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Art I.—*Fixation of Phosphate in Some Victorian Soils.*

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[School of Agriculture, Melbourne University.]

[Read 9th April, 1942; issued separately 1st May, 1943.]

Abstract.

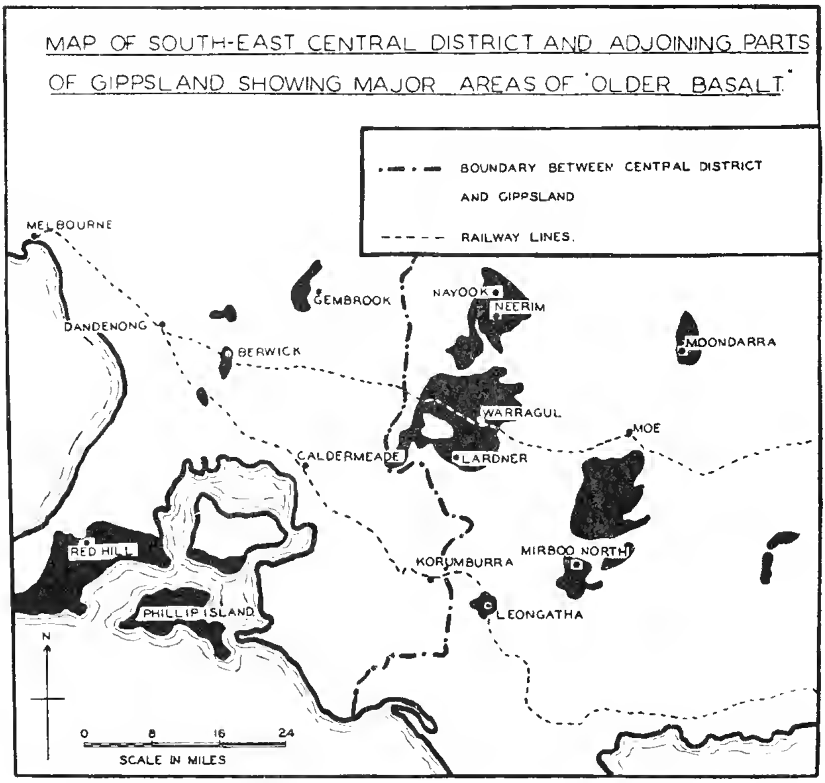
Red soils on basalt in Gippsland give greater growth of pasture with lime and superphosphate than with superphosphate alone, on account of fixing phosphate in an unavailable adsorbed form. Various chemical extractions are recorded for these and for other soils which respond normally to superphosphate. The ratio of adsorbed to adsorbable phosphate is much lower for the high-fixing than for normal soils.

Most Victorian soils show evidence of phosphate deficiency which can be remedied by the application of superphosphate. An isolated group of deep red loams on oligocene basalt in South Gippsland near Mirboo North (see map), have shown a greater growth of pasture with lime and superphosphate, than with superphosphate alone; lime alone has little effect. This suggests that part of the added phosphate is being fixed by the soil in a form not available for plants, and that the addition of lime increases the availability of this phosphate. The term "fixation" has long been used to describe the conversion of soluble phosphate, added to the soil, into forms insoluble in water. In this paper the term is restricted to include only the conversion into forms not available for plants.

Soils occur in many parts of the world which fix soluble phosphate so firmly that plants can obtain little benefit from the application of superphosphate. These soils include both acidic and alkaline types; the present paper is concerned with acidic types only. The Hawaiian soils formed from basalt are the most widely quoted example of this problem. In Australia the most striking example is found on the basaltic country around Lismore, on the north coast of New South Wales. The climate of both these areas is warm and wet. The soils are friable and permeable, though high in clay; they are high in sesquioxides and red is the predominating colour. These are extreme cases in which added superphosphate has no effect at all. This conversion of phosphate into unavailable forms is slight in the red basaltic soils of South Gippsland, and is shown only by the additional response to lime and superphosphate mentioned above. Presumably the lime acts by reducing the activity of aluminium and iron compounds.

The literature on this subject is voluminous. In acid soils fixation in an unavailable form has been attributed to two constituents, free ferric oxide and kaolinite, which hold phosphate as an anion on their surfaces. Usually importance is attached to the role of free ferric oxide in phosphate fixation, but Burd and Murphy (1) hold that kaolinite is mainly responsible, on account of the activity of the surface layer of alumina in its crystals.

The discussion of the problem by Burd and Murphy is particularly useful and is summarized and commented on in the following paragraphs. The analytical work reported here is a repetition of their methods, which were devised in order to estimate the phosphate status of the soils and to predict any future deficiencies. They chose 14 widely differing Californian soils, and obtained a good correlation between experimental results and field experience.



Absorbed Phosphate.

Burd and Murphy extract the soil with $0 \cdot 1$ N NaOH and thus determine the "adsorbed phosphate" by replacement with hydroxide. Dickman and Bray (2) suggest the use of neutral fluoride as a replacing ion since it does not dissolve organic matter. However, the small amount of organic phosphorus dissolved by alkali does not seriously increase the estimate of adsorbed phosphate.

The capacity of the soil to adsorb phosphate was next estimated by shaking a sample of soil with a solution of KH_2PO_4, filtering and washing, and again determining the phosphate extracted by alkali. This figure is called the "adsorption capacity." The ratio of adsorbed phosphate to adsorption capacity, expressed as a percentage, is called the "degree of saturation." The higher this degree, the less firmly held and therefore the more available will any added phosphate be.

Burd and Murphy consider that it is useful to compare the "adsorption deficit"—that is, the difference between the two NaOH extractions—with the total phosphate. Thus Aiken clay, (see Table 1), which shows the most acute deficiency of their samples, has a far greater adsorption deficit than it has total phosphate. On the other hand, Yolo silty clay loam, which shows no phosphate deficiency, has a total supply of phosphate far above its adsorption deficit.

Unless the degree of saturation is high, adsorbed phosphate can only be available to plants by anionic exchange between the root hair surface and the soil particles. An extracting solution containing an anion of high replacing power should only be used for determining adsorbed phosphate, not for estimating available phosphate.

Dilute Acid Extracts.

The traditional line of attack is extraction with dilute acid. This can only give an approximate picture of the conditions existing between the plant and the soil. The plant obtains its phosphate by solution from soil particles due to an increase in acidity of the soil solution around the root. The best an acid extraction can do is to try to reproduce the simple acidity effects in the neighbourhood of the root hairs. Extraction with citric acid cannot do this since it also releases adsorbed phosphate. Phosphate adsorbed on the positive parts of soil colloids can be displaced by citrate ion, and although some plants may excrete organic anions which are strongly adsorbed, in general plants cannot use adsorbed phosphate unless the individual soil particles are themselves fairly well saturated with phosphate. Burd and Murphy describe the choice of citric acid as a solvent as "perhaps the most unfortunate occurrence in the history of soil phosphate investigation."

Hydrochloric acid comes close to the ideal since chloride ion has low displacing power. Burd and Murphy used 0·01 N HCl. The solution of sulphuric acid and ammonium sulphate recommended by Truog (12) is as high as M/40 in sulphate ion. It would therefore be expected to dissolve adsorbed phosphate more vigorously than dilute hydrochloric acid. Russell and Prescott (10, p. 89) found that sulphuric acid alone dissolved three times as much phosphate as did hydrochloric acid of the same normality.

Field Evidence in Victoria.

Most of the evidence of the phosphate status of the Victorian soils here described is given by experiments conducted by the Victorian Pasture Improvement League (V.P.I.L.) which has established numerous plots in southern districts to determine the best treatments with fertilizer. These plots are mowed periodically and the clippings weighed.

The superphosphate is applied annually at the rate of 2 cwt. per acre; (some plots receive an additional 1 cwt.); lime was only applied at the beginning of the experiments at the rate of 1 ton of calcium hydroxide per acre. This took place in 1935 for Lardner and Mirboo, and in 1932 for Korumburra, Caldermeade and Pakenham.

Superphosphate causes greater growth throughout the growing season of August to January. Any additional growth caused by lime is only obtained at the first spring cut in September (15, p. 216).

DESCRIPTION OF SOILS.

The soils tested are described below. They are referred to throughout this paper by their place names.

Red Soils.

Samples were taken from three sets of V.P.I.L. plots on the red soil formed on basalt near Mirboo North, in the hills of South Gippsland. The profiles of these are similar, viz. dark reddish brown friable clay loam at the surface, passing gradually to red friable clay at a depth of a foot. The soils are remarkably permeable in spite of the high proportion of clay. Solid rock is not usually found within several feet of the surface, but there may be occasional "floaters." The original vegetation was a heavy Eucalyptus forest, and particles of charcoal and baked clay are found in the surface soil, being residues of forest fires. The average annual rainfall is 45 inches.

Mirboo I. From Mr. Bickerton's property at Limonite. Application of lime caused a 50 per cent. increase over superphosphate alone in each of the years 1936-9. Organic carbon 4·1 per cent., pH 5·4.

Mirboo II. From Mr. Austin's property, Mirboo North. Lime caused 30 per cent. increase over superphosphate alone in the years 1936-7, and about 20 per cent. thereafter. Organic carbon 2·8 per cent., pH 5·8.

Mirboo III. From Messrs. Edney, Mirboo North. Lime caused no increase over superphosphate alone in 1936, then 30 per cent. increase each year 1937-39. Organic carbon 4·1 per cent., pH 5·8.

Samples were taken from two other places on the basalt near and north of Warragul.

Lardner (rainfall 40 inches) from V.P.I.L. plots on Mr. Teese's property. This soil is on the edge of the basalt and differs strikingly from the Mirboo soils. It is greyish brown with ironstone concretions from the surface downwards. It is deficient in potassium and has given no additional growth with lime. Organic carbon 3·8 per cent., pH 5·4.

Nayook (rainfall 48 inches). This soil is under Eucalyptus forest. The profile is essentially similar to the Mirboo samples. Organic carbon 4·2 per cent., pH 5·5.

A further sample was included from the Lismore district, New South Wales, since this type has been intensively studied by Holman (5) and Parbery (8).

Wollongbar (rainfall 52 inches). Red friable clay loam, overlying red friable clay, with weathered basalt at about 5 feet. No response to lime has been established here. The fixing power for phosphate is very high. Organic carbon 3·4 per cent., pH 4·0.

Grey and Black Soils.

A sample developed on Oligocene basalt was taken from Berwick (Vic.), where both reddish-brown and black soils are formed on this same parent material.

Berwick (rainfall 34 inches). Black friable clay overlying greyish black heavy clay, with decomposing rock at 2 feet (6, p. 192). Subsoil much less permeable than the red types. No evidence of added growth with lime. Organic carbon 4·2 per cent., pH 5·6.

The remaining samples are taken from other V.P.I.L. plots. They show no response to lime, but are included for interest as they lie near the red soils of Mirboo under a similar climate.

Korumburra (rainfall 46 inches). The surface soil is a grey clay loam with a yellowish grey clay at 12 inches, which passes into decomposing rock which is a felspathic sandstone of Jurassic age. This is an immature podzolic type. Organic carbon 2·9 per cent., pH 5·3.

Caldermeade (rainfall 30 inches). Dark grey clay loam, passing into heavy clay at 8 inches. The land is flat and low-lying and has been described as "swamp fringe" type by Goudie (3). Organic carbon 4·2 per cent., pH 5·0.

Pakenham (rainfall 34 inches). Light grey sandy loam, overlying yellow sandy clay at 18 inches. This is a well-marked podzol similar to Harkaway sand (6, p. 187). Organic carbon 2·5 per cent., pH 5·5.

The mean annual temperature for the Victorian stations is close to 57°F.; rainfall reaches a maximum in winter and early spring. At Wollongbar the mean annual temperature is 67°F.; the rain falls mainly in summer and autumn.

All the surface soils in the Victorian samples are from 0–3 inches, subsurface from 3–12 inches. The surface sample from Wollongbar is from 0–9 inches.

The two Californian soils already referred to have been thus described (16).

Aiken clay is a somewhat lateritic soil developed on basalt in rolling country. The surface is a dull red clay which passes gradually into the subsoil which is a more pronounced red, compact and with a heavier texture, being high in clay. Both soil and subsoil are mildly acidic in reaction and contain aggregates or concretions cemented by sesquioxides of iron and manganese and with accumulated phosphate in an insoluble and unavailable form.

Yolo silty clay loam is a deep immature light coloured alluvial soil, alkaline in reaction, rich in lime and mineral plant nutrients, but low in organic matter.

ANALYTICAL METHODS.

Phosphate in Adsorbed Condition.

Thirty gram of soil was shaken for 1 hour with 150 c.cs. 0·1 N NaOH. The suspension was centrifuged and the supernatant liquid was poured off, diluted with an equal volume of 0·1 N NaOH, and filtered through a porcelain candle. An aliquot of 20 c.cs. of the black filtrate was boiled with 15 c.cs. concentrated sulphuric acid in a Kjeldahl flask, adding 5 gm. $Na_2SO_4.10H_2O$ and 1 gm. $MnSO_4$ crystals as catalyst. The colourless product was diluted, filtered from silica, and made up to 100 c.cs. with distilled water. An aliquot of 5 or 10 c.cs. was neutralized with ammonia using α-dinitrophenol as indicator, and the phosphate determined colorimetrically.

Adsorption Capacity.

Thirty gram of soil was shaken for 15 hours with 150 c.cs. of KH_2PO_4 solution containing 3 mg. PO_4 per cc. The soil was filtered and washed with distilled water until 1500 c.cs. had passed through. It was then shaken with 150 c.cs. 0·1 N NaOH, and treated in the same way as the previous soda extract. When determining the adsorption capacity of soils after the removal of free ferric oxide (see below), the suspension after extraction with soda was flocculated with sodium sulphate, instead of being filtered through the candle.

This method yields a lower figure for adsorbed phosphate than would be given by the alternative method of simply determining the phosphate left in the solution of KH_2PO_4 after coming to equilibrium with the soil. The difference between the two methods is not very serious. Burd and Murphy say that they leached out "free phosphate" in the soil with distilled water. However, even after prolonged washing the soil still yields some phosphate to distilled water and the above method has been used in order to remove the most lightly held fraction.

Acid-soluble Phosphate.

Thirty gram soil was shaken intermittently with 150 c.cs. ·01 N HCl for 24 hours. The temperature of the suspensions was kept close to 20°C. during the day.

Before the phosphate in the extract could be determined colorimetrically, organic matter and ferric iron had to be destroyed. The extract was evaporated to dryness and treated successively with 1 c.c. concentrated hydrochloric acid containing a drop of nitric acid and hydrogen peroxide prepared by mixing sodium peroxide and sulphuric acid. The residue was left to stand overnight with an acid solution of sodium sulphite to destroy ferric iron. The phosphate was then determined colorimetrically.

Colorimetric Determination of Phosphate.

The method used (reduction of phosphomolybdate) was based on that given by Truog and Meyer (14). The aliquot was neutralized in a 50 c.c. standard flask with ammonia, using α-dinitrophenol as indicator. The volume was made up to about 40 c.cs., 2 c.cs. molybdate solution added (a 2·5 per cent. ammonium molybdate solution in 10N–H_2SO_4); then 5 c.cs. diluted stannous chloride solution, and the volume made to 50 c.cs. The blue colour was compared with the standard after 10 minutes.

A 3·75 per cent. solution of hydrated stannous chloride in N HCl was stored under paraffin and diluted with water (1 : 10) as required.

The sodium hydroxide and ammonia solutions were stored in waxed bottles to avoid contamination by silicate which also forms a blue compound under these conditions.

Phosphate Soluble in Concentrated Hydrochloric Acid.

The soil was boiled for 2 hrs. with concentrated hydrochloric acid, and the phosphate determined gravimetrically as phosphomolybdate.

Free Ferric Oxide.

This was found using the method of Truog et al (13) viz. extraction with Na_2S at pH 7 followed by acidification with oxalic acid.

Organic Carbon.

This was determined by the approximate volumetric method of Tiurin (11).

DISCUSSION OF RESULTS.

Dilute Acid Extracts.

The amounts extracted by dilute acid (Table I. col. 6) are very low compared with the American figures except that for Aiken clay, which appears to be of the same order as the red soils from Mirboo. Plots of the red soils which have been annually topdressed with 2 cwt. per acre of superphosphate for the last five years give similarly low figures, whether treated with lime or not. The uncultivated forest soil from Nayook gives a strikingly low figure.

TABLE 1.—PHOSPHATE STATUS OF VARIOUS SURFACE SOILS.

All Australian samples are 0–3 inches except Wollongbar, 0–9 inches.

Locality or Soil Type.	PO_4 per 100 gm. Soil.		Present Degree of Saturation.	PO_4 per 100 gm. Soil.		PO_4 Soluble in ·01 N HCl.	Field Evidence of Phosphate Status.
	Adsorption Capacity.	In Adsorbed Condition.		Adsorption Deficit.	Dissolved by Conc. HCl.		
	mg.	mg.	%	mg.	mg.	p.p.m.	
Mirboo I. ..	173	26	15	147	116	1·2	20–50 per cent. increase with superphosphate. Lime + superphosphate, 50 per cent. above superphosphate alone
Mirboo II. ..	161	18	11	143	72	0·7	Over 50 per cent. increase with superphosphate. Lime + superphosphate, small additional increase
Mirboo III.	192	16	8	176	100	1·0	100–200 per cent. increase with superphosphate. Lime + superphosphate, 30 per cent. above superphosphate alone
Nayook ..	246	3	1	243	56	0·1	Forest
Lardner ..	173	11	6	162	122	0·7	50 per cent. increase with superphosphate only after adding potassium
Wollongbar	308	19	6	289	920	1·3	Pasture not improved by phosphate with or without lime. Symptoms of deficiency observed.
Korumburra	165	60	36	105	108	1·2	Nearly 100 per cent. increase with superphosphate. No improvement with lime.
Caldermeade	106	47	45	59	130	5·6	50–100 per cent. increase with superphosphate. No improvement with lime
Pakenham ..	90	26	39	64	48	1·7	Big increase with superphosphate
Berwick ..	52	15	29	37	64	2·3	Increased growth with superphosphate
Aiken clay	547	22	4	525	160*	2·0†	Extreme phosphate deficiency
Yolo silty clay loam	55	27	48	28	200*	91	No phosphate deficiency

* Fusion analyses.

† Burd and Murphy give this figure as 0·2 mgm. per cent. (p. 335). It is probably a misprint for <0·2. Murphy on page 351 of the same issue records all acid extracts of Aiken clay as being <0·2 though he apparently did not determine the actual amount present.

When working with a soil from Lismore similar to Wollongbar. Holman (5) found that over the pH range of 8 to 2 both native and added phosphate were completely insoluble.

The grey soils of Korumburra and Caldermeade, after ten years of topdressing with 3 cwt. superphosphate per acre, show increases in extractable phosphate; viz. from 1·2 to 4·0 and from 5·6 to 7·5 parts per million respectively. The black soil at Berwick developed on the same parent material as the red Gippsland soils has a higher figure for soluble phosphate.

The pH values of the acid extracts of the unlimed samples were either within or close to the range 4·0–4·5; the limed plots gave extracts 0·5–1 pH unit above the unlimed.

Table 2 shows that the sub-surface horizons contain much less phosphate in the adsorbed condition or dissolved in dilute acid. This would be expected, and confirms the general opinion that the top few inches of soil are the most important.

TABLE 2.—PHOSPHATE STATUS OF SUBSURFACE HORIZONS (3–12 INCHES).

Locality.	In Adsorbed Condition.	Extracted by ·01 N. HCl.
	mg. PO_4 per 100 gm. soil.	p.p.m. PO_4
Mirboo I.	5	0·1
Mirboo II.	8	0·3
Mirboo III.	8	0·4
Nayook	0·1	0·1
Korumburra	13	0·5
Caldermeade	14	0·2

Adsorbed Phosphate.

Dealing next with adsorbed phosphate, the most important feature of Table 1 is the figure for percentage saturation, which shows a good correlation with experience in the field. This figure is high for the grey or black soils (Korumburra, Caldermeade, Berwick, Pakenham) which respond normally to superphosphate; and for Yolo silty clay loam, which naturally yields an ample supply of phosphate to plants. It is low for the red soils. Of these, the soils of Mirboo are recorded as giving additional response to superphosphate when lime is added. Lardner gives no such response to lime. An acute deficiency in potassium has been found there, and this may be a complicating factor.

Aiken clay is very deficient in phosphate, but Burd and Murphy give no indication of the effect of applied superphosphate or lime.

The soil from Wollongbar is peculiar. It is very high in total phosphate, but has a low percentage saturation, and yields little phosphate to dilute acids or in the Neubauer test (8). The pastures, consisting mainly of Paspalum, give no indication of response to superphosphate with or without lime. This soil may be similar to Hawaiian soils quoted by Heck (4) where the fixing power is so intense that liming to pH 6·5, which he calls the point of maximum solubility of the phosphate, causes only a slight improvement.

Free Ferric Oxide.

Free ferric oxide (Table 3), while lower in the red soils of Gippsland than in the Wollongbar sample, is higher than in the neighbouring grey soils such as Caldermeade. In the black sample from Berwick, however, it is actually higher than in the red soils of Mirboo.

TABLE 3.—FREE FERRIC OXIDE AND ITS EFFECT ON ADSORPTION CAPACITY.

Locality.	Free Ferric Oxide.	Adsorption Capacity PO_4 per 100 gm. Soil.	
		Before Removing Fe_2O_3.	After Removing Fe_2O_3.
	%	mgm.	mgm.
Mirboo I.	4·9	173	13
Nayook	3·2	246	13
Lardner	2·9	173	7
Wollongbar	11·2	308	22
Korumburra	2·7	165	n.d.
Caldermeade	1·0	106	n.d.
Pakenham	1·7	90	n.d.
Berwick	5·2	52	n.d.

The adsorption capacity of the soils after the removal of free ferric oxide is very low. It must be concluded that in the soils studied, the greater part of phosphate fixation takes place on the surface of free ferric oxide.

Silica-sesquioxide Ratio.

Any study of the fundamental nature of the problem of phosphate fixation should include a knowledge of both the chemical composition and physical structure of the colloid in the soils taken. This has not been attempted, but the following figures for silica-sesquioxide ratios of similar soils are of interest. Prescott and Hosking (9) give a $\frac{SiO_2}{R_2O_3}$ ratio of 0·7 for their sample from Wollongbar; this was much the lowest ratio of all the red basaltic soils from Queensland and New South Wales which they studied. A common figure for this group of soils was 1·4. Red soils on basalt near Berwick have a ratio of 1·7 (6, p. 234). It is likely that the red Mirboo and Nayook soils are similar.

Staining Tests.

Lundblad (7) has suggested an approximate method of finding the colloidal properties of soils, by measuring the amounts of methylene blue and alizarin R which the soil can adsorb. The amount of each dye adsorbed depends on the amount and nature of colloidal matter in the soil. The cation of methylene blue is adsorbed onto the negative part of the colloid (silicate or humate) and the anion of alizarin R onto the sesquioxides. The ratio of $\frac{\text{cation adsorbed}}{\text{anion adsorbed}}$ thus gives a measure of the silica-sesquioxide ratio.

Table 4 shows the results obtained following Lundblad's method using alizarin S instead of alizarin R.

TABLE 4.—CAPACITY OF SOILS TO ADSORB METHYLENE BLUE AND ALIZARIN S.

Locality.	Methylene Blue Adsorbed by 1 gm. Soil.	Alizarin S. Adsorbed by 1 gm. Soil.	Relative Adsorbing Power $\frac{\text{Col. 1.}}{\text{Col. 2.}}$
	mg.	mg.	
Mirboo I. ..	52	15	3·5
Lardner.. ..	42	17	2·5
Wollongbar ..	20	17	1·2
Korumburra ..	38	12	3·2
Caldermeade ..	66	8	8·2
Pakenham ..	22	4	5·5
Berwick ..	80	16	5·0

The siliceous soils of Caldermeade, Berwick and Pakenham have high ratios. Wollongbar, as expected, is low, Mirboo, Lardner and Korumburra intermediate. Soils with a relatively low ratio and a high capacity for adsorbing alizarin S, would be expected also to have a high adsorption capacity for phosphate. This does not mean that all these soils have a high fixing capacity for phosphate, as they already may be fairly saturated, e.g. Korumburra. The low ratio for Korumburra can be correlated with its high ferric oxide content.

CONCLUSION.

In conclusion, it appears that the analytical methods suggested by Burd and Murphy will be useful in diagnosing the state of phosphate in the field; and as more figures are obtained, their usefulness should increase.

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[PROC. ROY. SOC. VICTORIA, **55** (N.S.), PT. I., 1943.]

ART. II.—*Studies in the Physiology of Host-Parasite Relations.*

III. FACTORS AFFECTING RESISTANCE TO BACTERIAL WILT OF SOLANACEAE.

By B. J. GRIEVE,

Botany School, University of Melbourne.

[Read 14th May, 1942; issued separately 1st May, 1943.]

Abstract.

Studies on invasion of potato and tomato plants by *Bacterium solanacearum* show that high soil moisture, temperatures over 66°F., light intensity over 800 ft. candles, and high humidity favour the disease under glasshouse conditions. A correlation was made with the conditions obtaining in the field in Victoria. The rate of movement of the parasite in the vessels was 5·0 mm. per hour for potato and 2·2 mm. per hour for tomato at 73°F. The minimum, optimum and maximum temperatures for growth of *B. solanacearum* were 15°C., 32°C. and 35°C. respectively.

Significant increases in height, vessel size and in water content developed in plants grown in wet soil conditions. The increased water content is believed to be the factor which influences the susceptibility of the plant to invasion. Results of growth experiments showed a positive relation between spread of disease and vigour of growth in the host.

Introduction.

The literature on Bacterial Wilt of Solanaceae caused by *Bacterium solanacearum* E.F.S. (*Phytomonas solanaceara* Bergey *et al*) includes references indicating that resistance or susceptibility of plants to invasion is related to such external factors as soil moisture, temperature and humidity and to such internal factors as "sappiness" of plants. Smith (1914, 1920) in the United States of America commented on the fact that turgid, rapidly growing tomato plants were more susceptible to the disease, and Van der Meer (1929) working on Slime Disease of Tobacco in Sumatra demonstrated that plants growing in wet soil were more rapidly invaded than those in drier soil.

In no case however, has any attempt been made to analyse the resistance or susceptibility of the plant under varying environmental conditions in terms of the growth physiology of the host and of the parasite. In the present paper the approach to the problem has been made from this angle. The effect of soil moisture, temperature, light and humidity on invasion has been studied under partially controlled conditions. A study has also been made of the growth of healthy plants under similar environmental conditions in order to see if there was any relation between vigour of growth in the host and parasitism by *Bacterium solanacearum*. The growth of the parasite in culture media at different temperatures has also been investigated so that the information might be related to invasion at different temperatures in the host.

Materials and Methods.

Methods of inoculation and histological techniques were as described in an earlier paper (Grieve, 1940).

The majority of the experiments were carried out in a glass-house at Melbourne University; some in pots in the open and others in a compartment with constant light, temperature and humidity at the Botany School, Cambridge.

For the experiments both potato (var. Carman) and tomato plants (var. Marglobe) were used. The latter proved more suitable and were used in greater numbers. As many of the experiments involved comparisons between plants subjected to different environmental conditions, a method had to be adopted to ensure that the plants were as closely similar as possible at the start of the experiment. The principle of the "paired plant" method of Bolas and Melville (1933) was accordingly adopted for the work. Plants from one sowing were grown to a selected leaf stage and then graded into pairs or threes of equal size and vigour. Factors such as height, leaf area and stem thickness were taken into account in pairing.

When two sets of conditions were being compared, two groups of plants were made, the individuals of any pair being in opposite groups. Members of one series then continued growth under the original set of environmental conditions while their opposite numbers were subjected to the changed conditions. Or again both series continued their growth under changed conditions. In the experiments dealing with the effect of soil moisture on invasion, tomato and potato plants in sets of threes were grown to the selected leaf stage under identical conditions of soil watering and then some days before inoculation, heavy watering of one series was commenced and continued for the duration of the experiment (Wet Soil Series). Members of the second series received the normal amount of watering (Normally Watered Series), while members of the third series received only sufficient water daily to keep them turgid (Dry Soil Series). The water in the dry soil series varied from 6 to 8 per cent. of the moisture free soil in different experiments; in the normally watered soil from 18 to 20 per cent., while in the wet soil series it varied from 29 to 31 per cent. In some experiments the disease was allowed to run its course, observations being made on occurrence of symptoms in each series. In other experiments sample plants were taken at intervals from each series and the degree of invasion established by infection testing and sectioning. For the experiments dealing with the effect of light on invasion, plants were grouped in threes of equal size and vigour; one set of plants was exposed to normal light in the glasshouse (this was heavily whitewashed in summer so that the maximum values rarely rose above 1,000 foot candles (ft. c.) and the average during the experiments was 800 ft. c.), the second and third sets were shaded by calico to give decreased light intensities of 400 and 130 ft. c. respectively. Pots were so arranged in the glasshouse bench as to expose the plants to approximately the same environmental conditions. In the humidity testing experiments, members of one group were placed under glass cabinets, while their opposite numbers remained exposed on the glasshouse bench. The same procedure of pairing plants was followed for the experiments on growth and water content of healthy plants held under different soil moisture conditions. Samples of ten plants from each set of conditions were taken at the start, and after convenient time intervals until the conclusion of the experiment, the means were then determined. For dry weights the plants were left in an oven at 100°C. for 24 hours. Light intensity was measured at three hourly intervals using a Weston Light Meter and a mean determined, while average temperature was computed from a thermograph record. The probability of the results being due to chance were calculated according to Fisher's modification of "Student's Method".

Experimental Results.

PART I.—THE EFFECT OF CERTAIN PARTIALLY CONTROLLED ENVIRONMENTAL CONDITIONS ON RESISTANCE TO BACTERIAL WILT.

SOIL MOISTURE.

The results of glasshouse experiments involving observations on 102 potato plants and 60 tomato plants ranging in development from the fifth to the eighth expanded leaf stage are summarized in Table 1.

TABLE I.—THE EFFECT OF SOIL MOISTURE ON BACTERIAL INVASION.
(Temperature 69°F.–75°F.; Light Intensity, 600–800 ft. c.)

——	Dry Soil.	Normal Soil.	Wet Soil.
Potato—Days for wilting ..	21·6	10·7	9·2
Mean diff. with S.E. ..	10·9 ± 0·73	1·5 ± 0·36	
Value of P.	<0·01	<0·01	
Tomato—Days for wilting ..	23·4	11·6	7·6
Mean diff. with S.E. ..	11·8 ± 0·97	4·0 ± 0·50	
Value of P.	<0·01	<0·01	

The results of these studies show that plants growing in dry soil are significantly more resistant to spread of the bacterial wilt organism in the tissues than those grown in normally watered soil, while plants growing in wet soil are very susceptible. Only 60 per cent. of the total plants inoculated under dry soil conditions developed wilting symptoms whereas all inoculated plants in wet soil wilted.

In the field, infection very commonly occurs from the soil through damaged roots, so experiments were made to test the effect of soil moisture on invasion using tomato plants in which lateral roots were slightly damaged. It was found that eighteen to twenty-five days elapsed before wilting developed in plants growing in soil moist conditions and forty days and above before it developed in plants in dry soil. Very frequently infection failed to occur in the latter group of plants.

The period elapsing between exposure of damaged roots to the possibility of infection and actual invasion, under either set of conditions could not be accurately determined, but fifteen to twenty days elapsed before bacteria could be seen in the tap root. Root invaded plants wilted much more rapidly and completely once the bacteria entered the main root system than did plants which were needle prick inoculated. This is due to the fact that invasion of all stem bundles commonly occurs in the root infected plants with consequent early interference with the transpiration stream.

The name " Sore Eye " disease of tubers describes a condition where there is a mattery bacterial exudate from the eyes of infected tubers and particles of moist soil cling around them. This condition in the field is peculiar to soils in which the soil moisture content is high as in the Koo-wee-rup area in Victoria. The "Sore Eye" appearance was produced experimentally in tubers of stem-inoculated potato plants growing in the open in large pots in which the soil moisture was kept high. The condition did not develop in similar soil with a lower water content. The "Sore Eye" condition is due to intense proliferation of the bacteria in the tuber bundles leading to destruction of the eye tissues with consequent bacterial exudate.

The above results show clearly that high soil moisture favours heavy and rapid bacterial invasion, while in dry soil, plants are more resistant to the spread of the organism in the tissues. As the disease occurs most seriously in the moist soil of the Koo-wee-rup area in Victoria, the results indicate a positive relation between soil moisture and the incidence of the disease in the field.

AIR TEMPERATURE AND LIGHT.

Experiments dealing with the effect of air temperatures were carried out in a glasshouse during the years 1937, 1940 and 1941. No facilities were available for the control of temperature, so, to test the effect of different temperature levels the experiments were done during different seasons, i.e., summer and early and late autumn. Light intensity was decreased during the experiment in summer and early autumn by the use of calico shades over batches of experimental plants. Plants at the same leaf stage in the different seasons were selected. Results are presented in Table II. The broad effect of light was tested during summer months at an average temperature of 73°F. in the glasshouse, results being given in Table III.

TABLE II.—EFFECT OF AIR TEMPERATURE ON INVASION IN TOMATO.

(Three replications of 5 plants inoculated at the five-leaf stage.)

Mean air temperature	73°F.	66°F.	59°F.	50°F.
Mean light Intensity in ft. candles. .	400	400	400	200
Days for wilting	5·4	5·9	24·3	No infection
Mean difference with S.E. . .	(0·5 ± 0·4)	(18·4 ± 1·03)		
Value of P.	0·3–0·2	<0·01		

Two experiments at a constant temperature of 77°F. were carried out at the Botany School, Cambridge, in a controlled environment compartment. Half the plants (total number = 12 in each experiment) were given 1,000 ft. c. continuous lighting and the other half 500 ft. c. continuous lighting. Results are included under Table III.

The criteria of successful invasion by the parasite were epinasty and wilting and the times of occurrence of these were recorded. Sections also were cut at different levels to assess the relative numbers of the organisms present in the vessels.

TABLE III.—EFFECT OF LIGHT ON INVASION IN TOMATO.

(Three replications of 5 plants inoculated at the five-leaf stage.)

Mean light intensity in ft. candles ..	800	400	130
Mean air temperature	73°F.	73°F.	73°F.
Days for wilting	4·1	4·8	7·0
Mean difference with S.E.	(0·7 ± 0·3)	(2·2 ± 0·97)	
Value of P.	0·05–0·04	0·05–0·04	

EXPERIMENTS IN A CONTROLLED COMPARTMENT.

Light intensity in ft. candles	1000 (continuous)	500 (continuous)
Air temperature (constant)	77°F. (continuous)	77°F. (continuous)
Days for wilting	2	2

Table II. shows that invasion at 73°F. and 66°F. was significantly more rapid than at 59°F. No significant difference was found between the times of wilting for the two higher temperatures. At 50°F. the plants were still growing slowly but no symptoms developed after inoculation. Sections showed that the bacteria had failed to multiply.

From Table III. it may be seen that reduction of light by half significantly affected the time of appearance of wilting in the glasshouse experiments, but there was no difference in the case of the controlled compartment experiments. With reduction to one-sixth the normal light value, epinasty developed before wilting and the incubation period for wilting was significantly longer. It may be noted that the incubation periods given in Tables II. and III. are shorter than those in Table I. This occurs because plants used in the soil moisture experiments were somewhat older being at the 7th expanded leaf stage at the time of inoculation. The above results indicate that both temperature and light strongly influence invasion rate as indicated by time of appearance of symptoms.

ATMOSPHERIC HUMIDITY.

A comparison was made between the degree of invasion in tomato plants grown on a glasshouse bench at an average temperature of 73°F. where the relative humidity varied but averaged approximately 55 per cent. and others grown at the same temperature but enclosed in glass cabinets. Owing to the absence of wilting symptoms in plants kept under highly humid conditions the criteria of invasion used were relative numbers of bacteria in the vessels, and the rate of movement up and down the bundles. It was found that exposure to the high humidity consistently increased susceptibility as shown by a greater multiplication of the bacteria in the vessels leading to their breaking out of the xylem into other tissues. The rate of movement of the bacteria in the vessels under both sets of conditions was however approximately the same. The experiments also served to show that the spread of the bacteria in the vessels is largely independent of transpiration rate since water loss from the plants under highly humid conditions is negligible.

RATE OF MOVEMENT OF THE PARASITE IN THE VESSELS.

In the earlier stages of invasion up to incipient wilting, the bacteria are largely confined to the vascular bundles (Grieve, 1939) and it is possible to determine the rate of progress of the parasite up and down invaded vessels. Experiments were performed at an average temperature in the glasshouse of 73° F. and under three sets of soil moisture conditions. The organism was inoculated into main stem bundles at a point 2 to 3 inches above soil level or alternatively a short distance below the apex of the plant. The distance moved by the bacteria was determined using a staining and sectioning method. Two corrections were applied. The first was for average vessel length. This was necessary because the organisms on inoculation are carried to various points up and down the length of the vessels punctured, under the influence of the negative pressure in the tracheae. The second correction was for the vessel incubation period. This is the time taken by the parasite to multiply to such a degree as to fill the vessels into which it was originally introduced before commencing to spread to others. This was found at 70–75° F. to be approximately 24 hours in the case of plants growing in normally moist soil, 18 to 20 hours in wet soil and variable periods up to 72 hours and over for plants in dry soil. Results are given in Table IV.

TABLE IV.—MEAN RATES OF MOVEMENT OF BACTERIA IN VESSELS IN MMS. PER HOUR.

(Mean Temperature 73°F.)

Host.	Direction of Movement.	Dry Soil.	Normal Soil.	Wet Soil.	
Tomato ..	Up	0·3	0·8	1·1	
	Down	0·3	1·0	1·1	
	Total	0·6	1·8	2·2	
	Mean diff. and S.E.	1·2 ± 0·3		0·4 ± 0·17	
	Value of P. ..	0·01		0·1–0·05	
Potato ..	Up	..	2·3	3·7	Mean diff. and S.E. 2·4 ± 0·2 P. <0·01
	Down	..	1.3	1·3	
	Total	..	3.6	5·0	
	Mean diff. and S.E.	..	1·4 ± 0·27		
	Value of P. ..	..	<0·01		

It is to be observed that the rate of movement in potato plants is greater than in that of tomato and that this rate is greatest in wet soil. Comparing the rates of upward and downward movement in each plant group, the evidence is that in potato the bacteria move upward in the xylem more rapidly whereas in tomato there is no significant difference between the rates under each set of soil conditions. An interesting result was obtained when tomato and potato plants were inoculated in bundles near the top of the stem. The bacteria grew back very rapidly in the vessels, rates as high as 4·0–5·0 mms. per hour being obtained in potato under normal soil moisture conditions. The interest in determining the rates of upward and downward movement lay in connection with suggestions by earlier investigators that transpiration was an important factor in the upward movement. These results together with those in the preceding section do not favour such a view.

VESSEL DIMENSIONS IN POTATO AND TOMATO PLANTS.

It will be seen from Table IV. that the rate of movement of the bacteria in the vessels of potato plants is consistently higher than in tomato plants when both are of similar age and growing under the same environmental conditions. It appeared therefore, that internal factors peculiar to each plant were operative in producing the differential speeds of vessel invasion observed. Among such factors would be (*a*) length and diameter of vessels, (*b*) food content in vessels.

The second of these does not allow of satisfactory determination with present techniques. It seems reasonable to suppose however that there would be certain differences in metabolites present in the vessels of the two plants and that these would react on bacterial growth.

Length of vessels was determined using the mercury method and mean diameters estimated from camera lucida drawings. Results are given in Table V. In fig. 1, a comparison is given of the relative stem cross-sectional areas and of the diameters of vessels of potato and tomato plants (both at the 7 expanded leaf stage) cut two inches above soil level.

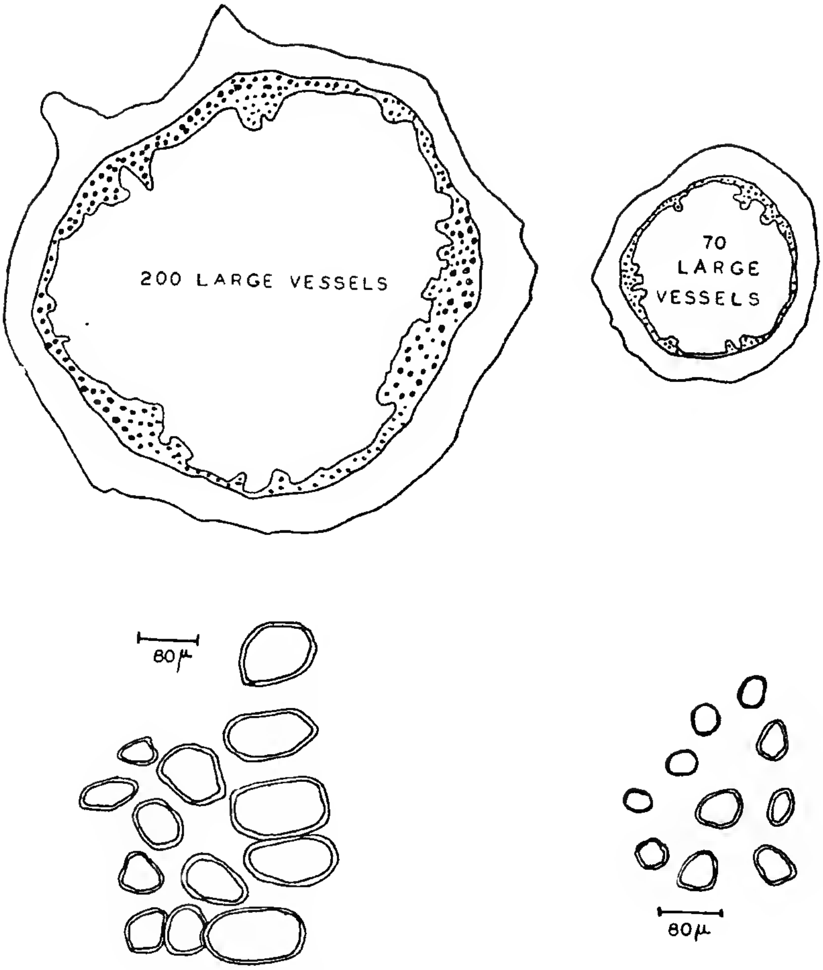

Fig. 1.—Comparison of relative cross-sectional areas and of diameters of vessels of potato and tomato plants at the 7 expanded leaf stage.

TABLE V.—VESSEL DIMENSIONS IN TOMATO AND POTATO PLANTS AT THE 5TH–6TH LEAF STAGE.

—	Mean Diameter Near Stem Base.	Length in Cms.
Tomato	63 x 60 μ	5·0 ± 2·4
Potato	108 x 96 μ	6·5 ± 2·0

Reference to Table V. shows that vessel diameters in potato are rather greater than in tomato and it is possible that this difference in size *per se.* is related to the more rapid spread of the organism in the former. It is conceivable also that the larger vessels might contain more metabolites which sustain the growth of the bacteria.

GROWTH OF BACTERIUM SOLANACEARUM AT DIFFERENT TEMPERATURES.

To determine the minimum, optimum and maximum temperatures for growth of the pathogen, experiments were carried out in solid media. Needle point transfers were made on plates, poured with beef extract agar at pH 6·7, so that eight equi-distant colonies were grown in each petri dish. Two dishes were grown at each of the temperatures shown in fig. 2. The diameters of the colonies were measured after six days and averaged, and this mean diameter was taken as the measure of growth. The optimum temperature for growth over a six-day period is seen to occur (fig. 2) at 32°C. after which there is a very sharp fall when the temperature is raised to 35°C. When

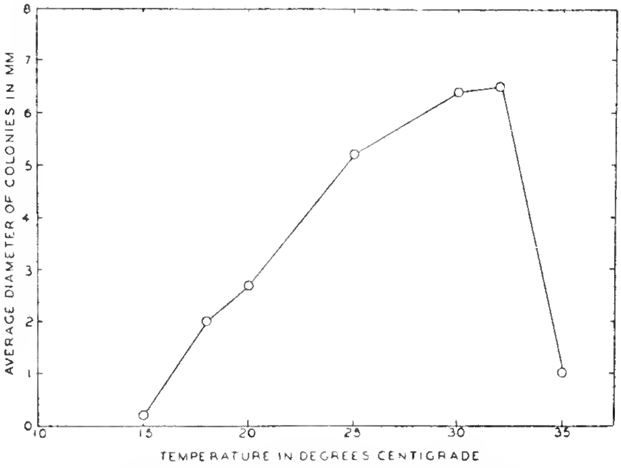

FIG. 2.—The effect of temperature on the development of *B. solanacearum* as measured by average colony diameters on nutrient agar (pH 6.7) after six days' incubation.

the time of incubation of the plates was increased beyond six days, growth in size of the colonies at 30°C. and 32°C. proceeded much more slowly and this reduction in growth rate was associated with the production of a deep brown to black pigment. Colony growth at 20°C. and 25°C. continued normally up to 14 days so that colonies at 20°C. during this time came to approximately the same size as those at 30°C. Colonies at the lower temperatures (20°–25°C.) showed no brown pigment formation, but on transfer to the 30°C. incubator, pigment developed within three days.

COMPARISON WITH OTHER INVESTIGATORS.

Van der Meer (1929) working in Sumatra with a strain of *Bacterium solanacearum* E.F.S. causing Slime Disease of Tobacco, found a positive relation between high soil moisture and rapidity of wilting of infected plants. The present results for "Sore Eye" potato disease in Victoria conform with her findings in regard to soil moisture.

From data in Table I. of Van der Meer's paper, the rates of movement of bacteria in tomato plants grown under "dry" and "wet" soil conditions have been calculated and are shown in Table VI. A period of 24 hours was assumed to apply for vessel incubation period. The climatic conditions were probably such as to favour rapid invasion although Van der Meer makes no mention of temperature or of light values. Table VI. also includes a comparison of Van der Meer's results with those of the author. The values for "wet" soil plants agree fairly closely. The differences in the case of "dry" soil plants is probably due to the fact that the moisture content of the soil in Van der Meer's experiments was lower than that of the soil used by the author.

TABLE VI.—RATE OF MOVEMENT OF BACTERIA IN TOMATO STEMS IN MMS. PER HOUR.

Authority.	Upwards.		Downwards.	
	Dry Soil.	Wet Soil.	Dry Soil.	Wet Soil.
Van der Meer	0·0	1·0	0·0	1·0
Grieve	0·3	1·1	0·3	1·1

Both sets of data show that rate of movement is very much greater in the plants growing under conditions of high soil moisture. Estimation of rates of movement in potato plants from data obtained by Smith (1914) in U.S.A., gave values ranging from 0·9–1·7 mm. per hour which are considerably lower than those obtained by the author.

Vong (1937) has calculated the rate of movement of *B. solanacearum* in tobacco plants. He found that it was greater in the downward direction being the order of 0·2692 mm. per hour as against 0·2586 mm. per hour upwards at 25°C. (77°F.) and 24 hours after inoculation. Vong's calculation of the rate to four significant figures suggests a very high degree of uniformity of plant material in relation to invasion. Such uniformity does not occur in potato and tomato plants used in the author's experiments.

The minimum, optimum and maximum temperatures for migration of *B. solanacearum* according to Vong (1937) are 15°C., 32°C., and 40°C. respectively. The author's results are in agreement with the first two values, but the maximum for growth in the Victorian strain was found to be 35°C.

Smith, in the United States of America (1914), reported that the minimum for growth was 10°C., the optimum 35°–37°C. and the maximum 41°C. Eddins (1936) reported a minimum temperature of 55°F. (12·8°C.) for the development of the disease in the field in Florida (U.S.A.). It appears therefore that the temperature relations of the organism vary in different parts of the world.

Van der Meer (1929) was of the opinion that increased susceptibility to invasion of plants grown under conditions of high soil moisture was due to increased "sappiness" of the plants. This view had also been sponsored earlier by Smith (1914, 1920). In neither case, however, was any fundamental research undertaken on the relation between "sappiness" and susceptibility.

PART II.—EFFECT OF CERTAIN PARTIALLY CONTROLLED ENVIRONMENTAL CONDITIONS ON THE GROWTH OF HEALTHY TOMATO PLANTS.

SOIL MOISTURE.

In the course of the experiments on the rate of invasion in tomato plants under various soil conditions, it was observed that those plants growing in wet soil appeared to show greater growth in height and leaf area as well as greater "sappiness" than those grown under drier soil conditions. It appeared likely that these differences bore some relation to the increased susceptibility of the plant, so experiments to obtain quantitative data were commenced. In three experiments, batches of 50 to 60 tomato plants growing under the same soil conditions were first graded into pairs as described earlier. Determinations for dry weights and water content apply to stem parts from the cotyledon scars upwards. The variability between members of a pair at the beginning of an experiment was found to be small. Members of one group were next watered heavily to produce soil moist conditions (soil moisture varying from 29–31 per cent. of moisture free soil in separate experiments), and the plants of the sister group watered lightly to give dry soil conditions (soil moisture varying from 6 to 8 per cent. of moisture free soil in different experiments). Treatment was continued for periods varying from 5 to 21 days when a further sample of ten plants from the soil moist group with their opposite numbers from the dry soil group was made. Results of representative experiments for the attributes of water content and height are given in Tables VII. and VIII. Mean values at the first and second samplings for ten plants of each group in two experiments are plotted in figs. 3 and 4.

TABLE VII.—EFFECT OF SOIL MOISTURE ON WATER CONTENT IN TOMATO.

(Experiment 3.—22/5/'41 to 27/5/'41.—Sample after 5 days of exposure to wet and dry soil conditions.)

Pair Number.	Wet Soil. (W).	Dry Soil. (D).	Difference. (W–D).
1	94·20	93·00	1·20
2	94·98	94·06	0·92
3	94·95	93·84	1·11
4	94·91	93·02	1·89
5	95·05	94·00	1·05
6	95·27	93·14	2·13
7	94·70	93·23	1·47
8	94·41	94·33	0·08
9	95·61	94·55	1·06
10	95·42	92·85	2·57
Means	94·950	93·602	1·348 (P. <0·01)

TABLE VIII.—EFFECT OF SOIL MOISTURE ON GROWTH IN HEIGHT IN TOMATO.

(Experiment 2.—16/3/'41 to 6/4/'41.—Sample after exposure of 21 days to wet soil and dry soil conditions.)

Pair Number.	Wet Soil. (W).	Dry Soil. (D).	Difference. (W–D).
	cms.	cms.	cms.
1	21·0	15·0	6·0
2	25·3	17·0	8·3
3	21·5	20·0	1·5
4	21·0	15·0	6·0
5	13·5	11·5	2·0
6	15·5	11·5	4·0
7	13·0	12·5	0·5
8	14·0	11·5	2·5
9	10·3	9·5	0·8
10	16·5	10·0	6·5
Means	17·16	13·35	3·81 (P. <0·01)

The tables and figures show that significant differences occur in water content and in height between the wet soil and dry soil plants. The mean changes between the percentage water contents of the paired plants during the experiment tabled was 1·35 which is highly significant even with the small sample of ten plants. In the experiment dealing with the effect of soil moisture in growth in height, the mean change between the paired plants was 3·81 cms. which is again highly significant. In figs. 3 and 4. the mean differences in height and in water content between samples of ten plants at the beginning and end of two experiments is given. A significant difference also was found to occur between leaf areas of plants grown in wet soil and dry soil, but no significant difference was found between the dry weights of plants grown under such conditions.

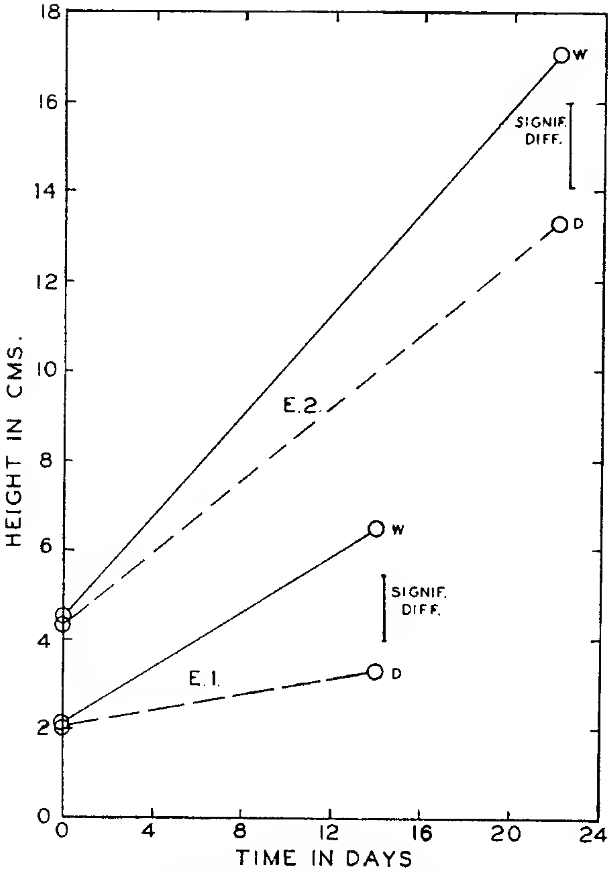

FIG. 3.—The effect of soil moisture on growth in height in tomato plants. Mean values for ten plants in each group in each experiment.
W = wet soil, D = dry soil.

Microscopical examination of sections cut at soil level and at the level of the third leaf from the apex, showed that the vessels in plants grown in wet soil were larger and more numerous than those in the plants from dry soil. With the aid of a microprojector and a planimeter the actual areas of the xylem were determined and were found to be consistently greater in plants from wet soil. Fig. 5 shows a typical example, in which the area of the xylem in the stem of the plant growing in wet soil is 3·5 sq. cms. as against 1·7 sq. cms. for the plant in the dry soil. The percentage areas of the xylem relative to the whole stem area in both were found to be approximately the same.

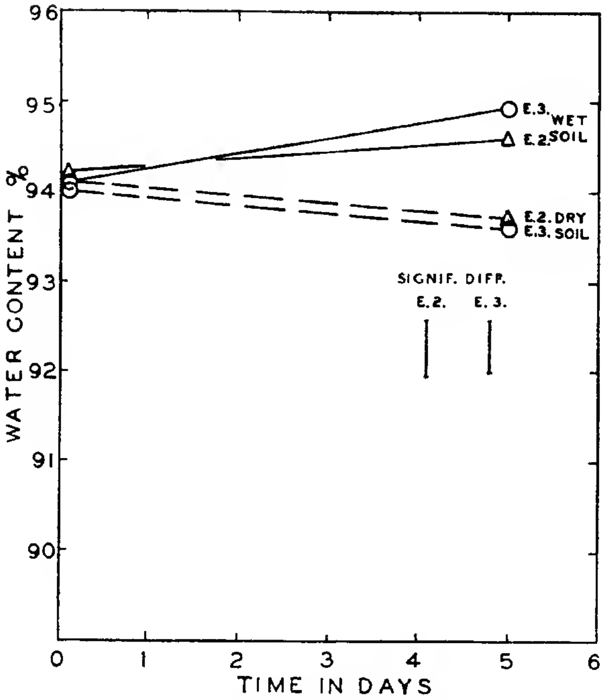

FIG. 4.—The effect of soil moisture on water content in tomato plants. Mean values for ten plants in each group in each experiment.

These experiments show that important physiological and anatomical differences arise between tomato plants growing under wet soil conditions and those growing under dry soil conditions. The increased "sappiness" of the plants in wet soil, their increased height and the anatomical changes therein appear to be directly or indirectly the outcome of the significant increase in the water content in such plants. The relation of these changes in the host to susceptibility to bacterial invasion will be discussed later.

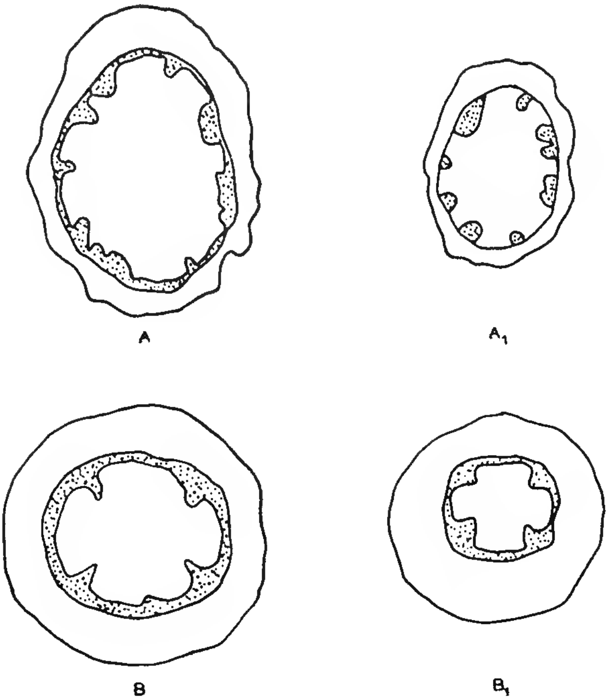

FIG. 5.—Relative development of vascular tissue in tomato plants grown in wet soil (left) and dry soil.
A, A_1 = stem; B, B_1 = root.

AIR TEMPERATURES.

In the section dealing with the effect of temperature and of light on rapidity of invasion in tomato, it was shown that the most rapid spread of the parasite in the vessels (as judged by symptoms) occurred at an average temperature between 66°F. and 73°F. at an average light intensity of 800 ft. c.

It was a matter of common observation that plants under these conditions appeared to be growing faster than those at the lower temperature levels where invasion was also slower. This suggested that the activity of the parasite was related to the vigour of growth in the host when soil moisture content was normal. A considerable body of data on the effect of temperature and light at different seasons of the year on the growth of tomato plants (var. E.S.I.) is available from the work of Ainsworth and Selman (1936), Bolas (1934), Bolas and Selman (1935), and Bolas, Melville and Selman (1938). This data could be used in relating vigour of growth of the plant to rapidity of invasion by the parasite, but it was decided that it would be of value to obtain data for the growth of the tomato variety used (Marglobe) under the seasonal conditions obtaining in Melbourne. Accordingly five series of experiments were carried out at different seasons giving a range of temperature and light values. Plants with three to four expanded leaves were used in the different experiments (except for Expt. 1 in which plants were at the five leaf stage) during summer, autumn and spring, since it is preferable to use plants at the same stage of development rather than plants of the same age (Bolas, Melville and Selman (1938).

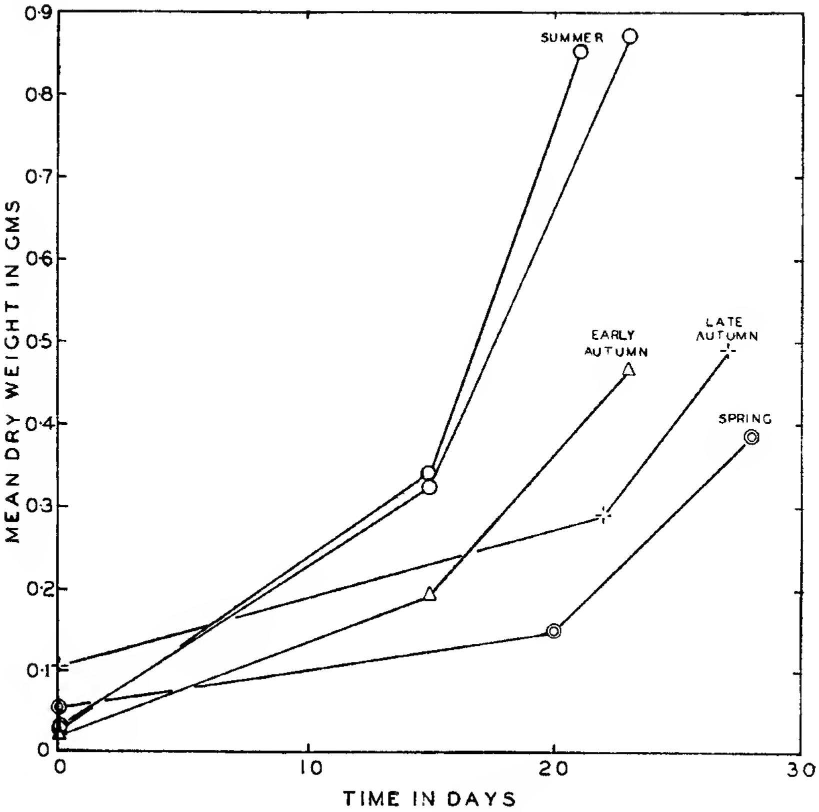

FIG. 6.—Dry weight growth curves for tomato plants at different seasons.

Results of experiments are summarized in Table IX. Fig 6 shows growth curves for the five series, mean dry weights of whole plants being plotted against time in days. Dry weights give the most comprehensive summary of growth but it was considered of value to examine another measure of growth, namely, height. Growth curves for height are shown in fig. 7. These curves show that growth during autumn and spring is lower than during summer with its higher temperature and light values.

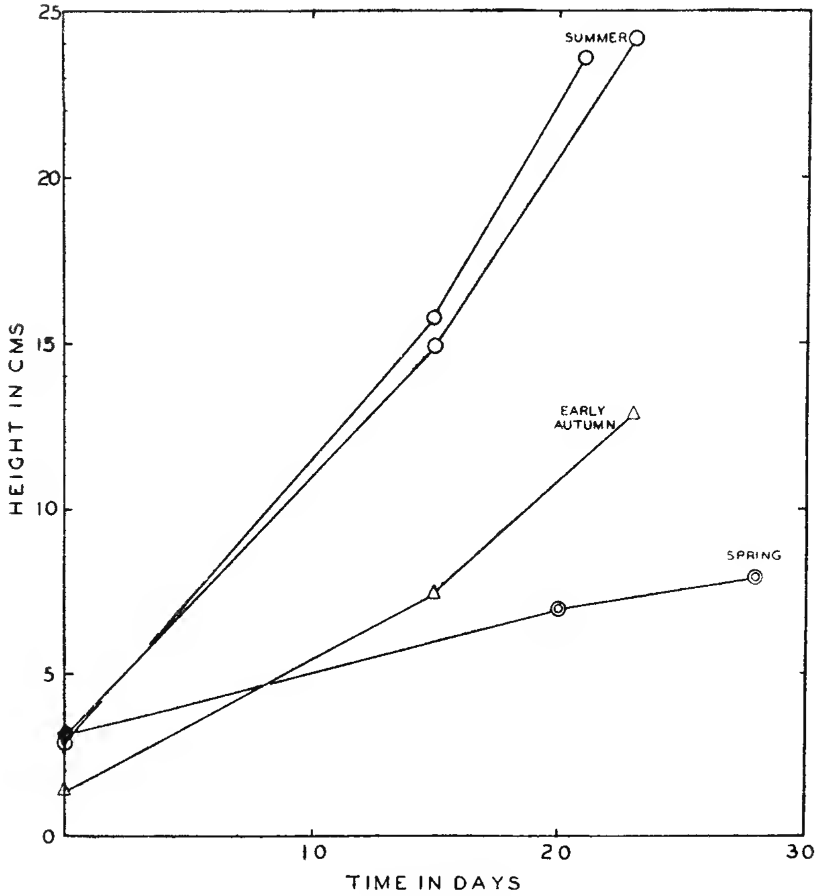

FIG. 7.—Growth curves for height in tomato plants grown at different seasons.

When the logarithms of the dry weights were plotted against time the curves obtained approximated to straight lines and the slope of these curves was taken as a measure of the growth rate—

$$\text{Growth Rate} = \frac{\log Wt_2 - \log Wt_1}{t_2 - t_1}$$

where Wt_1 and Wt_2 are the dry weights of the whole plant at the beginning (t_1) and at the end (t_2) of the experiment. Growth rates plotted against time of year are shown in fig. 8. The higher growth rate for summer is associated with higher light and temperature values.

These results show general agreement with the more extensive data of Ainsworth and Selman (1936). Representative growth curves from the data of these workers are plotted in fig. 9 for comparison.

The relation between the growth of the host at different seasons and the growth and rapidity of invasion by the parasite *B. solanacearum* is discussed in the following section.

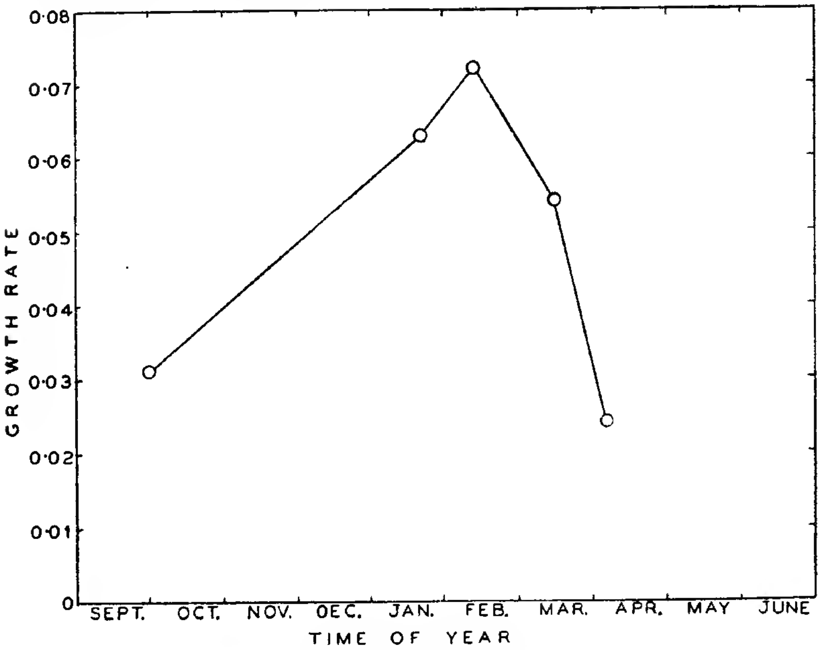

FIG. 8.—Growth rates in tomato plants at different times of the year.

TABLE IX.—GROWTH OF TOMATO PLANTS AT DIFFERENT SEASONS.

——		Expt. 1 13·3·41 to 9·4·41 Av. Temp. = 62°F.	Expt. 2 17·9·41 to 15·10·41 Av. Temp. = 59°F.	Expt. 3 12·1·42 to 2·2·42 Av. Temp. = 75°F.	Expt. 4 20·1·42 to 12·2·42 Av. Temp. = 78°F.	Expt. 5 27·2·42 to 21·3·42 Av. Temp. = 69°F.
Sample I.	Time in days	0	0	0	0	0
	Height in cms.	..	3·2	3·2	2·9	1·4
	Dry wt. in gms.	0·109	0·052	0·030	0·029	0·026
Sample II.	Time in days	22	20	15	15	15
	Height in cms.	..	7·0	14·85	15·3	7·5
	Dry wt. in gms.	0·290	0·138	0·321	0·340	0·194
Sample III.	Time in days	27	28	23	21	23
	Height in cms.	..	7·9	24·15	23·7	12·8
	Dry wt. in gms.	0·480	0·387	0·872	0·850	0·466

Dry weights and heights = means of ten plants.

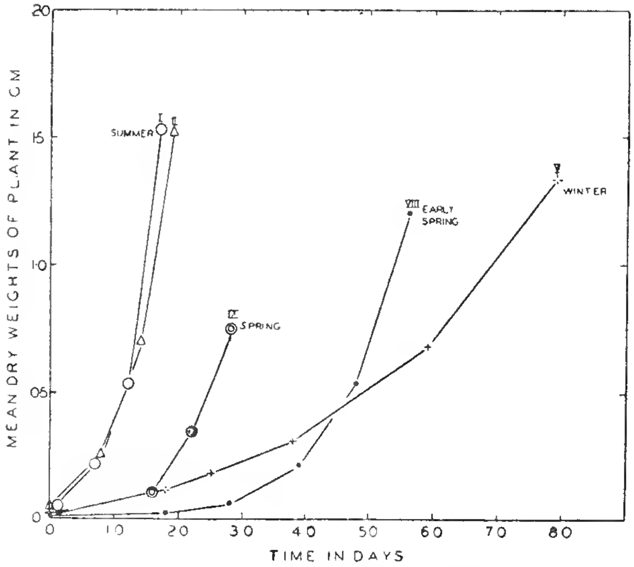

FIG. 9.—Growth curves for tomato seedlings. Plotted from Ainsworth and Selman's data (1936).

Discussion.

From the data presented it is apparent that under the conditions of these experiments there is a relation between maximum "invasiveness" and soil and air moisture, temperature and light intensity. The first three factors affect the physiology both of the host and of the parasite, while light affects the physiology of the host. In attempting a closer analysis of the relation between these factors and susceptibility to invasion, we may consider first how they affect those processes or conditions in the plant which might react favourably or unfavourably on the parasite.

GROWTH RATE AND WATER CONTENT.

Under suitable conditions of light and temperature, high soil moisture has been shown to affect favourably the growth in height and leaf area of healthy tomato plants as compared with those grown in dry soil. No significant difference, however, was found between the dry weights of plants grown under wet soil and dry soil conditions. The water content of wet soil plants rose significantly higher than those of the dry soil series and it appears that it is this factor which affects in large measure certain aspects of the growth of plants.

Increase in size in the plant may be considered to be the result of cell division and cell enlargement. The importance of water to these processes is obvious. Referring to the soil moisture experiments, it may be concluded that under dry soil conditions the relative deficiency of water exercised a depressant effect on cell growth which was reflected in the smaller height and leaf area of such plants. The comparative observations on the growth of healthy plants covered only those in wet and dry soils and no quantitative data on differences between the plants grown in normal soil-moisture and those of the two extremes is available. Rough comparisons made while other experiments were in progress indicated, however, that plants in wet soil were " sappier " than plants growing in normally watered soil.

The terms " sappiness " and " sappy " have been applied to certain glasshouse grown plants which, owing to the conditions of their culture, develop a relatively high water content and which consequently show certain well defined differences from the normal. Such plants are rather larger than normal, the leaves are thinner and of a paler green colour and there is a lack of anthocyanin pigment in the stem. The manner in which the increased water content acts on the plant to bring about these changes is not known. Miller (1929) and Shaw (1934) suggest in the case of " sappy " apple twigs that changed moisture conditions in the intercellular spaces may be concerned. This does not, however, appear to be in accordance with our knowledge of water relations in tissue development.

The finding that no significant increase in dry weight developed between the dry and wet soil series is interesting. In this connection Melville's work (1937) on the relation between water content and carbon assimilation in tomato (var. E.S.1) offers a likely explanation. He found that there was a marked rise in assimilation as the initial water content of whole plants increased from 89 to 91·5 per cent., but with values above 91·5 per cent. (in " long-night " plants) a rapid decline in assimilation set in. The condition of " long-night " plants approximates in some degree to that of plants from moist soil in so far as water content is concerned. Data on water content in the experiments here reported was taken only for stem and leaf parts and the values even for plants from dry soil were higher than Melville's figure of 89 per cent., but they would have been considerably reduced if the roots had been included. It is possible therefore that the same feature of depressed assimilation would occur. Thus any depression in assimilation in plants from dry soil due to water content below 90 per cent. would be compensated by a similar depression in assimilation in plants from wet soil when the water content reaches such a high level as to be pathological.

