. It is filled with air, although the mouth appears to be closed throughout the first instar. After about five minutes the insect wriggles

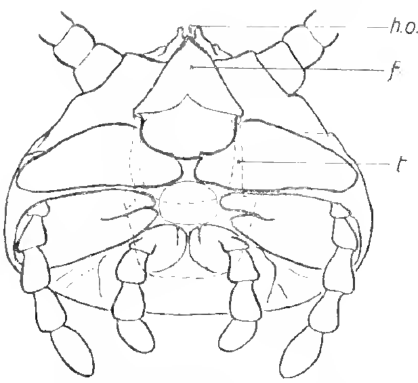

Fig. 3.—Head of 1st instar from ventral surface showing hatching organ and tentorium; *f.* frons; *h.o.* hatching organ; *t.* anterior arm of tentorium

free of the shell. In captivity almost all of the eggs hatched, and there were very few deaths during the early instars. Other references to the hatching organs of *Lepisma saccharina* are included in the Bibliography (Heymons, van Emden, Wigglesworth).

2. The Early Instars.

The development of the first fourteen instars was followed. The length of the successive stadia showed considerable variation even at a constant temperature of 23°C. (Table I.). The distinctive characteristics of the successive instars were not easy to define, for these resembled each other closely in all but the few features described later. The new instars were distinguished by their complete coat of scales which are tightly adherent during the first few days of the stadium. In general, growth results in a gradual increase in size, and in the elaboration of both the internal and the external structures present in the young insects. The feeding habits are the same. The cells of the mid-intestine are already differentiated as in the adult. The gizzard has the same form as in the adult though there are fewer serrations and hairs on the teeth. The malpighian tubules are relatively large until about the twelfth instar. The eyes have twelve ocelli as in the adult, but these are rather more rounded.

TABLE I.—DURATION OF EARLY STADIA AT 23° C.

Instar.	Number of Insects.	Average Length of Stadia Days.	Range Days.	Instar.	Number of Insects.	Average Length of Stadia Days.	Range Days.
1	40	3	3 4	8	16	37	24–46
2	14	11	6–15	9	17	41	25–64
3	20	13	10 15	10	9	39	27–57
4	4	17	16–19	11	6	39	24–51
5	10	23	16–35	12	2	39	33 46
6	16	25	16 37	13	2	43	40–47
7	18	31	19 46				

As the silverfish is not heavily chitinized, and the segments are easily stretched, measurements of the total length of the body were of little value. Instead, the measurement of certain organs which have well defined limits, and which do not change during the stadium, were compared. The following organs were selected (fig. 4) :—

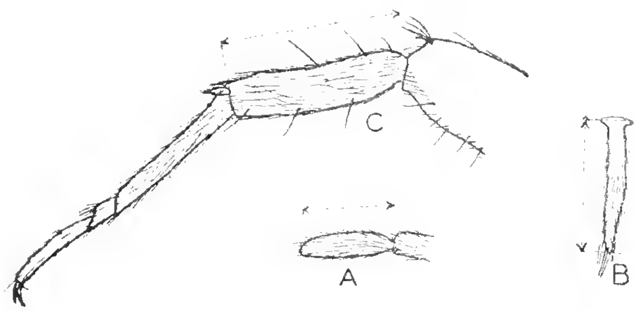

FIG. 4.—Parts used for comparative measurements of the early instars; *A.* Terminal segment of maxillary palp; *B.* Style; *C.* Anterior edge of metathoracic leg.

(*a*) The terminal segment of the maxillary palp.

(*b*) Styles.

(*c*) The anterior edge of the tibia of the metathoracic leg. The antennae and posterior appendages were also measured when these were complete.

One hundred insects were used. They were kept at 23°C. and five to ten individuals of each instar were killed and mounted in De Faure's fluid so that the measurements could be made.

Preliminary observations on the change in size of the selected organs during the stadium showed that no further change occurred after the second day. (The measurements were usually made about four days after ecdysis.) Since it was necessary to kill the insects to make the measurements, the increase in size of an individual could not be determined. The organs of both the right and left side were measured and these were found to be usually the same size. (Exp. error ± 0.003 mm.) When the measurements differed, the mean of the two was used. The individuals of any one instar varied considerably, but a consideration of all the information enabled the instar to be decided with some degree of certainty. The average measurements for each instar are shown in Table II. The lengths of the styles

TABLE II.—AVERAGE MEASUREMENTS (MM.) FOR THE INSTARS 1–14.

Instar.	Anterior edge of head to posterior tip of abdomen.	Terminal Segment Maxillary palp.	Anterior Edge Metathoracic Tibia	Styles.		Antennae.	Cerci.	Appendix Dorsalis.
				Seg 9	Seg. 8.			
1st ..	2.9	0.130	0.210	..	..	1.16	0.505	0.72
2nd ..	3.4	0.160	0.265	..	..	2.35	1.04	1.52
3rd ..	4.4	0.170	0.312	..	..	2.78	..	..
4th ..	4.8	0.184	0.360	0.107	..	3.3	1.87	2.75
5th ..	4.8	0.206	0.404	0.252	..	3.9	..	..
6th ..	4.9	0.232	0.402	0.338	..	4.0	..	..
7th ..	5.5	0.244	0.501	0.396	..	4.5	2.8	3.8
8th ..	5.7	0.264	0.566	0.470	..	5.3	3.1	..
9th ..	7.0	0.287	0.624	0.532	0.160	5.6	3.7	4.5
10th ..	7.2	0.294	0.678	0.617	0.210	6.1	3.9	5.4
11th ..	7.8	0.325	0.747	0.699	0.291	..	..	6.0
12th ..	8.0	0.356	0.833	0.745	0.451	7.9	5.6	6.0
13th ..	9.7	0.373	0.904	0.856	0.571	8.5	6.5	8.5
14th . (Last Observed)	9.4	0.421	0.985	0.902	0.586	10.4	6.9	8.5

for the two sexes have been averaged together; for, although in the mature insects the relative lengths in the two sexes is different, the ratio being 1 : 1.56 for the male and 1 : 1.46 for the female, no consistent difference was found in these early instars.

There are also characteristic changes which enable certain instars to be distinguished fairly easily. Among these may be mentioned the following:—

The first instar is a pale cream colour without hairs or scales. The appendages are soft and relatively short, and the anus appears to be closed.

The second instar is a darker cream. The chitin is firmer and the appendages are longer and can be freely vibrated by the insect. A few bristles mark the position of most of the "brushes" of the adult. [The number of bristles increases in the following instars and the bristle pattern may be found to be characteristic for each instar (cf. Buxton, 1938). The articulations are distinct even after the bristles have been lost. The patterns were however not studied in detail as it was realized that the size of the selected organs seemed to give an easier indication of an instar.]

The third instar is very active. It is dark cream in colour with purple tinting on the edges of the thoracic terga and the anal lobes. This colour persists in the succeeding instars.

The first three instars can be distinguished also by the tarsal segments. Each leg of the newly hatched insect has two tarsal segments. In the next instar, however, a septum develops on the second tarsal segment of the third leg, and in the third instar all the tarsi are three-segmented as in the adult.

In the fourth instar the scales are present. In this instar also the styles first appear, one pair being developed on the ninth sternum. They are "stubby" with many transverse "wrinkles." (The second pair of styles, which develops on the eighth sternum, does not appear until the ninth instar in the male and the eleventh instar in the female.)

It is interesting to note that the development during the first four instars resembles that of *Thermobia domestica* as described by Adams (1933).

In the fifth, sixth and seventh instars no particular distinguishing characters could be recognized.

In the eighth instar the genitalia first appear (fig. 5). They develop as two small lobes on the intersegmental membrane at the base of the cleft in the ninth sternum. This cleft first appears on the second instar, and becomes more and more marked until,

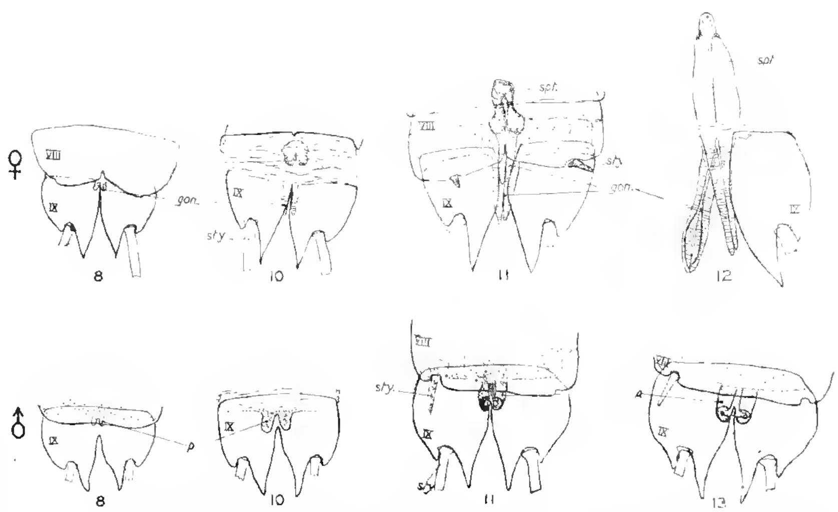

FIG. 5.—The genitalia of the young nymphs ventral view; female 8th, 10th, 11th, and 12th instars; male 8th, 10th, 11th, and 13th instars; *gon.* gonopophyses; *p.* penis; *spt.* spermatheca; *sty.* styles.

in the eighth instar, the two sexes can be distinguished by its shape. The two sexes can be further distinguished by the small cleft in the eighth sternum of the female, which also develops in the early instars and extends deeper in the successive instars until this sternum, too, is completely divided.

In the males these two lobes remain short until by the eleventh instar the shape of the penis can be distinguished. By this stage too the internal organs have formed. The reproductive organs of the adult male are shown in fig. 6A. In the nymphs the various parts can be distinguished. There are seven large testicles: the vasa deferentia are short, thin-walled, and slightly dilated at the distal end, and the two fuse immediately anterior to the penis. In the next instar they lengthen and form two loops between the two nerves of the cerci. In the thirteenth instar the vesiculae seminales form, and the rolled edges of the penis fuse ventrally so that this now has the same form as in the adult.

In the female the lobes elongate and in the tenth instar a second pair develops from the membrane between the eighth and ninth segments. In the eleventh instar the posterior lobes

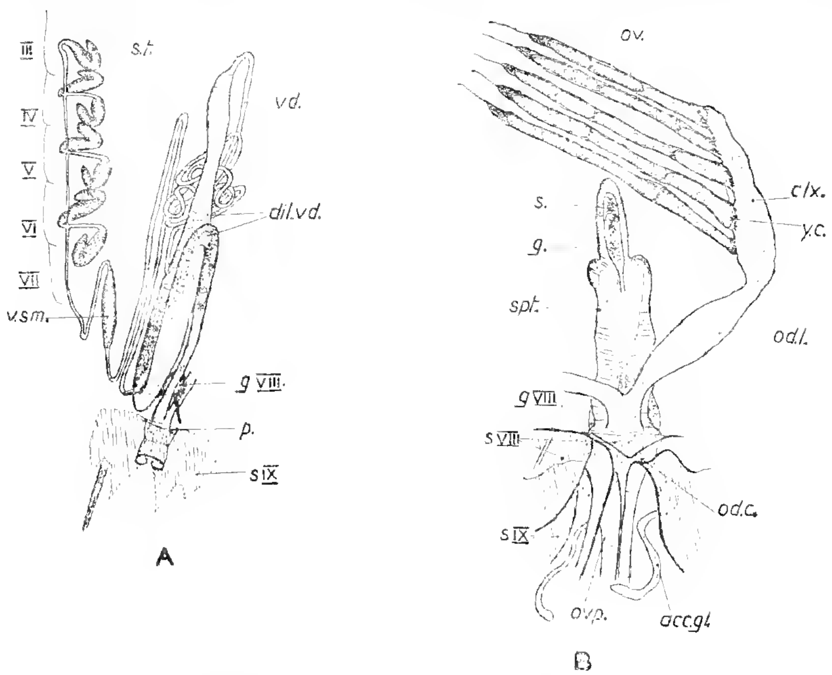

Fig. 6.—Reproductive organs of adult male *A.* and female *B.* (ventral view).
MALE:—*dil.vd.* dilated part of vas deferens; *gVIII* 8th ganglion; *p.* penis; *sIX* 9th sternum; *s.t.* sperm tube; *v.sm.* vesicula seminalis.
FEMALE:—*acc.gl.* accessory glands; *clx.* calyx; *gVIII* 8th gangiion; *od.c.* oviductus communis; *od.l.* oviductus lateralis; *ov.* ovariole; *ovp.* ovipositor; *s.* sperm, and *g.* granulated material in anterior prolongation of spermatheca, *spt.*; *t.f.* terminal filament; *y.c.* yellow cells.

elongate to within about 0.14 mm. of the points of the sternum, and the anterior pair extends ventrally to the base of the cleft in the ninth sternum. In the next instar the anterior pair are only a little shorter than the posterior pair, which now extend to within 0.08 mm. of the points of the sternum. In the thirteenth instar the two dorsal (posterior) lobes fuse and interlock with the two ventral (anterior) lobes as in the adult and the complete ovipositor projects about 1.2 mm. beyond the sternum.

At the same time the spermatheca develops. It appears first in the tenth instar as a short lobe directed anteriorly from the gonopophyses. In the twelfth instar it is already 0.6 mm. long and though the walls are still thin and undifferentiated, the two side sacs and the central neck are indicated (fig. 5). In the next instar the spermatheca has developed further and though it is still soft, the anterior prolongation, the neck region, and the two lateral pouches have well marked walls.

The internal reproductive organs have also formed by the thirteenth instar although the accessory glands and the "yellow" glands are not yet pigmented. The ovarioles still contain many small cells, the ova being not yet differentiated. The form of the organs in the adult female is shown in fig. 6B.

The detailed examination of the instars was not continued further than the fourteenth instar, as a preliminary examination showed that later development was concerned only with a very gradual increase in size.

In view of the extensive studies of growth rates which other workers have made, it is interesting to analyse the measurements of the instars of the silverfish in the same way.

The percentage increase in the average dimensions of the organs in the successive instars is shown in Table III, and it will be seen that this percentage increase is fairly constant, except during the first few instars. Apparently at its first appearance the organ is not as fully developed as is consistent with the later growth increments.

TABLE III.—RELATIVE INCREASE IN LENGTH OF PALPS, TIBIAE, AND STYLES FOR THE FIRST 14 INSTARS.

Instars.	Percentage Increase in Length.		
	5th Segment Maxillary Palp.	Metathoracic Tibia.	Styles of 9th Sternum.
1–2	123	126	..
2–3	110	118	..
3–4	105	115	..
4–5	112	112	235
5–6	113	114	135
6–7	105	108	114
7–8	108	113	117
8–9	109	110	119
9–10	110	109	113
10–11	110	110	116
11–12	105	111	113
12–13	113	108	106
13–14	..	109	115

Measurements were also made of the adult insects, comparing the organs of one side which were removed with those of the other side after the ecdysis. Although the adult insects increase in size over a period of several years, no regular increase in the size of these organs was observed, and in some cases they were the same size or smaller than those of the other side in the previous instar. Part of this discrepancy was probably due to regeneration.

The growth co-efficient (Huxley, 1932) of an organ is generally found by measuring its increase relative to that of the body when expressed by the formula:—

$$y = bx^{a}$$

where y is the size of the body; x is the size of the organ; b is a constant and a is the growth co-efficient.

i.e., the graph of log. (size of body) against log. (size of organ) is a straight line of slope.

Since the growth co-efficients of any two organs can be represented in this way, the relative growth of the two organs must follow the same type of curve. The relative growth of the palp and styles was compared with that of the metathoracic tibia, and the value of a for the palp was found to be 0.8, and for the styles 1.48. The same growth rates seem to be maintained until maturity. In fig. 7 the measurements of the individuals of three instars are shown. There is an almost continuous gradation in size between the instars, which is only to be expected when so many ecdyses are concerned in the growth of a nymph so similar in form to the adult.

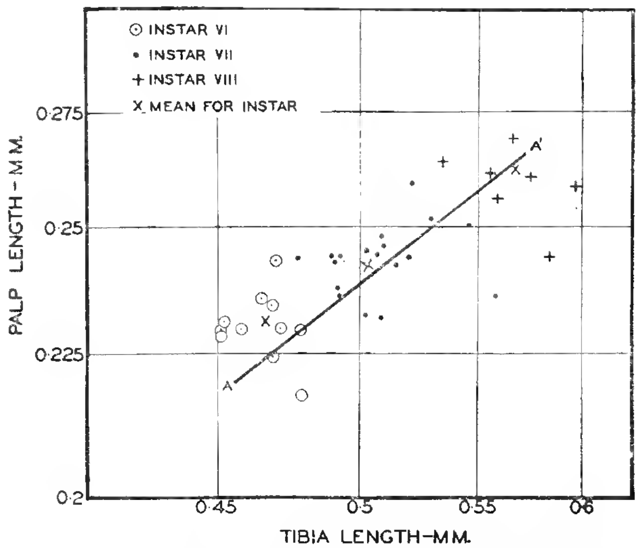

FIG. 7.—Variation in length of palp with length of tibia for three successive instars. Plotted on log-log scale. The slope of A-A¹ is the growth co-efficient of first 14 instars.

3. The Adult.

Ecdysis and Feeding:—Ecdysis continues after the silverfish reach sexual maturity. The relation of ecdysis to feeding was followed by observing the daily feeding of twenty individuals maintained at 24°C. In every case the insects did not feed during the last third of the stadium. During the first portion of the stadium they fed actively, although usually, there was a short period of one to three days before feeding began. These periods of no feeding presumably allow time for the old chitinous lining of the alimentary canal to be shed and the new one formed. (See p. 46.)

The insects which are found at night crawling about the floors and walls are usally in this feeding period of the early portion of the stadium. A number of these insects were collected and the rate of moulting watched; for example, one group of eighty-two insects collected on March 8th, 1937, started to moult ten days after capture (fig. 8). This continued for 60 days, when the last insect moulted. In another group of 30 insects caught on the 27th July, 1937, the same thing was observed; but, in this group, the last ecdysis did not occur until more than 100 days after capture. About 80 days after capture (October) the numbers of insects moulting greatly increased, probably because of the increasing room temperatures.

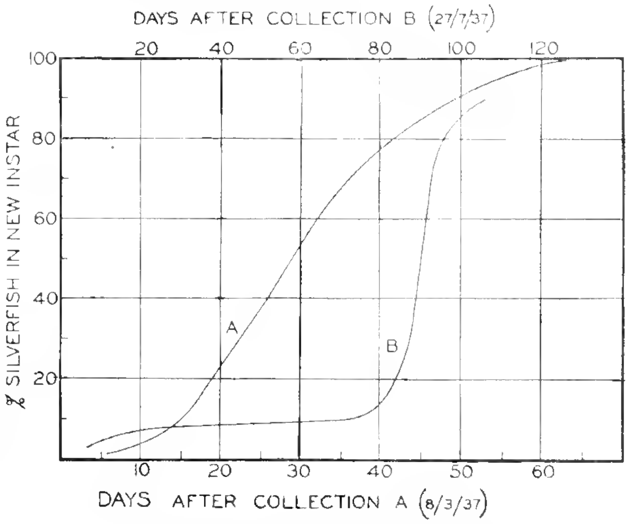

Fig. 8.—Length of time after capture before ecdysis occurred. Note the effect of increasing room temperatures in the rapid ecdysis in October of the insects collected 27.7.37. (Graph B.) The time scales of the two graphs are different.

Ecdysis:—The approach of ecdysis can be seen by the darkening of the new scales beneath the cream chitin of the old cuticula, from which, by the end of the stadium, most of the scales have been rubbed. This darkening increases during the last two to three days of the stadium. When the new cuticula is completely formed, the insect starts to work the abdomen gradually forward until free of the last two segments of the old cuticula. Ecdysis then proceeds more rapidly. The abdomen expands and contracts; a deep furrow develops in the mid-dorsal line of the thorax and along the epicranial suture; the head is bent ventrally with the antennae and legs directed posteriorly, and the thorax is "hunched" until the furrows split. The head is dragged free, followed by the antennae and legs, and the cuticula is worked off the end of the abdomen. This part of the ecdysis is completed in ten to fifteen minutes.

The linings of the crop, gizzard, hind intestine and spermatheca are cast at the same time. Dissections showed that even before the new cuticula had formed, the lining of the crop and hind intestine were free in the lumen of the alimentary canal. The crop lining was broken off at the pharynx and with the lining of the gizzard passed back with the faeces.

It may be noted that in most insects the crop lining is cast through the mouth. In the case of the silverfish, the crop remains attached to the gizzard, and casting through the mouth is prevented by the arrangement of the large teeth of the gizzard. These can, however, be pushed backwards through a narrow opening for they fold into one another.

Under experimental conditions it was noticed that the silverfish were very slow-moving during the last days of the stadium. At this time, and during ecdysis they were readily attacked by other silverfish (particularly if the diet was not adequate). The exuviae were often eaten. Under unfavourable conditions it often happened that the insects died when the first split developed, or else they failed to draw the thorax out of the cuticle which then broke at the anterior end of the abdomen.

Mating and Egg Laying:—The cycle of growth and ecdysis influences mating and egg laying. The two sexes occur in about equal numbers. The spermatophore is probably formed at the time of copulation. It consists of a loose bag (1.5 mm. diameter) enclosing a coiled tube which ends on a long neck and pointed cap. It is presumably formed by the vasa deferentia of both sides (fig. 6) for the vas deferens of one side never seemed to contain fewer sperm or less gelatinous material, as might have been expected if the spermatophore were formed by one side only.

The neck of the spermatophore is pushed through the vagina into the body of the spermatheca, the tip fitting into the base of the anterior prolongation. The sperm are passed forward into the prolongation, preceded by a mass of finely granulated material. The female then eats the spermatophore from the base of the ovipositor, and in less than fifteen minutes there is no longer external evidence that mating has occurred. Copulation has not been observed but it is difficult to see how the long neck of the spermatophore could get into the vagina of the female unless transferred directly by the male. (Compare Sweetman, 1938).

The chitinous lining of the spermatheca is always thick in the fertilized females; but whether this is merely due to age, or whether it is due to the stimulation of mating is not known. The posterior part of the prolongation of the spermatheca is closely constricted and must relax to permit movement of the sperm. There is also another constriction at the base of the body of the spermatheca. This is distended by the entrance of the spermatophore.

Mating probably occurs after each ecdysis as the contents of the spermatheca are lost when its lining is cast. On several occasions it was noticed that the females bearing spermatophores were in the early part of their stadium. The stage of development of the eggs at mating does not seem to be important, for sperm were found in the spermatheca of females with either medium sized or large eggs, and in other females containing large eggs no sperm were found. Females isolated from males continued to lay fertile eggs until ecdysis. The eggs laid after this soon turned yellow and shrivelled. Usually two or three batches were laid after the separation and then the females continued to live for two years apparently quite normally, but laid no more eggs.

The stimulus for the formation of the spermatophore is not known, but it is not a seasonal process. Dissections of males throughout the year revealed that the vesiculae seminales always contained active sperm, and on one occasion—in June, 1938—a number of insects were transferred from room temperature (about 10°C.) to 24°C. and several spermatophores were formed overnight. Apparently the males were in a condition to function as soon as the temperatures increased.

The length of time the eggs take to develop in the ovarioles is not known, but the development is not seasonal. Both large and small eggs were found in the ovarioles in both winter and summer. The lower two or three eggs apparently mature at the same rate in each of the ovarioles, and development proceeds at the same rate in the two ovaries.

An attempt was made to watch the rate of egg laying of isolated pairs of adult insects and of groups of three or four insects—220 in all—but very few eggs were laid under these conditions and the males were frequently eaten by the females. Dissections showed that the females contained nearly mature eggs but there was no evidence that copulation had occurred. This is in accord with the observations of Sweetman (1938), who found that several males were necessary to stimulate the act of copulation.

Another series of observations was made on 124 females and 96 males held in groups of 10 to 40 insects. These were watched from February, 1937, to June, 1939, and during this time 4,573 eggs were laid (during this period 34 females and 24 males died or were removed). The average number of eggs laid per year by each female was 56. This occurred mainly in the summer, between the end of November and the middle of March, but a comparison of the rate of egg laying over the whole period showed some relation to room temperatures; for example, in 1938, egg laying continued until July, during which time the temperature was higher than in 1937. Again in March, 1939, higher temperatures resulted in greater egg laying.

V. The Effects of Temperature and Humidity.

1. Temperature.

Length of Stadium:—The effect of temperature on the length of the adult stadia, on the nymphs, and on the eggs was tested.

The apparatus used was the multiple temperature incubator developed by Andrewartha (1935) for Thrips, and provided ten different temperatures. The temperatures of the insect containers were affected by outside temperatures to some extent, and it was necessary to calculate from the daily readings the mean temperatures for any period under consideration. The insects were provided with the standard diet (p. 36) and the humidity in each container was controlled by a 4 per cent. solution of sulphuric acid. This kept a relative humidity of about 96 per cent. and prevented the growth of moulds which became troublesome at higher humidities. Other experiments showed that the insects were not affected as long as the relative humidity was above 50 per cent.

In the final tests 39 insects were used and the average temperature was calculated for the period of each instar. These temperatures were then grouped into intervals of 1°C. and the mean length of the stadium for the temperature interval was calculated. Although the insects used were of about the same size, there was considerable variation in the lengths of stadia (Table IV.). However, the average lengths of the stadia showed clearly the increasing rate of growth at temperatures above 16°C. The greater activity above 20°C. was also evident from the rapidity with which the food was consumed.

Table IV.—Average Length of Adult Stadia at Various Temperatures.

Temperature °C.	Average Length Stadium.	Range.	Number of Insects.	Temperature °C.	Average Length Stadium.	Range.	Number of Insects.
	Days.	Days.			Days.	Days.	
29	15	..	2	22	43	30–58	4
28	17	20–15	2	21	46	38–65	6
27	30	13–44	10	20	67	49–106	11
26	40	35–46	2	18	59	50–68	2
25	39	24–50	8	16	129	121–142	4
24	51	36–79	3	15	165	100–239	4
23	37	21–46	6	14	220	106–263	4

The eggs and young nymphs were also subjected to a range of temperatures (Table V.). The individual rates of development were uniform for the egg and the first two instars.

TABLE V.—AVERAGE LENGTH OF HATCHING PERIOD AND 1ST STADIUM AT VARIOUS TEMPERATURES.

Temperature °C.	Period of Hatching.	Length of First Stadium.
	Days.	Days.
29·5	20	5
25·3	27	5
25·0	30	5
24·0	34	5
23·0	46	7
21·0	49	9

At temperatures below 13°C. the insects became torpid, and at 11°C. ecdysis stopped even if the cuticula had been partly shed. However, the process was completed when, a week later, the insects were put in a temperature of 24°C. Adult insects survived several months at 1°C. but second instar nymphs were killed in two days by the low temperature and at 11°C. survived for only twenty-five days. At 12°C. the length of life increased to seventy days.

Length of the Life Cycle:—In Melbourne, the life cycle extends over several years. Owing to some difficulty during the first year in providing a supply of food adequate for growth, insects have not yet been reared from egg to maturity. However, the total length of the life cycle can be estimated from observations of different periods. For example, in November, 1937, thirteen nymphs 4 to 10 mm. long were collected in the laboratory. These had probably developed from eggs laid the previous summer. By November, 1938, they had grown 10 to 12½ mm. and some laid eggs during the first week of December, 1938.

Under the conditions maintained for the stock insects (24°C.), eggs hatched in 34 days, the nymphs reached the thirteenth instar, 9½ mm. in eleven months, and would probably reach sexual maturity in eighteen months. At this temperature egg laying continued throughout the year.

It is interesting to compare these conditions with those maintained for *Thermobia domestica* (Sweetman, 1938).

Activity and Distribution:—These results obtained under controlled conditions may be compared with observations of the insect's normal activity. It is assumed that the mean air temperatures give a measure of the conditions obtaining in the insects' microclimate.

The prevalence of silverfish in the capital cities as judged from the reports of residents, pest destroying firms, and the Government Entomologists, can be related to the length of the period the temperatures are above 16°C., the limiting temperature for active feeding and growing. It is only in those places which have long periods of temperature higher than 16°C. that the silverfish can increase to pest numbers. In a brick or stone house an indoor temperature of 16°C. normally corresponds to an outside temperature of about 55°F. (data received from the Commonwealth Meteorological Bureau, Melbourne). For example, the average daily temperatures were above this limit in Hobart for six and a half months, and Brisbane for the whole year. Very high temperatures do not limit the distribution of the silverfish in Australia, for air temperatures do not persist long enough above 30°C. to cause death.

The activity of the silverfish during the year in Melbourne can be related to the air temperature. During the winter months the metabolism is slow. Digestion proceeds slowly and observations on the stock insects showed that even some days after feeding, the crops still held many large fragments of digestible material. Since the need for food is reduced, the silverfish are seldom to be found at night on the walls and floors. For example, 25 weekly collections at 10 p.m. were made in one building during the period May to November, 1937. The average winter catch was fifteen, but during October, the number caught increased to 80. In all, 770 large insects were collected during this period.

These figures give an indication of the number of silverfish in a building which was not considered to be very badly infested. An occasional spraying was the only control used. Evidently

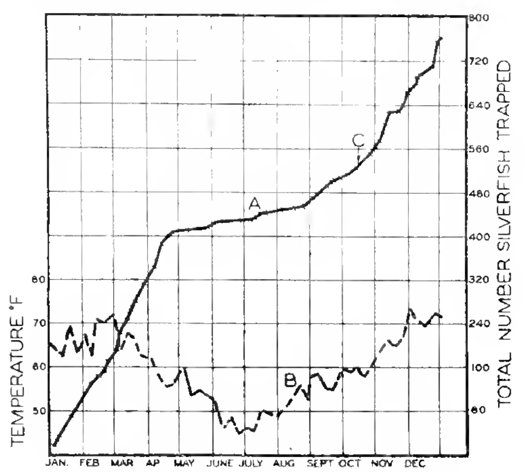

FIG. 9.—Influence of temperature on activity of silverfish. A. Progressive total of silverfish trapped in the sinks in one laboratory during 1937. The sinks were cleared each day. From October (point C) collections in other places also greatly increased. B. Mean weekly temperatures.

not all the insects are ranging on the walls and floors at the same time; for after an exhaustive search on four successive nights in October the same number of insects were caught on each occasion.

The number of insects accidently trapped in the sinks in one laboratory showed this same increase as the weather became warmer (fig. 9). Daily counts were made during 1936 and 1937, and, in both years, the numbers trapped increased greatly after October, when the mean weekly temperatures increased from 12.8° to 15.9°C.

High Temperatures:—The increased activity at higher temperatures continues to about 24°C.; but, temperatures higher than this are fatal, death occurring after a period which decreases from several months at 26°C. to one hour at about 41°C. (Table VI.). The effect of high temperature on other species of insect has been studied by many other workers (e.g., Buxton, 1931, Mellanby, 1932) with particular reference to the effect of moist and dry air, and to the possibility of some regulation of body temperature by the insect, at least, for short periods.

TABLE VI.—MINIMUM PERIOD OF EXPOSURE AT HIGH TEMPERATURES.

Temperature °C.	Period of Survival.	Number of Insects.
41·5	1 hour	9
40·0	15 hours	9
33·6	6 days	1
33·1	9½ ,,	4
32·6	9 ,,	6
31·3	24 ,,	2
31·0	16 ,,	2
30·1	8 ,,	7
29·5	21 ,,	5
29·0	11 ,,	2
26·0	4 months	10

These results were obtained in the multiple temperature incubator during the tests on maximum lethal temperatures.

The tests on silverfish were carried out by placing the insects in a test tube (2 in. x ¼ in.) suspended in a Florence flask in which humidities of 5 per cent. and 85 per cent. were maintained by solutions of sulphuric acid. The introduction of the silverfish through a tapering glass tube lowered the temperature of the flask, which required 30 minutes to return to that of the water bath in which it was immersed. The bath temperature was maintained to within ± 0.02°C. and a correction of 0.25°C. was applied, when necessary, to allow for the initial temperature drop. About 250 insects were used. After preliminary tests, 24 groups of nine insects each were used to determine the lethal temperatures for exposures of one hour and fifteen hours respectively.

In addition sixteen tests were made with periods other than one hour and fifteen hours.

For exposures of one hour, the highest temperature at which all the insects survived was 41.5°C. At higher temperatures an increasingly greater percentage of the insects died; but the mortality was lower in the dry air (fig. 10). Similarly for exposures of fifteen hours, the highest temperature at which all the insects survived was 38.8°C. Presumably, even during the short exposure of one hour, the body temperature of the insect was reduced by evaporation of the body fluids, though this point was not checked by measuring the weight lost by the insects during the test. After exposures of fourteen hours the effect of evaporation was still appreciable, but, presumably, in still longer exposures, this loss of water would be so great that the lethal temperature would be lower in dry air owing to the desiccation of the insects.

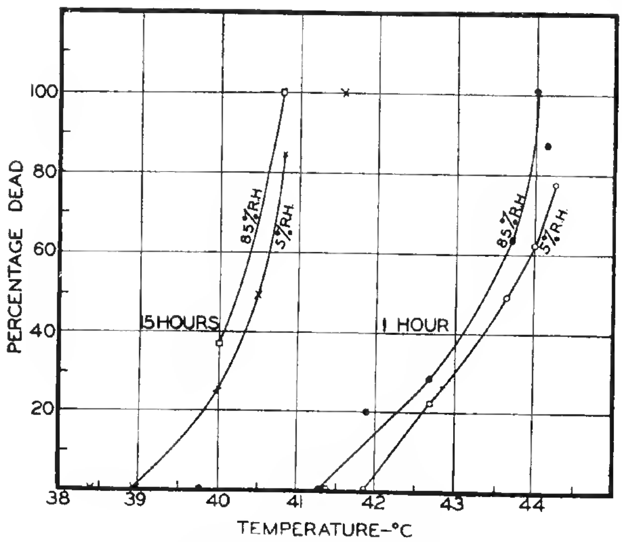

FIG. 10.—Lethal Temperatures for Exposures of one and fifteen hours in air of 85 per cent. and 5 per cent. Relative Humidity.

The variation in the reaction of the individual silverfish to the high temperatures is in accordance with that found in other insects. In the case of the silverfish, the variation was about the same in the two series of experiments, and was not greater in dry air as Buxton (1931) had found with *Rhodnius*.

In the third series of experiments, exposures of various periods were used, and those which caused the death of all the insects at the various temperatures (about five insects being used for each test) have been summarized in Table VII.

TABLE VII.—MAXIMUM PERIOD OF SURVIVAL OF ADULTS AT HIGH TEMPERATURES.

Temperature °C.	Fatal Period.
45·0	30 mins.
44·0	40–45 „
43·8	60 „
42·4	75 „
41·5	15 hours
39·5	40 „
38·0	72 „

After the silverfish had been exposed to high temperatures for fifteen hours or more, there was no difficulty in determining which were dead; but after a short exposure many became merely torpid. Some died but others recovered during the next 24 hours (and behaved normally at subsequent ecdyses). To take these insects into account the percentage dead at each temperature was calculated from the number dead 24 hours after the end of the test.

During exposure to high temperatures the silverfish moved about very rapidly. As soon as they were lifted out of the thermostat to cool, they became torpid, but again moved about actively when put back into the high temperature enclosure. This could be repeated several times. Finally, after 24 hours at room temperature, some of the torpid insects recovered. This behaviour is interesting in view of the possible causes of the lethal effects of high temperature which Mellanby has suggested. The only visible effect of the high temperatures was associated with the fats. The large fat bodies on the dorsal wall of the abdomen became so clear in the dead insects that the internal organs could be seen through the thin chitin. This "clearing" did not occur in the insects which merely became torpid, or in the insects killed by exposures of fifteen hours and longer.

The fact that the lethal temperatures were higher in dry than in moist seemed to indicate that the insects had some control over their body temperature, and an attempt was made to measure their rate of heating after they had been transferred to a higher temperature.

The method used was that generally adopted, i.e., the piercing thermocouple (Robinson, 1928ii); but a consideration of results showed that the silverfish was so small that the temperature of the couple was determined by conduction along the wires rather than by the temperature of the insect itself. It was concluded that only in an insect above a minimum size (depending on the conductivity of the tissues), would the thermocouple be at the same temperature as the insect.

A still more serious drawback to the method was the unavoidable injury to the silverfish. Although the silverfish could live for longer than one week while impaled on the junction, provided the crop had not been pierced, they were susceptible to high temperatures and died after an exposure of one hour at 30°C. It was therefore not possible to test temperatures so high that any control of the body temperature by the insect itself could be expected to operate.

For the calculation involved in determining the rate of heating it was desired to know the specific heat of the insect. A calorimetric determination was attempted but the rise in temperature, which continued for one hour, was too great to have been derived solely from the heat of the insects, and it seemed probable that it was partly due to the heat of wetting.

The high value for the Specific Heat (1.4) obtained from the figures of Bodenheimer and Schmidt (1931) may be due to the inclusion of this "heat of wetting" in the total rise in temperature. No indication of the rate of temperature rise was given.

2. The Effect of Humidity.

The silverfish takes no liquid but must obtain its water from that absorbed by the food, and from that produced by the oxidation of foodstuffs. There is no excessive loss from the alimentary canal because water is absorbed in the hind intestine and rectum and the faeces are dry when extruded; but there is a continual loss from the tracheal system. The tracheae open at ten spiracles (fig. 11A), which have no closing mechanism, but are protected to some extent by the folds of the intersegmental membranes on which they are situated (fig. 11B). This simple tracheal system and the thin cuticle make the silverfish particularly susceptible to dry conditions. The effect of a range of humidities was studied and an attempt was made to understand the water relations of the tissues, when death occurred from drying. For most of the tests, adult, early stadium insects were used.

Water Content:—The water content of normal silverfish was determined by—

(*a*) drying at 103°C.;

(*b*) ether extraction of fat and water from the fresh insects.

The average water content of 165 insects was 72.4 per cent. The agreement of the results from the two methods showed that drying at 103°C. caused no appreciable decomposition of the tissues although the insects became brown during the process.

The individual determinations varied between 70.5 per cent. and 82 per cent. water. Variations of this order have been found in other insects. In the silverfish this variation could not be correlated with the moisture content of the food (as Robinson, 1928, had found in the grain weevils) although the food varied from paper (7–8 per cent. water) to a mixed diet containing some fresh plant tissue.

The relationship between the water content and the body weight can be shown by curves on a log/log scale. The "k" value for the silverfish 0.96 compares with the values for both the mealworm 0.975, and the wax moth 0.96 (Huxley, 1932) and shows that there is no relative change in the water content with body weight.

Effect of Dry Air:—The insects survived only short periods in air over calcium chloride. The average length of life of 35 insects was thirteen days; but there was considerable variation, the extreme limits being three days and 26 days.

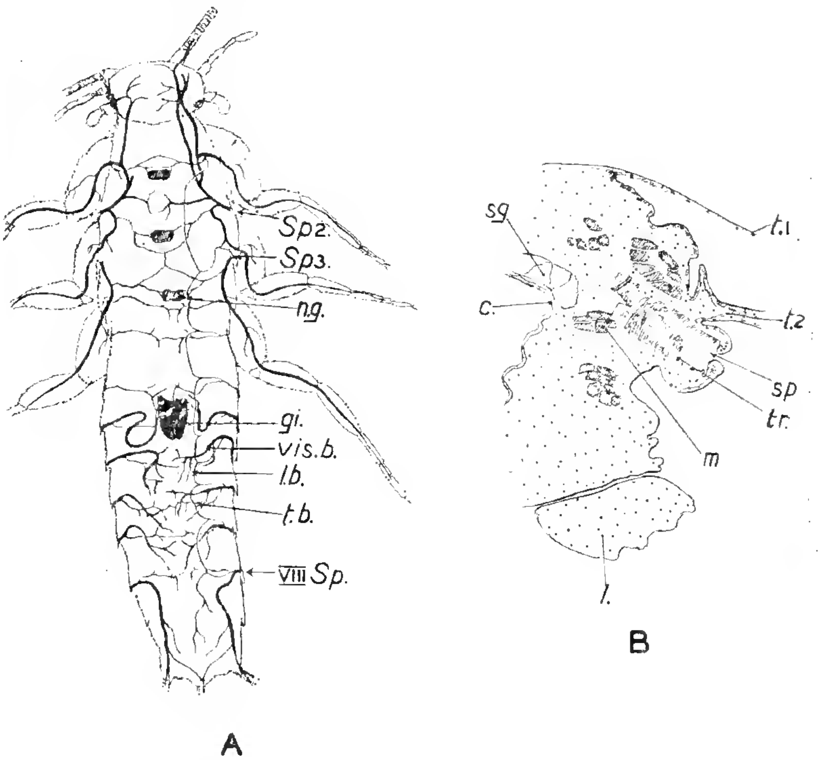

FIG. 11. TRACHEAL SYSTEM.—A. Dorsal View:—The dorsal system has been removed from the left side; *n.g.* nerve ganglion; *gi.* gizzard; *l.b.* lateral branch; *t.b.* transverse branch; *vis.b.* visceral branch. Sp_2, Sp_3, *VIIISp.* Spiracles of meso and meta thoracic segments and 8th abdominal segment.
B. Opening of 1st trachea:—Drawn from two successive sections 7μ. thick $\times$ 245; *l.* leg; *m.* muscle; *t1.t2.* terga I and II; *tr.* trachea; *sp.* spiracle; *s.g.* salivary gland; *c.* crop.

The rate of loss of water was determined from daily weighings of eighteen silverfish held at 24°C. Each insect was held in a small tube $\frac{1}{4}$ in. x $\frac{1}{2}$ in. Nine were fed and nine starved. Two of each lot were kept under stock conditions as controls. These and the one survivor were killed at the end of the test of 24 days, and the dry weight of all the insects determined. The total weight of the faeces was 0.15–0.6 mg., and was included in the weight of the insects at each measurement.

The individual rates of loss showed considerable variation but there was no significant difference between the fed and starved groups. The metabolic losses are small under these confined conditions, and as Gunn (1933) has shown, the loss of weight may be taken as a measure of the loss of water. The silverfish died after losing 20 per cent. to 75 per cent. of their weight. The average loss per day was 4.6 per cent.

The period of survival could not be correlated either with the rate of loss of weight, with the percentage of water lost until death, or with the water content of the body at death. For this latter figure the whole weight of the body was used, as the weight of the chitin is relatively small. No attempt was made to consider the water content of special tissues as Mellanby has suggested (1937).

The rate of loss of weight gradually decreased towards the end of the period, but it was usually the same five days before and after death, i.e., death was not followed by a suddenly increased loss of water. Even in insects still more susceptible to drying, e.g., *Phlebotomus* larvae, Theodor (1936), the rate of loss of water did not change at death.

Comparison of the Loss from Insects at Different Times in the Stadia:—The loss of water from insects late in the stadium was compared with that from insects early in the stadium. The insects were starved throughout the tests. Although during the first three and a half days the rates of loss of weight of the two groups was the same, over the whole period the late stadium insects lost water more rapidly than those early in the stadium. Their total loss until death was 66 per cent. compared with 57 per cent. for the early stadium, and the water content of the tissues at death was lower, 53 per cent. compared with 62 per cent. for the early stadium. (A determination of other groups of insects from stock showed a water content of 74.1 per cent. for the late stadium compared with 73.2 per cent. for the early stadium.) The late stadium insects also survived for a shorter period, the mean length of life for the group being 12.4 days compared with 16.3 days for the early stadium insects.

The slower rate of loss from the early stadia was probably due to the added protection of the layer of scales which are rubbed off the thin cuticle later in the stadium.

Loss of Water at Ecdysis:—Ecdysis is accompanied by changes in weight which are probably due to changes in the water content of the body. Even in moist air the insects lost about 8 per cent.

of their body weight during the seven days preceding ecdysis. This loss continued during the day after ecdysis and then the weight slowly increased.

The insects are most susceptible to dry conditions during the period of ecdysis, and after about four days' exposure they were not able to complete the moult. Death occurred usually after the old cuticle had split along the thorax.

Effect of Various Humidities:—The various humidities were maintained in Mason jars by sulphuric acid solutions of the required concentration. The insects were held in small tubes suspended in the jars, and paper and casein were provided. The tests were made at room temperatures.

The critical humidity seems to be about 55 per cent. There was some evidence that the length of life decreased at very low humidities (Table VIII.), which evidence is supported by the fact

TABLE VIII.—LENGTH OF LIFE AT VARIOUS HUMIDITIES.

Relative Humidity.	Number of Insects.	Period of Survival.	Range.
%		Days.	Days.
0–19	13	12	5–26
26–45	52	15	6–40
50–52	49	28	> 70
55	8	> 146	

that the rate of loss of weight was greater at the lower humidities (fig. 12, Table IX.). There was also some evidence that the length of life was shorter at higher temperatures for any given relative humidity.

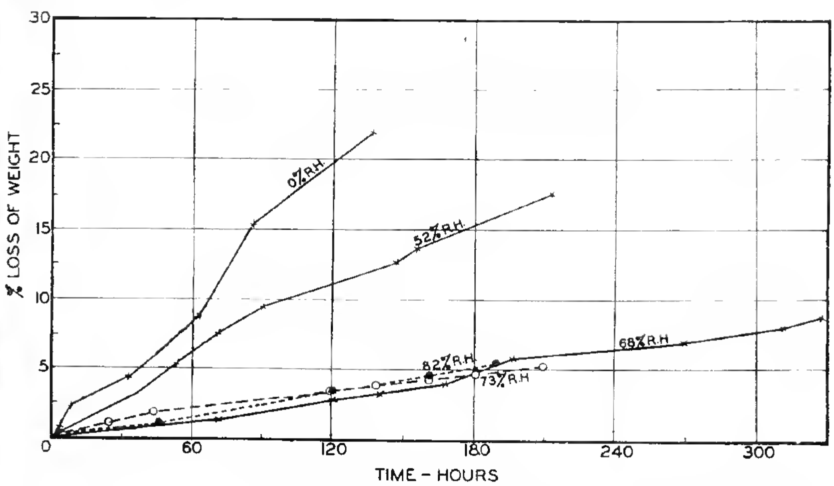

FIG. 12.—Rate of Decrease of Weight of System (Insects and Food) when held at various humidities.

Table IX.—Change in Weight of Insects Held at Various Humidities at About 18°C.

—	Relative Humidity.			
	52 Per Cent.	68 Per Cent.	73 Per Cent.	82 Per Cent.
Initial weight (mg.)	353·7	338·4	253·5	382·3
Number of insects	13	13	14	15
Period of test (hours)	300	300	210	190
Total loss of weight of food and insects as percentage of initial weight	29·3	9·5	5·4	5·5
Food eaten (mg.)	11·1	33·9	12·5	35·7
Food eaten as percentage of initial weight of insects	3·1	10	4·9	9·3
Change in weight of insects as percentage of initial weight	−26	+0·5	−0·4	+3·8

The effect on recently laid eggs from stock insects was also tested. The nymphs survived at humidities above 55 per cent., but at lower humidities they died during the second ecdysis. At a relative humidity of 35 per cent. they died during the first ecdysis, and in dry air they failed to hatch, or died during the first instar.

When measuring the rate of loss of weight, new stadium insects were used, and were weighed separately from the food only at the beginning and end of test period. In the more humid conditions they ate sufficient food to maintain their body weight, and a relative humidity of 82 per cent. actually increased their weight by 4 per cent. In dry air they lost more weight than could be replaced from the food. Some general disturbance experienced in dry air may account for the low food consumption, and for the fact that their length of life was not increased by feeding.

Absorption from Moist Air:—Under natural conditions silverfish are not subject to dry conditions for long periods. The fact that they survived for some months when subjected to dry periods of 1, 4, and 7 days with intervening periods of one day in moist air, indicated that they could absorb moisture from the moist air. Preliminary tests indicated that the increase in weight of partly desiccated insects was proportional to their loss in weight during the preceding period in dry air. Insects which were collected while freely ranging on the walls, did not change in weight during a period of five days in moist air.

In subsequent experiments, the insects were held in dry air for various periods, and then left for four hours in air of 99 per cent. relative humidity. Every care was taken to eliminate condensation, so that the change in weight might be due only to absorption from the air.

A 300-cc. Florence flask containing 20 ccs. of 2.3 per cent. sulphuric acid was immersed to the stopper in a water bath which was maintained at 23.5°C. ± 0.02°C. Three small glass vials 2½ in. x ½ in. were suspended in the flask by wires. After the insects had been kept in the dry air for the required period, they were rapidly run into one of the vials through a small glass funnel and rested on a small piece of rubber in the bottom of the tube. After four hours they were transferred to closed weighing bottles and weighed immediately, and again after drying at 103°C. for six hours.

TABLE X.—THE ABSORPTION OF WATER FROM MOIST AIR AT 23.5°C.

Previous History.	Dry Weight.	Change as Percentage of Dry Weight.	Initial Water Content Percentage.
	mg.		
From stock	36·9	− 1·1	75·4
From stock	41·9	− 0·2	72·4
In moist air, 96 hours	43·9	− 1·8	71·9
Desiccated, 4 hours	40·3	− 4·6	71·2
Desiccated, 15 hours	39·0	+ 2·1	70·9
Desiccated, 72 hours	35·4	+ 2·8	73·5
Desiccated, 96 hours	48·1	+ 3·9	69·4
Desiccated, 119 hours	34·5	+ 4·1	71·4
Desiccated, 144 hours	39·7	+ 1·5	73·0

In all but two experiments, the increase in weight was proportional to the length of the previous desiccation (Table X.). It was thought that the water content of the tissues after desiccation ("initial water content" in Table X.) would depend inversely on the length of the period of desiccation, but no such relationship was found, probably because there was some variation in the amount of food consumed during this period, with consequent variations in the amount of the water loss replaced from the food. The change in weight of insects from moist air (maintained with a dish of water in a closed tin 12 in. x 9 in. x 6 in.) was measured for comparison. These actually decreased in weight. Insects from stock suffered little change in weight, which shows that under the stock conditions they maintain a water content which is in equilibrium with an air of 99 per cent. relative humidity.

Humidity Preference.—With certain experiments it was necessary to provide a supply of moisture by means of a cotton plug in an inverted tube of water. In the open vessels the silverfish congregated on this wet surface; but in the closed vessels, the humidity was raised, and they no longer rested on the plugs.

An attempt was made to measure their response to a humidity gradient. The method recommended by Gunn, 1936, was used, but the extreme limits of humidity achieved by water and concentrated sulphuric acid, was 44 per cent. to 64 per cent. with 56 per cent. in the middle (as measured by a humatograph). The silverfish showed no preference for any region, even after the tests had been continued for one week.

Discussion:—These experiments show that silverfish are fairly susceptible to dry conditions, and that they derive at least part of their water from moist air.

No definite information about the water relation of the tissues at the time of death from desiccation could be obtained. The figure of most value seemed to be the "water content of the tissues at death." All the various species studied by other workers died when the water content of the tissues was reduced to 53–62 per cent., even though the different species lived in dry air for very different lengths of time. However, the water content at death of individual silverfish varied within still wider limits, 30–76 per cent., and even the individuals which survived desiccation the longest showed no closer similarity in this, or in the rate of loss of weight during the last days of life.

Though adaptation to dry conditions might not be expected, there seemed to be, at the higher humidities, some relationship between the amount of food eaten and the loss of weight. In air drier than 52 per cent. relative humidity the water lost was not replaced from the food eaten, but rather, less food was eaten than at the higher humidities. Buxton found that in starving mealworms, the metabolism of dry matter was proportional to the loss of water, and the water content of the tissues remained constant. He considered this to be an adaptation to dry conditions; but later experiments with a wider range of insects showed that this could not be generalized and Mellanby, 1936, showed that metabolism is controlled solely by temperature and not by humidity.

Since the insects can take up moisture from a humid atmosphere, and since they tend to congregate near moist surfaces, dryness is probably not a limiting factor under natural conditions. Even at 60 per cent. relative humidity the loss of water was only 0.14 mg. per day.

VI. Nocturnal Habits.

Under natural conditions the silverfish feed at night. Shortly after dusk (approximately 8 p.m. in summer and 6 p.m. in winter) they emerge from the crevices of a room and move about the floor and walls usually in short runs with long pauses between. At daybreak, they return to the crevices again. They seem to be able to find shelter very easily, and, when disturbed at night by a bright light, they turn about and seek the crevice from which, presumably, they have emerged. If far from the wall, they seem to make short runs in random directions, but even then, they usually reach cover within ten minutes. This reaction to light was watched during both day and night in half-covered petri dishes some of which were exposed to strong artificial light.

The insects in the illuminated dishes always sheltered in the shaded part. During the day, even in the completely shaded dishes, the insects only occasionally moved about and fed; but as dusk fell, they moved about and fed even in the illuminated dishes.

When suddenly illuminated, the insects, after a pause of about half a minute, started to move their antennae actively. After one to two minutes they started to move about. By the end of seven minutes they reached the shadow of the piece of paper in the dish, and did not move into the light again.

Besides avoiding light in this way, the silverfish took shelter in a crevice between two glass slides and remained there quietly although they were still exposed to the light.

VII. Spraying.

The nocturnal habits of the silverfish are important in determining the effectiveness of the use of sprays as a means of control, for the insects sheltering in the crevices can seldom be reached by the spray. The vapour alone of a kerosene-lethane-pyrethrum mixture is not lethal so that they are not killed unless they come in contact with the spray droplets or the sprayed surface. In one test a cupboard of 170 c.dm. capacity was sprayed at the rate of 1 cc. per 40 c.dm. This was sufficient to make a very strong smell, but did not kill the silverfish in a petri dish protected from the falling spray by a sheet of filter paper which was removed ten minutes after the spraying.

The toxic effect of the spray on wood persisted for some hours. It was noticed that for four to six hours after the spraying of a room had been completed, dead insects could still be collected. In some cases these had crawled 3 feet to 4 feet beyond the sprayed area. The persistence of the toxic effect of the sprayed wood was further tested by confining silverfish at intervals on the surface of pieces of wood which were sprayed with a measured amount of fluid.

After a spraying of 1cc. per 14 c.dm. the insects were killed by four minutes' contact with the wood, two and a half hours after spraying. Even after the wood had been kept three days in the closed cupboard, the insects were killed by being confined on its surface for another two days.

Spraying therefore is most effective if done at night, and if at least one foot of the surface around the crevices is made thoroughly wet so that the insects cannot escape from the sprayed areas during their first moments of stimulated activity.

Both *C. longicaudata* and *L. saccharina* were used in the spray tests. *C. longicaudata* suffered a higher mortality because the torpid insects exuded a small drop of fluid from the mouth. This coagulated and fixed the head to the surface so that even when the insect recovered it could not get free.

The lethal effect of Paradichlorbenzene ("P.D.B.") and naphthalene depended on the vapour and not on contact with the insect.

VIII. Conclusion.

Whether *C. longicaudata* is a native of Australia is not known, but it is now widely distributed and it is the only one of the many silverfish in Australia which occurs in great numbers in buildings. *Thermobia domestica* Pack. and *Lepisma saccharina* L., the two common silverfish of Europe and North America are also found here, but large numbers occur only in isolated habitats.

Though the rate of egg laying is comparatively low, the long life of the adults leads to a rapid increase in numbers. For example, assuming that each female lays 56 eggs per year and that there are no fatalities, the progeny of one pair would lay 470,000 in the seventh year.

Climatic conditions in most parts of Australia are favourable for rapid development, and by its nocturnal habits, it escapes the most severe periods of heat and dryness.

It feeds on a wide variety of materials and ranges far in search of food, and probably under normal conditions lack of food does not limit its development. No natural control appears to operate and it seems that artificial control methods must be continuously applied to protect particular articles and to reduce the numbers of the insects.

IX. Summary.

The long-tailed silverfish, *C. longicaudata,* is widely distributed in Australia and is becoming a pest of increasing importance.

It is a general feeder, eating plant and animal remains as well as commercial goods such as papers, wallpapers, and artificial silk. The selective attack on wallpaper and writing and printing paper is due to the palatability of certain constituents. In wallpaper the palatable materials are the starch and dextrin sizes which are mixed with the pigment to produce the thick coloured layer on the face of the paper. In writing paper the palatable material is the chemical pulp containing degraded celluloses. Papers containing more than 45 per cent. mechanical pulp are not eaten and the unpalatable materials in this pulp are associated with the "ether extract" fraction.

The surface of papers and artificial silk can be rendered unpalatable by spraying with a 1 per cent. solution of tricresylphosphate in a petroleum solvent ("White Spirits").

Digestion occurs mainly in the large crop, where the action of the gizzard is supplemented by that of cellulose digesting bacteria, and by enzymes which pass forward from the mid-intestine.

The pH of the successive regions of the alimentary canal was found by feeding the insects with indicators and noting their colour in the intestine.

Methylene blue and Sudan III were absorbed from the mid-intestine and showed that there were three distinct regions in the epithelial lining. They also stained certain organs of the body and were finally removed by the malpighian tubules.

The life cycle from the egg to sexual maturity takes two and a half to three years and the adult insect continues to grow, moult, and lay eggs for at least four more years. The successive instars can be distinguished to some extent by the relative size of certain organs and by the state of development of the gonopophyses and reproductive organs.

The insect's activities are greatly affected by the periodic ecdyses. Feeding occurs only during the first part of each stadium. Fertilization occurs after each ecydsis. Egg laying occurs throughout the summer months and on the average 56 eggs are laid by each female each year.

Yeast and ground wheat provide an adequate diet for the development of the nymphs. Adult insects have survived for three years on a diet of paper only, and for nine months without any food.

Under experimental conditions active feeding and growth begin at about 16°C. The "optimum" is 25°C., and continuous exposure to temperatures higher than this cannot be survived for long periods. Below 11°C. development stops and the insects become torpid. The distribution of silverfish in Australia in pest numbers, and their activity during the year, can be related to air temperatures.

The lethal temperatures for exposures of one hour and fourteen hours are lower in dry than in moist air, and indicate some control of the body temperature by the evaporation of body fluids. Attempts were made to measure the body temperature with a thermocouple and to measure the specific heat of the tissues.

On the average adult insects live only thirteen days in dry air, during which time the water content of the tissues is reduced from 72 per cent. to 58 per cent. They are most susceptible to dry conditions during the period of ecdysis. Insects early in the stadium can survive a greater loss of water than insects late in the stadium. Humidities above 52 per cent. are not fatal, and the water lost is replaced from the food. The insects congregate on a damp surface but do not show any preference for air of 64 per cent. relative humidity over 44 per cent. relative humidity. Partially dried insects take up water from moist air, so that the effect of short periods in dry air is not cumulative, provided that there are intervening periods in moist air.

Their nocturnal habits are important in determining the effectiveness of spraying as a means of control. They are killed by contact with the spray droplets, or with the sprayed surface on which the toxicity of the spray persists for several hours.

From the nature of the insect's life cycle, its feeding habits, its temperature and moisture requirements and the absence of natural enemies, it is concluded that control measures must be continuously applied to keep this species under reasonable control.

Acknowledgment.

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Appendix.

In the following table is summarized the behaviour of the various materials tested as deterrents. Usually 90 per cent. alcohol was used as the solvent, and the concentration measured in grams per cc. of solvent or else a saturated solution (S) was used. Although several concentrations of each material were tested, only the behaviour of the most concentrated solution of each is included in the table.

In some cases the decomposition of the material was appreciable only after the sprayed paper had been exposed to sunlight for two weeks. This decomposition was evident by the discoloration of the paper, or by the subsequent ready attack by the silverfish. Some of the materials acted as stomach poisons and others proved toxic before the paper was eaten. During the tests the insects were confined on the surface of the sample or were held in a closed vessel (3 in. x 6 in. x 12 in. high) so that the toxicity was caused either by contact or by the vapour. In such cases new groups of insects were used, after the paper had been exposed to the air. The effect of the vapour alone was investigated only for mercuric chloride. Paper sprayed with this material caused the death of silverfish held in a test tube, when supported 1 in. above the insects so that it was out of reach.

—	Concentration.	First Attack Days.	Toxic. When Eaten.	Toxic. Without Eating.	Decomposes or Volatile.	Discolours Paper.
MATERIAL.						
Phenoi Derivatives.						
Acetylsalicylic acid	S.	27	—	—	—	—
Acetylsalicylic acid (Sodium salt)	5%	27	—	—	—	—
Amylmetacresol	1%	60	—	+	+	+
Beechwood creosote	10%	2	—	—	—	—
Catechol	5%	27	—	—	—	—
Chlor. betanaphthylsalicylate	—	> 240	—	—	—	+
Dibromobetanaphthol	S.	100	—	+	+	—
Dihydroxynaphthoic acid	S.	270	—	—	—	+
Dinitrophenol (2·4)	S.	27	—	—	—	—
Diiodothymol (Sodium salt)	S.	27	—	—	—	—
Diphenol	1%	27	—	—	—	+
Diphenylphenol	S.	35	—	+	+	—
Gallic acid	S.	4	—	—	—	—
" Hexol " disinfectant	—	70	—	—	—	—
Hexyl phenol	10%	180	—	+	+	—
Hexylresorcinol	1%	60	—	—	—	+
Hydroquinone	5%	27	—	—	—	—
Methylsalicylate	—	7	—	—	—	—
Metacresol	10%	20	—	+	—	—
Metacresol (Sodium salt)	10%	20	—	+	—	—
Metacresotinic acid (Sodium salt)	S.	—	—	—	+	+
Monochlorophenol (Sodium salt)	10%	70	—	—	—	+
Naphthol	S.	—	—	+	+	+
Parahydroxybenzaldehyde	5%	27	—	—	—	—
Parahydroxydiphenyl (Sodium salt)	S./2	20	—	—	—	—
Paranitrophenol	5%	—	—	+	+	+
Paranitrophenol (Sodium salt)	S	27	—	—	—	—
Paratertiaryamylphenol (Sodium salt)	2%	60	—	+	+	+
Paracyclohexylphenol (Sodium salt)	S.	> 200	—	+	+	—
Resorcin	5%	27	—	—	—	+
Saliginin	S.	27	—	—	—	—
Sulphosalicylic acid	5%	30	+	—	—	—
Sulphosalicylic acid (Sodium salt)	S.	60	—	—	—	+
Tannic acid	4%	30	—	+	+	+
Thiodiphenylamine	S.	—	—	—	—	+
Thymol	S.	60	—	+	+	+
Tricresylphosphate	1%	—	—	—	—	—
Tribromphenol	S.	180	—	+	+	+
Other Compounds.						
Abietic acid	S.	14	—	—	—	—
Aloes	S.	40	—	—	—	—
Ammoniacum	S.	14	—	—	—	—
Aluminium chloride	4%	35	—	—	—	—
Antimony sulphate	S.	15	—	—	—	—
Anthracene	S.	15	—	—	—	—
Barium oxalate	S.	31	—	—	—	—
Barium thiosulphate	S.	5	—	—	—	—
Borax	17%	13	—	—	—	—
Cetyltrimethylammonium bromide	—	1	—	—	—	—
Citronella	—	60	—	—	—	—
Copal	S.	14	—	—	—	—
Malic acid	5%	17	—	—	—	—
Mercuric chloride	0·5%	30	+	—	—	—
Mercuric cyanide	S./4	30	+	—	—	—
Mercurochrome	0·3%	14	+	—	—	+
Mercurosal	1%	50	+	—	—	—
Metaphen	0·2%	20	+	—	—	—
Pyridine	5%	2	—	—	—	—
Sea Water soap	—	4	—	—	—	—
Sodium fluoride	S.	26	+	—	—	—
Stannous ammonium chloride	4%	20	—	—	—	—
Stannous chloride	S.	25	—	—	—	—
Tartar emetic	S.	> 240	+	—	—	—
Tetramethylthiuramdisulphide	—	20	—	—	—	—
" Titrol "	10%	5	—	—	—	—
Triethanolamine	1%	60	—	—	—	+

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FIG. 1.

FIG. 2.

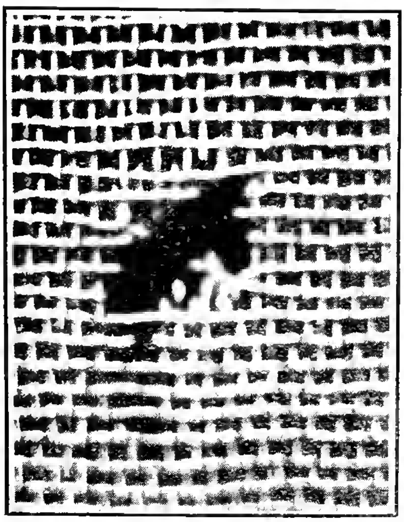

FIG. 3

FIG. 4.

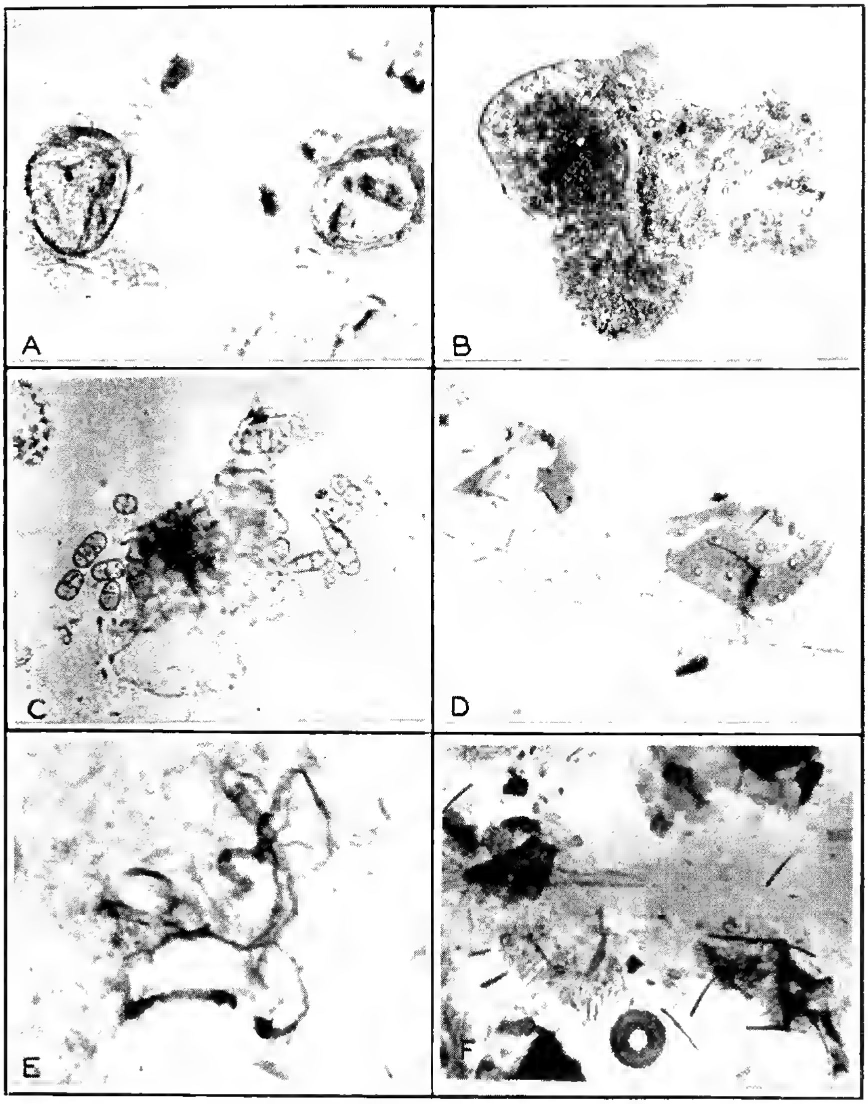

Fig. 1.

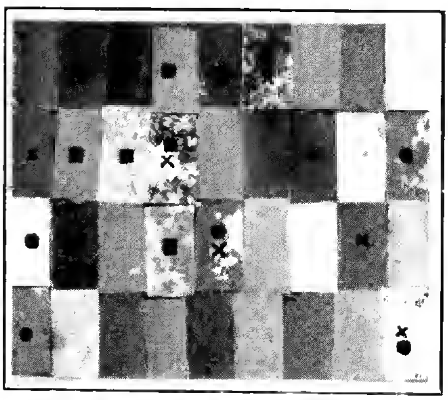

Fig. 2

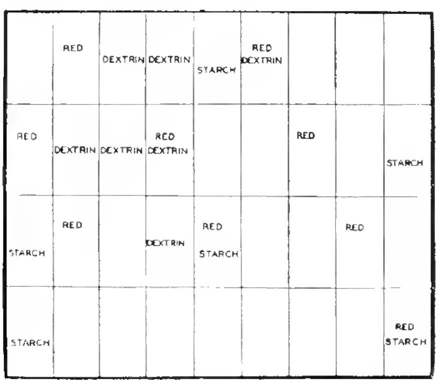

Fig. 3

Explanation of Plates

PLATE 1.

FIG. 1.—*Ctenolepisma longicaudata* Esch.

FIG. 2.—Damage on wallpaper × 138.

FIG. 3.—Damage on artificial silk net × 8.6.

FIG. 4.—Damage on artificial silk fabric. × 4.5.

PLATE 2.

FIG. 1.—Fragments from contents of crops.
A. Pollen grains. × 276.
B. Edge of leaf. × 62.
C. Fungal spores × 318.
D. Chitin showing bases of setae × 396.
E. Fibres from paper stained with Herzeberg's reagent. × 76.
F. Chitin and setae. × 310.

FIG. 2.—Section of wallpaper samples after test of one week.

FIG. 3.—Key to composition of samples shown in Fig. 2. The unlabelled samples contain the sizes, gum, glue and casein.

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Art. IV.—*The Question of Recent Emergence of the Shores of Port Phillip Bay.*

By EDWIN SHERBON HILLS, Ph.D., D.Sc.

[Read 8th June, 1939; issued separately, 1st March, 1940.]

In spite of the definite terms in which a belief in Recent emergence of the shores of Port Phillip Bay has been expressed by some authors, the question has of late become controversial. Jutson has recently reviewed the evidence (1931), but although he adduced much new information bearing on the subject, he was unable to draw any decisive conclusion.

The author has re-examined the shores of the Bay, in order to discover criteria that might perhaps settle the matter. The eastern shores, from which little evidence concerning changes in sea level had formerly been obtained, were traversed from the Quarantine Station at Portsea to Brighton, and critical stretches of the western shores were also studied in detail. It may be stated in advance that what appears to the author to be definite evidence of Recent emergence has been observed at practically all localities where the conditions of erosion and deposition are such as to favour its preservation.

I. The Eastern Shores.

Raised Shore Platforms.

Three difficulties present themselves in the interpretation of shore platforms. Firstly, where the coast is composed of horizontal or gently dipping strata of different degrees of resistance to weathering and erosion, not only may the development of normal shore platforms between low and high water mark be interfered with, but also, rock ledges formed by resistant beds above high water mark may simulate raised abrasion platforms. This is well illustrated at Rickett's Point, where an abnormally broad shore platform has been developed on the upper surface of the resistant Red Beds, which, there, is situated between low and high water levels. The Red Beds rise towards the south, and at Table Rock a well marked ledge, above high tide level, has been produced on their upper surface by the more rapid weathering and erosion of the overlying softer rocks. With such geological conditions, especially where differential weathering and erosion are less obvious, the recognition of any slightly elevated abrasion platform that might be present is difficult.

The second difficulty is related to the amount of emergence. It is well known that no immediately obvious raised shore platforms occur around the shores of Port Phillip, and it was therefore realized that the amount of any Recent emergence which might be discovered would probably be small. Under these circumstances raised abrasion platforms might still be subjected to the attack of storm waves. They would never have been very broad, and after erosion only remnants of them would remain. These would be difficult to distinguish both from rock ledges and from irregularities in the normal shore platforms.

The third difficulty is the fundamental one that the principles underlying the development of shore platforms, even with a stationary sea level and uniform rocks, are by no means fully understood (see e.g. Bartrum, 1935). Where possible emergence or other changes in the physiographic conditions introduce complications, the interpretation of shore platforms becomes very involved, and the author realizes that more intimate studies than he has yet been able to undertake may require some modification of the ideas put forward in this paper.

RAISED SHORE PLATFORMS IN GRANITE.

Shore platforms that are regarded as "raised" abrasion platforms by the author, occur at the foot of Oliver's Hill, Frankston, and 1 mile north-east of the mouth of Tanti Creek, Mornington. At the north-eastern corner of Dromana Bay, a granite platform, whose interpretation is open to some doubt, occurs above high tide level. Throughout the descriptive portion of this paper the words "raised" and "uplifted" will be used with reference to emergence due either to eustatic movements of sea level or to tectonic movements.

At the above localities the raised platforms range up to about 3 feet above high tide level. At each there is also a well-developed abrasion platform now being cut between high and low water levels. These latter platforms are covered with a veneer of rounded pebbles and small boulders in various degrees of dispersion. In places, pebble beaches have been built up above low water mark; elsewhere the pebbles are widely scattered, and in places sand occurs on the platform.

At Frankston and Mornington water-worn pebbles rest upon the raised platforms (pl. III, fig. 1). It has been suggested to the author that these and similar high level pebble beds around the eastern bayside may be storm beaches. Evidence will be brought forward below to indicate that this is not the correct interpretation, but in the present context it is desirable to emphasize that the pebbles rest upon definite platforms, now some feet above high water level, which have been cut in uniform massive granitic rocks. Horizontal jointing in these granites cannot be regarded as determining these platforms, for the granites of the coastline in the Frankston, Mornington, and Mount Martha districts are, with very local exceptions, extremely closely jointed and shattered by steeply dipping joint planes, major horizontal joints being absent. No obvious petrological differences between the rocks of the presumed raised platforms and of the normal platforms below them were observed.

At Frankston and Mornington the raised platforms are seen in section at the foot of the cliffs, although at Frankston part of the platform has been laid bare of its cover of pebbles and talus. In Dromana Bay, on the other hand, remnants of the presumed raised platform rise as table rocks above the normal shore platform, and are not covered with pebbles.

It may be observed in a profile view that these table rocks have a general similarity in elevation, although rising gently towards the base of the cliff. There the raised platform is better preserved (pl. III., fig. 2), and in one locality a well marked notch is situated at the junction of the cliff face with a platform remnant. The tops of the presumed platform remnants range from about 1 ft. 6 in., to 3 ft. 6 in. above the platform now being formed, and are still subject to wave attack.

Passing away from the commencement of the granite cliffs near Dromana, the platform remnants become lower and smaller, until none are preserved. Where it is well developed, the platform resembles in some respects the storm wave platforms described by Bartrum (1935), being in places above high tide level, and having a steep drop at its seaward edge, where a normal profile is developing. Storm wave platforms are, however, rarely developed in massive igneous rocks; they are found only at localities subject to very vigorous wave action, and are backed by cliffs that show no signs of weathering. It is probable, too, that a considerable tidal range aids their formation. In none of these respects are the conditions in Dromana Bay comparable. The tidal range is small, only 3 to 4 feet; the cliffs are weathered, the rocks are massive, and violent waves of an intensity commensurable with those on exposed ocean coasts are not formed in Port Phillip.

At the commencement of the cliffs (see pl. III., fig. 2, right hand side) the appearance is given that as the detrital material which overlies the granite at this point is eroded away, the cliff so exposed is not homogeneous, but has resistant rock near its base overlain by softer rock above. Some suggestion of this is also to be seen in small coves cut into the granite, and it may be that the rock of the platform is more resistant to erosion than that above it. This in turn can perhaps be related to the saturation of the rocks below high tide level, as in the formation of platforms of the Old Hat type (Bartrum, 1935). In the present instance, however, the platform is not horizontal either along the coast or in profile, and is in part above high tide level.

It must therefore be further postulated, following the above assumptions, that emergency has occurred accompanied by tilting, and that wave erosion of the resistant rock above present high tide level has produced the seaward inclination of the platform.

Raised Shore Platforms in Tertiary Sandstones.

Localities where these have been observed are as follows:—Between Grice's Creek and Davey Point; near the mouth of Tanti Creek, Mornington; and on the north side of Fisherman's Point, Mornington. These platforms are essentially similar to those in the granites at Frankston and Mornington. They are overlain by deposits of water-worn pebbles similar to those on the normal shore platforms at each locality. Their seaward edges are being eroded during storms, and thus the platforms and their covering pebble beds are seen in section at the back of the present beaches (pl. IV., fig. 3).

Between Grice's Creek and Davey Point the platform is well exposed on a small point, where a thick kitchen midden rests on the pebble bed (pl. III., fig. 3). At this point the platform is about 2 feet above average high water level. At Tanti Creek the platform is seen to rise in the cliff section south of the creek, on to the slopes of a hill. Where it is flat, nearer the creek, it is about 3 feet above high water level. Where it rises on to the hill, boulders derived as talus from the latter can be seen to rest upon the slopes. These are not water-worn, but as the slopes flatten and the pebbles pass down on to the platform, they become rounded, pitted, and covered with a ferruginous coating, exactly resembling in these features the pebbles and boulders on the present beach.

At Fisherman's Point the platform is about 5 feet above average high water level, and the base of the pebble bed that rests on it has been cemented by calcareous infiltrations.

As with the granite platforms, those cut in Tertiary sandstones at the above localities are clearly not determined by differences in the rate of weathering and erosion of the strata. In all their features, excepting their elevation above sea level, they closely resemble the platforms now in course of formation at existing sea level.

The High Level Pebble Beds.

The suggestion has been made that the pebble beds which rest upon the above-described platforms, and similar high level pebble beds at various localities around the eastern shores of the Bay, are storm beach deposits. Several considerations may be urged against this view

Firstly, it is a matter of experience and observation that no marine deposition has gone on at the level of the pebble beds for a long period of time. On the storm beach hypothesis it is necessary to postulate that the pebble beds are ancient storm beaches, and that the physiographic conditions have changed since they were built up. It is indeed clear that they formed before the aborigines began to make extensive use of the shellfish along the shores for food, since no kitchen middens underlie them. On the other hand, they are in every instance covered either by kitchen middens or by talus from the cliffs. It is evident that the platforms and pebble beds afforded dry, flat camping grounds, conveniently situated near the shore. The growth of vegetation on the middens and talus which cover the pebble beds is a further indication that for a long period they have been out of reach of the waves, except at rare intervals during severe storms. The latter, however, have in no known instance added to the deposits, but have invariably tended to erode them away.

In consideration of the evidence concerning the nature of the pebble beds and the rock platforms on which they rest, it appears reasonable to link the two, and to regard the platforms as raised abrasion platforms, the pebble beds as beach deposits formed by wave action on these platforms before they were elevated. The analogy with the platforms now being cut, is then very close.

