PROCEEDINGS

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ROYAL SOCIETY'S HALL
9 VICTORIA STREET, MELBOURNE 3000

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Two Sympatric, Sibling Species of *Eucalyptus* from the West Coast of Western Australia

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Abstract: Two new species of *Eucalyptus* are described from the coastal areas and adjacent islands of Western Australia (lat. 24°45′S to lat. 29°S). They are assigned to the informal section of series Dumosae in which the testa is brown-netted. The two species closely resemble one another in gross morphology of buds and fruits but can be separated with certainty on characters of the venation and on oil gland size. The two species are sympatric in overall distribution and are sometimes found together in the same locality. One of these species (*E. baudiniana*) is named in honour of Captain N. Baudin, the Commandant of the voyage of discovery on which it was first collected. The other (*E. tamala*) is named from a locality where of the two, it alone occurs.

INTRODUCTION

In 1960 Gardner stated that *E. foecunda* Schau., a Western Australian species, was close to, if not identical, with *E. leptophylla* F. Muell. from South Eastern Australia. This concept has since been widely accepted. Subsequent to its original description, he added, *E. foecunda* had been 'confused by all who have written on *Eucalyptus* with another distinct species from the coastal districts between the Murchison River and Dongara, as well as Dirk Hartog Island and the Abrolhos. . . . The differences between the two are at present under investigation'. Gardner coined the manuscript name '*E. lucida*' (referring to its shining leaves) for this undescribed species. Examination of the specimens known to Gardner and of others since collected has enabled us to distinguish two species almost entirely on the basis of vegetative characters. These constitute the entity known to Gardner. The second species has almost the same geographical distribution as the first and superficially closely resembles it but can be readily separated from it (Fig. 1).

MATERIALS AND METHODS

The methods used in examination of the specimens were the same as those described by Carr, Carr and Milkovits, 1974.

The following specimens were examined:

1. A. S. George 11601, 7.9.1972. In white sand among open scrub. Nr. Notch Point, Tetrodon Loop. Dirk Hartog Island.
2. A. S. George 11607, 7.9.1972. In sand among open scrub. 7 m south of Homestead. Dirk Hartog Island.
3. R. D. Royce 5967, 19.7.1959. Red sand S. of Quoin Bluff, Dorre Island, Shark Bay.
4. R. D. Royce 5982, 21.7.1959. On ridges, red sandy soil, Bernier Island, Shark Bay.
5. R. D. Royce 6018, 23.7.1959. In red sand, Bernier Island, Shark Bay.
6. J. R. Ford Dec. 1964. 5 m NE. of Tamala.
7. P. G. Wilson 6717, 12.5.1968. 3 km E. of Kalbarri, near top of Limestone hill, Meanarra Hill.
8. D. L. Serventy 63, no date. Wallaby (Wallabi) Island, Abrolhos.
9. A. R. Main 13.2.1963. E. Wallabi Island, Abrolhos.
10. C. A. Gardner 'D 59', 4.4.1945. 19 m E. of Perenjori on Damperwah Road.
11. N. T. Burbridge 2.9.1947. 7 m N. of Geraldton near White Peak.
12. D. J. & S. G. M. Carr 408, 17.3.1968. 16·2 km on road S. from Denham, Peron Peninsula.
13. D. J. & S. G M. Carr 972, 25.8.1969. 58 km from Coastal Highway, on Bungabandi Creek Road.

A number of collections was made by S. G. M. Carr in 1966 along the road to Tamala

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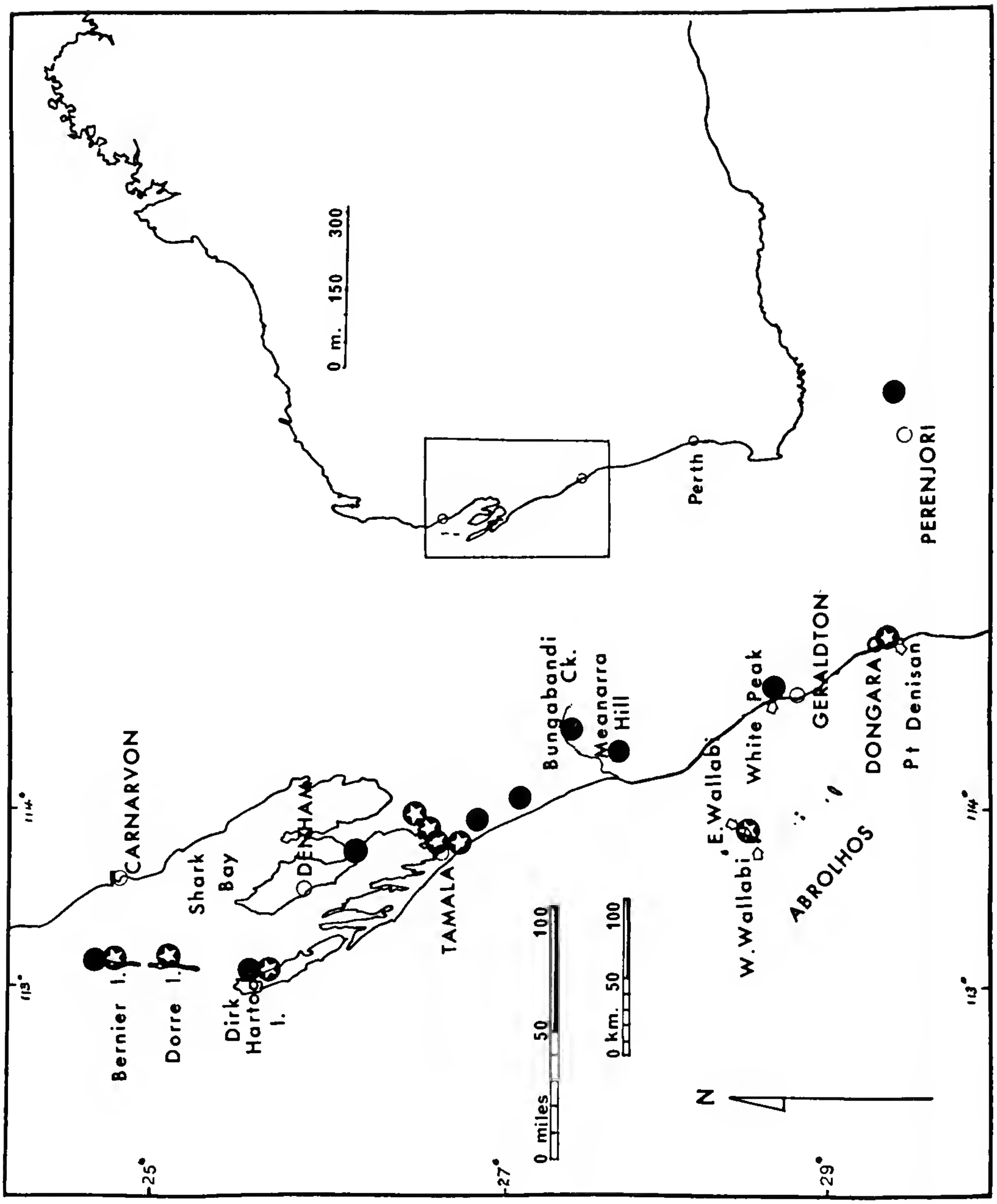


FIG. 1—Map showing localities of collection of specimens of Group A ● and Group B ✪.

Station at distances between 16 and 42 km from the turn-off from the Denham road (Carr 390-394, March 1968). Another four collections were made in 1968 in the same area (Carr & Carr 1002-1005, August). Specimens 1-11 are housed in the Western Australian Herbarium (PERTH). In addition the following materials from the New South Wales Herbarium have been examined:

E. oraria L. A. S. Johnson, holotype. L. A. S. Johnson, 10.12.60, N.S.W. 54051, 'About 5 m N. of Dongara'. (The locality appears to be at least uncertain, possibly unknown. The original locality given on the label, '5 m north of Geraldton', has been crossed out and the one cited above substituted. Presumably the specimen was collected on or near the NW. Coastal Highway. Localities along a long stretch of this road have been searched in vain by several botanists).

W. A. Oldfield, Murchison River. N.S.W. 54052.

Capitaine Baudin, 1801. Côte occidentale de la nouvelle Hollande. N.S.W. 54053.

J. Drummond, 2nd collection 87, 1884. N.S.W. 54054.

These three old specimens are cited by Johnson (1962) as identical with *E. oraria.*

Following the publication of Chippendale's (1974) list of photographs of *Eucalyptus* specimens held in Europe, the following specimens from Kew, all labelled '*E. oraria*' were examined:

C. Baudin, West Coast (Kew negative no. 602): 'to Governor King, see the specimen in Herb. Banks, of which this is a fragment given me by Mr. Dryander'. This presumably refers to the Baudin specimen mentioned in Bentham (1867) under *E. foecunda* Schau.

Oldfield, Yatthoo Flat, Limestone Hills, Murchison River (labelled Sheet 1, Kew negative no. 603).

Oldfield, Murchison River ('spear-wood') (labelled Sheet 4, Kew negative no. 606).

RESULTS

The W.A. specimens and those of our own collection can readily be classified into two groups (listed in Table 1). Group A has coarser venation, simpler marginal venation and larger oil glands than Group B. Once comparisons have been made between some specimens of the two groups other specimens can be sorted using a hand lens. However, the use of vegetative characters in the identification and classification of eucalypts is unconventional and we have therefore subjected most of the specimens at our disposal to a rigorous and detailed examination. The results of this comparative examination are set out below.

TABLE 1

MEANS OF MEASUREMENTS OF MAXIMUM DIAMETERS OF 50 OF THE LARGEST OIL GLANDS

Specimen	*Mean diameter* (μm)
GROUP B	
Serventy, Abrolhos	28·0
Oldfield, Yatthoo Flat (Kew)	29·0
Carr, 394, Tamala	32·0
Ford, Tamala	32·3
Royce, 6018, Bernier Island	33·8
A. S. George, 11601, Dirk Hartog Island	34·5
Royce, 5967, Dorre Island	35·8
Carr, 393, Tamala	36·7
GROUP A	
Carr & Carr, 972, Bungabandi Creek	44·4
Burbidge, White Peak	45·3
Baudin, Côte occidentale (N.S.W. specimen)	45·5
Royce, 5982, Bernier Island	46·4
Gardner, Perenjori	48·0
Oldfield, Murchison River Sheet 4 (Kew specimen)	48·2
Baudin (Kew specimen)	48·7
A. S. George, 11607, Dirk Hartog Island	49·8
P. G. Wilson, Meanarra Hill	52·0
Carr & Carr, 408	52·0

(1) *Venation:* Representative adult leaves of the specimens were cleared and photographed (Pl. 1) and drawings were made of the venation. Some of these drawings are arranged for comparison in Fig. 2. They show a clear difference between specimens in the coarseness of the ultimate venation, i.e. in the size of the smallest vein islets. This difference persists irrespective of the relative sizes of the leaves and their general shape, although these factors have consequent effects, of course, on the main venation pattern. Consistent differences in costal vein angles to the midrib, the numbers or thickness of costal veins or the thickness of the midrib, between patterns of dissection of the panels of lamina between costal veins by subordinate veins, or of branching patterns of the subordinate veins cannot be discerned. Nevertheless, the leaves of Group A give the overall impression of being more coarsely veined than those of Group B, consistent with the obvious differences in scale of the ultimate venation shown in Fig. 2.

(2) *Marginal Venation:* Photographs of the marginal venation at about the midpoint of representative adult leaves of different specimens are grouped in Pl. 2. Two patterns are revealed:

In specimens of Group A the space between the marginal vein (often called the 'intramarginal vein') and the margin of the leaf is crossed by simple, short ribs dividing the space into rhom-

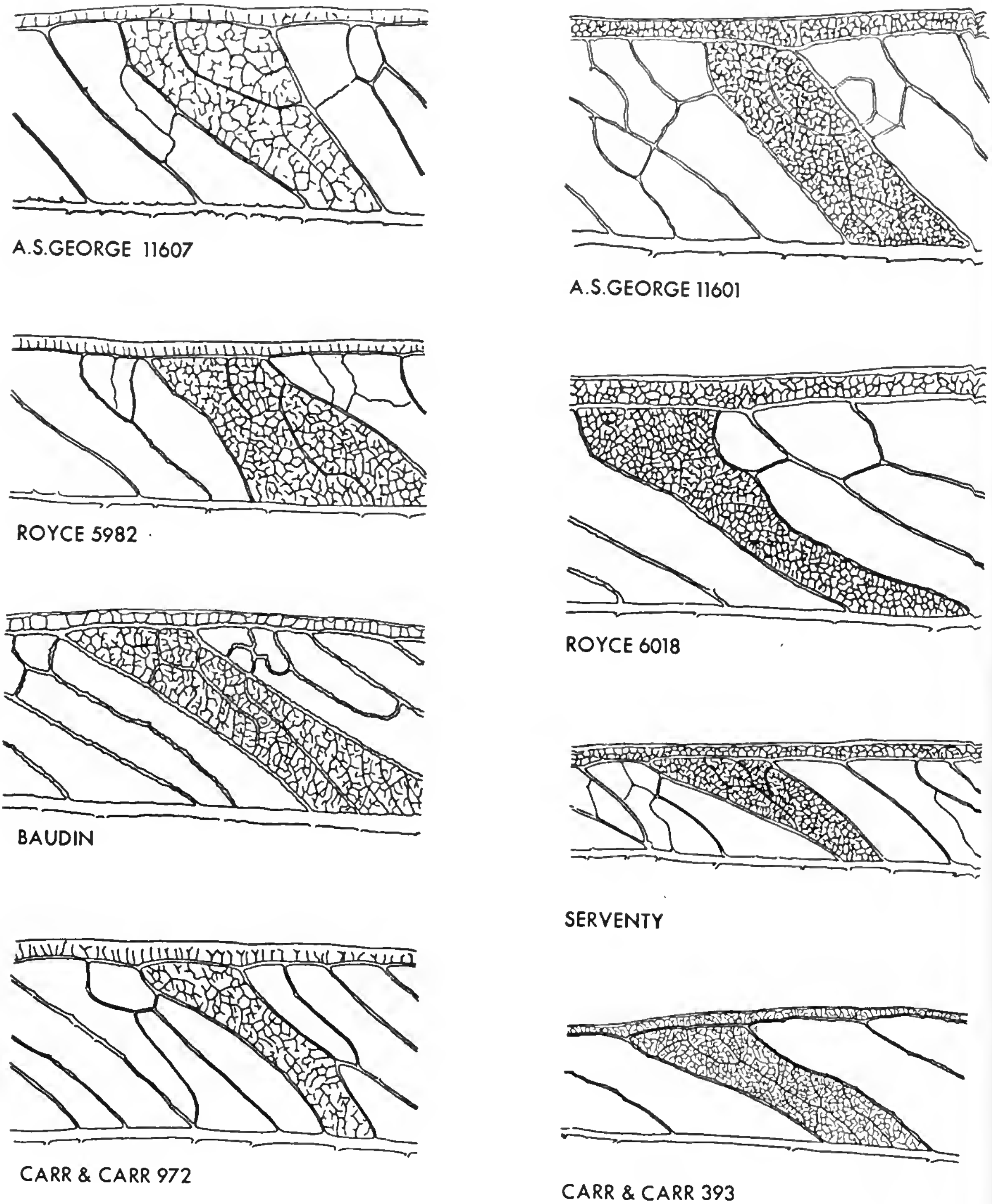


FIG. 2—Drawings, made from photographs, of the venation patterns of the middle portions of adult leaves, representative of specimens of Group A (all to the left) and Group B (all to the right). The Baudin specimen is N.S.W. 54053. (All × 2·4.)

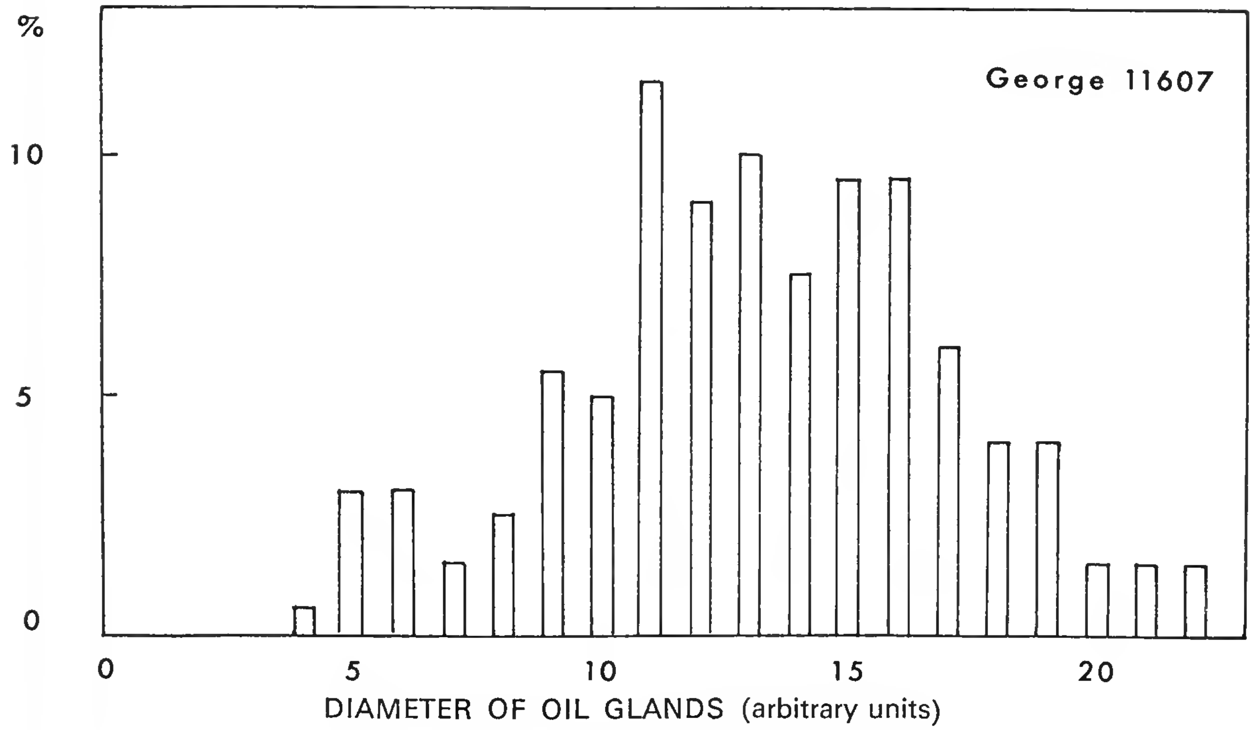


FIG. 3—Graph of the frequency of distribution of the diameters of 200 oil glands of adult leaves of George 11607.

boidal frames, each of which may contain one or two oil glands. These ribs are either unbranched or may bear short extensions into the frames; these extensions are minute venules which mostly terminate in the frames themselves.

In specimens of Group B the space between the marginal vein and the margin is divided into relatively large and irregular areas by much-branched vein loops, extending from the marginal vein. These areas are filled with a complex reticulum of finer venation and each may contain numerous oil glands. This character is always associated with the finely reticulate venation of the rest of the leaf, characteristic of specimens of Group B.

The differences in marginal venation between the two Groups are best developed in leaves of adult form and examination of the margins at about the middle third of such leaves with a hand lens should suffice to classify specimens.

(3) *Oil Glands:* Table 1 shows that measurements of the oil glands also allow the specimens to be sorted into two groups. Since any leaf will have a wide range of sizes of oil glands it is necessary to explain how measurements of this kind can be used to make comparisons. The first oil glands in the leaf appear in association with the midrib, when the leaf primordium is only a few mm long. Oil glands are also initiated in association with the marginal veins, which are the next element of the venation to be blocked in. These early oil glands continue to enlarge for a time during the further expansion of the leaf and they therefore eventually constitute some of the largest oil glands of the mature leaf. As the main costal venation is blocked in, oil glands appear between the lateral veins. By the time the leaf is about half its mature width there are more than a dozen developed oil glands—usually those which will attain the intermediate sizes—in each of the panels bounded by main lateral veins. As the vein islets are blocked in they also acquire oil glands, the smallest of which occupy the smallest territories within the venation pattern. All of these oil glands continue to expand after initiation, at first rapidly then very slowly until the maximum size (which is partly determined by the number of epithelial cell layers initiated) is reached. Oil glands cease to be initiated and expand before the leaf reaches its maximum size. The population of oil glands consists, therefore, of a number of sets each corresponding roughly to a stage of blocking in of the venation and consequently of diminishing initial and maximum size. A frequency distribution of diameters of oil glands is therefore not normal but consists perhaps of several overlapping distributions (Fig. 3). Direct statistical comparisons between

the sizes of oil glands of different specimens are therefore difficult, despite the fact that visually the oil glands of a given specimen may collectively be obviously smaller than those of another. We have therefore chosen to use a simple, practical discriminant. This is the mean maximum diameter of 50 of the largest oil glands which can be found in microscope fields along the marginal vein and near the midrib of cleared leaves. In surface view oil glands are approximately spherical but large ones near the margin may become ellipsoidal during expansion of the leaf. The measurement is taken along the longest diameter of the whole of the lumen of the gland. The measurements are not amenable to simple statistical treatment. Fortunately, in the present instance, the differences support the results of visual comparison and are large enough to be convincing. Using this criterion the specimens again separate into the same two groups (Table 1) as are found using venation criteria.

(4) *Phytoglyphic Analysis:* By this we mean (Carr, Milkovits & Carr, 1971) an examination by scanning electron microscopy of the surface features of the leaf cuticles, and by light microscopy of stained cuticle preparations and of thin (1-2 μm) sections of leaves. Scanning electron microscopy revealed no differences of value to the present study. The cuticles are uniformly plane, without ornamentation, even around the stomata. On the basis of details of the stomata in median section (at right angles to the length of the pore) the specimens fall into two groups (Pl. 3). Specimens of Group A have stomata in which the edges of the outer cuticular 'flaps' are often bent inwards towards the guard cells and are not raised above the level of the surrounding cuticle. The flaps of the stomata of Group B, on the other hand, are often raised well above the level of the surrounding cuticle and tend to form an arch above it. The sections shown in Pl. 2 are chosen to represent configurations typical of the majority of the stomata to be found on the 'free' part of the lamina of the leaf. Near the margin of the leaf, where the cuticle is thicker, the stomatal sections may have a different shape, the cuticular flaps are often larger and more erect. In addition, eucalypt stomata are dimorphic (Carr & Carr, in preparation). A minority (1-5%) are much larger and of a different form. Our comparisons here refer to the majority of the stomata found between the midrib and the margin. The anatomy of the cuticle itself shows some differences between the specimens. The thin outermost layer of the cuticle of Carr and Carr 972 is birefringent. This birefringent layer may in part be responsible for the very shiny appearance of the leaves which led Gardner to the name 'lucida'. The Tamala trees also had somewhat shiny leaves and the leaves of Royce's 5982

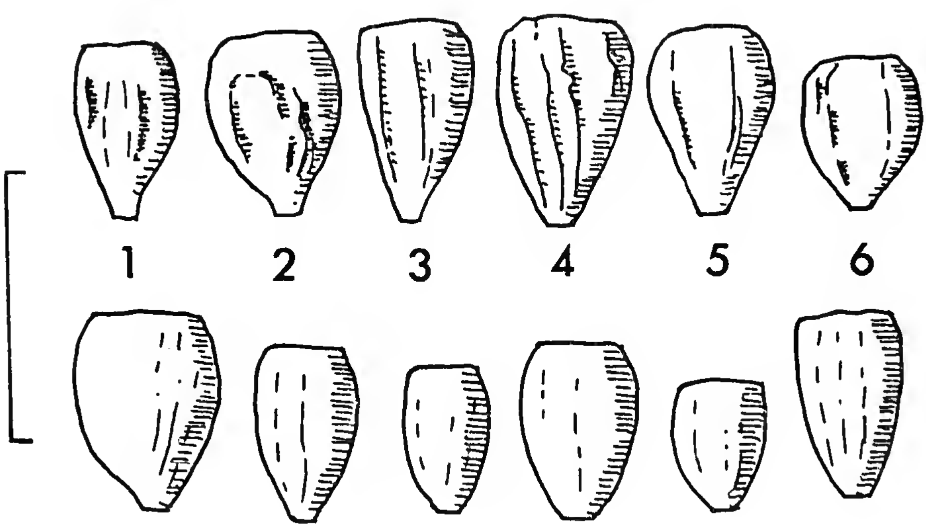


FIG. 4—Drawings, made from photographs, of representative fruits of specimens of Group B (upper row) and Group A (lower row). Upper row: 1. George 1101. 2. Royce 6018. 3. Royce 5967. 4. Carr & Carr 393. 5. Carr & Carr 394. 6. Ford. Scale line on left equals 1 cm. Lower row: 1. George 11607. 2. Royce 5982. 3. Carr & Carr 972. 4. Wilson. 5. Burbridge. 6. Gardner.

(from Bernier Island) (Group A) were recorded as 'shining' so it appears that this is not a discriminant field character. All the specimens have a birefringent inner zone of the cuticle.

(5) *Fruits:* As is usually the case in eucalypts, the fruits of a given specimen are relatively uniform in size and shape, but there is a wide range in both size and shape between the fruits from different collections. In general it would be difficult to assign fruits to Group A or to Group B, as determined on vegetative characters. Nevertheless, the fruits of Group A are generally thinner-walled and smaller than those of Group B and they differ subtly in shape (Fig. 4). In Group A the fruits are sessile or very shortly stalked, light brown when mature. They vary in size from 4-7 mm long by 3-5 mm wide. They are usually subcylindrical, narrowed gradually to

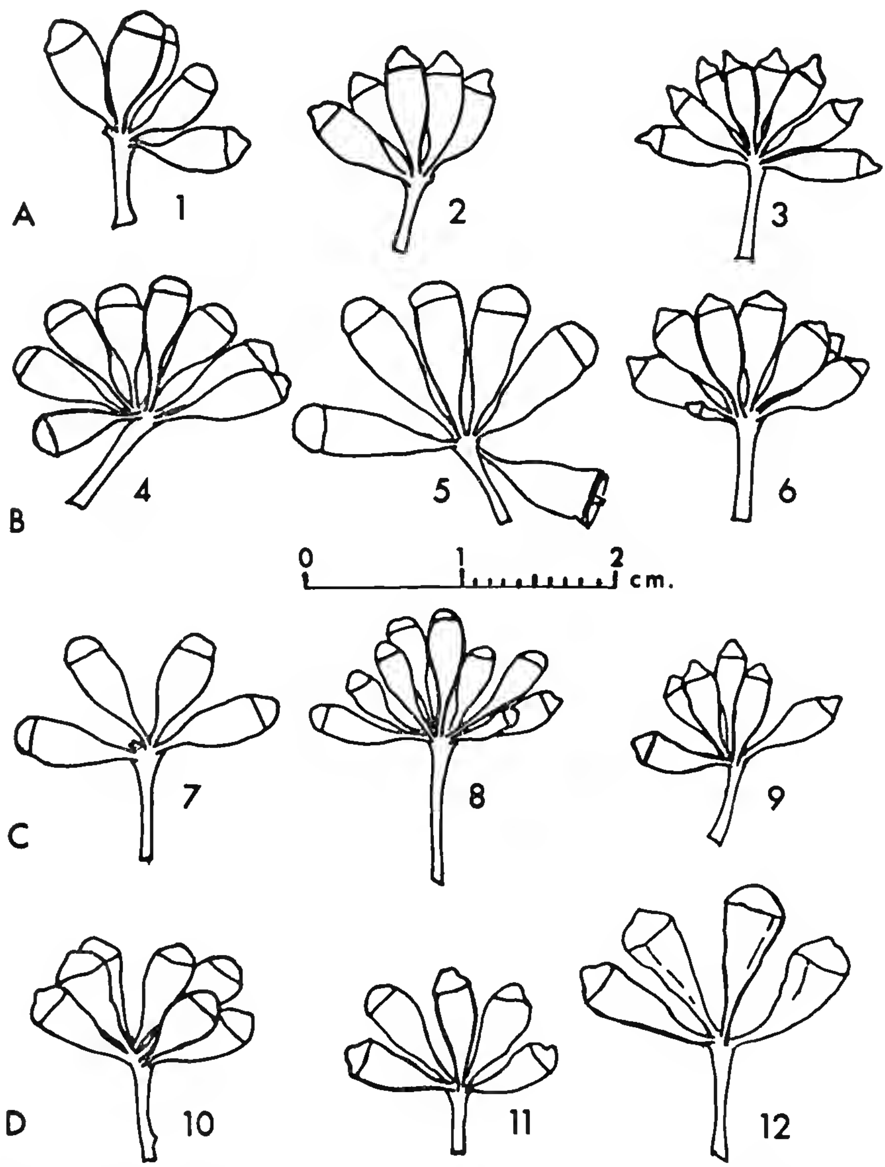


Fig. 5—Drawings of mature flowers; rows A and C, Group A. Rows B and D, Group B. For comparisons, the George specimens are numbers 1 and 4, the Royce specimens from Bernier Island, numbers 2 and 5. 1. George 11607. 2. Royce 5982. 3. Carr & Carr 972. 4. George 11601. 5. Royce 6018. 6. Carr & Carr 1004. 7. Wilson. 8. Serventy. 9. Gardner. 10. Ford. 11. Royce, Dorre Island 5967. 12. Carr & Carr 1003.

the orifice, the maximum diameter being at a distance of 30% of the length or more below it. There are 3 or 4 loculi. The valves are triangular with short blunt tips, sunk (in some specimens deeply) below the level of the orifice.

In colour, shape and position of valves, number of loculi and length of stalk the fruits of Group B resemble those of Group A. However, they tend to be larger, ranging in size from 5-9 mm long by 3·5-5 mm wide. They are pyriform or conical, *abruptly* narrowed to the orifice from a maximum diameter only 20% or less of the length below the orifice. The fruits of Group B are thick-walled, more or less furrowed or even *sulcate*. Those of Group A are smoother, usually only slightly furrowed. The depth of insertion of the valves is often (but not invariably) deeper below the orifice in the fruits of Group A than in those of Group B.

One interesting point is that the fruits of specimens of the two Groups from adjacent localities tend to resemble each other to some extent. Thus the fruits of George 11601 and 11607 from Dirk Hartog Island have similarities of shape, as do the two Royce specimens from Bernier Island (Fig. 4). On the other hand the Tamala specimens—all of Group B—show a wide range of size but not of shape.

(6) *Flowers:* The inflorescences are stalked and consist of 7 to 15 flowers. They are axillary and atonic (i.e. distributed along the annual shoot and not restricted to any particular region of it). Flowers are formed and become fully developed in a single season. No consistent differences in the position or composition of the inflorescences or in the anatomy of the flowers themselves by which specimens of Group A, distinguished by vegetative characters, are separable from specimens of Group B. There are differences between individual specimens in flower size and shape and these entrain consequent differences in anther and ovule size and shape. The operculum is rounded in some specimens, apiculate in others but these differences bear no reference to the two groups based on vegetative characters. However, just as the fruits of specimens of the two Groups from adjacent localities may tend to resemble one another in shape, so also, in some cases, do the flowers (Fig. 5). It is noticeable that in the same locality the flowers of specimens of Group A (like the fruits) tend to be smaller than those of Group B (Fig. 5 cf. 1 and 4, 2 and 5). However, at Tamala a wide range in size is shown by the flowers of the trees which are all of Group B.

In the flower bud the stamens are all inflexed and at least the outer filaments have some oil glands. The anthers are all potentially fertile (i.e. there are no regular staminodes). The anthers are versatile, the outer ones tapering, in outline resembling a truncated inverted triangle. The gland in the connective is sub-terminal and not visible from the front (adaxial) side of the anther. The anthers open by slits parallel to their length. The style is usually shorter than the dome of the inflexed stamens. The stigma is hemispherical and wider than the style. The style contains oil glands. The ovular structures are in four longitudinal rows and up to 15 to 16 transverse rows. There are as many as 10 rows of ovules, on the margins of the placenta.

(7) *Seeds:* Seeds are present in very few of the collections available for examination. Seeds were available from the two A. S. George specimens, from those of Main and Wilson and from our own collections. All the seeds conform to the third group of the informal category 'Dumosae' of Carr and Carr, 1969: 'the third group has brown seeds without wings and with a shallow, dark netting of anticlinal cell walls on the surface'. (The quoted passage goes on to say that this group includes '*E. oraria*' but this referred not to the Johnson holotype but to our own Tamala collections.) The number of seeds per capsule is small—one or two per loculus, often fewer. The specimen A. S. George 11601 had few capsules and these produced fewer than half a dozen seeds in all. Some of the flowers of this collection proved on examination to be functionally male (Carr, Carr & Ross, 1971). The size of the seeds bears a relationship to the size of the flowers and fruits and there are marked differences in shape (Fig. 6) but neither size nor shape bears a relationship to the grouping established on vegetative characters.

(8) *Seedlings:* It proved possible to raise seedlings from seeds of our own collections and from the two made by A. S. George. In all cases the cotyledons are reniform. The seedling leaves are opposite for 7-9 pairs in the Tamala seedlings and for 5-7 pairs in the seedlings from Carr and Carr 972. The Tamala seedlings developed small lignotubers by the time they had about 15 pairs of leaves, but the Carr and Carr 972 seedlings had not developed them even after another 10 leaf pairs had been laid down. The seedling leaf shape is quite different in the two sets of seedings (Fig. 7). The early leaves—up to node 6—of Carr and Carr 1004 (the seedlings of which are typical of those of the Tamala specimens) are ovate, at least half as broad as long, sometimes broadly pointed. The early seedling leaves of Carr and Carr 972 are broadly lanceolate, and they are longer and narrower than the corre-

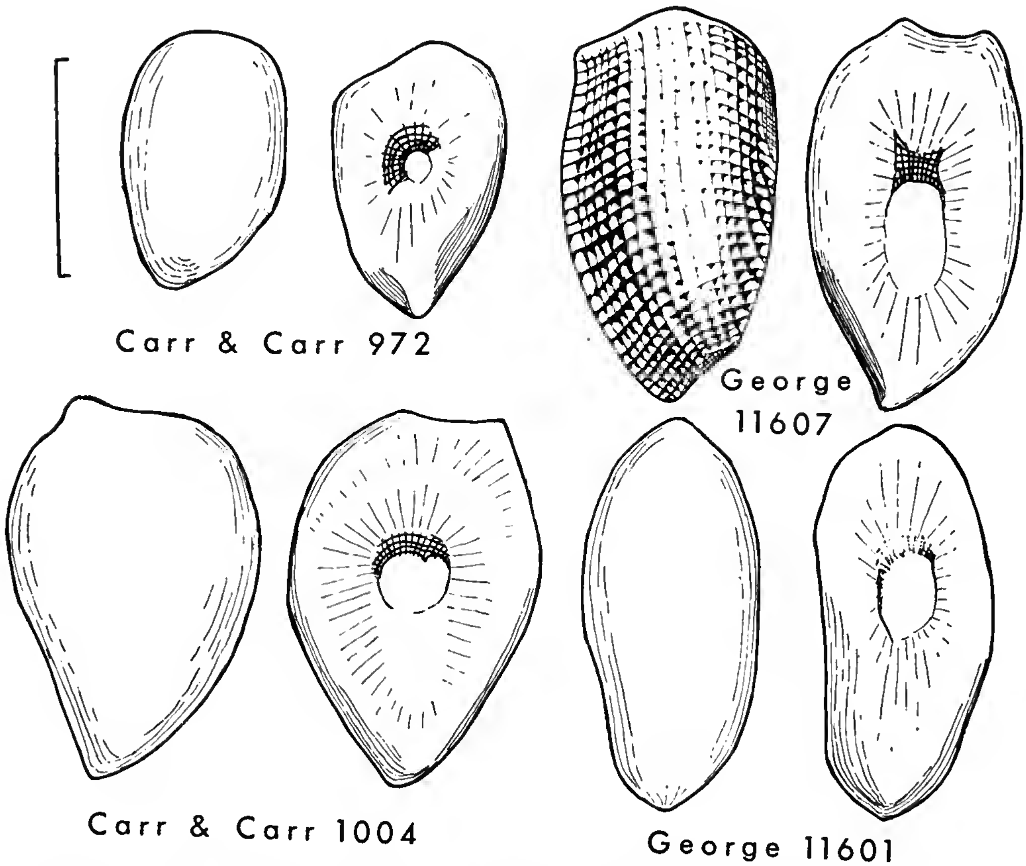


FIG. 6—Seeds. All have the same 'netted' pattern shown for the seed of George 11607. Upper row, Group A. Lower row, Group B. The scale mark, top left, represents 1 cm.

sponding seedling leaves of the Tamala seedlings.

The seedling leaves of the two George specimens show similar differences in shape. George 11601 has broadly ovate leaves. George 11607 has longer, more lanceolate leaves which are relatively narrower than those of 11601. Thus the specimens of Group A have seedling leaves which are relatively narrower and are usually longer than those of Group B, which are ovate, at least half as wide as long.

There are further points of difference between the two sets of seedlings. For instance the oil glands of George 11607 are almost twice as large (diameter 28 μm) as those of 11601 (15 μm). The venation is different, the marginal vein of 11607 being strong, close to the edge of the leaf, while that of 11601 is relatively weak and somewhat distant from the edge. Finally, the minor venation between the marginal vein and the edge of the leaf in each case echoes the characteristics described above for the mature adult foliage. Similar differences are found between the Tamala specimens and Carr and Carr 972. In seedling leaves of the latter the oil glands have a maximum diameter of 30 μm, in those of Carr and Carr 1004 they are no larger than 13 μm. The marginal vein in 972 is strong and close to the edge of the leaf, in 1004 it is weak and consists of a series of loops, distant from the edge and dominated by the costal bundles (Fig. 7). The minor venation within the margin in the 972 seedlings closely resembles that of the adult leaves of the same specimen while that of 1004 resembles its parent's adult leaves. Thus the early seedling leaves of specimens within a Group resemble one another remarkably and show many differences from those of the other Group.

(9) *Tree Form and Bark Character:* Few collections yielded seeds for examination. Even fewer provided information on the tree form and bark character. The Royce specimens were low mallees, 1-1·5 m high. The A. S. George specimens were 'spreading mallees', 11601 a few feet high, 11607 1·5 m high. The Gardner spe-

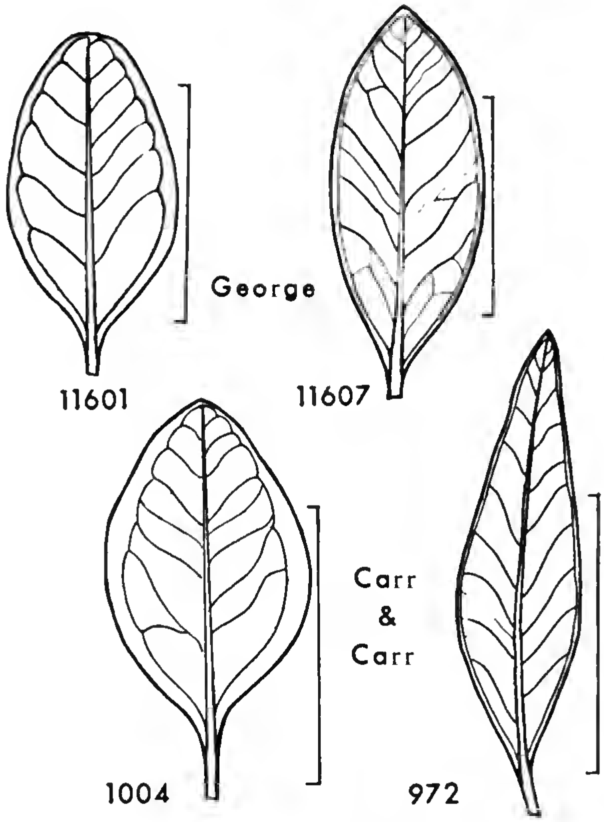


FIG. 7—Seedling leaves, Group A to the right, Group B to the left. The scale marks represent 1 cm. Each leaf is from the 5th pair of a seedling.

cimen was a mallee. The Oldfield specimen from Yatthoo Flat was a 'shrub branched from the root, 6-8 feet tall'. In Bentham (1866) a specimen of Oldfield's is cited under *E. foecunda* as having 'dark, smooth bark'. The Wilson specimen was a mallee, 4 m tall. No specimens of bark were with these or any specimens other than our own. For his 11601, George records 'bark smooth on upper branches, rough lower down', but there are no notes for the bark of 11607. It is possible that in other cases the stems were not considered to have developed a characteristic adult bark. Our larger Tamala specimens were all many-stemmed mallees up to 12 feet high with smooth grey bark on the branches but with rough bark in several layers, peeling in long broad strips from the lower trunks (Pl. 4). In contrast, Carr and Carr 972 was a single-stemmed tree, 6·2 m high with dark grey bark with a brownish tinge which is rough and close-textured (not exfoliating) for about 1·5 m, then smooth on the upper trunk and branches. This tree was typical of others of the same kind in the locality, but tall mallee forms also were present. It is unfortunate that only our own specimens provide information on the form of the mature tree and the nature of the bark on stems which could be regarded as full grown. For the present, we must assume that the mature bark of specimens of Group A is brownish, coarse and close-fitting, while that of specimens of Group B is greyish and exfoliating in long broad strips.

(10) *Stem Anatomy:* All specimens examined proved to have oil glands in the pith. For the Tamala specimens this was already stated in Carr & Carr, 1969.

DISCUSSION

(1) *Two sibling species.* We have shown that the specimens examined can be divided into two groups (listed in Table 1) on the basis of a number of vegetative characters of the adult leaves, the seedlings and of the bark. Differences found in the adult leaves are echoed in the seedling leaves and the seedlings of the two Groups are as distinct as the adults. On the other hand, no clear and consistent differences of the same order have been found in the reproductive structures of the two Groups. There are, it is true, slight differences in size, shape and thickness of the wall of the fruits but to establish these categorically would require special study of a much wider set of collections. Some collectors (George, Royce, Oldfield) have provided specimens of both Groups from the same general locality and there seems to be almost complete overlap in their geographical distribution.

In view of these facts we propose to name the two Groups as separate species, *E. baudiniana* (Group A) and *E. tamala* (Group B). The two must be very closely related—probably sibling—species. To account for their sympatric distribution there must be some barrier to interbreeding. It is possible that the barrier is ecological, perhaps edaphic, but the field data accompanying most of the specimens are quite inadequate to establish any such hypothesis. Most of the area of occurrence has coastal limestone as well as sandy soils. It seems likely that the species are both lime and salt tolerant. It is unlikely that the barrier is phenological—both species flower at about the same time of year (July to September). The barrier could be due to incompatibility in either pollination or fertilization.

No correlations of such characters as leaf gland size, coarseness of venation, fruit, flower or seed size with latitude can be distinguished for either species. Indeed at one locality (Tamala) the oil gland sizes for *E. tamala* span virtually the whole range for that species. It would appear, therefore, that in their quantitative aspect, these vegetative characters have no particularly strong selective advantage or disadvantage. This strengthens the case for regarding the two Groups as separate species, not as ecotypes of a single species.

(2) *Relationship to other species and specimens.* Since the part of the coast on which these species occur, especially that in Shark Bay, was visited by many of the early explorers of the continent, specimens are likely to have been collected by them. There are specimens in the Paris herbarium of a eucalypt collected in 1801 on the voyage led by Captain Baudin. It will be shown elsewhere (Carr & Carr, in preparation) that this must have been collected on Bernier Island, whence came also two of the Royce specimens. Photographs of the Baudin specimens were presented by Hj. Eichler to the Western Australian Herbarium in 1966. The specimens are labelled 'Côte occidentale de la Nouvelle Hollande' and were annotated by Maiden in 1903 as '*E. incrassata* Labill. v. near *E. foecunda* Schauer'. It seems certain that the N.S.W. specimen 54053, consisting of four detached leaves, six detached umbels of mature flowers and a short twig with a few immature fruits, was given to Maiden from the Baudin specimens. Our examination of it shows it to belong to *E. baudiniana*, and the name is given in honour of N. Baudin. Since Royce has also collected the other species, *E. tamala*, on Bernier Island, and bearing in mind the fact that in their 'low mallee' aspect the two species look extraordinarily alike in the field, it seemed possible that both species might have been collected on the Baudin expedition. However, the Baudin specimen at Kew is also of *E. baudiniana*.

In the same month as Gardner's note on an undescribed species (see Introduction) appeared in print, L. A. S. Johnson was in Western Australia and took the opportunity to try to collect material of it. Subsequently, in 1962, he described, without illustration or reference to Gardner, a single fragment as the type of a new species, *E. oraria*. The locality from which his fragment was collected appears to be unknown or at least uncertain (see Materials and Methods). The specimen has 33 leaves and 13 fruits. There are no flowers or seeds but, invoking a circular argument, Johnson adduced characters of the flowers from other materials, including the Baudin fragments in the N.S.W. Herbarium and the N.S.W. Oldfield specimen, which can both be shown to be not equivalent with his own fragment, the holotype of *E. oraria*. The Drummond specimen is mixed. Thus the description of the species is based on mixed material. The only valid comparisons which can be drawn between the holotype and any other specimens must be made on the basis of the leaves and the fruits. The fruits of the holotype have the valves practically flush with the orifice—a character not shared by any of the other specimens considered above. Unless and until more material can be provided by Johnson, the specimen labelled as the type of *E. oraria* is best relegated to the category of indeterminate fragments which all too often plague the eucalypt taxonomist and which, unless concerning them there are forensic, plant geographical (see Carr & Carr, 1975) or other special questions to be settled, should be discarded or consigned to the 'miscellaneous' box. It is particularly frustrating to have to deal with modern, let alone old, taxonomic entities so poorly authenticated and so vaguely described as *E. oraria*, said by its author to be 'sometimes found in association with *E. dongarraensis*' but which, in fact, has failed to be found again in the type locality of that species, despite diligent search.

The two new species differ from *E. foecunda* in the presence of glands in the pith, in the shape and mode of dehiscence of the anthers and in the orientation of the nectary. They can be distinguished from three other species which grow in the same area and resemble them and each other closely, particularly when all have the form of dwarf mallees, as is often the case. These species all have glands in the pith, anthers with parallel cells and brown netted seeds. If flowers are available *E. loxophleba* Benth. and *E. accedens* W. V. Fitzg. can be recognized on the basis of stamen characters. In both, the filaments are inserted close to the base of the anthers. *E. accedens* has a strongly ornamented cuticle, that of *E. loxophleba* is plain. Both species have bisected cotyledons. In *E. brachycorys* Blakely the cotyledons are reniform. The stamens resemble those of the new species except that the anthers have short sterile tails and the filaments are inserted on a broad, erect staminophore. However, the characters of the style are more than sufficient to distinguish this species from the two new ones. It is sharply expanded in the upper half and extends beyond the cone of stamens in bud to occupy a pocket in the operculum. The cuticle is ornamented. The situation with regard to *E. brachycorys* is complicated by the existence of one, or perhaps two, related species which are undescribed.

DESCRIPTIONS OF SPECIES

Eucalyptus baudiniana D. J. et S. G. M. Carr sp. nov.

Arbor usque ad 7 m alta vel frutex multicaulis; lignotuber ignota. Cortex brunneola-grisea laevis trunco superiori et ramis, aspera brunneola textu crebro trunco inferiori. Glandulae oleosae cortici desunt, medulla adsunt. Cotyledones reniformes integrae; folia plantularum ovato-lanceolata paribus primus paucis, basim versus latissima, non plus quam dimidio latioria quam longa. Folia matura alternantia, anguste lanceolata ad lanceolata 3·5-8 cm longa, 0·6-1·9 cm lata, vivide viridia nitentia. Rete venarum grossum (ex comparatione cum *E. tamala*), venulae inter venam marginalem et marginem pro ratione parve ramulosae, glandulae oleosae maximae plerumque plus quam 40 μm diametro.

Inflorescentiae pedunculatae, axillares, 7-15 flores. Pedunculus 5-10 mm longus, parum compressus. Flores pedicellis brevibus 6-8 mm longis. Operculum duplex, sepalinum precociter deciduum. Stamina omnia fertilia, omnia in alabastro inflexa. Filamenta alba, saltem ea serierum exteriorum maturitate glandulis oleosis. Antherae loculis parallelibus, rimis longitudinalibus dehiscentes, filamentum medio vel parum infra medium affixum, glandulo ab anteriori non manifesto. Stylus cylindricus, in alabastro cono staminum inflexorum vix longior, stigma stylo latius, stylo glandulis oleosis. Ovula et ovulodia seriebus 4 longitudinalibus, ovula marginalia placentae parti proximali.

Fructus 4-7 mm longus, 3-5 mm latus cylindroideus, basi in pedicellum decrescens, in siccitate vix rugosus. Valvae inclusae (saepe profunde), erectae nectario verticali appressae, triangulares apicibus brevibus obtusis.

Semina brunnea testa reticulata, palea rufobrunnea, seminibus brevior.

A tree to 7 m tall or a many-stemmed shrub, lignotuber not seen. Bark brownish grey and smooth on upper trunk and branches, rough brownish and close-textured on lower trunk. Oil glands absent from the bark, present in the pith. Cotyledons reniform entire, first few pairs of seedling leaves ovate-lanceolate, widest near the base, not more than half as wide as long. Adult leaves alternate, narrow-lanceolate to lanceolate 3·5-8 cm long, 0·6-1·9 cm wide, bright green and shining. Venation pattern coarse (in comparison with that of *E. tamala*), minor veins between the marginal vein and the margin relatively unbranched, the largest oil glands usually more than 40 μm diameter.

Unit inflorescences stalked, axillary, consisting of 7-15 flowers. Peduncle 5-10 mm long, slightly compressed. Flowers shortly stalked, 6-8 mm long. Operculum double, the sepaline one shed early. Stamens all fertile, all inflexed in bud. Filaments white, oil glands present at maturity at least in those of the outer rows. Anthers with parallel cells, dehiscing by longitudinal slits, filament inserted at or just below the middle, gland not visible from the front. Style cylindrical, scarcely longer than the cone of inflexed stamens in bud, stigma wider than style, style with oil glands. Ovules and ovulodes in 4 longitudinal rows, the ovules marginal on the proximal part of the placenta.

Fruits 4-7 mm long, 3-5 mm wide cylindroid and tapering into the pedicel, scarcely wrinkled when dry. Valves included (often deeply), erect against the vertical nectary, triangular with short blunt tips.

Seeds brown, surface of testa netted, chaff reddish brown, shorter than the seeds.

Type: Bungabandi Creek Road, 36 miles from junction with North-west Coastal Highway (approx. 27°S, 15°22′E). 25 June 1969, D. J. and S. G. M. Carr 972 (holo: PERTH).

Distribution: Coastal areas of Western Australia between Bernier Island and Geraldton, inland as far as Perenjori.

Eucalyptus tamala D. J. et S. G. M. Carr sp. nov.

Frutex multicaulis usque ad 3 m alta; lignotuber adest. Cortex grisea, laevis trunco superiori; aspera, fibrosa, exfolians in lacinias longas, latas trunco inferiori. Glandulae oleosae cortici desunt, medulla adsunt. Cotyledones reniformes integrae; folia plantularum prima ovata, minus quam bis longiora quam lata, apice rotundata vel in apiculum obtusum contracta, vena marginali profundi-lobata. Folia matura alternantia, anguste lanceolata ad lanceolata, 3·5-9 cm longa, 0·8-1·9 cm lata, vivide viridia nitentia. Rete venarum tenue densum, venulae inter venam marginalem et marginem multo ramosae, glandulis oleosis numquam plus quam 38 μm diametro.

Inflorescentiae pedunculatae, axillares, 7-15 flores, pedunculo 5-10 mm longo, parum compresso. Flores pedicellis brevibus 6-8 mm longis. Operculum duplex, sepalinum precociter deciduum. Hypanthium operculo longius. Stamina omnia fertilia, omnia in alabastro inflexa. Filamenta alba, saltem ea serierum exteriorium maturitate glandulis oleosis. Antherae versatiles rimis longitudinalibus dehiscentes, filamentum medio vel parum infra medium affixum, glandulo ab anteriori non manifesto. Stylus cylindricus, in alabastro cono staminum inflexorum vix longior, stigmate tam lato quam stylo. Glandulae oleosae parti inferiori styli tantum adsunt. Ovula et ovulodia seriebus 4 longitudinalibus, ovula marginalia placentae parti proximali.

Fructus 5-9 mm longus, 3·5-5 mm latus, sessilis vel subsessilis, plerumque obconicus vel obpyriformis, abrupte orificium versus contractus, cristis irregularibus plus minusve longitudinalibus, loculis 3 vel 4. Valvae profunde inclusae, triangulares apicibus brevibus obtusis, erectae nectario verticali appressae.

Semina brunnea usque ad 1·8 mm longa, 1·0-1·2 mm lata, testa reticulata. Palea aurantiaco-brunnea, seminibus brevior.

A many-stemmed shrub (mallee) up to 3 m tall, lignotuber present. Bark smooth and grey on upper trunk, coarse, fibrous and exfoliating in long, broad strips from the lower trunk. Oil glands absent from bark but present in the pith. Cotyledons reniform, entire; first seedling leaves ovate, less than twice as long as broad, rounded at the tip or tapering to a blunt point, marginal vein deeply-lobed. Adult leaves alternate, narrow lanceolate to lanceolate, 3·5-9 cm long, 0·8-1·9 cm wide, bright green and shining, oil glands never more than 38 μm diameter. Venation fine and dense, small veins between margin and marginal vein much branched. Unit inflorescences axillary, stalked, consisting of 7-15 flowers, peduncles 5-10 mm long, slightly compressed. Buds shortly-stalked, 6-8 mm long. Operculum double, the sepaline one falling early. Hypanthium longer than the operculum. Stamens all fertile, all inflexed in bud, filaments white, those of at least the outer rows containing oil glands at maturity. Anthers versatile, dehiscing by longitudinal slits, filaments inserted at or slightly below the middle, gland not visible from the front. Style cylindrical, scarcely longer than the cone of inflexed stamens in bud, stigma as wide as the style. Oil glands present only in the lower half of the style. Ovules and ovulodes in 4 longitudinal rows, the ovules marginal on the proximal part of the placenta. Fruits 5-9 mm long, 3·5-5 mm in diameter, sessile or nearly so, usually obconical or obpyriform, contracted abruptly to the orifice and with irregular, more or less longitudinal, ridges, loculi 3 or 4. Valves deeply included, triangular with short blunt tips, erect against the vertical nectary. Seeds brown, up to 1·8 mm long, 1·0-1·2 mm wide, testa netted. Chaff orange-brown, shorter than the seeds.

Type: Roadside (Tamala Station Road), 26 miles from junction with Denham Road (26°35′S, 113°55′E). 27 June 1969, D. J. and S. G. M. Carr 1003 (holo: PERTH).

Distribution: Coastal areas of Western Australia between the latitudes 24°45′S and 29°S, Bernier Is., Dorre Is., Dirk Hartog Is., Houtman Abrolhos.

ACKNOWLEDGMENTS

We are most grateful to Mr. R. D. Royce, formerly Curator, Western Australian Herbarium for generous help enabling us to make field collections and for the loan of materials from the Western Australian Herbarium. We should like to thank Dr. R. D. Hoogland for the Latin diagnoses.

REFERENCES

Bentham, G., 1867. *Flora Australiensis.* Vol. III. *Myrtaceae to Compositae.* London, Lovell Reeve & Co.

Carr, Stella G. M. & Carr, D. J., 1969. Oil glands and ducts in *Eucalyptus* L'Hérit. I. The phloem and the pith. *Aust. J. Bot.* 17: 471-513.

——— & ———, 1975. Eucalypt identification based on anatomy of leaf and stem. *Proc. R. Soc. Vict.* 88:

———, ——— & Ross, F. L., 1971. Male flowers in eucalypts. *Aust. J. Bot.* 19: 73-83.

———, Milkovits, Lydia & Carr, D. J., 1971. Eucalypt phytoglyphs: the microanatomical features of the epidermis in relation to taxonomy. *Aust. J. Bot.* 19: 173-190.

Chippendale, G. M., 1974. Herbarium specimens of *Eucalyptus* photographed in Europe, August 1972-July 1973. *Technical Note No. 7. Forestry and Timber Bureau, Canberra.*

Gardner, C. A., 1960. Trees of Western Australia. No. 79. *Eucalyptus foecunda. J. Agric. W.A.* 1, Fourth Series No. 12, 2-3 (*Bulletin No. 2827 W.A. Department of Agriculture*).

Johnson, L. A. S., 1962. Studies in the taxonomy of *Eucalyptus. Contrib. N.S.W. National Herbarium* 3: 103-126.

DESCRIPTION OF PLATES 1-4

Plate 1

Photographs of middle portions of cleared adult leaves representative of Group A (all to the right) and Group B (all to the left) (all × 12).

1. A. S. George, 11601. 2. A. S. George, 11607. 3. Royce, 5967. 4. Royce, 6018. 5. Carr, 394. 6. Gardner.

Plate 2

Photographs in polarized light of the margins of adult leaves of specimens of Group A (the two rows to the right) and of Group B (the two rows to the left). The photographs show the marginal vein (to the left) and the margin (to the right). The marginal vein of no. 6 is to the left and out of the field of the photograph. (All × 25.)

1. Main. 2. George, 11601. 3. George, 11607. 4. Wilson, 6018. 5. Serventy. 6. Royce. 7. Royce, 5982. 8. Baudin, N.S.W. 54053. 9. Ford. 10. Carr & Carr, 1003. 11. Carr & Carr, 972. 12. Burbidge.

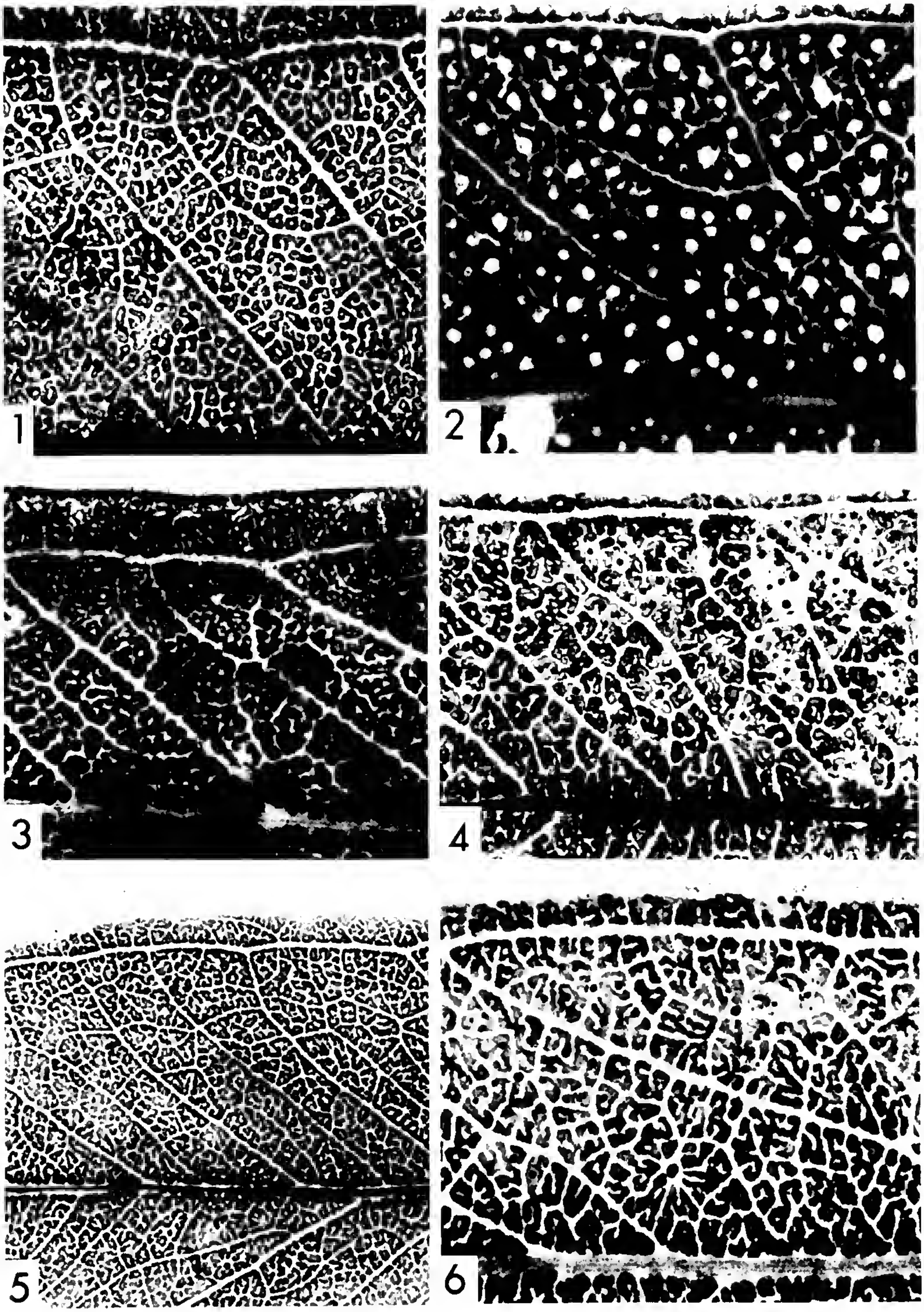
Plate 3

Photographs of median sections of stomata of adult leaves of specimens representative of Group A (1-4) and Group B (5-8) (all × 300).