The changes in the host under wet soil conditions which appear to have the closest bearing on the growth of the parasite are (*a*) increase in water content, (*b*) increase in size of vessels. Increased water content leading to increased "sappiness" has a very definite effect upon the growth of the parasite. This effect, independent of possible complications due to increased transpiration, is shown in the massive multiplication of the organisms in vessels of plants held under highly humid conditions. Precisely how it acts upon the parasite is not clear. Van der Meer (1929) performed experiments on the growth of *B. solanacearum* on moist and dry agar and concluded that high moisture gave most active growth of the pathogen. Similar experiments by the author with *B. solanacearum* and other bacterial plant pathogens demonstrated that they too gave better growth on moist agar. Walter (1925), moreover, demonstrated that high relative humidity is a general condition for successful growth of many micro-organisms. Van der Meer's view that because this particular parasite grew better on moist agar it therefore should grow better in the vessels of a "sappy" plant consequently seems open to question. It is difficult to understand why, if water *per se*, is important, the mere increase of it in the xylem vessels and parenchyma cells should affect the parasite so much in the case of prick inoculated plants. Earlier experiments (Grieve, 1940) showed that even in plants at the wilting stage the water columns in the tracheae remained continuous. It seems more likely that the more successful parasitism in wet soil plants may be due to greater availability of metabolites for bacterial nutrition made possible by the enhanced water supply. It is possible that, in some way not at present understood, reduced absorption of water in dry-soil plants affects deleteriously the absorption of mineral salts and the leakage of other food materials into the tracheae.

Brown (1936) discusses the question of water content in relation to parasitism and suggests (e.g. for *Bacillus carotovorus* Jones) that there is a relationship between water content and enzyme action by the parasite. In sub-turgid tissues the enzyme cannot operate. While the author has no evidence that enzyme action of the type evidenced by *B. carotovorus* exists in the case of *B. solanacearum*, the possibility of some such mechanism also being operative is not excluded.

It is of interest to note that a close relationship between high water content and susceptibility to invasion has been recorded in the case of several other diseases e.g. of pear to *B. amylovorus* (Shaw, 1934); of tobacco leaves to *B. angulatum* and *B. tabacum* (Clayton, 1935), and potato leaves to *Phytophthora infestans* (Napper, 1933).

Increased transpiration in moist soil conditions is associated with increased water content of tomato plants (Foster and Tatman, 1937), but there is no evidence in the experiments reported here, to suggest that this increased transpiration has any effect in speeding up invasion by carrying the bacteria upwards in the vessels. On the introduction of bacterial cells into the vessels by needle prick they are carried up and down to various points in the punctured vessels under the influence of the negative pressure in the tracheae. They then multiply in these vessels until they become packed tight, after which spread occurs to other vessels by breakdown of walls. Once the bacterial column is formed in the bundles it appears to progress upwards and downwards mainly by multiplication of bacterial cells although some local motility of the organism has been observed at the apex of the column. This mode of progression indicates that transpiration has little direct effect on the rate of movement of the bacteria. Further evidence is provided from the experiments on invasion under very humid conditions where plants in which transpiration was almost negligible were invaded as rapidly as plants which were transpiring freely. Confirmatory evidence from another source was provided by an infection experiment in which two sets of plants (six plants per set) were grown in a controlled environment chamber at 77°F. under light values of 1,000 ft. c. and 500 ft. c. respectively. The plants under the higher light intensity transpired 22 per cent. faster than those under the lower light intensity, yet the incubation period for initial symptoms and for complete wilting was the same for both.

Although increased transpiration does not directly affect the upward movement of the bacteria, it is possible that it can affect their growth rate. Thus a higher transpiration rate may lead to more rapid transport of salts actually present in the xylem, leading to an increased salt concentration in one part which would favour more active growth of the parasite. Again it is likely that the nutrition of the bacteria might be favourably affected by increased rate of uptake of salts from the soil under the influence of higher transpiration rate. The consensus of opinion among plant physiologists has inclined to the view that transpiration rate bears no relation to salt absorption. Freeland (1937), however, has recently brought forward evidence which suggests that salt uptake is not independent of transpiration.

The increase in vessel size and number which was demonstrated for plants growing in wet soil might be expected to be an important factor in the more rapid spread of the bacteria in these plants. But it is not easy to obtain proof that increased size of vessel *per se.* does facilitate bacterial movement because a whole complex of factors is involved rendering the plant more susceptible.

The limited experiments on growth of healthy tomato plants reported in this paper indicated that increase in dry weight and height was related to temperature and light, being greatest in summer at mean temperatures of 75–78°F. and mean light intensity of 800–900 ft. c., and least in late autumn (no experiments were used in winter) at an average temperature of 62°F. and 400 ft. c. light intensity.

The interrelation of light and temperature for tomato plants (var. E.S.1.) under conditions of glasshouse culture has been studied in considerable detail by Bolas (1934). He found that maximum rate of assimilation (relative increase in dry weight) from 84–90°F. occurred with 1,000 ft. c.; at 75°F. with 600 ft. c. falling off with rise of light intensity to 1,000 ft. c. and at 59°F. with 100 ft. c. decreasing with light intensity above this.

Considering the bacterial invasion experiments (Tables II. and III.) on the basis of the results of Bolas and the author, it is clear that susceptibility to invasion by the parasite is associated with vigour of growth in the host, since the inoculated plants growing at 73°F. and 800 ft. c. would be growing close to the optimum rate. With reduction of light intensity to 130 ft. c. at 73°F. (Table III.) a considerable depression of growth in the host might be expected. The reduction in invasion speed which occurs at this temperature and light combination, is believed to be directly attributable to the light factor in depressing growth since reduced transpiration would not exert any effect and any consequential increase in water content might be expected to favour bacterial invasion.

The effect of temperature is more complex in that it affects both the growth of the host and of the pathogen.

The decrease in assimilation rate as the temperatures drop from 73°F. to 59°F. reacts in some fashion on the bacteria leading to a slower rate of growth in them (Table II.). Possibly the depression of the growth rate in the host at lower temperatures reacts deleteriously on the volume of metabolic products available for utilization by the bacteria. Temperature, however, also acts directly on the growth of the pathogen (see fig. 2). At 15°C. (59°F.) little growth is occurring and at 18°C. (64°F.) the rate of growth is only 31 per cent. of that at 32°C. (90°F.) so that a great deal of the depression in invasion rate may be directly attributable to the effect of lowered temperature on the growth of the parasite. That not all of the depression in growth is due to a direct temperature effect on the parasite is shown by the fact that when assimilation rate is reduced by a big decrease in light intensity, temperature remaining the same at 73°F., the bacterial growth rate is reduced. This suggests that the change in growth rate in the host under altering conditions of temperature and light affects the rate of multiplication of the organisms by varying the availability of metabolic products for its nutrition. Studies on the food requirements of *B. solanacearum* carried out in these laboratories (Mushin, 1938) showed that this organism could utilize a variety of organic and inorganic compounds as sources of nitrogen and carbon food. Of such potential food substances likely to be found in the plant, sucrose and glucose served as sources of carbon and gave a rich growth in the presence of a source of nitrogen, e.g. potassium nitrate. Substances such as peptone, tyrosine and glutamic acid served both as a source of carbon and nitrogen to maintain the growth of *B. solanacearum.* The parasite grows primarily in the xylem vessels and here one might expect to find salts including potassium nitrate and sugars together with amino acids which have "leaked" into the xylem. Despite the absence of precise information on just what metabolites are selectively utilized by the pathogen in the host, it appears possible that the retarding action of reduced light on susceptibility to invasion is due at least in part to depressed bacterial metabolism arising from a lowered availability of food material in the xylem.

That factors other than, or in addition to, those examined by the author, may be concerned in determining the virulence of the parasite or the susceptibility of the host in other parts of the world, is indicated by the work of Eddins (1936). He noted that bacterial wilt occurred in all types of sandy soil in Florida, U.S.A., and was more serious when rainfall was less and temperatures were above 77°F. Here temperature is an important factor but soil moisture does not come into question. The hydrogen ion concentration of the soil was shown to be important and Eddins claims control of the disease by the use of sulphur, whereby the acidity of the soil is increased.

Note on Control of the Disease.

Important factors which have been recorded in the course of this paper as affecting the incidence of the disease (tested mainly under glasshouse conditions) are (*a*) soil moisture, (*b*) temperature, and (*c*) atmospheric humidity. These three factors are known to apply in the field in Victoria. The combination of high soil moisture, high temperatures and high relative humidity is known to be responsible for increased losses in potato crops in certain years.

Control of the disease in Victoria is being achieved in large measure by seed selection, and by drainage (e.g. of the Koo-wee-rup area) which minimizes the operation of the soil moisture factor.

In New South Wales (1939, 1940) the disease is recorded as occurring on sandy as well as on heavy wet soils. This suggests that in that State some other factor besides soil moisture is important in predisposing plants to infection or in altering the virulence of the parasite. Possibly the pH factor (Eddins, 1936) may be concerned in sandy soils in which case the use of sulphur would be beneficial although Paul (1939) failed to control bacterial wilt in Ceylon by its use.

Summary.

1. High soil moisture favours heavy and rapid invasion of potato and tomato plants by *Bacterium solanacearum*, while in dry soil the plants are more resistant to the spread of the organism. Since the disease occurs most seriously in the moist soil of the Koo-wee-rup area in Victoria the results indicate a positive relation between soil moisture and the incidence of the disease in the field.

2. Both temperature and light influence invasion rate as judged by incubation period of symptoms. Average temperatures between 66°F. and 73°F. with average light intensity of 800 ft. c. in the glasshouse during summer months gave most rapid spread of the disease in the host.

3. Plants grown under conditions of high humidity were more susceptible than plants under normal glasshouse conditions. Transpiration rate was shown to have no direct effect on the movement of the parasite up the vessels.

4. The rate of movement of *B. solanacearum* in the bundles of potato and tomato plants at different soil moisture levels was determined. Optimum rates in wet soil at 73°F. were 5·0 mm. per hour for potato and 2·2 mm. per hour for tomato.

5. The minimum, optimum and maximum temperatures for growth of the parasite were found to be 15°C., 32°C. and 35°C. respectively.

6. A study on physiological and anatomical changes in tomato plants arising out of growth in wet soil as against dry soil, showed that significant differences in height, leaf area and water content developed, while vessels were larger and more numerous. The increased water content is believed to be the factor which influences the susceptibility of the plant to invasion.

7. Results of growth experiments indicated that spread of the disease in the host was related to the vigour of growth in the host.

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Art. III.—*Problems of Stratigraphic Correlation in the Indo-Pacific Region.*

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Abstract.

The stratigraphic correlation of marine deposits of Jurassic, Cretaceous, and Tertiary age in the Indo-Pacific Region is reviewed. Results of recent bio-stratigraphic studies in the East Indies are compared with the available data on the stratigraphy of New Guinea and of some of the other islands in the south-western Pacific. The significance of larger and smaller foraminifera for the stratigraphic subdivision of the sequence of Indo-Pacific Tertiary deposits into Series and Stages is discussed. Some features of the distribution of sediments and fossils which are believed to indicate important events in the geological history of the Region are enumerated.

Contents.

Introduction.

The present paper deals with stratigraphic correlation of Jurassic, Cretaceous, and Tertiary marine deposits in an area between the eastern shores of the Indian Ocean in the west and Fiji in the east and between Borneo and New Guinea in the north and tropical Australia in the south. This is the greater part of what is known in zoogeography as the Indo-Pacific Region. Although important areas of this zoogeographic province are not included in this review (Central Pacific Islands, Philippines, islands in the western Indian Ocean), the use of this convenient name appears to be justified.

Several distinct structural units are recognizable in the Indo-Pacific Region: the opposed stable areas of Sundaland in the north-west and Australia in the south-east, including the Sahul shelf and the southern portion of New Guinea; the belt of moderate young folding around the margins of Sundaland, and the volcanic arcs accompanying this belt; the arc system of the strongly folded Timor-East Celebes geosyncline; two branches of this geosyncline, one in New Guinea and another one, the Westralian geosyncline (Teichert 1939), in North-western Australia. The latter is now structurally incorporated in the stable area while the former has been transformed into a mountain range indicating considerable young folding and faulting. East of New Guinea the folded zone continues in the general direction towards New Caledonia, the New Hebrides, and New Zealand. Beyond this belt there is another stable area, including Fiji and Tonga. The real geological boundary of the Pacific Ocean, based on a dividing line between the areas of andesites and basalts, passes north and east of it. Some authors assume the existence of a largely submerged extension of the Australian stable area, the Melanesian continent, between this boundary and Northern New Guinea.

The great advances made in recent years in the stratigraphy and palaeontology of key areas in the Indo-Pacific Region, connected with the names, among many others, of W. L. F. Nuttall, L. F. Spath, Oostingh, Tan, Umbgrove and van der Vlerk, F. Chapman and Miss I. Crespin, convinced the author that the time for a critical stratigraphic review of the whole region had arrived and that this work could be expected to stimulate further discussion of one of the most fascinating problems of regional geological history.

The present review is not a complete discussion of Indo-Pacific post-Triassic stratigraphy. Its scope is limited to marine sediments because of the uncertainty of age and relations of most of the volcanic rocks of the region, and the comparative insignificance of other non-marine deposits outside Australia. It deals with problems of correlation without presenting detailed descriptions of stratigraphic sequences. For details the reader is referred to stratigraphic summaries covering many parts of the region and quoted in the bibliography.

It is not intended to discuss here the structural theories proposed by numerous authors in explanation of the complex features of the area between Australia, Asia and the Pacific Ocean. Biostratigraphic correlation merely contributes towards the solution of fundamental geological problems by placing the geological events in their proper sequence and relation and by establishing analogies and differences in the geological history of areas which are to be considered as structural units (stable areas, mobile belts, geosynclines, etc.).

The uncertain and varying definitions of the term "geosyncline" call for some explanation concerning its use in the following discussion. Recently Jean Tercier (1939) compared the latest data on marine sedimentation in the East Indies and elsewhere with Haug's classical and widely accepted views on facies, depth zones, types of deposition, and geosynclines. The present writer, while not entirely in agreement with Tercier's conclusions, is unable to discuss in the limited space available this vast and important problem and has to refer the reader to Tercier's review, particularly to his chapter on "Facies and types of marine sedimentation" (l.c. pp. 87–93), where the five fundamental types, i.e. paralic, epicontinental, geosynclinal, oceanic, and continental, are discussed and defined.

"Present judgment as to methods of stratigraphic palaeontology places weight on the value of evolutionary stages determined in any stock, relies on the testimony of a relatively small number of carefully identified guide fossils that for various reasons may be regarded as most reliable, and endeavours to take full account of ecologic elements in the interpretation of faunal and floral assemblages." (R. C. Moore, Stratigraphy, in: Geol. Soc. Amer. Fiftieth Anniversary Volume, June 1941, p. 203.)

The American system of stratigraphic terminology, recently formulated by H. G. Schenck and S. W. Muller (1941) shows a much needed way in which confusion in stratigraphy can be avoided. In the Correlation Table accompanying the present paper an attempt is made to distinguish between local terms agreeing in form and definition with the Formations or Groups of this system, and mere descriptive designations. The author does not consider a paper on regional correlation as the proper medium for the creation of new stratigraphic terms which must be based on local stratigraphic data but he ventures to express the hope that in due course all definable lithogenetic units will receive proper and unequivocal formation names. The question whether under certain circumstances some local rock-stratigraphic terms should receive the rank of regional "Stages" replacing the European stage terms or whether in this case an entirely new set of names of independent derivation has to be created, is still open for discussion. The common use, in some parts of the region, of the words "Series" or "Beds" instead of "Formation" is a problem of minor importance. The establishment of "Zones" in post-Jurassic Indo-Pacific sediments is a vital task of future palaeontological research.

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He is further indebted to Mr. W. Baragwanath for arrangements facilitating the re-drawing of the accompanying Correlation Table; and to Mr. W. J. Parr for assistance in the preparation and publication of this paper.

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I. Jurassic and Cretaceous.

1. JURASSIC.

Recent studies of the Mesozoic of the East Indies (Wanner 1931, Umbgrove 1935, 1938) established the existence of a geosyncline extending from Timor through some of the Molucca Islands (Ceram), to East Celebes. The western margin of this geosyncline is formed by the stable area of Sundaland (Malaya, West Borneo, West Celebes) which was only in part affected by intermittent Jurassic and Cretaceous transgressions, and by the zone Sumatra-Java-Soemba, the Mesozoic history of which is only incompletely known but does not suggest geosynclinal conditions. A southern branch, the "Westralian geosyncline" (Teichert 1939), indicates the revival, in Jurassic time, of an important Palaeozoic geosyncline. Faunal relations of the East Indies and Western Australia around the Australian shield with New Caledonia and New Zealand in Jurassic time are well known but the part played by New Guinea in relation to other Mesozoic areas is at present not fully understood.

Stratigraphic correlation in the Jurassic is based on a standard system of ammonite zones which owing to greater climatic uniformity in Jurassic time can be adapted for world-wide use with comparative ease. Stratigraphic terms used in the following discussion are based on the latest revision of this system recently published by S. W. Muller (1941).

THE JURASSIC OF NEW GUINEA.

Owing to peculiarities of facies and preservation of fossils the Jurassic sequence of New Guinea is well known palaeontologically although Jurassic rocks have only rarely been seen in situ.

UPPER LIAS is known from Western New Guinea (Etna Bay) where *Coeloceras moermanni* Kruizinga was found (Kruizinga 1926). A Liassic lamellibranch (*Ctenostreon cf. terquemi* Tate) was determined by Bullen Newton (1916, p. 9) from Central New Guinea. Liassic rocks have not been found in situ.

BAJOCIAN is represented by occurrences of *Stephanoceras* (Etheridge 1890, Gerth 1927), including *S. etheridgei* Gerth from Western New Guinea and a similar species described by Etheridge from pebbles found in the Strickland River in Papua. The BATHONIAN of New Guinea is at present not clearly distinguishable.

CALLOVIAN is well represented. Terpstra (1939, p. IV. 2) described micaceous clay-shales in situ, with "*Macrocephalites*", undetermined belemnites, *Homomya* and *Inoceramus* from the Woesi River (Upper Lorentz River basin), where the Jurassic is transgressively overlain by Oligocene. Callovian ammonites from pebbles were described by G. Boehm (1913) from Western New Guinea where they are considered to be derived from known beds outcropping nearby. Some of the ammonites figured by R. Etheridge jun. (1890, pl. 29) from the Strickland River gravels represent Callovian forms. Their nomenclature has been revised by later authors as follows:—

FIG. 1.—"*Stephanoceras* allied to *S. lamellosum*," now *Kamptokephalites etheridgei* Spath (1928, p. 200, pl. 12, fig. 3).

FIG. 2.—"*Stephanoceras* allied to *S. blagdeni*," now *S. aff. etheridgei* Gerth (1927).

FIG. 3.—"*Stephanoceras* allied to *S. lamellosum*," now *Macrocephalites keeuwensis* β G. Boehm, or *M. waageni* Kruizinga *non* Uhlig (Kruizinga, 1931).

FIG. 4.—"An ammonite allied to *A. lingulatus*."—?

FIG. 5.—"*Stephanoceras* allied to *S. calloviensis*," now *Dolikephalites flexuosus* Spath (1928, p. 210, pl. 12, fig. 4).

Macrocephalites keeuwensis G. Boehm, according to Spath not a single species but a group of more or less related forms, was first described from the Callovian of the Sula Islands and is also known from Western New Guinea and from Sepik River pebbles (Schlüter 1928).

OXFORDIAN was described by Broili (1924) from Western New Guinea where *Belemnopsis gerardi* (Oppel) and *Buchia* ("*Aucella*") *malayomaorica* (Krumbeck) (described as ?*Pseudomonotis* sp., l.c. pl. 2, figs. 10, 11) occur in dark-grey clay shales. The species have also been seen by the writer in collections from Central New Guinea. Gerth (l.c.) mentions a *Peltoceras* sp. Schlüter (l.c.) found in the Sepik pebbles *Perisphinctes burui* (*taliabuticus*) G. Boehm and *Inoceramus* *galoi* G. Boehm, well known species of the Mefa beds of Buru and the Wai Galo beds of the Sula Islands. These beds are placed by Spath in the *cordatus*-zone of the Oxfordian.

No representative species of the uppermost Oxfordian zones and of the Kimmeridgian are known among the ammonites of New Guinea.

TITHONIAN. Schlüter (l.c.) described from the Sepik pebbles the species *Kossmatia desmidoptycha* Uhlig, *Haplophylloceras strigile* (Blanford), and *Blanfordiceras cf. wallichi* (Gray), considering their age as transitional to Cretaceous. They are also known from pebbles derived from Tertiary conglomerates on the Toarim River, Northern New Guinea. According to Spath they represent the uppermost Jurassic.

Jurassic beds of the Sula Islands and New Guinea are generally developed as shales with hard siliceous fossiliferous nodules ("Geodenschiefer"). Facies and affinities of the Jurassic in New Guinea suggest that part of Western and Central New Guinea was a geosynclinal area. It extended possibly into Eastern New Guinea where within the limits of E. R. Stanley's "Astrolabe-Kemp Welch Series" (1923) the present writer found *Pentacrinus sp.* and *Entolium sp.* in slightly altered sandy limestones overlying phyllites at Goilala on the Upper Aibala River. The phyllites overlie highly metamorphic schists (E. R. Stanley's "Owen Stanley Series").

CORRELATION.

Towards the east, only Tithonian ("Portlandian") is known in New Caledonia where the La Foa formation (Piroutet 1917) with *Berriasella cf. novoseelandica* transgressively overlies Triassic. According to Piroutet no earlier Jurassic horizons are known. In New Zealand (Kawhia Harbour, Trechman 1923) the Oxfordian *Buchia-Belemnopsis* assemblage as well as the Tithonian clearly indicate East Indian affinities.

Towards the west the same Jurassic faunal sequence extends into the area of the Spiti shales of the Himalaya (Uhlig 1910). According to Spath (1933, p. 662) this classical section shows a faunal gap apparently corresponding to the break in the New Guinea ammonite fauna:

Spiti shales {
Chidamu beds.—Tithonian.
Faunal gap.—Uppermost Oxfordian and Kimmeridgian.
Belemnite beds.—Middle Oxfordian.
(Callovian species known from the basal beds.)

Umbgrove (1938, p. 24 f.) although considering our knowledge of New Guinea as inadequate, admits the possibility of this area having formed a geosyncline in Jurassic time after a probably continental period in the Triassic. There are strong indications of the existence, in Jurassic time, not only of a restricted "Westralian" but of a Circum-Australian geosyncline. It differed from the Timor-East Celebes geosyncline in a less complete record of Jurassic stages, in more consistently terrigenous facies, and partly also in less pronounced post-Jurassic ("Pacific" or "Young Kimmeric") folding.

2. CRETACEOUS.

Wanner (1931) and Umbgrove (1935, 1938) have published summaries of the Mesozoic history of the East Indies to which the reader is referred for more detailed information. Some additional data and new aspects are discussed here.

(*a*) Sumatra and Borneo.—Lower Valanginian with *Neocomites* is known from Sumatra. Other evidence of Lower Cretaceous is seen in the occurrence of *Orbitolina* in Sumatra, Java, Borneo and Celebes. Umbgrove (1935) has pointed out that in the absence of reliable specific determinations these occurrences cannot be considered as evidence of a "Cenomanian transgression" but indicate only Barremian to Cenomanian age of these generally transgressive rocks.

The Seberuang Formation of Western Borneo is now known (Zeijlmans 1939) to represent a complete sequence of Cretaceous from transgressive Valanginian with *Neocomites* and *Thurmannia* (Bedoengan beds) through *Orbitolina*-bearing rocks to Turonian and Senonian with mollusca and *Globotruncana* (Selangkai beds).

Cenomanian is also known from Western Borneo as sandstones with *Nerinea* and limestones with *Knemoceras pinax* Krause and *Schloenbachia*. In South-east Borneo *Orbitolina*-bearing beds are followed by richly fossiliferous limestones with *Nerinea* and rudistids, of Martapoera. Martin considered these beds as Senonian of Indian (Ariyalur) affinities.

(*b*) In the "Timor-East Celebes Geosyncline" a transition from highest Jurassic to lowest Cretaceous beds with *Duvalia* (Timor) and *Hibolites subfusiformis* (Misol) probably exists. These beds are followed, according to Wanner (1931), by limestones with "*Globigerina, Discorbina*, and *Pseudotextularia*" which are very widely known from the eastern part of the Archipelago. "*Discorbina*" is of course the well-known *Globotruncana* and "*Pseudotextularia*" includes *Gümbelina*. After considerable discussion on the age of these beds, Umbgrove (1938, p. 19) describing the sequence of Misol according to Weber, considered them to represent Barremian to Cenomanian, lying above beds with *Hibolites subfusiformis* (Valanginian-Hauterivian) and below beds with *Inoceramus* and *Durania*, containing Maestrichtian and possible slightly older forms (Wanner 1931, p. 600).

Beds containing *Globotruncana* cannot be as old as Barremian and are possibly not older than Cenomanian. In Mexico, the Gulf Coast region, North Africa, the Alps, Apennines, Greece and the Caucasus detailed micropalaeontological investigations have failed to detect any evidence of pre-Cenomanian *Globotruncana*. The widely quoted *G. canaliculata* Reuss (= *G. linneana* d'Orbigny sp.) however has been described from the Aptian and Albian of the Pyrenees and the Balearic Islands as well as from the Albian Red Chalk of England. It is a common species in the Turonian and Senonian elsewhere. The Seewer beds of the Western Alps which resemble the *Globotruncana* rocks of the East Indies closely, are Turonian, and most of the similar "Couches Rouges" are Senonian. The existence of an unbroken sequence of Cretaceous rocks in the Timor-East Celebes geosyncline can be proved only by detailed micropalaeontological investigations. *Globotruncana stuarti* (Lapparent) found by Tan Sin Hok in rocks from Western New Guinea and determined by Glaessner from the pink limestone first discovered near Port Moresby by J. N. Montgomery (in: B. K. N. Wyllie 1930, vol. 4, pt. 5, p. 34) proves Upper Campanian-Maestrichtian age of the rocks containing it. This species is also clearly recognizable in a photograph of an "inclusion of Cretaceous *Discorbina*-limestone in a Tertiary e—5 limestone" from Celebes, published by van der Vlerk and Dozy (1934, pl. 2, fig. 1).

(*c*) In North-western Australia Dr. Raggatt (1936) found the Cretaceous commencing with transgressive Upper Albian. The following summary of the sequence in the North-west basin was recently given by C. Teichert (1939, p. 85).—"The lower part of the Cretaceous series consists of about 1,100 feet of greensands, siltstones, and cherts of the Winning series. Belemnite beds, probably not far above the base of the series, are considered to be of Albian age and the early part (Neocomian) of the Lower Cretaceous seems therefore not to be represented. A Lower Cretaceous transgression seems also to have affected the coastal regions much further south at Perth, where I. Crespin reports the finding of foraminifera of that age in strata about 1,650 to 1,750 feet below sea level". The belemnite beds referred to contain according to Whitehouse *Dimitobelus diptychus* (McCoy) and have been named "Cardabia beds" by Glauert.

Near Darwin, the Point Charles bed contains a fauna of ammonites considered by Whitehouse (1926, p. 279) as typical of the *substuderi*-zone of the Upper Albian, and also the world-wide Upper Albian to Cenomanian *Aucellina gryphaeoides* Sow. "Above the ammonite bed in this region is a whitish rock with impressions of belemnites. . . . It is probably . . . Uppermost Albian or Lower Cenomanian. At Melville Island a bed has yielded *Acanthoceras* and *Inoceramus*. This is obviously

Cenomanian in age, while from the ammonites present it appears more definitely to represent the *baylei*-zone of the Upper Cenomanian." (Whitehouse l.c.). In Sir T. W. Edgworth David's Correlation table of Cretaceous rocks of the Commonwealth (1932, table H) the sequence near Darwin is shown as follows:—

Cenomanian— { Melville Island drab-coloured mudstone.
Point Charles bed.

Upper Albian—{ Ferrugineous shales of the *aequatoriale*-zone.
Fanny Bay radiolarian shales with belemnites and *Ichthyosaurus*.

Cenomanian is not definitely known from the North-west basin where the Winning series is followed by chalks, clay shales, *Inoceramus* marls, glauconite sand, and sandy polyzoal limestone (Cardabia series of Raggatt, *non* Glauert). The limestone, probably Maestrichtian according to Spath, contains *Ostrea vesicularis* Lam. and other fossils. From the greensand Spath (1940) described Lower Maestrichtian ammonites including *Kossmaticeras, Kitchinites, Pachydiscus aff. gollevillensis* Grossouvre, etc. The chalks probably correspond at least in part to the Gin Gin chalk several hundred miles further south containing *Uintacrinus* and *Marsupites* (Upper Santonian, according to Spath Santonian and Campanian). The foraminiferal fauna of the North-western Cretaceous determined by Miss Crespin (1938*a*) appears to suggest Lower Senonian rather than Turonian or Cenomanian age of the chalks and Upper Senonian (Campanian-Maestrichtian) for the higher beds, judging from the occurrence of several world-wide index species.

In Queensland and Central Australia the Roma beds with *Ancyloceras, Tropaeum, Tetrabelus, Peratobelus, Maccoyella, Pseudavicula* etc. represent, according to Whitehouse (1930, p. 37) Aptian, and the Tambo beds are Upper Albian (*Puzosia, Anisoceras, Labeceras, Aucellina, Inoceramus*, etc.).

(*d*) In New Guinea, as in Australia, no early Cretaceous marine fossils have been discovered, the fauna of the so-called "transition beds" representing, according to Spath, the uppermost zone of the Jurassic. Early reports suggest the occurrence of Cretaceous of Australian affinities (Apt-Albian) in Central New Guinea. Apart from pebbles with Jurassic ammonites mentioned above, Capt. Everill found fossils in situ on the Strickland River, five days' journey by whaleboat above Carrington Junction (Cecilia Junction). C. S. Wilkinson (1888, p. 204) who examined the samples, stated after quoting from Capt. Everill's report: "The high precipices along the river are formed of sandy calcareous strata, of a dark greenish colour, full of fossil shells of Cretaceous age; amongst those collected are *Gryphea, Modiola, Aviculopecten, Protocardium, Cidaris*, ammonites, *Inoceramus*, etc. . . . The specimens of fossiliferous greensand rock collected from the Strickland River lithologically resemble the Cretaceous beds of New South Wales and South Australia." This description makes it quite unlikely that the black siliceous nodules containing Jurassic ammonites which were found in the Strickland River gravels as well as—much later—in the Sepik River are derived from these outcrops. Similarity of fauna and facies of these pebbles suggests a common source, probably in the Strickland-Sepik divide on the north side of the Main Range.

A few years later R. L. Jack and W. H. Rands (1894, p. 93) reported on Cretaceous fossils collected by Sir William MacGregor on the Upper Purari River. MacGregor's route map shows the locality to be near Biroe Village (north of lat. 7°, long. 144° 50′). "The limestones, although containing numerous fossils, have only one which is in a condition to be recognized. This one, however, a belemnite, is of the utmost importance as this cephalopod is most characteristic of the Cretaceous rocks of Europe and Queensland. The genus has not been met with before, so far as I am aware, in New Guinea. I sent the specimen to Mr R. Etheridge, jun., who confirmed my identification. Other Cretaceous fossils have been obtained from the Strickland River . . . It is evident that the Purari blue limestones must be classed at Cretaceous, and of course, if my surmise that they belong to the same formation is correct, so must the green sandstone." (R. L. Jack, l.c., p. 93, 30th April, 1894). The description of individual samples shows that the limestones contain abundant bivalve shells "and some gastropods like *Anchura*." A. Gibb Maitland (1905, p. 47) used the name "Purari River beds" for this occurrence of Cretaceous.

Sir W. MacGregor's observations and R. L. Jack's determinations received striking confirmation when early in 1940 Dr. S. W. Carey re-visited the locality of the reported Cretaceous on the Upper Purari, and collected samples of rocks and fossils, in connection with geological exploration work carried out in Papua by the Australasian Petroleum Company. The fossils were subsequently examined by the present writer. Among them was a belemnite belonging to the family Dimitobelidae Whitehouse, abundant bivalve shells the most common of which is *Pseudavicula cf. papyracea* Etheridge, and the "gastropods like *Anchura*" mentioned by R. L. Jack. The belemnite was sent to Dr. F. W. Whitehouse who determined it as *Tetrabelus n.sp.* This genus is known (Whitehouse 1924, 1930) from the Roma beds (Aptian) of Australia and from the Upper Albian of India. The preservation of the other mollusca in very hard rock makes specific determinations difficult and uncertain. Among others, the following genera are represented in the fauna: *Nucula, Trigonia, Lima, Ostrea, Exogyra, Mytilus, Ptychomya, Natica, Nerinea.* A small *Lingula* and a tooth of *Lamna* were also found, as well as smaller foraminifera, ostracods, and echinoid remains.

Fossils collected by Patrol Officers of the Papuan Service in the Kerabi Valley north of Mt. Murray in Papua were mentioned by E. R. Stanley (1923, p. 26). They include large ammonites. Stanley states " The majority of these specimens appear to be related to the Upper Cretaceous ". They are now being examined by F. W. Whitehouse whose preliminary determinations (*Acanthoceras sp., Mantelliceras papuae nom. nud.*) were included in Sir T. W. Edgworth David's correlation chart of the Cretaceous rocks (1932, table H). These determinations prove Cenomanian age of the Kerabi Valley beds.

The Cretaceous of New Guinea includes beds with mollusca resembling those of the Australian Roma and Tambo series (Apt-Albian), Cenomanian with *Acanthoceras*, and Upper Senonian in *Globotruncana*-facies.

(*e*) The Cretaceous of New Caledonia, although still quite incompletely known, appears to have a similar range and development. According to Piroutet (1917) three " stages " can be distinguished. Each of them is locally found transgressive on Triassic rocks. The lowest is the Dumbéa with *Cardium caledonicum* Munier-Chalmas and *Pellatia garnieri* Munier-Chalmas, followed by andesites. The next higher stage is the Moindou in which three main subdivisions and a large number of fossiliferous horizons are recognizable. Lamellibranchs (*Trigonia, Cardium aff. dubuchense, Exogyra cf. couloni* Defr., etc.) and gastropods are almost the only groups of fossils mentioned. A *Trigonia* from the higher part of this stage is said to be comparable with one from the Maryborough beds (Roma) of Queensland but other Australian Cretaceous lamellibranchs may also be present in the Moindou. Judging from the then available data Piroutet did not find any other striking resemblances with Australian species. He believes the Dumbéa and lower Moindou to represent " Eocrétacé " (Barremian?) and the basal upper Moindou to be " Mésocrétacé " (Apt-Albian?). The Upper Moindou may be Cenomanian.

The highest Cretaceous stage in New Caledonia is the St. Vincent containing *Kossmaticeras cf. bavani* Stol. (determined by Prof. Kilian), *K. loganianum* Whiteaves, *K. cumshevaense* Whiteaves, *Puzosia cf. gaudama* Forbes and a large number of other fossils including an *Inoceramus* described by A. Heim and A. Jeannet (1922). This is clearly a Senonian fauna showing considerable similarities with the Santonian (?) Batley fauna of New Zealand and similar Pacific assemblages (Benson 1928).

In New Zealand according to Finlay and Marwick (1940, p. 83) " the oldest post-Hokonui formation for which a definite Cretaceous age has been established is the Taitai series ". It contains the well-known Australian genera *Maccoyella* and *Aucellina* and is Upper Aptian. Albian, Cenomanian, and younger Upper Cretaceous stages are also represented.

CORRELATION.

Lower Cretaceous to Cenomanian sediments west of the Timor-East Celebes geosyncline are mostly rich in *Orbitolina* and *Nerinea* and show Mediterranean affinities. What is known of deposits of the same age from New Guinea and New Caledonia shows epicontinental rather than geosynclinal development and suggests similarities with the fauna of the Cretaceous of Australia and New Zealand) Dimitobelidae, aviculid lamellibranchs, no *Orbitolina*), rather than with Borneo and Sumatra. In both areas however relations with the Cretaceous of India are found.

The molluscan fauna of the Senonian shows some characteristic Indo-Pacific or rather Indian and Pacific features, in Borneo as well as in North-western Australia, New Caledonia, and New Guinea. The pelagic smaller foraminifera (*Globotruncana*, *Gümbelina*) become rock-forming for the first time, these rocks from the Timor-East Celebes geosyncline and New Guinea closely resembling rocks of the same age from the Alpine geosyncline in Europe.

II. Tertiary.

1. METHODS OF CORRELATION.

Biostratigraphic correlation of Mesozoic marine deposits is based on zones which are either worldwide or at least useable within the wide limits of a palaeo-zoogeographic province. Correlation of Tertiary deposits is a much more difficult problem on account of climatic differentiation, topographic isolation, and close stratigraphic subdivision of deposits representing a comparatively short time interval. No world-wide scale of fossil-zones based on well-defined ranges of a set of index species exists. A sequence of Tertiary faunal assemblages was long ago established in Europe and it is not surprising to find that workers in other continents first turned to this sequence for guidance by means of direct comparison and correlation. As long as no scale of zones is available, the next higher unit in stratigraphic classification, the stage, must be the basic unit for measuring Tertiary geologic time. The recognition of the European stages in the East Indies proved so difficult that a number of workers gave up and even condemned attempts at inter-continental correlations.

Four different lines of approach to stratigraphic problems in the East Indies, the key area for the Indo-Pacific Tertiary, have been followed.

(*a*) K. Martin (1919, and earlier publications) was the first to examine critically collections of mollusca and other fossils. He found them so different from the standard European assemblages that he decided to determine their age by means of Lyell's method, i.e., according to their more remote or closer affinities with the Recent molluscan fauna of the Indo-Pacific Region. This affinity was expressed in percentages of living species for each fauna described. The stratigraphic results of Martin's work were adversely affected by insufficient stratigraphic field evidence on the succession and relations of mollusca-bearing beds and by the much-discussed dangers of the percentage-method. This stratigraphic tool, far from being an exact statistic method for which it was occasionally mistaken, gives generally no more than what even its most determined critics concede, i.e., "a general indication as to early, middle, or late Tertiary age" (Finlay and Marwick 1940, p. 91). In the special conditions of the East Indies this should be read as "early, middle or late *Neogene* age", for which subdivisions the figures are approximately 8-20, 30-45, 50-60 per cent, respectively.

(*b*) H. Douvillé (1905, and other publications) tried to correlate East Indian Tertiary deposits by comparing assemblages of larger foraminifera with those found in Western Europe. Douvillé's method soon lost favour as a result of confusion then arising over the delimitation of Tertiary stages and the distribution of larger foraminifera in the type areas (F. Sacco, 1905), as well as because of the limited number of species common to both regions and insufficient knowledge of the vast intervening regions of the "Middle East". It appears now, after nearly forty years, that in spite of these difficulties Douvillé's correlations of Aquitanian, Burdigalian and Helvetian with Indo-Pacific formations appear in many cases to be approximately correct.

(*c*) Van der Vlerk endeavoured to avoid the danger of confusion by dividing and correlating the Tertiaries of the East Indies according to the local sequence of foraminiferal assemblages. In collaboration with Umbgrove (1927) he created local "stages" designated by the letters "a" to "f" (subdivided into "zones" designated by numbers), and based on the distribution of larger foraminifera. The stages "g" and "h", based on other criteria, were added later in order to complete conveniently the subdivision of the Tertiary. The stages were not explicitly referred to type sections but were linked in a general way with the stratigraphic sequence observed by the authors in East Borneo and elsewhere. Later correlation (Leupold and van der Vlerk, 1931) generalized these stages and zones so that they finally included stratigraphic units in which the distinctive foraminifera had not been found.

While not inclined to use European series and stage terms generally, van der Vlerk (1931, p. 207) showed in a chart " the most probable comparison " between European and East Indian subdivisions. Stages " a " and " b " are placed in the Eocene, " c " and " d " in the Oligocene, " e " and part of " f " including the West Progo and Njalindoeng mollusca-bearing beds are considered as Lower Miocene, the rest of the " f-stage " including the Tjilanang and Lower Palembang beds and the " g-stage " are Upper Miocene and the " h-stage " with the Sondé beds is Pliocene.

Gerth (1935) presented additional evidence for the distinction of Eocene, Oligocene and Miocene in Java by comparing occurrences of larger foraminifera with supposedly similar assemblages from Sind, South-west France, and the West Indies.

(*d*) The collaboration of the palaeontologists Koenigswald (vertebrates), Oostingh (mollusca), and Tan Sin Hok (larger foraminifera) with the field geologists of the Netherlands East Indies Geological Survey placed the study of the Tertiary in the East Indies and indeed throughout the Indo-Pacific Region on a firm base. Koenigswald's work established the sequence of definitely Lower Pliocene, Upper Pliocene, and Pleistocene vertebrate faunas in Java. They were stratigraphically correlated with marine molluscan faunas described by Oostingh, by means of which correlation was extended over larger areas. Tan Sin Hok developed elaborate and important methods of morphological analysis of the structure of larger foraminifera (1932, 1936*a*, 1939). His latest views on the general subdivision of the Tertiary of the East Indies are here summarized. He finds (1936, 1939*a*) that the following boundaries are palaeontologically recognizable :—

(1) Eocene/Oligocene.
(2) Aquitanian/post-Aquitanian (e/f).
(3) Between two subdivisions of the " Middle Neogene " corresponding to van der Vlerk's " f_1–f_2 " and " f_3 " respectively.
(4) Between Middle and Upper Neogene (top of *Lepidocyclina*-bearing sequence, top of " f-stage ").

Thus he recognizes :—

Neogene	Upper Neogene (formerly g–h).
	Upper Middle Neogene (f_3).
	Lower Middle Neogene (f_{1-2}).
	Lower Neogene (Aquitanian, " e," included in Miocene).
Palaeogene	Oligocene (c–d, distinguishable from Aquitanian only where reticulate nummulites are present).
	Eocene (a–b).

Tan Sin Hok concludes (1939*a*, p. IV. 100) " The further differentiation of these main divisions can only be successful from the investigation of actual geologic sections, and moreover, if the several species of larger foraminifera can be defined in a more objective manner. To this purpose the phylogenetic line of investigation will be of great use. In many cases a further subdivision of these stages can at present better be done by the use of local stratigraphic names."

Such names have recently been introduced by Oostingh (1935, 1938, quoted with alterations from Le Roy, 1941, p. 5, p. 110; and modified after Oostingh 1939, p. IV. 141).

Plio-Pleistocene	—Bantamian (Bodjong beds).
Pliocene (post-Pontian)	Sondian (Kali Glagah Upper Pliocene vertebrates). Cheribonian (Tjidjoelang Lower Pliocene vertebrates).
Miocene	Unnamed stage (e.g., non-marine Genteng beds). Preangerian (Upper Middle Neogene of Tan). Rembangian (Lower Middle Neogene of Tan).

These "stages" are based on well-defined molluscan assemblages and guide species many of which were collected from mapped and stratigraphically well known areas in Western and Central Java.

2. Correlation of Eocene and Oligocene Deposits.

Eocene.

Tan Sin Hok has pointed out that definite evidence for age distinction and superposition between beds with and without *Assilina* ("a" and "b" according to van der Vlerk and Umbgrove) is lacking. It appears from recent critical investigations on nummulites (Caudri 1934) that there is no evidence yet for an extensive representation of Lower Eocene in the East Indies. The oldest nummulites correspond, according to Caudri, to those found in India close to the Laki/Kirthar boundary. P. Arni (Ueber die Nummuliten und die Gliederung des Untereocaens. *Eclogae Geol. Helvet.* 32, p. 150, 1939) points out that certain assemblages from isolated outcrops of Eocene in Java contain species occurring also in the Uppermost Lower Eocene of Europe. The upper limit of the Eocene is marked by the sudden disappearance of *Discocyclina.* Occurrences of marine Eocene are scattered through the East Indian Archipelago from the Andaman to the Kei Islands, but the history of the period cannot be traced yet in detail (Umbgrove 1938).

Chapman and Crespin (1935) described nummulites, *Discocyclina, Asterocyclina* and *Pellatispira* from the Giralia limestones found by Rudd and Condit in North-western Australia. *Discocyclina* limestones occur there also at Red Bluff and Cape Cuvier (Crespin 1938).

In Western and Central New Guinea Eocene is known as foraminiferal limestones with nummulites, *Alveolina, Discocyclina, Lacazina,* etc. (Rutten 1927, Crespin 1938*b*). *Lacazina wichmanni* Schlumberger is definitely Eocene and not Cretaceous as suspected by Umbgrove (1935, p. 143). Limestone pebbles from the upper Fly River from which Bullen Newton (1918) described foraminifera and Gregory and Trench (1916) corals are not Eocene but Lower Miocene or Upper Oligocene (e-stage). All the corals are described as new species except one which is a new variety of a *Porites*. They can obviously not be used for age determination. The foraminifera are described as *Alveolina wichmanni* Rutten, *Lacazina wichmanni* Schlumberger, *Orthophragmina* sp. *Carpenteria conoides* Rutten, and miliolines with transversely plicated chamber walls "suggesting a relation to *Pentellina saxorum*." The description of the miliolids which cannot be verified from the illustration, suggests *Austrotrillina* Parr (1942) but not the erroneously quoted *Miliola saxorum* which has a normal chamber wall. "*Orthophragmina*" (Bullen Newton l.c. p. 209, pl. 9, fig. 4) refers to an oblique section showing only rectangular median chamberlets and is therefore a *Sorites*. Differences between the supposed *Lacazina* and Schlumberger's species were noticed by Bullen Newton, their alveolinid characters were observed by Miss Crespin (1938*b*, p. 5), and spiral coiling is indeed plainly shown in fig. 2 (l.c.). The species figured is probably *Neoalveolina pygmea* Hanzawa.

In south-eastern New Guinea Eocene is represented by the Port Moresby beds. Gibb Maitland (1905, p. 47) originally used this name for the entire sedimentary series of the Port Moresby district considering its age as Pliocene. It is now known to range, with at least two breaks, from Upper Cretaceous to Pliocene. The name Port Moresby series was later restricted to the Eocene rocks of Port Moresby consisting of siliceous argillites, cherts, tuffs, and marls with abundant *Globigerina*, *Globorotalia*, *Gümbelina* and radiolaria, with intercalated bands and lenses of limestone containing nummulites, *Pellatispira* and *Discocyclina*. (J. N. Montgomery, F. Chapman, in: Wyllie 1930, vol. 4. List of Fossils quoted by I. Crespin 1938*b*, p. 4.) The Port Moresby beds are associated with serpentines and gabbro. Slight contact metamorphism is found in palaeogene *Globigerina-Globorotalia* limestones. The intrusions are therefore partly Palaeogene or younger. Some of the limestones in Stanley's Astrolabe-Kemp Welch series (Boioro and Mafulu limestones) are probably Palaeogene.

The Eocene of New Caledonia (J. Deprat 1905, Piroutet 1917) shows a similar facies of nummulitic limestones, marls and cherts, associated with an enormous development of serpentine. It is reminiscent of the "serpentine series" and cherts described by Tipper (1911) from the Andaman Islands and of similar rocks of the Arakan Yoma where according to Evans and Sansom (1941) "the main intrusions of serpentinized gabbros and peridotites occurred probably in late Cretaceous and Eocene times." Eocene foraminiferal limestones resting on tuffs and lava flows are known from Eua, Tonga Islands (Hoffmeister 1932).

OLIGOCENE.

In north-western India (Sind) a break corresponding to a major orogenic phase divides the Middle Eocene (Lutetian) Kirthar from the Oligocene Nari. "The lower Nari beds are often crowded with nummulites. These usually belong to the species *N. intermedius* and *N. vascus*. . . . The genus *Lepidocyclina*, Carter's *Orbitolites mantelli*, makes its appearance at a very low horizon in the Lower Nari, often at the very base of the formation. . . . In the Upper Nari the lepidocyclines are also very abundant but are not accompanied by nummulites. . . . All the Nari lepidocyclines appear to belong to one species *L. dilatata*." (Vredenburg 1906, pp. 90f.). The Nari nummulites have since been recognized by Nuttall (1925) as *N. intermedius* and *N. clipeus*. *L. dilatata* was described from the Nari by the same author (1926). As these forms (except *N. clipeus*) are known from Europe, they enabled Nuttall to confirm Vredenburg's correlation of the Nari (as far as it contains *N. intermedius* and *L. dilatata*, Lower Nari according to Vredenburg), with the Stampian (Rupelian) of Europe. "In the Upper Nari, thin discoidal forms predominate, often reaching a diameter of 10 centimeters. This is *L. elephantina* Munier-Chalmas, probably identical with the Burmese form described by Carter as *Orbitolites mantelli var. theobaldi*." (Vredenburg, l.c., p. 91). *Lepidocyclina elephantina* was first described from the Chattian (Upper Oligocene) of Isola di Malo in Northern Italy and also from the Aquitanian Schio beds. The Upper Nari was correlated by Vredenburg with the Chattian.

In Burma the Oligocene is more complete. It is subdivided (Glegg 1938, Cotter 1938) into:

Okhmintaung sandstone (Singu molluscan fauna).
Padaung clay (including beds with *L. elephantina*, Yenangyat and Minbu faunas).
Shwezettaw sandstone.

These three "stages" are believed to correspond approximately to the Chattian, Rupelian, and Lattorfian of Europe. Vredenburg correlated the Singu mollusca with the Upper Nari and the equivalents of the Padaung with the Lower Nari. If this is true then *L. elephantina* appears earlier in Burma than elsewhere.

In the East Indies *Camerina intermedia* characterizes the stages "c" and "d." *Eulepidina papuaensis* Chapman appears in beds assigned to stage "d" by Leupold and van der Vlerk (1931). At its type locality, the Bootless Inlet limestone of Port Moresby.

Papua (Chapman 1914, and also in: Wyllie 1930, vol. 4) *E. papuaensis* occurs together with *C. intermedia* so that these beds must be considered as Oligocene. The occurrence of *Spiroclypeus* in the same beds is doubtful. The stratigraphic relation of the Bootless Inlet limestone to the Eocene Port Moresby beds is uncertain. *E. dilatata* has not been found together with nummulites in the East Indies. Douvillé (1905, p. 435) recognized in material from Borneo a distinction between older beds with reticulate nummulites without *Eulepidina* and younger beds (Stampian) with the same nummulites and "*Eulepidina* of the *formosa* group". Leupold and van der Vlerk (1931) and Koolhoven (1933) confirmed this subdivision. Their evidence was not accepted by Tan Sin Hok who however does not deny that the first appearance of the subgenus *Eulepidina* distinguishes the later (Rupelian) from the earlier (Lattorfian) stage.

This raises the question of the representation of the Upper Oligocene (Chattian) in the East Indies, since the Rupelian is generally considered as Middle Oligocene (Vaughan 1924, pp. 712f.). A number of authors let the Aquitanian follow immediately after the Rupelian but this does not seem to be the correct procedure. Although no complete marine sequences are known in the type areas, detailed work elsewhere in Europe has shown that "type" Aquitanian and "type" Chattian do not overlap.

The highest beds with reticulate nummulites are invariably followed in complete sections in the East Indies by beds with *Eulepidina*, *Spiroclypeus*, *Miogypsinoides* and other larger foraminifera. This is stage "e" of van der Vlerk and Umbgrove. The top of this stage was recognized by H. Douvillé, Gerth and Tan as the top of the Aquitanian. The main criterion used for defining the base of stage "e" is the same as that applied by Vredenburg for the distinction between Lower Nari (Rupelian) and Upper Nari (Chattian). Tan (1939*a*) quotes the following European species from the "e-stage": *Lepidocyclina elephantina* Munier-Chalmas, *L. dilatata* (Michelotti), *L. marginata* Michelotti, *Miogypsinoides complanata* (Schlumberger), *Heterostegina assilinoides* Blankenhorn. Most of these are known from Upper Oligocene and Lower Miocene (Chattian-Aquitanian). Accordingly, the stage "e" is placed in Chattian and Aquitanian in the European scale (Tan, 1932, Table IV.). Umbgrove has in a number of his publications insisted on the occurrence of important transgressions in a higher horizon of stage "e". Tan, in his critical reviews, does not find sufficiently clear evidence for the recognition of any of van der Vlerk's five "zones" of this stage, and therefore the horizons of transgressions cannot be as accurately fixed within the stage as Umbgrove maintained. Umbgrove's observations agree however in a general way with

Lepper's statement of overlap by the Pyawbwe clay (Aquitanian) and an important unconformity in the uppermost parts of the Oligocene in Burma (quoted by Glegg, 1938).

No molluscan assemblages of "e-age" have been described from the East Indies and direct correlation with Burma is therefore impossible. The Rembang fauna, believed at the time of Vredenburg's work to be Aquitanian, has since been found to be younger and to occur together with typical post-Aquitanian foraminifera.

In the Cape Range limestones of North-western Australia (F. Chapman 1927, I. Crespin 1938) different assemblages of larger foraminifera, mainly *Eulepidina*-species, corresponding to the "e-stage" fauna of the East Indies, have been found. Oligocene is known from New Guinea and New Ireland (Schubert 1911) but has not been reported from the New Hebrides or New Caledonia.

Tan Sin Hok (1939*a*, p. IV. 100) has warned us that only the presence of genuine reticulate nummulites is stratigraphically important, that their absence may be caused by ecologic conditions and that "in some cases the discrimination of a 'genuine' *Camerina* from *Operculinoides* Hanzawa is very difficult, the latter being *Camerina*-like operculines which also occur in the Indo-Pacific Neogene." Such forms are still creating much confusion in stratigraphy and a revision of the group is urgently needed. It includes *Nummulites niasi H.* Verbeek (= *N. variolaria* Brady 1875, non Sowerby, see R. D. M. Verbeek and R. Fennema, Descr. géol. de Java et Madoura, 1896, vol. 2, p. 1157), *N. makullaensis* Carter (Vredenburg 1906) from the Gaj; *N. doengbroeboesi* Verbeek (Schubert 1911), and possibly other species.

3. CORRELATION OF MIOCENE DEPOSITS CONTAINING LARGER FORAMINIFERA.

In some recent classifications of the Tertiary of the East Indies the use of the term "Miocene" is still avoided. It is admitted that it is at present difficult, if not impossible, to define satisfactorily both the upper and the lower boundaries of this series. It would be easy and perhaps convenient to regard all post-nummulitic *Lepidocyclina*-bearing beds as Miocene but this is not in agreement with the use of the term elsewhere and with its original definition and the typical sequence of rocks covered by it. There is some difference of opinion about the position of the Aquitanian. This, in the writer's opinion, is a purely arbitrary matter to be settled by agreement and not by investigation. The majority of authors now include it in the Miocene. If we accept this view then the lower boundary of this series in the East Indies is not, at present, biostratigraphically definable. A similar question arises concerning the top of the Miocene. If the Pontian is regarded as uppermost Miocene then all pre-Cheribonian Neogene deposits are Miocene as the Cheribonian includes, by definition, beds containing the earliest post-Pontian fauna of vertebrates. If it is possible, as it appears to be, to distinguish a "g-stage" from the Cheribonian, then this "g-stage" is Miocene under the first of the two alternative delimitations of the Series. If, however, the Pontian is not included in the Miocene then the top of the Miocene is at present not definable.

That the problem is a general one is shown by a statement recently made by G. E. Pilgrim (1940, p. 9):

> "The numerous stages or sub-stages into which I have divided the geological succession does not imply that the correlation makes any pretence at being more than approximate, but have been used partly because that is the only means by which I can take account of the large number of American faunas and partly because the system names Miocene, Pliocene and Pleistocene have at present no meaning since they have not been employed by every writer in the same sense."

Notwithstanding these difficulties, a certain part of the East Indian Tertiary sequence is definitely Miocene. This is Tan Sin Hok's "Lower and Upper Middle Neogene", Umbgrove and van der Vlerk's "f-stage", and Oostingh's Rembangian and Preangerian. These latter names appear to be well suited for general use in the Indo-Pacific Region. The Rembangian is tentatively correlated with the Burdigalian and the Preangerian with the Vindobonian (Helvetian-Tortonian) of Europe. Definite evidence, however, is available only for the correlation of the base of the Burdigalian with the base of the Rembangian, the rest being conjectural as long as no further palaeontological evidence is found. In the light of new stratigraphic and micropalaeontological data earlier inter-regional correlations based on mollusca cannot be considered as satisfactory.

Vredenburg (1921*a*, p. 328) and Martin (1931, p. 7) correlated as follows:—

Younger Miocene	Odeng beds—Talar—(Sarmatian-)-Pontian. Tjilanang beds—Vindobonian.
Older Miocene	Njalindoeng beds—Pyalo—U.Gaj—Burdigalian. Rembang beds—Kama—L.Gaj—Aquitanian. Progo beds (not correlated).

Gerth (1929, p. 595) has shown that the foraminiferal fauna of the Rembang beds is definitely post-Aquitanian (probably Burdigalian) and that the Progo beds are not greatly different in age. Van der Vlerk (1924) found that in both Njalindoeng and Tjilanang beds only *Trybliolepidina* represents the lepidocyclines and Gerth (l.c., p. 596) concluded that both are "Younger Miocene", younger than the Rembang beds and possibly Vindobonian. According to the same author the Odeng beds are equivalents of the Tjilanang beds. The absence of pre-Rembangian molluscan faunas in Java and the incomplete knowledge of Vindobonian molluscan assemblages from India add to the difficulty and uncertainty of molluscan correlation.

The beds containing the Progo and Rembang molluscan faunas and the "f_{1-2}" assemblage of larger foraminifera have been named Rembangian by Oostingh. This stage is characterized, according to Tan Sin Hok (1939*a*, p. IV. 99) by *Katacycloclypeus*, *Miogypsina bifida* L. Rutten, *M. polymorpha* L. Rutten, *M. musperi* Tan, *Alveolinella* of the *bontangensis*-type (= *Flosculinella*), *Lepidocyclina angulosa* Provale, *L. inflata* Provale, and some other lepidocyclines.

Beds with this foraminiferal fauna are followed in numerous sections examined in East Borneo, Java, Sumatra, and New Guinea by beds containing a younger Miocene molluscan fauna, and instead of the foraminifera mentioned above, a younger assemblage with *Lepidocyclina (Trybliolepidina) rutteni* van der Vlerk, *L.* (*T.*) *orientalis* van der Vlerk, some *Miogypsina*, and *Alveolinella* of the *quoyi* type. They were named "Preanguerien" (here adapted to "Preangerian" according to English spelling) by Oostingh. Tan (l.c.) quotes also *Cyclolepidina* (*recte Multilepidina*) *suvaensis* Whipple as typical for this stage and claims to have found it in Java in the highest *Lepidocyclina*-bearing beds. At its type locality, in the Suva formation of Fiji and in Rembang (Java), the species occurs together with *Katacycloclypeus annulatus*, evidently in beds of Rembangian age.

No distinctive larger foraminifera are found in post-Preangerian beds, reports of *Lepidocyclina* and *Miogypsina* being based either on incorrect assumption of Pliocene age for rocks underlying Pleistocene raised reefs (Tan 1936*a*, p. IV. 85), on unconfirmed determinations, uncertain stratigraphic data, or derived specimens from older beds.

The correlation of *Lepidocyclina*-bearing rocks throughout the Indo-Pacific Region presents little difficulty. The Cape Range limestones of North-western Australia (Crespin 1938) contain not only "e-stage" assemblages but also a fauna with *Flosculinella bontangensis* and *Austrotrillina* which can be considered as Rembangian. The *Lepidocyclina*-bearing rocks of the north coast of New Guinea were described as "Conglomerat-zone" by Zwierzycki (1921, 1927) and as Aitape series by Nason-Jones (in: Wyllie, 1930). Some part of Zwierzycki's "*Globigerina*-

zone" contains *Lepidocyclina* and is probably Preangerian. *Lepidocyclina*-limestones have repeatedly been reported in situ in the high mountains of the Main Range of New Guinea, including Mt. Carstenz where the "e-stage" fauna occurs, the upper Lorentz River (Terpstra 1939), the upper Digoel River (van Bemmelen 1940) where "e-stage" limestones are followed by a predominantly arenaceous and argillaceous stage tentatively considered as Burdigalian, and the upper Fly River (e-stage, Crespin 1938*b*). In samples from New Ireland Schubert (1911) found *Lepidocyclina* and *Miogypsina*. A soft *Globigerina*-marl with *Miogypsina laganiensis* and *M. epigona* was incorrectly assigned by him to the Pliocene. In the Solomon Islands the Orovavi limestone of Bougainville with "e-stage" foraminifera described by Mawson and Chapman (1935) is the oldest known formation. The folded tuffs and foraminiferal marls observed by Guppy (1887) on a number of islands of the Solomon group and considered by him as "Recent", probably represent the younger Tertiary stages. From the New Hebrides (Santo and Malekula) F. Chapman (1905, 1907) described *Lepidocyclina*-limestones which were later named Laleppe formation by Mawson and Chapman (l.c.). Chapman figured foraminifera closely resembling *Lepidocyclina ferreroi* Provale and *L. inflata* Provale, *L. cf. martini* Schlumberger, as well as *Alveolinella cucumoides* Chapman representing the *bontangensis*-group. The Laleppe formation is evidently Rembangian.

4. CORRELATION OF MIOCENE AND PLIOCENE DEPOSITS NOT CONTAINING DISTINCTIVE LARGER FORAMINIFERA.

THE STAGE "G".

To van der Vlerk's stages "a to f", all characterized by distinctive larger foraminifera, Umbgrove (1929, reprint, p. 5) added a "stage g", specifically for the Antjam and Domaring beds of Borneo. He explained:

> "It is of frequent occurrence that beds, free from Orbitoidides and situated above the Tertiary containing *Lepidocyclina-Miogypsina* are called 'Pliocene'. But when we do that, we forget the fact that there is not yet any certainty at all, as to whether the horizon of the Tjilanang beds may be correlated with the whole of the Vindobonian. It is quite possible that it only corresponds with two or one (or even less than that) of the sub-divisions of the Vindobonian (Helvetian-Tortonian-Sarmatian); in which case a part of the Tertiary, that is younger than the beds containing Orbitoidides, must be considered as belonging to the Miocene.

> In Netherlands E. Borneo (Bulungan) the Miocene beds containing *Lepidocyclina* are followed immediately by the Antjam beds and the Domaring beds (Leupold) which are designated as Tertiary-g in 'Wetenschappelijke Mededeelingen No. 9' in which the Anthozoa of this horizon have also been described. It can serve no purpose to carry on the classification by letter any further as long as there are no data for fixing the boundaries and for ascertaining which organisms are distinctive ".

H. Gerth (1931, p. 146) has pointed out that the Antjam beds contain two species of corals (*Astrocoenia minutissima* Gerth and *Hydrophyllia applanata* Gerth) belonging to genera unknown from the Pliocene or Recent and that these beds should therefore be considered as Miocene. Two years later, however, he transferred the first of these species to the genus *Stylophora* which is well represented in the Pliocene.

At the same time Leupold and van der Vlerk (1931) still avoiding the terms Miocene or Pliocene added a stage "h" to the letter-scale and quoted the following percentages of Recent mollusca in the higher stages:—

h —50–60 per cent.
g —35–45 ,, ,,
f_3 —30 ,, ,,
f_{1-2}—8–20 ,, ,,

The percentage of recent species of mollusca appears to be the only feature defining stage "h", apart from the multitude of formations referred to it.

Stage "g" is defined by the Antjam beds as "type sequence", and by a fauna of mollusca containing 35-45 per cent. of Recent species. This appears to be an imaginary criterium as none of the five localities from which Martin described such assemblages belongs definitely to the "g-stage". According to Gerth (1931, p. 147) the Odeng beds with 43 per cent. are stratigraphic equivalents of the Tjilanang beds with 34 per cent. and f_3-lepidocyclines, while the fauna from shallow wells near Batavia with 36 per cent. is according to Rutten (1927, p. 102) probably Pliocene or Pleistocene. Furthermore, there is some doubt concerning the age and stratigraphic position of the Antjam and Domaring beds. The former overlie unconformably the Koendjang beds, age and foraminifera of which are unknown, and the latter overlie with apparent unconformity the Menkrawit beds (f_3) and are stated to correspond to the upper part of the Kampong Baroe beds which is Pliocene (Leupold and van der Vlerk 1931, pp. 619, 621, 624).

Apart from the rather unfortunate original definition, there is other evidence for the existence of an Uppermost Miocene stage without lepidocyclines. Le Roy's recent studies on smaller foraminifera (1941) led to the conclusion that the Sangkoelirang beds are partly younger than Preangerian and older than Cheribonian, implying the existence of an intermediate stage corresponding in stratigraphic position to Umbgrove's stage "g" In parts of Java this intermediate stage is represented by unfossiliferous deposits, largely of volcanic origin (Genteng beds of West Java, Koembang beds of Central Java) which are followed by Lower Pliocene (Cheribonian). In Eastern Java the *Globigerina*-marls of the Lower Kalibeng beds (Duyfjes 1938) follow unconformably above the Rembang beds and are overlain by Pliocene Upper Kalibeng beds and Pleistocene Poentjangan and Kaboeh beds. A fauna of smaller foraminifera described by Koch (1923) from Kabu (Kaboeh) was apparently taken from the Lower Kalibeng beds. Koch remarks that in the definitely Pliocene fauna from the Fufa beds of Ceram (Fischer 1921, 1927) only very few species are extinct and that this fauna, therefore, must be younger. Most of the extinct species found at Kabu occur also in the Kar Nicobar fauna which Koch considered as Pliocene. He determined the age of the Kabu fauna as lowest Pliocene or Upper Miocene. Two "index species" are mentioned, *Uvigerina javana* Koch and a "*Globigerina sp.*". This was later named *G. kochi* Caudri (1934) but should be placed in *Sphaeroidinella*. Neither of these species has subsequently been found in definite Pliocene. Van Es (1931) assigns these *Globigerina*-marls from Kabu to the Uppermost Miocene, "g-stage". Duyfjes considers "the greater part of the Kalibeng beds" as Pliocene but appears to be prepared to admit Uppermost Miocene age of their lowest part. A fauna of smaller foraminifera described as "Miocene" by Yabe and Asano (1937) from West Java occupies a similar stratigraphic position.

There is no evidence anywhere of *Lepidocyclina* and *Miogypsina* having survived the Tortonian (possibly even Helvetian). As the vertebrate fauna proves post-Pontian age of the Cheribonian (Lower Pliocene of Java) and as it is generally assumed (Douvillé, Tan, and others) that the highest *Lepidocyclina*-bearing stage (Preangerian) corresponds to the Vindobonian (Helvetian-Tortonian), we expect to find an intermediate, or "g"-stage, of approximately Sarmatian-Pontian age.

It is admitted that more direct evidence of the existence and fauna of this stage must be awaited before it can be fully defined and named.

SIGNIFICANCE AND AGE OF THE FORAMINIFERAL DEPOSITS OF KAR NICOBAR AND FIJI.

Larger foraminifera, although known from many lithologically different rock types, are rare in argillaceous sediments and do not usually occur in rocks containing abundant pelagic foraminifera.

Many of these *Globigerina*-marls some of which may be stratigraphic equivalents of older *Lepidocyclina*-bearing rocks in different facies, have been classified as "Mio-Pliocene" or Pliocene on account of the absence of distinctive larger foraminifera. Undoubtedly, Indo-Pacific Tertiary smaller foraminifera can be utilized for distinctions between "*Globigerina*-marls" of different age and will be found not less useful for stratigraphic purposes than larger foraminifera when more detailed descriptive work is done. It is not possible to describe here new foraminiferal assemblages, but a critical review of the distribution of the smaller foraminifera known from the Tertiary of the East Indies, numbering about 650 species, shows that several well known species are restricted to Miocene deposits.

Until recently (Le Roy 1941), Schwager's work on Kar Nicobar (1866) and Cushman's work on Fiji (1934) were the only more or less complete descriptions of assemblages of Indo-Pacific Tertiary smaller foraminifera. Later work proved them to be representative of the whole Indo-Pacific Region. Although originally described as "Upper Neogene", they were both in recent years generally referred to the Pliocene. This classification which will be shown here to disagree with geological field data as well as with the composition of the fauna, made it impossible to distinguish between Miocene and Pliocene assemblages of smaller foraminifera.

Samples containing the Kar Nicobar fauna were taken by Hochstetter from some 20-30 feet of folded argillaceous rocks with sandstone bands overlain by young raised reef limestones. The argillaceous rocks of the Nicobar Islands were later included by Oldham (1885) in the Achipelago series. Tipper (1911) placed it in the Miocene. E. R. Gee (1926) found locally in Ritchie's Archipelago from which Oldham's stratigraphic term was derived, a late Tertiary, Pliocene or Pleistocene sequence of very loosely consolidated shelly mudstones containing numerous mollusca and occasional corals and echinoids, and a Miocene series of grey and greenish clays, argillaceous sandstones, white shelly limestone, and occasional conglomerates, representing the Archipelago series of Oldham, which is more affected by earth movements than the upper almost horizontal beds. This group includes foraminiferal limestones with *Lepidocyclina*, overlying clays on Wilson Island. While Tipper considered the Miocene Archipelago clays as younger than limestones with *Lepidocyclina cf. sumatrensis,* Gee found that similar limestones are interbedded in the Archipelago series. All geologists agree that the clays and sandstones of the Nicobar Islands belong to the Archipelago series which is Miocene, and is closely connected with *Lepidocyclina*-bearing rocks.

The foraminiferal assemblage described by Schwager contains 104 species, 34 of which occur in the Recent Pacific fauna. The percentage of Recent species is therefore 33. Forty-eight species are also known from the Suva formation of Fiji; 53 species are recorded from other localities in the East Indies; 30 of these are extinct. Of this number 14 were found in the Bulongan fauna (Koch, 1926) with *Lepidocyclina* (stages e–f), 9 in the Uppermost Miocene (stage g), and 7 in Upper Miocene and Pliocene. The fauna shows relations only to Miocene assemblages of smaller foraminifera. The conclusion of a Miocene age of the Kar Nicobar fauna agrees with the revised age of the closely related Fiji fauna.

The age of the Suva formation of Fiji was recently discussed by H. Ladd (1934, p. 99 ff.) who tried to reconcile contradictory palaeontological data with each other and with the field evidence. The Suva formation is undoubtedly younger than the Viti limestone with *Lepidocyclina (Eulepidina) formosa* Schlumberger (e-stage). The majority of the earlier authors considered the larger fossils of the Suva formation as Miocene or early Pliocene. Among the "small and incomplete" molluscan fauna Ladd distinguished an older assemblage with 9·5 per cent. Recent species and a younger fauna with 21 per cent. Recent species. He found a number of species which had been recorded from Miocene only and accordingly placed the Suva formation in "Lower to Upper Miocene" (f and g stages) but admits, on the evidence of smaller foraminifera and corals the possibility of Pliocene age of part of the Suva formation.

In the light of later data Whipple's determination of the age of the Suva larger foraminifera as "e-stage" which according to Ladd disagreed with the balance of stratigraphic evidence, has to be modified. In the Suva area, in close proximity to the type section, the following assemblage of larger foraminifera was found: *Katacycloclypeus annulatus* (Martin), *Cycloclypeus neglectus* Martin, *Multilepidina suvaensis* (Whipple) (= *M. luxurians* Tobler sp.?), *Lepidocyclina (Trybliolepidina) aff. radiata* Martin, and several microspheric lepidocyclines described as *L. dilatata* (Michelotti), *L. dilatata var. laddi* Whipple (= *subradiata* H. Douvillé?), and *L. papulifera* H. Douvillé. This is a Rembangian assemblage (see Caudri 1939, locality *27b* and others). The occurrence of a microspheric form described as *L. dilatata* is unimportant while the occurrence of *Katacycloclypeus* and *Multilepidina* which are unknown in the "e-stage", is decisive.

Ladd states (l.c., p. 95): "Cushman identified 95 species of smaller foraminifera from Station 371 which lies only 2 miles from the type section on Walu Bay and at about the same elevation. The same marls outcrop at many points between the two stations, and as all of them are horizontal it is certain that the marls of Station 371 are very close stratigraphically to the type section of the Suva formation."

In Cushman's publication (1934) 118 species of smaller foraminifera are described and most of them are figured. Approximately 64 species or 54 per cent. are Recent. Forty-eight species occur also at Kar Nicobar. Of 28 extinct species also known from other localities not more than three have been recorded from both Miocene and Pliocene deposits, the others are known from Miocene. Of these, 10 come from beds originally determined as Miocene, 3 from Kabu, later assigned to the Upper Miocene, and 24 are known from Kar Nicobar.