VEGETATED CLIFFS.

The long stretches of vegetated cliffs that lie behind the backshore deposits in the majority of small bays on the eastern shores of Port Phillip are considered to be of some significance in relation to uplift (pl. III., fig. 3). If the protecting beach deposits are to be regarded as due to normal progradation at present sea level, then some change in the conditions of erosion and deposition along the bayside must be postulated to account for the general cessation of erosion, except at headlands and places where the nature of the rocks or the presence of deep water offshore favours it. No reason for such a change has been put forward, and the author can suggest none Furthermore, the nature of any such change would be the reverse of that which might be postulated to account for the high level pebble beds, if these are regarded as storm beaches. In the latter case, retrogradation must be regarded as proceeding; in the former, progradation.

On the other hand, a slight Recent uplift would fit the observed facts very well, accounting for both the raised pebble beds and the vegetated cliffs. Such an uplift would have the effect of temporarily removing the base of the cliffs from the zone of active wave attack. Before they could be again subjected to such attack, that portion of the abrasion platform which had been raised above high water level would have to be removed. It is considered that this has occurred on the headlands and in belts of soft rock on the eastern shores of the Bay. Elsewhere various stages in the removal of the platforms are to be seen, the common condition near the headlands being shown in pl. IV., fig. 3. Here the raised abrasion platform and its covering pebble bed are exposed in section. Further from the headlands, erosion would be subordinate to deposition, and the raised platforms would be covered with blown sand or low beach ridges, forming a dry backshore zone on which vegetation could become established, so further protecting the cliffs. This is to be observed at many localities, such as Portsea, Sorrento, and Rickett's Point, where bathing boxes, boat sheds, and even dwellings have been built on the backshore deposits. In a small bay adjoining Table Rock, between Rickett's Point and Beaumaris, a pine tree is well established on the grass and scrub covered backshore.

Raised Sandy Beaches and Shell Beds.

Commencing at the "First Settlement in Victoria," near Sorrento, and extending with few interruptions to The Rocks at Dromana, is a flat stretch of country, the seaward edge of which is marked by a low cliff. This gradually descends from 8 or 10 feet above ordinary high water near Sorrento and Rye, to only 1 foot or so at The Rocks. At the First Settlement, shell beds occur near the base of this low cliff. These first appear on the flanks of a cliff composed of Pleistocene dune limestones, where unworn *Arca trapezia* occurs, together with gasteropods and paired and single valves of other pelecypods. No systematic collection from these or the other shell beds around the coast has been attempted. The specimens collected were the commonest at each locality, and they were submitted to Mr. F. A. Singleton, who kindly determined them. All are referable to species now living, but it is notable that oysters and Arcas, which are common in the shell beds, are now extremely rare in Port Phillip. Indeed it is doubtful if *Arca* now lives in the Bay, although it occurs in Western Port.

At the First Settlement the *Arca* band passes up on to the flanks of the Pleistocene dune, ascending to a height of 5 to 6 feet above ordinary high water level. It descends within about 1 chain towards the east, passing into horizontal shell beds whose upper surface is about 3 feet above average high water level. *Arca trapezia* was not obtained from these shell beds, which, however, contained numerous oysters (*Ostrea* cf. *sinuata*) and other species of mollusca which may all be collected on the present beaches.

Towards Rye the shell beds pass into well stratified beach sands containing only isolated shells. These sands have developed a calcareous *B* soil-horizon about 4 to 5 feet above ordinary high water, and the soil is overlain by a uniform and extensive kitchen midden. Between the First Settlement and the White Cliff at Rye, old sand dunes overlie the above-described beach deposits in places. The top of the beach sands can be discerned beneath the dunes as a horizontal band which breaks the sandfall slope of the cliffs. These dunes are therefore younger than the beach sands into which the shell beds at the First Settlement pass, while these shell beds are in turn younger than the Pleistocene dunes at the latter locality. The younger dunes, although calcareous, are very little consolidated, and in many places fall away at the angle of rest of the sand, whereas the Pleistocene dunes are consolidated. At a point about 1 mile west of the Canterbury jetty, between Rye and Sorrento, fossilized bones of a bird were obtained from the younger dunes (pl. IV., fig. 2). These were examined by Mr. G. Mack of the National Museum, who states that they probably belong to a genus of Procellariiformes (Tubinares), approaching the Giant Petrel (*Macronectes*) in size. They are definitely not *Puffinus* (Mutton bird). The bones are not mineralized, and their reference to a type of bird that is still common around the coast is a further indication of the youth of the dunes as compared with those of Sorrento, from which bones of an extinct species of kangaroo have been obtained (Gregory, 1902).

In view of the above evidence and the fact that no extinct species have been obtained from the shell beds, these and the overlying dunes are both regarded as Recent.

Between Rye and The Rocks no shell beds were observed, but at all localities where exposures were visible, stratified beach deposits ranging from fine sand to coarse broken shells were found to underlie the kitchen middens and superficial sand drifts along the coast. The elevation of these beach deposits ranges up to about 4 feet above high water level. They are in places overlain by low sand ridges with intervening swales.

The above beach deposits and shell beds appear to have been originally laid down below high water mark, to judge by similar formations along the existing beaches. This is indicated by the arrangement of the shells in well-defined layers, the majority lying with their convex surfaces uppermost. The common occurrence of paired valves and of unworn shells, even of fragile types, further points to deposition below the swash mark, possibly between low and high water level, or even lower. In the beach sands the stratification is well defined by coarse and fine layers, or by black bands rich in magnetite, ilmenite, and other heavy minerals such as zircon (pl. IV., fig. 2).

There can be therefore no doubt that emergence has occurred in this district. Any suggestion that results simulating emergence might have been caused by the constriction of the mouth of

Port Phillip, due to the formation of the dunes of the Sorrento peninsula, cannot be substantiated. It has been considered that this constriction would cause a reduction of high tide level in the Bay, but the raised beach deposits are younger than these consolidated dunes, and therefore their emergence cannot be related to the above cause. The gradual fall in elevation of the raised beaches towards The Rocks indicates that their emergence was caused, at least in part, by tectonic movements.

THE CEMENTED BAND AT PORTSEA.

An unusual feature shown in the cliffs at Point McArthur, near Portsea, is probably of some significance with regard to uplift. The calcareous Pleistocene dunes at this locality are consolidated, but about 2 feet above high tide level they are cemented by secondary calcium carbonate into an especially resistant band, which is about 1 ft. 6 in. to 2 feet thick. This hard band traverses the inclined bedding planes in the dunes indiscriminately, and, as levelled from one side of a small cove to the other, is horizontal (pl. IV., fig. 1). Beneath the resistant band a wave notch has been excavated.

The existence of the band in the cliff face, above high tide level, suggests that some change in sea level has occurred, since no factor can be suggested which would operate at such an elevation to induce cementation of the dunes. It is probable that the hard band was formed by deposition of secondary calcium carbonate in the body of fresh water that exists in the dunes at about high tide level. With a stationary sea level, the hard band would then appear in the cliffs at high tide level, and it is suggested that its present elevation of about 2 feet has been brought about by an emergence of this order of magnitude.

THE CARRUM SWAMP.

In the district between Mordialloc and Frankston the coast is fringed with a series of sand ridges. Behind these ridges is the Carrum Swamp, which before it was drained and cultivated was about 2¾ feet above the level of highest observed spring tides at the mouth of Mordialloc Creek, or about 4½ feet above ordinary high water. The shallow alluvium of this swamp overlies sand containing marine shells of the same species as are now found in Port Phillip. *Arca trapezia* also occurs in these sands, the level of which in the northern part of the swamp is about 3 feet or less below the present surface of the drained swamp alluvium.

The Carrum Swamp is bounded on its inland side by a second arcuate line of sand ridges, along which Wells' road runs, being so situated because the ridges are not subject to flooding as is the land on either side. An excellent map on which the above features are shown in detail is in the possession of the Lands Department, and was used in the preparation of fig. 1.

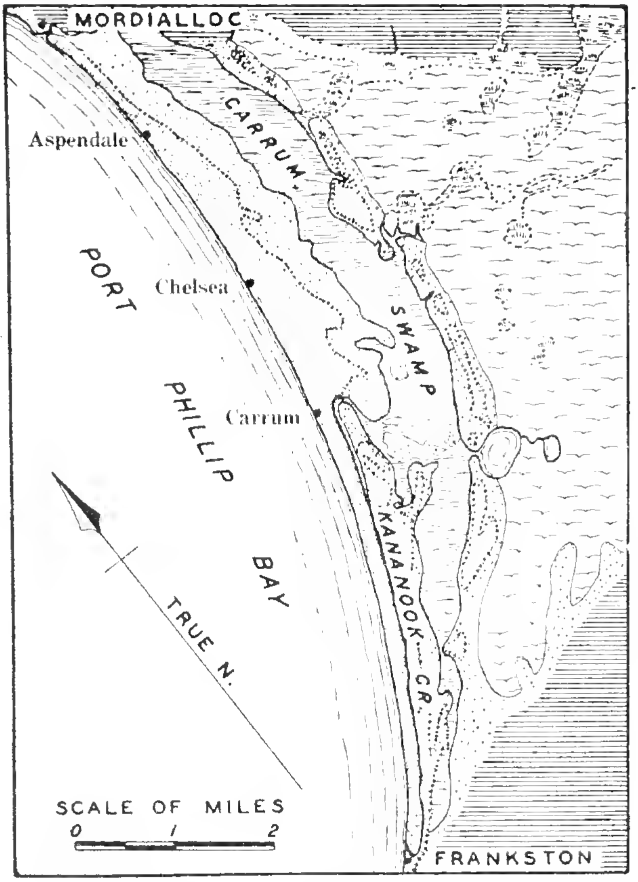

FIG. 1.—Map showing the coastal and inland sand ridges between Mordialloc and Frankston. Close stippling, high sand ridges. open stippling, low sand flats, originally covered with reeds and tea tree. Horizontal ruling, high land north and south of the swampy areas.

It is clear that at an earlier date the shoreline was situated along the Wells' road sand ridge. The retreat of the shore to its present position was then brought about by some sudden change. If this had come about by normal progradation and building of beach ridges, the latter would occur in the Carrum Swamp. No beach ridges occur there, and the sudden retreat of the sea for a distance of over 1 mile is best accounted for by postulating uplift. This is supported by the greater elevation of the alluvium behind the Wells' road ridges than that in the

Carrum Swamp (10 feet above highest spring tides as against $2\frac{3}{4}$ feet). The shell beds may have been uplifted, or they may have been laid down in a lagoon formerly situated between the Wells' road sand ridges and those along the new coastline. It is difficult to decide on this point in view of the settling down of the swamp deposits since they have been drained.

The course of the Kananook Creek, which is diverted southwards near Carrum and flows for $4\frac{1}{2}$ miles parallel to the coast, to reach the sea at Frankston, is notable. The creek occupies a marshy depression between two well-defined but complex sand ridges whose origin is not yet clear. It is highly improbable that the creek should have suffered such an extensive diversion simply as a result of the formation, by normal progradation, of a series of beach ridges barring its mouth. It occupies an unbroken trough between the two main ridges, and is too sluggish to have cleared this for itself, being only at about sea level throughout its length. A slight uplift after the formation of an earlier coastline along the seaward edge of the ridge along which the railway runs at Seaford would, however, have probably led to the formation of the second ridge, on which the Point Nepean road is situated, leaving a swale between the two. This would be then used by the creek.

THE YARRA DELTA.

On the map published by Selwyn (1854), the superficial deposits of the aggraded area at the head of Hobson's Bay, known as the Yarra Delta, are described as "Recent upheaved estuary bottom, consisting of beds of sand and clay with recent shells resting on red Tertiary sandstone." Sections given by Selwyn (1854) and by Lucas (1887) show that the surface of the sand formations fringing the seaward edge of the West Melbourne Swamp rises to $7\frac{1}{2}$ to 10 feet above high water level. Parallel ridges described as "blown sand" are more probably beach ridges, as described by Jutson (1931), and these rest upon "sands and Recent shells." These sands are in places current bedded, and are regarded as marine by Selwyn and Lucas. They are 2 feet above high water level in some parts.

II. The Western Shores.

As remarked upon by Jutson, these are physiographically distinct from the eastern shores, long stretches being flat and undergoing progradation, while the eastern shores are cliffed in many places. An important area which has been much discussed is that between the Williamstown Racecourse and the Military Reserve at Altona. Near the Williamstown Racecourse occur the so-called Altona shell beds, which have been described by Hall and Pritchard (1897), Grant and Thiele (1902), Pritchard (1909, 1910), and by Jutson (1931). The shells are all of living species, and all palaeontologists who have referred to them agree that they are Recent (see Singleton, 1935). Grant and Thiele showed that the shell beds are 8 feet thick, the top being $7\frac{1}{2}$ feet above high water level. I am informed by Dr. H. S. Summers, who collaborated in the levelling, that the datum used was the swash mark of the highest observed tides in the neighbourhood. These authors noted that the shells occur in distinct layers, with marine and estuarine types interbedded. They concluded that the beds are therefore not storm beaches, and that an uplift of at least 10 feet has taken place since they were deposited. Pritchard, however, decided that they are storm beaches, and Jutson described them as beach ridges probably formed by storm waves at existing sea level.

In regard to their nature, the following points are of importance. The beds are well stratified and not current bedded. Individual bedding planes can be traced for some yards both parallel to and at right angles to the coast. They contain thin-shelled forms in a perfect state of preservation, and a majority of the concavo-convex shells lie with their convex surfaces uppermost, indicating that they were deposited below high water level, out of reach of the turbulent swash of waves breaking on the beach. These features are in the author's opinion quite sufficient evidence that the beds are not storm beach ridges, for in these stratification is typically irregular, or even absent, and thin-shelled forms are broken.

The relationship of the beds to the other shell and sand ridges of the district is also significant. Jutson has given a general description of these ridges, and of the associated swamp deposits with marine shells that occur on the beds of three shallow ephemeral lakes in the Altona district. This district has been mapped on a scale of 200 feet to 1 inch under the direction of the author, and fig. 2 is based on this work. In the vicinity of Altona and Seaholme townships the ridges have been disturbed and cannot be traced in detail. North-east of Seaholme the ridges are composed in part of shelly limestone similar to the type locality near the Williamstown Racecourse (fig. 2), and in part of sand with scattered shells. The ridges rest upon the surface of the Newer Volcanic basalt, which appears in some of the intervening troughs. Along the seaward edge of the basalt is a rather sudden drop of a few feet to an area of tidal flats and low beach ridges, the land on the higher side of this drop being entirely out of reach of wave action at existing sea level. This stretch of coast faces the south-east, a quarter from which storm winds are extremely rare. The fetch of such winds is also relatively short, and the water offshore is very shallow. It is therefore scarcely conceivable that storm waves of sufficient intensity to flood the basalt plain, and to deposit beach ridges on it up to 8 feet above the highest known high water mark,

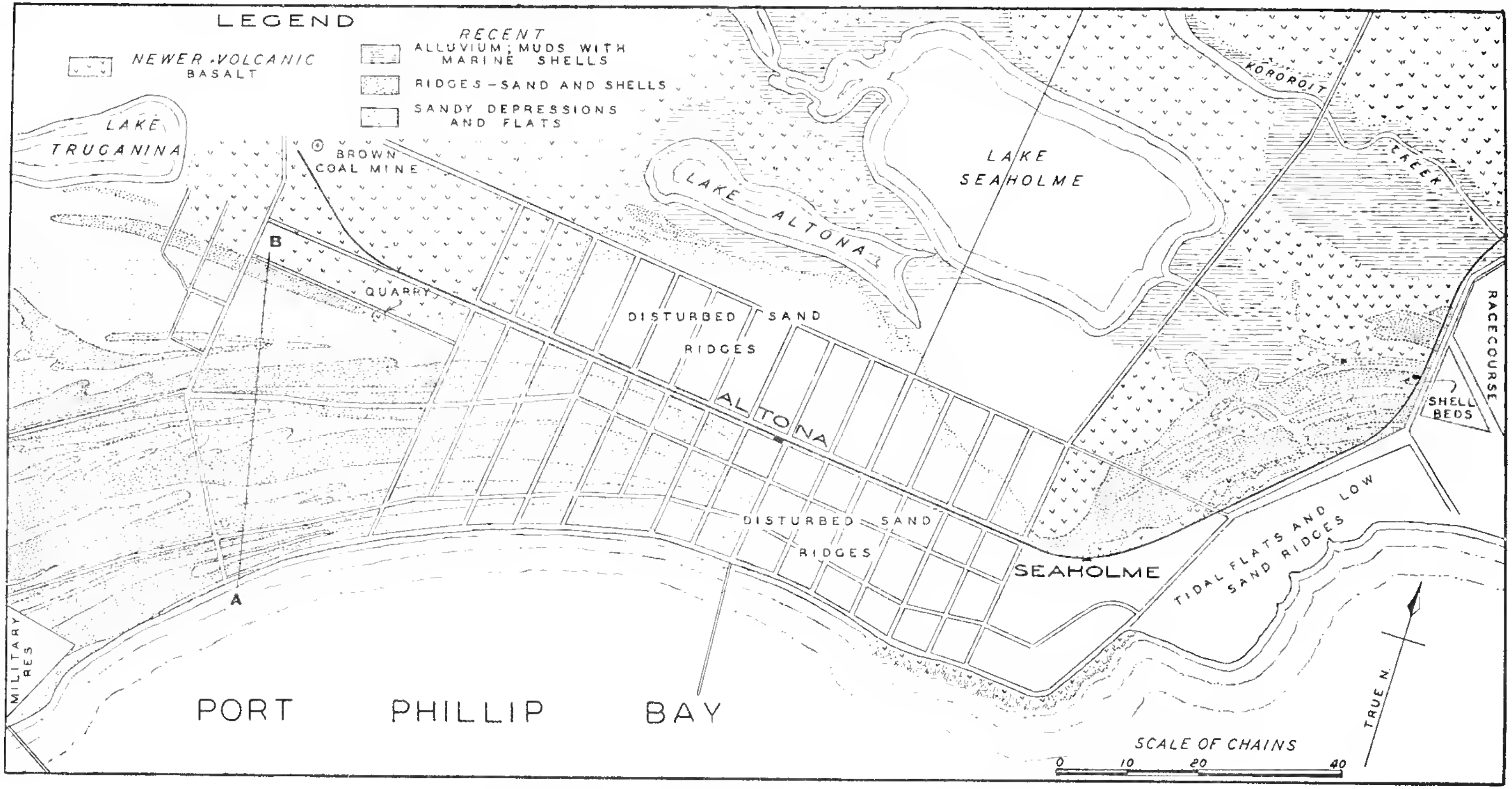

FIG. 2.—Map of the sand and shell ridges in the Altona district.

should ever have been generated in this area under the existing conditions. Furthermore, even if such a possibility could be entertained, no good reason can be suggested for the formation of an orderly succession of such ridges at gradually decreasing elevations towards the coast.

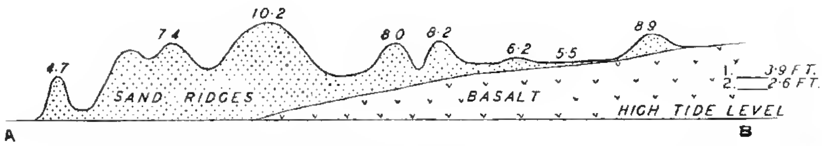

FIG. 3.—Section along the line *A–B* in Figure 2. Vertical scale, 1 in. = 22 ft.; horizontal scale, 1 in. = 14 chains. 1. Elevation of marine shells *in situ* in muds, Lake Truganina. 2. Elevation of redistributed marine shells on the bed of Lake Truganina.
Note.—The ridge nearest *A* is a beach ridge formed at existing sea level.

The view that these ridges are not beach ridges is further supported by their external form. A beach ridge is typically high compared with its breadth, owing to its formation by waves breaking within a narrow zone along the foreshore.

The ridges at Altona and Seaholme, on the other hand, are relatively low and broad. A ridge 4 chains wide is, for example, only 4 or 5 feet above the neighbouring swales. That wind erosion subsequent to their formation was not the cause of this is indicated by the approximate parallelism of the bedding planes in the shell beds with the upper surface of the ridge they form, and also by the preservation of the swales between the ridges, which would have been partially obliterated by blown sand had the tops of the ridges been removed by the wind. Beach ridges formed at existing sea level are present in this district. They are quite distinct in form from the other ridges whose origin is in question.

Of particular significance, too, are the shape of the ridges in plan, and their spacing. Regular spacing of beach ridges, with intervening swales, can be brought about with a stationary sea level if a headland nearby is retrograding, so causing regular variation in the trend of the littoral currents. In the present example no such factor has been effective. The ridges have been "plastered" along an extensive stretch of flat coastline, from Williamstown to Werribee. Under these circumstances, and with a stationary sea level, beach ridges would have been piled successively one against the other, the intervening depressions being irregular and narrow. Actually, they are well spaced, and in places are separated by wide sandy flats, as for example south of the old brown coal mine. In addition, some of the ridges, especially in the Altona area, exhibit peculiar lobate or digitate projections from their landward sides (fig. 2). These projecting spits run off the main ridges towards the north-east. No beach ridges known to the author exhibit such features.

If the beach ridge hypothesis be rejected, it remains to indicate the mode of origin of the ridges and swales. The great breadth of the ridges compared with their height, the variation they show from shell beds to sand with included shells and pebbles, their regular spacing with low troughs between them, and their lobate landward edges suggest that they are raised banks such as are common off the existing beaches around the Bay. Examination of these banks has revealed that, as with the ridges, their seaward edges are typically smooth, but their landward edges are either lobate or furnished with oblique minor ridges running off at an acute angle into the troughs. Such banks occur in series, with well-defined troughs between them. In structure, external form, and spacing they are closely analogous to the Altona ridges.

It is therefore suggested that the underlying form of some at least of the ridges is that of submarine banks formed when the level of the sea was sufficiently high to cause it to flood over the basalt plains in the areas where the above described ridges occur. It appears probable that, either at this time or as the sea retreated, these banks were added to in places by the growth of beach ridges, but the shell beds near the Williamstown Racecourse, and the lobate ridges near Altona, are regarded simply as upraised submarine banks.

Shell Beds in Swampy Areas.

The elevation above high water mark, of marine shells *in situ* in black mud on the banks of Lake Truganina was determined as $3\frac{1}{2}$ feet. These muds contain paired valves of pelecypods, which are little disturbed and approximately in their position of growth. Comparable deposits now forming are found at half tide level or lower, and it is clear that emergence must have occurred, raising these marine shells above sea level. Bearing in mind the fact that similar black muds containing marine shells are now forming only below high tide level, it is also clear that the shell beds exposed at high tide level in the banks of the Kororoit Creek and those slightly above high tide level beneath the flats north of the Williamstown Racecourse must have also been uplifted.

Such shell beds are common along the eastern side of the Bay, and it may be emphasized that in deciding whether or not they have been uplifted, it is essential to remember that back-shore deposits and beach ridges, which can be built up above high tide level by normal progradation, have irregular stratification. They typically contain worn and broken shells, paired valves and complete delicate forms being rare or absent. Furthermore, they are never composed of shells set in fine mud, but consist of the coarser grades of sediment available along the shores.

Thus, the shell beds above mentioned, and similar occurrences at Werribee, Duck Ponds Creek, Corio Bay, and elsewhere (see Jutson, 1931, for details), which are now at or above high tide level, must have been uplifted. Indeed, at the Duck Ponds Creek the shell bed falls from about 5 feet above sea level near the Geelong road to sea level about a quarter of a mile downstream, and then passes beneath the waters of Corio Bay. The uplift at this locality was therefore tectonic. It has already been pointed out (Hills, 1938) that the raised Recent shell beds at Portarlington were probably elevated by earth movements, and Chapman (1929, Chap. XIV.) also favours the view that the emergence of the Recent deposits described by him was due to the same cause.

POINT LONSDALE.

The thick shell beds that occur on the floors of the shallow salt and freshwater lakes in this district are most impressive. Concavo-convex shells are almost all arranged with their convex surfaces uppermost, and the deposits are well stratified, with gently inclined bedding planes. Dr. H. S. Summers informs me that a line of levels from the shores of Swan Bay to the top of the shell beds near the lake called Lake Lonsdale by Jutson, was run by him in collaboration with Mr. E. Broadhurst. The upper parts of the shell deposit are at least 1 foot above highest high water mark in Swan Bay. Furthermore, it is obvious in the field, as noted by Jutson, that the floors of some of the smaller lakes in the district, including the freshwater lake, are higher than the bed of Lake Lonsdale. Marine shell beds also occur around these lakes, so that the indications of uplift are further supported.

RAISED SHORE PLATFORMS IN BASALT.

From the south-eastern corner of the Rifle Butts at Williamstown, to the wheat stacks near the old Fort, the coast is formed of Newer Volcanic basalt. In this locality a well-defined low cliff marks the edge of the basalt plains, and between this cliff and the present shoreline is a basalt platform some 20-30 yards wide. This is not normally subject to wave attack, but parts of it were awash during the exceptionally high tides that accompanied the floods of December, 1934. The platform is grassed, and is covered with large loose boulders of basalt resembling those on the present beach. At the seaward edge of this platform there is in places a drop of about 3 feet to the present beach. Marine shells occur in black soil on the platform, and also in the joint planes of the basalt. The storm beaches built at the back of the existing beaches extend up for a short distance on to the seaward edge of the platform, but no further, and the suggestion is very strong that the platform is a raised abrasion platform backed by a former sea cliff. The summit of the latter is approximately 5 feet above the platform, and this in turn 2 to 3 feet above the present abrasion platform.

Evidence that the latter is a true abrasion platform and not merely the original surface of a flow is afforded by the presence near the old fort of a small lava blister with its summit eroded away. No alternative explanation which would adequately explain the existence of the low scarp, here regarded as a former marine cliff, and also of the boulder-covered platform above high tide level can be suggested by the author.

III. Date of the Emergence.

The age of the emergence to which the above-described features may be ascribed is shown by the following lines of evidence:—

1. At Point Lonsdale and Sorrento the raised shell beds post-date the consolidated Pleistocene dunes.

2. Between Sorrento and Rye the raised shell beds and beach deposits post-date the consolidated Pleistocene dunes, but antedate other calcareous dunes, which are not consolidated. The latter have yielded bones of a bird similar to a living form, but they are fixed by vegetation, and clearly were formed under physiographic conditions different from those now obtaining. It is suggested that there is no considerable difference in age between these dunes and the underlying raised beach deposits. This is indicated by the absence of weathering or erosion of the surface of the beach deposits upon which the dunes rest (pl. IV., fig. 2).

3. The palaeontology of the Altona shell beds has been discussed by Hall and Pritchard, by Grant and Thiele, and by Pritchard. Singleton (1935) has also referred to them. They contain only living species, and are regarded as Recent.

4. Chapman (see Jutson and Coulson, 1937) has shown that the Portarlington shell beds also contain only living species, and there is no good reason for regarding them as other than Recent.

5. None of the species collected by the author from the other shell beds is extinct, according to Mr. Singleton's identifications. The palaeontology of the shell beds was not, however, studied in detail.

6. The author agrees with Jutson that the uplift of the Kororoit Creek and Altona shell beds is of later date than that which caused the development of the high level terraces along the Moonee Ponds Creek and the Maribyrnong River.

The emergence is therefore regarded as Recent.

IV. Nature of the Emergence.

Differential elevation of Recent marine deposits has been noted at Portarlington, Duck Ponds Creek, and between Sorrento and Dromana, indicating that, at least in part, the emergence was due to tectonic movements of uplift.

Evidence of Recent emergence is so common along the Victorian coast, however, that a eustatic fall of sea level may be suspected of having contributed to it. Such Recent emergence has been described by others, or has been observed by the author at Marlo, the Ninety Mile Beach, Waratah Bay, Cape Patterson, Port Phillip Bay, Apollo Bay, Warrnambool, and Portland. Proof that eustatic movements have occurred must, however, await further detailed studies in Victoria and in other States.

V. Acknowledgments.

The author is indebted to Dr. H. S. Summers for information concerning the Altona and Point Lonsdale districts, to Mr. F. A. Singleton and Mr. G. Mack for determination of fossils, to Mr. H. B. Hauser and Mr. G. Baker for assistance in levelling, and to Mr. J. S. Mann for help in regard to photography. Topographic information was kindly made available by the Secretary of the Air Board, and by officers of the Lands Department and the State Rivers and Water Supply Commission. The Altona ridges were partially mapped by Miss E. Mann, Mr. N. L. Spielvogel, and Mr. J. M. Carey, under the direction of the author.

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Fig. 1

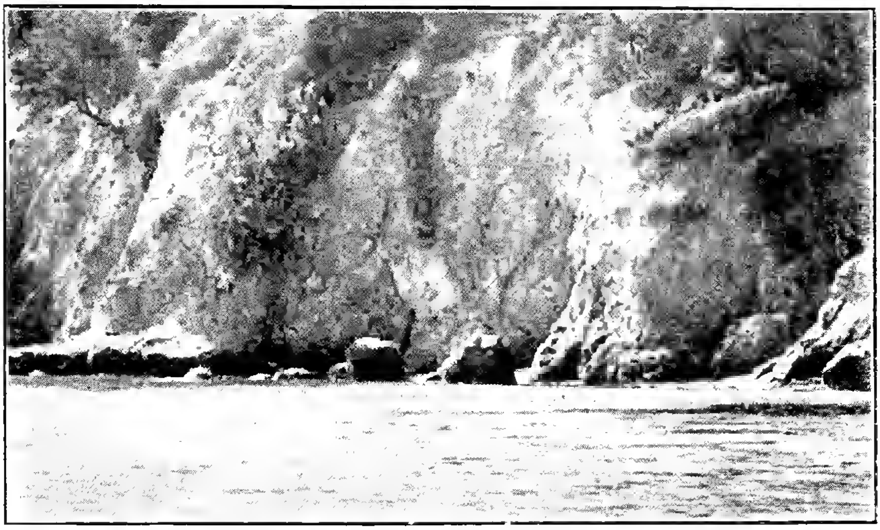

Fig. 2.

Fig. 3.

Fig. 1.

Fig. 2.

Fig. 3.

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Explanation of Plates.

PLATE III.

FIG. 1.—Raised abrasion platform in granite, overlain by pebbles and talus, Oliver's Hill, Frankston.

FIG. 2.—Raised shore platform in granite, Dromana Bay.

FIG. 3.—Raised abrasion platform and pebble bed covered with aboriginal kitchen midden. Note vegetated cliff in background. Between Grice's Creek and Davey Point.

PLATE IV.

FIG. 1.—The cemented band in Pleistocene calcareous dune-rock, Point McArthur, Portsea.

FIG. 2.—Raised beach deposits showing normal stratification (in the excavation) overlain by calcareous dune sands. The remains of a fossil bird were obtained from the latter in the small upper excavation. West of Canterbury jetty, Rye.

FIG. 3.—Raised abrasion platform in Tertiary sandstone, overlain by pebbles. Fisherman's Point, Mornington.

[Proc. Roy. Soc. Victoria, **52** (N.S.), Pt. I., 1940.]

Art. V.—*A New Trilobite from Cootamundra, N.S.W.*

By EDMUND D. GILL, B.A., B.D.

[Read 8th June, 1939; issued separately, 1st March, 1940.]

The purpose of this paper is to record Upper Silurian sediments at Cootamundra, New South Wales, and to describe a new trilobite which is a characteristic member of the fauna. Mr. W. E. Williams of Cootamundra has sent to the National Museum, Melbourne, a collection of fossils and some rock specimens from this area. I wish to thank him for also making available his geological sketch-map and notes, from which the following stratigraphical data have been compended. The strata strike approximately north and south, being bounded by porphyry hills in the west, and schistose hills in the east. Pitch causes conglomerates and grits to outcrop in the north, forming Bandangan Hill. The Cootamundra fauna is preserved in fine-grained shales, and the following is a provisional faunal list:—

PLANTAE	*Fragmenta indeterminata* comparable with those in the Victorian Yeringian of Lilydale and district.
ANTHOZOA	Tabulate coral, indet.
CRINOIDEA	Crinoid joints, indet.
POLYZOA	Branching form.
BRACHIOPODA	*Atrypa reticularis* (Linnaeus).
	Atrypa aff. *scotica* (McCoy).
	Camarotoechia sp.
	Dalmanella aff. *elegantula* (Dalman).
	Lingula sp.
	Rhipidomella aff. *oblata* (Hall).
	Spirifer sp.
	Stropheodonta sp.
PELECYPODA	*Cypricardinia* sp.
	Leiopteria sp.
	Palaeoneilo aff. *spectabilis* Chapman.
	Palaeosolen sp.
	Paracyclas aff. *lirata* Hall.
	Pterinea sp.
GASTEROPODA	*Loxonema* sp.
	Pleurotomaria sp.
PTEROPODA	*Tentaculites* aff. *tenuis* Sowerby.
TRILOBITA	*Calymene* (*Gravicalymene*) *cootamundrensis*, sp. nov.

CALYMENIDAE, H. Milne Edwards, 1840.

Calymene, Brongniart, 1822. Gravicalymene, Shirley, 1936.

GENOTYPE: *Gravicalymene convolva* Shirley.

CALYMENE (*Gravicalymene*) *cootamundrensis*, sp. nov.

CARAPACE:—Small, elongate, sub-ovate, widest across posterior of cephalon and tapering to posterior end of pygidium.

CEPHALON:—Sub-quadrilateral, approximately one-quarter of total length of carapace. Moderately convex. (See fig. 2.) Surface ornamented with tubercles of varying sizes. The mould shows that the larger tubercles, at any rate, are perforated in their apices by canals which apparently connect the exterior with the interior of the test. Glabella bell-shaped in outline, and standing well above the fixed cheeks; does not overhang preglabellar field; anterior border extends a little beyond the anterior border of the fixed cheeks. Three distinct lobes on each side, reducing in size posterior-anteriorly. First and largest lobes rounded-quadrilateral, with furrows deep and directed obliquely backwards. Second lobes rounded with their long diameter transverse; much smaller than first lobes but bigger than third. Second furrows deep, running almost straight in from axial furrows. Third lobes distinct and of rounded shape. Third furrows short and not so deep as others. Incipient fourth lobes present. Axial furrows deep and wide; contracted at the base. The "antennary pits" are placed outside the fourth lobes on each side in the axial furrows. Preglabellar field recurved with roll-like edge, which thins away at its ends. Fixed cheeks convex. Eyes anterior to second lobes, and nearer lateral margin of cephalon than axial furrow. Free cheek suture follows lateral border of cephalon very closely then swings in a fairly sharp curve to eye. From the eye the suture proceeds practically straight forward to anterior border of cephalon. (The nature of the suture was determined from material collected after the line-block of the whole trilobite was made.) Genal angles truncated so that the lateral border forms almost a right angle with the posterior border of the cephalon. Posterior intra-marginal furrows broad; the posterior walls are steeper than the anterior. The corresponding marginal ridge is grooved for about one-third of its length at the glabellar end on the interior surface (as shown by the internal cast). Occipital groove much narrower, longitudinally, than intramarginal furrows. Occipital ring narrows at the extremities, which turn in towards the corners of the fixed cheeks.

THORAX:—Consists of twelve or thirteen segments. Type incomplete, preserving ten whole pleurae and part of eleventh and twelfth. Axis approximately semi-circular in cross-section, and about one-third of width of thorax; tapers posteriorly to accommodate itself to the narrower pygidial axis. Axal furrows deep. Axal rings and pleurae strongly grooved. Axal knobs fairly conspicuous. The pleurae run horizontally out from the axis to the fulcra, and then bend down vertically. The fulcra are situated half-way along the length of the pleurae.

Pygidium—Convex, with drawn-bow outline. The axis is approximately semi-circular in cross-section and covers almost the full length of the pygidium. There are six axal annulations and four prominent lateral ribs grooved distally half their length. In addition there is on each side of the axis at the posterior end a very short ungrooved rib.

Measurements of specimens:—

(1) Holotype cephalon—

Width across base	.. ..	15 mm
Length (minus preglabellar field)	..	6 mm.

(2) Paratype thorax-pygidium—

Greatest width of thorax ..	..	12 mm.
Length of thorax (incomplete)	..	15 mm.
Greatest width of pygidium ..	..	8 mm.
Length of pygidium	.. ..	5 mm.

(3) Paratype cephalon (right side incomplete)—

Width from left genal angle to centre of glabella	.. .. ..	7.5 mm.
Length of cephalon	.. ..	7.5 mm.

Matrix:—Yellow to brown fine-grained shale.

Occurrence:—Oak's Creek, Cootamundra, N.S.W.

Horizon:—Upper Silurian.

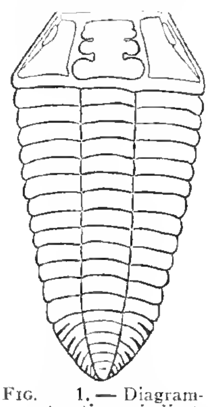

Fig. 1.—Diagram-restoration indicating the general proportions of *Calymene* (*Gravicalymene*) *cootamundrensis*, sp. nov. × 2 approx.

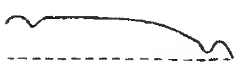

Fig. 2.—Profile of the cephalon of *Calymene* (*Gravicalymene*) *cootamundrensis*, sp. nov. × 4.

Observations:—The new species is not uncommon in the Cootamundra shales. As it is the only trilobite found in that locality, there is the greater confidence in concluding that the separated cephalon and thorax-pygidium presented as the types belong to the same species. Three cephala, two pygidia, and part of a thorax have been found associated on the same piece of shale $2\frac{1}{2}$ inches square.

Shirley, after describing the British species of Calymene (1931, 1933) presented a subdivision of the genus into nine genera (1936). Noting that the thorax and pygidium were relatively static, he concentrated on the cephalon and came to the conclusion that the variations of fundamental phylogenetic importance were:—

(1) The presence or absence of papillate lobes in the glabella with corresponding buttresses on the fixed cheeks.

(2) The plain, ridged, or roll-like character of the preglabellar field.

Principally by means of these criteria Shirley established his new genera. The genus Gravicalymene is characterized by the absence of papillate lobes and buttresses, and the presence of a roll-like edge in the preglabellar field. In describing fossils from the Baton River beds, New Zealand, Shirley (1938) referred *Calymene angustior* Chapman, a Victorian Yeringian form, to his new genus Gravicalymene. As far as the author is aware, *Gravicalymene cootamundrensis*, sp. nov., is only the third species to be referred to this new genus. The absence of the papilla-buttress structure is a feature confined to the Ordovician forms of " Calymene " in Britain and Scandinavia, but rare occurrences in the Silurian are known from America and Bohemia, (*C. celebra* Raymond and *C. baylei* Barrande). *G. convolva* Shirley belongs to the British Bala, but *G. angustior* (Chapman) and *G. cootamundrensis,* sp. nov., appear in the Australian Upper Silurian, and *G.* cf. *angustior* occurs in the New Zealand Lower Devonian.

Affinities:—*G. cootamundrensis* is nearest *G. angustior* (Chapman), (Chapman, 1915; Shirley, 1938, p. 487, cf. Etheridge and Mitchell, 1917.). They share such important features as the position of the eyes anterior to the second lobes (a rare character, according to Shirley), and the presence of an incipient fourth lobe. However, the new species is only about half the size of *G. angustior,* and as the fossils associated with *G. cootamundrensis* do not show abnormality in size, the difference cannot be environmental. Also the new species is much more elongate, and the quadrilateral cephalon with its narrow free cheeks are distinguishing features. The cephalon of the new species is much flatter than that of the compared species. *G. cootamundrensis* has similar proportions to some specimens of *Calymene niagarensis* Hall (1843), which, although it is a papillate form (according to Shirley, but not shown in the figure quoted), has a roll-like preglabellar field like Gravicalymene. The quadrilateral cephalon and narrow free cheeks conspicuously mark off the new species.

Acknowledgment.

I wish to thank Mr. D. J. Mahony, M.Sc., director of the National Museum, Melbourne, for the study facilities provided for me in that institution. Also, I am grateful to Mr. L. A. Baillôt of the Melbourne Technical College for expert assistance with the photography.

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Description of Plate.

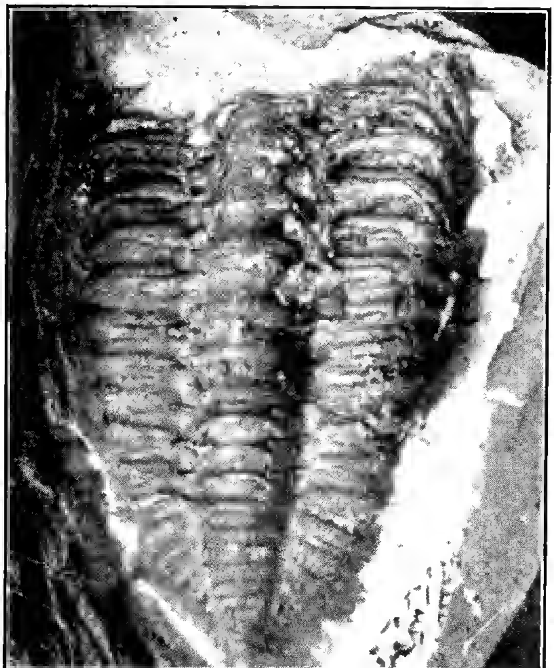
(1) Thorax and pygidium (Paratype) of *Calymene (Gravicalymene) cootamundrensis*, sp. nov. × 4 approx. (No. 14083.)

(2) Mould of cephalon (not No. 14084) showing ornament. × 4 approx. (No. 14085.)

(3) Cast of cephalon (Holotype). × 4 approx. (No. 14084.)

(4) Cast of another cephalon showing outline and nature of preglabellar field (Paratype). × 4 approx. (No. 14086.)

The numbers in brackets are the registered numbers of the specimens in the National Museum, Melbourne.

1.  1.

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[Proc. Roy. Soc. Victoria, 52 (N.S.), Pt. I., 1940.]

Art. VI.—*Observations on the Mineral and Vitamin Content of Australian Milk.*

By R. C. HUTCHINSON, B.Sc.

[From the Australian Institute of Anatomy, Canberra.]

[Read 13th July, 1939; issued separately, 1st March, 1940.]

Introduction.

The vitamin content of cow's milk has been shown to vary within reasonably wide limits, while it is well known that the mineral content, although remarkably constant, also varies within what might be termed physiological limits. During the routine analysis of a number of sweetened and unsweetened condensed milk samples from various parts of the world, Professor J. L. Rosedale, of the King Edward VII. College of Medicine in Singapore, found that the Australian samples were low in vitamin A. In a private communication he suggested that an explanation of the difference may be found in the reputedly low phosphorus content of Australian soils, and some support was given to this hypothesis by Richmond's (1930) suggestion that lecithin, because of its phosphorus content, may be an index of the vitamin (presumably vitamin A) content of butter-fat. Initially, the object of this investigation was to investigate Professor Rosedale's hypothesis and in so doing to determine the vitamin A content of a large number of Australian milk samples. Later, however, it was decided to extend the investigation with the object of discovering any correlations which might exist between the major vitamin and mineral constituents of milk.

One hundred and sixty-eight samples of mixed milk, representing the milk from 6,460 cows, were collected over a period of twelve months from New South Wales, Victoria and Tasmania. One hundred and twenty-five samples were known to be from afternoon milkings. The mineral constituents estimated were:—calcium, phosphorus, potassium, sodium, magnesium, sulphur, and iron. The vitamins estimated were:—vitamin A and carotene, vitamin B_1 (thiamin), vitamin B_2 (riboflavin), and vitamin C. The last named was estimated in each sample within twelve hours of collection and the milk was only exposed to direct daylight at the time of collection and while the estimation was being carried out in the laboratory. The methods employed for the estimation of the vitamin constituents were chosen because they involved the minimum amount of time and gave results, the relative values of which were reliable. But because the methods employed were non-biological the results are considered comparative only, although during preliminary work results obtained by these methods were checked against results obtained by well-controlled biological methods for the same samples and, so far as the results could be compared, they were in good agreement.

Methods of Analysis.

Fat was estimated by Richmond's (1930) modification of the Roese Gottlieb method. The specific gravity was determined with a Westphal balance and corrected for temperature.

VITAMIN A AND CAROTENE.

A pint of milk was centrifuged, the skim milk separated and kept for later determinations, the cream churned into butter, portion of the butter dissolved in petroleum ether and the whole transferred to a separating funnel containing distilled water. The ethereal layer was separated, washed and evaporated under suction at about 30°C. Because facilities were not available for estimating carotene spectro-photometrically, it was estimated in the warm residual butter-fat by a modification of Palmer's (1922) colorimetric method. Several workers have found that for butter-fat the graph given by Palmer gives carotene values which are several times too high, and Barnett (1934) has obtained a correction factor .28 which enables more accurate results to be obtained. However, Barnett assumes that carotene is the only colouring matter of consequence in butter-fat, but Gillam (1934) has shown that the ratio of carotene to xanthophyll in English butter-fat is fairly constant, being approximately 14 : 1 by weight, and has estimated the carotene value at approximately 94 per cent. of the total yellow colour of the butter-fat. This result is supported by the work of Baumann and Steenbock (1933) on an American butter-fat. Hence a more accurate conversion factor would be .263. Introducing this modification and simplifying Palmer's expression we have:—

$$\text{Percentage carotene} = \frac{.00268 \times .263 \times K_2Cr_2O_7 \text{ equivalent}}{\text{Depth of butter-fat}} = \frac{\text{Reading on } x \text{ axis in fig. I}}{\text{Depth of butter-fat}}$$

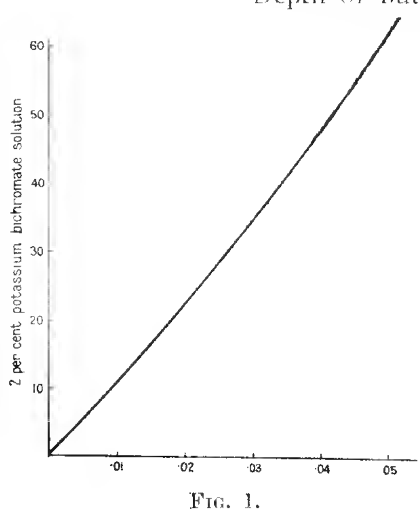

FIG. 1.

To estimate vitamin A, 2 gms. of butter-fat were saponified with 15 cc. of N/2 alcoholic potassium hydroxide, 20 ccs. of water added, the whole transferred to a separating funnel and extracted with two quantities of 25 ccs. of ether. The ethereal extracts were washed with water, then with N/2 aqueous potassium hydroxide and again with water, after which the ether was evaporated under suction at about 30°C. The residue was dissolved in purified ethyl alcohol, made up to 10 ccs. and vitamin A estimated in the solution with a Hilger Vitameter A using the factor 1600.

VITAMIN B_1.

In 1935, Schopfer published a paper showing that vitamin B_1 is a growth factor for the mould *Phycomyces blakesleeanus*, and he outlined a method for the estimation of vitamin B_1. It was later found (Robbins and Kavanagh (1937), Sinclair (1937), Schopfer and Jung (1937)) that both vitamin B_1 and its degradation products promote the growth of the mould. Hence the method about to be described for the estimation of vitamin B_1 actually estimates vitamin B_1 and any of its breakdown products which might be present in fresh milk.

Into 50 cc. Erlenmeyer flasks were placed 0.2 cc. of skim milk, each milk sample to be analysed, being done in triplicate. Skim milk was used, for otherwise a thin layer of butter-fat settled on the surface of the media and the slight anaerobic conditions thus introduced inhibited the growth of the mould. To each flask was then added 10 ccs. of a medium consisting of :—

Glucose	166.8	gms.
Asparagin	6.4	,,
$MgSO_4 + 7H_2O$	0.84	,,
KH_2PO_4	2.5	,,
H_2O	1,665	ccs.

and the pH was adjusted to approximately 6.6 by the addition of one or two drops of dilute sodium hydroxide.

A standard range was also set up containing 10 ccs. of media as before, but in place of milk the following amounts of vitamin B_1 were added :—0.5, 0.4, 0.3, 0.2, 0.1, 0.01, 0.001 international units. These flasks were set up in duplicate and all the flasks then plugged and sterilized at 107°C. for 10 minutes. A culture of *Phycomyces blakesleeanus* was prepared a fortnight previously in 100 ccs. of Wort Agar, made as follows :—25 ccs. of malt extract, 4 gms. of agar, and 200 ccs. of water were made up and autoclaved at 110°C. for 15 minutes. Several grams of the spore bearing mycelium were removed with sterile forceps and thoroughly washed in sterile water contained in a beaker covered with a watch glass. Each flask was then inoculated with two drops (about 0.2 cc.) of the spore bearing suspension by means of a sterile pipette. The suspension was stirred frequently to ensure that the spores did not sediment. The inoculated flasks were then left in the dark at room temperature (22°C.) for ten days. All the mycelia were then removed, washed in running water, alcohol, and ether, rolled into small balls, dried in a hot air oven at 110°C. and then weighed.

From the weights of the mycelia in the standard flasks, a graph, of which Fig. II. is typical, was drawn, and from this graph the amounts of vitamin B_1 in the other flasks calculated.

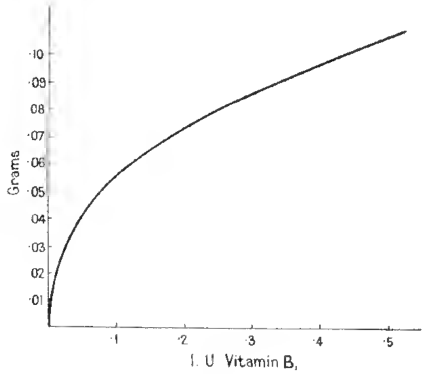

Fig. 2.

VITAMIN B_2.

Was estimated in 100 ccs. of skim milk according to the second method described by Weisberg and Levin (1937). The aqueous solution of riboflavin contained much foreign matter, but this did not interfere with the estimation. The relation between the fluorescence intensity of sodium fluorescein (May and Baker Limited) and vitamin B_2 is given in Fig. III., which differs slightly from that given by Weisberg and Levin, for it is a straight line which does not pass through the origin.

VITAMIN C.

To 10 ccs. of milk were added 10 ccs. of 20 per cent. trichloracetic acid; the solution was mixed well and then filtered. The precipitate was washed once with a little distilled water and the filtrate made up to 25 ccs. A burette was charged with this solution and it was added drop by drop to a standardized solution of 2:6 dichlorphenolindophenol until the red colour was just discharged. Knowing the strength of the dichlorphenolindophenol solution, the vitamin C present was determined.

ASHING.

300 ccs. of milk in a porcelain basin were dried on a water bath, a little alcohol being added to facilitate evaporation. When dry, the residue was heated over a bunsen to set the carbon and then placed in a muffle at a temperature of 400°–450°C. To

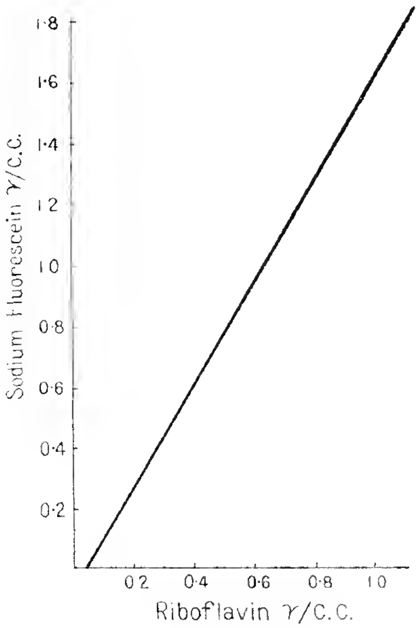

FIG. 3.

complete the incineration, the carbonized mass was cooled, mixed with water, dried, and returned to the muffle. The following determinations were carried out in duplicate on the ash which was dissolved in the minimum amount of hydrochloric acid and the volume made up to 100 ccs.:—

1. *Calcium.*—25 ccs. of the ash solution were made alkaline with ammonia and the resulting precipitate filtered off and washed. The filtrate and washings were kept for the sulphur determination. The precipitate was then dissolved in the minimum amount of hydrochloric acid, sodium acetate solution added and adjustment made to pH 5.0, using congo red as indicator. Calcium was then precipitated at 40°C. with an excess of saturated ammonium oxalate, the solution allowed to stand one hour, filtered, washed with water and a little dilute ammonia, incinerated and weighed as CaO.

2. *Magnesium.*—The combined filtrate and washings were evaporated to about 100 ccs., and 20 ccs. of nitric acid added. The beaker was covered, evaporated to dryness, 5 ccs. of hydrochloric acid were added, then evaporated almost to dryness and the residue dissolved in hot water. The magnesium was precipitated by the addition of 3 ccs. of a 10 per cent. solution of ammonium phosphate and sufficient ammonium hydroxide to make the solution slightly alkaline. The solution was stirred vigorously, allowed to stand 15 minutes, 15 ccs. of ammonium hydroxide added and the precipitation allowed to proceed over-

night. It was then filtered, washed with dilute ammonia, transferred to a crucible, dried, ignited, and weighed as $Mg_2P_2O_7$.

3. *Sulphur.*—The filtrate from the calcium estimation to which 10 ccs. of concentrated hydrochloric acid had been added was evaporated almost to dryness. It was then made up to 250 ccs., 5 ccs. of dilute hydrochloric acid added, and boiled. Some acidified 3 per cent. barium chloride was also boiled and 8 ccs. slowly added to the sulphate solution. It was left for an hour, filtered, washed, ignited, cooled, three drops of a mixture containing 1 cc. of alcohol and 2 ccs. of sulphuric acid added, incinerated and weighed as $BaSO_4$.

4. *Potassium.*—To the filtrate from the sulphate determination, barium hydroxide solution was added in slight excess and it was evaporated to about 50 ccs. Ammonium carbonate was added, the solution filtered into a porcelain dish, washed with hot water and evaporated to dryness. Moisture and ammonium chloride were driven off, 5 ccs. of hot water added, the solution filtered into a tared beaker, the residue washed, one drop of hydrochloric acid added, the filtrate evaporated to dryness and weighed as $NaCl + KCl$. 15 ccs. of 20 per cent. perchloric acid were added and it was evaporated almost to dryness. To the almost dry, cold residue 10 ccs. of a washing solution consisting of 1 cc. of 20 per cent. perchloric acid in 100 ccs. of 98 per cent. alcohol were added. The solution was stirred well, set aside for 5 minutes, decanted through a tared sintered glass crucible, placed on the steam bath to remove alcohol, dissolved in the minimum amount of hot water, evaporated, 10 ccs. of washing solution added, stirred, filtered, dried for one hour at 130°C. and weighed as $KClO_4$.

5. *Sodium* was calculated from the two above results by difference.

6. *Phosphorus.*—The original solution was again made up to 100 ccs. and to 15 ccs. a little methyl orange was added and the solution boiled to drive off carbon dioxide. The solution was neutralized with sodium hydroxide, 25 ccs. of 10 per cent. calcium chloride and a few drops of phenolphthalein added and the solution titrated with N/10 sodium hydroxide until a slight pink remained permanent after mixing. The percentage phosphorus was given by—

$$\frac{\text{cc. N/10 NaOH} \times .1551}{\text{weight of milk taken.}}$$

7. *Iron.*—To 35 ccs. of the remaining ash solution diluted to 100 ccs. were added 10 ccs. of concentrated hydrochloric acid. The iron was precipitated with 4 per cent. cupferron, filtered under suction, washed with water, dilute ammonia and again with water. The precipitate was transferred to an annealing cup, heated over a bunsen, incinerated and weighed directly as Fe_2O_3.

Results.

The results of the analyses are given in Tables I. and II.

Table I.—(Mineral Constituents.)

Number.		Specific Gravity.	Per-centage Ca.	Per-centage P.	Per-centage K.	Per-centage Na.	Per-centage Mg.	Per-centage S.	Per-centage Fe.
1	..	1·0315	·130	·082	·156	·044	·011	·009	·000090
2	..	1·0320	·125	·088	·148	·042	·009	·010	·000108
3	..	1·0310	·120	·086	·142	·042	·012	·009	·000072
4	..	1·0332	·107	·087	·134	·048	·011	·008	·000081
5	..	1·0331	·134	·090	·145	·051	·009	·013	·000126
6	..	1·0330	·118	·097	·148	·050	·013	·008	·000081
7	..	1·0321	·122	·094	·142	·049	·014	·008	..
8	..	1·0325	·111	·090	·138	·051	·011	·007	..
9	..	1·0320	·120	·086	·140	·057	·010	·008	·000108
10	..	1·0317	·118	·075	·145	·054	·013	·008	·000108
11	..	1·0315	·125	·091	·152	·045	·014	·010	·000065
12	..	1·0317	·128	·086	·150	·040	·012	·010	·000073
13	..	1·0310	·127	·078	·146	·042	·011	·011	·000068
14	..	1·0315	·140	·084	·150	·045	·013	·016	·000084
15	..	1·0311	·119	·080	·144	·047	·012	·009	·000104
16	..	1·0320	·125	·085	·147	·050	·011	·009	·000070
17	..	1·0311	·130	·084	·143	·045	·012	·010	·000081
18	..	1·0310	·135	·087	·150	·050	·011	·012	·000210
19	..	1·0311	·116	·079	·135	·058	·009	·009	·000089
20	..	1·0312	·125	·087	·142	·053	·012	·009	·000090
21	..	1·0310	·116	·082	·140	·048	·009	·008	·000075
22	..	1·0316	·117	·083	·143	·050	·010	·009	·000080
23	..	1·0315	·112	·080	·145	·049	·011	·008	·000099
24	..	1·0311	·130	·084	·148	·051	·011	·010	·000088
25	..	1·0305	·126	·080	·146	·040	·010	·009	·000074
26	..	1·0314	·125	·079	·146	·043	·014	·007	·000081
27	..	1·0311	·122	·075	·151	·041	·011	·008	·000086
28	..	1·0311	·126	·084	·147	·042	·011	·009	·000109
29	..	1·0310	·125	·079	·147	·049	·009	·009	·000079
30	..	1·0310	·122	·079	·139	·045	·011	·008	·000063
31*	..	1·0317	·097	·082	·125	·046	·007	·007	·000062
32	..	1·0304	·117	·077	·138	·060	·011	·008	·000084
33	..	1·0304	·124	·075	·140	·055	·011	·009	·000088
34	..	1·0313	·110	·078	·139	·048	·010	·009	·000078
35	..	1·0307	·120	·082	·145	·049	·014	·009	·000090
36	..	1·0312	·123	·080	·150	·045	·007	·009	·000067
37	..	1·0305	·112	·082	·145	·041	·010	·008	·000080
38	..	1·0314	·121	·070	·151	·042	·009	·008	..
39*	..	1·0303	·099	·076	·147	·045	·011	·008	·000092
40	..	1·0312	·126	·075	·153	·046	·010	·010	·000105
41	..	1·0314	·119	·081	·142	·047	·011	·008	·000096
42	..	1·0304	·119	·076	·148	·050	·012	·008	·000065
43	..	1·0319	·131	·082	·154	·046	·011	·010	..
44	..	1·0314	·126	·078	·153	·053	·011	·009	·000101
45*	..	1·0300	·117	·080	·145	·040	·010	·008	·000068
46	..	1·0310	·119	·081	·148	·050	·011	·009	·000067
47	..	1·0315	·089	·074	·136	·051	·011	·009	·000067
48*	..	1·0319	·134	·092	·145	·048	·010	·012	·000070
49*	..	1·0310	·120	·078	·148	·047	·010	·009	..
50	..	1·0299	·112	·077	·139	·050	·011		..
51	..	1·0306	·125	·085	·151	·053	·013		..
52	..	1·0313	·118	·0 0	·148	·048	·011	·009	..
53	..	1·0298	·135	·079	·157	·058	·019	·012	..
54*	..	1·0320	·122	·088	·156	·050	·013	·009	..
55	..	1·0323	·111	·081	·152	·046	·011	·007	..
56	..	1·0320	·116	·080	·150	·051	·012	·009	..
57	..	1·0301	·095	·079	·142	·041	·012	·008	..
58	..	1·0300	·116	·080	·148	·040	·011	·009	..
59	..	1·0298	·102	·080	·147	·042	·010	·008	..
60	..	1·0316	·128	·086	·149	·041	·010	·009	..
61	..	1·0306	·120	·081	·148	·040	·011	·009	..
62	..	1·0313	·123	·078	·151	·042	·011	·009	..
63	..	1·0316	·126	·080	·150	·041	·010	·008	..
64*	..	1·0318	·128	·088	·148	·055	·011	·012	..
65*	..	1·0316	·108	·080	·139	·052	·011	·009	..
66	..	1·0324	·118	·089	·142	·049	·012	·009	..

TABLE I.—(MINERAL CONSTITUENTS)—*continued.*

Number.	Specific Gravity.	Percentage Ca.	Percentage P.	Percentage K.	Percentage Na.	Percentage Mg.	Percentage S.	Percentage Fe.
67 ..	1·0323	·110	·084	·144	·047	·009	·008	..
68* ..	1·0310	·131	.081	·152	·046	·011	·011	..
69* ..	1·0316	·114	·085	·118	·047	·011	·008	..
70* ..	1·0317	·135	·082	·154	·051	·016	·011	..
71* ..	1·0316	·119	·080	·148	·048	·011	·009	..
72 ..	1·0295	·108	·080	·146	·044	·010	·009	..
73* ..	1·0300	·127	·086	·150	·012	·011	·009	..
74* ..	1·0308	·130	·088	·154	·048	·013	·011	..
75 ..	1·0330	·111	·080	·148	·049	·011	·007	..
76 ..	1·0317	·118	·082	·145	·050	·011	·007	..
77 ..	1·0316	·125	·084	·148	·052	·010	·008	..
78 ..	1·0333	·130	·081	·151	·051	·011	·010	..
79 ..	1·0321	·125	·080	·144	·056	·011	·009	..
80 ..	1·0328	·121	·079	·143	·051	·011	·010	..
81 ..	1·0320	·133	·080	·147	·049	·015	·010	..
82 ..	1·0338	·121	·086	·143	·045	·013	·009	..
83 ..	1·0316	·119	·082	·138	·051	·010	·009	..
84 ..	1·0308	·122	·089	·127	·041	·011	·007	..
85 ..	1·0307	·124	·078	·130	·039	·010	·008	..
86 ..	1·0321	·099	·080	·119	·039	·009	·006	..
87 ..	1·0315	·122	·081	·134	·043	·011	·009	..
88 ..	1·0309	·123	·084	..	..	·011	·006	..
89 ..	1·0303	·127	·086	·130	·039	·010	·004	..
90 ..	1·0310	·135	·088	..	..	..	..	..
91 ..	1·0302	·129	·083	..	..	·012	·005	..
92* ..	1·0308	·120	·083	·140	·053	·011	·007	..
93* ..	1·0319	·124	·088	·152	·055	·012	·008	..
94 ..	1·0308	·114	·080	·138	·054	·012	·007	..
95* ..	1·0319	·119	·089	·136	·045	·011	·007	..
96 ..	1·0320	·130	·086	·143	·048	·011	·010	..
97 ..	1·0315	·121	·085	·148	·045	·009	·011	..
98* ..	1·0313	·094	·074	·140	·044	·013	·009	..
99* ..	1·0311	·123	·081	·149	·052	·008	·010	..
100 ..	1·0317	·124	·087	·156	·048	·011	·009	..
101 ..	1·0318	·129	·088	·150	·050	·012	·009	..
102 ..	1·0319	·127	·081	·146	·051	·010	·008	..
103 ..	1·0321	·105	·084	·132	·047	·012	·007	..
104 ..	1·0312	·122	·074	·138	·042	·011	·008	..
105 ..	1·0309	·121	·078	·143	·052	·010	·008	..
106 ..	1·0308	·129	·082	·146	·048	·011	·009	..
107 ..	1·0317	·132	·078	·156	·046	·012	·009	..
108 ..	1·0317	·129	·080	·153	·041	·011	·008	..
109 ..	1·0312	·124	·079	·146	·045	·009	·008	..
110 ..	1·0315	·129	·079	·150	·048	·012	·008	..
111 ..	1·0314	·120	·082	·138	·055	·011	·007	..
112 ..	1·0313	·114	·081	·142	·039	·013	·007	..
113 ..	1·0319	·120	·072	·140	·048	·010	·012	..
114 ..	1·0328	·135	·088	·154	·045	·013	·010	..
115 ..	1·0319	·124	·079	·134	·050	·011	·009	..
116 ..	1·0318	·134	·083	·138	·049	·011	·009	..
117 ..	1·0314	·129	·085	·140	·050	·011	·012	..
118 ..	1·0315	·114	·082	·128	·056	·011	·008	..
119 ..	1·0312	·132	·092	·145	·052	·012	·011	..
120 ..	1·0322	·130	·085	·142	·054	·014	·010	..
121 ..	1·0312	·126	·075	·135	·045	·011	·010	..
122 ..	1·0313	·124	·087	·138	·045	·013	·011	..
123 ..	1·0324	·127	·086	·135	·046	·011	·009	..
124 ..	1·0329	·121	·073	·138	·048	·009	·008	..
125 ..	1·0318	·109	·076	·124	·048	·010	·008	..
126 ..	1·0317	·116	·074	·130	·046	·010	·007	..
127 ..	1·0314	·117	·080	·148	·047	·012	·010	..
128 ..	1·0304	·112	·079	·145	·042	·009	·010	..
129 ..	1·0311	·122	·084	·150	·048	·012	·009	..
130 ..	1·0312	·119	·086	·146	·049	·011	·008	..
131 ..	1·0324	·125	·078	·148	·052	·012	·007	..
132 ..	1·0314	·102	·066	·138	·041	·013	·005	..
133 ..	1·0309	·121	·085	·111	·050	·011	·008	..
134 ..	1·0314	·120	·080	·140	·048	·011	·008	..
135 ..	1·0309	·119	·079	·143	·046	·010	·010	..
136 ..	1·0309	·114	·077	·141	·058	·011	·007	..
137 ..	1·0325	·129	·077	·153	·056	·013	·009	..

TABLE I.—(MINERAL CONSTITUENTS)—*continued.*

Number.	Specific Gravity.	Percentage Ca.	Percentage P.	Percentage K.	Percentage Na.	Percentage Mg.	Percentage S.	Percentage Fe.
138 ..	1·0329	·121	·084	·149	·040	·011	·008	..
139 ..	1·0319	·105	·075	·147	·045	·008	·007	..
140 ..	1·0329	·114	·086	·148	·050	·012	·008	..
141 ..	1·0316	·094	·078	·119	·045	·011	·007	..
142 ..	1·0313	·118	·074	·134	·048	·010	·012	..
143 ..	1·0318	·097	·078	·145	·050	·008	·009	..
144 ..	1·0311	·110	·082	·132	·038	·009	·009	..
145 ..	1·0323	·118	·078	·131	·056	·011	·010	..
146 ..	1·0320	·119	·082	·137	·052	·010	·012	..
147 ..	1·0317	·108	·089	·141	·054	·010	·008	..
148 ..	1·0301	·140	·085	·158	·059	·011	·009	..
149 ..	1·0308	·126	·083	·153	·050	·011	·008	..
150 ..	1·0300	·123	·082	·151	·042	·012	·007	..
151 ..	1·0326	·125	·089	·147	·046	·011	·008	..
152 ..	1·0323	·117	·084	·148	·050	·012	·007	..
153 ..	1·0326	·110	·080	·144	·048	·011	·010	..
154 ..	1·0318	·095	·071	·135	·049	·010	·010	..
155 ..	1·0313	·112	·078	·132	·042	·011	·009	..
156 ..	1·0310	·121	·081	·134	·048	·011	·010	..
157 ..	1·0309	·131	·087	·147	·042	·011	·011	..
158 ..	1·0317	·133	·078	·146	·050	·014	·012	..
159 ..	1·0312	·121	·078	·142	·053	·010	·009	..
160 ..	1·0321	·125	·080	·150	·044	·011	·008	..
161 ..	1·0315	·114	·076	·141	·046	·011	·009	..
162 ..	1·0316	·126	·079	·138	·048	·012	·010	..
163 ..	1·0315	·128	·078	·154	·052	·011	·009	..
164 ..	1·0315	·119	·089	·150	·054	..	·008	..
165 ..	1·0311	·135	·079	·157	·056	·011	·014	..
166 ..	1·0318	·116	·078	·148	·048	·011	·009	..
167 ..	1·0311	·129	·082	·145	·046	·011	·010	..
168 ..	1·0316	·120	·081	·139	·048	·011	·009	..
Mean ..	1·0318†	·120	·082	·144	·048	·012	·009	·000087

† See text.

TABLE I.—(VITAMIN CONSTITUENTS.)

Number.	Percentage Fat.	Percentage Carotene in B.F.	I.U. Vitamin A /gm. B.F.	I.U. Vitamin B_1 /100 ccs.	Mgms. Vitamin B_2 /100 ccs.	Percentage Vitamin C.
1 ..	4·37	·00082	51	19	·22	·00260
2 ..	4·53	·00036	48	25	·17	·00226
3 ..	4·55	·00070	48	17	·12	·00080
4 ..	4·95	·00048	54	20	·22	·00034
5 ..	4·14	·00060	53	24	·17	·00044
6 ..	3·95	·00105	35	22	·16	·00036
7 ..	4·75	·00059	33	20	·18	·00074
8 ..	5·35	·00076	35	15	·12	·00186
9 ..	3·20	·00029	40	20	·12	·00046
10 ..	4·25	·00062	41	18	·17	·00200
11 ..	4·15	·00071	68	20	·16	·00048
12 ..	5·55	·00110	52	15	·15	·00180
13 ..	5·20	·00054	54	19	·19	·00250
14 ..	5·15	·00125	56	10	·17	·00178
15 ..	5·05	·00136	29	20	·19	·00079
16 ..	4·43	·00096	57	21	·20	·00087
17 ..	6·20	·00238	54	19	·12	·00128
18 ..	5·10	·00119	44	19	·16	·00230
19 ..	4·78	·00110	35	18	·17	·00198
20 ..	4·40	·00065	36	20	·15	·00290
21 ..	4·10	·00031	33	17	·14	·00052
22 ..	4·37	·00078	34	24	·12	·00248
23 ..	5·62	·00102	28	14	·16	·00032
24 ..	5·40	·00068	36	14	·15	·00094
25 ..	4·60	·00085	40	20	·20	·00224
26 ..	4·25	·00096	50	18	·14	·00108

TABLE I.—(VITAMIN CONSTITUENTS)—*continued.*

Number.	Percentage Fat.	Percentage Carotene in B.F.	I.U. Vitamin A /gm. B.F.	I.U. Vitamin B_1 /100 ccs.	Mgms. Vitamin B_2 /100 ccs.	Percentage Vitamin C.
27 ..	4·10	·00075	66	15	·22	·00056
28 ..	5·22	·00062	61	22	·16	·00224
29 ..	4·65	·00059	29	18	·15	·00240
30 ..	4·48	·00046	31	19	·14	·00054
31 ..	4·05	·00031	58	10	·18	·00032
32 ..	5·45	·00112	67	19	·17	·00044
33 ..	5·10	·00107	62	17	·16	·00034
34 ..	5·05	·00113	46	20	·17	·00034
35 ..	5·05	·00155	61	19	·15	·00050
36 ..	4·23	·00036	53	19	·19	·00032
37 ..	6·10	·00204	38	18	·18	·00048
38 ..	5·10	·00118	45	25	·16	·00258
39 ..	4·58	·00075	38	20	·18	·00303
40 ..	3·92	·00084	45	20	·12	·00240
41 ..	4·67	·00112	56	24	·15	·00172
42 ..	4·30	·00058	55	18	·19	·00192
43 ..	4·00	·00084	66	19	·16	·00206
44 ..	4·47	·00078	50	22	·21	·00192
45 ..	5·52	·00153	60	15	·19	·00048
46 ..	5·30	·00062	36	18	·21	·00254
47 ..	4·20	·00070	40	15	·16	·00224
48 ..	4·50	·00093	40	21	·18	·00192
49 ..	4·15	·00103	45	14	·17	·00234
50 ..	4·00	·00142	33	14	·21	·00172
51 ..	5·12	·00094	37	15	·16	·00238
52 ..	4·55	·00090	34	18	·21	·00168
53 ..	4·18	·00189	41	17	·12	·00188
54 ..	3·98	·00088	56	19	·21	·00184
55 ..	4·45	·00133	57	17	·26	·00220
56 ..	3·85	·00145	68	19	·18	·00160
57 ..	4·93	·00148	74	17	·22	·00046
58 ..	4·65	·00078	52	19	·17	·00192
59 ..	4·75	·00115	54	15	·16	·00101
60 ..	4·90	·00138	63	19	·25	·00186
61 ..	5·62	·00165	70	17	·21	·00238
62 ..	3·65	·00109	60	18	·17	·00182
63 ..	3·50	·00158	62	20	·12	·00196
64 ..	4·05	·00045	59	19	·22	·00192
65 ..	3·95	·00150	66	18	·24	·00190
66 ..	5·00	·00116	56	15	·12	·00224
67 ..	4·50	·00148	51	18	·18	·00122
68 ..	4·70	·00148	55	19	·19	·00184
69 ..	5·15	·00206	72	15	·22	·00252
70 ..	4·90	·00228	44	18	·23	·00182
71 ..	5·73	·00058	38	25	·17	·00184
72 ..	4·80	·00190	52	21	·18	·00162
73 ..	6·75	·00119	55	20	·19	·00240
74 ..	6·00	·00228	40	14	·22	·00123
75 ..	3·80	·00107	33	20	·17	·00250
76 ..	4·55	·00125	45	24	·12	·00222
77 ..	3·60	·00119	36	18	·18	·00062
78 ..	3·43	·00141	49	14	·18	·00108
79 ..	3·15	·00138	39	15	·13	·00188
80 ..	4·00	·00145	35	18	·18	·00092
81 ..	3·40	·00174	67	14	·20	·00156
82 ..	5·30	·00242	45	17	·19	·00120
83 ..	3·83	·00135	38	19	·17	·00098
84 ..	3·95	·00070	33	17	·12	·00250
85 ..	3·80	·00183	37	20	·12	·00222
86 ..	3·45	·00098	40	21	·14	·00148
87 ..	4·25	·00135	47	19	·20	·00260
88 ..	3·85	·00111	29	17	·09	·00306
89 ..	3·65	·00167	34	19	·17	·00150
90 ..	3·70	·00060	35	19	·18	·00054
91 ..	3·90	·00245	33	20	·27	·00044
92 ..	5·00	·00090	46	..	·17	·00096
93 ..	4·60	·00078	46	24	·17	·00084
94 ..	4·40	·00081	36	19	·18	·00093
95 ..	5·15	·00101	45	16	·17	·00139
96 ..	..	·00098	47	19	·20	·00200
97 ..	..	·00105	68	18	·19	·00098
98 ..	4·12	·00065	52	20	·16	·00192

TABLE I.—(VITAMIN CONSTITUENTS)—*continued.*

Number.	Percentage Fat.	Percentage Carotene in B.F.	I.U. Vitamin A /gm. B.F.	I.U. Vitamin B_1 /100 ccs.	Mgms. Vitamin B_2 /100 ccs.	Percentage Vitamin C.
99 ..	3·98	·00058	44	25	·13	·00128
100 ..	..	·00019	29	20	·16	·00130
101 ..	4·33	·00155	56	18	·17	·00084
102 ..	5·34	·00134	44	24	·14	·00238
103 ..	4·88	·00221	54	19	·16	·00156
104 ..	4·28	·00190	57	23	·20	·00044
105 ..	4·27	·00105	33	18	·12	·00036
106 ..	4·63	·00045	34	15	·19	·00172
107 ..	4·35	·00056	35	28	·16	·00068
108 ..	4·85	·00095	28	20	·13	·00034
109 ..	4·04	·00060	36	18	·17	·00036
110 ..	3·85	·00058	36	18	·15	·00206
111 ..	4·65	·00030	40	15	·19	·00044
112 ..	5·25	·00161	68	19	·30	·00042
113 ..	3·10	·00172	61	21	·12	·00302
114 ..	4·15	·00121	56	14	·15	·00117
115 ..	4·05	·00150	60	14	·15	·00192
116 ..	5·45	·00065	40	19	·16	·00151
117 ..	5·10	·00084	37	15	·18	..
118 ..	5·05	·00120	33	18	·17	·00192
119 ..	4·95	·00114	38	17	·17	·00166
120 ..	4·33	·00074	45	26	·17	·00086
121 ..	6·10	·00036	67	14	·20	·00268
122 ..	5·00	·00048	35	23	·16	·00192
123 ..	4·68	·00056	38	19	·18	·00258
124 ..	4·30	·00098	57	20	·28	·00136
125 ..	4·00	·00145	62	22	·17	·00248
126 ..	4·90	·00200	46	23	·18	·00220
127 ..	5·63	·00058	61	13	·15	·00068
128 ..	4·90	·00054	35	24	·19	·00232
129 ..	6·45	·00079	39	25	·22	·00240
130 ..	6·10	·00082	49	27	·20	·00168
131 ..	3·70	·00067	45	22	·16	·00210
132 ..	4·65	·00104	36	18	·16	·00254
133 ..	3·50	·00092	53	16	·15	·00224
134 ..	3·53	·00040	38	20	·14	·00322
135 ..	3·05	·00084	45	21	·17	..
136 ..	4·10	·00112	28	17	·19	..
137 ..	3·30	·00084	45	16	·18	..
138 ..	5·20	·00058	56	15	·23	..
139 ..	3·73	·00065	55	23	·16	..
140 ..	3·85	·00153	66	25	·15	..
141 ..	3·42	·00078	33	15	·17	..
142 ..	4·25	·00103	40	22	·17	..
143 ..	3·75	·00093	35	19	·29	..
144 ..	3·45	·00070	52	20	·22	..
145 ..	3·70	·00090	38	21	·23	..
146 ..	3·95	·00102	44	14	·15	..
147 ..	5·15	·00132	62	16	·22	..
148 ..	4·12	·00145	55	20	·17	..
149 ..	3·98	·00148	51	22	·18	..
150 ..	4·33	·00165	56	18	·15	..
151 ..	5·34	·00109	50	24	·19	..
152 ..	4·88	·00058	60	22	·14	..
153 ..	4·28	·00970	36	15	·19	..
154 ..	4·27	·00107	40	18	·17	..
155 ..	4·63	·00086	30	15	·17	..
156 ..	5·05	·00075	45	18	·18	..
157 ..	5·10	·00084	56	19	·22	..
158 ..	4·20	·00078	66	25	·17	..
159 ..	4·75	·00068	59	15	·14	..
160 ..	3·90	·00070	62	11	·19	..
161 ..	4·10	·00090	60	18	·14	..
162 ..	4·00	·00135	60	20	·10	..
163 ..	4·65	·00111	63	25	·18	..
164 ..	5·20	·00167	54	21	·19	..
165 ..	4·85	·00063	62	20	·19	..
166 ..	3·90	·00065	51	14	·13	..
167 ..	4·20	·00058	65	19	·18	..
168 ..	4·06	·00079	43	20	·17	..
Mean ..	4·51	·00104	47·6	18·8	·17	·00156

General Discussion of Results.