1. George, 11601. 2. Royce, 6018. 3. Serventy. 4. Carr & Carr, 394. 5. George, 11607. 6. Royce, 5982. 7. Carr & Carr, 972. 8. Wilson.

Plate 4

Photographs to show the habit and bark character of *E. baudiniana* (1-3) and *E. tamala* (4, 5). No. 1 is Carr and Carr, 972; 2 shows the shining leaves; 3 is a close-up of the lower part of 2 (arrow) and shows the smooth bark on the young stem and close-grained bark on the lower trunk. No. 5 is a group of mallees on the Tamala Station Road and 4 shows the bark exfoliating from the lower trunk of one of the stems.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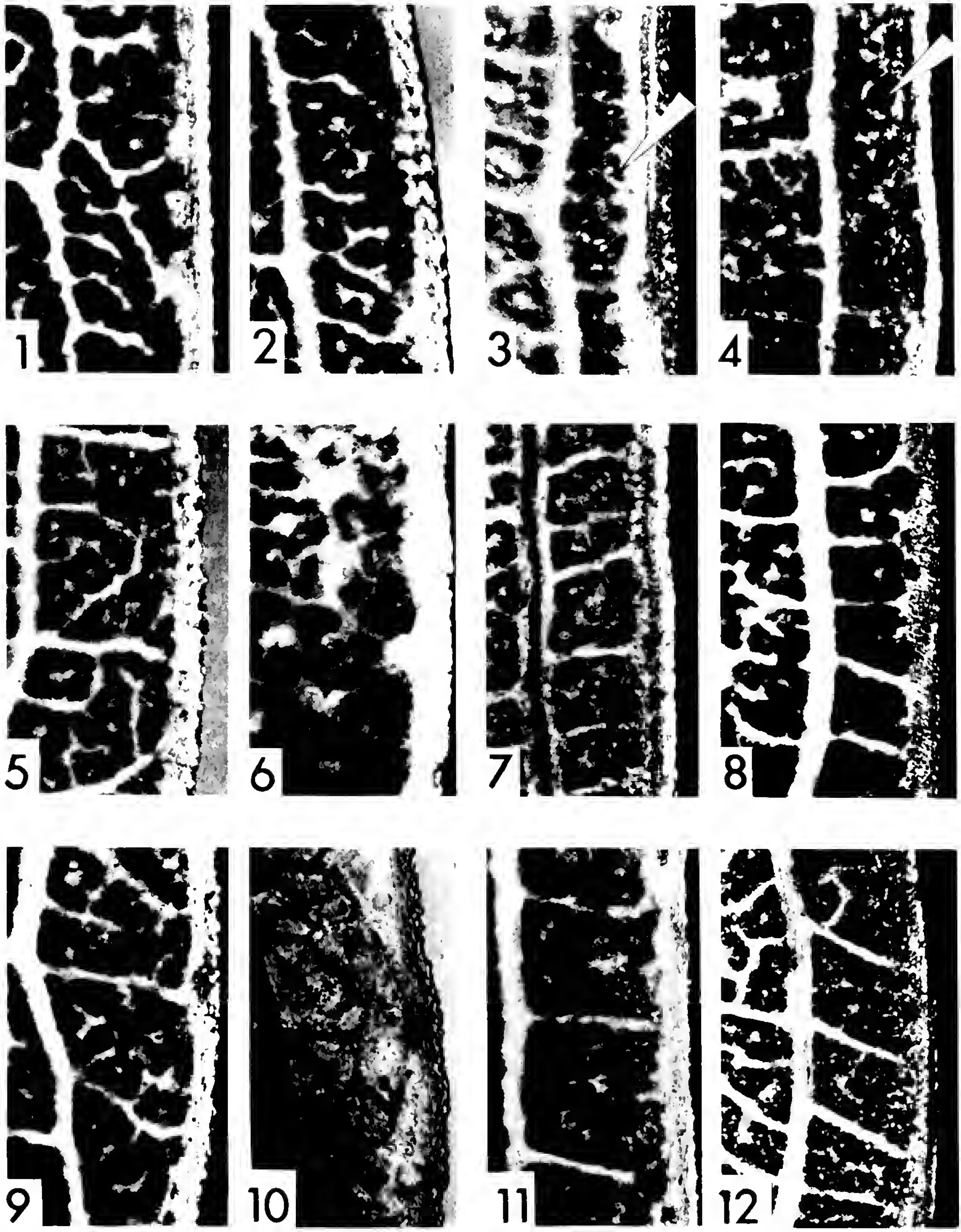
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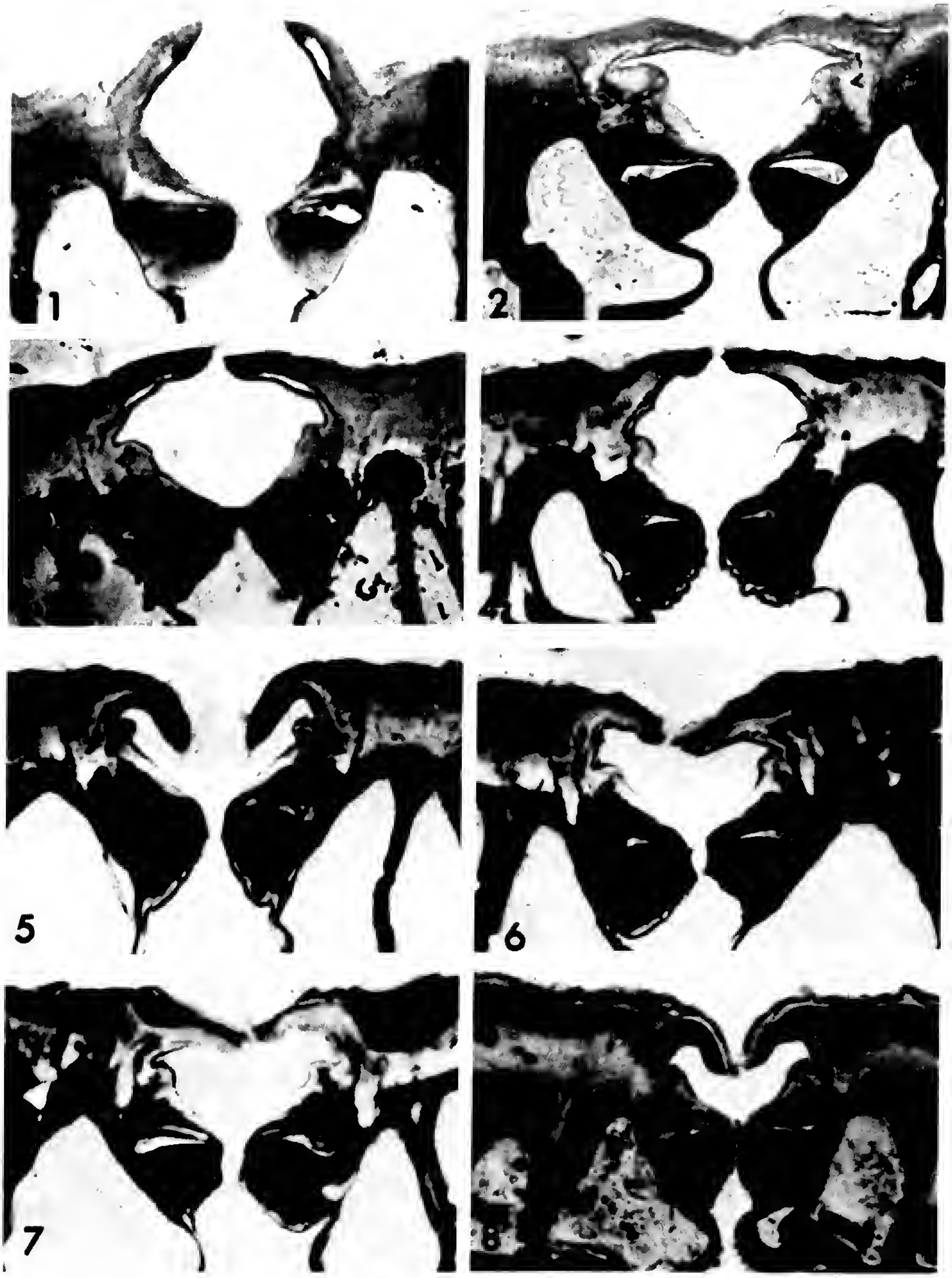
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SOIL EROSION 1955 TO 1974
A Review of the Incidence of Soil Erosion in the Dundas Tableland Area of Western Victoria, Australia

By MARGARET E. MARKER*

ABSTRACT: This paper presents a review of soil erosion incidence in the Dundas Tableland area of western Victoria after a lapse of almost 20 years. In 1955 the author concluded that the area was naturally unstable. At that time mass slope movements were widespread and both sheet and gully erosion were serious. In 1974 mass slope movements had been reduced by 66%. Slope stability had been almost re-established although erosion remained active along the drainage lines as a result of the time lag in catchment readjustment. The improvement is attributed to alteration in the hydrological balance brought about by pasture improvement, rabbit eradication, conservation control measures, and latterly by changing land use as beef cattle replace both sheep and dairy cattle.

INTRODUCTION

Empirical soil erosion studies necessarily record a given situation at one moment in time. Repetitive and comparative studies of the same area over time are, however, rare, despite acknowledgement of the dynamic processes involved. This paper records, after a lapse of 19 years, some changes in soil erosion intensity in the Dundas Tableland area of western Victoria and attempts to account for the differences seen, in terms of alteration to the hydrological balance.

The Dundas Tableland area was originally selected for study as soil erosion there was both severe and localized (Fig. 1). Isolation of contributory factors was therefore possible. Fieldwork was carried out during the spring and early summer of 1955 following a series of good seasons and firm agricultural prices. The area was revisited during January 1974, again following a good pasture growth season. Since both studies were undertaken in favourable seasons impressions were comparable. However, during the intervening years drought and economic recession had affected the district.

THE AREA

In 1955 landslides scarred many slopes in the Dundas Tableland area. Most catchments were affected by sheet erosion, to a greater or lesser extent, and gullied drainage lines were commonplace. Accelerated erosion was already then 100 years old; landslides and gullies became manifest from 1850, within 13 years of first settlement (Robertson 1853). The 1955 study† of the relationship between soil erosion and landform processes concluded that the area was naturally unstable (Marker 1959). A precarious hydrological balance, established following a dynamic Cainozoic geomorphic history, had been upset by European land utilization.

The Dundas Tableland area is a former promontory between the Murray Basin and Otway Sunkland Tertiary depositional troughs. A resistant Tertiary lateritic palaeosol has been dissected by periodic rejuventation as the Cenozoic seas withdrew. Slopes, separated by level laterite-capped interfluves, are concave upwards and often also oversteepened at the base. The laterite palaeosol has developed on sediments of varying ages and cohesion, with the result that erosion susceptible strata and associated soils are juxtaposed in a dynamic geomorphic situation.

† The 1955 study was presented as M.Ag.Sc. (Melbourne) dissertation; in 1974 the author was visiting lecturer in the Department of Geography, Adelaide University, in receipt of CSIR (South Africa) post-doctoral bursary.

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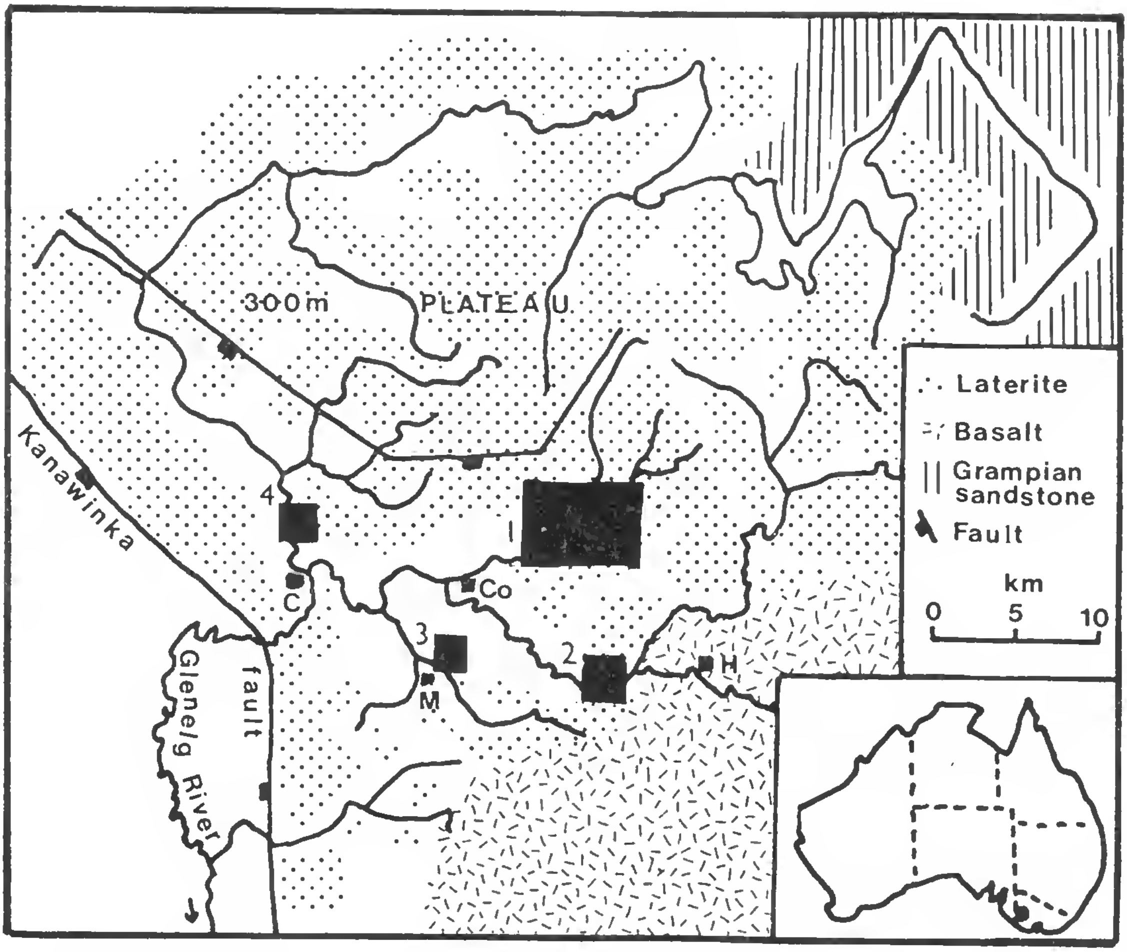

FIG. 1—Location map showing sites of four detailed study areas: 1. Koroit Creek, Coleraine; 2. Murndal; 3. Merino; 4. Noss, Casterton. (C = Casterton, Co = Coleraine, M = Merino, H = Hamilton.)

SOIL EROSION 1955 TO 1974

Soil erosion intensity in 1974 is much diminished and its manifestations are less conspicuous. Sheet erosion now affects only a low percentage of slopes, totally unvegetated landslides are rare and slumping gully walls have become the exception rather than the rule (Pl. 5). The impression gained is one of marked general improvement.

Slope instability was always accentuated by deep incision, by cracking montmorillonite clay soils developed from Permian glacial and fluvoglacial deposits and from Mesozoic lacustrine sediments, and by seepage affecting the B and C clay horizons of the 10 m thick laterite palaeosol capping. The largest and most severe landslides were initiated in these laterite clay horizons on the upper slopes. Smaller mass movements were initiated mid-slope and on the footslope undermined by channel incision.

In any catchment affected by soil erosion of this nature, the future re-establishment of equilibrium conditions will be manifest on the slopes before the channels become stabilized. Four areas severely affected by slope mass movements in 1955 were therefore studied in detail to establish whether the impression of general improvement was valid (Fig. 2). The areas included a total of 100 landslides, of which 35 were already inactive in 1955 and 5 are new features (Table 1). Some movement was perceptible in 28% of all landslides but of these, only 12% were actively mobile. This figure of 28% compares favourably with the figure of 64% for 1955. The general impression that improvement has occurred and that slope stability has been restored appears to

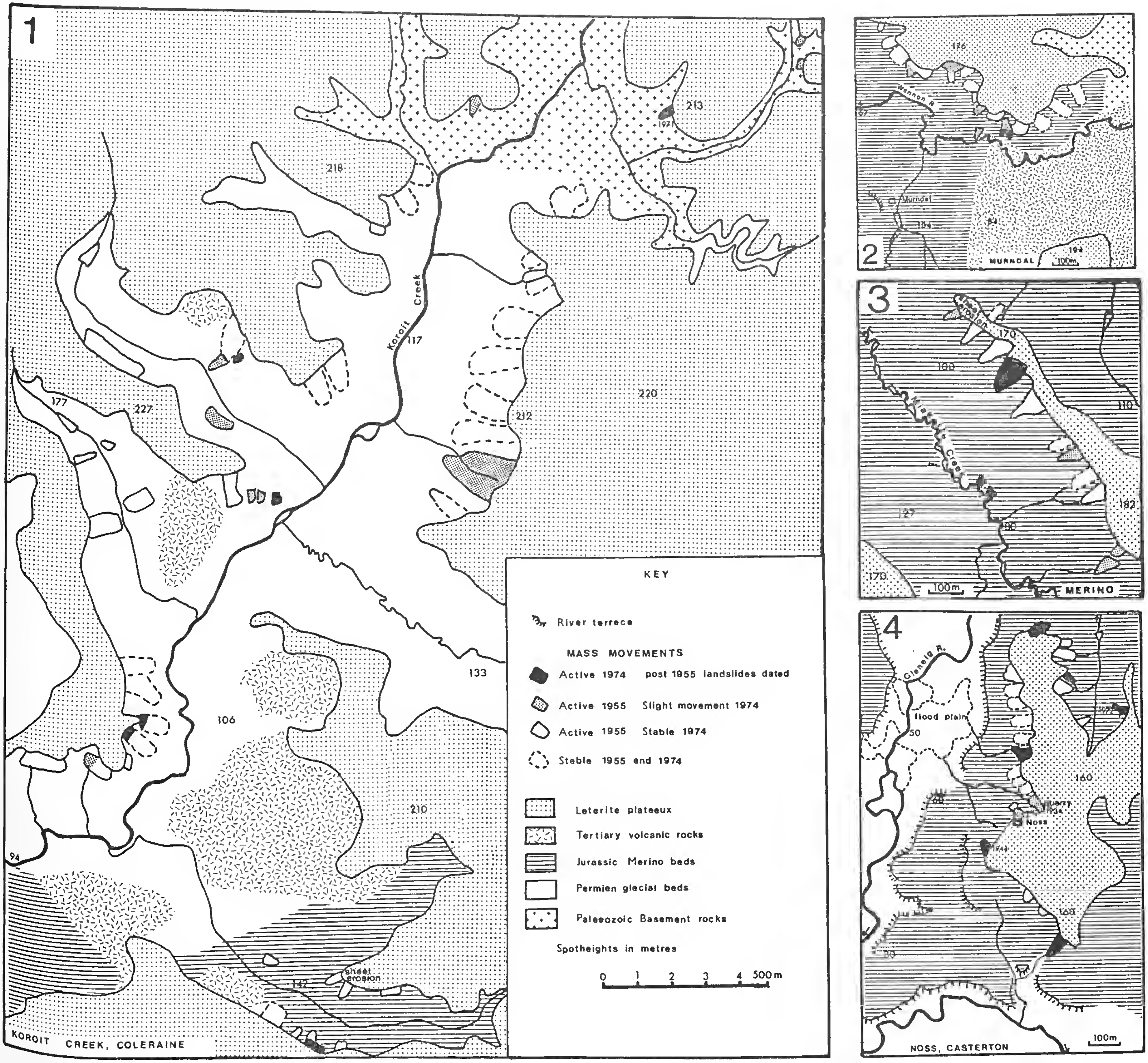

FIG. 2—Detailed study areas: 2·1 Koroit Creek, Coleraine; 2·2 Murndal; 2·3 Merino; 2·4 Noss, Casterton. (Key applies to all figures; alluvium left blank on figure 2·4.)

TABLE 1

LANDSLIDE INCIDENCE (numbers) AT FOUR SELECTED SITES 1955 AND 1974

	Murndal	Noss	Koroit	Merino
Total landslides	20	22	46	12
1974 Active (partially vegetated)	1	6	4	1
1974 Slightly active	4	1	7	4
1974 Sub Total	5	7	11	5
1955 Active (unvegetated)	13	14	25	9
1955 Stale old scars	6	7	19	3
Post 1955	1	1	2	1

TABLE 2

LANDSLIDE VULNERABILITY GRADIENTS

	Mean altitude (m)		Parent material	Overall gradient	Mean angles of landslide (degrees)	
	Laterite plateau	Drainage line			Fracture zone	Solifluction tongue
Murndal	175	70	Mesozoic beds	1:3	33	22
Noss	162	60	,, ,,	1:3	24	16
Koroit Creek	206	142	,, ,,	1:3	23	15
	201	105	Permian beds	1:5	25	14
Merino	180	80	Mesozoic beds	1:6	20	11

be valid. Only 44% of all active 1955 landslides still show signs of movement. Furthermore, since these figures have been derived from analysis of four particularly vulnerable areas, it is likely that over the entire area the percentage improvement is greater.

Mass slope movements occur most readily on long steep slopes immediately beneath the laterite capping (Table 2). The vulnerable slope at Murndal is undercut by the Wannon River (Fig. 2.2), the slope at Noss near Casterton (Fig. 2.4) is a former river cliff now terminating in a terrace footslope. However, mass movement also occurs on shorter slopes where tributary creek junction is vigorous. This appears to be the case in the upper Koroit Creek catchment north-east of Coleraine (Fig. 2.1), and in the Miakite Creek catchment near Merino (Fig. 2.3). Although this may represent basal sapping, it is more likely to indicate the presence of seepage water which lubricates the tongue movement while feeding into the gully. Mass flowage, or solifluction, occurs prior to collapse, along concave slip planes, in the upper, more compact portion of the slope. Solifluction is self maintaining on very low angle slopes when soil coherence is low or lubrication is available. The problem of slope stability is therefore related to the availability of seepage water which is a function of the hydrological balance.

In most cases slopes of less than 20° are stable but where landslides have once occurred, movement can continue on slopes of 10° to 20°, and in one case localized oversteepening has resulted in continuing movement on an overall slope of only 5°. On unstable, triple-lattice, expanding clay soils, solifluction is the normal slope recession process, excess water providing a trigger mechanism. Many landslides were initiated in 1946, an exceptionally wet year with abnormal autumn rains, in 1952, and again in 1971. These were all wet years following a series of adequate rainfall seasons when soils rapidly reached a state of saturation (Fig. 3). A further important factor is the incidence of heavy autumn rainfall when the vegetation cover is thin, after summer drought. In 1971 when most of the new landslides occurred, the April rainfall in Hamilton was 123 mm, 67 mm above average.

Although gully erosion was also a serious problem in 1955, the area affected by mass slope movements was greater than that dissected by gullying. Indeed only a few headwater catchments on the 300 m plateau were free from gully rejuvenation. Main channels were incised 7 to 8 m below the 1840 flood plain level. Downstream, shifting braided channel patterns had replaced deep meandering streams, as a response to increased bed load and reduced bank stability. Today incised channels are a reminder of this

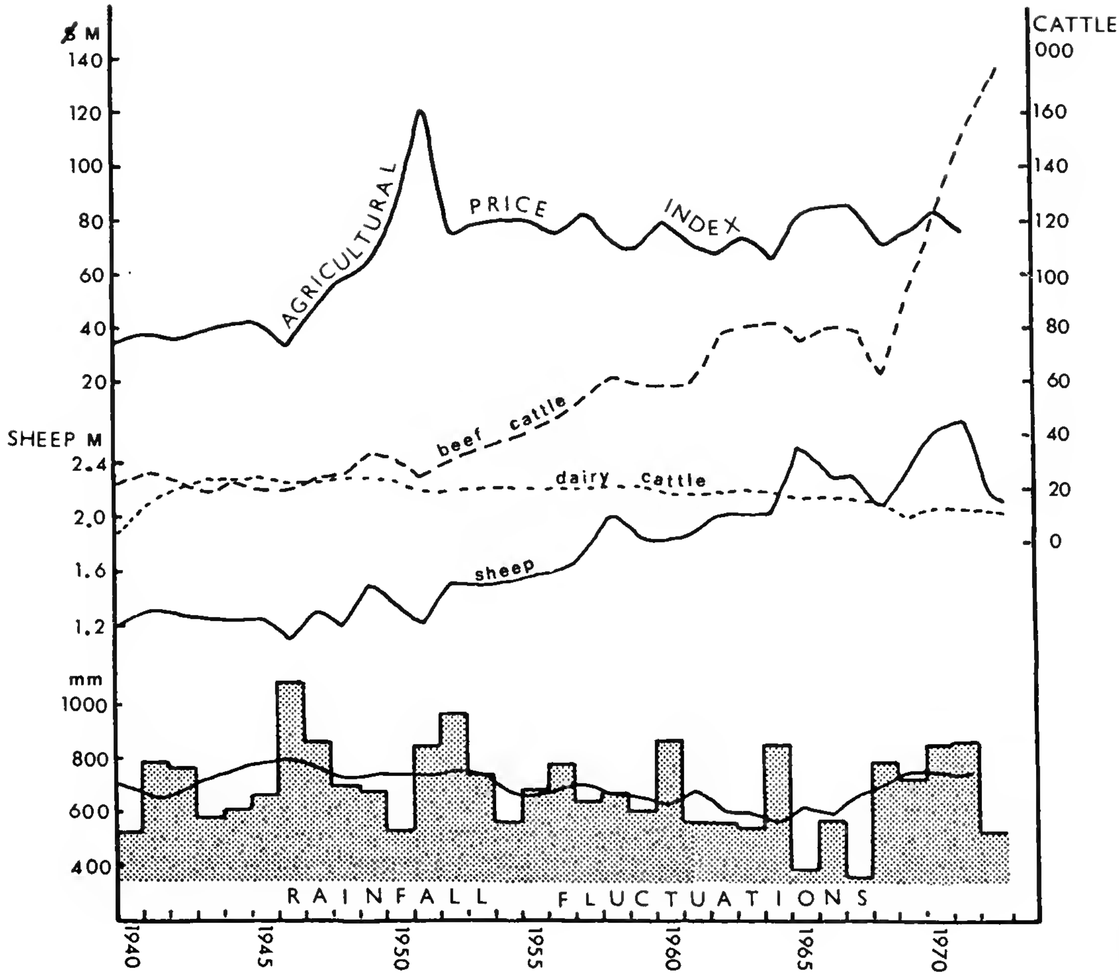

FIG. 3—Stock numbers for counties Dundas and Follett in relation to rainfall fluctuations measured at Hamilton and an agricultural price index. The agricultural price index was derived from annual values of pastoral and dairy products, modified by the annual Cost of Living Index (after Annual Statistics for Victoria). The smoothed rainfall curve is plotted from five year running means.

gully legacy but many banks, recolonized by vegetation, are slumping to new angles of rest. *Phragmites communis* is planted along banks to confine channels and *Typha* sp. is a volunteer species on many sandy gully floors. The reduction in the number of actively incising gullies is marked. Less conspicuous are the insidious effects of gully side seepage, attendant salting and slumping, of headwall undercutting and of downstream siltation (S.C.A. pers. comm.). The dominance, in 1974, of the channel network erosion problem is itself a measure of the catchment improvement that has occurred over the past 19 years.

DISCUSSION: EROSION IN TERMS OF HYDROLOGICAL BALANCE

Pre-settlement

The Dundas Tableland area is geologically vulnerable. Periods of Cenozoic incision and active slope recession have alternated with periods of stationary base level when equilibrium has been re-established. Superimposed on these geological long term changes in equilibrium have been those since 1837 on an historic scale. The latter are manifestations of changes in the hydrological balance.

TABLE 3
STILLSTAND ALTITUDES (m)

Dergholm plateau		Wannon (Coleraine)	Wannon (Murndal)	Glenelg valley	
Laterite plateau	160	200	180	180/200	
Pliocene shore	110	150 (gravel)	150	130	
? Lower Pleistocene		100	120	120	
			75/80		
		60/70	67/73	60/70	Killara delta
		±50	±50	50	flood plain

In Lower Pliocene time and possibly as late as Early Pleistocene, the laterite surface was adjusted to a shoreline at ±150 m above present sea level. Pleistocene sea level fluctuations, superimposed on a general emergence caused repercussions on landform development. Traces of stillstands can be identified as rock cut and alluvial river terraces and their knick points are still receding upstream (Table 3). The post-Pleistocene time span has been too short for the achievement of total stability. Yet the first settlers came into an area with no visible erosion, an area of timbered interfluves, grassed slopes and flood plains protected by tall tussock grass.

1837-1955

The advent of European settlement in 1837 initiated changes sufficient to upset the existing precarious hydrological balance. Water use was reduced by timber felling and ring-barking on the tablelands, by heavy stocking with concomitant decrease in perennial grass species, from 37 in 1840 to 4 or 5 by 1857, and increase in annual species (Robertson 1853) and by burning with intent or by accident. Hooved trampling, cultivation up and down slope, and destruction of the natural vegetation cover reduced infiltration. Run-off increased, sheet erosion followed, and drainage lines, vulnerable after the destruction of tussock grass, were incised, with attendant water table lowering (Marker 1959, Downes 1964). Drought at the turn of the century when stock numbers had reached a peak, followed by rabbit invasion, ensured that an eroded landscape remained the norm.

Closer settlement after 1918, tied to dairy and stock fattening, meant intensive use of small subeconomic farm holdings. By 1955 these smaller farms in the south-west of the region had attempted some pasture improvement using superphosphate and subterranean clover, but soil fertility had risen to a level inimical to indigenous perennial grass species and the land was barren by the end of each dry season. This was the situation in 1955.

1955-1974

The present improvement in the erosion position is the result of another change in the hydrological balance. Run-off has decreased and infiltration has increased proportionally, allowing the slopes to achieve equilibrium but maintaining activity along the drainage lines. Despite the reduction in interfluve tree density with the death of older trees, more land clearance, and the sale of timber during the recent recession, water use has risen on the tablelands. Higher density pastures improved by the addition of superphosphate and trace elements are utilizing more water. The re-establishment of a dense root network has improved soil structure thereby increasing water holding capacity and infiltration. On the best soils sown pastures mixtures are now used and *Phalaris tuberosa*, a heavy water user, has been planted extensively. Lucerne and *Phalaris* are also both planted on alluvial terraces. Less water runs off since more is held and used.

The elimination of rabbits by myxamotosis in the late 1950s was a further factor in the recovery of pastures and soil erosion decrease. Once the extent of rabbit damage was appreciated, rabbit eradication became a viable proposition. Not only have pastures improved and stock carrying capacity risen but erosion prone areas such as landslides and gullies are now free from warrens. Revegetation and stabilization has followed rabbit eradication. Rabbit burrows allowed water to penetrate disturbed areas, thereby promoting lubrication.

Much of the improvement is undoubtedly due to programmes initiated by the Soil Conservation Authority of Victoria since 1950, for considerable sums of money have been spent in the district. Conservation surveys pinpointed the causes of accelerated erosion, potential danger sites and urgent rehabilitation locations. Although many of the first conservation sites were selected for their severe erosion problems, the degree of stabilization and revegetation is a measure of the Authority's success. The Authority's work has both promoted and been facilitated by an increasing Australian awareness of the environment and the need for conservation. Implementation of catchment control schemes, which require the co-operation of a number of land owners, is eased in the present climate of opinion. A further factor has been a general tendency for farm amalgamation, with the elimination of small sub-economic farms, thus making the withdrawal of erosion prone areas from grazing and for conservation a working proposition. Catchment conservation programmes consisting of fencing creek banks to prevent stock trampling and to permit natural vegetation regeneration are well under way on many of the 300 m plateaus. *Typha* sp. is welcomed and some planting of *Phragmites communis* has been undertaken. Infiltration is enhanced, scour prevented and such areas incidentally become wildlife preserves.

Small earth dams are installed which serve to break stream velocity and to raise the local water table. Such sequences of dams are conspicuous in the former dairying areas near Merino. With the demand for beef cattle watering points and the realization, brought home during the recent drought, of the vulnerability of many farm water supplies, the popularity of these sequences has increased. The net result is a further improvement in the hydrological balance.

Improved pasture yields encourage subdivision into smaller paddocks. Fencing can then be aligned under Soil Conservation Authority advice, to separate slopes of different erosion hazards. Subsidized fencing of vulnerable areas has always been part of the Authority's policy and some landowners have also fenced landslide areas and planted them to kikuyu grass or trees.

A further factor in land improvement can be indicated. Following rising beef prices, lower wool prices and rising costs of wool production there has been a swing towards beef production. The number of beef cattle has risen steeply; a drop in sheep numbers is apparent since 1971, even although the momentum of the swing has not yet been fully felt. Dairy cattle numbers have been declining slowly (Fig. 3). Beef raising has affected marginal dairy farms near Merino where beef calves are now reared on the less productive section of former dairy herds. Reduction in the intensity of dairy farming has reduced trampling and the dangers of run-off concentration. Beef cattle cause less damage than either sheep or dairy cattle since they graze at lower densities, tend not to follow one another so closely and do not camp on and under erosion scars. The effects of the change in land-use to beef production on the pasture cover and infiltration rates is already conspicuous, even though the statistical significance of the change is still small when the area is considered as a whole. The improvement is most noticeable on farms that made the change some years ago.

The Future

It appears that the past 19 years have coincided with a renewed adjustment towards a state of precarious equilibrium. Slope stability has been almost achieved. Nevertheless, further changes in the form of decreasing bed load and decreased run-off but continuing seepage will necessarily continue to be felt along the drainage lines. However, the landslides that can be attributed to specific instances of mismanagement are a reminder of the precarious balance between hydrology and landform process. The 1970 Koroit landslide resulted from the misalignment of a road. Stabilization of the twin Balmoral Road landslides was achieved only after the road was altered and water ceased to drain into the slip zones. At Noss a serious landslide followed quarrying for gravel between 1920 and 1930 and stabilization is only now being achieved following the establishment of dams in the quarry floor, fencing the actual landslide, and planting to kikuyu grass.

Slumping and landslides are normal slope recession processes on incoherent parent materials overlain by clay soils. In the Dundas Tableland area, Tertiary deep weathering with fossil laterite acting as a caprock and montmorillonite-rich clay soils render the area prone to slumping. Individual landslides occur widely spaced in time and localized in position. They are triggered by factors promoting instability. Potential instability is enhanced by fluctuating climatic conditions and attendant agricultural prices (Fig. 3). However, the re-establishment of a new balance over the past 19 years despite drought conditions and an economic recession suggests that either these factors are now unimportant or, more probably, that conservation policies have gained sufficient momentum to over-ride their detrimental effects. If the latter is justified, it augurs well for the future of the region.

CONCLUSION

A marked decline in the incidence and severity of soil erosion is recorded after a lapse of 19 years despite partially unfavourable climatic and economic conditions. For this reason the increased catchment stability is attributed to an altered hydrological balance brought about by reduction in direct run-off. The reduction in run-off is attributed to pasture improvement, rabbit eradication and effective erosion control measures. A contributory factor has been the reduction in the number of sheep and dairy cattle and a rise in the number of beef animals, particularly over the past four years. There is also a greater awareness of the need for conservation and this in itself is a measure of the success of conservation policies.

Complete stability cannot be envisaged. The landscape has a history of periodic rejuvenation over the post-Pliocene period and its present vulnerability to erosion is an inevitable result of the geological structure.

ACKNOWLEDGMENTS

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REFERENCES

Downes, R. G., 1964. Land management problems following disturbance of the hydrological balance of environments in Victoria Australia. *7th Technical Meeting: International Union for Conservation of Nature and Natural Resources, Athens.* 11-19 Sept., 1958.

Marker, M. E., 1959. Soil erosion in relation to the development of landforms in the Dundas area of Western Victoria. *Proc. R. Soc. Vict.* 71: 125-136.

Robertson, J. G., 1853. Letter to Governor Latrobe (from *Letters from Victorian Pioneers*, ed. Bride T. F. Heinemann, pp. 153-170).

DESCRIPTION OF PLATE 5

Landslide scarred slopes south of Coleraine: 1. Slides active in 1955, now revegetated and stabilized. Gully walls have slumped to a new angle of rest and are also now stabilized.

2. Slide initiated since 1955 on a potentially unstable slope. Gully is still actively slumping. Timber on skyline marks position of tableland laterite capping.

1

2

3

The Yapeenian (Upper Lower Ordovician) Succession in Central Victoria, Australia

By A. N. McLaurin*

ABSTRACT: Two areas of Upper Lower Ordovician (Yapeenian) rocks from Central Victoria have been mapped in detail. One of the areas is situated west of Gisborne and the other at Chinamans Creek, Muckleford. From this mapping and comparative studies with other areas, a third Yapeenian zone (Ya3), based on the entry of *Apiograptus*, has been designated. Direct superposition of graptolite faunas in the Yapeenian has been demonstrated.

INTRODUCTION

To demonstrate superposition of Yapeenian graptolite zones an area of Ordovician rocks west of Gisborne and a small outcrop of Ordovician rocks north-west of Castlemaine were mapped in detail. These areas were chosen because of their good exposure and ready accessibility. All place names referred to in this paper are shown in Fig. 1.

The Yapeenian stage of the Victorian Lower Ordovician was designated by Harris and Thomas (1938) for *Oncograptus* and *Cardiograptus* beds overlying the Castlemainian *Isograptus* beds and underlying the Darriwilian *Glyptograptus* beds.

The name was derived from Yapeen, a small hamlet south-west of Castlemaine. Two zones were recognized by Harris and Thomas:

Ya1 Zone of *Oncograptus*

Ya2 Zone of *Cardiograptus*

In the Ya1, *Oncograptus* enters with *Tristichograptus ensiformis*, *Pseudisograptus manubriatus* and *Didymograptus v deflexus*.

The genus *Tristichograptus* Jackson and Bulman has been known under the name of *Trigonograptus*, principally from the species *T. ensiformis* J. Hall. However, the type specimen of the type species of *Trigonograptus*, *T. lanceolatus* comprises two stipes of a *Didymograptus* lying side by side (Jackson & Bulman 1970). These authors proposed the new name *Tristichograptus* with *T. ensiformis* as the type species.

The genus *Pseudisograptus* was proposed by Beavis (1972) and is here used for the manubriate isograptid species, *Didymograptus manubriatus* T. S. Hall, *Isograptus dumosus* Harris and *Isograptus hastatus* Harris.

The Ya1 fauna survives into the Ya2 where it is joined by *Cardiograptus*. The existence of beds containing *Cardiograptus* but not *Oncograptus* were recognized by Harris and Thomas. They suggested that when this occurs the subdivision should be shown as Ya2b and the beds with an *Oncograptus-Cardiograptus* fauna as Ya2a.

Another form figured by Harris and Thomas from the Yapeenian was ? *Glossograptus crudus*.

Recent work by Cooper and McLaurin (1974) has shown that this form has a development that parallels *Pseudisograptus manubriatus*. Its relationship to the glossograptids is uncertain. Cooper and McLaurin described this form as a new genus, *Apiograptus* with ? *Glossograptus crudus* as the type species.

Harris and Thomas failed to point out that *Apiograptus* is restricted to the Ya2 *Cardiograptus* beds. Detailed mapping west of Gisborne and at Chinamans Creek has indicated that this is the case. The details of this mapping follow.

AREA WEST OF GISBORNE

An area 10 km west of Gisborne was mapped at a scale of 1 : 8,330 using enlarged aerial photographs as a mapping base. Critical sections were measured by a tape and compass survey.

The well-entrenched Distil and Saltwater Creeks, which after their confluence become Jackson Creek, drain the area. Drainage direction is to the east and is approximately at right angles to the strike of the basement Ordovician rocks. A nearly continuous section is exposed in the

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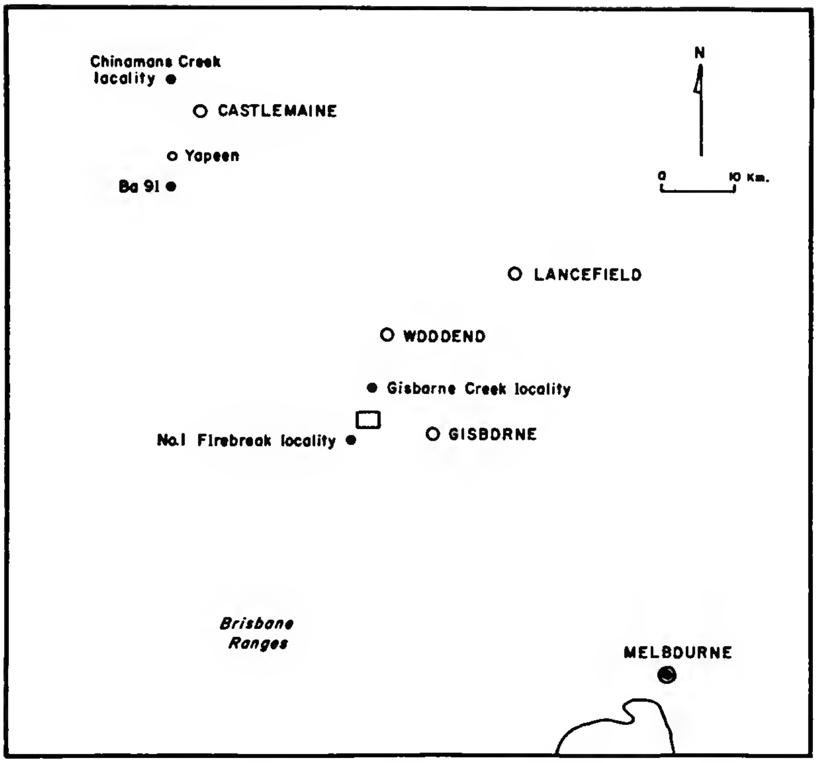

FIG. 1—Locality map. The area enclosed by the rectangle is shown in Fig. 2.

stream courses. Gaps are, however, present due to covering.

All the rocks exposed within the area are of Ordovician age. They range in age from Lower Ordovician (Castlemainian) to Middle Ordovician (Darriwilian) and are younging to the west. They comprise beds of sandstone, siltstone, shale and slate. Graptolites are confined to bands of black slate.

Structurally the area comprises a series of tight plunging folds which bring about frequent repetition of the same bed. Facing was determined by using the cleavage-bedding relationship and by using ripple marks and sole marks.

A detailed description of the sequence follows and reference should be made to the accompanying geological sketch map (Fig. 2) for details of localities. Figures and details of the authorship of the graptolites are given by Thomas (1960).

The sequence is described from east to west, that is in ascending order.

The most easterly mapped graptolite occurrence is the Bullengarook Slate Quarry (locality 1). Sited in massive beds of easterly dipping black slate, the quarry allows ready collection of Upper Castlemainian (Ca3) graptolites. The fauna comprises:

Isograptus victoriae victoriae Harris
I. victoriae maximus Harris.
I. victoriae lunatus Harris
I. victoriae maximo divergens Harris
I. caduceus imitatus Harris
Pseudisograptus dumosus (Harris)
Maeandrograptus tau Harris
Tetragraptus amii Elles and Wood
T. quadribrachiatus J. Hall
T. serra (Brongniart)
Didymograptus nundus T. S. Hall
D. nitidus J. Hall
D. cf. *cuspidatus* Ruedemann
Dichograptus tenuissimus Harris and Thomas

About 0·5 km to the west westerly, dipping black slates, containing a similar Ca3 fauna, outcrop on Jackson Creek.

Jackson Creek then swings to the north-west where a small quarry has been worked in westerly dipping black slates (locality 3). The slates contain a Lower Yapeenian (Ya1) fauna. The following forms are common:

Oncograptus upsilon T. S. Hall
Isograptus victoriae divergens Harris
I. forcipiformis (Ruedemann)
Tristichograptus ensiformis (J. Hall)

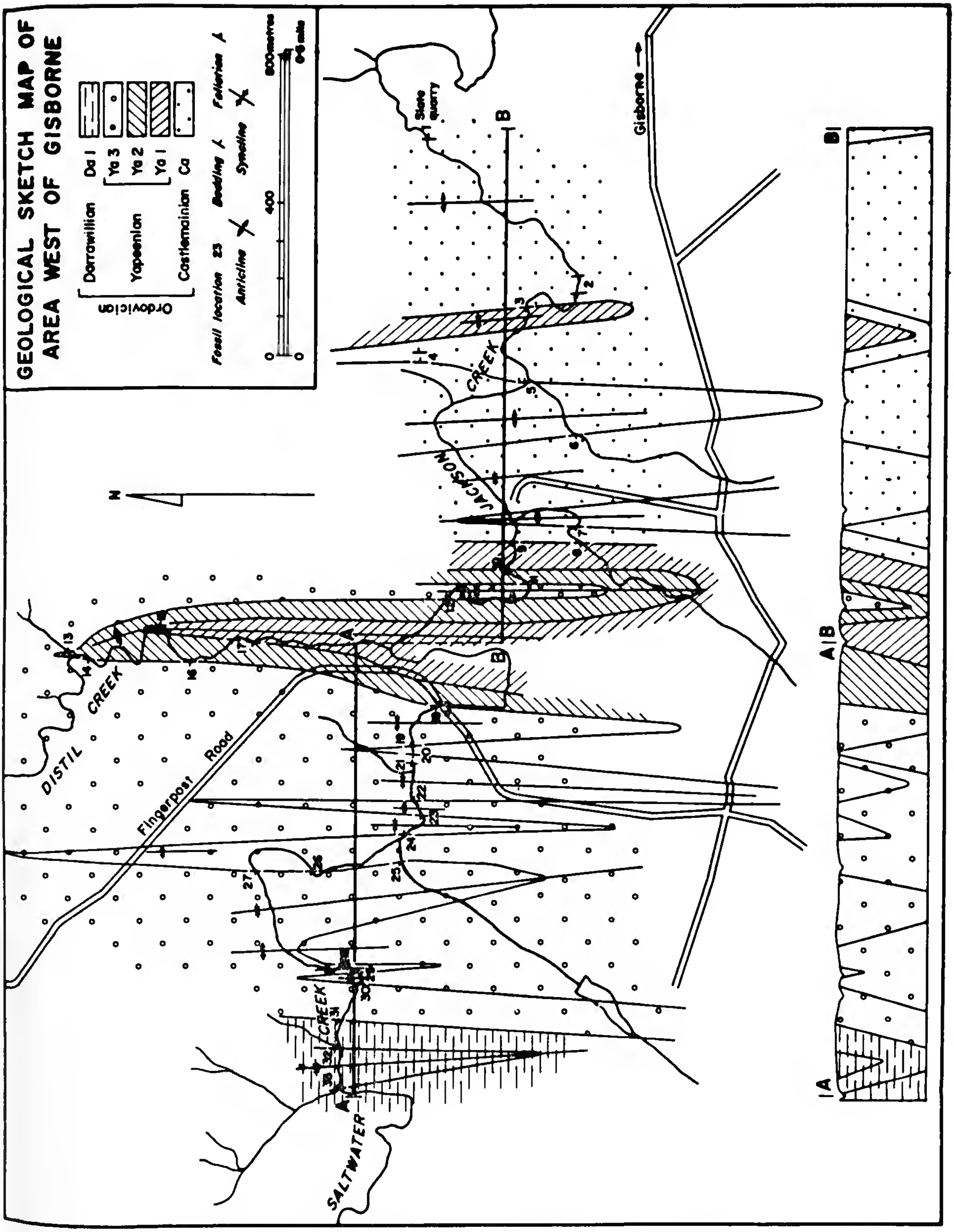

Fig. 2—Geological sketch map of the area west of Gisborne.

It is from this locality that Harris (1933) figured *Oncograptus upsilon* (his Fig. 21).

Further west, at the junction of a small northerly flowing creek with Jackson Creek, a Castlemainian (Ca3) fauna is found in easterly dipping black slates demonstrating the presence of a small syncline, the core of which contains Yapeenian sediments, between localities 2 and 5.

On another small northerly flowing creek, further to the west, a bed of west dipping shale yielded a Ca3 fauna:

Isograptus victoriae victoriae Harris
I. victoriae maximo divergens Harris

To the north-west, on Jackson Creek, a bed of black slate dipping west contains a Lower Yapeenian (Ya1) fauna (locality 9):

Oncograptus upsilon T. S. Hall
Isograptus victoriae divergens Harris
Pseudisograptus manubriatus (T. S. Hall)

Sixty-four metres to the west, a Yapeenian (Ya2) fauna is found in westerly dipping black slates (locality 10):

Oncograptus cf. *biangulatus* Harris and Keble
Cardiograptus morsus Harris and Keble
Pseudisograptus manubriatus (T. S. Hall)
Skiagraptus gnomonicus (Harris and Keble)

Ripple marks in an underlying sandstone bed indicate that the facing is right way up.

Thirty-two metres west a bed of westerly dipping black slate (locality 11) contains the following assemblage:

Apiograptus gisbornensis (Harris and Thomas)
Cardiograptus morsus (narrow form)
Isograptus victoriae divergens Harris
Pseudisograptus manubriatus (T. S. Hall)
Tristichograptus ensiformis (J. Hall)

This bed, stratigraphically higher than the bed outcropping at locality 10, does not contain a typical Ya2 fauna. *Oncograptus* is definitely lacking; the narrow form of *Cardiograptus* is present and a new form, *Apiograptus*, makes its entry. This is the fauna designated as Ya2b by Harris and Thomas (1939).

Assuming an absence of major faulting the thickness of the strata from the bottom of the Ya1 bed at locality 9 to the bottom of the *Apiograptus* bed outcropping at locality 11 is ninety-five metres.

The next outcrop of black slate to the west (locality 12) is very highly cleaved. Graptolites are difficult to extract and poorly preserved, the only recognizable forms found were indeterminate species of *Isograptus* and *Didymograptus*. In keeping with the general structure a high Yapeenian age would be expected for this locality.

Along Distil Creek, to the north-east of locality 12, a north plunging anticline runs parallel to the stream valley. The core of the anticline contains beds with a Ya2 fauna (localities 15, 17):

Cardiograptus morsus Harris and Keble
Oncograptus upsilon Harris and Keble

These beds are overlain to the west and the north by beds with *Apiograptus gisbornensis*.

At locality 19 on Saltwater Creek is a bed of black slate dipping steeply east. The fauna from the base of this bed is:

Oncograptus biangulatus Harris and Keble
Pseudisograptus manubriatus (T. S. Hall)

At 0·8 m above this horizon the following fauna was collected:

Apiograptus crudus (Harris and Thomas)
Cardiograptus morsus Harris and Keble
Tristichograptus ensiformis (J. Hall)
Dichograptus cf. *octobrachiatus* J. Hall
Isograptus victoriae divergens Harris
I. caduceus imitatus Harris
Phyllograptus sp.

Apiograptus crudus is distinguished from *Apiograptus gisbornensis* by its wider rhabdosome.

This fauna is of interest because of the association of *Oncograptus* and *Apiograptus crudus*. It has already been demonstrated, in the section along Jackson Creek, that *Apiograptus gisbornensis* beds succeed those with *Oncograptus*. This bed with *Apiograptus crudus* is considered as basal Upper Yapeenian. It is repeated by folding then overlain to the west (locality 21) by a bed with an *Apiograptus gisbornensis*, *Cardiograptus morsus* (narrow form) fauna which is more typical of the Upper Yapeenian.

The 3 m thick bed of black slate outcropping at locality 21 is repeated by folding nine times in a distance of approximately 640 m to the west.

At locality 24, just downstream from the intersection of an unnamed northerly flowing creek with Saltwater Creek, a more complete collection of Upper Yapeenian graptolites may be made:

Apiograptus gisbornensis (Harris and Thomas)
Cardiograptus morsus (narrow form)
Isograptus victoriae divergens Harris
I. victoriae maxima divergens Harris
Pseudisograptus manubriatus (J. Hall)
Didymograptus v deflexus Harris
Skiagraptus gnomonicus (Harris and Keble)
Maeandrograptus tau Harris
Phyllograptus densus Ruedemann
Dichograptus octobrachiatus J. Hall
Loganograptus sp.

The westerly dipping black slate outcropping at locality 30 yielded:

Apiograptus gisbornensis (Harris and Thomas)
Cardiograptus morsus (narrow form)

About one hundred and twenty metres to the west is a one metre thick bed of black slate dipping west (locality 31) containing a Darriwilian fauna (Da1):

Glyptograptus austrodentatus austrodentatus Harris and Keble
Paraglossograptus tentaculatus (J. Hall)
Glossograptus acanthus Elles and Wood
Tristichograptus ensiformis (J. Hall)

Eighty metres to the west a three metre thick bed of westerly dipping black slate (locality 32) contains:

Glyptograptus austrodentatus austrodentatus Harris and Keble
Isograptus victoriae divergens (Harris)
Tristichograptus ensiformis (J. Hall)

Although stratigraphically higher than the bed at locality 31, there is little difference between the two faunas which are both of Da1 age.

This section demonstrates the progression from an isograptid fauna of the Castlemainian to the *Oncograptus-Cardiograptus* fauna of the lower to Middle (Ya1-Ya2) Yapeenian and then to the entry of *Apiograptus* in higher Yapeenian beds which is followed by *Glyptograptus* in the Lower Darriwilian (Da1).

CHINAMANS CREEK, MUCKLEFORD

This important locality is the type locality of *Cardiograptus morsus* and *Apiograptus crudus.* Good exposure allows bed by bed collecting of graptolites. Sandstone and shale beds, dipping east at between 75° and 80° and striking at 347° outcrop on the north bank of Chinamans Creek, 6·4 km north-west of Castlemaine. Grid reference from the Melbourne 1 : 250,000 sheet is 221,432.

The sequence, from top to bottom of the exposure, is summarized in Table 1.

The Yapeenian (Ya2) *Oncograptus-Cardiograptus* fauna is found in beds two to four. Bed four passes into bed five: both beds have identical lithology. However, in the higher bed *Oncograptus* is absent and *Cardiograptus morsus* (narrow form) makes its entry.

An unfossiliferous interval of 0·6 m (bed six) separates the *Apiograptus* fauna of bed seven from the underlying *Oncograptus* fauna. This sequence is very similar to that already described from locality 19 on Saltwater Creek.

The fauna in bed nine is the more typical *Apiograptus gisbornensis* Upper Yapeenian fauna which is identical to the fauna already described from the area west of Gisborne.

RANGE OF *Oncograptus* and *Cardiograptus*

It has been shown by earlier authors and this work that *Oncograptus,* as *Oncograptus upsilon,* enters the graptolite sequence with *Tristichograptus ensiformis* and *Pseudisograptus manubriatus* ushering a new event, which by definition, is the beginning of the Yapeenian.

Oncograptus has been reported from Upper Castlemainian beds outcropping at McKenzies Hill near Castlemaine by Harris (1933). This is a doubtful record, as a recent collection from this locality contained a Castlemainian fauna and no examples of *Oncograptus* was found. The locality from which Harris apparently collected his specimens is sited in a small water race. A block containing *Oncograptus* could have been transported from nearby Yapeenian sediments during construction of the race.

On the other hand, *Oncograptus* survives into the Darriwil. *Oncograptus biangulatus* outlives *Oncograptus upsilon* and is found in beds of Lower Darriwilian (Da1) age. For example, a bed of pink shale outcropping on the Number One Firebreak track, 0·8 km south of the Blackwood Road near Gisborne yielded:

Glyptograptus austrodentatus austrodentatus Harris and Keble
Pterograptus sp.
Isograptus victoriae maximo divergens Harris
I. victoriae velatus Harris
Cardiograptus morsus (narrow form)
Oncograptus biangulatus Harris and Keble

The presence of *Glyptograptus* and *Pterograptus* together with the absence of *Apiograptus* place this fauna as basal Darriwilian. *Cardiograptus* and *Oncograptus* are leftovers from the Yapeenian and are not found in higher Darriwilian beds. For a genus that ranges through the Upper Yapeenian time interval represented by the *Apiograptus* fauna, *Oncograptus* is unusually scarce in beds of this age. It has been found closely associated with *Apiograptus crudus* only at locality 19 on Saltwater Creek. At Chinamans Creek, *Apiograptus* occurs 2·5 metres higher in the sequence than *Oncograptus.* One explanation for the scarcity of *Oncograptus* during the Upper Yapeenian could be the method of graptolite emplacement by turbidity currents and the ensuing grading of the fauna, examples of which have been described by Moors (1968).

The existence of *Cardiograptus* in Lower Darriwilian beds is well established in Victoria. Harris and Thomas (1937) recorded *Cardiograptus morsus* (narrow form) with *Glyptograptus austrodentatus austrodentatus* and *Skiagraptus gnomonicus* from Sapling Gully in the Brisbane Ranges. From black slates outcropping along the upper reaches of Gisborne Creek this author has collected *Cardiograptus morsus* (narrow form) associated with a typical Darriwilian (Da1) fauna:

TABLE 1

CHINAMANS CREEK SECTION

	Bed	*Fauna*	*Thickness in Metres*
12	Yellow silty shale	Not fossiliferous	1·3
11	Brown quartzite	Not fossiliferous	0·6
10	Yellow micaceous sandstone with minor shale beds	Not fossiliferous	8·5
9	Orange shale	*Apiograptus* cf. *gisbornensis* (Harris and Thomas) *Cardiograptus morsus* (narrow form) *Skiagraptus gnomonicus* Harris and Keble *Didymograptus v deflexus* Harris *Tristichograptus ensiformis* (J. Hall) *Isograptus victoriae divergens* Harris	0·8
8	Massive yellow sandstone with minor sandy shale beds	Not fossiliferous	3·3
7	Pink shale	*Apiograptus crudus* (Harris and Thomas) *Pseudisograptus manubriatus* (T. S. Hall) *Tristichograptus ensiformis* (J. Hall) *Phyllograptus* sp.	0·5
6	Orange shale	Not fossiliferous	0·6
5	Bluff shale	*Cardiograptus morsus* Harris and Keble *Cardiograptus morsus* (narrow form) *Tristichograptus ensiformis* (J. Hall) *Isograptus victoriae divergens* Harris *Tetragraptus serra* (Brongniart) *Didymograptus* sp. *Phyllograptus* cf. *densus*	1·9
4	Bluff shale	*Cardiograptus morsus* Harris and Keble *Oncograptus biangulatus* Harris and Keble *Phyllograptus densus* Monsen *Isograptus victoriae divergens* Harris *Didymograptus v deflexus* Harris	0·3
3	Yellow sandy shale	Fossils rare *Tetragraptus* sp.	0·8
2	Bluff to pink shale	Fossils rare *Didymograptus v deflexus* Harris *Tetragraptus* sp. ?*Oncograptus* sp.	0·8
1	White sandstone	Unfossiliferous	3+

Glyptograptus austrodentatus austrodentatus Harris and Keble
Glossograptus cf. *acanthus* Monsen
Paraglossograptus tentaculatus (J. Hall)

Finally Thomas (1935) records *Cardiograptus morsus* together with *Glyptograptus* from a spoil heap of the old Guildford Plateau shaft north-east of Strangways Railway Station.