The distribution of extinct species occurring in the Fiji fauna indicates Miocene age. The percentage of recent species is much smaller than in definitely Pliocene assemblages (88 and 94 per cent. in the Fufa beds of Ceram, 75 to 89 per cent. in Java) and lies between that of the Bulongan fauna (48 per cent., " e " or " f " stage) and that of the Kabu fauna (61 per cent., probably " g-stage "). The fauna of smaller foraminifera of the Suva formation of Fiji is therefore not Pliocene but Miocene and apparently contemporaneous with the Rembangian assemblage of larger foraminifera found in close proximity to the type section.

STRATIGRAPHIC POSITION.

The stratigraphic position of important known assemblages of smaller foraminifera from the Indo-Pacific Region is graphically shown in Table 1.

TABLE 1.

Series.	Stages.	Sumatra and Mentawei Islands.	Java.	Ceram, Borneo.	Fiji.	Per cent. Recent Species.
— — —	Bantamian	——	Bodjong* LR West Java* YA Sonde* BV	Ceram* F, K	——	>70
Pliocene	Sondian	——		— — — —		
	Cheribonian	——		——		
	" g "	" Fluvio - brackish " LR Siberoet LR	Kabu K West Java YA	Sangkoelirang LR ↓	——	60-70
Miocene	Preangerian	" Transitional "* LR Kar Nicobar S Telisa* LR ↓	——	?	Suva C	<60
	Rembangian		——	Bulongan* K ↓		
	" e "	—?—	——	—?—	——	?

(Explanation of abbreviations and symbols used :
Authors' names—
LR—L. W. Le Roy 1939, 1941.
YA—H. Yabe and K. Asano 1937.
BV—L. Boomgart and J. Vroman, 1936.
F—P. Fischer 1921, 1927.
K—R. Koch, 1923, 1925, 1926.
C—J. A. Cushman 1931, 1934.
S—C. Schwager 1865.
Arrows indicate that the fauna or part of it may be older.
Assemblages shown as extending over more than one stage may but do not necessarily represent the whole of these stages. * designates age determinations suggested by the authors named).

The figures for percentages of Recent species included in Table 1 are approximate. They are based on the following results of counts and calculations which owing to limitations of space cannot be fully discussed here:—

STAGES "e–f":		
Telisa, "Transitional" (Le Roy)	24	per cent.
Kar Nicobar (Schwager)	30	„ „
Bulongan (Koch)	48	„ „
Fiji (Cushman)	54	„ „
STAGE "g":		
Sangkoelirang (Le Roy)	60	„ „
Kabu (Koch)	61	„ „
West Java (Yabe and Asano)	65	„ „
Siberoet (Le Roy)	69	„ „
PLIOCENE:		
Bodjong (Le Roy)	73	„ „
West Java (Yabe and Asano)	86	„ „
Ceram (Koch)	88	„ „
Sondé (Boomgart and Vroman) (includes Pleistocene)	89	„ „
Ceram (Fischer)	94	„ „

It is not correct to assume that within the limits of the stages the fauna with the lower percentage is necessarily older. The transition from Miocene to Pliocene is evidently accompanied by a more rapid and therefore clearly expressed change in the composition of the foraminiferal fauna which definitely advanced the previously and subsequently fluctuating ratio. This gives an approximate indication of the age of an assemblage of foraminifera equal in value to the different and much lower percentages of Recent molluscan species.

MIOCENE INDEX FORAMINIFERA.

Of greater importance for stratigraphic correlation are index species of known, restricted, vertical range. The ranges of certain important larger foraminifera are shown on the accompanying chart, according to the latest available data. The following tentative list of selected species of smaller foraminifera, all recorded from more than one locality, is based entirely on published data arranged according to the chart (p. 67). These data do not enable us yet to distinguish index species for the different stages of Miocene and Pliocene among the smaller foraminifera but they prove that a considerable number of important Miocene species have never been found in younger deposits. Some of them are placed on record in the following list:—

Austrotrillina howchini (Schlumberger).
Bifarina crenulata Le Roy.
Bulimina microlongistriata Le Roy.
Cassidulina murrhyna (Schwager).
Cassidulina bicornis (H. B. Brady).
Chrysalogonium polystoma (Schwager).
Cibicides fijiensis (Cushman).

Cibicides dorsopustulosus Le Roy.
Clavulinoides szaboi (Hantken).
Dentalina stimulea (Schwager).
Dorothia subrotundata (Schwager).
Eggerella? subovalis (Schwager).
Eponides multiseptatus (Koch).
Gaudryina solida Schwager.
Karreriella siphonella (Reuss).
Lagena castrensis Schwager.
Lagena schwageriana Cushman.
Listerella victoriensis Cushman.
Marginulina subtrigona Schwager.
Marginulina subbullata Hantken.
Nodosaria arundinea Schwager.
  " *crassitesta* Schwager.
  " *equisetiformis* Schwager.
  " *hochstetteri* Schwager *et var.*
  " *inconstans* Schwager.
  " *koina* Schwager.
  " *skobina* Schwager.
Pulvinulinella bengalensis (Schwager).
Pyrulina labiata (Schwager).
Robulus javanus (Koch) *et var.*
Siphonina australis Cushman.
Siphonodosaria adolphina (d'Orbigny).
  " *maculata* (Schwager).
  " *insolita* (Schwager).
  " *setosa* (Schwager).
Sphaeroidinella kochi (Caudri).
  " *seminulina* (Schwager).
Textularia solita (Schwager).
Uvigerina gemmaeformis Schwager.
  " *hispida* Schwager.
  " *javana* Koch.
Vaginulina perprocera (Schwager).
Vaginulinopsis gradata Thalmann.
Vulvulina nicobarensis (Schwager).

5. Further Problems of Tertiary Correlation.

Much further work on stratigraphy and palaeontology of the Pacific Islands is required before the stratigraphic classification of the Tertiary sediments developed in the key areas of the East Indies can be extended over the whole Indo-Pacific Region. The main problems can be outlined as follows:—

(1) Correlation of the two post-Aquitanian Miocene stages (Rembangian and Preangerian) characterized in Java and elsewhere by distinctive species of mollusca, larger and smaller foraminifera.

(2) Confirmation of the existence of the Uppermost Miocene stage " g ".

(3) Correlation of the Cheribonian, Sondian, and younger molluscan faunas of Java which are known to represent the European Pliocene and Pleistocene on account of their relations to vertebrate-bearing beds, with the molluscan faunas of the same age from New Guinea and other islands.

(4) Study of the smaller foraminifera of the " Younger Tertiary " deposits reported from many islands between New Guinea and Tonga, with special reference to stratigraphic ranges, recognition of species restricted to the Miocene, and the gradual increase in the number of Recent species in younger deposits.

Faunal relations between the surprisingly uniform Tertiary of the Indo-Pacific Region and that of South-eastern Australia and New Zealand are limited and are either created by " eurythermic " species which were able to cross the boundary of the tropical belt or by short-lived climatic or ecologic changes creating a suitable environment for warm-water species and genera. In the Tertiary of Victoria the Batesfordian containing a group of *Lepidocyclines* as well as *Austrotrillina* and perhaps some other Indo-Pacific smaller foraminifera forms a short-lived link with the Indo-Pacific Region. I. Crespin (1941, p. 254) concludes " The Middle Miocene age is supported by a close study of the *Lepidocyclinae* (so characteristic of this stage) and *Cycloclypeus* and their relationships with Indo-Pacific assemblages ".

In New Zealand " *Miogypsina* appears for the first time, and is abundant in, and limited to, the Hutchinsonian. This also applies to our various species of *Lepidocyclina*, which are all Nephrolepidine ". (Finlay and Marwick 1940, p. 94.) Mr. W. J. Parr drew the writer's attention to the fact that F. Chapman had described *Lepidocyclina (Eulepidina) dilatata* (Michelotti) from Hokianga South Head, North Auckland, McKay's loc. 733 (F. Chapman, The Cretaceous and Tertiary Foraminifera of New Zealand. *N.Z. Geol. Survey, Pal. Bull.* No. 11, 1926, p. 93, pl. 20, f. 1) Material from this locality which was kindly made available by Mr. Parr from his rich collections, proves beyond doubt that a typical *Eulepidina* occurs in New Zealand, together with an undescribed species of *Nephrolepidina*, and also, according to F. Chapman (l.c.) together with *Miogypsina irregularis* (Michelotti). The species of *Nephrolepidina* mentioned by Finlay and Marwick have not been described or figured from New Zealand. These authors place the Hutchinsonian in the " Lower Miocene ".

Specific features and generic ranges of the majority of the Indo-Pacific larger foraminifera differ considerably from species and distribution of the same useful group of fossils in tropical

Central America. Owing, perhaps, to the vast distance in space or to the absence of Tertiary land bridges across the Pacific Ocean which would have provided suitable shallow-water environment, faunal links are extremely rare. In this respect the smaller foraminifera show very promising signs of intercontinental relations. To any student of the Indo-Pacific Miocene smaller foraminifera, the Bowden fauna of Jamaica or the fauna of the Port-au-Prince beds of Haiti recently described by Coryell and Rivero (Journ. of Paleont., vol. 14, No. 1, 1940), appear strikingly familiar. The uncertain stratigraphic position of Indo-Pacific Tertiary foraminiferal assemblages has hitherto prevented authors from attempting trans-Pacific faunal correlations. This work remains outside the scope of the present review.

III. Notes on the Geological History of the Indo-Pacific Region.

1. The relations of the Jurassic of New Guinea, North-western Australia, New Caledonia, and New Zealand suggest the existence of a Jurassic Circum-Australian geosyncline connected with the Timor-East Celebes geosyncline and linked with the Tethyan sea in the Himalaya.

2. While there are indications of a marine transition from Jurassic to Lower Cretaceous in the Timor-East Celebes geosyncline, pre-Aptian marine Cretaceous deposits appear to be absent in Australia and New Guinea. A similar but still ill-defined break is found between Jurassic and Cretaceous in New Caledonia. The time of this break corresponds to the important epi-Jurassic (Pacific or Young Kimmeric) phase of folding in New Zealand and elsewhere.

The time following immediately after the close of the Jurassic Period, shows throughout the area of the Jurassic Circum-Australian geosyncline clear signs of what Sir T. W. E. David, referring to Australia, called a "vast geographical change" (1932, p. 171). Aptian, Albian, Cenomanian, and possibly also Barremian are locally transgressive on Jurassic, Triassic, and older beds. The geographical continuity of the Tethyan fauna is temporarily interrupted by ecological (climatic?) and possibly also topographic barriers.

3. The range of *Globotruncana* rocks throughout the area shows that in the Senonian Epoch the Mediterranean (Tethyan) affinities in the Circum-Australian zone are restored, at least as far as planktonic foraminifera are concerned. The typically Mediterranean Senonian larger foraminifera (*Orbitoides,* etc.) are not yet known beyond Northern India and Burma, and there are certain specifically Pacific features in the Upper Cretaceous molluscan fauna.

4. Throughout the region east of Burma no fossiliferous deposits of Uppermost Cretaceous (Danian) or Lowest Tertiary age are known. The Eocene rest generally unconformably on older rocks (Umbgrove 1938, Table 6).

The late Cretaceous Laramic orogeny must have finally broken the continuity of Tethyan faunal relations. Epi-Cretaceous folding movements are reported to be widespread throughout the Timor-East Celebes geosyncline and extended probably to New Guinea where conditions before the end of the Cretaceous Period reverted to geosynclinal, and to New Caledonia. The Westralian part of the former Circum-Australian geosyncline shows according to Raggatt (1936) no signs of movement after the deposition of a typically epicontinental series of Upper Cretaceous sediments.

5. The difference between the western and eastern parts of the Circum-Australian area of Palaeogene deposition is very marked.

Umbgrove (1938, p. 34) states that in the East Indies "all marine Palaeogene sediments have been deposited in shallow epicontinental seas (neritic and littoral). The strong relief as we know it at this moment—the many deep sea basins—originated much later".

In south-eastern New Guinea and New Caledonia the Eocene is rich in siliceous rocks, partly containing abundant radiolaria, and is affected by basic intrusions. Although the presence of intercalated beds with abundant nummulites and other larger foraminifera makes an abyssal origin of the siliceous rocks improbable, their geosynclinal character can hardly be denied in view of many examples of similar rocks formed in pre-Tertiary geosynclines. More than purely ecological differences between the two areas appear to be expressed in this inequality of Palaeogene deposition. It is probably connected with the important "diversity of structural controls" between the Australian-Asiatic and the Australian-Pacific boundary zones, which was first postulated by W. N. Benson (1924, p. 133). If the existence of a similar development of siliceous rocks and basic intrusions in late Cretaceous and early Palaeogene time in the Arakan Yoma-Andaman arc is confined, then these occurrences would point to a remarkable parallel between the border zones of the Indian Ocean and of the Pacific.

6. During the Palaeogene and Miocene enormous thicknesses of sediments began to accumulate in some basins of gradual subsidence within the generally epicontinental and more or less stable areas. Umbgrove refers to these remarkable basins as "idiogeosynclines". North and South-east Sumatra, the central

belt of Java, and several basins in East Borneo are examples of such areas which contain the richest oil-bearing strata of the East Indies (Umbgrove 1938, pp. 39 ff., and also in: Vening Meinesz 1934, pp. 155 ff.).

Most of these idiogeosynclines began their existence later, in early Miocene time, partly in connection with a widespread transgression which Umbgrove named "Beboeloeh transgression" dating it as Upper Aquitanian (e_5). Other authors are only prepared to admit that transgressions occurred between Upper Oligocene and Lower Miocene. Several idiogeosynclines appear to have existed in the New Guinea area. Sedimentation in the idiogeosynclines ended generally in the Pliocene with the deposition of sediments in paralic facies (shallow water marine beds with coal and non-marine intercalations). The idiogeosynclines have been subjected generally to folding in late Pliocene and Pleistocene time.

On the north coast of New Guinea, in New Ireland, and in the Solomon Islands some of the widespread *Globigerina*-sediments belong to the Pliocene and Pleistocene. Locally even very young chalky radiolarian rocks are known (Tan Sin Hok 1926). This pelagic fauna and sedimentation indicates free connection with the open sea along the outer Pacific border rather than young submergence to abyssal or bathyal depth of these areas which are at present definitely rising.

7. The old Timor-East Celebes geosyncline, while not known to differ from adjoining areas in Tertiary sedimentary history, is characterized by strong intra-Miocene folding. According to the Dutch geologists a belt of less intensive folding follows the West coast of Sumatra and the South coast of Java and extends further eastwards.

8. Areas of more or less undisturbed Tertiary are found on the Sahul shelf and in North Celebes. Sundaland, including the east coast of Sumatra, the Malay Peninsula, and Western and Central Borneo, had become stabilized and was in Tertiary time above sea level. Plio-Pleistocene folding and uplift joined the area of the surrounding idiogeosynclines to that of Sundaland the Pleistocene outline of which is believed to be marked by a subsequently submerged shelf.

On the Sahul shelf and in North-western Australia mainly coralline and foraminiferal limestones were deposited in Tertiary time. In the former area the same type of sedimentation appears to continue to the present time while in the latter late Miocene or Pliocene folding or warping created wide folds with low-dipping flanks (Raggatt 1936, p. 169).

9. Data on the geology of New Guinea and other Pacific Islands are insufficient for general statements on their Tertiary history. Umbgrove considers late Miocene folding of the Main Range of New Guinea as possible and van Bemmelen (1939) assumes a Burdigalian (Rembangian) phase of folding followed by renewed Upper Miocene-Pliocene sedimentation. There is also ample evidence of Plio-Pleistocene folding. Fiji and Tonga, belonging to a stable area beyond the Circum-Australian folded belt, were subjected to uplift commencing in Miocene time (Ladd 1934, Hoffmeister 1932).

10. Our knowledge of the important young or Recent movements in the Pacific Islands will be greatly advanced when "raised reef limestones" and foraminiferal sediments will be assigned to the various Tertiary stages which some of them undoubtedly represent, or to the Quaternary, according to their fauna. In many earlier reports they have been summarily described as Recent or Pleistocene deposits in accordance with their often misleading general appearance. Recent work in the Fiji and Tonga Islands as well as Mr. F. Chapman's and Miss I. Crespin's numerous contributions to the problem show the paramount importance of the results of modern biostratigraphic work in the East Indies as a base for our understanding of the whole Indo-Pacific Region.

It is hoped that the critical review presented here will contribute, by stimulating discussion of the problems outlined, to further progress.

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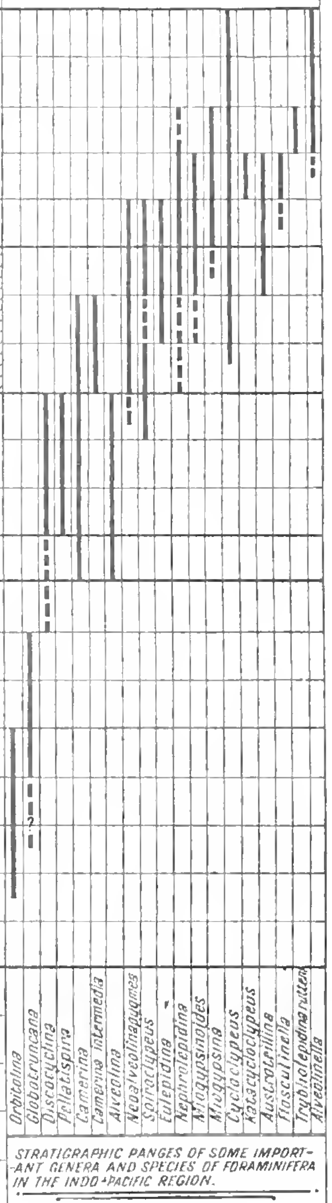
Correlation of Marine Rocks in the Indo-Pacific Region

Compiled by M F Glaessner 1942.

	EUROPEAN STAGES	INDIA (Selected areas)	BURMA	ANDAMAN AND NICOBAR ISLANDS	EAST INDIAN ARCHIPELAGO Western Part	EAST INDIAN ARCHIPELAGO Eastern Part	NORTH & N. WEST AUSTRALIA	QUEENSLAND	NEW GUINEA	SOLOMON ISLANDS	NEW CALEDONIA	NEW HEBRIDES	VITILEVU (FIJI)	EUA (TONGA)
PLIOCENE		Gwadar Mekran		(Highest Tertiary beds of Andaman Islands)	× Bantamian @ × Sondian @ Cheribonian @	Fufa beds and × equivalents @	Yardie Creek Coralline limestone		Brown coal zone Fossil zone Finsch Coast Brown coal beds: Cape Possession & equivalents @	? (Foraminiferal marls and tuffs)		(?Pliocene at Malekula)		(Coralline limestones)
MIOCENE	Pontian Sarmatian	Talar Mekran @	Irrawaddy @		× "g"	"g"			Globigerina zone × @ "g"	↓		↓		
	Tortonian Helvetian	NORTHERN INDIA	〰 Obogon @	? ● × Archipelago series	● × Preangerian @	● "f3"	?		● (Beds with Lepidocyclina rutteni,	↓		? ↓	? ↑	? (Foraminiferal tuffs with Aturia)
	Burdigalian	Upper Gaj	Kyaukkok (Prome, Pyalo) @		● × Rembangian @	● "f1-2"	●		Lepidocyclina limestone and conglomerate ● ● AITAPE ● Katacycloclypeus annulatus,	↓ ?		● Laleppe	● × Suva	?
	Aquitanian	● Lower Gaj @	Pyawbwe (Kama) @ 〰	〰?〰 ▨	● "e"	● "e"	● Cape Range Limestones		● Spiroclypeus Eulepidina Neoalveolina)	● Orovavi limestone			● Viti	▨
OLIGOCENE	Chattian	● Upper Nari	Okhmintaung (Singu) @	▨			?		〰?〰 ● (Beds with Camerina intermedia) Bootless ● Inlet Limestone					▨
	Rupelian	● Lower Nari 〰	● Padaung @	▨	● "d"	● "d"			〰 ▨					▨
	Lattorfian	▨	Shwezettaw	▨	● "c"	● "c"			▨					▨
EOCENE	Wemmelian Ledian	▨ Mula Pass (of Baluchistan)	● Yaw Pondaung @	▨ ?	● "a+b" @	● "a·b"	● Giralia limestone		〰?〰 (Discocyclina Alveolina Lacazina Limestones) Port Moresby beds		(Limestones marls and ● cherts)			(Discocylina ● limestone)
	Lutetian	● Kirthar @	Tabyin Tilin	(Eocene of Andaman Island)	〰?〰	〰?〰	?		● ↓ ●					
	Ypresian	● Laki @	Laungshe	〰?〰					〰?〰 ?		▨			
PALEOC.	Thanetian Montian	● Ranikot @	?	(Equivalents of Axials)	▨	▨	▨		▨ ?		▨			
CRETACEOUS	Danian	SOUTHERN INDIA Niniyur	"Axials"		▨	▨	▨		▨		▨			
	Senonian	Ariyalur			Martapoera	(Inoceramus-Radiolites marl)	(Limestone, Greensand Chalks) "Cardabia"		(Globotruncana limestones)		St. Vincent 〰?〰			
	Turonian	Trichinopoli				(Globo-truncana rocks)	↓ ?		?					
	Cenomanian	Utatur			Seberuang (West Borneo) (Orbitolina rocks in Java and Sumatra)	Upper Fatjet	Melville Island beds		Kerabi Valley ammonite beds		? ↑			
	Albian	Coral reef limestone 〰				Limestones and equivalents (No evidence of Albian, Aptian Barremian)	(Cherts & Siltstone) Cardabia beds "Winning" 〰	Tambo	? Purari River limestones and sandstones		Moindou			
	Aptian	KACH Ukra Hill					▨	Roma						
	Barremian Hauterivian	▨					▨	▨	? ▨		↓ ?〰〰? Dumbea ?〰?〰?			
	Valanginian Infravalanginian	▨ Lochambel			(Valanginian in Sumatra)		▨ ?	▨	▨ ?		▨ ?			
JURASSIC	Tithonian	Umia Chidamu				(more or less complete in geosynclinal facies)	▨	▨			La Foa 〰			
	Kimmeridgian	Katrol	Himalaya, Spiti shales				▨	▨	(Unknown)		▨			
	Oxfordian	Kantcote Dhosa (Belemnite beds)					(Buchia Belemnopsis beds of Broome)	▨	Buchia Belemnopsis beds		▨			
	Callovian	Chari						▨	(Shales with Ammonites etc.)		▨			
	Bathonian	Patcham			(Dogger and Malm in Borneo)		?	▨			▨			
	Bajocian				(Dogger in Sumatra)		(Beds with Ammonites)	▨			▨			
	Lias				(Lias in Borneo)			▨			▨			
Bibliographic References →		Cotter 1938a Holland 1926 Pilgrim 1928 Spath 1933 Vredenburg 1906, 1921, 1921a	Clegg 1938 Cotter 1938 Evans and Sansom 1941	Gee 1926 Oldham 1885 Tipper 1911	Le Roy 1941 Leupold and Van d Vlerk 1931 Oostingh 1938 Umbgrove 1935, 1938 Wanner 1931 Zeijlmans 1939	Caudri 1934 Fischer 1927 Leupold & Van d Vlerk 1931 Umbgrove 1935, 1938 Wanner 1931	Crespin 1938, 1938a Raggatt 1936 Singleton 1940 Teichert 1939 Whitehouse 1926	David 1932 Whitehouse 1926	Broili 1924 Crespin 1938b, 1939 Gibb Maitland 1905 Schubert 1911 Stanley 1923 Wyllie & others 1930 Twierzycki 1921, 1927, 1932	Guppy 1887 Mawson and Chapman 1935 Schubert 1911	Benson 1928 Piroutet 1927	Chapman 1905, 1907 Mawson 1905	Ladd 1934	Hoffmeister 1932



STRATIGRAPHIC RANGES OF SOME IMPORTANT GENERA AND SPECIES OF FORAMINIFERA IN THE INDO-PACIFIC REGION.

— EXPLANATION OF — SYMBOLS USED —

- ● Larger foraminifera } Described from Tertiary formations
- × Smaller foraminifera } Described from Tertiary formations
- @ Larger fossils } Described from Tertiary formations
- 〰 Unconformities
- ▨ Depositional or erosional hiatus or non-marine deposition.

[PROC. ROY. SOC. VICTORIA, 55 (N.S.), PT. I., 1943.]

ART. IV.—*The Geology of Bindi, Victoria.*

By A. J. GASKIN, B.Sc.

[Read 9th July, 1942; issued separately 1st May, 1943.]

Abstract.

South of Mt. Tambo, Middle Devonian limestones unconformably overlie metamorphic schists and gneissic granite. The granite is intrusive into sandstones, presumed to be of Upper Ordovician age. A flow of rhyo-dacite overlies the schist complex, and is conformably overlain by the Middle Devonian limestones. Petrographically the flow is identical with flows at Buchan, classed with the "Snowy River Porphyries".

The structure of the limestones is a westward-dipping monocline of variable dip, which has been faulted into its present position, with the development of an extensive shear zone along its north-eastern boundary. Upper Devonian conglomerates overlie the limestones, with no evidence of a major angular unconformity. The conglomerates have been involved in the shearing processes, with the limestones.

Introduction.

The area dealt with in this paper comprises the major portion of the Parish of Bindi, together with portions of the surrounding parishes of Moonip, Eucambene, Terlite-Munjie and Ensay. The approximate boundaries are: to the north and west, the Tambo River; to the east, the Nuniyong Plateau; and to the south, Junction Creek and the ranges west of Mount Bindi. Access to the parish is gained by a single track from Tongio, which is on the Omeo Highway, about 60 miles north of Bairnsdale.

The earliest published reference to the area is that of A. R. C. Selwyn (1866) in which he suggests that the Bindi limestones overlie the "plant-bearing sandstones and conglomerates" of

Mount Tambo. The age of the limestones was shortly afterwards established as Middle Devonian by McCoy, who in 1876 listed the fossils then known.

A. W. Howitt, in his classic paper on the Devonian rocks of North Gippsland, produced evidence to show that the limestones underlie the Mount Tambo beds and overlie the quartz porphyry and gneissic granite. He also showed that the Tambo beds were not metamorphosed to the same extent as the Upper Ordovician, attributing the changes produced in the Tambo beds near their contact with the granite, to percolation of siliceous solutions along this plane of weakness. Although he found westerly dips to prevail throughout the limestones, he postulated a synclinal attitude for these beds, regarding them as having been deposited on a granite-quartz porphyry basement complex, and subsequently undergoing open folding and erosion. Their denuded remnants were then covered by the Tambo beds.

J. Stirling (1884) noted the occurrence of marble at Bindi, and assigned its origin to the contact metamorphic effect produced in the Middle Devonian limestones by the quartz porphyry, which he considered to be intrusive. In the bed of Old Hut Creek, he recorded "protruding blocks of purplish and brownish conglomerate, the dip being rather obscure." Since these blocks were at a lower level than the limestone outcrops, he considered that they, and the analogous Tambo beds, underlay the Middle Devonian. It can now be shown, however, that this apparent discrepancy is due to faulting. In a later paper (1886) he developed his idea, mapping a coarse reddish conglomerate as extending underneath the Bindi limestones and outcropping along most of their eastern boundary. During 1886, however, he worked in collaboration with Howitt, and they concluded that the porphyry was not intrusive, the marmorisation being due to the pressure exerted on the limestone by a once considerable thickness of overlying rocks. Howitt also showed that the evidence given by Stirling regarding the Lower Devonian age of the Mount Tambo beds was inconclusive. In a report on a survey of the parish of Bindi, O. A. L. Whitelaw lists and briefly describes the various formations. His summary of the history of the area in no way differs from that given by Howitt.

Physiography.

The Bindi limestones lie in a topographic basin, bounded on all sides by steep ridges of harder rocks. The limestones have been let down into their present position by faulting, and, owing to their greater susceptibility to erosion, the area in which they occur has been reduced in level below that of the surrounding ranges.

In the northern part of the area, the Tambo River flows westward, skirting the edges of the massive conglomerates and sandstones of Mount Tambo, and forming the northern boundary of the parish of Bindi. Just before reaching the granite, the river swings in a right-angle bend, and flows southwards through a zone of fractured gneissic rock which extends parallel to the old fault line determining the western boundary of the limestone. In this part of its course, the river is joined by three tributaries—Old Paddock Creek, Bindi Creek and Junction Creek. Old Paddock Creek drains the acid lava flows covering the eastern portion of the parish of Bindi and the lower ridges of the Nuniyong Plateau. In its upper course, this creek flows north-west, following the strike of the limestones along their eastern escarpment, and then cuts through the limestone escarpment to flow westward through less resistant shaly limestones. Bindi Creek flows north-west through the centre of the area, draining the dip slopes of the limestones. Junction Creek marks the southern boundary of the basin. It rises on the western slopes of Mount Bindi and flows westward over the metamorphic rocks of this part of the area.

The greater part of the limestone is covered with a thick mantle of reddish soil, and is almost treeless, the rounded grassy slopes contrasting sharply with the forests and rugged peaks of the surrounding ranges, many parts of which are so precipitous as to be almost inaccessible. With the exception of a sheep station and one or two small farms along Bindi Creek, the district is uninhabited, the only part which has been surveyed by the Lands Department being the limestone area contained within the parish of Bindi.

The Metamorphic Complex.

The basement complex of the Bindi area comprises rocks typical of the Metamorphic Complex of north-east Victoria. The eastern portion of the parish of Bindi is composed of regionally metamorphosed sillimanite-garnet-mica schists and gneisses, comparable with the rocks described by Howitt (1888) in the "Omeo Series," and later described as regionally metamorphosed Upper Ordovician sediments by Tattam (1929). In the western portion of the parish a gneissic granite is intrusive into acutely folded sandstones and shales, which show no trace of regional metamorphism. They are, however, lithologically identical with the series extending to the south of Bindi, which is mapped as Upper Ordovician by the Geological Survey The occurrence of such widely different metamorphic types within the parish of Bindi could be due either to extensive faulting or to a stratigraphical unconformity between the regionally metamorphosed series and the almost unaltered sandstones and shales. The sharp line of junction between the two formations seen at Junction Creek and the absence of basal conglomerate in the sandstone-shale series suggests that faulting has been the more probable mechanism. In the regions to the south and south-west of Bindi, the Palaeozoic formations are similar in most respects to the rocks of the Junction Creek area, generally comprising indurated and silicified sandstones. The boundary line separating these types from the regionally metamorphosed Omeo series is defined by a system of faults, one of which strikes N.N.W. through the Bindi area. A similar abrupt junction to that at Junction Creek occurs at Tongio Gap, where Howitt (1888) describes a major fault striking N.W. and persisting for many miles.

Schists and Gneisses of the Omeo Series.

Howitt originally divided this series into two main groups of rock types:

(i) Schists and phyllites resulting from the alteration of a series of Upper Ordovician sediments.

(ii) Gneisses and schists produced by the effect of pressure metamorphism on the intruding granites, i.e., ortho-gneisses.

Both groups are present in the portion of the complex exposed on the western and northern slopes of Mount Bindi. Owing to the inaccessibility of the country, little is yet known regarding the relative positions of the bands of sillimanite schist and gneiss, graphitic schist, and biotite schist which make up this region. The various bands of schist and gneiss alternate rapidly, reflecting the original compositions of the sediments, which can be inferred to have comprised sandstones, aluminous shales, carbonaceous sandstones, and types intermediate between these. The general strike of the beds is slightly to the west of north, dips generally being erratic, but always at high angles. Lustrous, fine-grained, sillimanite schists are well developed along the southern bank of Junction Creek, immediately south of the limestone termination, and east of the extension of the line of faulting which determines the western boundary of the limestone. West of this line of faulting, the schists are absent, their place being taken by granite and indurated sandstone.

Upper Ordovician.

The ridges of indurated sandstone and shale occupying the south-west corner of the parish of Bindi represent the north-eastern boundary of the sandstones typical of the Swift's Creek district. In the lack of palaeontological evidence they are provisionally regarded as belonging to the lithologically similar Upper Ordovician formations of north-east Victoria. Although indurated and disrupted by a local granitic intrusion, they show no trace of the intense metamorphism which has affected the (?) Upper Ordovician rocks in the eastern portion of the parish. The granite causing the contact metamorphism of the sediments is typical of the plutonic rocks of the metamorphic complex of north-east Victoria, showing petrographic similarity with both the gneissic granites of Omeo and the more normal granites of Ensay, to the south of Bindi. Movement along flow planes during the later stages of intrusion, coupled with the development of cataclastic structures by movement along shear planes subsequent to consolidation, has given the rock a foliated appearance, which is more strongly marked in the outcrops near Junction Creek, where the rock grades into an ortho-gneiss.

It is probable that a small area of sericite-chlorite schist on the northern slopes of Cairn Hill belongs here, since it shows little affinity to the rest of the Omeo schists. It probably represents a small roof pendant of Upper Ordovician, similar to those found to the west across the Tambo. Field relations at this point are rendered obscure by the presence of a number of massive quartz veins between the schist and the limestones. Mineralised fissures in the quartz contain chalcopyrite, azurite, and small amounts of gold and silver.

Acid Extrusives.

Along their eastern boundary, the Bindi limestones rest partly on metamorphic rocks, and partly on an acid lava flow which occupies the north-eastern portion of the parish and the areas to the north, on the east side of Mount Tambo. This flow was included by Howitt (1876) in the extensive series of eruptives and pyro-clastics forming the "Snowy River Porphyries." Stirling, however, later (1886) described the flow at Bindi as distinct from the main mass of L. Devonian eruptives in eastern Victoria. The present work confirms Howitt's views, correlating the flow at Bindi with petrographically similar types at Mt. Cobberas, Wombargo, and Murrendel. Tuffaceous phases occurring at Bindi show the characteristic features of the fragmental rocks common in the "Snowy River Porphyry" complex. These tuffs are well exposed along the southern limits of the lava flow, comprising several varieties intermediate between massive red lavas and silicified white tuffs streaked and spotted with purple and red material. The similarity of this rock in the field to the conglomerates of Mount Tambo seems to have given rise to Stirling's misconception as to the "Lower" Devonian age of the latter series. The tuffaceous material definitely underlies the Middle Devonian, but, when sectioned, bears no resemblance to a true conglomerate.

A petrographic examination of the massive lava (see p. 23) shows that the rock is of the rhyo-dacite type, corresponding to dellenite as described by Brögger. The toscanites and quartz-latites approach the dellenites in composition, but are to be distinguished therefrom by slight differences in the composition of the plagioclase and the amount of quartz present, respectively. Considering the similarity between the flow at Bindi and other flows scattered throughout the Snowy River volcanic complex, it is expected that the bulk of the complex will eventually be shown to be composed of true "volcanic" rocks, so that the term "Snowy River Porphyries" should at present be replaced by the more noncommittal term "Snowy River Series." Such a series could be understood to include rhyo-dacites, pyroclastics and tuffaceous extrusives, as well as true hypabyssal porphyries and porphyrites, if the existence of such can be established. Skeats (1909) suggested that some of the more fluidal types should be termed rhyolites. Evidence is now pointing to the term "rhyo-dacite" as a useful general, though fairly exact, description of most of the rocks comprised in the "Snowy River Complex."

Bindi Limestones.

NORMAL LIMESTONES.

The "Bindi limestones" consist of shallow-water marine limestones and calcareous shales, which have been shown on palaeontological grounds to be of Middle Devonian age. (Howitt, 1876; McCoy, 1877). The beds have been regarded as having originated under shallow water conditions in a small marine basin, isolated from the main sea in which the more extensive limestone deposits of the Buchan district were being formed. (Howitt, 1876; Whitelaw, 1898). However, the present boundaries of the limestones are not those defined by the limits of sedimentation in the original sea or estuary, but are largely fault boundaries. It is thus inferred that the Devonian limestones and conglomerates in this area once formed part of more extensive formations, the bulk of which has been removed by erosion. The existing remnants at Bindi have been preserved by down faulting. Howitt (1878) described similar extensive faults along the edges of the limestones at Buchan and Murrendel.

Lithology.—The limestones occupying the central areas of the tilted fault block have entirely escaped cataclastic disruption, whilst near the eastern edge of the fault block extreme deformation indicates the extent of the faulting. These latter features of deformation will be described below in the section on marmorised limestones. The normal limestone beds in the central areas show few signs of shattering or flexure, and preserve their original relations to one another. These beds comprise massive blue-grey limestones, with minor amounts of impure thin-bedded limestones. The thick massive limestones are rich in stromatoporoids and corrals, whilst the thin argillaceous beds are crowded with brachiopods. Along the north-eastern boundary a few outcrops of fine sandstone and shale are exposed.

Along Old Paddock Creek, black calcareous shales are interbedded with thin discontinuous bands of massive, sparsely fossiliferous, limestone. The alternation of shale and limestone is fairly regular, the distance between any two bands of limestone rarely exceeding 6 in. The conditions under which such a deposit could form would probably occur in a marine environment subject to a seasonal influx of water charged with fine silt. The presence of such argillaceous material in quantity would render impossible the growth of the fossils which usually characterize limestone deposits; thus it is found that the shale is completely unfossiliferous, whilst the recognizable forms in the limestone bands are both stunted and rare.

In general, the thick beds of "stromatoporoid" limestones are the purest in the area, and correspond closely with the normal Buchan limestones in lithology. Thinly laminated argillaceous limestones with innumerable brachiopods are widespread in the Bindi area, and are usually rich in both carbonaceous and sulphur-bearing impurities. The white chalky limestone mentioned by Whitelaw (1898) is a secondary deposit, similar in some respects to travertine. It is friable in texture, often with a "honey-comb" surface structure, and is most abundant on the dip slopes of the limestones.

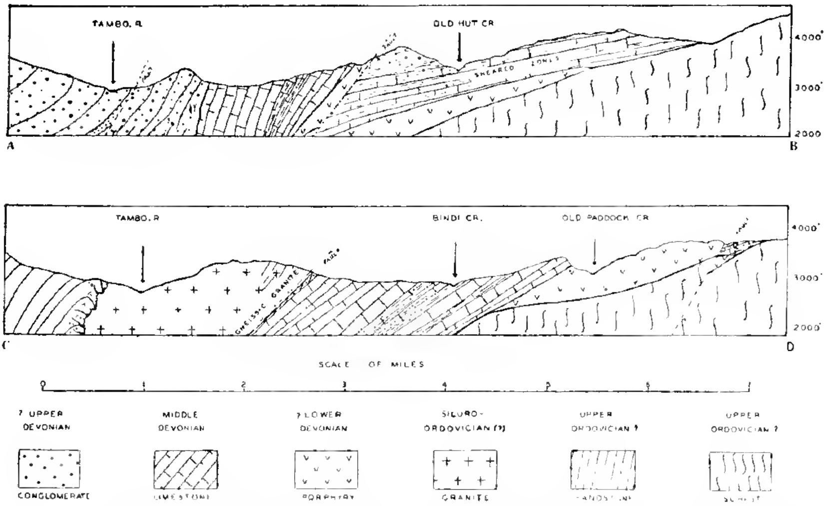


Fig. 1.—Diagrammatic sections across the Bindi Limestones from A to B and from C to D on the geological sketch. Contours are approximate and vertical scale 1 inch = 4,000 feet.

Field Relations.—The whole of the unaltered limestones occupying the central area of the parish of Bindi appear to be contained in one single block, which has undergone tilting in a westerly direction combined with slight torsional flexing, giving gradually increasing dips as the northern boundaries are approached. Dips in the southern portion of the area range from 15°W. to 30°W., whilst in the northern half of the area the range is from 50°W. to 80°W.

A continuous series of dips can be observed along Old Paddock Creek, where a traverse from west to east suggests that the major structure has originally been a broad, open, monoclinal fold of limestone, the western edge of which has been faulted into contact with the granite, whilst the eastern extension of the fold has been removed by erosion. The area of limestone further to the east seems to represent a down-faulted block which possibly formed the footwall of an extensive thrust fault, shearing along which has caused intensive distortion of the limestone and the Tambo conglomerates which here overlie them (see "Marmorised Phases"). Thus it is found that dips at the contact of the limestones with the granite are from 60°W. to 80°W., i.e., the beds dip into the granite at a high angle. Proceeding eastwards, the inclination of the beds gradually decreases, until on their eastern boundary they become horizontal, then, over a small area north of Old Hut Creek, they dip eastwards at about 30°. This is probably due to drag associated with the subsidence of the north-eastern block. The limestones cannot be traced any further eastward owing to the sudden appearance of sheared and distorted purple conglomerates belonging to the Mount Tambo series.

An alternative view could be advanced regarding the structure of the limestones, whereby the beds are overfolded along a north-south axis, to form an acute asymmetric syncline with its axial line crossing Old Paddock Creek at a point about 600 yards east of the limestone-granite contact. The fact that no such axis could be detected in the beds along Old Paddock Creek discredits this synclinal hypothesis. Since the whole of the limestone outcrops across the area appear to represent beds conformable to one another, the total thickness of limestone and calcareous shale in the series is of the order of 3,000 ft.

The eastern boundary of the limestones is an erosion escarpment up to 200 ft. in height, which forms cliffs along the upper portions of Old Paddock Creek and Bindi Creek. Definite evidence that the beds were originally continued on towards the east, over the rhyo-dacite core of the fold, is provided by the occurrence of sheared and "stretched" marmorised limestones for some miles beyond the eastern boundary of the normal limestones. The significance of this occurrence has been apparently overlooked by Howitt and Whitelaw. Although Stirling (1884) recognized the northern limit of the zone, he did not attempt to explain the intensely sheared rock types.

Although earlier reports of Stirling and Howitt mention basal conglomerates in the Bindi limestones, which they emphasized as confirming the basin-deposition theory, no such basal conglomerates could be found along either the eastern or western

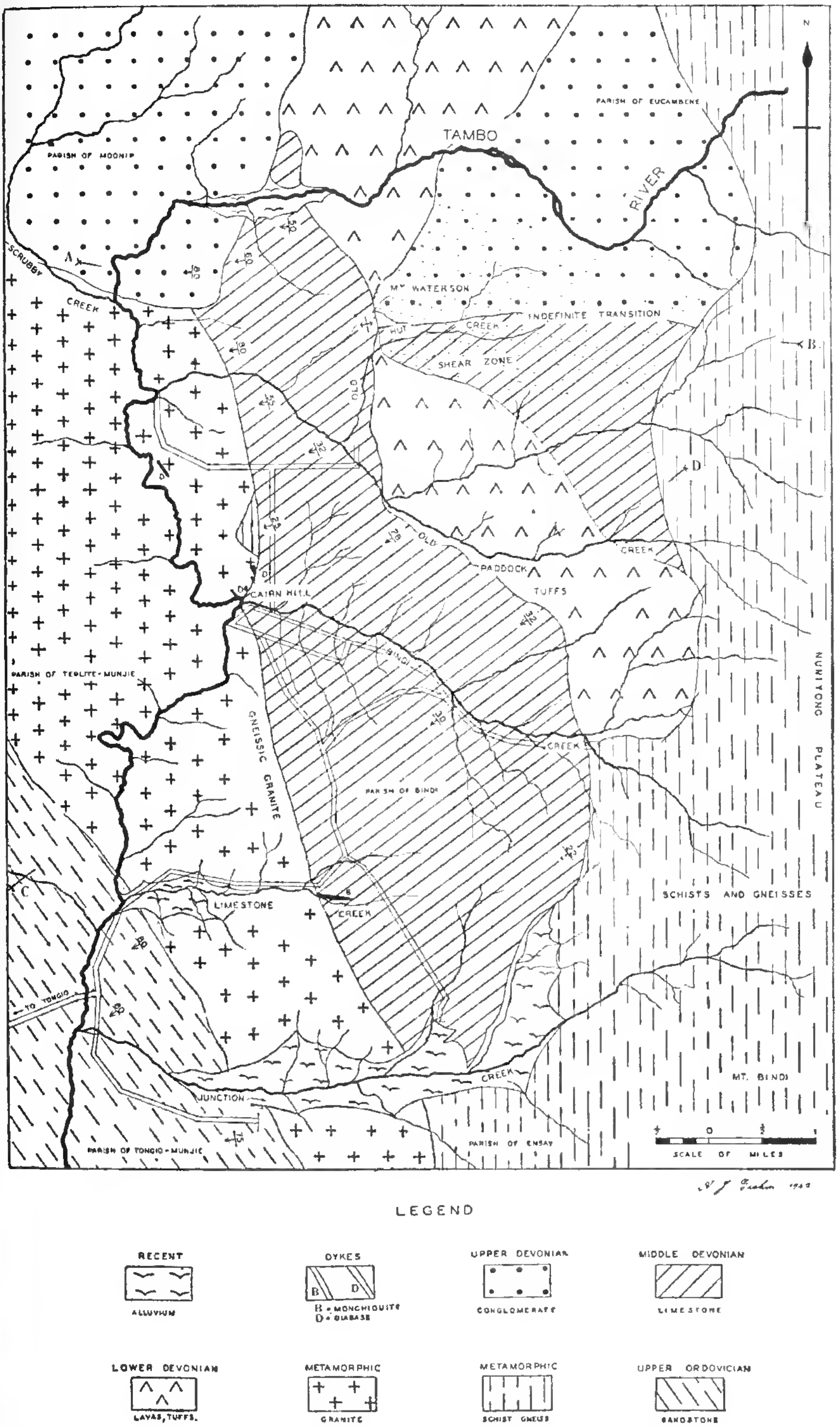


Fig. 2.—Geological Sketch Map of the Bindi Area.

boundaries of the limestones. The basal beds of the limestone series are well exposed in the cliffs of the erosion escarpment, and everywhere it was noted that the basal beds were massive and shaly limestones exactly corresponding to the beds occurring higher up in the series. These calcareous beds rest directly on either the rhyo-dacite, its tuff phases (which strongly resemble conglomerates in the hand specimen), or the metamorphic rocks in the southern corner of the area. The supposed "basal conglomerates" may be identified with the uppermost "tuff" bands of the lavas.

In the extreme south of the parish, the limestones disappear at Junction Creek, without any apparent lithological or structural changes having taken place, and are replaced on the southern bank of the creek by precipitous cliffs of Upper Ordovician shales and sandstones to the west, and to east the metamorphic granite and schist of Mount Bindi.

To the north, the limestones pass under the conglomerates and sandstones of Mount Tambo. The two formations have strikingly similar attitudes, the extreme angular unconformity noted at Tabberabbera between Middle Devonian limestones and shales and Upper Devonian sandstones and conglomerates (Skeats, 1929) being absent. The southern extremity of the Mount Tambo beds overlaps the western boundary of the limestones to a slight extent, but in the field there is no indication of the mechanism by which this has been brought about. The limestones here dip at about 80°W., and, within a few yards, are abruptly replaced to the north by coarse felspathic sandstones and conglomerates of the Mount Tambo series in a massive sequence of beds striking parallel to the limestones and dipping like them at about 80°W. The north-eastern corner of the limestone area shows the beds dipping fairly steeply to the west, with a rugged erosion scarp where they have been removed from the crest of the fold, exposing once again the core of rhyo-dacite, which itself shows signs of broad folding and fracturing where it is exposed along the Tambo River.

The western boundary of the limestones is remarkable primarily for the straight-line junction between the sediments and the granitic rocks. In the field the line of junction can be traced for six miles over steep hills and down into valleys without any major deviations from a north-south line. This boundary cannot represent the boundary of a basin-like deposit, which should show an indented line of junction depending on the altitude of the surface outcrops. In addition, the limestone beds dip to the west throughout the area. A formation deposited in a marine basin, or subsequently converted into a structural basin by folding, would show beds dipping in opposite directions on either side of the area of outcrop, hence it must be assumed that the junction between the limestone and the granite at Bindi is the result of faulting along a north-south line. Abundant evidence of cataclastic disruption can be found at the fault junction. Most of the disruption has apparently taken place in the border zone of the granite, which shows considerable shearing. Fault agglomerates and slickensided surfaces are developed to some extent on the hillsides north and south of Bindi Station, but elsewhere the rock in the crush zone is sheared and broken up into a characteristic mass of fine quartz particles interspersed with biotite, chlorite, and secondary calcite. The entire absence of any traces of thermal metamorphism in the limestones shows that the granite has not intruded these beds. Intensive search failed to reveal any evidence of recrystallization or even of induration in the limestones along their western boundary.

Palaeontology.—The fossils in the limestones, though abundant and often well-preserved, are limited throughout to a few characteristic generic and specific groups. A review of the literature has shown that the following forms from Bindi have been recorded.

STROMATOPOROIDEA.—*Stromatopora concentrica* Goldfuss, 1826.
Syringopora speleana Etheridge, Jr., 1902.

PORIFERA.—*Receptaculites australis* Salter, 1859.

ANTHOZOA.—*Favosites multitabulata* Etheridge, Jr., 1899.
(*F. gothlandica* of Stirling, 1886.)
Campophyllum gregoryi Etheridge, Jr., 1892.
Cystiphyllum (?) sp.

BRACHIOPODA.—*Atrypa aspera* Davidson, 1865.
Atrypa reticularis Linnaeus, 1767.
Chonetes australis McCoy, 1876.
Spirifer yassensis De Koninck, 1877.
(*S. laevicostata* of McCoy.)
Spirifer howitti Chapman, 1903.

PELECYPODA.—*Pterinaea* sp.

CEPHALOPODA.—*Danaoceras* (?) *bindiense* Teichert 1939.
(*Phragmoceras subtrigonum* of McCoy.)
Goniatites sp. (?)

PISCES.—*Phlyctaenaspis* (?).
(*Asterolepis* of McCoy.)

Most of the forms previously recorded from Bindi were identified in the course of the present survey, although types such as the ganoid scales mentioned by Whitelaw (1898) and the Asterolepid recorded by McCoy (1877) were not observed. Fragmental forms occur which bear some resemblance to the *Phragmoceras subtrigonum* of McCoy, which has recently been re-described as a new form related to *Danaoceras* (Teichert. 1939). A thin, but well-defined band of blue limestone about 80 ft. up the cliff along the western bank of Old Paddock Creek is crowded with well-preserved casts of *Tentaculites,* closely comparable with *T. ornatus,* one or two specimens showing traces of striae between pairs of individual transverse ribs. *Leptaena* and *Orthis* are plentiful in the shaly limestones along Bindi Creek. A cast of a form strongly resembling *Cyclonema* was also found in the Bindi Creek beds. The massive limestones to the east of this locality yielded a large *Euomphalus,* and numerous sections of shells of the *Loxonema* type. Crinoid ossicles and long stems (up to 4 in.) are extremely abundant throughout the whole of the Bindi deposits, but no calices have been observed.

A comparison of the fauna with that of Buchan indicates general similarity, though the trilobites, gasteropods, and lamellibranchs found at Buchan are unknown or very rare at Bindi.

On the whole, the fossils are typically Devonian types, some such as *Spirifer yassensis* and *S. howitti* being characteristic of the Middle Devonian, whilst *Leptaena, Orthis, Chonetes* and others persist throughout both the Silurian and Devonian. An exact determination of the horizon of the deposit relative to the European series could probably be obtained by detailed examination of the Stromatoporoid or Coral faunas. Thus, if the previous identifications of *Stromatopora concentrica* are upheld, the possible age of the Bindi limestone series is restricted to the Givetian horizon of the Middle Devonian.

MARMORISED LIMESTONES.

Rocks of both the Middle Devonian limestone series and the Mount Tambo conglomerate series are exposed over an area of about 5 square miles surrounding the upper reaches of Old Hut Creek. The appearance of these rocks in the hand specimen and under the microscope indicates that they have undergone intense shearing, with consequent elongation of the various sedimentary components along the shearing planes. The dominant mechanism of elongation could have been either "stretching" of the material in the direction of movement of the sheared layers (elongation along the "A" axis of the tectonite) or elongation due to "rolling" of the material between shear surfaces with consequent extension of the grains and pebbles in a direction parallel to the intersection of complementary shear planes, but at right angles to the direction of movement (i.e., elongation by rotation about the "B" axis of the tectonite).

The first process would require extensive intergranular movement along shear planes at a low angle to the horizontal (about 25° as shown by the dip of the elongated fragments). Such movement could only have been produced by thrust faulting. In the field, the direction of slip along such a fault, as deduced from the direction of elongation of the sedimentary components, is in approximate agreement with the direction from which the compressive forces producing the granite-limestone thrust fault in the west must have acted. There is thus some reason to attribute the distortion and marmorisation of these rocks to the action of a second thrust plane extending underneath the eastern boundary of the normal limestones.

Elongation by rotation about a "B" axis would correspond in the field to the action of normal block-faulting. The shear zone in such a case would be a downthrown block, defined by a north-south fault along its western edge. It seems very improbable that block faulting could result in a shear zone of such lateral extent as that exposed in this part of the Bindi area.

Lithological Characteristics and Field Relations.—The Middle Devonian beds in the shear zone comprise massive blue limestones grading into calcareous conglomerates, the latter being in turn replaced by the siliceous conglomerates of the Mount Tambo series. This apparent gradation suggests that the time interval between the deposition of these formations was not as great as their allocation to the "Upper" and "Middle" Devonian periods would suggest. It is possible, however, that intermixing of the two formations has occurred during faulting.

At the western boundary of the shear zone, the limestones are almost normal, with abundant recognizable fossils (Plate 1, fig. 5). Proceeding eastward, however, the shear planes become more pronounced until the rock grades into a fine-grained "marmorised" type, in which the bedding planes have been almost obliterated (Plate 1, fig. 6). As far as could be determined, the pinkish iron-stained seams which represent the original bedding strike approximately north-west, dipping at 50°–55° to the south-west.

The shear planes, along which the rock cleaves readily, strike at 68°–70° west of north, dipping in a southerly direction. Towards the north, the limestones are gradually replaced by calcareous conglomerates, in which the pebbles are considerably elongated in the direction of the shear planes. The dip of the "stretched" pebbles along the direction of elongation is at a low angle to the west.

Further to the north in the shear zone, the calcareous conglomerates are themselves replaced by siliceous conglomerates, at first yellow to brown in colour, but ultimately showing the reddish-purple tints characteristic of the Mount Tambo beds.

The northern portion of the sheared area is composed entirely of these purple conglomerates, which are obviously the sheared representatives of the normal purple conglomerates exposed on the slopes further north at Mount Tambo. The strike of the shear planes in these latter conglomerates is rather different from that in the marmorised limestones, being 25 degrees west of north, whilst the dip is indeterminate owing to the massive nature of the bedding. Tension gashes are strongly developed at right-angles to the elongation of the pebbles.

Considering the extent and unusual lithological features of the sheared formations, it is surprising that so little mention of their occurrence has been made. Stirling (1884) in a note on the deposit suggested that the marmorisation was due to the quartz porphyry (rhyo-dacite) which he regarded as intrusive into the limestones. Howitt later discredited this view, and suggested that the changes in the limestones were due to the hydrostatic pressure exerted by an enormous thickness of overlying rocks. It is now apparent that a sufficient mass of rock could not overlie the limestones so as to marmorise one portion and yet leave the beds one hundred yards away almost unaffected. Whitelaw (1898) does not seem to have recognized the sheared easterly extension of the limestones, as his map shows the whole of this particular area as Upper Devonian conglomerate. The significance of a shear zone of such dimensions lies in the fact that its existence confirms, to some extent, the importance of faulting in the structural control of this particular portion of the Dividing Ranges.

Mt. Tambo Series.

The course of the investigation into the relations of the Bindi limestones provided some opportunities of examining the formation which constitutes Mount Tambo and the surrounding rugged country extending southward to Mount Waterson in the parish of Bindi. Two significant facts were specially noted in regard to the age of the Mount Tambo beds:

(1) In every case where the normal contact relationships between the Mount Tambo beds and the Middle Devonian limestones can be observed, it is found that the limestones are inclined in the same direction and to much the same extent as the Mount Tambo beds, and underlie the latter.

(2) Although the relationships in the north-east of the area are complicated by a shear zone due to faulting, the Middle Devonian limestones are separated from the typical Mount Tambo conglomerates by a zone of calcareous and siliceous conglomerates which may represent transitional deposits connecting the two formations.

A rather obscure exposure on the limestone-granite junction about $1\frac{1}{4}$ miles south of Bindi Creek shows coarse conglomerates between the two formations, dipping at a slightly higher angle than the limestones, but in the same direction. The rock is identical with the basal bed of the Mount Tambo series as described by Howitt (1876) and contains fragments of quartzite, quartz, and indurated slate.

The inference to be drawn from these statements is that, although the Mount Tambo series is on a higher horizon than the Middle Devonian limestones, the relationship between these two formations is in the nature of a disconformity, in contrast to the well-marked angular unconformity between the Middle Devonian Tabberabbera shales and the Upper Devonian Iguana Creek beds. Hence, assuming that the Middle Devonian beds of Bindi and Tabberabbera are contemporaneous, it seems that the Mount Tambo beds should be placed on a considerably lower horizon than the Iguana Creek beds. The matter cannot be decided on palaeontological grounds, since, although the Upper Devonian age of the Iguana Creek beds is suggested by the presence in them of the Cordaites-Archeopteris flora, no authenticated fossils have ever been recorded from the Mount Tambo beds. A single fish plate has been found on the top of Mount Tambo, but its affinities are not restricted to the Upper Devonian. Selwyn (1866) reported "plant-beds" at Mount Tambo, but no traces of any such have ever been subsequently found.

Much of the lithology of the Mount Tambo beds has been described by Howitt (1876) and Whitelaw (1898). However, an examination of the beds of this series exposed in the parish of Bindi showed two types not previously recorded: (1) sheared conglomerates; (2) arkoses. The rocks of the former group have already been noted as the Upper Devonian equivalents of the sheared limestones. Notwithstanding their hard and brittle nature, the quartz pebbles and grains of the Tambo beds have been distorted by the faulting into long needle-like splinters. The formation covers an area of a few square miles in the north-east of the parish, the resistant character of the rock giving rise to the precipitous heights of Mount Waterson. The arkoses form the massive sequence north-west of the Bindi limestones. The formation is remarkably uniform throughout the first 200 feet from the limestone contact, the general appearance being that of a yellowish grit, containing rare rounded quartz pebbles. The extent of this arkose has not been determined in the field.

Section No. 6012 shows the arkose to consist of rounded quartz grains set, with numerous felspar fragments, in a fine-grained siliceous ground-mass.

The edges of many of the quartz grains are not smooth, however, but show angular projections and embayments, suggesting that little transportation preceded sedimentation. The large angular fragments of felspar crystals also suggest rapid sedimentation at no great distance from the parent granite. The granitic rocks to the south of the outcrop are a possible source of the arkose components. However, the biotite, chlorite, and muscovite of the granitic rocks have not been found in the arkose. The quartz grains in the latter show intense internal strain effects, undulose and "shatter" extinction being much more prominent in these grains than in the quartz crystals of the granite (Plate 1, fig. 4).

Hypabyssal Intrusions.

Pegmatite.—Coarse tourmaline-bearing pegmatites, aplites and masses of graphic granite are common in the metamorphic "Omeo Schist" series in the south-east of the area. The dykes are similar in all respects to those commonly found throughout the whole of the north-eastern "Metamorphic Complex." One pegmatite vein occurs in the granitic rock in the south-west of the area.

Diabase.—A suite of decomposed basic dykes strikes north-west through the granite slightly to the north of Bindi Creek. The disturbed nature of the rocks in this region makes it impossible to trace the individual dykes for any appreciable distance, but all were found to end at the limestone contact. A well-exposed dyke in the bed of the Tambo River could be traced for 20 feet, but was then found to be cut off, presumably by faults. The dyke represents a fragment torn from a longer dyke by the faulting in the granite, there being many small fragments of similar dykes in the surrounding granite. These dyke fragments are almost indistinguishable from massive limestone in hand specimens. The dykes themselves are rarely more than 2 feet in thickness.

Monchiquite.—A peculiar type of basic dyke or dykes outcrops in the south-west portion of the limestones, immediately north of Limestone Creek. The accumulated thick soil on the hillside at this point obscures the shape of the outcrop as a whole, but fragments of the rock are exposed over an oval area of greatest length about 300 yards, suggesting a plug-like intrusion rather than a dyke. The surrounding rock is massive limestone, and fragments of it may be seen to be included in the basic dyke near the contact of the two rocks. The heat of the intrusion has only been sufficient to drive off the CO_2 of the limestone, leaving an impure yellow lime.

Petrographic Descriptions.

[Numbers in brackets refer to slides in the collection at the Department of Geology, Melbourne University.]

Sillimanite Schist.

The hand specimen is a greenish-brown fine-grained lustrous schist. It outcrops along Junction Creek to the east of the indurated Upper Ordovician-granite series. A large part of the section (No. 5991) is composed of sillimanite (fibrolite) in extremely fine felted fibres. A few shreds of reddish-brown biotite grade out into masses of fibrolite.

The large amount of sillimanite present—about 50 per cent. of the rock—in the complete absence of cordierite, pinite or andalusite, can conveniently be accounted for by assuming the metamorphic process to have been of a fairly intense thermal type, combined with a certain amount of orogenic pressure. The oriented structure of the schist, parallel layers of sillimanite alternating with chlorite-quartz layers, shows that stress conditions have been of importance during its formation.

All biotite has subsequently been chloritized, with the exception of isolated, red-brown shreds, occupying the centres of thick masses of fibrolite (Plate 1, fig. 3). Pleochroic haloes are frequent in the biotite and are represented in the chlorite by dark non-pleochroic stains. The haloes often surround recognizable zircons, which are plentiful in both schist and gneissic granite. Much of the fibrolite is intergrown with quartz, the needles of the former penetrating the edges of the quarz grains and giving them their serrated boundaries. Usually the central areas of the quartz grains are fairly free of included needles, but smaller grains are often split up into shred-like laminae, by bands of fibrous sillimanite. The simultaneous extinction of a number of these minute laminae over certain areas indicates the boundaries of the original grain. These grains are thus similar to the quartz sillimanitisé, as described by Barrow (1893), in which, however, sillimanite needles occupy the central portions of the quartz grains, leaving the edges of the latter relatively clear. A few crystals of orthoclase and oligoclase are scattered throughout the section. The similarity between the composition of the latter ($Ab_{72}An_{28}$) and that recorded by Tattam from many of the granitic and metamorphic rocks of the complex suggests that this felspar is magmatic in origin.

GNEISSIC GRANITE.

Section No. 5996 represents the outcrops to the west of the schist-granite contact on Junction Creek. Megascopically, the rock appears to be a moderately coarse-grained granite, showing fairly strong foliation, with parallel orientation of large elongated felspars. In thin section, however, the foliation is not so apparent. Large anhedral grains of normal granitic minerals—quartz, felspar, and biotite—are cemented together by a fine-grained matrix of quartz and sericite. The fine-grained quartz is obviously of metamorphic origin, having been deposited from solutions produced by local breakdown under pressure of the large primary quartz grains, resulting in the typically crenulate outlines shown by the latter. The whole is an early phase of true "mortar structure." Sericite, derived from the extensive decomposition of large areas of orthoclase and microcline-microperthite, is commonly intermingled with the siliceous matrix. A small amount of sericite is usually associated with crystals of oligoclase which are extensively fractured and kaolinized, with numerous embayments of clear secondary quartz, distinct from primary quartz, with its characteristic strings of minute inclusions.

Biotite is unaltered in the Junction Creek gneissic granite, but has been completely chloritized in the granitic rocks further to the north along the Tambo River. Well-defined rectangular patches of reddish biotite in minute flakes occur in Section 5996, and resemble the "knots" in schists described by Tattam (1929). Muscovite is ubiquitous throughout the gneissic rocks in the area. Small grains of zircon are common, and in Section 6001 large grains of apatite are gathered together with interstitial quartz, in a small segregation suggesting local concentration of mineralizers.

RHYODACITE.

A section (No. 5980) of the massive porphyritic rock forming the eastern bank of Old Paddock Creek contains phenocrysts of quartz, felspar, and altered ferromagnesian minerals, set in a fine-grained siliceous ground-mass containing much finely disseminated hematite. The quartz phenocrysts are embayed and devoid of inclusions. The felspar phenocrysts, approximately equal in number to the quartz, comprise plagioclase (sodic andesine $Ab_{35}An_{65}$) and orthoclase, and are extensively kaolinized. The plagioclase is approximately equal in amount to orthoclase. Phenocrysts of ferromagnesian minerals have been replaced by magnetite (now extensively oxidized to hematite), which frequently preserves forms characteristic of crystals of biotite, or, more rarely, pyroxene. Many of the magnetite clots have been drawn out along flow lines, resulting in the high concentration of hematite dispersed throughout the ground-mass, the hypocrystalline texture of which suggests devitrified glass.

An unusual feature is the association of minute crystals of hypersthene with a particularly large area of hematite. The intensity of the pleochroism and the low optic angle (about 30°–40°) indicate a variety rich in iron. The concentration of the hypersthene crystals along the margins of the hematite clot suggests that they have originated by reaction of the siliceous ground-mass with the magnetite. The sequence of reactions during the formation of the rock would thus include recrystallization of biotite prior to extrusion, then, on extrusion, break-down of the biotite to magnetite, and, finally, reaction of the magnetite with the remaining liquid to give small quantities of hypersthene.

TUFFACEOUS RHYODACITE.

Section No. 5997 represents the rock from the south-western limit of the lava flows. It is similar to the massive lava, but contains in addition numerous embayed fragments of quartz surrounded by thick mantles of minute, interlocking, quartz crystals.

DYKES.

(*a*) *Diabase.*—Section (5979) is taken from the dyke (D.4) exposed in the bed of the Tambo River. The rock is fine-grained, of trachytic texture, composed of laths of felspar and a ferromagnesian mineral now so decomposed as to be indeterminate. The only other recognizable minerals are secondary calcite and sericite. The rock is conveniently described as "diabase" because of its appearance in the hand specimen and advanced alteration.

(*b*) *Diabase:* (*Chilled Margin*).—Section (5981) shows the contact of one of the diabases exposed on Cairn Hill, with the surrounding granite. A distinct border phase about 5 mm. in width extends in from the contact, which is sharply defined. Large crystals of augite, now extensively altered to serpentine, are set in a dark, fine-grained ground-mass, just inside the contact. These phenocrysts do not occur in the portions of the dyke away from the contact.

(*c*) *Monchiquite.*—This rock, which forms the basic plug near Limestone Creek, varies in appearance from a dense, black, glassy material, to a red-brown mass set with numerous black phenocrysts of hornblende, ranging up to an inch in length. Sections (Nos. 5983–5989) show that the texture varies from basaltic, with numerous small phenocrysts, to porphyritic, with a hypocrystalline ground-mass. The porphyritic variety appears to represent a chilled border phase, and often contains fragments of indurated limestone.

The sections show a variety of stages of resorption of hornblende, which is of the oxy-hornblende type, pleochroic from yellow to dark red-brown. During resorption, magnetite dust and pyroxene (titanaugite) are formed, the magnetite gradually extending throughout the body of the phenocrysts (Plate 1, fig. 2). Depending on the relative movement between the phenocryst and ground-mass, the pyroxene is either swept away as it produced or deposited as a shell around the parent hornblende. A striking instance of this latter formation is shown in Section 5985 (Plate 1, fig. 1), where the parent hornblende has formed an optically continuous shell of pyroxene and magnetite around itself, thus shielding the inner hornblende from contact with the ground-mass. At a later stage, this shell has been breached, allowing the ground-mass to pour in. In all instances where pyroxene has crystallized round hornblende, the "C" axes of the pyroxene shell, and the inner hornblende fragments, coincide. The extinction positions of the shell and core are thus separated by an angle of about 30°–40°. A similar series of resorption stages is described by Larsen (1937) in the hornblendes of the Colorado andesites. The evidence in these lavas suggested that concentration of mineralizers rather than pressure conditions is the determining factor in the amphibole-pyroxene equilibrium. Thus as the mineralizing vapours escape on extrusion, the hornblende becomes unstable and breaks down to pyroxene. In the case of the small hypabyssal intrusion at Bindi, most of the resorption must have occurred before final intrusion as a dyke or plug, i.e., loss of mineralizers must have occurred while the magma was contained in a subterranean chamber large enough to maintain a high temperature for a period of time sufficient for most of the resorption to take place. Numerous small olivines are present in all sections, rarely attaining large dimensions, and usually much altered to serpentine. The ground-mass is composed of small laths of oxy-hornblende and titanaugite set in a glassy base containing rare minute felspars. A few of the larger pyroxene laths have a green central zone, which may be soda-augite.

MARMORIZED LIMESTONE.

Section No. 6011 represents the fine-grained pinkish "marble" outcropping in the centre of the shear zone near the locality commonly known as "Marble Gully." The rock here represents a fossiliferous limestone which has been subjected to intense shear, so that most of the original structure has been obliterated.

Microscopically, the rock is composed of minute grains of calcite, interlaminated with carbonaceous material and hematite. The minute size of the individual calcite grains renders their examination difficult, but their appearance in elongated masses, which "tail off" into the surrounding matrix, suggests considerable intergranular movement under conditions of shearing stress, rather than recrystallization under pressure.

Section No. 5982 is taken from a calcareous conglomerate outcropping a short distance north-west of the locality of Section 6011. The slide contains a pebble of massive blue limestone about 1 inch in length, which shows a moderate amount of recrystallization, and considerable elongation with development of tension gashes and slip planes. Two distinct groups of shear surfaces can be observed.

(1) The trace of the (ab) plane of the tectonite is not well defined in this particular section, but, as far as can be determined, it makes a slight angle with the axis of elongation of the pebble as a whole. The

actual elongation of the pebble has thus been produced by a mechanism distinct from that of direct rupture, which, although it is responsible for the S surfaces of Group (1), has produced only a subsidiary distortion of the pebble.

(2) The main process which has caused the elongation of this particular pebble has been gliding along the slip planes of the individual calcite crystals. The minutely displaced lamellae are everywhere well defined, and show a decided statistical preference for one particular plane in the fabric. Sander (1930) has shown that all such lamellae boundaries in deformed calcite grains are crystallographic "e" planes (0112). Although it can be stated that the rock is a tectonite which shows little mimetic recrystallization, the evidence for translation along the single slip-plane mentioned above is not reliable enough, when taken from a section on an ordinary microscope, to show that the fabric has not been produced by B-rotation. Thus, it is still possible that a universal stage determination would show a series of intersecting slip planes all parallel to a well-defined "B" axis.

Tension gashes, although normal to the axis of elongation, have been filled with crystals of secondary quartz which show parallel alignment along a direction which makes an angle of 20°–30° with the axis of elongation, i.e., the crystals are arranged "en echelon" in each tension gash. It seems necessary, therefore, to recognize two distinct phases of tectonic activity, the first of which produced the tension gashes during elongation of the pebble, whilst the second gave rise to the orientation of the quartz crystals. The undulose, sub-parallel extinction of the quartz suggests that pressure operated after, as well as during, the growth of the crystals.

Age Relations and Tectonics.

Upper Ordovician.—At Bindi, rocks of this age comprise both contact and regionally metamorphosed types. Both types are, as far as is known, contemporaneous, and are distinguished by the degree of alteration. The fact that both are represented in the limited area of the parish of Bindi is probably due to extensive faulting along a line striking N.N.W. through this area.

(?) *Siluro-Ordovician.*—The granites which have intruded and altered the Upper Ordovician sediments are provisionally classed here. They have been tentatively classed as Lower Devonian by previous workers (Skeats, 1931). However, their relations with the overlying Middle Devonian rocks at Bindi show that the contact is in the nature of an enormous unconformity, the extent of which can be assessed from the following evidence:—

(1) The metamorphic basement complex comprises intensely folded schists and gneisses, whilst the overlying formations are relatively flat-lying lavas and Middle Devonian limestones.