In Table I. the mean specific gravity was not obtained by summing all the specific gravities and dividing by their number. To average specific gravities they should be first calculated to specific volumes, these averaged, and the average specific gravity deduced from the average specific volume. The average specific gravity then was calculated from the following:—

$$S.G. = \frac{1}{\dfrac{\dfrac{1}{1.0315} + \dfrac{1}{1.0320} + \dfrac{1}{1.0310} + \cdots\cdots\cdots + \dfrac{1}{1.0316}}{168}}$$

When the specific gravity and fat content of milk are known, the total solids and solids-not-fat may be readily calculated by means of Richmond's (1930) milk scale. The mean total solids and solids-not-fat content of the milk samples estimated in this manner are 13.50 and 8.99 per cent. respectively.

A slight direct correlation was found to exist between the solids-not-fat and phosphorus content of the samples, the Pearsonian coefficient of correlation being .40.

In Table III. the composition of milk from different breeds of cattle including the Australian Illawarra Shorthorn is compared. It will be seen that the composition of milk from Australian Illawarra Shorthorn herds resembles that from Ayrshire rather than Guernsey or Jersey herds. All samples were from afternoon milkings.

TABLE III.—COMPOSITION OF MILK FROM COWS OF DIFFERENT BREEDS.

Breed.	Number of Samples.	Total Solids Per Cent.			Fat Per Cent.			Solids-not-fat Per Cent.		
		Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
		%	%	%	%	%	%	%	%	%
Australian Illawarra Shorthorn	16	14·32	11·67	13·02	4·93	3·35	4·35	9·39	8·32	8·67
Ayrshire ..	12	14·10	11·94	13·18	5·05	3·50	4·43	9·05	8·44	8·75
Guernsey ..	4	14·81	14·36	14·56	5·45	5·30	5·37	9·36	9·06	9·19
Jersey ..	10	15·53	13·04	14·25	6·10	4·50	5·36	9·43	8·54	8·89

VITAMIN A AND CAROTENE.

Very few figures have been published on the vitamin A content of butter-fat which are comparable with those obtained during this investigation. In the large majority of cases the estimations have been carried out on butter-fat from a small number of cows, a particular breed of cow, or on butter-fat obtained during a

TABLE II.—FREQUENCY DISTRIBUTION OF RESULTS.

																				Mean
Specific Gravity D. F.	295 1	296 0	297 0	298 2	299 1	300 4	301 2	302 1	303 1	304 4	305 2	306 3	307 2	308 6	309 6	310 11	311 11	312 9	313 8	314 9
Fat .. D. F.	.. ..	.. ..	.. ..	.. ..	.. ..	3·1 2	3·2 2	3·3 1	3·4 3	3·5 5	3·6 1	3·7 6	3·8 4	3·9 8	4·0 13	4·1 11	4·2 8	4·3 13	4·4 6	4·5 6
Carotene .. D F.	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	30 3	36 2	42 1	48 6	54 3	60 16	66 11	72 8	78 12	84 12	90 6	96 9	102 6
Vitamin A .. D. F.	.. ..	.. ..	..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	28 3	30 5	32 1	34 13	36 17	38 11	40 12	42 2	44 6	46 15	48 4
Vitamin B_1 D. F.	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	10 2	11 1	12 0	13 1	14 12	15 18	16 4	17 12	18 25	19 28
Vitamin B_2 D. F.	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	9 1	10 1	11 0	12 14	13 4	14 9	15 14	16 20	17 31
Vitamin C .. D. F.	.. ..	.. ..	.. ..	.. ..	36 10	44 8	52 7	60 2	68 2	76 2	84 5	92 3	100 4	108 2	116 1	124 3	132 3	140 2	148 3	156 1
Calcium .. D. F.	< 100 9	102 2	103 0	104 0	105 2	106 0	107 1	108 3	109 1	110 4	111 3	112 5	113 0	114 7	115 0	116 6	117 5	118 7	119 11	120 10
Phosphorus .. D F.	.. ..	.. ..	.. ..	66 1	67 0	68 0	69 0	70 1	71 1	72 1	73 1	74 5	75 6	76 4	77 4	78 17	79 14	80 23	81 12	82 16
Potassium .. D. F.	< 126 4	126 0	127 1	128 1	129 0	130 3	131 1	132 3	133 0	134 5	135 4	136 2	137 1	138 11	139 5	140 8	141 4	142 9	143 6	144 4
Sodium .. D. F.	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	38 1	39 4	40 6	41 7	42 13	43 2	44 5	45 15	46 12	47 7	48 22
Magnesium D. F.	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	07 2	08 3	09 13	10 28	11 75	12 24
Sulphur .. D F.	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	04 1	05 0	06 4	07 20	08 43	09 53
Iron .. D. F.	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	..	.. ..	.. ..	.. ..	060 1	065 6	070 5	075 3	080 8	085 3

Specific Gravity D. F.	315 12	316 11	317 11	318 7	319 8	320 8	321 5	322 1	323 4	324 3	325 2	326 2	327 0	328 2	329 3	330 2	331 1	332 2	333 1	.. ..	.. ..	.. ..
Fat .. D. F.	4·6 8	4·7 8	4·8 5	4·9 9	5·0 5	5·1 11	5·2 8	5·3 5	5·4 2	5·5 3	5·6 4	5·7 1	5·8 0	5·9 0	6·0 1	6·1 3	6·2 1	6·3 0	6·4 0	6·5 1	< 6·6 1	.. ..
Carotene .. D F.	108 10	114 9	120 6	126 2	132 3	138 6	144 6	150 6	156 5	162 1	168 4	174 2	180 0	186 1	192 3	198 1	-04 2	210 0	216 0	222 1	228 2	< 234 3
Vitamin A .. D. F.	50 5	52 9	54 9	56 14	58 5	60 8	62 10	64 3	66 6	68 7	70 1	72 1	74 1	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
Vitamin B_1 D. F.	20 25	21 8	22 8	23 4	24 8	25 8	26 1	27 1	28 1	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
Vitamin B_2 D. F.	18 21	19 18	20 8	21 6	22 11	23 3	24 1	25 1	26 1	27 1	28 1	29 1	30 1	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
Vitamin C .. D. F.	164 3	172 5	180 4	188 8	196 11	204 4	212 1	220 4	228 7	236 5	244 4	252 8	260 5	268 1	276 0	284 0	292 1	300 2	308 1	316 0	324 1	.. ..
Calcium .. D. F.	121 10	122 8	123 5	124 7	125 12	126 8	127 5	128 4	129 8	130 7	131 3	132 2	133 2	134 3	135 6	136 0	137 0	138 0	139 0	140 2	.. ..	.. ..
Phosphorus .. D F.	83 5	84 11	85 8	86 11	87 6	88 8	89 6	90 2	91 1	92 2	93 0	94 1	95 0	96 0	97 1	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
Potassium .. D. F.	145 12	146 9	147 9	148 21	149 3	150 12	151 6	152 4	153 5	154 5	155 0	156 4	157 2	158 1	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
Sodium .. D. F.	49 10	50 18	51 10	52 8	53 5	54 5	55 5	56 4	57 1	58 3	59 1	60 1	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
Magnesium D. F.	13 13	14 5	15 1	16 1	17 0	18 0	19 1	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
Sulphur .. D F.	10 24	11 8	12 9	13 1	14 1	15 0	16 1	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
Iron .. D. F.	000 7	095 1	100 2	105 2	110 4	115 0	120 0	125 1	< 125 1	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..

particular season. Such results, obtained by spectrophotometric methods, have been published by Baumann et al. (1934), Beeson (1935), Booth et al. (1934), Gillam et al. (1936), Peterson et al. (1935), and Sutton and Kraus (1936). Sherman and Sherman (1937) give the mean vitamin A value of 86 samples of butter-fat as 50.60 ± 1.80 international units per gram, which differs only by three international units from the figure in Table I. Crawford et al. (1932) have determined the vitamin A activity of Australian butter-fat biologically, but because of the method used, the results are not directly comparable with those in this work. The frequency distribution table shows carotene to be a very variable constituent.

VITAMIN B_1.

Very few figures are to be found for the vitamin B_1 content of milk. Baker and Wright (1935) have published 23 international units per 100 ccs., which is four international units higher than the results obtained during this investigation, whilst Pyke (1937) found two samples contained 6 and 11 international units per 100 ml.

VITAMIN B_2.

Comparatively little work has been published on the vitamin B_2 content of milk. The figures .2 to .3 mgm. per 100 ccs., .1 mgm. per 100 ccs., and .176 to .26 mgm. per 100 ccs. have been obtained by Euler and Adler (1934), Kuhn et al. (1934), and Whitnah et al. (1937) respectively.

VITAMIN C.

The vitamin C content of milk has been investigated by many workers and appears to vary from $< .3$ (Levy and Fox, 1935) to 2.92 (Whitnah and Riddell, 1937) mgms. per 100 gms. 1.77 mgms. per 100 gms. which is slightly higher than the figure (1.56 mgms. per 100 gms.) given in Table I., is the mean of nineteen results obtained by Levy and Fox (1935), Whitnah and Riddell (1937), Ranganathan (1935), Fujita and Ebihara (1937), Meulemans and De Haas (1937), Rasmussen et al. (1936), Harris and Ray (1935), Correns (1937), Birch et al. (1933), Whitnah and Riddell (1936), Van Wijngaarden (1934), Kon and Watson (1937), Riddell et al. (1936), and Ferdinand (1936).

POTASSIUM, SODIUM, MAGNESIUM, AND SULPHUR.

Sherman (1936) gives .143 for the percentage of potassium in whole milk, Richmond (1930) .150, Crichton (1930) .168, and Trunz (1903) gives .136 and .149 per cent. For sodium Sherman gives .051 per cent., Richmond .037, Crichton .056, and Trunz gives .032 and .042 per cent. For the amount of magnesium in whole milk, Forbes et al. (1917) and Hart et al. (1909) each give .011 per cent., Sherman .012 per cent., Forbes et al. (1918) and Richmond .013 per cent., while Trunz gives the range .011 to .015 per cent. and .012 to .017 per cent. König (1904) gives .007 per cent. as the amount of sulphur in whole milk which has been ashed. (Approximately 72 per cent. of the sulphur in milk is lost in ashing). These figures are in good agreement with those obtained during this survey.

IRON.

Table IV. gives the iron content of milk according to various investigators:—

TABLE IV.—IRON CONTENT OF MILK.

Investigator.	Parts per Million.	Investigator.	Parts per Million.
Anselm (1895)	·62– 84	Lesne et al (1930)	·95
Davies (1931)	1·5–2·4	Langstein (1911)	·21–·49
Edelstein and Csonka (1912)	·28– ·49	Macfarlane (1932)	·48–·68
Elvehjem (1926)	·35– ·36	Nottbohm and Dorr (1914)	·21–·19
Fendler et al. (1914)	2·8–8·4	Sherman (1936)	2
Friedjung (1901)	·84–1·82	Soxhlet (1912)	·18–·84
König (1896)	·35–4·69	Trunz (1903)	·22–·36
		This Investigation	·87

These figures vary considerably, but the figure for Australian milk is well within the common range.

CALCIUM.

Table V. shows that the mean figure for the calcium content of Australian milk agreees very well with figures obtained by overseas investigators.

TABLE V.—CALCIUM AND PHOSPHORUS CONTENT OF MILK.

Investigator.	Percentage Ca.	Percentage P.
Bunge (1901)	..	·077–·084
Burr and Witt (1935)	·083–·141	·071–·117
Cranfield et al. (1927)	·132	·102
Crichton (1930)	·119	·100
Davies and Provan (1928)	·124	·105
Forbes et al. (1917)	·103	·078
Forbes et al. (1918)	·117	·094
Golding et al. (1932)	·128	·107
Hart et al. (1909)	·084–·097	·076
Hutchison (1906)	..	·096
Katagama (1908)	·119	·094
Katagama (1908)	·127	·098
König (1904)	·112	·080
Meigs et al. (1926)	·100	·087
Meigs et al. (1926)	·132	·114
Richmond (1930)	·109	·096
Sheehy (1921)	..	·090
Sherman (1936)	·118	·093
Sommer and Hart (1926)	·135	·095
Sommer and Hart (1926)	·124	·113
Sommer and Hart (1926)	·142	·102
Sommer and Hart (1926)	·129	·103
Trunz (1903)	·137	·083–·103
Trunz (1903)	·128	·089–·100
Wellmann (1937)	·118–·146	·096–·155
This Investigation	·120	·082

PHOSPHORUS.

Table V. compares the mean figure for the phosphorus content of Australian milk with twenty-five figures obtained by overseas investigators. It will be seen that three of the overseas figures are slightly lower and one practically equal to the Australian figure, whilst twenty-one are definitely higher. Hence it was considered reasonable to conclude that the phosphorus content of the Australian samples was low.

However, it was within the normal range according to Bunge, Burr and Witt, Wellman (see Table V.) and the following investigators. Sommer (1929) gives the range .068 to .119 per cent., Cranfield et al. (1927) (673 samples) .076 to .135 per cent., although 80 per cent. of the samples fell between the range .092 to .111 per cent., and Crichton (1930) has found it to be .073 to .127 per cent. for 220 samples.

It was at first thought that this low figure may be due to the method of estimation, but this was checked against the well-established method of titrating the ash solution with uranium acetate using potassium ferrocyanide as external indicator when both methods gave results in good agreement.

It has been recognized for some decades that many Australian soils, particularly the superficial soils, are deficient in phosphorus and this has been indirectly proved by the remarkable results which follow the use in New South Wales, Victoria, and Tasmania of phosphatic fertilizers. In an article by Cherry (1907) Victorian clay soils were compared with American clay soils, the clay soils being chosen because they contained a higher percentage of phosphorus than other soils. It was shown that Victorian clay soils contained 63 parts of phosphoric acid per 100,000 parts, whereas American clay soils contained 207 parts per 100,000. The Mallee soils were even lower, containing only 47 parts per 100,000.

During a survey conducted by Henry and Benjamin (1933), it was found that of 56 soils analysed from the southern coastal belt of New South Wales, only eight samples contained as much as five parts per 100,000 of citrate soluble phosphoric acid, the remaining 48 samples averaging 2.3 parts per 100,000.

Many other papers have been written containing data on the low phosphorus content of Australian soils. In the eastern States there is the work of Taylor and Hooper (1938), Taylor and England (1929), Taylor and Penman (1930), and Taylor et al. (1933), whilst in Western Australia there is the work of Hosking and Burvill (1938) and Teakle (1929).

In unpublished work carried out in this laboratory it was found, after analysing eighty-six samples of soil collected from dairy farms situated on the northern coastal belt of New South Wales, that each of these soils was very low in phosphorus.

Many research workers have found that the mineral content of pastures, fodder crops, cereals, &c., is related to the mineral content of the soils on which they are grown. In order to investigate this, one hundred and fifty-six samples of pastures and fodder crops were collected from the eighty-six previously mentioned dairy farms at the time the milk and soil samples were collected. The phosphorus content of these samples, dried at 100°C., was determined by a method similar to that used for milk, and the results together with comparative figures by overseas investigators are given in Table VI.

TABLE VI.—PHOSPHORUS CONTENT OF FEEDS.

Feed.	Remarks.	P Per Cent.	Number of Samples.	Country.	Authority.
Mixed pasture	From fertilized land	·149	11	Australia ..	This investigation
" "	From unimproved land	·178	46	" ..	" "
" "	Good pasture ..	·46	..	New Zealand	Rigg and Askew (1929)
" "	Poor hill pasture	·33	..	" "	" " "
" "	From both manured and unmanured land	·335	40	England ..	Armstrong (1907)
" "	From cultivated land	·32	24	England and Wales	Godden (1926)
" "	From hill country	·26	35	Scotland ..	" "
" "	From natural pasture	·29	22	" ..	Orr (1929)
" "	From cultivated land	·32	24	" ..	" "
" "	From poor hill country	·26	35	" ..	" "
" "	.. .. ..	·29	12	Kenya ..	Orr and Holm (1931)
" "	.. .. ..	·223	60	Mauritius ..	Lincoln (1937)
" "	Natural Pasture	·303	86	United States	Newlander et al (1933)
" "	" "	·19	96	" "	Archibald and Bennett (1933)
Fresh lucerne*	From fertilized land	·419	19	Australia ..	This investigation
" " *	From unimproved land	·411	33	" ..	" "
" " *	.. .. ..	·625	..	England ..	Woodman (1934)
" "	.. .. ..	·457	..	South Africa	Fox and Wilson (—)
Green oats ..	From fertilized land	·520	4	Australia ..	This investigation
" " ..	From unimproved land	·554	4	" ..	" "
Fresh sorghum	From fertilized land	·097	16	Australia ..	This investigation
" "	From unimproved land	·089	5	" ..	" "
Bran ..	.. .. ..	·98	5	Australia ..	This investigation
" ..	.. .. ..	1·32	..	America ..	Morrison (1936)
" ..	.. .. ..	1·20	..	Indiana ..	Purdue Uni. Agr. Exp. Sta. (1938)
" ..	.. .. ..	1·452	..	Europe ..	Heubner and Reeb (1908)

* Pre-budding period.

From this table it was seen that the phosphorus content of these pastures and fodder crops was very low. In some cases it was lower in crops grown on fertilized land than in crops grown on unfertilized land. This throws doubt on the testimonies of the farmers who supplied the information regarding fertilization of these lands, although it is possible that soils on which these crops grew may have been so low in phosphorus that the amount of fertilizer used restored but little of the deficiency.

The mean phosphorus content of the mixed milk from these eighty-six dairy farms was .081 per cent. This does not differ appreciably from the mean figure given in Table 1.

The question now arises as to whether the amount of phosphorus ingested by the cow determines the phosphorus content of milk. This question has been investigated by many workers and an excellent review of literature on the subject is included in a paper by Crichton (1930). On summing up the results of the various investigations a conclusion similar to that expressed by Forbes and Keith (1914) developed, namely, that the character of the feed may vary the phosphorus content of the milk, but only within normal limits.

Many of the milk samples collected during this survey were from herds which have been feeding for cow-generations on low phosphorus diets and often in localities where the conditions were so severe that cases of osteophagia were frequently observed (Henry and Benjamin, 1933). Where such conditions prevail, it seems reasonable to assume that this low phosphorus content of the milk can be due to no other cause than the low phosphorus content of Australian pastures and fodder crops, or indirectly to the low phosphorus content of Australian soils. This conclusion does not support that of Kincaid (1911), who analysed four milk samples from Victoria.

Correlations between the Vitamin and Mineral Constituents.

In a preliminary examination points were plotted for every value of each of the vitamins A, B_1, B_2, and C against the values for the mineral elements from the same milk sample. Twenty-eight graphs were thus obtained. These graphs were carefully examined, but in no instance could any correlation be detected between any two sets of results. Indeed, there was such a lack of correlation that it was considered unnecessary to apply any statistical treatment.

No correlation was found to exist between any of the vitamin and any of the mineral constituents of milk.

In view of the opinion expressed by Richmond (1930) that lecithin, because of its phosphorus content, may be an index of the vitamin content of milk, the lecithin content of thirty samples of milk was estimated by the method of Bordas and Raczkowski (1902) and the results examined as before, but again no correlation was detected. The mean figure for the lecithin content of these samples was .066 per cent.

A Correlation between the Phosphorus Content of Pasture and the Vitamin A Content of Milk.

Samples of feed as well as samples of milk were collected from most farms visited during this investigation, and during the examination of results, a most interesting correlation was found to exist between the phosphorus content of the pastures upon which certain herds grazed and the vitamin A content of the butter-fat from these herds.

On certain farms, which were comparatively large holdings, the herds were feeding on pasture alone. These farms (indicated by an asterisk in Table 1.) were situated in the coastal dairying districts of New South Wales, the most southern being situated in the Richmond district and the majority of others in the Grafton district. According to information gathered from each farmer, these herds had been feeding in the same paddocks for several cow-generations, the pasture feed had never been supplemented with hand feed of any kind and the paddocks had never been artificially fertilized, so that the mineral and vitamin intake of these herds remained fairly constant throughout the year and from one year to another.

The specimens of pasture and milk were collected in late summer when pastures were poorest, but on each farm there was abundance of green grass on which the cattle could feed and, as will be seen later, the diet contained a large excess of carotene. The pasture samples, which were collected with the assistance of the farmers, were taken from many parts of the field and much care was taken to obtain a truly representative sample. The samples were not cut, but plucked by hand in order to simulate a cow's method of grazing, and herbage not eaten by the cow was not included in the sample. On most farms couch (*Cynodon* sp.) was the predominating grass, and on some farms this was the only pasture grass. Paspalum (*Paspalum* sp.) and various species of clover were also common, but native grasses other than couch constituted a very small portion of any pasture.

TABLE VII.

(Phosphorus and protein expressed as percentage of pasture dried at 100°C.)

I.U. Vitamin A /gm. of B.F.	Breed of Herd.	Percentage P in Pasture.	Percentage Protein in Pasture.	Carotene in Pasture mgms/kg.
58	Mixed	·217	10·12	180
38	"	·085	9·04	190
60	Jersey	·171	10·51	240
40	Mixed	·098	6·72	200
45	"	·133	6·56	200
56	"	·202	10·73	190
59	"	·186	9·05	180
66	"	·209	10·62	180
55	Jersey	·187	12·43	200
72	Mixed	·325	13·15	210
44	"	·101	10·20	250
38	"	·116	9·72	190
55	"	·169	9·54	190
40	Jersey	·147	10·89	200
46	Mixed	·096	9·05	200
46	"	·111	10·21	190
45	"	·186	12·20	180
52	Australian Illawarra Shorthorn	·132	8·45	200
44	Mixed	·124	8·35	180

Table VII. gives the amount of vitamin A per gram of butter-fat in the mixed milk from these herds and the percentages of phosphorus, protein, and carotene in the pastures upon which the herds were feeding. It will be seen that a direct correlation exists between the vitamin A content of the butter-fat and the phosphorus content of the pasture, the coefficient of correlation being .97.

The carotene content of the pastures was estimated by a method similar to that given by Bolin and Khalapur (1938) and it will be seen from Table VII. that the poorest pasture contained 180 mgms. of carotene per kilogram or approximately 288,000 international units of vitamin A per kilogram (Fixsen and Roscoe, 1937-38). According to the work of Fraps et al. (1937) and Guilbert and Hart (1935), cows on these pastures were receiving a large daily excess of vitamin A.

Hence it would appear that the vitamin A content of butter-fat is influenced in some way by the phosphorus as well as the carotene ingested by the cow as suggested by Professor Rosedale. However, there may be other underlying factors such as the stage of growth of the pasture, for it will be seen that there is also a considerable degree of correlation between the protein and phosphorus content of the pastures. Unfortunately, most of the milk samples were from mixed herds, and because of this the table loses some of its value. An interesting piece of confirmatory evidence is given by the following fact, however. The mean vitamin A content of five samples of mixed milk from cows feeding on pasture but receiving in addition a daily ration of bran (a rich source of phosphorus) was two international units higher than the mean figure for the results given in Table VII.

No similar correlation was found to exist between any of the other vitamins and the phosphorus or protein intake of the herd.

Summary.

Fat, vitamin A, carotene, vitamin B_1, vitamin B_2, vitamin C, calcium, phosphorus, potassium, sodium, magnesium, sulphur, and iron have been estimated in 168 samples of mixed milk. Methods and results have been presented. The mean results of all analyses appear in the following table:—

Specific gravity	1·0318	Calcium	·120 per cent.
Total solids	13·50 per cent.	Phosphorus	·082 per cent.
Solids-not-fat	8·99 per cent.	Lecithin	·066 per cent.
Fat	4·51 per cent.	Potassium	·144 per cent.
Carotene in Butter-Fat	·00104 per cent.	Sodium	·048 per cent.
Vitamin A in Butter-Fat	47·6 I.U./gm.	Magnesium	·012 per cent.
Vitamin B_1	18·8 I.U./100 ccs.	Sulphur	·009 per cent.
Vitamin B_2	·17 mgm/100 ccs.	Iron	·000087 per cent.
Vitamin C	·00156 per cent.		

By comparing the results with overseas figures it has been shown that the phosphorus content of the Australian milk, although within normal limits, was low. It has also been shown that no correlations exist between the vitamin and mineral constituents of milk. Subject to certain conditions, a correlation was discovered between the vitamin A content of butter-fat and the phosphorus content of the pasture.

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ART. VII.—*Experiments on Manganese Deficiency Disease ("Grey Speck") of Cereals.*

By G. W. LEEPER, M.Sc.

[Read 13th July, 1939; issued separately, 1st March, 1940.]

Introduction.

In a previous paper (2) the writer described some experiments on manganese deficiency (or "grey speck") disease of cereals. The present paper deals with further work on the same subject extending over five years. A short account is first given of the present state of knowledge with regard to this disease.

Many important crops are liable to this disease, including wheat, barley, and especially oats. The soils on which crops are affected—here called "deficient soils"—have a pH value of at least 6.5, usually over 7.0. The disease may be overcome by lowering the pH of the soil below 6.5, by adding a compound of manganese to the soil, or by spraying the affected plants with a solution of a manganese salt. Descriptions of the symptoms, various experiments in the field, and descriptions of some deficient soils are referred to in (2). Since deficient soils often contain normal quantities of total manganese, the deficiency must be due to a very low availability of that manganese.

It appears that the forms of manganese in the soil which take part in chemical reactions are firstly the bivalent ion, mostly attached to the colloids as exchangeable manganese; and secondly, higher oxides of manganese, which range from highly active to relatively inert forms. The only evidence as to the chemical composition of the higher oxides has been provided by Naftel (3) whose work favours the formula Mn_2O_3 which should probably therefore replace the former conventional formula MnO_2. The writer has suggested that this Mn_2O_3 may be divided into four fractions in order of activity according to arbitrary tests. The most reactive fraction (*a*) can oxidize the organic matter of the soil at pH 2; the next fraction (*b*) can oxidize quinol at pH 7; fraction (*c*) can oxidize hydrosulphite but not quinol at pH 7, while (*d*) is still less active. It was further suggested that plants can utilize only the bivalent ion and fractions (*a*) and (*b*) of Mn_2O_3. In neutral or alkaline soils if aeration is good, the bivalent ion is mostly changed into the higher oxides, and it appears that then the health of sensitive plants such as oats depends on the presence of appreciable quantities of manganic oxide in forms (*a*) and (*b*). Healthy alkaline soils contain over 100 parts per million of manganese in this reactive form, while deficient soils have less than 25 parts. It appears that waterlogging, which has been successful in pot tests, cures the disease by reducing some of the manganic oxide to the bivalent state, after which it reverts under normal drainage to more reactive forms of manganic oxide; soluble manganese compounds when added to deficient soil are transformed into reactive forms of manganic oxide and so may remain available even though insoluble, while compounds which acidify the soil restore bivalent manganese permanently to the system and so cure the deficiency.

This report deals only with results obtained in plot and pot tests, with a review of the relative values of various methods of treating the soil in order to overcome the trouble. It is hoped that further chemical experiments concerning the forms and transformations of manganese in the soil may be published at a later date. The introductory account that has just been given is inadequate and some of the theory will probably have to be modified, but it will serve as a background for the experiments on plants that are recorded here.

The possible treatments of the disease are:—

(*a*) Thorough acidification of the soil with sulphur or otherwise.

(*b*) Addition of ammonium sulphate at or about the time of sowing. (This is equivalent to a minor and local acidification of the soil.)

(*c*) Addition of soluble or easily available compounds of manganese with the seed.

(*d*) Spraying the crop with dilute manganese sulphate as soon as symptoms of deficiency occur.

(*e*) Waterlogging for two or three weeks before sowing.

(*f*) Sterilizing the soil with formalin or some other suitable compound.

Of these methods, treatment with sulphur has already been shown to overcome the deficiency disease and to give better results with wheat than even large additions of manganese. In Europe and North America, however, where large areas of soil are deficient, little use has been made of sulphur, and the only acidic material used is ammonium sulphate, which would often be used in any case as a source of nitrogen. A comparison of sulphur and ammonium sulphate has therefore been made in plot experiments to be described. Method (*c*)—addition of soluble compounds of manganese with the seed—always increases the yield of both straw and grain, and is the only practicable method on highly calcareous soils, such as that of Corny Point, South Australia, where barley is sown (5) with a manganiferous superphosphate drilled in with the seed. Method (*d*)—the use of manganese sulphate as a spray—causes a spectacular recovery of sick plants, though two or three sprayings may be needed. Methods (*c*) and (*f*) can be tried only in pot tests; the former (waterlogging) has been included in this work, but not the latter (sterilizing) which, however, has given spectacular results in the hands of Gerretsen (1).

Plot Experiments in 1934 to 1938.

Experiments were carried out in these years on the same plots as in 1932–3; the results of the earlier experiments have been reported (2). The soil is a grey sandy loam with 0.2 per cent. $CaCO_3$ and of surface pH about 7.5, uniform in texture to a depth of eighteen inches and overlying a yellow clay. The surface soil has not been developed in situ and probably consists of sweepings from the roads of crushed basalt which formerly served Melbourne. Twenty plots each of one square yard are available so that five treatments can be replicated four times. Experimental errors are inevitably large on such small plots, but differences between treatments are often highly significant in spite of this, and the same differences occur again in subsequent years, thus greatly increasing the significance of the results. In previous years, in which wheat had been grown continuously, the best yields were found on the four plots which had been brought by sulphur to a pH of 6.0 to 6.5. Twelve other plots had been left alkaline and had been given $MnSO_4$ in various ways. The addition of manganese always led to yields higher than the controls though residual effects one year after application were poor.

Plot Experiments in 1934.

Experiments in 1934 were designed partly to confirm previous results, partly to compare the effects of ammonium salts with nitrates as a source of nitrogen on this soil. The plots were treated as follows:—the control plots (A), the sulphured plots (B), and the plots (C) that had been most heavily treated with manganese in the two previous years (4 cwt. per acre $MnSO_4$ crystals), were sown with 2 cwt. superphosphate and 260 lb. $NaNO_3$; of the two other sets of plots, those given $MnSO_4$ with the seed in 1933 (D) were again given 1 cwt. per acre $MnSO_4$ crystals with the seed, as well as the same superphosphate and nitrate as the controls, while the plots tested for residual effect of manganese in 1933 (E) were given 2 cwt. superphosphate and 200 lb. ammonium sulphate. In this way all plots were given equal amounts of nitrogen.

Free Gallipoli wheat was sown on May 22nd, during a very dry spell which lasted for three weeks longer. Germination was slow and patchy on all the plots given $NaNO_3$, but was normal and uniform on the four plots given ammonium sulphate. These plots (E) were outstanding throughout the winter, both in colour and in height. They had also produced the greatest number of tillers on October 3rd, when tillers on the other plots fell in the same order as in 1933, i.e., the $MnSO_4$ plots (D) were superior to the controls (though barely significantly) while the sulphured plots (B) again showed no increase over the controls; the tillers of (B) were, however, decidedly strong, and the total weight of the crop at this stage could not have been so much in favour of (E) compared with (B) as the tiller count indicates.

On October 10th there began a two-month spell of exceptionally wet weather, during which thirteen inches of rain fell, thus prolonging the growing season. However, the effects of sulphur and manganese were the same as in more normal years. The sulphured plots performed far better than any others during October and November, excelling in survival rate of tillers to ears, and especially in the weight of grain per ear. The $MnSO_4$ plots (D) also showed high figures for these values. The ammonium sulphate plots, however, fell right back and produced comparatively poor ears. There was a heavy incidence of foot-rot (*Ophiobolus graminis*) on all the alkaline plots, including a considerable amount even on the manganese-treated plots (D) where the plants were free from manganese deficiency disease and would have been expected to be more resistant. The acidic plots, however, were fairly free from disease.

The results of this year's work (Table I.) confirm those of former years. It is interesting to notice the all-round superiority of this year's manganese (D) over residual manganese (C); although in fact the soil of (C) contained 33 per cent. more added manganese than (D), this added manganese in plots (C) had evidently become much less available by the winter of 1934. The approximate equality of (B) and (D) is similar to what was found in 1932, but is in contrast to the marked superiority of sulphur over added manganese in 1933.

TABLE I.—FREE GALLIPOLI WHEAT, 1934.

—	Tillers.		Ears.			Grain.	
						Bushel per Acre.	
	Per Plant.	Per Sq. Yd.	Per Sq. Yd.	Percentage Surviving.	Gm. per Ear.	Mean.	Range.
A. Control	2·93	225	105	47	0·58	10·9	7·8–14·6
B. Sulphur	3·24	223	**158**	**71**	**1·16**	**32·6**	26·7–41·6
C. $MnSO_4$, Residual ..	3·00	233	127	55	0·75	**17·0**	16·2–18·1
D $MnSO_4$ with seed ..	3·13	264	**183**	**69**	**0·94**	**30·5**	29·5–32·0
E. Am_2SO_4	**3·46**	**300**	**174**	**58**	0·51	15·7	11·2–21·5

Standard error of mean of four plots, 1·88 bushels per acre.
Figures significantly different from control are in black.

The most interesting result, however, is the comparison of thorough acidification (B) with the use of ammonium sulphate (E). This comparison gives opposite results according as the crop is cut in the spring or grown for grain. It should be noted that the conditions are weighted in favour of (E), which had received a dressing of $MnSO_4$ two years before; this residual manganese should be made available by the ammonium sulphate more easily than the rest of the soil's manganese. In spite of this, the plants of (E) deteriorated during the last two months of growth.

Plot Experiments in 1935.

Since the wheat had suffered badly in 1934 from *Ophiobolus,* the experimental crop chosen in 1935 was Algerian oats. Experiments were designed to answer the following problems:—

1. Manganese deficiency has been dealt with either by keeping the soil alkaline and adding soluble manganese at sowing, or by acidifying the soil without adding any manganese. The latter method produces a healthier, and in some years a bigger crop of grain than does the former, but tillering on the acidified plots has shown no increase over the control plots and has been markedly below that of the alkaline plots to which $MnSO_4$ was added. This behaviour may be due to a difference in the forms in which manganese exists in the soil, or else to a general effect connected with pH and lime status. This could be tested by comparing the two treatments, (*a*) sulphur alone, and (*b*) sulphur with $MnSO_4$ at sowing.

2. The residual effect of a previous treatment with $MnSO_4$ has been shown (2) to be strikingly small. The author suggested that this was due to the completeness of precipitation of the added manganese in the surface inch or two of soil; and chemical analysis showed that this precipitation had in fact taken place. Information on the effect of thorough mixing of the surface ten inches of soil should settle this issue.

3. It would be useful to confirm the conclusions of 1934 regarding the inferiority of an ordinary dressing of ammonium sulphate to a heavy sulphuring.

The twenty plots were divided as before into five groups each of four replications, as follows:—

A. Control, no manganese added at any time.

B. Sulphured in 1932 and 1933, no manganese added at any time.

C. Alkaline, given 4 cwt. per acre $MnSO_4$ in 1932–1933. These were thoroughly mixed to a depth of ten inches just before sowing, but no more manganese was added.

D. Alkaline, given 1 cwt. per acre $MnSO_4$ in each year, 1932–3–4. Not dug at any time.

E. Given 1 cwt. $MnSO_4$ in 1932 and made acidic with excess sulphur in 1935. 56 lb. per acre $MnSO_4$ crystals added with seed in 1935.

Plots A, B, C, and E were sown with superphosphate and sodium nitrate; plots D were sown with superphosphate and ammonium sulphate. The total amount of nitrogen (48 lb. per acre) was the same for each plot. The first of the problems mentioned above should be solved by comparing B with E, the second by comparing C with A and D, the third by comparing D with B and E.

The seed was put in in the last week of May. Germination was uniformly good. As in 1934, the plants that had been given their nitrogen as ammonium sulphate showed a better colour and were taller during the early stages of growth. Some of the plants of group E, however (sulphur and $MnSO_4$), made poor growth at first, and many leaves showed a red colour at the tip. A few of the worst affected plants on these plots remained stunted to the end of the experiment, but the majority recovered, as described below. These toxic symptoms were evidently due to the unintentionally high acidity of the soil, which had a mean pH of 4.3 over the surface six inches; the added manganese probably made conditions worse.

The symptoms of grey-speck (manganese deficiency) became marked by 21st July—an earlier date than had been noticed for wheat, which is less sensitive than oats. The affected areas included all the alkaline plots (A, C, D) and patches on the previously sulphured plots (B). These bad patches had a mean pH value of 6.8, while healthy patches on the same plots had a mean pH of 5.7—a correlation with pH that has often been noticed elsewhere. By the end of August, the plants of treatment C (residual manganese, dug in) were somewhat healthier than those of treatment D (residual manganese, not dug in): these in turn were rather better than the controls (A). During September, however, all the plants on these twelve alkaline plots (A, C, D) died, and during October their place was taken by a vigorous growth of Wimmera rye-grass (*Lolium subulatum*) together with other plants, notably *Phalaris minor*, *Briza minor*, and *Vicia sativa*.

Grain-bearing heads were confined to the plants of treatment E (which recovered very well from their earlier poisoning), and to the more acidic patches of treatment B. The yield of the former plots was 60 per cent. above that of the latter. Since only five of the eight sulphured plots were uniformly free from grey-speck, the results do not provide a clear answer to the first of the three problems at the beginning of this section, concerning the reason for the low tillering of wheat on the sulphured plots, though it seems likely that pH is the main factor. The inferiority of ammonium sulphate to sulphur is again strikingly confirmed, while the failure of the plots that had been thoroughly dug shows that the absence of a good residual effect of manganese sulphate cannot be due, as the author suggested, to a lack of mixing of the surface layers with the rest of the soil, but must be due to a change in the nature of the manganese compounds concerned.

PLOT EXPERIMENTS IN 1936.

The work of previous years has shown that the addition of large amounts of manganese to the soil here studied has only a slight residual effect in the years after the application, even if the soil is thoroughly mixed to a depth of eight inches or so. On the other hand, the addition of 80 parts per million of manganese in the form of "active" manganic oxide has made it possible for oats to grow healthily on the highly-deficient soil from Mount Gambier in the second year after application (see below). A waterlogging of two weeks also has kept a pot of Mount Gambier soil healthy for four years at least, after the waterlogging. It is of interest therefore, to try to find out whether extremely heavy applications of manganese compounds will restore the University soil permanently to a state in which it will grow healthy oats or wheat. In 1936, besides confirmatory tests with sulphur and ammonium sulphate, the further treatments were tried of 12 grams per square yard of manganese as freshly precipitated MnO_2 (or about 60 p.p.m. Mn) well mixed with the surface six inches of soil, and the incorporation into a plot of about 50 Kg. of the soil of the same plot which had had three weeks' waterlogging in a pot. Neither of these treatments succeeded in overcoming the disease of the oats.

The plants on the strongly acidic soil looked poor during June and July, but later made excellent growth. The plants given ammonium sulphate developed "grey speck" during the first warm days of August, and steadily deteriorated thereafter. The only plants which yielded well were those on the acidic soil and those given $MnSO_4$ with the seed, the former being significantly better. The effect of manganese deficiency is so much more acute on oats than on wheat that the sulphured plots are already far superior to controls when tillers are counted, though the manganese-treated, alkaline plots produce rather more tillers than the sulphured plots.

Another treatment which was tried on other plots and which proved futile was a heavy dressing of blood manure (which contains very little manganese and differs in this respect from farmyard manure). In another experiment four plots were sown with seed which had been soaked for two days in 0.1 per cent. $KMnO_4$ and was deeply stained with MnO_2. The plants on these plots were decidedly healthier than controls or manured plots during the winter and until the end of August, but collapsed with the first warm days of spring and finally produced only insignificant amounts of grain.

PLOT EXPERIMENTS IN 1937.

While it appears that oats do not benefit from any residual effect of added manganese compounds on this soil, it is possible that the less sensitive wheat plant may do so. Wheat was therefore tried this year, and the plots that had been heavily treated with manganese dioxide or mixed with previously waterlogged soil were compared with those on which $MnSO_4$ was applied with the seed. At the same time a new line of inquiry was made. A few European workers have claimed that a heavy dressing of quicklime improves the growth of oats on deficient soils. Since this suggests that there is an upper limit of pH, as well as a lower limit, to the incidence of "grey speck" disease, the problem may best be approached by adding alkaline material to bring the pH well above 8, preferably to about 9. Four plots which had never received additional manganese but had been sulphured some years before (Plots B of 1934) were treated with caustic soda at the rate of about 2 tons per acre.

The growth on the acid plots (pH 4.5–5.0) was the same as usual; there were fewer tillers in September than on the control plots, but the survival rate was very high (87 per cent.) and the average weight of the ears was much higher than on any other plots, so that the final yield was the best, though the difference between the acidic plots and the manganese-treated plots is not significant. (The figures here tabulated refer to the weight of the whole ear and not of the separated grain.) The residual effect of a heavy application of manganese compounds two years previously appears to come close to that of an application of $MnSO_4$ with the seed—a result in marked contrast to that obtained with oats. Finally the caustic soda had such a bad effect on the soil that both germination and subsequent growth were very poor. Results are collected in Table II.

TABLE II. GHURKA WHEAT, 1937.

Treatment.	Tillers.		Ears.			Total Yield Gm. per Sq. Yd.
	Per Plant.	Per Sq. Yd.	Per Sq. Yd.	Percentage Surviving.	Gm. per Ear.	
A. Control	2·06	167	125	75	0·82	103
B. Caustic soda	1·93	44	28	64	0·86	24
C. $MnSO_4$, Residual	2·27	179	132	74	1·19	**157**
D. $MnSO_4$, with seed	2·16	180	148	82	1·26	**186**
E. Acidic	2·00	142	123	87	1·64	**202**

Standard error of mean of total yield, 15·5 gm.
Yields significantly greater than control are in black.

PLOT EXPERIMENTS IN 1938.

These experiments were designed with two main ends in view. Firstly, it was desirable to repeat the previous year's experiment with caustic soda under more favourable conditions for germination, and this was achieved by digging gypsum into the surface layers shortly before seeding. Secondly, it would be interesting to compare the growth of plants on soil that has been acidified or given some other improving treatment, with the growth of plants which are sprayed with a soluble manganese salt as soon as the symptoms of deficiency occur, but which otherwise grow on "deficient" soil.

The plots this year comprised:—(A). Soil untreated but plants sprayed with 1 per cent. $MnSO_4$ as soon as deficiency shows; (B). Highly alkaline, treated with gypsum; (C). and (D). Slightly alkaline, residual manganese only; (E). Highly acidic. This arrangement left the plots without the conventional "controls." However, the "residual manganese" plots could be relied on to give very low yields with which the others could profitably be compared. The oat variety Dawn was sown, and calcium nitrate was added to all plots at the rate of 1 cwt. per acre. The symptoms of grey speck appeared about the middle of August. The plants of group (A) were sprayed with a fine spray of 1 per cent. $MnSO_4$ (so as to ensure that every leaf was wetted) on 16th and again on 26th August. The plants immediately recovered, and the symptoms did not reappear. The highly alkaline plots at this time showed surprisingly good growth, with as healthy a colour as those on the acid soil.

When the tillers were counted early in October the acidic and highly alkaline plots were outstanding (see Table III.). However, the latter plots were very patchy, with some healthy plants and some sick. Samples of surface soil taken under healthy plants had a pH of 8.5 to 8.7, while samples around the sick plants had a pH of about 7.5.

TABLE III.—DAWN OATS, 1938.

Treatment.	Tillers.	Ears.		Grain.		Total Yield
	Per Sq. Yd.	Per Sq. Yd.	Percentage Surviving.	Gm. per Ear.	Gm. per Sq. Yd.	Gm. per Sq. Yd.
A. Sprayed	151	**114**	**76**	0·61	**70**	**312**
B. Caustic soda	**213**	**99**	46	0·56	54	**294**
C. Residual Mn	132	51	38	0·33	17	105
D. Residual Mn	139	70	50	0·47	33	152
E. Acidic	**196**	**147***	**75**	0·82	**120***	**463***

Figures significantly greater than "controls" (C) are in black.
Those significantly the greatest in the column are also asterisked.

The spring was very dry and warm, no rain of importance falling after early August, and the grain ripened in late November. As the figures show, the acidic plots gave the usual high survival of tillers to grain-bearing heads and a high yield of grain per head. The sprayed plants also showed a good survival of tillers but a relatively poor yield of grain. This no doubt was due to the fact that the primordia had already suffered from manganese deficiency before the symptoms of "grey speck" appeared. The soda-treated plots did not fulfil their earlier promise; but the final yield included a number of large plants bearing much grain (from the most alkaline patches) besides a greater number of typically "deficient" plants.

Summary and Discussion of Plot Experiments.

The results up to date may be summed up as follows:—

Oats.

1. *Acidification of the soil with sulphur* to below pH 6.5 gives the highest yields both of straw and of grain, and its superiority over the controls appears in the middle of August.

2. *Application of ammonium sulphate* with the seed causes somewhat increased vegetative growth during June and July only, and thereafter has no advantage over controls which have been given nitrogen as nitrate.

3. *Alkalinization of the soil with caustic soda* causes a marked improvement, especially in vegetative growth up to the end of September. This improvement appears to depend on raising the pH of the soil over 8.5.

4. *Application of manganese sulphate* with the seed causes an increase in tillering (24 per cent. in one case) but the survival of tillers to heads and the final yield are less than on acidic plots. The optimum application of manganese sulphate has not been tested, but the routine rate in these experiments was 1 cwt. of the crystalline salt per acre.

5. *The residual effect* of manganese compounds applied to this soil in the preceding year is slight.

6. *Spraying plants with $MnSO_4$* as soon as they develop symptoms of "grey speck" causes immediate improvement, but both the tillering and the yield of grain are low in consequence of the deficiency during the first two months of growth.

7. *The incorporation of blood manure* into the soil is useless.

Wheat.

1. *Acidification of the soil with sulphur* to below pH 6.5 causes rather poorer growth than on the control plots during the winter months, and a slight depression in tillering. In late September, however, the tillers are strong, and the plants on acid soil have

a better colour from that time on. Survival of tillers to ears and weight of grain per ear are high, and the final yield is better than is obtained with any other treatment.

2. *Application of ammonium sulphate* with the seed causes much better winter growth and a greater production of tillers in late September, than any other treatment; the total weight at this time, however, may not be greater than with other successful treatments. The survival of the tillers to ears and the production of grain per ear are poor, and the final yield is little better than on the controls.

3. *Application of manganese sulphate* with the seed causes an increase in tillering, up to 30 per cent. compared with controls, but the survival of tillers to ears and the weight of grain per head, though superior to controls, are less good than on acidic plots, and the final yield of grain is never greater and is sometimes less than on the acidic plots.

4. *The residual effect* of manganese compounds applied in moderate amounts to this soil in the preceding year is marked, though it is less than that of a fresh application. However, a heavy application of freshly precipitated manganese oxide, well mixed with the top eight inches of soil, appears to exert a residual effect as good as that of a fresh application.

These results may be compared with those of Townsend and Wedgworth (6) who grew French beans (*Phaseolus vulgaris*) on a highly-deficient soil consisting of burned peat, and studied both the immediate and the residual effect of adding sulphur or manganese sulphate to the soil. They found that heavy applications of manganese sulphate (100 lb. per acre) did immediate good, but this good effect could hardly be seen in the succeeding crop. Light applications of sulphur (5 cwt. per acre), which were insufficient to bring the pH into the acid region, had a good effect which was only temporary. A heavy application of sulphur which brought the pH down to 6.0 appeared to do lasting good, although its immediate effect was to depress the yield. It appears that some intermediate product of oxidation such as thiosulphate, may be responsible both for the temporary good effect of small amounts of sulphur (due to its reducing action) and for the temporary bad effect of larger amounts (due to direct toxicity). A spray of dilute manganous sulphate led to excellent vegetative growth; but these workers did not compare the various treatments with regard to reproductive growth.

Pot Tests.

Pot tests carried on during the last five years have been directed to two ends, namely, attempting to cure deficient soils, and attempting to make healthy soils deficient by heavy liming.

Experiments with Deficient Soils.

The former work has been especially concerned with the soil from Mount Gambier (South Australia), where Samuel and Piper (4) made the first Australian studies of manganese deficiency in the field. This soil is a deep, permeable sandy loam, derived from basaltic ash, and highly immature. Manganese deficiency of cereals occurs on this soil type in places where the reaction is neutral or alkaline; the free calcium carbonate which is responsible for the alkalinity may be derived from the layers of Tertiary limestone through which the volcanic ash burst its way. The various treatments that have been attempted on a calcareous sample of this soil are described below. In every experiment a sensitive variety of oats was the test plant, viz., Algerian or Dawn for winter and spring, and Tasmanian White Oats for early summer. The pots are 3 feet high and hold 25 Kg. of soil.

(1) Acidification to a pH value of 6.5 or less. This brings about a complete cure, as was reported by Samuel and Piper (4). Such treatment is of little practical value, since huge amounts of acid are needed to destroy the free calcium carbonate.

(2) Addition of a manganese compound, uniformly mixed with the whole of the soil in the pot so far as to ensure that the roots reach the manganese. Two pots were used here, one of which was given crystalline manganese sulphate and the other freshly prepared "active" manganese dioxide, completely free of water-soluble manganese. The $MnSO_4$ was added at the rate of twenty parts of manganese per million of soil, and the MnO_2 at the rate of 80 parts. This was done in October, 1934. The plants on the treated pots made excellent growth during the next two months, while the two controls suffered severely from grey speck (part of this experiment was reported in a previous paper). At least one crop of oats has been grown on these pots in each year since then, and the plants have always done much better than the controls, which regularly succumb to grey speck. Slight symptons of manganese deficiency have occasionally been noted on the leaves of the pot that was given manganese dioxide, but the plants have always recovered later. Evidently the long-term residual effect of added manganese on this soil is far more marked than on the University soil. No reason for such a difference can be suggested, but the relative importance of various stages in the cycle of biological and non-biological changes through which manganese moves must differ from one soil to another. There remains, of course, the possibility that interactions with other elements may be involved.

(3) Prolonged waterlogging. When the pots were prepared in October, 1934, the outlet from one pot was closed and water was added so as to stand about an inch above the level of the soil. After four weeks of waterlogging, drainage was restored. Very sick oat plants were immediately transplanted into this

pot, and they proceeded to make excellent growth. The subsequent history of this pot has been remarkable; with no addition of manganese at any time and with normal drainage (which is naturally very free on this soil) six healthy crops of oats have been grown. On one occasion only, during a hot spell in December, 1937, a few leaves showed slight symptoms of grey speck; but there were no symptoms in 1938.

It appears therefore that a single waterlogging has brought about a lasting cure. This soil normally contains a large reserve of manganic oxide just below the level of availability to plants (2, p. 250), and the waterlogging has apparently promoted some of this reserve to a more available state. Oat plants growing on this pot contained the high figure of 54 parts of manganese per million in 1935. Unfortunately, this cure does not seem to be a practicable one in the field. The winter rainfall at Mount Gambier is heavy, averaging 12 inches from June to August inclusive, but this water soaks quickly through the soil. One plausible method of inducing waterlogging in the field would be to make the soil highly alkaline with sodium carbonate or hydroxide and to rely on the hydrophilic properties of the resultant sodium clay to cause waterlogging during the winter. The soil would naturally have to be reclaimed later with gypsum. A preliminary experiment was done in 1938 to test this idea; 56 gm. of crystals of sodium carbonate was added to a pot of Mount Gambier soil, and water equivalent to about an inch of rain added every four days during August and September. The oats which were sown in the next month succumbed very quickly to manganese deficiency; this was not surprising, since the soil did not approach to a waterlogged condition during the period of treatment.

Pot tests were also carried on with a gravelly soil from the southern wheatbelt of Western Australia. This soil contains about 50 per cent. of ironstone pebbles about half an inch to an inch in diameter, and is of low fertility, apart from its manganese deficiency. The incorporation of freshly precipitated manganese dioxide into the pot of this soil greatly improved the growth of oats as compared with the control; a still better result was obtained by a fortnight's waterlogging, the results of which have persisted for two years.

The University soil was also waterlogged in a pot for three weeks, but the plants which subsequently grew on this soil suffered from manganese deficiency. It is surprising that the treatment which was so successful with two deficient sandy soils should fail with a third.

Attempts to Make Healthy Soils Deficient.

The author suggested previously that an extraction with a solution of quinol in normal ammonium acetate at pH 7 might serve to determine the amount of available manganese in a soil, and that podzolic soils containing not more than 25 parts of such manganese per million might become "deficient" on liming to pH 7 or beyond. Tests in small pots have since been carried out, and they tend to confirm the above suggestion. The following figures (Table IV.) relate to the properties of certain soils from Southern Victoria; the "available" manganese is that which is extracted in the cold by normal ammonium acetate together with that which is extracted by a 0.2 per cent. solution of quinol in normal ammonium acetate. All the soils are podzolic and derived from sedimentary material, except the University soil. The Bellarine soil has been included for comparison, though it was not used for pot tests; this sample was taken from land adjoining an area on which oats had suffered from manganese deficiency following heavy liming several years earlier.

TABLE IV.—SOILS TESTED FOR EFFECT OF HEAVY LIMING.

—	Description and Location of Soil.					
	Light Grey Sandy Loam, Timboon.	Grey Fine Sandy Loam, Coleraine.	Grey Sandy Loam, University.	Grey Sandy Loam, Bellarine.	Grey Sand, Cranbourne.	Grey Sandy Loam, Narre Warren.
pH	5·3	5·8	5·0	5·4	3·4	5·6
Available Manganese p.p.m.	1	17	15	8	2	7

The treatments consisted of varying applications of calcium carbonate, the heaviest of which brought the pH of the soil above seven in each case. The experimental plant was oats, either Dawn or Algerian, and all pots were given an adequate supply of calcium nitrate and potassium phosphate.

1. *Timboon Soil.*—The plants on the alkaline pots suffered severely from manganese deficiency; this occurred as soon as the soil had been made alkaline.

2. *Coleraine.*—The first result of heavy liming was to cause greater growth on this soil, though symptoms of manganese deficiency also appeared. Three years after liming, the plants suffered severely from deficiency.

3. *University.*—The soil from some garden beds, which have never been limed, is the same in origin as that on which the experimental plots are now located. The first year after heavy liming, the oats made better growth than on the acid soil, but in the second year they succumbed to manganese deficiency.

4. *Cranbourne.*—This is an extremely poor soil which must be limed before ordinary crops will grow well on it. Overliming, however, immediately brings about symptoms of deficiency.

5. *Narre Warren.*—During the twelve months which have passed since samples of this soil were brought to pH 7.3 in pots, improved growth has been the only result of liming.

From these experiments it appears that a considerable time must elapse before certain soils with a fair original reserve of available manganese are adversely affected by liming to above pH 7, but where the reserve is low, deficiency appears soon after the lime is applied.

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[Proc. Roy. Soc. Victoria, **52** (N.S.), Pt. I., 1939.]

Art VIII.—*Studies on the Australian Clavariacea, Part* III.

By STELLA G. M. FAWCETT.

[Read 13th July, 1939; issued separately, 1st March, 1940.]

Genus **Clavaria** (*continued*).

In two previous papers (1 and 2) Groups 1, 2, 3, 4, 7, 8, 9 and 10 of the genus *Clavaria* were dealt with. In this part additions are made to Groups 9 and 10 of the genus and in addition one species of *Physalacria* is described.

Group 10 (continued).

Clavaria flava Fr. ex Schaeff. Fung. Bavar. pl. 175, 1763.

? *C. lutea* Venturi. I miceti del agro Bresciano, p. 36, pl. 41, fig. 4, 1845-1860.

C. flavo-Brunescens Atk. Ann. Myc. 7, 367, 1909.

Plate VI, figs. 1 and 2, text. fig. 1*d*.

Plate VII, fig. 5.

Plants very variable in size, ranging from 4-18 cm. diameter and 5-16 cm. height. Base comparatively stout and obtuse, occasionally tapering, not deeply rooting, smooth, or with a few broad, shallow furrows. Arrangement of the branches variable: a large number of small branches, which soon divide to form the ultimate tips, may arise from the top of the trunk, or there may be a few large primary divisions which branch once or twice to form the ultimate tips. The latter are usually rather delicate and bluntly cusped, forming a close mass, sometimes they are obtuse, few in number and thick.

Axils for the most part rounded, branches spreading, lacking a strongly upright tendency. Surface of branches usually smooth but occasionally finely and evenly rugose. Colour, Maize Yellow, Chrome Yellow, Antimony Yellow, base whitish, not staining when bruised. Flesh creamy or white, paler than the surface, crisp and brittle in youth, becoming softer and more translucent with age. Taste and odour, mild, slightly fungal.

Spores about Maize Yellow in colour, elliptical, with an obliquely terminal mucro, distinctly and evenly roughened, $3.2–4.3 \times 7–11\ \mu$. Habitat—on the ground in forests.

This species is very variable in form but its colour is distinct and is generally described as a clear pale yellow without a tint of orange. It approaches *C. ochraceo-salmonicolor* in form and colour but may be distinguished from it by its fine, unexpanded tips. Although, in colour, it resembles *C. sinapicolor,* it may be distinguished from this species by its solid, compact, relatively smooth base, by its spreading habit and short branches and mild indistinct odour.

CLAVARIA FLAVA var. AUREA Coker. Clavarias of the U.S. and Canada, p. 124, pl. 38 and 85. Chapel Hill, 1923.

(Plate VII, fig. 1, text fig. 1. (E).)

Plants branched and bulky, often very large (25 cm. broad), usually about 10 cm. high and 8 cm. broad. Branching irregularly and sub-dichotomously from a short, stout base into very many branches which divide three, four or five times before the ultimate tips are formed. These are bluntly rounded, and short. The whole forms a close mass. Branches cylindrical, generally smooth, but tending to be rugose in age; axils acute. Flesh crisp and brittle in youth, becoming much softer and rather lax at maturity, somewhat translucent. Colour, base whitish for a variable distance, body of plant Apricot Buff to Orange Buff or Ochraceous Buff. Tips, Capucine Yellow or paler, becoming concolorous in age. Flesh coloured like the surface but with a distinctly pinkish tinge which it retains throughout the life of the plant. In age, under moist conditions, the colour of the body of the plant does not change appreciably but in a dry atmosphere the entire plant tends to become Pinkish Cinnamon or Cinnamon Buff. Taste and odour indistinct, mild.

Spores faintly, but evenly roughened, elliptical with a broad, obliquely terminal mucro, 3.5–4.5 (occasionally 4.8) $\times$ 7–9.5 μ. Habitat—on ground in forests and heathlands, very abundant on burnt soil.

This plant may be distinguished from the typical *C. flava* by its richer colour and pinkish, rather translucent flesh and from the deeper coloured form of *C. ochraceo-salmonicolor* by its unexpanded, paler tips and by the colour of the flesh. Intermediate forms are very difficult of identification.

CLAVARIA OCHRACEO-SALMONICOLOR Clel. Trans. Roy. Soc. S.A., lv, 1931, pp. 152-160.

(Plate VI, fig. 3, fig. 4, text fig. 1.(F.))

Plants branched, large or medium-sized, 5-15 cm. high and 5-14 cm. broad. Trunk distinct, stout, solid, 2-4 cm. broad; giving rise to numerous primary branches which divide three to five times before the ultimate tips are formed. Axils acute, branches with strongly developed, broad longitudinal furrows which originate in the axils. Ultimate tips rather broadly expanded, consisting of two to five more or less hemispherical knobs. The tips and upper branches form a very close cauliflower-like mass but with the tips distinct and not fused. In fresh specimens the tips do not differ in colour and texture from the body of the plant but in the dried state they show a difference in colour, being near Honey Yellow, while the body of the plant is about Cinnamon Buff or Pinkish Buff. Flesh white or pale, solid, brittle. Taste and odour indistinct. Colour (of living plants) very variable, Naples Yellow, Antimony Yellow, pale Orange Yellow, Capucene Buff, Capucine Orange. Tips generally slightly darker in colour than the rest of the plant.

Spores ochraceous, evenly and finely roughened, oblong elliptical, with an obliquely terminal mucro, 8.1–10.5 × 3.9–5.2 μ. Habitat—on the ground in forested or heathy areas.

The above description is considerably more restricted than that given by Cleland. Although the species has a wide colour range, its form is fairly constant and the spores do not vary a great deal in length. From the range of spore size given by Cleland (7.5–13 × 3.7–5.5 μ) it would appear that he had included *C. flava* and its variety *aurea* and possibly *C. capitata*, all of which show colours similar to those of *C. ochraceo-salmonicolor*.

The species may be distinguished from *C. flava* and *C. flava* var *aurea* by its expanded tips, and narrow axils. It may be separated from *C. capitata* by its non-viscid and separate tips and shorter spores.

Clavaria filicicola n. sp.

(Plate VI, figs. 4 and 5, text fig. 1. (H).)

Plantae ramosae, parvae, plerumque 2-4 cm. altae, in forma variae, surgentes e mycelio denso et albo quod se cum fibris truncae Dicksoniae conjungit. Basis plantae aliquantum crassa, abrupte e mycelio surgens, sine radicibus perspicuis, saepe tomentosa a mycelio. Rami, qui duo et magni aut plures et minores esse possunt, sine discrimine oriuntur. Hi in vicem raro se dividunt et plerumque apices ultimos portant. Apices acutissimi sunt parvi et nonnumquam divaricantes sunt. Caro plantae est solida et ubi novella est facile frangi potest sed cum aetate mollior et flexibilior fit. Sapor et odor nullus. Color plantae juvenilis alba, grandioris "Maize Yellow" ad "Ochraceous Buff." Hymenium levis, in similitudenem pulveris aetate mutatem est. Basidia quattuor sterigmata habent. Sporae "Maize Yellow" in massa, perspicue asperae, quae saepe collabuntur, oblongo-ellipsoidae cum mucrone obtuso et obliquo, 5.6–7 × 3.6–3.9 μ. *Hab. in trunca Dicksoniae antarcticae plerumque aut inter bases frondium viventium aut infra eas. Loc. Turton's Pass, Apollo Bay. Mai.*

Plants branched, small, usually 2–4 cm. high, rather variable in form, arising from a dense white mycelium which binds together the fibres of the Dicksonia trunk. Base of plant stout, in relation to size of plant, often woolly from the mycelium, branching very irregularly into two large branches or into many crowded smaller ones which in turn may be very sparingly branched, but generally give rise to the ultimate tips which are very sharply pointed, small, and sometimes divaricating. Flesh solid, brittle in youth, becoming softer and more pliable in age. Taste and odour none. Colour, pure white when young, Maize Yellow to Ochraceous Buff when old.

Hymenium smooth, apparently powdery when old. Basidia with four sterigmata. Spores Maize Yellow in bulk, distinctly rough, often irregular by collapsing, when fresh, oblong elliptic with broad obliquely terminal mucro, 5.6–7 × 3.6–3.9 μ. Habitat—on trunks of *Dicksonia antarctica,* usually immediately below the crown of leaves. Locality—Turton's Pass, Apollo Bay. May.

This species most closely resembles *C. gracilis,* but may be distinguished from it by its stouter and more solitary habit, rough spores, lack of distinct odour, and chiefly by its very characteristic place of growth. *C. gracilis* is found only under pine trees.

CLAVARIA ABIETINA. *Non-Virescent Form.* Coker, Clav. U. S. and Canada, p. 182. Chapel Hill. 1923.

? *C. corrugata* Karst. Nat. Faun. et Flora Fenn., p. 371. 1868. (Text fig. 1. (G).)

Plants branched 3.7 cm. high and 2–5 cm. broad, growing in large colonies under *Pinus radiata,* arising from a dense white subiculum which mats the fallen needles together. Trunks stout, equal to about one-fifth of the plant in height, irregular and incrassated, deeply channelled in age, branching very irregularly, often palmately three or four times. The ultimate branches generally erect, but may be spreading, tips short, acute, spreading, usually produced in a palmate or cristate fashion, axils acute. Surface of young plants smooth, in older specimens much incrassated. Branches often fusing with one another, sometimes uniting the upper parts of separate plants by this process.

Flesh of densely interwoven hyphae, tough, opaque, often hollow or loosely stuffed in the centres of older branches, soft and rather flexible. Colour—Cream Buff, Chamois, Pinkish Buff. Tips whitish. Not staining when bruised. Smell slight, like radish, taste mild, indistinct.

Hymenium smooth in younger parts of plant, often double in older parts. Basidia with four sterigmata. Spores yellowish, oblong elliptical, often broader at the distal end, finely and evenly roughened, 6.2–8.1 × 3.1–4.3 μ. Locality—Sherbrooke, under *Pinus radiata.* May.

This plant may be distinguished from *C. gracilis,* which favours the same habitat, by its stouter habit and deeper colour. Cooke records *C. abietina* for Victoria giving the spore measurements as 7–10 × 4–6 μ and the habitat as "Fir woods." If the spore measurement is correct it is most likely that Cooke had *C. apiculata* (spores 3.7–4.6 × 7.4–9.2 μ) as the spores of the various forms of *C. abietina* are much smaller than this. If, however, the spore measurement is incorrect and Cooke really had a form of *C. abietina* it is possible that he had the *flaccida* form which Cleland has recorded (as *C. flaccida*) from Callitris woods in South Australia. It is most likely that Cooke's specimen was also collected in *Callitris* woods, as it must necessarily have been collected prior to 1892 when there were no extensive plantations of introduced Conifers in the State. There is also some evidence to show that in the past the various species of *Callitris* were known as "Firs."

In view of the constant association of *C. gracilis* and *C. abietina* (non-virescent form) with species of *Pinus,* it is most probable that they are not native and have been introduced with these trees; as, although many of the Victorian pine plantations abut on native forest and are growing under apparently similar conditions, neither *C. gracilis* nor *C. abietina* (non-virescent form) are found growing away from the pines in the native forest.

GENUS **Physalacria.** (Fr. ex. Schw.) Pk.

PHYSALACRIA INFLATA (Fr. ex. Schw.) Pk. Bull. Torrey Bot. Club, 9: 2: 1882.

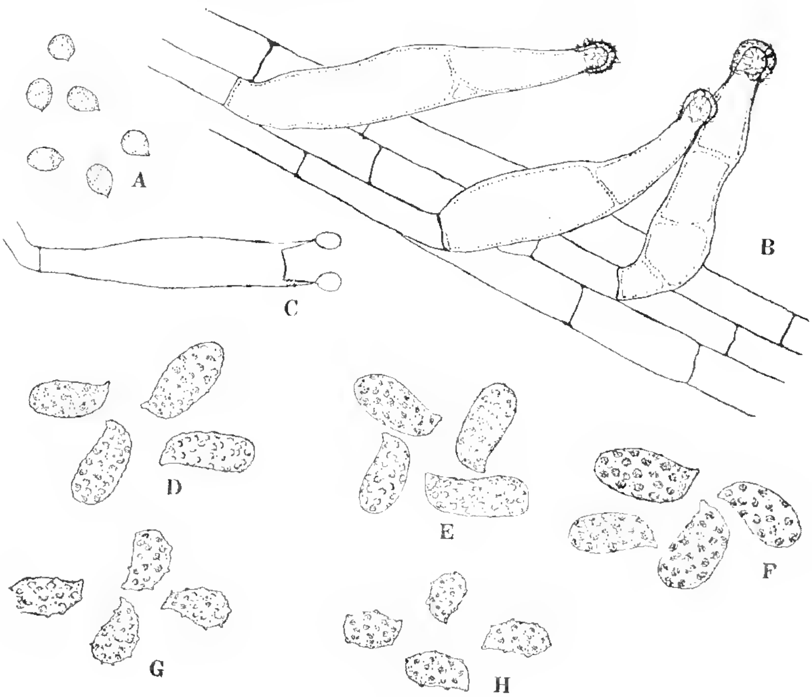
(Plate VII, figs. 2 and 3, text fig. 1 (A), (B), (C).)

Plants small, usually 0.4–1 cm. high, occasionally 1.3 cm., at maturity, consisting of an irregularly-globose, swollen, thin-walled bladder, 0.3–0.5 cm. diameter, supported on a firm slender stalk 0.1–0.15 cm. diameter, and 0.3–0.6 cm. long. In some cases the irregularities of the head are confined to the undersurface and resemble gills as they radiate from the stalk. Frequently, the likeness to a small, white-spored Agaric is increased by the collapse of the upper part of the bladder over the lower. When young, the heads are almost uniformly globose. The plants most often occur in extensive colonies in groups of two or three, occasionally singly, or in dense clusters with the heads closely appressed and obscuring the stalks. Colour, when young, pure white; in age, yellowish, or brownish-white. Texture, rather membranous, resisting tearing.

Under the lens, the head and stalk appear to be covered in short, glistening bristles, owing to the presence of strongly projecting cystidia. These are irregularly cylindrical structures bearing a knob-like process at the apex. This process is relatively thick-walled and on the outside is covered by a mucilaginous substance. The hymenium is sharply delimited, occurring only on the head, covering it entirely. Basidia inconspicuous among the cystidia, two-spored.

Spores smooth, white, sub-globose or elliptical, 2–3 × 3–4 μ. Mucro very inconspicuous. Habitat—on dead wood in very wet gullies. Localities: Sherbrooke, November, February, March; Ferny Glen, Apollo Bay, May. Not previously recorded for Australia.

This plant has a very complicated history. De Schweinitz collected it and, giving it the manuscript name *Leotia inflata,* sent it to Fries, who, however, published it as *Mitrula inflata* (Elenchus Fungorum, Vol. 1, pp. 234 and 235), referring to de Schweinitz's name. Later, in Epicrisis (p. 584), he repeated the description with the name *Mitrula inflata albida.* In 1878, Cooke (Mycographica, p. 204) for no apparent reason, changed the name to *Spathularia inflata.* In 1882, Peck proved that the



TEXT FIGURE I.

A. Spores of *Physalacria inflata;* B. Cystidia from stem of *P. inflata;* C. Basidium of *P. inflata.*

Spores:—D. *C. flava.* E. *C. flava var. aurea.* F. *C. ochraceo-salmonicolor.* G. *C. abietina. Non-virescent form of pines.* H. *C. filicicola.*
Magnification:—A, D, E, F, G, H, 1,125. B, C, 500.


1
2
3
4
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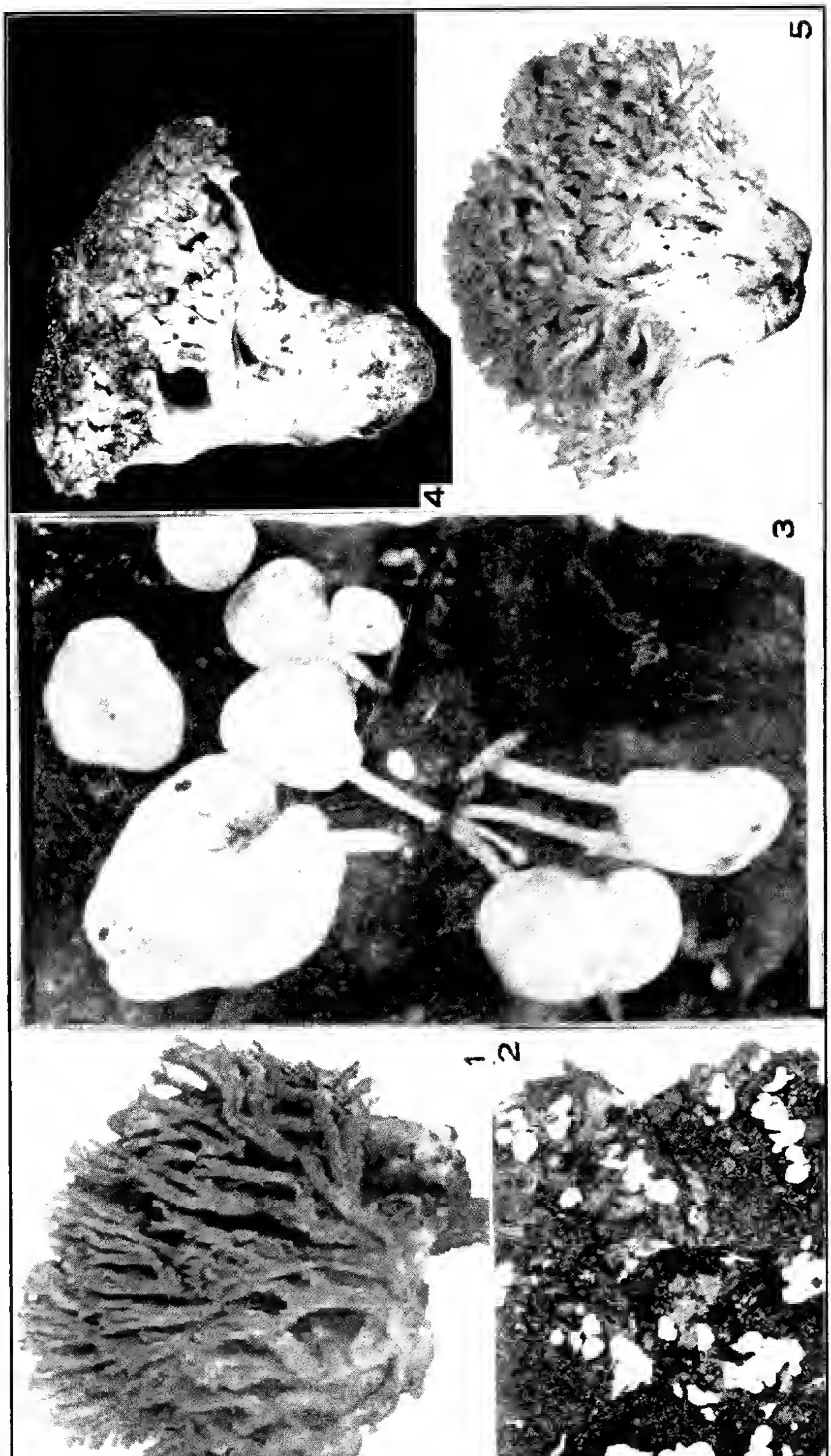

plant was, in reality, a Basidiomycete, and suggested that the previous authors had mistaken the large cystidia for empty asci. As he found that the hymenium completely covered the head he placed the plant in the Clavariaceae, establishing the name *Physalacria*.

In 1923, Krieger (3) removed the genus to a primitive position in the Agaricaceae, renaming it *Eoagaricus*. This name, however, is not valid, as the Rules of Botanical Nomenclature do not permit such a change. He stated that the hymenium was confined to the under surface of the head and that the upper and under surfaces showed differences in texture and colour. He interpreted the irregularities which are frequently seen on the under surface of the older plants as primitive gills. In the Victorian plants the hymenium covers the entire head and there are no apparent differences in texture or colour between the upper and lower surfaces. There can be no doubt that our plants are correctly identified as they agree exactly with Peck's description. Thus there is no evidence in support of Krieger's statements. It is possible that the plants on which he based his work were abnormal. Therefore it seems that *Physalacria* should be retained in the Clavariaceae.

References.

Fawcett, S. G. M.—*Proc. Roy. Soc. Vic.*, vol. LI, part I, pp. 1-20, 1938.

Fawcett, S. G. M.—*Ibid.*, vol. LI, part II, pp. 265-280, 1939.

Krieger, L. C.—*Bull. Maryland Acad. Sci.*, 3: 7, 1923.

Explanation of Plates.

Unless otherwise stated, all photographs are natural size.

Plate VI.

1. *Clavaria flava.* Rugose plant.
2. *C. flava.* Smooth plant.
3. *C. ochraceo-salmonicolor.*
4. *C. filicicola.*
5. *C. filicicola.* (× 3).

Plate VII.

1. *C. flava* var *aurea.*
2. *Physalacria inflata.*
3. *Physalacria inflata.* (× 9). Note cystidia on the stalks and heads.
4. *C. ochraceo-salmonicolor.*
5. *C. flava.*

[Proc. Roy. Soc. Victoria, 52 (N.S.), Pt. I., 1940.]

Art. IX.—*The Shore Platforms of Mt. Martha, Port Phillip Bay, Victoria, Australia.*

By J. T. JUTSON, B.Sc., LL.B.

[Read 13th July, 1939; issued separately, 1st March, 1940.]

Contents.

Introduction.

The writer has previously considered (1) in a general way some of the wave-cut rock platforms of Port Phillip Bay and its immediate vicinity. The present paper is intended to be the first of a series systematically describing the main platforms ot the Victorian coast.

The bearing of the facts here recorded on the question of the recent emergence of the shoreline is reserved for later discussion.

General Description of the Mt. Martha Coast.

The coast-line described stretches north-westerly from the north-east corner of Dromana Bay, on the eastern side of Port Phillip Bay, to Martha Point, and thence north-easterly to just beyond Martha Cliff, which is a short distance south of the mouth of Balcombe Creek, a total distance of about three and a half miles (fig. 1).

Along this line the granodiorite dome of Mt. Martha is betrunked by cliffs, which are due to marine abrasion. The Mt. Martha dome is separated from the similar dome of Mt. Eliza to the north, and from the granite dome of Arthur's Seat to the south, by belts of low-lying country, more or less covered by recent deposits.

The Mt. Martha coast is exposed to the action of powerful waves which are developed by the strong southerly and south-westerly winds which sweep across the bay. The average range of the tide is from 2 to 3 feet.

The important aspects of the Mt. Martha granodiorite for the purposes of this paper are its system of joints and its degree of weathering at various points along the coast-line.

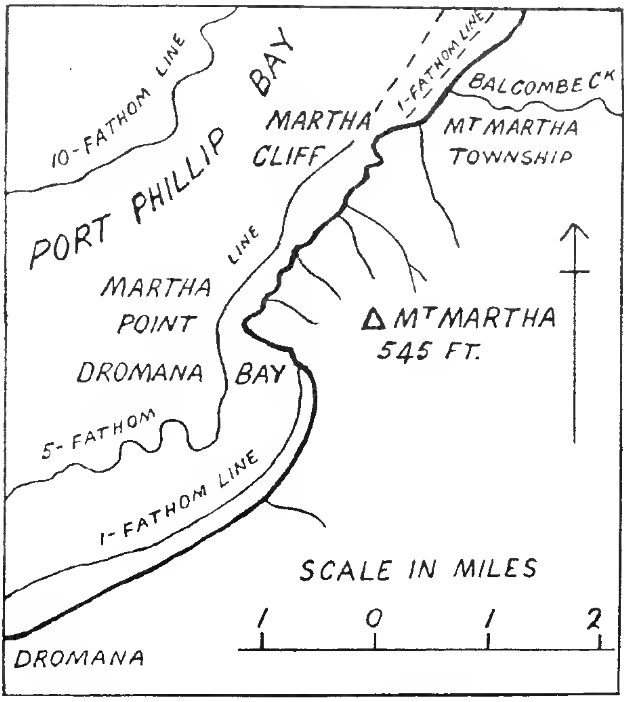

Fig. 1.—Map of the Mt. Martha coast.