It is therefore surprising that *Cardiograptus* was not found in the mapped Lower Darriwilian beds along Saltwater Creek. Such faunal variations, however, are not uncommon in the Victorian sequence.

SUMMARY OF YAPEENIAN ZONATION

Bed by bed collecting of graptolites from Chinamans Creek does demonstrate the superposition of the *Apiograptus* fauna above an *Oncograptus-Cardiograptus morsus* fauna. Detailed mapping in the area west of Gisborne demonstrates details of the Yapeenian sequence, although direct superposition cannot always be distinguished due to complicated structure and apparent grading of fauna.

As a result of this mapping the zoning of the Yapeenian can be redefined as shown in Table 2. A new Ya3 zone is introduced, and this replaces the Ya2b zone designated by Harris and Thomas (1938). The Ya3 zone is defined by the interval represented by the incoming of *Apiograptus* to the incoming of *Glyptograptus*.

The Ya3 zone can be divided into two sub-zones based upon the two species of *Apiograptus*. *Apiograptus crudus* enters the basal Ya3 beds but soon gives way to *Apiograptus gisbornensis* which is much more widespread in its occurrence. Basal Ya3 beds have been found only at Chinamans Creek and along the Saltwater Creek. Accordingly this subdivision is not formalized.

The *Isograptus victoriae* fauna has been left out of the tabulation as this fauna has little stratigraphic value during the Yapeenian. *Isograptus victoriae divergens* appears in basal Yapeenian beds and remains in force during the Yapeenian.

Each of the three Yapeenian zones is characterized by the entry of a new genus:
Ya3 Zone of *Apiograptus*
Ya2 Zone of *Cardiograptus*
Ya1 Zone of *Oncograptus*

Each of the Yapeenian zones is a discrete

TABLE 2
UPPER LOWER ORDOVICIAN ZONATION

Fauna		*Zone*
Glyptograptus austrodentatus austrodentatus	Harris and Keble	Darriwilian (Da1)
Tristichograptus ensiformis	(J. Hall)	
Paraglossograptus tentaculatus	(J. Hall)	
Glossograptus acanthus	Elles and Wood	
Cardiograptus morsus (narrow form)		
Oncograptus biangulatus	Harris and Keble	
Apiograptus gisbornensis	(Harris and Thomas)	Yapeenian (Ya3)
Cardiograptus morsus (narrow form)		
Tristichograptus ensiformis	(J. Hall)	
Pseudisograptus manubriatus	(T. S. Hall)	
Apiograptus crudus	(Harris and Thomas)	
Cardiograptus morsus (narrow form)		
Tristichograptus ensiformis	(J. Hall)	
Pseudisograptus manubraitus	(T. S. Hall)	
Oncograptus biangulatus (only at the base)	Harris and Keble	
Cardiograptus morsus	Harris and Keble	Yapeenian (Ya2)
Oncograptus biangulatus	Harris and Keble	
Oncograptus upsilon	T. S. Hall	
Tristichograptus ensiformis	(J. Hall)	
Pseudisograptus manubriatus	(T. S. Hall)	
Oncograptus upsilon	T. S. Hall	Yapeenian (Ya1)
Tristichograptus ensiformis	(J. Hall)	
Pseudisograptus manubriatus	(T. S. Hall)	
Isograptus victoriae victoriae	Harris	Castlemainian (Ca3)
I. victoriae maximus	Harris	
I. victoriae maximo divergens	Harris	

mappable unit. From mapping in the area west of Gisborne, the Ya1 zone has a thickness of 64 m, the Ya2 zone 31 m and the Ya3 zone 130 m. In calculating thicknesses no estimation of modification due to faulting or thickening due to folding has been made.

The Ya3 zone may be recognized in all major areas of Yapeenian outcrop in Victoria, especially the type area at Yapeen. From a collection, held in the National Museum of Victoria and made from the Victorian Geological Survey locality, Ba91, south of Yapeen, this author has identified:

Apiograptus gisbornensis (Harris and Thomas)
Cardiograptus morsus (narrow form)
Didymograptus v deflexus Harris
Pseudisograptus dumosus (Harris)

Ba91 is the type locality of *Didymograptus v deflexus*. The fauna from this locality is identical with faunas already described from Gisborne and Chinamans Creek.

Apiograptus has been recorded from Lancefield by Harris and Thomas (1935). The Ya3 zone is also found at other localities in the Gisborne-Woodend area.

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REFERENCES

Beavis, F. C., 1972. The manubriate isograptids. *Geol. Mag.* 109: 193-204.

Cooper, R. A. & McLaurin, A. N., 1974. *Apiograptus* gen. nov. and the origin of the biserial graptoloid rhabdosome. *Special Papers in Palaeontology* No. 13: 75-85.

Harris, W. J., 1933. *Isograptus caduceus* and its allies in Victoria. *Proc. R. Soc. Vict.* 46: 79-114.

Harris, W. J. & Thomas, D. E., 1935. Victorian Graptolites (new series). Part III. *Ibid.* 47: 288-313.

——— & ———, 1937. Visit to the Brisbane Ranges. *Rec. Geol. Surv. Vict.* 5: 432-434.

——— & ———, 1938. A Revised Classification and Correlation of the Ordovician Graptolite Beds of Victoria. *Min. and Geol. J.* 1: 62-72.

Jackson, D. E. & Bulman, O. M. B., 1970. On the generic name *Trigonograptus* Nicholson 1869. *Proc. Geol. Soc. Lond.* 1663: 107-109.

Moors, H. T., 1969. The Position of Graptolites in Turbidites. *Sediment. Geol.* 3: 241-261.

Thomas, D. E., 1935. The Muckleford Fault in the Guildford-Strangways Area (near Castlemaine, Victoria). *Proc. R. Soc. Vict.* 47: 213-224.

———, 1960. Zonal Distribution of Australian Graptolites. *J. Proc. R. Soc. N.S.W.* 94: 1-58.

4

Provenance Studies on Tambo River Bedload Deposits, Eastern Victoria

By A. Goede*

ABSTRACT: The geological nature of the Tambo River drainage basin is summarized and a lithological map presented. At nine sample points along the course of the river the lithological composition of the gravel load in the long axis size range of 32-64 mm was determined. Its relationships with the outcrop pattern were investigated using the techniques of Tricart (1959).

For a number of rock types the ratio between the percentage area of outcrop (Q_o) and the percentage content in the bedload of the stream (Q_l) was investigated and this ratio (Q) was found to be characteristic for each lithology.

Application of the technique to a number of basins may aid understanding of the inter-relationships between the nature of fossil alluvial deposits and the lithological composition of the basins from which they were derived.

INTRODUCTION

Where it emerges from the highlands at Bruthen, the Tambo River in East Gippsland, Victoria, has a catchment of approximately 1700 km^2. Steep slopes and a local relief of up to 600 m characterize the basin, with the highest peaks in the northern part reaching heights of more than 1500 m.

Much of the river channel is gorge-like, with short stretches of floodplain and river terraces restricted to small basins where the river passes through more erodible rocks. The stream carries a heavy bedload and the channel is wide and shallow with a tendency towards braiding where the presence of fossil alluvial and colluvial deposits allows rapid bank erosion.

The Tambo River was originally selected for this study because of its heavy bedload and because access is facilitated by the fact that it is paralleled for much of its course by the Omeo Highway.

Contour information is available for the whole of the catchment but the scale and quality of map cover varies. The methods used required the compilation of a lithological map of the basin. Unfortunately, geological mapping is of a variable standard and the limited information available on some parts of the basin restrict the usefulness of the techniques applied.

REGIONAL SETTING

Climate and Vegetation: Climate is extremely variable because large altitudinal range and extreme local relief cause marked variations depending on site and aspect. The only climatic stations within the basin are located in river basins and valleys at low elevations, and show marked rainshadow effects.

Examination of the records of higher altitude stations elsewhere in the Victorian Alps suggests for mean annual precipitation a range from 1750 mm in the highest parts of the basin down to 600 mm in sheltered valleys within 300 m of sea level. Mean annual temperature ranges from 5°C at the highest elevations to 14°C near sea level. Although snow is frequent in winter above 1000 m, there is no evidence of significant present day periglacial weathering and mass movement, but fossil periglacial landforms indicate much colder conditions in the past.

Most of the catchment remains under forest, with clearing restricted to small basins developed on more erodible rocks and to the floodplain and terraces of the Tambo River. Land clearing has locally caused severe accelerated erosion resulting in increased reworking of older alluvial and colluvial deposits. Vegetation ranges from dry open sclerophyll forest below 500 m to wet

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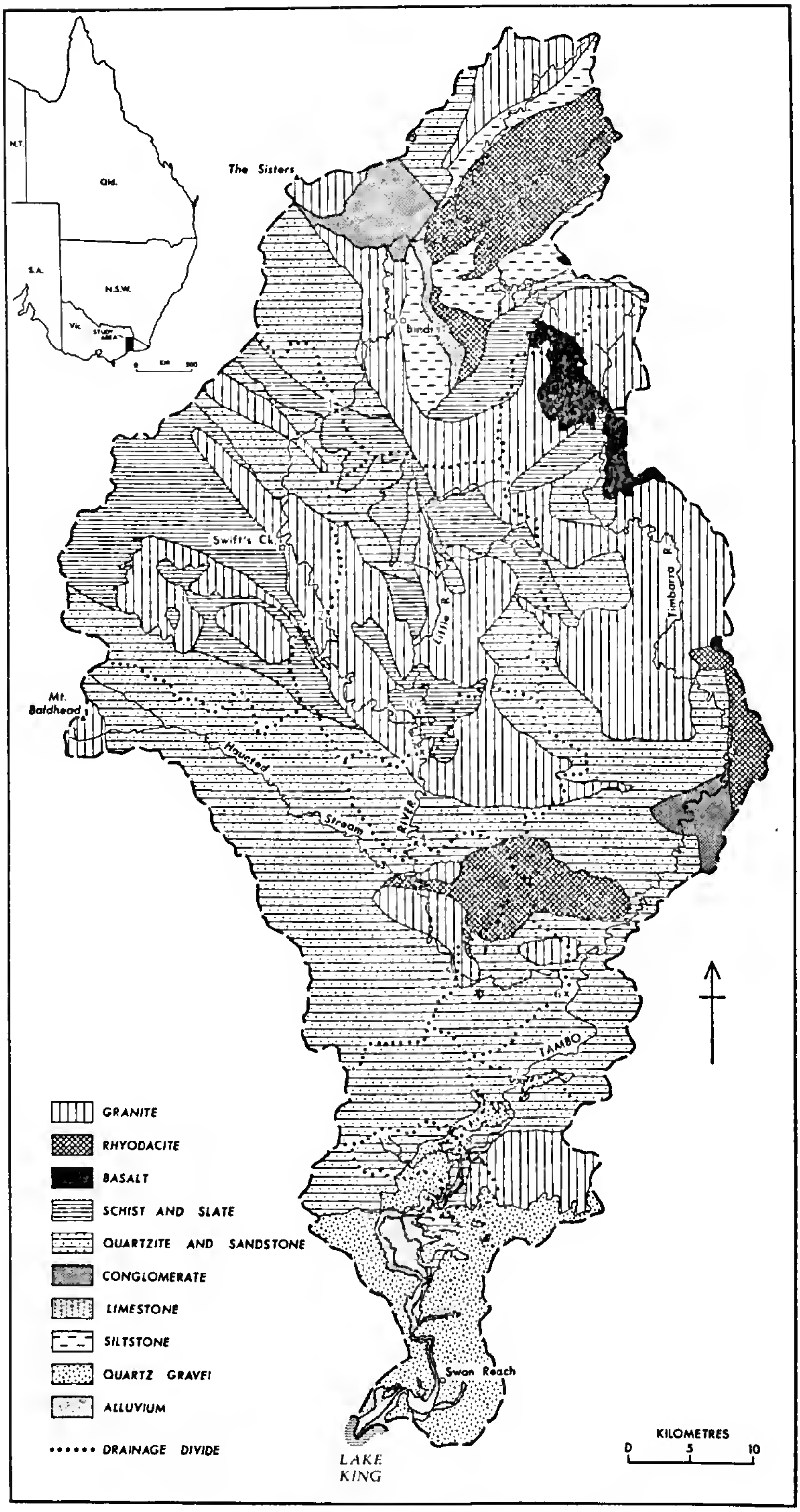

FIG. 1—Lithological map of Tambo River basin.

sclerophyll forest and some sub-alpine woodland at higher altitudes.

Geology and Geomorphology: The geology of the catchment area of the Tambo River has not been mapped systematically with the exception of a small area around the mouth of the Tambo which is included in the Bairnsdale geological sheet (1 : 63,360) published in 1960. To compile a lithological map of the area (Fig. 1) requires recourse to and reliance on published regional studies such as those by Gaskin (1943) of the Bindi area, Fletcher (1963) whose mapping included part of the Timbarra River catchment, and Tattam (1929) who studied the metamorphic belt extending into the Tambo catchment from Omeo to the south-east as far as Ensay. Other material is available in the form of published and unpublished reports and maps produced by the Geological Survey of Victoria including material prepared for inclusion in the Geological Map of Victoria (1 : 1,000,000) published 1963. Some information was also obtained from unpublished theses in the Geology Department of the University of Melbourne. The most important study was by W. Williams (unpublished) which included some detailed mapping of the granite complex in the Brookville-Swifts Creek-Ensay area.

An excellent summary of the geology of East Gippsland is given by Talent (1969). While dealing mainly with the stratigraphic sequence and geological history it also includes small sections on landforms and geological structure. A briefer account of the physiography, geology and mineral resources of the East Gippsland region is given by Thomas (1954), while some information on the geological structure of the area is found in Thomas (1958). Determination of potassium-argon ages of some of the East Gippsland granites by Evernden and Richards (1962) has helped to elucidate the geological history. A brief account of the geological nature of the area will be given (Fig. 1). Percentage area of outcrops refers to the area drained by the river at sample point 9, a short distance upstream from Bruthen.

Granitic rocks occupy nearly 30% of the drainage basin and range in age from Ordovician to Triassic. They vary from massive granites and granodiorites to gneissic granites and granite porphyries. As the present state of geological mapping does not allow the exact nature of each outcrop to be determined, they have been grouped together for the purpose of analysis.

The term rhyodacites is used to refer to outcrops of acid to intermediate volcanic rocks which are predominantly composed of rhyodacites and rhyolites but also include some ignimbrites and tuffs. These rocks are assigned to either the Silurian Mitta Mitta Volcanics or the Devonian Snowy River Volcanics and crop out over only 7·5% of the drainage basin. Nevertheless, they make an important contribution to the bedload.

Basalt outcrops in the drainage basin are confined to a belt 16 km long and up to 5 km wide underlying the Nunniong-Nunnett Plains and make up only 1·3% of the basin area. They are probably mid-Tertiary in age (Talent 1969, Beavis 1962).

Schists and slates are characteristic of the metamorphic belt associated with granitic intrusives and extend into the Tambo catchment from Omeo to the south-east as far as Ensay. They occupy just over 13% of the catchment area.

Outcrops of quartzite and sandstone are not readily distinguished at the present scale of geological mapping and have been grouped together. Most of the outcrops consist of great thicknesses of uniform, rhythmically bedded sandstones and quartzites of probable Ordovician age. These sediments represent a typical turbidite sequence characterized by graded beds, small scale cross bedding and flute casts. Sandstones are also present in the Wombat Creek Group of Silurian age and the Lower Devonian Timbarra Formation.

Plio-Pleistocene quartz gravels (Haunted Hills Gravels) make a significant contribution to the bedload of the Tambo River north-east of Bruthen and downstream from sample station 7. These gravels are clearly fluviatile in origin but are found 100 m and more above the present day river. Their distribution is shown separately in Fig. 1. Their contribution to the bedload of the Tambo cannot be separated from that made by quartzite and sandstone. The same applies to quartzitic material derived from conglomerates found in the Silurian Mount Waterton formation. Quartzites and sandstones together with quartz gravels and conglomerates make up nearly 45% of the drainage basin.

Limestone has a restricted distribution, cropping out near Bindi where it occupies only 0·41% of the catchment area. The limestone is correlated with the Buchan Caves Limestone of Devonian age (Gaskin 1943) and has an average dip of 30° to the WSW. with a prominent cuesta scarp marking the eastern boundary of the outcrop.

Siltstones are present in several geological horizons including the Silurian Wombat Creek Group as well as the Devonian Timbarra and

Taravale Formations. Together their outcrops account for only 3·9% of the drainage basin area.

In his description of the geology of East Gippsland, Talent (1969) gives a broad classification of five landform types of which three are represented in the area of study.

1. *Mountainous tracts* are defined as areas of strong relief with deeply incised valleys with accordant ridge tops common over distances of many miles. Occasional prominent mountain masses stand above these accordant summit levels as though representing residuals above a former widespread erosion surface.
2. *Tablelands* are undulating surfaces with broad valleys and low divides bevelling the high parts of the topography more or less regardless of rock type. Areas of Tertiary basalt (e.g. the Nunniong-Nunnett tablelands) are included in these.
3. *Intermontane basins* comprise small areas of low relief that are due to differential erosion of more easily eroded rocks. Examples from within the Tambo catchment given by Talent include the Bindi and Ensay-Swifts Creek areas.

A large proportion of the Tambo River catchment can properly be described as mountainous tract. As indicated in the introduction it is characterized by extreme local relief and very steep slopes.

Of considerable importance in relation to this study is the occurrence of periglacial and possibly glacial landforms and deposits in the Victorian Alps, since it must be considered highly likely that much of the gravel bedload of the present day Tambo River was made available by the prevalence of mechanical weathering by freeze and thaw, particularly at higher elevations during the cold stages of the Pleistocene.

Evidence for Pleistocene glaciation in the Victorian Alps has been brought forward by Carr and Costin (1955) who have claimed that the presence of ground moraine, asymmetrical hills, U-shaped valleys, truncated spurs and hanging tributary valleys is evidence of cirque and valley glaciation on the Bogong High Plains, Mount Bogong, Mount Hotham and Mount Feathertop. Beavis (1959) has since made a critical reexamination on the Bogong High Plains of the evidence presented by Carr and Costin and contends that their evidence is not substantiated by detailed field examination. He claims that '. . . it is possible to assert that no indisputable evidence of Pleistocene glaciation has been found on the Bogong High Plains'. More recently the evidence for glaciation of the Victorian Alps has been reexamined by Peterson (1969) in a number of areas and his findings are essentially in agreement with those of Beavis in that no unequivocal evidence of glaciation has been found. None of the localities where the presence of glacial features has been suggested falls within the area drained by the Tambo River and on present evidence glaciation cannot be considered as a process contributing to the gravel bedload of the river during glacial periods.

On the contrary, evidence of periglacial landforms appears to be widespread at higher elevations although little work has been done to assess their extent. Carr and Costin (1955) briefly mention the occurrence of boulder runs (?), stone polygons and stripes from several localities, particularly in association with basalt. The only detailed study of periglacial landforms is by Talent (1965) who has described blockstreams of rhyodacite boulders from Mt. Wombargo, Big Hill and the Cobberas extending down to altitudes of about 1200 m, and the occurrence of stone banked terraces composed of the same rock type. Evidence of the fossil nature of both landforms is presented. His observations indicate the susceptibility of the rhyodacites to frost weathering and this is of interest, because these rocks crop out extensively at higher elevations in the headwaters of the Tambo River and pebbles derived from them form a substantial proportion of the gravel load of the Tambo in the size range studied.

In the Victorian Alps little information is available on the lower limit to which periglacial processes were active but on the highlands of southern New South Wales this limit is thought to be at least 1000 m and possibly 700 m (Galloway 1965), while in Tasmania the limit was down to 300 m or even lower (Davies 1965, 1967). Using these figures as a guide, the general level of the lower limit of periglacial processes in the past must have lain somewhere between 500 and 1000 m. Davies (1969, pp. 12-13) has stressed, however, that this limit may vary depending on lithology and states that 'different rock types react differently to frost weathering and frost-induced mass movement—they vary in their readiness to be mobilized by frost. Because of this, periglacial conditions may appear to have extended nearer to sea level on some rock types than on others'. Much of the bedload transported by the Tambo River at present is probably derived by the reworking of colluvial aprons, fan deposits and older alluvial terraces built up under periglacial conditions. Remnants of massive gravel terraces and alluvial fans are particularly well preserved near Swifts Creek between Tongio and Doctors Flat.

Natural reworking of older gravels by the river has been accelerated by anthropogenic factors of which mining has been the most important. The late 19th century saw an upsurge of mining in the area, mainly of deposits of gold and cassiterite occurring in the form of alluvial deposits as well as some reefs and veins. The effect of mining operations has been to increase the amounts of older alluvial deposits being reworked by the stream as well as introducing 'foreign' material from hard rock mining operations: some of the vein quartz found in the gravel samples is probably derived from this source. The increase in load was undoubtedly further augmented by the resultant undercutting of alluvial banks adding still further to the supply of sand and gravel bedload of the stream.

SAMPLING

The method of sampling basically followed the pioneer study in this field by Tricart (1959) which, despite its original approach, seems to have made little if any impact in the English speaking world.

Sampling was restricted to a narrow size range (32-64 mm) as it has been shown (Tricart 1959) that lithological composition is strongly dependent on particle size and that, if the whole spectrum of particle size is examined, each rock type may be characterized by a narrow size range where its contribution to the sediment load is at a maximum. This modal value appears to depend on the physical and chemical properties of the rock and on the conditions of physical and chemical weathering which in turn are strongly influenced by climate.

The size range 32-64 mm was selected because particles in this range are sufficiently abundant to allow large samples to be collected, yet large enough to allow rapid visual determination of lithological type and accurate measurement of shape and roundness of quartzite and rhyodacite pebbles. The results of shape and roundness measurements are published elsewhere (Goede 1975).

Nine sample stations were established on gravel bars (either point or midstream bars) along the course of the river. The relatively small number of stations reflects the fact that the study reported here is part of a project involving the examination of sphericity and roundness of rhyodacite and quartzite pebbles. More or less equal spacing of stations was aimed for but actual sample localities frequently depended on accessibility

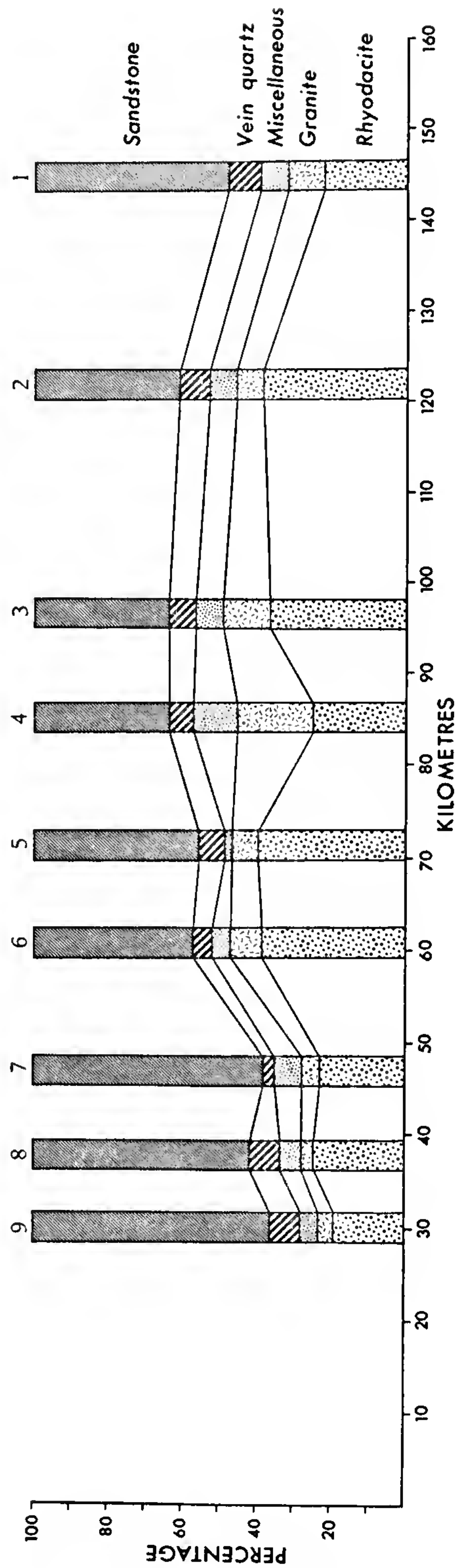

FIG. 2—Lithological composition of samples.

and the presence of abundant pebbles in the size class being sampled. At a selected point a peg was driven in and a circle one m in diameter set out. Working from the centre outwards two hundred pebbles within the long axis size limits of 32-64 mm were collected and identification of lithological content made on the spot.

Identification was made easier by the near absence of chemical weathering in most rock types. Pebbles were generally clean and fresh,

TABLE 1
Relationships between lithology of samples and outcrops.

Sample No.	Granites			Rhyodacites			Sandstones, quartzites			Limestones		
	Q_ℓ	Q_0	Q	Q_ℓ	Q_0	Q	Q_ℓ	Q_0	Q	Q_ℓ	Q_0	Q
1	9.5	25.75	0.37	22.5	20.56	1.10	52.5	27.02	1.94	-	2.05	-
2	7.0	27.32	0.25	38.5	11.63	3.31	40.0	27.19	1.47	-	1.15	-
3	12.5	32.28	0.39	38.0	8.72	4.36	36.0	25.76	1.40	-	0.87	-
4	20.0	33.29	0.61	30.0	7.55	3.97	36.5	28.39	1.29	-	0.78	-
5	7.0	28.02	0.25	39.5	8.07	4.90	44.5	40.00	1.11	-	0.62	-
6	8.5	27.45	0.31	38.5	8.14	4.74	46.5	41.40	1.12	-	0.59	-
7	4.5	29.95	0.15	23.0	8.07	2.86	62.5	41.75	1.50	-	0.44	-
8	3.0	29.20	0.13	24.5	7.87	3.11	60.0	43.30	1.39	-	0.43	-
9	4.0	29.34	0.14	20.5	7.49	2.74	64.0	44.40	1.44	-	0.41	-
$\bar{Q}$			0.29			3.45			1.41			

Sample No.	Basalts			Vein quartz			Schists, slates			Siltstones		
	Q_ℓ	Q_0	Q	Q_ℓ	Q_0	Q	Q_ℓ	Q_0	Q	Q_ℓ	Q_0	Q
1	-	0.80	-	8.5	?	-	7.0	8.61	0.81	-	15.21	-
2	1.0	0.45	2.22	8.0	?	-	5.5	23.66	0.23	-	8.60	-
3	1.0	0.34	2.94	7.5	?	-	5.0	25.58	0.20	-	6.45	-
4	-	0.31	-	6.5	?	-	7.0	23.75	0.29	-	5.93	-
5	-	0.24	-	7.0	?	-	2.0	18.46	0.11	-	4.58	-
6	-	0.23	-	5.0	?	-	1.5	17.74	0.08	-	4.40	-
7	3.5	1.49	2.35	3.0	?	-	3.5	14.13	0.25	-	4.21	-
8	2.5	1.45	1.72	7.0	?	-	3.0	13.80	0.22	-	4.10	-
9	-	1.38	-	8.0	?	-	3.5	13.12	0.27	-	3.90	-
$\bar{Q}$			2.31						0.26			

although granite particles frequently showed a pronounced tendency towards granular disintegration, and slight weathering out of quartz and feldspar phenocrysts was observed in some rhyodacite pebbles at stations 8 and 9 (Fig. 1).

ANALYSIS OF THE DATA

The lithological composition of each of the nine samples collected along the Tambo River is illustrated in Fig. 2. It can easily be seen that the composition of the bedload within the size range studied is dominated by two lithologies: rhyodacites and sandstones. Others, including granites which crop out over large areas, form only a minor component. The deficiency in granite content appears to be due to the observed rapid granular disintegration of granite pebbles present in the bed material. The percentage of rhyodacite pebbles decreases markedly downstream from the Timbarra River junction (between stations 6 and 7) and reflects the more limited extent of outcrops of this rock in the Timbarra catchment.

To relate the lithological composition of samples to outcrop patterns a lithological map of the whole of the Tambo catchment was compiled (Fig. 1) and all information available at that time included. Unfortunately, the patchy nature and variable quality of geological mapping in the area renders the investigation of relationships between areas of outcrop and gravel composition less rewarding than might otherwise have been the case.

The approach used is similar to that used by Tricart (1959) for a number of rivers in France. For each rock type within each sample, Q_l, the percentage content in a particular sample, has been calculated. Similarly, at each sample point and for each lithology, Q_0, the percentage area of the catchment over which a particular lithology crops out, was also computed. Q is the ratio Q_l/Q_0 and gives an indication of the yield of material from a particular lithology, within the size class examined, in relation to other rock types. A value greater than one indicates an above average yield, a value of less than one below average yield (Table 1). For each rock type the values of Q from the nine stations have been averaged to give $\bar{Q}$. Although there is a good deal of variation between samples, a particular value of $\bar{Q}$ was found to characterize each lithology.

Values of Q_l, and therefore Q, cannot be determined for limestones and siltstones due to their absence from all nine samples. For basalts, Q_l cannot be determined for five samples and the value of $\bar{Q}$ represents the mean of the values of Q of the four remaining samples. The absence of pebbles belonging to these rock types appears to be due to relatively small areas of outcrop within the basin, particularly of limestones and basalts, and also because pebbles of limestones and siltstones are rapidly removed during transport: the latter are prone to rapid disintegration and the former are attacked by solution processes and are also subject to rapid abrasion because of their low hardness.

In the case of vein quartz it is not practicable to determine areas of outcrop and this problem has been discussed at length by Tricart (1959). Vein quartz is probably most common in the granitic rocks but also occurs in other rock types. Even if areas of outcrop could be calculated the value of $\bar{Q}$ would be suspect as a true measure of relative yield of debris under natural conditions in the size class being considered. Mining operations may well have provided a significant source of vein quartz in the recent past.

For rhyodacites, sandstones and basalts the value of $\bar{Q}$ is above one, although figures for basalt must be treated with caution because of the small number of pebbles involved. In the size class examined rhyodacites yield more material per unit area of catchment than any other rock type. This may reflect their susceptibility to frost weathering during cold climatic conditions (Talent 1965). The common occurrence of outcrops at high elevations, together with the resistance of these rocks to abrasion, breakage and chemical weathering under the prevailing environmental conditions, are other factors that must be considered.

For schists, slates and granites the value of $\bar{Q}$ was less than one, reflecting the tendency for these rocks to yield fragments that are rapidly broken down into smaller detritus during transport.

It was decided to investigate for one well represented lithology, rhyodacite, the possible relationships of Q with mean distance from outcrop (Di_r) and mean altitude of outcrops (Al_r) for each station. Mean distance from outcrops indicates the mean distance of transport and should be directly related to the amount of abrasion and breakage suffered by a sample of rhyodacite pebbles. Mean altitude was investigated to test the possibility that rhyodacite pebbles were derived predominantly by periglacial processes during the Last Cold Period of the Pleistocene. If so, one would expect outcrops at high elevations, where climatic conditions were more severe,

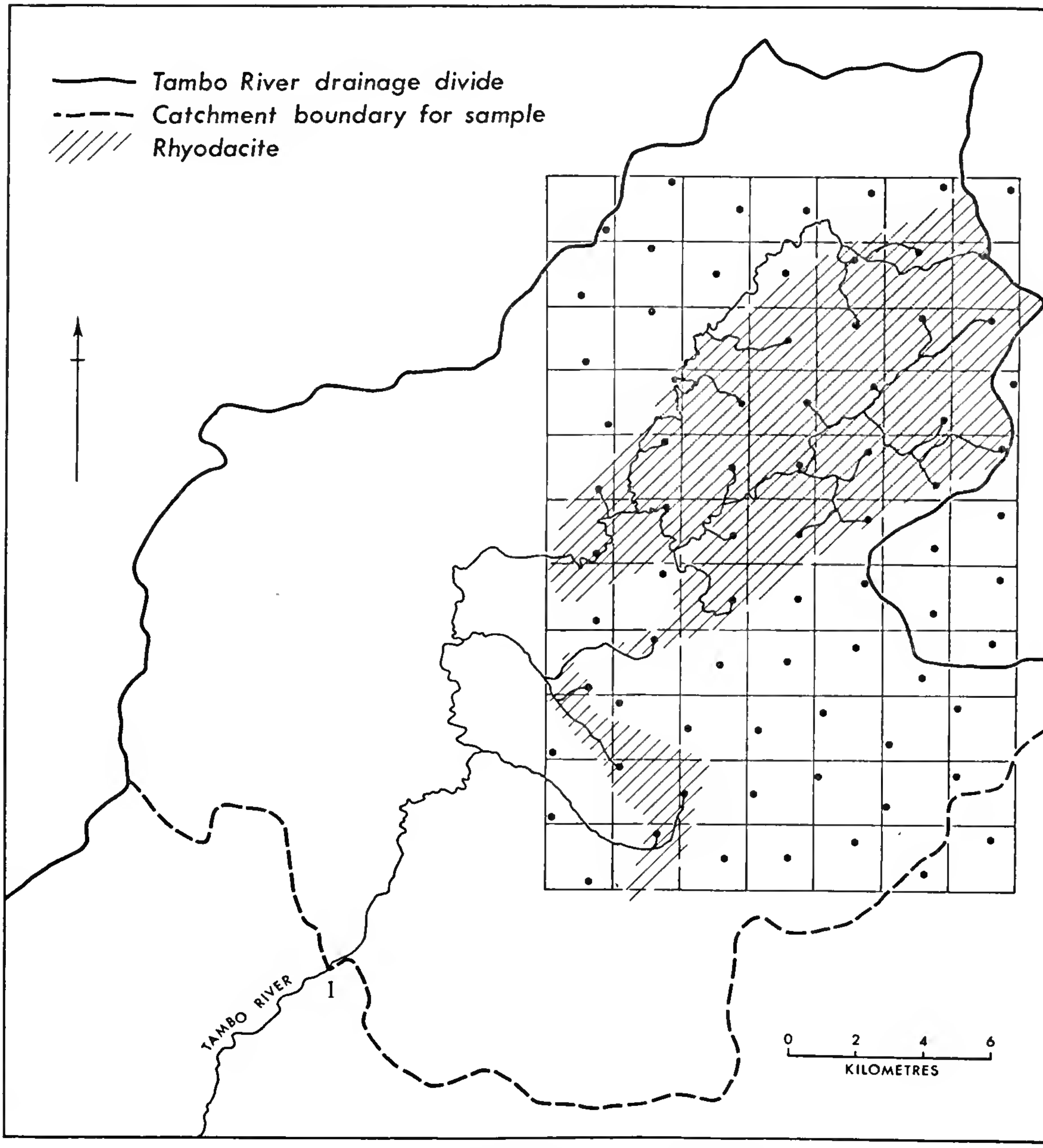

FIG. 3—Sampling grid for outcrops of rhyodacite.

to have contributed more material per unit area than those at lower elevations.

The first step was the superimposition of a 2000 m sampling grid over the catchment. Most of the area is covered by the 1 : 100,000 Omeo and Benambra topographic sheets with metric contours and grid, enabling the existing grid to be used for sampling. On non-metric maps covering the remainder of the area a metric sampling grid was superimposed. One sample point was selected within each grid square using the stratified systematic unaligned method of sampling in order to ensure an unbiassed estimate of mean altitude (Berry & Baker 1968). For each sampling point mean altitude of the outcrops (Al_r) was determined as follows. If a point fell on a contour its height was considered to be that of the contour while if it fell between two contours its height was taken as being half-way between the two. Where contour information was in feet the same procedure was followed but in conversion to metric units each value was rounded off to the nearest multiple of 20 m. From each point the distance to the location of the nearest gravel sample station was measured by the horizontal distance down the slope to the nearest stream and from there downstream along the channel. The horizontal distance rather than the slope distance was used because it is more easily measured. With the values involved in this study horizontal distances are very large compared with vertical distances. Changes in values obtained by substituting slope distance for horizontal distance would be very small and well within the margins of error for measurement of horizontal distance from topographic maps. Fig. 3 illustrates the sampling procedure in the area upstream from sample station 1. From this information the mean distance (Di_r) from rhyodacite outcrops to the sample location was calculated for each station. Correction factors were applied where distances were measured on maps of different scales. The measurements are shown in Table 2.

The next step was the correlation of Q with Al_r and Di_r. The correlation coefficient between Q and Al_r was ·036 indicating virtually no relationship between Q and mean altitude of outcrops. Correlation between Q and Di_r yields a coefficient of ·480 (Student's $t = 1{\cdot}155$) and while this is not significant this may well be due to the small number of samples involved ($n = 9$). It indicates that 23% of the variation in Q can be explained in terms of variations in distance from outcrops.

Some of the variation in Q undoubtedly reflects error variance since the value of Q is subject to errors in geological mapping, sampling and field identification of rhyodacite. Since Q is related to Q_l, variations in Q are also induced by the varying abundance of other rock types.

Another related aspect of the lithological com-

TABLE 2
Values of Al_r and Di_r for samples of rhyodacite.

Sample No.	No. of points	Q	Al_r (m) (mean altitude of rhyodacite outcrops)	Di_r (km) (mean distance from rhyodacite outcrops)
1	31	1.10	1040.00	35.20
2	31	3.31	1040.00	57.91
3	31	4.36	1040.00	82.81
4	32	3.97	1040.38	92.03
5	40	4.90	928.00	87.54
6	41	4.74	921.95	97.59
7	54	2.86	830.37	95.23
8	54	3.11	830.37	104.50
9	54	2.74	830.37	112.16

position of the gravels investigated by Tricart (1959) was the relationship between changes in Q_l (ΔQ_l) and changes in Q_0 (ΔQ_0) between stations. He considered the significance of three possibilities.

Case 1—$\Delta Q_l > \Delta Q_0 > 0$
Case 2—$\Delta Q_l > 0 > \Delta Q_0$
Case 3—$\Delta Q_l < \Delta Q_0$

He further claimed that the three cases just stated gave information relating to the physical behaviour and degree of reworking of particular rock types between two stations. Before considering this it must be pointed out that Tricart's three cases are not exhaustive—other relationships may occur. To cover all possible relationships the following cases must be considered.

Case 1—$\Delta Q_l > \Delta Q_0$ (a) both positive
(b) ΔQ_l positive, ΔQ_0 negative
(c) both negative

Case 2—$\Delta Q_l < \Delta Q_0$ (a) both positive
(b) ΔQ_l negative, ΔQ_0 positive
(c) both negative

Case 3—$\Delta Q_l = \Delta Q_0$ rare occurrence

Values of ΔQ_l and ΔQ_0 are set out in Table 3 for three lithologies: rhyodacite, sandstone and granite. Behind each pair of values the case which applied to the relationship between them is indicated. It can be seen that the relationship appears to vary in a completely random manner both within and between lithologies, and does not therefore support Tricart's contention. The influences of lithological constituents other than the one being considered probably affect the values of both ΔQ_l and ΔQ_0 to such an extent that the relationship between them has little if any meaning.

TABLE 3
Values of ΔQ_l and ΔQ_0 for Rhyodacite, Sandstone and Granite.

	Rhyodacite			Sandstone			Granite		
Sample No.	ΔQ_ℓ	ΔQ_0	Case	ΔQ_ℓ	ΔQ_0	Case	ΔQ_ℓ	ΔQ_0	Case
1	+16	-8.93	1(b)	-12.5	+0.17	2(b)	-2.5	+1.57	2(b)
2	-0.5	-2.91	1(c)	-4.0	-1.43	2(c)	+5.5	+4.96	1(a)
3	-8.0	-1.17	2(c)	+0.5	+2.63	2(a)	+7.5	+1.01	1(a)
4	+9.5	+0.52	1(a)	+8.0	+11.61	2(a)	-13.0	-5.27	2(c)
5	-1.0	+0.07	2(b)	+2.0	+1.40	1(a)	+1.5	-0.57	1(b)
6	-15.5	-0.07	2(c)	+16.0	+0.35	1(a)	-4.0	+2.50	2(b)
7	+1.5	-0.20	1(b)	-2.5	+1.55	2(b)	-1.5	-0.75	2(c)
8	-4	-0.38	2(c)	+4.0	+1.10	1(a)	+1.0	+0.14	2(a)
9									

CONCLUSION

Investigation of the relationships between the lithology of the Tambo River drainage basin and the lithological composition of gravel samples after the manner of Tricart (1959) has confirmed the Q ratio as a useful indicator of the relative contributions made to the bedload by different rock types in the size class studied. The accuracy of the Q ratio values can probably be improved substantially when accurate geological maps are available for the whole of the basin.

However, the relationship between ΔQ_t and ΔQ_0, which was considered by Tricart to give significant information on the physical behaviour of different rock types, appears to have no real meaning in the example studied and illustrates the problems involved in dealing with variables based on percentage values.

REFERENCES

BEAVIS, F. C., 1959. Pleistocene glaciation on the Bogong High Plains. *Aust. J. Sci.* 21(6): 192.

———, 1962. The geology of the Kiewa area. *Proc. R. Soc. Vict.* 75: 349-410.

BERRY, B. J. L. & BAKER, A. M., 1968. Geographic sampling, pp. 91-100 in Berry, B. J. L., and Marble, D. F. (eds.). *Spatial Analysis.* Prentice-Hall, New Jersey.

CARR, S. G. M. & COSTIN, A. B., 1955. Pleistocene glaciation in the Victorian Alps. *Proc. Linn. Soc. N.S.W.* 80: 217-228.

DAVIES, J. L., 1965. Landforms, pp. 19-23 in Davies, J. L. (ed.), *Atlas of Tasmania.* Lands and Surveys Department, Hobart.

———, 1967. Tasmanian landforms and Quaternary climates, pp. 1-25 in Jennings, J. N., and Mabbutt, J. A. (eds.), *Landform Studies from Australia and New Guinea.* A.N.U. Press, Canberra.

———, 1969. *Landforms of Cold Climates: An Introduction to Systematic Geomorphology,* Vol. 3. A.N.U. Press, Canberra, 200 pp.

EVERNDEN, J. F. & RICHARDS, J. R., 1962. Potassium-argon ages in Eastern Australia. *J. geol. Soc. Aust.* 9: 1-49.

FLETCHER, K., 1963. The Snowy River Volcanics west of Buchan, Victoria. *Proc. R. Soc. Vict.* 76: 169-180.

GALLOWAY, R. W., 1965. Late Quaternary climates in Australia. *J. Geol.* 73: 603-618.

GASKIN, A. J., 1943. The geology of Bindi. *Proc. R. Soc. Vict.* 55: 81-108.

GOEDE, A., 1975. Downstream Changes in Shape in the Pebble Morphometry of the Tambo River, Eastern Victoria. *J. Sed. Petrol.* (in press).

PETERSON, J. A., 1969. *The Cirques of Southeastern Australia:* Studies in morphology and distribution; history and significance. Unpublished Ph.D. thesis (Monash University, Victoria), 417 pp.

TALENT, J. A., 1965. Geomorphic forms and processes in the highlands of Eastern Victoria. *Proc. R. Soc. Vict.* 78: 119-135.

———, 1969. The geology of East Gippsland. *Ibid.* 75: 277-284.

TATTAM, C. M., 1929. The metamorphic rocks of north-east Victoria. *Geol. Surv. Vict. Bull.* No. 52, 52 pp.

THOMAS, D. E., 1954. Physiography, geology and mineral resources, pp. 18-24 in *Resources Survey —East Gippsland Region.* Central Planning Authority of Victoria.

———, 1958. The geological structure of Victoria. *Proc. R. Soc. N.S.W.* 92: 182-190.

TRICART, J., 1959. L'Étude comparée de la composition des alluvions fluviatiles et de la nature lithologique du bassin; moyen d'analyse des systèmes d'érosion. Revue Géomorph. dyn.: 10 (1-4), 2-15.

5

STUDIES IN VICTORIAN VEGETATION

1. Computer Sorting of Plant Associations in the Northern Brisbane Ranges

By P. B. Bridgewater*

ABSTRACT: Computer techniques for sorting vegetation data into plant associations have been applied to the open-forest of the northern Brisbane Ranges. Data were collected by a large group of field investigators, which provided a rapid means of collecting samples from a wide range of plant communities.

Two plant associations form the major area of vegetation in the Brisbane Ranges—the Xanthorrhoeo-Platylobietum and the Eucalypto-Acacietum pycnanthae. Both associations have a number of sub-associations and variants. Such vegetation variation is related, in the first instance, to edaphic and climatic factors.

INTRODUCTION

The Brisbane Ranges rise sharply to 470 m at the west of the volcanic plains between Melbourne, Geelong and Bacchus Marsh. The range divides about the tributaries of the Little River into northern and southern halves. This article deals with vegetation of the ridges and hill tops north from Reillys Creek.

Seven *Eucalyptus* species are found as constituents of the vegetation: *E. baxteri*, *E. dives*, *E. goniocalyx*, *E. macrorhyncha*, *E. obliqua*, *E. polyanthemos*, *E. sideroxylon*, with *E. ovata* occurring in occasional pockets near watercourses. Following the structural classification of Specht (1970), the vegetation falls largely into the open-forest category. With such a range of tree species, appearing at times almost randomly mixed, classification of this vegetation as one category is unsuitable, particularly if more detailed studies are envisaged.

Frankenberg (1971) lists three sub-alliances for her alliance described as 'Red Stringybark-Red Box-Peppermint', which would presumably include the vegetation of this area. With such reliance solely on *Eucalyptus* species as ecological indicators, this classification may also be regarded as inadequate. Such a complex mixture seemed an ideal testing ground for a more detailed application of the Zurich-Montpellier system (Bridgewater 1971).

Computer programs capable of rapid handling of large data sets have been written by the author, and modified by Mr. J. R. Busby, for a Burroughs B5500/B6700 computer. In this way, many of the tedious processes associated with hand-sorting a large data set are removed. All the vegetation data were collected by a field group of the Monash University Biology Society. This exercise was a pilot attempt to see if data could be quickly culled and analysed from an area. Such data are easily held in a bank for use in further ecological/land-use studies.

The collected data have been treated in two ways: firstly to provide an 'overview' of the vegetation trends in this area, and secondly as a basis for the floristic description of plant associations in Victoria—and the rest of Australia. Future papers in this series will deal with coastal heathland, saltmarsh and temperate rainforests.

DATA COLLECTION

All data from vegetation samples were recorded on cards printed with a numbered list of species likely to be found in the area. Data were then transferred to computer punch cards for processing. No samples were taken close to

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watercourses, so vegetation associated with *E. ovata* is unrepresented.

Sample sites were selected to include as wide a range of physiognomically different vegetation as possible, within the area. Samples were generally taken in areas of homogeneous, or undisturbed, vegetation (Bridgewater 1971), but some areas which appeared ecotonal, or gradal, were sampled as well, in an attempt to gauge the vegetation variation.

An initial computer program (INDATA/CHECK) was used to print out the samples as they are encoded on the punch cards, and also to calculate the frequency of each species occurrence. This allows for easy checking of coded data against the field records for any coding errors.

DATA SYNTHESIS

A number of programs appear in the literature which attempt to simulate the processes of the Z-M system (e.g. Moore et al. 1970, Ceska & Romer, 1971). Both of these were written for IBM machines, and are not suitable to take advantage of the large processing facility offered by the Burroughs machine.

The principles on which the programs operate are similar, and formed the basis for the operations of the Monash program (ZUMONT/SORT). This program attempts to detect species/relieve coincidences and operates in the following way. It initially searches for all those species which occur in 15 to 70 per cent of the samples under consideration. Species which fall between these limits are those which would be 'potential differential species' (PDS) (Bridgewater 1971). The PDS with the greatest number of occurrences is selected and all the samples in which it occurs are found. The remaining PDS are scanned and those which occur in at least 50% of these samples are selected. If none can be found then the first species is printed out as a 'single species' and is not considered further in the analysis. The PDS with the next highest number of occurrences is then selected and the process is repeated until all the PDS are rejected or a suitable species group is found. If such a group is found the samples involved are then scanned to ensure that each sample contains at least 50% of the selected PDS. Those which do not contain 50% are rejected. If no samples are rejected then this group is printed out and the PDS in this group are not considered in subsequent calculations. Of the remaining PDS the one with the highest number of occurrences is selected and the process is repeated. If some samples are rejected then the PDS are scanned again and those eligible PDS which occur in at least 50% of the remaining samples are selected. If there is no change in the number of PDS then the group is printed out. If there is a change in the number of PDS then the samples are scanned again as above. This sorting of samples and species within the one group can be repeated for up to 20 times before being automatically terminated. Calculations proceed until all PDS are printed as 'single species' or members of a group. Finally all those samples which contain species groups are printed out with the numbers of the species groups which they contain.

A third program (ZUMONT/PRINT) allows a full table to be printed by the computer, with the order of species and vegetation samples determined by the operator. Initially the order will be that suggested by the results of ZUMONT/SORT, with the order subsequently decided by the operator in the same way that he would reorder a hand sorted table. The important feature is that the raw data are used at each stage, minimizing the possibility of error.

TABLE 1

SPECIES GROUPS GENERATED BY ZUMONT/SORT

1. *Eucalyptus sideroxylon*
   Eucalyptus macrorhyncha
   Acacia pycnantha
   Haloragis tetragyna
   Dianella revoluta
   Cladia aggregata
   Xanthorrhoea australis
2. *Platysace lanceolata*
   Helichrysum obcordatum
3. *Pultenaea gunnii*
   Epacris impressa
   Stypandra caespitosa
   Campylopus introflexus
   Acrotriche serrulata
   Tetratheca ciliata
4. *Eucalyptus polyanthemos*
   Veronica perfoliata
5. *Eucalyptus goniocalyx*
   Danthonia pallida
   Hypnum cupressiforme
6. *Acacia mitchellii*
   Pimelea humilis
   Grevillea steiglitziana
   Platylobium obtusangulum
   Lepidosperma laterale
   Hakea sericea
   Eucalyptus baxteri
7. *Parmelia* spp
   Caladenia carnea
8. *Tetratheca ericifolia*
   Leucopogon virgatus

Table 2

FINAL TABLE OF ALL VEGETATION SAMPLES, PRODUCED BY PROGRAM ZUMONT/PRINT.

See text for details of the sample groups.

SAMPLE GROUP	I	II	III	IV	V	VI	VII
Samples	00046 00042 00047 00002 00066 00067 00068 00069 00070 00071 00044 00043 00045 00048 00041 00038 00040 00039	00052 00053 00054 0000I 00004 0000S9	00060 00062 00065 00026 00007 00003 00057 00058 00064 00063 00061 00037 000S6 0005I 00055	00005 00008 00025 00018 00006 00023 00024 00027 000I1 00021 00032 00022 00020	00033 00034 0003I 00030 00029	00016 00035 000I9 000I0 000I7 00028	000I3 00009 00012 000I4 00036 00049 000IS
EUCALYPTUS OIVES	3 3 + 3 3 + +		+ 2 2			3	2 2
MONOTOCA SCOPARIA	+ 4 2 2 + + +	3 +		+		+ +	2 2 + +
ISOPUGON CERATOPHYLLUS	+ +						
PULTENAEA HUMILIS	+ 2 3 + 2 2						
HIBBERTIA ACICULARIS	2 + +		2	+ 4 + 2 4			+
CASSYTHA GLABELLA	+						+
LEUCOPOGON ERICIOOES	+ + + 2 2						
CLAUDNIA SPP.	+ + + 2 +	+	2 2 + 3 2	2 +			
EUCALYPTUS OBLIQUA	+						
BANKSIA MARGINATA	+ 2 2						
GOMPHOLOBIUM HUEGELII	4 2						
DAVIESIA VIRGATA	2 2 3 3 3		+	+ + +			+
STACKHOUSIA VIMINEA	2 2		4				
CORREA REFLEXA	2 2 3 3 +						4
PULTENAEA PEDUNCULATA	3 + + 2 2 + 3 + +						
COMESPERMA VOLUBILE	+ + +						
HELICHRYSUM SCORPIOIDES	+ + + + + +	+	+ +	2 + + +		2 + +	+ +
HAKEA SERICEA	2 4 + 2 3 3 2 + 2 2 3 4 + 2	+	3			3	+ 3 3
ACACIA MITCHELLII	+ 2 2 3 2 2 + + +	2	+			2	+ + +
PIMELEA HUMILIS	3 2 2 2 2 2 + 2 2 2 2	2		2			+ +
GREVILLEA STEIGLITZIANA	2 3 3 + 2 2 + + 3 2		+	2		3 2	2 2
LEPIDOSPERMA LATERALE	+ + + 2 3 2 2 3 2 + 3 2	+					2
ACROTRICHE SERRULATA	2 + 3 2 + 2 3 3	+ 2 3	2 + + +	+ + 2	2		+
TETRATHECA CILIATA	+ + + + + + 2 + + 2 2 +	2 2 2 +	2 +				+
XANTHORRHOEA AUSTRALIS	4 S 4 4 4 2 4 3 3 4 4 4 3 4 3 3 3	4 2 4 S	S 3 2 2 4 3 3 4 2 4	+		4	3 3 2
EUCALYPTUS BAXTERI	4 4 3 4 2 2 2 3 3 4 2 4 4 3 3	2 3					
PLATYLOBIUM OBTUSANGULUM	+ 2 2 + + + + + 2 2 + 2 2 3 2	+ +					3 +
LEUCOPOGON VIRGATUS	+ + 2 2 + 2 3 2 + 2		+			2	2 +
EPACRIS IMPRESSA	+ + 2 + + + 2 2 2 + + +	2 2 2	2 2 2 2 2	3		+ 2	2 + + + +
CAMPYLOPUS INTROFLEXUS	2 3 + + + + 2 2 +	2 3 3	2 2 3 2 + 4 3 + +	2 2 4 3 3 2	3		
STYPANORA CAESPITOSA	+ + + 2 2 + 3 3 3	+ + +	+ 2 + 3 + + 3	+		2 + +	2 +
PULTENAEA GUNNII	+ 2 + + +	2 2 4 3	3 3 2 3 + 3 2				+ 4 +
GERANIUM MOLLE			+ 2 2				
STICTA SP.			+				
LUZULA CAMPESTRIS			2 + 2				
THUIDIUM FURFUROSUM			+ 3				
PLANTAGO VARIA		3 3 +	2 2 2 + 3 3 2				
POLYTRICHUM JUNIPERINUM		+	2 +				
WAHLENBERGIA GRACILENTA	+ 2	+	+ + + 2 2 3				
BRYUM BILLAROIERI			2 2				
EUCALYPTUS GONIOCALYX	+ 3	2	2 3 3 3 4 3 3 2 2 3 2 + 3 4 3		3	3 +	
DANTHONIA PALLIOA			2 2 2 4 + + 4 3 4 3 3			+ +	+ 3 3
HYPNUM CUPRESSIFORME	+	+	2 2 2 2 4 2 3 2 3 + 3	3 3 2	3	4	
EUCALYPTUS POLYANTHEMOS			2 3 + 3 3 3	3 + + 4 3 3 2 2 3 3 + 3	+	+	+
VERONICA PERFULIATA			3	3 3 2 3 3 2 3 + 3 + 3 2		+ 3	
PARMELIA SPP.	+	+	+ 3	3 2 2 3 2 + + +	2 +	3 +	2
CALADENIA CARNEA		+ +		2 + + + + + + + +		+ +	+
DODONAEA CUNEATA				3	2 4		
PROSTANTHERA DECUSSATA					4 3 4 2		
BRACHYLOMA DAPHNOIDES				+ 2 + +	3 2 2		
PHEBALIUM LAMPROPHYLLUM					+ 3 +		+
BORONIA ANEMONIFOLIA					4 3		
PLATYSACE LANCEOLATA	+ + + + + + + +	2	2 + 2	3 3 2 2 3 4 R 2 3 + 3 2	3 3 2 3 +		+ + 2
HELICHRYSUM OBCORDATUM	+ + + 2 4 3			3 3 3 3 + 5 4 +	5 3 + 4 2	+	+ 2
EUCALYPTUS SIDEROXYLON		2 2 2 3	3 3 3 4 4 5 4 3 4 3	3 4 4 4 4 3 3 3 3 3 3 4	3 3 4 4 4	+ + + 2 3	3
ACACIA PYCNANTHA	+ +	+ 3	2 3 3 3 2 3 3 + 2	3 2 3 3 2 + 3 3 +	4 2 4 2	3 + 3 + 3	+
EUCALYPTUS MACRORHYNCHA	4 3 3 3	2 3 2 3 3 3	2 + 2 4 2 2 2 3 3 4 3 3 3	+ 3 + 4 4	3 2 +	4 4 + 3 3	3 3 4 3 3 +
HALORAGIS TETRAGYNA	+ + + 3 + 2 + + + + 2 + + +	2 2 2 + 3	2 2 2 + + 2 2 3 2 2	3		4 + + +	2 +
DIANELLA REVOLUTA	+ + + 2 + + 2 2 + + 2 + +	2 + + +	+ + + + +	+ 2 2 + 3 3 + 2	+ + 2	+ 2 +	+ + +
CLADIA AGGREGATA	+ 4 S + 4 + 4 + 2 + 4 4 + 3	3 + 4 + 3	2 2 3 3 3 + + 2 3 4 3 2 2	3 3 2 2 4 + 3 3	2 4 4 +	3 3	3
POA AUSTRALIS	+ 2 + + 3 2 2 + 3 3 + 3 3 4 3	2 3 2 2 2 3	3 + 3 + + + 3 2 3 + 4	2 3 + 2 3 + 2 3	3 3	2 3 3 2 4	+ 3 3 +
TETRATHECA ERICIFOLIA	+ + + + + + 2 3 +			3			+ + +
ACACIA OXYCEORUS	+ 2 3						+
LEPTOSPERMUM MYRSINOIDES	+ 2 + +	+ +					+
LEPTOSPERMUM JUNIPERINUM	+	2					
HOVEA HETEROPHYLLA	+ + + 2 + + 2		2				+
CORREA REFLEXA	+ + 2 +	+ +	+	+			
DROSERA WHITTAKERI	2 3 2 3 2 2	3 2 2 5	3 2 2 2 2	+			2 2 +
DILLWYNIA GLABERRIMA	+ 2	+		+ 2 3 +	2		2 2 +
SENECIO QUADRIDENTATUS		+ + +	2 + + + 3 2 + 2	+ 2 + +		+ 3	
ACACIA ASPERA			3	4 +	5 4	4 + +	3 3
ACACIA ACINACEA	+	+	2 + 2 3			3 + +	
ACACIA ACULEATISSIMA	+ +					+	
BAECKEA RAMOSISSIMA		2	+	+ +			+ 3
MARIANTHUS PROCUMBENS	2	+		+ +			2 +
RHAGODIA HASTATA	+			+ + +		2 +	+
PTEROSTYLIS SPP.		+ +		3 2			
CALANDRINIA CALYPTRATA			2 + + +	2			
CARPOBROTUS ROSSII				2 + +		+	
CASSINIA LONGIFOLIA		+ +		+ + 3 + 2 3		3	
DROSERA PLANCHONII	+	2 +	2	+ +			+
PULTENAEA DAPHNOIDES			+ +				+
DROSERA AURICULATA	+ + +	2 2	+			+	+
DILLWYNIA CINERASCENS	+						+ +
ASTROLOMA HUMIFUSUM	+		2	3 4	2	3	
LIVERWORT			+				
CF BREUTELIA		3 2 4	3 2 2 2				
AIRA CARYOPHYLLEA	2					4	
PTEROSTYLIS PARVIFLORA			2		+		
THELYMITRA PAUCIFLORA	+				+		
PIMELEA LINIFOLIA		+	+ +		+	+	
ACACIA MYRTIFOLIA	+		+			2	+
GOODENIA LANATA		+	2 + 3				+
DILLWYNIA SERICEA	+ + +	+	2 + +				
LEPIDOSPERMA FILIFORME	+ 2 2 + 2						
BRACHYCOME CILIARIS	4 4 3 3						
HIBBERTIA FASCICULATA	+						
BURCHARDIA UMBELLATA	+ + + + + +		+ +				
ACACIA GUNNII			2 2 2 2 2				
PTYCHOMNION ACICULARE	+ + +	2	2				
CRASPEDIA GLAUCA			3 2				
ACAENA ANSERINIFOLIA	+	+	+ 2 3				
PELARGONIUM RODNEYANUM			2 2				
PTERIDIUM ESCULENTUM			2 2				
STELLARIA MEDIA			+ +				
OXALIS CORNICULATA			+				
LOPHOCOLEA SEMITERES	+						
DAVIESIA ULICIFOLIA	+ +						
STYLIDIUM GRAMINIFOLIUM							

Listings of the three programs described here are available on application to the author.