(2) The mineral content of the sillimanite-garnet schists and gneisses indicates that they were formed under conditions of temperature and pressure such as would exist near the intruding granites, in a geosyncline during orogenesis. A considerable period of time would be required for the removal of the upper levels of the folded geosyncline before the flat-lying limestones could be deposited. The interval between Lower and Middle Devonian seems inadequate.

Lower Devonian.—Lavas and tuffaceous extrusives underlying the Middle Devonian limestones in the north-eastern districts of Bindi are provisionally grouped as Lower Devonian. They are identical with the massive varieties among the Snowy River "porphyrites" underlying the Buchan limestones. Howitt (1878) has shown that these latter flows are conformable to the Middle Devonian, grading upwards through calcareous breccias and tuffs into normal limestones, so that their age may possibly be early Middle Devonian. Evidence relating to this point has been collected and correlated by Professor E. W. Skeats (1909, p. 182).

Middle Devonian.—The Bindi limestones are placed here on palaeontological evidence. They show some faunal differences from the Lower Devonian (?) Lilydale limestones, but show similarities with the Buchan and Tabberabbera beds. The Mount Tambo beds may belong here, as no marked unconformity is apparent between their basal members and the top of the limestone series.

Upper Devonian.—The Mount Tambo series is provisionally allotted to an early Upper Devonian age. The fact that this series has been involved with the Middle Devonian in an orogeny which is possibly connected with orogenic activity in Central Victoria towards the close of the Devonian, suggests that the Tambo beds are older, and the Iguana Creek beds are younger, than this orogenic period. This assumes that the diastrophism affecting the Tambo beds was not of local character.

Post-Upper Devonian.—The monchiquite penetrating the limestones is placed here. The rock resembles the Tertiary dykes in other parts of the State. Rock sections in the Howitt collection show that an exactly similar type occurs at Back Creek, Buchan, though its stratigraphical relations have not been observed by the author.

The evidence to be found at Bindi is not complete enough in itself to allow a definite decision to be made regarding the course of events in the tectonic history of the area. A detailed survey of the districts to the south and north-west would have to be made before any suggested sequence of events could be regardeed as proved. However, the following observations have suggested the sequence that will be given below:—

(1) There is a considerable difference in constitution between the rocks forming the western side of the igneous-metamorphic basement and those forming the eastern side of the area. No transition phases could be found on an east-west traverse along Junction Creek. By analogy with the similar petrographic break which occurs along the Tongio Gap fault (about 10 miles west of Bindi), it is suggested that the abrupt junction in the basement complex has been brought about by extensive movement along a pre-Middle Devonian fault.

(2) The limestones dip west at an average angle of 30 degrees, as far as the granite boundary. Since the contact here is not intrusive, and the dips at the contact increase to 60°–70°, the only possible explanation is that of a fault junction. This contact can be observed in a cliff section in the Tambo valley, and suggests that the granitic rocks have been thrust over the limestones. Mineralized quartz veins are prominent along this fault junction and slickensided surfaces are common in the nearby granite.

(3) In the marmorized zone in the north-east of the parish of Bindi, the extent and intensity of the deformation provide confirmatory evidence of the importance of fault action in the tectonic history of the area. The faults in this zone are not sharply defined, but are probably of the same nature as the thrust fault in the west of the parish.

From the above points, the following sequence is suggested:

(i) Pre-Devonian faulting, which is required to bring the highly metamorphosed Omeo series into contact with little altered sediments which are, as far as is known, contemporaneous. Subsequent deposition of the Devonian limestones and conglomerates, coupled with later thrust faulting along the line of the pre-Devonian fault, has obscured the actual position of the latter.

(ii) The extrusion of the acid lavas and the deposition of the limestones and conglomerates was followed (probably at the close of the Devonian) by an era of strong compressive forces directed along an east-west line. The granitic rocks in the basement complex of eastern Victoria yielded to this compression by breaking up along thrust planes into crystalline wedges. The overlying Devonian sediments were folded to an extent depending on their distance from the orogenic regions of Central Victoria. Thus, at Tabberabbera, the folding of the Middle Devonian rocks is acute, whilst at Buchan, further east, it is much less intense. At Bindi, only a thin lava flow separates the Middle Devonian limestones from the crystalline basement. Thus, movement along thrust faults in the basement rocks has brought portion of the basement complex above the level of the limestones. The western extension of the limestones has been sharply cut off, whilst their eastern extension has been drawn out in a shear zone some three miles in width. Conglomerates of the Mt. Tambo series have also been involved in this shear zone, whilst some of the western members of the series have been forced upwards by the granitic wedge, great masses of quartzites and contorted phyllites being developed along the contact of the wedge with the overlying conglomerates.

Summary.

The basement rocks at Bindi comprise types characteristic of the metamorphic complex of north-east Victoria. They are unconformably overlain by acid lavas which form part of the Snowy River Volcanic Series. The extreme nature of the unconformity suggests that the Lower Devonian age previously given for the granites of the metamorphic complex should be reconsidered. Middle Devonian limestones conformably overlie the acid lavas and tuffs. Their lithological, palaeontological, and structural characteristics are described. The Mount Tambo series, comprising conglomerates, sandstones and arkoses, overlies the Middle Devonian limestones, with little or no angular unconformity. Both the Mount Tambo series and the Bindi limestones have been involved in a series of thrust faults, developed in the underlying crystalline rocks. The sedimentary series owe their

preservation and present attitudes to this thrust faulting. An extensive zone of intense rock deformation occurs in the east of the area, and is shown to be due to fault movement.

In conclusion, I would like to acknowledge my indebtedness to Professor H. S. Summers and the staff of the Geology School for their ready advice and assistance during the progress of this investigation; to the various students of geology, whose companionship made field investigations in little-known and rather inhospitable country not only possible but enjoyable; and to Associate-Professor E. S. Hills especially, for his invaluable discussion and criticism of the ideas expressed in this paper.

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Description of Plate.

Fig. 1.—Monchiquite. Bindi. Basal section of augite-magnetite shell during resorption of oxy-hornblende phenocryst.

Fig. 2.—Monchiquite. Bindi. Early and late stages in the resorption of oxyhornblende phenocrysts. The left-hand phenocryst has been almost completely replaced by magnetite and augite.

Fig. 3.—Sillimanite Schist. Junction Creek. Bindi. Contorted mass of fibrolite needles, surrounding shreds of a mineral resembling biotite.

Fig. 4.—Arkose. Bindi. A rounded quartz grain appears in the lower right-hand corner. The matrix is composed of fragmentary quartz, plagioclase and orthoclase.

Fig. 5.—Marmorized limestone from shear zone. Bindi. The black streaks represent traces of shear planes.

Fig. 6.—Normal limestone. Bindi.


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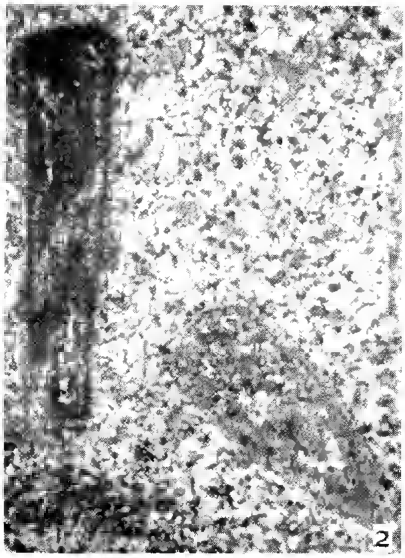
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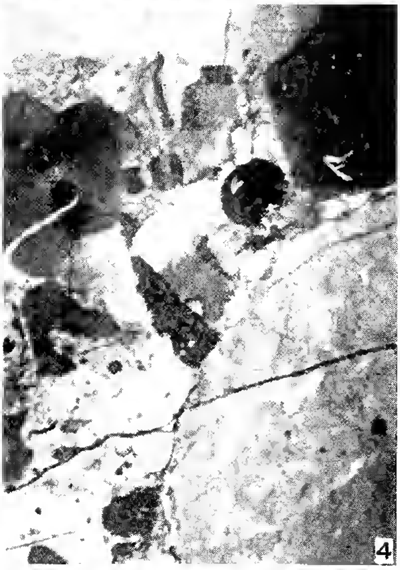
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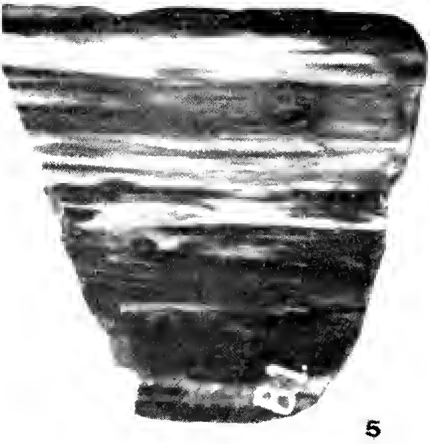
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[PROC. ROY. SOC. VICTORIA, **55** (N.S.), PT. I., 1943.]

ART. V.—*Mechanism of Abnormal and Pathological Growth: A Review.*

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Abstract.

Recent work is reviewed on the mechanism of abnormal and pathological growth in plants with special reference to those effects induced by *Bacterium tumefaciens*, *Bacterium solanacearum* and *Rhizobium* spp. The hypothesis that indole-3-acetic acid, produced by the organism in the plant, induces the cell proliferation or other stimulation effect is regarded as unlikely.

While the phenomena still strongly suggest the working of a growth-substance mechanism, researches so far have not substantiated the alternative hypothesis that the physical presence of the bacteria stimulate the plant to increased production of growth-substance leading to cell proliferation.

Other trends in recent research on this problem are indicated.

In a number of plant infections, growth correlations are disturbed, such disturbance being reflected by overgrowth, inhibition of growth, development of new organs or growth movements. For many years these conditions have been used in symptomatology without more than a passing suggestion as to how they were brought about. With the discovery of the auxins and other synthetic growth-substances and the recognition of the similar effects they are able to produce in healthy plants, attention has been increasingly directed toward the elucidation of the mechanism of abnormal and pathological growths.

The original viewpoint was, that since growth-substances were so important in the normal development of plant tissues, the finding of their presence in unusual amounts in certain abnormal tissues would indicate that they were responsible for these conditions. With increasing research in this field this viewpoint has undergone some modification. The present review represents a summary of progress made and of present trends.

TYPES OF ABNORMAL AND PATHOLOGICAL GROWTH.

The literature in plant pathology contains numerous references to abnormal conditions induced in plants as a result of fungal, bacterial and virus infection. These conditions may arise from successful parasitism or from controlled parasitism and may be delimited as follows:—

Overgrowth.

(*a*) Galls, tubercles or callus formation due to rapid multiplication of cells (hyperplasia) and increase in cell size (hypertrophy), whereby a more or less irregular overgrowth appears on shoot or root. Examples include Crown Gall, Club Root, Maize Smut, Rust Galls, Fiji Disease of Sugar Cane, Root Tubercles of Leguminosae and Swollen Leaf Teeth of Ardisia.

(*b*) Stimulation of cambial and other meristematic centres leading to abnormalities in size and number of parts. Examples include Witches Brooms, Fasciation, Crown Gall, Hairy Root, Big Bud of Tomato, Virus enations.

Adventitious Root Formation.

Roots arising in unaccustomed places on the stems of intact plants. These occur in Bacterial Wilt of Solanaceae, Crown Gall, Fusarium Wilt of Tomato and Bacterial Canker of Tomato.

Growth Movements.

Nastic Responses. Change of position of a bilaterally symmetrical organ due to differential growth. Epinasty and hyponasty, expressing conditions where the upper or lower side respectively of a dorsi-ventral leaf grows faster than the other, leading to a downward or an upward bending of the leaf. Examples include Bacterial Wilt of Solanaceae, Crown Gall, Fusarium Wilt of Tomato and Rose Wilt Virus.

Many of the abnormal growth effects listed above may occur in the same plant as a disease runs its course.

The fundamental problem in all these cases is the explanation of the physiological cause of the atypical cell multiplication and organ formation and movement. This has been pointed out by Riker and Berge (1935), and Riker (1939) in their studies on Crown Gall. Investigation so far has been confined to analysis of relatively few of the atypical growth effects. For the better appreciation of the investigations to be described, it appears desirable to outline briefly the auxin theory of growth, salient features of the effects induced by certain synthetic growth substances and the essential techniques involved.

OUTLINE OF THE AUXIN THEORY OF GROWTH AND EFFECTS ON PLANTS OF CERTAIN SYNTHETIC GROWTH-SUBSTANCES.

The idea that a hormone is concerned in growth and growth-movements goes back over a quarter of a century, but success in obtaining an active substance from the coleoptile tip of *Avena* was first obtained by Went (1928). His fundamental experiment was to extract growth-substance by cutting off the tips of oat coleoptiles and placing them upon a small rectangular plate of moist agar. After one to two hours the tips were removed and the agar plate cut up into blocks of equal size and placed on one side of the stumps of decapitated coleoptiles. The result was a curvature away from the agar blocks (negative curvature), indicating that some chemical growth-promoting substance had diffused out of the tips into the agar and then out of this into the decapitated coleoptiles. The degree of curvature was proportional, within limits, to the concentration of the substance in the agar blocks and the method has been widely applied in the comparison of the amounts of growth-substance in different plant parts and the interpretation of tropic phenomena. There appears little doubt that cell elongation is promoted by the presence of the plant growth-substance. On the other hand the application of this same substance to roots retards their growth.

By another line of research Nielsen (1928, 1930), demonstrated that a fungus, *Rhizopus suinus*, excreted into its culture medium a substance which could be extracted with ether and which induced curvature in *Avena*. A similarly active substance was also obtained from bacteria by Boysen-Jensen (1931). This substance, which was also found in urine (Kogl, Haagen-Smit and Erxleben, 1934), was shown by Kogl and Kostermans (1934), and Thimann (1935) to be identical with indole-3-acetic acid. The name hetero-auxin was coined for it. Prior to the identification of hetero-auxin, Kogl and Haagen-Smit (1931), found human urine to be rich in an active substance, since isolated in crystalline form and named auxin. Later Kogl, Erxleben and Haagen-Smit (1934), discovered and isolated a second active substance (distinct also from hetero-auxin) in urine. The original auxin was then designated auxin "a" ($C_{18}H_{32}O_5$) and the new one auxin "b" ($C_{18}H_{30}O_4$). These with hetero-auxin ($C_{10}H_9O_2N$) comprise the auxin group. All three are active in the *Avena* test. Hetero-auxin can be readily synthesized, but so far the other two have not.

Subsequently a variety of growth-substances were synthesized of which we may name α-naphthalene-acetic acid, β-3-indole propionic acid and γ-3-indolebutyric acid. The above named acids were also found to be active in the *Avena* test (Avery, Burkholder and Creighton, 1937).

Hitchcock (1935) opened up a new field of investigation which has a close bearing on abnormal growth, by his experiments on the effect of introducing hetero-auxin and other synthetic growth-substances in lanoline or in water solution into such plants as tomato and tobacco. He found that various growth phenomena including epinastic response, cambial stimulation and adventitious root formation followed such application. Some synthetic compounds while producing the above effects in tomato plants were not active in the *Avena* test.

Certain members of the vitamin complex are being investigated in relation to abnormal and pathological growth and may prove of some importance in the interpretation of these phenomena. Thiamin (Vitamin B_1) which is produced by the normal plant is recognized as a root growth factor (Bonner, 1938).

Techniques.

In quantitative work on growth-substance in plants, certain specialized techniques are used which may also be briefly outlined here to clarify statements as to methods used in investigations on abnormal growths produced by infective agents.

1. *Diffusion Technique and* Avena *Test.*

A modification of Went's original hormone diffusion method is used. The cut surfaces of normal (control) and abnormal tissues are placed on separate agar plates and the growth-substance present allowed to diffuse into the agar over a two-hour period. Each agar plate is then cut into twelve small blocks which are applied unilaterally to sets of decapitated *Avena* coleoptiles. Bromide prints record the negative curvatures after a two-hour period and the relative amounts of growth-substance diffusing from the normal and abnormal tissues can be assessed. This method has, however, been found to be of limited value for comparative investigations when dealing with green plants such as tomato.

2. *Ether Extraction of Growth Substance.*

A valuable method involving ether extraction developed by van Overbeek (1938), has been modified to suit conditions for investigations on abnormal growth. In the author's modification, normal and abnormal plant parts taken from " paired " plants are allowed to extract overnight at 4°C. in specially purified ether. The ether is evaporated on an electric hot-plate at a temperature below 60°C., down to 2 cc. in each container, transferred by pipette to centrifuge tubes which are standing in boiling water, so that the remainder of the ether is rapidly boiled off. Then 1 cc. of 1·5 per cent. agar is added to the tubes and thoroughly mixed with the residues. After two to three hours the agar is remelted and poured into small brass moulds. The chlorophyll-containing layer is sliced off and plates of standard size (8 x 10·7 x 1·5 mm.) cut from the agar. These again are cut into twelve blocks of equal size and applied unilaterally to *Avena* coleoptiles. Emphasis has been placed by some workers on the necessity for complete removal of auxins from plant tissues by repeated extractions but there appears no reason why the amounts obtained in a single extraction should not represent the relative amounts of free auxin present in the normal and abnormal tissues.

3. *The Pea Test.*

Briefly this consists of measuring the inward curvature of split portions of etiolated pea stems, which curvature occurs in the presence of certain growth-substances including indole-3-acetic acid. The method was developed by Went (1934). Thimann and Schneider (1939) have devised a similar but much more delicate test, using split coleoptiles of *Avena.*

4. *Treatments with Indole-3-acetic acid (Hetero-auxin) and other Synthetic Growth-Substances.*

These substances are frequently mixed with lanoline (method of Laibach, 1935) before application to stems or petioles of test plants. Concentrations ranging from 0·01 per cent. to 3·0 per cent. have been used. They may also be effectively introduced into test plants from small glass tubes drawn out to a capillary. The tube is filled with a water solution of the growth-substance and the capillary end of it inserted into the stem so that the liquid can slowly drain into the tissues (method of Zimmerman and Wilcoxon, 1935). Hetero-auxin can also be introduced into the plant through intact roots, by watering the soil with a strong water solution (Hitchcock and Zimmerman, 1935).

5. Phycomyces *Assay for Vitamin B_1.*

The fungus *Phycomyces Blakesleeanus* requires an external supply of thiamin (vitamin B_1) for growth and from this fact Schopfer and Jung (1937) have developed a quantitative biological assay. The fungal spores are sown into a basic thiamin-free medium to which thiamin extracted from test plant material is added. Comparison may then be made of the relative thiamin contents of normal and abnormal tissue on the basis of dry weight of fungus formed in a standard time.

Overgrowth.

1. Crown Gall.

Some overgrowth conditions are due to strong parasitism, while certain others again arise from controlled parasitism (under which heading we can include symbiosis). One of the best known of the former and one on which a considerable volume of information is available, is Crown Gall. These galls arise on plants through parasitism by *Bacterium tumefaciens* Sm. & T. and this disease has been the subject of a great many studies, not only on account of its intrinsic interest but also because of its suggested analogy with cancerous conditions in man. Following infection, proliferation of cells leads to callus and gall formation, the galls being either primary or secondary. Other growth phenomena also occur and may be mentioned here, although their physiology will be discussed later. Adventitious roots were frequently observed to be present in the vicinity of the growing galls. Smith, Brown and Townsend (1911), recorded their presence originally but detailed observations were first made by Brown (1929). She showed that Paris Daisy and Balsam plants in particular, reacted to inoculation by strong adventitious root formation in addition to gall formation. Epinasty of leaves of infected plants does not appear to have been recorded before 1937, although as Locke, Riker and Duggar (1937, 1938) point out, this phenomenon doubtless had frequently been observed by those studying Crown Gall.

Smith (1922), and Riker (1923) showed that the cambium was stimulated to activity in the presence of *B. tumefaciens*. Riker (1923), recorded the course of the early cell divisions initiating gall formation following infection. The walls were laid down in the portion of the mother cell near the intercellular spaces containing the bacteria. Up to the time when they could still be clearly observed, such cell walls formed a more or less distinct sheath round the bacteria.

There appears to be general agreement that the hyperplastic and hypertrophic growth, which, in various manifestations, generally follow Crown Gall inoculations, is due to some influence exerted by the bacteria. Crown Gall appears ideal as a test case for evolving an explanation of the physiological cause of the atypical cell multiplication, and prior to the development of the growth-substance theory, a considerable body of literature had already grown up concerning the possible importance of a great variety of chemical substances. These have been critically reviewed by Riker and Berge (1935), and will not be considered here, this review being concerned with the approach to Crown Gall through studies on growth-substance.

The view that growth-substance is concerned in Crown Gall formation arises from the fact that a close analogy exists between the stimulation effects induced in plants by such substances and the symptoms of the disease. Brown and Gardner (1936), and Kraus, Brown and Hamner (1936), demonstrated that indole-3-acetic acid could stimulate the multiplication of cells in French Bean plants, leading to the formation of galls which were structurally closely similar to those arising after infection by *B. tumefaciens*. Other points of similarity were recorded by Locke, Riker and Duggar (1938). Responses which suggest an increase in the amount of growth-substance present in infected plants include (1) epinasty of leaf petioles, (2) increased initiation of adventitious roots, (3) stimulated cambial activity, (4) inhibited development of certain buds, and (5) delayed abscission of senescent leaves.

With these similarities in mind, research on the mechanism of cell proliferation in Crown Gall has led to the formulation of the following hypotheses :—

(1) The parasite produces a growth-substance in the course of its metabolism which incites the cells of infected plants to abnormal division.

(2) The host plant reacts to the presence of the parasite by an excessive formation of auxins which induce the hyperplasia.

(3) Growth-substances produced by the parasite and by the host are jointly responsible for gall formation.

A viewpoint recently suggested, which has arisen out of negative evidence in relation to the above hypotheses, may also be listed here. It is to the effect that growth-substances of the auxin or hetero-auxin type are not important in relation to gall formation, but that other phyto-hormones, possibly of the vitamin complex, may be concerned.

It appears desirable to consider each of the above hypotheses in the light of the experimental evidence presented.

Growth-substance Production by the Parasite.

Nemec (1930) studied the effect of smearing some fresh culture of *B. tumefaciens* on the cut upper surface of chickory roots held under moist air conditions. He found that vigorous callus development was followed by adventitious root formation. Normally, buds developed from the cut upper surface but these were inhibited in the presence of the parasite. Nemec concluded that growth-substance from the bacteria was responsible for the effect. Brown and Gardner (1936) showed that it was possible to extract from the culture in which *B. tumefaciens* had grown, a growth-substance capable of inducing galls. These workers adopted the view that it was not the mere presence of the organism which leads to overgrowth, but rather the stimulus of certain products of its metabolism. In a later paper (Brown and Gardner, 1937), they suggested that secondary galls were also due to some stimulating substance which travelled through the stem, after being given off by the parasite at the site of the primary gall. Link, Wilcox and Link (1937) and Berthelot and Amoureux (1938) claimed that *B. tumefaciens* produced hetero-auxin in culture. The latter workers considered that this growth-substance played an important part in the genesis of Crown Galls. The former workers found that ether extracts of broth cultures of the parasite caused local killing in addition to stimulation effects, when applied to test plants. This indicated that some substances other than hetero-auxin were present in the crude ether extract. They concluded, however, that hetero-auxin was a chemical agent by means of which, possibly in conjunction with others, *B. tumefaciens* induced galls.

Gioelli (1940) tested the effect of filtered cultures of *B. tumefaciens* on plant tissue cultures of *Sterculia platanifolia.* He found that cambial stimulation occurred which was similar to that induced by hetero-auxin. This led him to conclude that the organism induced the proliferation by the action of hormones.

Locke, Riker and Duggar (1938, 1939*a*) first reported evidence which was in conflict with the hypothesis being considered. They demonstrated that both attenuated and virulent cultures of *B. tumefaciens* produced approximately the same amount of growth substance in media. There appeared to be no relation between the ability of the one and the inability of the other to form galls, and their ability to form growth-substance in culture. These workers concluded that it seemed better to reserve judgment regarding the importance of the role played by hetero-auxin in the development of Crown Gall. Other evidence adduced in support of their view was as follows:—(1) Indole-3-acetic acid was relatively ineffective in stimulating tissue inoculated with an attenuated strain of Crown Gall organism, whereas very small amounts of active substance diffusing from virulent gall inoculations were highly effective in this respect. (2) Responses of various plants, including bean and sunflower, to indole-3-acetic acid, did not parallel their response to Crown Gall bacteria. (3) The volume of culture which must be extracted and the number of bacteria present to give a small amount of growth-substance (optimum value 125 gammas per litre) is out of all proportion to the number of organisms present in a typical Crown Gall.

Grieve (1940) also reported that pathogenic and non-pathogenic cultures of *B. tumefaciens* produced approximately equal amounts of growth-substance. A similar result was obtained for *B. solanacearum, Aplanobacter michiganense and B. flaccumfaciens.* These results indicated that production of indole-3-acetic acid in media was not peculiar to bacteria which induced abnormal cell division, since *B. flaccumfaciens* did not produce any such effects in its host, the French bean. It is interesting that it is this plant which has proved so useful in demonstrating cell proliferation arising from infection by *B. tumefaciens*, by extracts of *B. tumefaciens* and by synthetic indole-3-acetic acid. The inference may be drawn from the above experiments that there is no necessary relation between growth-substance formation in media and in the host.

White (1942) claims that it is possible to produce a gall on a plant by implanting, at cambium level, a fragment of tissue derived from a bacteria-free tumour arising originally on a plant inoculated with *B. tumefaciens.* This would appear to provide further evidence that a product of bacterial metabolism is not causally involved in the atypical cell proliferation.

The writer is of the opinion that the balance of evidence indicates that it is unlikely that bacterially produced hetero-auxin plays any major role in atypical cell multiplication.

Excessive Growth-Substance Production by the Host.

Leonian (1937), in the course of a review of "Growth Hormones in Plants" (Boysen-Jensen), suggested in the case of Hairy root, tumours, galls and other pathological conditions, that such abnormal growths were the result of excessive production and concentration of auxins in an attempt to overcome the invader (sic), rather than to growth-substances furnished to the host plant by the pathogen. Link, Wilcox and Link (1937) also suggested that the parasite "probably not only furnishes a more or less continuous supply of hetero-auxones (hetero-auxin) but through abnormal growth or lethal effects of the host disturbs normal production, activation and transport of auto-auxones (plant auxins)". Link and Eggers (1941), using an ether extraction method in conjunction with the *Avena* test, presented evidence to show that there was a significantly greater amount of growth-substance present in gall tissue than in control tissue. In discussing this result they stated that "in addition to auxones, including auxins furnished by the parasite, the host cells—local and distant—also contribute to the hyperauxony of the affected organ".

Locke, Riker and Duggar (1938) showed that virulent cultures of *B. tumefaciens,* when inoculated into tomato stems above the inoculation points of an attenuated strain (which by itself only produced slight stem swelling) induced strong gall formation at the points of entry of the latter. These workers suggested therefore, that some substance from the tissue inoculated with the virulent strain, diffused down through the stem and stimulated cell division at the inoculation points of the attenuated strain. In similar experiments, hetero-auxin in lanoline paste applied in high concentration (30 mgm. per gram of paste), either failed to diffuse in quantity to the inoculation points of the attenuated culture or at least produced little effect there, as there was no significant increase in cell proliferation. A point of interest was that the stimulating effect of the virulent culture on gall development at the point of inoculation of the weak strain, was not exerted as markedly in the upward direction (Riker, 1940). This is perhaps only to be expected in accordance with the polar movement of growth-substance when in physiological concentration. The non-polar upward and downward movement of hetero-auxin in stems (see Brown and Gardner, 1936) apparently occurs when concentrations of this substance are high. The relative failure of hetero-auxin to induce increased cell proliferation, either at the point of inoculation of the attenuated strain or at any other point on the stem of tomato, is interesting in view of the results of Brown and Gardner (1936) for French bean. The difference may be due, in part, to the host or to the mode of application. Locke, Riker and Duggar (1938, 1939*b*) agreed with Leonian (1937) that growth-substance was more likely to be a product of host cells under the influence of bacterial action rather than a direct bacterial metabolic product. They found that it was not possible, however, to distinguish between growth-substance from the foliage of the normal plant and from that in Crown Gall culture. The growth-substance extracted from the plant resembled indole-3-acetic acid in its sensitivity to acid and alkali. In this connection it may be noted that in recent papers Lefèvre (1938), and Haagen-Smit, Leech and Bergen (1941), have reported the presence of indole-3-acetic acid in higher plants.

Gall Formation Due to Growth-substance Produced Both by Parasite and by the Host.

Link, Wilcox and Link (1937) and Link and Eggers (1941), whose work has been reported in the preceding two sections, incline to the view that growth-substances are produced both by the parasite and by the plant. Each source contributes to the significantly greater amount of active substance which they found to be present in galled tissues.

View that growth-substances of the Auxin and Hetero-auxin Type are not Important in Gall Formation.

Riker, Birch Henry and Duggar (1941), using quantitative ether extraction methods, re-examined the question of growth substance content of inoculated and control tissue. In these experiments, involving a large number of *Avena* tests, they failed to find any significant difference between the auxin content of control and inoculated tissue. This held true over periods ranging from 1 to 16 days after inoculation. Similarly, no significant difference could be detected between the amounts of auxin diffusing from stems bearing galls and from control stems. A further interesting point was that when comparable plants were inoculated and grown at temperatures at which gall formation occurred (27°C.) and at which it did not occur (31°C.), there was found to be no significant difference in auxin production.

They therefore concluded that the gall formation was not due to the production of hetero-auxin or similar growth-substances as measured by the ether extraction and *Avena* technique. These negative results led them to examine the production of other active substances including vitamin B_1, biotin, flavin and pantothenic acid, in relation to the cell-stimulating property of the parasite. A preliminary note (Birch Henry, Riker and Duggar. 1942) indicates that vitamin B_1, as assayed by the *Phycomyces* method does not appear to have any causal role in Crown Gall development.

It should be pointed out that the experiments of Link and Eggers (1941), in which they showed that there was a significantly greater amount of growth-substance present in galled tissue, were on a comparable scale to those of Riker, Birch Henry and Duggar (1941). Since the results of these two groups of workers are diametrically opposed, it appears that the question as to whether there is present a greater amount of growth-substance in Crown Gall tissue, must be left open.

A consideration of the above lines of evidence indicates that the high hopes of the solution of the Crown Gall (cell proliferation) problem in terms of the production of hetero-auxin or similar growth-substance by the parasite, have not been realized. There are, however, very strong indications that some growth-substance mechanism is involved in infected plants. The most promising approach now, in the opinion of the writer, would be through a more thorough study of auxin and " food factor " relations in the normal and infected plant. The trend of modern research on the growth-substance theory, while maintaining the necessity of auxin for growth, indicates that even in the presence of adequate auxin, a second " food factor " is necessary. Schneider (1938) has shown this to be sugar in the case of *Avena*. It is possible, therefore, that the pathogenicity of the Crown Gall organism is related to its ability to supply some relatively simple " food factor " in the course of its metabolism. The local accumulation of this in addition to the usual " food factor " may upset the normal balanced growth at the point of entry of the parasite, leading to overgrowth. The work of Locke, Riker and Duggar (1938), in demonstrating that inoculation of tomato stems with a virulent strain, stimulated gall formation at the point of inoculation with an attenuated culture, may yet prove to be important in relation to such a " food factor " hypothesis.

2. OTHER OVERGROWTH CONDITIONS CAUSED BY PARASITES.

Data on other overgrowth conditions caused by strongly parasitic organisms is at present meagre and in most cases has not advanced beyond the preliminary stage. Link, Wilcox and Link (1937) reported in the case of *Ustilago zeae,* causing Smut Galls on maize, and *Taphrina deformans* causing Peach Leaf Curl, that a substance giving tests for hetero-auxin could be extracted from the organisms. Moulton and Link (1940) in a short abstract, state that *Ustilago zeae* grown on a tryptophane-free medium is capable of producing " auxins ". Link and Eggers (1941) refer to Moulton's work (Thesis 1941) on Smut Galls of Maize and state that, using delicate methods of extraction, more " auxin " was obtained from gall tissues than from healthy tissues. " Auxin " as used here appears to be used as a general term meaning growth substance.

Overgrowth due to Controlled Parasitism (Symbiosis).

Root Nodules of Leguminosae.

The root nodules of Leguminosae on account of their important relation to agricultural practice have attracted a great deal of attention from scientists. It is only recently, however, that attention has been focussed in greater degree on the mechanism of cell proliferation inducing the nodule formation. The condition is of interest to the pathologist because it lies on the border line of parasitism. It has long been debated whether the relationship of the nodule organism to its host plant constitutes an instance of true symbiosis or an instance of controlled parasitism. The work of Brenchley and Thornton (1925), in which they showed that when *Vicia faba* was grown on a boron deficient solution the bacteria attacked the host cells, followed by the researches of Thornton (1930*a*), in which he demonstrated that parasitism develops in the case of inoculated lucerne seedlings placed in the dark, swung opinion to the viewpoint of controlled parasitism. Under normal conditions, the organism and the plant live in equilibrium and the advantages are mutual.

Two of the fundamental problems involved are, firstly, how the bacteria enter the plant and, secondly, how the nodule is formed, that is, how the bacteria bring about the proliferation of cells. In order to understand how these occur it is first desirable to know something of the normal course of root infection. This has been clearly described and figured in the case of lucerne by Thornton (1936) and will be outlined here. The usual avenue of infection is via the root hairs and the earliest stage detected by Thornton was the formation of a small colony of the bacteria close to the distal end of the root hair, the tip of which usually becomes coiled into a short spiral. Infection takes place only in this deformed region, this deformation being apparently a necessary prelude, and manifests itself by the formation of a thread of bacterial zoogloea passing down the interior of the root hair. Nodules become visible to the naked eye within twenty-four hours after infection of the root hair. Nodules of clover and lucerne consist of a mass of proliferating cells mostly in the cortex but penetrating also into the pericycle (Thornton, 1930*b*). The central cells swell and become infected with bacteria and by the time that the nodule is a week old the cytoplasm of the infected cells in the central region, becomes filled with bacteria. Thornton and Rudorf (1936) state that there is present at the distal end of a healthy legume nodule, a cap of meristem cells by whose continued division the nodule grows in length. This meristem is also concerned with the differentiation of the lateral endodermis and vascular strands.

Sufficient has now been given of morphology and structure to allow us to consider possible mechanisms of the formation of the nodule. It was discovered as early as 1900 by Hiltner that filtered secretions of the bacteria could induce deformation of the root hairs indicating that the organism excreted some active substance into its medium. Molliard (1912) working with rhizobia from bean, recorded the fact that sterile bacterial secretions could cause abnormal growth effects in roots of *Pisum*. He found that roots of peas allowed to grow in such solutions were retarded in growth, showed increased cell division, radial enlargement in the pericycle and deformation of cortical cells as compared with control roots which had grown in non-inoculated media. Molliard concluded that the organism excreted some active substance into its media which brought about conditions similar to those whoch obtained in actual infection.

Secretions from *Rhizobium meliloti* were shown by Thornton (1936) to stimulate both the production and growth in length, and deformation of the root hairs of lucerne. The substance was non-specific in its action, in that filtrates of cells from one cross inoculation group, deformed root-hairs of plants belonging to another group (McCoy, 1932). Its action in increasing production and length of root hairs would bring it into the class of growth-substances. As Wilson (1940) points out, the deformation of the hair on the basis of hormone in the filtrate is not so easily explained. One would not expect differential rates of growth as the concentration of the hormone should be the same on all sides of the root hairs. An interesting point arises here in that this substance stimulates growth in length of root hairs; all growth-substances so far tested have an inhibiting effect on elongation in root tissue. The possibility must be considered that root hairs are organized in a similar fashion to and consequently react in a similar way to the cells of coleoptiles on the application of growth substance. There appears, however, to have been no investigations on the effect of auxins on root hairs.

Thimann (1936, 1939) was the first to examine the question of the mechanism of nodule formation in the light of the auxin theory of growth. He postulated the following series of events after the bacteria enter the root tissues:—Small amounts of an auxin, among other substances, are produced in the course of bacterial metabolism, especially when the organisms attack carbohydrate or protein in the invaded cells. This substance causes enlargement of the cells in which it is produced and also being readily diffusible enters the pericycle behind the cortical tissue inhabited by the bacteria and there stimulates growth and division giving rise to the first stages of a lateral root initial. In the presence of continued auxin production, however, this potential lateral root is prevented from elongating; instead its cells increase in size isodiametrically while certain of the uninfected cells are stimulated to division by auxin diffusing out of the infected area. In this way he considers "a shapeless mass of parenchymatous tissue is produced which is essentially a lateral root prevented from elongating." The evidence on which Thimann based his hypothesis was as follows:—(*a*) The auxin activity of young nodules (2 to 3 mm. in diameter) was of the order of 10 to 12 plant units per nodule for three hours' diffusion. (*b*) Auxin was demonstrated to be present not only in the apical meristematic region but also in the basal portion which consists of infected cells. (*c*) Application of auxin to very young lateral roots resulted in complete inhibition in growth elongation, swelling due to radial elongation of cortical cells, together with divisions in the cambium and pericycle. (*d*) Indole-3-acetic acid was produced in culture media containing tryptophane in which rhizobia had grown. Thimann's general conclusions were that the course of nodule formation involves the production of indole-3-acetic acid by the bacteria which probably liberate it in the course of breakdown of tryptophane present in the nodules. He cites the work of Molliard (1912), noted earlier, pointing out that the effect of indole-3-acetic acid on the root is exactly the same as that of the sterile filtrate tested by Molliard.

Wilson (1937, 1940) discussing Thimann's work indicated that the idea of indole-3-acetic acid being the long sought stimulant was attractive, but rightly pointed out that more experiments were required. He also considered that further evidence was necessary to determine whether secretions from the root nodule bacteria would cause a response similar to that obtained when synthetic hetero-auxin was applied. Regarding this last point it would appear that the work of Molliard (1912) demonstrates, in the case of *Pisum* roots, effects of filtrates which are similar to those induced by auxins. However, if Thimann's hypothesis is to apply generally, it is still necessary to demonstrate nodule-forming phenomena, other than root curling, when bacterial secretions are applied in the case of lucerne, clover, etc. A further difficulty which may be mentioned is that many investigators believe that the structure of the nodule does not indicate a modified lateral root as Thimann states. Fred, Baldwin and McCoy (1932) discuss the evidence for and against this conception of its nature, and conclude:—"It (the root nodule) is distinctly not a modified lateral root, for it has no central cylinder, root-cap nor epidermis. Furthermore, it does not digest its way out from the cortex of the main root but remains covered with a considerable layer of cortical parenchyma."

It has been shown by a number of workers, Link (1937), Chen (1938), Thimann (1939), and Georgi and Beguin (1939) that various species of *Rhizobium* produced indole-3-acetic acid in culture. The position has been complicated, however, by the fact that both effective and ineffective strains of nodule bacteria and also organisms which live as contaminants in the nodules, all produce comparable amounts of growth-substance. Thus Chen (1938) found that effective and ineffective strains of clover bacteria when growing vigorously in liquid culture produced similar amounts of growth-substance as assayed by Went's split pea test (Went, 1934). Old laboratory strains that had lost the ability to infect and produce nodules were, however, found to produce less. Georgi and Beguin (1939) reported that four species of *Rhizobium* in culture produced indole-3-acetic acid. According to them the ineffective strains appeared to be more efficient growth-substance producers than the effective strains. *B. radiobacter,* a contaminant living in the nodules, was also found to produce growth-substance. These workers consequently question whether indole-3-acetic acid plays a causal role in nodule growth.

Chen, Nicol and Thornton (1940) appear to accept the view that initiation and maintenance of the apical meristematic cap of the nodule is due to growth-substances produced by the bacteria. Discussing the difference between nodule production by effective and ineffective strains, they state that the arrested growth in the ineffective nodules is due to the stopping of cell division in the apical cap, which in turn would appear to be related to the early arrest or decrease in growth of the contained bacteria. The decrease in bacterial growth might be taken to indicate that less growth-substance would be produced and consequently less cell division would occur. These workers made the interesting observation that juice from roots (of peas and soy beans) bearing effective nodules gave better growth for the organism in culture than did control juice, and that juice from roots of plants with ineffective nodules gave growth significantly poorer than control juice. Chen, Nicol and Thornton (1940) suggest that the stimulating effect was possibly concerned with the products of nitrogen fixation. It seems possible, however, that it may be some active growth-substance which is produced in the plant as a reaction to infection by effective strains and that as it can stimulate bacterial growth it may also be concerned in the cell proliferation.

Link and Eggers (1940), and Link, Eggers and Moulton (1941) present evidence to show that more growth-substance (as assayed by the *Avena* test) can be obtained by ether extraction from nodules of kidney bean and garden pea, and to a lesser extent for soy bean, than from denodulated roots, while less still could be obtained from roots grown in sterilized quartz sand. They conclude from this that nodules of bean, soy bean and pea have greater and different auxin contents than the roots which bear them and that these in turn have greater auxin content than the roots when grown in sterilized substrates. This represents a more cautious view than that expressed earlier by Link

(1937) when he stated that indole-3-acetic acid was one of the chemical agents, if not the primary one, responsible for the formation of nodules in certain leguminous plants. Thimann and Schneider (1939) although not comparing nodules with denodulated roots, pointed out that nodules of *Phaseolus vulgaris* were very active in producing growth-substance as tested by the quartered coleoptile test.

In conclusion we may say, that in the case of root nodules of Leguminosae, there appears to be no doubt that the bacteria secrete some chemical substance which causes the increase in length and deformation of root hairs in nature and also under laboratory conditions. According to Nicol (1938) the chemistry of this substance is still obscure. Its physiological activity, however, would appear to put it in the class of growth-substances. The mechanism inciting cell proliferation in the nodule is still in doubt. The hypothesis that indole-3-acetic acid (produced by bacterial metabolism in the plant) is causally related to cell proliferation is not favoured by the balance of evidence. Nor does it appear likely that the substance, referred to above, which is responsible for root hair deformation, can be the cause of the overgrowth.

There appears to be no conflict of evidence so far on the question of heightened growth-substance content in the nodules, and it therefore appears likely that a hormone mechanism is involved. This increased growth-substance would appear to be developed by the plant as a response to the bacterial infection.

Further research on the identity of the stimulating substance for "effective" nodule bacteria found in the roots of pea and soy-bean, will, it is believed, prove helpful in the solution of the problem.

Adventitious Root Formation.

Adventitious roots develop as a host reaction in tomato and certain other plants following infection by *Bacterium solanacearum*, *Bacterium tumefaciens*, *Aplanobacter michiganense* and *Fusarium bulbigenum* var. *lycopersici*. Such disease-induced roots, which generally show on the stem surface as small nodular projections, are to be distinguished from those which may develop on healthy plants under glasshouse conditions.

Hunger (1901), Smith (1914, 1920), Bryan (1915), and Grieve (1936, 1940) have reported on their occurrence in the case of *B. solanacearum*. In this disease the adventitious roots on tomato plants develop characteristically over several internodes along the path of the primary bundles, spreading later to the secondary tissues. Plants which show the reaction include tomato, African Marigold, garden Nasturtium and Sunflower (Grieve, 1940).

The presence of induced adventitious roots in plants such as Balsam, tomato and Paris Daisy infected with *B. tumefaciens* has been recorded by Brown (1929), Link, Wilcox and Link (1937) and Locke, Riker and Duggar (1938). Grieve (1940) pointed out that tomato plants artificially inoculated with *B. tumefaciens* show fewer adventitious roots, which are also more localized in distribution, than is the case for *B. solanacearum*. These differences appear to be related to the different distribution of the bacteria in the two diseases. Again, adventitious root formation in tomato, arising from infection with *A. michiganense*, ranges from abundant to scanty. Smith (1914, 1920) first reported their occurrence but found them to be relatively few in number. He concluded that this was due to the fact that this phloem parasite rapidly invaded the root primordia.

Fisher (1935) first mentioned root initials as being associated with infection by *Fusarium lycopersici* and this observation was confirmed by Wellman (1941).

That a stimulus of some sort was involved in adventitious root formation in the case of *B. solanacearum* was envisaged by Hutchinson (1913) and Smith (1920). Grieve (1936) pointed out the similarity of the reaction to that induced by ethylyene and carbon monoxide gases (Crocker *et al* 1932, Zimmerman *et al* 1933), and indole-3-acetic acid (Hitchcock, 1935a). Locke, Riker and Duggar (1938) noted this also for *B. tumefaciens* infections and Wellman (1941) for Fusarium Wilt.

The extended development of the adventitious roots along the vascular bundles in the case of tomato and African Marigold plants infected by *B. solanacearum,* made these plants suitable hosts for an examination of the mechanism of adventitious root formation. The disease differs from Crown Gall in that it is possible to ascertain the relation of the bacteria to the developing roots. Thus Grieve (1940) pointed out the following relations of *B. solanacearum* to the induced roots:—

(*a*) Adventitious roots frequently commenced to develop ahead of advancing columns of bacteria in vessels.

(*b*) Development of the root primordia, once initiated, continues to the stage where the root becomes visible as a nodule at the surface of the stem, even though the bacteria during this period gradually block all the vessels nearest the incipient root.

(*c*) Where vessels are rapidly filled with bacteria, no adventitious roots develop.

This histological study also established the fact that the action of the bacteria, in the case of tomato at least, was not always excited from a distance as Hutchinson (1913) and Smith (1920) believed. Nevertheless it strongly suggested that the bacteria were inducing the roots either directly by the production of some stimulatory substance or indirectly by their interference with the metabolism of the plant.

Grieve (1936, 1939, 1940) reported the extraction of a physiologically active substance from culture media containing glucose, peptone and mineral salts in which the bacterium was grown. This extract in crude form gave positive tests for hetero-auxin and induced adventitious roots on application to tomato and African Marigold.

Experiments with virulent and non-virulent cultures of *B. solanacearum* showed, however, that they produced approximately equal amounts of growth-substance. The same held true for pathogenic and non-pathogenic cultures of *A. michiganense*, *B. tumefaciens* and *B. flaccumfaciens*.

The suggestion that *B. solanacearum* produced growth-substance by acting on naturally occurring or artificially introduced tryptophane in the xylem was experimentally tested but no evidence of such production was obtained. This led the writer to doubt whether the bacteria initiated the adventitious root primordia through the medium of hetero-auxin production, and led to the formulation of the view that the mechanical blocking by the bacteria might induce the effect through disturbance of the normal hormone movement.

Experiments involving cutting and blocking of the xylem with inactive substances gave results which supported this view. Ether extractions of growth-substance which were assayed by the *Avena* test, showed, however, no significant difference in the amounts present in comparable healthy and infected plant parts.

Further experiments are required to check this, but the writer is of the opinion that significant auxin differences are not necessary, since the amount of auxin necessary to induce adventitious root formation *in vivo* is minute. One must also envisage the using up of some of this auxin in bringing about the root formation.

The problem of adventitious root formation in the case of *B. tumefaciens* is bound up with the general problem of gall formation and the conclusions reached there apply. The evidence of Locke, Riker and Duggar (1938, 1939), of Riker, Berch, Henry and Duggar (1941) and of Grieve (1940) makes it appear reasonably certain that hetero-auxin formation by the parasite is not causally related to adventitious root formation. Opinion also is still divided on the question of relative amounts of auxin in galled tissues as compared with comparable healthy plant parts.

With regard to *A. michiganense* no investigation appears so far to have been made, apart from the observation that pathogenic and non-pathogenic cultures of this organism produce approximately the same amounts of growth-substance (Grieve, 1940).

Wellman's paper on Fusarium Wilt (1941) merely reported adventitious root formation. The course of the disease here is not unlike that of Bacterial Wilt (*B. solanacearum*) in so far as symptoms are concerned and should prove a suitable subject for research on the mechanism of adventitious root formation.

It would be interesting to know whether the toxin produced by *Fusarium bulbigenum* var. *lycopersici,* has any bearing on the reaction.

Growth Movements—Epinasty and Hyponasty of Leaves.

Epinasty of leaves seems to be generally associated with adventitious root formation, both occurring as symptoms in the same disease, e.g., plants infected with *B. solanacearum* (Hunger 1901. Smith, 1920), *B. tumefaciens* (Locke, Riker and Duggar, 1938), and *Fusarium bulbigenum* var *lycopersici* (Wellman 1941). Leaflet epinasty has also been recorded as a primary symptom in the case of Rose Wilt Virus (Grieve, 1941) and there is a strong tendency toward it in young tomato plants infected with tomato Spotted Wilt. Hyponasty of leaves has been observed in plants infected by *Bac. phytophthorus.*

The only investigations so far available on leaf epinasty induced by parasites are those by the author (Grieve, 1936, 1939, 1940, 1943).

The reaction in the case of infection by *B. solanacearum* was shown to be an irreversible growth reaction and invasion of one lateral trace sufficed to induce it.

An experimental investigation of possible causes of the response showed that toxin production, ammonia production and hydrogen-ion effects were not involved. Experiments on mechanical blocking gave largely negative results (1939), although in later experiments (1940) there appeared to be some evidence which favoured it.

A growth-substance which gave the tests for hetero-auxin, was found to be produced in media in which the bacterium had grown, and this substance induced epinasty in leaves of young tomato plants.

No significant difference between the growth-substance content of comparable portions of infected and control stem parts of tomato plants showing leaf epinasty could be detected by the ether extraction method. Examination of the hormone distribution in the upper and lower halves of reflexing petioles has, however, shown a significantly greater amount in the upper halves. In normal petioles there is a greater concentration in the lower half (Grieve, 1943).

In 1939 the writer made the suggestion that the normal petiolar position was conditioned by a balanced hormone mechanism and that the disturbance of this would lead to epinastic response. The results given above show that the growth reaction of epinasty is associated with an increased concentration of auxin towards the upper surface. This redistribution of growth substance, which has also been demonstrated to occur in the case of leaf epinasty associated with Crown Gall, is induced by the bacteria. No definite conclusion as to how the redistribution of growth substance in the basal part of the petiole is effected, can yet be made. As the writer pointed out (1939), however, the balance of the normal growth controlling mechanism at the base of the petiole is very delicate. This is reflected by the fact that ethylene in one part in 10 million of air, as well as very small amounts of growth substance from bacterial cultures, suffice to disturb it. It is not unlikely, therefore, that even a small stimulus from the invading organisms can initiate a chain of reactions leading to the redistribution of hormone with consequent epinastic response.

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ART. VI.—*The Geology of Warrnambool.*

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

[Read 11th June, 1942; issued separately 1st October, 1943.]

Abstract.

A coastal strip of over two miles wide of consolidated Pleistocene calcareous dunes overlies a bedrock of horizontally-bedded Miocene marine limestone. Inland from the dunes is a plain of ?Pliocene olivine basalt overlying siliceous fluviatile sands and gravels, which rest on the bedrock limestone. Holocene shell beds prove a relative land uplift of at least 14 ft. 6 in. Tuff from the extinct Tower Hill volcano overlies a great deal of the area.

Contents.

Introduction.

This paper presents the results of a study of the area comprehended within the boundaries of the city of Warrnambool. A reconnaissance was made of the country within ten miles of the city to establish the general relationships of the formations appearing in the area of detailed study.

The Miocene Limestone.

The bedrock of the Warrnambool District consists of Miocene marine sediments of Barwonian age in thick beds lying horizontally. The strata which outcrop are highly calcareous sediments, sometimes soft and friable, but often considerably indurated with secondary calcite. They form part of the Miocene beds which extend across the south-western part of Victoria into south-eastern South Australia.

The presence of Miocene limestone at Warrnambool has been noted by Wilkinson (1864-5), and in a list of Tertiary fossils Dennant and Kitson (1903) record "*Pecten foulcheri, Magellania insolita, Magasella woodsiana,* and *Lovenia forbesi*" from that city. Murray (1887, p. 104) refers to Miocene marine beds on the Hopkins River.

The writer has found fossils on the northern and south-eastern rim of the Tower Hill crater, also at the outcrops of limestone marked on the map (fig. 2); behind the tennis court at Woodford; in a quarry on the west side of the bridge near the State School at Curdie's River; in the cut for the drainage of Lake Gillear; in a road cutting on the south side of the Cobden-Colac road on the west side of the bridge over the creek which is a branch of the Curdie's River, and in a road cutting on the hill on the Cobden side of Jancourt.

In Western Victoria the Miocene sediments attain a considerable thickness, but at Warrnambool their thickness has not been proved. A bore described by Griffiths (1891) went through dune rock and then Miocene limestone to a depth of 398 feet, where it was still in the latter formation. Many bores have been put down for water in the district, but the deepest other bore of which I have knowledge is one at Wangoom which was sunk to a depth of 170 feet, all of which was marine limestone. At Portland, a bore put down in the Botanic Gardens traversed 2,265 feet of Tertiary rocks without reaching the underlying strata.

The Miocene beds are very fossiliferous, although the preservation is usually very poor. *Lovenia forbesi* and *Ditrupa* appear to be the commonest fossils, the latter often occurring in bands closely crowded with the tests. Brachiopods, pelecypods, and bryozoa are common in the river section on the west bank of the Hopkins River north of the bridge (fig. 1). Dr. F. A. Singleton kindly examined a collection of fossils made by Mr. George Jorgensen and the author. He stated that they indicated a Barwonian age, but on the material collected a closer determination of age could not be made. Mr. Parr kindly examined some material collected from the Miocene limestone at Warrnambool, but the foraminifera were too poorly preserved for determination.

The Pliocene Basalt.

Basalt is seen in the north-east corner of the city of Warrnambool (fig. 1), but this is only the edge of a great lava plain which stretches away to the north (Hills, 1939). It is mostly vesicular and somewhat decomposed, but parts of the flow are dense and comparatively fresh, being of a light bluish colour in hand specimen. A sample collected from the road cutting at the gate of Mr. Wall's property about half a mile north-west of the

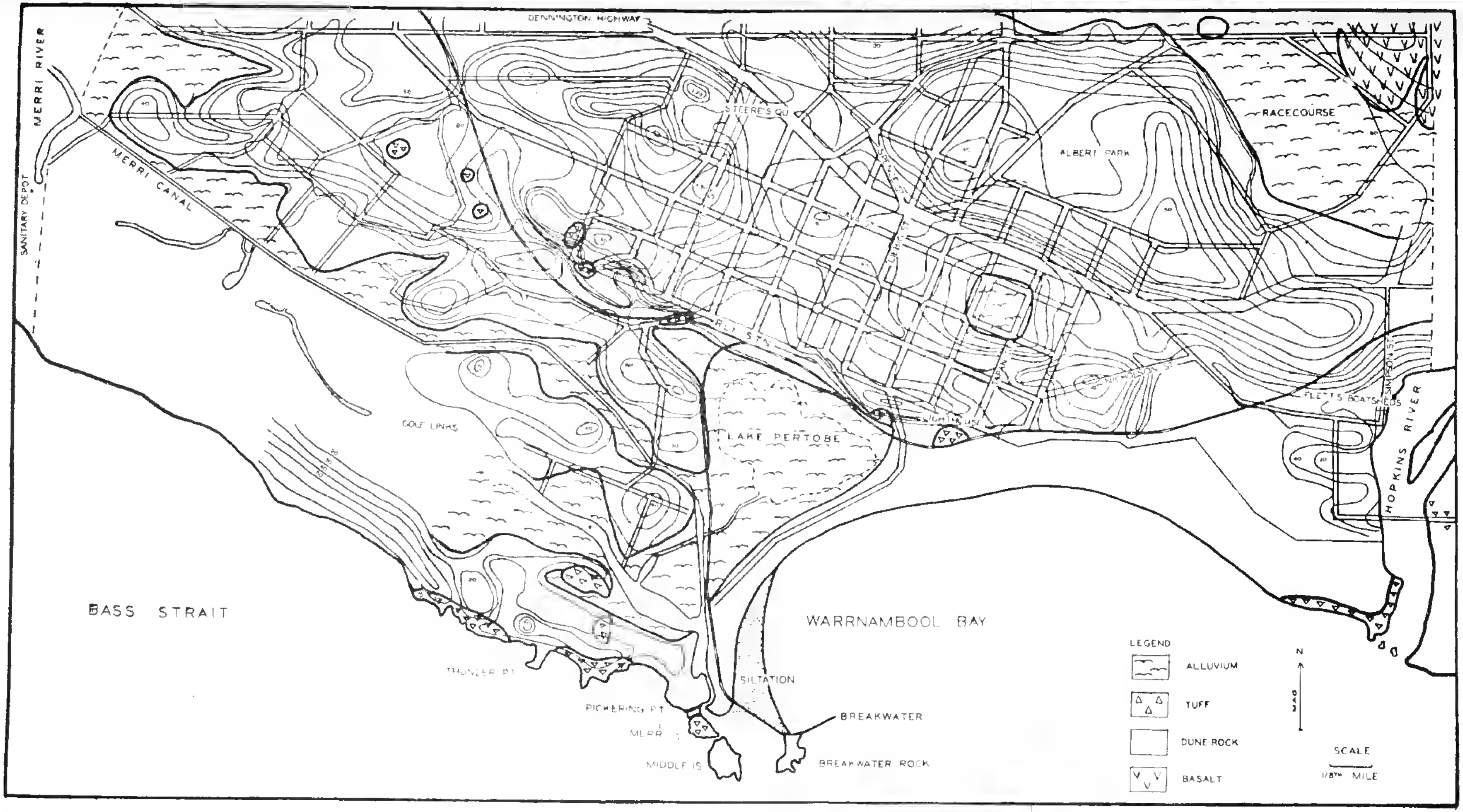

FIG. 1.—Geological Map of the City of Warrnambool, taken from the city map, with 10 feet contours from a sewerage map kindly loaned by the City Engineer, Mr. G. M. Chisholm, B.C.E., C.E.

Wollaston Bridge (fig. 2) has been determined by Dr. A. B. Edwards as an olivine basalt of the Footscray type. The basalt has been used as a building stone in a few instances at Warrnambool, but its chief economic use is for road metal and screenings.

The following evidence has a bearing on the age of the basalt:

1. The flow overlies extensive post-Barwonian fluviatile deposits (fig. 2). Current-bedded sands and gravels have been quarried to a depth of 15 feet on the Wollaston Estate, where basalt superimposes them. Remains of sticks were obtained from a thin clay seam interbedded with the gravels.

2. The pre-basaltic terrain is a diversified one. For instance, sections along the banks of the Merri River at Woodford show a thickness of basalt of about 20 feet, but a boring record ¼ mile away near the stone house of Mr. Ben Morgan shows 80 feet of decomposed basalt, 15 feet of clay, and so to the bedrock. A bore at Cudgee Milk Depot proved only 9 feet of basalt, whereas there are basalt quarries nearby. The basalt is seen to occupy small valleys at White's Lane and the Racecourse, but ¾ mile behind the Half-Way Hotel towards the Merri River, a bore has shown 60 feet of decomposed basalt to be present.

3. To the north and north-east of Warrnambool the basalt flow which reaches that city (fig. 2) is covered by another flow of more recent date. On Mr. Good's property at Winslow, the following deposits were bored:

Decomposed basalt	..	30 feet
Tuff ..	..	2 ,,
Fresh basalt	..	30 ,,
Yellow clay ..	..	20 ,,
Marine limestone	..	—

A bore on Mrs. McNamara's property near the State School at Cooramook traversed:

Basalt ..	..	80 feet
Gravel ..	..	15–18 ,,
Dense basalt	..	4 ,, (not pierced)

A bore ¼ mile off the Ellerslie Road towards Framlingham went through:

Basalt ..	..	124 feet
Coarse gravel	..	15 ,,
Very dense basalt	..	25 ,,
Black clay ..	..	20 ,,
Yellow clay	..	5 ,,
Marine limestone	..	—

A similar series of deposits was traversed by a bore on the Aborigines' Reserve at Framlingham. The Hopkins Falls on the Hopkins River are apparently due to the river flowing off the younger flow on to the older.

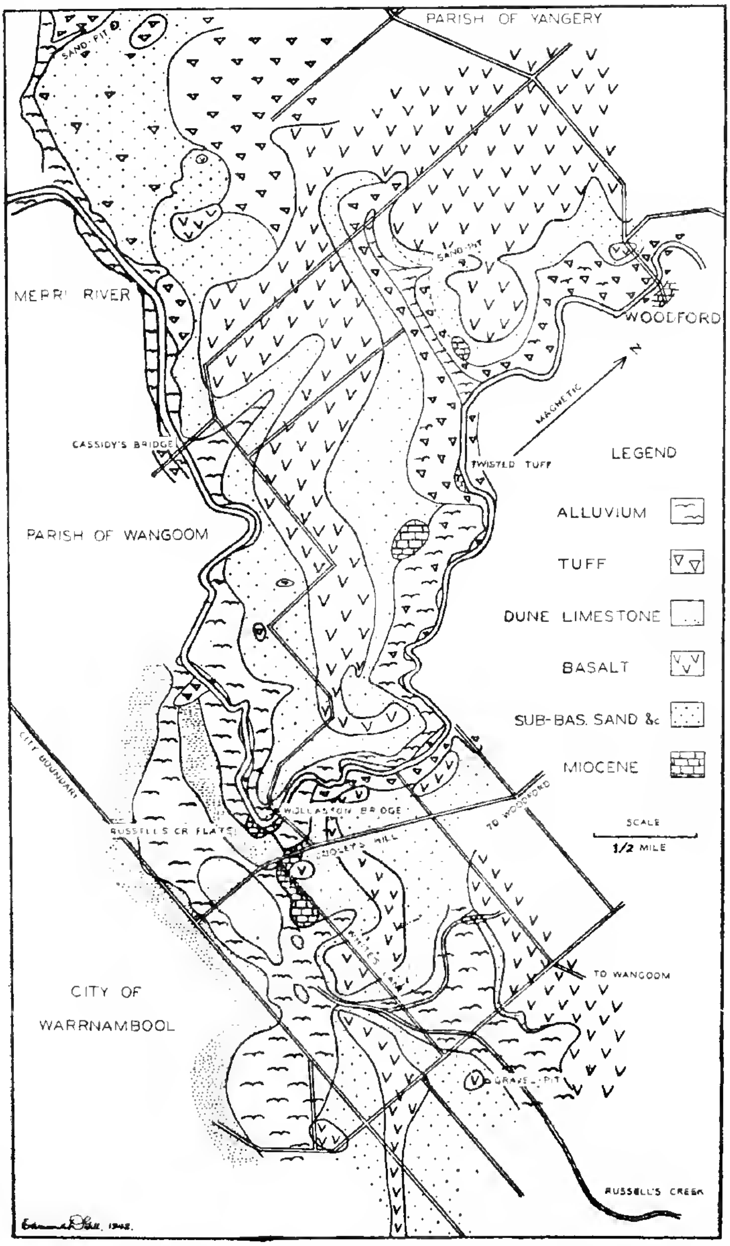

FIG. 2.—Geological Map of an area north of the City of Warrnambool, based on plans of the Parishes of Wangoom and Yangery.

4. Consolidated dune limestone (Pleistocene) rests on the eroded surface of the basalt. This can be seen in a road cutting in White's Lane (fig. 3) which is the furthest point inland at which the dune rock is found, and so presumably a remnant of the oldest line of.dunes. As it is believed that the dune-building began with the Ice-Age (= Pleistocene), it may be inferred that because the dune rock overlies the eroded basalt, that the basalt is not younger than Upper Pliocene.

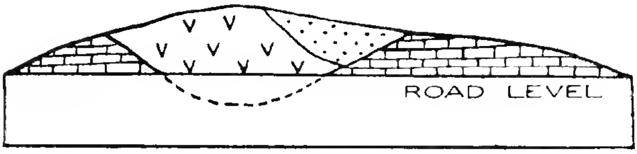

FIG. 3.—Road Section at White's Lane, north of Warrnambool, showing consolidated dune rock resting on the eroded surface of the basalt.

5. The basalt has been widely dissected by streams (fig. 2), and the records of the very numerous borings made for water in the district show the flow to be mostly in a state of decomposition. Buckshot gravel is plentifully developed over the basalt, tens of thousands of tons of this material having been used for road-making in the Warrnambool shire.

Thus the decomposition of the basalt, its dissection by streams, and the big development of buckshot gravel all indicate an older rather than a younger age for it.

From the evidence for the age of the basalt outlined in this section of the paper it will be seen that this lava flow is post-Miocene in age and pre-Pleistocene, and may therefore be referred to the Pliocene period.

The Pleistocene Dunes.

1. Extent and Character.

Murray (1887, p. 131) writes, "The sand rocks of Post-Tertiary age along portions of the coastline, as at Warrnambool and Cape Otway, are aerial deposits formed by the action of the wind blowing sand into dunes and hillocks which subsequently consolidated owing to the presence of calcareous matter derived from the shell fragments associated with them. These rocks have been partly denuded, and their materials are now in course of fresh distribution by every wind." Etheridge (1876) and Pritchard (1895) have also given a general account of these dunes. Rawlinson (1878) and Mahony (1917) made observations on the Warrnambool dunes, the latter giving a chemical analysis of the dune material.

The dunes are a conspicuous feature of the coast from some distance east of the Hopkins River as far as Port Fairy which is 16 miles west from Warrnambool. The city of Warrnambool is built on the dune rock. In this paper the consolidated dune sandstone (if one thinks of its texture) or limestone (if one thinks of its chemical composition) is treated separately from the loose sand of the present mobile dunes. The former are considered to be Pleistocene in age, while the latter are of Holocene age.

The consolidated dune rock is extensively developed at Warrnambool where it is very thick and stretches inland for 2¾ miles. At this distance inland the Merri River runs for over 3 miles parallel to the coast, flanked on one side by basalt and on the other by dune rock. At Albert Park the dune limestone reaches a height of over 160 feet above sea level. Mr. Keith McCrabb informs me that bores put down at his own place (46 Spence-street) and at the Paragon Cafe in Liebig-street, traversed 96 feet and 65 feet respectively of dune rock. Mr. Bruce informs me that a bore put down at the premises of Bruce and McClure, Lava-street, proved a depth of 80 feet of dune rock. All these places are about 70 feet above sea level. A bore put down at the Sanitary Depot near Levi's Point penetrated 110 feet of dune sandstone before reaching the marine limestone which was bored a further 10 feet. The location of the bore is 43 feet above sea level, so the sandstone occurs to a depth of 67 feet below sea level at this point which is about ⅓ mile from the coast.

The Admiralty Chart of the coast shows that the shore platforms, which are formed of consolidated dune sandstone and shallow waters, extend seawards for about a quarter of a mile. Seven hundred yards out from the mouth of the Hopkins is the "Hopkins Reef" which is of the same rock. A line of section taken east from Pickering Point through Breakwater Rock traverses half a mile of island and platforms before entering moderately deep water. Taking into account the shore platforms (Plate II., fig. 4), there is a width north and south of 3 miles of dune rock at Warrnambool. The presence of rock stacks and the fact that the pebbles washed up on the beach are all dune rock shows that it stretches out to sea for some distance. In some rock stacks aeolian bedding can be clearly seen running down as far as visibility extends below the low water level. Thus, stretching round the coast for some 20 miles there are these dune deposits extending inland from one to three miles, and on the evidence of bores and coastal features occurring to a depth well below the present sea level.

The material of the dunes is predominantly calcareous, consisting of comminuted shells, echinoid tests and polyzoa, and of foraminifera. Three published analyses give the percentage of carbonate of lime as 92·43 (Officer, 1891), 86·25 (plus 6·64 of magnesium carbonate—Mahony, 1917), and 92·85 (Coulson, 1940, p. 330). In a cutting on the road to Cassidy's Bridge, 200 yards north of the Warrnambool-Dennington highway, a quartzose sandy soil can be seen under 18 inches of tuff. This quartzose layer is probably due to leaching of the limestone in which there is a small percentage of quartz. Crocker (1941) so explains similar horizons in the South Australian dunes.

The dune rock is sometimes comparatively soft, and friable. The rock, when even and compact, is used for building purposes, being sawn into blocks with ordinary steel saws. The consolidated dune limestone is mostly traversed by calcitic seams sometimes 3 inches wide. In places the sandstone is so indurated that it is glassy and splintery when broken, as, for example, at the east end of Albert Park where it is crushed for road-making purposes.

Caves are common in the dune limestone as they are in the Miocene marine limestone. In the excavations for the sewerage system several more of these caves were located. Belvedere Cave, which is a few hundred yards upstream from Flett's boatshed on the Hopkins River is in Miocene limestone and possesses the remains of stalagmites and stalactites. Many other caves are known in the district (*vide* Bonwick 1858, and Osburne 1887).

The aeolian bedding in the dune rock at Warrnambool shows that at the time of their formation the prevailing winds were south-west as they are now (Rawlinson, 1878). This is shown also by the disposition of the tuff deposits. The windward slopes of the dunes are 10 to 15 degrees, and the leeward slopes 30 to 33 degrees.

Another conspicuous feature of the dune sandstone is the presence of buried soil horizons such as noted previously at Warrnambool by Murray (1887, fig. 45) and Archibald (1894), and at Portland by Coulson (1940). The soil layers vary in thickness from 2 feet to a few inches, and can best be seen in the cliff sections along the coast, especially in the vicinity of Thunder Point where five layers can be seen counting the one under the tuff. The lowest (Pl. II., fig. 2) is 3 feet thick and can be followed for ½ mile round the cliffs, where it ultimately fades out in an "unconformity" which is only a cross-bedding. Such unconformities are due to the planation of an older dune which had been consolidated, and the building of a later one on the eroded surface. An unconformity (Pl. II., fig. 5) thus represents a break in the process of dune-building as does a soil horizon. Three other soil horizons can be seen close together at Thunder Point (Pl. II., fig. 3), and a fifth under the Holocene tuff which caps the cliff (Pl. II., fig. 7). Soil horizons can again be seen at Pickering Point, Ryot-street road cutting, Simpson-street road cutting, Nicholson-street Quarry, and Albert Park Quarry. That at Pickering Point as well as some noted in sewerage excavations have been indurated by the deposition of calcareous matter in them. Further, the soil layers are fossiliferous containing numerous land shells, and sometimes carbonized plant fragments. The dune rock itself contains occasional Helicid land shells. The discovery of alleged human impressions in the dune sandstone has occasioned much discussion (Officer, 1892; McDowell, 1899; Pritchard, 1895; Gregory, 1901; MacDonald, 1904; Chapman, 1914) but they are generally regarded as very doubtful. Footprints of birds and animals have been found (Chapman, 1914).

2. ORIGIN.

Present conditions are not adequate to account for the Warrnambool dunes because:

1. Although of aeolian origin, the dunes descend to a considerable distance and depth beneath the sea, in spite of a Recent uplift of about 15 feet above sea level (p. 143).

2. The presence of soil layers and of unconformities in the dune rock indicates some alternation of conditions.

3. The present quantity of shells and other calcareous tests available for fragmentation into sand cannot account for the accumulation of so immense an amount of dune-rock.

4. The dune-rock cliffs are at present being rapidly broken down by wave action, i.e., the existing forces of denudation markedly exceed those of construction.

5. Offshore there is a submarine valley, partly at least in the dune rock.

As the wind-bedded rock extends below the present sea level, the dunes must have been built when the sea was relatively much lower than it is now. In recent times the sea has been about 15 feet higher than now (p. 143), but in Pleistocene times there was a big eustatic drop in sea level. Hills (1939) has drawn attention to the work of Sayles (1931) on the ancient dunes of Bermuda, and suggested an analogy between them and Australian formations. Sayles states that the soil horizons in Bermuda represent the less adverse conditions of the interglacial periods. Daly (1935) states that the last eustatic drop in sea level was of the order of 75 metres which would join Tasmania and Victoria, and this fits in very well with the essential identity of the faunas and floras on both sides of Bass Strait. An Ice Age origin for the dunes also explains the third point set out above, concerning the quantity of material involved in the construction of the dunes. Of this Daly (1935, p. 197) writes, "When, with each major glaciation, the strand-line moved outward over the gently sloping shelves surrounding continents and islands, wide areas of loose marine sands and muds were exposed to the winds. The dried sands were lifted and carried inland by the onshore winds." Furthermore, since the deposition of the dune sandstone, marine and estuarine shell beds have been laid down (probably by post-glacial high-level seas) along the lower reaches of the Hopkins River, in Lake Pertobe, at Dennington, at a locality near Tower Hill, and at Port Fairy. Also since the deposition of these shell beds the Tower Hill volcano has been active and then become extinct. The consolidated dune sandstone is therefore older than Holocene and is to be referred to the Pleistocene period. If the soil horizons represent interglacials, then the formation covers most, if not all, of the Pleistocene period.