The granodiorite is much and, in places, irregularly, jointed, but the strongest and most persistent joints are those which are vertical or close to the vertical. These vertical joints cut one another at various angles but two sets approximate towards a right angle.

The inner portion of the granodiorite up to varying heights above sea level (with perhaps a maximum of 30 feet, but this is a mere approximation) is a tough, practically undecomposed rock, highly resistant to erosion. The outer shell is decomposed and at each end of the outcrop, that is, to the immediate south of Balcombe Creek and just to the north of Dromana, the decomposed rock passes below sea level to an unknown depth (fig. 2). Decomposition is greatest at the extreme northern and southern ends of the rock mass.

The north-westward-trending coast (which may for convenience be termed " the southern coast ") has at its south-eastern end a platform cut in decomposed granodiorite at the foot of fairly low cliffs (pl. VIII, fig. 1). This platform may be termed "the southern platform", and is later described. North-west from the platform the cliffs steadily rise to a height of 40 or 50 feet. They are steep and, in most portions, are covered by vegetation to within 3 or 4 feet of their base. Occasionally, a rocky bare cliff 8 to 10 feet high appears, above which is the vegetated steep slope.

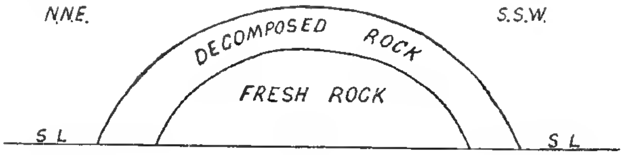

FIG. 2.—Diagrammatic section through the granodiorite dome of Mr. Martha. *S L*, sea-level.

In places at the foot of the cliffs just mentioned sharp projections or buttresses (the crests of which vary in height from approximately 2 to 10 feet above mean sea-level) of the undecomposed granodiorite occur, separated from one another by tiny bays and gulches (pl. VIII, fig. 3), the latter in some cases ending in tunnels ("caves") the position and outlines of which are generally determined by the vertical or nearly vertical joints. The gulches are up to 30 feet in length and are a few feet deep and wide. The "caves" penetrate the cliffs for about 6 feet and reach the same figure in height. The buttresses run out to sea, approximately at right angles to the coast-line, for about 30 feet and are from 4 to 20 feet wide. They have a rough outline, owing to the absence of strong horizontal joints and to the existence of close-set irregular ones in addition to the vertical master joints. The buttresses may become isolated from the cliffs and so form stacks, which in turn may be worn down to reefs.

Towards Martha Point traces only of a wave-cut rock platform are found.

In some of the small bays masses of coarse shingle, the components of which are fresh granodiorite with diameters up to 12 inches or more, are thrown up on the beach to the base of the cliffs; and similar shingle also rests in moderate quantities on the platform of decomposed rock mentioned above. In addition there are many rounded boulders of the fresh granodiorite up to 4 feet in diameter. These are either blocks broken away along joint planes with their corners rounded by the sea, or masses due to spheroidal weathering, which is well shown *in situ* at the foot of the cliffs. It may be noted that the term "shingle" is used in this paper as a general term to cover pebbles and boulders from an inch to about 18 inches in diameter.

Treating now the north-eastward-trending coast, which may be referred to as "the western coast", a platform cut in the decomposed granodiorite occurs to the south and east of Martha Cliff.

It may be termed "the northern platform". It generally resembles the southern platform, except that the steep cliffs behind it are higher than those flanking the southern platform. The remainder of this part of the coast has high cliffs composed of the fresh granodiorite in their lower portions and of decomposed granodiorite in their upper portions, the lower portions being, as a rule, steeper and with less vegetation than the upper portions.

This western coast, other than its northern end, has a crenulated outline, similar to that of the southern coast, except that the gulches are deeper, wider and longer, and the buttresses have a maximum greater width (some have been noted up to 30 feet wide) than those of the southern coast.

Shingle occurs on the western coast, usually in small quantities, in the little bays and between the buttresses (pl. VIII, fig. 2), but within a mile south of Martha Cliff there are some substantial banks. The shingle consists of fresh or somewhat decomposed granodiorite with occasional pebbles of ferruginous grit and sandstone. It also occurs, in a few instances, on the northern platform.

Along the western coast no platform in the fresh granodiorite is visible at the foot of the cliffs, except occasional patches a few square yards in area.

In their early form the buttresses have no uniformity in height, and their surfaces slope seaward at a moderate angle to the horizontal (pl. VIII, fig. 2). The occurrence of the buttresses is due to the action of the sea in creating gulches along comparatively weak areas of the fresh rocks, and to the stripping by atmospheric erosion of the softer material above the projections. This process continues until a buttress or a portion of it becomes low enough to be attacked by the sea, when it may be reduced almost to a horizontal plane and gradually lowered until it becomes a reef, which may in turn be removed by the waves (pl. VIII, fig. 4).

Progradation has taken place to a small extent in places along the southern coast.

The form of the cliffs and the abundance or scarcity of vegetation growing thereon reflect the character of their component rocks. Thus the cliffs of granodiorite decomposed to below sea-level are steep owing to the rapid undermining at their base, and are comparatively bare of vegetation on account of their steepness (pl. VIII, fig. 1). They have a young shore profile. The cliffs with fresh granodiorite at their base, and decomposed granodiorite above are steep in their lower hard portions, but moderately inclined and covered with abundant vegetation in their upper softer portions. They have a shore profile which, broadly speaking, is early mature.

The sea, even when moderately smooth, reaches the headlands and the heads of the gulches and small bays between the buttresses. In the larger bays of the southern coast, especially where banks of shingle occur, it is probable that only at rather exceptionally high tides or during storms do the waves reach the foot of the cliffs.

The cliffs less resistant to erosion with their accompanying well-developed wave-cut platforms are composed of brown rocks (decomposed granodiorite) and the more resistant cliffs, with few visible traces of wave-cut platforms, are in their lower portions, composed of grey rocks (fresh granodiorite). It will be convenient to refer to these two types in this way.

It may here be noted that the brown rocks in places at the foot of the cliffs have become somewhat tough again by the introduction of iron oxide.

The Nature and Mode of Formation of the Platforms.

The Normal Platforms.

The southern platform commences at the north-eastern corner of Dromana Bay, whence it runs continuously north-westerly for about 100 yards (pl. VIII, fig. 1). Thence it occurs at intervals in the same direction for some distance. Its average width is probably less than a chain and its surface, although generally very level, is broken in places by small stacks up to 8 feet high Heavy granodiorite shingle covers certain areas.

The northern platform, which lies to the east and south of Martha Cliff, is about 500 to 600 yards long and averages perhaps from a chain to one and a half chains in width. It carries small stacks a few feet high.

Both platforms are exposed at low tide, but are not covered by every high tide. They have been cut by the sea in the brown rock, in which the degree of decomposition varies, the most decomposed rocks along the coast-line occurring at the northern and southern ends of the granodiorite dome. This feature is reflected in the surface character of the platforms, in that the more decomposed the rock, the smoother the platform. This is especially noticeable in the northern platform where, at its southern end, there are pronounced irregularities—both major and minor—on its surface. These gradually decrease northward until, where the platform runs east from Martha Cliff, most of the major projections are smoothed away and only very minor ones remain. These minor ones, however, make in parts an unusually irregular platform surface within low vertical limits. To a less extent, the same features are repeated on the southern platform. No "rampart" similar to that described by C. K. Wentworth (2) occurs at the outer edge of either platform.

Where the granodiorite is thoroughly decomposed at the extreme southern end of the dome, the rocks are so easily removed that a platform is cut at a lower level than the normal platforms here described, and becomes covered with detritus.

The platforms are practically horizontal (pl. VIII, fig. 1) except, in places, for a width of a few yards at the base of the cliffs, whence they slope seaward at angles varying from about 5° to 8° similarly to the ordinary sandy beach. This is a common feature in most of the Australian platforms that the writer has examined. As the platform advances landward this sloping area will be planed down to the general level, but a new narrow area slightly inclined seaward will be formed immediately in front of the cliffs as the latter retreat landward. This narrow sloping strip coincides with Wentworth's "abrasion ramp" (2) and is due to wave planation.

At their landward edges the platforms are flanked by moderately high, steep cliffs of the brown rock and at their seaward edges the platforms descend sharply into the sea to a depth of from 4 to 10 feet, according to the distance any particular portion of the edge is from the high tide shoreline (fig. 3). (The sea bottom off the edge of the normal platforms is part of what is later described as the "ultimate platform"). The seaward edges of the surfaces of the platforms are very uneven, owing to the action of the waves in locating differences of resistance to erosion in the component rocks.

In the production of the normal platform, the comparative softness of the rocks nullifies the effect of geological structure and enables the sea to produce a platform with a relatively smooth surface exposed between tide marks (pl. VIII, fig. 1).

The normal platforms are constantly being extended landward by abrasion by the sea at the foot of the cliffs, and are constantly being destroyed at their seaward edges by the sea's attack (fig. 4). For a platform to exist, the rate of advance landward must at some period have been greater than the rate of destruction seaward. Once, however, the platform is established, it may widen or narrow, or eventually disappear altogether, according to the lithological nature and geological structure of the rocks at various points. Thus, if the component rocks of the cliffs changed from "soft" to "hard" rocks, erosion (other things being equal) would slow down and the rate of advance be retarded, and if at the same time the outer portion of the platform were or became composed of "soft" rocks, the rate of erosion would be either actually or relatively increased, with the result that the platform would become narrower. Conversely, if the component rocks of the cliffs became less resistant to erosion and the rocks at the seaward edge were or became more resistant to erosion, the rate of advance would be accelerated and the platform would widen. Further changes in the respective rates of erosion would bring about further changes in the width of the platform, with the possibility always of its disappearance and later re-birth. Alteration in the geological structure of the rocks and other factors, such as changes in the direction or power of the waves, might also check or hasten the growth of the platform.

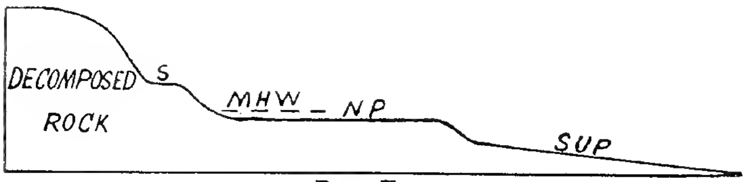

Fig. 3

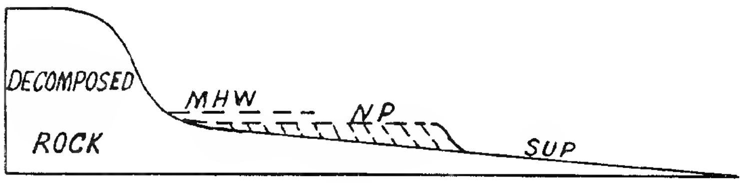

Fig. 4

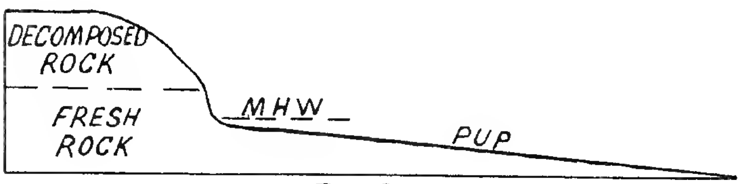

Fig. 5

FIG. 3.—Diagrammatic section showing the shelf, *S*; the normal platform, *N P*; the secondary ultimate platform, *S U P*; and the steep cliff, all in the decomposed rock. *M H W*, mean high-water level.

FIG. 4.—Diagrammatic section showing the removal by marine abrasion of the normal platform, *N P*; the extension thereby of the secondary ultimate platform, *S U P*, to the steep cliff, all in the decomposed rock. *M H W*, mean high-water level.

FIG. 5.—Diagrammatic section showing the formation in the fresh rock of the primary ultimate platform, *P U P*; the short steep cliff in the lower fresh rock; and the comparatively gentle slope of the cliff in the upper decomposed rock. *M H W*, mean high-water level.

It might be noted that exposure of the rocks at low tide will, to some extent, bring about their alternate wetting and part drying, which may aid in the disintegration of the rocks and thus facilitate their removal by the waves. This process however does not fulfil the conditions of water-levelling, including the presence of an outer rampart, as laid down by Wentworth (2). Since also the platforms are not solution benches (Wentworth (3)), wave planation is regarded as the dominant factor not only in the production of the abrasion ramps, but of the normal platforms as a whole.

THE ULTIMATE PLATFORM.

The ultimate platform, as here defined, is that rock bench which is almost entirely hidden from direct observation being, except at its extreme landward edge, generally covered by the sea, even at low water (pl. VIII, figs. 2, 3, 4). It appears to have a fairly rapid fall seaward, and is thus in marked contrast with the normal platform. In fact, it resembles the platform figured in nearly every geological text-book, although, so far as the immediate vicinity of the shore is concerned, it is probably the exception rather than the rule.

The ultimate platform has two aspects: First, as a primary platform, in that a normal platform has apparently never preceded its formation (fig. 5). Secondly, as a secondary platform in that the normal platform is first cut and the ultimate platform results from the destruction of the normal platform (figs. 3 and 4). These two aspects will be separately dealt with.

The ultimate platform as a primary platform.—This platform occurs off the middle portion of the Mt. Martha coastline, where the grey rock occurs at sea-level and for some height above it, and where there is no development of the normal platform.

Observation shows that the sea does not wear down the grey rock to a smooth plane, inclined or horizontal. The process by which destruction takes place may be described as quarrying (pl. VIII, fig. 2). The sea, armed with detritus, erodes channels along the strong vertical or nearly vertical joints and the channels gradually lengthen, widen and deepen. There are numerous, moderately widely spaced cross joints, either inclined at various angles or approximately horizontal; many close-set irregular joints also occur, these joints in some instances being not more than 3 inches apart. When the sea has worked along the vertical joints for some time, a block, from 2 or more feet to 3 inches across in any direction, can be dislodged by a violent blow of the waves, or by gradual undermining. The dislodged block is then further attacked and is eventually removed as shingle or sand. The result is that the surface of the grey rock tends to be irregular, especially in view of the fact that there is no system of strong horizontal joints.

There must be lines of weakness in the grey rock, although the latter appears to be homogeneous, since the sea acts selectively in cutting the deep and wide gulches between the buttresses as already described.

These processes therefore militate against the formation of an even-surfaced platform exposed at low tide, except in very limited areas, as, for example, at the foot of the cliffs in the small bays and between the buttresses, where such surfaces, sloping upward to the cliffs at angles of from 5° to 8°, occur, and form abrasion ramps. Similar surfaces of small area can be seen under water at low tide (though even these surfaces are marked by sand and shingle). The sea, however, is encroaching on to the cliffs and therefore a platform is being cut which is not open to direct observation, and the surface of which may be very irregular. Since also the sea-bottom gradually deepens, the platform must have a steady fall seaward and extend in that direction, but how far, will depend on the position of the shoreline at the commencement of the present cycle of marine abrasion. Whether the platform is free from, or covered by, detritus is at present unknown. Doubtless both conditions occur. Probably also, on the whole, the platform is being steadily degraded.

The retreat of the cliffs is slow compared with that of the cliffs flanking the normal platforms. This gives the sea time to cut more deeply, and so form the primary ultimate platform without the production of the normal platform as a temporary feature.

The ultimate platform as a secondary platform.—This class of platform is formed by the abrasion by the sea at a lower level than the normal platform (figs. 3 and 4), and with apparently a steady fall seaward similar to that of the primary ultimate platform. The difference between the two types of the ultimate platform is that the primary platform is cut in the grey rock without any relation to the normal platform, whereas the secondary platform is cut in the brown rock subsequently to the formation and results from the destruction of the normal platform.

Usually the secondary ultimate platform on its landward side abuts against the low cliff at the seaward edge of the normal platform, which the sea is constantly cutting away. In this manner the secondary ultimate platform grows landward. So long as the rate of advance of the normal platform at its landward edge is equal to or greater than the rate of destruction of the same platform at its seaward edge, the normal platform will intervene between the cliffs and the secondary ultimate platform. If, however, the converse happens, then the normal platform will disappear and the secondary ultimate platform will reach the shore (fig. 4). This has happened to the northern normal platform in some tiny bays where the conditions to ensure such a result have been favourable. In that case the secondary ultimate platform will generally resemble the primary one, except that possibly the surface below water of the former will be smoother than that of the latter.

The manner in which the normal platform may be widened, narrowed, totally destroyed and re-born is outlined above under the heading of the normal platforms.

Shelves above the Normal Platforms.

Towards the southern end of the northern normal platform there are a few short shelves a few feet wide rising to 8 feet above that platform (fig. 3). They are free from detritus (although above the shelves detritus occurs on the cliff face and the ledges projecting therefrom) thereby indicating the fact that the sea, by waves or spray, reaches these shelves and, by the removal of the debris formed by atmospheric erosion and perhaps even by direct abrasion, is mainly responsible for the occurrence of the shelves. That the spray reaches the shelves is shown by the presence of living marine mollusca there, as well as by direct observation.

Summary.

At the northern and southern ends of the granodiorite dome of Mt. Martha the rock at the coast-line is decomposed ("soft") but between these outcrops it is fresh ("hard").

An almost horizontal platform (the normal platform) cut in the soft rocks at each extremity and backed by steep cliffs of the same class of rock, is exposed at low tide.

The coast-line of the hard rocks is broken into a series of tiny bays and gulches, between which are pronounced buttresses. A platform cut in this hard rock by the waves slopes steadily seaward and its fall is so comparatively rapid that, except at the heads of the small bays and gulches just mentioned, it is not exposed at low tide, thus offering a marked contrast with the normal platform. It coincides with the wave-cut platform of the text books and, since it appears to be both an original and (as regards the present cycle of erosion) a final form, subject to its gradual lowering if not protected by marine deposits, it is termed a primary ultimate platform.

The normal platform, although it is advancing at its landward edge, yet is being destroyed at its seaward edge, and another platform, due to such destruction, is being cut in the soft rocks at a lower level and appears to slope steadily seaward. This lower platform is another type of the ultimate platform but, since it is of secondary origin, it is termed a secondary ultimate platform.

The decomposed rocks favour the formation of a coast-line, mostly smooth in outline; of the normal and secondary ultimate platforms; and of steep cliffs with scanty vegetation. Geological structure has apparently little influence on the making of those features. On the other hand, the hard rocks and their geological

structure favour the formation of the contrasted crenulated coast-line; of the primary ultimate platform; and, except in their lower portions, of sloping cliffs with abundant vegetation.

The normal platforms are due to wave planation, and the ultimate platforms to the quarrying action of the sea and wave planation combined.

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Explanation of the Plate.

Plate VII.

Fig. 1.—The north-east corner of Dromana Bay. The normal platform and the steep cliffs, all cut in the decomposed granodiorite.

Fig. 2.—South of Martha Cliff. The sloping vegetation-covered cliffs; the buttresses of fresh granodiorite, with the alternating gulches at the foot of the cliffs; and the small bay, with shingle covering a strip of the primary ultimate platform, which rapidly falls beneath the sea.

Fig. 3.—East of Martha Point. A succession of buttresses, planed almost level by the sea, and gulches in the fresh granodiorite, being transient features in the formation of the primary ultimate platform.

Fig. 4.—South of Martha Cliff. A further stage in the formation of the primary ultimate platform. The buttresses of fresh granodiorite are mostly reduced to small reefs.


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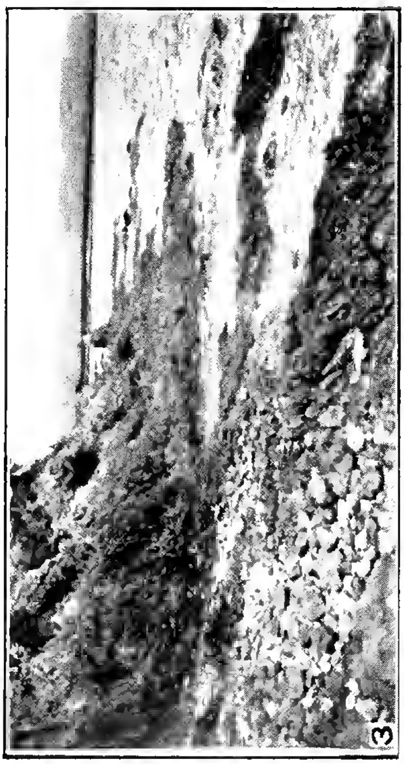
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[Proc. Roy. Soc. Victoria, **52** (N.S.), Pt. I., 1940.]

Art. X.—*Soil and Land Utilization Survey of the Country Around Berwick.*

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[Read 13th April, 1939; issued separately, 1st March, 1940.]

Contents.

I. Introduction.

The object of the work reported here has been to obtain exact information concerning the potentialities and the present use of the land in a section of the coastal strip of south-eastern Australia in which rainfall is seldom seriously deficient. The provision of money from the University of Melbourne's Commonwealth Research Fund in 1937-38 made it possible to carry out a detailed study of a sample area in such country.

The area chosen for this survey covers 59 square miles and is centred approximately around Berwick, which is 27 miles east of Melbourne. Its boundaries do not coincide with those of a parish or shire, but were chosen in order to include representative portions of non-agricultural rugged hills, gentler foothills, and undulating to flat land. The general level of natural fertility in this area is low, though there are some fertile patches. The mean annual rainfall is 30 inches, increasing to 40 on the higher hills, and is fairly well distributed through the year. In all these respects the district is typical of Gippsland as a whole, although for statistical purposes it is included in the Central District, and lies just west of the boundary of Gippsland.

The survey consists of two main sections, namely, the mapping of soil types and the collection of information from the individual farmers as to their activities. For the latter purpose, questionnaire sheets were drawn up to deal with each of the main occupations. Circulars were first sent to all farmers with a holding of more than 20 acres, explaining the object and nature of the inquiry. Each of these farmers was later visited and the soils on his property were mapped. The information has been so tabulated that no details of any individual farmer's activities are disclosed.

The project was greatly facilitated through the kindness of the Royal Australian Air Force in providing us with aerial photographs at the scale of 4 inches to the mile. The individual contact prints, measuring 7 inches square and covering 1,980 acres, proved invaluable in the field in providing reference points for mapping and in indicating boundaries of properties and of soil types; these prints were also very helpful in arousing the interest of many of the farmers. We should like to record here our gratitude to the Royal Australian Air Force.

II. Description of the Surveyed Area.

The location of the area is shown in fig. 1, together with the railways and chief towns in the neighbourhood. Dandenong, with over 4,000 inhabitants, is the largest town in the neighbourhood and is one of the most important markets for livestock in the State. It is the terminus of a suburban electric-train service from Melbourne. The surveyed area was chosen with the idea that it was far enough away from the metropolis to be free from any suburban characters; though this is not quite correct, it is approximately true. The area is typically rural; the only factory in the district is one at Officer, at which building tiles and pipes for agricultural drains are made.

Topography.

The surveyed area may be divided into two portions, lying north and south of the main road from Melbourne to Sale (the Princes Highway). This coincides roughly with the 200-foot contour (as shown on the Military Survey).

The land to the north of the highway is hilly, and constitutes the south-western extremity of the great mountain chain of eastern Victoria; the highest point within our area is Upper Beaconsfield (700 feet), and the 1,000-ft. contour lies 5 miles away to the north. The hills to the east of Cardinia Creek are fairly steep, slopes of 14 degrees being frequent. West of Cardinia Creek the round-topped hills of basalt are the dominant feature. Slopes are generally gentler here, and the highest point, west of Harkaway, is 550 feet, from which the country falls away sharply to the west.

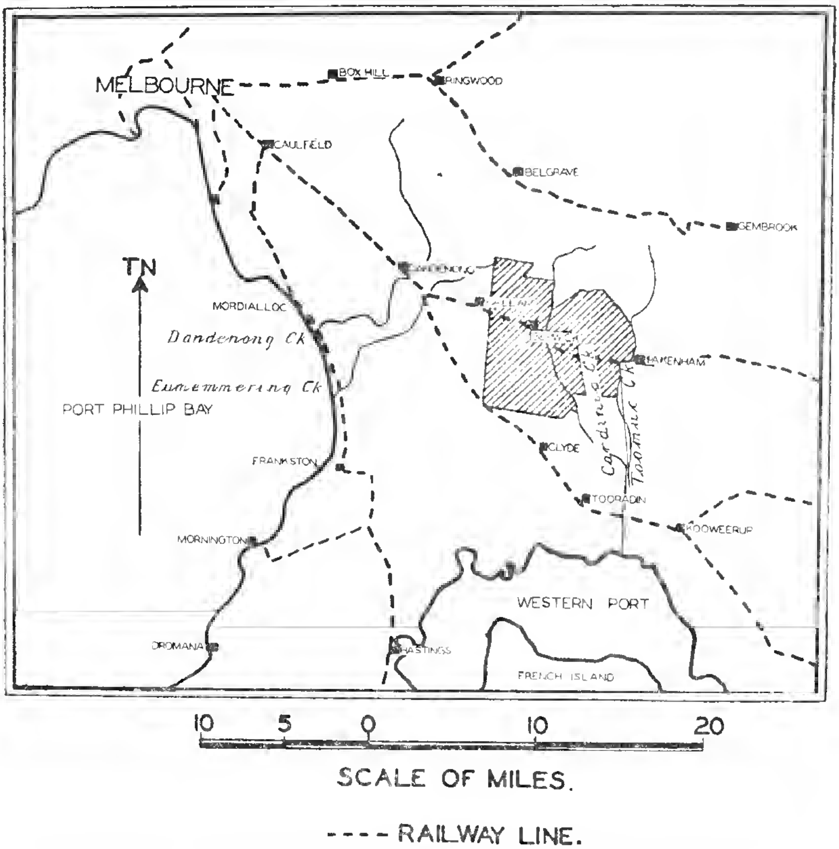


FIG. 1.—Position of surveyed area relative to surrounding country.

The land to the south of the highway is gently undulating or flat, except for a few hills near Berwick, and the 200-ft. contour comes south of the road at only a few points. The 50-ft. contour includes the south-eastern corner of the area, and from here to the coast of Westernport Bay (9 miles away) the land is very flat. This country to the south-east of our area is the great basin of Koo-wee-rup, formerly a swamp and now reclaimed by means of a network of drains and embankments.

Natural Drainage.

Cardinia Creek and Toomuc Creek, which rise about 5 miles away to the north, are the only well-defined streams. Little water runs in them in summer and autumn, but their flow does not cease altogether except in the severest drought. Further to the south the two creeks join and the water flows through one of the major drains of the Koo-wee-rup scheme into Westernport Bay.

The western part of the area drains by the Eumemmering Creek into Port Phillip Bay. Hallam Valley, lying just south of Berwick and Narre Warren, collects water which joins the Eumemmering 4 miles to the west of Narre Warren. The divide between these two systems is defined by the ridge of basalt coming through Harkaway and Berwick to the south of Beaconsfield, and then swinging south-west to Cranbourne.

There are numerous minor watercourses, most of which are artificial and have been cut in order to drain swampy patches. Many of these have scoured, even in very gently sloping country. Toomuc Creek itself provides a striking example. This creek formerly spread over flat country near its present course with no defined bed, and the present narrow course from the point where the main road crosses it has been scoured out since the land was settled, having been started, according to tradition, by a furrow that was scooped out for the purpose of drainage. Even more spectacular ravines have been scoured out at the foot of the hills north from Narre Warren (see pl. X, fig. 3). In one property a straight drain was cut in the early days of settlement and a gully has now been formed 30 feet deep and over half a mile long, bisecting the farmer's property. The rapid run-off of water from the deforested hills around has probably contributed to this effect.

Geology.

Kitson's rapid survey (1) in 1901 of the country around Berwick is the only account of the geology of this district, except for a note (2) on the unimportant gold mining in Haunted Gully, where the reservoir now lies for the supply of water to Mornington Peninsula. The geological boundaries as defined in the present survey are shown in fig. 2.

The geological history of the district is as follows. The bedrock consists of folded and compressed Silurian marine mudstones which are soft where they are exposed. In the Devonian age there was an intrusion of granodiorite below the surface of the Silurian bedrock. This granodiorite has since been exposed in places in the north (such as Harkaway) by the erosion of the Silurian rocks. In Oligocene or Lower Miocene times streams of basaltic lava started near the northern fringe of the area and flowed through the valleys, moving first south and then southwest through Cranbourne. The present surface of this flow is 600 feet above sea-level just north of Harkaway, 300 feet at Berwick township, and 100 feet at Cranbourne, after which it is lost below the present level of the land. There were at least two flows of this basalt, the later flow being denser (3); they are

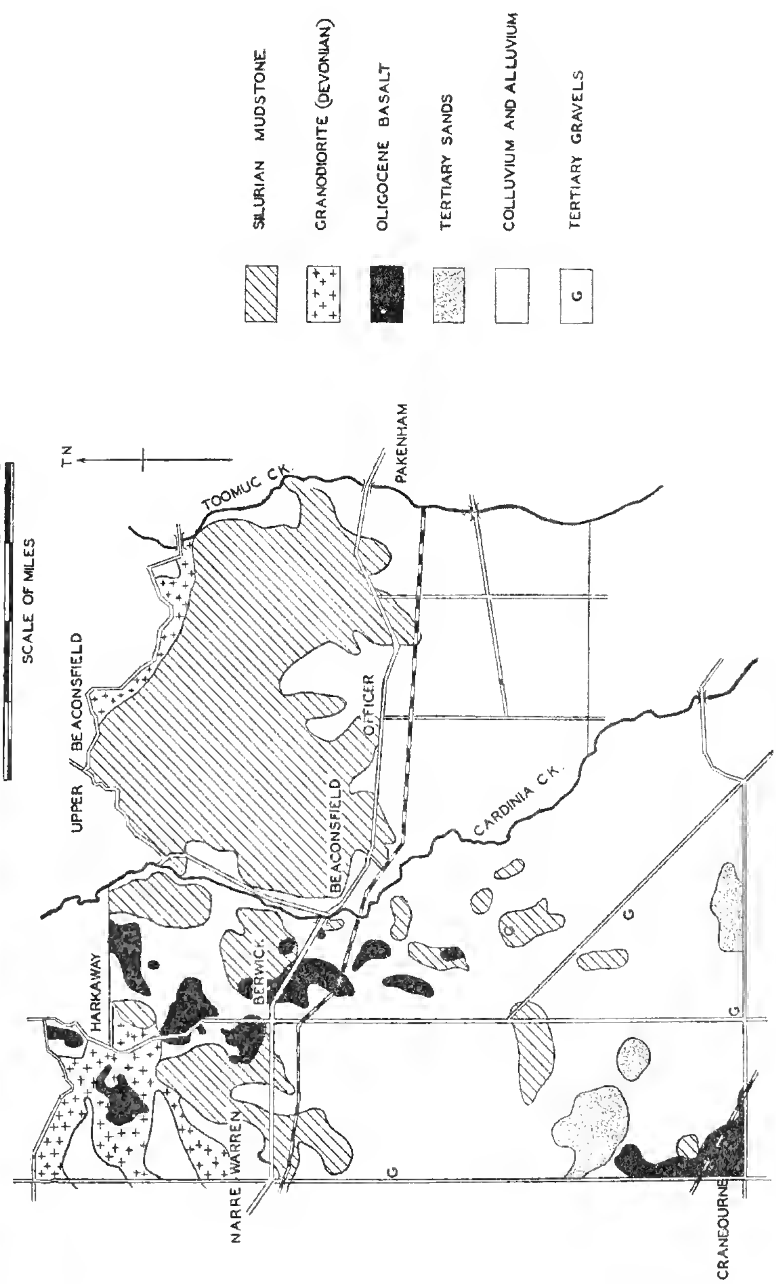


FIG. 2.—Geological Map of Berwick Area.

separated or covered by a sandy sediment in a few places giving rise to some curious mixed soil profiles in which the upper and lower layers are developed from different materials. There is a good example at the northern end of Wilson's quarry at Berwick. Here a foot of light-grey sandy loam which could not have been formed from basalt overlies the material derived from the lower flow of basalt.

The Silurian rocks have been eroded more rapidly than the basalt, with the result that the basalt which once filled the valley now stands out as smooth hills with rather steep sides. At some places, such as the town of Berwick itself, the process has reached the stage where the Silurian rock and the basalt are on about the same level. Near Harkaway the basalt rests on granodiorite, and here also is a ridge with both rocks on the same level.

The flat and undulating country to the south of the highway is formed of material brought down from the granodiorite and from the Silurian rocks. Frequent changes in course and in the fineness of the material carried by former creeks have resulted in the high variability of the soil to-day over much of this southern country. A few gentle hills of Silurian rock remain uncovered, dotted here and there over the plain. The land has been mapped as "colluvium" wherever there is no rock within 6 feet of the surface.

Definite remnants of Tertiary river-beds occur at a few places; there are two groups of these, a deep sand and a gravelly clay. Both of these deposits are quarried for local use. The so-called gravel beds are used for road-making, but are undesirably high in clay for the purpose. We have not attempted to map the boundaries of these gravelly deposits accurately, but have merely marked the sites of gravel pits. It is possible that some of the land marked on the soil map as "Toomuc sandy loam" is derived from the same Tertiary deposits.

III. Climate.

Total Annual Rainfall.

The mean annual rainfall over the country south of the highway is close to 30 inches. There are no stations within this area which send in daily reports to the weather bureau at Melbourne, but monthly records have been kept since 1887 by the Patterson family, now at "Jesmond Dene," Cardinia Creek (4). The average here to the end of 1937 is 31.55 inches. We have also used the figures which have been either taken from (4) or supplied from personal records by the courtesy of local residents, for several other places, including Narre Warren, Berwick, Pakenham, Cranbourne, and Clyde. Some of these records extend over too short a period to calculate a reliable average, but if the figures are compared with those for the same years at "Jesmond Dene," and it is assumed that the mean ratio of the rainfall of each station to that of " Jesmond Dene " remains steady, it appears that all these stations have between 28.5 and 30.5 inches. A rainfall of about 30 inches is the rule in the flatter country within 25 miles east of Port Phillip Bay, and the excess of rain over that falling at Melbourne (average 25.6 inches) is probably due to the moisture carried by westerly and south-westerly winds which have recently passed over water.

The annual rainfall at " Jesmond Dene " has ranged from 46.54 inches in 1924 to 18.39 inches in 1908. The median rainfall is 31.25 inches. The mean deviation of all years from this median is 4.45 inches or 14 per cent.

North of the highway, rainfall increases sharply with altitude. Upper Beaconsfield, 700 feet high, with 38.5 inches, is typical of the higher land within the surveyed area, and the orchards in the foothills above Officer probably receive about 33 inches.

Distribution and Effectiveness of the Rain.

The value of a given annual rainfall naturally depends on its monthly distribution. The monthly averages for " Jesmond Dene " are given in Table I. Temperature and evaporation are not recorded in this district, but the mean figures for Melbourne must be close to the local values and they are therefore incorporated in the table.

Table I.—Mean Monthly Rainfall from 1887 to 1937 at " Jesmond Dene," Cardinia Creek, and Mean Figures for Temperature and Evaporation at Melbourne.

—	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Rain ..	214	159	257	288	270	277	271	279	298	328	249	265	3,155
Temp. ..	67·4	67·6	64·6	59·4	54·1	50·4	48·8	51·0	54·1	57·7	61·3	64·9	58·4
Evap. ..	643	504	401	241	149	113	109	150	232	336	454	574	3,905

Rain and evaporation are recorded in " points " of one hundredth of an inch.

Although at first sight it appears that the rainfall is evenly distributed, the year is in fact divided into a wet season (winter and early spring) and a dry season (summer and early autumn). The climate has some of the character of the Mediterranean type of dry summer and wet winter, but differs from it in the extension of the rainy season well into the spring and in the occurrence of erratic storms of tropical origin which particularly favour the eastern half of Victoria during the summer and early autumn. Apart from these irregular tropical spells, the summer is typically dry and sunny, with occasional bouts of hot north winds blowing from the arid interior, which contribute to the high evaporation. The liability to dry spells may best be seen from Table II, in which the median rainfall is tabulated instead of the mean. Since

TABLE II.—VARIABILITY OF MONTHLY RAINFALL AT "JESMOND DENE," 1887-1937.

—	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Median rainfall ..	168	104	215	263	255	273	261	270	272	323	222	250
Mean deviation from median ..	125	105	135	146	95	96	90	88	92	124	109	122
Percentage deviation	74	101	63	55	37	35	34	33	34	38	49	49
No. of times month's rain fell below 1 inch ..	14	22	12	6	3	3	3	0	1	3	7	9

the chances are equal that in any year or month the rain will be below the median, it is a more informative figure than the arithmetical mean, which may be compounded from several dry months and a few very wet ones. This table demonstrates the high reliability of the rain during the six cooler months, May to October, whether one considers the percentage variability or the possibility of a total of less than 1 inch. Fig. 3 illustrates the most important material in Tables I and II. The high reliability of rain in spring is especially important, since the temperature is then high enough for rapid growth. In fact, from 1885 to 1937 the combined rainfall in September and October had only three times fallen below $3\frac{1}{2}$ inches, viz., in 1888, 1896, and 1914. In 1938 the figure was only 173 points, and since the autumn of 1938 was also abnormally hot and dry, this year stands out as the worst since records were taken.

Summer rainfall is erratic and is generally too low to be of much use to plants except in abnormally wet years, in which the growth of pastures is prolonged well into the summer. If we use Trumble's principle (5) that the moisture in the soil falls below the point at which plants permanently wilt when the ratio of rainfall to evaporation (P/E) is less than one-third, then in 29 summers out of 50 there were at least two successive months too dry for growth. Or taking the arbitrary standard tnat a month with P/E less than one-half is dry, there were 30 summers with at least three such dry months in succession. In spite of this, summer-growing forage crops—especially maize and millet—are widely used. These are sown in late spring, when rainfall is relatively reliable, and they grow on the moisture conserved in the wetter months. The more clayey soils of the depressions naturally hold greater reserves of water, so that they can be used relatively safely for summer crops without gambling on the weather. Possibly the maize plants on some of the depressions get their roots within reach of permanent water.

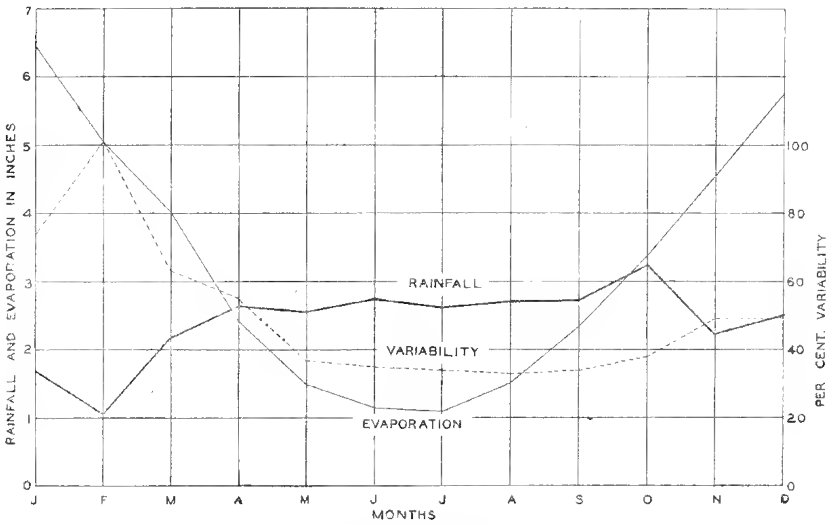


FIG. 3.—Median monthly rainfall, showing also percentage variability and mean evaporation.

Pastures are however far more important here than crops, and the most valuable constituents of the pastures are subterranean clover and perennial rye grass. With regard to these, the most important among the more variable factors in the weather is the "break of the season" in autumn—that is, the date after which the soil does not dry out until the following summer. This "break" may occur at any time from early March to mid May, and the earlier date is highly desirable, since rain coming while the soil is warm allows the annual plants to become well established.

Much the same general considerations apply to the settled hilly country for about 2 miles to the north of the highway as to the flatter country to the south. These foothills receive 10 to 20 per cent. more rain, and presumably lose less water by evaporation. The natural rainfall, however, is often too little for the orchards during the summer, and many orchardists irrigate their trees.

During June, July, and August frosts are not severe, and in the majority of winters the air temperature never falls below freezing-point. However, the mean temperature of the soil, again using the Melbourne records, is between 45° and 50°F., and this is too low for rapid growth. During winter and early spring there is no lack of rain; on the contrary, there is often an excess, and the saturation of the soil helps to keep growth at a low rate. The subsoils consist generally of relatively impermeable clay, and it is likely that drainage is a limiting factor to growth throughout the district. The effect of the cold period in winter is well shown in the very low figures for the growth of pastures for almost all stations in Southern Victoria which have been recorded by the Victorian Pasture Improvement League and published from time to time in the Journal of the Department of Agriculture of Victoria. The local conception of a "good winter" is one with rain below the average, and therefore with a minimum of water-logging.

IV. Description of Soil Types.

The basis of the classification and mapping of the soils (see fig. 6) is the *profile*—that is, the set of characteristics which one observes in the face of a pit, or occasionally in a roadside cutting. Such a profile consists of a succession of layers, known as horizons, differing from one another in texture and colour, and other less obvious features. Each "soil type" is known by a place-name and a term which describes the texture of the surface soil. The same place-name may be attached to two types if they are closely related to each other.

The soil types described in this section fall into four main groups, namely:—

Podzolic types,

Heavier soils on low-lying land,

Soils developed on basalt,

Miscellaneous, unnamed types.

Podzolic Types.

The predominant tendency among soils both in the surveyed area and in Gippsland is to develop a profile with the characteristics of a "podzol." A "podzol" develops typically in regions of fairly heavy winter rainfall; it has a low reserve of calcium, magnesium, and potassium, which have been washed away with drainage water, and consequently it is definitely acidic. Its reserve of phosphate is similarly low. Physically, much of the finest material has been removed from the upper layers and concentrated at lower depths, so that the sandy surface contrasts sharply with a clayey subsoil. Further, the downward movement of iron compounds has left the surface grey, and has given the subsoil a yellow shade. Some podzols are also marked by a particularly light colour just below the surface (see pl. X). The colour and texture of the five podzolic types of this district are illustrated in fig. 4.

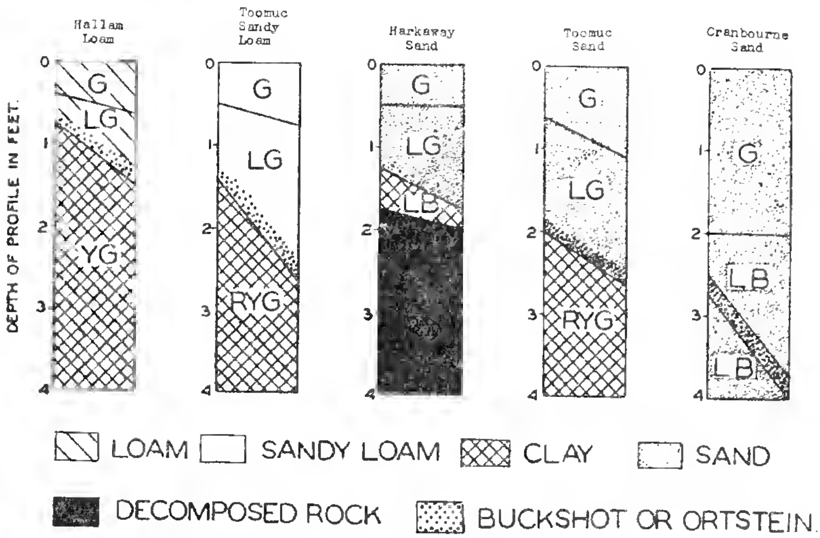


FIG. 4.—Profiles of five Podzolic soil types. Letters stand for colours as follows:—B, brown; G, grey; L, light; R, red; Y, yellow.

1. *Harkaway Sand.* (See also pl. X, fig. 2.)

This type is found on the granodiorite in the hilly country to the north. Boulders several feet across occupy some of the land, but in many places the soil is deep; this combination of boulders with deep soil is commonly found in country developed from granite or granodiorite. The typical profile is as follows:—

Horizon 1. (0–6 inches)—Grey loamy sand or sandy loam.

Horizon 2. (6–18 inches)—Light-grey sand. Soft concretions containing iron oxide and organic matter may occur near the bottom of this sandy horizon.

Horizon 3. (18–24 inches)—Sandy clay, often with a greasy feel due to mica. The colour is a mottling of grey, yellow, and red, with red predominating.

Horizon 4. (24 inches downwards)—This sandy clay grades imperceptibly into decomposing rock, in which the amount of clay gradually diminishes with depth as a smaller proportion of clay-forming minerals are decomposed.

The transition from Horizon 2 to 3 is very sharp, and may take place at any depth from 15 to 21 inches. This marked difference between surface and subsoil is usually a sign that the soil is highly mature—implying, in this case, that the rain has already washed away the reserves of valuable elements.

However, the persistence of small grains of hornblende and other primary minerals in the surface layers, as revealed by microscopic examination of the " fine sand " fraction, is a redeeming feature of these soils, and the analysis of a single sample indicates that this type is better provided with potassium than the other light types of the district.

2. *Cranbourne Sand.*

This is found especially in the south-west of the area. It has been developed on deep sand deposited by rivers in Tertiary times, the original source of the quartz sand being the granodiorite from the hills to the north. It is likely that this sand has been affected by wind-blowing since it was laid down. The typical profile is as follows:—

Horizon 1. (0–23 inches)—Grey loose sand, becoming lighter in colour below about 9 inches.

Horizon 2. (23–46 inches)—Light-brown sand.

Horizon 3. (46–48 inches)—Dark-brown cemented layer. This consists of sand cemented together by organic matter and other material washed down in colloidal solution. It is described in other countries by the German term " Ortstein ", and is locally known as " coffee-rock ".

Horizon 4. (48–78 inches)—Sand containing small nodules of clay. Though the percentage of clay is very low, its presence is obvious to the feel. This layer is often wet. In many places the sand extends to a depth of many feet.

The vegetation of this type (see p. 236) is characteristic. It has been left uncleared longer than any other type on the south of the main road, since it is chemically very poor, and is so sandy that it retains very little water as a reserve against drought.

3. *Toomuc Sand.*

This soil has developed on mixed colluvial material derived from granodiorite and Silurian mudstone. It occurs mainly as small ridges 1 foot or more above the level of Toomuc sandy loam, a more important type with which it is usually associated.

The following is a typical profile:—

Horizon 1. (0–10 inches)—Grey loose sand, becoming lighter in colour with depth.

Horizon 2. (10–31 inches)—Light-grey sand, sometimes with a brownish colour.

Horizon 3. (31–33 inches)—Ironstone gravel or continuous ortstein (" coffee rock ") rests on the top of the clay.

Horizon 4. (33 inches downwards)—Sandy clay, grey with red and yellow mottling, persisting to a depth of several feet.

Rushes grow on many patches of this type, giving evidence that underdrainage is particularly poor.

4. *Toomuc Sandy Loam.*

This has also developed on the material washed down from the hills, or in some cases from Tertiary sediments that have been consolidated to form ridges of sandy or gravelly clay. The typical profile is as follows:—

Horizon 1. (0–6 inches)—Grey or light-grey sandy loam.

Horizon 2. (6–24 inches)—Very light-grey sandy loam or sand. Concretions of ironstone gravel are common at the bottom of this layer. In wet weather this layer becomes a semi-fluid mass and animals or machinery may sink deep into it. This is an example of the popularly termed "spewy" soil.

Horizon 3. (24–46 inches)—Light to medium clay, mottled yellow and grey, with red mottling increasing with depth.

Horizon 4. (46 inches downwards)—Light red-brown heavy clay.

The transition between horizons 2 and 3 is sharp. The depth at which clay occurs is normally between 20 and 26 inches, but it may be as little as 17 inches. Every transitional stage between this type and the next one (Hallam loam) occurs in the field. It shares with Hallam loam the unpleasant property of readily forming very hard clods.

5. *Hallam Loam.*

This type is formed on the material washed from the hills on to the lower, gentle slopes. Most of this material is derived from Silurian hills. The following is a typical profile:—

Horizon 1. (0–6 inches)—Grey or light-grey loam, with a floury feel due to its high content of silt. Liable to set very hard after rain.

Horizon 2. (6–13 inches)—Light-grey loam, or silty loam. This is quite structureless and is like the sub-surface of Toomuc sandy loam. Charcoal is very common in this horizon.

Horizon 3. (13–16 inches)—Light brownish-grey clay loam. Concretions of ironstone are characteristically but not invariably present. The presence of concretions at this level is doubtless due to the frequently semi-fluid nature of the surface layers through which the ironstone sinks, till it rests above the clay.

Horizon 4. (16–30 inches)—Greyish-brown heavy clay, only slowly permeable to water.

Horizon 5. (30 inches downwards)—Heavy clay with red, yellow and grey mottling.

The clay may continue for many feet, merging gradually into decomposed Silurian rock. As with the Toomuc types, the contrast between the grey loam at the surface and the yellowish clay of the subsoil is very marked, and the transitional layer (Horizon 3) is often absent. The frequent ironstone gravel, which is up to half an inch in diameter, bears witness to the fact that drainage has periodically been very slow and the subsurface waterlogged. The depth of the impermeable clay layer is usually 12-16 inches, but may be found anywhere between 9 and 20 inches.

5. (*a*) *Hallam Loam* (*Silurian Phase*). (See pl. X, fig. 1.)

There is little essential difference between the soils formed directly on the Silurian rock and those formed on the wash from the hills. In all cases there is a high percentage of silt throughout the profile, and a transition at a depth of about 1 foot from a grey silty loam to a yellowish-grey impermeable clay. Where the rock occurs within 6 feet of the surface we have mapped the soil as the "Silurian Phase." Most of the country so mapped has rock within 3 or 4 feet of the surface. This naturally occurs on the top and the upper slopes of hills. The layer of gravel lying above the subsoil clay consists partly of smooth ironstone grains, many of which are nearly spherical, and partly of long yellowish flakes of siliceous material, presumably fragments of parent rock, cemented by iron compounds and so made resistant to weathering.

The weathered Silurian rock has a remarkably yellow colour, and this shade is characteristic also of the subsoils of this phase.

5. (*b*) *Rugged Silurian Country.*

The surface of Hallam loam is easily converted by rain into an amorphous semi-fluid mass, which is particularly liable to sheet erosion. Consequently, the depth of surface soil is much less on the steeper slopes, and only shallow, rocky soils occur in the northern country where slopes of about 14 degrees are common. Such soils are non-agricultural, and have been mapped as a separate type.

Heavier Soils on Low-lying Land. (See fig. 5.)

The two types that come under this heading contain more clay than those just described, and consequently do not show any marked contrast of light surface and heavy subsoil. They occur on low-lying land, and it is clear that they have been continually receiving fine material that has been washed down from the higher land around them. Thus they not only differ from the podzolic soils in the absence of contrast between the surface and subsoil and by their waterlogging for long periods, but the method of their formation also gives them a quality of relative immaturity. The natural vegetation is swamp tea-tree, and several strips of this still remain.

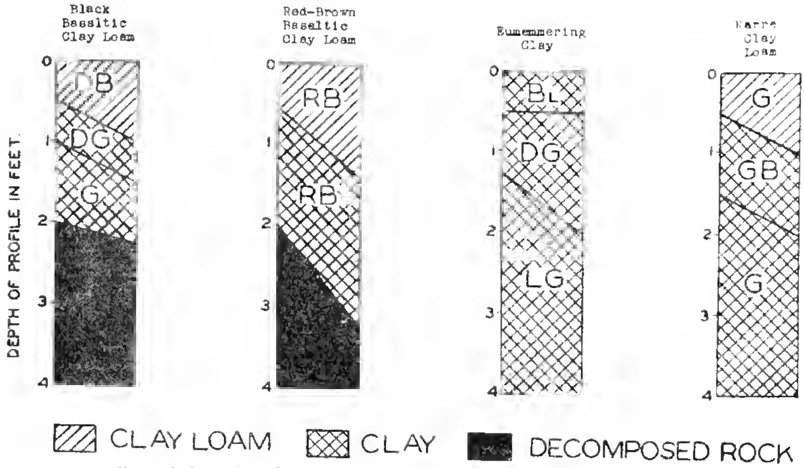


Fig. 5.—Profiles of four heavier soil types showing the colour and range in depth of the various horizons. Letters stand for colours as follows:—B, brown; BL, black; G, grey; D, dark; L, light; R, red.

6. *Narre Clay Loam.*

This occurs in depressions, often as long tongues corresponding to drainage lines, among the lighter types in the country to the south.

The following profile is typical:—

Horizon 1. (0–9 inches)—Grey clay loam with brown mottling.

Horizon 2. (9–18 inches)—Grey light clay with brown mottling.

Horizon 3. (18–31 inches)—Grey clay.

Horizon 4. (31 inches downwards)—Clay, mottled with grey, yellow and red, extending for several feet.

It is characteristic that light clay occurs at a depth less than 12 inches. The brown mottling of the surface soil is characteristic, and indicates the conditions of poor drainage under which the soil has been developed; the alternate reduction of iron compounds during periods of waterlogging and their oxidation during dry spells has led here to the deposition of ferric oxide as rusty streaks rather than as gravelly concretions. The soil cracks in dry weather and is often difficult to work, but it is regarded in the district as a desirable type. The clay in the deep subsoil is sometimes relatively light, especially where the type occurs on the higher levels. This is due to the fact that this soil is formed on natural lines of drainage, down which sand has been washed as well as the finer fractions. Some of the tongues of this type in the south-east of our area have important amounts of coarse sand, and approximate in texture to a sandy clay loam.

7. *Eumemmering Clay.*

The main continuous occurrence of this type is one of 1,010 acres in the Hallam Valley section, on land draining into the Eumemmering Creek. It also occurs in other basins where minor watercourses have spread over the land in such situations that the movement of water has been slow enough to allow suspended clay to settle, while swampy conditions have persisted long enough each year to allow a fair accumulation of organic matter. The swamp tea-tree reaches its greatest development in this environment.

The following profile is typical:—

Horizon 1. (0–6 inches)—Black clay, somewhat friable, drying into small crumbs when properly worked.

Horizon 2. (6–16 inches)—Dark-grey plastic, heavy clay.

Horizon 3. (16–35 inches)—Grey plastic, heavy clay.

Horizon 4. (35 inches downwards)—Heavy clay, with light-grey and yellow mottling.

The depth of the friable surface layer may be as little as 3 inches. It is at the best a refractory soil which can be easily worked only over a narrow range of moisture contents. It is particularly troublesome during the frequent wet winters and springs.

This soil invites comparison with the types found in the Koo-wee-rup district, which also was formerly a tea-tree swamp. No detailed survey has been done in this district, but the better soils have a great reputation and have produced splendid crops of potatoes. This first-class land of Koo-wee-rup, however, at such places as Daimore is relatively peaty, and it is said that it can be worked at any moisture content. Eumemmering clay is not at all peaty, and is probably comparable to the second-class land of the outer areas of the former swamp of Koo-wee-rup. Such land was probably wet for only certain periods of the year and did not therefore accumulate as much organic matter as did the more permanently swampy land. Eumemmering clay to-day contains only about half as much organic matter as the better Koo-wee-rup types, and its subsoil is far less permeable. The quality of Eumemmering clay does not seem to be associated with the nature of the hills from which the clay has been brought down. Thus Hallam Valley, receiving its material from hills of basalt and Silurian rock, appears closely similar to other basins of Eumemmering clay deriving their material from Silurian hills only.

Soils Developed on Basalt. (See fig. 5.)

The soils developed on the basalt are strikingly different from the others in the district. The horizons grade imperceptibly into one another and there has been no visibly recognizable removal of iron compounds from the surface. Two types have been mapped, according to the colour of the surface soil. They are of small extent and have not been given names beyond the description of colour.

8. *Red-brown Clay Loam on Basalt.*

This type is usually spoken of as "red"; the following is a typical profile:—

Horizon 1. (0–9 inches)—Dark red-brown clay loam, rich in organic matter and very friable.

Horizon 2. (9–17 inches)—Reddish-brown friable clay loam, differing from surface soil mainly by its lower content of organic matter.

Horizon 3. (17–27 inches)—Red friable clay.

Horizon 4. (27–39 inches)—Red friable clay mottled with yellow.

Horizon 5. (39 inches downwards)—Light-brown decomposing basalt, of the texture of a gritty loam.

Many red soils are shallower and more stony than this type sample (C 109). Near the edge of flows a variety occurs containing large concretions of ironstone. This covers a small area, and is not mapped.

9. *Black Clay Loam on Basalt.*

Horizon 1. (0–10 inches)—Very dark-brown to black clay loam, rich in organic matter and fairly friable.

FIG 6. SOIL MAP OF BERWICK AREA

Horizon 2. (10–27 inches)—Grey or dark-grey heavy clay.

Horizon 3. (27 inches downwards)—Decomposing basalt, light-brown and gritty.

Strictly speaking one should distinguish between the black soils on higher slopes and those on the gentler, lower slopes. It is quite plain that the latter crack more on drying than the former, and as might be expected they have a deeper subsoil, in which the clay is as plastic and heavy as any in the district. The type sample was chosen as it occurs in the only extensive patch of black soil on basalt, but is not thoroughly representative, because being low-lying it has received both quartz sand and finer material from surrounding non-basaltic land. All these basaltic soils appear to be resistant to erosion, are rich in organic matter and friable considering their clay content, and possess a stable crumb structure which confers on them a good permeability. Small rocks or "floaters" occur through the profile, and often make it impossible to sample below a few inches. Every intermediate colour occurs between the extremes of "red" and "black"; only the soils with really bright colours are mapped here as "red", the rest being "black".

The reason for the existence of the two types is not known. Similar contrasts occur farther east in Gippsland, and it seems very likely that these soils are analogous to the basaltic soils around Burnie, in North-western Tasmania, which have been surveyed by Stephens (6). Differences in soil type are not associated with any difference in the parent rock or in topography, except that red soils are not found on flat land. It is said that the black soils hold the moisture better and give heavier crops, but the red are more easily worked.

The native flora was undoubtedly very dense, and has left its mark in the high organic matter of the soil. To-day an occasional tall "white gum" (*E. viminalis*) remains on the basaltic country, a tree that contrasts with the much smaller "peppermints" around it on the podzolized types.

A very interesting feature of the basaltic ridges is the suddenness with which the soil changes at the foot of the slope into the poor podzolic type; the effect of basaltic wash is evidently very slight.

MISCELLANEOUS TYPES.

A few areas have been mapped as "miscellaneous sandy types." These are all podzolic and naturally poor.

(i) Along Cardinia Creek is a line of deep sand, which is presumably a former bed of the creek. The profile varies from place to place, but typically there is sand to a depth of 4 to 5 feet, overlying a yellowish sandy clay. The sand is generally less coarse than Cranbourne sand; its colour ranges from grey at the surface to light-brown in the lower levels, which sometimes contain soft brown concretions. Several small pits have been worked for this sand.

(ii) A small patch of deep fine sand changing to clayey sand below 4 feet occurs north-east of Officer. Its geological origin is obscure.

(iii) Interbasaltic sands.—Sandy deposits occur on the edge of the lava flows to the north of Berwick. Three of these consist of coarse sand, and the soil developed on them is grey coarse sand turning to light-grey below the surface, and changing at 3 feet to reddish-brown coarse sand with small inclusions of clay. A fourth deposit, covering a larger area than any of the others, consists of finer material, though probably it also was deposited by streams flowing at the edge of the basalt. The soil developed on this is a grey fine sand with ironstone concretions at 18 inches, lying over mottled red and yellow clay at 22 inches.

(iv) An unclassified "very fine sandy type" has been mapped with a different symbol from the soils just described. This soil occurs north of Beaconsfield, and has a remarkably silty feel, due to the large proportion of very fine sand which it contains. The surface is a grey silty loam, and the colour becomes lighter with depth: this passes at 22 inches into a yellowish-grey silty clay, and at 33 inches into a light clay which is mottled with red, yellow, and grey. This soil appears to be developed from foot-hill wash from the Silurian hills, which seem to have provided at this point an abnormal concentration of very fine sand and silt.

Significance of Soil Type.

The foregoing descriptions, and the more detailed analyses in a later section of the paper, show how greatly the soils of this district differ from one another. If the production of cash crops were common here, no doubt these differences would be reflected in the agricultural reputations of the various types. All the land is capable of being cropped, except where the slopes are too steep. However, grass is by far the most important crop throughout the district, except the Silurian hills where fruit is grown. It appears that, with the exception of the non-agricultural Silurian hills, there is little to choose between the various soil types as regards the productivity of well-managed pastures. Good pastures, including perennial rye grass, can certainly be established on all these types. However, the general development of good pastures in this district is so recent that there is no guarantee that the perennial pastures on the soils of low inherent ferility will prove as permanent as those on the better soils.

It is not possible to compare the various soil types with one another on the score of prices paid when land changes hands, but the soils on the basalt would probably command a higher price than the others.

Saline Patches.

Patches of land affected by a high concentration of salt are a conspicuous feature of the country, especially within 2 or 3 miles from Narre Warren. These patches occur at the foot of gentle slopes, and may spread out for 150 yards or more over the flats. The only plant that grows on most of them is a stunted form of a species of Plantago, and as shown in plate XI this alternates with bare ground. The immediately surrounding land carries less tolerant plants (see p. 237), and a few yards further away there may be normal pasture.

These concentrations of salt are evidently associated with certain properties of climate, topography, and soil. It is at first sight surprising to find accumulations of salt under an annual rainfall of 30 inches, with low evaporation during the winter. However, most of the rain comes as relatively light showers, and falls of over 1 inch in 24 hours make only a minor contribution to the yearly total; on this account, salt is not washed out so thoroughly as in districts where each fall of rain is heavy. The salt falls with the rain, being blown in from the sea in the form of evaporated spray, and its occurrence is not connected with the weathering of rocks. This matter has been fully discussed by Prescott (7) for Australia in general, and by Teakle (8) for the south-west of Western Australia. It may be estimated from unpublished data kindly supplied by Mr. V. G. Anderson that the annual fall of sodium chloride on the land near Berwick is 80 pounds per acre. The local concentration of this salt to give 10 tons per acre in the surface foot depends on soil and topography.

The soil of the ridges above the salt patches is one of the podzolic types, Hallam loam or Toomuc sandy loam, with a sharp boundary between the permeable surface and the subsoil, which is only slowly permeable. The rain after saturating the surface layers flows down the hill on the top of the clay, becoming more saline on its way as pure water is evaporated or transpired by plants. The water when it is checked at the foot of a slope may thus contain the salt that has fallen over many times the area of the salt patch.

History.

These salt patches are characteristically much more acidic than the surrounding land. This fact suggests that the high concentrations of salt are recent, since land that has long been influenced by salt is usually neutral or alkaline. The older settlers also believe that the salt has appeared or has spread since the land was cleared, as has undoubtedly been the case elsewhere in Australia. However, it is said that there were at least a few salt patches when the land was first settled.

Treatment.

These patches make up so small a proportion of the average holding that even the most progressive farmers have not taken measures against them. The barrenness is certainly due to salt and not to acidity; liming does not improve matters. Crops which tolerate high concentrations of salt have not been tried.

V. Land Utilization: (A) General Considerations.

HISTORICAL INTRODUCTION.

When Victoria was first occupied by white men the whole of this district was covered by forests of various species of Eucalyptus, or by dense scrub on some of the flats. Settlers first arrived about 1835, but their numbers were small until the completion of the first survey by the Lands Office in 1852. In this survey the virgin bush was divided into blocks mostly of 640 acres, with a few of 320 acres; roads were marked out and small areas set aside for townships.

When the survey was completed the Lands Office offered some of the blocks for sale to members of the general public for £1 an acre. However, many of the eventual settlers had to pay considerably more than this, partly because some of the land was auctioned by the State but mainly as a result of the activity of speculators. Many blocks were bought by settlers who had not previously seen them, and this probably accounts for the fact that the first land to be alienated included low-class as well as high-class country. This applied, for instance, to a colony of Germans who settled around Harkaway, on country consisting largely of uninviting hills of granodiorite.

After partly clearing their blocks, the settlers started by growing crops, especially wheat and barley, which were the most profitable cash crops at the time. Wheat on the basaltic country north of Berwick originally yielded as much as 50 bushels per acre. A flour mill was also built at Berwick about this time.

During the sixties the price of wheat and barley fell, and rusts began to infect the wheat, which then consisted of non-resistant varieties such as White Tuscan and Purple Straw. There was accordingly a rapid change from cropping to dairying and mixed farming, for which also the freshly cleared land was used. Since then dairying has been the most important industry in the district.

The population of the district increased rapidly during the late fifties and early sixties, and a township sprang up at Berwick, where a post office, churches, and public halls were built about this time. The first schools were privately owned but a State school was opened in 1859. The district of Berwick was created a shire in 1868, and its progress since then is summarized in Table III.

TABLE III.—SHIRE OF BERWICK, 1880-1937.

Year.	Area in Square Miles	Population.	Number of Dwellings.
1880	312	3,200	..
1890	300	4,700	..
1900	387	6,500	..
1910	387	6,430	1,400
1920	384	7,900	1,600
1930	384	9,400	2,355
1937	384	9,700	2,550

This early settlement extended as far east as Cardinia Creek. To the south of the Prince's Highway and east of Cardinia Creek, settlement first took place in the seventies and eighties. Originally this land was used mostly for grazing sheep and beef cattle but dairying now plays a more prominent part. In the stony and hilly country east of Cardinia Creek and north of the Highway, settlement started considerably later; in fact, apart from the few orchards, much of this country though alienated is still not even cleared.

The surveyed district is close to Melbourne, and the lightly timbered flat to undulating country (especially in the south) was cleared at comparatively low cost. The district was favourably situated therefore for the supply, first of dairy butter and eggs, and later of wholemilk also, to Melbourne. Before the introduction of the cream separator about 1890 the butter was manufactured on the farms. The early German settlers around Harkaway walked along bush tracks to Melbourne with the homemade butter and eggs and sold them in the market. As better roads were made, carts and drays were used for transport, and eventually the railway. With the development of butter factories and of refrigeration on ships, the export of butter rapidly became an important industry which gave a good return to the dairy farmer supplying cream for manufacture into butter. In spite of this the dairy farmer in this district has long considered that supplying wholemilk to Melbourne is more profitable than producing cream for butter.

The development of the sheep and beef cattle industries in this district has been less striking than that of dairying. Close proximity to the metropolis is not so valuable to these industries as it is to dairying. However, there have always been a number of farmers in this district who derive part or all of the farm income from sheep, grown in former years for their wool but in recent years mainly for the sale of fat lambs.

More recent developments have been the planting of scattered apple orchards in the hills, mostly between 1915 and 1922, and various attempts at closer settlement, which are dealt with in a later section.

The price at which land changes hands naturally varies with individual cases, but farmers in the district have paid about £13 an acre during 1937 and 1938 for unimproved property under native grasses.

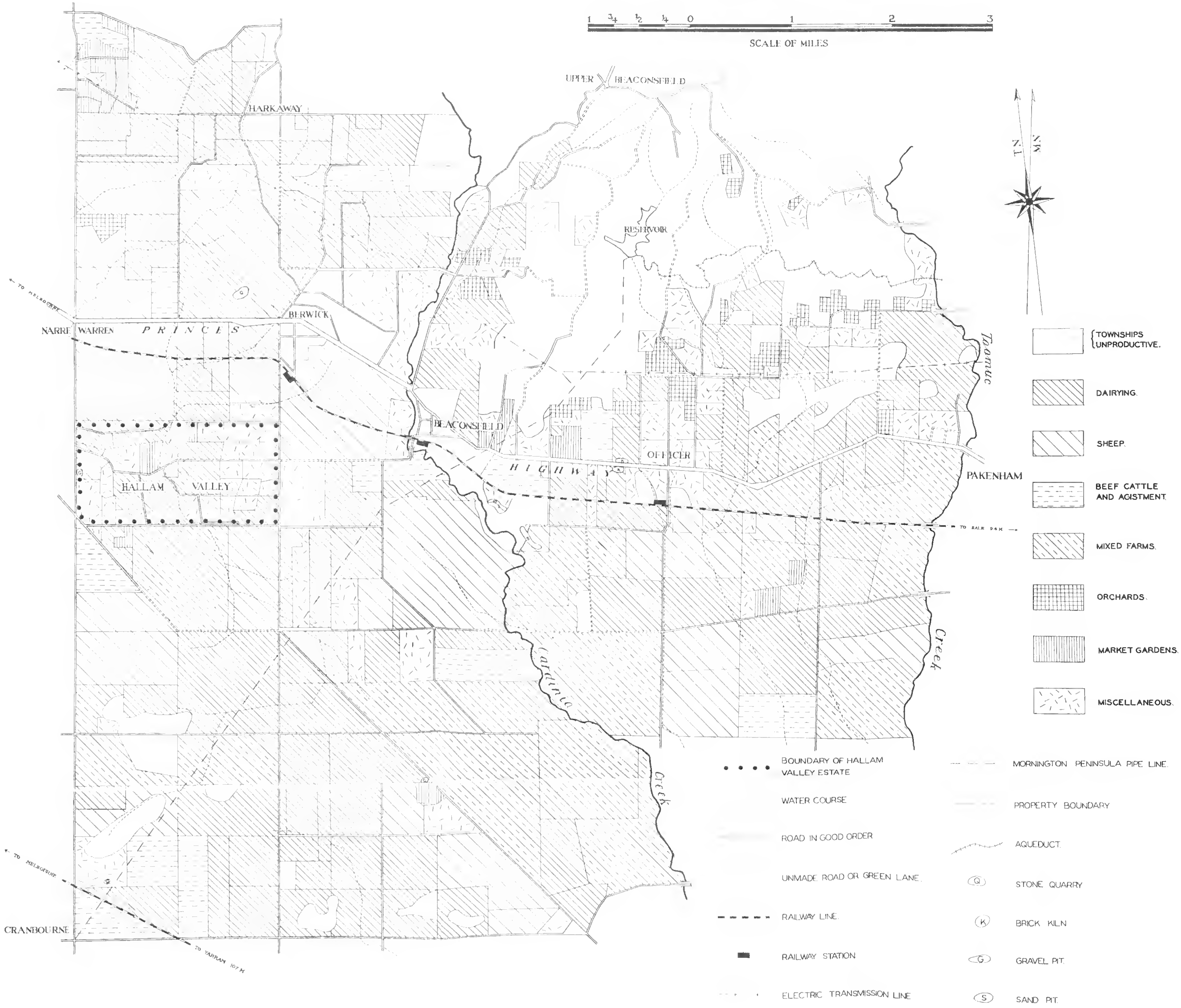
DEFINITION AND DISTRIBUTION OF FARM TYPES.

For the purposes of this survey 192 farmers were considered in detail. (The word "farmer" is used in a general sense in this paper, and includes the term "grazier.") This figure includes every one whose holding is not less than 20 acres. Information was not complete for all of these men; on this account, some of the group totals in the following Tables (as in Table VI.) fall short of the totals given in Table IV. The various types of farming, as discussed here, and as summarized in Table IV., are defined as follows:—A *dairy farmer* is one who milks a herd averaging more than eight cows, and who derives more than 80 per cent. of his farm income from dairying. Similarly, *sheep*, and *beef cattle and agistment farmers* are those deriving more than 80 per cent. of their farm income from these respective occupations. A *mixed farmer* is one who derives more than 20 per cent. of his farm income from each of at least two types of farming; usually sheep and dairying. *Orchardists* are those who derive at least 80 per cent. of their farm income from the sale of fruit. The *miscellaneous* group includes all other persons whose holdings exceed 20 acres, but who could not be classified according to the above scheme. This class is composed mainly of market-gardeners and flower-growers, and persons who work as labourers in addition to owning a small property.

TABLE IV.—DISTRIBUTION OF FARMERS ON BASIS OF OCCUPATION AND SIZE OF HOLDING.

Size of Holding (Acres).	Number of Farmers of Given Occupation.						
	Dairy.	Sheep.	Mixed.	Beef Cattle or Agistment.	Orchardists.	Miscellaneous.	Total.
20–99	38	4	1	1	22	21	87
100–199	33	3	7	4	2	6	55
200–299	8	6	5	4	. .	1	24
300–399	4	4	3	. .	. .	. .	11
400–599	2	1	6	. .	. .	. .	9
>600	1	4	1	. .	. .	. .	6
Total farmers . .	86	22	23	9	24	28	192
Total acres . .	12,040	6,850	7,420	1,580	1,140	1,980	31,010
Percentage of Total Area	39	22	24	5	4	6	100
Average size of farm in acres	140	311	321	176	48	71	162

FIG 7. MAP OF BERWICK AREA SHOWING LAND USE.



The distribution of the various types of farm is shown in fig. 7. The land mapped as *unproductive* is covered with "Peppermint" timber (*Eucalyptus australiana*) or is useless because of dense bracken or rushes. It will be seen that the farm types are scattered more or less at random over the area. Comparison with the soil map (fig. 6) indicates that apart from the orchards, which are confined to the Silurian foothills, soil type is not correlated with the type or size of farm. This is partly because cash crops like potatoes, which might force dairying and grazing off the better soils, are not grown here, and partly because even such inherently poor types as Toomuc sandy loam carry good pasture if well managed. Nor does there appear to be any relationship between the distribution of particular farm types and main roads, as might be presumed in the case of dairy farmers supplying whole milk to Melbourne. This is not really surprising since there are fine highways and a close network of fairly good side roads, and the dairy farmers are willing to transport milk to the highways if necessary.

The area within the boundaries of the map (fig. 7) is 40,170 acres, of which 31,010 acres are occupied by men who are actively engaged on the land and 2,550 acres are taken up by roads, townships, &c. Most of the remaining unproductive land lies in the rugged hills in the north-east of the area, where 5,200 acres are under native timber.

Systems of Tenure and Length of Tenure.

The systems of tenure under which the properties are conducted are shown in Table V. In this classification "owned" properties are not necessarily freehold; many of them are being bought under long-term "hire purchase" agreements. Rentals for leased properties vary from about 15s. to 30s. per acre per annum, depending on the type of country and the extent to which it has been improved. A few farmers in addition to

Table V.—Distribution of Farmers on Basis of Systems of Tenure.

System of Tenure.	Number of Farmers of Given Occupation.						
	Dairy.	Sheep.	Mixed.	Beef Cattle and Agistment.	Orchardists.	Miscellaneous.	Total.
Ownership	61	19	22	8	24	24	158
Leasehold	21	3	..	1	..	4	29
Sharefarmers ..	4	..	1	..	..	..	5
Total farmers ..	86	22	23	9	24	28	192
Owned farms as percentage of total ..	71%	86%	96%	89%	100%	86%	82%

Note.—"Owned" farms include those which are being bought under long-term hire-purchase agreements.

owning their property also lease part, or all, of an adjoining property, for grazing dry dairy cows, sheep, or beef cattle. Of the 192 properties considered, 158, or 82 per cent., are owned by the present occupiers. It is noticeable that all orchards are owned by the occupiers, whereas only 70 per cent. of dairy farms are so owned.

Table VI shows the length of time each property has been held by the present farmer or by his family. These figures indicate the extent to which land has been changing hands over the past few years. Only about half of the dairymen, sheep farmers, and miscellaneous group have been here longer than five years, and about one-third have been longer than ten years. Orchardists and mixed farmers are obviously the most stable, 45 per cent. having been here longer than twenty years. This movement of farmers is probably associated with inflated land values and the immobility of orchardists is possibly due to general depression in the industry. Fifteen per cent. of the properties are held as leasehold. Several of the owners of these properties are descendants of original selectors, and are living in retirement in Melbourne. It is obvious that leasehold is not a stable arrangement—for example, among the dairy farmers, only 1 in 20 of lessees (5 per cent.) has been here as long as ten years, compared with 45 per cent. for owners. The chief drawback of the leasehold system is lack of security of tenure, in consequence of which there is little incentive for the tenant to improve the pastures, buildings, fences, and water supply; in fact, much more top-dressing is done on "owned" than on "leased" properties.

Table VI.—Distribution of Farmers on Basis of Length of Tenure.

Number of Years on this Property.	Number of Farmers of Given Occupation.						
	Dairy.	Sheep.	Mixed.	Beef Cattle and Agistment.	Orchardists.	Miscellaneous.	Total.
0–2	22	9	..	..	..	7	38
3–4	19	1	2	..	2	3	27
5–9	12	6	3	3	4	3	31
10–14	7	1	3	1	3	3	18
15–19	9	1	4	1	3	..	18
>20	15	3	10	3	10	4	45
Total	84	21	22	8	22	20	177

Note.—For a property worked on the share basis, the figure refers to the owner and not to the share-farmer.

The number of share farmers (5) is too small to allow any conclusions to be drawn.

SIZE OF HOLDINGS.

As shown in Table IV, the size of holding varies with occupation, from an average of 48 acres for orchardists to an average of 321 acres for sheep farmers. The large proportion of dairy farms in the smaller size-groups is noticeable; 82 per cent. of dairy farmers have less than 200 acres, compared with 37 per cent. of all other graziers (sheep, cattle, and mixed farmers). These figures must be qualified by the following facts:—(*a*) Sixteen farmers have land outside the area in addition to that within the area; and (*b*), four farmers own more than one property within the area, but we have counted each farm as a unit. About 10 per cent. of the land included in this table is unproductive, being covered with bracken, scrub, or timber, which is only slowly being cleared.

PASTURES.

The pastures may be divided into three classes:—(*a*) Unimproved native pastures which took possession after the timber was cleared, and in which kangaroo grass and wallaby grass are dominant; (*b*) improved but low-grade pastures, in which subterranean clover and perennial rye grass occur together with high percentages of inferior grasses and flatweeds; and (*c*) highly improved pastures, comprising perennial rye grass, subterranean clover, white clover, and cocksfoot. The areas of these classes were estimated by inspection on the various properties, and are summarized in Table VII. The relative importance of the last-named class (at present 23 per cent. of the total) is rapidly growing. It is rather higher among those grazing sheep and beef cattle than among the dairymen. The difference between the figures for total grassland and total area includes cropland (about 1,500 acres) as well as unproductive land.