RESULTS

Some 70 samples were obtained from the Brisbane Ranges, involving 110 species. The program ZUMONT/SORT produced eight species groups, including 28% of the species found. Table 1 lists these eight groups, which formed the basis for a first table. Two additional sorts were performed on the data, and these results are shown as Table 2.

This table is useful in that all the collected data are shown, and the floristic relationship of all the samples can clearly be seen. A group of species (*E. macrorhyncha, Haloragis tetragyna, Dianella revoluta, Cladia aggregata,* and *Poa australis*) extend through the range of samples. Most species, however, are concentrated in distinct groups of samples, or have only a few scattered occurrences.

The samples fall into seven major groups, each identified by a distinct group of species. The simple environmental notes gathered on the recording cards, together with information on soil characteristics, allow a simple picture of vegetation-environment relationships to be built up, as a prelude to a more detailed investigation.

Sample group I occurs on the highest parts of the ridge plateau, and corresponds fairly closely to the occurrence of a deposit of Sandringham Sand, overlaying the Ordovician shales and sandstones that make up the rest of the range. As might be expected, many of the species that identify these samples as a separate group are common to coastal heathland and heathwoodland situations. It is interesting to note the major area of occurrence of *Grevillea steiglitziana*, a species endemic to the range, is within the area of this group of samples.

Sample group II is transitional between groups I and III, with the soils often being duplex in nature. Group III, with an abundance of bryophytes and herbaceous plants, comprise samples found on the south facing slopes, where conditions are likely to be colder and wetter than north facing slopes. Group IV occurs on the north facing ridges, and at the northern end of the ridge plateau, whereas group V is located down slope in north facing gullies on the northern half.

Groups VI and VII are both small aggregations of samples, which do not appear to be identified by distinct species groups. They may represent transitional areas, or vegetation that was undersampled.

The species groups which identify these sample groups are quite distinct, although fractions of some groups may serve as differential species to sub-groups of other sample groups. For example, *Epacris impressa, Campylopus introflexus, Stypandra caespitosa* and *Pultenaea gunnii*—all identifying species for sample group I—act as differentiating species for one of two sub-groups in sample group III. This is a working example of the modern view of species 'fidelity', propounded by Ellenberg (1960).

Group I is seen to be highly variable, and possibly undersampled, whereas groups III, IV and V appear less variable, and are probably represented by sufficient samples.

The segregation of *Eucalyptus* species in the table is quite revealing. Whilst some definite associations can be found (particularly *E. macrorhyncha-E. sideroxylon*), an appraisal of the vegetation using all the species present shows the patterns established by *Eucalyptus* less useful. *E. polyanthemos*, for example, whilst forming one of the identifying species for group IV, acts as only a differential species for a sub-group of group III. When the distribution of all the species is considered, however, all the ambiguities disappear.

Thus far, the results have been considered using all samples collected, viewed together as a vegetation system for this particular locale. The other aim of this exercise was to make a step in establishing a basis for description and classification of floristic associations. Two associations have been derived from the data, and are shown in Tables 3 and 4. One corresponds to sample group I, the other is formed from groups III, IV and V. Because only the species occurring in the associations are shown in the tables, they have greater clarity than the table including all the samples.

Both these tables have been prepared using the raw data and the computer program ZUMONT/PRINT, which will print out small sections of the data as directed by the operator.

Nomenclature of plant associations can be a stumbling block. The standard combination of a physiognomically dominant species and a 'characteristic' species to name an association is followed here, as the resulting names are quite descriptive of the vegetation. Vegetation of Table 2 would become the Xanthorrhoeo-Platylobietum, with Table 3 the Eucalypto-Acacietum pycnanthae. Both of these associations have further sub-divisions, discussed below.

These associations have been formed without including dubious, or apparently transitional vegetation samples (group II, VI and VIII). Such samples are not discarded but stored for

TABLE 3

ASSOCIATION TABLE OF THE XANTHORRHOEO-PLATYLOBIETUM, PRODUCED BY PROGRAM ZUMONT/PRINT

SAMPLE NO.	0046	0067	0047	0002	0042	0066	0069	0068	0070	0071	0044	0048	0043	0045	0041	0038	0040	0039
EUCALYPTUS MACRORHYNCHA	4	3	3	3														
PLATYSACE LANCEOLATA	+	+	+	+	+							+	+	+				
EUCALYPTUS DIVES			3	+	3						3	+	3					+
MONOTOCA SCOPARIA	+		4	2							2	+	+	+				
ISOPOGON CERATOPHYLLUS						+									+			
PULTENAEA HUMILIS						+					2	2	3	+		2		
HIBBERTIA ACICULARIS											2		+	+				
CASSYTHA GLABELLA														+				
LEUCOPOGON ERICIOIDES		+	+						+	2	2							
CLADONIA SPP.	+						+				+		2	+				
EUCALYPTUS OBLIQUA						+												
BANKSIA MARGINATA			2		+						2							
GOMPHOLOBIUM HUEGELII							4				2							
DAVIESIA VIRGATA				2											2	3	3	3
STACKHOUSIA VIMINEA															2	2		
CORREA REFLEXA									2	2	3	3			+			
PULTENAEA PEDUNCULATA						3			+	+	2	3	2	+			+	+
COMESPERMA VOLUBILE															+	+	+	
HELICHRYSUM SCORPIOIDES						+	+								+	+	+	+
HELICHRYSUM OBCORDATUM			+									+			+	2	4	3
HAKEA SERICEA	2	3	+	2	4	3	+	2	2	2	3	2	4	+				
ACACIA MITCHELLII	+				2	2		3	2	2	+	+	+					
PIMELEA HUMILIS		2				3	2	2	2	2			+		2	2	2	2
GREVILLEA STEIGLITZIANA		3		2		3	+		2	2	+			+	3	2		
LEPIDOSPERMA LATERALE		+	+			+	3	2	2		2	+	3	2	3	2		
ACROTRICHE SERRULATA		+				2		3				2			+	2	3	3
TETRATHECA CILIATA	+			+	+	+			+	+	2	+		+	2	2	+	
XANTHORRHOEA AUSTRALIS	4	2	4	4	5	4		4	3	3	4	3	4	4	4	3	3	3
EUCALYPTUS BAXTERI		3			4	4	2	4	2	2	3	2	3	4	4	4	3	3
PLATYLOBIUM OBTUSANGULUM	+	+			2	2		+	+	+	+	+	2	2	2	2	3	2
LEUCOPOGON VIRGATUS			+	+		2			2			2	+		3	2	+	2
EPACRIS IMPRESSA	+	+	+	2		+		+	2	2		2			+	+	+	
CAMPYLOPUS INTROFLEXUS					2	3	+				+	+	+		2	2	+	
STYPANDRA CAESPITOSA	+				+	+						+	2	2	3		3	3
TETRATHECA ERICIFOLIA	+		+	+		+			+					+		2	3	+
HALORAGIS TETRAGYNA	+	+	+		+	3	+	2	+	+		+	+	2	+		+	
DIANELLA REVOLUTA		+	+	+	+	2		+	2	2		+			+	2	+	+
CLADIA AGGREGATA	+	+	5	+	4	4	+	4	2	+	4	3	4	+				
POA AUSTRALIS				2	+	+	3	+	2	2	+	+	3	3	3	3	4	3
PULTENAEA GUNNII	+			2								+	+		+			
HOVEA HETEROPHYLLA				+	+	+						+		2			+	2
LEPTOSPERMUM JUNIPERINUM													+					
LEPTOSPERMUM MYRSINOIDES	+										2		+	+				
ACACIA OXYCEDRUS	+		2									3						
CORREA REFLEXA		+				+		2		+								
DROSERA WHITTAKERI		2		2		3	2	3		2								
WAHLENBERGIA GRACILENTA									+	2								
BRYUM BILLARDIERI																		
EUCALYPTUS GONIOCALYX			+													3		
HYPNUM CUPRESSIFORME											+							
PARMELIA SPP.				+														
ACACIA PYCNANTHA				+					+									
DILLWYNIA GLABERRIMA				2	+													
ACACIA ACINACEA													+					
ACACIA ACULEATISSIMA				+												+		
MARIANTHUS PROCUMBENS				2														
RHAGODIA HASTATA				+														
DROSERA PLANCHONII						+												
DROSERA AURICULATA		+		+											+			
DILLWYNIA CINERASCENS			+															
ASTROLOMA HUMIFUSUM															+			
AIRA CARYOPHYLLEA	2																	
THELYMITRA PAUCIFLORA															+			
ACACIA MYRTIFOLIA																+		
DILLWYNIA SERICEA			+								+	+						
LEPIDOSPERMA FILIFORME							+		2	2	+				2			
BRACHYCOME CILIARIS			4		4						3	3						
HIBBERTIA FASCICULATA											+							
BURCHARDIA UMBELLATA		+	+			+					+		+	+				
ACACIA GUNNII																		
PTYCHOMNION ACICULARE		+				+	+											
CRASPEDIA GLAUCA																		
DAVIESIA ULICIFOLIA		+				+												

TABLE 4

ASSOCIATION TABLE OF THE EUCALYPTO-ACACIETUM PYCNANTHAE, PRODUCED BY PROGRAM ZUMONT/PRINT

SAMPLE NO.	0060	0062	0065	0026	0007	0003	0057	0058	0064	0063	0061	0037	0056	0051	0055	0008	0025	0018	0005	0006	0023	0024	0027	0011	0021	0032	0022	0020	0033	0034	0031	0030	0029
EPACRIS IMPRESSA	2	2	2		2	2										3																	
CAMPYLOPUS INTROFLEXUS	2	2	3	2	+	4				3	+			+		2			2	4	3	3	2									3	
STYPANORA CAESPITOSA	+	2		+	3	+		+							3								+										
PULTENAEA GUNNII	3	3	2				3					+	3		2																		
SENECIO QUADRIOENTATUS		2				+	+		+		3		2	+	2			2	+						+			+					
GERANIUM MOLLE								+					2	2																			
STICTA SP.														+																			
LUZULA CAMPESTRIS													2	+	2																		
THUIOIUM FURFUROSUM													+	3																			
PLANTAGO VARIA	2	2	2						+	3			3		2																		
POLYTRICHUM JUNIPERINUM										2					+																		
WAHLENBERGIA GRACILENTA			+				+	+	2		2		3																				
EUCALYPTUS GONIOCALYX	2	3	3	3	4	3	3	2	2	3	2	+	3	4	3															3			
OANTHONIA PALLIDA	2	2	2		4	+	+	4	3			4	3		3																		
HYPNUM CUPRESSIFORME	2	2		2			2	4	2	3	2		3	+	3								3			3	2		3				
BRYUM BILLARDIERI											2				2																		
ACACIA ACINACEA	2	+				2		3																									
ONOSERA WHITTAKERI	3	2			2			2					2											+									
XANTHORRHOEA AUSTRALIS	5	3					2	2	4	3		3	4	2	4												+						
EUCALYPTUS POLYANTHEMOS	2	3	+	3		3				3						+		+	3	4	3	3	2	2	3	3	+	3	+				
VERONICA PERFULIATA				3													3	2	3	3	3	2	3	+	3	+	3	2					
PARMELIA SPP			+			3										2		2	3	3	2	+	+	+						2			+
CALAOENIA CARNEA																		+	2	+	+	+		+	+		+	+					
OOOONAEA CUNEATA																										3					2	4	
PROSTANTHERA OECUSSATA																													4	3	4	2	
BORONIA ANEMONIFOLIA																													4		3		
PHEBALIUM LAMPROPHYLLUM																														+	3		+
PLATYSACE LANCEOLATA				2	+	2										3	3	2		2	3	4	R	2	3	+	3	2	3	3	2	3	+
HELICHRYSUM OBCOROATUM																				3	3	3	3	+		5	4	+	5	3	+	4	2
BRACHYLOMA OAPHNOIOES																						+	2	+			+			3	2		2
EUCALYPTUS SIOEROXYLON	3	3	3	4	4	5		4	3		4		3			3	4	4		4	4	3	3	3	3	3	3	4	3	3	4	4	4
ACACIA PYCNANTHA	2	3		3		3	2			3	3			+	2		3		+	2	3	3	2		+	3	3	+	4		2	4	2
EUCALYPTUS MACRORHYNCHA	2		+		?	4	2	2	2	3	3	4	3	3	3	3	+				4	4								3	2	+	
MALORAGIS TETRAGYNA	2	2	2				+		+	2	2	3	2		2	3																	
OIANELLA REVOLUTA			+	+					+			+	+				+			2	2	+	3		3		+	2		+	+		2
CLAOIA AGGREGATA	2	2	3	3		3	+	+	2	3		4	3	2	2	3	3		2	2	2	4	+				3	3		2	4	4	+
POA AUSTRALIS		3	+	3	+	+	+			3	2	3	+	4				3	3	+	2		3	+	2			3		3			3
EUCALYPTUS OIVES			+				2		2																								
MONUTOCA SCOPARIA																+																	
HIBBERTIA ACICULARIS				2												+	4				+		2				4						
CASSYTHA GLABELLA																																	
CLAOONIA SPP.	2		2				+		3						2							2	+										
OAVIESIA VIRGATA													+				+			+	+												
STACKHOUSIA VIMINEA			4																														
PULTENAEA PEOUNCULATA																																	
HELICHRYSUM SCORPIOIOES				+										+				2		+			+					+					
HAKEA SERICEA												3																					
ACACIA MITCHELLII												+																					
PIMELEA HUMILIS																			2														
GREVILLEA STEIGLITZIANA														+		2																	
ACROTRICHE SERRULATA		2	+										+	+			+					+	2										2
TETRATHECA CILIATA	2				+																												
LEUCOPOGON VIRGATUS		+																															
CORREA REFLEXA				+																					+								
OILLWYNIA GLABERRIMA																						+		2	3			+					2
ACACIA ASPERA						3										4				+										5			4
BAECKEA RAMOSISSIMA					+																											+	+
MARIANTHUS PROCUMBENS																								+	+								
RHAGOOIA HASTATA																		+	3	+			+										
PTEROSTYLIS SPP.											2							2															
CALANORINIA CALYPTRATA		+					+				+							2															
CARPOBROTUS ROSSII																		2	+					+	+								
CASSINIA LONGIFOLIA																		+	+	3				+	2			3					
OROSERA PLANCHONII				2													+																
PULTENAEA OAPHNOIOES			+												+																		
OROSERA AURICULATA												+																					
ASTROLOMA HUMIFUSUM				2										+			3										4						2
LIVERWORT				+																													
CF BREUTELIA				3						2			2		2																		
PTEROSTYLIS PARVIFLORA														2																			+
PIMELEA LINIFOLIA								+						+																+			
ACACIA MYRTIFOLIA												+																					
GOODENIA LANATA											2	+		3																			
OILLWYNIA SERICEA	2	+										+																					
PTYCHOMNION ACICULARE										2																							
CRASPEOIA GLAUCA													3	2																			
ACAENA ANSERINFOLIA								+					2	3																			
PELARGONIUM ROONEYANUM										2					2																		
PTERIOIUM ESCULENTUM											2				2																		
STELLARIA MEOIA							+						+																				
OXALIS CORNICULATA		+																															
LOPHOCOLEA SEMITERES																																	
OAVIESIA ULICIFOLIA																																	
STYLIOIUM GRAMINIFOLIUM																																	

use when more data are available. Such data, with the described associations, may be fused with new data as they are collected. Such incorporation and fusion of data is the basis of the 'successive approximation' approach of Poore (1956).

Some species are common to both associations (e.g. *Haloragis tetragyna, Dianella revoluta.*) As such, tbey may indicate that these two associations are part of the same vegetation alliance (sensu Braun-Blanquet 1964, not as Frankenberg 1971), or that tbey may be wide-ranging 'companion' species. Because of the very small area involved, only the associations have been named at this stage.

Both associations have sub-associations, and within those variants. The Xanthorrœo-Platylobietum has two sub-associations: tbe Haketosum (differential species: *Hakea sericea, Acacia mitchellii*) and the Daviesietosum (differential species: *Daviesia virgata, Stackhousia viminea, Correa reflexa, Pultenaea pedunculata, Comesperma volubile, Helichrysum scorpioides*). Within the Haketosum there are a number of variants.

The Eucalypto-Acacietum also has two sub-associations: the Danthonietosum (differential species: *Danthonia pallida, Hypnum cupressiforme, Eucalyptus goniocalyx, Xanthorroea australis*) and the Helichrysietosum (differential species. *Helichrysum obcordatum, Platysace lanceolata*). As noted in previous discussion these two sub-associations represent south and north facing sides of the range. The vegetation on the ridge tops and gullies now appear as two separate variants.

DISCUSSION

The processes outlined above take relatively little time, both from the operator and computer. Such rapid process techniques, which leave the raw data intact, but intelligible, are increasingly needed in a social situation which demands instant appraisal of ecosystem potential. That such is unobtainable is obvious, but data of any kind are invaluable in a bid to make complex decisions as fairly as possible.

A floristic classification of vegetation allows an evaluation of botanical quality, and, additionally, comparison with other data from other environmental and zoological sources. Indeed, side-by-side botanical and zoological surveys in sensitive areas are urgently needed.

Some criticism has been made in the past of the apparently cumbersome nomenclature system, e.g. Patton (1933). The advantages of the system used are that it cannot be confused with casual names (applied without a considered analysis of the vegetation); that it can be understood by non-English speaking botanists; and that it is compatible with an existing system internationally used.

NOTE: All vascular plant nomenclature follows Churchill and de Corona, 1972.

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REFERENCES

BRAUN-BLANQUET, J. J., 1964. *Pflanzensoziologie*, Berlin.

BRIDGEWATER, P. B., 1971. Practical Applications of the Zurich-Montpellier System of Photosociology. *Proc. R. Soc. Vict.* 84: 255-262.

CESKA, A. & ROMER, H., 1971. A Computer Program for Identifying Species-releve groups in vegetation studies. *Vegetatio* 23: 255-277.

CHURCHILL, D. M. & DE CORONA, A., 1972. The Distribution of Victorian Plants. Melbourne. National Library of Australia ISBN 0959975802.

ELLENBERG, H. C., 1960. Konnen wir eine gemeinsame Platform für die verschiedenen Schulen in der Waltypenklassifikation finden. *Silva Fennica* 105: 26-32.

MOORE, J. J., FITZSIMONS, P., LAMBE, E. & WHITE, J., 1970. A comparison and evaluation of some phytosociological techniques. *Vegetatio* 20: 7-20.

PATTON, R. T., 1933. Ecological studies in Victoria. The Cheltenham flora. *Proc. R. Soc. Vict.* 45: 205-218.

POORE, M. E. D., 1956. The use of phytosociological methods in ecological investigations. IV. General discussion of phytosociological problems. *J. Ecol.* 44: 28-50.

SPECHT, R. L., 1970. Vegetation. In Leeper, G. W. (Ed) *The Australian Environment*. CSIRO & MUP, Melbourne.

6

Some Aspects of the Vegetation of the Dandenong Ranges, Victoria

By Paul K. Gullan[1], John R. Busby[2] and David M. Churchill[3]

Abstract: A vegetation survey of the Dandenong Ranges is described and the major vegetation types defined both structurally and floristically. Three analytical survey techniques (two numerical) are briefly compared for their efficiency in this context, particularly in demonstrating environmental trends. Finally, the role this work could play in future vegetation research in the Dandenongs is discussed.

INTRODUCTION

The Dandenong Ranges, an area popular with amateur botanists, has received little attention from professionals despite its impressive vegetation and close proximity to Melbourne. Clifford (1952) began serious studies in the area when he produced a distribution map of its major eucalypts. But this work was never followed up and a description of structure and composition of the vegetation is still wanting.

It is the purpose of this paper to provide this description and at the same time compare the vegetation variation with some broad environmental trends.

SAMPLING METHODS

All data were collected (during the months April to July 1971) from 10 × 10 m square quadrats, selected from the area to be surveyed so that they satisfied the two following criteria:

(i) The area did not show signs of recent disturbance (clearing; soil removal; non-native plants constituting a cover, visually assessed, of 10% or more; presence of refuse, etc.).

(ii) The area was not recently burnt (coppicing trees, blackened trunks, large numbers of seedlings, or fire records that we know of, indicated burning in the previous 10 years).

The reasons for using these criteria were two. First, for a preliminary description of the vegetation it was considered desirable to include as few complicating factors as possible. Thus sampling was biased towards undisturbed, mature vegetation, to lessen the problem of determining possible environmental controllers of vegetation variation. Second, objective sampling techniques, using a regular grid or random selection, were impracticable due to the fragmentation of the vegetation (Pl. 6). Therefore the area was surveyed from aerial photographs to determine the locations of potential quadrat sites, and then checked on the ground using criteria (i) and (ii) (Fig. 1).

The quadrat size was chosen by the minimal area technique (Braun-Blanquet 1964) which was applied at three randomly chosen sites (randomly chosen from a number of sites already considered suitable for sampling), and at each site the point of flattening on the species/area curve was found to be 100 m². This technique has been criticized many times in the past (Rice & Kelting 1955, Goodall 1970) but the present authors (and others, e.g. Grunow 1967) believe that despite these criticisms, and because no reasonable alternatives exist, it can still be of use in choosing a quadrat size. It is perhaps worth noting at this point that the area of 100 m² also fulfils the less strict criterion of Williams (1971a) that the quadrat size should be large in comparison to the plants it will contain.

In each quadrat all species of vascular plants that were rooted in, or vertically projected over it, were recorded (with the exception of filmy ferns). Each was given a value based on a visual estimate of its cover-abundance using the Braun-Blanquet scale (Table 1). This type of data collecting, although not strictly quantitative, is useful when time is limiting and/or conditions for collecting more accurate data are difficult

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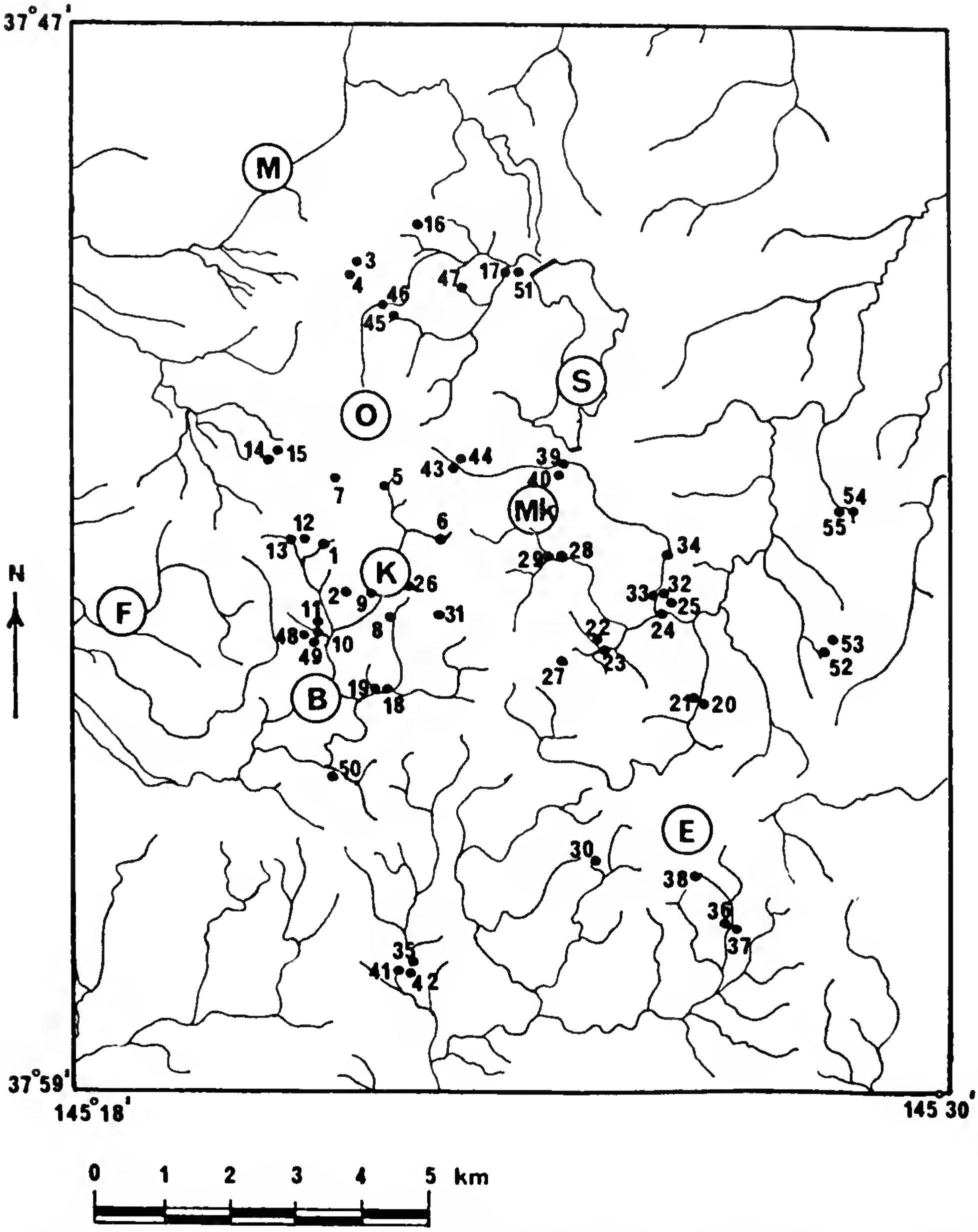

FIG. 1—Map of study area. Black dots are quadrat sites and their numbers correspond to those in Figs. 2 and 3. Encircled letters represent major townships. O = Olinda, F = Ferntree Gully, Mk = Monbulk, M = Montrose, B = Belgrave, E = Emerald, S = Silvan Reservoir.

(Bannister 1966, Kershaw 1968, Noy-Meir 1971).

ANALYTICAL METHODS

As is often the case for primary survey, the choice of the analytical techniques was based on a combination of both theoretical and practical considerations. Practical limitations were imposed by the computer facilities available, which although able to cope with most numerical analyses on small data sets, could not adequately handle the total data collected (a matrix of 55 quadrats and 144 species) using anything but the simplest techniques. On theoretical grounds the maximum information can be gathered from the data if the different, but complementary, strategies of ordination and classification are used together (Anderson 1965). Thus in choosing a classification and ordination system, both economy (in computer use) and efficiency (most workable solution obtainable with the least trouble) were sought.

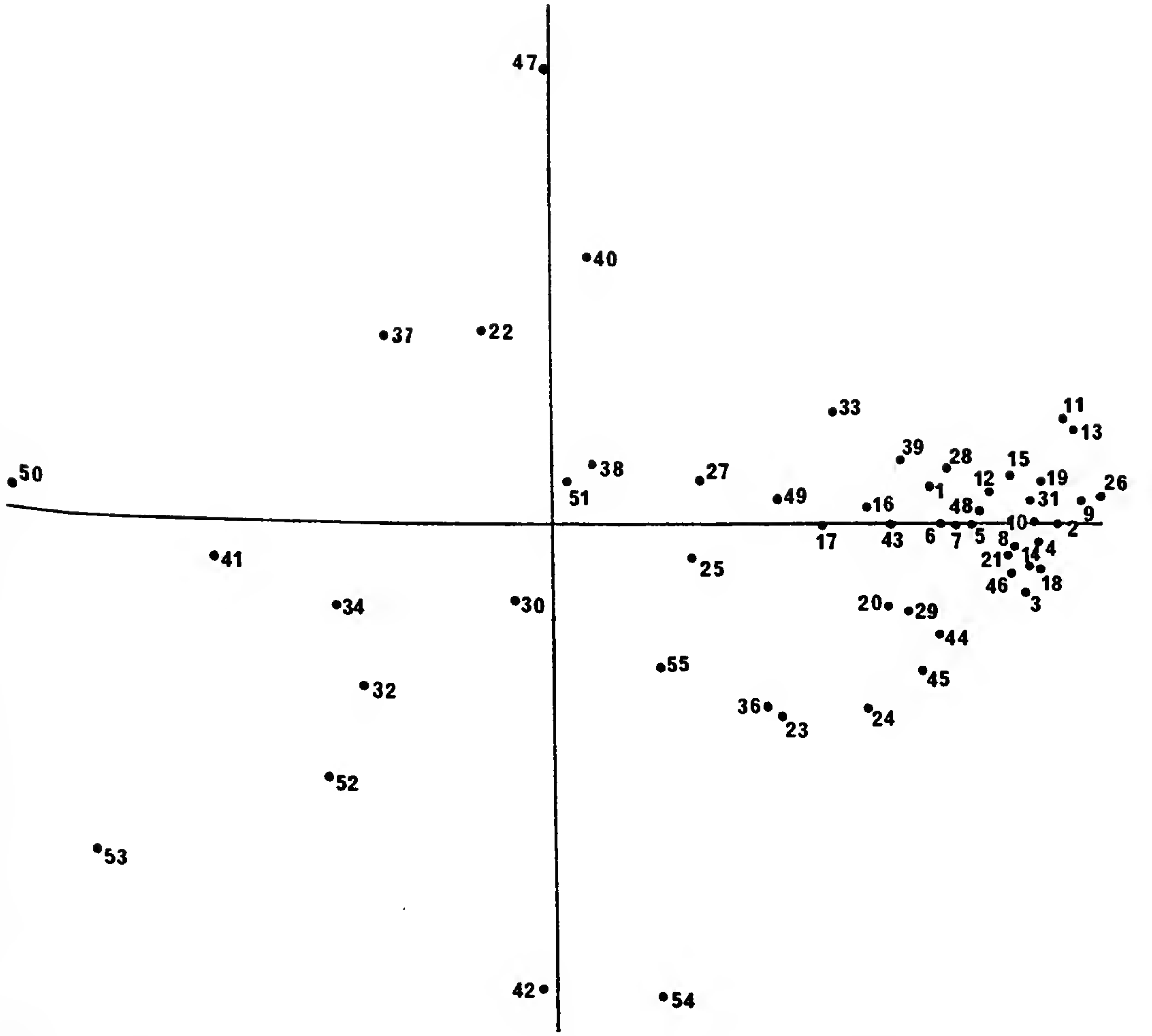

FIG. 2—'Reference set' ordination of the Dandenongs data. Numbers on the diagram correspond to quadrat numbers also represented on the two-way table.

The classification procedure used was the normal and inverse association analysis of Williams and Lambert (1960) (a hierarchial, monothetic, divisive system), and the results were represented on a two-way table as in Lambert and Williams (1962). This technique was chosen because of its success in a wide range of situations (Gittens 1965, Greig-Smith et al. 1967, Grunow 1967, Flenley 1969, Edgell 1969, Allen 1971) and because the computational facilities available to us (a Burroughs 5500) precluded the use of any of the theoretically superior polythetic analyses (Williams et al. 1966, Williams 1971b).

Similarly on theoretical grounds many authors regard principal components analysis (PCA) as the ideal ordination solution (Orloci 1966, Austin 1968, Goodall 1970, Noy-Meir 1971), but once again limited computer facilities meant that a simpler ordination had to be used. Fortunately this did not necessarily mean that the resulting analysis was inferior, for as Beals (1973) points out, PCA was never designed for ecological data, and extensive empirical evidence (from Beals 1973) suggests that Bray and Curtis (1957) 'reference set' ordination (nomenclature Anderson 1971) is probably suitable for a wider range of vegetation types.

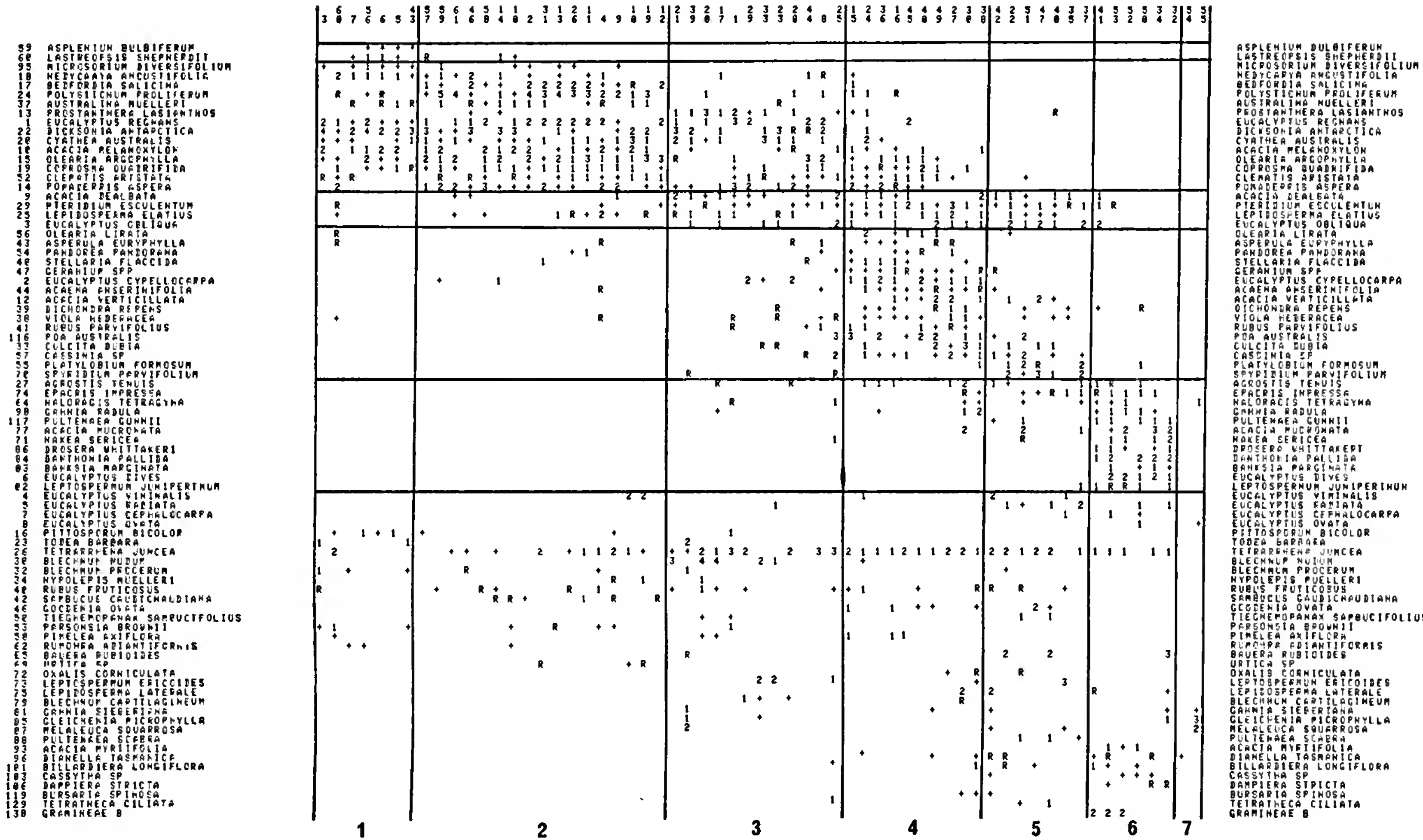

FIG. 3—Numbers across the top represent quadrats and vertical lines delineate quadrat groups. Horizontal lines delineate blocks of frequently co-occurring species. (Note that six extra quadrats have been included. These were collected after the initial analysis was completed but are easily fitted into the existing classification by placing the new quadrats close to those with which they show an affinity. This is a property neither of the numerical analyses possesses).

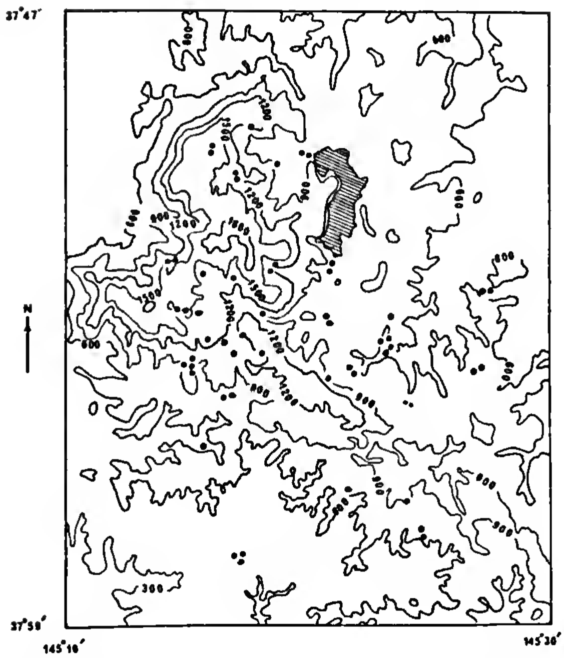

Fig. 4—Topography of study area measured in feet above mean sea level. Black dots are quadrat sites. The area shown is identical with that of Fig. 1.

The ordination chosen for the Dandenongs study is a reference set type devised by van der Maarel (1969). In principle it is the same as that of Bray and Curtis (1957), and uses the same coefficient of similarity (i.e. the Czekanowski). But it differs in that the choice of reference stands is more likely to produce a spread of quadrats representative of a major gradient in the vegetation. This is primarily because of the use of a 'negative correlation tendency' (NCT) calculation, instead of relying merely on high interstand difference as in the Bray and Curtis method (see van der Maarel 1969, for detailed explanation and practical example).

As well as the ordination and classification techniques a simple procedure of hand-sorting data on a two-way table was employed. This approach is based on the Zurich-Montpellier (Z-M) system of phytosociology (Braun-Blanquet 1964, Bridgewater 1971) except that only cover-abundance values are used in the table (sociability is ignored) and no attempt is made to define the status of the groups in a predetermined hierarchy. Major groups on the table may be formations, associations, alliances, etc., but for the purposes of the analysis only 'noda' (sensu Poore 1955) are sought.

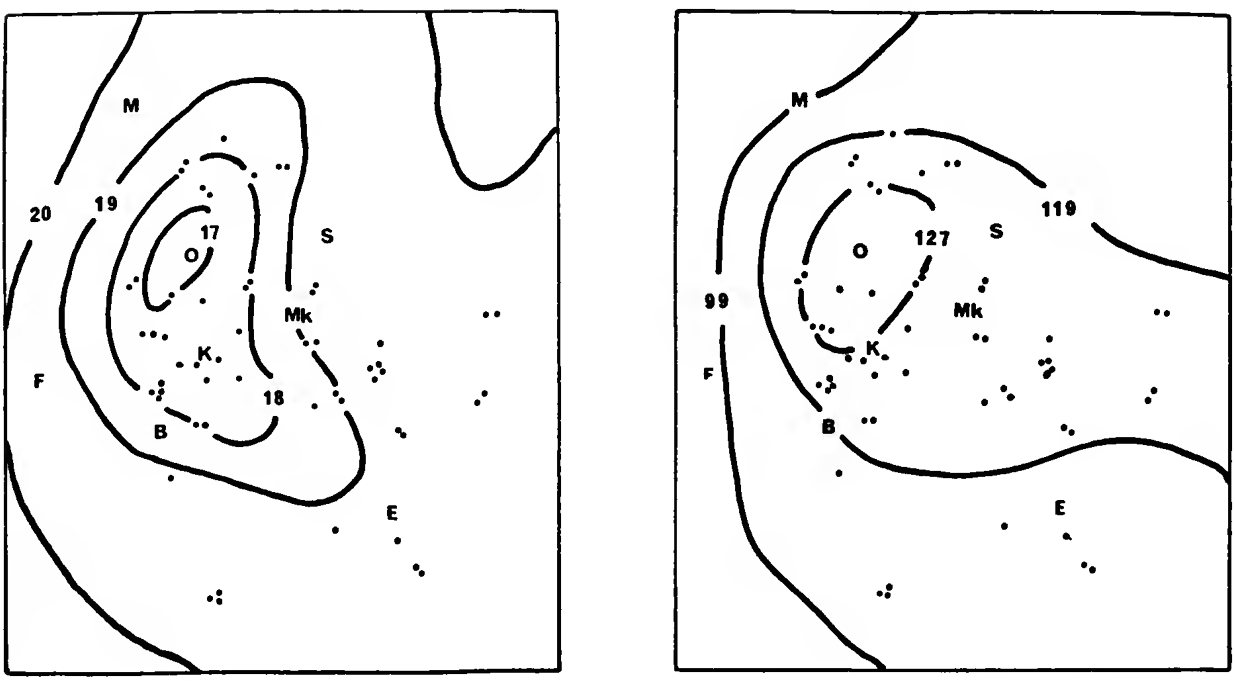

Fig. 5—(a) Average daily maximum temperature (annual) in °C. (b) Average annual rainfall in cm. Dots are quadrat sites and area in both diagrams is identical with that of Fig. 1. Letters represent major townships, e.g. Mk = Monbulk, etc. Data from climatic survey Region 10, Port Phillip, Victoria. Bureau of Meteorology Publication, 1968.

Success with this technique, when compared to more complex numerical approaches (Moore et al. 1969, Dale & Anderson 1972), suggests that it may well prove to be an efficient, rapid method of data processing. The only computer facilities necessary are for a program (ZUMONT/PRINT, written by JRB) which prints the two-way table in a form specified by the user.

RESULTS

The Analyses: The association analysis classification was extremely fragmentary and difficult to interpret in both dendrogram and two-way table forms. Only the first two divisions appeared to form ecologically recognizable groups, and these were very heterogeneous in nature, containing many quadrats with less than 20% of their species in common. As a result, little emphasis was placed on this analysis for producing a final vegetation description.

The ordination was more successful: in general similar quadrats were placed close together on the scatter diagram and the two ends of the major axis of variation represented distinctly different vegetations (Fig. 2).

Both 'quantitative' and qualitative forms of the ordination were calculated (c.f. association analysis where only presence/absence data can be accommodated) but the differences between them was only slight (correlation coefficient 'r' calculated between 55 equivalent random distances on the two ordinations was 0·86; P less than 0·001). Therefore, it was assumed that, for the purposes of this survey, the extra time involved in calculating the ordination from 'quantitative' data was unwarranted, an assertion that van der Maarel (1969) makes for primary surveys in general.

The ordination suggested that the vegetation variation was of a continuous, rather than a discontinuous nature. Several authors have suggested that ordinations usually overemphasize the presence of a continuum, and some (Austin & Orloci 1966) say that this is particularly true of the Bray and Curtis type. However, a comparison of the main vegetation gradient (i.e. the first axis on the ordination) with some broad environmental measurements (see Figs. 4 and 5, altitude; mean annual daily temperature; mean annual rainfall) lends some support to the ordination picture. All parameters appear to follow the main continuous gradient, i.e. there are no sharp changes that might suggest discontinuities in the vegetation.

No detailed soil analyses were attempted in this study, and the authors recognize its incompleteness because of this. However, some idea of the variation in the edaphic environment can be gained by referring to Fig. 6 (a map of the area's geology) and also to the work of Clifford (1952), which gives tentative soil types for different combinations of rainfall and parent material. At this level of resolution all quadrats other than those south of Belgrave and Emerald (see Fig. 1) should be on some form of kraznozem, while the others are on silty-loam podzols. Because of this relative uniformity, and coarseness of resolution, no further attempt was made to compare the vegetation variation with edaphic factors.

Of the three techniques of analysis employed here, the modified Z-M was the most successful. The species and quadrats were sorted on the two-way table in basically the same way as is outlined in Bridgewater (1971) and the final result, unlike the ordination, can show all of the original data. (Although in this case only the most common species, and those characteristic of

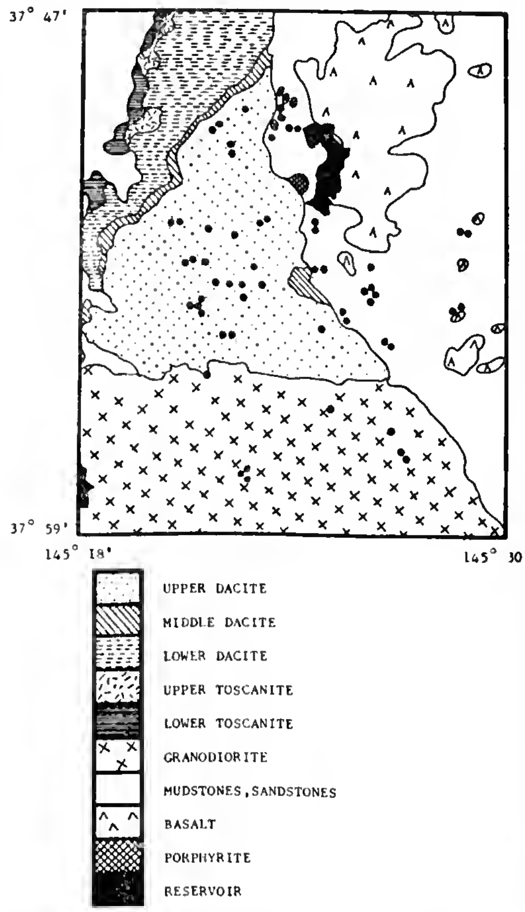

FIG. 6—A simplified geological map of the study area, after Edwards (1955). Black dots are quadrat sites. The area shown is identical with that of Fig. 1.

groups, are shown in Fig. 3, for convenience of representation in this paper, a complete two-way table can be obtained on request to the senior author.) This property is a most useful one as Fig. 3 demonstrates: not only are the major groups and the nature of the variation (continuous or discontinuous) demonstrated, but the constituents of the groups and the species involved in the variation can also be shown.

The two-way table, like the ordination, suggests a fairly continuous change in vegetation, and within this continuum seven groups have been defined (by eye). These groups when plotted on the scatter diagram agree quite well with the ordination, i.e. quadrats in the same groups usually appear close together. Thus the two techniques complement each other and add some confidence to the final description by their close correlation.

The Vegetation: The seven groups defined on the two-way table represent three major types of vegetation which are best developed in groups 2, 4 and 6 (the 3 major noda). Groups 3 and 5 are transitions between these three and group 1 has so much in common with group 2 that it can be regarded as a sub-group, or perhaps a transition between it and another unsampled vegetation. Group 7 consists of two quadrats taken in an isolated patch of vegetation that is entirely different from the rest, and because of the small sample size will not be discussed further.

The arrangement of the groups on the two-way table, as well as corresponding fairly well with the ordination, represents a gradient in the environmental variables mentioned earlier (Table 2). But although the two models of vegetation variation show correlations to these changes in the environment, no cause/effect relationships are proved by them. Nevertheless some supportive evidence of plant/environmental interaction can be obtained by a closer look at the constituent plants of the main vegetation groups.

Groups 1 and 2 can be described (on the basis of structural data collected) broadly as tall open forest (Specht 1970) with a top storey of fairly sparse-canopied trees ranging in height from about 50 to 70 m (e.g. *Eucalyptus regnans*, *E. cypellocarpa*). The understorey consists chiefly of broad-leafed trees (about 3-20 m) and an abundance of pteridophytes, particularly *Polystichum proliferum* and the tree ferns *Dicksonia antarctica* and *Cyathea australis*. (All plant names follow those given in Churchill & de Corona 1972.)

Group 4 is also tall open forest (Specht 1970) but generally top storey heights are less (about 50 m maximum; mainly *E. cypellocarpa* and *E. obliqua*). The understorey contains few pteridophytes, some of the larger woody angiosperms are small-leafed, and the grass *Poa australis* agg. is common. Particularly characteristic of this vegetation is the diversity and abundance of small herbaceous plants (e.g. *Geranium* spp., *Stellaria flacida*, *Dichondra repens*, *Viola hederacea*, *Asperula europhylla*), all of which possess thin mesophytic leaves.

Finally group 6, an open forest (Specht 1970) with a top storey of less than 12 m in height (*E. dives*, *E. radiata*) is characterized by a fairly dense understorey of small-leafed, sclerophyll, woody shrubs.

Thus the transition from group 1 to 6 represents changes in plant life-form as well as floristic variation. While the environmental causative factors involved are almost certainly varied, and include edaphic factors not considered in this study, the variation in plant life-forms is not inconsistent with what would be expected if the environmental parameters in Table 2 were among these causative factors.

DISCUSSION

The vegetation of the Dandenongs, although fragmented and heavily disturbed in places, still maintains a distinctive variation. The continuous nature of this variation suggests that the environmental controlling factors would vary in a similar manner, rather than exhibit sharp discontinuities. And that this is true for some broad climatic changes is quite evident from meteorological information about the area. Nevertheless some problems arise in the interpretation of, and the conclusions one can draw from such information. In particular, the long history of disturbing influences on this area (Coulson 1959) means that the possibility that the observed variation may be largely the result of human interference cannot be ignored. This possibility can be minimized by sampling according to criteria (i) and (ii), but as the human influence is quite old and its effects are not understood, there is no way of eliminating it completely.

Therefore the results of this survey describe some of the Dandenongs vegetation as it stands today. It cannot offer any information about how it will react to any disturbing influences, as the sampling was biased against this and no previous records of the vegetation are available. However, it does supply a basis for future work in that later surveys will be able to determine the effect of further development on the vegetation that is, at present, the least disturbed.

An obvious next step in this survey would be to map the distribution of the major three vegetation types. But this is unfortunately not a useful exercise with the present data, because of the large distances between many of the quadrats and the fairly rapid changes in vegetation, particularly in areas with steep slopes (e.g. quadrats 43, 44 and 40). To produce a viable vegetation map of the study area it would be necessary to conduct more detailed ground surveys to outline the extent of the three groups and the transition zones between them. The present survey should be an aid to this exercise in two ways:

(a) Fig. 3 shows almost complete floristic data for all the sample sites and thus the species most likely to be useful in rapid identification of vegetation type (i.e. those which occur consistently and more or less exclusively in a group) are easily found (Table 3).

(b) Table 2 gives some indication of the type of vegetation one would have expected in areas no longer covered by native forest.

This process of primary sampling followed by extensive groundwork and presumptive reconstruction is the only feasible way of approaching vegetation mapping in fairly large and developed areas such as the Dandenongs.

Table 1

Cover/Abundance Scale and Equivalent Numerical Values

Cover/ Abundance Symbol	*Species Performance in Quadrat*	*Arbitrary Numerical Equivalent*
R	rare, erratic, cover less than 5%	0
+	occasional, cover less than 5%	1
1	common, cover less than 5%	2
2	very common, cover less than 5% or cover 5-20%, any number of individuals	4
3	cover 20-50%, any number of individuals	6
4	cover 50-75%, any number of individuals	8
5	cover 75-100%, any number of individuals	10

Table 2

The Means for Three Environmental Variables Over the Seven Vegetation Groups

Group Number	*Mean Altitude (m)*	*Mean Annual Daily Temp. (°C)*	*Mean Annual Rainfall (cm)*
1	381 m	16	129
2	361 m	16	121
3	253 m	17	121
4	287 m	17	121
5	202 m	18	117
6	195 m	18	117
7	160 m	18	121

Table 3

The Plants Considered to be Characteristic of the Three Major Vegetation Types

Notice that these groups could be tentatively defined and named on the basis of a species of Eucalyptus. *However, it should not be assumed from this that vegetation can necessarily be defined in this way as a general rule: for example, at least three other eucalypts are common in this area but have little value as indicators of general floristic trends.*

Group 1 & 2
Eucalyptus regnans
Polystichum proliferum
Dicksonia antarctica
Cyathea australis

Group 4
Eucalyptus cypellocarpa
Acaena anserinifolia
Poa australis
Geranium spp.

Group 6
Eucalyptus dives
Epacris impressa
Danthonia pallida
Leptospermum juniperinum

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REFERENCES

Allen, T. F. H., 1971. Multivariate approaches to the ecology of Algae on terrestrial rock surfaces in North Wales. *J. Ecol.* 59: 803-826.

Anderson, A. J. B., 1971. Ordination models in Ecology. *Ibid.* 59: 713-726.

Anderson, D. J., 1965. Classification and Ordination in vegetation science: controversy over a non-existent problem? *Ibid.* 52: 521-526.

Austin, M. P., 1968. An ordination study of a chalk grassland community. *Ibid.* 56: 739-757.

Austin, M. P. & Orloci, L., 1966. Geometric models in ecology. II. An evaluation of some ordination techniques. *Ibid.* 53: 217-227.

Bannister, P., 1966. The use of subjective estimates of cover abundance as the basis for ordination. *Ibid.* 54: 665-674.

Beals, E. W., 1973. Ordination: Mathematical elegance and ecological naivete. *Ibid.* 61: 23-35.

Braun-Blanquet, J., 1964. *Pflanzensoziologie.* Berlin. 865 pp.

Bray, J. R. & Curtis, J. T., 1957. An ordination of the upland forest communities of Southern Wisconsin. *Ecol. Monogr.* 27: 325-349.

Bridgewater, P. B., 1971. Practical application of the Zurich-Montpellier system of phytosociology. *Proc. R. Soc. Vict.* 71: 255-262.

CHURCHILL, D. M. & DE CORONA, Anne, 1972. *The distribution of Victorian Plants.* Melbourne. National Library of Australia. ISBM 0959975802.

CLIFFORD, H. T., 1952. On the distribution of species of *Eucalyptus* in the region of the Dandenong Ranges, Victoria. *Proc. R. Soc. Vict.* 65: 30-55.

COULSON, H., 1959. *Story of the Dandenongs 1838-1958.* Cheshire, Melbourne.

DALE, M. B. & ANDERSON, D. J., 1972. Qualitative and quantitative information analysis. *J. Ecol.* 60: 639-654.

EDGELL, M. C. R., 1969. Vegetation of an upland ecosystem Cader Idris, Merionethshire. *Ibid.* 57: 335-359.

EDWARDS, A. B., 1955. The rhyolite-dacite-granodiorite association of the Dandenong Range. *Proc. R. Soc. Vict.* 68: 11-149.

FLENLEY, J. R., 1969. The vegetation of the Wabag region, New Guinea Highlands: A numerical study. *J. Ecol.* 57: 465-490.

GITTINS, R., 1965. Multivariate approaches to a limestone grassland community. III. A comparative study on ordination and association-analysis. *Ibid.* 53: 411-425.

GOODALL, D. W., 1970. Statistical plant ecology. *Annual Review of Ecology and Systematics* 1: 99-124.

GREIG-SMITH, P., AUSTIN, M. P. & WHITMORE, T. C., 1967. The application of quantitative methods to vegetation survey. I. Association-analysis and principal components analysis of rain forest. *J. Ecol.* 55: 483-503.

KERSHAW, K. A., 1968. Classification and ordination of Nigerian Savanna vegetation. *Ibid.* 56: 467-482.

LAMBERT, J. M. & WILLIAMS, W. T., 1962. Multivariate methods in plant ecology. IV. Nodal analysis. *Ibid* 50: 775-802

MAAREL, E. van der, 1969. On the use of ordination models in phytosociology. *Vegetatio* 19: 21-46.

MOORE, J. J., FITZSIMONS, P., LAMBE, E. & WHITE, J., 1970. A comparison and evaluation of some phytosociological techniques. *Ibid.* 20: 1-20.

NOY-MEIR, I., 1971. Multivariate analysis of the semi-arid vegetation in south-eastern Australia: Nodal ordination by component analysis. *Proc. Ecol. Soc. Aust.* (1971): 159-193.

ORLOCI, L., 1966. Geometric models in ecology. I. The theory and application of some ordination methods. *J. Ecol.* 54: 193-215.

POORE, M. E. D., 1955. The use of phytosociological methods in ecological investigations. I. The Braun-Blanquet system. *Ibid.* 43: 226-244.

RICE, E. L. & KELTING, R. W., 1955. The species-area curve. *Ecology* 36: 7-11.

SPECHT, R. L., 1970. Vegetation. In Leeper, G. W. (Ed.). *The Australian Environment* 4th ed. CSIRO & MUP. Melbourne.

TALLIS, T. H., 1969. The blanket bog vegetation of the Berwyn Mountains, North Wales. *J. Ecol.* 57: 765-787.

WILLIAMS, W. T., 1971a. Strategy and tactics in the acquisition of ecological data. *Proc. Ecol. Soc. Aust.* 6: 57-62.

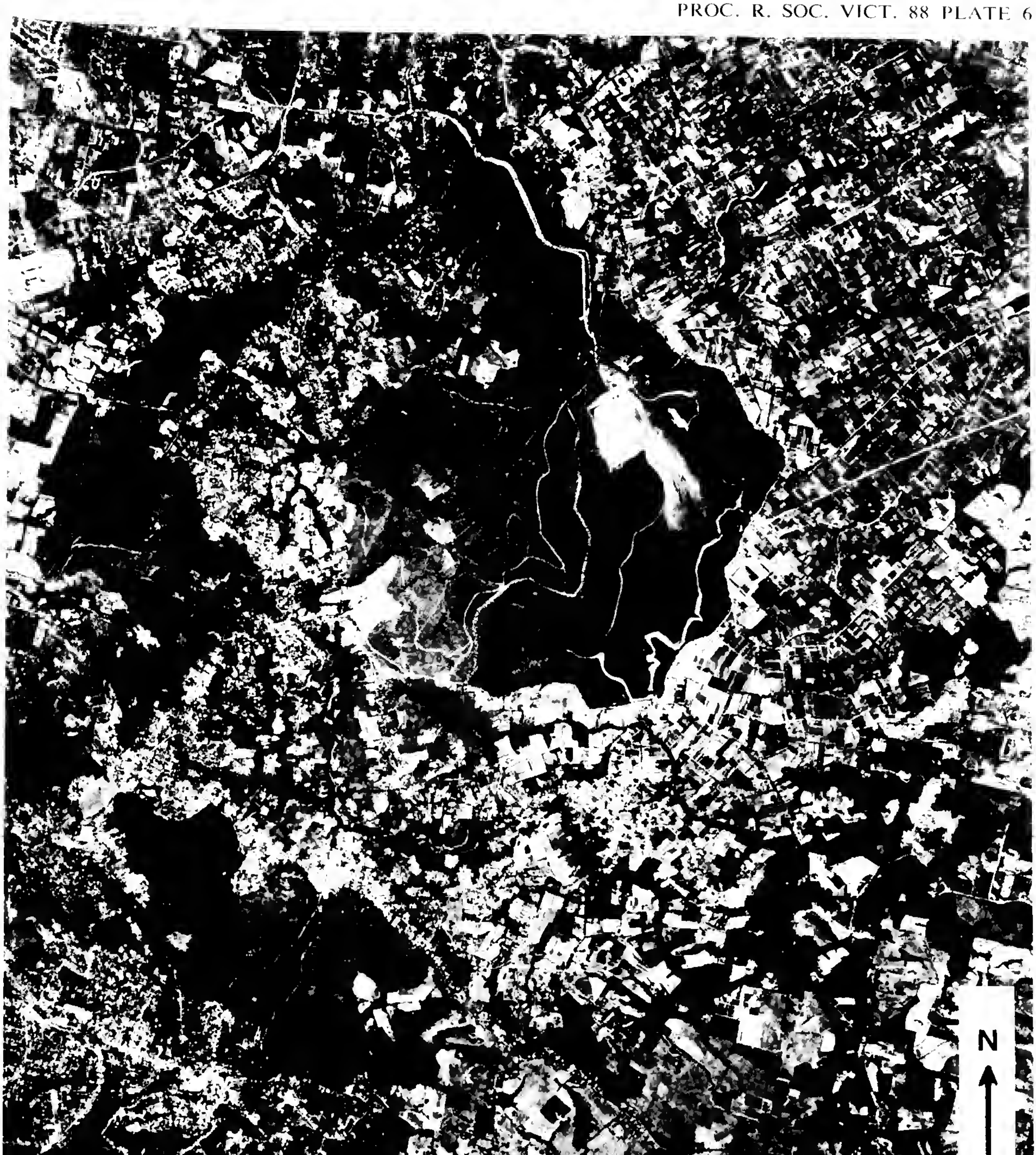
———, 1971b. Principles of clustering. *Ann. Rev. of Ecol. and System.* 2: 305-326.