Mr. W. J. Parr has kindly examined material collected from the beach on the west side of the mouth of the River Hopkins, and from the Pleistocene dune sandstone at Steer's Quarry, Warrnambool. From the former locality he has determined *Discorbis dimidiatus* (Jones and Parker), *D. australis* Parr, *Elphidium macellum* (Fichtel and Moll), *E.* sp. indet., and *Quinqueloculina lamarckiana* d'Orbigny. From the latter locality the same species of *Discorbis* and *Elphidium* were found, in addition to *Quinqueloculina* sp. indet., and *Triloculina trigonula* (Lamarck). Mr. Parr has noted that the species of foraminifera are all common in Victorian shore sands, but that in the above samples they were commoner in the Hopkins beach sand than in the Warrnambool dune rock.

In discussing the dunes of the adjacent Portland District (which has a similar structure to that of Warrnambool), Coulson (1940) claims that " The widespread 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." Thus Coulson holds that ordinary dune-building forces in this part of Victoria could not have elevated the sand above 100 feet. However, it should be noted that—

1. Similar sea-line dunes occur at Warrnambool (60 miles from Portland) to over 160 feet, and these may be compared with those on King Island to 250 feet (Debenham, 1910), at Sorrento to 225 feet (Gregory, 1901), at Anderson's Inlet to 250 feet, in the Glenelg area to 300 feet, and in West Australia to 300 feet (Etheridge, 1876).

2. Coulson postulates uplift to explain dunes at 400-500 feet, yet explains dunes from 500-740 feet as due to migration up slopes. May not the dunes at 400-500 feet be due to similar migration?

3. The factors limiting the height of such dunes (as described, e.g., by Cornish, 1896-7, and Olsson-Seffer, 1907) apply only to sands in open country, and not to sands migrating up slopes. Worcester (1939, p. 229) refers to the piling up of dune sands to over 1,000 feet in the San Luis Valley, Colorado.

The present writer is of the opinion that there has been no post-Pliocene uplift of the order of 400 feet in the Portland-Warrnambool area.

The Holocene Shell Beds.

In 1917 Chapman and Gabriel listed shells collected from a small patch of rock about 100 yards upstream from Flett's boatsheds on the west bank of the River Hopkins. Deposits extending for about a mile have now been traced on the east bank of the river, overlain by tuff (Pl. II., fig. 8). In the section shown in the photograph there are the following thicknesses of deposits:—

9 inches soil.

3 ft. 3 in. tuff.

3 inches to 1 foot agglomerate composed of sand and angular fragments of dune rock.

14 ft. 6 in. limestone composed of numerous Holocene shells in cemented calcareous sand.

The rock is often crowded with shells, many of the bivalves having the two shells still together, showing that they were deposited in quiet waters and not thrown up on to a storm beach by waves. The shells are generally whole. The highest placed fossil observed was collected from 11½ feet above high-water mark (the river is tidal as far up as Allansford). Flat smooth pebbles of dune sandstone are common in this Holocene deposit, a layer of 9-inch thick being developed in one locality. Chapman and Gabriel thought that the Hopkins shell-rock was part of the Pleistocene dune formation (pp. 4, 13). However, the examination of further outcrops on the opposite bank of the river shows that the deposit is resting on dune rock, and is largely composed of materials derived from the dunes, and therefore is to be regarded as post-dune. The fossils are all of recent character. The same authors attributed the height of the shell bed to "local uplifts due to volcanic activity in the western district" (p. 5). An explanation based on the world-wide drop in sea level in recent times advocated by Daly (1935), is also feasible.

Similar Holocene shell beds occur on the flats at the northern end of which is Lake Pertobe, where boring has proved a thickness of 20 feet of sediments over the dune-rock. Chapman and Gabriel (1917) also reported on shells collected from this locality but considered that "this deposit probably belongs to a later episode than the shell-beds underlying the tuffs." The Merri Canal has exposed these beds, some of which are still loose and some consolidated. The beds are packed with shells, most of which are whole, and many of the bivalves have the two shells still in place. At the upstream end of the flats, near the Warrnambool Woollen Mill, oyster shells are common. On the Merri Canal 4½ inches to 5 feet of these Holocene shell beds are exposed above river level on the west bank.

Shell beds are also known at Dennington (Chapman and Gabriel, 1917, p. 4), where a fauna was obtained 8 feet from the surface, and underneath volcanic tuff. Records of bores show that underneath this shell bed there is a boulder bed of at least 15 feet thickness. Behind the ocean foredunes there is a swampy area which leads right up to Dennington (fig. 4). In very rough weather the sea washes over into this swamp. On the road from Warrnambool to Dennington about 200 yards east from the turn off to Cassidy's Bridge, an excavation for a large electric power line pole brought up numerous flat pebbles and sea shells, some of the latter being water-worn.

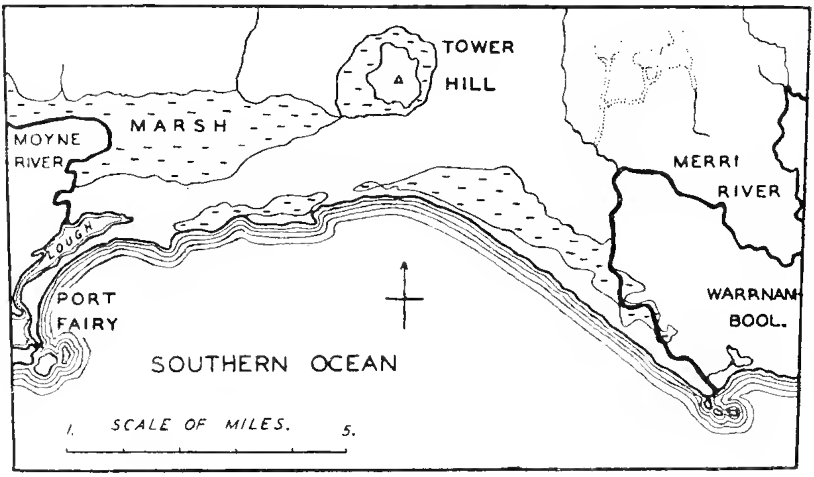

FIG. 4.—Map (after Archibald, 1891) showing stream-pattern in Warrnambool District.

The shell beds at Dennington, Lake Pertobe, and Hopkins River, rising to a maximum height of 14½ feet above sea level, indicate a relative uplift of the land of at least that amount. This is referred to in the present paper as the 15 feet uplift.

Shell beds not unlike those at Warrnambool are known also at Port Fairy (Rawlinson, 1878, p. 31), Gellibrand (Murray, 1877, p. 127), and in the Port Philip area (Hills, 1939, p. 90). Coulson (1940) has brought forward evidence of a 10-ft. relative rise of the land in the Portland district. David (1914) remarks, "The so-called raised beach of about 15 feet is so general around Australia, that it is probably due to a eustatic negative movement of the sea surface" (p. 289).

That the relative fall in sea level at Warrnambool was a recent one is corroborated by some physiographic features. On the north boundary of Lake Pertobe is the precipitous scarp of Cannon Hill (Pl. II., fig. 6). This is an old sea cliff, while the gentler slope in the foreground is due to the piling of volcanic tuff against this cliff. When a trench for a water main was dug at the railway crossing just west of the Warrnambool railway station, a sea shell (*Trochus undulatus*) was found in dune rock under tuff. This shell was complete and is the only sea shell which has been found in the dune rock. It is significant that it is at the foot of this cliff. The scarp passes in one direction round to the Woollen Mill, and in the other past the lighthouse towards the Hopkins River.

The Holocene Tuff.

Nine miles west of Warrnambool is the extinct volcano of Tower Hill, which was of the explosive type, and tuff and fine lapilli ejected from it extend eastwards a little beyond Warrnambool. Apart from accumulations in depressions such as the valley of the Merri River, the capping of tuff does not exceed 3 feet in the vicinity of Warrnambool. Greater thicknesses are found to the north-east of the volcano, showing that the prevailing winds during the eruption were south-west as they were in the Pleistocene (deduced from the orientation of the dunes), and are now. Errey (1894, p. 24) thought that the tuff had been laid down under water. There is no evidence for this apart from the tuff in the river beds. Similar stratification of the tuff (Pl. II., fig. 7) is seen on the top of the cliffs at Thunder Point, on the sides of the hills, and in the hollows. Tuff is prominent all along the banks of the River Merri, so much so that locally the rock is known as "Merri stone". It is also an important constituent of the river flats where sometimes it is bedded and sometimes mixed with alluvium. An interesting structure observed in the banks of the Merri River (Pl. II., fig. 1) is a sub-circular arrangement of the "stratification". The weathering of the variant textures in the tuff shows that apparently the volcanic dust mixed with the water of the river until a viscous consistency was attained, whereupon it was turned over so as to appear somewhat like a stiff cake mixture which has just been stirred.

In addition to the tuff shown on the maps, there are many little patches too small to be so recorded. Former small hollows in the terrain have been filled up and levelled off with deposits of tuff. Also some soils show by their colour and texture that they have been admixed with tuff. An interesting profile is to be seen in a quarry between Nicholson-street and the railway line (Pl. II., fig. 9). From the bottom up the layers are:—

Consolidated dune limestone.
18 inches black " fossil " soil horizon.
6 inches buff coloured calcareous sand.
6 inches tuffaceous sand layer.
2 inches present black soil layer with grass.

The Merri River runs for a considerable distance on a bed of tuff, which can be seen outcropping on its banks to a depth of 10 or 15 feet, and in places there are small islands of tuff. For some distance upstream from the Wollaston bridge, the tuff is piled high against the eastern side of the valley.

The tuff is fossiliferous in places. Carroll (1898) found the skeleton of a dingo at Tower Hill 60 feet from the surface. Walcott (1920, p. 69) refers to " large and deep footprints, measuring about 9 inches in length, in volcanic tuff, which were exposed in the floor of a cutting made to connect Nestle's Milk Factory with the railway line at Dennington, near Warrnambool ". Chapman (1926) records a leaf, *Eucalyptus* sp., from the tuff.

The stratification of the tuff (Pl. II., fig. 1) as seen at Warrnambool and to even more marked degree at Tower Hill itself, shows that the volcanic activity was intermittent. Bonwick (1858, p. 61) records a layer of black soil and remains of vegetation at a depth of 120 feet interbedded with tuff. On the west bank of the Merri River, ¼ mile upstream from the Wollaston bridge, the following section can be seen (the lowest outcropping stratum being named first:—

15 inches dark-grey ash with fine lapilli.
5 inches light-grey ash, graded thick to fine upwards.
2 inches clay.
3 inches ash with fine lapilli.
8 inches laminated clay in layers of about ½ inch.
6 inches dark ash with fine lapilli.
9 inches clay and ash mixed, merging upwards into light-grey ash.

The alternation of beds of fine clay with beds of tuff indicates a discontinuity at least at this point in the deposition of the volcanic material. However, such alternation of bedding is rare.

The volcanic ejectamenta are of very recent age because—

1. They rest on the Holocene shell-beds described above (Pl. II., fig. 8). This means that the tuff is later than at least the beginning of the post-glacial recession of the sea (if the 15-foot relative rise of the land at Warrnambool is due to this cause).

2. At Cannon Hill, Warrnambool, the tuff rests against the base of an old sea cliff which is only a few feet above sea level. The town clerk of Warrnambool (Mr. H. J. Worland) has a photograph showing high seas washing over the foredunes into the lake at the bottom of this cliff. The preservation of this bank of tuff without apparent erosion, and of a similar bank a little further east near the lighthouse (fig. 1) is evidence that the tuff has been deposited since the completion of the post-glacial recession of the sea.

3. Where tuff rests on hillsides in the areas mapped, it has been noted that it always follows the present contours of the countryside.

4. The Merri River has not yet cut through the tuff in its bed.

5. Mulder (1909) claims that the meaning of aboriginal names " shows that they saw the volcanoes in action, but at a period so remote that even tradition had died out, the names only surviving."

However, Mr. A. S. Kenyon (personal communication) informs me that the meanings given by Mulder are incorrect, and are to be ascribed to " wishful thinking and blackfellows' courteous replies ".

The Holocene Alluvium.

Along the Merri River from Cassidy's Bridge upstream, there are river flats situated generally about 15 feet above river level. Tuff outcrops along the banks of the river for most of the way, and it is commonly met with in excavations on the flats. The alluvium is itself sometimes seen clearly to contain tuffaceous material. The deposition of tuff in the valley is considerable as so much was washed off the sides of the valley into the river course. The result was a building up of the river bed by more than 15 feet, thus slightly rejuvenating the stream which has cut through this new bed to an average depth of 15 feet. Below Cassidy's Bridge are many swamps and flats covered with reeds. These are covered in flood-time, whereas the high level alluvium just referred to is not now reached by flood waters. Many of these low-level flats are in the nature of dune swales which have been extended by fluviatile and marine action.

Russell's Creek, a tributary of the Merri River, has two levels of alluvium in the upper and lower parts of its course respectively, and these will be described in the physiography section.

The map of Warrnambool constituting fig. 1 shows a patch of alluvium in the vicinity of Japan-street. This is a swale hollow which used to become a lake in winter until a tunnel 27 chains long was cut through a dune ridge to the sea.

Lake Pertobe is bounded on the east, west, and south by alluvial deposits which have been superimposed on the Holocene marine shell-beds already described. In the winter the lake extends considerably, and the alluvium is thus partly lacustrine and partly due to wash from the higher ground surrounding the flats. The alluvium near the lake abounds with the shells of small freshwater mollusca. Alluvium with similar shells occurs on the south bank of the Merri River near the outcrop of Miocene limestone 2½ miles upstream from Wollaston Bridge (*vide* fig. 2).

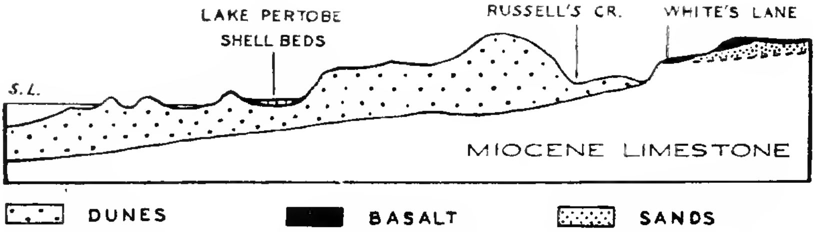

FIG. 5.—Geological Section along Liebig-street, Warrnambool, projected to the Wangoom Road in the north, and to a short distance seawards from Pickering Point in the south.

The Holocene Dunes.

Fringing the ocean for the whole area mapped (fig. 1) there are mobile dunes which are Holocene in age, although composed of the same calcareous sand as the Pleistocene consolidated dunes. For most of the distance they cap the consolidated dune cliffs, but east of Lake Pertobe they occur at sea level. Originally these dunes were closely covered with ti-tree (Osburne, 1887) as is indicated by the presence of numerous root incrustations (cf. Hall, 1901).

The former Government botanist, Baron von Mueller, introduced marram grass as a means of re-anchoring the sand of the mobile dunes, and where developed this treatment has proved successful (cf. Matthews, 1934, p. 90). However, as the grass grows higher so the dunes mount, with the result that they are now much higher than formerly. For instance, the dunes at the Warrnambool Beach (east of Lake Pertobe) used to be so low that during the winter storms the sea water would drive over them and run into Lake Pertobe towards Cannon Hill, but now they have built up to about 20 feet high.

At the mouth of the Hopkins River (west side), at Thunder Point, and at a few other points, the mobile dunes can be seen to be resting on a bed of tuff from 2 to 3 feet thick.

Palaeogeography and Physiography.

North of the city of Warrnambool there runs a clearly defined scarp from 15 to 20 feet high, which is probably the Pliocene shoreline. This scarp consists chiefly of basalt, which is to be expected since it is so resistant a rock, but it is not simply due to differential erosion because the basalt occurs in some places at a lower level in front of this scarp, e.g., at the north-east corner of the Warrnambool racecourse and at White's-lane. The Pleistocene dunes were piled against this barrier, and the Merri River has 3½ miles of its course marginal to it. From the scarp the underlying Miocene limestone shelves away southwards towards the sea, as the following figures indicate:—

At White's-lane, about 70 feet above sea level.

Albert Park, about 26 ft. 6 in. above sea level.

Spence-street, about 20 feet below sea level.

Lava-street, about 10 feet below sea level.

Sanitary Depot, about 67 feet below sea level.

On this slope, which would be left dry by the retreating Pleistocene sea, the sand dunes were built up, and in time consolidated by the secondary deposition from percolating waters of calcium carbonate. The advancing sea began the demolition of these dunes, the sea being then some 15 feet higher than it is now. Parts of the post-Pleistocene shore line can still be seen as described in the section on the Holocene shell beds. Borings have shown that the dune rock floor below the Lake Pertobe shell beds slopes from the foot of Cannon Hill to a depth of 26 feet below ground level when the beach is reached.

Lady Bay (or Warrnambool Bay as it is called on some maps) is an inundated swale, the line of islands and shore platforms on its seaward side being a continuation of the line of dunes which constitute the coastal cliffs. A former course of the Merri River was along the swale behind this first row of dunes. However, sand from the mobile dunes kept blowing into the stream tending to block it and in any case washing into the harbour, so a canal was cut to divert the river. This canal followed the swale behind the second row of dunes. Fig. 1 shows how the alluvium of Lake Pertobe extends up behind the third row of dunes, and Bonwick (1858) suggested that the Merri once flowed out at this point too. The seaward sloping floor beneath Lake Pertobe is consonant with this idea. The present course of the Merri River after leaving the basalt is along the hindermost of the swales which is marginal to the basalt. It is clear too that the Merri River at one time flowed into the sea west of Dennington (fig. 4), and it is probable that it was then that the estuarine beds were deposited there. The Admiralty chart shows a submarine valley south of Tower Hill. The exit to the sea south of Dennington was ultimately blocked by the shifting sand of the mobile dunes, and the impounded waters then found an outlet along the first swale to Lady Bay. A similar thing has happened at Port Fairy to the Moyne River forming the Belfast Lough as it used to be called (Belfast is an earlier name for Port Fairy). *Vide* fig. 4.

The valley of Russell's Creek, a tributary of the Merri River, is characterized by two areas of alluvial flats differing 20 to 30 feet in height, and caused by two bottlenecks in the course. The first constriction is near the mouth of the stream where a line of strongly consolidated dunes is the obstacle. A local base level of erosion has been developed called the "Russell's Creek Flats". The second constriction is in the basalt north of the racecourse.

Bands of hard travertine retard the weathering of the dune rock. Sometimes a whole slope of a hillside can be seen to be determined by the presence of such a band. It is marked along the shoreline where travertine bands form cliff tops which are sometimes undercut by erosion. The erosion of the cliffs is often rapid, due to the washing out of soil layers, which causes the cliff above to collapse. There are wide shore platforms with many solution cups, and in places there are rock stacks and islands rising above the level of the platforms. Caves have also developed in the cliffs. The rapidity of the erosion of the cliffs is indicated by the disappearance of aboriginal kitchen middens which are common along the cliff-tops. In the eleven years the author has had this part of the coast under observation, one of these middens has completely disappeared. No middens have been found under the volcanic tuff and since this deposit is geologically so recent the length of time of human occupation of the area must be very brief.

The River Hopkins (on the eastern border of the city) is tidal as far as Allansford, where it leaves the basalt. At the mouth there is a bar and a little offshore there is a reef. Mobile dunes cap consolidated dune sandstone on both sides of the mouth, and formerly sand often blew across the mouth blocking the river until the next storm swept it clear. In the interests of fishermen a channel has been blasted through the dune rock bar. North of Flett's boatsheds (west bank) there are high Miocene limestone cliffs, while on the east bank are the Holocene shell-beds. A regular layer of tuff can be seen surmounting the east bank, while on the west bank the tuff occurs only at intervals—generally in hollows. In the lower reaches of the river the stream follows the boundary between the Pleistocene dune rock and the Miocene bedrock. A low island once existed upstream from the bridge (fig. 1), but the erection of a causeway forming the approach to the bridge from the east bank produced new river currents which eroded away the island to a wide mudflat which is bare at low tide and covered by about a foot of water at high tide. South of Lady Bay there is only one submarine valley, which suggests that the Hopkins and Merri Rivers may have entered the sea by a common stream when the sea level was lower than it is now.

In the map (fig. 4) it is seen that the direction of flow of streams is dominantly in two directions—the one, north to south, and the other, west-north-west to east-south-east. Although the streams flow on Miocene limestone, Pliocene basalt and sub-basaltic fluviatile deposits, Pleistocene dune limestone, and Holocene tuff, they all conform to this same stream pattern. The reason is that the physiography is dominated by the basalt, because where streams flow on the Miocene limestone or sub-basaltic deposits they are superimposed, where they flow on dune rock, the dunes are aligned to the basalt, and where they flow on tuff, they flow in courses previously determined.

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Description of Plate.

Plate II.

Fig. 1.—Subcircular "stratification" in tuff on bank of Merri River south of Woodford. *Vide* text p. 145.

Fig. 2.—The lowest and largest soil horizon seen in the cliffs at Thunder Point.

Fig. 3.—Cliff near Thunder Point showing three soil horizons close together and a fourth under the tuff at the top of the cliff. The horizons are numbered on the photograph 1-4.

Fig. 4.—Shore platforms in dune rock near Breakwater Rock.

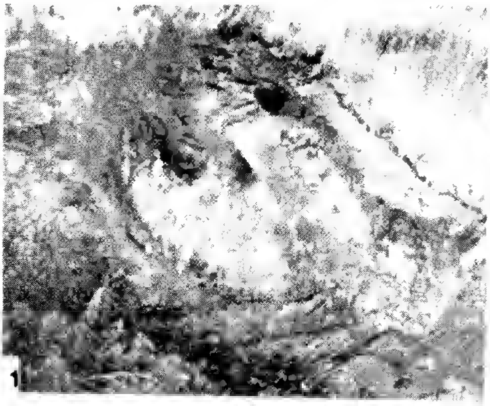
Fig. 5.—Road section, Nicholson-street, Warrnambool. On the planated surface of an older dune, a newer one has been constructed. The arrow on the left of the photograph indicates the break between the two formations.

Fig. 6.—Cannon Hill, Warrnambool, with Lake Pertobe in the background. In the foreground, the slope is composed of tuff piled up against the old sea cliff, which is represented by the precipitous rocks seen beyond the slope.

Fig. 7.—Banded tuff on soil layer, which in turn rests on consolidated dune rock at Thunder Point, Warrnambool. The lower end of the ruler is resting on the dune rock.

Fig. 8.—Holocene shell beds on the Hopkins River, surmounted by a layer of tuff. The arrow on the right of the photograph indicates the upper limit of the shell beds and the beginning of the tuff.

Fig. 9.—Profile in quarry near Nicholson-street. For details *vide* text, p. 146.



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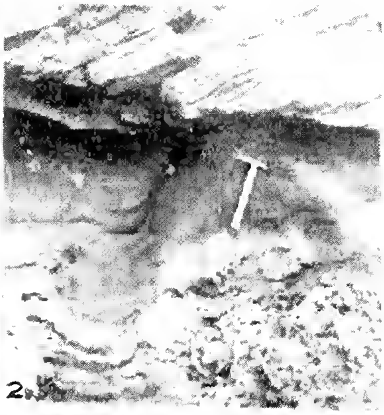

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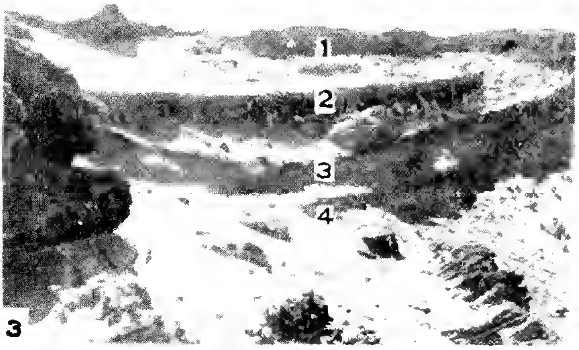

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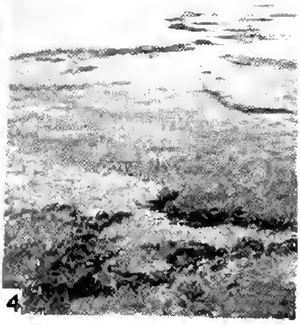

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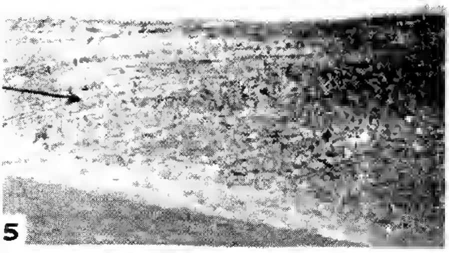

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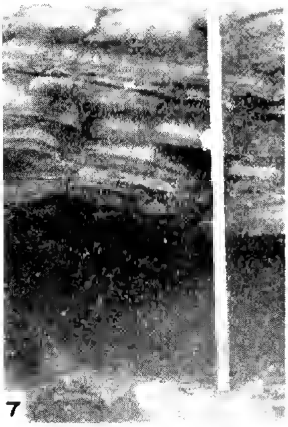

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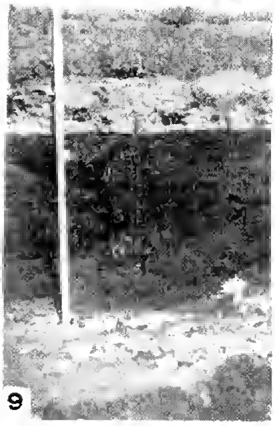

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Art. VII.—*The Genus Lepidocyclina in Victoria.*

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[Read 13th August, 1942; issued separately 1st October, 1943.]

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Abstract.

The systematic study of the genus *Lepidocyclina* in the Victorian Tertiary sediments, shows that it is represented by the subgenus *Trybliolepidina* which is characteristic of the upper Middle Miocene and Upper Miocene in the Indo-Pacific region. Three species occur, viz., *L.* (*T.*) *batesfordensis* sp. nov., *L.* (*T.*) *howchini* Chapman and Crespin and *L.* (*T.*) *gippslandica* sp. nov. The *Lepidocyclina* horizon in Victoria is placed near the boundary between the Burdigalian and Vindobonian stages in Europe.

Introduction.

The genus *Lepidocyclina* was instituted by Gümbel in 1870, and belongs to the group of orbitoidal foraminifera which is of considerable importance in the zoning of the Tertiaries in all parts of the world. It is abundantly represented in the Miocene in the Indopacific region, which includes Australia. The species of *Lepidocyclina* found in the Miocene deposits of Western Australia are referable to those recorded from the Netherlands East Indies, Papua and New Guinea, but the Victorian forms suggest the presence of an embayment in South-Eastern Australia in which other species, but still with Indopacific affinities, flourished. Further support to this theory is given by the molluscan species, which are distinct from those recorded from Western Australia where the affinities are definitely Indopacific. This applies both to Pliocene and Miocene species. Other foraminiferal genera in Victoria with similar tendencies include *Cycloclypeus*, the species of which show relationship with *C. indopacifica* Tan, and *Austrotrillina howchini* (Schlumberger). This latter form, originally described from Clifton Bank, Muddy Creek, Hamilton, Victoria, has been found in only two other localities in the State, namely, the Mallee Bores and at Skinner's section, Mitchell River, Gippsland. The common Indopacific Middle Miocene genera *Miogypsina* and *Flosculinella* have not been found in Victoria.

Lepidocyclina is developed in three separate areas in Victoria. (1) In Western Victoria at Clifton Bank, Hamilton, and in the Hamilton Bore, where numerous tests are present in the samples from 30 feet down to 230 feet. (2) South Central Victoria in the Port Philip Basin, where rich *Lepidocyclina* limestone deposits occur at Batesford, Keilor, and Flinders. The genus is also present in bores in this area. (3) East Gippsland in outcrops and numerous borings. These occurrences will be discussed in Section 6.

Previous Literature on the Victorian Lepidocyclinae.

The Orbitoids were first recognized in Victoria by the late Professor Howchin, who, in 1889, referred to them as *Orbitoides dispansus*, *O. mantelli* (Morton) and *O. stellata* Howchin from Hamilton.

In 1891, Hall and Pritchard recorded *O. mantelli* from the Batesford quarries near Geelong.

In 1904, Lémoine and Douvillé proved that the forms described by Howchin as *Orbitoides* belonged to the Eocene to Miocene genus *Lepidocyclina.*

In 1910, F. Chapman published his paper on "A Study of the Batesford Limestone," in which he listed three species of Lepidocyclinae—*L. marginata, L. martini* and *L. tournoueri.* He also identified a species from Green Gully, Keilor, and from Hamilton as *L. verbeeki.* In 1914 the same author reviewed the various Victorian *Lepidocyclina* localities in his "Homotaxial Relationship of the Australian Cainozoic System."

In 1925, Chapman and Singleton referred to the presence of *Lepidocyclina tournoueri* and *L. martini* in the Middle Miocene bryozoal limestones of Victoria.

In 1926, the writer listed five species of *Lepidocyclina* from vertical sections in a limestone from Green Gully, Keilor—*L. tournoueri, L. marginata, L. martini, L. verbeeki,* and *L.* (*Eulepidina*) *murrayana.*

In 1930, Chapman and Crespin recorded *L.* (*Nephrolepidina*) *borneënsis* and *Cycloclypeus communis* from borings in Victoria. In 1932, they listed five species of *Lepidocyclina* including two new forms *L. hamiltonensis* and *L. howchini* as well as *Spiroclypeus margaritatus* from the Victorian Tertiaries. Other species recorded were *L. martini*, *L. radiata* and a trigonolepidine form, *L. sumatrensis* forma *mirabilis*. Also in 1932, they zoned the "Lower Miocene" beds in borings in Gippsland on the presence or absence of *Lepidocyclina* and *Cycloclypeus*.

In 1936, the writer listed eleven species of *Lepidocyclina* and one of *Cycloclypeus* from Victoria.

During recent years, palaeontological reports on material from borings in the Tertiary rocks of Victoria have been made by the Geological Branch of the Department of the Interior, Canberra, now the Mineral Resources Survey Branch of the Department of Supply and Shipping, on behalf of the Victorian Mines Department and private companies engaged in the search for oil. These reports contain records of the occurrence of *Lepidocyclina*, which are herein made available for publication for the first time.

Remarks on Previously Recorded Species.

Prior to the present investigation the following species of *Lepidocyclina* were recorded from the Victorian beds:—

Lepidocyclina (*Nephrolepidina*) *angulosa* Provale.
L. (*N.*) *borneënsis* Provale.
L. (*N.*) *hamiltonensis* Chapman and Crespin.
L. (*N.*) *howchini* Chapman and Crespin.
L. marginata (Michelotti).
L. (*N.*) *martini* Schlumberger.
L. (*Eulepidina*) *murrayana* Jones and Chapman.
L. (*N.*) *radiata* (Martin).
L. (*N.*) *sumatrensis* (Brady).
L. (*N.*) *sumatrensis* (Brady) forma *mirabilis*.
L. (*N.*) *tournoueri* Lémoine and Douvillé.
L. verbecki Newton and Holland.

In 1939 the writer was privileged to visit the Netherlands East Indies to study with Dr. Tan Sin Hok of the Geological Museum, Bandoeng, Java, the relationship of the *Lepidocyclinae* of that country with those of Australia, Papua and New Guinea. The results of this investigation and further intensive research on hundreds of Victorian specimens are—(1) that the number of species present in Victoria is three, one of which is the already described form *L. howchini*, the other two being new and now designated *Lepidocyclina* (*Trybliolepidina*) *gippslandica* and *L.* (*T.*) *batesfordensis*, and (2) that the records from Victoria of species originally described from outside Australia are incorrect.

The study of the Victorian *Lepidocyclinae* reveals three outstanding characteristics:—

(*a*) All specimens exhibit polygonal features.

(*b*) All megalospheric specimens examined belong to the subgenus *Trybliolepidina* and not to *Nephrolepidina* as previously considered.

(*c*) The median chambers in both megalospheric and microspheric specimens are chiefly ogival to spatulate in shape, hexagonal ones being sometimes present in the rayed portion of the test.

It is these features which exclude from the Victorian assemblage such species as *L.* (*N.*) *tournoueri*, *L.* (*N.*) *borneënsis* and *L. marginata*. All microspheric specimens have been previously recorded as *L. marginata*, a species in which the median chambers pass from ogival to hexagonal. In the Victorian specimens they are ogival around the protoconch, becoming spatulate to elongate-spatulate towards the margin of the shell. The majority of specimens in horizontal section show a tendency to be strongly rayed for a short distance out from the protoconch.

L. tournoueri is nephrolepidine and non-polygonal, with the median chambers typically hexagonal in shape. The species is rare in the Indopacific being probably replaced by *L. borneënsis* Provale. Chapman recorded *L. tournoueri* as the most abundant species in the bryozoal limestone at the Filter Quarry, Batesford. The dominant form there is gently biconvex, and slightly polygonal in outline; the median chambers are typically ogival to spatulate and the embryonic and nepionic apparatus is trybliolepidine. The species is now referred to as *L.* (*T.*) *batesfordensis*.

L. borneënsis, which is apparently the Indopacific representative of *L. tournoueri* is also non-polygonal and nephrolepidine and does not appear in Victoria. Specimens recorded as *L. angulosa* and *L. sumatrensis* are merely fractured tests of *L.* (*T.*) *gippslandica* or *L.* (*T.*) *howchini*, all gradations of fracture being available especially in the Gippsland populations. The specimens listed as *L. murrayana* are abnormal forms of *L.* (*T.*) *gippslandica* or *L.* (*T.*) *batesfordensis*. *L. sumatrensis* forma *mirabilis* is included here. All specimens previously referred to as *L. radiata* now belong to *L.* (*T.*) *gippslandica*. Martin's description (1880) of the external features of *L. radiata* is applicable to this new species. " Test flat, 8 mm. in diameter, very thin, furnished in the centre with a thick, button-like elevation. From this, nine rays run towards the periphery. These rays are sharply distinguishable from the flat, extended part of the test, lying between them; they are single for their entire extent and end close to the periphery. Between each pair of rays the border of the test is always scalloped once. The surface shows a series of very fine discontinuous ridges, parallel with the outer edge. Nothing is known of the inner structure. There the rays of the fossil neither bifurcate nor reach the edge. Occurrence of single specimen—Sindangbarang, Preanger, Java." It is unfortunate that the type description is based on the external characters of a single specimen, which is housed in the Leiden Museum, Holland. Nothing is known of the internal structure, but Tan, who has seen the specimen, suspects that it is Trybliolepidine or Cyclolepidine. Until recently *L. radiata* was considered as belonging to " e " stage (Lower Miocene), but it is now known (communication from Tan) that " it must have been derived from the young Tertiary (Young Miocene) Bantang Series of Southern Preanger." Tan had hoped to collect from the type locality but present conditions have prevented this. It is this dearth of information regarding the true characters of *L. radiata* that makes it unsafe to refer to it as a basic species.

The specimens which have been recorded as *L. martini* belong partly to *L.* (*T.*) *gippslandica* and partly to *L.* (*T.*) *howchini*. It is known that *L. martini* is a trybliolepidine but the shape of the median chambers in the rayed portion of the test is hexagonal, whilst in the Victorian specimens, especially in *L.* (*T.*) *gippslandica* and *L.* (*T.*) *howchini*, it is typically elongate spatulate. Schlumberger's description (1900) of the external features of *L. martini* is as follows " Shell star-shaped, thickened at the centre, thinned towards the margin, furnished on the rim with six to eight prominent rays, some sharpened others more or less tongue-shaped. The surface of well preserved individuals has some small granulations at the centre." The type locality is Batoe Koetjing, Madoera. *L.* (*T.*) *howchini* has six to eight blunt rays and usually the surface is rather smooth, although some specimens have a few strong pustules towards the centre of the shell. Specimens referred to as *L. verbeeki* were chiefly from the Hamilton Bore. These are now included under *L.* (*T.*) *batesfordensis*.

Systematic Study of the Genus.

CONSIDERATION OF THE EMBRYONIC AND NEPIONIC APPARATUS.

MEGALOSPHERIC GENERATION.

The division of the Lepidocyclinae into subgenera was originally based on the arrangement of the embryonic (initial) chambers, but in recent years the study of the nepionic (auxiliary) chambers is considered of equal importance.

In 1904 Lémoine and R. Douvillé recognized two different types of embryonic apparatus and also distinguished between the microspheric and megalospheric forms. H. Douvillé, in 1911, instituted the terms *Nephrolepidina* and *Eulepidina* for these two types. In 1924, he added two more subgenera, namely *Isolepidina* and *Amphilepidina*, the former being based on the structure of the embryonic apparatus and the latter, not only on the shape of this apparatus but also on that of the median chambers. In 1928, Van der Vlerk created the new subgenus *Trybliolepidina*, Galloway in 1933 designating as its type species Van der Vlerk's *L. rutteni*, described in 1924 from Tji Boerial, Preanger, Java. Van der Vlerk considered this subgenus an important index group indicating the top of stage " f " or Upper Miocene. Gerth, in 1930, stated that "As species of *Lepidocyclina* which show a transition from the *Nephrolepidina*-stage to the *Trybliolepidina*-stage have already been found in the older Miocene, the occurrence of *Trybliolepidina* is not a true indication for the younger Miocene. But if *Trybliolepidina* is only found without true *Nephrolepidina*, it is very probable that beds of the younger Miocene have to be dealt with." He considered the "older Miocene" as Burdigalian, the "younger Miocene" as Vindobonian. In the same year Tan pointed out that not the subgenus *Trybliolepidina* but some of its species are stratigraphically important. Vaughan and Storrs Cole (in Cushman 1940) considered that the subgenus should not be recognized their reasons being based on Caudri's work in 1939.

Recent investigations on material from bore section and outcrops in North-west Australia, Papua and New Guinea indicate that this subgenus is of definite stratigraphic value. The stratigraphically highest *Lepidocyclina* to be met with in these areas always belongs to the subgenus *Trybliolepidina*.

The outstanding feature of the study of crowds of Victorian specimens is the persistence of the type of nepionic apparatus, which has one or two nepionic chambers fewer than *L. (T.) rutteni*, the species upon which *Trybliolepidina* is based, and two or three more than in *Nephrolepidina*. The shape of the embryonic apparatus is practically uniform in all sections, the large protoconchal chamber partially embracing the smaller deuteroconchal one.

In discussing the median section of a megalospheric *Lepidocyclina* a certain convenient terminology is used. It was introduced by Henbest (1934) and later developed by Tan (1935).

1. The embryonic or initial apparatus refers to the two most central chambers, the protoconch (P) and the deuteroconch (D). The way in which the deuteroconch embraces the protoconch differs according to the subgenus.

2. The primary stolons are the connecting links between the protoconch and the deuteroconch. They are of two kinds—(*a*) the protoconchal stolons which links the two embryonic chambers, and (*b*) the deuteroconchal stolons which link the deuteroconch with the (nepionic) chambers which immediately surround it.

3. The nepionic chambers are the auxiliary chambers found immediately on the external wall of the embryonic apparatus. They are of two kinds—(*a*) the primary auxiliary chambers (P) which are two in number and overlap the junction between the protoconchal and deuteroconchal chambers, and (*b*) the adauxiliary chambers (Ad) which are attached to the external wall of the deuteroconch, being developed from the deuteroconchal stolons. They vary in number according to the subgenus. Six are the characteristic number in the Victorian specimens. They are absent in the subgenus *Eulepidina.*

4. The nepionic stolons are two in number and are produced from the nepionic chambers on either side of the frontal wall. They are called posterior and anterior. They are frequently difficult to see in sections.

5. The neanic stage is the series of budding immediately surrounding the nepionic chambers, being an intermediate stage between the embryonic apparatus and the cyclic chambers which continue until the shell has completed growth.

The structure of the embryonic and the nepionic apparatus in the Victorian Lepidocyclinae is illustrated in Fig. 1. Fig. 1A represents a median section through a megalospheric specimen of *L.* (*T.*) *batesfordensis* from the old Filter Quarry, Batesford. Fig. 1B is of a specimen of *L.* (*T.*) *gippslandica* from No. 5 Bore, Parish of Glencoe, Gippsland. Both sections were cut and the structural features indicated under the supervision of Dr. Tan Sin Hok.

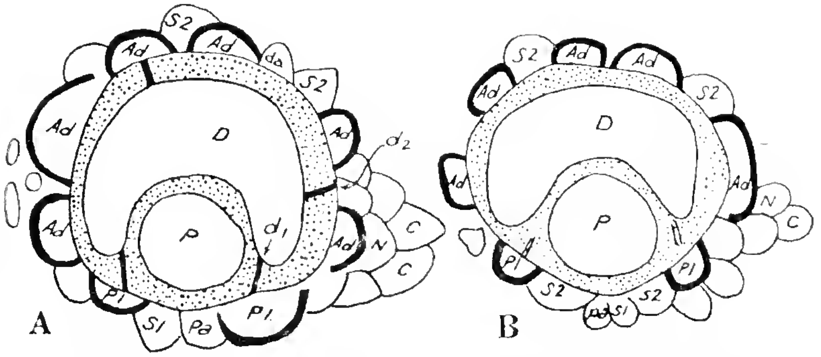

FIG. 1.—P, protoconch; D, deuteroconch; Pl, primary auxiliary chambers; Ad, adauxiliary chambers; S1, S2, symmetric nepionic chambers; pa, asymmetric nepionic chambers; da, asymmetric deuteroconchal chambers; N, neanic stage; C, cyclic chambers; d1, primary stolons; d2, stolons linking deuteroconch with adauxiliary chamber.

It will be noticed that the embryonic apparatus consists of two chambers—the protoconch (P) which is partly embraced by a larger chamber, the deuteroconch (D). The outer wall of the embryonic apparatus is thick, a persistent feature of the trybliolepidine type. Four deuteroconchal stolons are seen in the Batesford specimen but none is visible in the Glencoe form. Two primary stolons (d_1) link the deuteroconch with the primary auxiliary chambers just at the point where the deuteroconchal wall meets the protoconch. Two other deuteroconchal stolons (d_2) are visible passing through the deuteroconchal wall into adauxiliary chambers. Surrounding the external wall of the embryonic apparatus in the Batesford species are eight nepionic chambers, which represent budding periods. Two primary auxiliary chambers (pa) overlap the point where the protoconchal and deuteroconchal walls meet, while six adauxiliary chambers (Ad.) bud off from the external wall of the deuteroconch. This number is fairly uniform in the Victorian specimens. In the Batesford population there are variations from 5 to 8 with 4 very rare. In *L.* (*T.*) *rutteni,* they vary from 6 to 11. In *L.* (*T.*) *gippslandica* adauxiliary chambers are present with 4 to 6 being the most constant. Three specimens showed 3, which suggests Nephrolepidine ancestry.

In all sectioned specimens, the chambers constituting the juvenarium are ogival in shape.

Microspheric Generation.

The structure of the embryonic apparatus of all microspheric forms of *Lepidocyclina,* whether nephrolepidine or trybliolepidine, is fairly constant. In the Victorian specimens, there is a large initial chamber which is surrounded by six smaller initial ones arranged in a single spiral. The polygonal arrangement of the median chambers is not apparent until four spirals of larger chambers have been developed. The plani-spiral arrangement of the microspheric nucleoconch is constant in all genera of the Orbitoididae, the specific determinations being made on the shape of the median chambers.

Workers on the Lepidocyclinae in Europe and the Netherlands East Indies have, for the most part, given definite specific names to microspheric forms without regard to the megalospheric species to which they may be related. This method of nomenclature is incorrect when the microspheric generation occurs with a population of megalospheric specimens all of which can be referred to the one species. Such is the case in the Upper Quarry at Batesford, where parts of the limestone are made up almost entirely of tests of megalospheric and microspheric examples of a single species of *Lepidocyclina,* and similarly in the Gippsland bores. As a result, in this work, the microspheric form is referred to as " Form B " of the species with which it is closely associated.

Description of Species.

LEPIDOCYCLINA (TRYBLIOLEPIDINA) GIPPSLANDICA sp. nov.

(Plate III., figs. 1-7; Plate VI., figs. 22-28.)

FORM A.

Lepidocyclina (*Nephrolepidina*) *radiata* Chapman and Crespin (non Martin), 1932, p. 95, pl. xiii., figs. 15-17.

Lepidocyclina (*Nephrolepidina*) *martini* Chapman and Crespin pars (non Schlumberger), 1932, pl. xii., figs. 11-14. Crespin, 1936, p. 10, pl. ii., figs. 25, 26.

External characters of holotype.—Test with polygonal outline. Surface smooth except for 9 pustules on central boss. Nine rays extend from central portion towards periphery, where they flatten out and do not protrude beyond edge. Median chambers seen towards edge of shell. Diameter of test—5 mm.; thickness at central boss—2 mm.

Internal characters of tectotype.—(*a*) Median Section. On account of the wavy nature of the test, it is difficult to obtain perfect sections. Median chambers thin walled, arranged in polygons, with narrow rays which commence a short distance out from the embryonic apparatus, and broaden out towards margin. Chambers in rays chiefly elongate spatulate, rarely hexagonal. Chambers immediately surrounding nepionic apparatus ogival and between rays pass from ogival to spatulate towards periphery. Embryonic apparatus trybliolepidine, with 7 nepionic chambers. Outer wall of protoconchal and deuteroconchal chambers thick. Width of protoconchal chamber 0·16 mm., deuteroconchal 0·33 mm.

(*b*) Vertical section. Test biconvex. Lateral chambers rounded, showing curved horizontal walls; thin walled, 9 layers; strong pillars in central portion.

Locality of holotype and tectotypes.—No. 5 Bore, P. of Glencoe at 70 feet (Com. Pal. Coll. Nos. 39 and 212).

Paratypes.—(*a*) No. 15 Bore, P. of Stradbroke at 45 feet. External characters similar to holotype. Polygonal outline pronounced, 9 rays showing thickening and broadening towards periphery. Surface slightly pustulate, due to weathering of specimen. Central pustules strong. Diameter—5 mm.; thickness at central boss—2 mm.

(*b*) Locality as (*a*). Test rayed, with 10 flattened rays protruding beyond edge of shell, due to fracturing of test between rays. Surface rough, central boss pustulate. Diameter—4 mm.; thickness at centre 1·5 mm.

(*c*) Skinner's Section, Mitchell River, P. of Wuk Wuk. Test fractured but 8 flattened rays visible. Surface slightly roughened with weathering. Pustules on central boss. Diameter—5 mm.; thickness 2 mm.

Observations.—As previously stated, perfect specimens of *L.* (*T.*) *gippslandica* exhibit the external features of *L. radiata* Martin, as well as intergradations between Scheffen's form *L.* (*T.*) *rutteni* forma *globosa* and *L. martini* Schlumberger. In horizontal section the persistent shape of the median chambers which range from ogival to spatulate, with occasional tendency to hexagonal in the rayed portion prevents the species being classed with *L. martini.* In vertical section the species is closely comparable with *L.* (*T.*) *rutteni* forma *globosa* not only in the general outline but in shape of the lateral chambers which are rounded rather than rectangular. In the horizontal direction, the similarity is in the structure of the embryonic apparatus, which shows 4 adauxiliary chambers. In *L.* (*T.*) *gippslandica* the number varies from 4 to 5. Two specimens had 6 and two had 3. The main difference is that in *L.* (*T.*) *rutteni* forma *globosa,* the rays are 5 in number, and strongly developed, the chambers in that region being typically hexagonal.

L. (*T.*) *gippslandica* is the predominant species in the Gippsland borings and outcrops. The majority of specimens are small averaging about 3·5 mm. in diameter. This slight variation from the size of the type is due to the fracturing of the margin of the test to a distance fairly close to the central portion. In populations such as are found in No. 5 Bore, P. of Glencoe, at 70 feet, in No. 15, P. of Stradbroke at 45 feet, and in Brock's Quarry, the gradual gradation from perfect specimens as exhibited in the type specimen, to those smaller fractured ones, such as predominate the populations, can be well studied, and it is only by such study that the existence of only one species can be demonstrated.

The species is recorded from the base of the New Quarry at Batesford (collected by F. A. Cudmore) where it is associated with *L.* (*T.*) *batesfordensis,* the main development of the latter species being in the upper beds of the section. In the Gippsland bores *L.* (*T.*) *gippslandica* is always most abundant in the zone where it is associated with *Cycloclypeus victoriensis* var. *gippslandica* Crespin which underlies that in which *L.* (*T.*) *batesfordensis* is recorded. A similar sequence is found in the Hamilton Bore in Western Victoria, where *L.* (*T.*) *gippslandica* is replaced by the smaller rayed form *L.* (*T.*) *howchini,* which is very common below the lowest depth at which *L.* (*T.*) *batesfordensis* is present.

L. (*T.*) *gippslandica* is associated with *Austrotrillina howchini* (Schl.) at Skinner's, as well as with *Hofkerina semiornata* (Howchin), *Planorbulinella inaequilateralis* (Heron-Allen and Earland), *P. plana* (H-A. and E.) and *Gypsina howchini* Chapman, which are always present.

Occurrence.—The localities for the holotype and paratypes have already been listed. Further localities include 56 bores in Gippsland. The shallowest depths from which the species have been recorded are at 45 feet in No. 15 Bore, P. of Stradbroke, and at 50 feet in No. 5 Bore, P. of Glencoe, and the greatest depth in the Holland's Landing Bore, P. of Bengworden South, where it was found at 1,886 feet. Cliff and quarry sections in Gippsland include Skinner's, Mitchell River, P. of Wuk Wuk; E. of Hillside Bridge, North Cliff, Mitchell River, P. of Moormurng; Boggy Creek at Bridge near junction with Mitchell River, P. of Wy Yung (collected by officers of Victorian Mines Department); Brock's and Le Grand's quarries, P. of Glencoe (coll. I.C.). Other localities include New Quarry, Batesford near base of section (coll. F.A.C.).

FORM B.

Paratype.—From No. 15 Bore, P. of Stradbroke, Gippsland, at 45 feet. External characters—Specimen with fractured edge, biconvex, with numerous pustules in central portion of test. Diameter—7 mm. Greatest thickness 2 mm. (Com. Pal. Coll. No. 198.)

Internal characters (based on a number of thin sections).—Median section—Microspheric nucleoconch, planispiral, showing circular arrangement of chambers in embryonic apparatus, with further initial chambers arranged in spiral. Arrangement of median chambers polygonal, showing 5 rays, in central portion of test. Chambers ogival in rayed portion passing to spatulate and elongate spatulate towards periphery. Test shows considerable regeneration.

Other paratypes.—(*a*) Brock's Quarry, P. of Glencoe. Test discoidal finely pustulose. Diameter 7 mm.; greatest thickness 2 mm.

(*b*) Same locality.—Test thin with indistinct rays present. Strong pustules in centre but surface covered with smooth concentric bands possibly due to weathering.

Observations.—Microspheric specimens are not common and as a result not many sections were available for study, but all showed similar internal features including the central polygonal arrangement of chambers and the ogival to spatulate median chambers.

The tests are not large, the diameter averaging 6 mm. One unusually large specimen with a diameter of 14 mm. was recorded from No. 7 Bore, P. of Glencoe, Gippsland, at 520 feet.

The rayed character of the central portion is a feature of many of the microspheric forms from the Netherlands East Indies, in which the median chambers are usually elongate-spatulate to elongate-hexagonal. The Victorian specimens are most closely comparable with *L. stratifera* Tan, in which ogival to spatulate chambers are predominant.

Occurrence.—Localities are as listed under the megalospheric form.

LEPIDOCYCLINA (TRYBLIOLEPIDINA) HOWCHINI Chapman and Crespin.

(Plate IV., figs. 8-15; Plate VII., figs. 30-35.)

FORM A.

Orbitoides stellata Howchin (*non Orbitulites stellata d'Archiac,* 1850), 1888, p. 17, pl. i., figs. 9-11.

Lepidocyclina (Nephrolepidina) howchini Chapman and Crespin, 1932, p. 94, pl. xiii., figs. 18, 19; Crespin, 1936, p. 8, pl. ii., figs. 17, 18.

Lepidocyclina (Nephrolepidina) hamiltonensis Chapman and Crespin, 1932, p. 93, pl. xii., figs. 8-10; Crespin, 1936, p. 8, pl. ii., fig. 19.

Lepidocyclina (Nephrolepidina) martini Chapman and Crespin (non Schlumberger), 1932, pars, p. 95.

Lepidocyclina (Nephrolepidina) radiata Chapman and Crespin (non Martin), 1932, pars, ibid., p. 96.

Holotype of variety.—Description of *L. (T.) howchini* as given by Chapman and Crespin. "Description of Holotype (from Hamilton Bore, 80-85 feet).—Test small, discoidal with blunt marginal prolongations. Surface strongly convex, central part of test with a group of strong papillae, smaller on surrounding area. Description of Tectotype.—Vertical section from 68-80 feet. Equatorial series narrow, lateral, chamberlets forming 6 layers superimposed on centrosphere, 5 vertical pillars shown in cross section in the central region. Dimensions.—Diameter of test 2·9 mm.; thickness of test, 1·17 mm. Diameter of centrosphere, 0·14 mm.; longest diameter of nucleoconch, 0·41 mm." (Com. Pal. Coll. No. 42.)

Plesiotypes.—(1) Howchin's locality at Clifton Bank, Muddy Creek, Hamilton. External characters—Test small compressed, discoidal, with 8 blunt marginal prolongations, giving stellate appearance. Surface rough, with 9 strong pustules on central portion. Diameter—3·5 mm.; greatest thickness—1 mm.

Internal characters—Median section. Median chambers thin-walled. Rays not pronounced; chambers chiefly ogival in shape, becoming spatulate towards periphery and in rayed portion. Nepionic apparatus trybliolepidine, with 8 nepionic chambers, comprised of 2 primary auxiliary and 6 adauxiliary, embracing the embryonic apparatus. Outer wall of protonchal and deuteroconchal chambers thick. Width of protoconchal chamber 0·20 mm.; of deuteroconchal 0·39 mm.

(2) Specimen from Flinders. Test small, with ten prolongations; biconvex, with strong pustules in centre, diameter—4 mm.

Observations.—A figure of a median section of *L.* (*T.*) *howchini* is not given by Chapman and Crespin but one is shown under "*L. hamiltonensis*." The trybliolepidine nucleoconch is present, with 7 nepionic chambers, including 2 primary auxiliary and 5 adauxiliary. The median chambers in the immediate vicinity of the nepionic apparatus are ogival and pass into spatulate, while the elongate-spatulate shape is recognizable in the rayed portion. Howchin's type specimen of "*O. stellata*" cannot be located either in the Geology Department, University of Adelaide, or in the Howchin Collection in the South Australian Museum. Numerous sections of topotypes have been studied, all showing trybliolepidine affinities. At the same time the study of this population at Howchin's type locality shows that "*L. hamiltonensis*" is synonymous with *L.* (*T.*) *howchini*. Perfect sections of this latter form are difficult to secure on account of the mode of preservation of the tests. All specimens from Muddy Creek and throughout the major part of the Hamilton Bore are iron-stained, those from the lower portion of the bore being partially replaced with glauconite.

L. (*T.*) *howchini* is very common at Flinders. It is recorded from the Tyabb Bore, Mornington Peninsula, and at Skinner's section, Mitchell River, Gippsland. It is exceedingly rare in the Gippsland bores. It is usually associated with *Amphistegina* and *Calcarina verriculata* at Hamilton and Flinders.

Tests are invariably small averaging about 3 mm., some of the Flinders specimens reaching 4 mm. The number of blunt prolongations vary from 6 to 8 and rarely 10, while the convexity of the tests is also variable. The surface ornament varies according to preservation, a feature well illustrated in the Flinders specimens which are frequently strongly pustulose.

Occurrence.—Western Victoria. Lower beds, Muddy Creek, Hamilton; throughout the Hamilton Bore down to 187 feet, becoming the predominant species below 80 feet. Port Philip region. Basal beds in New Quarry, Batesford; Water Bore, Avalon, Lara, at 315 feet; Water Bore; Victoria Golf Club, Cheltenham, at 221 feet; No. 1 Bore, Tyabb at 57-90 feet; No. 2 Bore, Tyabb at 173-176 feet; Flinders. Gippsland-Skinner's section, Mitchell River, near Bairnsdale.

FORM B.

Lepidocyclina marginata Crespin (non *Nummulites marginata* Michelotti), 1936, p. 9, pl. ii., fig. 21.

Plesiotype.—From Hamilton Bore. External characters from specimen at 91-96 feet. Test discoidal, biconvex, with numerous pustules chiefly on central portion. Diameter 5 mm.; greatest thickness 1·5 mm. (Com. Pal. Coll. No. 202.)

Internal characters of specimen at 86-91 feet. Median section—Embryonic chamber indistinct but surrounded by a single spiral embryonic chamber. This in turn is surrounded by chambers arcuate to ogival in shape. These chambers pass outwards into broadly spatulate ones. Hexagonal chambers rare in outer portion due to spatulate chambers not being sectioned through the centre. Polygonal arrangement only faintly suggested, but is stronger in less perfect sections. Vertical section of specimen at 36-38 feet. Structure indistinct because of ironstaining. Central median chambers thin in centre widening out towards margins of shell indicating polygonal character. Fifteen superimposed lateral layers only the outer 8 being continuous throughout the length of the test. The central ones rise convexly from the central median chamber before converging to it. Pillars in outer central portion of test. Lateral chambers slightly convex.

Observations.—Owing to the mode of preservation (all specimens being ironstained) good sections are difficult to obtain. The microspheric specimens from Hamilton are identical with those from Flinders both in external and internal characters. There is little variation in the size of tests. One Hamilton specimen from 86-91 feet had a diameter of 6 mm.; and another from Flinders, 7 mm.

Occurrence.—At various depths in the Hamilton Bore; Flinders; No. 7 Bore, P. of Parwan, at 316-329 feet.

LEPIDOCYCLINA (TRYBLIOLEPIDINA) BATESFORDENSIS sp. nov.

(Plate V., figs. 16-21; Plates VIII. and IX., figs. 36-46.)

FORM A.

Lepidocyclina tournoueri Chapman (non Lémoine and Douvillé), 1910, p. 295, pl. liv., figs. 1, 2, 6; Crespin, 1926, p. 114, pl. viii., fig. 7; ibid., 1936, pl. ii., figs. 16, 23.

Lepidocyclina verbeeki Crespin (non Newton and Holland), 1926, p. 115, pl. viii., fig. 10.

Lepidocyclina (*Nephrolepidina*) cf. *tournoueri* Singleton, 1941, p. 32.

Holotype.—External characters—Test discoidal, fairly evenly biconvex, with peripheral edge sharp and sometimes wavy. Pustules cover test but are stronger towards central portion. Surface smooth near periphery. Diameter 5 mm.; greatest thickness 1 mm.

Internal characters of tectotype.—(*a*) Median section. Median chambers thin-walled, arranged in polygons, with seven broad rays, extending almost to the margin of the test. Chambers immediately surrounding nepionic apparatus ogival in shape, passing from ogival to spatulate towards the edge of the test. Inter-radial chambers chiefly ogival to broadly spatulate. In radial portion they become elongate spatulate with some hexagonal.

Embryonic apparatus trybliolepidine, with 8 nepionic chambers. Outer wall of protoconchal and deuteroconchal chambers thick. Width of protoconchal chamber 0·27 mm.; deuteroconchal 0·5 mm.

(*b*) Vertical section.—Test biconvex, lateral chambers show slightly curved horizontal thin walls with eleven superimposed layers. Strong pillars in central portion.

Locality.—*Lepidocyclina* limestone, Upper Quarry (Australian Portland Cement Co.), Batesford, near Geelong, collected by Dr. F. A. Singleton. (Com. Pal. Coll. No. 206.)

Paratype.—New Quarry, Batesford (collected by F. Cudmore). Test smaller than holotype but with similar characters. Diameter—3·5 mm. Horizontal section shows similar rayed characters, with ogival to spatulate type of chambers. Nepionic chambers 6.

Observations.—Tests of *L.* (*T.*) *batesfordensis* occur in profusion in certain parts of the Batesford quarries. This species is that referred to *L. tournoueri* by Chapman. Specimens from the Filter Quarry were taken to Java by the writer and examined by Dr. Tan Sin Hok. The photograph of one of his sections is shown in Fig. 36. The arrangement of the embryonic apparatus excluded *L. tournoueri* as the possible species and an examination of a great number of sections excluded the possibility of its being present at Batesford. *L.* (*T.*) *batesfordensis* is typically trybliolepidine and polygonal, with chambers ogival to spatulate. As already stated, *L. tournoueri* is nephrolepidine, non-polygonal, with chambers chiefly hexagonal. In all sections examined the character of the embryonic apparatus is uniform, the number of nepionic chambers varying from 6 to 8. The specimens from the upper part of the New Quarry (collected by F. A. Cudmore) are similar in size to those from the old Filter Quarry; but those from the Upper Quarry (collected by Dr. F. A. Singleton and W. J. Parr) were consistently larger. Unfortunately in all cases, perfect horizontal sections were difficult to obtain owing to the wavy character of the test.

At Batesford *L.* (*T.*) *batesfordensis* is associated with *Cycloclypeus victoriensis* together with abundant *Amphistegina lessonii, Calcarina verriculata, Gypsina howchini, Planorbulinella plana* and *P. inaequilateralis.*

The population at Green Gully, Keilor, is dominated by large specimens of *L.* (*T.*) *batesfordensis,* similar to those from the Upper Quarry at Batesford. It is not common at Flinders but tests are fairly numerous in the upper portion of the Hamilton Bore. It is rare in the Gippsland borings being sometimes the first specimen of *Lepidocyclina* to be recorded in bore sections.

Occurrence.—Upper Quarry, Australian Portland Cement Works, Batesford, near Geelong; New Quarry, Batesford; Green

Gully, Keilor; the upper portion of the Hamilton Bore, P. of Yulecart, Western Victoria; Flinders, Mornington Peninsula; and in various borings in Gippsland.

FORM B.

Orbitoides mantelli Howchin (non Morton), 1891. In Hall and Pritchard, p. 10.

Lepidocyclina marginata Chapman (non *Nummulites marginata* Michelotti), 1910, p. 296, pl. iv., fig. 5; pl. v., figs. 1-3; Crespin, 1926, p. 115; 1936, p. 9.

Paratype.—External characters—Test large, discoidal, thin, biconvex, circular in outline. Numerous small pustules scattered over most of the unweathered test. Surface smooth towards periphery with lateral chambers frequently visible. Periphery rounded. Diameter—11 mm.; greatest thickness 2 mm.

Internal characters from tectotype.—Median section—Microspheric nucleoconch planispiral, showing circular arrangement of chambers in embryonic apparatus, which consists of a central initial chamber surrounded by six similar initial chambers arranged in a spiral. Arrangement of median chambers polygonal, showing 8 rays, as indicated in the megalospheric form. Rays do not extend to edge of test. Chambers surrounding embryonic apparatus and for some distance outwards, ogival in shape, passing into spatulate and elongate spatulate towards periphery. A few hexagonal shaped ones along outer margin.

Vertical section.—Horizontal median chamber thin in centre, widening out considerably towards each end of test. Sixteen superimposed lateral layers, only the outer five being continuous throughout the length of the test. The others rise gently convexly in central portion of test before converging to the central chamber. Lateral chambers thin-walled and straight-sided and do not alternate in their arrangement. A few pillars in centre of section.

Locality.—New Quarry, Batesford, near Geelong, collected by W. D. Chapman. (Com. Pal. Coll. No. 208.)

Another paratype.—Upper Quarry, Batesford (coll. F. A. Singleton). Test discoidal slightly biconvex. Surface free from pustules. Diameter—11 mm.

Observations.—This microspheric form was figured as *L. marginata* by Chapman (1910) who, at the same time, figured a megalospheric specimen. Douvillé (1904) states that only the microspheric form of *L. marginata* was known, but it is quite possible that *L. marginata* represented the microspheric generation of *L. tournoueri.* Chapman's figure (pl. liv., fig. 5) showing the megalospheric nucleoconch is referable to *L.* (*T.*) *batesfordensis,* fig. 2, representing the microspheric form of the same species.

The type median section of *L. marginata* shows it to be non-polygonal, while the outstanding feature of *L.* (*T.*) *batesfordensis* form B is its polygonal character.

In the upper quarry at Batesford, the several specimens available are all fractured but some idea of the diameter can be gathered, the variation being from 10 to 17 mm., the majority of specimens averaging 10 mm.

The rayed character of this microspheric form is exhibited in many species in the Netherlands East Indies. The strongly ogival shape of the median chambers in the vicinity of the initial apparatus together with the persistent spatulate shape of the later ones distinguishes the Victorian form from these in which hexagonal shaped chambers are predominant.

Occurrence.—Upper Quarry, Australian Portland Cement Co., Batesford, near Geelong; Green Gully, Keilor.

The Stratigraphical Position of the Lepidocyclina Horizon in Victoria.

The present investigation indicates that the *Lepidocyclina* horizon in Victoria can be divided into three zones. This zoning is supported by a close study of the Batesford section as represented in the New Quarry, where a systematic collection of material was made by F. A. Cudmore, and of bore sections at Hamilton and in Gippsland. The three zones are—(*a*) an upper one or *zone of L.* (*T.*) *batesfordensis*, which is characteristic of Batesford, where the assemblage is dominated by *Calcarina verriculata;* (*b*) an intermediate one or *zone of L.* (*T.*) *howchini*, typical of Hamilton, where *C. verriculata* is associated with *Hofkerina semiornata;* and (*c*) a lower one or *zone of L.* (*T.*) *gippslandica*, characteristic of Gippsland, where *H. semiornata* is common and *C. verriculata* exceedingly rare, with *L.* (*T.*) *batesfordensis* occurring very occasionally at the top of bore secsections. These zones will be more fully described at a later date.

Chapman (1910) made the first detailed study of the Victorian Lepidocyclinae in his work on the Batesford limestone, which led to the designation of the horizon as "Batesfordian." He recorded an assemblage of foraminifera, which, for the most part, is associated with all occurrences of *Lepidocyclina.* These forms are *Gypsina howchini, Planorbulinella plana, P. inaequilateralis* and *Calcarina verriculata.* In bores, none of these occurs above the horizon but the downwards range is extended somewhat. At Hamilton, *Hofkerina semiornata* is added to the assemblage, while in Gippsland it is very prominent but *C. verriculata* is exceedingly rare. On all occasions the above assemblage is associated with *Carpenteria proteiniformis, C. rotaliformis, Amphistegina lessonii* and *Operculina victoriensis.*

Singleton (1941) considers the "Batesfordian" as a stage underlying the Balcombian, but evidence from numerous borings in Gippsland proves that it is a substage of that stage. The association of *Lepidocyclinae* with numerous mollusca referable to Balcombian species both at Hamilton in Western Victoria and at Skinner's in Eastern Victoria, the presence of the genus in Balcombian marls in the Tyabb bores, Mornington Peninsula, and its persistent occurrence in Balcombian bryozoal limestones, in subsurface sections in which no stratigraphic break is apparent, support this view.

Age of the Lepidocyclina Horizon in Victoria.

The fact that the orbitoidal foraminifera are of such importance in zoning marine Tertiaries beyond Victoria, makes the restricted occurrence here of utmost value in determining a precise age for the beds. When Howchin (1889) described the first orbitoidal foraminifera in Victoria from Hamilton, he referred them to the Eocene genus *Orbitoides,* and for this reason beds containing such forms were recognized as Eocene for some years. Lémoine and Douvillé (1904) placed them in Eocene to Miocene genus *Lepidocyclina.* Chapman (1910) considered the limestones at Batesford to be equivalent of the Burdigalian of Southern Europe and Middle Miocene in age, on account of his record of *L. tournoueri* and *L. marginata,* while he referred the beds at Clifton Bank, Hamilton, and at Keilor to "probably Upper Aquitanian" because of his record of *L. verbeeki,* a species which is found in the Lower and Middle Miocene in the Indopacific. Present evidence points to the Keilor beds being stratigraphically equivalent to those at Batesford, with the Hamilton ones slightly lower. Chapman and Singleton (1925) stated that "the predominant development of polyzoal limestones was in the Middle Miocene-Burdigalian or Batesfordian, the typical zone fossil being *Lepidocyclina tournoueri* or *L. martini* or both." Crespin (1926) referred to the age of the *Lepidocyclina* limestone at Keilor as equivalent of the Batesfordian. Chapman and Crespin (1932) described *Spiroclypeus,* a typical "e" stage (Lower Miocene) genus from a single specimen in a limestone from the Hamilton Bore and *L. radiata* Martin from Gippsland, a species listed as belonging to "e" stage in the Netherlands East Indies, while regarding the subgenus of all species as *Nephrolepidina.* Because of this determination of *Spiroclypeus,* all *Lepidocyclina*-bearing rocks in Victoria were considered to be of Lower Miocene age (Chapman and Crespin 1935). The result has been considerable confusion. Crespin (1936) stated that the determination of the Hamilton specimen as *Spiroclypeus* was incorrect, and it was found later that *L. radiata* apparently belongs to younger beds than the Lower Miocene in the Netherlands East Indies. Crespin still placed the Batesfordian in the Lower Miocene, but suggested that the horizon would later prove to be younger in age, because of the absence of the typical "e" stage genera *Spiroclypeus* and *Eulepidina*, and the consideration that the subgenus of *Lepidocyclina* was *Nephrolepidina* which is typically lower to middle Middle Miocene. Singleton (1941) placed the horizon of the Batesfordian in the Lower to Middle Miocene at the same time elevating it to the position of a stage directly underlying the Balcombian. This classification was followed by Crespin (1941) in a report on the Holland's Landing Bore, Gippsland, the author stating that she agreed in the main with Singleton's sequence but placed the *Lepidocyclina* beds in the Middle Miocene.

The supposition, in 1936, that the Victorian Lepidocyclinae belonged to a younger age than Lower Miocene, was confirmed by investigations carried out with Dr. Tan Sin Hok in Java in 1939, the absence of true nephrolepidine Lepidocyclinae and the exclusive presence of trybliolepidine species indicating an horizon fairly high in the Miocene.

The Burdigalian species, *L. tournoueri* and *L. marginata*, are absent, the assemblage consisting entirely of rayed forms referable to the subgenus *Trybliolepidina*, which is characteristic of the upper portion of the Miocene in the Indopacific region. *Miogypsina*, a common genus in the Miocene of the Netherlands East Indies, North-west Australia, Papua and New Guinea, is unrepresented. *Austrotrillina howchini*, which ranges from Lower to Middle Miocene in this region, occurs with *Lepidocyclina* in Gippsland and at Hamilton, the original specimen being described from the latter locality. As far as is known this form has not been recorded above the "f_2" stage, in the Indopacific. The species of *Cycloclypeus* recently described from Gippsland (Crespin, 1941), have close affinities with this stage.

Evidence points, therefore, to the *Lepidocyclina* horizon in Victoria being not older than Middle Miocene with indications of being high in that part of the series. It is definitely not "e" stage, and is possibly referable to basal "f_3" stage. In correlating it with European stages, it is higher than Aquitanian and is probably to be placed near the boundary between the Burdigalian and Vindobonian.