TABLE VII. CLASSIFICATION OF PASTURES.

	Acreages Held by Owners of Given Occupation.					
	Dairy.	Sheep.	Mixed.	Beef Cattle.	Miscellaneous.	Total.
Unimproved native	3,800	2,130	2,100	520	990	9,540
Improved but low grade	4,110	2,670	3,070	420	270	10,540
Highly improved	2,080	1,780	1,590	560	40	6,050
Total pasture	9,990	6,580	6,760	1,500	1,300	26,130
Pasture top-dressed annually	6,230	5,000	5,140	1,100	220	17,690
Total area of properties	12,040	6,850	7,420	1,580	1,980	29,870
Number of farmers	86	22	23	9	27	167

Topdressing and Improvements.—An area of 17,690 acres, or 70 per cent. of the area under pasture, is now top-dressed each year at an average rate of 140 lb. per acre. If the 86 dairymen are grouped with fourteen mixed farmers with whom dairying is an important activity, to give a group of 100 farms carrying dairy cows, the properties on which less than 50 per cent. of the farm is top-dressed carry one stock unit per 3.4 acres, compared with an average of one stock unit per 2.0 acres for properties on which more than 50 per cent. is top-dressed. Most farmers top-dress their pastures in the autumn, but some of those who use large amounts of superphosphate apply part in autumn and part in spring.

Thirty-five per cent. of the pastures are harrowed annually, generally before topdressing in the autumn. On many farms it was obvious that more harrowing was necessary for the purpose of spreading cow manure.

There are two alternative methods of improving the native pastures. The pasture may be ploughed up and one or two crops, usually oats, rape, or maize may be grown, and in the following autumn a mixture of grasses and clovers sown down—mainly perennial rye grass and subterranean clover. This method is the more expensive but it leads to a first-class pasture quicker than the alternative method, which is to give the rough native pasture a vigorous harrowing and then to sow a few pounds of a mixture of subterranean clover and perennial rye grass, and to repeat this process annually for two or three years. In this way by annual topdressings of one to one and a half cwt. of superphosphate per acre the pasture is gradually improved, and after five or six years the fertility is raised to such an extent that perennial rye grass and white clover persist. This method is less expensive and in the long run it produces as good a pasture as the other, the native grasses being unable to withstand the competition of plants which flourish under the conditions of higher fertility.

Pasture Species.—Subterranean clover and perennial rye grass are the two outstanding plants in the better pastures in this district. Other useful pasture plants, however, have their place, and white clover is the most important of these. Cocksfoot is important on a few properties, particularly on the hills. Strawberry clover does well on the heavier soils along depressions in the flatter country to the south. A few farmers have successfully combined subterranean clover with paspalum (*P. dilatatum*) which makes its growth during the summer after the subterranean clover has died. Other introduced species such as Yorkshire fog, crested dogstail, and sweet vernal thrive in this district, but their value is doubtful. It has been suggested in neighbouring districts that *Phalaris tuberosa* should be introduced on the clay flats, since it could be particularly effective in protecting the soil from puddling by cattle during wet winters. This grass does not appear to be used here as yet.

Chemical Fertility.—1. Phosphorus and nitrogen.—The inherent fertility of the lighter soils is low, and that of the heavier soils on the basalt and on the flats was seriously depleted in earlier years. For 60 years the soil was exploited and no artificial fertilizers were used on the grazing land. Topdressing with superphosphate started about 1920 but was not carried on extensively until 1930, and its use is still increasing rapidly—in fact, over the past three years the total area topdressed has increased by 30 per cent.

The general experiences on the coastal soils in Southern Australia which have been impoverished by centuries of heavy rainfall, is that the fertility must be built up by annual applications of superphosphate combined with subterranean clover, which adds nitrogen to the soil in a readily available form. The Victorian Pasture Improvement League (hereafter referred to as V.P.I.L.) has set up a series of experimental plots at Pakenham, just outside our area, on land very similar to the Hallam loam within the area; the observations made on these plots confirm the general experience of the district, that superphosphate results in a greatly increased growth and is the fundamental fertilizer on this country.

The status of phosphorus and nitrogen in the soil is thus brought to a satisfactory level by the combination of superphosphate and clover. Two other elements, potassium and calcium, are also of interest as possible limiting factors in production.

2. Potassium. The experiments of the V.P.I.L. in the Western District of Victoria have shown that on certain light podzolic soils the growth of pasture is much increased by potash salts. Many podzolic sandy loams in our area are very low in available potassium, and it would not be surprising to find a response to potash on those properties that have been heavily cropped in the past. As yet, however, there is no positive information on this point.

3. Calcium. The whole of the country to the south of the highway, except for the few basaltic ridges, was formerly notorious for "cripples" in stock. This disease appears to be a malformation of the bones due to a lack of calcium. The trouble has disappeared from the district since the introduction of superphosphate, which thus appears to have acted as a source both of calcium and of phosphorus.

Great interest has been aroused by the possibilities of lime. The usefulness of lime on these pastures is still a controversial matter, but apart from some highly acidic patches lime does not increase the growth of grass, and, of course, if lime is applied it can only be considered as supplementary to superphosphate and not a substitute. Though there is no evidence that lime increases the yield of pastures, farmers of sound observation state that the stock prefer limed to unlimed pastures and are generally healthier on limed land. It seems likely that, if this is true, it is due to the provision of the necessary element calcium rather than to the neutralizing of acidity. The applications of lime have been light, of the order of two to three cwt. per acre.

Near Cranbourne in the sandhill country is a patch of 10 acres of land so intensely acidic (pH 3.1 to 3.5) that it will not even support subterranean clover, which is the most tolerant to acidity of all good pasture plants. Pot tests carried out at the School of Agriculture on samples of this sandy soil showed that about one ton per acre of lime was needed before subterranean clover and rye grass could persist. Such extremely acidic soil, however, is exceptional, and is not likely to be found in more than a few small patches.

Seasonal Growth.—Pastures produce a marked maximum of growth in the spring in this district, as elsewhere in southern Australia. The yields obtained on the experimental plots of the V.P.I.L. at Caldermeade are of interest in this respect. (Caldermeade is about 12 miles south-south-east of Pakenham, and is the only station of the V.P.I.L. making quantitative measurements which is near our area.) The pastures here are cut at convenient intervals and weighed; and the yield between mid-August and mid-November regularly amounts to two-thirds of the total for the year. Further, the yield in early summer (to the end of December) accounts for more than half of the remainder. The surveyed area probably shows an even sharper maximum in spring than does Caldermeade, where conditions are more favourable for growth into the summer. Dairymen supplying whole-milk to Melbourne have to meet the milk contracts all the year round, and hence it is desirable to overcome the effects of these major fluctuations if possible. The obvious way to do this is to conserve surplus pasture growth in late spring for use in the winter months when pastures are almost dormant. Conservation of meadow hay therefore constitutes a very important phase of the operations on the average dairy-farm. Sheep and cattle graziers usually stock more heavily during the spring flush, rather than conserve surplus growth as meadow hay. The various forms of supplementary fodder used on the farm may now be considered in turn.

FODDER CROPS.

Meadow Hay and Oaten Hay.—Fifty-eight dairy farmers grow oats, covering 660 acres and yielding about 1,200 tons. The varieties usually grown are Algerian for hay and Mulga for green feed. Except for these dairymen, oats are hardly grown at all, and the dairymen themselves have been steadily substituting meadow hay for oaten hay over the past few years.

Table VIII expresses the total hay (oaten and grass) conserved on properties in terms of cwt. per stock unit. The mean figure on the dairy farms is 16 cwt. per stock unit; on these

TABLE VIII.—DISTRIBUTION OF FARMERS ON BASIS OF CWTS. OF HAY CONSERVED PER STOCK UNIT.

Cwts. per Stock Unit.	Number of Farmers of Given Occupation.					
	Dairy.	Sheep.	Mixed.	Beef Cattle and Agistment.	Miscellaneous.	Total.
0	12	11	7	7	23	60
1–5	11	5	5	1	1	23
6–10	17	3	5	1	1	27
11–15	27	2	3	..	..	32
16–20	11	..	1	..	..	12
21–30	4	..	1	..	..	5
>30	4	..	..	..	2	6
Total	86	21	22	9	27	165

farms milking cows are given practically all the hay so that the figures underestimate the amount of hay conserved per milking cow. Only cautious conclusions can be drawn from the analysis of data collected because the figures are very approximate. This is due to the fact that the acreage of meadow hay cut and the yield per acre vary enormously from farm to farm and on any one farm from year to year. It appears that the average yield of meadow hay is about 25 cwt. per acre in the normal season. Table VIII shows that 36 per cent. of the total farmers conserve no hay and another 36 per cent. conserve each year between 1 and 15 cwt. per stock unit. This table shows how conservation of hay is almost confined to dairymen and mixed farmers, and even on the mixed farms the hay is conserved mainly for feeding dairy cattle.

It appears that even on dairy farms the amount of hay conserved is usually only sufficient to meet the normal winter requirements and there is very little reserve to cope with abnormally dry conditions such as those experienced during 1938. On all other types of farm the farm income could be increased considerably by conserving at least some of the surplus growth of the pastures in spring for the supplementary feeding of stock during the periods of limited pasture growth.

Green Crops.—The main crops under this heading are maize and millet grown for dairy cows, and rape, millet and mustard for sheep and fattening lambs. In favourable seasons oat crops are sown early in the autumn and give some useful winter feed to milking cows, as well as providing hay later in the year.

The acreage of maize and millet has decreased considerably over the past few years. This decrease may be correlated with pasture improvement. After ploughing up rough native pasture farmers would grow maize, millet, oats or rape for two or three years before sowing down to permanent pasture. Most of the productive area has now been treated in this way and farmers do not like ploughing up good pasture for the purpose of growing green crops or oaten hay.

Maize and millet are confined to 67 of the 100 farms on which dairying is a major activity. The respective areas under these crops are 430 acres and 300 acres; the total area works out at about 1 acre per three milking cows. By far the greater amount of these crops is chaffed with meadow hay and fed in the bails though on some farms the maize is cut and strewn in the pasture paddocks and the millet fed off. In addition to maize and millet, small areas of other crops such as mangolds, sudan grass and oats for green feed are occasionally grown.

About 25 per cent. of the sheep men grow some rape (usually 10 to 20 acres each) for fattening lambs and "topping off" store sheep, but this is the whole sum of the green crops grown by graziers.

Ensilage.—Only 5 per cent. of the farmers make ensilage of any description. Crops used for this purpose include maize and surplus pasture growth of all types. The silage is usually made in stacks, rather than in silos or pits.

Fodder Bought.—A great deal of fodder is bought for the supplementary feeding of milking cows during the periods when pastures are making little growth. Most dairymen rely to some extent on hay and green crops grown on the property and buy additional fodder according to the season. The quantities of such purchases are very variable. The weather was abnormally dry in 1938, and pastures made very poor growth. Hence farmers bought very large amounts of feed (mostly brewer's grains, bran, pollard, and chaff) in an attempt to maintain the milk supply of the herd and fulfil the contracts.

Amount of Stocking and Intensity of Stocking.

For the consideration of these two phases a stock unit was taken as one milking cow and factors were then adopted to convert other types of stock into stock units. The factors used are shown attached to Table IX, which indicates the number of stock units per farm. This number is, of course, considerably larger on the sheep and mixed farms than on dairy farms since the former are much bigger farms. However, dairying is represented by a greater total number of stock units than any other occupation in this district.

TABLE IX.—DISTRIBUTION OF FARMERS, EXCLUDING ORCHARDISTS AND MISCELLANEOUS GROUP, ON BASIS OF NUMBER OF STOCK UNITS PER FARM.

Number of Stock Units per Farm.	Number of Farmers of Given Occupation.				
	Dairy.	Sheep.	Mixed.	Beef Cattle and Agistment.	Total.
0–15	5	2	..	..	7
16–30	23	3	1	..	27
31–45	22	..	4	2	28
46–60	18	2	..	2	22
61–75	8	..	2	1	11
76–90	4	1	1	1	7
91–105	2	7	1	1	11
106–120	1	1	2	..	4
121–150	1	1	5	..	7
151–180	..	1	2	..	3
181–210	2	1	..	2	5
> 210	..	3	4	..	7
Total Farmers ..	86	22	22	9	139
Total Stock Units ..	4,020	2,630	2,930	810	10,390

The figures in the above table have been calculated using factors as follows:—One "stock unit" comprises 1 dairy cow, 1 dry cow, 1 heifer or steer over 9 months old, 1 horse, 2 calves under 9 months old, 10 sheep, or 15 lambs.

As may be seen from Table X, 60 per cent. of farmers carry stock at the rate of between 1.5–3 acres per stock unit. This table also shows that on the smaller properties (less than 100 acres) the intensity of stocking is greater than on the larger properties. The intensity of stocking is not markedly correlated with occupation, but it is highly correlated with the degree to which pastures have been improved and top-dressed. A particularly interesting fact is the absence of any connexion between carrying capacity and soil type on the more improved properties. Prominent farmers agree with our observations that with intelligent management the poorer podzolic types will carry as much stock as the richer basaltic types.

TABLE X.—DISTRIBUTION OF FARMERS, EXCLUDING ORCHARDISTS AND MISCELLANEOUS GROUP, ON BASIS OF ACRES OF PRODUCTIVE LAND PER STOCK UNIT AND SIZE OF HOLDING.

Acres of Productive Land per Stock Unit.	Number of Farmers Holding Acreages as Below.						
	20–99.	100–199.	200–299.	300–399.	400–599.	> 600.	Total.
< 1·5 ..	3	1	3	1	...	..	8
1·5–2·0 ..	14	1	3	..	1	..	19
2·0–2·5 ..	14	8	6	3	1	2	34
2·5–3·0 ..	9	9	5	2	2	1	28
3·0–3·5 ..	7	11	4	2	1	1	26
3·5–4·0 ..	1	6	1	1	1	1	11
4·0–5·0 ..	2	4	2	..	..	..	8
5·0–6·0 ..	2	2	..	..	..	..	4
Total	52	42	24	9	6	5	138

MISCELLANEOUS.

Subdivision.—The extent of subdivision ranges from an average of seven paddocks per property of less than 100 acres, to sixteen paddocks per property of more than 400 acres.

Water Supply.—The main source of water for stock is from dams. In addition many properties are served from water reticulated or fed direct from the two large creeks (Cardinia and Toomuc) running through the area. About 30 farmers have tapped the Mornington Peninsula Pipe Line; this, of course, ensures a permanent supply of water. In the flat and undulating country to the south many farmers have sunk bores and generally obtained an excellent supply of permanent water, at depths ranging from 30 to 80 feet.

Approximately a quarter of the farmers have an inadequate supply of water; that is, insufficient to cope with normal requirements during an average summer. Another quarter have a fairly good water supply from dams and creeks which is sufficient to cope with a normal summer but may fail during abnormally long periods of dry weather. About half of the farmers have a permanent supply of water; this includes farmers who have tapped the main pipe line and those who have a frontage on either Cardinia Creek or Toomuc Creek, and also about twenty men (mostly in the south) who have a more or less permanent supply of bore water.

Machinery.—The number, type and standard of implements on each property varies greatly. On practically every property apart from a few leasehold and "miscellaneous" farms, there are sufficient implements to carry out routine farm work such as ploughing, cultivating, sowing of crops and top-dressing. However, many farmers do not possess the implements necessary for making hay and do this work either by contract or with borrowed machinery. A development over the past three or four years has been the introduction of the sweep in haymaking. On most farms horses provide the power necessary for doing the farm work.

Windbreaks.—Bleak winds associated with antarctic storms occasionally blow from the westerly quarter during the colder months of the year. The chilling effect of these winds probably reduces the output of the dairy cows during the winter, and there is a risk of losing sheep after shearing in the spring through a sudden spell of cold wind. However, the desirability of plantations to serve as windbreaks for the stock in the paddocks has been appreciated only during the last few years. About 60 per cent. of the properties to-day carry plantations of fast-growing trees such as cypress.

CLOSER SETTLEMENT.

Since the early twenties the Closer Settlement Board has been active in buying land in various parts of Victoria, for the purpose of settling returned soldiers and others who could not otherwise afford to buy a property. Much of this land in Southern Victoria was divided into holdings of 100 acres or more, on which an efficient settler could dairy successfully. Other areas were cut up into smaller blocks (10 to 30 acres) designed for market gardening. These holdings were made available to settlers under long-term agreements which were more generous than the private purchaser would receive.

There have been three such areas in the district under survey. One of these areas was situated 1½ miles south-east of Officer but settlement did not take place and the small blocks reverted to larger holdings. A second, at Narre Warren North, has been fairly successful, and several flower-growers and market-gardeners are established there to-day. The third and largest undertaking was in Hallam Valley (see map, fig. 7, for boundaries within our surveyed area). This was one of the unsuccessful attempts at closer settlement in Victoria, and is considered here in more detail.

Hallam Valley Settlement.—The State Rivers and Water Supply Commission was responsible for the subdivision in Hallam Valley in 1927. The subdivided area runs just south of, and almost parallel to, the main Gippsland railway line, from Hallam station to Berwick station. The area here surveyed includes only sections 3A and 4 of this scheme. These are identical with allotments 25 and 26 in the Parish of Berwick, which were sold to the State Rivers and Water Supply Commission in 1924 for £15 to £18 per acre. This price reflected the optimism of the period, since the flat country was covered with dense tea-tree and was periodically waterlogged, while the rising land, which was naturally poor, had been cleared of timber but not otherwise improved.

The Commission cleared the swamp area of scrub and subdivided the land. The part in which we are here interested, comprising 1,153 acres, was cut up into 67 blocks, on most of which houses were built. The area of these blocks ranged from 12 to 26 acres, with an average of 17 acres; this small size was suitable for the intended occupation, namely, growing vegetables.

Two large drains were constructed through the settlement to carry off flood waters and natural drainage. The effectiveness of the drains was increased by the construction of levee banks. In addition, on the flatter and wetter parts of the settlement sub-surface drainage was assisted by 3-in. pipe drains. A network of roads was constructed and some were equipped with concrete drains. As the settlement was principally designed for market gardening, a system of water-supply pipes was installed on many blocks. Water was obtained by tapping the main pipe-line of the Mornington Peninsula water-supply scheme. The total capital cost of all these improvements was added to the initial cost of the land, bringing the cost to the settler to about £60 per acre in some cases.

The history of the settlement was disastrous. Within three years settlers were leaving, and by 1936 none of the original settlers remained. On the original 67 blocks there are now 32 houses only. Most of the holdings reverted to the Closer Settlement Board, and many of them have been resold; six farmers to-day own 35 former blocks between them. One is a market gardener, the others are small dairy farmers and apparently are quite successful. This grouping of blocks into dairy farms of 60 to 90 acres would appear to be the ultimate fate of this settlement. Several of the small blocks are vacant at present, and a few are held by men running poultry in small numbers. The rest of the houses are occupied by invalid soldier pensioners who may run a few cattle on agistment but otherwise do not use the land.

In reviewing the causes of this failure, one must recognize that market gardening requires an exceptional amount of knowledge and skill. The special features of districts around Melbourne in this respect have not yet been described in a publication, but it is certain that there is a great deal of special information which is jealously guarded by many of the producers. Without such special knowledge success would be achieved only by the painful process of experimentation based on trial and error, and it appears that the settlers had little previous experience. It would have been difficult for them to pay for water and to meet the high interest charges during such a period of trial. Further, while low prices were mainly responsible for the failure, there were local problems, associated with the two soil types which are found here—namely, Hallam loam (p. 189) on the rises and the strongly contrasted Eumemmering clay (p. 191) on the reclaimed swamp.

Hallam loam is a grey podzolic soil of low fertility, being poor in several essential elements. Moreover, it has a silty texture and tends to set to a hard surface after being saturated with water. It is, of course, common for market gardeners to work with poor and light soils and to add large amounts of fertilizer and manure, and in fact there are many successful vegetable growers nearer Melbourne whose soils are similar to Hallam loam. However, the land at Hallam Valley has no advantage to offset its greater distance from the city. The value of the land is also diminished by concentrations of salt on many of the lower slopes. The patches of salty land are larger and more numerous than elsewhere in the district, one patch covering about 10 acres.

The chemical fertility of Eumemmering clay is not low by Victorian standards. Its physical properties, however, lead to difficulties in working the soil. As with other clayey soils, expert judgment is needed in choosing the right degree of moisture for a cultivation. In a wet winter the soil remains permanently wet and gets badly puddled. The subsoil consists of such impermeable clay that the drains at a depth of 3 feet are not at all efficient. Since the soil retains large amounts of water, the loss of heat involved in the evaporation of this water in spring and summer keeps the temperature of the soil relatively low. On this account early crops are not possible, and vegetables come on the market in competition with all other mid-season or late districts, when low prices often prevail. In such conditions, only the most favoured localities can remain in production, and this area does not seem to have any competitive advantage over districts at a similar distance from the city. One naturally compares this area with the reclaimed swamp land round Kooweerup, which is a major source of mid-season vegetables for Melbourne and is a few miles further away. The better soil types of Kooweerup, however, are much superior to the Eumemmering clay.

V. Land Utilization: (B) Individual Occupations.

Dairy Farmers.

There are 86 farmers who derive more than 80 per cent. of their farm income from dairying. In addition, fourteen of the mixed farmers derive a considerable part of their farm income from dairying, and hence 100 farmers, or more than half the total in the district, are to some extent dairymen. These 100 "dairy farmers" are considered together in this section except in Table XI., which refers to the activities of the 86 full-time dairy farmers.

Table XI.—Distribution of Dairy Farmers on the Basis of Number of Milking Cows and their Percentage of Total Stock Units.

Number of Milking Cows.	Percentage of Total Stock Units.							Number of Farmers
	0–39.	40–49.	50–59.	60–69.	70–79.	80–89.	90–100.	
0–9	..	..	..	3	2	..	..	5
10–14 ..	..	..	3	2	..	1	..	6
15–19 ..	..	..	3	6	6	2	..	17
20–24 ..	..	1	1	6	..	..	..	8
25–29 ..	..	..	4	5	3	2	..	14
30–34 ..	..	2	4	4	4	2	..	16
35–44 ..	..	1	1	2	2	1	..	7
45–54 ..	..	..	3	4	1	..	1	9
55–74 ..	..	..	1	..	..	..	..	1
75+	..	1	..	1	1	..	..	3
	0	5	20	33	19	8	1	86

Size of Herd.—It will be seen from Table XI. that the predominant size of herd is 15–35 cows, and that the milking cows make up between 50 and 80 per cent. of the total stock units. The totals for the 86 dairymen are 2,504 cows and 4,020 stock units. The average size of herd would be little affected by including the full 100 dairymen in this table.

Stock Diseases.—There is not much detailed information available about stock diseases but evidently disease is not a major factor. In the interests of public health the Milk Board keeps a strict supervision over the source of Melbourne's milk supply. It is, of course, known that contagious abortion, mastitis, and tuberculosis do occur, but farmers are naturally reticent in giving information.

Breeds, Herd Improvement and Yields.—There are only two pedigree herds (both Jersey) amongst those considered. Most of the cows are mixed dairy types with a very large proportion of Jersey blood. Thirty-four of the farmers use pedigree bulls of which 21 are Jerseys and 9 are Guernseys. The remainder use bulls of mixed ancestry, usually with Jersey predominating.

A peculiarity in this district is the extent to which farmers buy cows in the Dandenong Stock Market. Information supplied by farmers suggests that the average annual replacement is in the region of 20 to 25 per cent.. About 45 per cent. of farmers breed enough stock for replacement, but under the conditions of a milk contract it is essential to buy extra milkers during the winter and at any other time when production falls below the minimum set by the contract.

Ten of the farmers have their herds regularly tested for butterfat; of these seven are members of the Pakenham Herd Testing Association and the remainder test privately. Very little information regarding yields is available. However, estimates of the yields of fifteen herds (including the ten herds cited above) comprising about 500 cows show the average production to be approximately 270 lb. of butterfat per cow, per annum. These include some of the best farmers in the district, so that the average for the whole district is probably far below this figure. Thus it appears very likely that herds could be much improved by the incorporation of the progeny of tested parents bred on the property. It might be argued that this is a wholemilk district, for which butterfat tests would be of little value, but even so it is surprising that farmers should not even weigh the milk of the members of the herd.

Milking Machines.—Only ten of the farmers use milking machines. Eight of these use a 3-unit plant, but two farmers with large herds have 5-unit plants. On the other 90 farms the milking is done by hand, in most cases by the farmer and his family. One reason that has been given against the use of machines is that some dairy retailers refuse to accept milk so obtained, since they believe that it is necessarily contaminated. Whatever truth there is in this assumption is probably due to lax methods of cleaning the plant. This does not seem, however, to be the main factor responsible for the prevalence of hand-milking. The reason appears rather to be that the initial cost of machines is high, and family labour is usually available; in fact, 85 per cent. of the total hand-milking is done by the farmer and his family, at an average of one milker to eleven milking cows. Wage ratings for dairy farm-labourers in this district are in general 25s. to 30s. per week plus keep, and it seems likely that this wage level would not be attractive to skilled men.

Pigs.—Little accurate information concerning pigs is available. Pig raising is confined to the 29 dairymen who produce cream. From the approximate figures collected it appears that these farmers annually breed and fatten one to two pigs per milking cow. This figure varies from year to year, and from one property to another, depending on such factors as the number of calves reared, the productivity of the herd, and the expenditure on extra feed, such as barley. The number of pigs fattened depends also on whether they are sold as baconers or porkers; the latter is the more usual. Some of the principles of pig management are not fully appreciated; many farmers feed only skim milk to the pigs, and do not attempt to balance the ration with cereals high in carbohydrates. It seems likely that this is one of the sidelines of the dairying industry which could be more profitably exploited.

Destination of Milk Products.—Thirty-five of the 100 farmers send all their milk to Melbourne dairies, and eleven send it to local butter and cheese factories. Twenty-five send their milk to Melbourne dairies, and sell some of their spring surplus to local butter and cheese factories. The remainder (29) keep pigs and sell cream to local or suburban butter factories. The local butter and cheese factories pay for wholemilk on a butterfat basis, paying slightly more per unit of butterfat for milk than for cream. This small margin, it is claimed, compensates for loss of profit from pigs.

There is no doubt that supplying wholemilk to Melbourne pays better than selling cream, or than supplying wholemilk to local factories. However, the former system has several drawbacks, the chief of which is the expense incurred through buying extra feed and also extra cows during the winter months to maintain the production above the minimum required by the contract. It is very desirable to do this, as the Melbourne retailer throughout the flush period in the spring and early summer commits himself to accept only as much milk as was supplied on the average throughout the winter. By bringing cows into production all the year round, and by buying more cows during the winter, the wholemilk producers avoid the necessity of having to sell a large spring surplus to the butter factories. Second in importance probably are the regular and often inconvenient hours which have to be kept because the milk has to be ready when the milk wagon calls. Thirdly, such dairy farmers have to work all the year round, and cannot "dry off" most of the herd during the winter months. Fourthly, fodder taints, such as that attributed to subterranean clover, give difficulty during the spring. Such taints are much more serious in wholemilk than in cream supplied to a butter factory. These and other minor factors tend to make the costs of producing wholemilk for the Melbourne supply considerbly greater than the cost of producing cream for manufacture into butter, but the increased returns much more than compensate for this.

Conclusions.—To sum up, it appears that the production in dairying could be considerably increased. In fact, the very lack of numerical information concerning production confirms this statement, since it shows that the breed of the cows is not being deliberately improved, and this is probably the weakest feature of the industry. The farmers do not generally breed their own cows, and those who do breed do not usually select them; if they did so select, the total production would probably be lower for the time being, and the rental value of the land may be too high to allow for the long-range policy of improving the breed.

MIXED FARMERS.

Information as to the activities of the mixed farmers is contained at various points in this paper. With two exceptions they combine dairying with sheep-raising; one combines dairying with orcharding, and one combines dairying with raising beef cattle.

SHEEP FARMERS.

General.—Information relating to the operations of sheep farmers may be obtained from the composite tables. Figures indicating the amount and intensity of stocking are not as reliable as the corresponding figures for dairy farmers because the number of stock on a sheep farm is continually changing. This is due to the fact that the farmer breeds lambs and buys "store" sheep which are sold when fat. Observations suggest that the fluctuations in numbers of sheep on the property are closely correlated with the growth curves of pasture as given in V.P.I.L. Reports. (See p. 204.) The difference between dairy and sheep farmers in this respect is that the dairymen conserve some of the surplus spring growth as meadow hay and feed it to the cattle in the winter. The sheep farmers, on the other hand, have many more stock on the property during the spring flush and sell these extra stock when pasture growth falls off.

In addition to the 22 full-time sheep farmers there are 22 "mixed" farmers interested in sheep, of whom eleven devote more than 50 per cent. of their property to sheep. Thus of 44 farmers grazing sheep 33 derive more than half of their farm income from this source. Some of these men concentrate solely on breeding and fattening lambs; others produce some fat lambs, and in addition buy and fatten store wethers and weaners. There are also some who run stud sheep. There are nine small studs of English breeds which provide sires not only for the farmer's own main flock but also for sale to other farmers in the district.

The wool clip is an important asset to all these men, but it does not constitute the main part of any farmer's income in this district, although farmers naturally pay considerable attention to the quality of the wool in their choice of breeding stock. The land has a high price, and this appears to determine its use for fattening sheep rather than growing wool. The wet and frequently bleak weather of the three winter months is also considered unfavourable to the fine-woolled breeds with their liability to footrot, though the winter here is probably less severe than in some of the wool-growing parts of the Western District of Victoria.

The Flock.—Considering the diversity of this occupation and the great fluctuations in the numbers and types of sheep on each property it is difficult to present in tabular form an accurate picture of the numbers of sheep. However, on the 44 farms considered there are approximately 22,000 breeding ewes which produce about 80 to 85 per cent. of fat lambs. In addition, about 5,000 store wethers are fattened annually. Comparison of the figures collected shows that on dairy farms the stocking is rather more intense than on sheep farms.

Approximately 80 per cent. of the sheep farmers have breeding ewes which are crossbred between the fine-woolled Merino and the meat-producing English types; the remainder have either Comeback, Merino, or English breeds of ewes. The crossbred produces a good class of wool and also stands the winter fairly well. Approximately 50 per cent. of the rams used for mating with these ewes are Southdowns; Border Leicesters are next in favour.

Wool Clip.—It is difficult to give definite information here because of the fluctuations in the number of sheep from year to year. The 1938 season was particularly unfavourable for collecting such information, because a number of sheep from Northern Victoria were being grazed in this district on agistment.

Diseases and Flock Management.—The incidence of disease is fairly low. In fact, the work associated with keeping the sheep healthy and in good order is carried out more efficiently than is the improvement of the pastures. Of the common diseases affecting sheep, footrot is easily the most important, especially on the flatter and badly drained properties. Other disorders such as liver fluke, lung worm, pulpy kidney, and blowflies cause a certain amount of trouble. The lambs are normally born from late June to August, and sold from late December to March or April. The time at which the sheep are shorn varies from early October to late November.

Beef Cattle and Agistment Farmers.

Of nine such farmers in the Berwick District, seven own their properties and run their own cattle, the other two take in agistment stock, which are mostly beef cattle. This number is too small for attempting statistical treatment, and so generalizations only can be made. However, some information on the operations of these graziers may be obtained from the various preceding Tables. The average size of holding is 176 acres; the standard of agriculture as shown by the amount of topdressing is comparatively high.

In addition to these men whose main occupation is running cattle, there are several mixed farmers who run some beef cattle, which eat the rough pasture which is not attractive to sheep. The possibility of developing the production of a small number of "baby beef" cattle on dairy farms has not been exploited, probably because the average dairy farm is just large enough to graze a herd which the owner and his family can manage efficiently.

Herefords are kept in the greatest numbers, and next in importance are Shorthorns. Most of the herds are very mixed in type, however, since they include many spayed dairy culls for fattening, also some of the beef men are interested in growing young dairy types up to the "springing stage" and catering for the large demand from local dairy farmers for milkers during periods of low production.

Most beef cattle farmers in the district agree that dairying, or even sheep farming, produces a larger cash return per acre; but, on the other hand, producing beef cattle is a much more congenial occupation.

Orchardists.

The 25 orchardists constitute only a small sample which is perhaps not representative of the many orchardists in the undulating or hilly country east of Melbourne. Most of the orchards in the surveyed area were planted between 1915 and 1922, and the majority of the present holders are the original settlers. The settlers spent much capital and energy in clearing the timber before planting their orchards. The cost of clearing was undoubtedly high, although no exact figures are available; and this cost, plus the living expenses for the five or six years during which the young fruit trees were growing and giving no return, consumed the holders' reserves or involved them in debts which were to prove a burden in the years to come.

Topography and Soils.—Orcharding is the only occupation in this district which is associated with particular soil types. Twenty-two out of the 25 orchards are on the Silurian phase of Hallam loam (described on page 189) situated on gentle to moderate slopes, and the other three are on Harkaway sand (page 187), derived from granodiorite.

Cultural Practices.—The owners do the regular work of the orchards themselves and employ very little permanent labour. They do, however, employ a good deal of casual labour for five or six weeks during the height of the picking season. The routine operations of the orchards call for little comment.

Every orchardist has, in a normal season, sufficient water for spraying. Seven out of the 25 orchardists also conserve sufficient water in dams to irrigate some of the trees. Irrigation is confined to the variety Yates as a rule, in order to get the fruit on these up to commercial size. Yates trees receive six to eight waterings during the summer, depending on the season and the supply.

The usual application of fertilizer is five or six pounds per tree of a mixture consisting of superphosphate, sulphate of ammonia, and chloride of potash, in the proportions 2:2:1. Most orchardists apply half a ton of lime per acre every two or three years. In some of the orchards the trees show only mediocre growth due to insufficient applications of fertilizer, in most cases because of the owner's lack of capital. A curious problem with which a few orchardists have to contend is the presence of land crabs or "yabbies." The crabs in the heavier low-lying flats excavate large holes (up to 30 inches in diameter) 2 or 3 feet below the surface. In wet weather the holes fill up with water and the sub-surface drainage problem is accentuated. Pouring solutions of copper sulphate down the tunnels is said to be effective against the crabs.

Size of Orchard.—The size of the holdings and the orchards is summarized in Table XII, in which one "mixed farmer" is included with those who are purely orchardists. These 25 orchardists hold 1,300 acres of land of which 370 acres are planted to orchard, 700 acres are cleared and in pasture, and the remaining 230 acres are still uncleared bush.

TABLE XII.—DISTRIBUTION OF ORCHARDISTS ON BASIS OF TOTAL HOLDING AND OF AREA PLANTED.

Distribution on Basis of Size of Holding.		Distribution on Basis of Area of Planted Orchard.	
Size in Acres.	Number of Orchardists.	Size in Acres.	Number of Orchardists.
20–40	12	3–9	3
40–60	7	9–13	10
60–80	2	13–17	4
80–170	4	17–21	5
		21–45	3

Varieties.—The most common varieties originally planted were Jonathan, Yates, and Delicious. These varieties are still very popular; but over the past six to eight years many old stock such as Reinette, Gravenstein, and Yates, have been reworked to Granny Smith. Yates has declined in popularity, partly because its good keeping qualities have become less important since cool storage developed, and partly because of the additional work involved in thinning and irrigating.

The present acreages of the several varieties are as follows:—

Jonathan	118
Granny Smith	68
Yates	63
Delicious	26
Miscellaneous—Democrat, Gravenstein, &c.	31
Young trees not yet full bearing	60

There are also 14 acres under pears, cherries, peaches and lemons.

Yields.—It appears that in this district there are large variations in the average yields between one orchard and another, and also on any one orchard from season to season. Fairly accurate figures for yield were available for 20 of the 25 orchards, and the average of these was 1.5 bushels per tree, or 150 bushels per acre. As some of the orchards average 2 to 3 bushels per tree it would seems that production for the district could be increased considerably.

Soil Fertility.—The natural chemical fertility of these soils is low; further, they are liable to erode, and the presence of stones up to 3 inches in length makes for difficult working, and increases the wear and tear on implements. It is a tradition in Victoria that fruit trees should be planted on poor country. The chief merit of this appears to be that the fruit from such trees keeps better in cool storage, but this hardly compensates for low yields, although other districts with somewhat similar soils and more favourable slopes have achieved a fair success.

Drainage.—Three hundred and twenty acres, or 87 per cent. of the area planted to orchards is tile-drained. The upper soil is loamy and permeable to a depth ranging from 6 to 15 inches, and the subsoil is a heavy clay; but many of the drains have been sunk too deeply into this clay, so that the improvement caused by drainage is not so general as one might have expected. In addition, some of the drains run in the direction of greatest slope and so lose most of their effectiveness.

Erosion.—It appears that on the stony Silurian soil, if the slope is greater than 5 degrees and the soil is cultivated there is a great tendency to erode. Since many of the orchard slopes are as steep as 10 degrees a great deal of surface soil is eroded and the fertility of the upper slopes is depleted; in fact, in some places the trees are now growing on the subsoil, all the surface soil having been washed away. It is obvious from the topography that much of this hill country should never have been devoted to a type of agriculture in which the soil is fallowed during the summer months. However, the capital has been expended and the difficulty now is how best to control erosion and increase fertility. It is said that the worst damage is done by thunderstorms in summer when the land is bare. The records for Melbourne show that a fall of at least half an inch of rain in an hour occurs on an average three times in four summers, and a fall of at least an inch in two hours occurs once in four summers. The corresponding figures for this orchard country are not known, but the frequency of heavy falls is certainly greater than in Melbourne.

Erosion can probably be minimized by cultivation along the contours instead of in the direction of the greatest slope as at present. However, some orchardists maintain that this hampers drainage, and the trees eventually die through "wet-feet." The accuracy of this latter statement has not been verified.

The possibility of planting trees along contours in order to facilitate contour ploughing, as has been advocated in other countries, has not been explored in this district.

Economic Position.—The orchardists of this district share in the general financial difficulties of the apple industry. Many of them have been particularly unfortunate, since after undertaking the heavy initial cost of clearing, draining, and planting, and providing for themselves during the five or six years while the young trees were still not producing, they were faced almost at once with low prices which did not allow them to recover their outlay. Further, while fertilizers and sprays involve a heavy annual expense, yields are generally not high, and many orchardists spend considerable labour and money in scooping back the soil that has been washed down the slopes. In these circumstances, and in view of the unlikelihood of any great rise in the price of apples, it appears that the only possible avenue of relief for many of these men is to supplement their income with sidelines. This possibility has not been exploited in the past; except for one man who is doing some poultry farming, another who has a tractor and is doing contract work for his neighbours, and two others who do some dairying, all the orchardists in this district depend almost solely on orcharding for a living. By keeping a few poultry and perhaps a few dairy cows they could increase their income substantially. It appears that if within the next few years the farm income is not increased by either higher yields or supplementary income from sidelines, then many of these orchardists must be absorbed in other industries.

Miscellaneous Farmers.

Of the 28 miscellaneous farmers only nine depend solely on their property for their income. Of these four are market gardeners, three are flower-growers, and two run poultry.

There remain nineteen holdings in this miscellaneous section, whose occupiers do not derive their main income from the property. Except for four owners who do not use their land at all, the small property is really a worker's home, and in addition provides a small income from the few dairy cows, and occasionally from stock on agistment. These men derive the rest of their income from other sources; viz., wages for work done for neighbouring farmers or for such bodies as the Country Roads Board, or alternatively from running a business in one of the local townships. As the means by which the miscellaneous farmers obtain their living are very diverse it is difficult to present in tabular form a picture of their activities. However, Table V shows that 86 per cent. of such properties are owned, and Table VI that most of the owners have been on their present properties for several years. While almost all the land held by such farmers is productive, the standard of farming is low. Pastures are poor, and there is little top-dressing or conserving fodder for the winter. This is not surprising where the owners have little capital and have other sources of income.

General Conclusions.

The area as a whole provides an example of the extent to which naturally poor country can be economically converted into good pasture land in a district of fairly generous rainfall. During the first half-century of settlement farmers increased their production by clearing fresh land rather than by intensifying production on land already cleared. More recently, however, intensification has become the rule; improvement with superphosphate and introduced pasture plants has been particularly rapid since about 1933, and is still progressing. There seems to be no reason, other than shortage of capital, why all the flat or gently sloping land should not be brought up to the carrying capacity of the better dairymen—namely, the equivalent of one cow to 2 acres; it should be possible for dairymen working at this capacity to confine their purchases of additional fodder to a protein supplement for two winter months. The present rate of stocking is approximately one cow to 3 acres. Such an improvement is independent of the further need for raising the quality of the cows.

The amount of cropping has never been great, and has declined for several years past. Heavy crops of potatoes and onions were grown in the early days on the basaltic soils, but these crops are not grown there to-day though they would probably still give good yields. The only cash crops grown in the district are small amounts of vegetables, for which this district does not seem to hold any particular advantage.

The definitely hilly country presents a different problem. This land is not suitable for agriculture, and in some places its exploitation has led to financial loss. Most of this section is probably best left under its present cover of Eucalyptus.

VI. Chemical, Physical, and Mineralogical Analyses of Soil Types.

A few samples were chosen from each main type going to a depth of 3 to 5 feet. Routine laboratory analyses were done on the various horizons of each of these typical profiles.

Mechanical Analyses.

Complete mechanical analyses were carried out on selected profiles from each type of soil. The details are given in Tables XIII to XXI, in which the percentages are in terms of oven-dry soil. The mechanical fractions are defined by the "International" limits, viz., Coarse sand, 2.0 to 0.2 mm.; Fine sand, 0.2 to 0.02 mm.; Silt, 0.02 to 0.002 mm.; and Clay, less than 0.002 mm. These figures have been recalculated to a basis of sand + silt + clay = 100, and the results are expressed diagrammatically for representative samples in Fig. 8. This diagram shows strikingly the sudden transition from the light surface to the heavy subsoil in the podzolic Harkaway, Hallam, and Toomuc types, and the

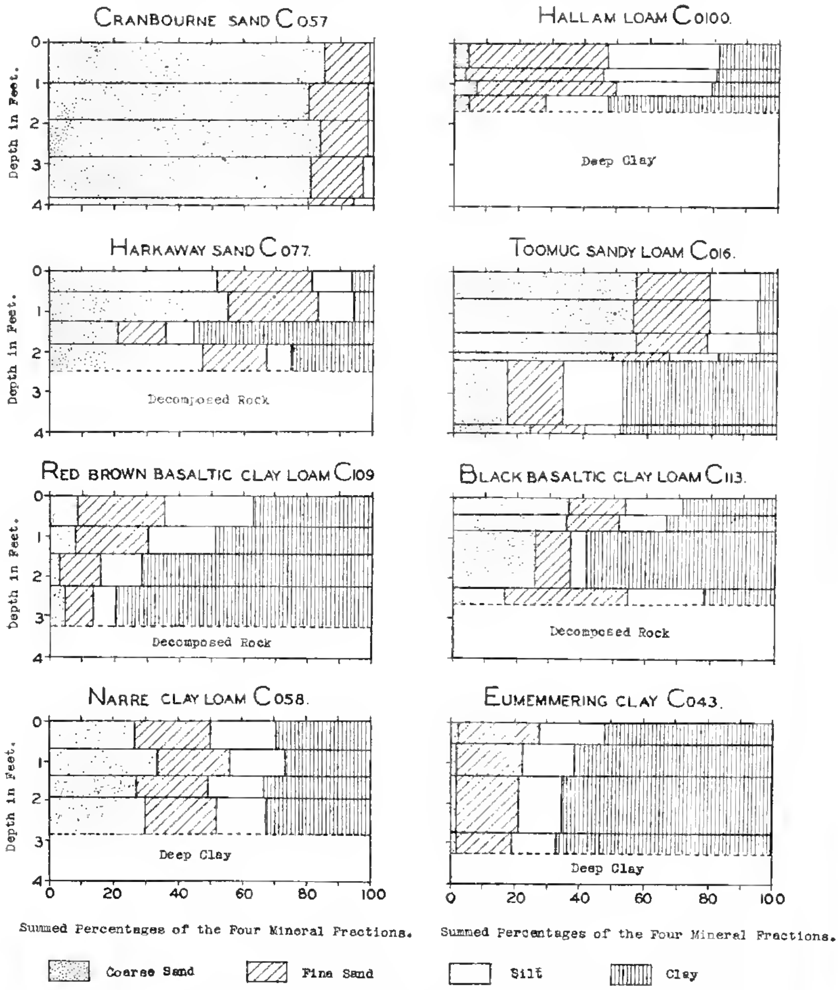


FIG. 8.—Mechanical composition showing in block form the summed percentages of the four mineral fractions throughout the profiles of eight major soil types. (Clay in Cranbourne sand is too small to show separately.)

relatively constant texture, or gradual change of texture through the profile, of the heavier Narre and Eumemmering types and the basaltic soils. The very sandy type, Cranbourne sand, also shows a large relative increase in clay in the subsoil, but the absolute quantity of clay is too small to be marked in the diagram. The ironstone gravel, which occurs above the clay horizon in many types, has been omitted from the diagram since it is not always present in the field. The diagram refers to the same material as is submitted to laboratory analysis—viz., the soil which passes a 2-mm. sieve.

Hallam loam is remarkably high in silt throughout the profile, a property which is evidently due to the silty nature of the Silurian rock from which its material has been derived. This siltiness is connected with the tendency of the surface soil to form clods, and with its erosiveness in the orchards. Harkaway sand, developed from the granodiorite, stands in marked contrast, with a low percentage of silt. This seems to indicate that the granodiorite hills have not played a considerable part in forming the material from which the silty soils of the plain were derived. Narre clay loam includes occurrences in which the subsoil is considerably heavier than in the two type samples.

A zone of maximum accumulation of clay can be seen in Cranbourne sand (C057), and on soils developed over the basalt (C113), the granodiorite (C077) and the Silurian sediments (C041).

The mechanical analyses of representative samples have also been plotted graphically in fig. 9, where the triangular method is

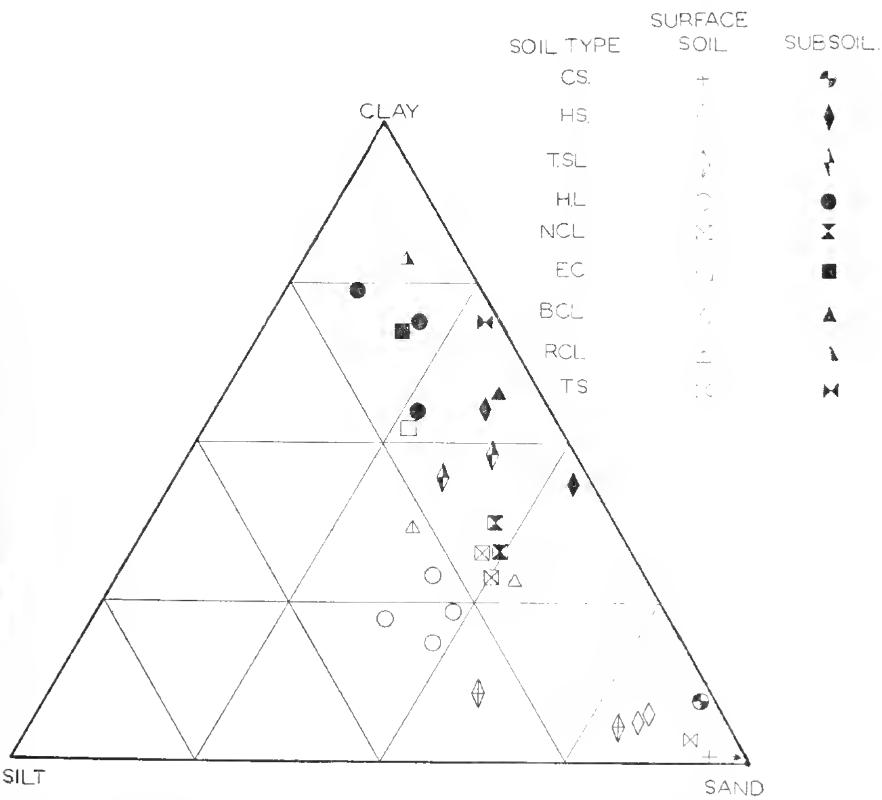


FIG. 9.—Mechanical analysis triangle. Distribution of mechanical compositions of samples of surface soil and subsoil of various soil types.

Explanation of Key.—C.S. Cranbourne Sand; H.S. Harkaway Sand; T.S.L. Toomuc Sandy Loam; H.L. Hallam Loam; N.C.L. Narre Clay Loam; E.C. Eumemmering Clay; B.C.L. Black Basaltic Clay Loam; R.C.L. Red Basaltic Clay Loam; T.S. Toomuc Sand.

adopted by which any mixture of sand, silt, and clay can be represented by a point. This shows in another way such facts as the contrast between surface and subsoil of the podzolic types (the latter lying much closer to the "clay" apex than the former) and the silty nature of Hallam loam, of which all four surface samples lie between the lines for 25 per cent. and 50 per cent. silt.

TABLE XIII.—MECHANICAL ANALYSES OF HARKAWAY SAND.

Soil No.	C013.			C077.			
Horizon	*a*†.	*b*.	*c*.	*a*.	*b*.	*c*.	d.
Depth (Inches)	0–10.	10–21.	21–32.	0–6.	6–15.	15–22.	22–30.
Coarse sand	59·2	61·3	47·6	49·7	54·1	21·3	47·5
Fine sand	22·2	22·3	6·7	28·5	27·9	14·6	19·5
Silt	9·8	8·5	2·5	11·4	10·6	8·6	7·9
Clay	7·5	6·6	43·9	6·0	5·9	55·3	24·8
Loss on Treatment* ..	3·0	1·7	1·5	4·1	1·3	1·3	1·1
Carbon	1·28	0·33	0·45	2·28	..	..	..
Nitrogen	0·11	0·02	..	..	..	..	..
Gravel (Field Sample) ..	..	..	..	..	11·1	2·3	8·5
pH	5·9	5·9	5·7	5·6	5·2	5·2	5·5
Comments	..	..	..	..	..	..	Decomposed Rock.

* This figure includes the organic matter destroyed by hydrogen peroxide in preliminary treatment, as well as the material dissolved at the next stage by dilute HCl.

† The letters *a*, *b*, *c* . . . as used here refer simply to the order of sampling of the various horizons, *a* being the first and *d* the fourth horizon to be taken in a profile. The letters are not meant to suggest any parallel with the technical meanings of *A*, *B*, and *C* horizons.

TABLE XIV.—MECHANICAL ANALYSES OF CRANBOURNE SAND.

Soil No.	C057.						
Horizon	*a*	*b*	*c*	*d*	*e*	*f*	*g*
Depth (inches)	0–12	12–23	23–34	34–46	46–60	60–64	64–66
Coarse sand	83·9	79·6	83·0	79·1	78·0	71·1	78·4
Fine sand	13·2	17·9	14·3	15·3	13·8	15·5	13·6
Silt	0·8	1·1	1·2	2·0	4·6	1·8	3·3
Clay	0·3	0·4	0·3	1·0	1·2	9·7	3·4
Loss on treatment ..	1·1	0·6	0·7	2·2	1·6	2·7	0·9
Carbon	0·89	0·42	..	1·05	1·05	..	..
Nitrogen	0·04	..	..	..	0·05	..	..
Gravel (field sample) ..	..	..	..	..	..	..	..
pH	4·9	4·7	4·3	4·6	4·9	..	4·8
Comments	..	..	..	..	Friable Ortstein	..	..

TABLE XV.—MECHANICAL ANALYSES OF TOOMUC SANDY LOAM.

Soil Number	C016.					
Horizon	*a*	*b*	*c*	*d*	*e*	*f*
Depth (Inches)	0–8	8–18	18–24	24–26	26–46	46–60
Coarse sand	55·6	55·2	56·7	49·3	16·9	23·9
Fine sand	22·8	24·2	22·6	18·3	17·0	17·3
Silt	14·8	14·7	16·0	14·7	18·3	11·2
Clay	5·5	6·1	5·5	18·3	47·8	48·6
Loss on treatment	3·5	1·8	1·3	1·3	1·9	1·1
Carbon	1·07	0·25	0·12	0·27	..	..
Nitrogen	0·06	0·02	..	..	..	..
Gravel (field sample)	..	..	..	..	..	..
pH	5·6	5·4	5·5	5·8	5·4	5·1

TABLE XVI.—MECHANICAL ANALYSES OF TOOMUC SANDY LOAM.

Soil No.	C092.						
Horizon	*a*	*b*	*c*	*d*	*e*	*f*	g
Depth (inches)	0–9	9–14	16–26	26–41	41–54	54–64	64–72
Coarse sand	14·5	23·4	16·3	21·3	9·0	12·2	16·6
Fine sand	40·0	39·8	23·8	29·6	26·7	24·5	21·4
Silt	29·6	25·3	17·3	16·0	19·6	20·6	22·1
Clay	10·2	9·7	41·9	32·2	44·7	42·0	39·9
Loss on treatment ..	3·9	1·8	1·3	1·1	1·1	0·8	0·5
Carbon	2·38	0·81	..	..	..	..	..
Nitrogen	0·15	..	..	..	..	..	..
Gravel (field sample) ..	..	..	..	..	..	..	..
pH	5·1	5·8	5·6	6·2	6·5	6·5	6·7

TABLE XVII.—MECHANICAL ANALYSES OF HALLAM LOAM.

Soil No. ..	C0100.				C041.				
Phase	Normal.				Silurian.				
Horizon ..	*a*	*b*	*c*	*d*	*a*	*b*	*c*	*d*	*e*
Depth (inches) ..	0–7	7–11	11–15	15–20	0–8	8–12	12–18	18–30	30–44
Coarse sand ..	4·6	3·5	6·7	4·5	2·4	2·4	4·8	0·8	0·4
Fine sand ..	40·8	41·8	42·7	22·1	34·2	33·4	31·6	8·6	8·6
Silt	32·0	32·7	29·2	18·9	35·5	33·6	31·4	16·3	35·9
Clay	17·9	19·1	20·5	55·1	21·0	25·2	29·6	72·9	54·6
Loss on treatment	5·3	3·8	2·5	1·4	5·8	3·7	2·7	1·3	0·6
Carbon ..	3·61	2·11	..	..	3·36	1·60	..	..	..
Nitrogen ..	0·24	..	..	..	0·20	0·12	..	..	..
Gravel (field sample) ..	..	..	9·7	1·7	..	..	..	..	..
pH	5·3	5·6	5·6	5·3	4·7	4·4	4·5	4·7	4·6
Comments ..	..	..	..	Deep clay	..	..	..	..	Soft rock

TABLE XVIII.—MECHANICAL ANALYSES OF HALLAM LOAM.

Soil No.	C050.	C038.				
Phase	Normal.	Heavy.				
Horizon	*a*	*a*	*b*	*c*	*d*	*e*
Depth (inches)	0–8	0–6	6–11	11–16	16–21	21–32
Coarse sand	2·9	11·3	2·2	16·8	4·4	6·8
Fine sand	42·5	27·9	42·8	31·3	15·2	15·6
Silt	27·0	26·2	23·8	19·2	11·1	8·6
Clay	22·5	27·2	25·8	30·6	68·1	69·2
Loss on treatment ..	5·5	9·5	5·7	4·0	3·3	1·8
Carbon	3·15	3·55	1·30	0·83	0·93	0·65
Nitrogen	..	0·28	..	..	..	..
Gravel (field sample) ..	..	..	..	35·0	..	..
pH	5·5	5·4	5·5	5·9	5·7	5·6

TABLE XIX.—MECHANICAL ANALYSES OF NARRE CLAY LOAM.

Soil No.	C058.				C042.			
Horizon	*a*	*b*	*c*	*d*	*a*	*b*	*c*	*d*
Depth (inches) ..	0–8	8–16	16–23	24–34	0–9	9–18	18–31	31–57
Coarse sand	24·9	32·4	26·7	29·3	20·6	25·2	23·5	24·3
Fine sand	22·0	21·3	21·6	21·1	23·9	23·1	23·1	22·1
Silt	19·3	16·7	17·2	15·5	17·8	17·2	15·9	15·6
Clay	27·1	25·6	32·5	32·0	30·0	31·9	35·1	36·7
Loss on treatment ..	4·7	3·2	2·3	1·9	5·5	2·6	1·4	1·0
Carbon	3·04	1·34	..	..	2·25	1·23	..	..
Nitrogen	0·19	..	..	..	..	..	..	..
Gravel (field sample) ..	..	..	..	..	..	..	..	..
pH	4·9	5·0	5·1	5·2	5·4	5·3	5·6	5·9

TABLE XX.—MECHANICAL ANALYSES OF TOOMUC SAND AND EUMEMMERING CLAY.

Soil No.	C059.			C043.			
Type	Toomuc Sand.			Eumemmering Clay.			
Horizon	*a*	*b*	*c*	*a*	*b*	*c*	*d*
Depth (inches)	0–14	14–32	32–37	0–6	6–16	16–33	33–42
Coarse sand	64·2	67·0	22·2	1·9	1·5	1·5	1·7
Fine sand	24·3	22·5	6·4	22·8	19·6	18·9	16·6
Silt	6·0	7·5	2·0	18·9	15·5	13·4	13·5
Clay	3·6	2·4	68·0	47·6	58·3	62·3	65·8
Loss on treatment ..	0·8	0·5	0·8	6·8	4·1	2·0	1·7
Carbon	0·84	0·17	..	3·46	2·05	1·06	1·47
Nitrogen	..	..	..	0·24	0·18	..	..
Gravel (field sample) ..	..	..	..	..	..	..	..
pH	4·1	5·5	5·0	5·5	5·8	6·6	6·7

TABLE XXI.—MECHANICAL ANALYSES OF RED AND BLACK SOILS ON BASALT.

Soil No.	C109.				C113.			
Phase	Red.				Black.			
Horizon	*a*	*b*	*c*	*d*	*a*	*b*	*c*	*d*
Depth (inches) ..	0–9	9–17	17–27	27–39	0–5	5–10	10–27	27–32
Coarse sand	8·4	8·0	2·9	4·5	33·4	33·8	24·1	15·3
Fine sand	26·2	23·0	13·1	9·3	16·0	15·8	10·2	36·1
Silt	26·8	20·7	13·6	7·5	16·5	13·7	5·4	22·3
Clay	35·9	48·1	71·3	79·0	26·2	32·1	54·5	20·8
Loss on treatment ..	2·8	3·1	1·3	1·5	6·8	4·5	2·0	2·2
Carbon	3·91	1·72	1·31	0·66	4·22	..	..	..
Nitrogen	0·25	0·12	..	..	0·29	..	..	..
Gravel (field sample) ..	..	..	..	..	..	..	..	..
pH	5·8	6·3	6·1	6·1	5·4	5·5	6·5	7·0
Comments	..	..	..	..	..	..	..	Decomposing basalt

Hydrochloric Acid Extract.

Representative soils were extracted with boiling hydrochloric acid (as in the International method). Analyses of these extracts for potassium and phosphorus (expressed conventionally as K_2O and P_2O_5 respectively) are collected in Table XXII. Though the number of samples analysed from each type is small, some general relations may be pointed out from the figures.

Potassium.—The amount of potassium extracted from a soil by strong hydrochloric acid is generally related to the percentage of clay, and this is the case with these soils also. If we take 0.1 per cent. K_2O as the dividing line between fair and poor soils, the lighter types are low in potassium while the loams and clays (with one exception) have a good store. The high figure for the Silurian rock (C041e) is remarkable. This rock is well provided with potash-rich feldspars, and these constitute a valuable reserve against the impoverishment of the soil by leaching. The degree of availability of the HCl-soluble but non-exchangeable potassium of some of these soils is a matter of great interest. The sandier types (Harkaway, and especially Toomuc) are poor not only in immediately available potassium, but also in their reserves of the element.

The soils formed on the basalt are rather low in extractable potassium; however, the roots of plants growing on most of the soils can reach the layers of decomposing basalt, which contain primary minerals carrying rich reserves of potassium.

Table XXII.—Potassium and Phosphorus Dissolved by Boiling Hydrochloric Acid.

—	—	Depth (inches).	K_2O	P_2O_5
Harkaway sand	C013*a*	0–10	·07	·019
	c	21–32	..	·010
Cranbourne sand	C057*a*	0–12	·012	·005
Toomuc sand	C059*a*	0–14	·015	·006
Toomuc sandy loam	C016*a*	0–8	·021	·016
	b	8–18	..	·004
	d	24–26	..	·006
	C006*a*	0–9	·06	..
	C092*a*	0–9	·05	·027
Hallam loam	C050*a*	0–8	·20	·028
	C0100*a*	0–7	..	·040
Hallam loam (silurian phase) ..	C041*a*	0–8	·24	·046
	b	8–12	·24	·015
	e	30–44	·47	·010
Narre clay loam	C058*a*	0–8	·05	·026
	C042*a*	0–9	..	·028
Eumemmering clay	C043*a*	0–6	·21	·059
	b	6–16	·22	·043
	C074*a*	0–10	·35	·113
Basaltic soils—				
Black	C102*a*	0–6	·09	..
	C103*a*	0–6	·11	..
	C113*a*	0–5	..	·038
Red	C104*a*	0–6	·07	..
	C106*a*	0–7	·21	..
	C108*a*	0–8	·06	·140
	b	8–20	·03	·130
	C109*a*	0–9	..	·053
	c	17–27	..	·041

Phosphorus.—Most of the soils analysed illustrate the general poverty of Victorian soils in phosphorus. Of the non-basaltic types, only Eumemmering clay reaches as high as 0.05 per cent. P_2O_5, and one sample of this type exceeds 0.1 per cent. The lighter types are poor or very poor, and even the two best samples of Hallam loam have been given unusual amounts of additional phosphate. The phosphorus content of the Silurian rock stands in marked contrast to the figure for potassium. The basaltic types are interesting. The deep, mature soils (C109, C113) have lost most of their original supply, but the immature sample (C108), which contains still decomposing basalt, is fairly rich in phosphorus. Figures of the order of 0.1 per cent. P_2O_5 have been obtained for several other soils on the basalt in this area, and these soils appear to be generally richer than the non-basaltic types.

Organic Matter.

Organic carbon (Table XXIII) was estimated by Tiurin's rapid approximate method (using the figure 1 ml. normal oxidizing agent equals 3.3 mg. carbon); the total organic matter may be calculated by multiplying these figures by 1.73. The figures range from low values for the sandiest types to high values for the basaltic types and Eumemmering clay. The total organic matter in some basaltic soils exceeds 10 per cent.—a figure which is evidently due to the high chemical fertility of these soils as well as to their moisture-retaining capacity; both of these factors

Table XXIII.—Distribution of Carbon Content of Surface Soils (by Tiurin's Method).

Soil Type.	Mean.	Carbon, Percentage.									
		0·5–1·0.	1·0–1·5.	1·5–2·0.	2·0–2·5.	2·5–3·0.	3·0–3·5.	3·5–4·0.	4·0–5·0.	5·0–6·0.	6·0–7·0.
Harkaway sand	1·6	..	2	..	1	..	..	..	..	..	..
Cranbourne sand	1·1	1	1	..	..	..	..	..	..	..	..
Toomuc sand	0·8	1	..	..	..	..	..	..	..	..	..
Toomuc sandy loam	2·2	..	1	..	..	1	1	..	..	..	..
Hallam loam	3·4	..	..	..	..	..	2	2	..	..	..
Narre clay loam	2·7	..	..	..	1	..	1	..	..	..	..
Eumemmering clay	4·4	..	..	..	..	..	1	..	..	1	..
Red-brown basaltic clay loam ..	5·3	..	..	..	..	..	..	1	1	2	1
Black basaltic clay loam ..	4·5	..	..	..	..	1	..	..	2	..	1

increase the annual addition of plant residues to the soil, and hence lead to a high content of humus. The relatively high figures for the samples of Hallam loam are interesting, and would hardly be expected from their pale appearance.

These samples, as might be expected, are also rather high in organic nitrogen, but the improvement in fertility caused by the growth of subterranean clover indicates that the quality of this nitrogen for plant growth is not high.

Salt Content of Soils.

Normal Soils.—The soils of the area are generally low in soluble salts, as might be expected from the nature of the climate. Several representative samples were analysed both for total salt (conductometrically) and for chloride.

The majority of surface soils contain less than 0.01 per cent. of sodium chloride. A few figures are collected in Table XXIV which shows that salt reaches moderate amounts only in a few deep subsoils.

Saline Patches.—The surface 6 inches of the bare saline patches contain as much as 0.8 per cent. of sodium chloride, with an average of 0.44 per cent. for nine samples. The lower layers are also saline, but the highest concentrations are invariably found on the surface; this indicates that water is held up by the clay subsoil in the second foot long enough for capillary rise and evaporation at the surface to be an important factor. The two series of samples quoted in Table XXV (C047 to C045, C050 and C051) are very interesting in showing how localized the salt is; a chain away from the edge of a bare patch the salinity is down to normal levels.

Analyses of the extracted salt show that sodium and chloride are the predominant ions, and magnesium and sulphate occur in appreciable amounts. The salt, in fact, approximates in composition to sea-salt.

Table XXIV.—Chloride in Normal Soils, Reckoned as Sodium Chloride.

Soil Type.	Sample Number.	Depth. (inches)	NaCl, parts per 100,000.
Toomuc sandy loam	C016*e*	26–46	10
	C092*e*	16–26	20
	C092*g*	64–72	100
Hallam loam	C038*a*	0–6	10
	C038*d*	16–21	10
Eumemmering clay	C043*a*	0–6	0
	C043*b*	6–16	20
	C043*c*	16–33	100
	C043*d*	33–42	170
	C061*a*	0–6	10
	C061*d*	25–32	80
	C074*e*	20–36	10

All the above samples have a clay texture except CO38*a*. Many figures for lighter soils have been omitted, all being low.

TABLE XXV.—CHLORIDE IN SALINE SOILS, RECKONED AS SODIUM CHLORIDE.

Soil Type.	Sample Number.	Depth. (inches)	Plant cover.	NaCl, parts per 100,000.
Toomuc sandy loam .. .. (Series within one chain)	C047*a*	0–8	Normal pasture	20
	C046*a*	0–6	Plantago	80
	C045*a*	0–8	Bare	260
	c	12–15	..	70
	e (clay)	28–36	..	60
Hallam loam .. .. (Series within one chain)	C050*a*	0–8	Normal pasture	10
	C051*a*	0–6	Bare	760
Toomuc sandy loam	C044*a*	0–7	Bare	330
	b	7–12	..	260
	c	12–18	..	160
	C065*a*	0–6	Bare	430
	b	6–15	..	100
	c	15–17	..	50

pH VALUES.

Reactions were determined by means of the quinhydrone electrode, using equal weights of soil and water. The distribution of the pH values of the surface, subsurface, and subsoil is shown in Table XXVI. Considering surface soils first, it will

TABLE XXVI.—DISTRIBUTION TABLE OF pH VALUES (QUINHYDRONE ELECTRODE).

——	Mean.	3·0–3·5	3·5–4·0	4·0–4·5	4·5–5·0	5·0–5·5	5·5–6·0	6·0–6·5	6·5–7·0	7·0–7·5
Harkaway sand—										
Surface	5·7	..	..	..	..	1	3	..	..	..
Subsurface	5·6	..	..	..	..	1	1	..	..	..
Subsoil	6·0	..	..	..	..	..	2	..	1	..
Cranbourne sand—										
Surface	4·4	1	..	..	1	1	..	..	..	..
Subsurface	4·3	1	..	..	2	..	..	..	..	..
Subsoil	4·5	..	1	..	1	1	..	..	..	..
Toomuc sand—										
Surface	4·1	..	..	1	..	..	..	..	..	..
Subsurface	5·1	..	..	..	..	1	..	..	..	..
Subsoil	5·3	..	..	..	..	1	..	..	..	..
Toomuc sandy loam—										
Surface	5·4	..	..	..	..	4	5	..	..	..
Subsurface	5·5	..	..	..	..	2	2	..	..	..
Subsoil	5·9	..	..	..	..	1	2	..	1	..
Hallam loam—										
Surface	5·4	..	..	..	3	3	4	1	..	..
Subsurface	5·4	..	..	..	1	2	1	1	..	..
Subsoil	5·3	..	..	..	1	..	2	..	..	..
Saline soils— (These all belong to above two types)										
Surface	4·8	..	..	2	4	..	..	..	1	..
Subsurface	5·5	..	..	..	2	..	2	..	1	..
Subsoil	5·6	..	..	..	..	2	1	..	..	..
Narre clay loam—										
Surface	5·1	..	..	..	2	2	..	..	..	..
Subsurface	5·3	..	..	..	..	3	..	..	..	..
Subsoil	5·4	..	..	..	..	2	1	..	..	..
Eumemmering clay—										
Surface	5·3	..	..	..	..	3	1	..	..	..
Subsurface	5·9	..	..	..	..	..	1	1	..	..
Subsoil	5·8	..	..	..	1	..	1	..	1	..
Red-brown basaltic clay loam—										
Surface	5·6	..	..	..	..	2	5	..	..	..
Subsurface	5·7	..	..	..	..	1	4	1	..	..
Subsoil	6·1	..	..	..	..	..	1	1	1	..
Black basaltic clay loam—										
Surface	5·5	..	..	..	..	1	2	..	..	..
Subsurface	6·2	..	..	..	..	..	1	2	..	..
Subsoil	6·6	..	..	..	..	..	..	2	1	1

be seen that acidic reactions are the rule throughout, only one normal surface soil reaching even to pH 6; and this is so in spite of the light dressings of lime which have been applied to some properties. The majority of the samples of the commonest types lie between 5 and 6, with a large number of readings more acid than 5.5. The lightest type—Cranbourne sand—is the most acidic of all throughout the profile, and is the only type on which acidity appears to limit the growth of plants—though, of course, only plants which are fairly tolerant of acidity are widely grown in this district in any case.

There is a tendency towards a higher pH value in the lower layers of some soil types, a tendency which is most marked in the black basaltic type.

The saline soils have been grouped separately; they are definitely more acidic than the normal soils of the same type, with the exception of one which is more alkaline than the normal soils. It is possible that these soils owe their acidity to recent accession of salt, in conformity with the general rule that the pH of a soil suspended in a salt solution is lower than in pure water; while the more alkaline sample may represent a more mature phase of the interaction of soil with a sodium salt.

Exchangeable Cations.

The four main elements extracted by leaching with normal ammonium acetate at pH 7 are recorded in Table XXVII. Those

Table XXVII.—Exchangeable Cations.

Soil Type.	Sample No.	Depth. (in.)	Exchangeable Cations. Percentage of Total.				Exchangeable Cations. Total in milliequiv. per 100 gm. Oven-dry Soil.	pH.	Percentage Clay.
			Ca.	Mg.	Na.	K.			
Harkaway sand	C013*a*	0–10	65	28	2	5	4·3	5·9	7·5
Toomuc sandy loam— Normal Phase	C016*a*	0–8	52	37	8	3	1·9	5·6	5·5
	C016*b*	8–18	58	32	7	3	0·9	5·4	6·1
	C016*e*	26–46	7	81	11	1	10·2	5·4	47·8
	C092*a*	0–9	55	38	5	2	4·2	5·1	10·2
	C092*e*	16–26	18	66	15	1	12·9	5·6	41·9
Saline phase	C045*a*	0–8	18	54	25	3	2·1	4·5	..
	C045*e*	28–40	10	64	25	1	6·1	5·4	..
Hallam loam— Normal phase	C0100*a*	0–7	58	37	3	2	9·2	5·3	17·9
	C0100*d*	15–20	19	71	9	1	15·7	5·3	55·1
Heavy phase	C038*a*	0–6	45	50	3	2	12·1	5·4	27·2
	C038*d*	16–21	23	70	6	1	18·8	5·7	68·1
Silurian phase	C041*a*	0–8	55	38	5	2	7·3	4·7	21·0
Narre clay loam	C058*a*	0–8	36	58	5	1	15·2	4·9	27·1
Eumemmering clay	C043*a*	0–6	42	52	4	2	23·7	5·5	47·6
	C043*b*	6–16	33	58	7	2	26·1	5·8	58·3
	C043*d*	33–42	25	59	14	2	30·1	6·7	65·8
	C074*a*	0–10	37	57	4	2	19·6	5·1	..
	C074*e*	20–36	26	67	5	2	21·9	4·9	..
Red-brown basaltic clay loam	C109*a*	0–9	53	39	3	5	13·4	5·8	35·9
	C109*c*	17–27	31	63	5	1	11·2	6·1	71·3
	C109*d*	27–39	26	66	6	2	10·5	6·1	79·0
Black basaltic clay loam ..	C113*a*	0–5	54	42	3	1	19·1	5·4	26·2

surface soils which are relatively low in clay are poorly supplied with these four elements; but even the heavier soils have not a very good supply, partly because of their acidity—in other words, because acidic hydrogen takes up a large proportion of the soil's capacity for holding cations. Most of the subsoils (which are high in clay) contain more of the exchangeable elements than the surface soils, though the red basaltic type C109c and d) is remarkably low in this respect. Such a low capacity for holding cations is a feature of highly ferruginous soils in other parts of the world.

The available *calcium* in the soil may be taken as equivalent to the exchangeable calcium. Among the podzolic types of soil (Harkaway, Toomuc, Hallam) this is always less than 0.15 per cent. of "lime" (CaO). If we accept G. W. Robinson's opinion (9) that lime is needed on all soils with less than 0.25 per cent. of exchangeable calcium reckoned as CaO (or 9 milli-equivalents per cent.) then all these types are deficient except the Eumemmering clay and the black basaltic type.

The figure for exchangeable *potassium* gives useful information as to the amount of available potassium. Here again the podzolic types are poorly equipped. Harkaway sand, containing reserves of primary minerals which keep up the supply, is probably safe against potassium deficiency, but the Hallam and Toomuc types are poor. Sample C016 was taken from a property which was heavily cropped with oats in former years, and on which there is reason to believe that the present pasture is deficient in potassium. The exchangeable potassium in the surface 8 inches corresponds to only 50 lb. of the element per acre.

Relative Importance of the Four Elements.—The surface soils contain calcium and magnesium in roughly equivalent amounts. The subsoils, however, contain magnesium in predominant amounts, even up to 80 per cent. of the total exchange capacity of the soil, while calcium drops to one-third, or even less, of the magnesium. Sodium also increases in the subsoil and reaches the same order as calcium in two normal samples. In a very poor saline soil sodium reaches 25 per cent. of the total, and calcium falls to third place.

This occurrence of magnesium- or magnesium-sodium-clays is common in Victoria, and appears to be related to the incidence of cyclic salt already referred to (p. 195). The uptake of calcium and magnesium by the native trees and grasses which formerly covered the country might also have an interesting connexion with these figures for exchangeable ions.

COMPOSITION OF CLAY FRACTIONS.

The material of less than 0.001 mm. diameter was isolated from selected soils and the results of a complete analysis are collected in Table XXVIII. Among the podzolic types the clays of the grey surface soils are highly siliceous, while those of the yellowish subsoils are relatively higher in aluminium and iron. The red basaltic soil is much less siliceous, both in the surface and in the subsoil. The high concentration of iron in the surface clay of this type is interesting. The high content of titanium in the surface clays of both types is striking; the parent rocks are also high in titanium.

TABLE XXVIII.—CHEMICAL COMPOSITION OF CLAY FRACTIONS BELOW 0.001 MM. DIAMETER.

Soil Types.	Depth. (in.)	Percentage Composition.				Molecular Ratios.	
		SiO_2.	Al_2O_3.	Fe_2O_3.	TiO_2.	$\frac{SiO_2}{Al_2O_3}$.	$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$.
Hallam loam, grey surface—							
C038*b* ..	6–11	43·4	19·9	9·4	7·8	3·65	2·81
C099*a*, *b* (Composite)	0–13	48·8	24·6	5·2	5·0	3·28	2·90
Hallam loam, yellow subsoil—							
C038*e* ..	21–32	41·3	25·2	10·9	2·5	2·73	2·14
C092*c* ..	16–26	42·5	27·0	9·5	1·6	2·63	2·15
Red basaltic—							
C109*a* ..	0–9	35·3	24·3	16·4	5·4	2·44	1·70
C109*d* (Composite)	27–39	37·7	32·5	9·3	1·0	1·95	1·67

MINERALOGY OF "FINE SAND" FRACTIONS.

The "fine sand" fractions (i.e., particles of diameter between 0.2 and 0.02 mm.) were isolated from selected samples, and the following information has been supplied by Miss A. Nicholls, M.Sc., who kindly examined them for their minerals.

Harkaway sand (on granodiorite).—Quartz predominant. Plagioclase and orthoclase common as large and fresh fragments. Hornblende rare. Mr. G. Baker has kindly provided the following information from a Rosiwal analysis of the granodiorite itself:—Quartz, 24 per cent.; orthoclase, 17 per cent.; plagioclase, 39 per cent.; biotite, 15 per cent.; hornblende, 5 per cent. Apatite also is present.

Cranbourne sand.—Almost pure quartz, feldspars absent.

Toomuc sandy loam.—Quartz predominant, a few grains of decomposed plagioclase and orthoclase

Hallam loam and Eumemmering clay.—Similar to Toomuc sandy loam.

These four soils, derived from unconsolidated sediments, contain only poor reserves of primary minerals.

Hallam loam (Silurian phase).—Richer in orthoclase and plagioclase than the four types just mentioned; especially as the parent rock is approached. Hornblende, apparently wind-blown, occurs in surface of both samples, in appreciable amounts.

Black basaltic soil (C113b).—This is a "mature" soil; most of the original minerals of the basalt have been decomposed and the fine sand contains mainly quartz. Plagioclase is less important than in the last-mentioned soil. Magnetite is common. A few grains of augite are present, probably due to the survival of a few "floaters" of rock through the profile.

The red and black soils formed on basalt through Gippsland are usually similarly devoid of the rich primary minerals which the original basalt contained.

VII. Botanical Surveys.

Several different associations of plants occur on the various types of land in this district. We are greatly indebted to Miss Y. Aitken, M.Agr.Sc., for carrying out a botanical survey of some of these associations, the results of which are given below :—

WOODED SLOPES OF HILL COUNTRY NORTH OF BEACONSFIELD. SOIL TYPES, HARKAWAY SAND ON GRANODIORITE AND RUGGED SILURIAN COUNTRY.