——— & LAMBERT, J. M., 1960. Multivariate methods in plant ecology. II. The use of the electronic digital computer for association analysis. *J. Ecol.* 48: 689-710.

———, ——— & LANCE, G. N., 1966. Multivariate methods in plant ecology. I. Similarity analysis and information analysis. *Ibid.* 54: 427-445.

DESCRIPTION OF PLATE 6

Aerial photograph of the Dandenong Ranges. Melbourne Mapsheet Project No. 766, 100 chains to 1 inch, 1969. Dept. of Crown Lands and Survey. (Reproduced by the permission of the Surveyor-General, Dept. of Crown Lands and Survey, Victoria.)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7

Structural Geology in the Kiewa Region of the Metamorphic Complex, North-East Victoria

By F. C. Beavis* and Joan C. H. Beavis*

Abstract: The detailed study of structure in three small areas is described. One area, the Tawonga Gap, is in low grade rocks on the western margin of the Complex; the second, the Snowy Creek area, Mitta Mitta, is similarly in low grade rocks on the eastern margin; the third area is Mt. Beauty, in the main high grade belt of High Plains Gneiss. It is established that (i) folds of at least two generations (and locally three) occur in the lower grade rocks on the margin: both groups of folds are Benambran; (ii) two generations of folds occur in the High Plains Gneiss, but these are not necessarily equivalent to the folding in the lower grade rocks; (iii) in the Tawonga Gap area, the boundary between slates and phyllites and the higher grade schists is in part transitional, in part faulted. The faulting is more complex than along the West Kiewa margin of the Complex.

A tentative relationship between folding, metamorphism, faulting and igneous activity in the Kiewa region is proposed.

INTRODUCTION

Igneous and metamorphic petrology, jointing and faulting in the Kiewa Region have been described previously (Beavis 1960, 1962). Folding in the metamorphic rocks was not examined more than superficially in the earlier work, and since 1962, therefore, field work has been directed to this aspect of the structure. It soon became apparent that the earlier (1962) analysis of folding was an over-simplification. Because detailed structural mapping of the whole region was almost impossible, three small areas were selected (See Fig. 1). Two of these are on the west (Tawonga Gap) and east (Snowy Creek) margins of the main high grade metamorphic belt and the third was chosen within the High Plains Gneiss, at Mt. Beauty where, in addition to excellent exposures, we were able to map the complete length of a tunnel across the area.

The region generally is notable for the extremely poor exposures, and the three areas were selected for exposures, particularly in road cuttings, which were better than elsewhere in the region. Two notes have been published previously (Beavis 1963, 1968); the earlier recorded two generations of folds at Snowy Creek, the later established, in the Tawonga Gap area, the nature of the foliation and in particular of the lithological layering, in the schists.

This paper describes structures in the three areas, and the regional generalizations drawn from the results. In addition, the nature of the metamorphic boundary in the Tawonga Gap area is described. Finally, using data presented here, and that presented in earlier publications, an attempt is made to relate faulting, igneous activity, folding and metamorphism in the region.

The assistance of Professor N. Rast for critical discussion, and the State Electricity Commission of Victoria for permission to use data collected while one writer was an officer of the Commission is gratefuly acknowledged.

METAMORPHIC ZONES IN THE KIEWA REGION

Seven metamorphic zones may be recognized in the regions:—

(i) *Zone of Slates:* Traditionally, the rocks of this zone have been regarded as non-metamorphic, and the margin of the metamorphic complex has been placed where the pelitic rocks show the development of a strong recrystallization schistosity. The rocks of the zone consist of sandstones, siltstones and slates; the two latter are strongly foliated (cleaved) and lineated, and all have undergone some recrystallization. The slates are pale grey, aluminous types with rare beds, particularly in the Mitta Mitta Valley, of black, highly

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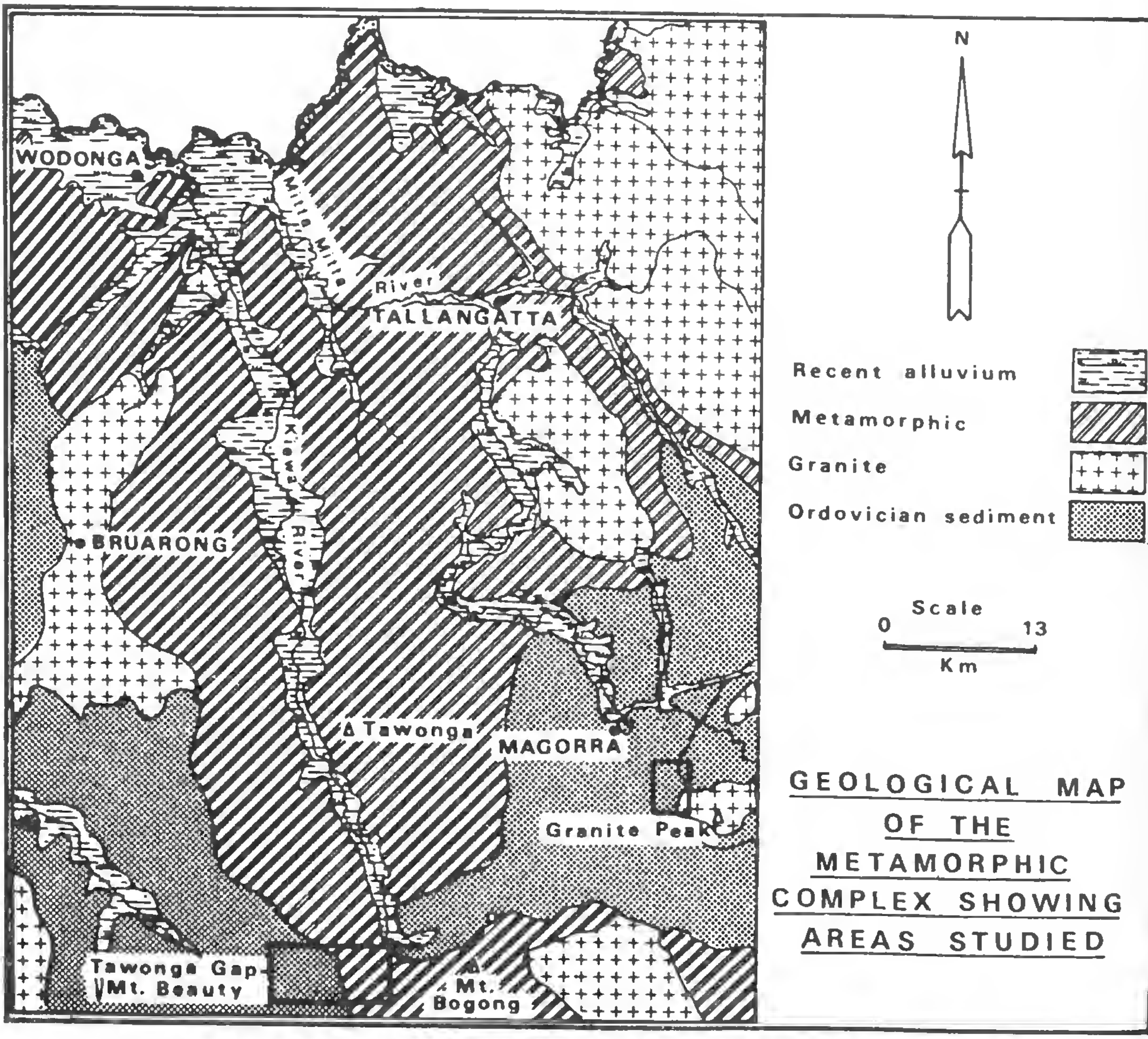

FIG. 1—Map of the North-East Metamorphic Complex showing the areas studied.

carbonaceous slate. The sandstones are quartzitic, or more commonly greywacke types. The latter are graded and normally pass upwards into laminated siltstones.

(ii) *Zone of Phyllites:* The pelitic rocks of this zone are fine satin textured, silver-grey-green in colour. High in the zone, the siltstones become phyllitic and bedding laminations show advanced transposition into the plane of the cleavage. The sandstones differ from those of the lower zone only in a more advanced recrystallization of the micas.

(iii) *Zone of Chlorite Quartz Albite Schists:* Because of the combined effects of transposition and metamorphic segregation, the pelites and semi-pelites have a strong lithological layering, with laminae of quartz and albite alternating with thicker chlorite-rich laminae. Within this zone, transposition of bedding laminae in the finer sediments into the plane of the foliation is complete. The sandstones show more advanced recrystallization, with albite the dominant feldspar. Primary sedimentary structures are difficult to discern, and, with the exception of graded bedding, are lost. Gross bedding separation surfaces can be distinguished.

(iv) *Zone of Biotite Schist:* Strongly foliated and lineated biotite schist alternates with bands of quartz schist and quartz feldspar schist. It is considered that these represent, respectively, the original pelitic and psammitic beds. The quartz feldspar schists are poorly foliated, but lineation

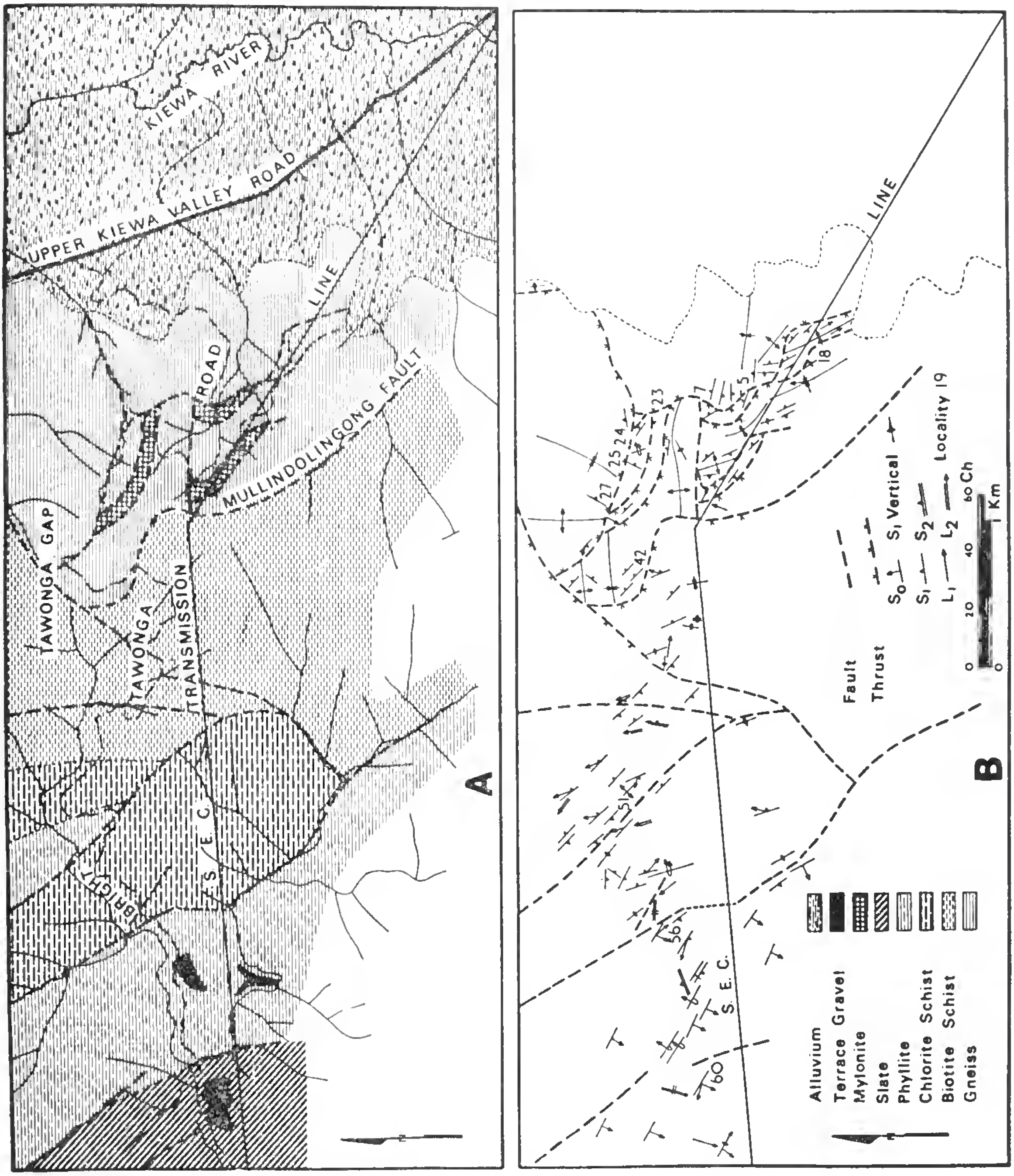

FIG. 2—Geological map of the Tawonga Gap area.

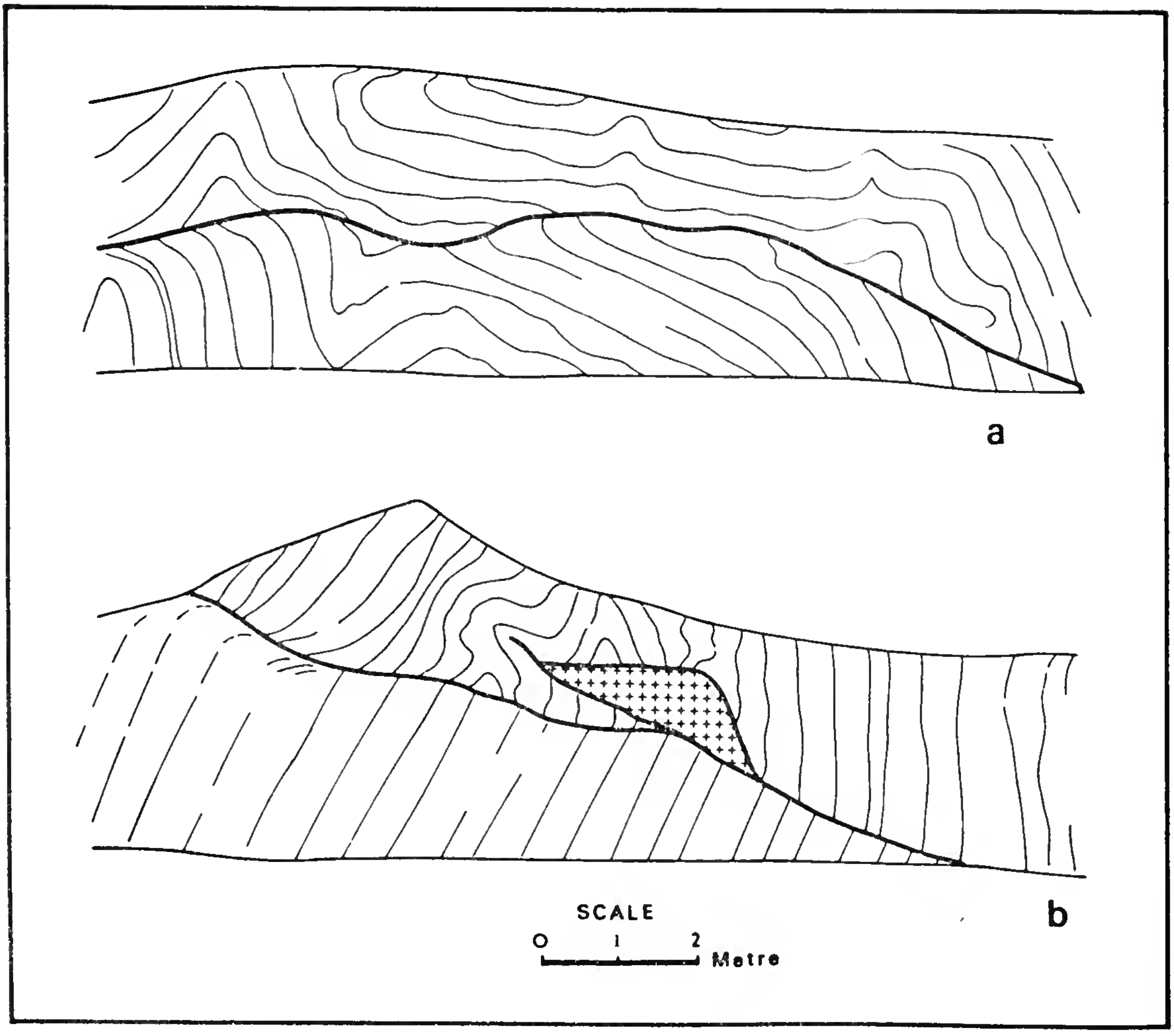

FIG. 3—Drawings of low angle thrusts in the High Plains Gneiss, Tawonga Gap.

tends to be more prominent than in the biotite schists.

(v) *Zone of Cordierite Schist:* Field distinction of original rocks is not possible, usually, in this zone, although some bands of quartz amphibole schist may represent original sandstones. Although foliation is prominent, lineation tends to be weak, the most noteworthy lineation being due to the dimensional orientation of the pinitized cordierite porphyroblast knots.

Biotite, cordierite and quartz are essential constituents but locally, particularly high in the zone, sillimanite, almandine and muscovite became important.

(vi) *Zone of Sillimanite Almandine Schist:* The schists of this zone are strongly foliated and coarse textured with some localized development of a coarse discontinuous lithological layering. The essential minerals are quartz; oligoclase; black, almost opaque biotite, partially replaced by sillimanite; almandine.

(vii) *High Plains Gneiss:* It has been emphasized (Beavis 1962, Leggo & Beavis 1968, Leggo 1968) that the 'typical' High Plains Gneiss does not exist. It is a strongly banded rock, but schistosity may be extremely prominent, weak, or absent. Segregation of biotite, and of quartz and feldspar into nodules is characteristic; this was considered by Tattam (1929) and Beavis (1962) to be due to the addition of igneous material, but Leggo (1968) has shown quite conclusively that this is not the case and that the nodules are a product of metamorphic segregation.

THE TAWONGA GAP AREA

Tawonga Gap is a low saddle, 666·3 m above sea level, on the north-south divide separating the Kiewa and Ovens Valleys. The area is one of deep weathering and thick vegetation, with few natural exposures. The data shown on Fig. 2 were derived for the most part from fresh cuttings on the Bright-Mt. Beauty road which passes through the Gap.

South from the Gap, the High Plains Gneiss is bounded on the north-west by the Tawonga Fault (Beavis 1960) and on the west by the West Kiewa Thrust Zone (Beavis 1962). Between Tawonga and Mt. Beauty township, some gneiss is exposed but this gives way very rapidly to chlorite quartz albite schist in Symonds Creek. The relationship between the two is unknown.

The Metamorphic Boundary at Tawonga Gap

Although in one section a transition from slate to phyllite was observed, all of the boundaries of the metamorphic zones which occur in this area (Slate, Phyllite, Chlorite-quartz-albite schist, Biotite schist) are faulted (Fig. 2). It was not possible, therefore, to determine either the width of the zones or the width of each zone removed by faulting. By comparison with the Mt. Blowhard-Mt. Hotham section to the south, it is clear that a considerable thickness of the Zone of Phyllites has been faulted out at Tawonga Gap, and by comparison with the eastern margin, it would seem that considerable thicknesses of the Biotite Schist and Biotite Sillimanite Almandine Schist Zones have been removed by faulting, and all of the Zone of Cordierite Schist.

Further south, in the valley of the West Kiewa River, the boundary between the High Plains Gneiss and the Zone of Phyllites is relatively simple and is marked by the West Kiewa Thrust Zone. At Tawonga Gap, the boundary faulting is a complex of high and low angle thrusts, although one, the Mullindolingong Fault, is more significant than the others since it forms the boundary between the Zone of Biotite Schist and the High Plains Gneiss. It must be stressed, however, that even the lesser faults are important since they were responsible for the faulting out of the lower grade rocks.

Low angle thrusts cutting the High Plains Gneiss are shown on Fig. 3 and Pl. 7. These structures generally dip at less than 10° and they may be horizontal. Most are irregular with both dips and strikes varying widely. The thickness of crush zones varies: that of brecciated zones is 0·2 to 1·0 m, and of mylonitized zones between 1 and 100 m. The breccia is slabby, with the platy surfaces lying parallel to the walls of the crush zone. The mylonites are fresh and form the boldest outcrop in the area; they are strongly foliated, with folding of the foliation common.

Near the thrusts, the gneissic foliation has been deformed by drag, and associated with drag is a system of radial joints. Apart from this jointing, the wall rocks are extensively broken by other joint systems, the intensity of jointing increasing closer to the thrusts, but the boundary of the crush zone is always sharp and clearly defined. The low angle structures appear to be restricted to the gneiss, on the Kiewa fall of the Divide. In the lower grade rocks of the Ovens fall, the faults are almost invariably high angle thrusts with dips of 70°. Strike is northerly. In all cases, the crush zones are brecciated and the crush zone is always less than 10 m thick.

Exposures of the Mullindolingong Fault are poor; the best is at locality 42 (Fig. 2) where it strikes SE. and dips 30° NE. Because one wall is obscured by alluvium and slip debris the thickness of the crush zone is uncertain. It consists of brecciated gneiss and biotite schist, with lenses of mylonite. Immediately north of Tawonga Gap the fault appears to dip more steeply and to strike NE. Near the Tawonga Gold Mine, strike is N. with dip 20° E. South of the Tawonga Gap only one exposure was found, in a small gully; here the fault appears to be horizontal.

The age of the faulting is unknown, but in view of the two sets of attitudes and the two types of crush zone material, two periods of faulting would seem to have been effective.

Folding in the Tawonga Gap Area

Folds of two generations have been recognized in both the low grade metamorphic rocks and in the High Plains Gneiss. The folds have been designated F_1 and F_2 where F_1 are the older. The F_1 folds of the gneiss are not necessarily equivalent to the F_1 folds of the low grade rocks. There is, in fact, some evidence to be presented later in this paper, that F_1 folds in the gneiss are the equivalent of F_2 folds in the low grade rocks.

The High Plains Gneiss

Lithological layering S_1 in the gneiss, frequently weak and discontinuous, is an emphasis of the lithological layering of the schists. The structure is in part original bedding and in part bedding transposed into the axial plane of the F_1 folds of the low grade rocks. In the gneiss, there is a schistosity S_1 parallel to the lithological layering. Folds in S_1 of the gneiss have a faint axial plane foliation S_2, which is defined by trains of biotite. Lineations and linear structures are rarely prominent, although one good example is shown on

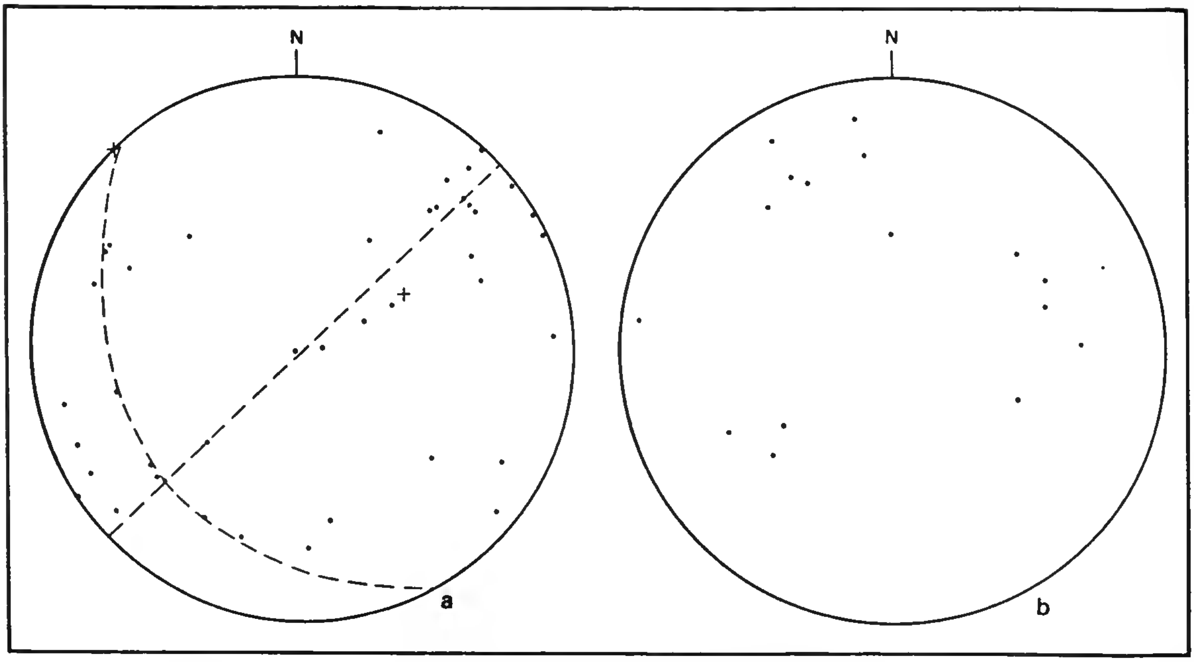

FIG. 4—Equal area projection of structural elements of the High Plains Gneiss, Tawonga Gap: a. Poles to foliation in gneiss; b. Lineations in gneiss.

Pl. 7, fig. 4, and another on Pl. 8, fig. 2. The former example, crenulations on biotite layers, is L_1 deformed in a F_2 synform.

The styles of the two generations of folds are quite distinct, and each generation (and style) has a more or less well defined trend. F_1 folds are open, with rounded hinge zones, planar to slightly curved limbs, and a weak axial plane foliation S_2. The F_1 folds may be symmetrical, isoclinal, and they may be upright or recumbent, but asymmetrical upright folds are more typical. Fold axes trend between N30°E. and N30°W. The trend of F_2 folds is E.-W. These folds have a rounded to box like profile, and occur as isolated flexures in an otherwise uniformly dipping S_1.

On Fig. 4 are shown equal area projections of the structural elements. Data were inadequate for analysis. Field observations showed that F_1 folds, with northerly trend, plunged from 5° to 45°. F_2 folds have plunges to east or west, and while it may vary from less than 10° to over 70°, steep plunge is the more common. Fig. 4a shows a tentative interpretation of poles to S_1 lying in two girdles with poles B_1 and B_2. The lineations recorded are clustered about these poles, but with less than 20 lineations recorded, it is not possible to generalize.

The Low Grade Metamorphics

In the slates and phyllites, bedding S_0 is the most prominent structural element, but in the schists, foliation S_1 (schistosity and lithological layering, which are parallel) dominates the structure. Except in F_1 fold hinges, S_0 and S_1 are parallel or nearly so, which is indicative of isoclinal folding. This type of folding was directly observed at a number of localities. Lineation L_1 is a set of coarse microfolds with wave length 2-5 mm, the larger being observed in the higher grade schists (Pl. 8, figs. 3 and 4). Locally, cleavage mullions occur in the slates (Pl. 8, fig. 1).

All of the F_1 structures have been deformed by the later F_2 movement, and in the low grade rocks F_2 folds, the associated axial plane cleavage S_2, and lineations L_2, are all important structural elements. All of the F_2 folds appear to be small mesoscopic structures, and no large F_2 folds were observed. Without exception, plunge of F_2 folds is steep.

The effects of the deformation of F_1 structures by F_2 movements are shown on Pl. 6, fig. 3, and on Fig. 5. The deformation of L_1 is of particular interest. On the assumption that L_1 was here originally horizontal, the development of the present pattern can be seen to have occurred by slip on S_2. The surface S_1 which contains L_1 also contains L_2 due to the intersection of S_1 and S_2.

The near coincidence of πS_0 and πS_1 on Fig. 6 indicates not only the essential parallelism of

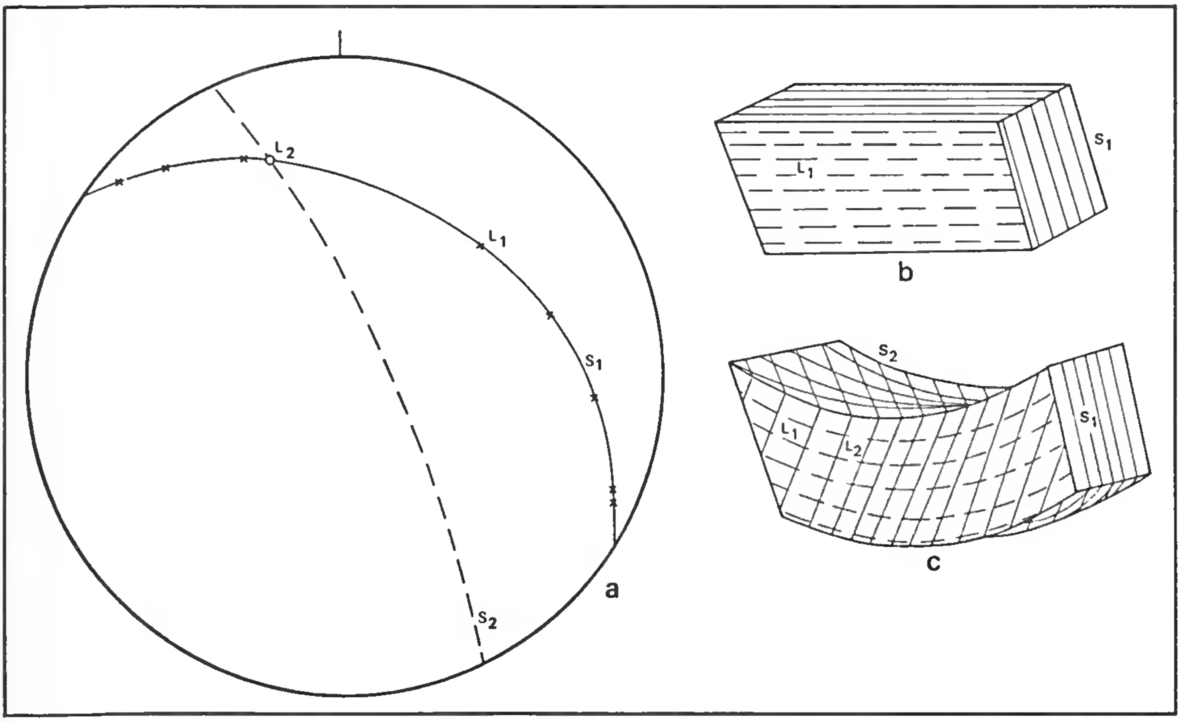

FIG. 5—a. Equal area projection showing deformed L_1 at locality 43; b., c. Diagrams showing progress of deformation.

these two elements, but also their common folding about the axis of the F_2 folds. L_1 tends to lie in a girdle which contains βS_0 S_1, while there tends to be a concentration of L_2 at β_2. The synoptic diagram shows the possible relationship of the elements.

THE SNOWY CREEK AREA

The importance of this area is in the fact that evidence is available permitting the dating of the F_1 and F_2 folds in the low grade rocks. The area lies on the eastern margin of the metamorphic complex, and the rocks examined all lie within the Zone of Phyllites. Kenny (1937) first noted structural complexity, which was shown later (Beavis 1963) to be due to several generations of folds having been developed in the rocks. At the southern extremity of the area, the slates, phyllites and sandstones are faulted against relatively high grade schists, and have been intruded by the Banimboola Granodiorite, which has imposed a contact metamorphism on the slates and sandstones (Fig. 7).

Structural Elements and Their Relationships

Bedding, S_0 is the most prominent element of the structure, tending to obscure other planar elements. In many cases, examination of sawn faces was necessary to determine the nature of the form surface of a fold, the prominence of S_0 obscuring the fact that S_1 was an element which had been folded also. Slaty cleavage S_1 is strongly developed in the pelitic rocks and, where contact metamorphism has been effective, this structure has received an emphasis so that it becomes a fine schistosity. Except in the hinge zones of F_1 folds, S_1 and S_0 are either parallel or intersect in an extremely acute angle.

Cleavages and kink bands S_2 may be more pronounced in some of the pelitic rocks than S_1. S_2 forms the axial surface of F_2 folds; S_2 normally cuts S_0 and S_1 at high angles, although sometimes $S_1 \lambda S_2$ is very sharp, and occasionally the two are parallel. The absence of S_2 from the sandstones suggests that the deformation of the pelitic rocks by slip on S_2 was the major F_2 activity. F_3 elements (S_3) are of two types, but both are fracture cleavages. One is a set of fractures parallel to the axial planes of F_3 folds, the other is a set of *en echelon* fractures forming kink bands. Whereas both F_1 and F_2 structures have been emphasized by contact metamorphism, F_3 structures have not, and clearly post-date the Banimboola intrusive activity.

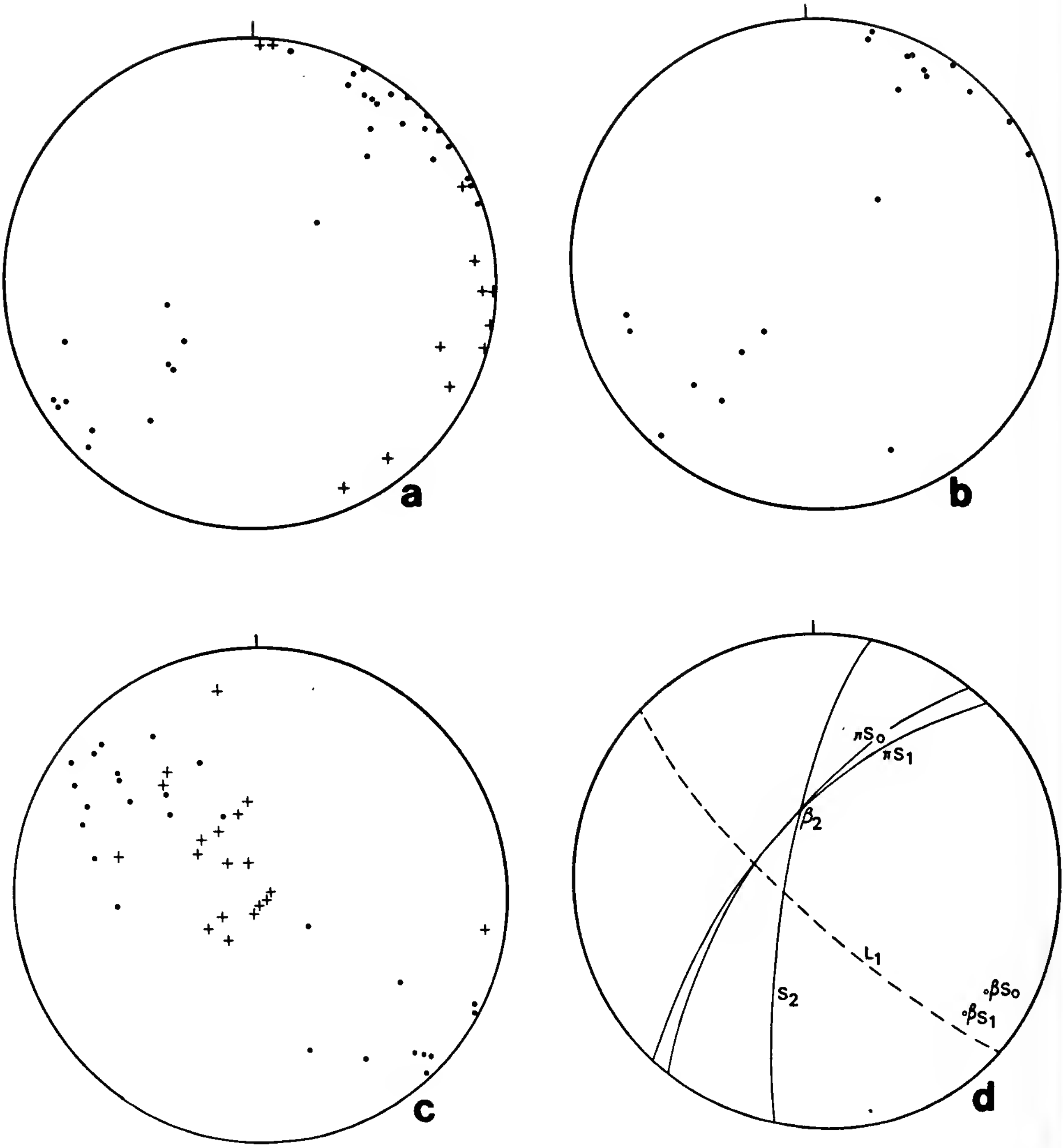

FIG. 6—a. Equal area projection of poles to S_2 (0) and S_1 (+); b. Equal area projection of poles to S_2; c. Equal area projection of L_1 (0) and L_2 (+); d. Synoptic diagram: Tawonga Gap.

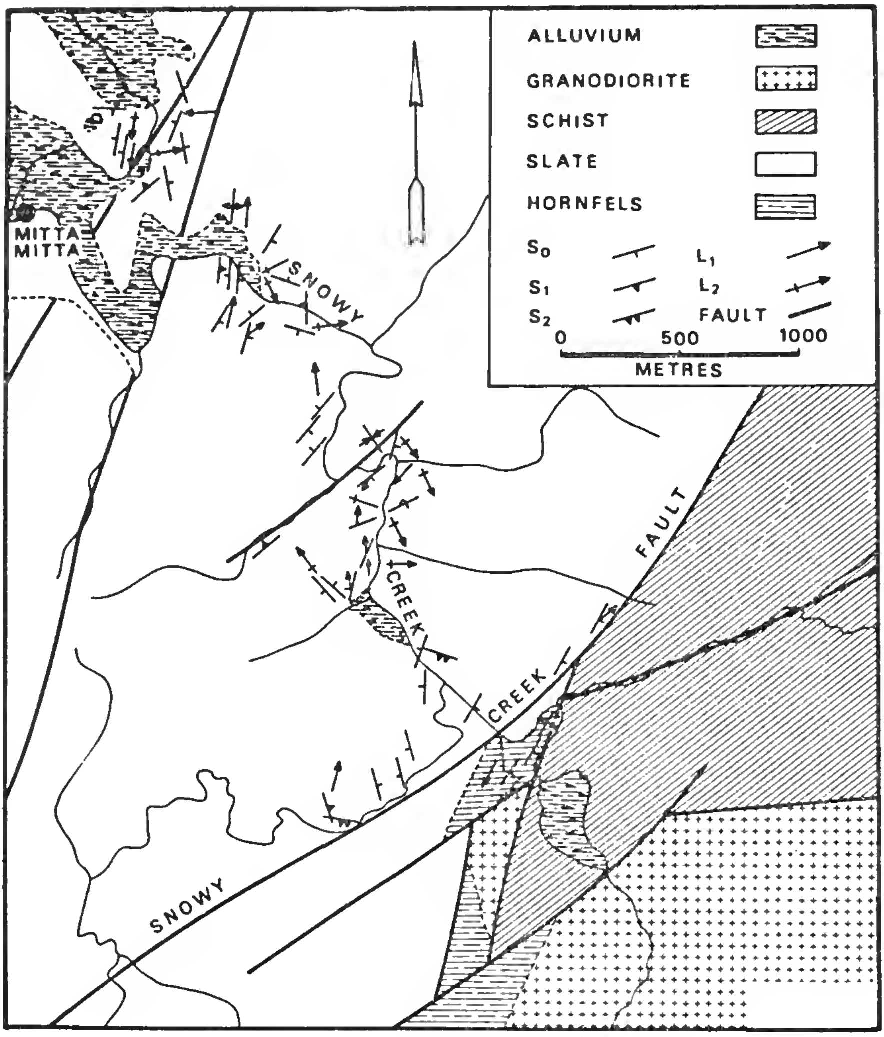

Fig. 7—Geological map of Snowy Creek area.

Three generations of linear structure occur. Lineations L_1 are due to S_0-S_1 intersection in the slates and phyllites: in the siltstones it is formed by the hinges of small folds; fold mullions are prominent linear elements in the sandstone. Cleavage mullions are extremely common L_2 structures, but L_2 may also be an intersection structure.

F_1 folds have a 'similar' style. Large folds with axial plane separation of 10 m are typical. The folds tend to be symmetrical, isoclinal, upright, but asymmetrical and even recumbent F_1 folds were observed. F_2 fold style is controlled by the lithology. In laminated siltstones, the folds have rounded hinges with axial plane separation of 3 cm to over 3 m. S_0 is apparently the form surface, but close study shows that S_1 is folded. In slates and phyllites, the folding tends to be cuspate, with the production of mullions: the synforms are open and rounded, the antiforms are sharply cuspate. These folds contain a penetrative crenulation cleavage, S_2, and a discrete fracture cleavage, S_2, which is restricted to the axial surface of the antiforms. Parallel style folds are restricted to coarser sandstones (Pl. 7, fig. 2). Since these rocks are poorly cleaved, the recognition of the folds as F_2 structures is difficult unless they contain deformed F_1 elements. The rare F_3 folds have a chevron style associated with which are the broad kink bands. These folds were noted only near Granite Flat.

The complexity of the fold geometry at the mesoscopic scale can be seen on Fig. 8, where two examples, one from the Mitta Mitta Gorge (a,b) and one from Snowy Creek 1·8 km up-

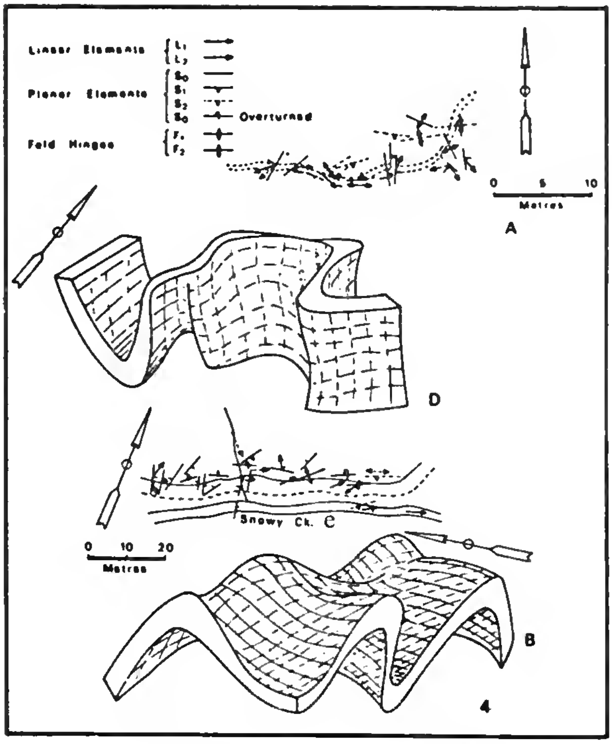

FIG. 8—Folding in the Snowy Creek area: a. Map of elements at Mitta Mitta Gorge, Mitta Mitta; b. Reconstruction of folding from data in a.; c. Map of elements, Snowy Creek; d. Reconstruction of folding from data of c.

stream from Mitta Mitta township, are illustrated. Both F_1 and F_2 folds have a wide variety of plunges, but generally, F_1 folds have a gentle plunge and F_2 folds plunge sharply. 'Overturned' plunging of some F_1 folds was noted. The projection of structural elements is shown on Fig. 9. The more or less similar distribution of S_0 and S_1 demonstrates the folding of both of these surfaces about the same axes during the F_2 movements. The poles to S_0 and S_1 lie in a more or less horizontal girdle with pole β_2 vertical. There is some suggestion of an E.-W. vertical girdle, with pole β^1 horizontal trending a few degrees E. of N.: the pattern of πS_0 alone does not demonstrate two phases of folding. F_1 folding was probably about gently plunging N.-S. areas, while F_2 was about one with trend NNW.-SSW. with steep plunge. The axial surfaces of F_2 folds have steep dips with strike WNW.

Age of the Folding

Throughout the area, F_2 structures have been superimposed on F_1 structures, with F_3 structures restricted to narrow belts near major faults. Recrystallization accompanied F_1 folding, but there is no evidence of either progressive or retrogressive metamorphism associated with the F_2 movements.

The low grade metamorphic rocks have been intruded by the Banimboola Granodiorite which has imposed a contact metamorphism and given a mimetic emphasis to F_1 and F_2 cleavages and lineations. The folding therefore predates intrusion. The Banimboola Granodiorite is overlain by the Mitta Mitta Volcanics, which in turn are overlain by the middle to upper Silurian Wombat Creek Group (Singleton 1965). The Granodiorite, therefore, is clearly early Silurian or epi-Ordovician, probably Benambran in age. Both F_1 and F_2 folds must therefore also be Benambran, and each must represent a distinct phase of the Benambran movement. The F_3 structures post date intrusion; the age of these folds is unknown.

THE MT. BEAUTY AREA

Folding in the High Plains Gneiss is considered in this section of the paper. The fundamental problem has been the determination of the nature of the foliation in the gneiss. Here, this is considered from the structural point of view. Leggo (1968) has considered the same problem from a petrological-geochemical basis.

The basic assumption made in this paper is that the High Plains Gneiss was derived from the sandstones and slates which flank the complex. This was considered to be the case by Tattam (1929) after petrological studies, Beavis (1962) from structural studies and Leggo (1968) after geochemical research. Since, on the western margin of the Complex, the boundary is faulted, evidence there is unavailable to support the basic assumption. On the eastern margin although faulting occurs, there does *appear* to be a transition from slate to gneiss. It is doubtful, however, if work of sufficient detail has yet been carried out to establish this transition with certainty.

Earlier in this paper it was shown that, in the Zone of Slates, three surfaces are present: S_0, S_1 and S_2. On the limbs of F_1 folds S_0 and S_1 are essentially parallel, but they intersect at a high angle in the hinge zones. Due to the initiation of transposition of S_0 into the plane of S_1 there tends, even here, to be a parallelism between the two structures. In the Zone of Phyllites transposition is more advanced, although major separation bedding planes show no evidence of transposition. Within the Zone of Chlorite Quartz Albite Schists there is a fine schistosity in the chlorite layers, and a strong layering due to complete transposition of S_0 into the plane of

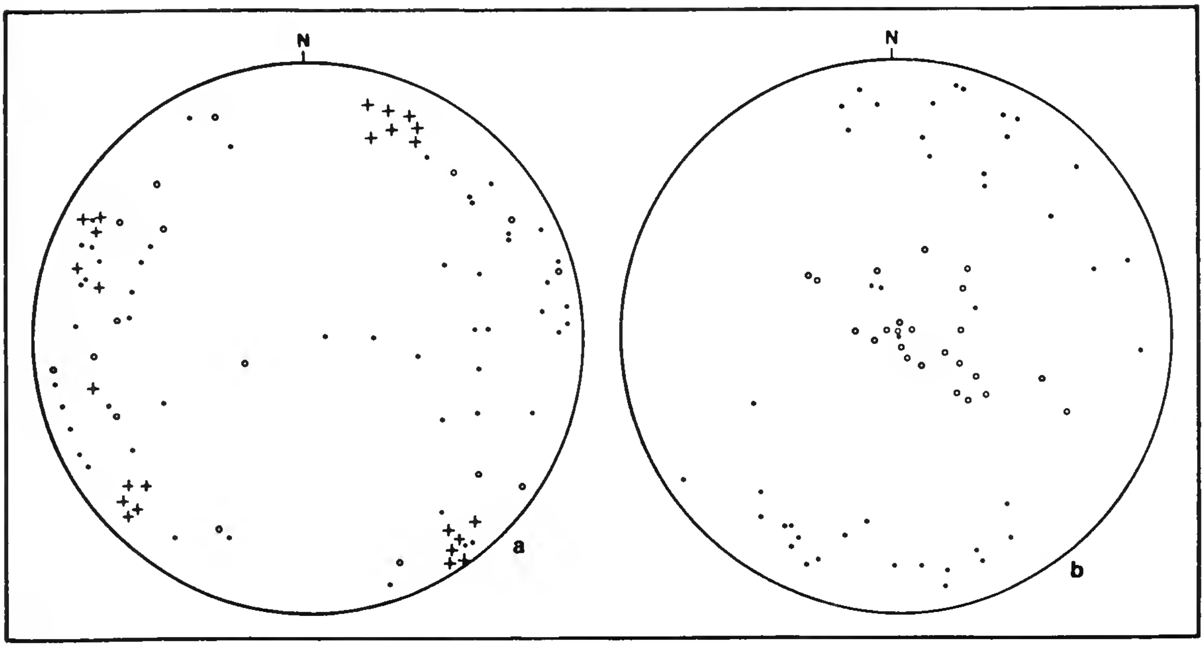

FIG. 9—a. Poles to S_0 (0), S_1 (0) and S_2 (+) in the Snowy Creek area; b. Projection of L_1 (0) and L_2 (0) in the Snowy Creek area.

S_1 and the marked progress of metamorphic segregation: the schistosity and layering are parallel, and major F_1 fold hinges can still be recognized. In the Zone of Biotite Schists lithological layering and schistosity S_1 dominate the structure. Major bedding separation planes can be seen only where layers of quartz schist occur interbedded with biotite schist.

The strongest planar structure in the Zone of Cordierite Schists is schistosity, due to the preferred dimensional orientation of quartz and biotite. Lithological layering is weak or absent, but bedding planes separating quartz amphibole schist and cordierite biotite schist can be readily distinguished. With transition to the Zone of Biotite Sillimanite Almandine Schists, lithological layering parallel to the schistosity again becomes prominent. The layering becomes at first progressively more pronounced, then discontinuous, and with the development of quartz-feldspar and biotite nodules, the schist passes into the High Plains Gneiss. Within the gneiss itself both the schistosity and layering are irregular, and in places, belts of non-foliated rock occur. These are poor in biotite and sillimanite, and may represent original thick beds of sandstone.

The schistosity of the micaceous layers is parallel to the layering even on fold hinges. However, some folds contain a weak schistosity parallel to the axial planes, which cuts the banding in the hinge zone, at a high angle. From this evidence it is clear that the banding and dominant schistosity S_1 have been derived from cleavage (and bedding transposed along the cleavage) in the low grade rocks. The weak axial plane schistosity present in some folds in the gneiss is S_2 developed during the F_1 folding and deformed during the F_2 folding, so that it is not seen in F_2 folds in the gneiss. The implication is that since F_1 structures of the low grade rocks are folded in F_1 folds in the gneiss, the latter are of later stage than the former and that the F_1, F_2, . . . folds of the low grade rocks are not equivalent to the F_1, F_2, . . . folds in the gneiss.

Macroscopic Fold Patterns in the High Plains Gneiss

On Fig. 10 have been recorded the attitudes and trends of the foliations S_1 in the gneiss in the Mt. Beauty area. Macroscopic fold hinges observed, and interpreted from the data are shown. It must be stressed that the interpretation of the folding was made in the absence of any lithological marker.

Several features are noteworthy:

(i) The frequency of horizontal or near horizontal foliations S_1;

(ii) The existence of two quite definite fold trends, one of which may be deformed by the other;

(iii) The development of overturned and recumbent folds.

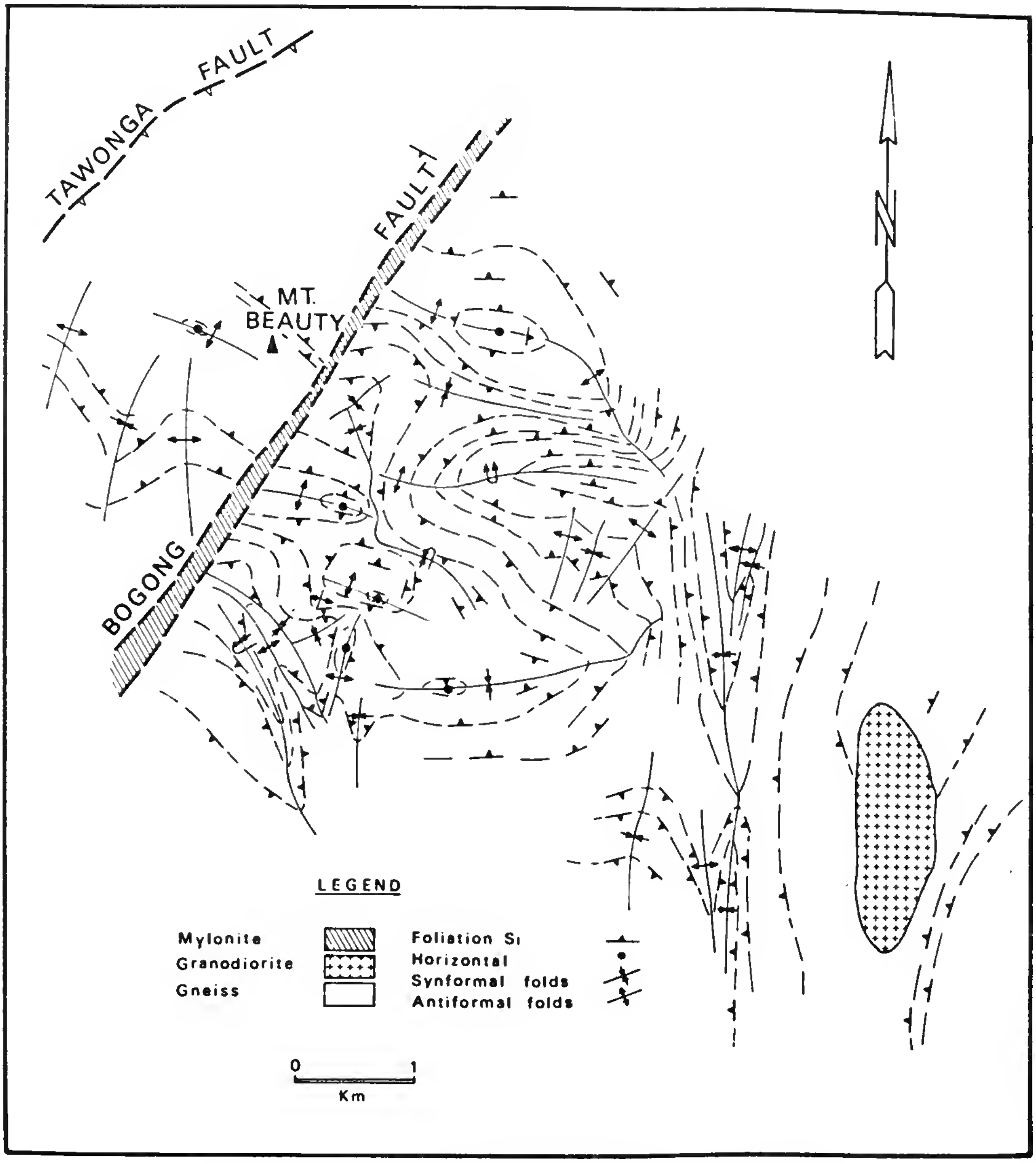

Fig. 10—Macroscopic folding in the High Plains Gneiss, Mt. Beauty.

The horizontal foliation appears to occur in two situations:

(i) on the limbs of recumbent folds, and

(ii) in areas of interference between the two sets of folds.

The projection of poles to S_I for this area (Fig. 11) reflects the complexity of the folding, and suggests that Fig. 10 may be an over-simplification. The most prominent girdle, with pole β_I, corresponds to one set of fold hinges. β_{II} corresponds approximately to the second set of fold hinges, but there are other possible girdles which seem unrelated to folding. It is unfortunate that outcrop data are inadequate for the isolation of attitudes which contribute to the several girdles. So far as field observation is concerned, there is evidence of only two sets of folds.

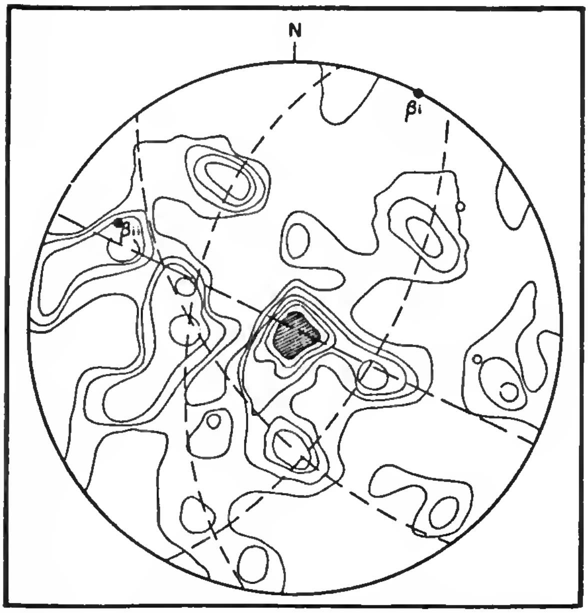

FIG. 11—Poles to foliation in gneiss at Mt. Beauty. Equal area projection, 224 poles. Contours 1, 2, 3, 5, 10, 15%.

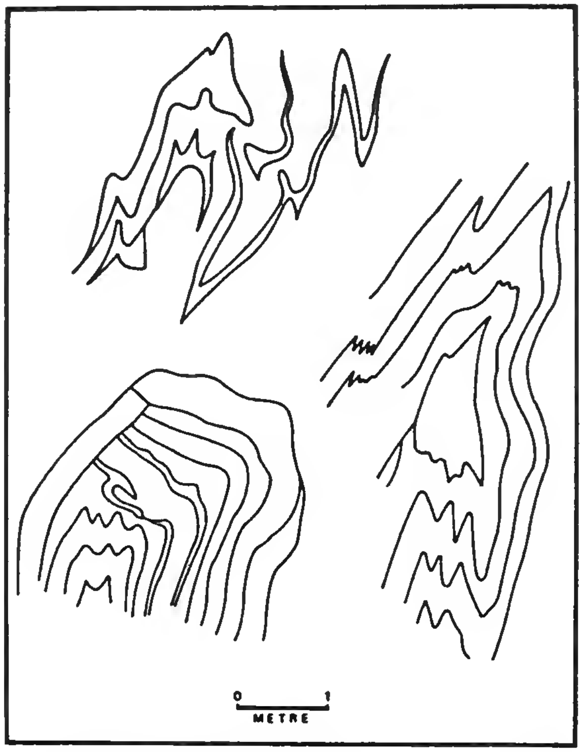

FIG. 12—Mesoscopic folds in High Plains Gneiss.

Mesoscopic Folds in the High Plains Gneiss

Two sets of mesoscopic folds were noted in the High Plains Gneiss at Tawonga Gap (p. 65). Some typical folds in the gneiss in the Mt. Beauty area are shown in Fig. 12. All of the F_1 folds have a 'similar' style, with generally sharp angular hinges, but rounded hinges may occur. In some cases, hinges have been isolated and these may be evidence (Fig. 12) of an earlier ($= F_1$ of low grade rocks) folding. F_2 folds tend to be isoclinal with rounded hinges and are generally smaller than F_1 folds. Axial plane foliation is absent.

The study of the mesoscopic folds confirms that the F_1 folds in the gneiss have, as form surface, structures imposed during F_1 deformation of the lower grade rocks. It is believed that:

(i) F_2 folds in gneiss have no equivalent in the low grade rocks;

(ii) F_1 folds in gneiss $\equiv F_2$ folds of low grade rocks;

(iii) F_1 folds of low grade rocks are represented in the gneiss only as isolated fold hinges, and otherwise have been destroyed.

METAMORPHISM, FOLDING, FAULTING AND IGNEOUS ACTIVITY IN THE KIEWA REGION

It is apparent that the metamorphic and tectonic history of the Metamorphic Complex is much less simple than indicated by previous workers (Tattam 1929, Crohn 1949, Beavis 1962). Table 1 shows a summary of the history of folding, metamorphism, faulting and igneous activity. This table is a presentation of relationships discussed in the remainder of this paper.

Folding

Three phases of folding have occurred:

(a) F_1 folds in low grade metamorphics (P_1).

(b) F_2 folds in low grade metamorphics and F_1 folds in high grade schists and High Plains Gneiss (P_2).

(c) F_2 folds in high grade metamorphics and High Plains Gneiss (P_3).

In addition there is evidence of minor localized phases of folding, e.g. F_3 folds in low grade rocks at Snowy Creek, Beechworth and Mt. Feathertop, and F_3 kink bands in High Plains Gneiss, mesoscopically, at Mt. McKay, and possibly macroscopically, although the evidence of this latter is not convincing. It is not justifiable to recognize a fourth phase of general folding in the Kiewa Region.

The first phase of folding, P_1, can now be recognized only in the low grade to medium grade metamorphic rocks. Folding was about gently plunging N.-S. axes; the folds are frequently isoclinal, and S_1, developed during this phase, is parallel, for the most part, to bedding. Recumbent folds occur rarely. Folding of this phase in the low to medium grade rocks are designated F_1. Only rarely is there any evidence of folds of this phase in the high grade schists and gneiss.