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Explanation of Plates.

Plate III.

Lepidocyclina (Trybliolepidina) gippslandica sp. nov.

Fig. 1.—No. 5 Bore, P. of Glencoe, Gippsland, at 70 feet. Form A. Holotype. No. 39. × 10. (After Crespin.)

Fig. 2.—No. 15 Bore, P. of Stradbroke, Gippsland, at 45 feet. Form A. Paratype. No. 93. × 10. (After Crespin.)

Fig. 3.—No. 15 Bore, P. of Stradbroke, at 45 feet. Form A. Paratype. No. 196. × 7.

Fig. 4.—Skinner's Section, Mitchell River, Gippsland. Form A. Paratype. No. 197. × 7.

Fig. 5.—No. 15, P. of Stradbroke, at 45 feet. Form B. Paratype. No. 198. × 7.

Fig. 6.—Brock's Quarry, P. of Glencoe, Form B. Paratype. No. 199. × 7.

Fig. 7.—Brock's Quarry, P. of Glencoe, Form B. Paratype. No. 200. × 7.

Plate IV.

Lepidocyclina (Trybliolepidina) howchini Chapman and Crespin.

Fig. 8.—Hamilton Bore, P. of Yulecart, Western Victoria, 80·85 feet. Form A. Holotype. No. 42. × 10. (After Crespin.)

Fig. 9.—Hamilton Bore, 48·53 feet. Form A. Paratype. No. 32. × 10. (After Crespin.)

Fig. 10.—Clifton Bank, Hamilton, P. of Yulecart, Western Victoria. Form A. Plesiotype. No. 201. × 8.

Fig. 11.—Hamilton Bore, 104·108. Form A. Paratype. No. 94. × 12. (After Crespin.)

Fig. 12.—Hamilton Bore, 80·85 feet. Form B. Plesiotype. No. 202. × 10.

Fig. 13.—Flinders, Mornington Peninsula. Form A. Plesiotype. No. 203. × 8.

Fig. 14.—Flinders, Mornington Peninsula. Form A, showing strong pustules. Plesiotype. No. 204. × 8.

Fig. 15.—Flinders, Mornington Peninsula. Form B. Plesiotype. No. 205. × 8.

Plate V.

Lepidocyclina (Trybliolepidina) batesfordensis sp. nov.

Fig. 16.—New Quarry, Batesford, near Geelong. Form B. Paratype. No. 206. × circ. 6.

Fig. 17.—Upper Quarry, Batesford. Form B. Paratype. No. 207. × 6.

Fig. 18.—Upper Quarry, Batesford. Form A. Holotype. No. 208. × circ. 7.

Fig. 19.—Upper Quarry, Batesford. Form A, showing fractured specimen. Paratype. No. 209. × circ. 9.

Fig. 20.—New Quarry, Batesford. Form A. Paratype. No. 210. × 8.

Fig. 21.—No. 7 Bore, P. of Colquhoun, Gippsland, at 480 feet. Paratype. No. 211. × 7.

Plate VI.

Lepidocyclina (Trybliolepidina) gippslandica sp. nov.

Fig. 22.—No. 5 Bore, P. of Glencoe, Gippsland, 70 feet. (Locality of Holotype.) Median section. Form A. Tectotype. No. 212. × circ. 20.

Fig. 23.—Embryonic and nepionic apparatus of Fig. 22, showing protoconchal and deuteroconchal chambers, two primary auxiliary and five adauxiliary chambers. × circ. 40.

Fig. 24.—Vertical section of specimen from same locality. Tectotype. No. 213. × circ. 20.

Fig. 25.—No. 1 Bore, Pt. Addis (Metung), P. of Bumberrah, at 872 feet. Median section. Form A, showing only three nepionic chambers. Tectotype. No. 214. × 17.

Fig. 26.—Vertical section of specimen from same locality. Tectotype. No. 215. × 14.

Fig. 27.—Embryonic and nepionic apparatus of another specimen from No. 5 Bore, P. of Glencoe, 70 feet, showing protoconchal and deuteroconchal chambers, two primary auxiliary and five adauxiliary chambers. Tectotype. No. 216. × 82.

Fig. 28.—No. 15 Bore, P. of Stradbroke, Gippsland. Vertical section. Form A. Tectotype. No. 217. × 17.

Fig. 29.—No. 15 Bore, P. of Stradbroke, at 45 feet. Median section of Form B, showing rayed character of central portion. Tectotype. No. 218. × 15.

Plate VII.

Lepidocyclina (Trybliolepidina) howchini Chapman and Crespin.

Fig. 30.—Hamilton Bore, P. of Yulecart, Western Victoria, 86·91 feet. Median section. Form B. Specimen ironstained. Tectohypotype. No. 219. × circ. 15.

Fig. 31.—Hamilton Bore, 36·38 feet. Vertical section. Form B. Specimen ironstained. Tectohypotype. No. 220. × 14.

Fig. 32.—Clifton Bank, Hamilton. Median section. Form A, showing embryonic and nepionic apparatus, showing protoconchal and deuteroconchal chambers, two primary auxiliary and six adauxiliary chambers, surrounded by ogival-shaped chambers. Tectohypotype. No. 221. × 53.

Fig. 33.—Hamilton Bore, 80·85 feet. (Locality of Holotype.) Median section. Form A. Tectotopotype. No. 222. × 14.

Fig. 34.—Hamilton Bore, 45·53 feet. Vertical section. Form A. Tectohypotype. No. 223. × 17.

Fig. 35.—Hamilton Bore, 80·85 feet. Median section. Form A. Tectotopotype, No. 224. × 14.

PLATE VIII.

Lepidocyclina (Trybliolepidina) batesfordensis sp. nov.

FIG. 36.—Old Filter Quarry, Batesford, near Geelong. Embryonic and nepionic apparatus of Fig. 37, showing two primary auxiliary and six adauxiliary nepionic chambers. Tectotype. No. 225. × 120. (Photo by Dr. Tan Sin Hok.)

FIG. 37.—Same locality as Fig. 36. Median section. Form A. Tectotype. No. 225. × 14.

FIG. 38.—Upper Quarry, Batesford, near Geelong. (Locality of Holotype.) Median section. Form A. Tectotype. No. 226. × 8.4.

FIG. 39.—Nepionic apparatus of Fig. 38, showing eight adauxiliary nepionic chambers. Tectotype. No. 226. × 36.5.

FIG. 40.—Upper Quarry, Batesford. Median section. Form A. Tectotype. No. 227. × 8.

FIG. 41.—Same locality. Vertical section. Form A. Tectotype. No. 228. × 14.5.

PLATE IX.

Lepidocyclina (Trybliolepidina) batesfordensis sp. nov.

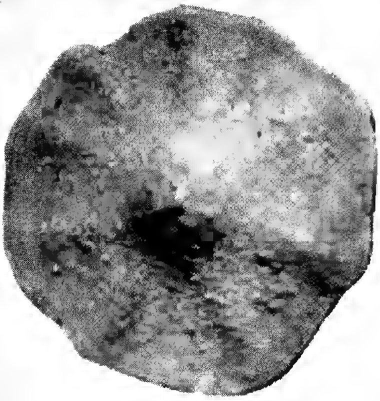
FIG. 42.—Upper Quarry, Batesford, near Geelong. Median section. Form B. Tectotype. No. 229. × 7.5.

FIG. 43.—Upper Quarry, Batesford. Vertical section. Form B. Tectotype. No. 230. × 7.5.

FIG. 44.—Old Filter Quarry, Batesford. Median section. Form B. Tectotype. No. 231. × 16.

FIG. 45.—Same locality as Fig. 45. Median section. Form A, showing eccentric protoconchal chamber. Tectotype. No. 232. × 50.

FIG. 46.—*L. (T.) gippslandica* sp. nov. No. 1 Bore, Pt. Addis (Metung), P. of Bumberrah. Median section, showing eccentric growth in deuteroconchal wall. Tectotype. No. 233. × 44.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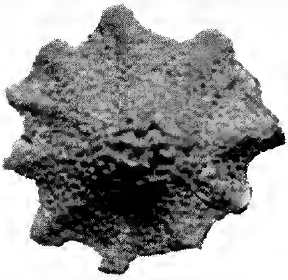
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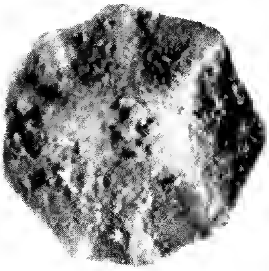
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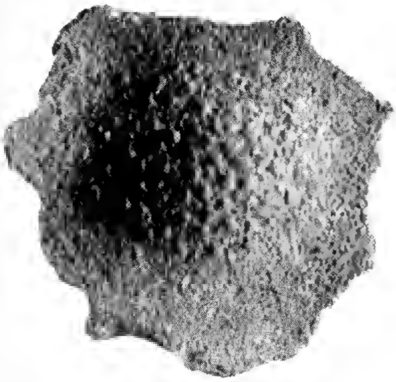
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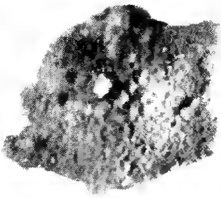
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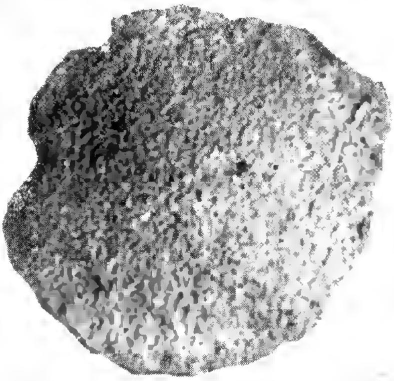
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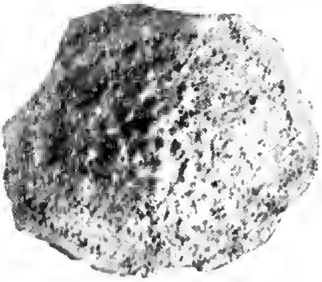
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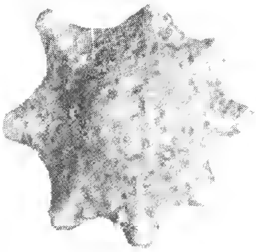

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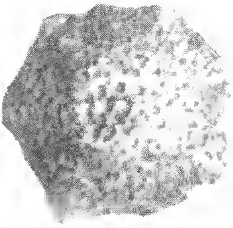

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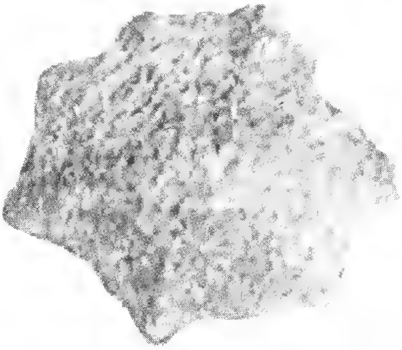

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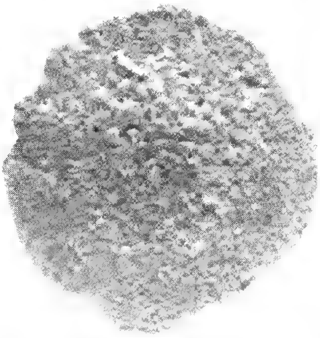

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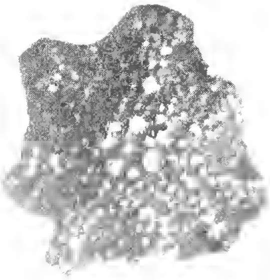

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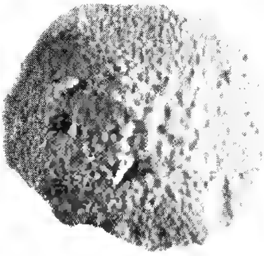

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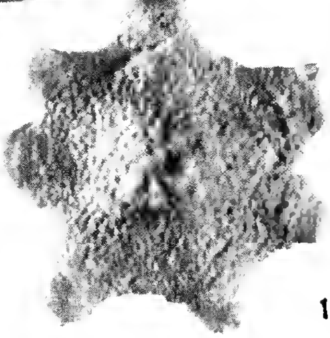

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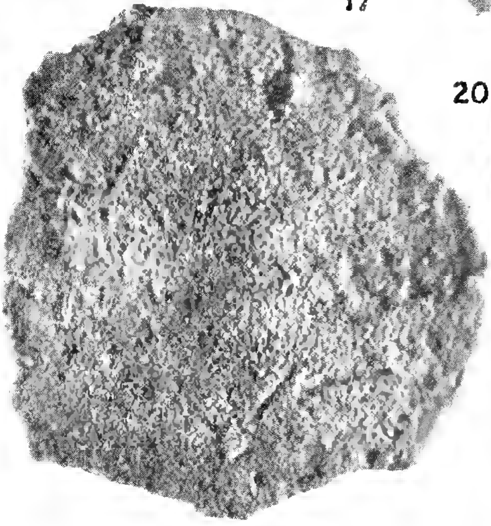

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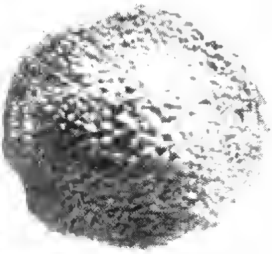

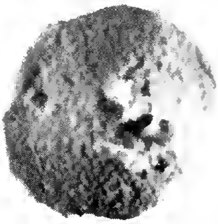

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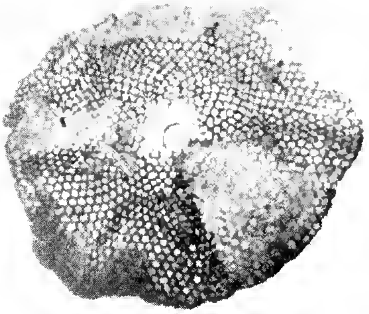
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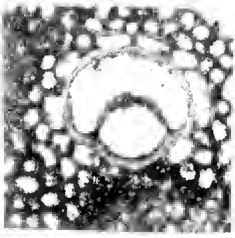
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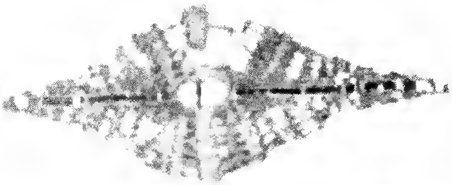
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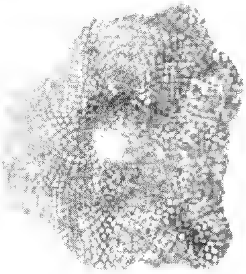
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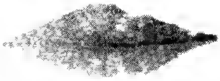
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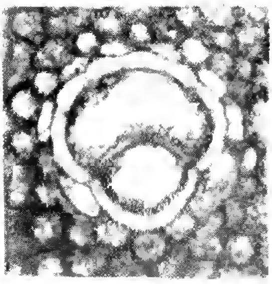
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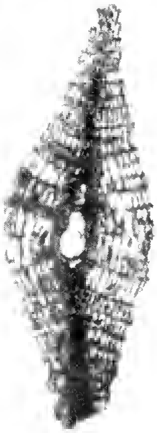
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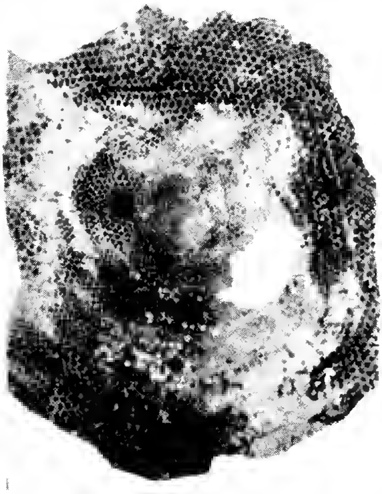

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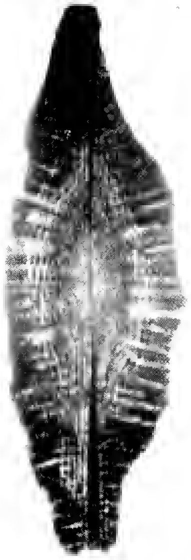

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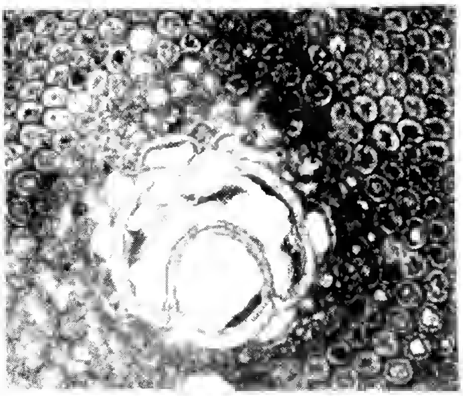

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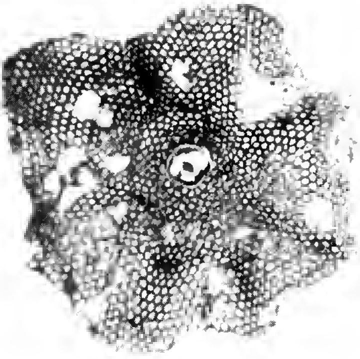

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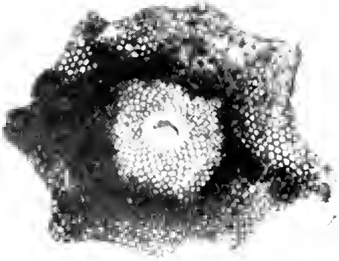

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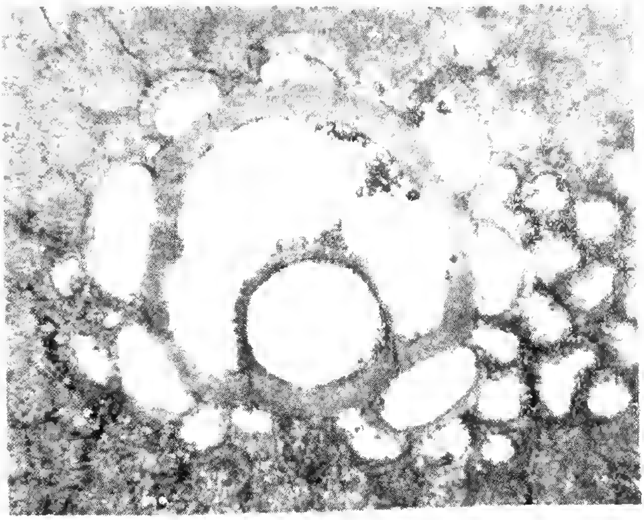
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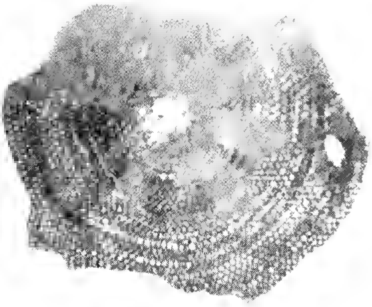
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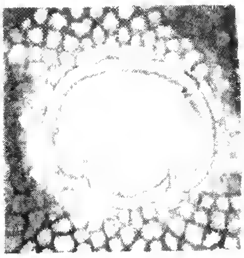
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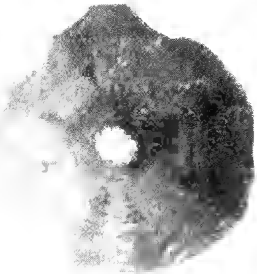
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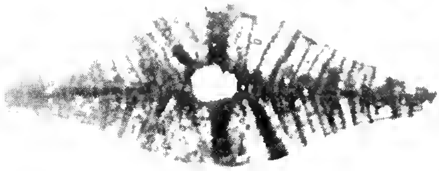
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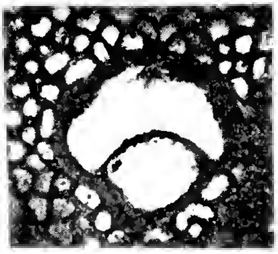

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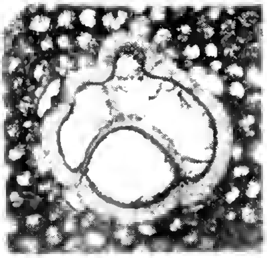

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[Proc. Roy. Soc. Victoria, **55** (N.S.), Pt. II., 1943.]

Art VIII.—*Jurassic Arkose in Southern Victoria.*

By A. B. EDWARDS and G. BAKER.

[Read 13th August, 1942; issued separately 1st October, 1943.]

Abstract.

The Jurassic rocks of Victoria consist chiefly of arkoses and mudstones, with minor amounts of grit, conglomerate, and black coal, and have been derived from a terrane consisting of Palaeozoic sediments and igneous rocks (granites, granodiorites, dacites, and associated tuffs). The arkoses consist essentially of notably angular grains of quartz, oligoclase, orthoclase, biotite, and fragments of andesitic tuff, cemented together by chlorite, epidote, zoisite, and secondary felspar. Oligoclase is the dominant felspar. Calcite sometimes takes the place of the more usual cementing minerals. It often gives rise to epigenetic calcareous concretions in which it commonly replaces grains of oligoclase felspar, but not the orthoclase.

The arkoses were derived chiefly from the igneous rocks, whereas the mudstones were derived chiefly from the Palaeozoic sediments. The Jurassic mudstones differ from the Palaeozoic mudstones, however, in that they contain considerable amounts of lime and soda, and the iron in them is chiefly in the ferrous state. The iron appears to occur mostly as more or less colloidal size particles of a chlorite-like mineral.

Chloritic cement in the arkoses appears to have been deposited from the connate waters of the mudstones which migrated into the arkoses during the compaction of the sediments; and the CO_2 of the calcite cement is thought to have been set free during the decomposition of the plant remains that occur throughout the sediments.

The felspars in the arkoses are surprisingly fresh, and persist in a fresh condition, even in the soils derived from the Jurassic sediments. Their state of preservation does not seem to be related to the climatic conditions prevailing at the time of their deposition, because the Jurassic climate appears to have been moist and more or less temperate. The more angular felspar grains are much less decomposed than the sub-angular grains, suggesting that the freshness of the felspar is due to the fracture of coarser grains of felspar just prior to burying, rather than to the mode of weathering of the parent rocks. The subsequent preservation of the felspars was due to the sealing of the arkoses by the interbedded mudstones, while their preservation in the soils is probably due to the immaturity of the soils.

Contents.

Introduction.

The Jurassic sediments of Victoria are of fresh-water origin, and consist essentially of interbedded mudstones and felspathic sandstones, or arkoses, which commonly show current bedding, together with minor amounts of felspathic grit, conglomerate, and bituminous coal seams.

As shown on the Geological Map of Victoria, they occur in three main areas, one centering about Merino, in Western Victoria, and extending westwards to the Glenelg River, a second forming the mountains of the Otway Ranges, with a north-easterly extension in the Barrabool Hills, near Geelong, and a third forming the South Gippsland Highlands. The details of these, and other minor outcrops of the Jurassic rocks, in position intermediate between the main areas, have been published by Selwyn and Ulrich (1866), by Murray (1887), by Hunter and Ower (1914), and by Skeats (1935). The most westerly record of the Jurassic rocks is from a bore 4,504 feet deep at Robe in South Australia, in which Jurassic mudstones and thin coal seams were encountered below a depth of 1,450 feet (Ward, 1926). Their most easterly recorded occurrence is at a depth of 3,158 feet, in Bore No. 1 at Goon Nure, south of Bairnsdale (Ann. Rept. Dept. Mines, Vic., 1938, pp. 22, 40).

The estuarine or lacustrine origin of the sediments has long been recognized, but it is impossible to decide whether they were laid down in a single great estuary or lake, or in a series of large lakes, because of the extensive Tertiary earth-movements which have affected them. In the Otway Ranges the Jurassic sediments have been subjected to faulting, and possibly to warping (Hills, 1940, p. 268; Coulson, 1939), while in the South Gippsland Hills they have undergone block-faulting (Hills, 1940, p. 269) and warping (Edwards, 1942A). The uniform nature of the arkoses, and particularly the distribution throughout them of fragments of a distinctive andesite or andesite-tuff, suggest that a single basin of deposition was involved, and that the isolated nature of the present outcrops arises from the subsequent earth-movements.

The thickness of the Jurassic sediments is not known, but was estimated at 5,000 feet by Selwyn (1868, p. 19). Bores have penetrated to 3,032 feet at Coalville in South Gippsland, and to 2,804 feet at Yaugher in the Otways, without passing out of the Jurassic, and on this account Hunter and Ower (1914) also estimate the thickness of the Jurassic sediments as about 5,000 feet, making allowances for about 1,000 feet of erosion, and a possible downward extension of another 1,000 feet below the bottom of the bores.

A study of the boring records suggests that the arkose forms about 40 per cent. of the total sediments in the exposed areas. This figure has only a qualitative value, because many more bores have been put down in areas known to contain workable seams of coal than in the wider areas where the absence of such seams has been established. Moreover, the thickness of individual beds of arkose and mudstone, as recorded in the bores, is often such that a bore needs to be in excess of 1,000 feet deep before it can be accepted as a reasonable sample of the proportions of the two lithological types present. The recorded range of uninterrupted thicknesses of arkose is from less than an inch up to 433 feet, and the majority of bores record one or more uninterrupted thicknesses of 100 feet, while many show an uninterrupted thickness of 200 feet. Similarly the known range of uninterrupted thicknesses of mudstone is from less than an inch up to 461 feet, but the latter figure is unusual, and uninterrupted thicknesses in excess of 100 feet are recorded in only a small proportion of the bores, while thicknesses in excess of 200 feet have been recorded only occasionally. Another difference between the arkose and mudstone beds is that successive beds of arkose may show a tremendous variation in thickness, whereas successive beds of mudstone tend to less extreme variation. This is presumably because the arkose beds are much more lenticular than the associated mudstone beds. This lenticularity, and the irregular minor folding which is often found in the Jurassic sediments, probably arise from differential compaction during lithification. (Edwards, 1942B).

The relative proportion of arkose to mudstone varies considerably in different localities, though it remains relatively constant for a restricted area. This is shown both by field studies and by the bore records. A study of the bore records, using only those in excess of 1,000 feet depth, where such exist, and averaging the proportion of mudstone and arkose obtained where more than one bore was available for a single parish, yielded some qualitative data concerning the distribution of the two rock types. The figures obtained are, however, of unequal value, because of the few bores that have been put down in the Otway and Merino areas, and because many of the bores, particularly in the Merino area, are only shallow. They indicate, however, that the arkoses are most abundant in the southern parts of the South Gippsland Highlands and of the Otway Ranges, constituting from 60 to 70 per cent. of the thicknesses of Jurassic bored in those parishes which are probably near the southern margin of the Jurassic basin. Northwards from this margin there is a falling-off in the proportion of arkose to as little as 25 per cent.

In the Merino area, mudstone is the dominant rock (Dunn, 1912), and the evidence of all of the bores available, despite their relative shallowness, only two or three exceeding 700 feet, is that the arkose forms less than 40 per cent. of the thickness of Jurassic bores, and in most parishes less than 20 per cent., falling as low as 4 per cent. in the deepest bore (756 feet), in Muntham.

The mudstones weather much more rapidly than the arkoses (Hunter and Ower, 1914, plate 9), and where the country consists of thick formations of these two rocks interleaved with one another, the arkose formations outcrop as hills showing dip slopes and escarpments (Ferguson, 1908).

Arkoses.

MINERALOGY.

The felspathic nature of the Jurassic sandstones, here termed arkoses, was first recognized by Selwyn (1853). The term arkose is used in the sense of Twenhofel (1932, p. 229), viz., "Arkose is a sedimentary rock composed of material derived from the disintegration of acid igneous rocks of granular texture." Brief petrographic descriptions of these rocks, from restricted localities, have been published by Richards (1910), Mahony (1922), Nicholls (1936), and Edwards (1942).

The present study is based on a collection of about 300 thin sections, largely drawn from areas in South Gippsland, but embracing the whole extent of the Jurassic outcrops. The greater proportion of this collection belongs to the Geological Survey of Victoria, the remainder being the property of the Geology Department of the Melbourne University. A noteworthy feature of the collection is that it includes sections of each successive change of lithology in four deep bores put down in South Gippsland. These are Bore No. 1 at Coalville (3,032 feet), the deepest bore in the Jurassic, Bore No. 1 at Powlett River (2,267 feet), Bore No. 1 at Berry's Creek, parish of Mardan (1,050 feet), and Bore No. 4 at Boolarra (900 feet).

The fresh arkose is characteristically greenish-grey in colour and is medium to fine-grained. The greater proportion of the grains are generally between 0·25 mm. and 0·50 mm. in diameter, and few exceed this size, though there may be a considerable number between 0·15 mm. and 0·25 mm. diameter, as is shown by Table 2. The fresh rock breaks across the grains, showing a dull matte-like surface, faintly speckled by the light-coloured felspar grains. The green colour arises from an abundance of chloritic cement. On weathering, the rock first becomes friable, and then, as the chlorite alters to limonite, the colour changes to brown. In thin section the grains are notably angular, particularly the quartz grains. Quartz, felspars, biotite, chlorite, and fragments of andesite are the essential components. The quartz and felspars are the more important constituents. Micrometric analyses show that the quartz forms from 10 to 15 per cent. by volume and the felspars 25 to 35 per cent., the higher figures in each instance coinciding with closer packing of the grains. Some of the quartz grains carry rows of dust-like inclusions, and very occasionally they are embayed after the manner of phenocrysts in acid lava-flows.

The felspars consist of oligoclase and orthoclase with minor amounts of perthite and microcline. The oligoclase is generally more abundant than the orthoclase and is commonly clear and limpid, whereas the orthoclase is generally cloudy. Very occasionally the felspar (generally orthoclase) is graphically intergrown with quartz.

Biotite is present as scattered flakes, often twisted or broken, and showing partial alteration to chlorite. Some of it is bleached, and most of the small amount of white mica present appears to be bleached biotite. Hornblende, pleochroic from green to brownish-yellow, and more or less altered to chlorite, is occasionally present, particularly in calcareous arkoses, as though the carbonate has had a protective effect, in the manner recorded by Bramlette (1942). Even in the calcareous rocks, however, it is generally much less abundant than biotite, except at Pebble Point, on the Otway coast, where it is the dominant ferromagnesian. Pyroxenes have been found only as very occasional grains.

Associated with these individual minerals, and constituting a distinct proportion of the rock, are sub-angular to rounded grains of an igneous rock. Some of these are glassy, others are microporphyritic, but all are of a uniform type. They consist of a fine-grained to glassy groundmass studded with microlites of a plagioclase showing almost straight extinction. In many grains the microlites show flow alignment. In others distinct microphenocrysts of andesine are present; and in some there are the chloritized remains of ferromagnesian minerals, so that the fragments are presumably derived from a fine-grained andesite, or an andesite tuff.

A calcareous arkose from Pebble Point contains fragments of sandstone, quartzite, mica-schist, chlorite schist, quartz schist, and what appear to be fragments of diabase tuff, in addition to the andesite fragments. Locally these rock fragments outnumber the normal mineral grains.

CEMENTING MINERALS.

The chlorite, to which the rock owes its colour occurs as irregularly-shaped patches cementing the grains together. It is apple-green in colour, and under crossed nicols appears almost isotropic or cryptocrystalline. Associated with it are irregular or idiomorphic patches of zoisite and yellow epidote. All three appear to be authigenic minerals, formed probably by the action of connate waters, during the process of lithification. Accompanying the chlorite is a little sericite, and clay material sometimes fills the interstices between grains. Staining with malachite green indicates that the clay is chiefly kaolinite.

In many sections the margins of the grains and the chlorite areas are outlined by a narrow rim of a colourless, anisotropic material. This mineral has a refractive index distinctly lower than the chlorite, and slightly lower than that of the felspars. Its birefringence is similar to that of the felspars, into which it often appears to merge. Occasionally it forms minute spherulitic growths, and in one section it was observed filling the cells of a fragment of wood. The closeness of its refractive index to that of the felspars suggests that it is authigenic albite, but it may be a zeolitic substance.

Calcite is present in small amounts in a number of thin sections as a cementing mineral; and occasionally it completely replaces the chlorite, when it may form as much as 40 per cent. of the rock. Where the calcite is abundant, there is abundant evidence that it has more or less completely replaced grains of oligoclase, although it does not seem to attack the orthoclase.

HEAVY MINERALS.

Samples of arkose from ten widely-spaced localities were examined for their heavy mineral contents, with the results shown in Table 1. Bromoform, of specific gravity 2·889, was used in the separations. As indicated by the index numbers, the heavy minerals amount to as much as 1 per cent. of the sample in only three instances. Of these, the sample from Ceres, near Geelong, and that from Griffith's Point, near San Remo, contain much material derived from the nearby Palaeozoic granites and their contact aureoles. The arkoses from localities distant from areas of granite or Palaeozoic sediments have much lower index numbers. The minerals in each assemblage are characteristically those of granitic rocks and contact metamorphosed sediments, and are closely comparable with those found in the sand fractions of soils formed from the Jurassic rocks (Nicholls, 1936). Biotite occurs throughout the assemblages as fresh or partially altered flakes, and there is a distinct relationship between the amount of biotite and the amount of apatite present in a particular assemblage. Presumably the apatite is released from the biotite during the crushing of the specimen, since similar apatite crystals

TABLE 1.—TABLE OF HEAVY MINERALS FROM SOME VICTORIAN JURASSIC ARKOSES.

District.	Locality.	Rock.	Index Number.	Actinolite.	Apatite—clear.	Apatite—dusky.	Biotite.	Cassiterite.	Chlorite.	Cyanite.	Epidote.	Garnet—colourless.	Garnet—pink.	Garnet—brown.	Hematite.	Hornblende.	Ilmenite.	Leucoxene.	Limonite.	Magnetite.	Pyrite.	Rutile—red.	Rutile—yellow.	Sphene.	Topaz.	Tourmaline.	Zircon—crystals.	Zircon—waterworn grains.	Zoisite.	White Mica.
Merino ..	4 miles north of Casterton	Brown sandy mudstone	0·1	V	a	o	a	..	o	V	o	r	r	r	..	V	r	r	C	o	r	r	r	o	V	C	o	..	r	r
Otways ..	Pebble Point, Princetown	Grayish - green calcareous	0·6	V	..	..	r	V	r	..	o	r	o	V	o	A	C	o	V	o	C	V	..	o	..	V	o	..	o	V
	Point Hayley, Apollo Bay	Green ..	1·0	..	r	..	o	..	C	..	C	r	r	r	o	..	o	r	V	o	..	..	..	o	V	r	r	r	r	r
	Carisbrook Cr., Great Ocean Rd.	Grayish-green	0·6	..	o	V	C	..	o	..	o	r	o	r	V	..	o	r	o	..	V	r	r	o	V	r	r	V	V	r
Barrabool Hills	Ceres, near Geelong	Green ..	1·3	..	o	V	o	V	o	..	r	r	r	..	o	..	o	r	r	o	V	o	..	r	V	o	C	o	o	r
South Gippsland	Griffiths Point, San Remo Pen.	Grayish-green	1·0	V	o	V	o	..	A	..	r	r	V	..	r	..	o	r	r	..	V	r	V	r	V	r	o	..	V	..
	Mirboo East ..	Brown ..	0·2	..	V	..	o	V	r	..	C	..	..	r	..	..	o	..	o	V	..	..	..	r	..	o	o	r	V	..
	Middle Creek ..	Grayish - green mottled	0·08	..	o	r	o	..	a	V	o	r	V	V	..	..	r	r	r	..	..	..	..	..	..	r	o	V	r	r
	Stony Creek ..	Brown ..	0·08	..	o	V	o	V	o	V	..	r	r	r	..	V	..	r	A	..	..	..	..	..	..	o	V	..	..	r
	Brookleigh, Tara Valley	Green ..	0·3	..	o	r	C	V	C	..	o	r	r	r	o	V	o	r	..	..	V	..	..	r	..	r	o	r	V	V

Key.—A—very abundant; a—abundant; c—common; o—occasional; r—rare; V—very rare.

occur as inclusions in the biotite Some of the apatite crystals contain inclusions of a fibrous pleochroic material. Comparable inclusions are found in apatites in the Palaeozoic dacites at Dromana (Baker, 1938, p. 265) and at Marysville.

The preponderance of well-shaped zircon, tourmaline and rutile crystals over water-worn grains suggests that the bulk of these minerals has been derived direct from igneous rocks, but the occasional water-worn grains may have come from older sediments. The ilmenite has a fresh appearance, and shows only partial alteration to leucoxene.

The epidote and zoisite, as might be expected from their mode of occurrence in the thin sections, show no signs of water-wear. The garnets, of which there are three varieties, brown, pink, and colourless, occasionally show signs of water-wear. Some of the garnet grains are surprisingly large, despite the fact that they were separated from crushed rock. Anatase was met with as only very occasional grains in the Casterton sample, although Nicholls (1936) has recorded it from the sand fractions of soils from all three of the main Jurassic areas.

MUD PELLETS.

A number of the sections contain small rounded pellets of mudstone, which range in size up to a centimetre in diameter. Occasionally these pellets are so crowded together that the arkose appears as a cement filling the interstices.

WOOD FRAGMENTS.

Fragments of coalified wood are present in a number of the sections, including some from the deep bores. Not infrequently these fragments are sufficiently well preserved to show the patterns of the cell structure of the wood.

SIZING ANALYSES AND PARTICLE SHAPE.

Five samples of arkose were used for sizing studies. Of these, four were selected on account of their abundant carbonate cement, which made it possible to break down the rock by treatment with dilute acid, and so preserve the shapes and sizes of the grains. The fifth sample was a friable rock, easily broken down in water with a minimum of grinding. The samples were taken from three widely separated localities, and at two of the localities two samples were taken, a little distance apart in the same bed. The results obtained by screening these disintegrated rocks through sieves are set out in Table 2. They show that the rocks are medium to fine-grained, and that the degree of sorting is uniform within a given bed, but varies greatly from bed to bed, some rocks consisting of well-sorted grains, others of poorly-sorted grains.

TABLE 2.—SIZING ANALYSES OF JURASSIC ARKOSES.

Fractions.	+0·5 mm.	+0·25 mm.	+0·15 mm.	−0·15 mm.	Clay.
Pebble Point, Princetown, residue of calcareous arkose, 40 per cent. carbonate	0·4	81·4	9·6	3·1	5·5
Bourne Creek, Kilcunda, friable arkose ..	2·3	66·0	17·2	10·8	3·7
Bourne Creek, Kilcunda, residue of calcareous concretion, 25 per cent. carbonate	..	59·6	23·8	15·8	0·8
Tarra Valley, South Gippsland, calcareous concretion, 45 per cent. carbonate	..	36·8	30·6	24·7	7·9
Tarra Valley, South Gippsland, residue of calcareous concretion, 49·3 per cent. carbonate	..	38·5	31·2	25·2	5·1

Mounts of these various sized fractions revealed that in every instance the mineral grains were predominantly angular to subangular. Rounded grains were rare. The quartz grains were chiefly angular, with occasional subangular grains. The felspars tended to be tabular cleavage fragments, and showed rather more rounding, angular and subangular grains being present in about equal proportions. The subangular grains of felspar were generally cloudy, while the angular grains were almost always clear. A number of grains both of quartz and felspar were wedge-shaped splinters, with fine points, while others had delicate points or protrusions on their corners, so that, while they may have been fractured during transport, they cannot have undergone a great deal of abrasion.

The ferromagnesian and other heavy minerals were concentrated in the −0·15 mm. fraction. The abundant hornblende of the Pebble Point rock, the hornblende and biotite of the Tarra Valley rocks, and the biotite of the Kilcunda rocks, were all concentrated in this fraction. This, no doubt, is a result of sorting during transport, the greater specific gravity of these ferromagnesian minerals causing smaller grains of them to be associated with coarser grains of quartz and felspar. The occurrence of the heavy minerals in this fraction is due, no doubt, to their original occurrence as small crystals.

POROSITY.

Measurements of absorption capacity range from 2 per cent. by weight for fresh rocks, to 10 per cent. for weathered rocks. Low absorptive capacity is associated with high FeO content, while high absorptive capacity is associated with low or negligible FeO content, so that the increase in porosity with weathering arises from a volume shrinkage of the cement as the chlorite changes to limonite.

CHEMICAL ANALYSES.

Comparison of the analyses of typical arkoses (Table No. 3) with available analyses of Palaeozoic sandstones from Victoria emphasizes the unusual composition of the arkoses. Their richness in alkalies and alumina, and their low silica contents, reflect their richness in felspars, while the dominance of soda over potash, and the abundance of lime, mark the preponderance of oligoclase over orthoclase. Variations in the individual analyses show that the total volume of felspar in the arkoses varies considerably from one locality to another, and that the relative proportion of orthoclase to oligoclase is equally variable, except that oligoclase is always the more abundant of the two. The plentiful chlorite in the arkoses is responsible for the unusually high FeO and MgO contents. In those analyses in which Fe_2O_3 dominates FeO, the samples were taken from weathered, brown rock, in which the chlorite is largely altered to limonite.

TABLE 3.—ANALYSES OF JURASSIC ARKOSES.

——	1.	2.	3.	4.	5.	6.	7.	8.	9.
SiO_2	65·50	64·13	64·00	63·60	62·18	61·92	61·04	57·90	57·57
Al_2O_3	15·49	18·59	15·88	16·38	17·13	15·75	16·06	18·76	17·96
Fe_2O_3	0·36	1·99	1·90	0·97	0·87	3·12	2·57	} 4·20	4·27
FeO	4·24	1·78	3·86	3·81	4·05	2·53	4·61	}	
MgO	1·92	1·24	1·81	1·92	2·60	2·47	2·55	1·31	1·51
CaO	3·50	1·34	2·02	2·15	2·19	2·13	1·92	3·40	1·38
Na_2O	2·60	4·36	3·42	4·19	2·15	2·76	2·00	2·88	2·64
K_2O	1·96	1·98	1·86	1·89	1·57	1·89	1·00	0·98	1·73
H_2O+ ..	1·89	3·43	3·84	3·02	0·96	4·05	4·13	3·65	5·37
H_2O- ..	0·54	1·38	1·04	1·18	3·31	1·78	1·90	4·35	6·57
CO_2	1·65	tr.	nil	tr.	1·32	..	..	1·77	0·50
TiO_2	0·60	..	..	0·69	..	0·81	0·87	0·81	0·72
P_2O_5	0·20	..	..	0·12	..	..	0·35	..	..
MnO	0·06	tr.	tr.	0·09	..	..	0·25	..	..
	100·51	100·22	99·63	100·01	98·33	99·21	99·25	100·21	100·22
Na_2O/K_2O ..	1·33	2·20	1·84	2·22	1·37	1·46	2·00	2·94	1·53

1. Arkose, cliff opposite Brookleigh, below the weir, Tarra Valley, near Yarram, South Gippsland; *Analyst*: A. B. EDWARDS.
2. Arkose, from McCann's Quarry, Ceres, Barrabool Hills; *Analyst*: H. C. RICHARDS, *Proc. Roy. Soc. Vic.*, n.s., xxii. p. 194, 1909.
3. Arkose, from Apollo Bay, Otway Ranges: *Analyst*: H. C. RICHARDS, *Ibid.*
4. Arkose, from Griffith's Point, San Remo, South Gippsland; *Analyst*: A. B. EDWARDS.
5. Arkose, from Apollo Bay, Otway Ranges: *Analyst*: P. G. W. Bayley, Rept. on Geol. Sheet A.47. *Spec. Rept. Dept. Mines*, 1901.
6. Arkose, from Craigleith Quarry, Pettavel Road, Barrabool Hills; *Analyst*: P. W. G. Bayley.
7. Arkose, near Coal Creek, Korumburra, South Gippsland: *Analyst*: P. G. W. BAYLEY.
8. Arkose, from No. 5 bore, State Coal Mine, Wonthaggi, South Gippsland; *Analyst*: F. F. FIELD.
9. Arkose, from dump in the Dudley Area, State Coal Mine, Wonthaggi, South Gippsland; *Analyst*: F. F. FIELD.

Another feature revealed by the comparison is the distinctly uniform SiO_2 and Al_2O_3 content of the arkoses as compared with the considerable range shown by these constituents in the more normal sandstones.

In Table No. 4 are shown the analyses of several arkoses in which the chloritic cement of the normal arkose has been more or less completely replaced by calcite, the culmination of this replacement being calcareous concretions (Table No. 4, Analysis No. 4), in which the carbonate content of the arkose rises as high as 50 per cent. of the whole. In these rocks the proportions of FeO and MgO remain unchanged, despite the absence of chlorite. In weathered specimens the ferrous carbonate has been converted to limonite. The unusually high MgO content of Analysis No. 3 in Table No. 4 suggests that some magnesium carbonate was introduced into the rock along with the calcium carbonate. Similarly the high MnO contents of the specimens showing most carbonate (Analyses Nos. 3 and 4 of Table No. 4) indicate that some manganese carbonate accompanied the calcium carbonate.

TABLE 4.—ANALYSES OF CALCAREOUS ARKOSES.

—	1.	2.	3.	4.
SiO_2	55·15	52·90	44·67	41·58
Al_2O_3	15·23	16·49	13·57	10·93
Fe_2O_3	4·49	0·78	4·87	2·40
FeO	0·98	4·86	2·76	1·89
MgO	2·79	2·92	3·82	1·30
CaO	5·43	7·14	9·97	21·06
Na_2O	1·16	2·58	1·18	1·86
K_2O	1·65	1·73	1·53	1·83
H_2O + ...	..	2·93	..	0·71
H_2O —	1·90	1·72	1·92	1·39
Ignition Loss	11·00	..	15·16	..
CO_2	..	4·65	..	14·93
TiO_2	0·59	1·10	0·52	..
P_2O_5	tr.	0·25	tr.	..
MnO	0·22	tr.	0·62	1·60
Cl	..	tr.	..	..
SO_3	nil	nil	nil	..
	100·59	100·05	100·59	101·48
Na_2O/K_2O	0·70	1·49	0·77	1·01

1. Calcareous arkose, allotment 76, parish of Longwarry, near Lang Lang River, South Gippsland; *Analyst*: F. F. FIELD, *Rec. Geol. Surv. Vic.*, 4. Pt. 4, 451.
2. Calcareous arkose, old shaft of Coal Creek Proprietary Mine, Korumburra, South Gippsland; *Analyst*: P. G. W. BAYLEY.
3. Calcareous arkose, allotment 74, parish of Longwarry; *Analyst*: F. F. FIELD, *Rec. Geol. Surv. Vic.*, 4, Pt. 4, 451.
4. Calcareous concretion in arkose (some manganese carbonate). Apollo Bay, Otway Ranges. *Analyst*: P. G. W. BAYLEY, *Spec. Rept. Dept. Mines, Vic.*, 1901 (Report on Geol. Sht. No. A. 47).

(Host rock, Analysis No. 5. Table 1.)

In three of these analyses (Nos. 1, 3, and 4, of Table No. 4) the Na_2O content is considerably lower than in any of the normal arkose analyses, being equalled or surpassed by the K_2O content. This confirms the evidence of the thin sections that the oligoclase in these rocks tends to be replaced by the calcite, while the orthoclase is not affected. Such replacement is not invariable, however, since in the fourth analysis (Analysis No. 2 of Table No. 4) the alkalies appear normal.

This variable behaviour of the carbonate on the felspars is further demonstrated by alkali determinations on the sand fractions of three of the rocks used in the sizing analyses (Table 2), namely, the residue of a calcareous concretion from near Brookleigh Farm, in the Tarra Valley, from which 49·3 per cent. of carbonate material had been leached with dilute hydrochloric acid; the residue of a calcareous concretion from near the mouth of Bourne Creek, at Kilcunda, from which 25 per cent. of carbonate had been leached; and the untreated fractions of a friable arkose from Bourne Creek, at Kilcunda. The alkali contents of the various fractions are shown in Table No. 5.

TABLE 5.—ALKALI CONTENTS OF SIZED FRACTIONS OF ARKOSES.

Fraction.	K_2O.	Na_2O.	Na_2O/K_2O.
1. *Residue of Tarra Valley Concretion.*			
+0·25 mm.	4·21	2·03	0·48
+0·15 mm.	4·93	2·02	0·41
−0·15 mm.	4·62	2·55	0·55
2. *Residue of Kilcunda Concretion.*			
+0·25 mm.	2·48	3·50	1·41
+0·15 mm.	2·02	3·20	1·57
−0·15 mm.	1·77	2·50	1·33
3. *Friable Arkose from Kilcunda.*			
+0·25 mm.	2·19	3·16	1·44
+0·15 mm.	1·76	2·71	1·54
−0·15 mm.	1·39	2·01	1·44

The figures show that in the Tarra Valley rock a large proportion of the oligoclase has been replaced by calcite, while in the Bourne Creek concretion, little or no replacement of oligoclase has taken place. This is confirmed by the appearance of the felspars in thin sections of the two concretions.

Another feature of these partial analyses is that the total amount of felspar in the two Bourne Creek specimens diminishes as the grain size of the fraction decreases. This feature is not shown by the Tarra Valley specimen, but is probably true of the sediments as a whole, since thin sections show that the proportion of felspars in the sandy mudstones is always much less than the proportion of felspars in the arkoses. The figures indicate, however, that there is no significant or progressive variation in the ratio of potash to soda in the various sized fractions of a particular rock, so that apparently the comminution and destruction of both orthoclase and oligoclase proceeded at equal rates, and was not selective.

CONCRETIONS.

CALCAREOUS CONCRETIONS.

Many of the arkose beds are characterized by calcareous concretions which are spherical, or less commonly, dumb-bell shaped. Their average diameter is between 3 and 6 inches, though some are larger. They are of epigenetic origin, since the bedding planes of the enclosing arkose pass through them without interruption. Occasionally these lines of stratification, as noted by Daintree (1862), are marked by films of coalified leaf remains. In the hand specimen the concretions appear identical with the enclosing arkose, but being harder, they project from weathered surfaces, especially cliff-faces and wave-cut platforms. They are generally structureless, though occasionally when weathered they break into concentric shells.

Thin sections show them to consist of the normal arkose minerals cemented together by coarse-grained crystals of calcite, the calcite sometimes invading and replacing the oligoclase. A typical concretion from arkose at Apollo Bay, in the Otway district, was found by V. R. Stirling (1901) to contain about 30 per cent. of calcite (Table No. 4, Analysis No. 4), while the enclosing arkose contained only 3 per cent. of calcite (Table No. 3, Analysis No. 5). That this is characteristic is shown by the fact that three concretions selected at random, two from the Tarra Valley, and one from Kilcunda, were found to contain 49·3 per cent., 43·5 per cent., and 25·0 per cent. of carbonate, respectively. In each instance the enclosing rock contained only a few per cent. of calcite cement.

The concretions do not occur in the shales or mudstones, and their restriction to the arkose is related to the higher porosity of these rocks. Presumably the concretions mark centres of slow crystallization of calcite from solutions filling the pore spaces of the arkose. The calcium carbonate in the adjoining rock was able to diffuse from all sides through the pore spaces to the widely spaced centres of crystallization, where it crystallized as a spherical meshwork of carbonate enclosing the mineral grains of the rock, at the same time converting the existing chlorite cement to carbonate. Insufficient carbonate was left in the surrounding rock to give it comparable hardness or bonding.

In other arkose beds calcite is present in abundance (Table No. 4, Analyses Nos. 1, 2, 3), but concretions have not formed. Either conditions did not permit diffusion to localized centres of crystallization, and crystallization occurred rapidly about many centres, or the supply of calcium carbonate was so great that the early-formed concretions continued to grow until the whole bed was cemented. The relatively small amount of carbonate in some of the beds, compared with the large amount in the concretions, suggests that the first explanation is the more probable. In places, however, there was an excess of carbonate available, and it formed veins of calcite, sometimes several feet thick.

PYRITIC CONCRETIONS.

In the Apollo Bay district, Stirling (1901) noted small pyritic concretions in the arkoses, presumably of similar general origin to the calcareous ones. Such concretions do not appear to be numerous in other Jurassic areas. At Wyelangata, also in the Otway area, however, small nodules of pyrite and veins of pyrite and calcite, carrying as much as 2 dwt. of gold per ton, occur in the bedding planes of mudstone beds (Easton, 1935). Pyrite, associated with calcite, is also found in thin films in the joints of coal seams at Kilcunda.

QUARTZ VEINS.

Stirling (1899) records the occurrence of thin quartz veins, carrying felspar, in the Jurassic near Mount Sabine.

Mudstones and Shales.

The mudstones and shales are generally blue or grey in colour, turning buff or brown on weathering. When rich in carbonaceous matter they are black. Like the arkoses, they are commonly current bedded. They range from sandy mudstone, containing numerous small angular fragments of quartz and a little felspar, in a fine-grained matrix of sericite and clay, to extremely fine-grained rocks in which little other than sericite can be made out with the microscope. The quartz grains, when present, are often wedge-shaped and sharp pointed. The proportion of felspars in the coarser mudstones and shales is always much less than that found in the arkoses, but both orthoclase and oligoclase are present. In the majority of mudstones examined there is an abundance of shreds and fibres of woody material, all the fibres lying parallel to one another and to the bedding planes, so they often reveal the presence of current bedding even in the finest grained sediments. This abundance of wood fibres indicates that broken-down plant remains were being supplied continually to the Jurassic basin of sedimentation.

The clay matrices of several samples were extracted, and tested by staining with malachite-green and saffranine-o, both before and after treatment with hydrochloric acid (Faust, 1940). This showed that in addition to kaolinite the clays contained a considerable proportion of a mineral or minerals subject to base exchange. A partial analysis of the composite fine clay remaining in suspension after twelve hours, from a typical blue mudstone from Cape Paterson, gave the results shown in Analysis No. 6, Table No. 6. Since as much as one-third of this material consisted of kaolinite, the mineral showing base exchange must be an iron-rich variety containing relatively little alumina.

It differs, however, from all the iron-rich clay minerals in that the bulk of its iron is in the ferrous state, whereas in the iron-rich clays the iron is in the ferric state. That this is general in the Jurassic mudstones is shown by the dominance of ferrous iron over ferric iron in their analyses (Table No. 6). This is in equally striking contrast to the state of the iron in the more normal Palaeozoic slates and mudstones in Victoria in which the iron is chiefly in the ferric state. According to Grim (1939), the common clay mineral of such rocks is illite. The clay-like mineral in the Jurassic mudstones, however, must be more akin to a chlorite in a very finely divided state.

When the analyses of the mudstones (Table No. 6) are compared with those of the arkoses (Table No. 3), considerable resemblances are noted, and certain differences. The SiO_2 content of the mudstones is much the same as that of the arkoses, and shows much the same range of variation. The Al_2O_3 content of the mudstones is a little higher than that of the arkoses of corresponding SiO_2-content. Lime, magnesia and iron oxides are present in much the same amount, and alkalies are still abundant; but whereas Na_2O is the dominant alkali in the arkoses, K_2O is dominant in the mudstones. In this respect the Jurassic mudstones and shales approach more closely to their Palaeozoic equivalents, which are dominantly potassic (Howitt, 1923), than do the arkoses. The consanguineous relationship between the

TABLE 6.—ANALYSES OF JURASSIC SHALES.

——	1.	2.	3.	4.	5.	6.
SiO_2	61·36	60·70	59·72	57·83	57·40	53·57
Al_2O_3	18·18	18·32	19·26	18·49	20·44	18·05
Fe_2O_3	4·26	1·18	0·80	0·41	1·14	1·95
FeO	..	3·18	3·06	1·79	2·44	13·35
MgO	1·26	2·02	1·92	1·59	1·50	2·81
CaO	1·68	2·00	0·82	1·53	0·98	nil
Na_2O	1·94	1·25	1·44	1·52	1·41	1·16
K_2O	3·32	2·64	4·17	2·42	3·66	2·09
H_2O+	4·23	4·13	5·01	7·72	5·99	..
H_2O-	3·10	3·35	3·50	5·32	3·63	..
TiO_2	..	0·90	0·99	0·63	0·90	0·60
P_2O_5	..	tr.	tr.	nil	tr.	
Cl	..	tr.	nil	tr.	nil	..
SO_3	..	nil	tr.	tr.	nil	..
	99·33	99·67	100·69	99·25	99·49	..

1. Shale from the roof of the Outtrim Colliery, South Gippsland; *Analyst*: F. E. A. STONE, *Ann. Rept. Sec. Mines*, 1898, p. 28.
2. Shale from above coal seam, east adit near shore, Kileunda; South Gippsland; *Analyst*: P. G. W. BAYLEY, *Ann. Rept. Sec. Mines*, 1906.
3. Shale from above seam in Coal Creek Mine, Korumburra, South Gippsland; *Analyst*: P. G. W. BAYLEY.
4. Shale forming the seatstone in coal mine, Kileunda, South Gippsland; *Analyst*: P. G. W. BAYLEY, *Ann. Rept. Sec. Mines*, 1906.
5. Shale from under coal seam in Coal Creek Mine, Korumburra; *Analyst*: P. G. W. BAYLEY, South Gippsland.
6. Composite clay fraction remaining in suspension after 12 hours, from blue Jurassic mudstone, Cape Paterson; *Analyst*: A. B. EDWARDS.

mudstones and the arkoses is shown, however, by their Na_2O and CaO contents, which are unusually high for such rocks, and arise from the abundance of plagioclase in their source material.

A minor but interesting difference between the arkoses and the mudstones, is the relative abundance of P_2O_5 in the arkose, in contrast with its relative absence from the mudstones. The P_2O_5 in the arkose occurs in small apatite crystals enclosed in biotite flakes, and with the increased comminution of the biotite flakes these apatite crystals were set free and then dissolved.

The mudstones, like the arkoses, have a relatively uniform composition, and hence a much more restricted range of composition than is shown by the normal Palaeozoic mudstones and slates.

Felspathic Grits.

Thin beds of felspathic grit occur at a number of places along the Otway and South Gippsland coasts, and in the Barrabool Hills. They are most prominently developed at San Remo, where they outcrop in the vicinity of Griffith's Point, and along the Western Port coast of the peninsula (Edwards, 1942B). Small pebbles of granite, arenaceous sandstone, shale, and slate are intermingled with the grit. The material is clearly derived from the nearby granite of Cape Woolamai, and the sediments of its contact aureole. Felspar has been separated from the quartz during deposition, so that quartz predominates in the grit. An alkali determination on a specimen practically free from mica and pebbles gave the values K_2O 1·99, Na_2O 1·39, as compared with K_2O 4·76, Na_2O 3·00, in the granite (Summers, 1914). The ratio of potash to soda in the grit is not significantly different from that in the granite, so that there has been no differential winnowing of orthoclase or oligoclase from the quartz during the formation of the grit, but merely of felspar from quartz. Where the grits are calcified, the calcite is found replacing the oligoclase in the grit, but not the orthoclase.

At Apollo Bay the grits occur as thin beds and lenses interstratified with arkose, as at San Remo, and again consist chiefly of granitic material with quartz grains preponderating. There are no outcrops of granite in the vicinity, but the character of the grits suggests that granite must occur somewhere nearby, either beneath the Jurassic sediments, or under the sea.

In the Barrabool Hills, similar grits are exposed at Buckley's Gorge, on the Barwon River (Coulson, 1930), where they are interbedded with arkoses, and with thin beds of conglomerate carrying granitic and other boulders.

The heavy minerals obtained from these grits are set out in Table No. 7. They are of a granitic nature. The zircons in both grits examined include both prismatic and water-worn forms, the water-worn zircons being the less numerous. The apatite crystals sometimes have coloured, pleochroic cores, like those found in Victorian granites (Baker, 1941). Some of those in the Apollo Bay grit contain inclusions of a fibrous pleochroic material. The ilmenites show partial alteration to leucoxene.

TABLE 7.—HEAVY MINERALS IN JURASSIC GRITS.

Mineral.	San Remo.	Apollo Bay.
Apatite	r	o
Biotite	r	a
Bleached Biotite	C	o
Chlorite	o	o
Epidote	..	r
Garnet	r	r
Hornblende	..	V
Ilmenite	o	o
Limonite	a	..
Magnetite	..	o
Rutile	V	r
Sphene	V	r
Tourmaline	r	o
Zircon	o	o
Zoisite	..	r

Key.—a—abundant; o—occasional; C—common; r—rare; V—very rare.

Conglomerates.

Two types of conglomerate occur in the Jurassic rocks: (1) those containing pebbles drawn from the Jurassic terrane, and (2) those in which the pebbles are all derived from earlier deposited Jurassic mudstones and arkoses. The greatest known development of the first type of conglomerate is exposed along the Tyer's River in South Gippsland, where it marks the boundary between the parishes of Tanjil East and Boola Boola (Murray, 1876; Whitelaw, 1899). Cliff sections along the eastern side of the Tyer's River show more than 100 feet of conglomerate resting unconformably on the Silurian, and dipping at from 5 to 12 degrees south. The conglomerate consists of well-rounded large and small pebbles of hard Silurian sandstone, quartzite, and quartz, in a sandy matrix, with a cement of iron oxide. Some indication of bedding can be seen in the conglomerate, with which are intercalated sandy and shaly patches, sometimes carrying plant remains. To the south the conglomerates pass beneath normal arkose and shale beds.

A similar conglomerate is exposed in the banks of Rintoul's Creek, to the east, but it is not so thick at this locality, and contains smaller pebbles of somewhat softer Silurian rocks.

Conglomerates with pebbles of pre-Jurassic rocks occur at a number of other localities, both in the Otways and in South Gippsland, but they nowhere else attain such a volume. Along the Otway coast they have been recorded as thin beds and lenses, associated with grits and arkoses, from Pebble Point (Wilkinson,

1864) and Castle Cove (Kitson, 1900). In the Barrabool Hills, they are exposed at Buckley's Gorge, on the Barwon River, near the local base of the Jurassic (Daintree, 1861; Wilkinson, 1864; Coulson, 1930). Marginal conglomerates, up to 3 feet thick, occur interbedded with grits and arkoses at Griffith's Point, near San Remo on the South Gippsland coast (Stirling, 1892; Ferguson, 1908; Edwards, 1942). Similar conglomerates occur in the Jumbunna district, where they form beds about 10 feet thick (Kitson, 1917).

Some of the Jumbunna pebbles are polished, and Kitson suggests they are derived from Permian (Permo-Carboniferous) glacial conglomerate beds.

At Chitt Creek, near Toora, Ferguson (1906) has described a lenticle of somewhat similar conglomerate at the junction of the Silurian with the overlying Jurassic. The pebbles consist of granite, resembling that of Wilson's Promontory, indurated sandstone and grit, chert, quartzite, felsite, and siliceous shale. Some of the pebbles were polished, striated and facetted, while others were not. Ferguson suggested that this conglomerate bed, which is about 3 feet thick, is of glacial origin, but Kitson (1917) is of the opinion that this and similar conglomerates in the Jurassic may be derived from resorted glacial beds of Permian age. Mahony (1930) classes this conglomerate and similar basal conglomerates underlying the Jurassic at Coleraine as of Permian (Permo-Carboniferous) age.

Isolated pebbles and boulders of foreign origin are sometimes found in the mudstones and arkoses, being more numerous in the coarser-grained sediments. Ferguson (1906) records the occurrence of two large boulders of granite near Kilcunda, while Hunter and Ower (1914) describe a pebble of granophyric granite found in the roof of No. 5 coal seam at Wonthaggi. Near Anderson's Inlet there are highly-polished pebbles of felsite, mica-schist, jasper, agate, carnelian, quartzite, quartz, sandstone, and silicified wood in the arkoses (Kitson, 1903). Felsite has been recorded from Waratah Bay (Stirling, 1894), but the other rocks are foreign to the district.

The second type of conglomerate, in which the pebbles all consist of Jurassic mudstone and sometimes arkose, and even coal, is of more frequent occurrence, but rarely exceeds a length of 20 feet, or a thickness of more than a foot. Kitson (1917) has described such conglomerates in the Jumbunna district, where he found pebbles and boulders of mudstone ranging in size from 2 inches by ½ inch up to 7 or 8 feet by 2 or 3 feet. In some rounded mudstone " boulders " over a foot in diameter he found well-preserved plant remains and casts of *Unio*. In other beds there were numerous rounded to sub-angular pellets of mudstone, many of them flattened and oval shaped. Some of these may have been "mud curls." Conglomerates of this type are exposed along the San Remo coastline (Edwards, 1942), and at Cape Paterson (Ferguson, 1908), along the Otway coast (Wilkinson, 1864; Kitson, 1900), and in the Barrabool Hills (Coulson, 1930). They are well developed in places in the roofs of the coal seams in the Wonthaggi State Coal Mine, where they form lenses 1 to 3 feet thick, extending over areas of an acre. They clearly arise from contemporaneous erosion of the Jurassic beds, and sometimes have themselves suffered erosion soon after deposition. Kitson (1917) describes such an occurrence in the Jumbunna district, where pebbles of coal in such a conglomerate have been partially eroded, and fresh arkose beds deposited on the eroded faces of the pebbles.

Coal Seams and Plant Remains.

Thin seams of black coal occur at a number of places in the various Jurassic areas, but workable seams are restricted to a belt about 50 miles long and 10 miles wide, running north-east from Kilcunda (Hunter and Ower, 1914). The individual seams are lenticular, and extend over only small areas. The best seams average between 2 and 3 feet thick, occasionally attaining thicknesses of as much as 9 feet, and they are generally much faulted. The coal is worked in the State Coal Mine at Wonthaggi (Platt, 1940), and in smaller mines at Kilcunda, Korumburra and Jumbunna. The coal at Korumburra and Jumbunna is of higher grade than that at Wonthaggi and Kilcunda, suggesting that there was a greater thickness of sedimentary cover in this part of South Gippsland.

Most workers have considered that the coal is of drift origin (Selwyn, 1853; Murray, 1895; Stirling, 1895; Kitson, 1917). The evidence cited in favour of such an origin is the absence of old soils beneath the coal seams; the occurrence of seams with both floor and roof consisting of arkose, or with a floor of arkose; the presence of current bedding in the rocks forming the roof and floor of the seams; the presence of quartz pebbles in the coal at Korumburra and Jumbunna, unaccompanied by any sandy material; the presence of fossil branches, roots, and tree trunks in the arkose beds, in positions in which they could not have grown. Hunter and Ower (1914), on the other hand, consider that the coal vegetation grew *in situ*, but offer little evidence in support of their belief.

The surface of the coal-forming peat was subject to contemporaneous erosion, since small washouts filled with arkose occur in the Kirrak and Shaft 18 areas of the State Coal Mine at Wonthaggi. One such washout in the Kirrak area failed to cut to the base of the coal seam, and is overlain by a 2-inch thick band of dirt (arkose) above which is about 12 inches of good coal. In this area of the mine the roof of the seam consists of arkose, sometimes showing current bedding and containing waterworn pebbles. Occasionally it gives place to runs of fine conglomerate.

The coal is bituminous, and is generally very finely banded, the individual bands or lenses of coal being as thin as 0·01 inch. Vitrain forms only a small proportion of these bands, the bulk of them consisting of dull coal. Occasionally, however, bands of vitrain occur as wide as 0·5 inches. Banding in coal is generally regarded as due to fluctuations in the water conditions of the swamp in which the coal vegetation grew (White, 1932), but there is a possibility that in these seams it might be due to deposition of drifted material. In a number of localities the arkoses occur as thin beds, often less than a centimetre thick, each bed separated from the next above by a thin layer of coalified leaf remains and wood fragments. Several hundred such beds may be exposed in a few feet in a single cutting. Deposition of the wood fragments without the intervention of the thin beds of arkose could well have given rise to a thin coal seam.

PLANT REMAINS.

No doubt can be entertained of the drifted nature of fragmentary plant remains just described, nor of the small twigs and branches of coalified wood found along the bedding planes of the arkose beds at many localities. Further evidence of drift is provided by the countless fibres of woody matter found in the mudstones.

The plant remains occurring in the arkose beds are generally fragmentary and waterworn, but well preserved, and often delicate, leaf remains are found in the mudstones. The Jurassic flora has not been studied exhaustively, but sufficient work has been done to reveal its general nature (Seward, 1904; Chapman, 1908, 1909; Stirling, 1900). It resembles the flora of the estuarine phase of the Yorkshire Oolite. There is a tendency for one or two species to predominate at any given locality, but they do not appear to be restricted to any particular horizon in the Jurassic, nor to provide a basis for zoning the deposits.

The only other fossils recorded are an occasional *Unio* (Selwyn, 1866; Stirling, 1900; Kitson, 1917), a few fossil fish (Etheridge, 1902; Woodward, 1907; Chapman, 1908), and the claw of a carnivorous Dinosaur (Woodward, 1907).

The Source Rocks.

By definition, the composition of an arkose is a direct reflection of the composition of the rocks from which its constituents are derived, and where the arkose extends over a wide area, it may be expected to show local variations in accordance with the changing nature of its terrane.

Such relationship appears to hold for the Jurassic sediments in Victoria. The Jurassic terrane consisted predominantly of Palaeozoic sediments, chiefly of Ordovician and Silurian age, and of Palaeozoic granitic rocks, porphyritic extrusives, and tuffs, with much less extensive outcrops of Cambrian sediments and epidiorites, of Carboniferous sandstones and shales, and of Permian tillites and glacial sandstones; and it is possible to trace, in some degrees, the contribution which each made to the Jurassic basin of sedimentation.

The clearest evidence of the origin of the source material is provided by the pebbles in the marginal conglomerates and grits of the Jurassic, which are largely derived from nearby Palaeozoic igneous rocks and sediments, as for example at the Barrabool Hills, where the Jurassic conglomerate contains pebbles of the nearby Heathcotian epidiorite, and of granite and contact metamorphosed Palaeozoic sediments, or at Tyers River, where the boulders consist essentially of Silurian sediments. Further evidence is provided by the marked difference in mica content between the Palaeozoic sediments and the Jurassic sediments. In the Palaeozoic sediments, especially those of Silurian age, muscovite is the predominant mica (Langford, 1916; Dunn, 1921), whereas it is a relatively uncommon mineral in the Jurassic rocks. In the Jurassic rocks, biotite is the dominant mica, and the bulk of the small amount of white mica present appears, from its specific gravity, which exceeds 2·889, to be bleached biotite. This predominance of biotite in the Jurassic rocks can only be attributed to the fact that biotite is the dominant, and often the sole, mica in the Palaeozoic granitic and extrusive rocks in the vicinity of the Jurassic sediments. The biotite, both in the Jurassic rocks and in the Palaeozoic igneous rocks, is characterized by inclusions of apatite crystals. Moreover, the hornblende which sometimes accompanies, or more rarely takes the place of, the biotite, is closely comparable with the hornblende found in certain of the Palaeozoic granitic rocks.

A small proportion of the felspar in the Jurassic arkoses may have come from the Palaeozoic sediments, since the Silurian sandstones contain a small proportion of fresh oligoclase (Junner, 1913; Langford, 1916) and the Ordovician carries small amounts of weathered orthoclase and oligoclase (Dunn, 1921), but the bulk of it was probably derived from the Palaeozoic igneous rocks. The excess of oligoclase over orthoclase in the arkoses is difficult to explain in terms of present exposures. Most of the orthoclase, and a large part of the oligoclase must have been drawn from the granitic rocks, considerable areas of which are hidden by the waters of Bass Strait, and the basalt plains of Western Victoria. These comprise granites, adamellites, and granodiorites. The relative proportions of the three are unknown, but it is unlikely that the granodiorite is sufficiently preponderant to account for the whole of the oligoclase in the arkoses. Micrometric analyses of the granitic rocks (Baker, 1942) show that, taken as a whole, they are not likely to contain more than about 30 per cent. by volume of oligoclase to 25 per cent. of orthoclase, and the Na_2O/K_2O ratio for such of them as have been analysed ranges from 0·67 to 1·42, while for the arkoses it ranges from 1·33 to 2·94, the average for nine analyses being 1·88. Part of the Na_2O in the arkoses occurs, of course, in fragments of andesite or andesite-tuff and as authigenic albite, but even so their Na_2O content could scarcely be accounted for by the granitic rocks unless they consisted predominantly of granodiorite.