The bush in this area is an association of trees, mainly Messmate (*Eucalyptus obliqua*), Peppermint (*E. australiana*), and Blackwood (*Acacia melanoxylon*), with scattered woody shrubs and tussock grasses. The trees are about 5 yards apart in the upper sections of the slopes, but they and the other growth become more dense lower down (cf., pl. XII, fig. 2), and begin to include more hydrophilic species such as *Melaleuca squarrosa* (Swamp Paperbark), rushes, &c. The amount of bare space in a square-foot quadrat is about 80 per cent. on the upper slopes, and about 70 per cent. on the lower slopes. The ground is covered mostly by dead leaves of Peppermint and Messmate. No distinct difference is evident between the flora from each type of soil on similar slopes. However, of the two species of tussock grasses, *Poa caespitosa* and *Danthonia pallida*, the former tends to be characteristic of the granodiorite and the latter of the Silurian country. The bush described here is typical of large areas, but its composition may well have been affected by the frequent fires since white settlers arrived.

SANDHILLS NEAR CRANBOURNE. (Soil type, Cranbourne Sand).

(*a*) *Virgin Scrub.*—The original vegetation of the deep sand, here named Cranbourne sand, is a xerophytic scrub association, of woody shrubs and some scattered trees. Typical quadrats show that about 50 per cent. of the ground is bare. The commonest tree is Peppermint (*E. australiana*), and Manna gum (*E. viminalis*) occurs occasionally as a stunted form.

The shrubs are much less varied than in the hilly country just described, and range up to 6 feet high. They are chiefly Silky Teatree (*Leptospermum myrsinoides*), with Wedding bush (*Ricinocarpus pinifolius*), Bundled Guinea flower (*Hibbertia fasciculata*), a species of Bush pea (*Pultenea* sp.), and Broom Spurge (*Ampera spartioides*) frequent.

In places where the scrub has been partly cleared, Bracken (*Pteridium aquilinum*) and Wild Parsnip (*Didiscus pilosa*) have formed closed communities.

(*b*) *Cleared land.*—Part of this area has been cleared, and is now an open association of Bracken, Sorrel (*Rumex acetosella*) and Yorkshire Fog (*Holcus lanatus*) with some Barley Grass (*Hordeum murinum*) and Silver Grass (*Festuca bromoides*), and Bent Grass (*Agrostis* sp.). In a depression, the greater moisture has made possible a complete cover of annual clovers (*T. recumbens, T minus*), White clover (*T. repens*), and Yorkshire Fog.

TEA-TREE SWAMPLAND. (Soil type, Narre clay loam.)

The slope described in the last paragraph descends to a tongue of tea-tree swamp. This land is covered by Swamp Paperbark (*Melaleuca ericifolia*) about 8 feet in height. This scrub is so dense that very few other plants survive. Tall sedge (*Carex appressa*) occurs near the edge of the scrub.

Where the scrub has been cleared the land carries a moderately open association of grasses, mainly native, and some herbs. Small tussocks of *Poa caespitosa* are the most prominent feature.

UNIMPROVED NATIVE PASTURE. (Soil types, Hallam loam, Toomuc sandy loam.)

The gently sloping land to the south of the Highway was formerly covered with species of Eucalyptus. Where the timber has been removed but the pasture has not been improved, this land carries to-day a characteristic association of native grasses. Such an association is found for example on the drier ground on the edge of the swamp just described. This is characterized by:—Kangaroo grass (*Themeda triandra*), various Wallaby grasses (*Danthonia semi-annularis, D. pilosa, D. penicillata*), and introduced plants, mainly Yorkshire Fog, Sweet Vernal grass (*Anthoxanthum odoratum*), Flatweed or Cat's ear (*Hypochaeris* *radicata*) and *Plantago coronopus.* Kangaroo and Wallaby grasses are typical of this better drained land, while *Poa caespitosa* is dominant on the swampy flats

Special Areas.

(*a*) *Very Acid Areas.*—In a cleared field of Cranbourne sand the normal pH ranges from 4 to 5, and the plant association consists of Bracken, Sorrel, Yorkshire Fog, Subterranean Clover, and Hair and Silver grass. Some highly acid patches occur, however, with a pH value close to 3.5; one sample even recorded pH 3.1. These patches carry a Sorrel association which is pure apart from several plants of Hair grass (*Aira praecox*). Even these tolerant plants, however, form such a sparse association that 90 per cent. of the ground is bare.

(*b*) *Saline Areas.*—A number of saline patches occur at the foot of slopes. The land here consists of quite bare areas alternating with pure stands of Buck's horn Plantain (*Plantago coronopus*). Towards the edge of such patches, Cat's ear, Couch (*Cynodon dactylon*), love grass (*Eragrostis diandra*), Sweet Vernal grass, and Wallaby grass occur in turn. The Plantain is very dwarfed compared with its growth in normal pastures, and occurs in a density of about 40 plants per 6-inch square. The high tolerance of this plant towards salt is well known.

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Explanation of Plates.

Plate IX.

Types of country in the Berwick district. (Photographs by B. A. Pearl.) Upper left—General view of plains from a basaltic hill. Upper right—Apple orchard on lower slopes in rugged Silurian hills. Lower left—Tongue of Narre clay loam carrying tea-tree. Lower right—Cleared basaltic hills in background, uncleared Silurian hills to right (looking north from Berwick).

Plate X.

Fig. 1.—Hallam loam on Silurian mudstone. The wooden handle is 14 inches long.

Fig. 2.—Harkaway sand, showing the very light sub-surface layer, resting on sandy clay.

Fig. 3.—Gully eroded, following the scooping out of a drain.

Plate XI.

Fig. 1.—House on Hallam Valley settlement.

Fig. 2.—Salt patch at foot of slope. The native grasses give way to Plantago.

Fig. 3.—Head of gully shown on preceding plate.

Fig. 4.—Salt patch at foot of a Silurian ridge. The bare ground has been badly eroded.

Plate XII.—Aerial Photographs.

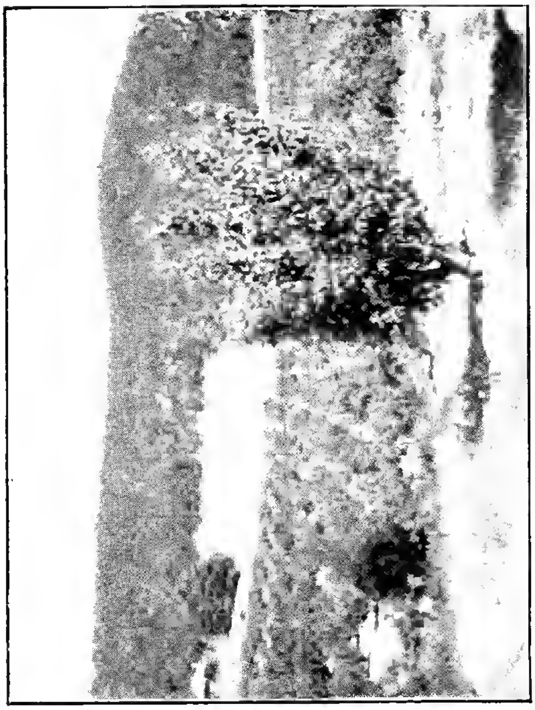
Fig. 1.—Bare patches, affected by salt, at the foot of parallel ridges of Silurian rock. The land between these patches is flat and poorly drained.

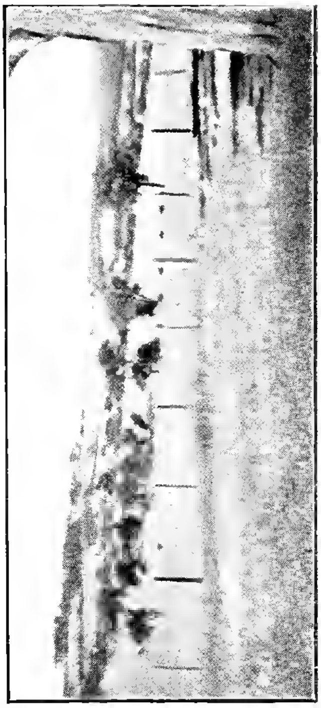
Fig. 2.—Orchard in rugged Silurian hills. The lighter patches in the timbered country are the ridges, the darker patches are the valleys which are more densely covered. The effect of erosion in the orchard is shown by the healthier trees in the basin.

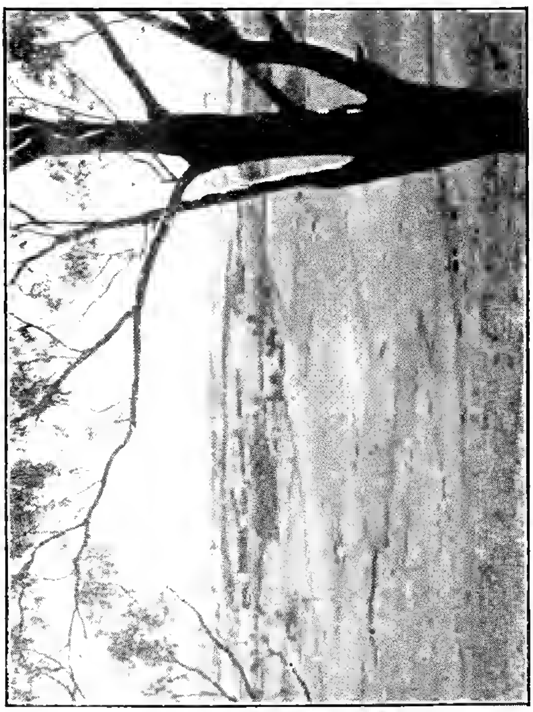
Fig. 3.—Highly improved pasture (white clover and perennial rye grass) in the upper centre, native pasture on the other side of the fence. The light patch in the improved property is being cultivated in preparation for a summer crop.

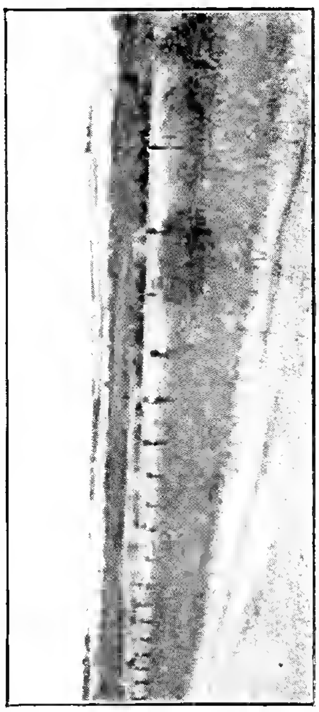
Fig. 4.—The dense vegetation is silver tea tree growing on Narre clay loam in a depression along a watercourse. The open timber just to the west is "peppermint" growing on the Silurian phase of Hallam loam on rising land.

Fig. 5.—A similar transition to that in fig. 4 showing on cultivated soil after rain. The dark soil is Eumemmering clay, the light soil is the Silurian phase of Hallam loam. There are some bad saline patches on the latter type, which have been eroded to a depth of 9 inches (plate XII, fig. 4).









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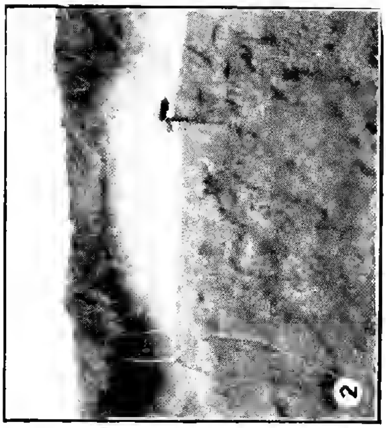

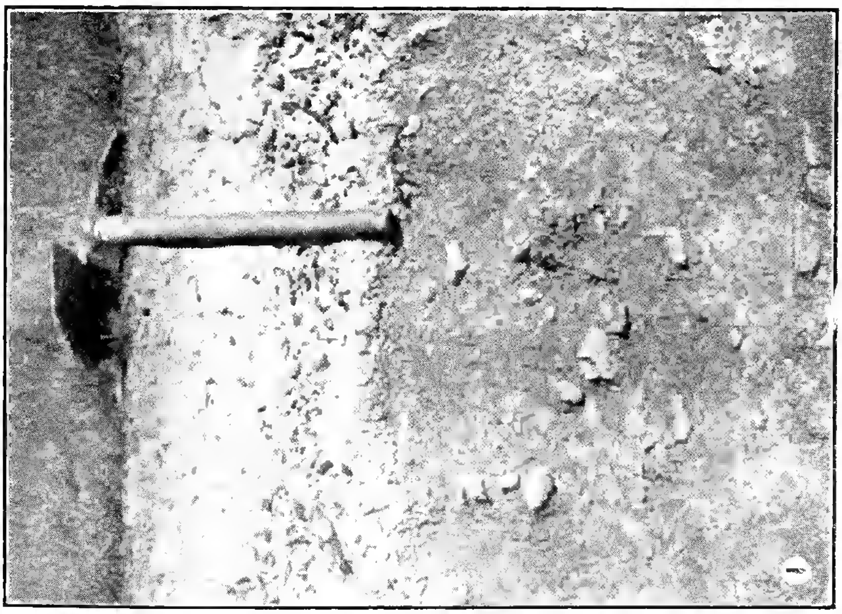

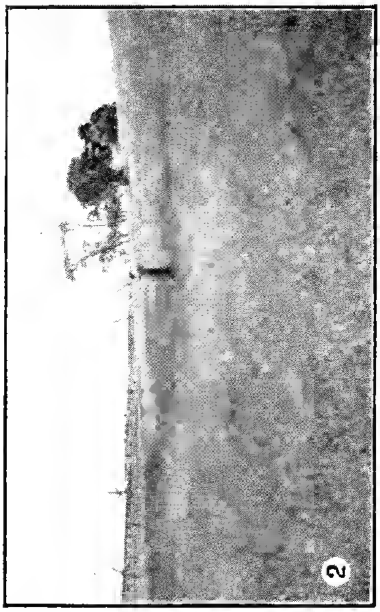

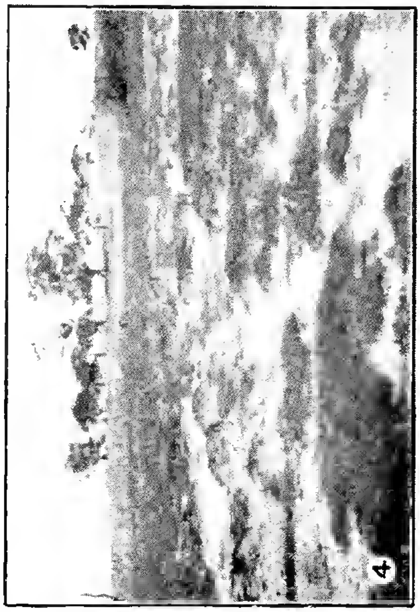

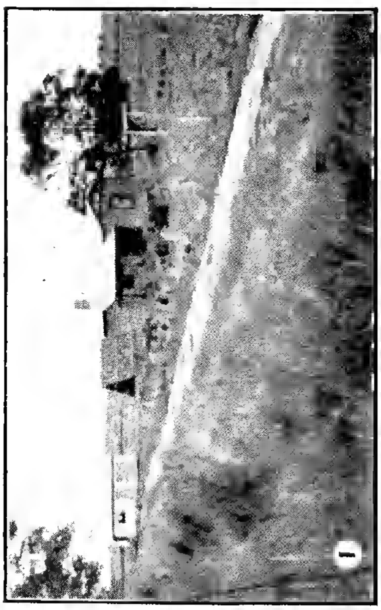

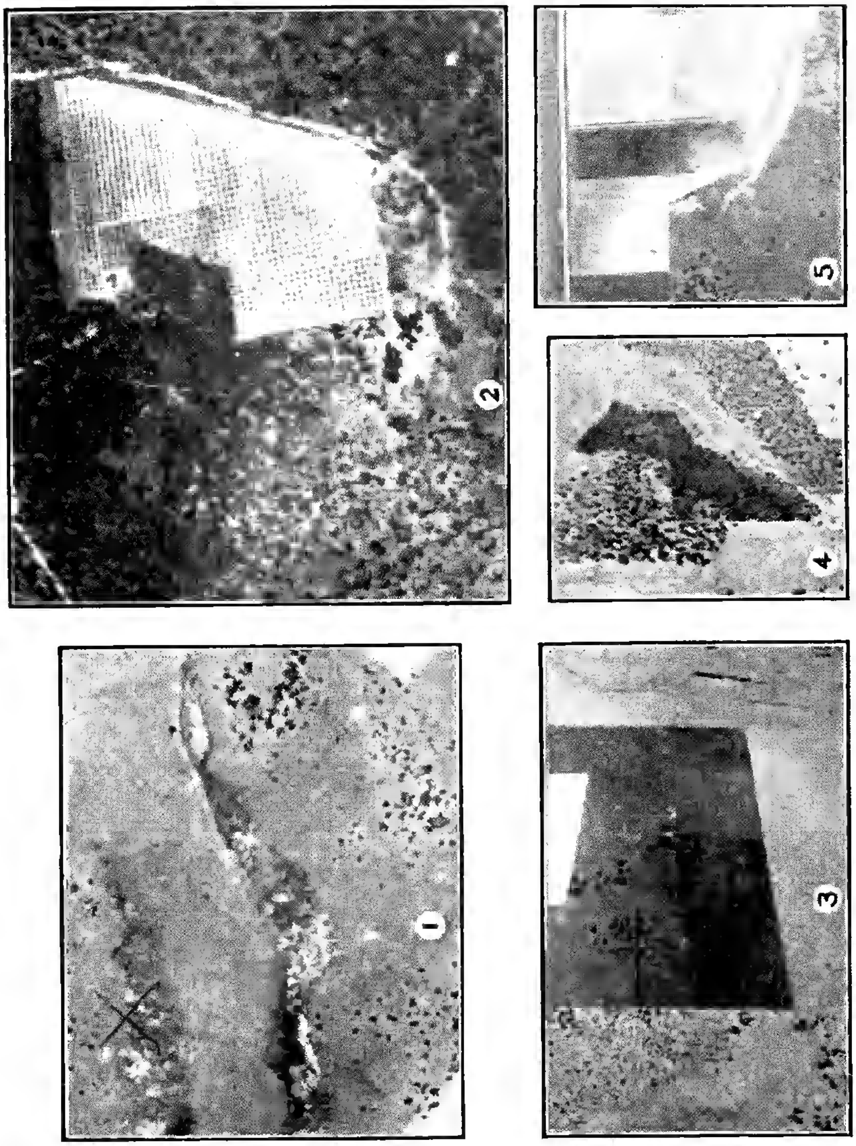

[PROC. ROY. SOC. VICTORIA, 52 (N.S.), Pt. II., 1940.]

The Silurian Rocks of Melbourne and Lilydale: A Discussion of the Melbournian-Yeringian Boundary and Associated Problems.

ART. XI.—By EDMUND D. GILL, B.A., B.D.

[Read 14th September, 1939; issued separately 1st July, 1940.]

Contents.

Silurian Type Areas.

In 1903 Professor Gregory (7) divided the Silurian rocks of Victoria into two series, namely:

2. Yeringian (Younger).
1. Melbournian (Older).

In 1933 Thomas and Keble (17) introduced a third and older division, and the succession now generally recognized (4) is:

3. Yeringian.
2. Melbournian.
1. Keilorian.

The Keilorian is typically developed near Keilor, north-west of Melbourne. These rocks were included by Gregory in the Melbournian. Melbourne is the type area for the Melbournian. Gregory specially mentioned the fossil localities at Moonee Ponds Creek and South Yarra (Improvement Works). I propose that, by reason of priority of systematic description in McCoy's "Prodromus" (12) and other publications, the Moonee Ponds Creek locality be regarded as the Melbournian Type Area, in the restricted sense. Such a distinction is needed as a basis for the further subdivision which the Melbournian requires.

In dealing with the Yeringian rocks, the beds are still called "Silurian" (although Ripper (16) and Hill (8) have recently suggested a Devonian age for the Cave Hill limestone), the reason being that this paper is concerned with the succession of the strata and not a discussion of their age.

The Lilydale district is the type area for the Yeringian. This area comprises the following original fossil localities:

(*a*) Cave Hill (bluish limestone).
(*b*) Wilson's (fawn shale).
(*c*) Hughes's Quarry (chiefly fawn sandstones).
(*d*) "Yering, near Coldstream" (yellow and purplish shales).
(*e*) Hull Road (reddish and occasionally white shales).

This number of localities has been greatly multiplied by recent investigations. The question of a restricted type locality is a difficult one because the limestones and shale faunules are almost mutually exclusive. I propose therefore that two restricted type localities be recognized, one for the limestones and one for the shales. Further, that these be Cave Hill and Hull Road respectively. Hull Road is the nearest of the original localities to Cave Hill, being separated from it by only 275 yards. A detailed survey of the area has shown that the two series of strata are conformable, there being regular easterly dips in between.

The Melbournian—Yeringian Boundary.

A problem awaiting solution is the precise location of the boundary between the Melbournian series and the Yeringian series. The chief difficulty lies in the fact that so many of the strata between Melbourne and Lilydale have so far yielded no fossils. The occasional discovery of new fossil localities, however, gives some hope of the needed palaeontological data being forthcoming even yet.

At Croydon there is a prominent scarp running north to the River Yarra. Jutson (10) described this as a fault scarp. It has generally been considered that in all probability this is the boundary between the Melbournian and Yeringian, the latter being faulted down against the former. Hills (9) on physiographic grounds denied the presence of this fault. The author, after a fairly detailed examination of the area, has reached the same conclusion. During the examination of the area under discussion, Yeringian fossils were found west of the so-called fault-line, proving that whether there be a fault there or not, it is not the boundary between the Melbournian and the Yeringian. These fossils were found on Yarra Road, which proceeds north to Wonga Park, at a location on the west side of the road in a cutting immediately south of Bryson Road (Military Map reference 298, 444). They were found in a whitish quartzitic sandstone having light touches of red ferruginous stain. The rock is often considerably pitted on the bedding planes. This is due, apparently, to the leaching away of calcareous organic fragments. The determining fossils are:

Phacops fecundus McCoy non Barrande.

Anoplia, sp. nov.

The first fossil is sometimes confused with *Phacops sweeti* Eth. fil. and Mitch. (6). It is common in the beds underlying the edge of the Older Basalt on the western side of Lilydale (i.e. Melbourne Hill, Lilydale), and has been collected from Ruddock's Quarry. The second fossil is a smooth Chonetoid brachiopod (described in MS) which is common in the Yeringian strata and particularly so at Ruddock's Quarry. The genus is new to Australia and is found in the Yeringian of the Kinglake District as well as at Lilydale.

It is relevant to record also three new fossil localities which help to link up the Yarra Road locality with the well-known Lilydale localities. Fossils of Yeringian affinities have been collected from:

(1) The corner of the Melbourne-Lilydale highway and Edward Road, called "The Black Springs". The strata from which the fossils were collected outcrop in the gutter on the north side of the main road, under the edge of the Older Basalt residual. The following were obtained at this point:

(*a*) In fawn shale—

Anoplia, sp. nov.
Atrypa reticularis (Linnaeus).
Bellerophon sp.
Leiopteria sp. (found also at Ruddock's Quarry).
Orthonota sp.

(*b*) In micaceous sandstone—

Lingula sp. (same form as from Hull Road, Lilydale).
cf. *Loxonema* sp.
Fronded crinoid stem (similar to one collected from Ruddock's Quarry).

I suggest that this locality be known as "Black Springs". It is so marked on the Military Map. Definite locality names are being suggested in order to prevent the use of a number of names for the same place. This has happened in the past and caused confusion. The localities are also shown on the map which accompanies this paper (fig. 1).

(2) The second new fossil locality is in a cutting on Manchester Road at the top of a hill 500 yards south of the Black Springs corner. Among the fossils from the greyish-brown shale of this site are:

Anoplia, sp. nov.
Nucleospira australis McCoy.
Orthoceras sp.

I suggest that this locality be known as "Manchester Road".

(3) The third new locality is in a cutting on the main Melbourne-Lilydale highway between North Croydon and Black Springs. The cutting is $\frac{3}{4}$ mile east of Brushy Creek, on the north side of the road. This collecting place yielded:

Chonetes bipartita Chapman.
Dalmanella elegantula (Dalman).
Phacops (*Acastina*), sp. nov. (?)

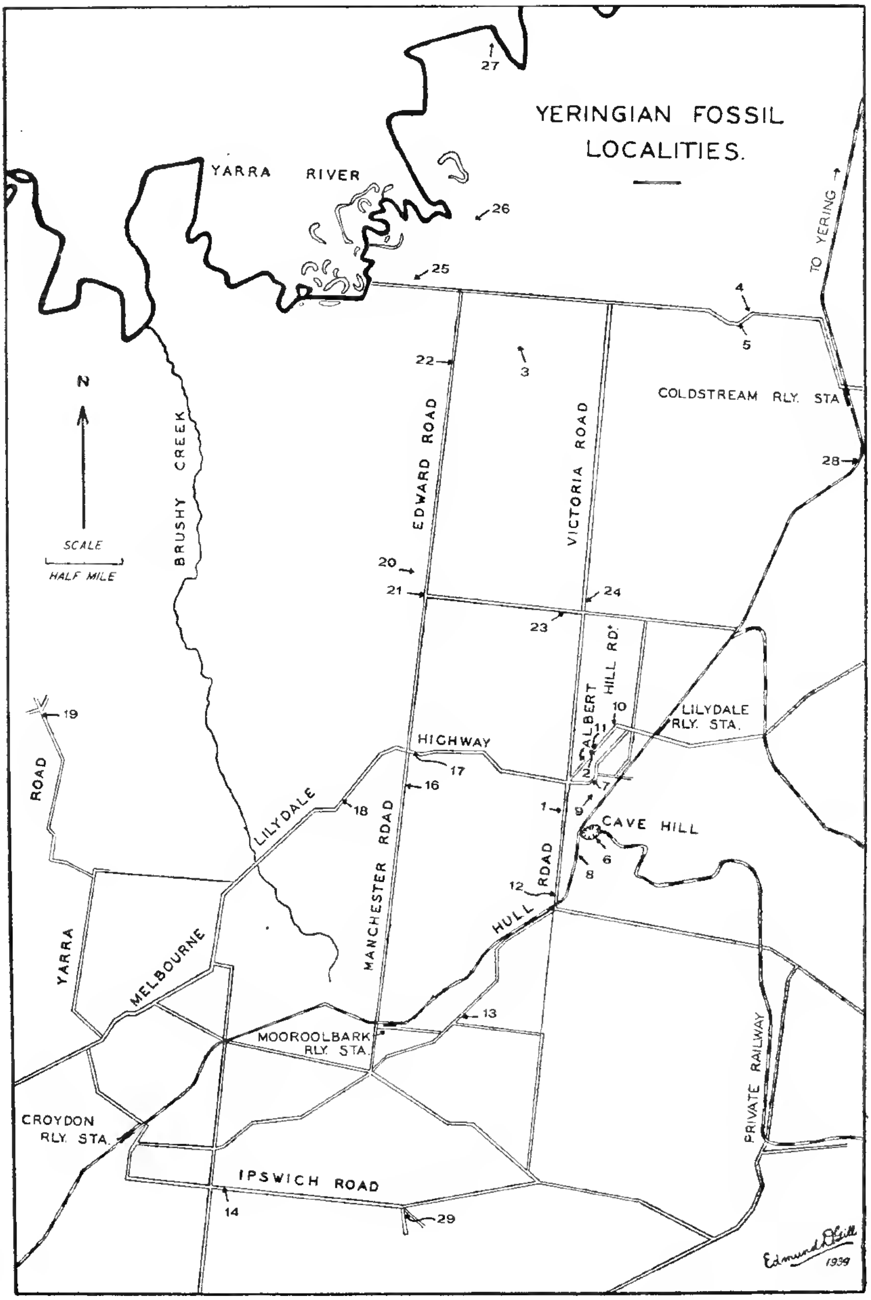

FIG. 1.—Map of Lilydale-Croydon Area showing Yeringian Fossil Localities.

Acastina Reed (15) is a sub-genus of trilobite not recorded from Australia before. A good specimen has been found among the fossils collected from the Lilydale shales by the late Rev. A. W. Cresswell. This is apparently the specimen recorded previously as *Dalmanites* sp. (3, and repeated in 6). The *Chonetes* is a typically Yeringian fossil. Besides the fossils listed above there was collected a series of circular and polygonal crinoid stem joints which constitute a typical Yeringian assemblage. Crinoid fragments are useful in stratigraphic correlations as Moore (13) has shown.

The fossils from the above locality were collected from hard, red shales, except for some of the crinoid stem joints which came from a micaceous sandstone. I suggest that this locality be named "West of Black Springs".

The three new fossil localities described occur between the Yarra Road locality and the well-known Lilydale localities. In 1911 Jutson (11) published a paper on the Warrandyte Goldfield in which he wrote "South-east from Warrandyte, the beds should become younger, until the youngest of the area would occur a little to the north of Croydon". This inference is now supported by the collection of Yeringian fossils on Yarra Road.

In 1855 Blandowski (1) recorded fossils from "Anderson's Creek, about a mile from the junction of that stream with the Yarra Yarra". He described two fossils but figured a number of others without naming them. Blandowski did not indicate what magnifications he used in figuring the fossils, but apparently they are all microfossils, for he writes, "The multitudes of very minute fossil remains . . . with a few exceptions, can be detected only by the aid of a powerful glass," and "I have discovered by a minute examination . . . the forms exhibited in the plate." A search was made recently for the stratum to which Blandowski referred. Similar rock with microfossils was found in the area described, and may be that to which Blandowski refers. However, no extensive collecting has been done yet. As far as present knowledge goes, the fauna of these beds is without stratigraphical significance. The forms are not known elsewhere in the Melbournian or Yeringian.

From grits in Anderson's Creek (precise localities not given) collected by Jutson (11) and the Geological Survey, there are specimens of a *Spirifer* having some affinities with *S. lilydalensis* Chapman.

Chapman (3) in his list of Silurian fossils records as part ot the Melbournian series the following fossils from "Anderson's Creek" which were collected from fine-grained, grey shales by the Geological Survey:

Cyrtolites sp.
Holopea wellingtonensis Eth. fil.
Orthoceras sp.
Palaeoneilo victoriae Chapman.

This faunal assemblage was no doubt considered to be Melbournian largely because of the presence of *Palaeoneilo victoriae* which has been recorded hitherto only from the Melbournian series (vide 3, p. 208). However, typical specimens have been found at Hull Road, Lilydale and Ruddock's Quarry. *Palaeoneilo* cf. *victoriae* has been collected from the Yeringian of the Kinglake district by Mr. R. B. Withers. Also, it has been recorded from Fraser's Creek and Broadhurst's Creek, both of which localities the author regards as Yeringian. The trilobite constituents of both these localities are definitely Yeringian. *Chonetes melbournensis* has been recorded from Broadhurst's Creek (3) but the specimen is not referable to that species. All the fossils from both localities are either exclusively Yeringian or common to both the Melbournian and Yeringian.

Holopea wellingtonensis, the other specific determination from "Anderson's Creek" is not found in any definitely Melbournian locality, but is recorded from Broadhurst's Creek. The species was described originally from Wellington Caves, N.S.W.

So it appears that the fossil assemblage from "Anderson's Creek" is quite indecisive. Further, the assemblage cannot be used as a stratigraphic guide because of uncertainty as to its origin. Although the fossils are marked "Anderson's Creek" they also bear the Geological Survey locality mark "B 22" which is "Watson's Creek, 2 miles below Wilson's Station". Because of the uncertainty of its location and the indecisiveness of its character, the fauna of the "Anderson's Creek" locality is of little value for the present purpose.

It has been noted that the most westerly Yeringian locality from Lilydale is Yarra Road. The most easterly Melbournian locality from Melbourne is that recorded by Chapman (3) as "Balwyn, near Templestowe" (note typographical error in punctuation). This locality, Mr. Chapman informs me, is a road cutting on the Bulleen Road on the north bank of the Koonung Koonung Creek. From this locality Mr. Chapman collected in 1905 the characteristic Melbournian fossil *Chonetes melbournensis*. Structurally, this locality is on the western limb of the Templestowe anticline.

There, unfortunately, the problem of the Melbournian-Yeringian boundary rests at present. The purpose of this paper is to bring the discussion up-to-date and to arouse interest in the problem. The area between Templestowe and Yarra Road is being searched for fossils, and the structure carefully mapped.

The Extension along Strike of the Type Yeringian Beds.

An accompanying problem to that of the westerly extension of the Yeringian beds, is the extent of their occurrence on the strike-line north and south of the type area. The average strike of the beds is about North 20 degrees East. It has often been commented that the strata at Lilydale are very fossiliferous, yet north and south of that area the rocks seemed to be devoid of organic remains. A recent survey has revealed the presence of typical, and in some cases plentiful, Yeringian fossils along the strike both north and south of the familiar Lilydale beds.

A. North of the Lilydale Area.

(1) In a road cutting (marked on the Military Map) at the top of a high hill in Edward Road nearly 1½ miles north of Ruddock's Quarry, the following have been collected:

Chonetes, sp. nov. (a form very common at Ruddock's Quarry).
Palaeoneilo sp.
Platyceras sp.

I suggest that this locality be termed "Edward Road Hill". This, as well as some of the other new localities, has been only cursorily examined so far, and may yield a fuller assemblage of fossils when more thoroughly investigated.

(2) In the property called "Devon Park" at the northern extremity of Edward Road, two fossiliferous localities have been found on the slopes which are part of the ancient south bank of the River Yarra. The first is at a small cut in the hillside on a track running west from the homestead to the River Yarra. The matrix is of grey shales such as are found at Ruddock's Quarry. A brief examination of the beds yielded:

Chonetes, sp. nov. (the form common at Ruddock's Quarry).
Orthoceras sp.
Phacops sp.

I suggest that this locality be known as "'Devon Park' West".

(3) The second locality in "Devon Park" is half a mile north of the terminus of Edward Road and almost in line with it, i.e. between the homestead and the downstream end of the Yering Gorge. From this place there have been obtained:

Anoplia, sp. nov.
Atrypa reticularis (Linnaeus).
Chonetes bipartita Chapman.
Dalmanella elegantula (Dalman).
D. testudinaria (Dalman).
Leptaena rhomboidalis (Wilckens).
Orbiculoidea cf. *selwyni* Chapman.
Rhynchotreta sp.
Spirifer sp.
Stropheodonta alata Chapman.
Strophonella euglyphoides Chapman.
Palaeoneilo sp.
Beyrichia sp.
Lindstroemia yeringae Chapman.

I suggest that this locality be known as "'Devon Park' North".

(4) A solitary fossil was chipped out of grey shales at the upstream end of the Yering Gorge, viz. *Chonetes bipartita* Chapman—a characteristically Yeringian form.

B. South of the Lilydale Area.

Apart from new fossil localities near Lilydale itself the following new collecting places are to be noted to the south:

(1) On Hull Road just north of where it passes under the Mooroolbark-Lilydale railway line, on the west side of the road in the gutter were found:

Strophonella euglyphoides Chapman (a typical Yeringian fossil).
Orthis sp.

I suggest that this locality be known as "Hull Road Railway Bridge".

(2) At Mooroolbark, on Hull Road, a mile south of the last-mentioned locality, in a cutting on the east side of the road north of the turn-off to Mooroolbark railway station (Military Map reference 347, 403), a particularly rich fossiliferous Yeringian series has been discovered. From these brownish shales the following forms have been recognized:

Anoplia, sp. nov.
Atrypa reticularis (Linnaeus).
Beyrichia sp.
Camarotoechia sp.
Chonetes aff. *cresswelli* Chapman.
C. robusta Chapman.
Conularia sowerbyi Defrance.
Cypricardinia aff. *contexta* Barrande.
Dalmanella elegantula (Dalman).
Fenestella margaritifera Chapman.
Goldius cf. *enormis* (Eth. fil.).
Goniophora australis Chapman.
Leptaena rhomboidalis (Wilckens).
Lindstroemia ampla Chapman.
L. yeringae Chapman.
Loxonema aff. *sinuosa* Sowerby.
Nucleospira australis McCoy.
Nuculites sp.
Orthis spp.
Palaeoneilo sp.
Pentamerus sp.
Rhipidomella sp.
Rhynchotreta sp.
Schizophoria sp.
Spirifer lilydalensis Chapman.
Spirifer sp.
Stropheodonta, sp. nov. (?)
Strophonella euglyphoides Chapman.
Strophonella, sp. nov. (?)

I suggest that this locality be called "Hull Road, Mooroolbark".

(3) At Croydon on the Ipswich Road on the rise a little east of Dorset Road, fossils were found in brownish shales in the gutter on the north side of the road, viz.:

Odontopleura rattei Eth. and Mitch.

Orthis sp.

Keilorites sp.

(4) The furthest south Yeringian locality on the strike of the Lilydale beds so far described is that at Kilsyth (2). However, a new locality was discovered recently by Dr. I. Cookson and the author at the corner of Wellington Road and Stud Road, four miles north of Dandenong. Dark, reddish shales outcrop in a cutting on the north-east corner of the crossing, and from these a number of not too well preserved fossils were collected. They include:

Chonetes bipartita Chapman.

Dalmanella elegantula (Dalman).

Both of these forms are characteristic of the Yeringian series. I suggest that this locality be known as "Rowville", the name of the place as shown on the Military Map.

Yeringian Fossil Localities.

Not a little confusion concerning Yeringian fossil localities has resulted from the fact that the actual sites have not been recorded on a map. In order to overcome this disability a map (fig 1.) accompanies this paper and the sites are numbered according to the list given below. Further, the use of more than one place-name for the same locality has often proved misleading. To overcome this further difficulty the accompanying notes have been compiled:

1. "Mooroolbark Road", "Kinsella's Gate", and "Hull Road" all refer to the red shales west of Cave Hill, outcropping in a road cutting 14 chains from the Melbourne-Lilydale highway. The road proceeds south from this highway at a point half a mile west of the township of Lilydale, and goes to Mooroolbark and thence to Croydon. The correct name for the road is Hull Road and I therefore propose that "Hull Road, Lilydale" be accepted exclusively as the locality name.

2. "Wilson's", as Cresswell has explained (5), is "On the old Melbourne Road, near the top of the hill, about half a mile above Lilydale." The fossils were collected "in the stuff thrown out of a sinking for a tank at Mr. Wilson's." This locality does not now exist, but on the same piece of road, called Albert Hill

Road by the residents, similar fossils have been collected from small outcrops and excavations. This locality and (1) have also been referred to simply as " Lilydale mudstone ".

3. " North of Lilydale ", " Hughes' Quarry " and " Yering " refer to the same place—a quarry at the summit of a low hill situated near the middle of the block of land bounded by the northern end of Edward Road, and the road which runs east to Coldstream, and Victoria Road. This section appears under the name of " James Shanley " on the Parish Plan of Yering. It has been said that " Hughes' Quarry " is the same as " Ruddock's Quarry " but this is not so because:

(*a*) The fossils so recorded are in a different matrix from the Ruddock's Quarry fossils.

(*b*) The following directions given by Cresswell (5) cannot be made to fit the Ruddock's Quarry locality—" About three miles to the north of the last mentioned point (Wilson's), and about fifteen chains to the west of the road that leads past the cemetery (N. and S. road) at an old quarry, known as Hughes' Quarry."

The road that leads past the cemetery is Victoria Road. I suggest that this locality be referred to exclusively by the original name of " Hughes' Quarry ".

4. " Section XII. Parish of Yering ", " Yering near Coldstream ", " West of Yering Railway Station ", " West of Coldstream Railway Station ", " Yarra Flats, Yering ", and " Mic. Black's Quarry, Coldstream " apparently all refer to the same locality, viz. an old quarry in a cutting (marked on the Military Map) on the road which proceeds east from " Devon Park " to Coldstream. The road forms the southern boundary of Section XII. of the Parish of Yering. The quarry is west of the Olinda Creek, at the edge of the river flats. The Geological Survey collected fossils from this place many years ago and labelled them " Sect. XII. Par. of Yering ". The late Mr. Geo. Sweet collected a good deal of material from this locality, and the specimens are now housed in the National Museum. All the locality names mentioned, except the last, are hopelessly inadequate for present purposes. The last is liable to confusion with Mr. W. Black's quarry on the edge of the Toscanite on the other side of Coldstream. Until recently, when purchased by Mr. M. Black, the piece of ground in question belonged to the property called " Flowerfield " (see Military Map). I suggest that the locality be called " ' Flowerfield ' Quarry ".

5. Fossiliferous strata outcrop at the southern end of the cutting at the northern end of which " Flowerfield " Quarry is situated. I suggest that this locality be called " ' Flowerfield ' Cutting ".

6. " Cave Hill " limestone quarry.

7. " Melbourne Hill, Lilydale ". This locality is a cutting on the main Melbourne-Lilydale road immediately west of the latter township. It is under the edge of the Older Basalt residual on the hill locally called " The Melbourne Hill ". The beds outcrop beside the entrance to a quarry in the basalt and downhill for some distance. The strata comprise yellow and brownish shales.

8. " Cave Hill South " is the locality name suggested for the outcrop of limestone on the strike of the Cave Hill beds in the railway cutting a quarter of a mile south of Cave Hill (14). It is situated on the west side of the line 22 miles 11 chains from Melbourne.

9. " Mitchell's Paddock " is in the large paddock owned by the Mitchell Estate, bounded on its western and northern limits by Hull Road and the Melbourne-Lilydale highway respectively. At this point there is an outcrop of highly fossiliferous grey shales extending on and off for a chain in the banks of a rivulet which runs only in the winter. The outcrop may be located by following the fence beside the highway for 10 chains 89 links from Hull Road to a corner post then proceeding 4¼ chains south.

10. " Albert Hill Road North " is practically at the northern limit of that road on the corner of an unnamed street on the west side of the road. Numerous fossils were collected from grey shales thrown up from a telegraph pole excavation.

11. " Albert Hill Road " is a locality about the middle of the road at the corner of another unnamed street south of that mentioned in (10). A trench dug on the west side of the road revealed highly fossiliferous grey shales. Fossils were also collected from the gutter on the east side of the road.

12. " Hull Road Railway Bridge ". This locality is described in section IIIB (1) of this paper.

13. " Hull Road, Mooroolbark ". Described in section IIIB (2).

14. " Ipswich Road, Croydon ". See section IIIB (3).

15. " Rowville ". See section IIIB (4).

16. " Manchester Road ". See section II. (2).

17. " Black Springs ". See section II. (1).

18. " West of Black Springs ". See section II. (3).

19. " Yarra Road ". See section II.

20. " Ruddock's Quarry ", North-west of Lilydale, is on the west side of Edward Road a little north of where it is joined by the road which proceeds west from the Lilydale cemetery. It is a disused quarry on the side of a hill a short distance from the road.

21. "Ruddock's Corner" is the name given the corner of Edward Road and the road which runs west from the Lilydale cemetery. The locality is near Ruddock's Quarry, and similar grey shales outcrop. Fossils were collected from rock dug out in the re-forming of the road and in the sinking of a hole for a telegraph pole.

22. "Edward Road Hill". See section IIIA (1).

23. "West of Lilydale Cemetery". In a cutting on the road which runs west from the Lilydale cemetery, about 10 chains from Victoria Road, brown sandstones outcrop which contain fairly numerous fossils.

24. "Victoria Road Cutting" is a cutting in Victoria Road immediately north of the cemetery. At this point brown to grey shales outcrop.

25. "'Devon Park' West". See section IIIA (2).

26. "'Devon Park' North". See section IIIA (3).

27. "Yering Gorge". See section IIIA (4).

28. "Coldstream Railway Cutting". In the long cutting just south of the Coldstream railway station at a point approximately 25 miles 51 chains from Melbourne, thinly-bedded shales outcrop containing *Styliolina*. A few brachiopods have been found in the surrounding strata.

29. "Kilsyth" is a locality recorded by Chapman (2). His description of it is "Kilsyth, about 2 miles from Croydon, on the road between the railway station and Mt. Dandenong, at a depth of about five feet from the surface." The fossils came from an excavation at the corner of Ipswich and Liverpool Roads.

NOTE.—The Military Maps referred to are the 1935 editions of Ringwood and Yan Yean.

Acknowledgment.

I have pleasure in acknowledging help in the field by Mr. D. R. Dickinson, B.Sc., of the Geological Survey, who was freed from other duties through the kindness of Mr. W. Baragwanath, the director of the Geological Survey.

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Art XII.—*The Physiography of the Gisborne Highands.*

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Contents.

Introduction.

In this paper the writer accepts the view, which he believes to be in accord with that of most physiographers, that in Australia during Tertiary times at least, one long erosion period occurred, in which much of the continent, including the area here dealt with, was reduced to a state of mature erosion or of peneplanation. An attempt is here made to trace the physiographic history of the area from this early erosion period, or if there was more than one, from the latest erosion period to the present day. The contoured maps of the Military Survey have been used for fixing altitude in part of the area. Elsewhere heights were measured differentially by aneroid, and are therefore only approximate. In some cases a sight level was used.

The names adopted are chiefly those in local use. One Mile Creek and Fisher's Creek are names used in the early days of settlement. Unnamed features which it has been necessary to refer to have, in most cases, been given the name of an adjoining landholder, as Hassed's Creek. Jackson's Creek is the name adopted by the Country Roads Board for the main stream of the district, which on the Quarter Sheet is called the Macedon or Saltwater River. Of this creek, the West Macedon branch, which comes from the north, is regarded as the main stream; the western branch is the Slate Quarry Creek. Hassed's Creek is a smaller tributary which runs parallel to the Bacchus Marsh road. The Newer Volcanic lavas are here referred to collectively as basalt.

Extent and General Description of the Area.

The area dealt with extends from the line of differential movement about 8 miles south of Gisborne, named by Fenner (1918) the "Gisborne Fault," to the Main Divide of Victoria in the north, and from the Rowsley Fault in the west, to a few miles east of Gisborne, as shown in Fig. 1.

The rocks represented consist of slates, shales, quartzites and sandstones of Ordovician age, gravels and conglomerates marked Older Pliocene on the Quarter Sheet, Newer Volcanic lava flows, and Recent Alluvium. A quartz-felspar dyke outcrops east of Cockatoo Gully, and another, decomposed to a white clay, near the Slate Quarry, about 6 miles west of Gisborne. At least two east-west dykes, 3 or 4 feet in width and decomposed to a soft brown clay, are exposed in the bed of the Pyrete Creek, east of Mt. Bullengarook and Haire's Hill.

Ordovician rocks prevail in the western portion of the area. Towards the south they are deeply dissected by Goodman's and the Pyrete Creeks and their tributaries. Mt. Bullengarook, 2207 feet, and Haire's Hill are volcanic hills. From Mt. Bullengarook long tongues of lava run south towards Bacchus Marsh, and north-west towards Gisborne. Much of this western area is Crown land, at present of commercial value, chiefly for saw-milling purposes. A slate quarry was worked many years ago, and was re-opened for a time during the war of 1914-1918. Alluvial gold occurs in small amount; the richest locality seems to have been about 5 miles south of Mt. Bullengarook, at Cockatoo Gully, which has cut into the gravel underlying the basalt. The late Mr. William Thom, in a personal communication to the writer, stated that the largest nuggets found in the district weighed respectively 36 oz., 17 oz., and 12 oz. All were found southward of Mt. Bullengarook. To the east of Gisborne township is an area of rich agricultural land in which the old surface features are almost entirely obscured by the Newer Volcanic lava flows. The north peak of Mt. Gisborne, 2,105 feet, is the highest point. The northern portion of the area is drained by Jackson's Creek, and the southern portion by tributaries of the Werribee River and the Kororoit Creek.

Previous Work.

The eastern portion of the area is included in Quarter Sheets 6 S.E. and 7 N.W., and these sheets remain the best guide to the area covered by them. However, some modifications are called for, and will be referred to as occasion arises.

Fenner (1) included the area, under the name of the "Gisborne Highlands," in his paper on the physiography of the Werribee area. He attributed the abrupt change of level between the Gisborne block and the Werribee plains to an east and west fault which he named the "Gisborne Fault," and on the evidence of the contour maps, he pointed out the probability that the head gullies of the Djerriwarrh Creek had been captured by the Pyrete Creek.

In 1920 W. J. Harris and the writer published a paper (2) dealing chiefly with the sedimentary rocks of the Gisborne district, in which it was shown that the bedrock of the area is of Ordovician age. On the evidence of graptolites, an important fault was shown to exist at the Djerriwarrh Creek, and agreement was expressed with Dr. Fenner regarding the probability of stream capture. Dunn's Gully (see Fig. 1) was erroneously marked "Cataract Gully" on the map accompanying that paper. Cataract Gully is the gully running south from Mt. Bullengarook over the basalt.

The Bullengarook Gravels.

On Quarter Sheets 6 S.E. and 7 N.W. several small areas of gravel and conglomerate are shown between Gisborne and Little Bullengarook or, as it is usually called, Haire's Hill. These sub-basaltic gravels and conglomerates are, however, much more extensive and continuous than the Quarter Sheets indicate. Their eastern limit, as far as can be seen, is in Aitken-street, Gisborne, near the Presbytery. On the Calder Highway, about a quarter mile north of the bridge over Jackson's Creek, sub-basaltic gravel which may be an outlying portion of the old gravels occurs. The northern boundary of the gravels runs from Gisborne along Jackson's Creek and the Slate Quarry Creek, to some distance west of the slate quarry. Near the junction of the Slate Quarry Creek and Jackson's Creek, the gravel extends somewhat further north to about half a mile north-west of the junction of the creeks. The western boundary runs south from the Slate Quarry Creek towards Mt. Bullengarook. For the greater part, this boundary is not clearly defined, but at Carrol's Lane the gravels are somewhat sharply cut off, probably by the erosion of Goodman's Creek. Some prospecting has been done here in the gravel, and if we may take the vertical distance between the lowest gravel in a prospector's shaft, and the highest gravel on the lane about 150 yards away, to be the thickness of the gravel sheet, it must have been not less than 60 or 70 feet at this point.

Gravel occurs on the northern flank of Mt. Bullengarook, and surrounds Haire's Hill except perhaps on the west side. From Haire's Hill the gravel boundary runs east and north-east to Gisborne. Within a few miles of Haire's Hill tributaries of the Pyrete Creek have cut into the gravel, and on the more level ground towards Gisborne it is difficult to define the boundary between the gravels and sands and the soil derived from the Ordovician bedrock. Several outlying patches of conglomerate occur as far south as Slocomb's Corner. The extreme dimensions of the gravel area are about 7 miles east to west by 4 miles north to south. A good section of the gravel is to be seen in a pit near Dohoney's Corner. Most of the material here is of a sandy nature, mottled red, and showing well marked current bedding. Occasional beds occur in which the pebbles and boulders range to more than 18 inches in diameter. On the roadside near the gravel pit a shaft has been sunk through gravel to bedrock, and the vertical distance from the bottom of the shaft to the top of the gravel-capped hill above the pit is between 60 and 70 feet. Throughout the gravels, except perhaps at the extreme eastern occurrence, large boulders occur intermingled with the finer material. On the road a mile north-west of Dohoney's Corner, rounded boulders nearly 2 feet long occur. West of Mt. Bullengarook some are at least 1 foot long, and at Slocomb's Corner and near Brucedale they may be 9-10 inches long. The pebbles and boulders consist of reef quartz, quartzite, sandstone, and very rarely of soft shaly material. They range from angular to completely rounded. No igneous pebbles have so far been found, and none which show any trace of glacial action.

Within about 2 miles of its northern edge the gravel has the form of a sheet, covering the bedrock entirely except where intersected by the basalt-filled valleys of old streams. At Slocomb's Corner and at Gisborne it occupies lower ground, with the bedrock rising up to 50 feet above it.

The contrast between the low, gravel-covered right banks of Jackson's and the Slate Quarry Creeks and their high, steep left banks of Ordovician rocks might suggest faulting. However, the highest gravel near Dohoney's Corner and at Mt. Bullengârook is almost equal in height to the Ordovician towards the north, and it is probable that the appearance of faulting is entirely due to erosion by these creeks. The northern edge of the gravel sheet is some 4 or 5 miles south of the main divide. About the same distance to the north of the divide, sub-basaltic gravel occurs near Woodend (5). As far as the writer is aware no gravel of similar age occurs between these points.

Source of the Gravel.

The nature and distribution of the gravel show that its source was to the north, that is in the direction of the present main divide. This implies uplift in that direction, with a change of grade at the northern edge of the gravel sheet. At the present day the heaviest floods do no more than move the existing gravel along the beds of the creeks, and deposit a little silt on some of the river flats. It seems, therefore, that in the production of the gravel, uplift was associated with torrential floods far exceeding any experienced at the present day. There seem to have been at first no definite drainage lines, but the gravel appears to have been swept down in a sheet, or by a number ot minor torrents, and spread out on reaching the lower grade, the flood water making its way eastward by Gisborne, south-west by Mt. Bullengarook, and southward by Slocomb's Corner.

The Old Erosion Surface.

As indicated, the Bullengarook Gravel sheet seems to have completely covered the bedrock over a considerable area, and since any differential movement would tend, from its inception, to produce greater surface relief, the old erosion surface in that area was not more uneven than that preserved under the comparatively thin gravel sheet.

It is reasonable to suppose that any wide level Ordovician area on the divides or elsewhere, where denudation is extremely slow, will at present show surface features resembling those of the old erosion surface. Probably the nearest approach to such an area lies immediately to the west of Gisborne, between the Bacchus Marsh and Melton roads. Even this area, with its low rounded hills and shallow, grassy gullies, is, owing to its proximity to the valley of Jackson's Creek, probably much more uneven than the more level parts of the old erosion surface.

Besides extensive level tracts, there seem to have been prominent hills and ridges rising conspicuously above the general level. On the western slope of Mt. Gisborne, bedrock occurs at a height of about 1,750 feet, which is 200 feet above that on the Melton road, less than half a mile away, and a ridge of bedrock in part covered by basalt extends north-east from that point to Gisborne. This ridge was of no great width, because towards the east no bedrock is exposed at the surface for more than 2 miles, and a bore put down on the north-west slope of Mt. Gisborne, about the 1,900 feet contour, penetrated a depth of 345 feet through basalt to bedrock. It seems clear that this ridge of bedrock existed at the time of the deposition of the Bullengarook gravel, and that it greatly influenced the drainage both at that time and later. There seems to have been high bedrock also at Mt. Bullengarook and at Red Rock. Mt. Tophet, with the broken ridge of bedrock running towards the north across the Calder Highway, was probably a prominent feature of the old surface.

The writer pictures the old erosion surface towards the end of the erosion period as consisting of wide, almost flat areas with here and there prominent hills and ridges, and at wider intervals still higher and older mountain masses such as the Macedon Ranges.

At Gisborne and at Slocomb's Corner, where outliers of gravel and conglomerate exist in valleys between low hills, some of the unevenness of surface may be due to denudation while the gravel was being laid down.

Differential Movement in the South of the Area.

Fenner attributed the abrupt change of level in the south of the area, largely on physiographic evidence, to a fault which he named the "Gisborne Fault" (1). Being unable to trace any distinct line, especially towards the west, which might with confidence be regarded as the line of a major fault, the writer prefers to refer to it as a line of differential movement.

The Age of the Movement Relative to the Main Divide.

If considerable differential movement had taken place on this line at the time of the deposition of the Bullengarook gravels, it might have been expected that similar gravels would also have formed on the lower block. The only locality where sub-basaltic water-worn gravel, which may be regarded as being on the lower block, has been noticed by the writer is near Coimadai, where there is little doubt, it has been brought down by the "Ancient Bullengarook River," and in part derived from the pre-existing gravel of Bullengarook.

Quarter Sheet 7 N.W. shows several small areas of Older Pliocene gravel, etc., near the Toolern Creek. Of these, all which lie to the north of Breakneck Hill are silicified bedrock or surface breccia. It is especially important to note that the small patch shown in the bottom of the gully close to Breakneck Hill is bedrock, and is not in the bottom of the gully but about 50 feet above.

A mile south-east of Breakneck Hill there is on the Quarter Sheet the note "Hard Crystalline Conglomerate". This rock can be traced back over a considerable area to the west of Toolern Creek, and across the Melton road. It is an extremely hard rock in which the original structure is hardly discernible. However, in places numerous small fragments of quartz and quartzite may be seen, and these are quite angular. It probably consists of material drifted or washed from the slopes, and subsequently metamorphosed by the lava, and probably resembled the "drift" which overlies the basalt near Sunbury (3). It might be thought that the wide, low-lying stretch of country where it occurs is the result of erosion. Its width, however, makes this unlikely, especially if, as is probable, the eastern branch of the Toolern Creek came into existence after the commencement of the Newer Volcanic period; and it seems more probable that it is the result of differential movement. The nature of this "Conglomerate" indicates that it was formed under climatic conditions differing from those that prevailed during the formation of the Bullengarook gravel, and similar to that of recent times, so that the differential movement is of later date than the uplift of the main divide. This conclusion is supported by the more mature erosion of the northern area in comparison with that bordering the southern edge of the Gisborne block.

Age of the Differential Movement Relative to the Newer Basalt.

The infilled valley of the old Toolern Creek was several hundred feet deep where it crossed from the higher to the lower block early in the Newer Volcanic period, and the infilling lava shows no sign of disturbance, so that the differential movement was probably complete at the commencement of the Newer Volcanic period.

Direction and Nature of the Movement.

From the Rowsley Fault the line of differential movement runs in a generally easterly direction for about 10 miles to Toolern Vale, where it turns north and apparently dies out in a few miles. While the general direction of the line of movement is as stated, considerable irregularities exist, especially near Toolern Vale. On evidence which like that obtained by Dr. Fenner is largely physiographic, it is suggested that the north and south portions of the movement, and part of the east and west portion near Toolern Vale, are due to simple faulting, but towards the west the movement is more complicated, with step faulting and monoclinal folding, the Coimadai fault being part of the main movement. The greatest elevation along the southern edge of the Gisborne block is north of Toolern Vale at Black Hills, 1,550 feet. It is noticeable that the Ordovician of the Black Hills to the east, and near Breakneck Hill to the west of the valley of the old Toolern Creek, is considerably higher than the basin of the old stream. This greater elevation suggests two interesting possibilities: a ridge of Ordovician through a low gap in which the old Toolern Creek found an outlet may have existed in the old erosion surface, or the differential uplift may have been greatest near the southern edge of the uplifted block, giving it a tilt towards the north.

The Pre-Basaltic Streams.

The grade of the pre-basaltic streams, except where they were rejuvenated by differential movement, appears for the most part to have been low. In only a few cases are their channels exposed, and even when later streams have cut through a tongue of basalt, the exact position of the old channel is often masked by hillside slipping. There is also the possibility of small earth movements having taken place since the time when the early lava flows occupied the old valleys (4) For these reasons, and in the absence of exact measurements of height, field relations have been given the most weight in attempting to trace the course of the old streams.

THE ANCIENT BULLENGAROOK RIVER.

The tongue of basalt which runs south from Mt. Bullengarook clearly occupies an old valley. A tongue of basalt also runs north-east from Mt. Bullengarook towards the West Macedon or main branch of Jackson's Creek. A narrow gap has been cut through this tongue by the Slate Quarry Creek near Waterloo Bridge, and the position of springs at the gap indicates the bottom of the old valley.

The mapping of the area near Dohoney's Corner, as shown on Quarter Sheet 6 S.W., requires modification. In the field it is sometimes difficult to distinguish volcanic from sedimentary areas, since surface drift covers the low-lying portions of both alike, and it is probable that at the time of the survey much that is now cleared and cultivated land was heavily timbered.

In the Quarter Sheet, bedrock is shown projecting north-east from Dohoney's Corner across Sections 30 and 31. This projection is really a ridge of gravel, or gravel-capped Ordovician. At Dohoney's Corner it is higher, and at the point where it is shown as ending, a few feet lower than the top of the basalt to the west, it dips a few feet but still continues as a prominent gravel ridge until it meets the Ordovician towards Jackson's Creek. If the basalt had flowed along an east-west valley, as would be inferred from the mapping on the Quarter Sheet, we might expect to find a ridge of basalt running in that direction, instead of which we find a gravel ridge running nearly north and south.

In the absence of a topographical survey of the locality, the following statement of heights obtained by aneroid and sight level is submitted: the highest point of the basalt north of Waterloo Bridge is 65 feet above its base near the bridge. The highest point of the basalt east of the gravel ridge is level with the base of the basalt near Waterloo Bridge. The lowest part of the gravel ridge is 40 feet above the top of the basalt to the east.

The gravel ridge at the time of the lava flow was doubtless higher than it is now, but probably was not quite as high throughout its entire length as the top of the basalt to the west. It seems to have branched towards the north, and in a hollow between the branches some basalt still remains. For the reasons given above, the writer believes that the infilled valley running north-east from Mt. Bullengarook was portion of the "Ancient Bullengarook River" valley, its only possible outlet being to the south. In that case the head of Jackson's Creek was one of the head-waters of that ancient river.

The base of the basalt is exposed at the head of Dunn's Gully, between Mt. Bullengarook and Haire's Hill, and a comparison was made by aneroid of its height there with the base of the basalt near Waterloo Bridge, with the result that it was found to be higher than that near the bridge by about 70 feet.

A quarter of a mile south of, and 120 feet higher than, the low basalt in Dunn's Gully, bedrock and gravel outcrop at the surface. Bedrock outcrops on the Bacchus Marsh road, west of Mt. Bullengarook. From about the same level as this outcrop, and on the northern slope of the mount, a well has been sunk 160 feet through basalt to bedrock. This still could not have been on the old river bed, which must have been further to the east, between the well and the gravel and bedrock outcrop, or directly under the mount.

On the Quarter Sheet, about a quarter of a mile north-east of Dohoney's Corner, a tongue of basalt is shown projecting south-west across Section 30. In line with this tongue and at the same level, running south-west across the Bacchus Marsh road, there is a wide, flat-bottomed depression, and about half a mile south of the corner at a low level, an outcrop of basalt of similar type to that towards the north. This outcrop has not been noted by the Survey. About a mile still further south, at what is known as "Chapman's" there is an outlier of basalt of similar type resting on gravel.

About three-quarters of a mile west of Rosslyn, Jackson's Creek has cut through a bar of basalt, exposing an old valley, the bottom of which is about 50 feet above the present level of the creek. These three points, which are in line with the tongue of basalt in Section 30, seem clearly to mark an old stream valley. A comparison of the depth of its channel with that of the old valley to the west of the gravel ridge suggests that the eastern stream was the greater. In that case obviously its source was not towards the south. It was probably an eastern branch of the Ancient Bullengarook River, with headwaters at Lawson's Creek, and the southern portion of its course occupied nearly the present position of the Pyrete Creek. The outlier of basalt at Chapman's is probably not the base but some higher remnant of a flow. Aneroid measurements failed to show any difference in height between it, the outcrop south of Dohoney's Corner, and the base of the bar of basalt at Jackson's Creek. Of these two branches of the Ancient Bullengarook River, the western may, by the accession of tributaries from that direction, have become the greater before their junction.

THE SLATE QUARRY CREEK.

This creek was evidently a tributary of the Ancient Bullengarook River, flowing for part of its course along the northern edge of the Bullengarook gravel sheet.

THE INFILLED BRUCEDALE-LITTLE SCOTLAND VALLEY.

Its relation to the neighbouring Ordovician shows that this stream trended north, a conclusion which aneroid measurements support. The bottom of the old valley at Little Scotland is only about 30 feet above the present creek level, so that this old stream could not have been a tributary of the Ancient Bullengarook River, but must have turned towards the east.

THE INFILLED VALLEY OF MURRAY'S SPUR.

The levels of the bedrock underlying the basalt show that this old valley trended south-west. It is in a direct line with the south-west portion of the Pyrete Creek, and drained the high ground near Mt. Gisborne. The base of the basalt at the south-west end of the spur is considerably lower than the lowest part of the divide between the Pyrete and Djerriwarrh Creeks, and the infilling basalt is of an early type.

THE OLD TOOLERN CREEK.

This creek drained the country to the south and south-east of Gisborne including the area where Mt. Gisborne now stands, and that now forming the basin of the Upper Djerriwarrh Creek. To the north-west of Breakneck Hill its tributaries must have trended north for about half a mile before turning east to join the main creek. That there was no outlet for them directly to the south is shown by the absence of lava tongues in that direction. Further evidence to this effect will be given later.

THE OLD BLACK HILL CREEK.

A small stream indicated by a lava tongue seems to have run south at the Black Hill road. It probably had only a small catchment area.

PRE-BASALTIC DRAINAGE TO THE EAST OF GISBORNE.

Reconstruction of the pre-basaltic drainage in the area to the east of Gisborne is difficult, owing to the basalt covering. If, as is probable, the drainage from the Macedon Ranges took approximately the course of the present Riddell's Creek, there would have been only a small catchment area for any streams immediately to the east of Gisborne.

An interesting problem presents itself at Red Rock Hill. To the south-east of the hill, bedrock outcrops at a height of 1,500 feet. On the southern flank of the hill, about a quarter of a mile north-west of this outcrop and from about the same surface level, a bore was put down which passed through 359 feet of basalt to bedrock, so that the height of the old surface at the bottom of the bore is 1,141 feet. Somewhat less than three-quarters of a mile west of the bore, bedrock is exposed in a creek at a height of 1,400 feet. An extensive area of bedrock occurs to the north and north-west of the hill, so that the outlet from the low ground could not have been in either of these directions. Neither could it have been to the south-east or directly to the south. An outlet may have existed to the south-west, in the direction of the Calder Highway, but this is doubtful, since the bedrock outcrops not far to the east of the Highway and also to the west of the Highway, about half a mile south of Deverall's Hill at a height of about 1,400 feet. A possible direction is to the north-east, when it may have turned south towards Mt. Tophet, or have continued north-east towards Clarkefield. It seems most probable that in pre-Newer Volcanic times a stream trending east occupied a position not far from the present Jackson's Creek, but somewhat further north, united somewhere east of Clarkefield with a stream coming from the direction of Lancefield, and that with the exception of the reversal and diversion of portions of the Ancient Bullengarook River, the chief drainage lines did not differ greatly in position and direction from those of the present day.

Lakes of the Newer Basalt Period.

Evidence of the existence of lakes during the Newer Volcanic Period is to be found in the south of the area at the Djerriwarrh Creek and south of Couangalt.

A bed of a material, which has been determined by Dr. A. B. Edwards to be impure diatomaceous earth, is exposed in the gorges of the Djerriwarrh Creek and some of its eastern tributaries, interbedded with the lava flows. Owing to the basalt cover, the extent of the deposit cannot be seen, but it appears to be about half a mile in length and breadth, and several feet thick. The surface of the underlying lava slopes towards the south, and the diatomaceous bed indicates the former existence of a lake on the sloping surface. There being no outlet for the overflow from the lake across the high bedrock to the south, it probably made its way eastward along the edge of the lava to the Toolern Creek. Diatomaceous earth altered by the basalt is also exposed near the bottom of the Toolern Creek valley, about a mile south of Couangalt. At this locality there is evidence that the old valley was blocked by an early point of eruption in the valley itself. A few blocks of altered diatomaceous earth also occur in another branch of the creek, about half a mile to the west.

The Existing Streams.

Excluding a few of the minor tributaries, it is probable that all of the present streams which flow over Ordovician rocks, and which have not been influenced by the basalt, are of pre-Newer Volcanic age, while all that are associated with the basalt had their origin during the Newer Volcanic period. These Newer Volcanic streams may vary considerably in age, and some may vary in age in different parts of their course. Hassed's Creek probably came into existence soon after the commencement, and the upper portion of One Mile Creek near the close, of the volcanic period.

The Pyrete Creek has its source between Haire's Hill and Dohoney's Corner. It runs in a southerly direction for about 4 miles, and then turns sharply to the south-west, crossing the strike of the Ordovician rocks in a zig-zag fashion for more than 4 miles before turning south again on reaching the Bullengarook lava tongue. It probably follows very nearly the course of a branch of the Ancient Bullengarook River. The Slate Quarry Creek was probably a tributary of the Ancient Bullengarook River, flowing for part of its course along the northern edge of the Bullengarook gravel sheet. Goodman's Creek and Dunn's Gully, with the Lower Pyrete Creek, are laterals to the Bullengarook lava tongue. Hassed's Creek is portion of the Ancient Bullengarook River reversed by the lava flows.

Jackson's Creek.—Evidence has been brought forward that the western portion of this creek was part of the Ancient Bullengarook River, diverted to an easterly course by the Bullengarook lavas. Further east its course was determined by lava flows from points of eruption to the north and the south. Toolern Creek propably occupies nearly the position of the pre-basaltic stream, but with considerably less catchment. Where it crosses the " Gisborne Fault," from the higher to the lower block, it is not lateral to but runs for about a mile along the centre of the narrow tongue of lava. This is probably due to the formation of a depression in the lava by the draining away of the central, more plastic portion. The Eastern Branch of the Toolern Creek commences as a lateral to the lava. The gullies near Breakneck Hill are probably about the same age as the Eastern Branch of the Toolern Creek.

The *Djerriwarrh Creek.*—The lake which existed in the Djerriwarrh area ultimately found an outlet to the south, either by tapping by a gully on the Ordovician, or by the raising of its level by a later lava flow. Once the outlet was formed, rapid downward cutting through the soft diatomaceous bed and the

Ordovician gave rise to the deep gorge of the Djerriwarrh Creek, which runs for nearly a mile parallel to, and about a quarter of a mile distant from, the western edge of the basalt.

The Points of Eruption and the Lava Flows.

Mt. Bullengarook and Haire's Hill.

The earliest flow from these centres appears to have taken a north-easterly direction along a branch of the Ancient Bullengarook River. The depth—upwards of 400 feet—of the gullies lateral to the lava flow south of Mt. Bullengarook, suggests that it is of an early date. However, Cataract Gully, on the basalt, is, except near its mouth, an insignificant depression which is crossed by a road without even a culvert being necessary, and is quite comparable with streams of similar catchment near Mt. Gisborne and on the Keilor Plains.

At Mt. Gisborne the commencement of activity seems to have taken place towards the northern flank of the present hill. Later, about the middle of the volcanic period, a rounded hill which sent out lava flows in all directions, except to the north-west where high bedrock was in the way, was built up, forming the central portion of the present mount. A series of eruptions then built up the north peak, and lastly the south peak was formed. Many other points of eruption, which need not be described here, exist in the area.

Stream Capture.

The writer formerly shared the opinion that the Upper Pyrete was at one time a head gully of the Djerriwarrh Creek, and was captured by a tributary of the Ancient Bullengarook River. He has since abandoned this view for the following reasons:—

Early in the Newer Volcanic Period the south-west reach of the Pyrete Creek was already entrenched in a valley which was far below the level of the divide between the Pyrete and Djerriwarrh Creeks. The evidence for this is the unfilled valley of Murray's Spur, which must have continued in a south-west direction. Evidence has been given which suggests that in pre-volcanic times the Upper Pyrete had a much greater catchment area than the present creek has, and it is unlikely that such a stream, if early in its history it flowed south towards the Djerriwarrh Creek in line with the strike of the Ordovician rocks, would not maintain its course, or that it would be captured by a tributary of an equal stream some miles to the west. It seems more probable that the south-west reach of the Pyrete is due to the configuration of the old erosion surface, and that the creek has occupied very nearly its present position since its commencement.

The River Flats of Jackson's Creek.

Along Jackson's Creek, wherever bedrock is exposed above a bar of basalt, a flat has been formed. The most important of these flats is that at Gisborne, its greatest width being about half a mile, and its length a mile and a half. A large flat exists at Rosslyn, above the bar at Little Scotland, which has been completely cut through, so that the Rosslyn flat is continuous with that at Gibsorne. The size of the flats at Gisborne and Rosslyn is probably due, not so much to the comparatively narrow bars of basalt which have been the direct cause of their formation, as to the wide stretch of basalt which the creek enters upon about half a mile east of Gisborne, and which has prevented the creek from reaching a sufficiently low level to breach the bars by undercutting. Waterloo Flat formed while the Slate Quarry Creek was cutting through the bar of basalt near Waterloo Bridge. This bar is now completely cut through. About a mile west of Rosslyn the remnant of a small terrace exists about 50 feet above creek level. This was probably a flat formed while the creek was cutting through the bar of basalt which it crossed at that point. To the east of the mouth of One Mile Creek a flat, several acres in extent, occurs in volcanic rock. The light scoriaceous nature of the rock, and the presence of beds of unconsolidated volcanic material, indicate that this was probably a point of eruption.

Some General Remarks.

It is difficult to decide when the evolution of the present topography began. It probably had its beginning long prior to the end of the last great erosion period. The Macedon Ranges, which lie to the north-east of the area particularly dealt with, have existed for a very long time as a prominent mountain mass. The course of a pre-basaltic stream was approximately that of the present Riddell's Creek (5). At that time this was probably the most important stream in the eastern area, and its basin seems to have extended in width approximately to a line from Gisborne to Sunbury. Acting, as it may have done, through a very long period of time, it would have an important effect in the development of the pre-basaltic topography.

The bedrock, which here and there rises above the basalt between Gisborne and Sunbury and between Mt. Tophet and Clarkefield, consists almost wholly of the hard sandstones and quartzites and the hardened shale beds of the "Riddell Grits" (2), and it is probable that these high areas of bedrock are due to their resistance to erosion and not to the Tertiary earth movements which affected the western portion of the Gisborne district.

No drift wood or fossils of any kind have been noticed in the Bullengarook gravels. It is probable that climatic conditions played an all-important part in their formation, and it is possible that the elevation of the main divide may have preceded the formation of the gravels by a long period. If this period had been greatly prolonged, however, there should be more distinct evidence of the existence of well-developed drainage lines in the area at the time of formation of the gravels.

If recent earth movements of appreciable magnitude have occurred, there should be rejuvenation of the streams and consequent rapid erosion in the areas affected. In the Gisborne flat, where beds of clay, sand, and gravel containing basalt pebbles occur, much work is being done by Jackson's Creek, by side-swinging, with but slight lowering of its bed. The same creek near Rosslyn has worn a particularly deep and steep-sided channel, which may be accounted for by the cuttng through of the bar of basalt at Little Scotland.

In places along some of the tributaries of the Pyrete and Djerriwarrh Creeks, a great deal of material has been removed quite recently. This material consisted chiefly of soil and fragments of rock from the hillsides, which had accumulated in the gully, so that the work done represents the widening rather than the deepening of the valley.

Toolern Creek, on its passage from the higher to the lower block, has worn a deep channel with projecting points of basalt with vertical walls and many fallen blocks. Above these points there are usually small flats at creek level, the occurrence of which on such a small stream shows that downward cutting has been slow and probably normal under existing conditions of grade and rock structure.

The most striking case of rapid erosion occurs near the mouth of Cataract Gully, where there are vertical columns of basalt 60 or 70 feet high, and the creek bed is littered with fallen blocks. This is doubtless due to the creek having reached the underlying gravel beds of the old Bullengarook River, and it seems probable that in the area dealt with, no appreciable earth movements have occurred since the commencement of the Newer Volcanic Period, and that the forces now acting are those of erosion only.

This statement is not intended to apply to the Coimadai area, which has not been closely examined. The writer has long suspected that the Coimadai limestone was derived from the Mt. Bullengarook lava, being led to that opinion by the abundant calcium carbonate in the cavities and associated with the basalt south of Mt. Bullengarook. The existence of the limestone basin adjacent to the lava stream is more difficult to account for.

Summary.

Gravels, referred to here as the Bullengarook gravels, cover a much more extensive area in the Gisborne Highlands than is suggested by the Quarter Sheets of the Geological Survey. The extreme dimensions of the gravel area are about 7 miles east to west, and 4 miles north to south, with a thickness of from 60 to 80 feet. The pebbles and boulders are unsorted and up to 2 feet in diameter. They range from angular to completely rounded, and consist essentially of reef quartz, quartzite, and sandstone. They occur in the form of a sheet, covering the bedrock except where intersected by the lava-filled valleys of old streams. The gravel came from the north, indicating uplift in the direction of the Main Divide, with a change of grade at the northern edge of the gravel sheet, associated with torrential floods in excess of any experienced at the present day.

In other parts of the area the surface is composed of widespread flows of volcanic rock, younger than the gravels. The old erosion surface underlying the gravels and volcanic rocks appears to have consisted of wide, almost flat areas with prominent hills and ridges here and there, dominated by the monadnock of the Macedon Ranges to the north.

The southern limit of the Gisborne Highlands is marked by a line of differential movement, which raised it above the basalt plains to the south. This differential movement occurred subsequently to the uplift of the Main Divide, but prior to the extrusion of the volcanic rocks.

The lava flows have largely obliterated the pre-basaltic drainage system, but it seems probable that the chief drainage lines did not differ greatly in position and direction from those of the present day.

Acknowledgments.

The writer gratefully acknowledges his indebtedness to Dr. A. B. Edwards for preparing the map in a form suitable for publication, and attending to the typing of the manuscript, and for much help during the progress of the work; and to Mr. H. E. Dixon, of Gisborne, whose extensive local knowledge has made his assistance of especial value.

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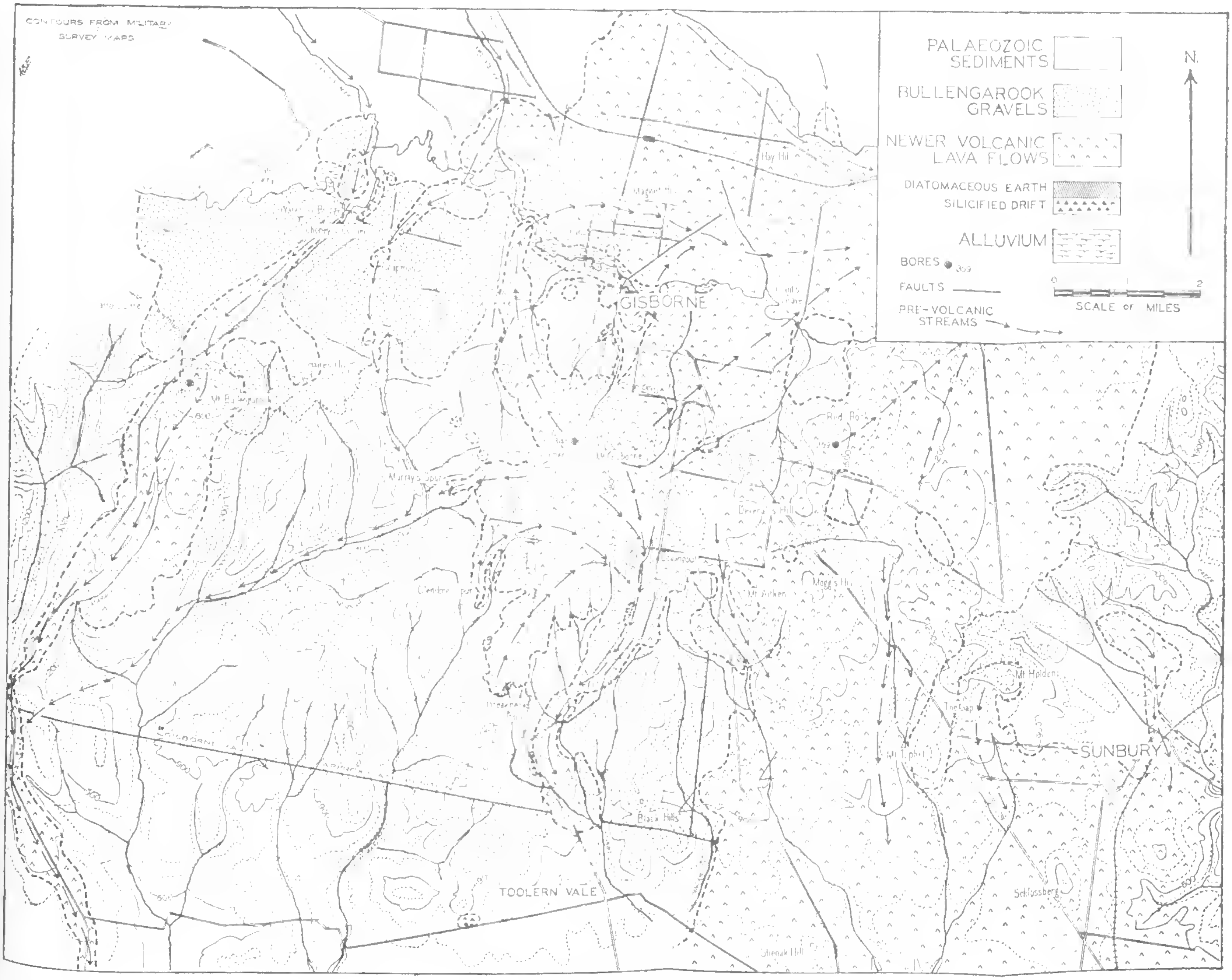

834/40. FIG. 1. Locality Map (see Crawford's Paper). [*Page* 279.]