The second phase of folding, P_2, of S_1 about steeply to gently plunging axes trending E.-W. to NW.-SE., is represented by F_2 folds in the low grade rocks, and F_1 folds in the high grade rocks. A crenulation foliation S_2 was developed. The folds are sometimes isoclinal, but may be recumbent.

Folds of the third phase, P_3, of general folding are restricted to the high grade metamorphics and constitute the F_2 folds in these rocks. The two surfaces S_1 and S_2 have been folded, and no axial plane foliation appears to have been formed.

F_3 folds in sediments, low grade and high grade metamorphics are very localized, and are of varying age: e.g. F_3 folds occur near the Snowy Creek Fault, in the aureole of the Beechworth Batholith, and near major faults of Mt. Feathertop and Mt. McKay.

The age of the folding is uncertain, but it is clear that in the Snowy Creek area F_1 and F_2 folds in the low grade rocks are Benambran, i.e. fold phases P_1 and P_2 are Benambran, and there is no evidence to suggest that P_3, the third phase, is not Benambran. This being the case, the Benambran folding must be considered as having had at least two, and possibly three, distinct phases with a differently oriented stress system for each phase.

Folds of the first phase are found only in low grade rocks. Transposition and metamorphic segregation have effectively destroyed these folds in the high grade metamorphics, and F_1 folds in the high grade rocks are to be regarded as second phase structures, which are present also in the lower grades as F_2 structures. The absence of a regional third phase of folding, P_3, in the lower grade schists, phyllites and slates, though folds of this phase are prominent in the High Plains Gneiss, requires some consideration.

The region occupied by high grade schists and the High Plains Gneiss obviously represent the deeper zones of the orogenic belt, and, as pointed out by Whitten (1966, p. 501), it is highly unlikely that each phase of folding at depth is necessarily reflected in rocks at shallow depth in a totally different tectonic environment. It should not be necessary to demand that all phases of folding were effective at all tectonic levels in an orogenic belt. If such a demand has to be met, it would be necessary, in the present case, to challenge relationships between the low grade schists and the High Plains Gneiss which, while admittedly not established beyond all possibility of dispute, rest on criteria assembled from a number of different approaches. That is, if it is demanded that phase P_3 folds be developed in all of the metamorphic rocks, the derivation of the high grade rocks from the slates must be rejected.

Metamorphism

The more important aspects of the metamorphic rocks are:

(i) the onset of metamorphic differentiation in very low grade slates;

(ii) the persistence of lithological layering throughout the metamorphic sequence, with a temporary weakening in the Zone of Cordierite Schists;

(iii) the weakening of schistosity from near the top of the cordierite zone;

(iv) the bending of the schistosity by growing cordierite porphyroblasts;

(v) pinitization of cordierite and sillimanite;

(vi) the existence of two generations of biotite in the high grade schists and gneiss, one of which is fibrolitized and dark coloured, the other light, strongly pleochroic, and which has not been fibrolitized;

(vii) large lenses of biotite; and of quartz and microcline, in the High Plains Gneiss.

Of lesser importance to the regional picture is the development of porphyroblasts of dark mauve cordierite and bright red andalusite in the biotite sillimanite almandine schist and in gneiss. These occur only in contact zones about later granodiorites. Textural and petrological evidence (Tattam 1929, Crohn 1949, Beavis 1962) indicate that the Complex is polymetamorphic, with the last main phase, M_3, one of the retrograde activity. Phase M_4 was localized about later intrusions. The first phase of metamorphism (M_1) is regarded as being more or less synchronous with the first phase of folding (P_1). The sediments were converted to slates, phyllites and low grade biotite schists. A fine schistosity was induced, and transposition of bedding occurred. At a later stage of M_1, metamorphic segregation began with the migration of quartz into the hinge zones of small folds and into kink bands. This emphasized the lithological layering due to transposition.

The second phase of metamorphism, M_2, was marked by the development of cordierite porphyroblasts, garnet and sillimanite, with the fibrolitization of earlier formed biotites and the development of second generation biotite. In the deeper parts of the orogenic belt, metamorphic segregation tended to emphasize the layering but with a

Table 1

FOLDING, METAMORPHISM, FAULTING AND IGNEOUS ACTIVITY IN THE KIEWA REGION

FOLDING (P)		METAMORPHISM (M)		IGNEOUS ACTIVITY (I)		FAULTING (C)		OROGENY
Phase	Event	Phase	Event	Phase	Event	Phase	Event	
P_1	Initial folding of sediments about N-S axes. Isoclinal folds in S_0.	M_1	Syntectonic development of schistosity and layering. Growth of biotite.					
P_2	F_2 folding of sediments and schists about steeply plunging axes. F_1 folding of High Plains Gneiss.	M_2	Syntectonic growth of cordierite, garnet, sillimanite. Emphasis of layering.					Benambran
P_3	F_2 folding of High Plains Gneiss. Localised F_3 folding of low grade rocks and gneiss.	M_3	Syntectonic retrograde pinitization of cordierite.	I_{1a}	Intrusion of Granodiorite:- post-tectonic.	C_1	High angle thrusting - West Kiewa Thrust.	
				I_{1b}	Extrusion of Mitta Mitta Volcanoes.			
				I_2	Syntectonic intrusion of Pretty Valley Granodiorite.			Bowning
		M_4	Contact metamorphism of High Plains Gneiss → andalusite and cordierite.	I_3	Post-tectonic intrusion of East Kiewa and Niggerheads Granodiorite.			Tabberabberan
				I_4	Post-tectonic intrusion of Big Hill Quartz Diorite.	C_2	Wrench faulting - Nelse, Spion Kopje. Early wrench movement of Tawonga Fault.	
				I_5	Pre to syntectonic extrusion of Bogong Volcanics.	C_3	Low angle thrusting on Tawonga, Snowy Creek and Mullindolingong Faults.	Kosciuskoan

Proc. R. Soc. Vict., Vol. 88, Art. 7, Beavis & Beavis. Table 1.

weakening of schistosity. The development of the lenses and porphyroblasts of biotite, quartz and microcline in the gneiss probably occurred in this phase. The P_2 phase of folding and M_2 phase of metamorphism were probably more or less synchronous, but there is little evidence either to support or refute this suggestion.

The retrogressive phase of metamorphism was probably associated with P_3 phase of folding. M_2 certainly predates I_3 since cordierites produced during I_3 were not pinitized. On the other hand, pinitization is extreme in cordierites in F_2 folds in the gneiss. The M_4 phase of metamorphism is a localized contact type.

Igneous Activity

Five phases of igneous activity have occurred in the Kiewa Region: four intrusive and one extrusive. The first phase I_1 was immediately post-Benambran and involved the intrusion of the Banimboola Granodiorite. This was followed later by the extrusion of the Mitta Mitta Volcanics (Phase I_{1b}). Both the Banimboola Granodiorite and the Mitta Mitta Volcanics are older than the Middle or Upper Silurian Wombat Creek formation.

Phase 2 of igneous activity (I_2) was the syntectonic intrusion of the Pretty Valley Gneissic Granodiorite (Beavis 1962) which contains xenoliths of High Plains Gneiss oriented concordantly with the foliation of the granodiorite. This phase is tentatively regarded as Bowning. The intrusion of the East Kiewa and Niggerheads' Granodiorites, and their associates, was post-Bowning, and constitutes Phase I_3. The youngest of the intrusives, the Big Hill Quartz Diorite and associated lamprophyres, are intrusive into I_3 masses. This phase, I_4, is regarded as post-Tabberabberan (Beavis 1962). The final phase of igneous activity I_5 involved the extrusion of basic to ultrabasic and alkaline lavas, with associated minor dyke intrusion, in the early Tertiary. Limburgites, basalts, olivine basalts and phonolites are characteristic. This activity probably marked the onset of the Kosciusko diastrophism which was represented in the Kiewa Region by intense faulting.

Faulting

The Kiewa Region is intensely faulted, and although attempts have been made to date the faults this was successful for only a few of the more important structures. It seems likely, however, that there have been three major phases of faulting. The first of these, C_1, is represented by the West Kiewa Thrust Zone. This predated the I_2 phase of igneous activity since the zone has been intruded by the Pretty Valley Gneissic Granodiorite.

Phase C_2 was marked by wrench faulting which appears to have been associated with post-Tabberabberan igneous activity. The faults produced by this phase included the Nelse and Spion Kopje faults and wrench movement on the Tawonga Fault. The final phase of faulting, C_3, was a low angle thrusting with the movement on the Tawonga and Mullindolingong Faults. These movements, which post-dated I_5, continued into the Quaternary, since Quaternary alluvials have been involved in faulting.

REFERENCES

Beavis, F. C., 1960. The Tawonga Fault. *Proc. R. Soc. Vict.* 75: 95-100.

———, 1962. The Geology of the Kiewa Area. *Ibid.* 75: 349-410.

———, 1963. Superposed folds in the Metamorphic Complex, North East Victoria. *Aust. Jl. Sci.* 26: 23.

———, 1968. Structures in schist, Tawonga, Victoria. *Proc. R. Soc. Vict.* 81: 119-126.

Crohn, P. W., 1949. The Geology of the Omeo District. *Ibid.* 62: 1-70.

Kenny, J. P. L., 1937. Dam Sites, Mitta Mitta River. *Rec. Geol. Surv. Vict.* 5: 465-468.

Leggo, M. D., 1968. Geo-chemical Studies in the Corryong District, North-East Victoria. Ph.D. Thesis, University of Melbourne.

——— & Beavis, F. C., 1968. North East Victoria. In *A regional guide to Victorian geology*, Ed. McAndrew, J. and Marsden, M. A. H. University of Melbourne. 43-53.

Singleton, O. P., 1965. Geology and Mineralization of Victoria. In *Geology of Australian Ore Deposits*, Ed. McAndrew, J. A., A.I.M.M.

Tattam, C. M., 1929. The Metamorphic Rocks of North-East Victoria. *Bull. Geol. Soc. Vict.* No. 52.

Whitten, E. T., 1966. *The Structural Geology of Folded Rocks.* Rand McNally. 663 pp.

DESCRIPTION OF PLATES 7-9

PLATE 7

Structures in the Tawonga Gap area:

FIG. 1—Low angle thrust in High Plains Gneiss, Tawonga Gap.
FIG. 2—Detail of thrust shown in Fig. 1.
FIG. 3—Small F_2 folds in weathered biotite schist, Tawonga Gap.
FIG. 4—F_2 fold in High Plains Gneiss, Tawonga Gap. Scale is given by hat in fold hinge.

PLATE 8

Linear structures in the Tawonga Gap area:

FIG. 1—Cleavage mullions in slate, Bright-Harrietville road.
FIG. 2—Banding and boudinage in High Plains Gneiss, Tawonga Gap.
FIG. 3—Deformed lineation in biotite schist, Tawonga Gap.
FIG. 4—Lineations in quartz schist, Tawonga Gap.

PLATE 9

Structures in the Snowy Creek area:

FIG. 1—F_1 anticline, Omeo Highway, Snowy Creek.
FIG. 2—F_2 fold, Omeo Highway, Snowy Creek.
FIG. 3—F_2 folds in slate, Omeo Highway, Snowy Creek.
FIG. 4—Linear structures, L_2 and L_3, Omeo Highway, Granite Flat. L_2 is vertical.


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Identification of a Eucalypt Fragment, Based on Anatomy of Leaf and Stem

By Stella G. M. Carr* and D. J. Carr*

Abstract: A leafy fragment of a eucalypt from Fenelon Island was treated as a test case for the use of phytoglyphic analysis in identification. Other vegetative characters proved useful in reducing the number of species to be considered (presence or absence of oil glands in the pith) or to confirm the subsequent identification (features of the venation). The fragment is identified as belonging to *E. socialis* or to a species so closely related as to be indistinguishable on vegetative characters alone. Only an examination of reproductive material could substantiate that it is not of *E. socialis* which has, in any case, a wide and as yet undescribed degree of variation.

INTRODUCTION

In 1971 and 1972, Dr. N. M. Wace (Department of Biogeography and Geomorphology, Australian National University) visited Fenelon Island in the Nuyts Archipelago, South Australia (Fig. 1) and collected material of a speeies of *Eucalyptus.* On neither occasion were fruits or flowers obtainable. The only material provided to us for identification was a leafy twig. The identity of such specimens is of importance to plant geographers but, in general, methods are not eurrently available for the identifieation of leafy fragments of eucalypts. We felt, however, that methods we had already developed for examination of the mieroanatomy of leaf epidermis might help with the problem of the Wace speeimens. We have coined the term 'phytoglyph' for the assemblage of microanatomieal eharaeters of the surface layers of leaves (Carr, Milkovits & Carr 1971). Experience with a wide range of euealypts has convineed us of the usefulness of the phytoglyph in the definition of groups or even as diagnostic of the species (Carr, Milkovits & Carr 1971, Carr 1972, unpublished work).

MATERIALS AND METHODS

The specimens listed below were examined eritically. Other AD and PERTH speeimens, not listed below, were also examined but less critically. Cuticular preparations representative of a very high percentage of all known euealypts have been prepared and of these a large number have been examined by seanning electron mieroscopy as well as by transmitted light microscopy. Other anatomical features have already been examined in specimens of nearly all known eucalypts (e.g. Carr & Carr 1969).

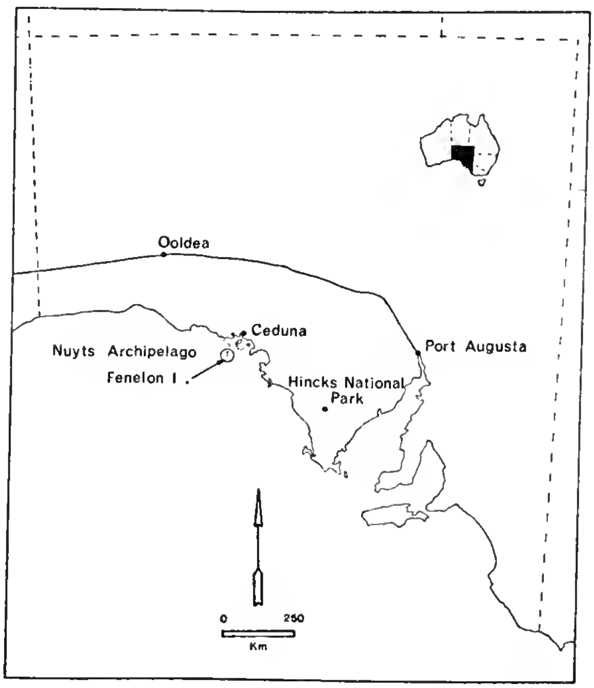

Fig. 1—Map showing South Australian localities mentioned in the text.

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N. M. Wace 286 Fenelon Island, Nuyts Archipelago, S.A., 5.x.1972. Low-growing mallee (45 cm), shoots arising from old burnt stump. From plateau area of island. Soil: sand over limestone (AD).

Eucalyptus socialis F. Muell. ex. Miq. J. B. Cleland s.n. Ooldea, S.A., August 1922 (AD). D. E. Symon 6323, 10.x.1968. Hinck's National Park (AD). D. J. and S. G. M. Carr 747, 33 km E. of Alice Springs, N.T., 27.v.1969.

C. youngiana F. Muell. B. Copley 2668, Ooldea, S.A., 29.vii.1969 (AD).

E. oldfieldii F. Muell. P. G. Wilson 4060, 114 km N. of Kalgoorlie, W.A., 9.iii.1969 (PERTH).

The leafy twigs (Fig. 2) provided by Dr. Wace were already dried. For examination, samples of stems and leaves were boiled in weak Teepol (detergent) until pliable. Hand sections of stems were examined in lactophenol. For cuticular preparations, pieces cut about 1 cm wide from the middle third of a leaf were macerated in hydrogen peroxide. The cuticle was then carefully lifted off and cleaned. For light microscopy, whole cuticle pieces were stained (Sudan Black or Acid Fuchsin) and mounted in glycerine jelly.

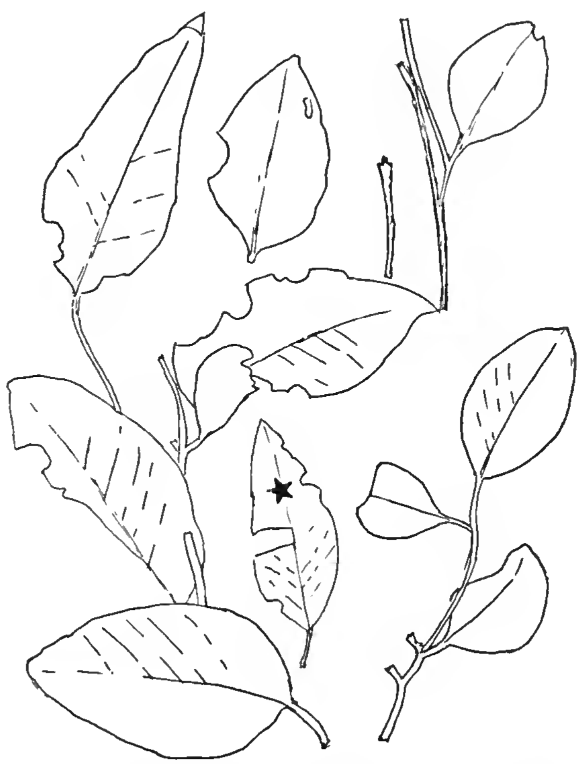


Fig. 2—Wace 286, Fenelon Island, × 0·5. The leaf from which a fragment was taken for this study is indicated with an asterisk. It was originally attached to the twig.

For scanning electron microscopy (SEM), pieces of cuticle were mounted on aluminium stubs, shadowed with gold-palladium and viewed in a JSM U3 scanning electron microscope and photographed on Polaroid film. For thin sections, narrow (1-2 mm) slivers of the middle third of a softened leaf were fixed in acrolein (10% solution in water), dehydrated in the series methyl cellosolve, ethanol, propanol, n-butanol and embedded in glycol methacrylate by the method of Feder and O'Brien (1968). Fixation was not essential, since the material had been dried, but even in dried material it seems to stabilize some tissue components. Of course, the cytoplasm is not preserved in dried materials, but fortunately we are concerned here only with the more stable materials of cell walls and cuticles. Thin (1-2 μm) sections were cut with glass knives on a Cambridge ultramicrotome, stained with the periodic acid-Schiff reagent and by toluidine blue (Feder & O'Brien, loc. cit.) and mounted in Depex. Photography of stained cuticles and leaf sections was on Agfa-Gaevert film 49 C 65 using Nikon optics. For venation studies, leaves were cleared in dimethyl sulphoxide (DMSO) and photographed with a Zeiss Tessovar. As a clearing agent, DMSO has the advantage of being non-destructive; it can readily be removed from the leaf which can then be dried and returned to the herbarium sheet (Fig. 2). Its only disadvantage is that it is dangerous to health.

RESULTS

Most herbarium specimens of eucalypts are essentially incomplete, and the tacit assumption is made that identification of an unknown is complete when a number of its characters tally with those of a known species. Only if a complete suite of material were available and if the characters and range of variation of each described species were completely known could the possibility be ruled out that an unknown specimen might be of an undescribed species. In the case of the vegetative specimen collected by Wace we must not rule out the possibility, however unlikely, that it is of an undescribed species. With this proviso we can move to the alternative hypothesis, that it is of a species already described, and try to equate it with a known species. The most likely species to be investigated are those which occur nearby on the mainland.

Wace 286 consists of leaves and a short length of stem. The leaves are isolateral, glaucous and broadly-ovate. The stems have intranodes. The specimen is too incomplete to show whether the shoot of which it forms part is of adult form or of an intermediate stage of development. However, taking into account the reported size of the plant from which it was taken, there is a possibility that the material is of intermediate form.

An examination of the stems reveals that the pith does not contain oil glands. We have shown (Carr & Carr 1969) that the presence or absence of pith glands is a valuable character for the identification of eucalypts. In the present instance, the absence of oil glands from the pith enables us to exclude about half of the South Australian species listed by Boomsma (1972) from consideration. Even a cursory examination of the leaf venation is sufficient to exclude South Australian members of the Renantherae. All of these have characteristically looped marginal veins distant from the margins and costal veins which intersect the midrib at a very low angle.

A preliminary examination of the leaf epidermis by light microscopy reduces the number of species to be considered to the members of a small group all of which are included in Bisectae (Carr & Carr 1969). The chief epidermal characters which distinguish this group from the other species of Bisectae which lack pith glands are the prominently sculptured cuticle and aggregation of stomata into groups or short lines. Other epidermal characters can be invoked to support the distinction but it is not necessary to discuss them at this point.

From this initial examination it was decided that Wace 286 resembled two species (*E. youngiana* and *E. socialis*) which occur on the adjacent mainland in South Australia and another (*E. oldfieldii*) which occurs only in Western Australia. The phytoglyphic characters which the four species have in common are as follows. The guard cells are rather deeply set and are not visible in SEM preparations viewed from the outside of the cuticle because they are overarched by broad outer stomatal ledges (Pl. 10, 11, figs. 10-13). The ledges themselves are inserted below the general level of the surface of the cuticle. They are smooth and the orifice they surround is narrow. The depressions in which the outer stomatal ledges are inserted are more or less circular to elliptical.

Each stoma is subtended by five or six, sometimes seven, subsidiary cells. The outer walls of the subsidiary cells are strongly thickened, the thickenings projecting above the surface as mounds. The ordinary epidermal cells have similar, but less prominent, thickenings. The thickenings stain deeply with the dyes used (Pl. 10, figs. 3-10). In the light microscope those of the ordinary epidermal cells are seen to be circular in outline but those of the subsidiary cells vary between circular and somewhat angular. The thickenings of the subsidiary cells appear to form rosettes around each stoma.

When the differences between the species are considered it is found that *E. oldfieldii* stands apart from the others because the cuticular thickenings of the ordinary epidermal cells contain deeply-staining lenses. Further, in this species, the thickenings of the subsidiary cells tend to be separate. In the Wace specimen, *E. socialis* and *E. youngiana* they are more or less confluent.

The stomata of *E. youngiana* are larger than those of the other species but stomatal size, in our experience, is not an invariant character of eucalypt species. However, *E. youngiana* has less prominent cuticular thickenings than the other species. SEM shows evident similarity between the Wace specimen and *E. socialis* in the angularity and disposition of the cuticular thickenings around the stomata (Pl. 11, figs. 11-14). On the basis of light microscopy of epidermal preparations and of SEM of surface features we may confidently exclude *E. oldfieldii* from consideration and tentatively identify the Wace specimen with *E. socialis*. Median sections through stomata add evidence which strongly supports this suggestion (Pl. 12, figs. 15-20).

The median profile of the stomatal space is, as we will show elsewhere, characteristic of the species. The large blunt, vertically orientated outer stomatal ledges of *E. youngiana* are quite unlike those of the other species (Pl. 12, figs. 15-18). The recurved outer stomatal ledges of *E. oldfieldii* and their position in relation to the guard cells distinguish this species from the others. It is also to be noted that the stomata in *E. oldfieldii* are smaller, and those of *E. youngiana* larger, than those of *E. socialis* and of Wace 286. It is clear from comparison of Pl. 12, figs. 15 & 16 and of Pl. 12, figs. 19 & 20 that the closest match for the Wace specimen is with *E. socialis*.

Finally, an examination of the venation of the leaves (Pl. 13, figs. 21-28) supports the identification. The low vein angles of the Wace specimen (circa 40°) are approached only by those of *E. socialis* (circa 43°). This may not be an important point since the comparison is made between only a single specimen and a few others and we have no means of telling whether any of them represent means or extremes of the range of vein angles characteristic of the species or even of a single tree. More reliable is the *pattern* of venation. The general venation patterns of the three species are similar. However, there are minor features of the veins close to the margin in

E. socialis and the Wace specimen which are not as those in the other species. In the Wace specimen and in *E. socialis* the minor veins which occur between the marginal vein and the edge of the leaf are reticulate and the oil glands of this part of the leaf are in more than one row. In *E. youngiana* and *E. oldfieldii* the minor veins in this part of the leaf are either simple and run from the marginal vein to the edge of the leaf or form single closed loops. The oil glands usually occur in only one row.

DISCUSSION AND CONCLUSION

With the proviso made above (Results) we believe that the specimen collected from Fenelon Island by Wace can confidently be identified as *E. socialis*. Some degree of variation in the phytoglyphic characters (as in others, e.g. venation) must be expected as a measure of the general range of variation within the species. An examination of other specimens of *E. socialis* confirms, for instance, that there is variation in that species in the degree of angularity of the thickenings of the cuticles. The characters of the specimens of *E. youngiana* and *E. oldfieldii* used to illustrate this study are, however, generally consistent with those of other specimens of these species which we have examined. Observed similarities to and differences from the Wace specimen can be confirmed. Geographical isolation of the Wace eucalypt on Fenelon Island could lead to incipient or full speciation but we have no reason from our examination of the material provided to suppose that speciation has progressed to any marked degree. In any case, to establish it would require critical biological as well as anatomical examination of more than a few specimens of the species in question.

We have shown that the content of taxonomic information in eucalypt leaves is very much larger than is generally supposed (Carr, Milkovits & Carr 1971). The methods we have applied are evidently sufficient in at least some cases, to enable identification of eucalypts to be made to the level of the species. Moreover, there are general phytoglyphic resemblances between the members of groups of species which on other grounds may be regarded as natural. In the SEM views (Pl. 11, figs. 11-14) we recognize certain similarities of pattern which would lead us to group the species used in this study and which are different from the patterns found in other groups. Similarly, in the sections (Pl. 12, figs. 15-20) there are microanatomical characters which may be unique to this group, We have not seen, for instance, the extraordinary intra-stomatal cuticular thickenings (Pl. 12, figs. 19-20) forming the line of closure of the stoma in any other group of eucalypts so far examined. Thus, even when identification to the species cannot be certainly made, a specimen examined by our methods may with certainty be referred to a group of species.

In many cases, and with experience, sufficient of the phytoglyphic characters can be seen in fairly crude, temporary preparations with the light microscope to enable rapid decisions to be made concerning unknown or dubious specimens. Critically, and for convincing demonstration, the methods described above may be applied but, carried out as a routine, they are not unduly time-consuming. The fact that an examination can be carried out using a fragment of a single leaf (Fig. 2) is advantageous since it is almost non-destructive to the whole specimen. It is to be hoped that more general use will be made of the abundant and reliable information contained in the microanatomy of the leaf, particularly in the phytoglyph, to solve difficult problems in the eucalypts as well as in other groups of plants.

REFERENCES

Boomsma, C. D., 1972. Native Trees of South Australia. *Dept. of Woods & Forests, S.A., Bulletin* 19.

Carr, Stella G. M., 1972. Problems of the Geography of the Tropical Eucalypts. In *Bridge and Barrier. The natural and cultural history of Torres Strait.* Ed. D. Walker. Publication BG/3, Research School of Pacific Studies, Department of Geography and Geomorphology, A.N.U. Press, Canberra.

——— & Carr, D. J., 1969. Oil glands and ducts in *Eucalyptus* L'Herit. I. The phloem and the pith. *Aust. J. Bot.* 17: 471-513.

———, Milkovits, Lydia & Carr, D. J., 1971. Eucalypt phytoglyphs: The microanatomical features of the epidermis in relation to taxonomy. *Ibid.* 19: 173-190.

Feder, N. & O'Brien, T. P., 1968. Plant microtechnique: some principles and new methods. *Amer. J. Bot.* 55: 123-142.

DESCRIPTION OF PLATES 10-13

PLATE 10

FIGS. 3-10—Stained cuticles examined by light microscopy. Wace (W) = Wace 286. *E. socialis* = Cleland, Ooldea. The arrow, Fig. 6, indicates the lens-like thickenings of the cuticle over ordinary epidermal cells of *E. oldfieldii*. Figs. 3-6, × 90. Figs. 7-10, × 280.

PLATE 11

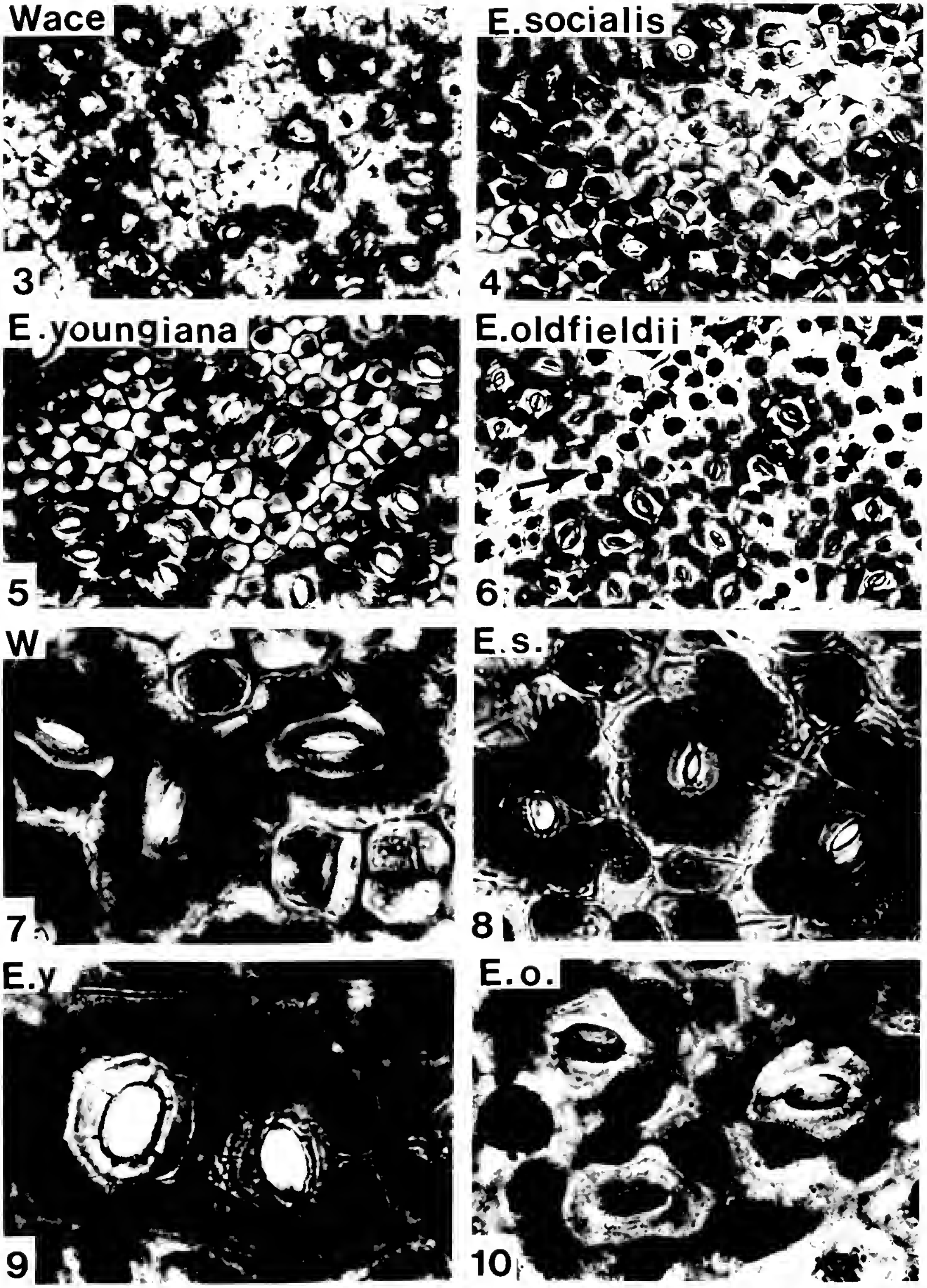
FIGS. 11-14—Scanning electron micrographs of cuticles. E.S. = *E. socialis* (Symon 6323). The other abbreviations as in Figs. 7-10. All at × 350.

PLATE 12

FIGS. 15-20—Median sections through stomata. E.S. = *E. socialis* (Cleland, Ooldea); osl = outer stomatal ledge. The other abbreviations as in Figs. 7-10. The arrows in Figs. 17, 19 and 20 indicate the cuticular projections which form the line of closure of the stomatal pore. Figs. 15-18, × 200. Figs. 19, 20, × 350.

PLATE 13

FIGS. 21-28—Venation of leaves. E.S. = *E. socialis* (Cleland, Ooldea); the other abbreviations as in Figs. 7-10. Arrows in Figs. 25-28 indicate the minor venation between the marginal vein and the margin of the leaf. Figs. 21-24, × 3. Figs. 25-28, × 6.


Wace
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E.socialis
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E.youngiana
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E.oldfieldii
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W
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E.s.
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E.y
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E.o.
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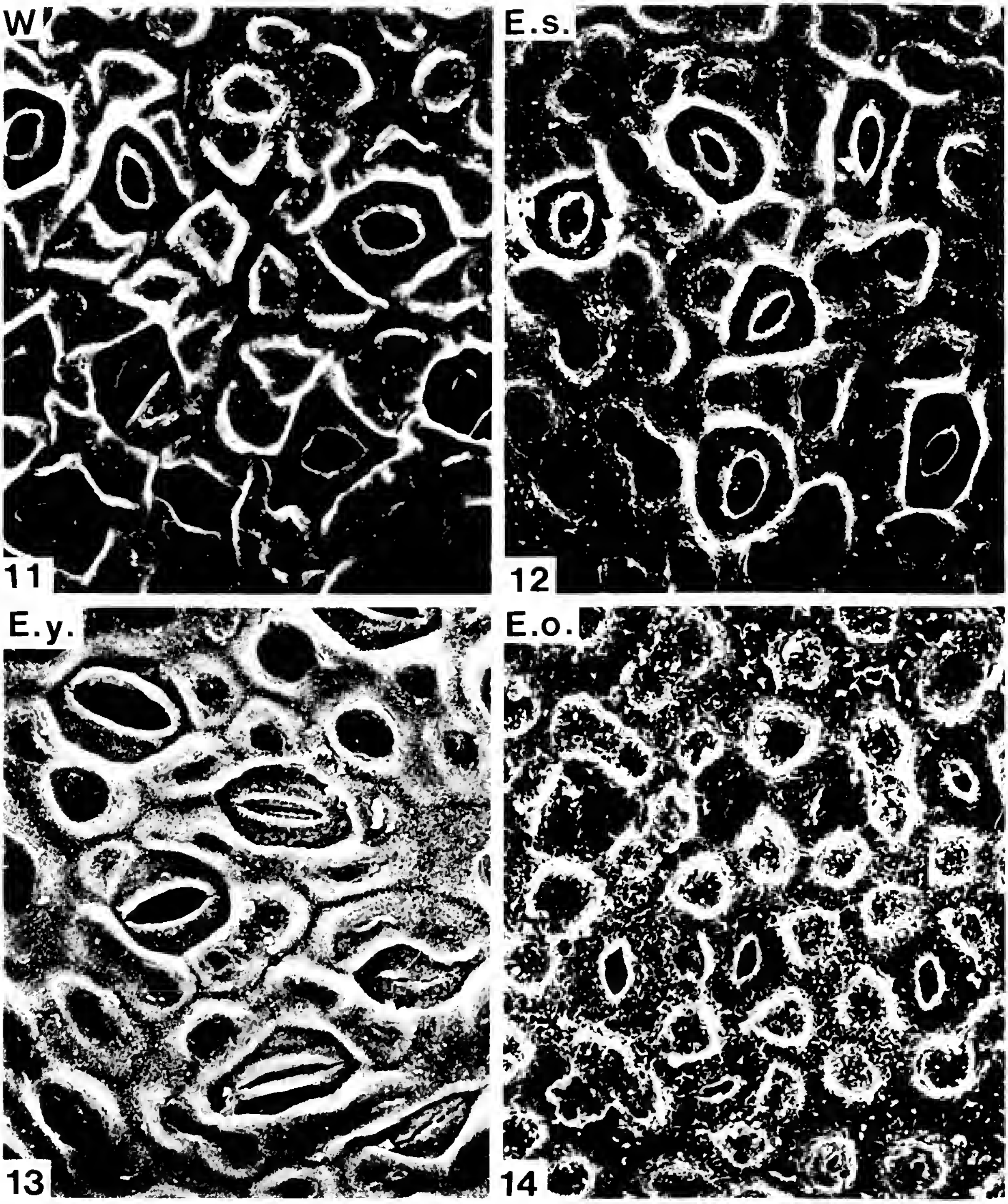
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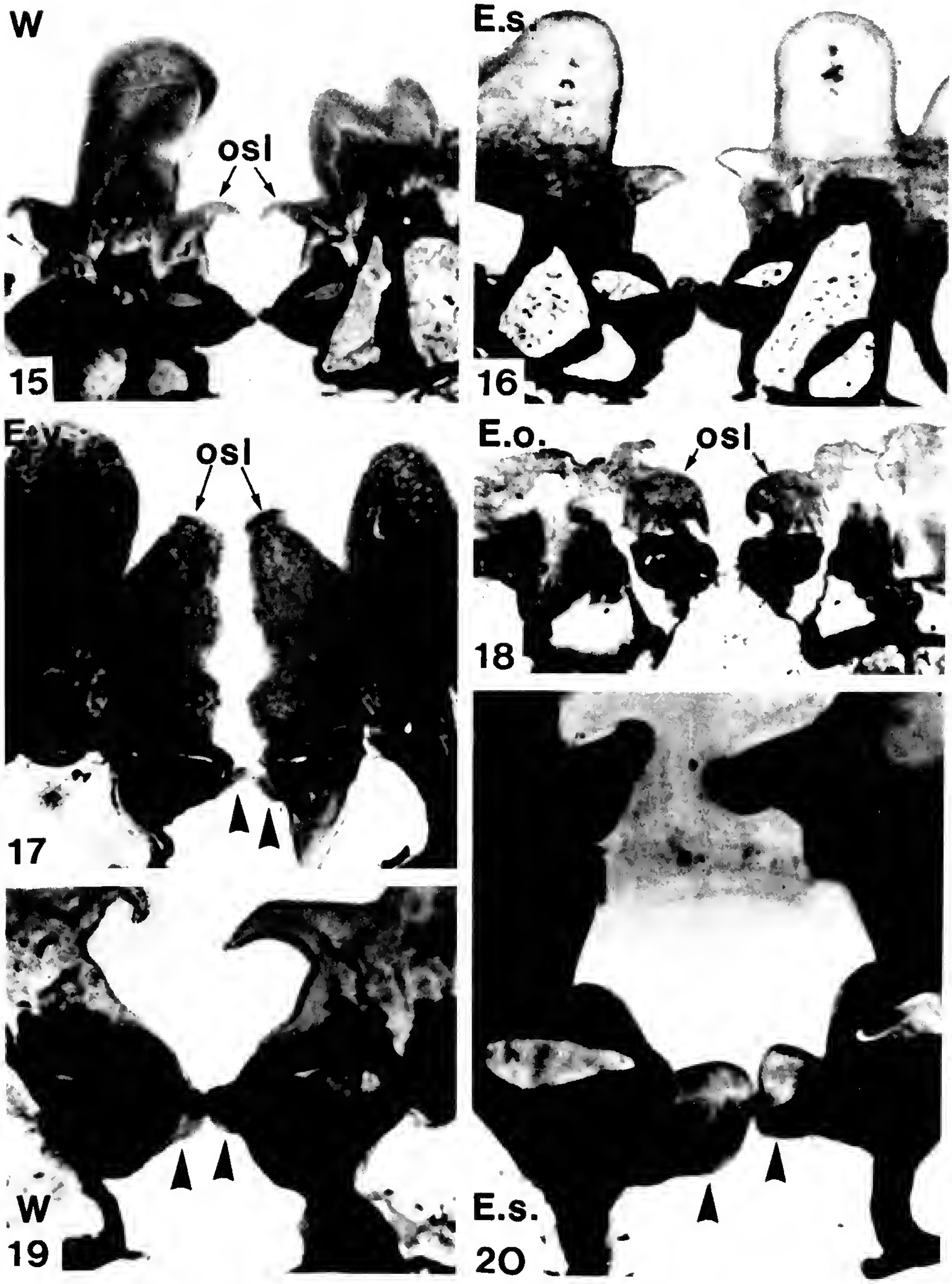
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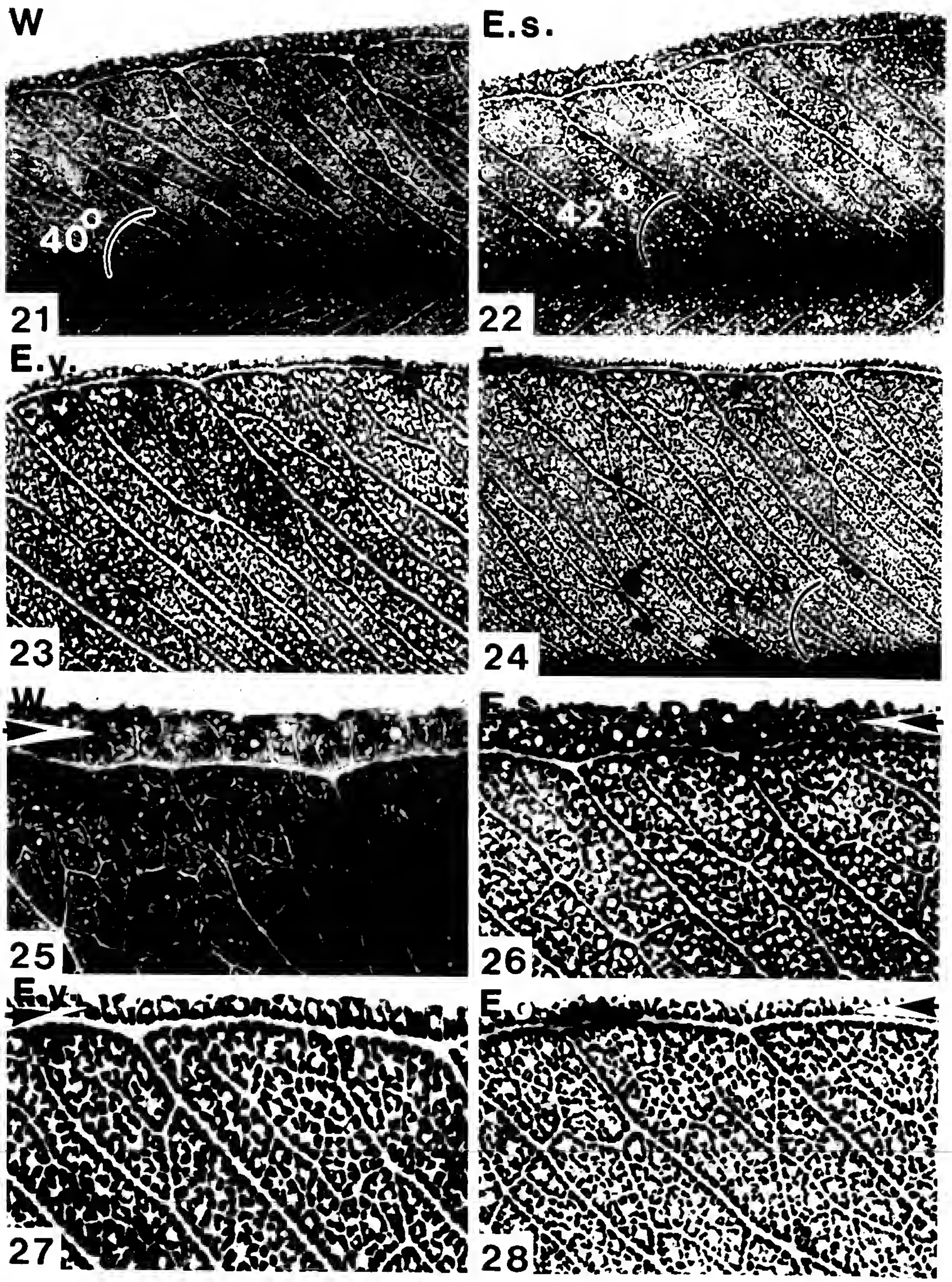
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The Vegetation at Sandy Point, Westernport Bay, Victoria

By John Robin* and R. F. Parsons*

Abstract: The fire and clearing history, vegetation and soils of coastal sands at Sandy Point Naval Reserve, one of the last remaining sizeable areas of native coastal vegetation near Melbourne, are described. The major communities are dominated by *Leptospermum laevigatum, Banksia integrifolia* and *Eucalyptus viminalis.* The distribution of these in relation to a variety of coastal sand soils and other factors is discussed. The important effects of fire and clearing on the vegetation are stressed.

INTRODUCTION

Sandy Point Naval Reserve (Fig. 1) is currently regarded as a 'unique virgin area' and one of the last sizeable areas of native coastal sand dune vegetation left near Melbourne (Champion 1974), containing 890 ha of native vegetation (Seddon 1974). As such, it is likely to be used increasingly for research on its plant and animal communities, which are presumed to be representative of those formerly widespread on coastal sands around the Melbourne area. In fact, it has already been used in a broad-scale study of the native vegetation of the Mornington Peninsula (Calder 1972), to prepare a key to native vegetation types near Melbourne (Calder, in preparation) and to study mammals (Ahern 1974) and birds (Davis & Reid 1974).

The aim of the present study is to document to what extent the area is undisturbed and to describe the present vegetation both as essential background to more detailed studies and because Victorian coastal vegetation is very poorly known or understood (the only detailed studies being those of Parsons (1966) and Turner, Carr and Bird (1962)). The study is particularly desirable because the area is unusually suitable geologically for critical studies of succession on coastal sands, as will be seen later.

The field work was carried out throughout 1974. Nomenclature for soils, vegetation forms and plant species follows Northcote (1971), Specht (1970) and Willis (1970, 1972) respectively, except where otherwise noted. A set of voucher specimens of all vascular plant species is lodged at La Trobe University Botany Department Herbarium.

CLIMATE

Rainfall data from a coastal site (Somers) about 4 km west of the study area show a mean annual rainfall of 79 cm with a winter maximum. For temperature, mean monthly minima range from about 5·5°C in July to 12·5°C in January, and maxima from 12·5°C in July to 24°C in January (see Australia: Bureau of Meteorology, 1968 for these and other climatic data).

GEOLOGY

The study was restricted to sands of Pleisto-

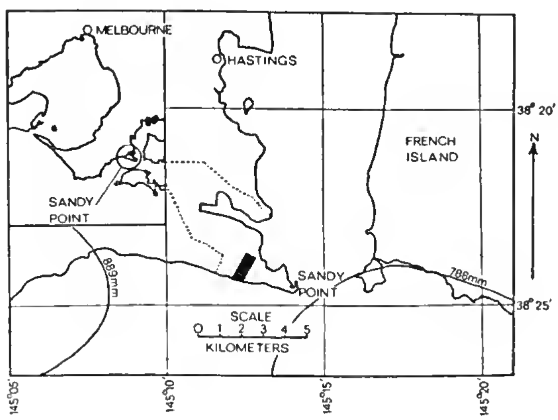

Fig. 1—Location of study area (blacked in), showing mean annual rainfall isohyets (mm). Dashed line shows boundary of Sandy Point Naval Reserve.

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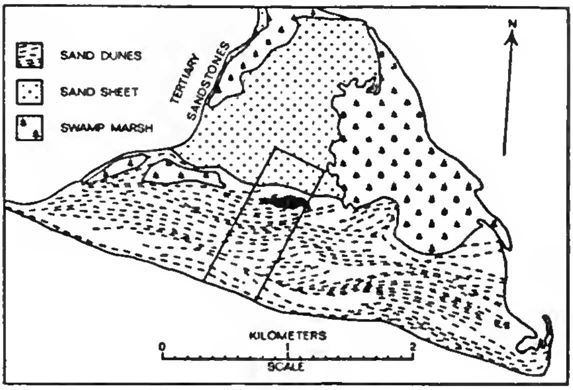

FIG. 2—Geology of Sandy Point after Jenkin (1962) and Victoria: Geological Survey (1967). Dune area and sand sheet both Pleistocene to Recent age, swamps and marshes include mangroves, salt marsh and fresh-water swamps. Area studied in detail shown by rectangle. Blacked in area shows low-lying sand area with *Poa* grassland mentioned in Appendix 1.

cene to Recent age (Fig. 2; Victoria, Geological Survey, 1967). For completeness, the sand areas both in the Naval Reserve itself and in the adjoining block of native vegetation on private property (Fig. 3) were included. The area in the south is referred to for convenience as 'dunes' (Fig. 2) while, strictly, it is made up of beach ridges (Seddon 1974). The more or less parallel dunes are between 1 and 8 m high above the adjacent swales; most are about 2 m high. The soil parent material is calcareous throughout. North of the dunes there is an abrupt change to the older, more leached sands of the sand sheet (Fig. 2). No calcareous sand was found in this area. Most of the sand sheet is very flat, with elevation from 3 m to 6 m above sea level but reaching 17 m above sea level in one small area. It is possible that the dunes and the sand sheet are of Recent and Pleistocene ages respectively.

The reserve contains a variety of other deposits, but these and the swamps within the sand area were not considered in detail in this study.

BIOTIC INFLUENCES AND DISTURBANCE

Major mammalian herbivores at present include the grey kangaroo (*Macropus giganteus*), the black-tailed wallaby (*Wallabia bicolor*) and the introduced rabbit (*Oryctolagus cuniculus*). Previously, cattle were grazed, especially in the north-west of the area (J. Wilson, Crib Point, Victoria, personal communication) and horses grazed the entire area in the 1930s (T. Hope-Campbell, Somers, Victoria, personal communication).

Valuable data on clearing and fire are available from the air photos of 1939, 1948, 1950, 1957, 1966, 1968, 1970 and 1973 (see also Pl. 1). The 1939 air photos show that a large part of the dunes carried only very scattered trees, certainly less than 25% of those now present. While this low tree density may possibly be due to partial clearing in the 1930s (Wilson, personal communication), the pre-1939 history is almost unknown. Fire, clearing and grazing may all be involved, but for convenience the area is mapped as 'pre-1939 clearing' in Fig. 3. Parts of an old fence were found along the exact southern margin of this 'pre-1939 clearing' area, adding weight to the suggestions of both partial clearing and grazing.

In about 1941 a large part of the sand sheet was completely cleared of trees for an air-strip; tree stumps were left, and it was not graded (Hope-Campbell, personal communication; 1948 air photos; Fig. 3).

Fire history prior to 1939 is not known. The 1939 air photos show some indistinct fire boundaries on the sand sheet. A large fire burnt almost the whole dune area in 1942 or 1943 (Hope-Campbell, personal communication; 1948 air photos) and is referred to here as the 1942 fire (Fig. 3). Many trees in the burnt area survived. Since, there have been only a few very small spot fires. It is important to note that a substantial area of dunes in the west has not been burnt or cleared at least since 1939.

At present, naval and military training operations are conducted in the area, but without serious damage to the vegetation. However, in some areas vegetation is destroyed by topsoil removal operations (Fig. 3).

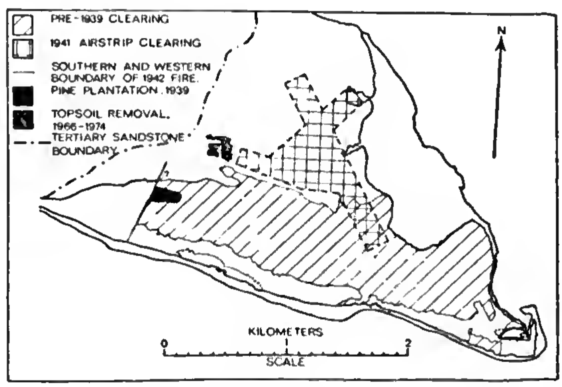

FIG. 3—Fire and clearing boundaries at Sandy Point. 1942 fire burnt most of the dune area down to the dotted lines shown. Unburnt, uncleared, triangular area in west is native vegetation on private property. Lines around coast show littoral zone.

SAMPLING

A detailed study of soils and vegetation was made in a central section of the reserve (Fig. 2) by stratified systematic unaligned sampling (Berry & Baker 1968) of one random quadrat per grid square in a 100 m x 100 m grid (50 quadrats in all). This is a 'restricted randomization' sampling procedure. Five quadrats fell in swamp or recently disturbed areas and were rejected. Two extra quadrats, 51 and 52, were done just north of the main study area to include uncleared *Eucalyptus viminalis* woodland on the sand sheet.

This study area sampled all the major coastal sand communities at Sandy Point except for the pure *E. viminalis* woodland on dunes found in the east. Although the whole reserve was not quantitatively sampled, for the convenience of future workers major vegetation boundaries over the whole reserve were mapped (Fig. 5).

SOILS

In each quadrat soil profiles were examined by augering to a depth of 2 m where practicable. Soil pH was determined in the field (CSIRO soil pH test kit) and the laboratory (Piper 1944) and the presence of $CaCO_3$ by addition of 1 M HCl.

The dune profiles are undifferentiated calcareous sands throughout (Uc 1.11 primary profile form, Table 1) for about 150 m inland from the coast. After that, non-calcareous surface horizons occurred. On the landward dunes Uc 4.21 soils occurred (Table 1), being separated from the Uc 1.11 soils by some rather indeterminate ones intermediate between these two principal profile forms. Such intermediate soils, with non-calcareous topsoils but little other profile development, are referred to hereafter as transitional soils. All the dune soils examined were

TABLE 1
SOIL PROFILE DESCRIPTIONS
(Representative examples of the three main soil groups)

1. Uc 1.11 soil. Leptospermum laevigatum open-scrub

Depth (cm)	Horizon	Description*	Laboratory pH	Presence of $CaCO_3$
0 - 8	A_1	Dark brown sand	8.1	+
8 - 60	C	Brown sand	8.6	+
60 - 92	C	Yellowish brown sand	8.1	+

2. Uc 4.21 soil. Banksia integrifolia woodland

Depth (cm)	Horizon	Description	Laboratory pH	Presence of $CaCO_3$
0 - 10	A_1	Dark brown sand	5.8	-
10 - 35	A_2	Brown to yellowish brown sand	6.2	-
35 - 40	B	Brownish yellow sand	6.6	-
40 - 55	C	Yellowish brown sand	8.5	+

3. Uc 2.33 soil. Leptospermum juniperinum heath

Depth (cm)	Horizon	Description	Laboratory pH	Presence of $CaCO_3$
0 - 8	A_1	Very dark gray sand with organic matter	4.5	-
8 - 85	A_2	Light gray sand	4.4	-
85 - 90	B	Dark reddish brown hardpan mottled with yellowish red	4.3	-

* All soil colours as Munsell colours on moist sample

underlain by non-coherent calcareous sand; no calcareous hardpans were observed.

The soils of the sand sheet were non-calcareous and acidic throughout, with sandy horizons over humus and iron oxide hardpans (Uc 2.33 primary profile form, Table 1).

In general terms, in moving inland from the coast in such coastal sand country, we expect age of deposit and degree of leaching to increase, causing soil pH, $CaCO^{3}$ content and general soil fertility to decrease (Bird 1965, Burges & Drover 1953, Turner, Carr & Bird 1961), and this is the pattern found here. Detailed studies in areas of similar climate and soil parent materials suggest that total soil phosphorus declines with increasing age of deposit and decreasing $CaCO_3$ content (Dimmock 1957, Parsons 1966, Parsons & Specht 1957). However, the high alkalinity of the young $CaCO_3$ and phosphorus rich dunes can cause serious lime-chlorosis problems for a number of native plant species (McCoy & Parsons 1974, Parsons & Specht 1967).

In well-drained sandy soils in the climate of the present study area, soil chloride levels are almost certainly negligible, as reported from similar areas (Dimmock 1957).

Throughout the period of the study, no water-tables were encountered in any of the soil holes.

VEGETATION

In circular quadrats of 4 m radius (which consistently sampled more than 80% of the species present in a stand) located as described previously, cover of all vascular plant species was subjectively estimated to the nearest 10% (cover as gross canopy coverage, Daubenmire 1968). As an initial analysis of rather heterogeneous data, the polythetic agglomerative analysis, HGROUP (Veldmann 1967; also called Ward's Method) was used (Fig. 4).

All quadrats dominated by *Leptospermum laevigatum* are grouped together and divided (with two exceptions) into immature stands (Group 1 in Fig. 4) and mature ones not burnt in 1942 (Group 2; Table 2). Nearly all the sand sheet quadrats are grouped and divided into *L. juniperinum-L. myrsinoides* heath (Group 3) and *Eucalyptus viminalis* woodland plus one heath quadrat (Group 4; Table 2). Although the *E. viminalis* woodland described from Uc 2·33 soils in Table 2 is from an area not cleared in 1941, *E. viminalis* woodland does also occur at present on the cleared area.

Finally, the remaining dune quadrats are grouped and divided into

(1) *Banksia integrifolia* open-forest, lacking *E. viminalis* and with *B. integrifolia* cover values greater than 60% (Group 5).

(2) *B. integrifolia* woodland, *B. integrifolia* cover values less than 60%, lacking *E. viminalis*, cover values for *Pteridium esculentum* greater than 90% and for *Scutellaria humilis* from 0 to 50% (Group 6).

(3) As for Group 6, but sometimes with sparse *E. viminalis*, cover values for *P. esculentum* from 10-90% and for *S. humilis* greater than 80% (Group 8).

Groups 5, 6 and 8 form a complex mosaic on the landward dunes which could not be accurately mapped, even at large scales. If grouped

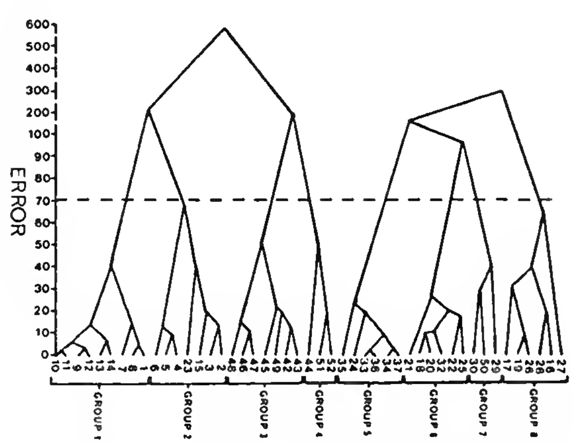

FIG. 4—Dendrogram from HGROUP classification of quantitative vegetation data (cover values). Note change of scale at 100 error units. Error scale gives measure of within-group diversity.

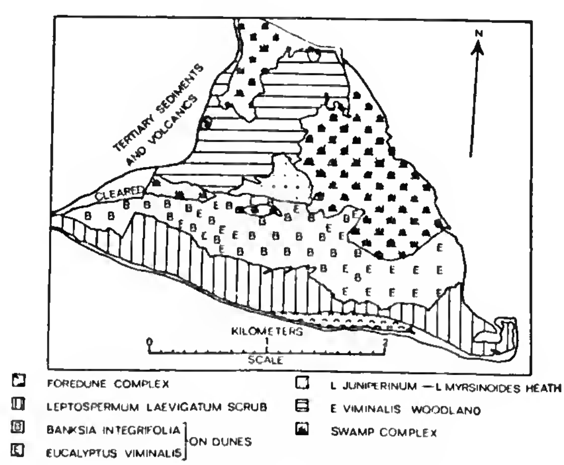

FIG. 5—Major vegetation boundaries in Sandy Point Naval Reserve in 1973 (from air photos). *Banksia integrifolia—Eucalyptus viminalis* on dunes refers to woodland.

TABLE 2
PLANT COMMUNITY DESCRIPTIONS
UD = undestory dominant. 'Differential species' used in the sense of Bridgewater (1971).