Some proportion of the felspar in the arkoses came from the extensively eroded dacites and rhyodacites of Dromana (Baker, 1938), and the Dandenong Ranges (Richards, 1909; Morris, 1914). In the majority of these rocks oligoclase phenocrysts greatly outnumber orthoclase phenocrysts, sometimes to their complete exclusion, as in the hypersthene-dacites of the Dandenong Ranges, in which oligoclase phenocrysts constitute about 25 per cent. by volume of the rock. Whether a sufficient volume of oligoclase could have been obtained from the original outcrop of these rocks, and whether it could have been spread so uniformly through the wide extent of Jurassic sediments from these centralized sources is open to considerable doubt. The difficulty can be overcome only by assuming, as do Hunter and Ower (1914, p. 195), that closely similar rocks occurred in the requisite volume in association with the granitic rocks that are known to exist beneath the waters of Bass Strait. Quartz-felspar-porphyry, or rhyodacite, closely resembling the Victorian rhyodacites, occurs in the south-eastern part of King Island, in the vicinity of the Bismuth Products mine.

Some proportion of the oligoclase may have been drawn from the same source as the fragments of andesite or andesite-tuff that are so characteristic of the Jurassic arkose beds. The source of these fragments cannot be established with assurance, but the available evidence suggests that they come from flows of andesite, or beds of andesite-tuff associated with the Upper Devonian dacites. It was suggested earlier (Edwards, 1942) that they represented tuff fragments falling into the Jurassic lake, but it was not realized then how uniformly the fragments are dispersed throughout the arkoses. Moreover, there is no evidence of contemporaneous igneous activity in this part of Australia. The Mesozoic igneous activity which gave rise to the great dolerite intrusions in Tasmania did not, apparently, lead to the formation of extrusive rocks. These intrusions did not develop until at, or near, the close of the Trias-Jura sedimentation in Tasmania, and, in view of the undifferentiated nature of the dolerite magma at the time of its intrusion (Edwards 1942c), it is most unlikely that it could have given rise to andesitic tuffs or lava flows.

The probability is, therefore, that the andesite fragments were derived from extrusive rocks or tuff beds associated with the Upper Devonian dacite suites, and it is significant in this connection that they can be matched with practically identical andesite fragments in a thick bed of tuff recently discovered along the eastern margin of the hypersthene-dacites of the Dandenong Ranges. This tuff bed, which is as yet undescribed, dips steeply towards the south-west, and apparently underlies the hypersthene-dacite. The steep dip indicates that a considerable volume of it has been eroded. Fragments of this andesite are abundant in the Lower Dacite flows at the northern end of the Dandenong Ranges, and fragments of somewhat comparable andesite are numerous in the rhyodacites of the Black Spur district (Edwards, 1932), so that there is some reason for thinking that rocks of this type may have been as widespread as the other Upper Devonian extrusive rocks with which they are associated.

The markedly greater potash content of the Jurassic mudstones and shales, compared with that of the arkoses, cannot be attributed to selective destruction of the oligoclase and concentration of orthoclase in the residue with increased comminution of the felspar grains, because the analyses of the sized fractions of the arkoses show that this did not happen (Table 5). It is rather a reflection of the contribution made by the Palaeozoic sediments to the Jurassic lake. The Ordovician and Silurian sediments, which make up the great bulk of these rocks, consist of sandstones, mudstones, shales and slates, with very occasional beds of limestone and conglomerate. The material from the sandstones, being largely quartz, served chiefly as a diluent to the felspars from the igneous rocks. Material from the mudstones, shales and slates must, however, have joined the more finely comminuted material from the igneous rocks, and since the fine-grained Palaeozoic sediments are dominantly potassic (Howitt, 1923), it follows that the marked increase in the potash content of the Jurassic mudstones relative to that of the arkoses is a reflection of the differential distribution of the sedimentary source material. Whereas the arkoses reflect chiefly the igneous aspect of the Jurassic terrane, the mudstones reflect chiefly its sedimentary aspect.

It is probable that the Permian tillites and glacial sandstones also contributed material to the Jurassic lake, but, since these rocks do not differ greatly in essential constituents from the other Palaeozoic source rocks, the extent of their contribution cannot be estimated. That they did contribute is suggested, however, by the nature of the garnets in the Jurassic rocks. The smaller, colourless and pink garnets in the arkoses probably came from the Lower Palaeozoic sediments, since these carry such garnets (Langford, 1916). Many of the colourless and pink garnets in the arkoses are distinctly larger, however, than those in the

Ordovician and Silurian sandstones, and these must have been derived from the Palaeozoic igneous rocks (Edwards, 1936; Baker, 1942), or from the Permian sediments (Scott, 1937), in which similar coarse garnets occur. The brown garnets of the arkoses have been matched only in the Permian sediments, and in the igneous erratics that accompany them, in the Bacchus Marsh district, where they have been noted in heavy mineral mounts prepared by Scott, though not recorded by him. The other possibility is that such garnets were derived from the rocks from which the erratics were drawn.

Origin of the Arkose.

Owing to the readiness with which felspars decompose when exposed in humid climates, an abundance of more or less fresh felspar in a sedimentary rock is commonly taken as an indication that the sediment was formed under arid or glacial conditions, such as would inhibit chemical weathering of the felspar during the breakdown of the parent rock and during transportation (Mackie, 1899). It is recognized that arkoses can be formed under the conditions of moist and temperate climates, but such arkoses have been thought to be of secondary importance only. and to be characterized by partially decomposed felspars (Barton, 1916).

This view of the relationship of felspars to climate has been challenged, however (Reed, 1928). The proportion of felspars in the arkoses deposited throughout the Cainozoic period in California has been found to remain unchanged, despite the gradual change of the climate of that region from a humid subtropical climate during the Eocene to a sub-boreal, semi-arid climate in the Pliocene, so that the long continued deposition of arkoses was independent of the climate (Reed, 1933). The preservation of the felspars in arkoses formed under humid climates is attributed to rapid deposition of the felspathic sediment, so that the felspars in it are " sealed " from further decomposition (Hatch, 1938).

The Jurassic Climate.

Sussmilch (1941) has suggested that the climate of Eastern Australia during the Jurassic period was not greatly different from the present climate. The evidence in Victoria is somewhat scanty. Absence of any stratigraphical break in the Jurassic implies the continued existence of an extensive fresh-water lake or estuary throughout the period of sedimentation, and hence a rainfall adequate to maintain such a water body. The abundant presence of plant remains, whether they grew in the hinterland, or in swamps in the lake, is further evidence of a moist climate; and the combination of ferns and coniferous trees that make up the flora suggests a moderate rather than an extreme temperature.

The possibility that glacial conditions existed during the early stages of the Jurassic sedimentation has been suggested by Ferguson (1906) to account for a supposedly Jurassic glacial conglomerate near Toora, in South Gippsland, but this view has been discounted on the grounds that this inextensive conglomerate, and some others elsewhere in the Jurassic, may be re-sorted Permian glacial deposits (Kitson, 1917). The presence of floe-ice has been envisaged as the transporting agent of the sporadic foreign pebbles found in the arkoses and sometimes in the mudstones (Kitson, 1917); but floating vegetation may have been responsible for their carriage. Moreover, the presence of *Ceratodus* and of large *Unios* in the sediments points to warm rather than cold conditions.

The abundant flora and coal seams of the Upper Triassic of Tasmania (Nye and Blake, 1938) suggest that the climatic conditions during this period were not greatly different from those of the Jurassic. Somewhat drier conditions may have prevailed, however, during the preceding stage of the Triassic, since local deposits of rock salt and epsomite are found in the Ross Sandstone series of Tasmania.

There is little, therefore, to suggest that the climate was sufficiently arid, or sufficiently cold, to greatly inhibit the decomposition of the felspars in the Jurassic terrane; and this finds support from the state of the felspars themselves, since a proportion of them are cloudy from partial decomposition, even in the freshest rocks.

THE CONDITIONS OF DEPOSITION.

The prominence of current bedding in the arkoses, and, to a somewhat less extent in the mudstones, leaves little doubt that they were " formed in shallow water under the influence of strong and constantly changing currents " (Selwyn, 1866, p. 18). The boring records show that the current bedding is characteristic throughout the explored thickness of the Jurassic. This feature led Murray (1884, p. 84) to suggest that some of the arkoses might be of wind-blown origin, but the angularity of the mineral grains disposes of this possibility.

The depth of water fluctuated since the sediments were subject to contemporaneous erosion. The top-set portions of current bedded arkoses were sometimes truncated, and previously formed beds, particularly of mudstone, were eroded, with the formation of conglomerates in which the pebbles consist chiefly of Jurassic mudstone. Occasionally, these " contemporaneous " conglomerates were eroded in their turn. Even the coal was subject to erosion, since some of these conglomerates contain pebbles of coal. If the interpretation of some of the mudstone pellets as " mud curls " is correct, the bed of the lake must have been exposed from time to time in some parts. The occurrence of washouts in the coal seams at Wonthaggi also points to this, as do occasional current ripple marks found in the State Coal Mine.

The preservation of the mud pellets and pebbles in the "contemporaneous" conglomerates suggests that they were rapidly reburied; otherwise such soft, recently-formed material would have been worn down to its component grains. The rapid alternation of extremely thin beds of arkose with films of plant remains also points to rapid deposition, and so does the well-preserved appearance of delicate fern fronds in some of the mudstones. Again, in many pieces of silicified wood, the grain is often beautifully preserved, suggesting that the wood was quite undecomposed when buried. This seems the more probable since in one specimen from Jumbunna the wood appeared to have undergone partial decay before silicification (Kitson, 1917).

FRESH FELSPAR.

The angular nature of the mineral grains, and the fact that even in the arkoses the individual grains are considerably smaller than those found in the Palaeozoic granitic rocks, shows that the mineral grains have been fractured during transport. Such fracturing probably accounts for the presence of the abundant grains of fresh felspar. Chemical weathering of a felspar crystal extends from the surface inwards, so that if a large crystal is fractured, some of the fragments that result may consist of fresh felspar. These fragments will then begin to weather at the surface in their turn. This seems to be what has happened in the Jurassic arkoses. As the examination of the sized fractions of the arkoses showed, in each fraction the angular, and presumably freshly broken, grains of felspar were clear and limpid, while the sub-angular grains, which had undergone more prolonged transport since being fractured, were generally cloudy from decomposition. It would appear, therefore, that angular fragments of fresh felspar can occur in a sediment quite independently of the climate under which the sediment was formed.

The angularity of the grains also indicates that the sediments suffered relatively little wear during transportation, or alternatively that transportation was not prolonged. The relatively fresh state of preservation of biotite, which is regarded as one of the chemically less stable minerals (Twenhofel, 1932, p. 226), is a further indication that the sands did not undergo prolonged transportation, though in view of recent work on the stability of minerals such evidence must be treated with caution (Russell, 1939, p. 44).

Such evidence as can be obtained points then to relatively rapid deposition in shallow waters subject to current action. This, combined with the interleaving of mudstone with arkose, resulting from fluctuating depth of water, would provide the necessary conditions for the formation of a "sealed deposit" in which fresh felspars might be preserved.

DIAGENESIS.

The carbonate cement of the calcareous arkoses was clearly introduced after the deposition of the sediments; and since the interstratification of the arkose beds with mudstone must have "sealed" them from surface waters, it seems likely that the carbonates were deposited from the connate waters in the sediments. Presumably the carbon dioxide was obtained from the plant remains during their decomposition or carbonization, while the lime was largely derived from comminuted plagioclase, since the carbonate readily attacked the oligoclase. The pyrite nodules and veins may have had a somewhat similar origin, since pyrite and calcite occur together in the joints of the coal. The sulphur of the pyrite may have been set free as hydrogen sulphide during the decomposition of plant remains, in which pyrite is unusually abundant.

The chlorite cement, with its associated zoisite, epidote and (?) albite, was also formed, no doubt, after the deposition of the sands, from substances in solution in the connate waters. The ferromagnesian minerals in the arkoses generally show partial alteration to chlorite, but they are not as abundant as the chlorite cement. The felspars, on the other hand, are often fresh and angular, so that they have not undergone much alteration or solution *in situ*, except where attacked by calcite. It seems, therefore, that while some of the cementing material may have been derived from the minerals in the sands, a considerable proportion of it must have been introduced from the muds, the finest clay fraction of which has been shown to be rich in a chlorite-like substance. Presumably as the muds became increasingly compacted, the water in them migrated into the more persistent pore spaces of the sands, and there deposited material carried in solution.

The abundance of springs and seepages in the South Gippsland Highlands and in the Otways district indicates that on exposure the arkose beds serve as channel-ways for underground waters. The felspars in such beds are little affected by the passage of the water. Two reasons can be advanced to explain this. Firstly, the abundant chlorite in the rock is more susceptible to attack than the felspar, so that the chemical activity of the water may be neutralized before it greatly affects the felspars. Secondly, the oxidation of the chlorite by the surface waters tends to convert it into limonite, which will form a protective coating about the felspar grains. There is no change in the MgO content of the rocks during this alteration of the chlorite to limonite, so that presumably the MgO, with the SiO_2 and Al_2O_3 of the chlorite, enters into clay minerals.

Even in the soils formed on the Jurassic rocks the felspars persist in abundance, and many of the grains are in a relatively fresh condition (Nicholls, 1936). It was thought that the felspars in the soils might be protected from weathering by a film of iron oxide, the residue of the original chloritic cement, but this is not so, and it seems likely, as Nicholls (1936) concluded, that either the potash and soda felspars are more stable than is generally believed, or more probably, that the Jurassic soils are so immature as to be little more than crumbled rock—crumbled through decay of the cement—and that soil erosion is so rapid as to remove the soil before the felspars can decompose *in situ.*

THE JURASSIC TERRANE.

Any attempt to reconstruct the Jurassic terrane must take into account the prominent development of fresh-water felspathic sandstones, or arkoses, in the Upper Triassic of eastern Tasmania (Nye and Blake, 1938, pp. 45-49). These rocks closely resemble the Jurassic arkoses of Victoria, both in their mode of occurrence, association, and mineral composition. The similarity extends even to the presence in them of fragments of andesite-tuff such as characterize the Victorian rocks. It seems highly probable that both series of arkoses derived much of their material from the same general source, namely, a land-mass that is now sunk beneath Bass Strait. As the numerous granitic islands in the Strait indicate, this land-mass must have been largely composed of granitic rocks, with associated Palaeozoic and older sediments. There must also have been extensive areas of dacites and andesite-tuffs similar to those now outcropping in Victoria, and to a more limited extent in north-eastern Tasmania.

There has been some tendency to think that the two series of arkoses were formed simultaneously, despite the different character of their flora; but such an assumption is not justified, since both series of sediments were marginal to the same land area, and would reflect its composition equally, even though the basins in which they were deposited were formed at somewhat different times.

These basins apparently underwent slow, but continued, subsidence, because the sediments that filled them are of a shallow water character throughout. In Victoria, a subsidence of the ordet of 5,000 feet keeping pace with deposition is required. In Tasmania a similar, though earlier, subsidence of not less than 2,000 feet is required, since the total thickness of the arkoses and the associated Ross Sandstones and Upper Sandstones is of this order (Nye and Lewis, 1928; Nye and Blake, 1938).

The land occupying Bass Strait was probably mountainous. This is indicated by the mountainous nature of Wilson's Promontory, and the likelihood that many of the islands in the Strait are the tops of submerged mountains.

The limits of the Jurassic basin cannot be ascertained, but where its floor has been encountered around the margin of the present outcrops, it commonly slopes steeply, and appears to have considerable relief. At Griffith's Point, near San Remo, the Jurassic sediments are known to persist to more than 850 feet below sea-level, while a mile away the Cape Woolamai granite, which is apparently part of the same fault block (Edwards, 1942), rises to 300 feet above sea-level. This granite contributed much of the material in the Jurassic rocks now exposed at sea-level. Either the Eastern Passage separating the two formations marks the site of a pre-Tertiary Older Volcanic fault, or there is a fall of more than 1,150 feet in the floor of the Jurassic basin in a distance of 1 mile.

In the parish of Kongwak, an island of Silurian rocks outcrops at 420 feet above sea-level (Kitson, 1917), while a bore a mile to the north-west penetrated to about 600 feet below sea-level, without encountering the Silurian. Bores near Wonthaggi, and along the Powlett River, suggest that the Silurian outlier in Kongwak is part of a Silurian ridge trending south-westwards from this point. In these bores (Ann. Rept. Sec. Mines, 1917, Plate iv.), the Silurian occurs at depths ranging from 322 feet (Bore No. 681, Wonthaggi) to 1,311 feet (Bore No. 175, Wonthaggi), while other bores as deep as 2,633 feet (Bore No. 9, Powlett River) on either side of the ridge have failed to encounter the Silurian. The variable depths at which the Silurian occurs is due in part to faulting. Comparable inliers of Palaeozoic sediments occur at Turton's Creek (Ferguson, 1925) and at Boolarra (Ferguson, 1917) in South Gippsland.

South-west of Foster, the Palaeozoic sediments of the Hoddle Range rise to a height of 1,000 feet at Bald Hill, while their contact with the Jurassic rocks a mile to the north and north-west is at from 300 to 500 feet above sea-level. Near Lavers Hill the fall is 250 feet in a quarter of a mile.

On the northern margin of the Jurassic rocks in South Gippsland, the base of the Jurassic is about 450 feet above sea-level where it overlies the Silurian along Tyers River. A quarter of a mile to the north the Silurian rocks rise as high as 800 feet, and about 2 miles to the north they reach 1,000 feet above sea-level.

Along the Otway coast, at Apollo Bay, grits derived from a not far distant granite occur at sea-level, while bores at Wild Dog Creek, 2 miles away, penetrated more than 1,470 feet of

Jurassic sediments without encountering the underlying rocks. Faults may be present in the intervening country.

Elsewhere the floor of the basin may have sloped more gently. Thus, on Phillip Island, the Silurian lies beneath the Jurassic at a depth of 460 feet below sea-level at Rhyll, and of 306 feet at Cowes, 4 miles to the west, while on the other side of the island at Pyramid Rock, which is 5 miles south of Cowes, granite and Palaeozoic sediments rise about 50 feet above sea-level.

The Jurassic basin appears to have been a long narrow trough, not less than 350 miles, and probably more than 450 miles, long, with a width somewhat in excess of 50 miles. It had an uneven floor, which may have been as mountainous as its hinterlands. Deeper or quieter waters prevailed in the west where there is a greater development of mudstones, and along the central part of the basin. The floor of this basin subsided to a depth of about 5,000 feet, sufficiently slowly to maintain shallow water conditions throughout the whole period of deposition. In the early stages, a number of islands occurred in the lake or estuary, but as subsidence progressed these islands were buried by the accumulating sediments. The continued subsidence accounts for the steepness of shorelines like that between Griffith's Point and Cape Woolamai.

The waters of the basin were subject to strong and changing current action over most of its area—an unusual feature for a lake, though perhaps not for a shallow estuary. There seems, however, to be a complete absence of any gradation into marine beds, both in the Victorian Jurassic and in the Tasmanian Triassic. There is also a lack of current ripple-marks, though such ripple-marks were observed in the roof of the main roadway of the Shaft 18 area of the State Coal Mine.

Slow subsidence, and an adequate rainfall, combined to bring material to the basin in a fairly fine state of subdivision, chiefly as sands and muds. There is a surprising lack of marginal conglomerates, and of quartzose grits, but this may be due to inadequate exposure, and to erosion. In the Tasmanian Triassic a series of basal grits and conglomerates from 50 to 100 feet thick is recognized, but the only approach to this series in Victoria is the development of conglomerates between Tyer's River and Rintoul's Creek. The continued rejuvenation of streams feeding into the basin lead to rapid erosion of the hinterlands, and caused the felspars from the disintegrating igneous rocks to be carried into the waters of the basin before they had time to decompose greatly by weathering. Once in the lake they were rapidly sorted and dispersed by wave and current action, and were soon buried beneath later additions of sediment. From time to time, when subsidence temporarily failed to keep pace with sedimentation, they were subjected to local re-erosion and deposition by the lake waters.

Acknowledgments.

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ART. IX.—*Phenomenal Colonization of Diatoms in Aqueducts.*

By A. D. HARDY.

[Read 12th November, 1942; issued separately 1st October, 1943.]

Abstract.

An algal infestation of aqueducts of the Melbourne and Metropolitan Board of Works supply occurred in 1941 and has, seasonally, recurred between cleansing operations. The algae were chiefly diatoms. In one of the channels which was affected for many miles, the diatomaceous growth appeared on the cement walls as an oyster-coloured, felt-like stratum and comprised about a dozen species of which a few were dominant. In parts the felt was composed exclusively of the diatom *Gomphonema oxycephalum* Cleve. var. *subacuta*, var. n.

The cause of this phenomenal colonization in a hitherto unaffected, 12-year old aqueduct has not been satisfactorily determined, but it is suggested that much carbon and ash entered the highland streams during the forest fires of 1939 and, with the silica resulting from the subsequent erosion, afforded an abundance of shell building material for the diatoms.

In the Spring of 1940 the open channels of the Melbourne and Metropolitan Board of Works Water Supply became infested with an abnormal growth of algae of which, especially in one channel, the greater part was almost wholly diatomaceous. The walls of the channel became covered with a felted stratum for miles; and this was replaced by new growth after cleaning operations by the Board's officials, or the natural peeling from the cement. The daily clearance of accumulations of masses involved labour diverted from other urgent work and on that account the growth was objectionable, but, otherwise, little inconvenience was caused, and no discomfort was experienced by consumers.

As the channels of the several aqueducts affected were those below their respective storage reservoirs, excepting one instance to which reference will be made, and not the inlet channels, a brief description of the four reservoirs is given.

THE RESERVOIRS.

The water supply for the reticulation of Melbourne and suburbs is obtained from the forested southern slopes of the Dividing Range, where the average annual rainfall is between 50 and 60 inches. The reservoirs—Yan Yean, Maroondah, O'Shannassy, and Silvan—all receive water from tributaries of the Yarra River; but Yan Yean receives via Toorourrong reservoir a supplementary supply diverted from the north side of the range.

1. The Yan Yean system comprises (*a*) Yan Yean reservoir which has its local catchment on Silurian formation; (*b*) Toorourrong reservoir, which receives water directly from tributaries of the Plenty River; the catchment area being part granite and part Silurian; (*c*) the supplementary supply from the north side of Mt. Disappointment where tributaries of King Parrot Creek are tapped at Silver Creek weir, and Wallaby Creek dam. The water is then gravitated to a saddle in the range, and descends to Toorourrong by a series of cascades and the natural course of Jack's Creek. This diverted water is from granitic formation.

Yan Yean reservoir has a capacity of 6,250 million gallons and an altitude of about 600 feet. A monthly collection of algae from this reservoir by the author in 1905-6 has been described by G. S. West (1).

2. Maroondah reservoir has an altitude of approximately 460 feet and has a dacite catchment area of about 40,000 acres. Its storage capacity is approximately 6,274 million gallons.

3. O'Shannassy reservoir, with a capacity of 930 million gallons, is at an altitude of about 1,200 feet, and collects water from the watershed of the Ligar River (originally " Bellell "). The greater part of this 32,000 acres is dacite. At the southern (lower) end of the catchment there is a small area of Silurian rocks. The highest point of the watershed is Mt. Arnold (4,300 feet). A few miles below the dam the O'Shannassy water is supplemented by water conveyed along an open channel and a siphon from McVeigh's where the Upper Yarra catchment is a Silurian area. Unlike Yan Yean and Toorourrong, but resembling Maroondah, the O'Shannassy reservoir is bounded by steep slopes to the water's edge, and shows a comparative paucity of phytoplankton and an almost complete absence of littoral host plants for the harbourage of diatoms and other algae.

This water flows in open channels and siphons about 22 miles to Silvan reservoir, with the addition of some from Corranderrk Creek in the Maroondah area.

4. Silvan reservoir is held by a dam 2,100 feet long and 140 feet high at an altitude of about 800 feet in the Dandenong Range. The local catchment is a dacite area of about 1,200 acres. The reservoir stores from this, and the borrowed O'Shannassy and Maroondah quotas, some 8,800 million gallons. The highest part of the local watershed is less than 2,000 feet. From the north end of Silvan, where the inlet and outlet are only about ½ mile apart, the mixed water is conducted by open channel and siphon about 5 miles to the Olinda service reservoir, at altitude 670 feet, and thence by underground pipes to various reservoirs and the reticulation.

THE AQUEDUCTS.

With the exception of siphons, the Board's aqueducts are cement-faced channels, varying in cross-section both in shape and area, but a brief description of the O'Shannassy-Silvan-Olinda channel at a point above the Silvan Inlet will serve, as the variations are immaterial in the present connexion. The cemented walls slope up from a 9 feet wide bottom at an angle of 45°, providing for a water depth of about 4 feet and a freeboard of 9 inches as at full flow on one date of inspection; the flow being then at the rate of 3·1 feet per sec. The channel is provided with wooden gratings in which the openings are from about $\frac{1}{2}$ in.–1 in. wide, set at an angle of about 30° from the horizontal, for the arrest of twigs, leaves and other forest debris, at siphon entrances, &c. At the pipe-head reservoir a further arrest is made on copper screens, the wires of which are about ·5 mm. apart.

The rate of flow, mentioned above, was sufficient to float innumerable fugitive masses of the algal felt, usually below the surface, to the gratings, where the larger masses were held. Others passed through, and on to Silvan reservoir where some sank, a few were caught on twigs, &c., and the remainder, passing through the north end of this reservoir, entered the Silvan-Olinda section, where, with the exception of very small fragments, they accumulated 5 miles down on the wire screen. A few fragments passed into the reticulation and clogged the meters.

The quality of the water which passed over miles of the felt was unaffected. The exclusively diatomaceous material was odourless and tasteless, tough and "gritty" between the teeth. Even when a mass was crammed into a jar, with only sufficient water to cover it, there was no objectionable odour after weeks or even months of stagnation. If drained and enclosed in a partially air-tight vessel, however, the material became maladorous within 24 hours. Material with considerable inclusions of green algae soon putrified in similar confinement. When dried, this oyster-coloured diatomaceous felt lost about 85 per cent. of its weight and assumed a greyish-green colour (due to loss of the camouflaging diatomin revealing the chlorophyll).

THE ALGAE OF THE CHANNELS.

In all the channels there are normally, between times of cleaning operations and especially in spring and early summer, species of *Spirogyra*, *Zygnema*, *Mougeotia*, *Ulothrix*, and, but more noticeable in that of Maroondah than the others, *Oedogonium* spp. The Zygnemaceae have not been collected in fruiting condition, cleaning of the channels anticipating the spore formation. The bright green streamers in the current attain a length of 12 inches or more, usually in a zone with limits approximately 6 inches and 24 inches below the surface. These streamers of filamentous algae strain from the water many small chlorophytes, diatoms, flagellates, &c. Myxophytes also abound in places, appearing as dark-green velvet-like patches extending from about 9 inches below the surface to some inches above, the aerial parts being revivified by increased volume of water. In these masses small animals find shelter: *Nais*, *Anguillula*, Rotifers, and Entomostraca. The rich microflora of the Yan Yean is represented in its channel by inclusion of some of its permanent constituents, including at times plankton species which are not, or rarely, in the phytoplankton of Maroondah, O'Shannassy or Silvan.

PREVIOUS ABNORMAL INCREASES OF ALGAE.

The first superabundance of any species was that of an unknown desmid, about 40 years ago. This plant (*Micrasterias hardyi,* G. S. West) remained in excess during some weeks, then slowly diminished, and, though permanently in the plankton, has not abnormally increased since.

In 1929, soon after the infestation of the Hume reservoir on the Murray River, by *Anaboena circinalis* Rabenh., the same species appeared in the Yan Yean, and so rapidly increased that the surface water appeared pea-green, and depth samples showed a vertical distribution. After some weeks' duration, its departure was hastened by chemical treatment, following which, however, a diatom, *Melosira granulata* Ralfs, became superabundant and, after the precipitation of the Anaboena, remained for some weeks, prolonging the turbidity of the water with a milky cloudiness. This diatom diminished in numbers, but, before it became normal, another diatom, *Rhizosolenia morsa* W. and G. S. West, supervened. This species further prolonged the turbidity during some weeks and then slowly diminished. These two diatoms, though permanent constituents of the Yan Yean plankton, have rarely appeared in the channel and then only as a few scattered individuals in an abundance of other algae. That the channel was not troubled with these during their abnormal increase in the reservoir was at least partly due to the Board regulating the flow from the variable inlet valves of the outlet tower at an early date, and reserving the water during the peak period of increase.

In Maroondah in 1928, two diatoms, *Cyclotella Meneghiniana* Kütz and *C. stelligera* Cleve and Grun, increased to such an extent that chemical treatment was contemplated, but the growth naturally diminished. The only other abnormal development of algae in this reservoir was the over-production of a desmid —*Staurastrum paradoxum* Meyen, var. *longpipes,* Nordst. This was subdued with an algicide.

In the O'Shannassy there has been from its early years a disproportion of animal forms up to the appearance of crustacea and a few chlorophytes in recent years. The protozoa *Lacinularia elliptica* and *Stentor igneus* increased to the extent of macroscopic visibility, the former like innumerable sago grains, the latter like myriads of poppy seeds, and caused turbidity in the normally crystal-clear water, but with no ill effect. Diatoms were very rare in the plankton.

At no time has there been an increase of diatoms in this reservoir or its channel until the occurrence under notice. The diatoms of the channel have been chiefly those of the Ligar River, at the inlet. In Silvan reservoir, also, where there is a meagre phytoplankton, no abnormal increase of diatoms or other algae has been observed, the only untoward occurrence in its history being a plague of entomostraca (chiefly Cladocera) and a recent marginal growth of *Potamogeton ochreatus* Raoul, which attained a height of over 20 feet, in dense formation, but too recently to be a suitable home for epiphytic diatoms.

THE INFESTATION OF THE O'SHANNASSY CHANNEL.

The felting of the sloping walls of the O'Shannassy-Silvan-Olinda aqueduct channel was extensive and almost continuous from the lower terminus to at least the Cement Creek crossing (where arrested accumulations were removed by the barrow load) and beyond, in diminishing quantity, but not beyond the Upper Yarra siphon which introduces water from the Silurian, a circumstance which at first seemed significant. But the felt also occurred sparsely in the Maroondah channel, in water from an exclusively dacite area.

The O'Shannassy felt is distinguished from that of the Maroondah by the predominating and, in parts, exclusive presence of a new variety of the diatom *Gomphonema oxycephalum* Cleve (8), which morphologically and in habit resembles *G. intricatum* Kütz.

SUGGESTION AS TO CAUSE OF THE COLONIZATION.

The foregoing description of the watersheds and channels does not indicate any topographical or geological factor as a cause of the origin of this phenomenal colonization. The only unusual meteorological occurrence which might have significance was the terrific heat wave, in the summer of 1938-9, during which temperatures in Victoria rose to 117° F., in the shade, and led to the devastating forest fires in that January. Much ash and carbon entered the forest streams, and later, during 1939-40, the soil erosion which followed the destruction of the foliage in many areas must have added a superabundance of silica to the water in those regions and so provided ample material for the construction of diatom frustules, which, according to one analysis (2) of diatomite, amount to 40,000,000 to a cubic inch, and, to another, approx. 80 per cent. silica (3). This explanation would apply to all the channels, but does not account for the predominance in one channel of a species of *Gomphonema* which is found sparsely in the sources of all; nor the adoption of the cemented walls as a substratum. However, William Smith (1857) (3) records for *Gomphonema intricatum* Kütz "forming a velvet-like stratum on the surface of a chalk cliff . . . Sussex, August, 1890."

During a peak period a 24 hours' accumulation at the lowest screen was found to weigh approximately 2,000 pounds or 300 dry weight (avoir.). This did not include much which was removed from local screens and gratings at several points higher up; e.g., two barrow loads were removed from the highest, at the Cement Creek crossing. Thus the transportation by stream flow amounted to many tons wet weight in a season; a fresh felt forming after the natural peeling or artificial removal of the old stratum.

In the foregoing account two methods of diatomite formation are suggested—(1) The generally recognized deposition of diatoms *in situ*, in calm or nearly calm water, as indicated by the sedimentation by *Melosira granulata* and *Rhizosolenia morsa* after abnormal increase in the Yan Yean reservoir; (2) the *ex situ* deposition after transportation over considerable distances varying with stream flow, and limited only by obstacles encountered. In the latter case unimpeded fragments might reach the sea and with the disintegration of the gelatinous matrix free the frustules of the dead diatoms to be carried further afield and appear in an apparently remote marine habitat. Rare specimens of fresh water species recorded for South Polar region (4) might thus be accounted for.

But because the extensive colonization described did not occur in the natural water courses, for lack of suitable substratum or other cause, the occurrence in the channels may be attributable to the artificial conditions. If so, it seems significant that in addition to an abundant food supply, the silica resulting from the bush fires and silt from post-fire erosion combined with the alkaline ingredient contained in the channel cement provided the necessary material for diatom-shell construction.

It is noteworthy that while the filamentous chlorophytes retained their accustomed hold on the other channels, where the diatoms while prolific were not dominant, the amount of green algae in the O'Shannassy channel was for the greater part negligible. At the same time metropolitan horse-troughs which, when constructed with iron accommodated green algae, have been devoid of algae excepting a thin film comprising a few species and diatoms, since the construction has been of concrete and cement.

NOTES ON SOME OF THE SPECIES.

Gomphonema oxycephalum, Cleve, var. *subacuta*, n. var. The type, described and figured by Cleve (8) has the upper part of the valve within an angle, which measures 25°. In the variety the margins of the upper part of the valve are often slightly concave and there is occasionally a slight constriction at the subacute apex. The proportions of length and breadth also vary considerably, e.g., 34 μ by 6 μ and 24 μ by 5 μ. The striae are more coarsely beaded; the hyaline space varies from narrow lanceolar to almost linear. The single stigma when present is not conspicuous. In general appearance the valve resembles *G. intricatum*, Kütz. In girdle view the new valves diverge about 10°.

Melosira granulata, Ralfs. This species is a constituent of the Yan Yean plankton, and has not been collected from O'Shannassy or Maroondah. It is normally rare in the Yan Yean channel and very rare in the felt. It increased abnormally in the Yan Yean in 1929. It is the sole species in some diatomites, viz., near Fraser Lake, Vancouver Id. B.C. (5), and Coonabarabran, New South Wales (6); it closely resembles, if not identical with, "*Melosira granulata*, Ehrenb." referred to by Card and Dun (6) as occurring in some Victorian diatomites. It is the almost exclusive species in some Canadian diatomites (5).

Hantzschia amphioxys (Ehrenb.) Grun. is in the highland streams and many lakes and pools in Victoria, and all the reservoirs and channels. It formed about the thousandth part (numerically) of the " Red Rain " (7) dust particles, from Central Australia, collected by me from the snow at Mt. Buffalo Chalet (4,500 feet) on July, 1935. By rough estimate about 30 lb. of the frustules of this species fell into the Yan Yean reservoir, after a dust storm of similar nature, in December, 1938. Empty frustules of any species occurring rarely in the channels without accompanying living representatives are therefore not listed (cf. 4).

Synedra ulna (Nitzch) Ehrenb., *S. radians*, G. S. West, *Tabellaria flocculosa* (Roth.) Kütz., *Eunotia crispula*, G. S. West, *Navicula viridis*, Kütz., *N. radiosa*, Kütz., *N. amphisboena* Bory., *N. bicapitata*, Lagerst., var., *Cocconeis placentula*, Ehrenb., *Cyclotella Meneghiniana*, Kütz., *C. stelligera*, Cleve and Grun., and *Cocconema gracile*, Ehrenb. were the most numerous species in the " mixed " parts of the felt.

Acknowledgment.

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Art. X.—*Eocene Deposits South-east of Princetown, Victoria.*

BY GEORGE BAKER, M.Sc.

[Read 10th December, 1942; issued separately 1st October, 1943.]

Abstract.

Deposits of Eocene age are described from the Pebble Point district, south-east of Princetown, on the south coast of Western Victoria. The fossiliferous "Pebble Point Beds" have been established as of Eocene age from the evidence set out in the two following articles by Singleton and Teichert respectively. The Older Tertiary sediments overlying the Eocene Pebble Point Beds, are tentatively referred to the Eocene, pending the outcome of further fossil investigations. The relationship between the Jurassic rocks of this district and the Eocene rocks is described, and reference is made to Miocene beds appearing in coastal sections six miles north-west of the Eocene deposits.

Introduction.

This paper deals with the occurrence, nature, and stratigraphical relationships of Lower Tertiary deposits exposed in coastal cliff sections between Pebble Point and the mouth of the Gellibrand River, in the parish of Latrobe, counties of Heytesbury and Polwarth (fig. 1). The basal beds of the series, consisting of ferruginous sediments, called the Pebble Point Beds, are assigned an Eocene age from independent fossil determinations made by Dr. F. A. Singleton (10), of Melbourne University, and by Dr. C. Teichert (11), of the University of Western Australia, on material collected by the author in January, 1942. Beds of clay and sandstone overlying the Pebble Point Beds, are probably also of Eocene age, but this has not as yet been conclusively established.

Pebble Point, which has a N.-S. trend, is 2½ miles south-east of the mouth of the Gellibrand River, and approximately 3¼ miles south-east of the township of Princetown, which is situated on the south coast of Western Victoria. It is made conspicuous among a number of small headlands having similar appearances by the presence of a marked storm-wave platform cut in the Eocene rocks about 25 feet above low-tide level. Adjacent headlands have wave-cut platforms in Jurassic rocks. Pebbles of jasper, flint, rhyolite, quartzite, and agate occur on the storm-wave platform at Pebble Point, and a prominent beach sand-ridge occurs in the bay immediately to the south-east. In the Pebble Point district, the Eocene deposits rest upon eroded Jurassic rocks (Pl. X., figs. 1 and 2) on the south-western flanks of the main Jurassic area in the Otway Ranges. They extend eastwards from Pebble

Point at heights in steep cliffs which are principally beyond reach, but in a north-westerly direction, the series dips gently at 5° seawards, so that from Pebble Point to within a quarter of a mile south-east of the mouth of the Gellibrand River, occasional access can be gained to several exposures of the Lower Tertiary deposits; many parts, however, are masked by cliff débris. The approximate thickness of the Lower Tertiary series between Pebble Point and the Gellibrand River mouth is given by Wilkinson (12) as 250 feet, and of this amount, the Pebble Point Beds of Eocene age total about 50 feet. Wilkinson's value was obtained by totalling the thicknesses of the strata at three different and relatively widely spaced cliff sections; a series of beds dipping at 5° and outcropping over a distance of some 2 miles, however, would have a total thickness of over 1,000 feet.

The general geology of the Princetown area is indicated on the accompanying map, which is based upon State parish plans in the southern portion of the counties of Heytesbury and Polwarth. Few surface exposures of the Jurassic rocks occur in the area embraced by the map, and then only in cliff faces and on wave-cut platforms at headlands. They are insufficiently extensive to appear on the map (fig. 1). Coastal exposures of the Tertiary rocks are

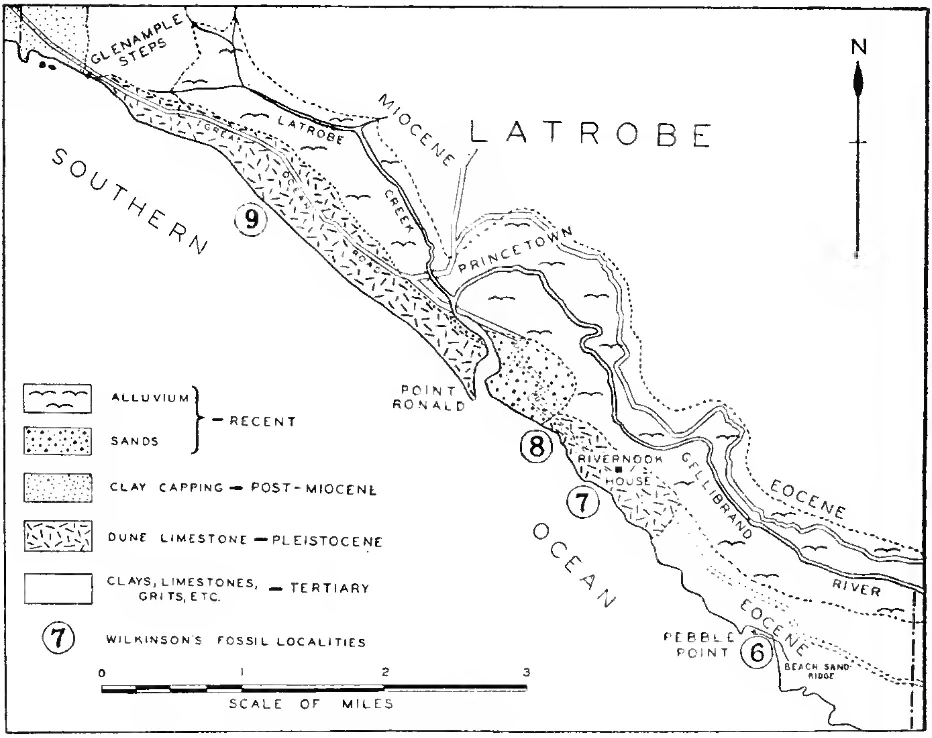

Fig. 1.—Geological map of coastline in the neighbourhood of Princetown.

principally absent from the plan, because of masking by covers of Recent sand dunes, Post-Miocene clays, and Pleistocene dune limestone.

PREVIOUS WORK.

The difficulty of access to the area and the rugged character of this little frequented portion of the Victorian coastline, are probably the principal reasons why the Pebble Point Beds and overlying deposits have received little detailed attention in the field.

The deposits were first placed on record by Wilkinson in his survey of the Cape Otway country in 1865 (12). Fossils collected during this survey, marked as coming from No. 6 locality by Wilkinson (i.e. — the Pebble Point coastal section), were subsequently determined as Nautilus, Cytheraea, and Cucullaea, and the deposits were classed in the field by Wilkinson as Miocene (12). So far, the author has been unable to locate the repository of the fossil material brought back by Wilkinson from this locality. Wilkinson's results were re-stated by Duncan in 1870 (5), in his examination of the fossil corals from Wilkinson's No. 7 locality (see fig. 1), and again by Murray in 1877 (8).

In their catalogue of described fossil species from the Cainozoic rocks of south-eastern Australia in 1903, Dennant and Kitson listed two species of *Trochocyathus* (4), *Flabellum candeanum* Edwards and Haime (4, p. 132), *Natica hamiltonensis* T. Woods (4, p. 113), *Volutilithes antiscalaris* McCoy (4, p. 100), *Vaginella eligmostoma* Tate (4, p. 94), and *Panopaea orbita* Hutton (4, p. 126) from a locality "Rivernook." This locality is marked on the State parish plan of Wangerrip as a small township a short distance inland from the coastal sections in which the Eocene rocks are exposed. The above fossil names appear in Dennant and Kitson's lists in a group classed by them as of Eocene—Oligocene age, this group also containing suites of fossils typical of Balcombian rocks.

Duncan had previously described and illustrated the fossil corals collected by Wilkinson from No. 7 locality as *Trochocyathus victoriae* (5, Pl. XIX., fig. 3) and *Trochocyathus meridionalis* (5, Pl. XIX., fig 2), while a form with a thin corallum from the same beds was described as *Cycloseris tenuis* (5, p. 301, and Pl. XX., fig. 8), and it was stated by Duncan that thin species of the Cycloserides group of corals are found in the Nummulitic beds of Southern France (5). *Cycloseris tenuis* Duncan (7, p. 362) and *Trochocyathus meridionalis* Duncan (7, p. 431), have so far only been recorded from the Older Tertiary beds south-east of the mouth of the Gellibrand River. Species of Cycloseris are regarded as primitive forms of the genus Fungia, so that *Cycloseris tenuis* is now classed as a sub-genus of Fungia, and becomes *Fungia* (*Cycloseris*) *tenuis* Duncan sp. Species of Cycloseris are most common in Upper Cretaceous and Eocene rocks (7, p. 486).

In 1904, Dennant described *Flabellum microscriptum* sp. nov. from Wilkinson's No. 7 locality, stating that it is apparently restricted to this locality and is accompanied by *Trochocyathus victoriae, T. wilkinsoni, T. meridionalis,* and a few species of mollusca, several of which are new and peculiar to the section (3, p. 53).

In the same year, deposits referred to by Chapman as " Black beds from east of the Gellibrand River " and from which shark's teeth were described, were classed as of Balcombian (Barwonian) age by Chapman (1, p. 277), i.e., as Oligocene according to the then current ideas of the age of the Victorian Tertiary deposits. The locality from which the shark's teeth were recorded, is given as A.W.7, i.e., Wilkinson's No. 7 fossil locality. The author has so far been unable to find shark's teeth in the " Black Beds " at this locality, but numerous examples occur in a sandstone band intercalated among the dark-coloured clay deposits at No. 7 locality. The forms identified by Chapman are *Odontaspis cuspidata* Agassiz sp. (1, p. 276), a form stated to occur in the Eocene and Miocene rocks of Europe and North America, and to have a time range from Upper Cretaceous to Miocene (1, p. 290). Another form, *Oxyrhina minuta* Agassiz (1, p. 283), is said to occur in the Oligocene of New Zealand. This was subsequently described as *Isurus minutus* Agassiz sp. by Chapman (2, p. 131), because of pre-occupation of the generic name Oxyrhina by another organism.

In 1923, Pritchard stated that the coarse grits with abundant broken and imperfect fossils east of the Gellibrand River, represented a shallow water phase of the lower horizon of the Janjukian (regarded then as of Eocene age by Pritchard), and that the predominating feature of the deposits was the mixed fauna of a strong littoral type (9, p. 935).

The Eocene age of the Pebble Point Beds (i.e., at Wilkinson's No. 6 locality), has been established by the contemporaneous recognition of the nautiloids *Aturoidea distans* Teichert sp. and *Nautilus victoriana* Teichert sp. (11) and the pelecypod Lahillia (10). It is noted that Aturoidea may even be of Upper Cretaceous age (11).

Mr. W. J. Parr and Dr. M. F. Glaessner have examined the matrix in which the Eocene mollusca were found, and also the clay beds overlying them, for foraminifera. No foraminifera were found in the clay beds, but the foraminiferal content of the Pebble Point Beds is listed in the accompanying appendix.

Occurrence, Nature, and Stratigraphical Relationships.

The bed from which the Eocene molluscs were collected is accessible in cliff sections at a point half a mile north-west of Pebble Point, at heights of some 40 to 50 feet above sea level, in a ferruginous series called the Pebble Point Beds, which are approximately 50 feet thick, and dip in a westerly direction. The contained fossils so far recognized are foraminifera, Aturoidea, Nautilus, Lahillia, Cucullaea, Nuculana, Limopsis, Eotrigonia, Dentalium, Natica, Turritella, a trochoid gasteropod, a small form of coral, large and minute fish teeth, claws of Callianassa, fish vertebrae, otoliths, whalebone fragments, and occasional fragments of fossil wood; the shelly fossils are often much broken and worn, and are embedded in a matrix of heavy grit with a ferruginous and argillaceous cement. The fossiliferous grit band overlies some 30 to 40 feet of shallow water, friable, sandy ironstones which form the base of the Eocene at this locality, and which so far have proved barren of determinable fossils, although rare, shell-like fragments can be detected.

The basal Eocene beds rest upon an erosion surface of arkoses (6) and occasional grits and mudstones of Jurassic age (Pl. X., figs. 1 and 2). Occasional grit bands, narrow veins and thicker bands of massive ironstone (limonite), occur in the Eocene sandy ironstones below the fossiliferous grit band, while narrow bands of copiapite-bearing clays and thicker bands of massive ironstone occur interstratified with the upper layers of the ferruginous beds.

Overlying the Pebble Point Beds occurs a deeper water sedimentary facies composed of dark-coloured, carbonaceous clays, which in parts contain abundant copiapite (basic iron sulphate) and structures resembling algal remains. The westerly dip of the series brings these clays down to sea level north-west of Pebble Point, and their thickness, as determined from a traverse along the coastal sections in the general direction of dip, is approximately 800 feet. Three bands of sandstone are interbedded in the carbonaceous clays, and are indicated in the coastal section (fig. 2). The nearest sandstone bed to Pebble Point, marked as "hard ferruginous sandstone" is partly ferruginous and possesses in parts rounded structures which have been produced by weathering. When broken open, some of these structures are found to be similar to "boxstones" in containing occasional casts and moulds of echinoids (Schizaster sp. indet.) and pelecypods, but the fossils are original to the deposit, and are not remanié as in true boxstones.

A second sandstone bed further to the north-west, contains numerous examples of a small form of Turritella, with corals, volutes, and Natica, while a short distance from this bed a third sandstone band 4-5 feet thick, contains abundant corals and shark's teeth, and occasional specimens of Voluta and Dentalium. This bed is marked in fig. 2 as the "Trochocyathus-Odontaspis" band, and the locality corresponds to Wilkinson's No. 7 locality. Between, above, and below these bands of sandstone, the carbonaceous clays appear at intervals in the coastal sections, but in many places they are masked by recent talus cones built up by landslides and large fallen blocks of rock. In parts, the clays are pale yellow and grayish in colour from weathering, but when wet, the darker coloured portions are intensely black. Occasional polyzoal remains occur in clays above the Trochocyathus-Odontaspis bed, while cross sections of echinoid spines appear in a microscope section of pyritic portions of the clay from a locality about 1½ miles north-west of Pebble Point. Portions of the clay beds are distinctly shale-like and somewhat of a bituminous character, especially above the Trochocyathus-Odontaspis bed, where crystals of gypsum and abundant pale yellow, earthy copiapite are also prominent. This carbonaceous shale is overlain by 35 feet of unfossiliferous, friable, red and yellow ferruginous sandstones which show chemical banding and contain occasional hard bands of limonite. These beds are followed by 25 feet of dark-gray clay with structures and markings resembling algal remains. The outcrops in the cliff sections at this locality, correspond in position with Wilkinson's No. 8 locality, which is about half a mile south-east of the mouth of the Gellibrand River. The beds here dip at 5° in a direction a few degrees north of west. They are overlain by sandy clays and ironstone, 8 to 10 feet of black clay, followed by further sandy clays and ironstone, which all dip north of west at 4°.

The Older Tertiary beds at the north-west end of this traverse, cease abruptly against Pleistocene dune limestone deposits a quarter to half a mile south-east of the Gellibrand River mouth. From here to the Gellibrand River, the coastal district consists of Recent dune sands (fig. 1). Two and a half to three miles north-west of the Gellibrand River mouth, clays containing a typical Balcombian (= Miocene) fauna, appear in the coastal sections, at a position corresponding with Wilkinson's No. 9 locality (fig. 1). These beds dip westerly at 5°, but the dip values diminish in amount in a westerly direction; they are stratigraphically several hundred feet above the Pebble Point Beds.

There is a considerable gap in exposures of the Tertiary rocks in the central portion of the traverse line along the dip of the Tertiary beds in the Princetown district, because the Pliocene ancestor of the Gellibrand River had carved out a valley some 4 to 5 miles wide and over 300 feet deep in the Older Tertiary deposits. This valley was subsequently infilled in successive stages with Pleistocene dune limestone, through which the present Gellibrand River has cut its course. As a consequence, no exposures of Tertiary sediments are present for a half to three-quarters of a mile between the Eocene beds south-east of the Gellibrand River; and the Miocene beds north-west of this river mouth. Difficulty of access to portions of the coastline north-west of the river mouth and the masking of the Tertiary rocks in most places by extensive talus cones containing large fallen blocks of Pleistocene dune limestone, are also partly responsible for the lack of detailed information concerning the beds intervening between Point Ronald and the Gellibrand Clays of Miocene age south-east of Glenample Steps (fig. 1).

The traverse along the coastal cliffs from Pebble Point to the mouth of the Gellibrand River, however, has yielded more favorable results, because the Older Tertiary rocks dipping in a general westerly direction, outcrop frequently over a distance of some 2 miles. The relationships of the various members of this series, as far as can at present be ascertained, are diagrammatically represented in fig. 2. East of the area embraced by the sketch geological section, the Eocene beds can be seen in parts at heights of 50 feet or more in high, steep cliffs, where they appear to be more or less horizontal; they have been traced out beyond Pebble Point, as far east as Moonlight Head. The Eocene also appears in road cuttings along the Great Ocean-road, on the northern side of the Gellibrand River, north-east of Rivernook House.

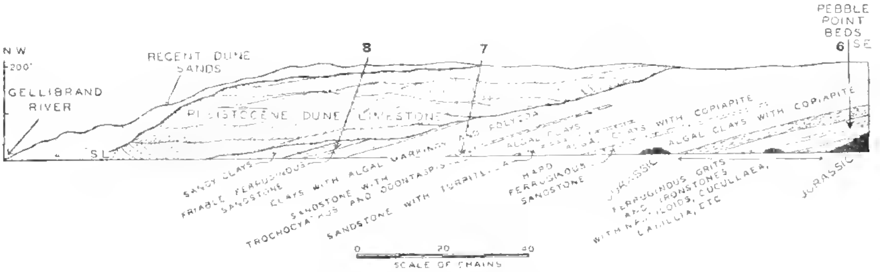

FIG. 2.—Geological sketch section along the coastal cliffs from the mouth of the Gellibrand River to Pebble Point. Dips of beds are exaggerated; the length of the section covers a distance of 2½ miles, and the maximum height of the cliffs is about 200 feet. Numbers above the section refer to Wilkinson's localities.

Eocene-Jurassic Relationships.

The unconformable junction between the basal beds of the Eocene and the eroded surface of the Jurassic sediments is sharply defined and relatively even in character in the cliff sections near Pebble Point. The surface of unconformity slopes down to sea-level $\frac{3}{4}$ mile north-west of Pebble Point, and becomes hidden by Recent beach sands, but a Jurassic outcrop of limited extent appears in the coastal sections beneath Lower Tertiary clays, a short distance further to the north-west, thus indicating occasional undulations in the Jurassic sediments forming the floor of the Eocene sea. South-east of Pebble Point, the surface of unconformity rises to considerable heights in steep cliffs, and continues easterly for 4 miles to the Gable and Moonlight Head, in the parish of Wangerrip, where it has a more or less horizontal disposition.

The Eocene beds, which are conformable with one another, show slight amounts of transgressive overlap north-west of Pebble Point. Sandy ironstones, grit bands and narrow bands of massive ironstone (limonite) dipping westerly at 5° overstep one another on to the erosion surface in the Jurassic sediments, a surface which slopes at 10° in a westerly direction. On account of this overlap, it is reasonable to assume that still older members of the Eocene series may be hidden below sea level west and north-west of the Pebble Point Beds. Boring operations will be required, however, to establish this point.

On the seaward end of a wave-cut platform, which is 140 yards wide at the third point north-west of Pebble Point, massive blocks of Eocene ironstone, composed principally of limonite, rest upon the Jurassic sediments. Their disposition suggests that they have been lowered several feet on to the Jurassic platform, by the removal from below them of the more readily eroded Eocene sandy ironstones.

Occasional narrow cracks, an inch or so wide and 6 or 7 feet deep in the Jurassic rocks, have been infilled with material the same as that comprising the basal Eocene beds. Rounded pebbles of reef quartz are conspicuous in the matrix occupying these cracks.

Age and Thickness of the Tertiary Deposits.

Of the dipping Lower Tertiary beds exposed south-east of Princetown and extending beyond Pebble Point, only the Pebble Point Beds of grits and ironstones can at present be assigned an Eocene age with any degree of certainty. Approximately 50 feet of these deposits are exposed above the surface of unconformity with Jurassic sediments, but for reasons given earlier, this fossiliferous, ferruginous series of Older Tertiary beds may have a greater thickness than is evident at the surface.

The conclusion that the deposits are of Eocene age is based upon Teichert's (11) and Singleton's (10) fossil determinations in the group of the mollusca, and is supported by evidence from the foraminiferal content (see appended list). The thickness of the sediments overlying Pebble Point Beds and terminating against dune limestone ½ mile south-east of the mouth of the Gellibrand River has been calculated graphically at about 1,000 feet. This value is obtained from the fact that beds dipping at 5° outcrop for some 2 miles; the effects of folding and faulting have been neglected from the calculation because there is no field evidence of such earth movements in the immediate locality.

Little conclusive evidence is at present available concerning the precise age of the deposits overlying the Pebble Point Beds north-west of Pebble Point In view of Duncan's description of the coral with a thin corallum. determined as *Cycloseris tenuis*, but now classed as *Fungia* (*Cycloseris*) *tenuis* (7, p. 362), and his record of abundant thin forms of the Cycloserides group in the Eocene sediments of Southern France, it is probable that the Tertiary deposits between the Pebble Point Beds and the Pleistocene dune limestone may also be of Eocene age. Other fossil forms like Odontaspis, Isurus, Trochocyathus, Turritella, and Schizaster, collected from the various members of this series, are types which elsewhere have a time range which includes the Eocene period, although they are not necessarily characteristic of that age, *Trochocyathus victoriae* Duncan sp., for instance, occurring Recent in Port Jackson and Port Stephens, New South Wales (7, p. 436), as well as in the Older Tertiary deposits above the Eocene beds of Pebble Point.

The fixation of the upper limit of these Eocene beds must, therefore, remain in abeyance until further evidence is forthcoming from investigations of the fossil content of the beds above the Pebble Point Eocene beds. From the field evidence, the author is inclined to the belief that all of the beds south-east of the mouth of the Gellibrand River are of Eocene age. This inclination is based upon the lithological and mineralogical similarities of those carbonaceous clays which are intercalated with the upper layers of the ferruginous Pebble Point Eocene beds, and those which occur at intervals up to 2 miles north-west of Pebble Point. There are also mineralogical similarities (see Table I) between the Eocene grit bands and the three sandstone bands containing Schizaster, Turritella, and Trochocyathus-Odontaspis, respectively (fig. 2). In addition to this, there seems to be no doubt in the field that all of the beds south-east of Princetown are conformable with one another. The Turritella band also contains a few gasteropods comparable with ones in the Pebble Point Beds.

The changes in the lithological character of the sediments from south-east to north-west, indicate a deepening of the Lower Tertiary sea in a general east to west direction, the littoral facies of undoubted Eocene age at Pebble Point, giving way in the north-west to clays containing occasional interbedded sandstones. Three miles north-west of Point Ronald, clays of Miocene age, with a typical Balcombian faunal assemblage and with similar dips to the Eocene deposits some 6 miles to the south-east, pass upwards, with diminishing dips, into Miocene limestones, calcareous clays and marls. These are more or less horizontal in the vicinity of Glenample Steps (see map, fig. 1) and extend westerly for many miles through Port Campbell, Peterborough, and Warrnambool.

Post-Miocene clays and Recent sand dunes overlie the Miocene limestones, while Pleistocene dune limestones rest unconformably upon the eroded surfaces of many members of the Lower Tertiary strata.

Lithology and Mineralogy.

The mineral species represented in the various lithological types of the Lower Tertiary series south-east of Princetown, are listed in Table 1. Those from the Jurassic sediments of the immediate neighbourhood have been added for purposes of comparison.

JURASSIC.

The Jurassic arkose near Pebble Point is calcareous (42 per cent. acid soluble), and contains a small amount (6 per cent.) of clay constituents. The sandy fraction of the arkose is composed principally of angular quartz, with some orthoclase and oligoclase, while there are also numerous sub-angular to rounded rock fragments of microscopic size, determined as andesite, muscovite schist, chlorite schist, sandstone, quartzite, mudstone, and hornfels (6) ; these rock fragments and the quartz grains are all of remarkably even grade size. Plates of fresh biotite, muscovite, green and reddish-brown hornblende, chlorite, colourless, pink and brown garnet, epidote, sphene, leucoxene, hematite, tremolite, zoisite, staurolite, and apatite, are also represented in addition to the minerals listed in Table 1. Thin sections of the arkose reveal abundant calcite acting as the cementing medium and forming rims to most of the small rock fragments and mineral grains. In this feature and in several other respects, the rock resembles some examples of the Jurassic arkose from the Gippsland bores, e.g., one from a depth of 1,163 feet in bore No. 4, at Boolarra.

TABLE 1.

		Rock.	Locality.	Calcareous Matter.	Rounded Quartz.	Angular Quartz.	Felspar.	Mica.	Glauconite.	Collophane.	Gypsum.	Iron Ores.	Limonite.	Pyrite.	Tourmaline.	Zircon.	Rutile.
Lower Tertiary.	1	Ferruginous Sandstone overlying 2	½ mile south-east of Point Ronald	−	+	(+)	+	+	−	−	−	+	+	−	+	+	+
	2	Carbonaceous Shale with Copiapite	½ mile south-east of Point Ronald	tr.	(+)	+	+	+	−	+	+	−	−	+	+	+	−
	3	Sandstone with Trochocyathus and Odontaspis	1 mile south-east of Point Ronald	+	+	(+)	+	+	+	+	−	+	+	+	−	+	+
	4	Sandstone with Turritella	1¼ miles south-east of Point Ronald	+	−	+	+	+	−	−	−	+	+	−	+	+	−
	5	Pyritic Clay . .	1½ miles south-east of Point Ronald	+	−	+	−	+	+	+	+	−	−	+	−	−	−
	6	Sandstone with "Boxstones"	1¾ miles south-east of Point Ronald	+	+	(+)	+	+	+	−	−	+	+	+	+	+	−
	7	Gritty Sandy Ironstone	¾ mile north-west of Pebble Point	+	(+)	+	+	+	+	+	−	+	+	+	+	+	−
Mesozoic.	8	Jurassic Calcareous Arkose	¾ mile north-west of Pebble Point	+	+	(+)	+	+	−	−	−	+	+	+	+	+	+

(+) Most common of types of quartz grains.

Lower Tertiary.

The sandy ironstone at the base of the Eocene series contains occasional fragments of angular quartz and felspar, and also reef quartz, Jurassic pebbles, and rare quartzite pebbles. In addition, rare rounded oolitic grains of the hydrated lime phosphate mineral collophane, pellets of glauconite and grains of black iron oxide, are set in a limonitic clayey base which forms the principal constituent of the rock.

Both the fossiliferous and the non-fossiliferous grit bands interbedded with the sandy ironstone, contain numerous large and rounded, translucent quartz grains, occasional gypsum crystals and quartzite fragments. These constituents are set in a clayey base which varies in composition from place to place. In parts, the base is ferruginous and phosphatic, and contains rare crystals of zircon, mica and tourmaline, pellets of collophane, and areas of glauconite sometimes associated with calcite. In other parts, the matrix is composed principally of calcite and limonite, while elsewhere, green and greenish-brown glauconitic mud is the most conspicuous constituent in the base of the rock. Smaller quartz grains in the grit bands are sub-angular to rounded and clear, the larger grains are frequently strained and granulated, and contain numerous strings of opaque, dust-like inclusions. Shell fragments are common in certain of the grit bands, and have in part been replaced by limonite and pyrite.

The carbonaceous clays overlying the basal ferruginous series contain pyrite in places. A section of pyritic clay, from 1½ miles south-east of Point Ronald, revealed that quartz grains present were rimmed with calcite as in the calcareous Jurassic arkose. The pyrite, which is finely granular, sometimes forms rims to, or entirely replaces the oolitic collophane grains present, but principally replaces the argillaceous material forming the bulk of the rock. The section of pyritic clay also revealed rare cross sections of echinoid spines and occasional shell fragments. Carbonaceous shale from ½ mile south-east of Point Ronald has certain characteristics akin to some oil shales. It has a sandy fraction of 7·5 per cent. and contains traces of calcareous matter. The sandy fraction is composed mainly of colourless, translucent, and milky grains of quartz. There are also flakes of mica up to 2 mm. across, and rare grains of heavy minerals (column 2, Table 1), while gypsum occurs as bladed crystals up to 3 mm. in length, and copiapite is abundantly developed along planes of fissility and as irregular clots. The cliffs here give off a sulphurous odour. A thin section of this shale indicated the presence of plant-like fragments.

Portions of the carbonaceous shale were tested for hydrocarbon compounds. After heating about 15 grams of powdered material to a dull red heat in a hard glass test tube, abundant carbon was left behind in the residue. Volatile constituents from dry distillation consisted of water from which halite cubes crystallized on cooling, a small amount of sulphur, and a few drops of colourless liquid which had an aromatic smell and which when examined microscopically, were seen to contain pale yellowish-green globules of a liquid which persisted for several weeks. The halite cubes, which were accompanied by skeleton crystals of the same material, were probably derived from salt spray driven against the cliff face from the sea. Ten to fifteen grams of the shale were powdered and treated with absolute alcohol, and the argillaceous matter filtered off. The filtrate was allowed to evaporate slowly, and at the end of this process, brownish-yellow hydrocarbon residues having wax-like properties, remained as a thin film on the bottom of the containing vessel. A positive acetone test for hydrocarbons was obtained by shaking up about 10 grams of the powdered shale with acetone and filtering. The addition of water to the clear filtrate, resulted in a milky colouration due to the formation of an emulsion. This milkiness did not develop in a control test carried out by adding water to pure acetone. Twelve grams of the powdered shale were subjected to 5½ hours' treatment with petroleum ether in a Soxhlet extraction apparatus. The residue obtained after evaporating the petroleum ether extract contained abundant small crystals of sulphur, a whitish, wax-like substance and a pale yellowish liquid with an aromatic odour. Owing to the small amounts of the residues obtained from each of the above tests, it has not been possible so far to arrive at any definite conclusion regarding the exact character of the hydrocarbon compounds present in the carbonaceous shale.

Of the interbedded sandstones in the clay series, the bed with structures resembling boxstones consists principally of quartz, with muscovite and some felspar set in a limonitic cement containing calcium carbonate and glauconitic material (column 6, Table 1, for rarer mineral species). The calcium carbonate forms rims around some of the sedimentary grains, and has also penetrated cleavage planes in certain of the mica plates. The sandstone band with Turritella contains some altered felspar and a carbonate cement in which angular to sub-angular quartz grains are set. The sandstone with Trochocyathus and Odontaspis has a ferruginous to calcareous cement, and contains a small proportion of oligoclase and mica. Nodular areas of pyrite up to 4 mm. across are numerous in this sandstone band, and frequently entirely replace the argillaceous matrix present in parts of the rock. Some of the angular to sub-angular quartz grains contain long, slender needles and minute prisms of apatite. Rare glauconite and oolitic pellets of brown coloured material, probably collophane representing fish pellets, &c., are also present in this sandstone.

The ferruginous sandstone overlying the copiapite-bearing, carbonaceous shale about $\frac{1}{2}$ mile south-east of Point Ronald, is friable and in parts micaceous, with angular to sub-angular quartz grains. Zircons occur both as clear, waterworn crystals and as examples with well preserved crystal faces like those in the Jurassic sediments. The other minerals present are listed in column 1, Table 1.

The minerals present in the Eocene sediments south-east of Princetown have several characteristics in common with the mineral assemblage of the Jurassic rocks upon which they rest. This is to be expected, as the basal Eocene beds are of terrigenous origin, their constituents being derived from a terrain composed of Jurassic arkose, grits, and mudstone. The pyrite in the argillaceous members of the Lower Tertiary series was probably formed by the action of H_2S evolved from decomposing organic material, with the aid of bacteria, on ferrous carbonate. Weathering of the pyritic matter has brought about conversion to basic ferric sulphate, resulting in the abundant development of the mineral copiapite in parts of the deposits. Hydrocarbon compounds present in the clays originate from plant material, represented by the dark carbonaceous markings resembling algal remains. The reef quartz pebbles in the Pebble Point Beds were derived from quartz veins which traverse the Jurassic sediments in parts of the Otways.

Summary and Conclusions.

A westerly dipping series of Lower Tertiary sediments composed of a basal ferruginous phase (called the Pebble Point Beds) overlain by a clay phase with interbedded sandstones, in coastal sections south-east of the township of Princetown, on the south coast of Western Victoria, have been assigned an Eocene age on their fossil content. They rest unconformably upon an eroded, somewhat undulating surface in Jurassic sediments, and show slight transgressive overlap. Balcombian (Miocene) beds in cliff sections some 5 or 6 miles north-west of Pebble Point, are separated from the older Tertiary sediments by a stretch of Pleistocene dune limestone which forms steep, rugged cliffs, at the base of which occasional outcrops of Tertiary rocks can be seen amongst large talus cones in those parts of the coast to which access can be gained. A considerable gap in certain parts of the Tertiary rocks between Pebble Point and Glenample Steps, has been created by the eroded valley of the present Gellibrand River and its Pliocene ancestor, so that no definite conclusions can be made at present concerning the exact relationship between the Eocene and the Miocene deposits. The Eocene deposits have no other equivalents, as far as can be ascertained, along these parts of the Victorian coastline, being known so far only from the Pebble Point district.

Transgressive deepening of the Lower Tertiary sea from east to west is shown by the passage from basal Eocene grits and sandy ironstones, through clays and shales with interbedded sandstones, into Miocene limestones and calcareous, fossiliferous clays.

Evidence of Post-Miocene earth movements is provided by the elevation of the area of Eocene and Miocene sedimentation to its present position above sea level, but there was apparently no significant disturbance of the beds from their original disposition on deposition, the recorded dip values probably being initial dips controlled by the slope of the erosion surface of the Jurassic coastline, rather than dips resulting from tilting on elevation.

Instead of a continuous period of erosion leading to peneplanation throughout the Cretaceous and Eocene and into Oligocene times in Victoria, as originally appeared to be the case, it now transpires, with the determination of the Eocene age of the Older Tertiary deposits south-east of Princetown, that in portion of south-western Victoria at least, down-warping had set in towards the close of Cretaceous times. Erosion throughout the Cretaceous period had led to the development of a somewhat peneplaned area in the Princetown district. Increased amounts of down-warping led to the deposition of deeper water sediments in the west until, at the close of Miocene times, there was a reversal of movement, and the Eocene-Miocene rocks were elevated to form a land mass. The southern fringe of this elevated theatre of Older to Middle Tertiary sedimentation has been subjected to marine attack since Miocene times.

Acknowledgments.

The author wishes to express his appreciation of the work of Dr. C. Teichert and Dr. F. A. Singleton, whose fossil determinations have proved the presence of Eocene deposits in Victoria, at the locality described in the text. Thanks are also due to Associate Professor E. S. Hills and Dr. M. F. Glaessner for valuable help and advice, to Mr. W. J. Parr for his examinations of the foraminiferal content of the sediments from south-east of Princetown, and to Mr. J. S. Mann for photographic preparations.

Appendix.

THE FORAMINIFERA OF THE EOCENE BEDS AT PEBBLE POINT, PRINCETOWN.

By M. F. GLAESSNER, PH.D., AND W. J. PARR.

The presence of foraminifera in the Eocene beds of the Pebble Point area was first recognized by G. Baker, M.Sc., who subsequently asked us to examine some of the matrix adhering to the larger fossils to obtain, if possible, evidence from the microscopic fossils as to the age of the deposit. As no deposits now accepted as of undoubted Eocene age have hitherto been recorded from South-Eastern Australia, we were glad to comply with this request. In addition to the material with which Mr. Baker has supplied us, we have examined some better preserved material collected by one of us (W.J.P.) from the same beds in October, 1915.

Ferruginous grits, such as occur at Pebble Point, are as a rule, unfavourable to the occurrence and recovery of foraminifera in any numbers, and it is accordingly not surprising that in the present case the microfossils are rare and of small size. After a considerable amount of searching, we have found about 28 species of foraminifera and two of ostracoda. From the examination of the material, it is, however, apparent that much better preserved specimens could be obtained by careful collecting of samples from the less ferruginous portions of the deposit.