[Proc. Roy. Soc. Victoria, 52 (N.S.), Pt. II., 1940.]

Art. XIII.—*The Cainozoic Volcanic Rocks of the Gisborne District, Victoria.*

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[Read 14th September, 1939; issued separately 1st July, 1940.]

Contents.

Introduction.

The volcanic rocks which cap much of the Gisborne Highlands (fig. 1) belong to the Cainozoic Newer Volcanic Series, and range in type from limburgite to acid-trachyandesite. The points of cruption from which the lavas issued stand up as prominent hills, of which Mt. Gisborne (2,105′) and Mt. Bullengarook (2,207′) are the two highest. The greatest variety of rock types lies within the area bounded on the north by the Melbourne-Bendigo railway line, on the west by Goodman's Creek, on the south by the Coimadai-Toolern Vale road, and on the east by the Black Hills road. This area has been mapped in detail (fig. 2), mainly by Mr. W. Crawford, of Gisborne. The laboratory study and chemical analyses were made by Dr. Edwards at the Geology Department, University of Melbourne, by the kind permission of Professor Skeats.

General Geology.

The Volcanic Hills.

The eroded volcanic hills of the Gisborne Highlands appear at their most striking when viewed across "The Gap" from Schlossberg Hill, on the north side of Mt. Alexander Road (Calder Highway) about two and a half miles north-west of Digger's Rest township. Similar volcanic hills, Mt. Kororoit and

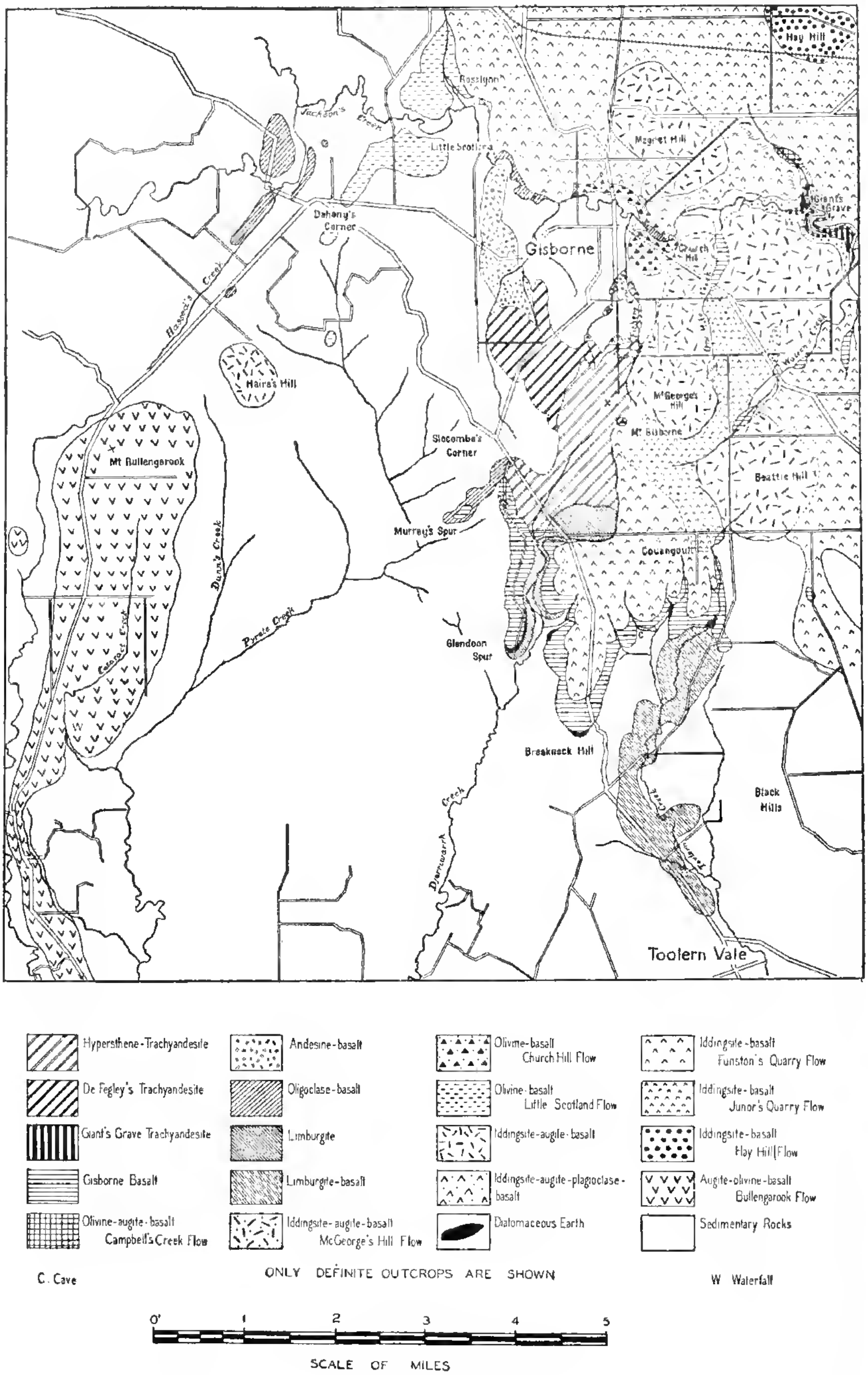

FIG. 2.—Geological Map of the Gisborne District, showing the distribution of the Newer Volcanic rocks.

Sheoak Hill, stand up to the south-west of this vantage point, on the northern margin of the low-level basalt plains abutting the Gisborne Highlands.

Several of these hills, namely Red Rock, Mogg's Hill, Deverall's Hill, O'Brien's Hill, and Mt. Holden, present closely comparable profiles—a more or less flat top surrounded by rocky cliffs on all sides but one, where there is an easy slope down to the surrounding plain. The sides of this sloping tract are also marked by rocky walls in their upper parts. These profiles arise from the fact that erosion of the scoriaceous material of the original cone has exposed the central plug of the volcano and the sides of the lava flow which breached the cone (fig. 3). The lavas that issued from these vents were among the latest extrusions of the district, and gave rise to a generally similar type of porphyritic iddingsite-augite-labradorite-basalt.

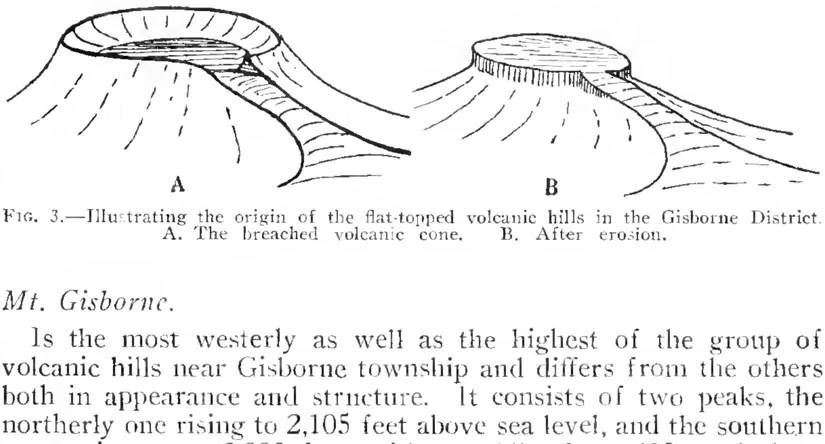

Fig. 3.—Illustrating the origin of the flat-topped volcanic hills in the Gisborne District. A. The breached volcanic cone. B. After erosion.

Mt. Gisborne.

Is the most westerly as well as the highest of the group of volcanic hills near Gisborne township and differs from the others both in appearance and structure. It consists of two peaks, the northerly one rising to 2,105 feet above sea level, and the southern one to just over 2,000 feet, with a saddle about 600 yards long connecting them. A third peak, McGeorge's Hill (1,900′) occurs on the north-eastern slope of the north peak, but really belongs to the group of flat-topped hills already described.

Mt. Gisborne is built up of a series of lava flows ranging in composition from limburgite to acid trachyandesite, with olivine-basalts predominating, and is the most complex Tertiary volcanic hill yet known in Victoria. It also appears to be the earliest centre of eruption in the Gisborne district, since its later flows are closely comparable with the flows from the adjacent cones. The volcanic activity appears to have commenced with the extrusion of flows of oligoclase-basalt, andesine-basalt, and limburgite. The andesine-basalt issued from near the northern flank of the present mount; the oligoclase-basalt flowed out to the west, filling a valley now represented by Murray's Spur; and the limburgite flowed southwards into a valley now represented by Glendon Spur. The vents from which these flows issued are hidden beneath later lava flows, and there is no evidence as to their order of extrusion. An extensive flow of limburgite-basalt occurred in the valley of the pre-basaltic Toolern Creek, and flowed down that valley towards Toolern Vale. The vent of this flow appears to have built up to a sufficient height to effectively dam the valley, and prevent any later extrusions from flowing down it. At about this time, also, the olivine-basalt of Church Hill, to the north of Mt. Gisborne, was extruded (probably from a vent near Magnet Hill, judging from its surface slope).

A period of quiescence followed these eruptions. Extensive deposits of impure diatomaceous earth, suggestive of temporary lake conditions, overlie the limburgite and limburgite-basalt flows (5).

The next extrusions are mostly characterized by the presence in varying amounts of partially resorbed hypersthene, labradorite, and anorthoclase. The most extensive are flows of olivine-basalt (the Gisborne Type). These directly overlie the diatomaceous earths, the oligoclase-basalt, limburgite, and limburgite-basalt, on the western and southern flanks of the mountain, and extend as far south as the higher Ordovician ground of the Breakneck and the Black Hills. On the east and north-east it is exposed beneath later basalts in several " windows " in creek beds, and along One Mile Creek in the vicinity of its junction with Jackson's Creek.

The Gisborne basalt was followed by the extrusion of a sheet of iddingsite-basalt (the Funston's Quarry flow), which extended as far south as the Ordovician hills, and also appears in the bed of Fisher's Creek, south of the township of Gisborne, and on the road leading from Gisborne to Mt. Gisborne, north-west of Section VII.

At least three flows of trachyandesite developed at this time. A glassy, basic trachyandesite (De Fegley's Flow) issued to the north-west, partially covering the earlier andesine-basalt flow down the pre-basaltic Carnegie's Creek. This in turn was partly covered by an acid, grey trachyandesite which also flowed out to the south-west, covering limburgite, Gisborne-basalt, and oligoclase-basalt, and to the north-east. Its full exent in this direction is hidden by later flows, but it is revealed in a " window " in One Mile Creek beneath the flow from McGeorge's Hill. A third trachyandesite, which outcrops as the third lowest of the four flows exposed in Jackson's Creek in the vicinity of the Giant's Grave, also probably came from Mt. Gisborne. Xenoliths in the trachyandesite suggest that a flow of hypersthene-basalt, now completely hidden, also occurred during this stage.

These were followed by an extrusion of iddingsite-augite-basalt from a new vent, McGeorge's Hill, on the north-eastern flank of the north peak of Mt. Gisborne. This stage seems to have coincided with a period of general activity throughout the district, when the various volcanic cones mentioned were formed. A generally similar type of lava issued from them all. Then a final extrusion from near the south peak gave rise to the Junor's Quarry flow of iddingsite-basalt (Ballan Type) on the eastern side of the mountain. This forked, going partly to the south-east and partly to the north-east, between and covering the porphyritic flows from McGeorge's Hill and Beattie Hill, as far as the Mt. Alexander Road.

Magnet Hill.

North of Gisborne and east of New Gisborne, is an oval-shaped hill of rather glassy porphyritic iddingsite-augite-basalt, more or less comparable with the McGeorge's Hill flow. It is probable that several flows issued from this vicinity. Only so can one explain the occurrence of an area of oligoclase-basalt to the south of Magnet Hill, in Jackson's Creek, and the olivine-basalt (Church Hill flow) which overlies this oligoclase-basalt. Iddingsite-basalt, which overlies the Church Hill flow and underlies the Magnet Hill porphyritic flow, may also have come from this source.

Hay Hill.

In the north-east corner of the area, is a small hill of fine-grained andesitic-basalt, overlying the widespread porphyritic type of the plain. It is similar to the latest (Junor's Quarry flow) flow from Mt. Gisborne.

Haire's Hill (Little Bullengarook).

West of Gisborne and close to the north-eastern flank of Mt. Bullengarook is Haire's Hill, a dome-shaped hill of porphyritic iddingsite-basalt which is more or less isolated, although a flow appears to have issued from it to the north-west.

Mt. Bullengarook (2,207′).

Immediately to the west of Haire's Hill provides a striking contrast. It consists of a pedestal of Ordovician sediments rising to at least 1,900 feet above sea level (5), capped by about 300 feet of basalts. The earliest flow appears to have been an oligoclase-basalt which flowed to the north, along what was presumably a continuation of the pre-basaltic Bullengarook River. This early flow has undergone a certain amount of erosion, and its outcrop is not everywhere continuous. Spoil from a well shaft on the northern flank of the hill indicates that this early flow is overlain by a porphyritic iddingsite-basalt similar to that of Hair's Hill. Overlying this there is a very considerable flow of porphyritic augite-olivine-basalt which flowed out to the south, filling the valley of the pre-basaltic Bullengarook River for a distance of twelve and a half miles. It is to this lava flow that Mt. Bullengarook owes its distinctive profile. A contour plan of this flow has been given by Charles Fenner (11, p. 260). In its widest part the flow is about a mile and a half across, but about four and a half miles downstream it narrows to almost nothing, and then widens again. There appears to be a distinct descent in level at this point, suggestive of a slight downwards movement of the block to the south. The basalt is similar on both sides of this point. Goodman's Creek and the Pyrete Creek (Dunns Creek at the northern end) have formed deep lateral streams on either side of this flow; while in the upper portions it has been deeply dissected by Cataract Creek, which starts as a slight depression on the surface of the lava, and quickly deepens into a gorge, with a waterfall where it spills over on to the Ordovician bedrock.

Lava Fields.

The form of the lava fields in the western part of the Gisborne Higlands is in striking contrast to those in the eastern part. The long narrow flow running south from Mt. Bullengarook is an excellent example of Keble's conception (14) of a "confined lava field," i.e. one in which the lava flow failed to completely fill the valley into which it flowed. The drainage flowing down such a valley is still retained between the original interfluves, but tends to reconstitute itself as a pair of lateral streams on either side of the lava field, which becomes elevated to the position of a ridge as erosion proceeds.

The lava field extending eastwards from Gisborne. on the other hand, is an example of an "extensive lava field." The earlier flows were confined within the pre-basaltic valleys, as in the western area, but repeated extrusions gave rise to such a volume of lava that the pre-basaltic topography was completely buried, except for the summits of a high ridge of Ordovician sediments trending north-east from Mt. Tophet towards Clarkefield, and the high ground to the west of Gisborne. The drainage was completely deranged, and developed as a new, sinuous stream (Jackson's Creek) consequent on the gradient of the lava plain. This stream has cut down below the surface of the plain, sometimes to the underlying bedrock, and has incised its sinuous course in the process giving rise to in-grown meanders. Where it crosses the infilled pre-basaltic valleys, as at the Giant's Grave, the extra thickness of lava flows has acted as a bar, causing the development of a narrow gorge. Where it has reached the softer bedrock the valley has widened as a result of undercutting, and flats have formed in which the stream has cut meanders.

The Giant's Grave.

This is a cut-off spur of one of the in-grown meanders. A pre-basaltic valley trending north-east existed at this point, and was infilled by a series of lava flows, of which four are exposed in section. The presence of soft or weathered rock at the base of the third flow (down) has enabled the stream to undercut the rock above this layer, until finally it breached the lava at this point, and broke through into its valley on the other arm of the in-grown meander. With further grading of its bed the stream has abandoned the meander, and has worn down the cut-off spur until it looks like an enormous burial mound set in a walled amphitheatre.

Waterfalls.

The gorge tract continues for some distance upstream to a waterfall, which has resulted from undercutting at the junction of the second and third lava flows of this series. Another waterfall occurs on Cataract Creek (Bullengarook flow) where the stream which has its origin on the surface of the small lava plain south of Mt. Bullengarook falls over the edge of the basalt on to the Ordovician sediments. Undercutting has produced a considerable waterfall at this point, and a narrow, gorge-like valley extends for some distance upstream.

Age of the Lava Flows.

Although the lava flows of the Gisborne district have a quite youthful appearance, the amount of erosion which they have undergone is sufficient to show that they are not of Recent age. They overlie the Bullengarook gravels (5), and were extruded after the differential uplift which raised the Gisborne Highlands above the plain to the south. There is no indication of any prolonged break between the lava flows at any stage; and since the later members appear to be contemporaneous with the basalts that cover these plains, and which are regarded as of Pleistocene age (4, p. 257), they are all probably of this age.

Petrology.

The volcanic rocks of the Gisborne district fall into two main groups:—(1) those which appear to be typical differentiates of an olivine-basalt magma, and (2) those which appear to be "abnormal" differentiates, namely the hypersthene-trachyandesites, and hypersthene-bearing basalts. For convenience the "abnormal" types are grouped together in the following petrological descriptions. The nomenclature used is the same as adopted in earlier papers (8, p. 256).

A. Abnormal Differentiates.

Trachyandesites.

Three flows of trachyandesite have been discovered in the Gisborne district.

Hypersthene-trachyandesite.

This rock outcrops on the north-western and south-western flanks of Mt. Gisborne, overlying the de Fegley's trachyandesite, Gisborne basalt, limburgite, and iddingsite-basalt (Funston's Quarry flow). It also outcrops in the bed of One Mile Creek, where it is overlain by the iddingsite-basalt, from MeGeorge's Hill. It consists of phenocrysts of sanidine, anorthoclase and plagioclase felspars, and of hypersthene, augite, and occasionally olivine, set in a hyalopiltic to pilotaxitic groundmass. Rounded xenocrysts of quartz are present in every section. The sanidine phenocrysts are simply twinned or untwinned, and rounded. Their margins are generally vermiculate, owing to reaction with the enclosing magma. Sometimes this process of resolution has progressed so far that only a "brain structure" of felspar remains. Occasionally this corroded felspar shows closely-spaced but very faint lamellar twinning, suggesting that it is anorthoclase. The plagioclase, which shows strong lamellar twinning and sometimes zoning, is also corroded and frequently more or less vermiculate. The maximum extinction angle obtained in the symmetrical zone was 32°, corresponding to a composition of about Ab_{40}. These felspar phenocrysts, especially the plagioclase, tend to gather into clots, in company with crystals of hypershene and sometimes aguite. Some of the clots attain to 2 and 3 cm. in diameter, and resemble norites. They represent the preliminary stage in the formation of the norite xenoliths described below.

The hypersthene is distinctly pleochroic with X = pinkish to yellowish, Y = colourless or pale green, Z = green. It has a (—) 2V between 60° and 90°, so that it probably contains 20 to 30 per cent. of the $FeSiO_3$ molecule (En_{70}). The larger hypersthene crystals are somewhat corroded and even vermiculate, though never so much as the felspars. Small lath-like crystals of hypersthene occur in the groundmass, and are generally edged with a monoclinic pyroxene showing an extinction angle of about 40°. Occasionally the hypersthene crystals occur in small clots, free from felspar. A monoclinic pyroxene with a large extinction angle and (+) 2V greater than 45° also occurs as phenocrysts. It is presumably an augite and is not vermiculate. The pyroxene fringing the laths of hypersthene in the groundmass may be of the same composition.

Every section contains one or two rounded grains of quartz. These appear to be xenocrysts derived from assimilated sedimentary rock. They do not show any semblance of the forms usually exhibited by quartz phenocrysts in rhyolites or similar rocks. Moreover, microphenocrysts of olivine with iddingsite are occasionally present. In weathered specimens this olivine is more or less altered to serpentine. Large apatite crystals (1 mm. x 0.2 mm.) enclosing fibrous inclusions parallel to the prism axis also make an occasional appearance. The fibrous inclusions are pleochroic from brown to black. The groundmass consists of microlites or small laths of oligoclase (Ab_{75}), incipient pyroxene crystals, and dark glass.

As the analysis (Table I., No. 1) indicates, this rock is an acid trachyandesite, which closely resembles the trachyandesite flows of the Coliban district (8, p. 258) both in chemical and mineralogical composition.

de Fegley's Trachyandesite.

This is a dense, almost glassy, black rock, studded with phenocrysts of felspar that may be as large as 5 mm. across, but are generally smaller. It forms a flow on the north-western flank of Mt. Gisborne, overlying the andesine-basalt that outcrops near Brucedale, and overlain by the trachyandesite just described. In hand specimen it somewhat resembles the black trachyandesite glass of the Coliban district (8, p. 258). In thin section it is seen to consist of phenocrysts of hypersthene, augite, partially resorbed plagioclase, and occasionally sanidine, in a hyalopilitic groundmass of oligoclase microlites (Ab_{80}), granules of pyroxene and abundant glass. Most of the glass is black and opaque under low magnification, but under high magnification resolves into innumerable globules of iron ore in a colourless base. Patches of a green, glassy material which turns yellow on weathering are also present.

The hypersthene phenocrysts are faintly pleochroic from pink to green, with (—) 2V between 60° and 90° (En_{70}), and are often partially resorbed, though some retain their idiomorphic outline. They enclose crystals of apatite and sometimes enclose granules or aggregated granules of augite. There is a marked tendency for the crystals to gather into glomeroporphyritic clots. The augite has (+) 2V greater than 45°, and although sometimes embayed, never shows the vermiculate structure so common in the felspar and hypersthene phenocrysts. The smaller plagioclase phenocrysts are rounded or lens-shaped, but the larger crystals and the sanidine phenocrysts (and anorthoclase?) show "brain structure" resorbtion to a marked degree. Xenocrysts of quartz are numerous. They are rounded and often appear to have suffered slight fusion at the edges. They never possess any suggestion of crystal outline, but are generally ovoid in shape and, like those in the acid trachyandesite, are probably derived from sediments.

A chemical analysis of this rock is shown in Table I., No. 2. It reveals it as a distinctly more basic variety of trachyandesite than the adjacent flow.

Giant's Grave Trachyandesite.

A further flow of trachyandesite, closely comparable in chemical composition (Table I., No. 3) to the de Fegley's flow, is exposed in Jackson's Creek in the gorge above and below the Giant's Grave, where it forms the third flow down from the surface. It extends from the waterfall above the Grave as far downstream as Watson's Creek, and outcrops in the bed of that creek, and also in the bed of Campbell's Creek for a short distanct upstream from its mouth. These exposures and a further one in the bed of a small creek (MacGregor's Creek) at the first bend downstream from the Giant's Grave, suggest that the bottom of the flow slopes to the north-east, in which case the lava flow came from the direction of Mount Gisborne. It overlies a flow of the Church Hill type of olivine-basalt, and is overlain by iddingsite-basalt, and iddingsite-augite-labradorite-basalt.

In microtexture also it resembles the de Fegley's flow. In the upper and lower parts of the flow the groundmass is largely glass which is practically opaque from the presence of iron-ore dust, and encloses a few highly vermiculate phenocrysts of labradorite and anorthoclase, together with an occasional crystal of aguite. In the central parts of the flow the groundmass is more crystalline, and consists of microlites of oligoclase, granules of iron ore, and greenish glass. Small microphenocrysts of pleochroic hypersthene are numerous, and occasionally have aggregated into clots along with stumpy columnar crystals of labradorite. Large phenocrysts of vermiculate labradorite and anorthoclase are not as numerous as in the chilled margins.

Hypersthene-basalt.

In the acid trachyandesite there occur numerous xenoliths, 2 to 3 cm. in diameter, of a grey, minutely vesicular rock, showing numerous growths about 1 cm. in diameter of radiating crystals suggestive of spherulitic growths. Thin sections revealed that these xenoliths consist of a hypersthene-basalt. Subsequently an ovoid xenolith of the same material, measuring 15 cm. x 10 cm. x 6 cm., was found and broken out of the trachyandesite. Further sections and an analysis were made of this rock, which is unique among Victorian basalts. Its close relation to the trachyandesites cannot be doubted.

It contains occasional phenocrysts of hypersthene and olivine The hypersthene shows distinct pleochroism from pink to green, and has (—) 2V between 60° and 90°, so that its composition may be taken as about (En_{70}). Occasionally it occurs in clusters of several crystals. The olivine phenocrysts occur only sporadically. They are corroded and rimmed with iddingsite. The bulk of the rock is a finely vesicular intergrowth of plagioclase and lath-like prisms of colourless hypersthene (bronzite ?) which are edged with a later pyroxene that has an extinction angle of 40°, measured from the extinction position of the hypersthene, and a distinctly higher birefringence. The size of the hypersthene core in these laths is variable. Sometimes it forms only a needle inside the augite, at other times it forms the bulk of the crystal. These laths are identical, except that they are larger, with the hypersthene laths in the groundmass of the acid trachyandesite. The plagioclase occurs as short, stumpy laths and as allotriomorphic plates intersertal to the pyroxene laths. It has a composition about Ab_{35}. Iron ore occurs as numerous rods in this base, often moulded on the laths of pyroxene; and as granules intergrown with the marginal augite, though never with the hypersthene cores.

The close affinity of this rock to the trachyandesites is brought out by the analysis (Table I., No. 4), which also reveals the relatively high proporition of ferromagnesians to felspars in the rock.

NORITE XENOLITHS.

Reference was made in an earlier paper (8, p. 294) to the occurrence of norite xenoliths both at de Fegley's quarry, Gisborne, and elsewhere. During the present study, further xenoliths of this nature have been found both in the de Fegley's trachyandesites and in the grey trachyandesite. These consist of prisms of hypersthene (about En_{70}) intergrown with laths and allotriomorphic plates of labradorite (about Ab_{35}), sometimes with accompanying augite. They are clearly derived from the aggregation of the hypersthene and plagioclase phenocrysts in the trachyandesites, and every stage in their growth can be observed.

Recently the Director of the Geological Survey (Mr. W. Baragwanath) discovered a block of such xenolithic norite, about 20 cm. x 20 cm. x 15 cm., on the dump from a shaft sunk on the Campaspe Deep Lead, near Kyneton. A selvedge of the enclosing rock still adhered to part of the block, and a thin section showed it to be the less acid of the two trachyandesites which occur in that district (8, p. 258), so that this norite block is presumably of the same origin as the smaller xenoliths found at Gisborne. This rock consisted of coarse allotriomorphic crystals of labradorite (Ab_{30}) and interlocking crystals of strongly pleochroic hypersthene (about En_{70}) and faintly violet augite, together with iron ores, and occasional large apatite crystals with black fibrous inclusions. An analysis of this rock was made (Table I., No. 5) as more or less representative of these cognate xenoliths, and, as will be seen, it differs considerably in chemical composition from any other Newer Volcanic rock on record in its high CaO content and low alkalies. In mineral and chemical composition it compares somewhat with certain highly porphyritic Japanese basalts (21).

GISBORNE BASALT.

This distinct variety of basalt occurs to the south-west, south, east, and north-east of Mt. Gisborne, and thin sections in the University collection (Nos. 3547, 3558) indicate that a similar rock occurs north-east of the area near Riddell. At Murray's Spur the Gisborne basalt overlies oligoclase-basalt; at Glendoon Spur and south of Mt. Gisborne it overlies limburgite and limburgite-basalt, and at the mouth of One Mile Creek it overlies olivine-basalts of the Church Hill type. It is overlain in its turn by the acid trachyandesite on the south-west of Mt. Gisborne, and by a variety of iddingsite-basalt flows. The Gisborne basalt was almost certainly extruded as several flows, which have minor differences but a strong general resemblance.

In hand specimen it is a dark greenish-grey rock, showing phenocrysts of felspar up to 5 mm. in diameter, with fewer and smaller phenocrysts of pyroxene and olivine. The phenocrysts consist of anorthoclase and labradorite, hypersthene and augite, and olivine. The felspars are the dominant phenocrysts, and occur in crystals which are characteristically vermiculate from resolution. The proportions of olivine and pyroxene, on the other hand, are variable. When the one is abundant, the other is generally scarce.

Anorthoclase occurs as only occasional, large and generally composite phenocrysts, and is always highly vermiculate. Sometimes resolution has gone so far that only a "brain structure" of the original crystal remains. The dominant felspar is a labradorite (Ab_{40}), which is usually less vermiculate than the anorthoclase. In both cases the marginal zone generally has a composition similar to that of the groundmass felspar, so that it forms a clear margin about a vermiculate core. The more lath-like of the labradorite phenocrysts sometimes show fracturing from differential movement.

The hypersthene, like the anorthoclase, has a variable distribution, being much more abundant in some thin sections than others. It is particularly prominent in specimens from the south-west of Mt. Gisborne. It is usually pleochroic in weak tints of green and pink, with (—) 2V between 60° and 90°, indicating a composition about (En_{70}). It is invariably rimmed with augite. The width of such rims varies from a mere line to as much as the width of the enclosed hypersthene, and frequently consists of an aggregate of small granules and prisms of augite accompanied by iron ore. The dominant pyroxene is an augite (2V greater than 45°) which tends to be idiomorphic, and sometimes has a marginal zone not cleared of iron ore inclusions. It is colourless to brownish, and shows a tendency to segregate into clots.

The olivine is always corroded, and is sometimes partly altered to serpentine, but never to iddingsite. In the sections in which they are scarce, the olivine crystals are sometimes rimmed with granular pyroxene, after the manner of the hypersthene crystals. Where they are numerous, however, such rims are absent. Occasionally crystals of corroded olivine may be completely enclosed within crystals of augite, so that there can be no doubt that the augite began to crystallize considerably later than the other phenocrysts. Rarely one also observes rounded xenocrysts of quartz fringed with small, more or less radially arranged prisms of augite; and in one section a large crystal of apatite, with fibrous inclusions, pleochroic from brown to black, was present.

The groundmass, which consist of plagioclase laths, augite granules, grains of iron ore, apatite needles, and a variable amount of green glass, frequently has a distinctive orthophyric appearance. This derives from the tendency for the labradorite laths (Ab_{50}) to occur as short, stumpy prisms (0.2 to 0.4 mm. x 0.1 mm) which abut against one another without any parallel arrangement, while the much smaller pyroxene and iron ore granules (0.1 x 0.1 mm.) are relegated with the green glass to the interstices. In those specimens in which the felspar laths are not so large in respect to the other constituents of the groundmass, this distinctive appearance is lacking.

The analysis of a typical specimen (Table I., No. 6) shows that despite the obvious mineralogical affinities with the trachyandesites, this rock is not greatly different in composition from the other varieties of basalt in the area. The higher CaO content, reflecting the numerous labradorite phenocrysts, in conjunction with the relatively high SiO_2 and the low Al_2O_3 and MgO, gives the analysis considerable resemblance to that of a tholeiitic-basalt, a point which is of some significance, as will be indicated later.

OLIVINE-AUGITE-HYPERSTHENE-BASALT.

This variety is known only as an inlier exposed in the bed of Campbell's Creek, in the north-east of the area mapped. It is dark, greenish rock, showing phenocrysts of felspar, olivine, and augite. The felspar phenocrysts consist of labradorite and anorthoclase. The labradorite (Ab_{45}) crystals are all columnar in shape, and are generally rounded at the corners, sometimes to the extent of being lens-shaped. Sometimes they have been corroded so as to form re-entrants along their length. They are accompanied by less numerous but extremely vermiculate crystals of anorthoclase.

The pyroxene phenocrysts all appear similar in ordinary light, being brownish with a tinge of violet. Generally they consist of a core of corroded pyroxene, with a narrow fringe of slightly more violet colour, which is charged with minute particles of iron ore, like the pyroxene phenocrysts in the main flow from Mt. Bullengarook. All show extinction angles of 25°–30°. When their optic axial angles were observed, however, some appeared to have 2V about 60°, while occasional crystals had a lower 2V (about 45°). A slide of this rock was kindly examined for me by Mr. Paterson of Otago University, who measured the optic angles on a Universal Stage. He found that in the main they had 2V ranging from 53°–55°. One crystal, however, showed (—) $2V = 70 \pm 5°$, indicating hypersthene, while another showed a (+) $2V = 40°$, indicating a pigeonite. He also noted that the 2V value was higher in the central part of one augite than on the margin, the range being from $2V = 55°$ to $2V = 47°$. He also attempted to make measurements on the fine-grained pyroxenes of the groundmass. Four measurements were obtained ($2V = 81°–86°$), which suggest that some hypersthene (bronzite) occurs among the groundmass pyroxene, in addition to diopsidic augite.

TABLE I.

——	1.	2.	3.	4.	5.	6.
SiO_2	60·94	56·73	56·90	48·68	49·50	48·15
Al_2O_3	14·46	15·24	15·03	15·32	16·09	13·80
Fe_2O_3	1·23	2·80	2·98	6·71	3·92	1·77
FeO	5·29	6·11	5·90	7·36	6·19	9·66
MgO	2·49	3·91	3·29	6·88	7·11	6·93
CaO	3·65	6·53	6·45	5·99	13·30	10·10
Na_2O	4·95	3·39	3·00	1·44	1·47	2·91
K_2O	3·96	2·97	2·79	1·04	0·29	1·29
H_2O + ...	0·78	0·20	0·32	1·10	0·10	0·71
H_2O −	1·45	1·48	1·21	2·90	0·21	1·90
CO_2	tr.	nil	nil	nil	nil	0·05
TiO_2	0·45	0·75	1·60	1·87	1·95	2·00
P_2O_5	0·02	0·32	0·02	0·05	0·02	0·15
MnO	0·06	0·21	0·07	0·17	0·14	0·06
TOTAL ..	99·73	100·64	99·56	99·51	100·27	99·48

1. Hypersthene-trachyandesite, Allot. xi., Parish of Gisborne.
2. Hypersthene-trachyandesite (De Fegley's flow), Allot. xvii., Parish of Gisborne.
3. Hypersthene-trachyandesite, third flow from surface, Giant's Grave, Jackson's Creek, Gisborne.
4. Hypersthene-basalt, xenolith in trachyandesite, Allot. xx., Parish of Gisborne.
5. Hypersthene-gabbro (norite), block of cognate xenolith in trachyandesite, spoil heap from mine shaft on the Campaspe Deep Lead, near Kyneton.
6. Hypersthene-augite-olivine-basalt (Gisborne type), bank opposite cave at Conangoult, Allot. xxxiii., Parish of Gisborne.

Analyst: A. B. Edwards.

Another surprising feature of this rock is that the plagioclase laths in the groundmass consist of oligoclase (Ab_{75}). It seems highly probable that this rock belongs to, or is associated with, the trachyandesite group. It underlies the iddingsite-basalts, and is not far distant from the Giant's Grave trachyandesite.

B. NORMAL DIFFERENTIATES.

OLIGOCLASE-BASALTS.

Oligoclase-basalt occurs as a flow extending northwards from Mt. Bullengarook, along Hassed's Creek to beyond its junction with the Slate Quarry Creek; in the bed of Jackson's Creek both upstream and downstream from the Calder Highway bridge at Gisborne, where it underlies the Church Hill olivine-basalt; and along Murray's Spur, south-west of Mt. Gisborne, where it underlies the Gisborne type of olivine-basalt.

In hand specimen the oligoclase-basalts are extremely fine-grained and sometimes fissile. Phenocrysts are practically absent, although olivine occurs as scattered microphenocrysts. The bulk of the rock is a fine plexus of plagioclase laths, augite prisms, iron ore and colourless glass. The plagioclase laths mostly show straight extinction, but some show angles up to 10° in the symmetrical zone, indicating that they have the composition of basic oligoclase (Ab_{75}). Flow structure is sometimes well marked, but is never as pronounced as in the typical oligoclase-basalts (macedonites) of the Macedon district. The rock in the bed of Jackson's Creek is particularly fine-grained. Calcite is sometimes present in amygdules of several coarse crystals, or intergrown with the felspar laths in ophitic fashion.

An analysis has been made of the rock from Murray's Spur, and is shown in Table II., No. 1. The high figure for CaO in this analysis is due to the abundant calcite in the rock (CO_2 2.11). The MgO is also high, and is reflected by the presence of olivine in the rock. This, in conjunction with the relatively basic nature of the plagioclase, has led to the rocks being classified among the more basic group of olivine-oligoclase-basalts (8, p. 272). With increase of olivine content and further basification of the plagioclase, this rock would grade readily into the type of olivine-basalt found between Dohoney's Corner and Little Scotland.

Attention may be drawn here to the peculiar rock forming the chilled margin (on the western side) of the limburgite-basalt flow in Toolern Creek. As will be seen from Table II., No. 9, the composition of this rock approximates in many respects to that of an oligoclase-basalt, combined with the features of a limburgite. In thin section it appears somewhat altered and carbonatized, as indicated by the high CO_2 content (3.02) of the analysis. Olivine occurs only in small amount in this chilled edge, although it is abundant in the adjacent unaltered limburgite-basalt (Table II., No. 7). Soda, on the other hand, is concentrated in the chilled margin.

ANDESINE-BASALT.

A flow of andesine-basalt, closely related to the oligoclase-basalts, forms a flow extending from beneath the de Fegley's trachyandesite, via Brucedale, to Little Scotland, and thence for a short distance down Jackson's Creek. It also outcrops in Fisher's Creek, at the edge of the trachyandesite.

This rock contains no olivine and only a sparse amount of pyroxene. It consists essentially of microphenocrysts of plagioclase (Ab_{50}) in the form of small sub-parallel laths and square cross-sections, together with an occasional microphenocryst of augite ((+) 2V greater than 45°) set in an extremely fine-grained base of plagioclase microlites (Ab_{70}), rods of iron ore, granular pyroxene, and abundant black glass. The felspar microlites and iron ore rods are arranged at random and do not show the fluxion structure that characterizes the felspar phenocrysts, indicating that the base was wholly glassy at the time of extrusion. In places the iron ore has aggregated and developed micro-ophitic intergrowths with the groundmass plagioclase. In some sections the intersertal glass is so crowded with iron ore granules as to appear opaque; but under high magnification it resolves into globules and trichytes of iron ore in a colourless (felspathic) glass. Calcite is prominently developed, as is indicated in the analysis (Table II., No. 2), filling vesicles and interstices. In one section rosettes of small pyroxene crystals associated with calcite have accumulated at the edge of a vesicle, the crystals growing radially into the vesicle. The augite is presumably of late formation, and of a composition similar to that in the groundmass. One crystal showed an acute bisectrix figure with (+) 2V greater than 45°, indicating a composition more or less similar to that of the microphenocrysts.

This rock is really intermediate between the andesine-basalts and the olivine-poor oligoclase-basalts, and has elsewhere been referred to the latter group (8, p. 270, Table III., No. 5). Further consideration of it suggests, however, that the Na_2O and K_2O contents are somewhat low for a typical oligoclase-basalt, and that the plagioclase is slightly too basic for the rock to be included in that group.

OLIVINE-BASALTS.

The varieties of basalt occuring under this heading bear considerable resemblance to the type described elsewhere as the Trentham type of olivine-basalt (8, p. 281), and although their chemical compositions (Table II., Nos. 3, 4) do not altogether conform, may be conveniently regarded as members of that group.

The Church Hill basalt.

This type occurs at Church Hill on the Calder Highway, at the eastern end of Gisborne township, overlying the oligoclase-basalt on the southern side of Jackson's Creek. It also outcrops along the northern bank beneath iddingsite-basalt; and it occurs in the bed of Jackson's Creek beneath the trachyandesite at the Giant's Grave.

It is a bluish-green rock in hand specimen, and somewhat altered. In thin section it is seen to consist of phenocrysts of a magnesian olivine and diopsidic-augite, sometimes aggregated into clots, set in a medium to fine-grained groundmass of labradorite laths, pyroxene prisms and granules, grains of iron ore, and abundant devitrified green glass. The olivine phenocrysts are partially resorbed, and are somewhat altered to green serpentine. The pyroxene crystals often appear to be in a state of arrested growth, with their ragged margins not yet cleared of numerous small grains of iron ore. The groundmass plagioclase is labradorite, with a maximum extinction angle in the symmetrical zone of about 30°, corresponding to a composition Ab_{45}. Occasionally laths attain the size of microphenocrysts; and sometimes the groundmass pyroxene forms irregular or lens-like patches in which it occurs in ophitic intergrowth with the groundmass plagioclase. The analysis of a typical specimen is given in Table II., No. 3.

Little Scotland Basalt.

A somewhat related flow of olivine-basalt extends from south of Dohoney's Corner to Little Scotland on the south side of Jackson's Creek, and similar rock outcrops on the north side of the Creek at Rosslyn, where it passes under the iddingsite-basalt. The olivine phenocrysts in this rock are quite fresh, and there is an absence of green glass from the base. Pyroxene occurs as occasional phenocrysts, but is restricted in the main to the groundmass, where it tends to occur as clusters of granules associated with grains of iron ore. Occasionally these clusters appear to have coalesced into microphenocrysts. The plagioclase laths of the groundmass appear somewhat less basic than those of the Church Hill basalt, and lie between basic andesine, Ab_{55}, and very acid labradorite, Ab_{50}. Calcite is present filling amygdules, and lining occasional vesicles. It also occurs in the groundmass, in ophitic intergrowths with the plagioclase laths.

The basalt at Rosslyn appears to be intermediate between this flow and the basic oligoclase-basalts. It has most of the features of the Little Scotland basalt, but is relatively free from olivine phenocrysts.

Augite-olivine-basalt.

One of the most distinctive basalts of the district is that forming the main southward flow from Mt. Bullengarook. This consists of numerous phenocrysts of augite, sometimes 1 cm. in length, with fewer crystals of olivine, in a groundmass of labradorite laths (Ab_{45}), augite prisms, iron ore, apatite needles, and felspathic glass. The augite phenocrysts are always rimmed with a narrow margin of granular augite, studded with minute grains or iron-ore. This granular augite appears to be coalescing or growing on to the phenocryst, and had not succeeded in clearing itself of iron ore at the time of extrusion. The same phenomena may be observed in other rocks of the district, both at the margins of the phenocrysts, and in the groundmasses, where the minute prisms of pyroxene seem first to cluster together and then coalesce into larger grains which progressively clear themselves centrally of the minute iron-ore grains that are associated with the prisms of groundmass augite.

The groundmass of the Bullengarook flow has a distinctive orthophyric appearance for several miles from the vent, because in this part of the flow the labradorite laths are much more strongly developed than the other minerals of the groundmass, being as much as five times the length of the pyroxene prisms. As a result, the augite prisms, iron-ore grains, and glass, form, together with plagioclase microlites, a dark base in which the coarser laths stand out. This feature becomes less pronounced as one follows the flow away from its source. The augite prisms and iron-ore granules grow in size, and tend to aggregate into micro-clots, while the felspathic glass crystallizes to an increasing extent. This combined with fluxion texture, detracts from the prominence of the earlier-formed laths of groundmass plagioclase.

A feature of one slide of very glassy rock from the western side of the vent is the presence of a number of minute flakes of biotite, strongly pleochroic from foxy red to pale straw. The biotite seems to have been the last mineral to form.

An analysis of this flow made from a specimen from the north wall of the vent reveals that it is practically identical in composition with the fresh limburgite-basalt of Toolern Creek, except for a slightly higher alumina content and lower titania (Table II., No. 4). Advantage was taken also of the coarseness of the pyroxene phenocrysts to separate sufficient for analysis. The analysis (Table III., No. 2) shows that they are fairly typical aluminous augites, closely comparable with the augite in the Mt. Koroit tuff, and the iddingsite-augite basalt overlying the Giant's Grave trachyandesite at Watson's Creek.

IDDINGSITE-BASALTS.

The more recent lava flows are all iddingsite-basalts, and belong to the widespread groups elsewhere designated as Malmsbury and Footscray basalts (8, p. 280). Three variations can be distinguished.

(1) *Iddingsite-basalts.*

These are finely vesicular, grey rocks, generally showing small phenocrysts of iddingsite in the hand specimen. They occur typically as the Junor's Quarry flow at Mt. Gisborne; at Hay Hill; as the second flow at the Giant's Grave; and as the Funston's Quarry flow, extending south from Mt. Gisborne. In this section they are found to consist of numerous, somewhat corroded phenocrysts of otherwise idiomorphic olivine (0.1–0.25 mm.) which have been altered marginally to iddingsite, in a fine-grained intergranular groundmass of plagioclase laths, pyroxene prisms, iron-ore grains, granules of iddingsite, and sometimes glass. Flow structure is often prominent, as in the Junor's Quarry flow. The felspar laths show extinction angles in the symmetrical zone ranging up to 30°, corresponding to Ab_{45}. The groundmass pyroxene prisms show extinction angles of 41°—43°, so that they are diopsidic. Very occasionally plagioclase and pyroxene occur as microphenocrysts.

The flow structure is less pronounced in the Funston's Quarry flow, in which the felspar laths tend to be thicker, and the pyroxene tends to occur as granules rather than as prisms. Analyses of the Hay Hill and Junor's Quarry flows are shown in Table II., Nos. 5 and 6 respectively.

(2) *Iddingsite-augite-basalts.*

In this variety both olivine and augite occur as phenocrysts. The olivine crystals range from 1.0 mm. down to 0.1 mm. in diameter. They tend to be idiomorphic, and show alteration to iddingsite. The smaller crystals are generally completely altered to iddingsite, while the larger ones have been replaced by iddingsite at the margin and along cracks. The iron ores are sometimes moulded upon the iddingsite rims.

The augite forms still coarser idiomorphic crystals, from 1 to 2 mm. in diameter, which are colourless to grey-violet. The rims are usually clear, but the central parts are often "spongy" with inclusions of iron ore and iddingsite granules. Occasionally they occur in clots in which the numerous individuals are much smaller than the single crystals. Very occasionally crystals are observed with a core that is pleochroic from greenish to yellowish, and with a low extinction angle. Such phenocrysts as showed an acute bisectrix figure had 2V greater than 45°, indicating that they were diopsidic; and a chemical analysis of a single extra-large crystal from the surface flow near Watson's Creek confirmed this (Table III., No. 3).

The groundmass consists of laths of labradorite (Ab_{40-45}) intergrown with rods of iron ore, granular pyroxene and iddingsite, representing a groundmass phase of olivine. A variable amount of glass occurs in the groundmass.

In some sections the felspar shows a tendency to be microporphyritic, indicating a gradation between this variety of iddingsite-basalt and group (3). Still more rarely a large crystal of enstatite is present, or a large vermiculate plagioclase.

This variety occurs at Mt. Bullengarook below the main flow, and at Haires Hill, Magnet Hill, and Beattie's Hill. The flow from McGeorge's Hill contains numerous plagioclase phenocrysts and is intermediate between this group and group (3) below.

(3) *Iddingsite-augite-plagioclase-basalt.*

This rock occurs as the surface flow at the Giant's Grave, where it is of wide extent, at Mt. Kororoit, to the south of the Gisborne Highlands, and at Red Rock and similar hills. It consists of numerous phenocrysts of iddingsitized olivine, augite, and labradorite in a fine-grained intergranular groundmass. The olivine crystals are idiomorphic, and range from crystals 1.5 to 2 mm. in length, down to small crystals in the groundmass. The iddingsite developed at a late stage, since it post-dates the shrinkage cracks in the larger olivine crystals, and is absent where the olivine is in contact with augite. The augite forms fewer but still frequent idiomorphic crystals ranging from 0.1 to 0.5 mm. in diameter. The central parts of these crystals are generally clear, but they are fringed with a narrow margin that has not cleared itself of iron oxide inclusions. The crystals show a large optic axial angle (2V greater than 45°), and is therefore diopsidic. Analysis of hand-picked pyroxene crystals from blocks of tuff associated with this type of rock at Mt. Kororoit (Table III., No. 1), shows this pyroxene to be a normal aluminous augite, similar to the augite phenocrysts in the iddingsite-augite-basalts, and the augite-olivine-basalt from Mt. Bullengarook.

The distinctive feature of this variety is the abundance of slightly rounded phenocrysts of labradorite (Ab_{40}) that occur in it. These are 1 to 1.5 mm. long and 0.2 to 0.3 mm. wide, with well developed lamellar twinning, and less frequently, zoning. They are generally rimmed with a narrow ragged margin of groundmass felspar. The groundmass is relatively fine-grained and intergranular. It is composed of plagioclase laths (Ab_{45-50}) and much smaller prisms of pyroxene (extinction angle 41°—43°), granules of iron ore and grains of iddingsite.

These three varieties of iddingsite-basalt appear to illustrate the manner in which the basaltic magma differentiated. In the one type olivine occurs alone as phenocrysts; in the next olivine and augite together form phenocrysts; while in the third olivine and augite are associated with basic labradorite, which is already beginning to re-dissolve. Presumably the plagioclase was the first of the three minerals to crystallize or begin to crystallize, and accumulated either by sinking or more probably by floating. Subsequently olivine began to crystallize and sink, giving rise to a graded MgO content within the magma; and was later joined by augite.

Limburgites and Limburgite-basalts.

Limburgite and limburgite-basalts occur on the south-western side of Mt. Gisborne, in the valleys of the Djerriwarrh and the Toolern Creeks respectively, where they attain thicknesses of over 50 feet.

The limburgite consists of crystals of olivine, which are either fresh or only slightly iddingsitized, and have idiomorphic outlines, accompanied by smaller prisms of greenish augite with narrow rims of titanaugite set in a groundmass of similar but still smaller prisms of augite, octahedra of magnetite, and brown glass. In some sections the magnetite crystals are almost as large as the augite prisms; in others the augite tends to show stellate growth. It has a 2V greater than 45°, so that it is probably rich in lime. Occasional xenocrysts of quartz occur as rounded grains rimmed with minute columnar prisms of pyroxene. Under high magnification the brown glassy mesostasis is seen to consist of colourless glass crowded with trichytes of iron oxide and minute prisms of violet augite. In patches the colourless glass has crystallized as felspar.

TABLE II.

——	1.	2.	3.	4.	5.	6.	7.	8.	9.
SiO_2 ..	51·59	51·82	49·83	45·40	52·01	49·25	45·81	46·28	46·24
Al_2O_3 ..	14·52	15·15	13·76	14·23	13·50	13·87	12·45	13·63	12·83
Fe_2O_3 ..	2·15	1·78	4·77	6·77	6·25	6·78	9·20	5·08	5·15
FeO ..	8·59	8·69	7·77	7·41	4·82	6·29	2·86	8·90	6·35
MgO ..	4·11	3·62	5·76	8·06	8·48	7·24	8·83	8·38	3·63
CaO ..	7·49	7·97	7·05	9·05	7·81	8·46	10·00	9·38	10·48
Na_2O ..	3·45	3·03	2·93	2·68	2·74	2·95	2·86	2·75	4·41
K_2O ..	2·10	1·41	1·84	1·14	1·17	1·76	1·07	2·43	1·64
H_2O +	0·98	1·37	0·50	1·20	0·67	0·12	1·97	0·21	1·10
H_2O −	1·10	0·77	1·95	0·95	0·24	0·85	1·55	0·47	1·45
CO_2 ..	2·11	1·42	nil	0·10	nil	0·05	nil	nil	3·08
TiO_2 ..	1·35	2·10	1·87	1·25	2·20	2·01	2·80	2·31	1·70
P_2O_5 ..	0·81	0·31	0·78	1·25	0·39	0·08	0·69	0·28	1·32
MnO ..	0·16	0·16	0·29	0·17	0·07	0·27	0·21	0·23	0·23
Cl ..	0·04	0·03	..	..	tr.	..	0·04	..	0·07
S ..	0·04	nil	..	..	tr.	..	nil	..	nil
BaO ..	0·03	0·03	..	..	..	..	0·04	..	0·05
TOTALS	99·90	99·66	100·10	99·66	100·38*	99·98	100·38	100·31	99·73

* Li_2O nil, CoO, NiO 0·03.

1. Olivine-oligoclase-basalt, west end of Murray's Spur, west-south-west of Mt. Gisborne, Parish of Gisborne. (*Quart. Journ. Geol. Soc.*, xciv., p. 271, Table III., No. 8.) A. B. Edwards.
2. Andesine-basalt, north-east corner of Allot. 25, Parish of Gisborne. (*Quart. Journ. Geol. Soc.*, xciv., Table III., p. 270, No. 5.) A. B. Edwards.
3. Olivine-basalt, Church Hill, Allot. 2, Parish of Gisborne. A. B. Edwards.
4. Olivine-augite-basalt, north side of Mt. Bullengarook (main flow). A. B. Edwards.
5. Iddingsite-basalt, Hay Hill. (*Bull. Geol. Surv. Vic.*, No. 24, p. 35.) A. G. Hall.
6. Iddingsite-basalt, Junor's Quarry, Allot. 17, Parish of Gisborne. A. B. Edwards.
7. Limburgite-basalt, Toolern Creek, Sect. 19, Parish of Yangardook. (*Quart. Journ. Geol. Soc.*, xciv., p. 290, Table IX., No. 1.) A. B. Edwards.
8. Limburgite, Djerriwarrh Creek, Allot. 5, Parish of Gisborne. A. B. Edwards.
9. Marginal rock of limburgite-basalt flow, Toolern Creek, road from foot of the Breakneck, Parish of Yangardook. (*Quart. Journ. Geol. Soc.*, xciv., p. 270, Table III., No. 6.) A. B. Edwards.

The limburgite-basalt flow in Toolern Creek differs from the Djerriwarrh limburgite in two respects. A proportion of the glass has crystallized out as plagioclase laths or microlites of composition about Ab_{55}—Ab_{50}. In addition the idiomorphic crystals of olivine are completely altered to iddingsite. The otherwise close similarity of the two rocks is shown by a comparison of their chemical analyses (Table II., Nos. 7 and 8). A third specimen which was analysed, from near the extreme edge or base of the limburgite-basalt in Lower Toolern Creek, is an extremely difficult rock to classify. The olivine crystals in it, which were distinctly less numerous than in the central parts of the flow, are much altered, and a considerable amount of calcite is present. The base is more glassy, moreover, and corresponds to the true limburgite of Djerriwarrh Creek in the practical absence from it of felspar. On the other hand, the analysis (Table II., No. 9) of this chilled edge of the Toolern limburgite-basalt is in many respects comparable with that of an oligoclase-basalt, and would be so classified if no account was taken of its field occurrence.

Mineralogy.

Pyroxenes.

Augites.

The common pyroxene in the Gisborne rocks, apart from the trachyandesites and closely allied types, appears to be a diopsidie augite. Approximate measurements of 2V were made whenever a crystal was found which showed an acute bisectrix figure; and these always gave values of 2V greater than (+) 45°, indicating diopsidic augite. In this the author follows Kuno's (17) use of the name pigeonite for monoclinic pyroxenes with (+) 2V less than 45°, and the name augite for those with (+) 2V greater than 45°. These measurements were confirmed for me by measurements of 2V of pyroxenes in the Campbell's Creek flow, made on a universal stage by Mr. O. D. Paterson of Otago University, New Zealand, through the kindness of Professor W. N. Benson. Mr. Paterson found that the augites showed (+) 2V of from 53° to 55°, with a tendency to be more pigeonitic at the margins than in the centre. One crystal had 2V = 55° in the centre and 2V = 47° near the margin. This would suggest that the groundmass pyroxene tends to be more pigeonitic than the phenocrysts, bearing out Barth's (2) observations.

The occurrence of large phenocrysts of pyroxene in several of the lava flows provided an opportunity for further check by determining their chemical composition. Clean samples for analysis were obtained from a block of tuff at Mt. Kororoit (south of the area mapped), from the Mt. Bullengarook (main flow), and from the iddingsite-basalt near Watson's Creek. The analyses (Table III., Nos. 1, 2, 3) show that all three are aluminous augites of generally similar composition.

It was not possible to make a direct comparison of the composition of the groundmass pyroxene in any of these rocks with those of the phenocrysts, owing to lack of means of achieving the necessary separation of the two pyroxenes. Recourse was made, therefore, to a specimen of olivine-oligoclase-basalt from Murray's Spur, thin sections of which appeared to contain very few phenocrysts of pyroxene. This rock was crushed to minus 100 mesh, and the ferromagnesians separated in bromoform in a hand centrifuge. The heavy fraction was re-centrifuged, dried, and the free iron oxides removed magnetically. It was then allowed to stand in cold concentrated hydrochloric acid for one month to dissolve the olivine associated with the pyroxene, after which it was washed, dried, and again centrifuged with bromoform to remove gelatinous silica produced by the breakdown of the olivine, and any remaining felspar. On examination under the microscope it appeared to be practically free from olivine or felspar. A considerable amount of iron ore remained, however, as minute inclusions in the pyroxene. As only a small quantity of material was left, it was analysed without further treatment.

TABLE III.

PYROXENES AND OLIVINE FROM GISBORNE DISTRICT.

—	1.	2.	3.	4.	5.
SiO_2	48·80	48·31	47·5	47·81	39·17
Al_2O_3	4·93	6·39	6·0	5·64	nil
Fe_2O_3	4·30	0·30	} 10·71	19·55 {	nil
FeO	8·37	8·28			9·88
MgO	14·57	14·15	14·3	10·85	49·48
CaO	17·60	18·19	19·5	13·16	nil
Na_2O	0·40	0·55	..	..	n.d.
K_2O	nil	0·25	..	..	n.d.
H_2O	0·15	0·30	..	..	1·00
TiO_2	1·20	2·37	0·5	3·40	nil
P_2O_5	tr.	tr.	nil	tr.	nil
MnO	0·17	1·13	1·5	0·07	0·41
TOTALS ..	100·49	99·46	100·0	100·48	99·94
CaO/MgO ..	1·208	1·285	1·294	1·213	

1. Pyroxene from tuff, Mt. Kororoit (similar pyroxene abundant as phenocrysts in lava flow).
2. Pyroxene phenocrysts, Mt. Bullengarook flow (Analysis No. 4, Table II.).
3. Pyroxene, large phenocryst (0·2 gm.) in basalt near Watson's Creek, Gisborne.
4. Contaminated groundmass pyroxene (0·3 gm.) from olivine-oligoclase-basalt, Murray's Spur, Gisborne.

Sample contained numerous micro-inclusions of iron ore, which accounts for the high FeO value. Only the CaO/MgO ratio can be compared with Nos. 1–3.

5. Olivine from iddingsite-basalt, Magnet Hill, Gisborne.

Analyst: A. B. Edwards.

TABLE IV.

FELSPARS FROM GISBORNE DISTRICT.

—	1.	2.
Na_2O	3·85	2·79
K_2O	7·36	0·48

1. Mixed felspars (sanidine, anorthoclase, and labradorite), from trachyandesite, Allot. xi., Parish of Gisborne.
2. Plagioclase from Mt. Kororoit tuff. Similar to phenocrysts in lava flow.

Analyst: A. B. Edwards.

The result is shown in Table III., No. 4, from which it will be seen that the ratio of CaO to MgO in this groundmass pyroxene is not greatly different from the CaO : MgO ratios of the analysed phenocrysts. The Al_2O_3 content is also comparable; but the iron and titania contents cannot be compared, owing to the contamination of the groundmass material with iron ores. It cannot be assumed, however, that these results disprove Mr. Paterson's observations as to the pigeonitic trend in the later pyroxenes, since in the rock selected it is possible that the augite which might have formed phenocrysts with slower cooling has entered into the composition of the groundmass pyroxene.

Hypersthenes.

The hypersthene, which is present in the trachyandesites and associated rocks, showed a (—) 2V greater than 60° and less than 90° in all the sections on which measurements could be made; and Mr. Paterson, in one measurement on a hypersthene crystal in the Campbell's Creek basalt, obtained a value (—) 2V = 70°, corresponding to $(En_{70}Hy_{30})$. He also detected the presence of a more magnesian hypersthene in the groundmass of this basalt, four measurements showing (—) 2V = 81°—86°, corresponding to a composition about $(En_{80}Hy_{20})$.

Pigeonite.

One phenocryst in the slide of Campbell's Creek basalt examined by Mr. Paterson gave a value of (+) 2V = 40°, indicating that it is a pigeonite, the first to be recorded in the Newer Volcanic rocks.

Olivines.

Approximate measurements of the optic axial angles of a number of olivine crystals were made from sections cut normal to an optic axis. These gave the impression that the olivine was magnesia-rich, with not more than 10 per cent. of $FeSiO_3$. This is borne out by the analysis of hand-picked olivine from a small clot in the iddingsite-basalt of Magnet Hill (Table III., No. 4).

Felspars.

Partial analyses were made of a hand-picked specimen of porphyritic felspar from the acid trachyandesite of Mt. Gisborne, and of plagioclase crystals obtained from a block of tuff at Mt. Kororoit. The felspar from the trachyandesite proved to be composite, consisting of sanidine, possibly anorthoclase, and labradorite. This is clear from the composition as calculated from the partial analysis (Table IV., No. 1). Such a composition would fall in the middle of the immiscibility gap of Alling's (1) felspar diagram.

The plagioclase from Mt. Kororoit is a basic labradorite (Table IV., No. 2), and is presumably similar to the phenocrysts which occur in the Mt. Kororoit and related lava flows.

Apatite.

The occasional large crystals of apatite with pleochroic fibrous inclusions in the acid trachyandesite, the norite xenolith, and the Gisborne basalt are identical with those found in differentiated rock types at Macedon and elsewhere (8, p. 303). The frequent association of this peculiar type of apatite with basaltic hornblende that is breaking down into aegirine and iron ore has led the author to the opinion that such apatite is a characteristic by-product of this breakdown. It may be noted here that such an apatite was found recently in association with a much altered phenocryst (xenocryst ?) of hornblende in a slide of anorthoclase-trachyte from Macedon district.

Petrogenesis.

Origin of the Trachyandesites.

In an earlier paper (8, p. 314) it was tentatively suggested that the trachyandesites in the Coliban district might have originated through the assimilation of sediments by the basalt magma as it stoped its way upwards in a cupola-like chamber. The Gisborne trachyandesites strengthen this supposition. Their intimate association with the other rock types forming Mt. Gisborne demonstrates beyond doubt their derivation from an olivine-basalt magma. They appear, however, to have followed a different mode of differentiation to that taken by the more usual trachytic and oligoclase-basalt differentiates of the Victorian basalt magma. The trachytic differentiates appear to have developed through the early crystallization of olivine, augite, and plagioclase, accompanied by a tendency for anorthoclase and sanidine to crystallize and float up into the top of the magma chamber. The trachyandesites, on the other hand, have developed as a result of the crystallization of hypersthene (with some augite) and basic plagioclase. This tendency has been superposed upon the tendency for anorthoclase and sanidine to form. The fact that the hypersthene and plagioclase subsequently became unstable and commenced to re-dissolve in the magma, suggests that this superposed tendency was a passing one.

At this stage it is necessary to digress briefly into some general considerations. It is well known that two types of basaltic petrographic provinces exist, and that quite different processes of differentiation develop in each. Kennedy (15) has introduced the terms "olivine-basalt magma type" and "tholeiitic magma type" to describe the parent magmas of these two types of province. The igneous rocks of the Cainozoic Circum-Japan Sea province (20) and those of the islands of Japan (21) respectively, provide excellent examples of the suites derived from these respective magmas. When the CaO and MgO contents of the rocks of these (and similar) suites are plotted against their Al_2O_3 contents, as in fig. 4, the curves obtained show characteristic features and differences. As fig. 4 reveals, differentiation of the undersaturated, or olivine-basalts, results in the removal of CaO and MgO from the more acid differentiates (residual magma)

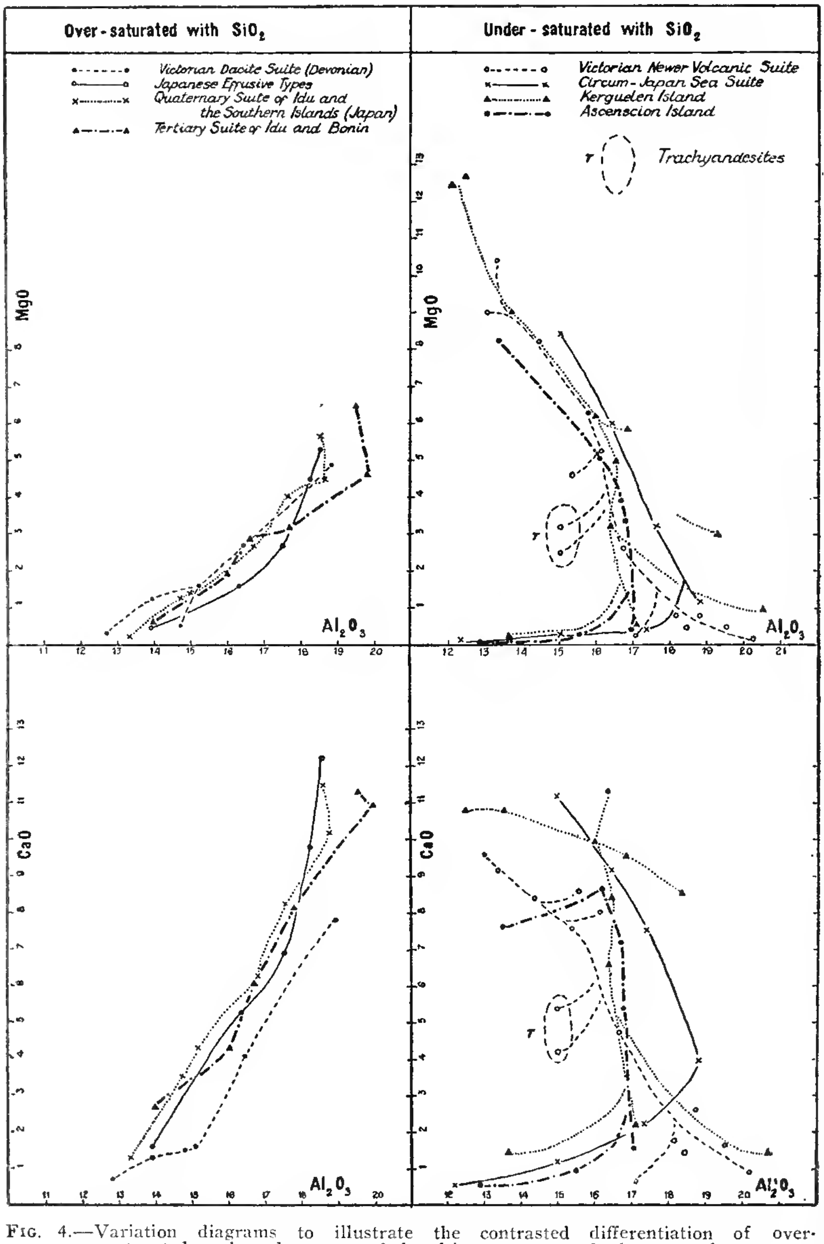

FIG. 4.—Variation diagrams to illustrate the contrasted differentiation of over-saturated and under-saturated basaltic magmas and the anomalous nature of the Victorian trachyandesites.

independently of Al_2O_3, which accumulates in the residuum. The differentiation of the saturated, or tholeiitic magma, on the other hand, leads to the simultaneous removal of CaO, MgO, and Al_2O_3, and yields an acid residuum relatively poor in Al_2O_3.

The olivine-basalt magma is undersaturated with SiO_2 from the outset, and contains abundant MgO. As a result olivine forms abundantly, and this tends to increase the SiO_2 content of the residual magma. Lime, on the other hand, begins to be precipitated partly as augite, a SiO_2-saturated mineral with a low Al_2O_3 content, and partly as basic plagioclase, which is rich in Al_2O_3 but poor in SiO_2. The olivine and augite tend to sink in the magma, whereas the tendency of the basic plagioclase is to float upwards. The trend, therefore, is for the increase of SiO_2 produced in the residual magma by the sinking of olivine to be balanced by the low SiO_2 content of the plagioclase that floats up into the residuum. At the same time only a small amount of Al_2O_3 is removed by either olivine or augite, while a considerable amount of it tends to be carried up into the residuum by the early-formed basic plagioclase. As a further outcome of this tendency, MgO is removed from the magma much more rapidly than CaO during the early stages of differentiation—a fact noted elsewhere (8, p. 311) in connexion with the olivine-basalts of Victoria.

The tholeiite magma, on the other hand, is saturated with respect to SiO_2 from the outset. The minerals which form early are found to be olivine (which forms in restricted amounts and soon re-dissolves), abundant hypersthene, with a lesser amount of augite, and abundant basic plagioclase. The residual magma is considerably more acid than that derived from the olivine-basalt magma, and presumably has a lower specific gravity, so that all these minerals tend to sink in it (at varying rates). The MgO is removed chiefly as hypersthene. The basic plagioclase, being the most Al_2O_3-rich of all common igneous rock-forming minerals, and at the same time the poorest in SiO_2 content of all the plagioclase series, leaves the magma depleted in Al_2O_3 and CaO, but relatively enriched in SiO_2; and some CaO and Al_2O_3 is removed by the augite.

The distinctive feature of the Gisborne (and Coliban) trachyandesites is that they have been derived by the temporary superposition of a "tholeiitic process of differentiation" upon a basalt magma which had previously been behaving as an olivine-basalt magma. In other words, the undersaturated olivine-basalt magma behaved temporarily as a saturated magma. A possible explanation of this anomaly is provided by Barth (3), who emphasizes the unlikelihood of there being just two types of primary basalt magma of well defined composition, and suggests that it is more probable that primary basalt magma, as a whole, is of a composition which varies locally between these two extremes of undersaturation and oversaturation with respect to SiO_2. So long as the primary magma is sufficiently undersaturated it will behave as an olivine-basalt magma, while so long as it is sufficiently oversaturated it will behave as a tholeiitic magma. If, however, a local primary magma lies in the more or less narrow range of composition between oversaturation and undersaturation, the manner of its differentiation will be highly susceptible to quite slight changes in the conditions affecting it, and may under some circumstances give rise to mixed end-products.

As has been indicated elsewhere (8, p. 313), the parent magma of the Cainozoic Newer Volcanic Series in Victoria appears to have approached this intermediate composition; for while it has behaved in the main as an olivine-basalt (fig. 4), the less differentiated rocks developed from it show some distinctly tholeiitic features and the trachyandesites reveal a tendency towards a tholeiitic line of differentiation (fig. 4). The suggestion is, therefore, that in certain localities the residuum of this differentiating magma became temporarily oversaturated with respect to SiO_2. This may have arisen under perfectly normal circumstances, such as those which give rise to small quantities of sanidine-rhyolites in association with larger amounts of trachyte and phonolite, as at Kerguelen Island (10) or as in the East Morton district of Queensland (13), or to rocks not quite so rich in SiO_2, such as the solvsbergites associated with trachytes in the Macedon district (18). Such rocks are formed, however, by the further differentiation of trachytic magmas, and are not produced by the crystallization of hypersthene and basic plagioclase. Moreover, they are a stable end-product, and not a temporary phase, which tends to revert to trachyte. On the other hand, in view of the assumption that these rocks differentiated within cupola-like protrusions above the main magma reservoir (7), some local assimilation of argillaceous and arenaceous sediments and perhaps granitic rocks is also envisaged. The numerous xenocrysts of quartz in the trachyandesites are suggestive in this respect. Where the primary magma was thoroughly undersaturated, this might have little or no apparent effect, but where, as in Victoria, the primary magma approached an intermediate composition, such assimilation might be just sufficient to produce a temporary period of local oversaturation which would pass away as more undersaturated magma was added from below. The question may legitimately be asked, why has this not happened at every centre of extrusion in Victoria? The answer may be that it has, to greater or lesser extent, but the products are not always available. The occasional norite-like xenoliths that are found in more or less "normal" lava flows, and the occasional presence of partially resorbed enstatite or hypersthene, may be regarded as indications of this tendency; although, as indicated elsewhere (10, p. 94), they may just as likely be the normal product of the intratelluric stage of differentiation of the magma.

THE DEVELOPMENT OF LIMBURGITES AND NEPHELINITES.

The origin of the small, sporadic flows of limburgite and nephelinite which are a feature of the Victorian olivine-basalt provinces presents a puzzling problem. These rocks, which consist essentially of olivine, pyroxene, and a variable amount of felspathic glass, with or without nepheline, were almost completely liquid at the time of their extrusion (intrusion), as is indicated by their fine-grained texture and the high degree of fluidity required for such "flash injections" as the monchiquite dykes of Bendigo (19). The gradational relationships which exist between these rocks, limburgite grading into olivine-nephelinite within the same flow (Jacobson, 1937, pp. 133-135), indicates a common origin for them. It may be noted also that the rare rock type, woodendite (18, p. 29), differs from the limburgites only in its relatively high potash and soda (3.2% of each).

Moreover, their small bulk, combined with their frequent association in the field with differentiated members of the olivine-basalt suites at what appear to be "centres of differentiation," suggests that they are not in themselves primary magmas but differentiates from the parent olivine-basalt magma; and that their differentiation has taken place presumably within a cupola (7).

Jacobson (12, p. 147) has suggested that such a "limburgitic liquid may be formed in the lower levels of a basaltic magma chamber only by the re-solution of some of the olivine which accumulates in this layer under gravitational control." It frequently happens, however, that olivine microphenocrysts in these rocks are idiomorphic in outline (6, p. 116; 8, p. 292). The olivine-nephelinites are suggested by Jacobson to be "limburgitic liquid" which has undergone a local enrichment in soda, possibly by gas-streaming.

Krokstrom (16) has provided a clue to another possible process by which such rocks could develop. He has shown that in some undersaturated, i.e. olivine-basalt, magmas, the plagioclase begins to crystallize before the olivine, and may even complete its crystallization before the pyroxenes commence to crystallize. As a result, the residual liquid tends to assume a pyroxenic composition. Crystallization of this liquid about the plagioclase gives rise to ophitic textures. Evidence of this tendency in Victorian basalts is found in the development of lens-like patches of ophitic pyroxene intergrown with laths of groundmass felspar, as in the Church Hill basalt at Gisborne, and elsewhere (8, p. 272). There is also plentiful evidence that in some of these rocks olivine and plagioclase have commenced to crystallize (and in some instances completed crystallizing) before the pyroxene began to crystallize. This is clearly the case in the Gisborne basalt and the iddingsite-augite-labradorite-basalts; and it is well shown where rocks of this sort have tachylytic selvedges (9). Lastly, there is the evidence provided by the occurrence of clots of olivine and "gabbro"—i.e. segregations of olivine and labradorite—that are found occasionally in the limburgites (and monchiquites) themselves, including the Bendigo monchiquites.

If as the result of intratelluric cooling, the onset of crystallization of the residual liquid, which has been enriched in pyroxene constituents in this way, is slow, what will happen? Anorthite, the most basic plagioclase, has a specific gravity of 2.74 to 2.76, and the sodic plagioclases are still lighter. The pyroxenes, on the other hand, have specific gravities ranging from 3.1 to 3.3 for enstatite to 3.5 for hedenbergite, and 3.2 to 4.1 for olivines. If the magma has a specific gravity anywhere approaching the specific gravities of these minerals that crystallize from it, it seems highly probable that the early formed plagioclase would float upwards, leaving an ultrabasic liquid behind. If the temperature of this liquid was relatively low, labradorite or even andesine might crystallize and float away, removing lime, soda, and a certain amount of potash simultaneously; whereas if the temperature of the liquid was relatively high, a correspondingly more basic plagioclase would crystallize, and remove only lime, thus leaving a relative concentration of soda and potash in the ultrabasic liquid. It may be noted in this connexion that even the true limburgites of the Newer Volcanic Province show considerable richness in both soda and potash (8, Table IX., p. 291). Presumably both these stages in differentiation might exist simultaneously in a cupola, since temperature would increase with depth, giving rise to a layer of limburgitic magma overlying and grading down into a layer of olivine-nephelinite magma, which in turn would overlie quite undifferentiated basalt magma.

Summary.

Most of the lava flows that cap the Tertiary gravels and Ordovician sediments of the Gisborne district are differentiation products of an undersaturated or olivine-basalt magma. The complex volcanic hill of Mt. Gisborne, however, is built up of a series of hypersthene-trachyandesites and hypersthene-bearing basalts, in addition to a variety of normal types. The trachyandesites and associated rocks contain numerous phenocrysts of partially resorbed hypersthene and basic plagioclase associated with phenocrysts of sanidine and anorthoclase in a still more advanced state of resorption, phenocrysts of olivine, and numerous xenocrysts of quartz, presumably derived from the intruded sediments. They present the apparent anomaly of a "tholeiitic process of differentiation" superposed on the normal (trachytic) process of differentiation. Since the parent magma from which all these rocks were derived was of a composition intermediate between oversaturation and undersaturation with respect to SiO_2, it is suggested that this local change in the

character of the differentiation may have been brought about by local assimilation of the invaded sediments making the magma saturated. Similar rock types are met with elsewhere in Victoria, but their full development in the Newer Volcanic Series is not yet known.

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Art. XIV.—*An Unusual Australite Form.*

By GEORGE BAKER, M.Sc.