Group and its differential species	Sub-group and its differential species	Other common species	Edaphic range	Soil pH*	Notes
Leptospermum laevigatum (*L. laevigatum*, *Senecio lautus*)	*L. laevigatum* open-scrub (*Acacia sophorae*, *Cotula australis*)	*Scirpus nodosus*	Uc 1.11	8.1 - 8.2	Unburnt in 1942
	L. laevigatum closed-scrub (*Centaurium pulchellum*, *Caladenia latifolia*)	*Clematis microphylla* *Leucopogon parviflorus*	Uc 1.11 and transitional	6.5 - 8.0	Burnt in 1942
Banksia integrifolia (*Geranium solanderi*, *Scutellaria humilis*)	*B. integrifolia* woodland (none)	*L. parviflorus* *Pteridium esculentum* UD	Transitional and Uc 4.21	5.8 - 6.5	
	B. integrifolia open-forest (none)	*C. microphylla* *P. esculentum* UD	Transitional and Uc 4.21	5.8 - 6.5	*Banksia* regeneration from 1942 fire
L. juniperinum (*L. juniperinum*, *L. myrsinoides*)	*L. juniperinum* - *L. myrsinoides* closed-heath (*Aotus ericoides*, *Epacris impressa*)	*Amperea xiphoclada* *Monotoca scoparia*	Uc 2.33	4.0 - 4.5	Cleared in 1941
	Eucalyptus viminalis woodland (*Gahnia radula*)	*L. juniperinum* UD *Lepidosperma concavum*	Uc 2.33	4.4	Not cleared

* Laboratory pH of surface soil

as one unit, this and all the other communities recognized by HGROUP are usually recognizable on air photos and so were used to construct a vegetation map (Fig. 5). Groups 6 and 8 have been combined on Table 2.

Group 7 is a heterogeneous, ecotonal group of one landward dune quadrat and two seaward sand sheet quadrats all with *E. viminalis* dominant and high *P. esculentum* values (Fig. 4).

Foredunes were absent from the study area, having been removed by wave action. At Sandy Point itself they carry *Ammophila arenaria-Spinifex hirsutus* open-grassland with *Cotula australis*. Moving inland, this community is replaced by low shrubs of *Acacia sophorae* and *Leptospermum laevigatum* and then by *L. laevigatum* open-scrub as is found behind the beach in the main study area.

The *L. laevigatum* dominates either an open-scrub or closed-scrub depending on time since burning (Table 2, Pl. 15). To landward, this is replaced by woodlands usually dominated by *Banksia integrifolia*, but sometimes with *Eucalyptus viminalis* dominant or co-dominant. It is hard to know to what extent differential clearing has determined these differences in tree dominance. Scattered young stands of *B. integrifolia* (seedling regeneration from the 1942 fire) have low open-forest structure (Table 2).

A floristically similar dune sequence has been described from Corner Inlet (Turner, Carr & Bird 1962). The factors determining these zonations are not well understood. Particularly at the seaward edge, instability of sand and exposure to wind and salt-spray are likely to be important. To landward, soil effects may become significant. For example, at Sandy Point *E. viminalis* is absent from sands which are calcareous right to the surface. Work elsewhere shows that, in Victoria, eucalypts are almost completely absent from such calcareous beach sands (except for occasional stands of *E. ovata*), probably because they are prone to lime-chlorosis on highly alkaline soils (Parsons & Specht 1967, McCoy & Parsons 1974). In contrast, *B. integrifolia* is common on calcareous beach sands elsewhere (Parsons 1966).

The relative distribution of *L. laevigatum* and *B. integrifolia* may depend not only on differential tolerance to factors like salt spray, but also on fire effects. The *L. laevigatum* closed-scrub originating from the 1942 fire contains dead *B. integrifolia* trees; these and the air photos suggest that *L. laevigatum* has spread inland at the expense of *B. integrifolia* as a result of the 1942 fire. Throughout the dune area studied, there are no strong vegetation differences between crests and swales.

Further inland, virtually all of that part of the sand sheet adjoining the dunes was cleared for an airstrip in 1941. This regenerated as closed-heath (air photos), but at present some parts are of woodland structure, while in the remainder, scattered trees, especially of *E. viminalis*, are now clearly emergent so that the structure is transitional to woodland (but referred to here as heath for convenience). The sand sheet markedly differs from the dunes both edaphically and floristically (Table 2).

It is clear that all the heath area was formerly *E. viminalis* woodland (1939 air photos) which still occurs adjacent to it in topographically and edaphically similar sites. An unusual feature of the heath area is the presence of some emergent young trees of *Banksia integrifolia*, a species not known from highly leached sands elsewhere (Parsons 1966). This occurrence may relate in some way to fire or clearing effects, as may the presence of a patch of *Leptospermum laevigatum*.

In moving from the dunes to the sand sheet, species like *Scutellaria humilis*, *Leucopogon parviflorus* and *Galium australe* drop out entirely and species exclusive to the sand sheet like *Leptospermum juniperinum*, *L. myrsinoides* and *Epacris impressa* become common. This marked change in floristics is likely to be caused at least partly by the greater infertility of the more strongly leached and more acidic sand sheet.

DISCUSSION

Geologically, the area has potential for chronosequence studies of plant succession on coastal sand like those of Burges and Drover (1953) and Olson (1958), as it has up to 18 parallel dunes almost certainly representing a time sequence and showing corresponding progressive changes in soil development. However, the time sequence of vegetation has been badly disrupted by differing histories of both fire and clearing which would make reliable detailed interpretation impossible. The soil development chronosequence appears intact and is certainly worth further study.

Clearly, there is a sharp discontinuity in age and corresponding soil properties from the dunes to the older, more strongly leached and more acidic sand sheet, and this corresponds exactly to the normal distinction between 'New Dunes' and 'Old Dunes' (and sand sheets) made elsewhere in southern Australia (Bird 1965, Parsons 1966, Turner, Carr & Bird 1962).

Considering the probable successional sequence on the 'New Dunes', the vegetation zones described here are broadly similar to those elsewhere in Victoria (Parsons 1966, Turner, Carr & Bird 1962). The precise successional relationships between *Banksia integrifolia* and *Eucalyptus viminalis* are not clear from these studies or the present one (because of fire and clearing effects). All that can be said is that the apparent dune climax at Sandy Point is a woodland in which either *B. integrifolia* or *E. viminalis* or both are dominants. Considering a longer time scale, it could be argued that continued leaching over long periods will convert the dune soils into the highly acidic type found on the sand sheet. In this case, the long term 'climax' would be *E. viminalis* woodland with a sclerophyllous under-storey.

A major finding of the work is that the whole reserve has suffered much more from human disturbance than has previously been thought. Clearing has modified about half of the total sand sheet area and about two-thirds of the dune area. Although there has obviously been a lot of tree regeneration since the 1939 air photos, it is not known to what extent this has reproduced the original proportions, distribution and density of tree species. Further, clearing is likely to have contributed very greatly to the high density of *Pteridium esculentum* in most of the *Banksia integrifolia* and *Eucalyptus viminalis* communities on the dunes, and this increase in *P. esculentum* may have had major effects on other under-storey species. It is significant that *P. esculentum* density where such communities are unburnt and uncleared in the west is generally much lower than in the cleared areas. Such clearing effects need to be carefully borne in mind in future biological work, both in comparisons within the reserve and in extrapolation to other areas. Also, they help to explain the floristically atypical nature of the heath at Sandy Point noted by Calder (1972).

The present study makes this reserve one of the very few (perhaps the only) areas of coastal vegetation in Victoria with a reasonably well-documented fire and clearing history. As such, and because there is a sizeable area of vegetation on private property in the west apparently never cleared and not burnt since before 1939, the area would be highly suitable for studies of the effect of fire on the regeneration of *Leptospermum laevigatum*, *Banksia integrifolia* and *Eucalyptus viminalis* communities, by comparing the nature and age structure of existing stands. Such considerations, along with the size of the area, its proximity to Melbourne and its diversity of animal species (Ahern 1974, Davis & Reid 1974) make it an invaluable biological resource.

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REFERENCES

Ahern, L. D., 1974. A trapping study to determine the habitat utilization and biology of small mammals at Sandy Point, Westernport, with particular emphasis upon *Sminthopsis leucopus* (Gray). B.Sc. (Hons.) Thesis, La Trobe University.

Australia: Bureau of Meteorology, 1968. *Climatic Survey Region 10—Port Phillip Victoria.* Bureau of Meteorology, Melbourne.

Berry, B. J. L. & Baker, A. M., 1968. Geographic sampling. In *Spatial Analysis: A Reader in Statistical Geography.* Ed. B. J. L. Berry and D. F. Marble. Prentice-Hall, New Jersey.

Bird, E. C. F., 1965. The geomorphology of the Gippsland Lakes. *Aust. Nat. Univ. Dept. Geog. Publ.* No. G/1.

Bridgewater, P. B., 1971. Practical application of the Zurich-Montpellier system of phytosociology. *Proc. R. Soc. Vict.* 84: 255-262.

Burges, A. & Drover, D. P., 1953. The rate of podzol development in the sands of the Woy Woy district, N.S.W. *Aust. J. Bot.* 1: 83-94.

Calder, W. B., 1972. The natural vegetation pattern of the Mornington Peninsula, with special reference to the genus *Eucalyptus.* M.Sc. Thesis, University of Melbourne.

Champion, R., 1974. *Westernport Region Conservation Survey.* Conservation Council of Victoria, Melbourne.

Daubenmire, R., 1968. *Plant Communities.* Harper & Row, New York.

Davis, W. A. & Reid, A. J., 1974. Victorian Ornithological Research Group. Westernport report no. 1; part 1. *Vict. Nat.* 91: 212-222.

Dimmock, G. M., 1957. The soils of Flinders Island, Tasmania. *CSIRO Aust. Div. of Soils Soil Land Use Ser.* No. 23.

Jenkin, J. J., 1962. The geology and hydrogeology of the Western Port area. *Victoria, Dept. Mines Underground Water Investigation Rept.* No. 5.

McCoy, A. & Parsons, R. F., 1974. Lime chlorosis of calcifuges on Australian coastal sands. *Flora (Jena)* 163: 37-45.

Northcote, K. H., 1971. *A Factual Key for the Recognition of Australian Soils.* 3rd ed. Rellim Technical Publications, Adelaide.

Olson, J. S., 1958. Rates of succession and soil changes on southern Lake Michigan sand dunes. *Bot. Gaz.* 119: 125-170.

Parsons, R. F., 1966. Soils and vegetation at Tidal River, Wilsons Promontory. *Proc. R. Soc. Vict.* 79: 319-354.

——— & Specht, R. L., 1967. Lime chlorosis and other factors affecting the distribution of *Eucalyptus* on coastal sands in southern Australia. *Aust. J. Bot.* 15: 95-105.

PIPER, C. S., 1944. *Soil and Plant Analysis.* Interscience, New York.

SEDDON, G., 1974. A landscape assessment of the southern Mornington Peninsula, Victoria. *Univ. Melbourne Centre for Environmental Studies Publ.* No. 2.

SPECHT, R. L., 1970. Vegetation. In *The Australian Environment.* Ed. G. W. Leeper. 4th ed. CSIRO, Melbourne.

TURNER, J. S., CARR, S. G. M. & BIRD, E. C. F., 1962. The dune succession at Corner Inlet, Victoria. *Proc. R. Soc. Vict.* 75: 17-33.

VELDMAN, D. J., 1967. *Fortran Programming for the Behavioural Sciences.* Holt, Rinehart & Winston, New York.

VICTORIA: GEOLOGICAL SURVEY, 1967. Western Port one mile to one inch geological map. Geological Survey of Victoria, Melbourne.

WILLIS, J. H., 1970. *A Handbook to Plants in Victoria.* Vol. I. 2nd ed. Melbourne Univ. Press, Melbourne.

———, 1972. *A Handbook to Plants in Victoria.* Vol. II. Melbourne Univ. Press, Melbourne.

APPENDIX 1 (pages 91-94)

Vascular plant species recorded from sand dunes and sand sheets at Sandy Point Naval Reserve and adjoining private property (see text). c = common, f = frequent, r = rare.

1 = *Leptospermum laevigatum* scrub on dunes, 2 = *Banksia integrifolia* + *Eucalyptus viminalis* woodland and forest on dunes, 3 = *L. juniperinum-L. myrsinoides* heath on sand sheet, 4 = *E. viminalis* woodland on sand sheet, 5 = *Poa labillardieri* grassland on low-lying sand area with restricted drainage (see Fig. 2). * = alien species. *Daucus glochidiatus,* also present in 1 and 2, is not included.

Appendix 1

	1	2	3	4	5
PTERIDOPHYTA					
ASPIDIACEAE					
Polystichum proliferum		r			
ASPLENIACEAE					
Asplenium flabellifolium		r			
DENNSTAEDTIACEAE					
Pteridium esculentum	r	c	c	f	
POLYPODIACEAE					
Microsorium diversifolium		r			
SELAGINELLACEAE					
Selaginella uliginosa			r		
GYMNOSPERMAE					
PINACEAE					
**Pinus radiata*		r			
MONOCOTYLEDONEAE					
ARACEAE					
**Zantedeschia aethiopica*		r			
CYPERACEAE					
Baumea juncea					f
Gahnia radula				f	
Lepidosperma concavum		c	f	c	
L. gladiatum	r	r			
Scirpus antarcticus		r			
S. nodosus	c	c	r	r	
IRIDACEAE					
**Homeria breyniana*		r			
CENTROLEPIDACEAE					
Centrolepis strigosa		r			
JUNCACEAE					
Juncus pallidus		f			f
J. vaginatus					f
Luzula meridionalis Nordenskiold	r	r	r		

	1	2	3	4	5
LILIACEAE					
**Asparagus asparagoides*		r			
Dianella revoluta		r	r		
Lomandra longifolia		r			r
ORCHIDACEAE					
Acianthus exsertus	r	r			
A. reniformis	f	f			
Caladenia latifolia	f				
Corybas diemenicus		r			
Dipodium punctatum		r		r	
Microtis unifolia		r			
Pterostylis longifolia		r		r	
POACEAE					
**Agropyron juncea*		Foredunes			
A. scabrum		f			
**Aira caryophyllea*		f		f	
Agrostis avenacea		f		f	f
**A. tenuis*		r			
**Ammophila arenaria*		Foredunes			
**Anthoxanthum odoratum*		r			
**Briza minor*		r		r	
**Bromus* sp.		r			
**Catapodium rigidum*	f				
Danthonia pilosa		f			
D. setacea		f		f	
Dichelachne crinita		c		c	
Distichlis distichophylla	r				r
Echinopogon ovatus		c			
Hemarthria uncinata					c
**Holcus lanatus*	f	f			f
Imperata cylindrica		f			
**Lagurus ovatus*	f	f			
Microlaena stipoides		r			

APPENDIX 1 (*continued*)

	1	2	3	4	5
EPACRIDACEAE					
Epacris impressa			c	r	
Leucopogon parviflorus	c	c			
L. virgatus			f	r	
Monotoca scoparia		c	r		
EUPHORBIACEAE					
Amperea xiphoclada			f	r	
Poranthera microphylla		r			
FABACEAE					
Aotus ericoides			c	f	
Bossiaea cinerea			r		
B. prostrata				r	
Dillwynia glaberrima			f		
Glycine clandestina	r	r			r
Indigofera australis		r			
Kennedia prostrata		r			
**Trifolium* sp.		r			
**T. dubium*		r			
**Ulex europaeus*		r			
GENTIANACEAE					
**Centaurium pulchellum*	f	f			f
GERANIACEAE					
Geranium solanderi	f	f			f
HALORAGACEAE					
Haloragis tetragyna			f	f	
HYPERICACEAE					
Hypericum gramineum			r		
LAMIACEAE					
Mentha diemenica var. *serpyllifolia*					r
Scutellaria humilis		c			

	1	2	3	4	5
LAURACEAE					
Cassytha glabella			r		
LORANTHACEAE					
Amyema pendula		r			
MIMOSACEAE					
Acacia armata		r			
Acacia longifolia var. *sophorae*	c	f			
A. melanoxylon		r			
**A. saligna*		r			
MYRTACEAE					
Eucalyptus viminalis var. *racemosa*		f	r	c	
Leptospermum juniperinum			c	c	
L. laevigatum	c	f	r		
L. myrsinoides			c	f	
Melaleuca ericifolia					f
M. squarrosa			r		
OXALIDACEAE					
Oxalis corniculata		f			f
PHYTOLACCACEAE					
**Phytolacca octandra*		r			
POLYGONACEAE					
**Acetosella vulgaris* Fourr.		r			
Muehlenbeckia adpressa	c				
POLYGALACEAE					
Comesperma volubile		r			
PRIMULACEAE					
**Anagallis arvensis*	c	c			
PROTEACEAE					
Banksia integrifolia	r	c	f		
B. marginata			r	f	

APPENDIX 1 (continued)

	1	2	3	4	5
*Poa annua	f	f			
P. labillardieri Steud.		c			c
P. poiformis	f	r			
*Setaria geniculata		r			
Spinifex hirsutus	Foredunes				
*Sporobolus africanus		f			
Stipa compacta		c			
Themeda australis		f			
*Vulpia bromoides	r	r			
DICOTYLEDONEAE					
AIZOACEAE					
Tetragonia implexicoma	f	f			
APIACEAE					
Centella cordifolia		r			
Hydrocotyle foveolata	r				
ASTERACEAE					
Apalochlamys spectabilis	r				
*Carduus tenuiflorus		f			f
*Chrysanthemoides monolifera		r			
*Cirsium arvense					r
*C. vulgare		f			f
*Conyza bonariensis	c	c	r		c
Cotula australis	c	r			
Gnaphalium gymnocephalum DC.		r			
G. sphaericum Willd.	r				
G. luteo album	r	r		r	
*Hypochoeris radicata	r	r			f
*Inula graveolens		r			
Lagenophora stipitata	f	f			f
*Leontodon taraxicoides		f			f
*Onopordum acanthium		r			
*Senecio jacobaea		r			r
S. lautus	c	r			
S. minimus x S. lautus		r			
S. minimus		f			r
S. quadridentatus		r			
*Sonchus asper		f			f
S. megalocarpus	f				
*S. oleraceus	r	r			
BORAGINACEAE					
Cynoglossum australe		r			
Myosotis australis	f				
BRASSICACEAE					
Cakile maritima	Foredunes				
CAMPANULACEAE					
Wahlenbergia quadrifida		r			
W. stricta		r			
CARYOPHYLLACEAE					
*Cerastium glomeratum	c	f			
Colobanthus apetalus	Foredunes				
*Stellaria media	c	c			
CHENOPODIACEAE					
Rhagodia baccata	r	r			
CONVOLVULACEAE					
Dichondra repens	c	c			c
CRASSULACEAE					
Crassula macrantha	f	f			
C. sieberana	f				
DILLENIACEAE					
Hibbertia acicularis			r	r	
H. sericea				r	
DROSERACEAE					
Drosera planchonii				r	
D. whittakeri			r	r	

APPENDIX 1 (*continued*)

	1	2	3	4	5
RANUNCULACEAE					
Clematis microphylla	c	c	r		
Ranunculus pumilio	r	r			
R. sp.		r			
ROSACEAE					
Acaena anserinifolia		r			r
**Rubus fruticosus* sp. agg.		r			
RUBIACEAE					
Galium australe	f	f			f
Opercularia varia			r		
SANTALACEAE					
Exocarpos cupressiformis		r			
SCROPHULARIACEAE					
**Verbascum virgatum*					r
Veronica gracilis					r
**V. persica*		r			
SOLANACEAE					
Solanum sp.		r			
S. nigrum		r			
URTICACEAE					
Parietaria debilis	f	f			

EXPLANATION OF PLATES 14 AND 15

PLATE 14

Upper—Air photo of Sandy Point, 1939. Dark zone along southern coast is *Leptospermum laevigatum* scrub. Partially cleared zone is immediately inland of this.

Lower—Air photo of Sandy Point, 1968, showing copious tree regeneration in cleared zone since 1939.

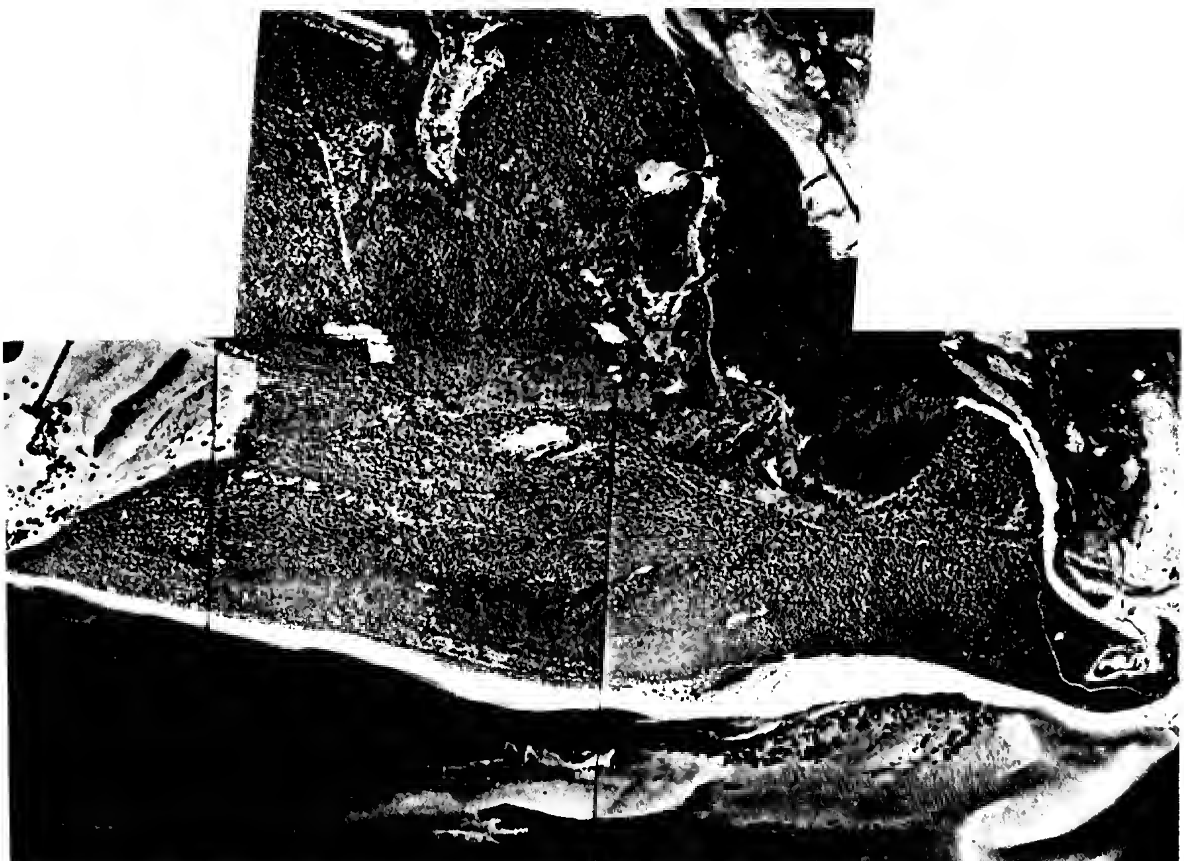
PLATE 15

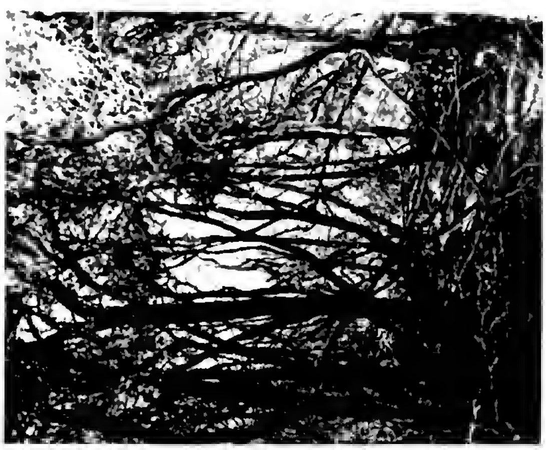
Top left—Leptospermum laevigatum scrub burnt in 1942.

Top right—Banksia integrifolia woodland with *Lepidosperma gladiatum* dominant in the understorey.

Bottom left—Leptospermum laevigatum scrub which regenerated after 1942 fire.

Bottom right—L. juniperinum-L. myrsinoides heath in foreground; trees of *Eucalyptus vimtnalis* and *Banksia integrifolia* in background.





10

Some Areas of Landslide Activity in Victoria, Australia

By E. B. Joyce* and R. S. Evans*†

Abstract: Four areas of landslide activity have been studied in Victoria, and these demonstrate the types of landslide which occur on two susceptible local rock types, Early Cretaceous arkose and mudstone, and Tertiary clay-rich sediments.

A detailed study of the geomorphological processes, rock structure and mechanisms of weathering and alteration operating in the *Windy Point area* along the Great Ocean Road, south of Lorne, has lead to an understanding of the causes of the landslide activity. The noted instability of the Early Cretaceous sediments in the Windy Point area is due to the strong jointing, the steep slopes with active undercutting by ocean and rivers, and most significantly weathering along the planar discontinuities of beds and joints. The presence of relatively fresh feldspar in the weathered arkose leads to crumbling, toppling and rock sliding rather than flow. A slope stability map of the Windy Point area has been prepared to show the most unstable areas.

At *Eastern View*, shallow compound rotational slides and flows on steep, cleared slopes occur in weathered Early Cretaceous arkose and mudstone, above the regolith-rock boundary.

Shallow earth and mud flows and deeper rotational slides occurring in the *Parwan Valley* and *Werribee Vale area* are due primarily to the high clay content of the poorly-cemented Tertiary sediments.

Flow failures and shallow slides within the soil developed on Tertiary sediments at *Lake Bullenmerri* appear to be due in part to the presence of montmorillonite from the decomposition of adjacent basaltic lava, together with a high degree of water saturation.

INTRODUCTION

The study of the stability of slopes, both natural and excavated, encompasses a broad range of scientific disciplines. A geomorphological approach has been used in this study of several areas of landslide activity in Victoria.

The *Windy Point area*, along the Great Ocean Road, south of Lorne, has been dealt with in detail as both natural slope failures and failures related to road construction are well known. The Early Cretaceous arkoses and mudstones such as occur at Windy Point appear to show a greater degree of instability than any other rock type in Victoria. Slides and flows on weathered Early Cretaceous sediments have been studied at *Eastern View*, north-east of Lorne.

The largely unconsolidated Tertiary sediments of Victoria are also noted for their instability, and two areas of landslide activity have been studied. The *Parwan Vallely* and *Werribee Vale area* shows numerous slide and flow failures in Tertiary sediments, and flow failures are also found on the north-west slope of *Lake Bullenmerri.*

The four areas studied are shown in Fig. 1. A general review of landslides in Victoria showing all known areas has been published elsewhere (Evans & Joyce 1974).

The classification of slope movements used in this study is that outlined by Nemčok et al. (1972). From a kinetic viewpoint the four broad groups of creep, sliding, flow and fall can be distinguished. Each group has been further subdivided according to the type of failure and the material involved, using criteria proposed by Coates (1970) and Hutchinson (1968). Where no genetic connotation is intended, the term 'landslip' has been used. The term 'landslide' covers those relatively rapid down-slope movements of soil and rock masses which occur primarily as a result of shear failure at the boundaries of the moving mass.

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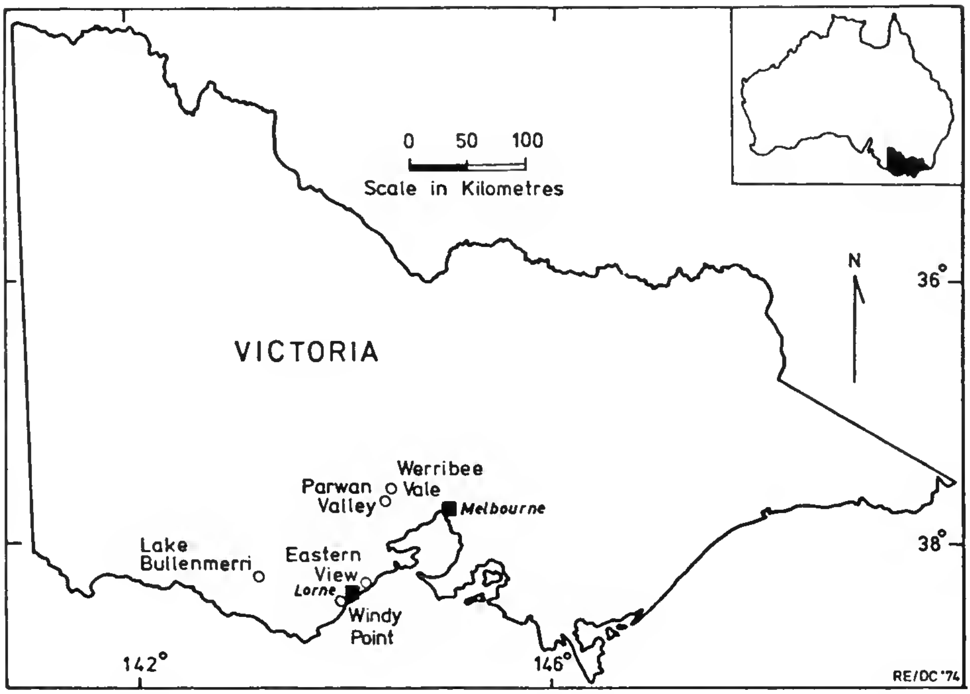

FIG. 1—Location of areas studied.

In slope stability studies there are two distinct types of failure. The material is regarded as a 'soil' where failure is governed by a surface passing through initially continuous material, but if the failure is governed by a surface developed along weak planes such as bedding or jointing, the material is considered to be 'rock'. Slope failures in the Windy Point area are essentially in rock masses, but the landslips in the three other areas studied are in 'soil'.

This article is based on a B.Sc. (Hons) Report prepared in 1973 by R. S. Evans under the supervision of E. B. Joyce in the School of Geology, University of Melbourne. R. S. Evans was responsible for the field and laboratory data.

THE WINDY POINT AREA

Landslipping throughout the Otway Ranges is well known and has long been a problem in road construction. The Windy Point area is south of Lorne, 118 km south-west of Melbourne, and is bounded by the St. George River on the north and the Cumberland River on the south, and extends an average 1·75 km inland from the coast (see Fig. 2). The study of the geology and geomorphology of this area, with both ancient and active landslips present, has given a better understanding of the processes and mechanisms involved.

The geology of the Lorne district has been described by Edwards (1962). This article looks more closely at factors such as weathering, and jointing. These influence the slope stability of the area, and this study leads to some conclusions on the stability of slopes on the Early Cretaceous rocks of Victoria.

GEOLOGY

The Early Cretaceous rocks of this part of the Otway Ranges consist primarily of freshwater interbedded arkose and mudstone, which have been broadly folded into a large plunging anticline during the Pliocene elevation of the Otways (Edwards 1962). The massive arkoses are strongly jointed and tend to show a regular pattern in the orientation of joints in relation to the fold axis. Several of the hills are capped with a thin veneer of Tertiary sands.

The petrology of the Early Cretaceous rocks of the Otway Ranges has been described by Edwards and Baker (1943); a brief description is included here. The main rock type is an arkose with the interbedded mudstone being far subordinate in volume.

The arkose when fresh is dark greenish-grey in colour and has a somewhat speckled appearance. Grain size analysis shows that the texture of the arkose is mainly fine sand size. Quartz

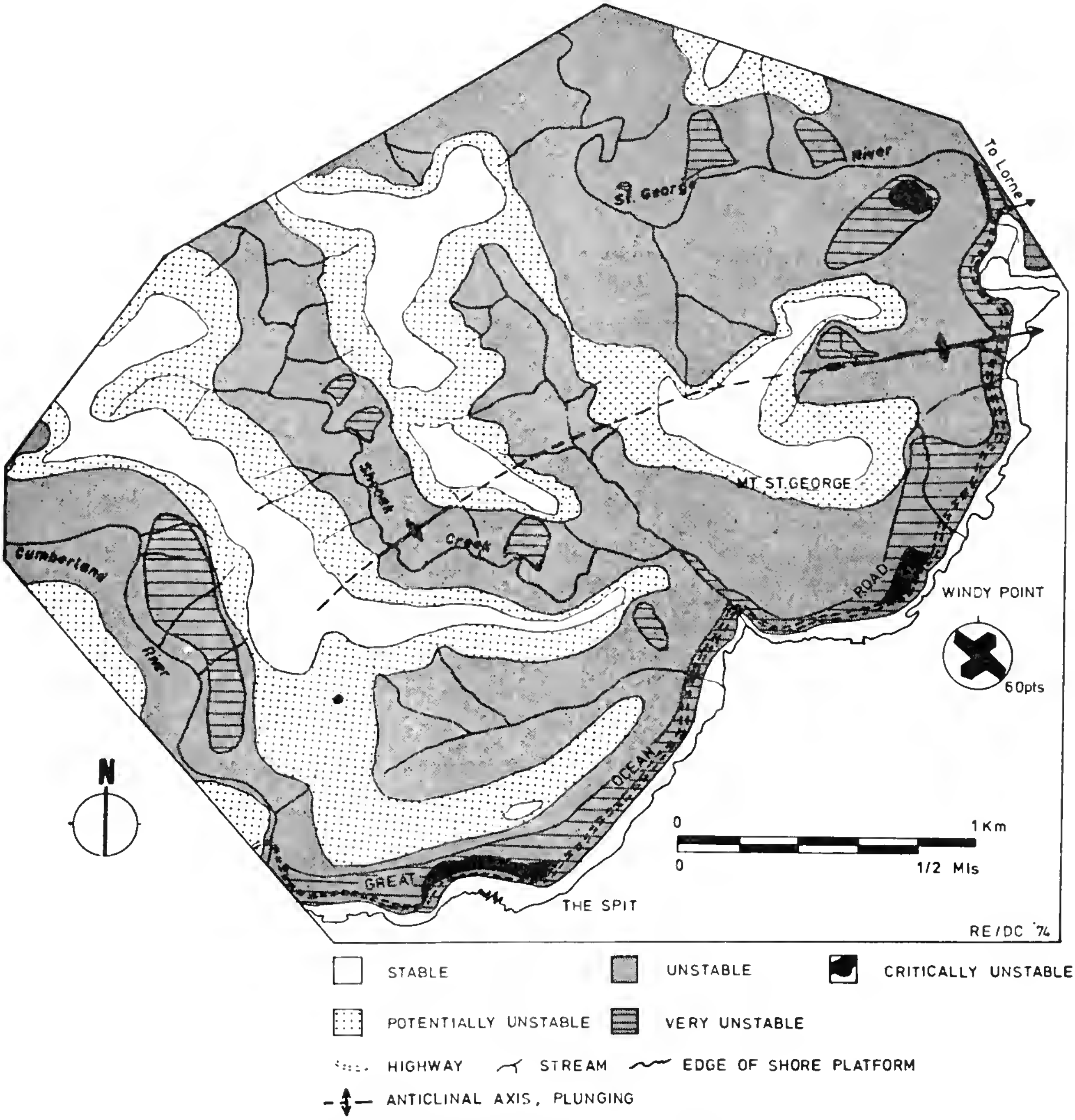

FIG. 2—Slope stability map of the Windy Point area, near Lorne, also showing the George Anticline, and a joint rosette for Windy Point area. Base Map Beec h Forest B. Department of Lands, Victoria (1957).

and feldspar make up the bulk of the rock with the feldspar being a mixture of oligoclase, and some orthoclase. The feldspars are clouded and speckled, even in the freshest samples. The cement consists of a complex assemblage of chlorite, biotite, carbonate, sericite, clay minerals and a little epidote. The greenish colour of the arkose is due to the chlorite cement. Edwards and Baker (1943) reported that kaolinite was the chief clay mineral, but x-ray diffraction analysis indicates that illite is the most abundant clay mineral in the study area, although kaolinite is present in some samples analysed.

The interbedded mudstones and shales are blue or grey-green in colour and are well-bedded, tending always to break along the bedding. These very fine-grained rocks commonly contain a mixture of sericite and clay minerals, mostly illite and kaolinite, with a little fine angular feldspar and quartz. Edwards and Baker (1943) state that the mudstone consists of clays which are liable to base exchange and contain iron-rich clay minerals, in which the bulk of the iron is in the ferrous state. Grim (1939) points out that the common clay mineral of this type is illite.

Thin black coal seams are common both within the arkose and the mudstones, but tend to be more numerous in the arkose. Edwards (1962) believed that the burial depth was between 700 m and 760 m which would imply that the associated clays are strongly overconsolidated.

Weathering and Alteration

The mechanism of breakdown of the Early Cretaceous arkose and mudstones and the products formed are very important in this study. Even in the freshest arkose, the feldspars are a little cloudy due to some decomposition; however, as weathering progresses, even to advanced stages, the feldspars remain relatively unchanged. Thin sections of very weathered samples show that breakdown occurs within the matrix, while the framework remains fresh. Grain size analysis of a weathered arkose shows that only a small proportion of the rock, that is the matrix, actually changes in grain size. Fresh arkose breaks across the grains, indicating the strength of the cement, but a weathered arkose is friable and crumbles easily, the relatively coarse feldspar grains producing a distinctly non-cohesive mass.

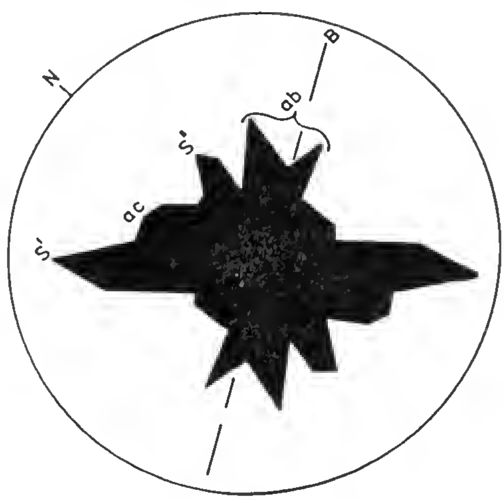

Fig. 3—Joint rosette for the George Anticline. Rosette Interval: 10°, 324 points. B is the statistical average of the strike of the fold axis.

Both the porosity and permeability should be changed by this alteration. Edwards and Baker (1943) stated that the increase in porosity with weathering arose from a volume shrinkage of the cement as the chlorite changed to limonite. The permeability should also increase as the fresh feldspar grains will tend to keep the weathered particles apart. The soil produced on the arkose tends to be immature, being little more than crumbled rock formed by the alteration of the matrix. Ferrous carbonate that may be present in some rocks is altered to limonite. Similarly, chlorite alters to limonite, producing a colour change from greenish-grey to brown.

The mudstones and shales tend to weather faster than the arkose. They produce a very cohesive brown to pale orange clay, composed largely of illite and kaolinite. The presence of thin coal seams could have a significant effect on weathering by producing organic acids which may accelerate the breakdown of cementing minerals.

Structure

A broad anticline dominates the structure of this section of the Otway Ranges. It is known as the George Anticline, as the fold axis outcrops in the exposed shore platform 200 m south of the mouth of the St. George River (Fig. 2). At this location the fold axis trends at 77° and plunges 15° east-north-east. This approximately symmetrical fold has dips on each limb of 25° to 37° and tends to show a curvature along its axis, with the south-western end of the fold axis curving to the south. This distinct warping to a trend of 36° can be seen clearly in aerial photographs of the shore platforms.

Near the Cumberland River the beds dip at low angles of approximately 5° east and the strike is approximately north, but varying greatly. Edwards (1962) and Medwell (1971) proposed a fault in this locality and the abrupt change of dip and strike suggests a fault striking at about 330° and extending up the valley of the Cumberland River. Minor high angle faults with south-easterly dip have been found in cuttings along the Great Ocean Road, for example at Windy Point.

The arkoses show extensively-developed joints, which are moderately spaced (300 mm to 600 mm), uncemented and generally planar, but some have a slight curvature. They are usually tight, but those that show some evidence of movement are slightly open. Unless significant movement has occurred, the joints generally do not have slickensides. They show a wide variation in smoothness, from quite smooth to moderately

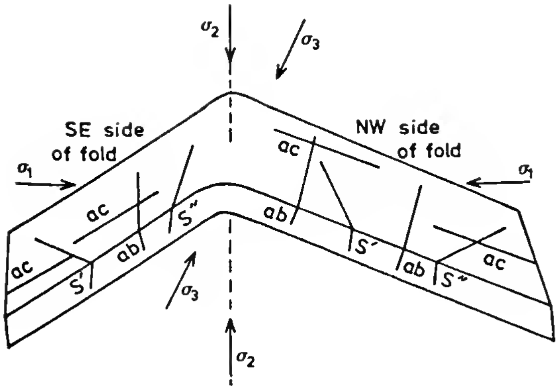

FIG. 4—Block diagram showing relationship of joints and stress directions in the George Anticline; σ_2 approximately vertical, σ_1 and σ_3 almost horizontal.

rough, with the majority smooth. A joint rosette for Windy Point is shown on Fig. 2. These joints are all very close to vertical, the majority of dips being greater than 80°.

A rosette for all joints in the George Anticline is given as Fig. 3. The statistical average of the strike of the fold axis is plotted as B and the nomenclature of the joints is that of Price (1966). The dominant joint direction is similar to Price's S′ shear joint, but the ac tension joint is obscured. Within a fold system, the ac joints normally form a distinct set with symmetrical distribution, whereas the ab joints are generally more dispersed (F. C. Beavis, pers. comm.), and this pattern is observed here. The ac joints are rarely normal to the fold axis (Turner & Weiss 1963) and this is also the case in this area.

Using a method outlined in Phillips (1971) the statistical averages of the two shear joints S′ and S″ were plotted on a stereogram and the σ_1, σ_2 and σ_3 stress directions were obtained. The axis of the intermediate principal stress (σ_2) is shown to be close to vertical, while the minimum principal stress (σ_3) is only 9° from the horizontal (Fig. 4). The stress system outlined above is that under which wrench faulting could be produced.

These results are indirect evidence for the possible existence of a wrench fault at the Cumberland River. The vertical direction of σ_2 would

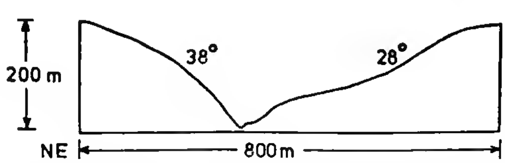

FIG. 5—Idealized valley slope profile in the Windy Point area, looking south-east, with surface slopes in degrees.

support Hills's (1940) suggestion that the Otways were once covered by Tertiary sediments which have since been largely stripped off as a horizontal σ_2 would be expected when the weight of overburden is small. This contrasts with the idea of Krause (1874), Hall (1909), and Coulson (1938), who pictured the Otway Ranges as an island in the Tertiary seas.

GEOMORPHOLOGY

Steep slopes are the most striking feature of the Windy Point area, both along the valleys and the coastline (Pl. 16B). Much of the coastline shows a well-developed shore platform, up to 125 m wide in places, with the slopes above up to 37°.

Three streams, the St. George River, Sheoak Creek, and the Cumberland River, flow into the sea in this area together with numerous small creeks and water courses. Only the St. George River has developed a significant flood plain.

The drainage pattern has two prominent directions. The slope normal to the divide of the updomed Otway Ranges has given a south-east direction of flow, and a direction parallel to the main fold axes (approximately 70°) is clearly shown by the Cumberland and St. George Rivers where massive arkose beds have formed a barrier to river erosion (Fig. 2).

The three rivers all show meandering courses, with cliffed amphitheatres adjacent to the convex sides of meanders. Undercutting associated with the development of meanders caused several ancient landslides adjacent to the St. George and Cumberland Rivers. Rapids are common on all three rivers where interbedded arkose and mudstone alternate rapidly, and gorges and several waterfalls have also developed along the rivers.

SLOPE FORM AND EVOLUTION

Degradation by river erosion is the main factor affecting slope form and evolution, and provides the trigger for mass movement which controls the evolution of the slopes. Slope failures are more common in lightly vegetated or grassed areas. All the valleys tend to show a distinct asymmetry, with the south to south-west facing slopes being approximately 10° steeper than the north to north-east facing slopes. The latter in general have a concavo-convex shape, often with undulations due to landslips on the steeper sections. The south to south-west facing slopes have a convex shape, steepening close to the valley bottom (Fig. 5).

The reason for this distinct asymmetry is not clear as there does not appear to be any difference in structure, or in the depth of weathering. However, the steeper south to south-west facing slopes tend to receive more rainfall from south-westerly storms, and, with increased saturation, they might fail more easily than the north to north-west facing slopes which receive more direct sunlight and hence are drier. On the gentler slopes short, shallow landslips are more common. Throughout the Windy Point area gulleying, tunnelling and slope wash are minor processes compared with landslip activity.

The same type of asymmetry has been studied by one of us (EBJ) in the South Gippsland Hills west of Korumburra where rocks of similar age and structure are found, but with their former dense forest cover largely cleared.

Soils

The soils developed on the arkose and mudstones of the Otway Ranges are described by Northcote (1962) as hard-setting, loamy soils with mottled yellow clayey subsoils. There is a trend through the profile from a neutral or very slightly alkaline topsoil to a distinctly acid subsoil, with pH = 5. The soil on the arkose is less well developed and not as thick as the soil on the mudstone. In general the soils are clay loams with low to medium plasticity and medium toughness.

Quaternary History

Uplift of the Otway Ranges took place during the Pliocene (Edwards 1962) and has been responsible for the development of the well-dissected topography. The domal uplift of the Otway Ranges was unlikely to have been a continuous event. The presence of hanging valleys (Edwards 1962), cobble beds (Gill 1972) and at the St. George River a high level terrace, all of which are now at an approximate elevation of 7 to 10 m above present sea level, suggest a temporary halt in uplift; however, the hanging valleys and the high level terrace might have resulted from rapid back cutting of the coastal cliffs. These features are considered unlikely to have been produced by a Quaternary higher sea level.

Following the final uplift in the Quaternary active downcutting of the rivers has continued. Evidence of minor fluctuations in sea level generally would not be preserved in this area due to the active downcutting of the streams and the retreat of the coastline by erosion. River terraces at approximately 1·5 m above present sea level are developed near the mouths of the three main rivers, and a 3 m terrace has also formed at the Cumberland River mouth. These terraces can be compared with the mid-Holocene maximum sea level of 2 m to 3 m suggested by Gill (1961) and Jenkin (1968).

Slope Stability

The early Cretaceous arkose and mudstone rocks in the vicinity of the Great Ocean Road near Lorne are well known for their slope instability, both in relation to recent road construction and to the mountainous Otway Ranges coastline which has been eroding during the Quaternary. Five slope failures have occurred in the area studied but only the one at Windy Point has achieved any notoriety. Along most of the south-east side of the Otway Ranges the bedding dips seaward, the arkose is well jointed, and comparatively thin clay strata are present; as a result the ocean-facing slopes are in a metastable state, and disturbance of their toe regions can be a trigger for failure.

The Windy Point Landslide

Windy Point is 3·2 km south of Lorne, on the Great Ocean Road (Fig. 1 and 2) and was the location of a large rock slide from 1968 until late 1971, when the slide was stabilized by cable anchoring. Windy Point is a minor headland of massive, strongly-jointed Early Cretaceous arkose, with minor thin mudstone beds which have largely decomposed to a silty clay (Pl. 16A). Two near-vertical prominent joint sets at roughly 90° to each other are present, but statistically

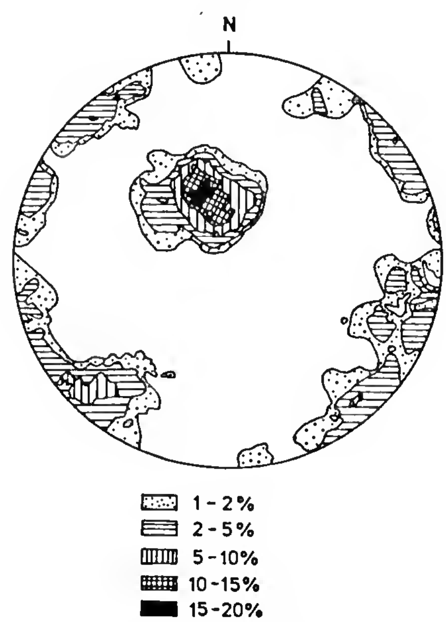

Fig. 6—Equal area projection of planar discontinuities (bedding and jointing) at Windy Point. 102 points.

there is a large range in individual values. The bedding strikes at 74° east from true north and dips at 27° south-east. An equal area projection of planar discontinuities for Windy Point shows the statistical dominance of the bedding (Fig. 6).

Windy Point is the site of an older rock slide, and removal of a small quantity of rock from its toe during road widening in late 1968 was enough to upset the delicate balance and initiate movement. Average movements of up to 2 cm per day, which greatly increased following rain, were observed high up on the slope. The opening of fissures Y-Y′ and Z-Z′ along the joints (Fig. 7 and Pl. 16A) was observed during late 1968 and 1969, with substantial movements during October 1970, when the direction of movement changed from down dip (164°) to more directly towards the road (120°), indicating an advanced state of failure. The fissures were then up to 20 m in depth, and approximately 200,000 tons of rock were moving down dip (Williams & Muir 1972).

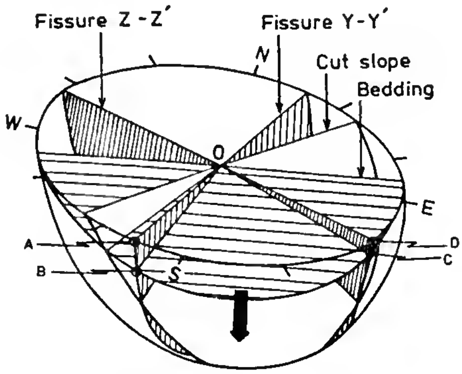

FIG. 7—Spatial diagram for Windy Point (method after John 1968). Note that the cut slope has removed support from the block bounded by A, B, C, D and O which may now slide along the bedding plane in the direction of the arrow (see also Pl. 16A).

After considering the possibility of relocating the Ocean Road, or causing the slide to fail rapidly by blasting or irrigating, it was decided that the only practicable solution was to stabilize the slide with cable-anchors. Thirteen drainage holes up to 53 m long, and inclined at 5° to 25°, were also drilled into the slope. Forty-five tensioned cable-anchors from 18 m to 43 m long provided a total anchor force of 7,740 tons and a factor of safety of 1·07. The anchors were distributed about the lower part of the slide to provide support for the entire rock mass. The shear strength of the slip plane was assumed to be frictional and since the failure conditions had just been reached it was also assumed that the angle of friction between the stable and sliding rock was equal to the dip of the slip plane, that is 27°.

Causes of Failure

The factors which contributed to the unstable situation are summarized by Williams and Muir (1972) as 'the steep natural slope which rises to a height of 330 m; the seaward (southerly) dip of about 27°; the presence of at least two thin (12 cm and 40 cm) beds of silty clay which partly underlie the massive beds of jointed sandstone and which intersect the lower part of the slope near road level. Other major factors include the two prominent and persistent sets of sub-vertical joints, the numerous minor joints at various angles; the numerous surface fissures and craters which resulted from earlier movements'.

The two main joints are the S′ shear joint and the ab joint which are found over the whole area (Fig. 3). As most of the rain water was reaching the silty clay horizons via the joints and fissures, it is quite possible that a considerable hydrostatic head was built up. Although most of the rock involved in movement is fresh, the mechanism of breakdown of the arkose influences the type of movements, with the feldspars remaining quite fresh while the cement breaks down. The weathered arkose is very friable, and upon failure the weathered rock would tend to crumble and topple, rather than failing by flow as might be expected if the feldspars produced illitic clay. The presence of coal seams, and of the swelling clay mineral chlorite (shown by X.R.D.), should also aid the breakdown, and the minor interbeds of clay would probably show a reduction in cohesion with time. Following heavy rains, water presumably percolates along fractures, and accumulates on top of the clay. Although the permeability of the clay zone would be low, it would soon absorb water until the clay zone would no longer exhibit resistance to shear. The interbedded clays at Windy Point may also have become thixotropic. On the other hand, the weathered arkose in the vicinity of the joints, being granular and having a much smaller pore space, would dilate as it became water saturated (Kerr & Drew 1965). This would provide a greatly increased load on the much weakened clay zone and the arkose would start to slide on the clay.

Another possible factor in the stability of the slopes in the Otway Ranges is the presence of high salt levels. Analysis of water samples from Sheoak Creek gave the following results: Calcium, 4 ppm; Magnesium, 3 ppm; Sodium, 19 ppm; Sulphate, 6 ppm; Chloride, 76 ppm.

Analyses from other parts of the Otway Ranges give similar results. The high content of Na^+ and Cl^- ions suggests that during storms salt spray is carried inland. The high NaCl in the rivers represents the removal of largely surface salt by normal erosion.

The soil profile in the area is distinctly acid, and persistent acid leaching depletes metal cations such as sodium and calcium (Prior & Ho 1972). The presence of NaCl would have two effects on the illitic and kaolinitic clay. NaCl is a strong electrolyte and by the law of mass action would replace exchange ions already present on the clay and cause them to flocculate, thus tending to stabilize any uniform slope. However, with a slope consisting of a well jointed arkose overlying clay, the salt could be leached down fissures into the clay horizon and by mass action effects would replace the exchangeable ions (largely H^+ and K^+), and possibly cause a contraction in effective clay volume since the replacing ion has a smaller hydrated ionic radius (R. J. McLaughlin, pers. comm.). This contraction could remove support from the overlying arkose and if it were already in a delicate state of stability it might fail. The latter situation would exist in most of the Otway Ranges, but the former situation exists on the slope at Eastern View to be described later.

Shallow slides in the Windy Point area appear to be the result of shrinking and cracking of the surface clay horizons during dry periods, and then during heavy rainfall water percolates through the cracks leading to quick swelling and weakening of the fractured soil mantle. The average soil from the area studied has a liquid limit of 48, a plastic limit of 13 and a plasticity index of 35. The relatively high liquid limit and plasticity index is a reflection of the high illite and chlorite content.

Slope Stability Map

Methods of prevention of slope failures should be applied to the most unstable slopes in an area. In an attempt to assess the relative stability of slopes in the area studied, a 'Slope Stability' map has been devised (Fig. 2). 'Slope Category' maps are of limited value as they depict only one of the factors influencing slope failures. Other representations of the stability of an area (e.g. Erskine 1973) depict only what has already occurred, and do not allow any prediction of future movement.

The method used in preparing the slope stability map was to look at the main factors influencing slope failures and then assess their relative importance in a simple quantitative way. Appendix I shows the criteria and method used in the construction of the map. Any slope stability map will unfortunately be subjective. The use of whole numbers is an attempt to remove at least part of the subjectivity, while still remaining relatively simple.

The value of the map is that anyone not familiar with the area can see at a glance which areas are the most unstable and hence require preventive action. For example, the section of the Great Ocean Road at The Spit which has been rated critically unstable on Fig. 2 is shown in Pl. 16B. If inadequate criteria are used or an area is poorly assessed some unstable areas may of course remain undetected.

The criteria used for the Windy Point area should be applicable to most of the Otway Ranges where similar geological and geomorphic conditions exist. Different criteria would be needed for other areas.

Summary

Natural slope failures and failures due to road construction occur in the Windy Point area. The Early Cretaceous arkose and mudstone is strongly jointed, with steep slopes, and weathers along bedding and joint planes leading to crumbling, toppling and rock sliding. Stabilization of slopes may be expensive as at Windy Point where $A200,000 has been spent. Preparation of a slope stability map can help in delineating areas of possible failure.

EASTERN VIEW

At Eastern View, 110 km south-west of Melbourne (Fig. 1) a slope shows a number of mass movement features which are not present at the forested Windy Point area. The slope was cleared near the end of the last century, and numerous failures have taken place, both on the main north-east-facing slope which has a stream below, and on the steep slope facing the ocean and the Great Ocean Road.

Geological Setting

The Early Cretaceous mudstone and arkose underlying the slopes has been completely weathered to a silty clay for a depth of 3 to 4 m. Slope failures are generally quite shallow and take place in the weathered mantle above the rock. Landslip activity is the main process of erosion acting on the slopes, but gullying and piping as well as some flows are active on the lower part of the north-east-facing slope.

Landslips Present

Most slope failures at Eastern View are shallow compound rotational slides, with a D/L ratio ranging from 1/60 to 1/30 (D = depth to failure surface from original surface, L = length; Crozier 1973). Nevertheless, most failures have an element of flow.

There is a high correlation between slope angle and slide concentration. Failures are most common on slopes greater than 16°, which appears to be the critical angle of slope failure. The morphology of the slides indicates rotation, and a major rotational slide has occurred on a slightly steeper part of the north-east-facing slope (Pl. 17A). The lower part of the slope first failed in 1913, the removal of support for material higher up the slope giving a non-equilibrium situation. As each successive slide worked its way up the slope further removal of support took place, and the slide reached nearly to the top of the slope in 1952. Since then reslipping of the earlier slides has occurred, with the prominent slide shown in Pl. 17A taking place in 1971. Altogether five cycles of movement can be determined.

The ocean-facing slope has a multiplicity of flows and rotational slides. Road construction at the foot of the slope is clearly a major contributing factor, but most of the slides took place one night in 1952 when 230 mm of rain fell. On slopes greater than 20°, which are often up to 30°, a regular succession of terracettes is developed. Terracettes tend to be on the edges of previously slipped areas where the unweathered rock is relatively close to the surface, and have a stabilizing influence, preventing larger rotational slides occurring.

SUMMARY

Shallow compound rotational slides and flows at Eastern View are due to steepening of slopes by streams, the ocean and road construction. Clearing of the land and grazing by cattle have also favoured landslips, and movement has often been triggered by rainfall.

PARWAN VALLEY AND WERRIBEE VALE AREA

The Parwan Valley and Werribee Vale area is near Bacchus Marsh, which is approximately 50 km west-north-west of Melbourne (Fig. 1). It represents two of the worst sites of mass movement and other types of erosion to be found in Victoria. Particularly in the Parwan Valley gully erosion, piping and sheet erosion are the main

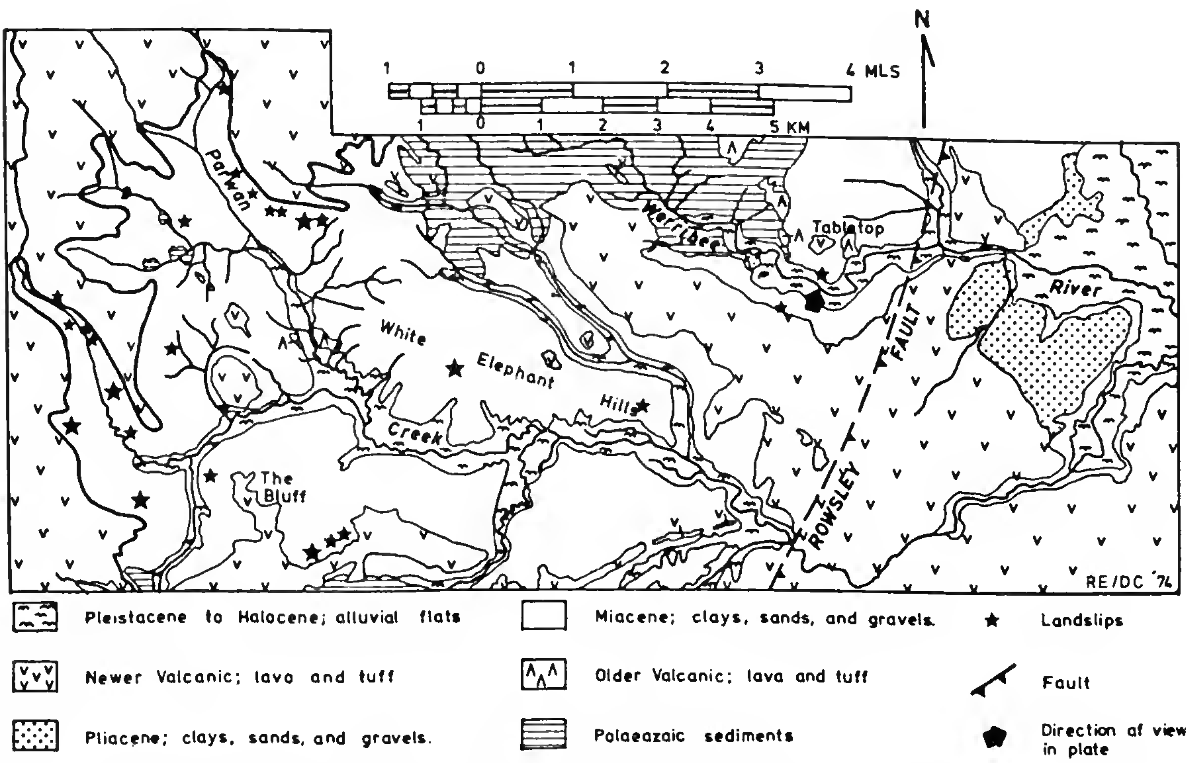

FIG. 8—Geological map of the Parwan Valley and Werribee Vale area (after Forbes 1948) showing landslips in Miocene sediments mapped from air photos and field reconnaissance (see also Pl. 17B).

processes of degradation but landslips of various ages are common also.