In the meantime, the following provisional list of species is placed on record:—

Dentalina sp.
Nodosaria sp.
Vaginulina sp. aff. *subplumoides* Parr.
Marginulina aff. *costata* (Batsch).
Marginulina aff. *glabra* d'Orbigny.
Lenticulina spp.
Planularia sp.
Lagena hexagona (Will.).
Lagena catenulata (Will.).
Lagena sp.
Globulina gibba d'Orbigny.
Guttulina problema (d'Orbigny).
Guttulina lactea (Walker and Jacob).
Guttulina sp. (adherent).
Angulogerina aff. *elongata* (Halkyard).
Eponides obtusus (Burrows & Holland) var. *westraliensis* Parr.
Gyroidina aff. *octocamerata* Cushman & Hanna.
Pulvinulinella sp. nov.
Baggatella sp. nov.
Ceratobulimina spp. nov.
Anomalina sp. nov.
Anomalina cf. *glabrata* Cushman.
Cibicides cf. *lobatulus* (Walker and Jacob).
Cibicides spp.
Globigerina sp.

Echinoid spines, bryozoan fragments, small mollusca, ostracods and fish teeth occur also in the washings.

All foraminifera are rare except *Anomalina* sp. nov. and *Cibicides* sp., which were found in considerable numbers.

From this list, we have drawn the following conclusions:—

1. The assemblage is unlike any other hitherto recorded or known to us from Australia. The most characteristic species of the deposit appear to be new. A number of other species have a long range in time.

2. There is no disagreement between the composition of the fauna and the determination of the Eocene age of the beds at Pebble Point as based on distinctive species of mollusca.

3. Our present knowledge of the foraminiferal assemblage of the ferruginous grits from Pebble Point is insufficient for an independent determination of their age. At least four out of a total of about 28 species appear to be closely related to species not known from Tertiary deposits younger than Eocene. One of these species belongs to the genus *Baggatella* which was described recently by H. V. Howe from the Middle Eocene of Texas, U.S.A. (see Louisiana Geol. Survey, Bull. 14, p. 79). The number of specimens at present available does not enable us to reach a more definite conclusion.

4. The composition of the fauna indicates deposition in shallow and rather cool water. This opinion is based on similarities with fossil foraminiferal assemblages from sediments known to have been formed under such conditions.

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Explanation of Plate.

PLATE X.

FIG. 1.—Lower portion of the cliffs at the second point north-west of Pebble Point, showing Jurassic beds on the wave-cut platform and in the base of the cliffs. Overlying them are westerly dipping Eocene beds.

FIG. 2.—Close-up of the unconformity between Eocene and Jurassic sediments at the second point north-west of Pebble Point, showing the even character of the old erosion surface at this locality.

(NOTE.—The dotted line in each photograph marks the surface of unconformity between Eocene and Jurassic rocks.)

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[Proc. Roy. Soc. Victoria, 55 (N.S.), Pt. II., 1943.]

Art. XI.—*Eocene Nautiloids from Victoria.*

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(Communicated by G. Baker, M.Sc.)

[Read 10th December, 1942; issued separately 1st October, 1943.]

Abstract.

Nautilus victorianus, n.sp., and *Aturoidea distans*, n.sp., are described from Tertiary beds on the south coast of Victoria. It is concluded that the occurrence of *Aturoidea*, which has not been previously reported from Australia, indicates an Eocene age of the strata in which the nautiloids were found. This is the first suggestion of the occurrence of Eocene strata anywhere in the eastern half of the Australian continent.

At the request of Associate-Professor E. S. Hills and Mr. George Baker, of Melbourne University, I have examined the remains of a few nautiloid cephalopods, collected by Mr. Baker early in 1942 from ½ mile north-west of Pebble Point, south-east of Princetown, on the south coast of Victoria, about 20 miles north-west of Cape Otway. According to information supplied by Mr. Baker, Jurassic sandstones are in this locality overlain by a series of fossiliferous marine sediments of Tertiary age, which begins with ferruginous grits and ironstones at the base. These strata contain a small mollusc fauna which includes *Cucullaea*, *Lahillia*, *Limopsis*, *Turritella*, and *Dentalium*. The nautiloid fragments were found in a grit band in this basal series (the Pebble Point Beds) 30-40 feet above the unconformity with the Jurassic. Mr. Baker has called my attention to an early report of the occurrence of nautiloids in this place which was published by Wilkinson in 1865 and was quoted almost *verbatim* by Duncan in 1870. Wilkinson lists "*Nautilus*," together with "*Cucullaea*," and "*Cytherea*," in the uppermost beds of a series of 50 feet of thin ferruginous sandy beds which lie on top of 45 feet of greyish-brown carbonaceous sandstone showing false bedding and containing hard nodules and fragments of carbonized wood (Jurassic). The locality where fragments of carbonized wood described as "2½ miles south-east of the mouth of the Gellibrand River" and is the same as that from which Mr. Baker obtained his specimens.

Also, it must be mentioned that Chapman (1915, p. 353) listed *Aturia australis* from the "Gellibrand River (low down in the series)" and it seems possible that this determination might have been based on fragments of *Aturoidea distans,* as described in the present paper, rather than on the true *Aturia australis* which seems to be a younger fossil.

It was found that the fragments collected by Mr. Baker belonged to four, perhaps five, different specimens of which one is here described as *Nautilus victorianus,* n. sp., whereas the other specimens belong to a new species of *Aturoidea* which is here described as *Aturoidea distans.*

The occurrence of *Aturoidea* in Victoria is of considerable interest as it seems to indicate the occurrence in that State of Tertiary strata of a greater age than any that have previously been reported from the eastern half of the Australian continent. It is one of the rarer nautiloid genera and the few species that have been assigned to it are all from strata of either Late Cretaceous or Eocene age. Apparently the genus developed out of *Hercoglossa* near the end of Cretaceous time and became extinct before the end of the Eocene, after *Aturia* had developed from it in the beginning of that period.

From the evidence furnished by this nautiloid it can be concluded, therefore, that the strata in which it was found are probably not younger than Eocene. They might even be as old as Upper Cretaceous, but since we are apparently concerned with the basal part of a continuous sequence which passes upwards into sediments of Miocene age, and since the genus *Nautilus* is not known from strata of pre-Tertiary age, an Eocene age of the nautiloid beds seems to be the most likely assumption.

Considering the fact that certain molluscs survive in Australian waters to-day which are closely related to forms that were more widespread in earlier periods, it might be argued that *Aturoidea* could have been something in the nature of an " Australian living fossil " of some period later than the Eocene. *Nautilus* itself with its present restricted range from the Java Sea to the Fiji Islands may be such a " living fossil." However, it should be borne in mind that the living species of *Nautilus* are the last descendants of a once vigorous strain which as late as the Miocene was widely distributed in various parts of the world. *Aturoidea* on the other hand was an unstable transition stage in an evolutionary lineage. Its few species are found widely apart and were never prolific in numbers of individuals.

Palaeontological Descriptions.

Family HERCOGLOSSIDAE.

Genus **Aturoidea** Vredenburg.

The genus *Aturoidea* has recently been discussed in detail by Miller and Thompson (1935) to whose descriptions the reader is referred. Its species have long been confused with those of other genera, especially *Aturia,* from which, however, they differ in important features. Miller and Thompson have drawn up the following exhaustive definition of the genus (1935, p. 566):—

"Conch sublenticular in shape, nautiliconic in its mode of growth; all known forms large. Whorls compressed, flattened laterally, rounded ventrally, impressed dorsally. Umbilicus closed; umbilical shoulders rounded. Septa asymmetrically sigmoidal: each mature suture forms a very broad, deep, blunt ventral saddle: on either side of it a long, narrow, asymmetrical, narrowly-rounded lateral lobe; a broad, deep, broadly rounded, asymmetrical lateral saddle; a long, broad, rounded lobe with its centre near the umbilical seam; a broad, deep, broadly-rounded saddle located on the sides of the impressed zone and extending to the dorsal lobe; the dorsal lobe apparently large, more or less V-shaped, but rounded. Siphuncle subdorsal in position (that is, much nearer the dorsum than the venter, but not in contact with the dorsum); orthochoanitic in structure—segments not expanded nor contracted within the camerae but essentially cylindrical in shape; septal necks relatively long (only slightly shorter than the connecting rings)."

Aturoidea differs from *Aturia,* first of all in the position of the siphuncle which is not marginal as in the latter genus, but somewhat removed from the dorsum; equally important is the fact that in *Aturoidea* the septal funnels extend only half-way to the preceding septum. Finally, the septa in *Aturoidea* are farther apart than in *Aturia;* in the former genus the lateral lobe reaches approximately to the level of the crest of the lateral saddle of the preceding suture; whereas in *Aturia* the lateral lobe invariably reaches below that level.

Miller and Thompson are undoubtedly right in regarding *Aturoidea* as a connecting link between *Hercoglossa* and *Aturia.* It is a rare genus, for as Miller and Thompson have pointed out, only six or eight species have been described from North America, from England, and from India, and each species is known by one or two specimens only. Most of the species of *Aturoidea* are from Eocene strata; two species (*Nautilus serpentinus* Blanford, *N. schweinfurthi* Zittel) from the Cretaceous of India and Africa have been referred to the same genus, but these are intermediate between *Hercoglossa* and*Aturoidea* and may perhaps not be typical representatives of the latter genus.

Whether *Aturoidea* should be included in the family Hercoglossidae as Spath proposed, or rather in the Aturiidae, is an arguable, though unimportant point. The former classification suggests itself on the basis of the characteristics of the siphuncle, the latter if the state of development of the sutures is considered more important.

ATUROIDEA DISTANS, n.sp.

[Plate XI., figs. 1-4.]

This species is known from fragments of three, perhaps four, specimens which were found close together. Although it is not possible from the available material to give an exhaustive description of the species, enough of it is known to describe all its important features and to justify its description as a new species which will, it is hoped, be easily recognizable if additional specimens should be found at some future date.

The species is of fairly large dimensions. It can be estimated that the largest fragments belonged to a specimen which had a diameter of about 185 mm. at some stage before it reached maturity. Complete with living chamber the diameter of that specimen might have been anything between 250 and 300 mm.

The shell is involute; its whorls have almost straight, diverging sides and an evenly, though not very strongly rounded venter. In one rather small fragment the height of the whorl is 29 mm., its width about 24 mm., and the height of the whorl above the impressed zone is 19·5 mm. The outside of the shell is marked by weak growth-lines which are convex laterally, forming a very shallow lateral sinus, and are very strongly curved backward as they cross the venter, indicating the existence of a deep hyponomic sinus.

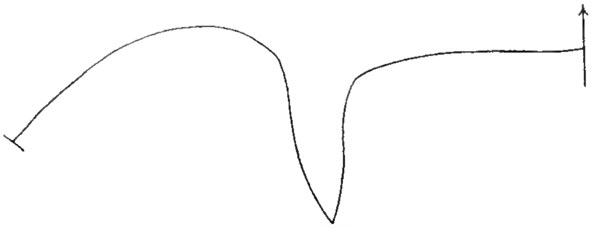

FIG. 1.—External suture of *Aturoidea distans*, n.sp. No. 1860, Department of Geology, Melbourne University.

The septa are moderately convex in the median region. The siphuncle is situated a short distance from the dorsal side. In the specimen in which the height of the whorl above the impressed zone was measured as 19·5 mm., the distance of the siphuncle from the dorsal side is 1 mm. The diameter of the siphuncle at this place is 1·5 mm. In a larger fragment in which the height of the whorl above the impressed zone is 58 mm., the distance of the siphuncle from the dorsal side is 6 mm. and the diameter of the siphuncle in this place is between 5·5 and 6 mm. It seems, therefore, that the distance between the siphuncle and the dorsal side is at any stage of growth roughly equal to or only very slightly smaller than the diameter of the siphuncle at the same place. The septal necks are orthochoanitic and extend for about half the distance between the septa. In one place where a measurement could be made the distance between two successive septa was 24 mm. and the septal necks were 12 mm. long.

The sutures are aturoid (fig. 1). The external suture consists of a strongly curved lateral saddle followed by a rather narrow, long, acute lobe which is situated well on the side of the whorl, about halfway between the umbilicus and the venter. The rest of the suture is straight as it crosses the ventrolateral and ventral parts of the conch. This part of suture remains slightly below the level of the lateral saddle. The sutures are set well apart and the lateral lobe terminates at or only very slightly below the level of the lateral saddle of the preceding suture. The internal suture forms a pair of saddles and a blunt dorsal lobe.

Occurrence.—Grit band, 30-40 feet above the unconformity between the Jurassic and the Tertiary. Second point north-west of Pebble Point, south-east of Princetown, Victoria.

Holotype.—No. 1860, Department of Geology, University ot Melbourne.

Paratypes.—Nos. 1861-1862, Department of Geology, University of Melbourne.

Remarks.—*Aturoidea distans* is easily distinguished from the few other species of the genus by the position of its lateral lobe which is unusually far away from the ventral side. From *Aturoidea spathi* Vredenburg from the Eocene Ranikot series of India it also differs conspicuously in its more broadly rounded ventral outline. A. *pilsbryi* Miller and Thompson from the Eocene of New Jersey, U.S.A., is similar in the position of the lateral lobe of the suture, but the lateral lobe is short, broad, and blunt instead of long, narrow, and acute as in *A. distans.*

Family NAUTILIDAE.

Genus **Nautilus** Linné.

Although many nautiloids of Palaeozoic and Mesozoic age have in the past been referred to the genus *Nautilus,* species that are sufficiently similar to the genotype, the living *Nautilus pompilius,* to be included in the same genus do not make their appearance before the Cainozoic. Hyatt (1897, p. 560) even hesitated to include Tertiary species into the genus and it may well be that up to the present day many species of Tertiary nautiloids are classified with *Nautilus* only because they have never been studied in sufficient detail. Although Spath has in recent years removed numerous species to a more satisfactory taxonomic position, the affinities of many others seem to require further elucidation.

While I am not in a position to be able to attempt a revision of the Tertiary species that are now commonly assigned to *Nautilus,* it is with some diffidence that I place the new species to be described here into that genus. Its affinities will be discussed below.

NAUTILUS VICTORIANUS, n.sp.

[Plate XI., figs. 5-7.]

Only one rather fragmentary specimen is at present available which, however, permits of the observation of most of the important specific characters.

The shell which this fragment represents had a diameter of at least 47 mm., but since only part of the living chamber is preserved the actual size must have exceeded this figure. The shell is broadly discoidal, almost involute, with an umbilicus about 4 mm. wide. The whorls are strongly and evenly rounded, with a deeply impressed dorsal zone. At the base of the living chamber the whorl is about 22 mm. high, 25·5 mm. wide, and the impressed zone is about 7 mm. deep.

The surface of the shell is marked with very faint growth-lines which are slightly sinuous; they indicate the existence of a rather shallow hyponomic sinus. The septa are rather strongly convex, rising rather steeply near the ventral side. The sutures (fig. 2) form a shallow umbilical saddle, followed by a shallow lobe which is situated close to the umbilical shoulder; the sutures then rise almost straight across most of the lateral sides to form the ventral saddle. The exact course of the internal suture could not be studied, but it can be seen that a dorsal lobe is present at all stages.

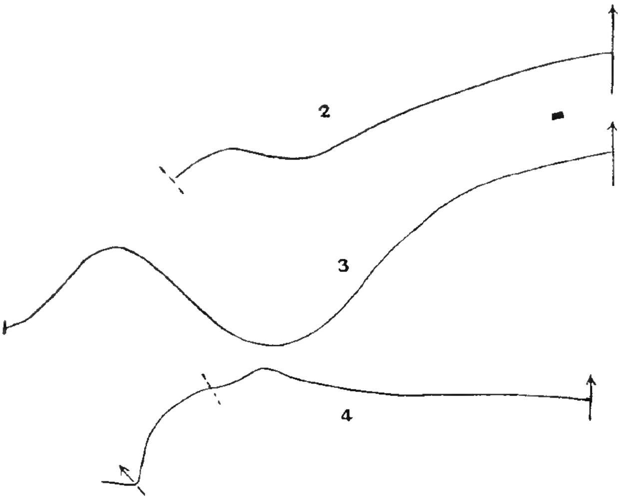

FIG. 2.—External suture of *Nautilus victorianus* n.sp., Holotype.

FIG. 3.—External suture of *Nautilus pompilius* Linné. No. 16248, Dept. of Geology, University of W.A.

FIG. 4.—Suture of *Nautilus geelongensis* Foord. No. 1863, Dept. of Geology, University of Melbourne.

of growth. At a stage where the whorl is 14 mm. wide the annular lobe is about 2 mm. long; at the base of the living chamber the length of that lobe seems to have decreased to about 1 mm. The septa are comparatively closely-spaced; in the whorl preceding the last whorl the distance between them when measured near the umbilicus is between 1 and 1·5 mm. The septal necks are short and orthochoanitic.

Occurrence.—In grit band 30-40 feet above Jurassic-Tertiary unconformity. Second point north-west of Pebble Point, south-east of Princetown, Victoria.

Holotype.—No. 1864, Department of Geology, University of Melbourne.

Remarks.—The only other Victorian nautiloid with which this species can be compared is *Nautilus geelongensis* Foord (1891, p. 332). The two species resemble each other in the degree of involution of the conch; both have a very small umbilicus. Their conchs are also similar in cross-section, but the ventral side of *Nautilus geelongensis* is slightly more broadly rounded than that of *Nautilus victorianus.* The two species can be most easily distinguished by their sutures which are more strongly sinuous in *Nautilus victorianus.* The external suture of *N. geelongensis* (fig. 3) is composed of a narrow, though shallow, lobe on the umbilical wall, followed by a low saddle on the umbilical shoulder which is in turn followed by a broad and shallow lateral lobe; the venter is crossed by a broad, low saddle. The internal suture possesses an annular lobe which is present at all stages of growth. On the other hand, the more pronounced and more asymmetrical lateral lobe whose deepest point is situated closer to the umbilical shoulder are features by which *Nautilus victorianus* can be easily distinguished from *N. geelongensis.*

Nautilus victorianus in some respects resembles species of the genus *Eutrephoceras.* Typical species of that genus have, however, a suture which, as Davies pointed out (1935, p. 351), is situated "entirely above (in front of) the guide-line," the latter being defined as "a straight line drawn from the centre of the shell-spiral at a tangent to the suture-line in the middle of the periphery," in other words, the suture on the whole is somewhat convex. The sutures are very slightly sinuous in the umbilical region and almost straight across most of the lateral sides and across the venter. There are, however, species which are commonly referred to *Eutrephoceras* and which have more sinuous and slightly concave sutures; one of these is *Eutrephoceras bryani* Gabb from the Eocene of New Jersey, a species which has been well illustrated and described by Whitfield in 1892. The suture of this species is entirely behind the "guide-line" and its lateral lobe is more strongly developed than in normal species of *Eutrephoceras.* "*Eutrephoceras*" *bryani* is perhaps the Tertiary nautiloid in North America which resembles *Nautilus victorianus* most, but I cannot help feeling doubtful about the systematic position of that species and wonder whether it would not be more correct to include it in the genus *Nautilus,* at least until the remaining Tertiary " Nautili " have been thoroughly revised.

For comparison with these Tertiary nautiloids an original drawing of a suture of *Nautilus pompilius* is here reproduced as fig. 4. It may be noted that this suture agrees well with the one of the same species which was figured by Reeside (1924, fig. 3), but less so with one depicted by Miller and Thompson (1933, p. 309) in which the umbilical saddle is much less prominent.

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Explanation of Plate.

PLATE XI.

FIG. 1.—*Aturoidea distans* Teichert, n. sp. Holotype. Lateral view, Nat. size.

FIG. 2 and 3.—A chamber of another specimen of the same species (fig. 2 septal aspect, 2 ×; fig. 3 side view, nat. size).

FIG. 4.—*Aturoidea distans* Teichert, n. sp. Septal aspect of a larger fragment, nat. size.

FIG. 5-7.—*Nautilus victorianus* Teichert, n. sp. Holotype. Nat. size.

All the specimens come from a grit band 30-40 feet above the Jurassic-Tertiary unconformity, from the second point north-west of Pebble Point, south-east of Princetown, Victoria.

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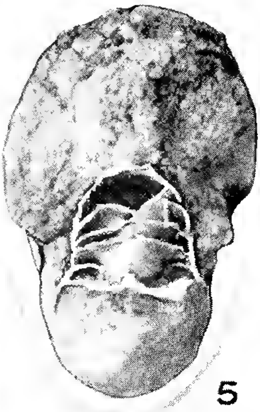

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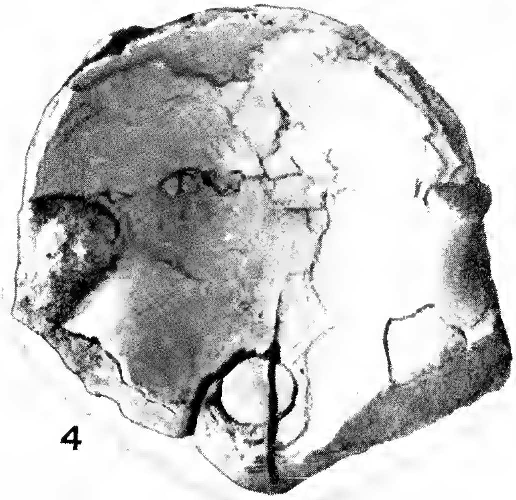

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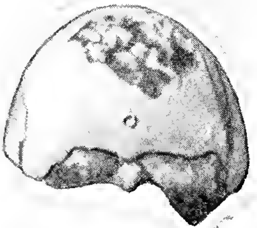

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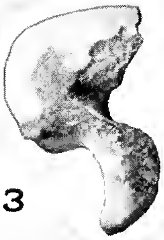

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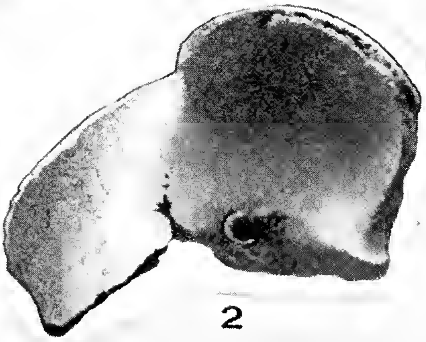

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[Proc. Roy. Soc. Victoria, **55** (N.S.), Pt. II., 1943.]

Art. XII.—*An Eocene Molluscan Fauna from Victoria.*

By F. A. SINGLETON, D.Sc.

[Read 10th December, 1942; issued separately 1st October, 1943.]

Abstract.

Lahillia-Cucullaea fauna from ferruginous grits near Pebble Point, S.E. of Princetown, shows relationships to the Wangaloan fauna of New Zealand and more distantly to those of the Late Cretaceous and Early Tertiary of S. America and Antarctica. It is very different from known Australian faunas and is tentatively referred to the Lower Eocene or possibly Paleocene. The following are described as new species: *Nuculana paucigradata, Cucullaea* (*Cucullona*) *psephea, Lahillia australica, Dentalium* (*Fissidentalium*) *gracilicostatum.*

Introduction.

The Older Tertiary marine deposits of Victoria were regarded by Tate and Dennant and by Hall and Pritchard as referable to the Eocene, a view still held by Dr. G. B. Pritchard. On the other hand, Professor McCoy since 1866 maintained that these beds, which for the most part are contained in the Barwonian System, were post-Eocene, a view officially adopted by the Victorian Geological Survey, and supported for the past 30 years by Chapman and by most other workers in this field, including the writer, who still believes the Barwonian deposits to be post-Eocene. Although he has recently stated (1941, p. 11) that " Paleocene to Middle Eocene horizons are as yet unknown in Australia . . .", the known Upper Eocene being confined to Western Australia, it now appears that marine deposits probably low in the Eocene, perhaps even Paleocene, are present in Victoria.

In the present paper is offered a preliminary account of the marine mollusca, other than the cephalopods, which are described by Dr. Teichert (1943), of the ferruginous grits which overlie the Jurassic strata in coastal sections near Pebble Point, about 2½ miles south-east of Princetown on the Gellibrand River. The stratigraphy is fully discussed by Mr. G. Baker (1943), to whom the writer is indebted for the opportunity to examine the fossils collected by him in January, 1942, from 30-40 feet above the Jurassic-Tertiary unconformity surface at the second point north-west of Pebble Point. Unfortunately, the very resistant matrix makes collecting difficult, and most of the present material is badly weathered and in many cases is too imperfect for specific description. Thanks are also due to Mr. W. J. Parr for placing at the writer's disposal fossils collected by him in October, 1915, from the same horizon on the south-east side of Pebble Point, and to Mr. J. S. Mann for the photographs. It is hoped that further collecting in the near future will furnish better material, and it is probable that the faunal list will be considerably increased.

Previous Literature.

The fossiliferous beds at this locality, which is Wilkinson's No. 6, are described (1865, p. 24) by him as ". . . 50 feet of thin ferruginous sandy beds, with small rounded quartz pebbles, the uppermost beds containing fossils principally, Cuculea, Cytheroea, and Nautilus, labelled No. 6; . . ." The *Cytherea* are undoubtedly the shells herein referred to *Lahillia,* which with *Cucullaea* are the largest and commonest bivalves in these beds. More accessible than Wilkinson's report are copious extracts therefrom made by Duncan, which include (1870, p. 292) the passage above cited.

Tate and Dennant do not refer to this locality in their account (1893, p. 214) of the Tertiary beds near Princetown, though in a later paper they state (1896, p. 140): "The Otway Eocenes are certainly underlain by Mesozoic strata, but at the Gellibrand these suddenly disappear close to Pebble Point, and are not met with again to the west on either the Victorian or South Australian coast."

Pritchard (1925, p. 935) apparently referred the present beds to the Janjukian as ". . . coarse grits and conglomerates with an abundance of broken and imperfect fossils at other localities [than the Spring Creek section, i.e., type Janjukian], which clearly represent this horizon, notably east of the Gellibrand River flanking the Jurassic . . .", but no one except Wilkinson appears to have published any identifications.

Systematic Description.

Class PELECYPODA.

Family NUCULANIDAE.

Genus **Nuculana** Link, 1807.

Nuculana Link, Beschr. Samml. Rostock, iii., p. 155, 1807.

Genotype (by monotypy): *Arca rostrata Chemnitz* = *Mya pernula* Müller. Recent, Northern Europe. Figured by H. and A. Adams, Gen. Rec. Moll., iii., pl. 126, figs. 4*a*, 4*b*, 1858.

Nuculana paucigradata, sp. nov.

(Pl. XII., figs. 1*a, b.*)

Holotype.—Shell of moderate size and inflation; anterior end regularly rounded, passing evenly into the gently curved ventral margin, posterior end thin, bluntly rostrate, posterior dorsal margin long, nearly straight; umbo low, anterior; surface with distant but strongly marked growth stages, more closely spaced towards the ventral margin, otherwise apparently smooth though somewhat worn.

Hinge with chevron-shaped teeth, about nine in anterior and fifteen in posterior series, which make an angle of about 145°, as well as three or four very minute teeth on each side of the small, deep, broadly triangular chondrophore; both series approximately linear, the anterior increasing in size, the posterior small but constant in size. Length 11 (slightly imperfect), height 6, thickness of valve 2 mm.; umbo, 4½ mm. from anterior end.

Type Locality.—Coastal cliffs 2½ miles south-east of Princetown, Victoria. Holotype from second point north-west of Pebble Point. Occurs also in bay south-east of this locality as well as on east side of Pebble Point.

Type Material.—Holotype (Pl. XII., fig. 1*a*, *b*) left valve, coll. and pres. G. Baker, Melb. Univ. Geol. Dept., Reg. No. 1868.

The holotype is slightly broken posteriorly, giving an appearance of truncation, but the growth lines and other specimens show the posterior end to be bluntly rostrate but not keeled. Though not uncommon, all the available specimens are more or less worn, and it is therefore with some misgiving that a specific name is given to the best of these. The length ranges from 10 to 13·5 mm., but one worn and slightly imperfect shell in the writer's possession, from the second bay north-west of Pebble Point, and apparently referable to the same species, measures 21 × 11 × 3·5 mm.

The anterior position of the umbo and lack of strong inflation of the shell seem to preclude reference to the subgenus *Jupiteria* Bellardi, which it otherwise resembles.

Of Australian Tertiary species, it distantly recalls the Kalimnan *N. praelonga* (Tate), which is at once separable by the postmedian position of the umbo. The New Zealand Wangaloan *N.* (*Jupiteria*) *taioma* Finlay and Marwick (1937, p. 16, Pl. 1, figs. 1, 3, 6) shows more resemblance, but the umbo is more nearly median and the shell is apparently less produced posteriorly.

Family CUCULLAEIDAE.

Genus **Cucullaea** Lamarck, 1801.

Cucullaea Lamarck, Syst. Anim. s. Vert., p. 116, 1801.

Genotype (by monotypy): *Cucullaea auriculifera* Lamarck (= *Arca labiata* Solander = *concamera* Bruguière). Recent, Indo-Pacific. Figured by Tryon, Struct. and Syst. Conch., iii., pl. 127, fig. 74, 1884.

Subgenus **Cucullona** Finlay and Marwick, 1937.

Cucullona Finlay and Marwick, N.Z. Geol. Surv. Palaeont. Bull. 15, p. 19, 1937.

Genotype (by original designation): *Cucullaea* (*Cucullona*) *inarata* Finlay and Marwick. Wangaloan (Danian), New Zealand. Figured by Finlay and Marwick, *op. cit.*, pl. 2, figs. 2-5.

Cucullaea (Cucullona) psephea, sp. nov.

(Pl. XIII.. figs. *7a. b*; *8a, b.*)

Holotype.—A gerontic right valve. Shell moderately large, heavily built, roundly subquadrate, inequilateral, much inflated; dorsal margin weakly shouldered, anterior margin steep, passing into the gently rounded ventral margin, posterior margin oblique, weakly insinuate; posterior slope with a broad but shallow groove from the umbo to the posterior sinus; umbo anterior, prominent, strongly incurved, slightly anterior to centre of hinge-line; surface where well-preserved almost smooth, with concentric lines of growth through which are seen faint submerged radii; these are exposed in the weathered portions as strong flattened radial ribs, about seven in 10 mm. at the centre of the disc, with interspaces about half as wide as the ribs; umbonal region eroded, with about eight well marked growth stages, usually but not always with increasing interspaces which are crossed by radial riblets, about seventeen in 10 mm. at 18 mm. from the umbo; towards the ventral margin the growth-lines become undulose, directed ventrally where they cross the ribs.

Ligamental area high and long, slightly concave, with twelve or thirteen deeply incised chevrons which bear on their dorsal surfaces fine grooves subparallel to the hinge-line but tending to curl upward at the far end from the umbo; the area is 10 mm. high and deeply encroaches on the hinge teeth, of which only the anterior end of three long, striated, subparallel teeth, slightly oblique, can be seen, the posterior series being obscured by matrix; the median portion of the hinge bears irregular denticulations, about six in 4 mm. Anterior adductor scar slightly impressed, inner ventral margin of shell crenulate, rest of interior obscured by matrix. Length 60, height 50, thickness of valve 27 mm. Length anterior to hinge 3, of hinge 45, posterior to hinge 12; maximum height of hinge from ventral border 36 mm. Ratio of anterior to posterior portion of hinge 0·96.

Paratype.—An ephebic right valve. The exterior is poorly preserved and weathering has exposed the underlying radial structure. The shape in the ephebic stage is less drawn out posteriorly than in the holotype and the posterior groove is scarcely recognizable.

Ligamental area with divaricate grooving largely eroded, exposing extremely fine vertical lineations, about eight per mm.; beneath the umbo are developed coarser irregular vertical ridges which on reaching the hinge-line give place to irregular transverse taxodont teeth. Anterior and posterior teeth each four in number, the upper ones long and nearly horizontal, the lower ones much shorter and inclining downward, the sides finely transversely striate. Anterior adductor scar scalene, posterior scar subquadrate, ridged anteriorly; ventral margin internally strongly crenate, about seven in 10 mm. Length 41, height 35, thickness of valve 17 mm.

Length anterior to hinge 2, of hinge 32, posterior to hinge 7; maximum height of hinge from ventral border 27 mm. Hinge ratio 1·00.

Type Locality.—Coastal cliffs 2½ miles south-east of Princetown, Victoria. Holotype and paratype from second point north-west of Pebble Point. Occurs also in bay south-east of this locality, on the east side of Pebble Point, and in fallen blocks about ¼ mile south-east of this latter.

Type Material.—Holotype (Pl. XIII., fig. *7a, b*), Reg. No. 1869, and paratype (Pl. XIII., fig. *8a, b*), Reg. No. 1870, right valves, coll. and pres. G. Baker, in Melb. Univ. Geol. Dept.

This species is very close to *Cucullaea (Cucullona) inarata* Finlay and Marwick (1937, p. 20, Pl. 2, figs. 2-5), from which it differs chiefly in being narrower in the umbonal region and in having a much weaker posterior sinus. It is not impossible that a longer series may bridge these differences.

To the well-known Barwonian species *Cucullaea corioensis* McCoy (see Singleton, 1932, p. 300, Pl. 26, fig. 19), it bears little relation, the present species having an evenly rounded instead of oblique ventral margin, whose internal denticulation is short and marginal instead of elongate and within the margin, longitudinal hinge-teeth directed obliquely outwards and downwards instead of upwards, and external surface smooth instead of radially ribbed. Indeed, the two species are not consubgeneric, *C. corioensis* being referable to *Cucullaea, s.str.*

It is probable, however, that McCoy's locality record (Prodromus Palaeont. Vic., decade iii., p. 33, 1876) of *C. corioensis* as "Rare east of Gellibrand River (very thick variety)" is based on the present species.

Family LIMOPSIDAE.

Genus **Limopsis** Sassi, 1827.

Limopsis Sassi, Giorn. Ligustico di Scienze, etc., i., p. 476, 1827.

Genotype (by subsequent designation, Gray, Proc. Zool. Soc. Lond., pt. 15, p. 198, 1847): *Arca aurita* Brocchi. Miocene-Pliocene, Italy. Figured by Brocchi, Conchologia Fossile Subapennina, pl. 11, fig. *9a, b,* 1814.

LIMOPSIS, sp. nov. (?)

(Pl. XII., fig. *2a, b.*)

Shell obliquely subtrigonal, moderately convex; dorsal margin short, shouldered at either end, anterior and ventral margins regularly rounded, the latter oblique and meeting with a slight angulation the steeply sloping posterior margin; umbo minute, prominent. Surface of shell poorly preserved, but marked by strong lines of growth; near the ventro-posterior angle the crossing of these by faint radii gives rise to an obscurely tessellate ornament.

Hinge-line strongly arched, with six anterior and five posterior teeth of unequal size, the posterior series slightly uncinate, encroached upon by the prominent and high ligamental area which is longitudinally striate and divided unequally by the very large, well-developed broadly triangular ligament pit, with undulous longitudinal striae. Inner margin of shell narrowly planate, less than $\frac{1}{2}$ mm. wide. Length 10·8, height 11·3, thickness (right valve) 3·3 mm.

The above description is based on a shell (Melb. Univ. Geol. Dept., Reg. No. 1872) from the second point north-west of Pebble Point, collected by Mr. G. Baker. Although the poor preservation of the exterior of this and of the other specimens available makes it undesirable to attach a specific name, there is little doubt that it is distinct from other Australian Tertiary species of *Limopsis.*

The nearest species in point of age, the Janjukian *Limopsis chapmani* Singleton, is much less oblique at corresponding sizes and is ovate in outline instead of almost subquadrate, the ligament pit is much smaller, and the planate inner margin is nearly three times as wide as in the present species.

Family CARDIIDAE.

Subfamily LAHILLIINAE Finlay and Marwick, 1937.

Genus **Lahillia** Cossmann, 1899.

Amathusia Philippi, Tert. und Quart. Verst. Chiles, p. 135, 1887. Not *Amathusia* Fabricius, Mag. f. Insektenk. (Illiger), vi., p. 279 (Lepidoptera), 1807, nor *Amathusia* Rafinesque, Analyse de la Nature, p. 119 (Neuroptera), 8vo, Palermo, 1815.

Theringia Cossmann, nom. nov., Revue critique de Paléozool, iii. (1), p. 45, Jan., 1899, as *lapsus* for *Iheringia*, corrected, *op. cit.*, iii. (2), p. 90, Apr. 1899. Not *Iheringia* Lahille, Revista Mus. La Plata, viii., p. 437 (Echinoidea), 1898.

Lahillia Cossmann, nom, mut., *op. cit.*, iii. (3), p. 134, July, 1899.

Genotype (for both *Amathusia* Philippi and *Lahillia*, by subsequent designation, Finlay and Marwick, N.Z. Geol. Surv. Palaeont. Bull. 15, p. 31, 1937); *Amathusia angulata* Philippi. Tertiary, Chile. Figured by Wilckens, N. Jahrb. f. Min. Geol. u. Pal., Beilage Bd., xviii., pl. 20, fig. 4, 1904 (exterior only); Ortmann, Rept. Princeton Univ. Exped. Patagonia, iv. (2), pl. 27, figs. 4*a*, *b*, 1902 (hinge).

It might be argued that *Theringia* Cossmann, though stated by him to be a typographical error, is nevertheless a valid substitute name for *Amathusia* Philippi. Strangely enough, the same misprint *Theringia* occurs, as a nomen nudum, in Bull. Soc. Géol. France [3], xxvi (6), p. 586, March, 1899, in a note on Lahille's paper. Since *Theringia* and *Iheringia* have each been used in two senses, it seems desirable to accept Cossmann's second substitute name *Lahillia,* which is well established in literature.

LAHILLIA AUSTRALICA, sp. nov.

(Pl. XII., figs. 3-5.)

Holotype.—Left valve, shell large, thin, roundly ovate, moderately inflated, anterior slope gentle, posterior slope steep; anterior dorsal margin straight, descending and passing smoothly into the evenly rounded anterior margin, posterior dorsal and posterior margins evenly but more gently curved than anterior end, meeting the broadly convex ventral margin without angulation; umbo prominent, broad, sub-median; lunule scarcely defined. Surface with low, broad, concentric folds, about 2 mm. wide with 5 mm. interspaces on the ventral slope, and somewhat irregular growth-lines, best developed on the posterior slope, where they are sharply raised and crowded.

Interior largely obscured by matrix, but hinge characters as far as seen closely agreeing with paratype. Length 76, height 73, thickness of valve 26 mm.

Paratypes.—Exterior poorly preserved but agreeing in sculpture with holotype. Right valve slightly more elongate; left valve markedly so, being more produced posteriorly; lunule in left valve excavate, bounded by a rounded ridge.

Hinge-plate thick; cardinal and posterior lateral teeth well developed, anterior laterals absent. Right hinge with small, blunt anterior cardinal, gently sloping on its dorsal and anterior surfaces and distant from the raised lunular margin, steeply sloping posteriorly to a large, deep, broadly triangular pit, inclined slightly forward. Posterior cardinal very strong and prominent, subtriangular, arising nearly opposite umbo but directed obliquely backward and drawn up to a blunt peg-like apex, somewhat recurved upwards; anterior surface descending steeply to the triangular socket of the left anterior cardinal, posterior slope steep, descending to surface of nymph, which is high and broad. A low narrow ridge runs down nearly vertically immediately behind the umbo and the posterior cardinal; it does not reach the latter but dies out about a quarterway across the hinge-plate. Behind this ridge is a shallow depression, but there is no definite pit for the left posterior cardinal. Posterior lateral very strong, elongate, blunt, above which is a deep, wide pit separating it from the raised posterior edge of the nymph. Hinge-plate anterior to cardinal teeth with a linear shallow depression below and parallel to the lunular margin, otherwise somewhat steeply sloping towards the ventral margin of the hinge-line, which is strongly sinuate, with downward curves opposite the posterior cardinal and posterior lateral.

Left hinge with strong, high anterior cardinal directed anteriorly at about 15° from the vertical, separated from the arched and raised lunular margin; the upper surface of the tooth recurved and somewhat rounded, its lower surface triangularly bevelled and buttressed anteriorly by a ridge which forms the lower margin of the broad triangular pit for reception of the right anterior cardinal. Left posterior cardinal narrow, low, directed posteriorly at about 25° from the vertical, decreasing in width and height until it dies out at the ventral margin of the hinge-plate. Surface of nymph slightly excavate, its upper edge bounded by a deep ligamental groove. Posterior lateral strong, but less heavy and elongate than that of right valve, and separated from the post-dorsal margin by a narrow elongate pit. Ventral margin of hinge-line only weakly sinuate below cardinal and posterior lateral teeth.

Adductor scars strong, deeply sunk, especially on inner sides, posterior the larger, situate high up near dorsal margin of shell. Pallial line obscure. Inner margin of shell smooth. Length 77, height 71, thickness of right valve 26 mm.; 78, 71, 26 mm. (left valve).

Type Locality.—Coastal cliffs $2\frac{1}{2}$ miles south-east of Princetown, Victoria. Holotype from second point north-west of Pebble Point; paratypes from east side of Pebble Point. It is also found between these localities.

Type Material.—Holotype (Pl. XII., fig. 5) left valve, coll. and pres. G. Baker, Melb. Univ. Geol. Dept., Reg. No. 1865; paratypes (Pl. XII., figs, 3, 4) right and left valves, coll. and pres. W. J. Parr, Reg. Nos. 1866-7.

The present species is less closely related in dentition to the genotype of *Lahillia,* as figured by Ortmann (1902, Pl. 26, figs. 9*a*, *b*), than to *Lahillia neozelanica* Marshall and Murdoch, the type of the subgenus *Lahilleona* Finlay and Marwick (1937, p. 31). From the hinge of the New Zealand shell as figured by these authors (1937, Pl. 4, figs. 8, 9) that of the Australian species differs in the more robust right anterior lateral, the slightly backward instead of forward sloping right posterior lateral, and the better developed left posterior cardinal. In other characters, the correspondence is close. *L. australica* has, however, a higher anterior dorsal margin and thus an oval outline instead of the subtrigonal shape of topotypes of *L. neozelanica* from Wangaloa, and may therein more closely resemble the high-shouldered Boulder Hill form of *L. neozelanica* reported by Finlay and Marwick.

Unfortunately, in none of the Australian shells is the pallial line clearly seen, but in one broken example it appears to descend steeply and obliquely forward from near the inner angle of the posterior scar without a sinus such as characterizes *Lahilleona.* For this reason and because of the backward slope of the posterior cardinal, a difference already noted by Wilckens (1924, p. 540) for the S. Patagonian *L. luisa* (Wilckens) of Upper Senonian age, the present species is not referred to *Lahilleona* although it otherwise appears so close to *L. neozelanica.*

Lahillia luisa, as figured by Wilckens (1910, Pl. 3, figs. 4-7, 11) from Graham Land, Antarctica, is a more elongate shell, more produced anteriorly and truncate posteriorly. In the left hinge the cardinals are more divergent and the ventral margin of the hinge is strongly instead of weakly sinuate; in the right valve this margin shows a very strong angulation posterior to the cardinals, while the posterior lateral tooth is at a greater angle to the horizontal than in *L. australica.*

Of the Tertiary *Lahillia larseni* (Sharman and Newton) (1900, pp. 59, 60, and Pl., as *Cyprina Larseni*; Wilckens, 1911, pp. 13, 14, Pl. 1, fig. 12) from Seymour Island, off Graham Land, the hinge-teeth and pallial line are unknown; it is, however, a more elongate shell than *L. australica.*

Class SCAPHOPODA.

Family DENTALIIDAE.

Genus **Dentalium** Linné, 1758.

Dentalium Linné, Syst. Nat., ed. 10, p. 785, 1758.

Genotype (by subsequent designation, Montfort, Conch. Syst., ii., p. 23, 1810): *Dentalium elephantinum* Linné. Recent, East Indies (Amboyna) and Philippine Islands. Figured by Pilsbry and Sharp, Tryon's Man Conch., [1] xvii, pl. 1, figs. 1-7, 1897.

Subgenus **Fissidentalium** Fischer, 1885.

Fissidentalium Fischer, Man. Conchyl., p. 894, 1885.

Subgenotype (by monotypy, as section): *Dentalium ergasticum* Fischer. Recent, Gulf of Gascony and Atlantic Ocean. Figured by Pilsbry and Sharp, *loc. cit.,* pl. 15, figs. 35-36, 1897.

DENTALIUM (FISSIDENTALIUM) GRACILICOSTATUM, sp. nov.

(Pl. XII., figs. 6*a*, *b*; Pl. XIII., figs. 9*a*, *b*.)

Holotype.—Shell moderately large, solid, tapering fairly rapidly, moderately curved, dorso-ventrally compressed, slightly elliptical in cross-section, wall thick, apex wanting.

Surface with fine longitudinal ribs, about 57 in number; at the narrower end the ribs are unequal in size, rather high, narrow, rounded above, and parted by furrows which are wider than the ribs; anteriorly the ribs become broader and flattened, so that the interspaces are relatively much narrower and almost linear. The longitudinal sculpture is crossed by faint lines of growth, more marked towards the larger end, where they indicate that the aperture was decidedly oblique, and by somewhat irregular growth stages, about eight in number. Length (imperfect) 22; transverse diameter of apertural end, 5·5; dorso-ventral diameter, 5; thickness of shell, 0·8; diameter of posterior end, 3·7 (transverse), 3·2 mm. (dorso-ventral). Change in direction of axis in 2 cm., about 8°.

Type locality.—Coastal cliffs $2\frac{1}{2}$ miles south-east of Princetown, Victoria. Holotype from bay between first and second points north-west of Pebble Point. Occurs also at Pebble Point and at the second point north-west of it.

Type Material.—Holotype (Pl. XII., fig. 6*a*, *b*; Pl. XIII., fig. 9*a*, *b*), coll. and pres. G. Baker, Melb. Univ. Geol, Dept., Reg. No. 1871.

Although the apical characters are unknown, the specimens available being very imperfect, the size and solidity of the shell and its numerous riblets justify its reference to *Fissidentalium*. The fineness of the ribbing and the thickness of the shell wall readily distinguish it from other Australian Tertiary species.

Age of the Fauna.

The paucity and imperfect preservation of the shelly fauna of the Pebble Point beds make correlation difficult, but it is at once evident that the occurrence of *Lahillia* sharply differentiates it from the known Australian faunas and links it rather with those of South America, Antarctica, and New Zealand.

In Chile, *Lahillia* ranges from the Upper Cretaceous (Senonian) Quiquirina beds to the Miocene Navidad beds, while in South Patagonia and in Graham Land the range is approximately the same. In no case is the relation to *Lahillia australica* particularly close. In New Zealand, Finlay and Marwick (1937, pp. 10, 13, 31-3) discuss the late Cretaceous records of *Lahillia* and refer its highest occurrence, as *Lahillia* (*Lahilleona*) *neozelanica*, in the Wangaloan, to the Danian. *Lahillia australica*, as noted under that species, appears closer to *L. neozelanica* than to the South American and Antarctic forms, were it not that the New Zealand shell is sinupalliate. Such a character implies so marked a distinction that it is unfortunate the Australian material does not permit a decision as between *Lahilleona* and *Lahillia, s. str.* The backward slope ventrally of the posterior cardinal tooth is a character shared with the Upper Senonian *Lahillia luisa* and on the whole *Lahillia australica* appears related more closely to the late Cretaceous than to the Tertiary species.

While *Cucullaea, sensu lato*, ranges from the Mesozoic to the present, the subgenus *Cucullona* has hitherto been reported only from the Wangaloan. Indeed, the Australian *C. psephea* is so close to the Wangaloan *C. inarata* as to suggest approximate identity of age.

Of the remainder, *Nuculana paucigradata* and the *Limopsis* afford little definite evidence as to age. The former only distantly resembles the Wangaloan *N. taioma*, while the latter is very different from the Wangaloa species.

Dentalium (*Fissidentalium*) *gracilicostatum* is also quite unrelated to the Wangaloan scaphopods: *Fissidentalium* did not appear, so far as the writer knows, before the Eocene.

The conclusions to be drawn from this survey are not very definite. The complete specific, and in part generic or subgeneric distinction from the Australian Janjukian faunas, even when the latter are of comparable shallow water facies, as at Table Cape, Tasmania, suggests a considerable time difference, so that it is unlikely that the Pebble Point fauna is younger than Eocene. The earliest occurrence of the *Lahillia-Cucullaea* association is in the Senonian of South America and Antarctica, where it is associated with ammonoids: in New Zealand, it is found without ammonoids on a higher horizon, the Wangaloan, correlated by Finlay and Marwick with the Danian, but not in the Bortonian (? Middle Eocene); and it persists into the Tertiary of South America and Antarctica.

The Pebble Point fauna, therefore, probably falls within the range from Danian to Lower Eocene, a conclusion supported by the occurrence (Teichert, 1943) in it of the Nautiloid genus *Aturoidea*, which elsewhere has this range. A correlation with the Wangaloan is suggested by the occurrence in both of *Cucullona*, but the writer is not fully convinced that the Wangaloan is Danian rather than Paleocene, and, moreover, the Wangaloan fauna contains a Cretaceous element as yet unknown in the fauna here described. The occurrence in the Pebble Point beds of *Fissidentalium* points also to an Eocene age, so that they may tentatively be referred to the Lower Eocene, with a possibility that they may be as old as Paleocene.

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Explanation of Plates.

PLATE XII.

FIG. 1A, B.—*Nuculana paucigradata*, sp. nov. Holotype. × 2.

FIG. 2A, B.—*Limopsis*, sp. × 2.

FIG. 3.—*Lahillia australica*, sp. nov. Paratype, right hinge, nat. size.

FIG. 4.—*Lahillia australica*, sp. nov. Paratype, left hinge, nat. size.

FIG. 5.—*Lahillia australica*, sp. nov. Holotype, nat. size.

FIG. 6A, B.—*Dentalium* (*Fissidentalium*) *gracilicostatum*, sp. nov. Holotype, *a*, lateral aspect; *b*, dorsal aspect, × 2.

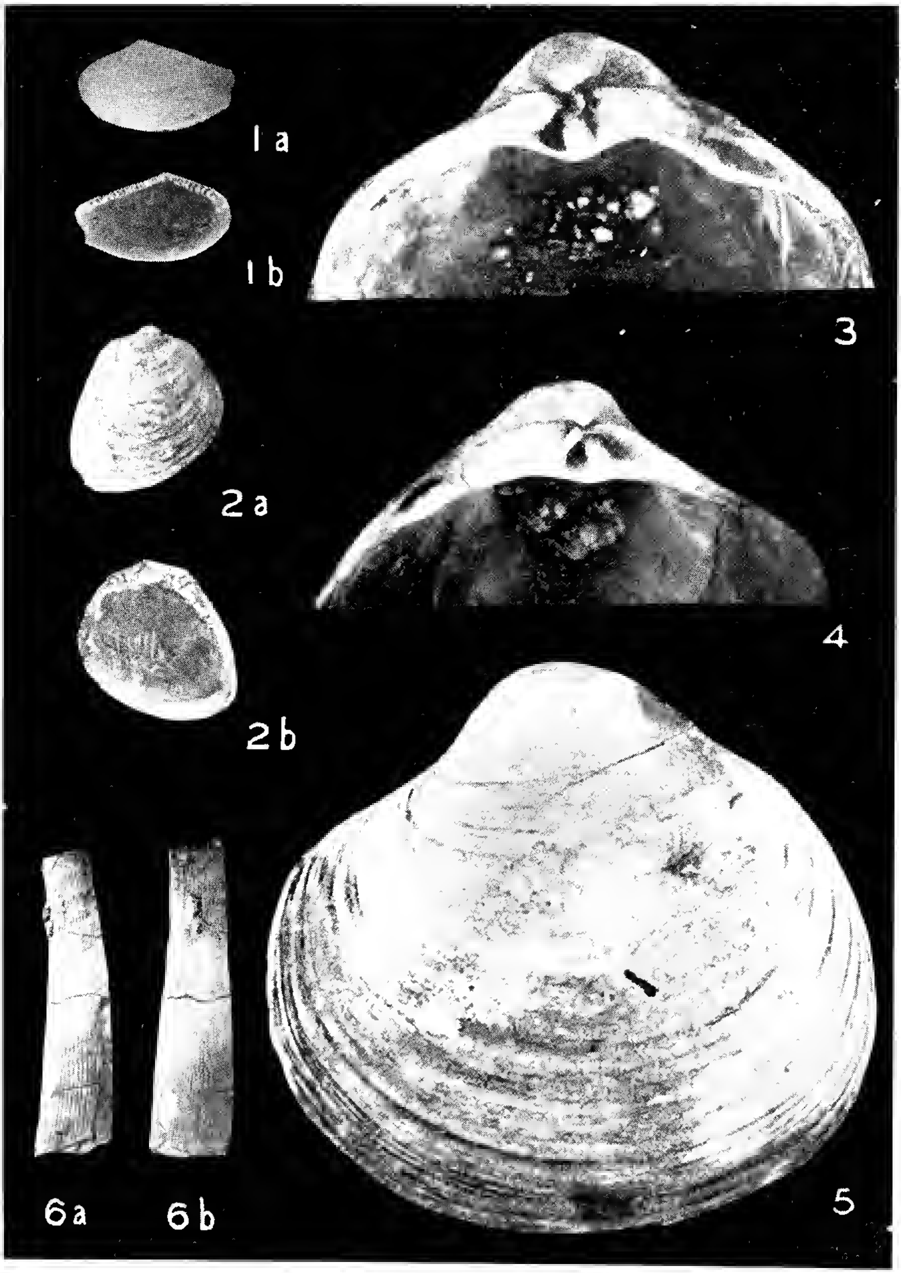
PLATE XIII.

FIG. 7A, B.—*Cucullaea* (*Cucullona*) *psephea*, sp. nov. Holotype, nat. size.

FIG. 8A, B.—*Cucullaea* (*Cucullona*) *psephea*, sp. nov. Paratype, nat. size.

FIG. 9A, B.—*Dentalium* (*Fissidentalium*) *gracilicostatum*, sp. nov. Holotype, a posterior portion of Fig. 6B. × 6; *b*, ornament. × 12.

NOTE:—Owing to discolouration by ferruginous stains, the shells were coated with ammonium chloride before being photographed.



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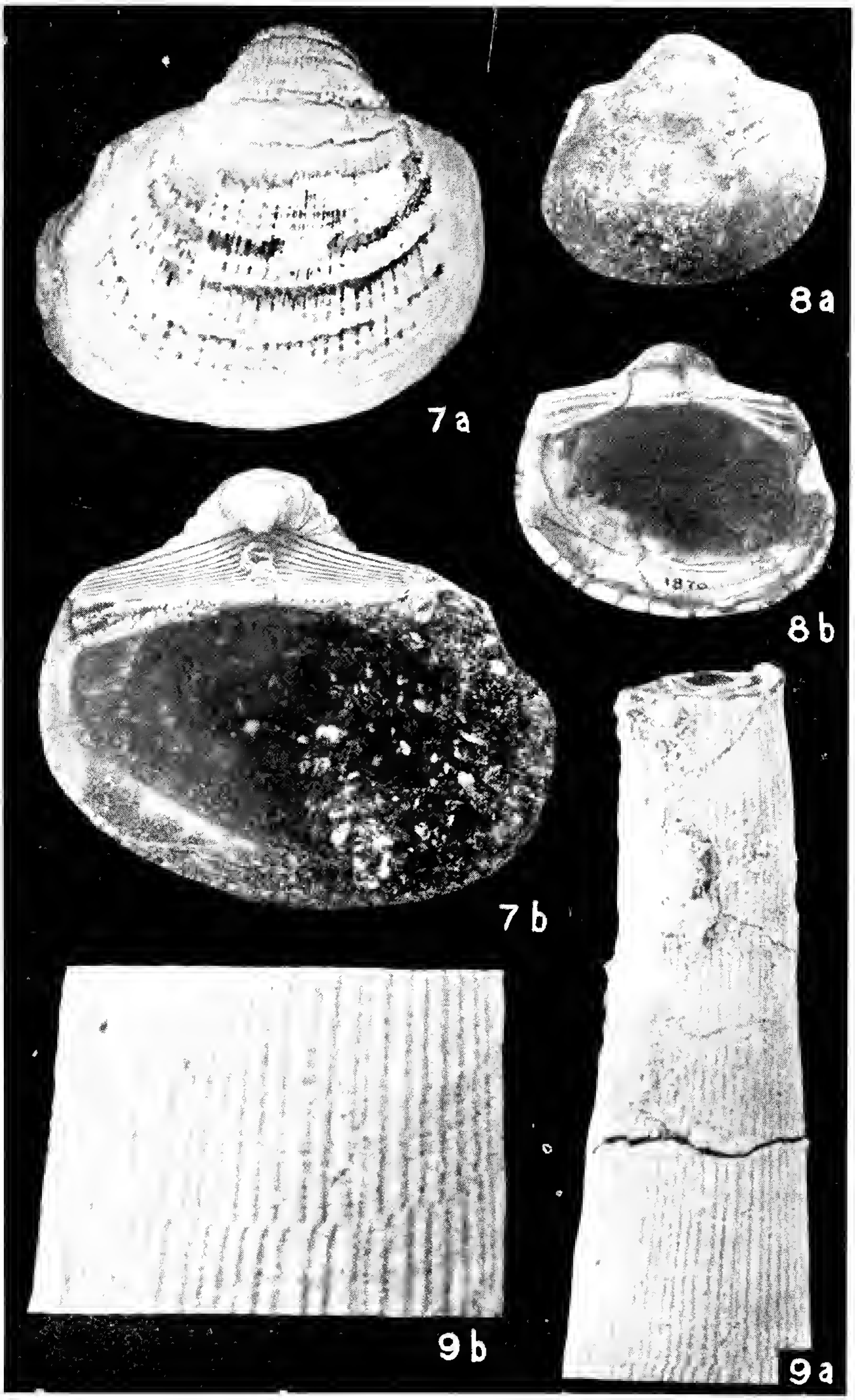

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Casey, Major Dermot A., M.C., c/o Melbourne Club, Collins-street, Melbourne, C.1	1932
Cherry, Prof. T. M., B.A., Ph.D., University, Carlton, N.3	1930

Clark, A. M., M.Sc., 9 Grattan-street, Hawthorn, E.2	1940
Clark, G. Lindesay, M.C., B.Sc., M.M.E., c/o Gold Mines of Australia Ltd., P.O. Box 856K, Melbourne, C.1	1931
Cudmore, F. A., 12 Valley View-road, East Malvern, S.E.6	1920
Davis, Captain John King, 35 Wills-street, Melbourne, C.1	1920
Dyason, E. C., B.Sc., B.M.E., 92 Queen-street, Melbourne, C.1	1913
Edwards, A. B., D.Sc., Ph.D., D.I.C., Geology School, University, Carlton, N.3	1930
Esserman, N. A., B.Sc., A.Inst.P., National Standards Laboratory, University Grounds, Sydney	1923
Gepp, Sir Herbert W., Box 1643, P.O., Melbourne	1926
Gill, Rev. E. D, B.A., B.D., 26 Winifred-street, Essendon, W.5	1938
Grice, J. Hugh, "Highfield," Lilydale	1938
Grimwade, W. Russell, B.Sc., 342 Flinders-lane, Melbourne, C.1	1912
Hartung, Prof. E. J., D.Sc., University, Carlton, N.3	1923
Hills, Assoc. Prof. E. S., D.Sc., Ph.D., Geology School, University, Carlton, N.3	1928
Hordern, A., 233 Domain-road, South Yarra, S.E.1	1940
Jack, R. Lockhart, B.E., D.Sc., F.G.S., c/o Broken Hill Pty Ltd., 422 Little Collins-street, Melbourne, C.1	1931
James, A., B.A., D.Sc., 23 Bayview-crescent, Black Rock, S.9	1917
Jutson, J. T., D.Sc., LL.B., "Darlington," 9 Ivanhoe-parade, Ivanhoe, N.21	1902
Keble, R. A., National Museum, Melbourne, C.1	1911
Lang, P. S., B.Agr.Sc., School of Agriculture, University, N.3	1938
Leeper, G. W., M.Sc., Chemistry School, University, Carlton, N.3	1931
Lewis, J. M., D.D.Sc., "Whitethorns," Boundary-road, Burwood, E.13	1921
MacCallum, Prof. Peter, M.C., M.A., M.Sc., M.B., Ch.B., D.P.H., University, Carlton, N.3	1925
Miller, E. Studley, 220 Kooyong-road, Toorak, S.E.2	1921
Miller, Leo F., "Moonga," Power-avenue, Malvern, S.E.4	1920
Millikan, C. R., M.Agr.Sc., Plant Research Laboratory, Swan-street, Burnley, E.1	1941
Morrison, P. Crosbie, M.Sc., 44-74 Flinders-street, C.1	1938
Nicholas, Geo. R., 48 Lansell-road, Toorak, S.E.2	1934
Orr, Dr. R. Graeme, M.A., B.Ch., 11 Maple-grove, Toorak, S.E.2	1935
Orr, Dr. W. F., 8 Collins-street, Melbourne, C.1	1932
Parr, W. J., 17 Bokhara-road, Caulfield, S.E.8	1927
Patton, R. T., D.Sc., M.F., Hartley-avenue, Caulfield, S.E.8	1922
Piesse, E. L., 43 Sackville-street, Kew, E.4	1921
Pittman, H. A. J., B.A., B.Sc.Agr. (Hons.), Dip.Ed., Plant Research Laboratory, Swan-street, Burnley, E.1	1942
Priestley, R. E., M.A., D.Sc., University, Birmingham	1935
Quayle, E. T., B.A., 27 Collins-street, Essendon, W.5	1920
Reid, J. S., 498 Punt-road, South Yarra, S.E.1	1924
Richardson, A. E. V., M.A., D.Sc., C.M.G., Council for Scientific and Industrial Research, 314 Albert-street, East Melbourne, C.2	1938
Rigg, Gilbert, 20 Finch-street, Malvern, S.E.5	1931

Rivett, Sir David, M.A., D.Sc., Council for Scientific and Industrial Research, 314 Albert-street, East Melbourne, C.2	1911
Rogers, J. Stanley, B.A., M.Sc., University, Carlton, N.3	1924
Sewell, Dr. S. V., 12 Collins-street, C 1	1936
Singleton, F. A., D.Sc., University, Carlton, N.3	1917
Stillwell, F. L., D.Sc., 44 Elphin-grove, Hawthorn, E.2	1910
Summers, Prof. H. S., D.Sc., University, Carlton, N.3	1902
Thomas, Dr. D. J., M.D., 81 Collins-street, Melbourne, C.1	1924
Tiegs, Assoc. Prof. O. W., D.Sc., University, Carlton, N.3	1925
Turner, Professor J. S., M.A., Ph.D., University, Carlton, N.3	1938
Vail, Lieut.-Col. L. E., 485 Bourke-street, Melbourne, C.1	1939
Wadham, Prof. S. M., M.A., Agr. Dip., University, Carlton, N.3	1932
Wettenhall, Dr. Roland R., "Aberfeldie," 557 Toorak-road, S.E.2	1938
White, Dr. A. E. Rowden, 14 Parliament-place, Melbourne, C.2	1938
Withers, R. B., M.Sc., Dip. Ed. Technical School, Brunswick, N.10	1926
Woodruff, Prof. H. A., M.R.C.S., L.R.C.P., M.R.C.V.S., University, Carlton, N.3	1913
Wright, Prof. R. D., D.Sc., M.B., M.S., F.R.A.C.S, F.R.A.C.P., University, Carlton, N.3	1941

COUNTRY MEMBERS.

Blackburn, Maurice, M.Sc., Fisheries Section, C.S.I.R., Cronulla, N.S.W.	1936
Caddy, Dr. Arnold, "Chandpara," Tylden, Vic.	1924
Caldwell, J. J., Geological Survey Office, Bendigo, Vic.	1930
Cox, H. M. S., Wombat Park, Daylesford	1931
Crawford, W., Gisborne, Vic.	1920
Currie, Mrs. Ian, Seven Oaks, Euroa	1941
Glaessner, M. F., Ph.D., c/o Mines Department, Melbourne	1939
Harris, W. J., B.A., D.Sc., High School, Echuca, Vic.	1914
Hope, G. B., B.M.E., "Carrical," Hermitage-road, Newtown, Geelong, Vic.	1918
Lawrence, A. O., B.Sc., Dip. For., 509 Ligar-street, Ballarat	1931
Mackenzie, H. P., Engr. Commr., R.N. (Ret.), Trawalla, Vic.	1924
Mann, S. F., Caramut, Vic.	1922
Quayle, D. S., 33 Gent-street, Ballarat	1939
Thomas, D. E., c/o Geological Survey, Mines Dept., Hobart	1929
Trebilcock, Captain R. E., M.C., Wellington-street, Kerang, Vic.	1921
White, R. A., B.Sc., School of Mines, Bendigo, Vic.	1918

ASSOCIATES.

Aitken, Miss Y., M.Agr.Sc., School of Agriculture, University, Carlton, N.3	1936
Alderman, A. R., M.Sc., Ph.D., F.G.S., Box 4331, G.P.O., Melbourne, C.1	1942
Bage, Miss F., M.Sc., O.B.E., Women's College, Kangaroo Point, Brisbane, Qld.	1906
Baker, G., M.Sc., Geology Department, University, N.3.	1935
Brazenor, C. W., National Museum, Russell-street, Melbourne, C.1	1931

Broadhurst, E., M.Sc., 457 St. Kilda-road, Melbourne, S.C.2 ..	1930
Buchanan, Gwynneth, D.Sc., University, Carlton, N.3	1921
Butcher, A. D., M.Sc., Fisheries & Game Dept., 605 Flinders-street, C.1	1936
Butler, L. S. G., No. 3 Los Angeles Court, St. Kilda, S.2	1929
Campbell, J. D., B.Sc., B.M.E., 1327 Burke-road, Kew	1932
Canavan, T., B.Sc., c/o Broken Hill Pty. Ltd., 422 Lit. Collins-street, Melbourne	1936
Carter, A. A. C., "Fairholm," Threadneedle-street, Balwyn, E.8 ..	1927
Chapman, W. D., Major, M.C.E., "Hellas," Stawell-street, Kew, E.4.	1927
Chapple, Rev. E. H., The Manse, Warrigal-road, Oakleigh, S.E.12 ..	1919
Clinton, H. F., Department of Agriculture, Public Offices, C.2 ..	1920
Collins, A. C., 3 Lawrence-street, Newtown, Geelong	1928
Colliver, F. S., 14 McCarron-parade, Essendon, W.5	1933
Condon, M. A., B.Sc., c/o Melbourne and Metropolitan Board of Works, Melbourne	1937
Cook, G. A., M.Sc., B.M.E., 58 Kooyongkoot-road, Hawthorn, E.2	1919
Cookson, Miss I. C., D.Sc., 154 Power-street, Hawthorn, E.2 ..	1916
Coulson, A., M.Sc., 66 Spencer-street, Essendon, W.5	1929
Coulson, A. L., D.Sc., D.I.C., F.G.S., 324 Cotham-road, Kew, E.4	1919
Cowen, Miss Margot E. H., B.Agr.Sc., 2 Leaburn-avenue, S.E.7 ..	1936
Crespin, Miss I., B.A., Mineral Resources Survey, Census Building, City, Canberra, A.C.T.	1919
Croll, I. C. H., M.Sc., 53 The Boulevard, Hawthorn, E.2	1934
Croll, R. D., B.Agr.Sc., 18 Russell-street, Camberwell, E.6	1940
Dadswell, Mrs. Inez W., M.Sc., University, N.3	1939
Deane, Cedric, "Rothley," Sorrett-avenue, Malvern, S.E.4 ..	1923
Dewhurst, Miss Irene, B.Sc., 2 Pine-grove, McKinnon, S.E.14 ..	1936
Drummond, F. H., Ph.D., B.Sc., University, Carlton, N.3	1933
Easton, J. G., 14 Royal-crescent, Camberwell, E.6	1938
Edwards, G. R., B.Sc., Powell-street, St. Arnaud	1937
Elford, F. G., B.Sc., B.Ed., 76 New-street, Brighton, S.5	1929
Elford, H. S., B.E., c/o Tait Publishing Co., 349 Collins-street, Melbourne, C.1	1934
Fawcett, Miss Stella G. M., M.Sc., Box 54, P.O., Omeo	1937
Ferguson, W. H., 37 Brinsley-road, E. Camberwell, E.6	1894
Fisher, Miss E. E., M.Sc., Ph.D., 1 Balwyn-road, Canterbury, E.7 ..	1930
Forster, H. C., B.Agr.Sc., Ph.D., 6 Glendene-avenue, Kew, E.4 ..	1938
Frostick, A. C., 9 Pentland-street, N. Williamstown, W.16	1933
Gabriel, C. J., 293 Victoria-street, Abbotsford, C.1	1922
Gaskin, A. J., M.Sc., 6 Olive-street, E. Malvern, S.E.5	1941
Gillespie, J. M., M.Sc., 22A Mereer-road, Malvern, S.E.3	1941
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
Goudie, A. G., B.Agr.Sc., Department of Agriculture, Melbourne ..	1941
Grieve, Brian J., M.Sc., Ph.D., D.I.C., 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
Holland, R. A., 526 Toorak-road, Toorak, S.E.2	1931
Holmes, W. M., M.A., B.Sc., 1 Balmoral-avenue, Kew, E.4	1913
Honman, C. S., B.M.E., Melbourne Technical College, 134 Latrobe-street, C.1	1934
Hutchinson, R. C., B.Sc., Dept. of Agriculture, Rabaul	1939
Jack, A. K., M.Sc., 49 Aroona-road, Caulfield, S.E.7	1913
Jacobson, R., M.Sc., 41 Thanet-street, Malvern, S.E.4	1937
Jessep, A. W., B.Sc., M.Ag.Sc., Botanical Gardens, Sth. Yarra, S.E.1	1927
Jona, J. Leon, M.D., M.S., D.Sc., Lister House, 61 Collins-street, Melbourne, C.1	1914
Kenny, J. P. L., B.C.E., Mines Department, Public Offices, C.2	1942
Kilvington, T., M.Sc., Physiology Department, University, N.3	1938
Lindsay, Miss Eder A., B.Agr.Sc., Agriculture School, University, N.3	1936
Lawry, Miss M. R., B.Agr.Sc., 18 Merton-street, Ivanhoe, N.21	1942
McCance, D., M.Sc., 144 Gatehouse-street, Parkville, N.2	1931
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
Manning, N., 55 Carroll-crescent, Gardiner, S.E.6	1940
Melhuish, T. D'A., M.Sc., Mt. Frome Lime Co., Burrow-road, St. Peters, Sydney	1919
Morris, P. F., National Herbarium, South Yarra, S.E.1	1922
Mushin, Mrs. Rose, 150 Garton-street, North Carlton, N.4	1940
Newman, B. W., B.Sc., Meteorological Bureau, Sydney	1927
Nye, E. E., College of Pharmacy, 360 Swanston-street, Melbourne, C.1	1932
Oke, C., 34 Bourke-street, Melbourne, C.1	1922
Osborne, N., 35 Dorrington-avenue, Glen Iris, S.E.6	1930
Prentice, H. J., B.Sc., 218 Esplanade West, Port Melbourne, S.C.7	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., "Fernlea," Upalong-road, Mount Dandenong	1923
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., 250 Riversdale-road, Hawthorn, E.3	1932
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., Animal Health Laboratory, Parkville, N.3	1937
Vasey, G. H., B.C.E., University, Carlton, N.3	1936
Wade, G. C., B.Agr.Sc., Plant Research Laboratory, Swan-street, Burnley, E.1	1941
Whincup, Mrs. Sylvia, B.Sc., Geology Department, University, N.3	1942
Wilcock, A. A., B.Sc., B.Ed., 21 Park-road, Maryborough	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, 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.), 7 Victoria-road, Camberwell, E.6 ..	1937

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The names of new genera and species are printed in italics.