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Among a collection of approximately 550 australites found by the author in the Sherbrook River District, east of Port Campbell, is one rare and unusual form resembling a deep elongated bowl in shape. Only one other similarly shaped specimen has come under the author's notice, and it is a rather larger example from Western Australia (probably the Kalgoorlie District) that was formerly in the collection of Mr. S. F. C. Cook of Kalgoorlie, but is now lodged in the Melbourne University collection (Register No. 3104). A somewhat comparable, but larger example, 10 mm. long and 6 mm. deep, has been described by E. J. Dunn as cup-shaped (2, plate XXIII.), who states that this is the only example approaching such a form that he has seen (2, p. 224).

The dimensions, weights, and specific gravities of the Port Campbell (I.) and of the Western Australian (II.) examples of bowl-shaped australites are shown in table 1.

Table 1.

——	Length in mm.	Width in mm.	Depth in mm.	Thickness at Lip in mm.	Thickness at Base of Bowl in mm.	Weight in Grams.	Specific Gravity.
I. ..	7·5	5	3	0·5	0·5	0·135	2·410
II. ..	9	4	3	0·5	0·75	0.149	2·442

Both of the specimens are a brownish bottle-green in colour, the Western Australian example being slightly darker than the one from Port Campbell. Under crossed nicols of the petrological microscope, both of these examples are completely isotropic.

The Port Campbell form was discovered on a gullied portion of the old road, a mile and a half east of the track to Loch Ard Gorge (1, map). The external surface, i.e., the anterior surface, of the specimen was uppermost, this being the usual position of rest of australites on the earth's surface. Both the anterior (external) and the posterior (internal) surfaces are covered with minute bubble pits, and the position of the centrally placed "core" is marked by a small cavity (fig. 1B). No flow phenomena are visible on any portion of the specimen.

The Western Australian example has a very smooth external surface. The position of the "core" at the bottom of the bowl (on the posterior surface), is marked by an elliptical area with well defined but fine flow lines (*c*, fig. 1A), having a complex, fold-like pattern. A pronounced bubble cavity (*b*, fig. 1A), situated to one side of the "core", is seen to possess numerous minute bubble pits on the walls, when examined under high magnification. As in the Port Campbell specimen, the lip of the bowl-shaped form is smooth and rounded (*l*, fig. 1A and B).

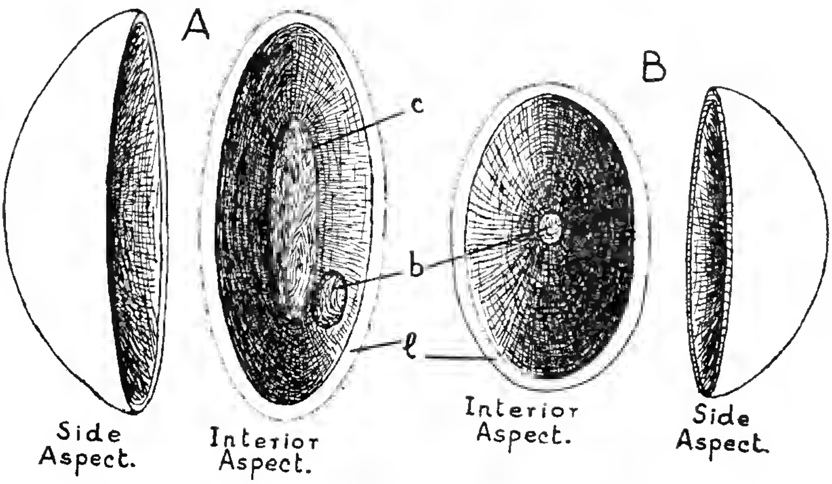

FIG. 1.—Bowl-shaped Australites, A. from Western Australia, x 5½, B. from Port Campbell, Victoria, x 5.

c. = flow-lined core.
b. = bubble cavities.
l. = rounded lip of bowl.

ORIGIN OF BOWL-SHAPED FORMS.

The original forms from which the bowl-shaped australites developed were probably flat and oval-shaped with a broad flange-like area, and a small central core, as in three or four flat examples from the Port Campbell District, which resemble the oval-shaped, flat form illustrated by Dunn (2, plate XXIII., fig. 7). During the end stages of the flight history of the flat, oval-shaped forms, while the australite glass was still in a semi-plastic condition, it is probable that the frictional resistance of the atmosphere against the anterior (forward) surface of the earthward-moving australite, was responsible for turning back the plastic portion of the broad flange to a position almost at right angles to its original position, thus producing a bowl-like form. Figures 1 and 6 on plate XXIII. of Dunn's illustrations (2), which show the flange slightly turned over towards the posterior (back) surface of the australites, may represent early stages in the above-suggested mode of development of bowl-shaped forms. It seems unlikely that the regular curving over of the flange towards the core could have been produced by impact of the semi-plastic australite glass against the earth's surface, as suggested by Dunn (2, p. 224). Under such conditions, flattening of either one side or the other would be expected, and this is not observed (see fig. 1). Moreover, it is now generally accepted that australites have completely solidified before reaching the ground.

The formation of the flat, oval-shaped australites from which the elongate, bowl-like forms are considered to have been produced is a matter for conjecture. No satisfactory explanation has as yet been advanced to account for their development. The evidence provided by one poorly developed disc-like form, and two nondescript fragments, from the Port Campbell District is rather suggestive of the production of flat, disc-like forms from flat fragments shed from larger forms of australites during flight. These poorly developed examples are flat, somewhat irregular in outline, and show incipient stages in the development of flanges. No intermediary forms between them and the regularly shaped discs, however, have as yet been found, so that the evidence available is by no means conclusive that disc-like australites were formed from fragments shed from larger specimens during flight.

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[Proc. Roy. Soc. Victoria, 52 (N.S.), Pt. II., 1940.]

Art. XV.—*The Sand Dunes of the Portland District and their Relation to Post-Pliocene Uplift.*

By ALAN COULSON, M.Sc.

[Read 12th October, 1939; issued separately 1st July, 1940.]

Contents.

Introduction.

The dune areas of south-western Victoria afford convincing evidence of uplift of the order of 400 feet. The movement began after the Upper Pliocene, and has continued throughout the Quaternary, the most recent elevation being about 10 feet. The dunes comprise both recent and ancient ("fossil") members, and are located in two main areas, viz., the valley of the Lower Glenelg River, and the coastal strip east of Portland. Much of the basaltic Portland promontory is capped by dune sands.

The country has a marked W.N.W. to E.S.E. trend, due chiefly to the coastline between Cape Bridgewater and the mouth of the Glenelg having this direction, but emphasized by the numerous transverse sand dunes parallel to the coast, by the great westerly bend in the Glenelg, by the Wanwin and Swan Lake faults, and by three lines of volcanic foci. In many respects the area can be regarded as a continuation, on a lesser scale, of the "Coorong" area, of alternate dune ridge and swale, which is the dominant feature (Fenner, 1930) of coastal south-eastern South Australia.

Nature and Extent of the Dune Formations.

The lower Glenelg dune-complex is 40 miles wide along Discovery Bay, and extends 25 miles inland. The bare shifting dunes of the two-mile-wide coastal strip gives place inland to older dunes fixed by vegetation, and their amplitude diminishes until north of Dartmoor they flatten out to a sandy plain at an altitude of 200 feet. In this sector the highest altitude attained is 250 feet, and the greatest amplitude of the dunes is about 100 feet.

On the eastern edge of the Glenelg basin, in Kentbruck and Balrook, the dune sands overlie basalt flows and attain altitudes varying between 400 and 500 feet. Similar conditions prevail throughout the Portland promontory, the dune formations ranging in altitude from 50 feet to 400 feet, according to the height of the underlying volcanic rocks, with two exceptionally high points at Mount Kincaid, where sands reach 500 feet, and Mount Richmond, capped by sands at 740 feet.

The dune ridges fringing Portland seldom exceed 100 feet in altitude, and the hinterland east of Mount Clay is a sandy plain, with underlying Tertiary limestone.

Attention is thus drawn to the range in age of the dune formations; it is apparent that the higher level sands of Portland promontory are older than the low-level ridges of Portland Bay, and that the innermost ridges near Dartmoor are older than the bare dunes of Discovery Bay.

The general orientation of the dune ridges is parallel to the coast, which runs roughly N.W.–S.E., and since the prevailing wind is south-westerly, the dunes are transverse ridges. Usually a foredune marks the shoreline, but in the Discovery Bay area, between Bridgewater Lakes and Swan Lake, there is an unusual arrangement of parallel dunes whose direction is oblique to the coast, being west–east rather than N.W.–S.E. No foredune is found in this stretch. The feature seems to be due to the merging of individual crescentic or sub-triangular dunes, whose leeward slopes originally ran N.S. and W.E. to form ridges in which the north–south slopes were obliterated, and the west–east slopes became pronounced. The commonest form (Pl. XIII., fig. 1) is the long irregular, sharp-crested ridge, with the windward side sloping at 10 to 15 degrees, and the leeward at 33 degrees maximum. However, there is endless variety in the size and shape of the dunes, and at either end of a crescentic dune the directions of the steep slopes may seem abnormal, e.g., if the main axis of the dune runs N.W.–S.E., the northerly end may curve round to run west, and at that point the steep leeward slope is towards the north; similarly at the southern end the steep slope may be to the south. But when the whole dune is considered, the dominant steep slope is to the north-east or east.

Wandering dunes, due to the merging of several dune ridges, attain considerable size. They possess flat or only slightly rounded tops, and steep sides sloping in several directions, e.g., north, east, and south. The altitudes may attain 220 feet, but they are composed of several individual dunes, none of which separately would exceed 100 feet amplitude. In no dune was there seen a steep slope to the west or south-west.

Destruction of previously built dunes by wind erosion leaves residual hummocks, fixed by rushes, marram grass, or ti-tree, standing 20 or 30 feet above the general sand-level. These residuals are common in the coastal strip along Discovery Bay. Residuals of older dunes can be found in many of the wind hollows and in places along the beach, where the consolidated rock, dune-sandstone, or dune-limestone, crops out. Old soil beds are also exposed in places.

That the process of consolidation by compaction and induration begins soon after a dune is built may be observed in many places in the lower Glenelg area. After a spell of heavy rain followed by dry conditions, large flakes and sheets of partly consolidated sandstone may be found in the wind-hollows and troughs of the ridges. These are not portions of residuals, but newly-formed rock. Sometimes they disintegrate, especially those on the surface, but within the dune they are permanent, and form definite bedding planes.

The shores of Bridgewater Bay and Portland Bay are skirted by continuous foredunes, about 20 to 50 feet high and 100 yards wide, and partly fixed by marram grass, rushes, and other plants. A swale or interridge depression from 300 to 800 yards wide separates the foredune from the first dune ridge, which has a core of consolidated dune-rock, whereas the foredune is very largely composed of incoherent sand.

The Narrawong Ridge (fig. 1), which runs at an altitude of 50 feet from Narrawong to Yambuk, is a true dune ridge as defined by Johnson (1919), viz., a beach ridge overlain by aeolian sand. The beach ridge is now at about 20 feet altitude; it

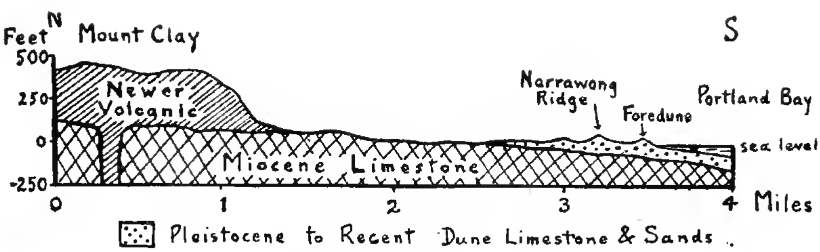

Fig. 1.—Section from Mt. Clay to Portland Bay.

contains abundant shells of species now living on the coast (see appendix) in a bed perhaps 2 feet thick. On either side of the main Narrawong Ridge are parallel raised beach ridges not capped by sand; in addition to their shells, they contain small rounded basalt pebbles. In allotments 4, 5, and 6, Narrawong, these pebbles attain 6-in. diameter, but elsewhere they are about 1 inch.

Between the Narrawong Ridge and the volcanic massif of Mount Clay there is a strip, about three-quarters of a mile wide, of Miocene limestone, with *Ditrupa, Lovenia,* &c. This is exposed in many places, and is quarried in allotments 47 and 48, Narrawong. East of Darlot's Creek it appears in Castlemaddie P.R. and further east, gradually descending beneath younger sands in the Bessiebelle district.

Considerable progradation of Henty Beach, Portland, can be attributed to the construction of training walls and a breakwater at the mouth of Wattle Creek, causing deposition of silt from the creek and sand brought by long-shore currents from the cliffs. In this manner a width of 4 chains has been reclaimed from the sea within the century of settlement.

A two-mile-wide sand plain stretches from Mount Richmond to Portland South. It is best developed in the Cashmore Heath district, where extensive drainage works to the Wattle Creek were constructed by the Public Works Department in 1916. This plain lies between the basaltic plateau of Gorae and the dunes of Bridgewater, and probably represents the initial sand plain left when the seabed emerged, though the presence of certain inliers of dune limestone, such as Limestone Hill at Cashmore, suggests that denudation has also been effective in reducing the dunes to a fluviatile plain.

About two miles east of the mouth of the Glenelg, in allotment 15A, Glenelg, and at the western end of the Long Swamp, there is a "rake" structure due to the attachment of five or six subsidiary dunes at an angle of 45 degrees to the direction of the main foredune. The effect has been to divide the Long Swamp into a chain of swamps.

Along Discovery Bay is a chain of swamps and lakes, viz., Long Swamp, Bulley Lake, Lake Mombeong (Bong Bong), Malseed's Lake, Swan Lake, and Bridgewater Lakes, which according to some opinions form the remnants of an abandoned course of the Glenelg River. There is no geological evidence, in the shape of old valleys, pebble beds, river cliffs, or the like, that this is so; the swamps are true dune lakes or basins of internal drainage in the swales.

Details regarding the altitude and directions of many of the dune ridges are given on the geological parish plans published by the Geological Survey of Victoria. These include Glenelg, Warrain, Kentbruck, Balrook, Drik Drik, Kinkella, Wanwin, Palpara, Mumbannar, Dartmoor, Wataepoolan, Myaring, Killara, Werrikoo, and Wilkin, but do not cover the area east of the Glenelg Basin. A geological map by Reid (1932, Plate V.), published in Hamilton by Western Petroleum Ltd., covers the area around Portland, and a small area near Heywood was mapped by Kenny (1939). The portions not mapped in detail were sketched in by personal observation extending over three years, but are subject to correction, particularly in the matter of surface sand. In many places a thin drift of sand masks volcanic rocks, and has been omitted; in others it is several feet in thickness and has been regarded as a definite formation. The accompanying map does not attempt to distinguish between Pleistocene and Recent sands and dune-limestone, though this is done on the parish plans of the Geological Survey.

Types of Sand and Dune-Rock.

All the sands except the most superficial are highly calcareous; the beach sands of Discovery Bay contain 75 per cent. of $CaCO_3$ and the finer sands of Portland Bay contain up to 93 per cent. $CaCO_3$. All are shell-sands derived from skeletons of marine molluscs and echinoderms, finely comminuted, with microzoa such as foraminifera and bryozoa. Where cliffs of Miocene limestone occur, as at Portland, the beach sands are more calcareous than those of the open coast, owing to the additional matter derived from erosion of the limestone. Complete shells are rare on the open beach, but in certain "Shelly Beaches" there are accumulations of pelecypods such as *Notocallista* in commercial quantities. All of the specimens collected, whether from loose sand, old soil beds, or consolidated dune-rock, are similar (see appendix) to species now living in Bass Strait, and may be of any age from Pleistocene to Recent. Identifications were kindly made by Mr. W. J. Parr (foraminifera), Mr. F. Chapman (land shells), Miss I. Crespin (shelly fossils), and the National Museum, Melbourne.

Mechanical analyses (see appendix) of sands were made at the State Laboratories under the direction of Mr. W. R. Jewell. They record the extreme fineness of the dune sands and of many of the beach sands, and indicate the efficient wind-sorting that took place during dune-building.

Chemical investigation was limited to estimations of $CaCO_3$, the method being to boil a weighed sample of sand with HCl. The purity of the sands enabled clay and humus to be ignored. No heavy minerals were observed in any of the sands; the residual grains after digestion with acid were invariably quartz, very fine, even-sized, and clear.

Five types of sand were established, though the differences between them are rather slight:

1. (*a*) Ocean Beach Sand.

Is typified by the creamy-yellow sands of the beaches of Discovery Bay. It consists of fragments of molluscan shells, coarse near the water's edge but finer up the beach, with spines of echinoids, and microzoa. Fine quartz grains may amount to 20 per cent. of the total. 57 per cent. of the sand passes through 80 mesh but is caught on 100 mesh.

1. (*b*) Dune Sands Derived from Ocean Beaches.

These constitute the unconsolidated dunes inland from the beach of Discovery Bay. They are similar in all respects to the beach sands but are more uniform in grain-size and the particles are more rounded.

2. (*a*) Portland Bay Beach Sands.

Typified by the very fine specked grey-white sands of Henty Beach, Dutton Beach, Nelson Bay, Narrawong, and Tyrendarra. It consists almost entirely of shelly matter, 93 to 98 per cent. $CaCO_3$, and over 50 per cent. of the grains are between 60 and 80 mesh. Recent tetractinellid sponge spicules are common, and distinguish this type.

2. (*b*) Portland Bay Dune Sands.

Similar to the 2(*a*) type, except that the sponge spicules are almost absent. They merge into less calcareous ocean beach sands east of Yambuk.

3. Old Sandy Soils.

Old soil beds are intercalated between the courses of dune limestone. They are often reddish-brown but sometimes almost black, and are seldom more than 1 foot thick. The small land snail *Charopa* is characteristic of the lower soil beds. In the uppermost sand bed capping the cliffs of the Portland promontory there are many shells of the large land snail *Rhytida* and less abundant *Succinea*. Identifications are given in the appendix. $CaCO_3$ content is about 50 per cent., and grain size coarser than the dune sands, mostly between 40 and 80 mesh, and very well sorted. In this type may be included the brecciated old soils, consisting of fragments of old dune-rock and soils, intercalated between normal beds of dune-limestone.

4. Siliceous Sands.

The upper layers of nearly all the dune sands, particularly those that have been fixed for some time, are strongly leached, leaving almost pure quartz, but the percentage of lime increases with depth. Leaching is most pronounced in the swamps and depressions. The thin sandy cappings on the basalt flows usually consists of very fine quartz grains. Such cappings are found on the Kangaroo Range in Balrook and Drik Drik, and on Mount Clay and Mount Kincaid; they probably represent dune sands that have drifted and been leached.

5. Dune Limestone.

Some of the dune-rock has suffered leaching, and is now a friable sandstone; more commonly the hardness has been increased by induration, resulting in travertine which sometimes attains flint-like hardness. However, all the rocks are calcareous and may be included under the name limestone; $CaCO_3$ ranges from 50 to 99 per cent. The rock was derived from pure shell-sand.

In the Werrikooian (?) flaggy limestone at Dartmoor there is a proportion of flakes of white mica, but none is found in the dune limestones.

Structures in the Dunes.

Most of the unconsolidated sand ridges are asymmetrical, with leeward slopes steeper than the windward. The maximum slope does not exceed 33 degrees, which agrees with the measurements recorded by Etheridge (1876), Cornish (1897), Beadnell (1910), Shotton (1937), and Bagnold (1938). Actually, this angle was only rarely obtained where fine dry sand was on the verge of slipping; in most cases the angle of rest was 32 degrees. The windward slopes averaged 7 degrees for long distances, but in the crescentic dunes steeper angles occurred at the curved ends, angles of 25 degrees being obtained on both sides. None of the dunes measured had a steep face longer than 2 chains, though the windward face might be 15 or more chains long.

Some of the arcuate dunes simulate barchans but lack the characteristic horns on the leeward side. Usually individual dunes are somewhat crescentic or sub-triangular in shape. The long ridges have serrated summits, often with curious miniature wind troughs at the very summit, carving it into innumerable small grooves at right angles to its length.

The internal structure of the newly-formed dunes is only partly revealed in the wind-hollows; stratification and incipient compaction are readily noted, particularly in the gently sloping windward beds (Pl. XIII., fig. 2). In the old consolidated dunes, however, admirable exposures in the cliffs enable the rock-courses of dune-limestone to be thoroughly examined. Thus it is possible to work out the windward and leeward slopes of the ancient dunes, using the criterion of Shotton (1937) that dips of 25 to 33 degrees represent leeward slopes, and those less than 25 degrees represent windward slopes. This idea was applied by Shotton and the Lapworth Club to the outcrops and exposures of Bunter (Triassic) sandstone in Shropshire and Worcestershire and revealed that the structures were really ancient barchans built by a prevailing east wind. Applying this method to the outcrops of old dune limestone in the Portland District, the directions of the steepest dips (rarely more than 28 degrees) were plotted wherever possible, and found to run mainly north-east, with some east and north. Thus they are similar to the modern dunes in having been built up by south-westerly winds.

Terminology for the windward and leeward slopes appears to need standardization: Shotton (p. 542) refers to leeward slopes as "deposition planes" and windward slopes as "planes of erosion", while Bagnold (p. 403) calls leeward slopes "encroachment planes" and windward slopes "planes of aeeretion".

Occasionally the cliff sections reveal what is apparently the crest of an old dune, resembling the axis of an asymmetrical anticline. An example of this oecurs in the cliff above the landslip near the Flat Rocks at Kappa Camp, Nelson Bay. This is probably the feature deseribed by Dennant (1887, p. 227) as a dome with quaquaversal dip, a term the suitability of which was disputed by Griffiths (1887, p. 72).

Minor features in the dune formations, especially where wind erosion has been active, are the "fossil trees", usually several inehes in diameter but at times about 18 inehes across, with hollow cores. They are due to incrustation about roots of ti-tree, &c., or in the larger "palmetto stumps" (ef. Sayles, 1931) possibly to incrustation around the bases of grass tree (Xanthorrea). Another feature is the miniature karst or irregular-surfaced travertine exposed on the west sides of the cliffs where wind erosion has removed 5 or 6 feet of soil.

After rain, it is interesting to note the leeward growth of the free dunes by the encroachment of dry sand over the moist firm sand on the steep side (Pl. XIII., fig. 3). Vegetation becomes covered by the moving sand and dies; the dead limbs are later exposed in troughs or wind-hollows as the dune migrates. No data are available on the rate of annual migration of the Portland dunes. The water table stands relatively high throughout the area, and the moisture content of the dunes is considerable. Consequently it is in the troughs and depressions that vegetation first gets a hold, usually rushes and grasses followed by ti-tree and larger plants, as described by Audas (1917), Patton (1934), and Coekayne (1911), leading to the ultimate fixation of the dune.

Solntion by underground waters is responsible for the formation of numerous small eaves, such as those in Batt's Ridges and the Bridgewater distriet, and at Puralka. In other plaees there are deep sink-holes (runaway holes), e.g., a sink-hole possibly 200 feet deep at Old Shelly Beaeh, Cape Nelson. Springs and seepages are common in the deeper valleys and on the coastal cliffs where the water table is intersected; at these points of emergenee stalaetitie growths are common.

Relation of Dune Formations to other Rocks.

The geological succession in the district is:—

RECENT alluvium, beach sand, dune sand, dune limestone (incipient), shell beds, shingle.

HOLOCENE basalt (Fitzroy River).

PLEISTOCENE dune limestone, shell beds, raised beaches.

LOWER PLEISTOCENE to UPPER PLIOCENE basalt, diatomaceous earth.

PLIOCENE oyster bed, shell beds, flaggy limestone.

MIOCENE marine limestone.

JURASSIC felspathic sandstone and mudstone.

Jurassic sandstone and mudstone outcrop in the Merino district, north of the area investigated, and exposures in the Portland district are limited to two small patches in the banks of the Glenelg and its tributary Stokes River, above Dartmoor. Borings reveal that they underlie the Tertiary limestone at Dartmoor and Mumbannar, and they probably extend south towards Portland, though at a great depth as the Portland bore did not bottom the Tertiary limestone at 2,265 feet. The dune limestone overlies the Jurassic, with or without the intervention of Miocene limestone.

The Miocene limestone is almost universal underground in the southern portion of the area, and outcrops in high spots at Heywood (Kenny, 1939), south of Mount Clay, and near the border at Nelson, as well as being exposed almost continuously along the banks of the Glenelg River, and in the sea cliffs of Whaler's Bluff and Double Corner at Portland. Wherever they come in contact, the dune limestone overlies the Miocene limestone unconformably.

Some difficulty exists with the subdivision of the Pliocene rocks of the area, owing to insufficient palaeontological work. Until recently, the oyster bed and associated shell beds of the Portland cliffs were doubtfully assigned to the Werrikooian (Upper Pliocene), but Miss I. Crespin, Commonwealth Palaeontologist, has classed a collection sent to her by the author as Kalimnan (Lower Pliocene). Details are given in the appendix. The fossils were collected from a road cutting in the face of the cliff near Double Corner, close to " Maretimo " homestead. Dune limestone does not come into contact with this formation.

Apparently the Werrikooian beds are restricted to the valley of the Glenelg. The type area occurs at the junction of Limestone Creek with the Glenelg, north of Dartmoor. There appear to be three beds, viz., upper: flaggy limestone; middle: Oyster bed (Ostrea limestone); lower: shell beds, which are the actual Werrikooian strata. There is probably not much difference in age between the (?) Werrikooian flaggy limestone and the oldest dune formations. After the Werrikooian beds were deposited in the estuary of the Glenelg, the post-Werrikooian uplift brought these beds into a position suitable for the building of the first dunes, probably in the early Pleistocene period. Possibly the flaggy limestone is part of the first aeolian deposits.

In regard to the relationship of the Newer Volcanic Series to the dune limestone, it must be recognized, as pointed out by Hills (1939, p. 130), that the Fitzroy River basalt is much younger than the other volcanic rocks of the district. In the Tyrendarra Stoney Rises the basalt fills a valley eroded in dune limestone and raised beach ridges associated with the Narrawong Ridge. Inliers of the dune rock and raised shell beds were found in allotment 7B, Homerton, Section B, part of Narrawong, at 25 feet altitude. The locality is shown on Sheet 1 (Helio) of the Fitzroy River Survey made by the State Rivers and Waters Commission in 1933-34. The basalt extends a little east of Wright's Bridge, allotment 56, Narrawong, and according to fishermen it forms a submarine bank trending south-west for some miles in Portland Bay, off Tyrendarra. This basalt is therefore younger than the dune limestone, and is Holocene in age.

The majority of the Newer Volcanic rocks west of Portland are older than the dune limestone since they underlie the dune formations. Their ages may therefore range from Pliocene to Lower Pleistocene. The basal portions of the dune rock often contain embedded pebbles of basalt; these occur in the cliffs of Cape Grant, Cape Nelson, and Cape Bridgewater. Nowhere is there evidence of intrusive basalt in the dune rock, though some earlier observers have stated this, mistaking yellow tuff beds for dune limestone. It should be pointed out that access to the cliffs and shore platforms is easier now than hitherto.

The age of the basalt of the Kangaroo Range at Drik Drik and Balrook has caused considerable discussion, initiated by the different interpretations of the geology by Keble, who mapped the Drik Drik sheet, and J. Foster, who mapped Balrook parish. Keble regards the scarp of the Kangaroo Range as due to erosion by the pre-Werrikooian Glenelg River, thus making the basalts pre-Werrikooian in age. This interpretation was adopted by Sussmilch (1937). Evidence in favour of some antiquity for this basalt is that it carries a heavy forest of Messmate (*Eucalyptus obliqua*) in a deep red soil, with Brown Stringybark (*E. capitellata*) in the sandy patches. J. Foster discovered an important sink-hole in allotment 35, Balrook, which is 80 feet deep. On the east face there is Tertiary limestone capped further up the hillside by the Kangaroo Range basalt; on the west side there is an upper bed of dune limestone about 30 feet thick, resting at an angle of 30 degrees on a red-brown bed consisting of fragments of basalt and scoria set in red ash and clay. Foster regards this lower bed as a fault breccia, but it possesses many of the features of ejectamenta. Scoriaceous basalt 70 feet thick is exposed in the east bank of the Glenelg, in allotment 3A, Balrook, about 1 mile from the sink-hole, and also on the opposite bank in the parish of Kinkella. Thus the basalt may be at the lower level for a reason other than faulting. The vents from which the main Drik Drik basalt flow was extruded are the twin hills, Mount Vandyke (Good Hill) and Mount Deception, in the parish of Cobboboonee. The rock is a holocrystalline andesine basalt with large white felspars and prominent olivines, similar in many respects to the Pirron Yallock type (Skeats and James, 1937) from the Stony Rises near Colac. By analogy it might be Holocene or Recent in age, but the stratigraphical evidence is at present very incomplete. There is no known bed of Werrikooian between the basalt and the Miocene limestone. Thin cappings of siliceous sands, probably drifted and leached dune sands, occur on the western margins of the basalt. It appears probable that the Drik Drik basalt is pre-dune limestone, and if the fault be admitted, possibly post-Werrikooian.

Basalt is brought into relation with dune limestone along a fault scarp, not previously described, which runs from Swan Lake to near Cape Bridgewater, and has caused a 200-ft. throw to the south. The old dune limestone has been displaced by this amount at the waterfall on Johnstone's Creek above Swan Lake. On the down-throw side the dune rock is exposed at intervals along the coast and in some of the depressions between more recent dunes in the sunkland. The below-sea-level beds of some of the Bridgewater Lakes may be attributed to this fault.

Evidence of Uplift of the Area.

GENERAL UPLIFT.

The pre-Newer Volcanic terrain was an immaturely dissected raised plain of Miocene limestone with relatively high points at Heywood, Condah, Narrawong, and Portland, and a wide bay where the lower Glenelg basin now exists. The coastline was further inland than at present, though its exact position is indefinite. In Lower Pleistocene times, or even earlier, the volcanic eruptions began at numerous vents along three main lines, viz., the northern, including Mt. Eccles, Mt. Eckersley, Mt. Deception, Mt. Vandyke, and vents near the junction of Moleside Creek with the Glenelg; the central, less defined, includes Mt. Kincaid, Mt. Richmond, and Mt. Clay; and the southern comprises Cape Bridgewater, Cape Nelson, Cape Grant, Lawrence Rocks, and Julia Percy Island. Possibly the southerly line of vents was submarine. Much of the extruded matter is tuff, which forms beds nearly 200 feet thick at Yellow Bluff, Cape Nelson, and over 100 feet thick at Cape Bridgewater, Cape Grant, and Lawrence Rocks. As far as is known, there is no evidence of fossils in the tuff, and the massive lava shows no spilitic characters.

The highest point in the district is Mt. Richmond, which is capped by dune sand at 740 feet. The sand is arranged in three tiers or arcuate dunes on the southern and western sides, each tier being about 100 feet high, bringing the base to the same level (400 feet) as the main plateau of the Bridgewater dune rock. The possibility of migration of sand dunes up the sloping sides of Mt. Richmond to form the three high level dunes must be considered. When the general level was 400 feet lower, the volcanic dome of Mt. Richmond would still have projected 340 feet above sea level, and dune sands may have been carried to that height provided that the slope was suitable. It so happens that the sides are very gently sloping, the mount being a large dome covering 4 square miles (see Fig. 2). Migration of dunes up considerable slopes is considered by Hills (personal communication) to have occurred at Cape Otway and Cape Schanck. It is suggested as the cause of the exceptionally high sands on Mt. Richmond.

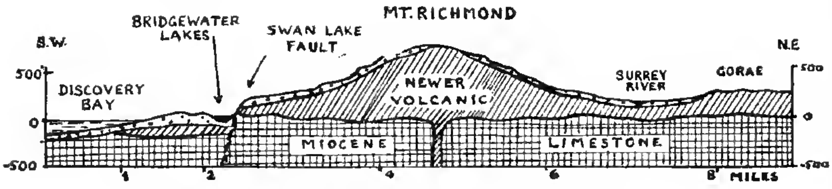

FIG. 2.—Section through Mt. Richmond to show high-level dune sands.

The widespread dune formations at 400 to 500 feet altitude, which cover the basaltic Portland promontory and its westward extension to Swan Lake and Mt. Kincaid, indicate uplift of the order of 400 feet, after allowing 100 feet as the height to which dune formations can be built and levelled off in this district. When the land was 400 feet lower all but the higher volcanoes were submerged. Probably Mt. Richmond (740 feet), Mt. Kincaid (664 feet), Cape Bridgewater (449 feet), and Mt. Clay (622 feet) had their summits above water. As uplift began, marine and aeolian sands were deposited on the shores of these islands at successively lower levels. Thus the higher deposits on the eminences are the older.

When the uplift had proceeded until the plateau of basalt flows was about to emerge, dune building became much more extensive, resulting in the widespread deposits now forming the innermost old dunes. Uplift may not have been continuous owing to the eustatic rise and fall of sea level consequent on release and withdrawal of sea water during the interglacial and glacial epochs of the Pleistocene. Sayles (1931) has pointed out how this affected dune building in the Bermudas, and Hills (1939) has suggested that similar conditions prevailed in Victoria. Glacial conditions reduced the level of the oceans and accelerated the building of dunes, but interglacial conditions caused a rise of sea level, inhibiting the growth of dunes, which became fixed by vegetation and developed soil beds. In the Portland district a total of five beds (some soil beds and some brecciated-sandstone beds) has been developed, which agrees with the suggestion of Hills that this may be the maximum number in the Victorian dune series.

With continued uplift, the higher dunes became stranded, others being formed further out on the receding shoreline. Not every dune ridge is a stranded foredune, as several ridges were formed at the one sea level, and would be stranded as a group. Wind planation and occasional marine transgressions reduced the summits of these dunes, making a platform of dune rock with fairly level top. Upon this, during interglacial periods, further generations, possibly two or three, of dune rock might develop, separated by the erosion planes and possibly by old soil beds. The complete sequence of dune formations could never be formed in any one place; usually the thickness of dune rock at one place does not exceed 100 feet; the maximum on the coastal cliffs is about 150 feet near Kappa Camp, Nelson Bay.

When the basaltic plateau had fully emerged, the bay which is now the basin of the lower Glenelg had become defined, and so had Portland Bay. During this uplift the formation of shallow water marine sediments in the Glenelg basin occurred, i.e., in Pliocene (probably Werrikooian) times, and was followed by dune building, which is still proceeding. The dune building along the shores of Portland Bay is of late Pleistocene age. Certain faults occurred in the late Pleistocene or Holocene, and that between Swan Lake and Cape Bridgewater let down a strip of country upon which new dunes began to form. Some of the basaltic capes were too steep for new dunes to form on them. Cape Bridgewater was probably the last of the volcanic islands to be tied to the mainland by the growth of sand dunes on the isthmus.

Latest Uplift of About 10 Feet.

The strongest evidence of the most recent uplift is afforded by the raised beaches at Nelson, Narrawong, and Tyrendarra, raised pebble ridges at Point Danger and Blacknose Point, possible raised shore platforms on some of the headlands, and possible raised marine caves in the Bridgewater district. The combined evidence points to a very Recent elevation of the order of 10 to 15 feet.

The raised beach at Nelson is shown on the geological parish plan of Glenelg, in allotment 14, at an altitude of about 10 feet. Similar deposits occur further east in a ridge protruding into the

Long Swamp. The Narrawong ridge, previously described, consists in its basal part of raised shelly beaches at 15 to 20 feet altitude.

On the eastern extremities of Point Danger and Blacknose Point there are pebble ridges at a height of 10 to 15 feet above the present storm beach pebble deposits.

Many low shore platforms, locally termed "Flat Rocks", occur around the base of the cliffs, particularly in the tuff beds, where they are very level. In the basalt, the shore platforms are irregular in level, due partly to variations in original hardness, and partly to differential erosion. No simple correlation is possible between the rock ledges at various heights on the several capes, though doubtless some of them are genuine raised platforms. Jutson (1939) has recently pointed out the possibility of formation of several levels of platforms with sea level at one height, in connexion with the hypothesis of recent elevation of the coast near Sydney, N.S.W. There are well-developed shore platforms on Lawrence Rock and on Julia Percy Island (McCoy Society, 1937).

Two of the caves on the steep eastern face of Cape Bridgewater are of special interest. One has its floor about 30 feet above sea level. It is high, narrow, and does not penetrate far into the cliff, but is inaccessible; thus it is not known what lies under the storm-tossed boulders on its floor. Griffiths claimed (p. 78) that its position was due to uplift, and probably this interpretation is correct. Another cave, the Water Cave, has its floor well below wave level, and has been found to penetrate several hundred feet, leading into a dry cave. This cave was attributed to later subsidence of a wave-cut cave. It may be pointed out that the tuff beds in the cliff are rather steeply inclined and are predisposed to fracture.

At Vance's Beach, Bridgewater Bay, on the north side of the road skirting Bridgewater Bay, there are two caves, almost filled with sand, in allotment 25, Tarragul. They are cut in dune limestone, and the floors are estimated to be 20 feet above sea level, so they are almost certainly raised wave-cut caves. They are separated from the beach by a foredune.

On the steep eastern bank of the Bridgewater Lakes near Lightbody's is a rock face in which several shallow caves appear. The floors are at 150 feet altitude. Bonwick (1857) thought that they were uplifted marine caves; there are shells, flint scrapers and small bones in the sand on the floor, but the shells are of the large edible kind collected by aborigines, and the bones are of mice dropped from hawks' nests in the roof of the cave. These caves are possibly solution caves exposed by the Swan Lake-Bridgewater fault scarp. The rock is dune limestone.

Numerous small caves at Drik Drik, Puralka, and in Batt's Ridges near Portland are apparently solution caves; it might be possible to obtain evidence of uplift from the fossil bones which are known to occur in some of them. Tindale (1933) who applied this method to the caves at Tantanoola, South Australia, correlated the fauna with the stages of development of the sand ridges of South-east South Australia, the period of formation ranging from Upper Pliocene to Recent.

Although terraces are absent on the larger streams, there are two terraces on Wattle Creek near its mouth, in Henty Park, Portland. The higher is about 30 feet altitude, and is well-marked at the entrance to "Burswood" on the south side of the creek; the lower at 10 to 15 feet occurs throughout Henty Park on the north bank. These terrace formations may, of course, have been due to earlier changes in the stream, or may be caused by uplift.

Conclusions.

Evidence of general uplift of the order of 400 feet is afforded by the widespread dune formations at that altitude. Migration to that height and on such a scale is not admitted. Pleistocene glacial and interglacial periods exerted some control on the rate of dune building by their effect on the sea level; this is reflected in the soil beds separating the dune formations. The most recent elevation was of 10 to 15 feet.

Acknowledgments.

Mr. W. Baragwanath supplied maps by the Geological Survey of Victoria; Mr. F. E. Levy supplied maps by Reid. Mr. F. Cudmore assisted with literature, and Mr. G. B. Hope with the loan of instruments. Palaeontological determinations were made by Miss I. Crespin and Messrs. F. Chapman, W. J. Parr, and R. A. Keble. Local information was obtained from Messrs. E. E. Bond, B. F. Egan, W. C. Hedditch, H. McLeod, B. O. Squire, F. S. Incoll, and others. Valued criticism of the paper was made by Mr. J. P. L. Kenny, Mr. J. T. Jutson, Prof. Bartrum, Dr. R. T. Patton, and Dr. E. S. Hills. The photos are the work of Mr. M. E. Andrews of Portland.

Appendix.

ESTIMATIONS OF $CaCO_3$ (A. Coulson).

BEACH SANDS.	$CaCO_3$ *Per cent.*
Mouth of Wattle Creek, Portland	93.00
Dutton Beach, Portland, between tide marks	98.75
Pebbly Beach, between tide marks	92.65
Swan Lake Beach, Discovery Bay	75.30
Cape Montesquieu Beach, Discovery Bay	74.75

	$CaCO_3$ *Per cent.*
DUNE SANDS, UNCONSOLIDATED.	
Dunes 170 feet high, Kentbruck	78.80
Dune 420 feet altitude, near old Mt. Richmond S. School	71.20
Malseed's Lake, wandering dune	79.70
Bridgewater Lakes, between Lightbody's and Kittson's	81.45
Mount Dryden, Cape Bridgewater	69.90
Lake Mombeong (Lake Bung Bung)	77.60
Tyrendarra foredune, 50 feet high	94.05
Mount Kincaid, at 500 feet	56.60
Warrnambool, mouth of Hopkins, foredune 50 feet	92.85
Port Fairy foredune, 50 feet altitude	59.90
Yambuk, foredune at mouth of Eumeralla River	92.60
DUNE ROCK, CONSOLIDATED.	
Bridgewater Lakes, in high caves	98.75
Cape Grant, in cliff face	72.50
Limestone Hill, Cashmore	93.75
400-ft. cliffs overlooking Swan Lake	52.05
Portland Cemetery, quarry near main gate	35.80
SILICEOUS SANDS, FROM SURFACE.	
Portland Cemetery	3.22
Blacknose Point, on road	1.15
Rifle Butts, surface	1.00
Rifle Butts cliffs, 20 feet down	5.30
West Gorae, near State School	8.00
SANDY SOIL BEDS IN DUNE LIMESTONE.	
Cape Grant, soil bed half-way up cliff	37.75
Cape Nelson, soil bed in cliff	59.90
Cape Montesquieu, soil bed in dune-rock	47.50
WERRIKOOIAN FLAGGY LIMESTONE.	
Dartmoor Railway Quarry	76.35

SIZING ANALYSES OF SANDS (W. R. Jewell, M.Sc.).

Type.	Locality.	On 20 Mesh.	20–40 Mesh.	40–60 Mesh.	60–80 Mesh.	80–100 Mesh.	Through 100 Mesh.
1 (*a*)	Discovery Bay	1·55	4·53	4·21	29·42	57·42	2·87
1 (*b*)	Kentbruck Dunes	1·03	8·92	23·07	56·43	6·45	4·10
1 (*b*)	Bridgewater Lakes, dunes	0·13	1·41	8·11	50·47	20·02	19·86
1 (*b*)	Mt. Dryden, 375′ dune	0·03	0·19	7·12	71·29	11·37	10·00
2 (*a*)	Shelly beach, between tide marks	0·69	0·93	3·22	46·01	29·15	20·00
2 (*b*)	Shelly beach, 100′ foredune	0·04	1·04	4·90	45·81	26·96	21·25
2 (*b*)	Henty beach, foredune	0·01	0·04	0·63	52·73	14·14	32·45
3	Cashmore Heath, surface soil	1·66	28·79	34·39	23·06	6·38	5·72
3	Cape Grant, old soil in cliff	tr.	0·80	47·64	50·57	0·63	0·36
4	Blacknose Point, surface soil	0·06	3·01	14·41	43·87	19·81	18·84

PALAEONTOLOGICAL DETERMINATIONS.

LAND MOLLUSCA. In uppermost soil bed, Portland Promontory. (F. Chapman.)

Rhytida gawleri Brazier.
Succinea australis Ferussac.
Laoma cf. minima Cox.

LAND MOLLUSCA. In old soil beds, Portland Promontory. (F. Chapman.)

Charopa tamarensis (Petterd).
Charopa spp.
Flammulina sp.

FORAMINIFERA. In uppermost sandy soil, Cape Nelson. (W. J. Parr.)

Uvigerina sp. aff pigmea d'Orbigny.
Discorbis dimidiatus (Jones and Parker).
Discorbis australis Parr.
Discorbis bertheloti (d'Orbigny).
Notorotalia clathrata (Brady).
Cibicides sp. cf. pseudoungerianus (Cushman).
Globigerina bulloides d'Orbigny.
Orbulina universa d'Orbigny.
Elphidium macellum (Fichtel and Moll).
Elphidium imperatrix (Brady).
Quinqueloculina sp.
Triloculina trigonula (Lamarck).
Triloculina insignis (Brady).

COLLECTION FROM THE OYSTER BED, DOUBLE CORNER, PORTLAND (Miss I. Crespin).

FORAMINIFERA—

Cassidulina subglobosa d'Orb.
Orbulina universa d'Orb.
Polystomellina howchini (Chap. & Parr).
Rotalia beccarii (Linne).
Elphidium imperatrix (Brady).
E. crispum (Linne).

ANTHOZOA—

Balanophyllia sp.

POLYZOA—

Cellepora fossa Busk.

PELECYPODA—

Anomia tatei Chap. & Sing.
Nuculana crassa (Hinds).
Clausinella subroborata (Tate).
Glycymeris striatularis (Lam).
Corbula coxi Pilsbury.

GASTEROPODA—

Bankivia howwitti Tate.
Liopyrga quadricingulata Tate.
Eleurnopsis sp.
Cancellaria sp.
Turritella spp.
Bittium sp.
Nassarius sublirella (Tate).
Natica cf. *hamiltonensis* Tate.

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Explanation of Plate.

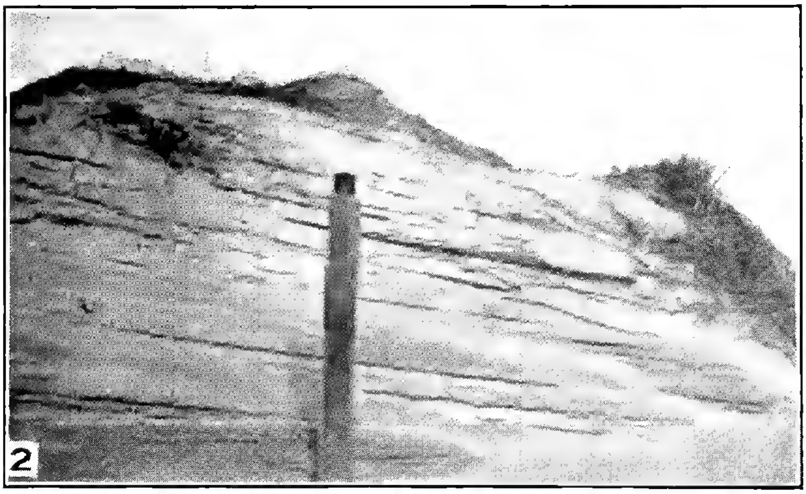
Plate XIII.

Fig. 1.—Sand ridge running east and west, oblique to coast, Discovery Bay, two miles west of Swan Lake.

Fig. 2.—Incipient compaction of sand in layers in a foredune, Discovery Bay, seaward side of Bridgewater Lakes.

Fig. 3.—Lee slope of dune with encroachment of dry sand (white) over-running wet sand (dark), Discovery Bay north of Bridgewater.

1



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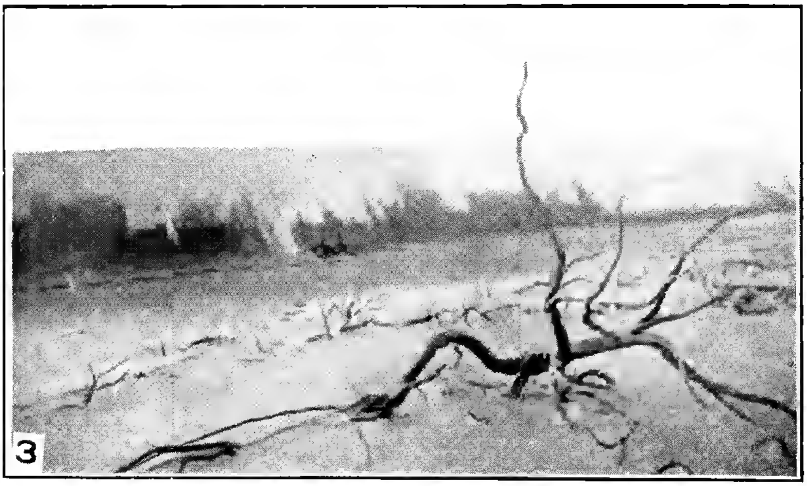

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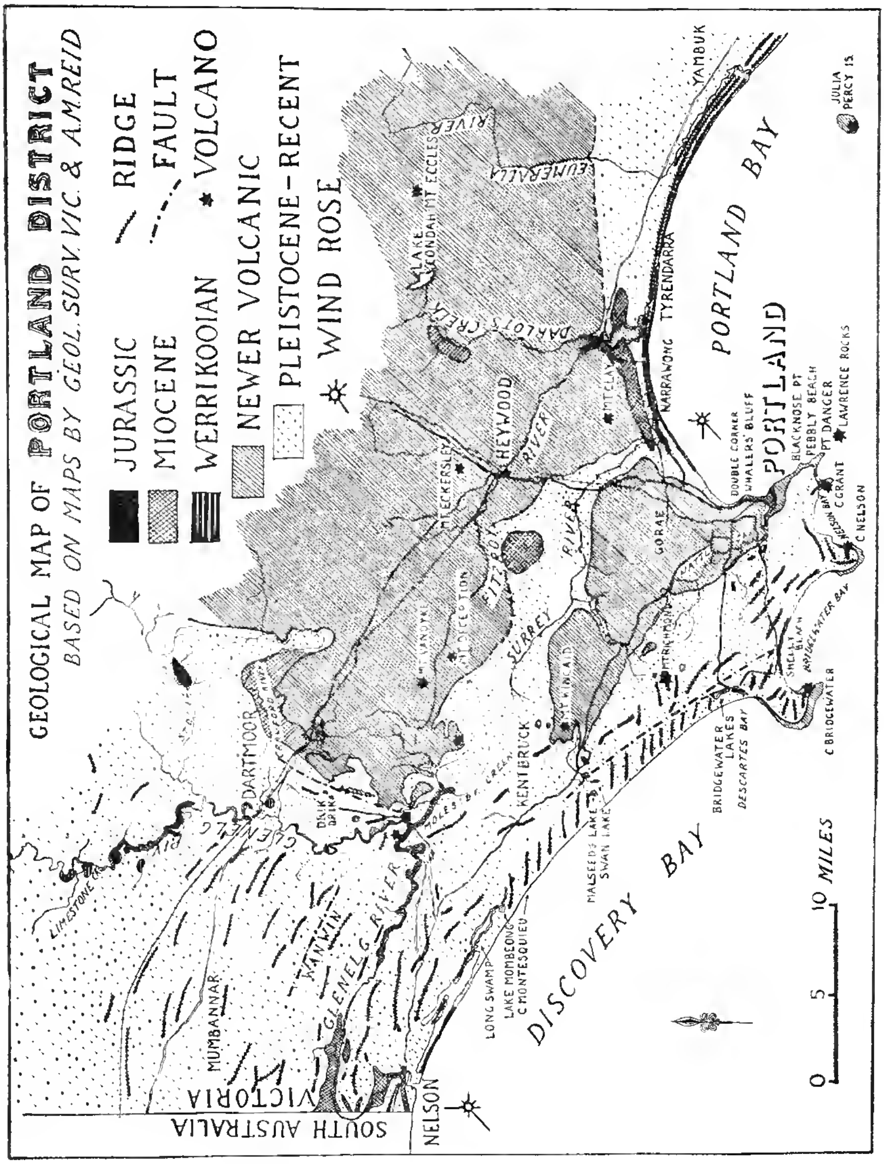

GEOLOGICAL MAP OF PORTLAND DISTRICT
BASED ON MAPS BY GEOL. SURV. VIC & A.M. REID
JURASSIC
MIOCENE
WERRIKOOIAN
NEWER VOLCANIC
PLEISTOCENE-RECENT
WIND ROSE
RIDGE
FAULT
VOLCANO
PORTLAND BAY
DISCOVERY BAY
PORTLAND
HEYWOOD
DARTMOOR
NELSON
SOUTH AUSTRALIA
VICTORIA
GLENELG RIVER
FITZROY RIVER
SURREY RIVER
EUMERALLA RIVER
DARLOTS CREEK
LAKE CONDAH
MT ECCLES
TYRENDARRA
NARRAWONG
YAMBUK
JULIA PERCY IS
GORAE
KENTBRUCK
MUMBANNAR
LIMESTONE
LONG SWAMP
LAKE MOMBEONG
C MONTESQUIEU
MALSEEDS LAKE
SWAN LAKE
BRIDGEWATER LAKES
DESCARTES BAY
C BRIDGEWATER
BRIDGEWATER BAY
C NELSON
C GRANT
NELSON BAY
DOUBLE CORNER
WHALERS' BLUFF
BLACKNOSE PT
PEBBLY BEACH
PT DANGER
LAWRENCE ROCKS
MT ECKERSLEY
MT KINCAID
MT CLAY
0 5 10 MILES

[Proc. Roy. Soc. Victoria, 52 (N.S.), Pt. II., 1940.]

Art. XVI.—*A Note on the Physiography of the Woori Yallock Basin.*

By A. B. EDWARDS, Ph. D.

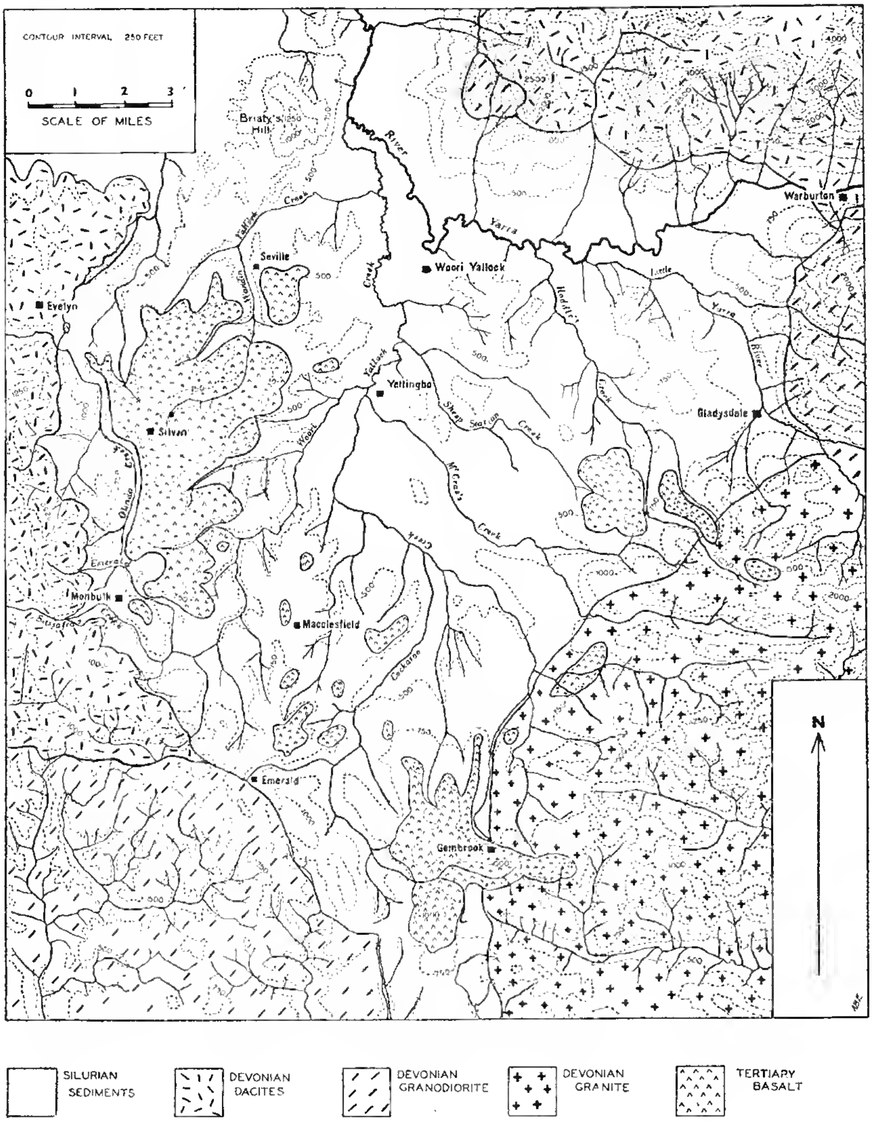
[Read 9th November, 1939; issued separately 1st July, 1940.]

Introduction.

The term Woori Yallock Basin appears to have been coined by Gregory (1903) to describe the relatively low-level area that lies between the Dandenong Ranges, on the west, and the Powelltown Ranges on the east (fig. 1). This area encloses the drainage system of the Woori Yallock Creek, Hoddle's Creek, and the Little Yarra River. It is a topographic basin due to differential erosion, and not a structural one. The floor of the Basin is composed of Silurian mudstones and shales that have been eroded much more easily than the igneous rocks of the Dandenong Ranges or the porphyritic granite of the Powelltown Ranges. The outlet is to the north, to the Yarra Valley, while at the southern end the Basin is closed by a narrow pass, at about 1,000 feet above sea-level, between the converging walls of igneous rock.

Structurally the area has the form of an anticlinal dome (dome in the sense of Thomas, 1939, p. 59), since Melbournian beds occur near Macclesfield, about the centre of the Basin (E. Gill: personal communication), while Yeringian beds occur to the north-east, north, north-west, west, and south-west (Gill, 1939).

In (?) Oligocene times the main valleys across the floor of the Basin were infilled with basaltic lava flows of the Older Volcanic Series, and the drainage reconstituted itself as a series of lateral streams more or less parallel to the pre-basaltic stream courses, and flowing to the north. Erosion of the basalts has progressed until now they occur only as residuals capping the ridges between the valleys. The geological boundaries have been mapped by Easton (1908), and the geology of Figure 1 is based upon his map, while the contours are taken from the Ringwood Sheet of the Military Survey, and the western sheet of the Boy Scout Jamboree Map of 1935. It will be seen that at present the floor of the Basin consists of a series of narrow, sub-parallel ridges, with undulating crests, converging towards the north, and separated by somewhat wider valleys up to 200 feet deep. These valleys and ridges trend at right angles to the walls of the Basin so that over the Basin as a whole their arrangement approximates to a fan-pattern.


CONTOUR INTERVAL 250 FEET
0 1 2 3
SCALE OF MILES
N
Warburton
Woori Yallock
Seville
Evelyn
Yellingbo
Gladysdale
Silvan
Monbulk
Macclesfield
Emerald
Gembrook
Yarra River
Little Yarra River
Woori Yallock Creek
Sheep Station Creek
McCrae's Creek
SILURIAN SEDIMENTS
DEVONIAN DACITES
DEVONIAN GRANODIORITE
DEVONIAN GRANITE
TERTIARY BASALT

Previous Observations.

It has been suggested by Gregory (1903), and by Keble (1918), that the pre-Older Volcanic streams in this Basin flowed southwards, through the low pass near Gembrook, to the Koo-wee-rup Swamp; and not northwards to join the Yarra as they do at present. Gregory offered no explanation of the reversal of the drainage from this postulated south-flowing system to the present system other than a very general reference to stream capture; but Keble explained it as due to a retardation of drainage through the "Gembrook bottle-neck" caused by the resistant nature both of the basalt which had infilled the valley at this point, and of the wall rocks of the valley. Such retardation, he suggests, slowed up the development of the system further upstream, and rendered it an easy capture to adjoining river systems.

If this conception of the pre-basaltic streams flowing southwards through the Woori Yallock Basin was correct, the whole of the land north of the Gembrook Pass forming their catchment must have been at a higher level than the level of the Pass at the time when the basalts were extruded. The same volume of water as previously would have found its way through the "bottle-neck" after a short period of lake formation; and despite Keble's suggestion that the lava flows "converged" on this point, there is nothing to indicate that the thickness of basalt at Gembrook is, or was, very materially greater than elsewhere within the Basin. This being so, the rejuvenated drainage of the Basin would have readily breached the lava flow in the "bottle-neck", after which, by undercutting the basalt, it would have established a valley in which it could cut down to the pre-basaltic level, and so, apart from other considerations, make unlikely such an extensive reversion of drainage as visualized by Keble. Moreover, it must be remembered that the adjoining river system—namely, the Yarra System—had also suffered retardation at this time, owing probably to the extrusion of basalt across its valley at Lilydale, and was developing, in the Yarra Valley, extensive river flats which even now are not undergoing erosion (Hills, 1934, p. 169). There are, therefore, grounds for thinking that if there had been a south-flowing drainage system in the Woori Yallock Basin prior to the Older Volcanic eruptions, such a system would continue to exist.

Gregory's Evidence (1903).

Gregory seems to have based his belief in the existence of this south-flowing river system on the following observation (Gregory, 1903, p. 107):—

"Looking across the Woori Yallock Basin (from Mt. Dandenong) to the hills that form its eastern border, we see that they form a long range sloping to the south; the hill crest is here and there notched and irregular; but a line joining the points on the range has a steady southward slope."

From this he concludes that "at one time this country must have been part of a peneplain with a slope to the south; down this slope rivers flowed at right angles to the course now followed by the Yarra. Remains of the valleys of these older rivers are well marked; thus, the ridge that forms the main watershed of Victoria (the Main Divide) is notched by a river-cut depression —the Kinglake Gap, north of Yarra Glen; and the divide between the Yarra and the rivers of Gippsland is notched by a similar depression east of Gembrook—the Beenak Gap—connecting the basin of Woori Yallock and the Koo-wee-rup Swamp".

Gregory's belief that the dacites and other volcanic rocks of the Dandenong Ranges and the Warburton Ranges were of early Tertiary age "formed at the beginning of the great series of eruptions which ended in the formation of the great basalt plains of Victoria" (Gregory, 1902, p. 213), no doubt caused him to overlook the significance of the difference between the level profile of the Warburton Ranges and the sloping profile of the Powelltown granite massif. This only became apparent after Skeats (1910*a*) had demonstrated the Devonian age of the dacites, when he (1910*b*, p. 188) suggested that "the level-topped, plateau-like character of the dacites" represented "remnants of a former extensive peneplain developed by long-continued subaerial denudation of the igneous and sedimentary rocks before Mid-Kainozoic times", and that subsequent uplift had "led to the dissection of this peneplain and the formation of another at a level of only a few hundred feet above sea-level, the softer sediments being easily base-levelled, and the more resistant dacites preserving remnants of the older peneplain". Hills (1934, p. 160) advances reasons for considering that this older peneplain is of Cretaceous age.

This being so, the true surface of the old peneplain is indicated by the level profile of the Warburton Ranges; while the south sloping surface of the distinctly lower Powelltown Ranges is simply the profile of the present erosion surface on those ranges, and since the granites which form them were probably not exposed at the surface in Cretaceous time, it affords no evidence as to the direction that post-Cretaceous streams would have taken through the Woori Yallock Basin. All that we can determine concerning these is that they must have been determined largely by the positions of the resistant dacite areas. The streams would, therefore, have developed mainly in the softer areas of sedimentary rocks between the dacite areas, much as they are now, and might in this way have become super-imposed on the deeper-seated granites which were probably not exposed at that time.

Keble's Evidence (1918).

Keble's conclusion was based upon his study of lava residuals, particularly those of the Woori Yallock Basin, which, on an uncontoured map, give the appearance of convergence towards Gembrook. Thus he states (p. 158):—

"A large tributary of this last-mentioned stream had its source somewhere north of the Woori Yallock residual, and was probably identical in its headwaters with the Watts. Its course is represented by the 'uncovered residual' of Steel's Range, the Woori Yallock residual, the Gembrook residual, the Pakenham residual, and by a line of conspicuous uncovered residuals disappearing into the Koo-wee-rup fault block towards the trunk stream. Above the Gembrook bottleneck this tributary received a tributary from the north-east; it originated on the westerly slope of Mt. Donna Buang."

When this statement is examined in detail, a number of facts appear which are irreconcilable with the general picture. Thus—

1. Steel's Range (Briaty's Hill), as indicated by Hills (1934, p. 168), owes its prominence to the fact that it is composed of silicified sandstones, more resistant to erosion than the adjacent Silurian sediments. It cannot, therefore, be an "uncovered residual", i.e., the floor of a pre-basaltic valley.

2. The basalt residuals along the upper part of Hoddle's Creek descend successively from 1,500 feet above sea-level to 1,300 feet and 750 feet, going towards the north-west, and Hoddle's Creek and Sheep Station Creek, which also flow in a general north-westerly direction, appear to be laterals of the flow represented by these residuals.

3. The line of basalt residuals extending from near Emerald to north of Macclesfield descends from about 950 feet at the southernmost residual to about 700 feet at the northernmost—a fall of 250 feet in 4 miles. The levels refer to the relatively flat tops of the residuals, since the bases are obscured by soil creep. Moreover, the Woori Yallock Creek and the Cockatoo Creek–Macclesfield Creek have formed as north-flowing laterals to this lava flow, and indicate its northward extension—now marked by an "uncovered residual"—to near Yellingbo, where they junction.

4. At Gembrook the basalt residuals stand at 1,050 feet to 1,100 feet above sea-level, and fall away to the north (1,000 feet). The branch of Cockatoo Creek, which is a lateral to the Gembrook residual, rises south of the southernmost point of the basalt, and flows northwards from this point.

5. The large residual extending from Monbulk to just south of Seville, ranges in height from 950 feet to 700 feet above sea-level. The surface is somewhat irregular, being highest in the central portion near Silvan. It seems probable that this residual

represents not a "confined" lava field, as Keble suggested, but a local "extensive" lava field, infilling the valleys of several streams which rose in the Dandenong Ranges and trended eastwards or north-eastwards, and also covering the interfluves between them. Some of these streams, like Emerald Creek and Sassafras Creek, subsequently crossed and breached the basalt, and joined its eastern lateral, Woori Yallock Creek. Others, like Lyre Bird Creek and Olinda Creek, were ponded into a lake behind the lava flows, and found an escape over a low divide south-east of Evelyn, being thus enabled to form a western lateral to the basalt as the present Olinda Creek.

Conclusion.

From this brief discussion it will be seen that there is no reliable evidence to show that any stream ever flowed southwards via the Woori Yallock Basin towards Western Port Bay. On the other hand, the levels at which the remaining basaltic residuals occur strongly suggest that the pre-Older Volcanic streams, like the present ones, flowed to the north to join the Yarra River. The Gembrook Pass, on this view, is not a river-cut depression but simply a low pass in the divide, such as may be expected in any divide wherever a zone of soft rocks occurs interposed between resistant rocks.

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[Proc. Roy. Soc. Victoria, 52 (N.S.), Pt. II., 1940.]

Art. XVII.—*Further Notes on Certain Marine Deposits at Portarlington, Victoria.*

By J. T. JUTSON and ALAN COULSON.

[Read 14th December, 1939; issued separately 1st July, 1940.]

Introduction.

As the result of criticism of our paper (2) by E. S. Hills (1) we re-visited the sections in September, 1939, and now offer the following remarks thereon.

The Pier Sections.

Our inspection shows that a considerable quantity of recent marine shells has been deposited on the upper part of the cliff face. These shells are clearly due to human agency, having, in all probability, been washed from the surface of the ground above the cliff, by very heavy rains, as we were informed by the Engineer for the Shire of Bellarine, who stated that shells are carried from the beach for use on footpaths. If these were the shells seen by Hills, then he was justified in regarding them as artificially laid over the ferruginous sands.

We desire to emphasize the fact that the shells referred to have been deposited in their present positions since our visits on which our paper was based. At that time there were thin horizontal bands of recent marine shells in the dark-coloured surface sands and in the outcrops of the brown sands some feet below. These bands were only found after close search and, as a result of their mode of occurrence and distribution, we came to the conclusion, after considering the possibility of their occurrence being due to human agency, that they were of the same age as the brown sands.

Recent gullying action shows that the upper dark-coloured sandy beds, containing an abundance of recent marine shells hitherto covered by "wash", have been artificially laid down and that, in addition to the shells, a considerable quantity of the brown sand has been carried farther down the cliff face. In some of these brown sand outcrops, there are thin horizontal shell bands; but most of the shell-bearing brown sand outcrops to which our earlier paper referred have been removed by rain action since that paper was written, so that a re-consideration of the evidence submitted by us is not altogether possible. As a result, however, of our recent investigation, we have come to the conclusion that the shell bands seen by us were the indirect result of human interference, and our first paper is modified accordingly. Consequently, the age of the brown sands, so far as based on contained fossils, must be left an open question. We would point out, however, that their location and lithology suggest that they are of the same age as the ferruginous beds of Steele's Rock section, whatever that may be.

The Steele's Rock Section.

The criticism of this section offered by Hills was anticipated and answered in our first paper, so that a reply to that criticism seems hardly necessary. We may, however, point out that our re-examination of the section has served to confirm our original conclusion, viz., that the ferruginous beds merge into the calcareous beds, the two being merely phases of the one series. Hills does not discuss the western portion of the section, where the evidence of the unity of the beds is strongest, as we pointed out in our first paper. He rests his disagreement with our interpretation on the relations of the rocks at the eastern end of the section, where he considers that the horizontal calcareous beds rest unconformably on the inclined and current-bedded ferruginous ones. Close examination, however, shows that the planes of stratification of the ferruginous beds can be traced faintly into the calcareous beds, the faintness being due to the fact that the stratification planes have been almost completely obliterated by the approximately horizontal division lines of the subsequently introduced carbonate of lime. In addition, there are, in the calcareous rocks small irregular unaltered patches of the ferruginous beds.

The part of the section just referred to is on the western side of the small headland which lies immediately to the south of Steele's Rock. If the calcareous band be followed round the headland to the eastern side of the latter, it can be seen to die out as an inclined lenticular patch in the yellow earthy limestone which rests conformably upon the ferruginous beds (fig. 1). This lenticle we regard as originally part of the limestone, and

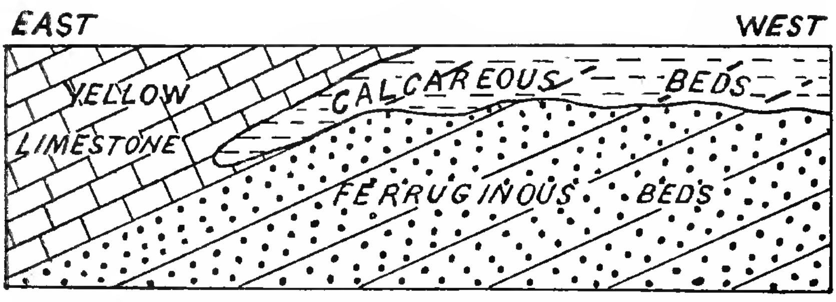

Fig. 1.—Diagrammatic section of the cliffs opposite Steele's Rock, Portarlington. The planes of stratification of the ferruginous beds pass faintly into the calcareous beds.

not as filling a cavity in the latter. There are therefore two sets only of distinct sedimentary beds in the section—the ferruginous sands and the yellow limestone. The calcareous rocks are common to both, but in a very limited degree to the limestone, and are merely an alteration phase of each.

In the calcareous beds, a few feet west of the lenticular patch just noted, we found on our re-examination two Recent marine shells, this being the first discovery of fossils in the extreme eastern end of the section.

The basal beds in the western portion of the Steele's Rock section as a whole, follow the very irregular surface of the Older Basalt, but above, the stratification, although indistinct, approximates in both the brown sands and the calcareous beds towards the horizontal. Deposition, however, was evidently rapid, as shown by the irregular pockets of shells. Even if the horizontality is only apparent and represents the strike of the beds, that does not affect their conformity.

Conclusions.

The want of undoubted fossil evidence as to the age of the Pier beds does not affect the conclusions we have drawn as to the age and significance of the Steele's Rock deposits. Neither does it affect our inferences as to the age of the upper ferruginous non-fossiliferous beds of the Bellarine and Mornington Peninsulas, and of the district to the east, north, and north-east of Melbourne; nor our proposed subdivision of the post-Tertiary rocks of the Port Phillip Bay district, since we regard the evidence of the Steele's Rock section as sufficient independently to support those ideas.

As a final remark, we desire to correct a misinterpretation of our paper by Hills. He states (p. 132) that we argue that the "Red Beds" of the Melbourne district are Pleistocene and not Barwonian and Kalimnan as formerly believed. Our references in every instance were to the uppermost non-fossiliferous beds, which all authorities have hitherto placed in the Upper Tertiary (pp. 319 et seq.). The Kalimnan age of some of the deposits was challenged by us, but we made no criticism of the Barwonian. That was outside the scope of the paper.

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Fenner, C., D.Sc., Education Department, Flinders-street, Adelaide, S.A. 1913
Ferguson, W. H., 37 Brinsley-road, E. Camberwell, E.6 1894
Finney, J. M., 387 Springvale-road, Forest Hill 1925
Fisher, Miss E. E., M.Sc., Ph.D., 1 Balwyn-road, Canterbury, E.7 .. 1930
Forster, H. C., B.Agr.Sc., Ph.D., 4 Eyre-street, Deepdene, E.8 .. 1938
Frostick, A. C., 9 Pentland-street, N. Williamstown, W.16 1933
Gabriel, C. J., 293 Victoria-street, Abbotsford, C.1 1922
Gill, Rev. Edmund D., B.A., B.D., 24 Thomas-street, Hampton, S.7 1938
Gladwell, R. A., 79 Cochrane-street, Elsternwick, S.4 1938
Gordon, Alan, B.Sc., c/o C.S.I.R., Yarra Bank-road, South Melbourne, S.C.4 1938

Grieve, Brian J., B.Sc., Ph.D., Botany School, University, N.3 .. 1929
Hanks, W., 7 Lake-grove, Coburg, N.14 1930
Hardy, A. D., 24 Studley-avenue, Kew, E.4 1903
Hauser, H. B., M.Sc., Geology School, University, Carlton, N.3 .. 1919
Head, W. C. E., North-street, Nathalia 1931
Heysen, Mrs. D., P.O. Box 10, Kalangadoo, South Australia .. 1935
Hoette, Miss Shirley, M.Sc., 23 Moorhouse-street, Armadale, S.E.3 1934
Holland, R. A., 126 Kooyong-road, Caulfield, S.E.7 1931
Holmes, Mrs. S. C. A., M.Sc., Ph.D., "Oakbank," Hampton-grove, Ewell, Surrey 1930
Holmes, W. M., M.A., B.Sc., Observatory, South Yarra, S.E.1 .. 1913
Honman, C. S., B.M.E., Melbourne Technical College, 134 Latrobe-street, C.1 1934
Jack, A. K., M.Sc., 49 Aroona-road, Caulfield, S.E.7 1913
Jacobson, R., M.Sc., Woodbine-grove, Chelsea 1937
Jessep, A. W., B.Sc., M.Ag.Sc., Dip. Ed., Horticultural Gardens, Burnley, E.1 1927
Jona, J. Leon, M.D., M.S., D.Sc., Lister House, 61 Collins-street, Melbourne, C.1 1914
Keartland, Miss B., M.Sc., 19 Glen-street, Hawthorn, E.2 .. 1919
Kilvington, T., M.Sc., Physiology Department, University, N.3 .. 1938
Lindsay, Miss Eder A., B.Agr.Sc., Agriculture School, University, N.3 1936
McCance, D., M.Sc., 144 Gatehouse-street, Parkville, N.2 1931
MacDonald, B. E., "The Heights," 127 Banksia-street, Heidelberg, N.22 1920
McIver, Miss Euphemia, M.Sc., Higher Elementary School, Rochester 1936
McLennan, Assoc. Prof. Ethel, D.Sc., University, Carlton, N.3 .. 1915
Macpherson, Miss J. Hope, National Museum, Melbourne . 1940
Melhuish, T. D'A., M.Sc., Mt. Frome Lime Co., Burrow-road, St. Peters, Sydney 1919
Moore, F. E., O.B.E., Chief Electrical Engineer's Branch, P.M.G.'s Department, Treasury Gardens, East Melbourne, C.2 1920
Morris, P. F., National Herbarium, South Yarra, S.E.1 1922
Newman, B. W., B.Sc., Meteorological Bureau, Sydney 1927
Nye, E. E., College of Pharmacy, 360 Swanston-street, Melbourne, C.1 1932
Nye, Rev. Edward, B.A., Wesley College, St. Kilda-road, Prahran, S.1 1934
Oke, C., 34 Bourke-street, Melbourne, C.1 1922
Osborne, N., c/o Australasian Petroleum Co., Port Moresby .. 1930
Paterson, Miss Helen, "The Wilderness," Warrandyte 1933
Petersen, Miss K., B.Sc., 56 Berkeley-street, Hawthorn, E.2 .. 1919
Prentice, H. J., B.Sc., 218 Esplanade West, Port Melbourne, S.C.1 1936
Pretty, R. B., M.Sc., Technical School, Wonthaggi, Vic. 1922
Raff, Miss J. W., M.Sc., F.R.E.S., University, Carlton, N.3 .. 1910
Rayment, Tarlton, Bath-street, Sandringham, S.8 1929
Richardson, Sidney C., 2 Geelong-road, Footscray, W.11 1923
Rosenthal, Newman H., B.A., B.Sc., 10 Oulton-street, Caulfield, S.E.7 1921
Rothberg, M., B.Agr.Sc., 1094 Lygon-street, N.4 1937

Sayce, E. L., B.Sc., A.Inst.P., Research Laboratories, Maribyrnong, W.3 1924
Scott, T. R., M.Sc., B.Ed., 27 Currajong-avenue, Camberwell, E.6 .. 1934
Shaw, Dr. C. Gordon, 57 Clendon-road, Toorak, S.E.2 1931
Sherrard, Mrs. H. M., M.Sc., 43 Robertson-road, Centennial Park, N.S.W. 1918
Stach, L. W., M.Sc., c/o Australasian Petroleum Co., Port Moresby, Papua 1932
Sutherland, Miss Jean L., M.Sc., Presbyterian Girls School, Glen Osmond, Adelaide, S.A. 1934
Thomas, L. A., B.Sc., c/o Council for Scientific and Industrial Research, Stanthorpe, Queensland 1930
Traill, J. C., B.A., B.C.E., 630 St. Kilda-road, Melbourne, S.C.3 .. 1903
Trüdinger, W., 27 Gerald-street, Murrumbeena, S.E.9 1918
Tubb, J. A., M.Sc., Fisheries Section, C.S.I.R., Cronulla, N.S.W. .. 1936
Vasey, A. J., B.Agr.Sc., "Westaways," Werribee 1937
Vasey, G. H., B.C.E., University, Carlton, N.3 1936
Wilcock, A. A., B.Sc., B.Ed., 294 The Avenue, Parkville, N.2 .. 1934
Wilson, F. E., F.E.S., 22 Ferncroft-avenue, E. Malvern, S.E.5 .. 1921
Wilson, Major H. W., O.B.E., M.C., C. de G., M.Sc., 630 Inkerman-road, Caulfield, S.E.7 1923
Wood, E. J. F., M.Sc., B.A., Fisheries Section, C.S.I.R., Cronulla, N.S.W. 1935
Wood, Assoc. Prof. G. L., M.A., Litt. D., University, Carlton, N.3 .. 1933
Woodburn, Mrs. Fenton, 21 Bayview-crescent, Black Rock, S.9 .. 1930
Wunderly, J., D.D.Sc. (Melb.), 2 Collins-street, Melbourne, C.1 .. 1937

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The names of new genera and species are printed in italics.