Geological Setting

Unconsolidated Miocene sediments underlie a relatively thin cover of Newer Volcanic basaltic lava flows (Fig. 8). These horizontally-bedded fluviatile Tertiary sediments vary greatly in composition and include incoherent boulder deposits, sands and clays, ferruginous sandstones and mudstones, and almost pure limonite. The sediments are very poorly cemented and their resistance to erosion is weak. The overlying basalt forms a protective cap but the easy erodibility of the sediments leads to undercutting of the basalt capping.

Movement along the Rowsley Fault scarp in the late Pliocene and Pleistocene has elevated the headwaters of the streams to the west by up to 170 m (Forbes 1948), and deep valleys have been cut by the Parwan and Yaloak Creeks, and the Werribee River (Fig. 8).

Landslips Present

Landslips are playing an important part in the enlargement of the Parwan Valley and their influence is seen in the steep, broken, white-streaked, and unstable slopes along the valley wall. Landslips are particularly abundant along the steeper cliff sections below the basalt flows. Forbes (1948) believes that the residual ridges and hills occurring within the valley (some of them capped with basalt which is at a lower level than that of the surrounding plain) probably represent landslipping on a grand scale. Rotational sliding around basalt residuals is common.

The main soil type in the Parwan Valley is a sandy clay loam with a columnar and blocky structure which permits the entry of water and thus facilitates erosion. X-ray diffraction shows that besides quartz and feldspar, there is much kaolin and some illite present. The predominance of kaolin is shown in the low liquid limit of 36, a plastic limit of 20 and thus a plasticity index of 16. These results agree with the observations that slipping (usually consistent with a higher liquid limit) is subordinate to gully erosion and piping. A viscosity test performed on the Miocene clay showed that it is fairly thixotropic, and once the heavily saturated mass has started to move there is little resistance to retard its motion, and so flows as distinct from slides are predominant.

Most slips in the Parwan Valley are shallow, elongate earth and mud flows with an average D/L ratio of 1/40. They are generally not very recent and have a characteristic rapidly-undulating surface expression with an indistinct head scarp and toe.

A very deep rotational slide is present on the flanks of Table Top in the Werribee Vale area (Pl. 17B and Fig. 9). The slide has a D/L ratio of 1/11 and is in Miocene sands and gravels with a lateritized 'ironstone' capping. In part the slide is due to the presence of an old concrete-lined irrigation channel constructed on the slope in the early part of the century. Approximately 100 m of the channel were carried away in the slide (Harding 1952). The main trigger was exceptionally heavy rain that fell during 1952. Several cycles of sliding are evident although the whole slide would have occurred quite rapidly. The steep scarp is now being heavily eroded by piping. Just to the west of this slide is a large amphitheatre-shaped region caused by several old deep-seated rotational slides which have produced a characteristic 'bumpy' area.

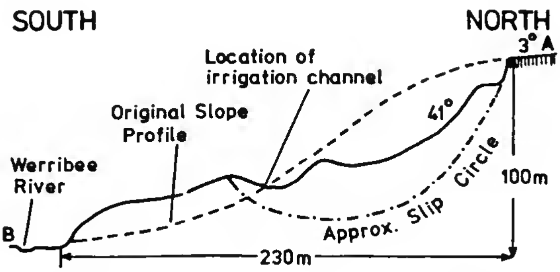

Fig. 9—Sketch cross-section of rotational landslide near Table Top, Werribee Vale, surveyed by pacing and Abney level (see Fig. 8 for location). Vertical shading indicates lateritized surface of Miocene sediments; surface slopes in degrees. For A-B see Pl. 17B.

More landslips occur in the upper part of the Parwan Valley than in the part closer to the Rowsley Fault (see Fig. 8). This appears to be related to the grain size of the sediments. Clay and silt-sized sediments occur to the east closer to the Rowsley Fault, and these erode mainly by sheet wash. In contrast, clay and sand-sized sediments in the upper part of the valley fail largely by flowing, as water can enter the sediments more easily and saturate them.

The burrowing work of rabbits, overgrazing and the removal of trees and much natural vegetation are significant factors causing slipping, gullying, piping and sheet erosion.

Summary

Shallow earth and mud flows often up to 300 m long are common on slopes greater than 25° in the Parwan Valley, and several deep rotational

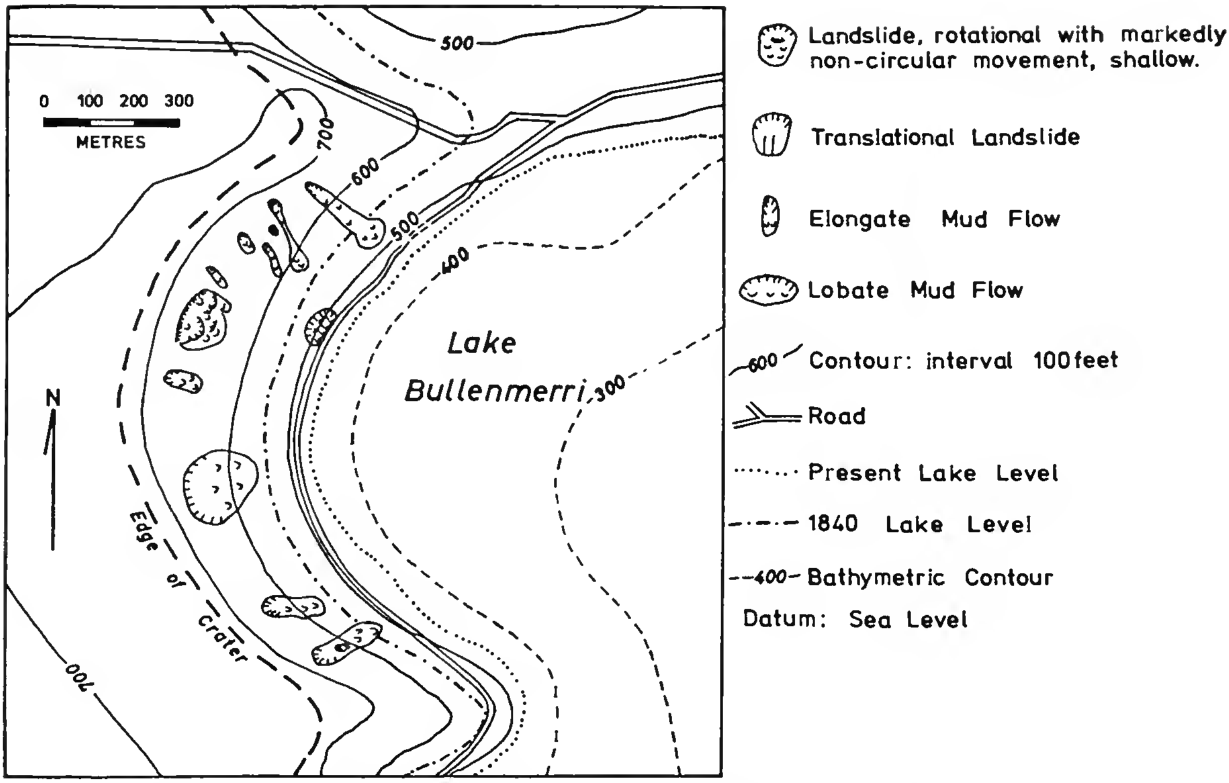

FIG. 10—North-west corner of Lake Bullenmerri crater showing location of landslips in September 1973 based on field reconnaissance. Base map, contours and lake levels after Currey 1970).

slides are also found in the area. The clay-rich poorly-cemented Tertiary sediments also erode readily by gullying, piping, and in some areas sheet erosion, and the effect of European settlement has been to increase the rate of erosion.

LAKE BULLENMERRI

Lake Bullenmerri is a lake in a volcanic crater near Camperdown, nearly 200 km west-southwest of Melbourne (Fig. 1). The crater was formed by a late Quaternary eruption of maar type, and is part of the Newer Volcanic province of south-eastern Australia (Ollier & Joyce 1973). Since the slopes were cleared of vegetation around the turn of the century (E. D. Gill, pers. comm.) the upper part of the north-west crater wall has been degrading by land slipping. A complete spectrum of different types of shallow landslip is present (Fig. 10).

GEOLOGICAL SETTING

The walls of the volcanic crater above Lake Bullenmerri consist of horizontal marine Oligocene siltstone and sandstone capped by approximately 20 m of Newer Volcanic lavas and tuffs. The slope developed on the sediments is predominantly concavo-convex with a relatively sharp break of slope at the base of the Newer Volcanic capping. The soil on the sediments is a silty clay loam with a depth of 1·5 m. Fragments of sedimentary and volcanic rock are common. Sliding is largely confined to slopes steeper than 20° on Tertiary sediments. A series of terraces indicate former water levels, with one prominent terrace about 15 m above present lake level.

LANDSLIPS PRESENT

Bullenmerri is a good example of what at first glance appears to be a few landslips, and a chaotic spread of slipped material, which, with more detailed examination, reveals an interconnected complex of numerous slides and flows. A number of different types of slips are present, the distinction being the D/L ratio. Shallow slips from 0·5 m to 1 m deep are either lobate or elongate mud flows, with flow occurring in the heavily oversaturated A and B soil horizons. One elongate mud flow is approximately 125 m in length but only 8 m wide, with a depth of 0·5 m. It has a D/L ratio of 1/250. These elongate mud flows occur on the relatively steep slopes of 24°, while the lobate mud flows are found on gentle slopes of less than 10°. Shallow non-circular rotational slides occurring on the steep slopes have a D/L ratio of 1/15.

In 1840 the lake level was 554 feet (Fig. 10), and in 1918 513 feet (Currey 1970). Three slides are below the 1840 lake level and field observations indicate that two of these slides are older than slides higher on the slope. Thus 1840 is a maximum limit to the age of sliding and most slides are likely to be much younger.

Three broad periods of landslip activity can be distinguished. An older cycle of large, deep, rotational slides has a present surface expression of broad, heavily-grassed amphitheatres and extensive, ill-defined toe mounds. This first cycle could possibly be related to exceptionally heavy rainfall recorded in 1911, 1916 and 1924. (See Evans & Joyce 1974). An intermediate age of slipping, possibly in 1952, is expressed as closely-spaced, sharp undulations of the ground surface with distinct boundaries at the toe and flanks. Most slips shown in Fig. 10 are of this age. Finally, resliding of the lower parts of the intermediate-age slips is evident in some elongate mud flows, and a shallow rotational slide took place in early September of 1973 following heavy rain. No apparent relationship exists between the falling of the lake level and the location of landslips on the slope.

The abundance of failures on the north-west slope can be related to the micro-climate. This south-east facing slope receives less sunlight and is thus more water-logged than the adjacent non-slipping slopes.

The inorganic clay of high plasticity present in the B horizon has a liquid limit of 77, a plastic limit of 29, and thus a plasticity index of 48. Clay mineral analysis shows the presence of montmorillonite (due to weathering of the volcanics), chlorite and kaolinite. Montmorillonite is well known for its role in facilitating failure. The high liquid limit shows the strong tendency to flow and is largely a reflection of the montmorillonite content. The nature of the clay minerals and the field observations indicate that when saturated the clays are very thixotropic.

Summary

The central slopes of Bullenmerri reveal a complex pattern of old and young slips with mud flow being the principal degradation process. Water seeping below the Newer Volcanic capping produces an extreme degree of water saturation in the Oligocene silts and clays and this, combined with the presence of montmorillonite and swelling chlorite in the soil, produces unstable slopes. On the steeper slopes, slope evolution proceeds by rotational slides and flows with undercutting and collapse of the Newer Volcanic capping. Major lake level changes have produced minor terraces, with some mud flows developing at the heads of the benches.

CONCLUSION

This study of four areas of landslide activity in Victoria has shown that the Early Cretaceous arkose and mudstones and the Tertiary sandstones and mudstones are the main rock types which have a high susceptibility to failure.

The noted instability of the Early Cretaceous arkose and mudstones of the Otway Ranges is due to the strong jointing, youthful topography, active undercutting by the ocean and rivers, and most significantly, weathering along the planar discontinuities of bedding and joints. The presence of relatively fresh feldspar in the weathered arkose leads to crumbling, toppling and rock sliding rather than flow. The abundance of chlorite and a reduction in cohesion of the interbedded mudstones with time also aids failure. Salt spray may have a stabilizing influence on slopes of uniform composition, but in other cases may lead to slope failure. A slope stability map devised for the Windy Point area, south of Lorne, has been used to assess the slope stability so that dangerously unstable areas can be delineated.

The slope at Eastern View shows predominantly rotational slides in the weathered silty clay soil. These slope failures are closely related to river, ocean and road undercutting.

Slope failures in the Parwan Valley and Werribee Vale area are due primarily to the high clay content of the poorly cemented Tertiary sediments. Flow failures in the soil developed on Tertiary sediments on the north-west edge of Lake Bullenmerri appear to be aided by the presence of montmorillonite from decomposition of the overlying volcanics. The soils are also prone to saturation from water seeping below the volcanic capping.

ACKNOWLEDGMENTS

The authors wish to thank Mr. Allan Muir of the Country Roads Board, Victoria, for his help in obtaining photographs and other information for the Windy Point area, and Mr. Don Campbell for redraughting the figures.

REFERENCES

Campbell, D. A., 1945. Soil-conservation studies applied to farming in Hawke's Bay, Part 11. *N.Z. Jour. Sci. Tech.* 27: 147-172.

COATES, D. F., 1970. *Rock Mechanics Principles*. Mines Branch Monograph 874, Ottawa, Canada.

COULSON, A., 1938. Notes on the physiography of the Geelong district. *Proc. R. Soc. Vict.* 51: 61-72.

CROZIER, M. J., 1973. Techniques for the morphometric analysis of landslips. *Z. Geomorph.* N.F. 17: 78-101.

CURREY, D. T., 1970. Lake Systems, Western Victoria. *Aust. Soc. Limnology Bull.* 3: 1-13.

EDWARDS, A. B., 1962. Notes on the Geology of the Lorne District. *Proc. R. Soc. Vict.* 75: 101-118.

——— & BAKER, G., 1943. Jurassic Arkose in Southern Victoria. *Ibid.* 55: 195-228.

ERSKINE, C. F., 1973. Landslides in the vicinity of the Fort Randall reservoir, South Dakota. *U.S.G.S. Prof. Paper* 675.

EVANS, R. S. & JOYCE, E. B., 1974. Landslides in Victoria, Australia. *Vict. Nat.* 49: 241-245.

FORBES, I. G., 1948. Erosion on the Melton Reservoir Catchment. *State Rivers and Water Supply Commission, Victoria.*

GEOLOGICAL SOCIETY ENGINEERING GROUP WORKING PARTY, Report, 1972. The Preparation of Maps and Plans in Terms of Engineering Geology. *Q. Jl Engng Geol.* 5.

GILL, E. D., 1961. Changes in the level of the sea relative to the level of the land in Australia. *Z. Geomorph.* Supp. 3: 73-79.

———, 1972. The relationship of present shore platforms to past sea levels. *Boreas* 1: 1-25.

GRIM, R. E., 1939. Properties of clays in Recent Marine Sediments—A Symposium. *Amer. Assoc. Petrol. Geol.*, Part 6: 466- 495.

HALL, T. S., 1909. *Victorian Hill and Dale.* Lothian, Melbourne.

HARDING, A., 1952. Extensive Landslide at Bacchus Marsh. *Aqua* 4 (2): 110.

HILLS, E. S., 1940. *The Physiography of Victoria.* Whitcombe and Tombs, Melbourne.

HUTCHINSON, J. N., 1968. Mass Movement. In *Encyclopedia of Geomorphology*. Ed. R. W. Fairbridge. Reinhold, New York. 688-695.

JENKIN, J. J., 1968. The Geomorphology and Upper Cainozoic Geology of South East Gippsland, Victoria. *Geol. Surv. Vict., Memoir* 27.

JOHN, K. W., 1968. Graphical Stability Analysis of Slopes in Jointed Rock. *A.S.C.E. Proc.* 94, No. 2 Soil Mechanics: 497-526.

KERR, P. F. & DREW, I. M., 1965. Quick-clay movements, Anchorage, Alaska: A preliminary report. *U.S. Air Force Cambridge Research Lab.*, 66-78.

KRAUSE, F. M., 1874. Report on the Cape Otway district. *Progr. Rept. Geol. Surv. Vict.*, No. 1: 99-107.

MEDWELL, G. J., 1971. Structures of the Otway Ranges. In The Otway Basin of South Eastern Australia. Eds. H. Wopfner and J. G. Douglas. *Special Bulletin, Geol. Survs. S. Aust. and Vict.*: 339-359.

NEMČOK, A., PAŠEK, J. & RYBÁR, J., 1972. Classification of Landslides and Other Mass Movements. *Rock Mechanics* 4: 71-78.

NORTHCOTE, K. H., 1962. *Atlas of Australian Soils*, Sheet 2. Melbourne-Tasmania Area. With explanatory data. CSIRO, Aust. and Melbourne University Press.

OLLIER, C. D. & JOYCE, E. B., 1973. Geomorphology of the Western District volcanic plains, lakes and coastline. In J. McAndrew and M. A. H. Marsden (eds.). *Regional Guide to Victorian Geology*, School of Geology, University of Melbourne: 100-114.

PHILLIPS, F. C., 1971. *The Use of Stereographic Projections in Structural Geology*. Edward Arnold, London.

PRICE, N. J., 1966. *Fault and Joint Development in Brittle and Semi-brittle Rocks*. Pergamon Press, Great Britain.

PRIOR, D. B. & HO, C., 1972. Coastal and mountain slope instability on the islands of St. Lucia and Barbados. *Engineering Geology* 6: 1-18.

TURNER, F. J. & WEISS, L. E., 1963. *Structural Analysis of Metamorphic Tectonites*. McGraw-Hill, New York.

VARNES, D. J., 1958. Landslide types and processes, Chap. 3 of Eckel, E. B. (ed.) *Landslides and engineering practice*. Natl. Research Council, Highway Research Board Spec. Rept. 29: 20-47.

WILLIAMS, A. F. & MUIR, A. G., 1972. The stabilization of a large moving rock slide with cable-anchors. *3rd South-East Asian Soil Mechanics Conference*, Hong Kong. November, 1972.

APPENDIX 1

CRITERIA FOR CONSTRUCTION OF A SLOPE STABILITY MAP FOR THE WINDY POINT AREA.

The stability of any locality is assessed using the criteria listed below and a corresponding numerical value assigned. The locality is then rated in one of five categories, ranging from Stable to Critically Unstable, according to the total numerical value.

1.	ANGLE OF SLOPE:	
	(a) 0– 5	0
	(b) 6–15	1
	(c) 16–26	2
	(d) 27–42	3
	(e) Over 42	4
2.	VEGETATION:	
	(a) Heavy Vegetation	0
	(b) Light Vegetation	1
	(c) Grass	2
	(d) No Vegetation	3
3.	ROAD CUTTING	4
4.	CATTLE GRAZING	1 or 2
5.	PROXIMITY TO WATER TABLE OR SPRINGS	0, 1, 2 or 3
6.	RIVER EROSION	1
7.	JOINTING	1
8.	BEDDING DIPS IN DIRECTION OF POTENTIAL FAILURE	1 or 2
9.	PREVIOUS LANDSLIDE ACTIVITY	2

STABILITY RATINGS:

1.	Stable	$\leqslant 5$
2.	Potentially Unstable	6–9
3.	Unstable	10–13
4.	Very Unstable	14–15
5.	Critically Unstable	$\geqslant 16$

The maximum possible value is 20 with a common Ocean Road cutting having a value of 15 and a common hill slope, 9.

Discussion

The subdivision of the slope angles is largely arbitrary. It is assumed that the steeper the slope, the greater the likelihood of failure. The 27°-42° grouping represents the range of the angle of friction values for different types of failure planes observed in the Otway Ranges. It is also assumed that the frequency of shallow mass movements under undisturbed forest is lower than that under scrub or pasture (Campbell 1945). Road cuttings have been given a very high priority (4) as the method of construction, largely blasting, and the vibrations of traffic are believed to affect significantly the stability of the slopes in the immediate vicinity. The proximity to the water table and thus the degree of saturation is a significant but highly variable factor. The rock type is presumed to be homogeneous over the area studied but its structure (largely jointing or bedding plane orientation) may be important. Evidence of previous landslide activity is considered significant as further movements can occur more easily if part of a slope has previously failed. The influence of undercutting by the ocean is not considered in this area as the Ocean Road runs along the length of the coastline.

DESCRIPTION OF PLATES 16 AND 17

Plate 16

A.—Oblique aerial photograph of Windy Point, near Lorne (see Fig. 2). Note vehicles on road for scale. Fissures $Y\text{-}Y^1$ and $Z\text{-}Z^1$ are also shown in Fig. 7 (Country Roads Board, Victoria, 70-5888, 22 March 1971).

B.—Great Ocean Road at The Spit, approximately 1·5 km south-west of Windy Point (see Fig. 2). Arrows indicate the old escarpment at top right indicating earlier movement, and the tension cracks developed above the road cutting in the centre (Country Roads Board, Victoria, 70-5883, 15 January 1971).

Plate 17

A.—Rotational landside at Eastern View, looking south-west (R. S. Evans, 15 July 1973).

B.—Rotational landslide in Miocene sediments near Table Top, Werribee Vale (for A and B see Fig. 9) (A. A. Baker 1956).


A


B

A

B

11

Rapid Growth Rates in Inflorescences of *Xanthorrhoea australis* R. Br.

By Ian A. Staff*

Abstract: Developing inflorescences of *Xanthorrhoea australis* growing at Mt. Slide, Victoria, were measured at weekly intervals until growth in length had ceased. A maximum growth rate of 49 cm for 7 days (an average of 7 cm per day) was recorded. Maximum diameter at the base was 5 cm while the maximum length of inflorescence of 300 cm was attained over about 75 days growth—an average of 4 cm per day. Weekly rhythmic fluctuations in growth rates were observed and relative growth rates in length were maximal in weeks one and four of the measurements. No clear relation between rainfall and growth was found and doubts are cast on the presumed longevity of plants of the genus *Xanthorrhoea*.

INTRODUCTION

From the time of botanists such as Sachs (1875), Pfeffer (1903) and Jost (1907) to present times, much research has been done on the measurement and evaluation of growth rates of roots, stems and leaves. Measurement of the growth rates of inflorescences, however, seems to have been largely neglected, even though elongation rates of some floral parts such as anther filaments have been carefully documented (Askenasy 1879). This report gives data collected from plants of the arborescent monocotyledon *Xanthorrhoea australis* R. Br., whose inflorescences reach a height of 3 metres (approximately 10 feet) within 11 weeks, although produced by a vegetative stem that protrudes only 1·5 m above soil level. These rapid growth rates occur in a dry sclerophyll forest where annual rainfall fluctuates between 84 and 145 cm (33-57 inches). The only other published report of inflorescence growth in *Xanthorrhoea* comes from Cleland (1913) who described measurements he made on a single inflorescence of *X. hastilis* R. Br.

MATERIALS AND METHODS

Between September and December 1968, approximately weekly measurements of inflorescence lengths of 20 plants of *Xanthorrhoea australis* were made including those shown in Pl. 18, fig. 1. These 20 were the only plants that flowered in the normal flowering season of 1968 in a large stand of several thousand plants located on the slopes of Mt. Slide, Victoria (37°32′S, 145°22′E). The normal flowering season extends between September and December, but the passage of a fire through a stand usually stimulates the plants to flower. Specht and Rayson (1957a), working in South Australia, observed flowering of *X. australis* only after plants had been burnt. In field work done in 1972, Gill and Ingwersen (pers. comm.) worked on stands of *X. australis* in south-eastern Australia. They found that experimentally burned plants produced inflorescences 80 days earlier than control plants in which inflorescences first appeared after 235 days. No fire had passed through the study area at Mt. Slide within the last two years as evidenced by the long, dead persistent 'skirts' of leaves visible around many of the plants' stems.

RESULTS

Each inflorescence produced by *X. australis* has a basal, cylindrical, faintly-ribbed, infertile, green scape, whose length ranges from 40-90 cm, and whose basal diameter is between 3-5 cm. The scape subtends a long, slightly-tapering spike with myriads of sessile flowers subtended by brown, scaly bracts that are prominent before anthesis, and give the developing spike a brown colour. Pl. 18, fig. 2, 3 show developing inflorescences protruding from above the mass of narrow, linear leaves that are produced by the stem.

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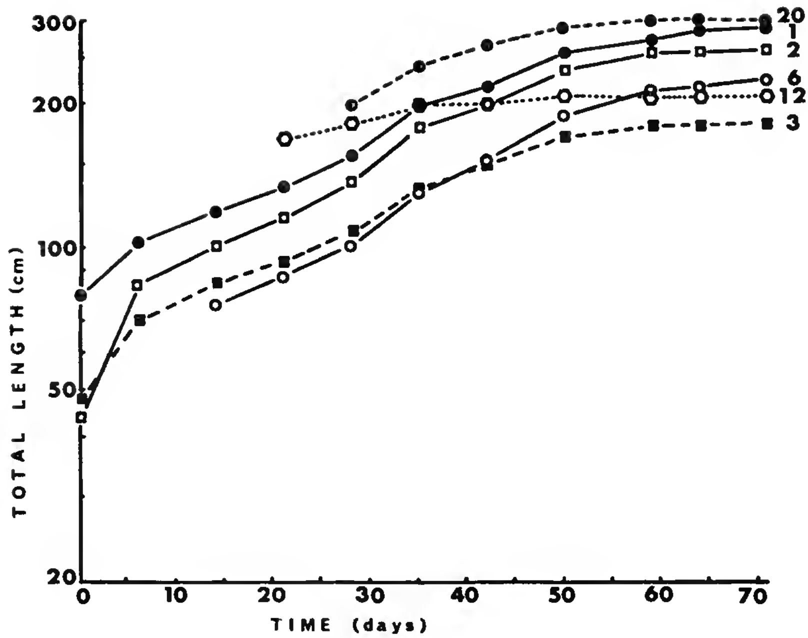

FIG. 1—Logarithmic plot of total length of six individual inflorescences (cm) versus time (days)

The plant's axis is sympodial, i.e. the inflorescence is terminal. The vegetative shoot apex is massive in size, of the order of 1·3 µm in diameter, similar to that described for *X. media*—the largest vegetative shoot apex yet recorded in the monocotyledons (Staff 1968). The terminal shoot apex of *X. australis* is normally converted into an inflorescence during the months of August to December, and the percentage of flowering is not high in a particular stand unless it has been burnt. As the numerous young leaves of the plant obscure young inflorescences from view, lengths cannot be measured until the inflorescences become visible. This resulted in initial measurements of inflorescences no shorter than 50 cm, and sometimes as long as 190 cm.

Fig. 1 shows the growth in total length of six inflorescences over a time of 178 days, while Fig. 2 shows the relation between average growth increment in length (cm) per day, versus time for four different inflorescences. Maximum growth rates occurred between days 28 and 35, and the highest growth rate observed was 49·0 cm per week, an average of 7·0 cm per day (Fig. 2-19). In many of the plants measured, three peaks of high growth rates occurred between days 1-6 (week 1), 28-35 (week 5) and 42-50 (week 7), but a graph of average growth rates for all plants (Fig. 3) had only two peaks—one in week 1 and the second in week 5. Variability in these results may be due to several factors such as variations in habitat within the communities, in genotype, and in age or size of plants, but it was thought that significant variations could be due especially to variations in physiological maturity of the plants measured. As an indication of the last criterion mentioned, an example can be drawn from the data presented in Fig. 2. Maximum anthesis of these inflorescences occurred during weeks 9, 9, 7, 6 for plants numbered 1, 2, 4, and 19 respectively. In an attempt to remove some of the irregularities caused by this variation in physiological age, and also in sizes of inflorescences, the length measurements were all converted to percentages of the maximum length attained by each inflorescence. The *first* 100% reading obtained chronologically for an inflorescence was taken as the last reading on the extreme right hand side of the new graph. The net effect was to standardize all the graphs for maximum size attained to 100%, as well as to transpose laterally graphs of plants that were out of phase physiologically with other inflorescences—e.g. the curve for plant no. 12 was moved back two weeks by this procedure (i.e. to the right with relation to other inflorescences). Fig. 4 makes a comparison between the average total length measurements plotted on the actual days that readings were collected and the adjusted plot. It can be seen that the latter graph provides

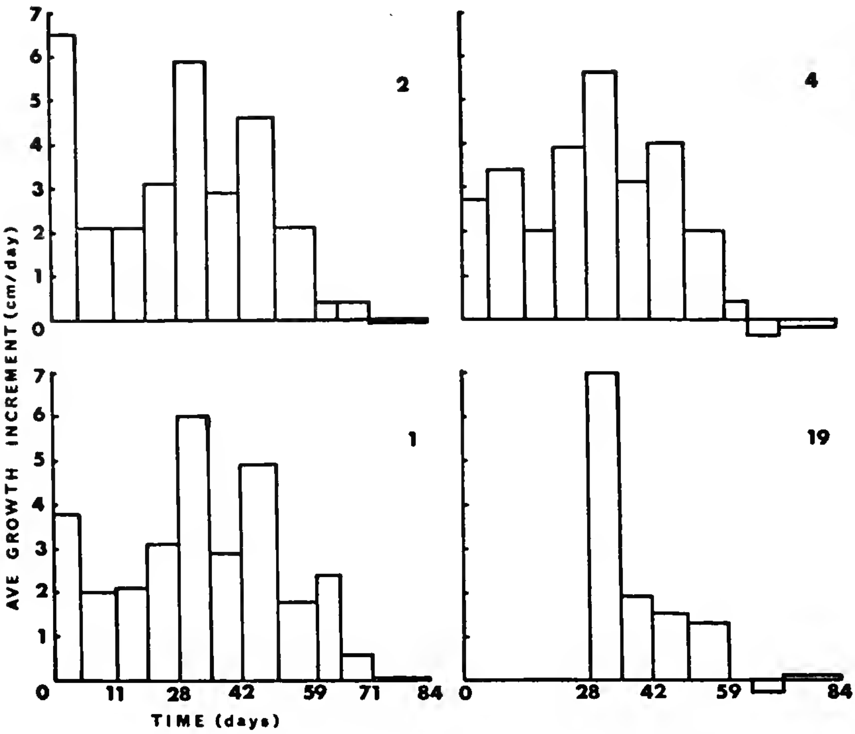

FIG. 2—1, 2, 4, 19. Average growth increments (cm/day) versus time of 4 individual inflorescences.

less variation in the standard errors of the mean, and probably gives a more meaningful indication of the average lengths of plants at similar growth phases. The curve thus obtained is biphasic, with the first sigmoid curve extending over days 0-21, followed by a second, protracted growth curve.

To see if there were any closely defined relationship between growth rates and rainfall, a plot of average growth rates (cm/day) was made on the same graph as rainfall, which was recorded for 11 weeks prior to and during the time span of the measurements (Fig. 3). No obvious link was seen and, in fact, during weeks with high growth rates (1 and 5), rainfall was low.

DISCUSSION

Kraus (1895) reported rapid growth rates of 977 cm in 7 days (139·6 cm/day) for a shoot of a bamboo, *Bambusa arundinacea*. He also reported that a shoot of *Bambusa gigantea* grew 7·85 m in length in 31 days, an average of 25·3 cm/day. Pfeffer (1903) recorded the production of 12 m of stems in a summer by species of *Humulus* and *Cucurbita*. The growth rates reported in this paper, when calculated on the basis of growth coefficients, or % increase of biomass, may not be as impressive as the growth rates of staminal filaments of *Triticum* and *Secale* (from a length of 4 mm to 7 mm in 2 minutes, Askenasy 1879). Nevertheless, the production of a massive stem in a relatively short time is always spectacular.

In *Xanthorrhoea australis*, the inflorescence, a determinate structure, attains a maximum length of 300 cm, and maximum diameter of 5 cm in a time span of about 75 days—an average of 4 cm/day with a maximum growth of 7 cm/day. The measurements made by Cleland (1913) on a single inflorescence of *X. hastilis* in Sydney showed a maximum elongation rate of 10·2 cm, which was maintained for three days, but the average growth rate over the period of observation, 60 days, was 3·0 cm/day. Gill and Ingwersen (1974) examined inflorescence growth in *X. australis* and found maximum elongation rates of 5 cm/day. This is a particularly interesting phenomenon, especially when one considers that such growth rates occur in a climate that is relatively cooler and drier than the tropical climates where such impressive growth rates of bamboos have been observed. Hartley (1969) recorded lengths of oil palm inflorescences of 40 cm developing in 3-4 months from small size, and this does not represent as rapid a growth in length as the *Xanthorrhoea* inflorescences.

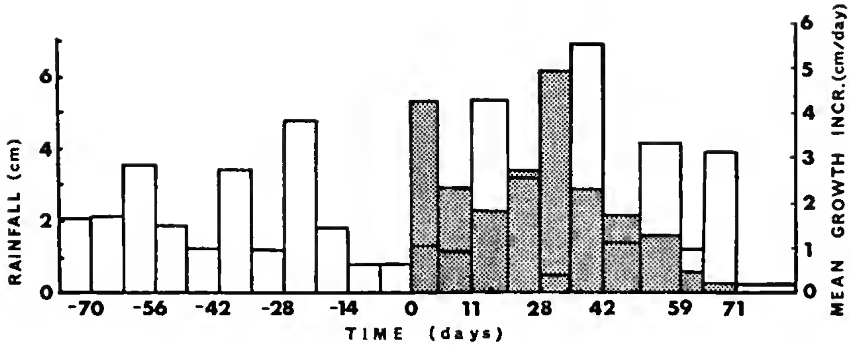

FIG. 3—Mean increment in length of all inflorescences/day versus time (weeks) (shaded), and rainfall (cm) at Kinglake Post Office from July 1 to December 9, 1968 (unshaded).

In Australia, the growth rate of the vegetative stem of the grass tree has traditionally been thought to be very slow. Lewis (1955) attempted to estimate the ages and growth rates of some specimens of *X. australis*. He suggested, on the basis of production of 2½ leaves per annum of some seedlings, that plants may be over 6,000 years old by the time that the stem reaches maturity at soil level (the stems of seedlings usually develop underground). Such an extrapolation is extremely misleading, as annual leaf production by plants rapidly increases after the first few years of establishment growth. Gill and Ingwersen (1974) working with stands of *Xanthorrhoea* in forests of *Pinus* and *Eucalyptus*, and in grasslands, were able to correlate burn scars on the plants with known dates of fires. This allowed them to establish for these plants a maximum elongation rate of stems of 3·1 cm/year for a period of 21 years. At this growth rate, a height of 300 cm (nearly 10 feet) would take 97 years to be produced. It is thus likely that estimates of great age of such plants are grossly in excess of actual age, which are probably of the order of 100 to 250 years.

From the data presented here, several significant points become apparent. First, by examining Figs. 1 and 2, it is clear that growth rates of individuals fluctuate considerably from week to week. In many plants, a week of high growth rate is often followed by a week of lower growth rate. It seems reasonable to interpret this as an example of rhythmic growth, the effect of which is not necessarily shown in the averages subsequently presented (Figs. 3, 4). Hallé and Martin (1968) have studied endogenous rhythmic growth phenomena of *Hevea brasiliensis* in the tropics. They found a repetitive cycle of 42 days, and suggested that one of the major factors responsible was competition between the apical meristem and the leaves for water. They also noted rhythmic growth in species of the woody monocotyledon *Dracaena*, and reviewed some of the relevant literature on rhythmic growth in tropical and temperate regions. Although he did not remark on it, rhythmic growth with a periodicity of 2 days can even be seen in data presented by Sachs (1875) on the growth of the flowering stem of *Fritillaria imperialis*. Cleland (1913) noted a diurnal variation of elongation in an inflorescence of *X. hastilis*, where most of the elongation occurred in the night.

Pl. 18, fig. 4 illustrates an unusual case of one inflorescence of *X. australis*, found at Anglesea, Victoria, whose growth resulted in a sinuous spike and in which the undulations could have been governed by rhythmic growth factors. However, as no data were collected on the growth of this inflorescence, it is impossible to know what were the actual causal factors that controlled this strange growth form.

Second, when an adjustment for varying growth phases of the plants, and for differences in final inflorescence height is made, a plot of average length versus time still shows a biphasic growth curve, with maximum growth rates occurring in weeks 1 and 4. Obviously, the first growth maximum is only partly recorded because of the difficulty in finding inflorescences in the field at very early stages of development, and the second one corresponds to the spurt of growth that precedes anthesis. As the gradient of the plot of growth in total length on a logarithmic scale versus time gives an indication of Relative Growth Rate (Evans 1972)—in this instance, growth rate relative to intial length—it is apparent from the adjusted plot in Fig. 4 that the highest relative growth rates (in length) occurred in weeks 1 and

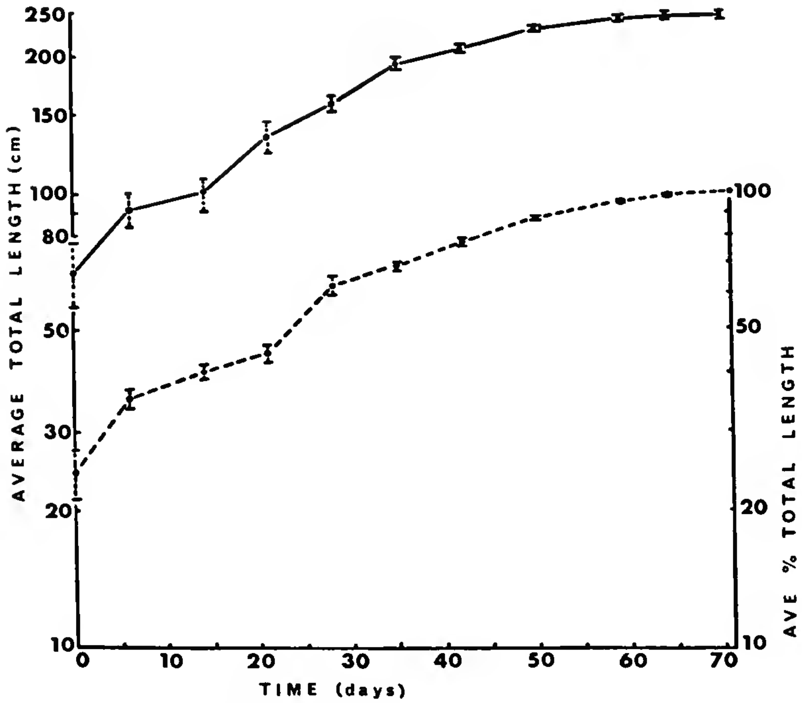

FIG. 4—Average total length (cm) of 20 inflorescences versus time (upper curve with solid line)—logarithmic scale on ordinate.
Average length (% total final length) of 20 inflorescences adjusted for similar physiological maturity (lower curve dashed line)—logarithmic scale on ordinate.

4. The steepest gradient of the graph in this figure occurred in week 1, and thus the maximum relative growth rate in length occurred in week 1, although the highest absolute growth increments per day occurred later, in week 4. In other words, in week 1, an increase from 24 to 35 cm represents an increase of 46% over the initial length, but in week 4, an increase from 44 to 62 cm represents an increase of 41% in length.

Although Specht and Rayson (1957b) showed that *X. australis* plants growing in sandy soil had a great capacity to intercept rain and to concentrate water in the soil immediately underneath the plants, no clear relation between rainfall and inflorescence growth could be seen in the present work. It is apparent that data on solar radiation and temperature should have been obtained to gain a better view of the effect of environment on inflorescence growth. Fitzpatrick and Nix (1970) in discussing the climatic factor in Australian grassland ecology, stress the need for quantifying climatic factors such as light, temperature and precipitation and do so in terms of a 'Thermal Index', a 'Light Index' and a 'Moisture Index'. For the oil palm, from work by Hartley (1967) and Broekmans (1957), the production of large, fertile inflorescences is greatly dependent on water availability even up to 2 years preceding the time of inflorescence maturation. This is understandable, as the inflorescence primordium may still be present in the leaf axil during the time of water deficiency. A parallel situation for *X. australis* inflorescence primordia does not exist, as they are not long-lived and further studies would be necessary in order to clarify the relationship between inflorescence growth and water availability.

Finally, the collection of data on the growth of inflorescences is a scantily researched field of investigation. Because of the almost cylindrical and unbranched form of the inflorescence of *Xanthorrhoea australis*, useful data can be obtained from these plants. The difficulties of collection of the data include low percentage flowering in unburnt stands and inaccessibility of the plants for regular measurement.

ACKNOWLEDGMENTS

I thank Mr. R. H. Norweb III, who acted as a research assistant while a visiting student from

Beloit College, Beloit, Wisconsin, U.S.A. The manuscript was finalized while the author was a Charles Bullard Research Fellow at Harvard Forest, Petersham, Massachusetts, U.S.A., on study leave from La Trobe University. The rainfall data were provided by Mrs. M. McMinn, Kinglake Post Office.

REFERENCES

ASKENASY, E., 1879. Ueber das Aufblühen der Gräser. *Verhandl. d. Naturh.-Med. Vereins zu Heidelberg N.F.* 2: 261-273.

BROEKMANS, A. F. M., 1957. Growth, flowering and yield of the oil palm in Nigeria. *J. W. Afr. Inst. Oil Palm Res.* 2: 187-220.

CLELAND, J. B., 1913. Note on the growth of the flowering stem of *Xanthorrhoea hastilis* R. Br. *J. & Proc. R. Soc. N.S.W.* 47: 72-74.

EVANS, G. C., 1972. The quantitative analysis of plant growth. In *Studies in Ecology*, Vol. 1. Blackwell Sci. Pub., Oxford, 734 pp.

FITZPATRICK, E. A. & NIX, H. A., 1970. The climatic factor in Australian grassland ecology. In *Australian Grasslands*, pp. 3-26. Ed. R. M. Moore. A.N.U. Press, Canberra. 455 pp.

GILL, A. M. & INGWERSEN, F., 1974. (Pers. comm.). Division of Plant Industry, CSIRO, Canberra, A.C.T.

HALLÉ, F. & MARTIN, R., 1968. Etude de la croissance rhythmique chez l'*Hevea brasiliensis* Müell.-Arg. *Adansonia*, sér. 2, 8: 475-503.

HARTLEY, C. W. S., 1967. *The oil palm (Elaeis) guineensis)*. Longmans, London.

———, 1969. Some environmental factors affecting flowering and fruiting in the oil palm. Pp. 269-286. In *Physiology of tree crops*. Eds. L. C. Luckwill and C. V. Cutting. Academic Press, N.Y.

JOST, L., 1907. *Lectures on plant physiology*. Translated by R. J. Harvey Gibson. Clarendon Press, Oxford.

KRAUS, G., 1895. Physiologisches aus den Tropen. *Ann. du Jard. Bot. Buitenzorg* 12: 196-216.

LEWIS, C. F., 1955. Observations on the age of the Australian grass tree, *Xanthorrhoea australis*. *Vic. Nat.* 72: 124-125.

PFEFFER, W., 1903. *The Physiology of Plants* Vol. II. Trans. & Ed. A. J. Ewart. Clarendon Press, Oxford.

SACHS, J., 1875. *Text-book of Botany—morphological and physiological*. Trans. A. W. Bennett and W. T. Thiselton Dyer. Clarendon Press, Oxford.

SPECHT, R. L. & RAYSON, P., 1957a. Dark Island heath (Ninety mile plain, South Australia). I. Definition of the ecosystem. *Aust. J. Bot.* 5: 52-85.

——— & ———, 1957b. Dark Island heath (Ninety mile plain, South Australia). IV. Soil moisture patterns produced by rainfall interception and stem flow. *Ibid.* 5: 137-150.

STAFF, I. A., 1968. A study of the apex and growth patterns in the shoot of *Xanthorrhoea media* R. Br. *Phytomorphology* 18: 153-166.

DESCRIPTION OF PLATE 18

FIG. 1—Part of the study area at Mt. Slide, Victoria, with specimens of *Xanthorrhoea australis* in flower. (Total length of inflorescence at left is 250 cm.)

FIGS. 2, 3—Two stages in the development of an inflorescence. (Total lengths are 83 and 100 cm respectively.)

FIG. 4—Unusually curved inflorescence observed at Anglesea, Victoria. (Total height is 170 cm.)


1
2
3
4

SHORT COMMUNICATION

OCCURRENCE OF THE ASCIDIAN *Styela clava* HERDMAN IN HOBSONS BAY, VICTORIA: A NEW RECORD FOR THE SOUTHERN HEMISPHERE

Introduction

The pleurogonid ascidian *Styela clava* Herdman is indigenous to the north-western Pacific, i.e. Japanese waters, the Sea of Okhotsk and parts of the Korean and Siberian coasts (Millar 1960). It was recorded as an immigrant to British waters by Carlisle (1954) who considered it to be a new species, *Styela mammiculata*. Millar (1960) showed that *S. mammiculata* Carlisle was in fact *Styela clava*.

Since its detection in Plymouth, *Styela clava* has been recorded from other localities on the south coast of England (Holmes 1969; Houghton & Millar Millar 1960; Stubbings & Houghton 1964), from Milford Haven, Wales (Coughlan 1969), from Cork, Eire (Guiry & Guiry 1973), and from the French coast of the English Channel (Monniot 1970). *Styela clava* in European waters thus appears to be spreading from the original point of introduction.

Occurrence in Hobsons Bay, Victoria

During diving studies in Hobsons Bay (37° 51′ S, 144° 55′ E) in December 1972 and January 1973, the author discovered *Styela clava* growing at depths of one metre or more below chart datum on the piles supporting two navigational beacons at the mouth of the River Yarra. Subsequent surveys have shown the species to occur widely within Hobsons Bay. Its most southerly occurrence to date has been at Point Ormond (144° 58′ E, 37° 53′ S) where a single specimen was taken from a sand/shell bottom at 3 m depth (Poore, personal communication). Preliminary surveys of the epibiota of artificial surfaces in other areas of Port Phillip Bay and in Western Port, the latest in January and February 1975 (Holmes, unpublished), have failed to detect the species outside Hobsons Bay.

Biology of *Styela clava*

Styela clava may attain a length of up to 160 mm (Holmes 1969); specimens of 145 mm length have been found in Hobsons Bay. Studies on the species in Southampton Water, U.K. (Holmes 1969) where water temperatures ranged between 2° and 23°C, showed that it bred throughout all but the coldest two or three months, with a marked peak of settlement in mid to late summer (late July to early September). Densities of up to 500 adults per m² were recorded from Southampton Water, where the species ranged up to mid-tide level in locations sheltered from the sun.

Styela clava appears to be a secondary settler, in the sense that it colonizes only those surfaces bearing a well-developed epibiota. In Southampton Water it was restricted to areas of low wave energy and almost maximum ramine salinity; Guiry and Guiry (1973) found a similar situation in Cork Harbour.

In Hobsons Bay, population densities of up to 600 adults per m² have been found on artificial test panels submerged in the upper sublittoral zone. No data are yet available on the timing of breeding in this area, where the annual temperature range is from about 10° to 23°C (Holmes, unpublished). A study of the annual gonadal cycle is currently in progress. As in Southampton Water, the species appears to be a secondary settler, appearing on test panels submerged for more than three months. Within Hobsons Bay the species is confined to relatively sheltered areas at depths below the halocline or in areas of high salinity and has not been recorded from the littoral zone. The precise effects of salinity fluctuations on the occurrence and survival of *Styela clava* remain to be investigated.

Method of Introduction and Further Spread

Several authors (e.g. Millar 1971) have suggested that the introduction of *Styela clava* to European waters was by accidental transport as fouling organisms on ships' hulls. Certainly, once established the species has spread around the coasts of the English Channel within twenty years. The precise route of introduction of *Styela clava* to Australian waters is problematic, as it may have been transported either from Europe or from its original home in the north-western Pacific. Opportunities for transport by both routes exist, since many vessels in the Japanese or European trade call at Melbourne, where Hobsons Bay forms part of the port area. It is clear, however, that *Styela clava* is able to survive and recover from a period of immersion at tropical temperatures.

For an organism such as *Styela clava* which has a sessile adult stage, extension of its range must, if not accomplished by man, be effected by larval dispersal. Studies by the present author (Holmes 1969) have shown that the maximal free-floating life of the eggs and larvae of *Styela clava* is of the order of 24 h at Victorian summer water temperatures. Given the fairly slow circulation of water within Port Phillip Bay (MMBW & FWD 1973) it seems probable that the spread of *Styela clava* around Port Phillip Bay by natural means would be slow. Furthermore, natural extension of its range to other inlets of the Victorian coast would seem to be difficult, as the highly exposed Bass Strait coast would act as a barrier to this species, which is apparently restricted to sheltered locations. In the absence of knowledge of the species' lower depth-limits it is not possible to determine whether spread through Bass Strait would be possible sublittorally.

Further spread of *Styela clava* from Hobsons Bay, or the possibility of further new introductions to Victoria or Tasmania appear to be possible only by transport on ships' hulls, be they of ships visiting from overseas or plying a coastal trade in southern Australia. The potential range for *Styela clava* in Australian waters cannot be predicted until data on temperature limits for breeding and survival are known.

References

CARLISLE, D. B., 1954. *Styela mammiculata* n. sp., a new species of ascidian from the Plymouth area. *J. mar. biol. Ass. U.K.*, 33: 329-334.

COUGHLAN, J., 1969. The Leathery Sea Squirt—a new ascidian from Milford Haven. *Nature in Wales*, 11: 192-3.

GUIRY, G. M. & GUIRY, M. D., 1973. Spread of an introduced ascidian to Ireland. *Mar. Poll. Bull.*, 4 (8): 127.

HOLMES, N. J., 1969. Aspects of the biology of *Styela clava* Herdman. Ph.D. thesis, Southampton University, U.K.

HOUGHTON, D. R. & MILLAR, R. H., 1960. Spread of the ascdidian *Styela mammiculata* Carlisle. *Nature, Lond.*, 185 (4716); 862.

MILLAR, R. H., 1960. The identity of the ascidians *Styela mammiculata* Carlisle and *S. clava* Herdman. *J. mar. biol. Ass. U.K.*, 39: 509-511.

————, 1971. The Biology of Ascidians. *Adv. Mar. Biol.*, 9: 1-100.

MMBW & FWD, 1973. *Environmental Study Port Phillip Bay. Report on Phase One, 1968-1971*. Melbourne and Metropolitan Board of Works and Fisheries and Wildlife Department of Victoria, Melbourne, 372 pp.

MONNIOT, C., 1970. Sur quatre ascidies rares ou mal connues des côtês de la Manche. *Cah. Biol. mar.*, 11: 145-152.

STUBBINGS, H. G. & HOUGHTON, D. R., 1964. The ecology of Chichester Harbour, S. England, with special reference to some fouling species. *Int. Rev. ges. Hydrobiol.* 49: 233-279.

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NOTE

Dr Rex Harland, Institute of Geological Sciences, Ring Road, Halton, Leeds LS15 8TQ, Yorkshire, England, furnishes the following informaton and requests that it be published in *Proceedings*: The holotypes and figured specimens that were lodged with the Department of Geology, University of Alberta, Edmonton, Canada and which were described by me and W. A. S. Sargeant in *Proc. R. Soc. Vict.* Vol. 83, Pt. 2, pp. 211-234, and by me in Vol. 84 Pt. 2, pp. 245-254, have now been permanently transferred to the Institute of Geological Sciences at Leeds (address above).

ROYAL SOCIETY OF VICTORIA

1975

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ABRIDGED REPORT OF THE COUNCIL

FOR THE YEAR ENDING 13 MARCH, 1975

PATRON

Sir Rohan Delacombe, at the end of his term of office as Governor of Victoria, resigned as Patron of the Society, and was elected to Honorary Life Membership. Sir Henry Winneke accepted the invitation of Council to become Patron of the Society.

MEETINGS AND LECTURES

MARCH 14—Following the Annual General Meeting, Dr. J. H. Willis delivered his Medal Lecture, *Some of Victoria's Rarest and Most Localized Plants*.

APRIL 4—Special Meeting, in conjunction with the Botany Club: *Dendrochronology—the Study of Tree Rings*. Professor C. W. Ferguson.

APRIL 18—*The Changing Pattern of Energy, Past and Future*. Sir Willis Connolly.

MAY 6—Special Meeting: *The Future of the NASA Space Programme*. Colonel David R. Scott, U.S. Air Force.

MAY 9—*Solar Energy for Australia*. Mr. R. N. Morse.

JUNE 13—*Bush Fire Research*. Dr. R. G. Vines.

JULY 11—*Recent Developments in Upper Atmosphere Research*. Professor V. D. Hopper.

AUGUST 8—*The Earth Resource Technology Satellite and its Application to the Survey of Australian Resources*. Mr. D. T. Currey.

SEPTEMBER 14—*Symposium on Westernport Bay*, held at Monash University. Mrs. M. M. Barson, Mr. B. C. S. Harper, Mr. T. M. Perry, Dr. D. Spencer-Jones, Dr. P. Bridgewater, Dr. W. T. O'Brien, Dr. J. B. Hinwood, Dr. D. W. Connell and Professor M. A. Shapiro. A Field Excursion to Westernport Bay was held on the day following the Symposium.

OCTOBER 10—*The Simpson Desert, 1973—Damp Birds and a few Fossils*. Mr. K. N. G. Simpson.

NOVEMBER 14—Soiree: *Earliest New Zealand Tetrapods*. Dr. T. H. V. Rich. Exhibits were contributed by the National Museum and the National Herbarium of Victoria; Departments of Botany and Zoology, Monash University; Fisheries and Wildlife Division, Ministry of Conservation; ICI Australia Limited; the Victorian Department of Mines; Mr. E. D. Gill.

NOVEMBER 21—Special Meeting: Seminar, *Food, Population and Energy*. Mr. N. B. Guyol and Professor N. Ginsburg.

DECEMBER 5—*Some Recent Advances in Biological Science*. Professor M. J. D. White; *Recent Advances in Applications of Computers to Chemistry*. Professor J. D. Morrison.

MEMBERSHIP

Membership at 1st January 1975 was: Honorary Life Members 4, Life Members 34, Members 531, Associates 71: Total, 640.

Council recorded with regret the deaths of Mr. T. M. Conroy, Mr. R. P. Crow, Sir Peter MacCallum, Mr. M. E. R. McCausland, Mrs. M. M. Moir and Mr. H. J. Prentice.

RESEARCH MEDAL

The Society's Medal for 1974 was awarded to Dr. A. W. Snyder, of the Department of Applied Mathematics, Research School of Physical Sciences, Australian National University, for his work on the physics of vision and on optical physics.

PROCEEDINGS

During the year the Society published Volume 86, Part 2 of '*Proceedings*' at a cost of $4163. Council acknowledges with gratitude grants towards the cost of publication from the Government of Victoria, the Ministry for Conservation (Westernport Bay Environmental Study and Division of Fisheries and Wildlife), the Department of Mines and the University of Melbourne.

LIBRARY

2402 volumes and parts were received during the year. 161 volumes were bound at a cost of $879. 565 items were borrowed from the Library.

HALL

In addition to the Society and the Royal College of Obstetricians and Gynaecologists, 16 professional and other bodies held 92 meetings on the premises.

The lawn sprinkler system and water main to the Hall were renewed at a cost of $877.

FINANCIAL STATEMENT

The chief financial problem of the Society at present is the devaluation of capital funds as a result of inflation. The Society's activities have been considerably strengthened of recent years through bequests from Members, but unless value is kept in these funds, this advantage will be greatly decreased. Therefore Council recently decided that a proportion of the interest accruing to these funds should be reinvested each year. Council has effected economies in operation wherever possible.

ACKNOWLEDGEMENTS

Council, on behalf of the Society, expresses its thanks to the many persons and organizations who have given valuable assistance during the year, including Mr. H. G. Stevens, Honorary Auditor; Sir Ian Potter, Honorary Financial Adviser; Mr. Leigh Masel, Honorary Solicitor; Mr. F. Suendermann on behalf of Sir Roy Grounds, Honorary Architect; ICI Australia Limited; The Parks, Gardens and Recreation Department of the Melbourne City Council; and Mrs. I. Sadik.

The death of Mr. A. Sadik was recorded with regret.

J. D. MORRISON,
President.

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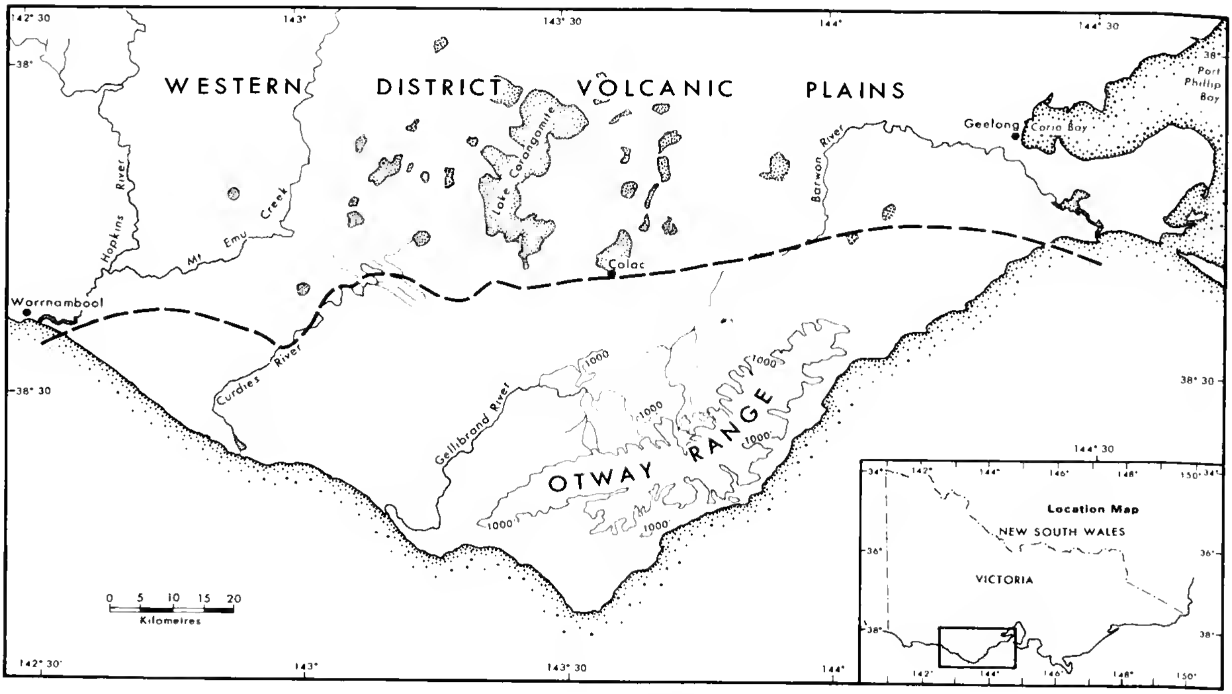

'THE OTWAY REGION'

THE OTWAY REGION SYMPOSIUM

9 OCTOBER 1975

FOREWORD

On October 9, 1975, the Society held a Symposium to attract discussion on 'The Otway Region', a district and coastal prominence in southwestern Victoria delineated for the Symposium as the area to the south of the dashed line on the accompanying map. Papers presented at this Symposium, and those read by title only, are included in this volume of the Proceedings. The date of publication of these papers is an embarrassing distance from the date of their presentation due to a restriction limiting the Society to a single volume each year if printing subsidies are to be realised. This resulted in a 1977 publication date and the Publications Committee apologises to recipients, and especially to authors, for the enforced delay.

The Otway Region comprises land under economic development, both agriculture and forestry, but so far lacking any major industrial enterprise. As here defined it contains no major sea port, but does exhibit an extensive coastline consisting of sand beaches and rocky headlands which are the subject of some of the papers. The Otway Range is the dominant feature of the region and presents an interesting geological story. Also, it affords a diversity of habits for indigenous biota, some of which seem to have closer affinities with Tasmanian fauna and flora rather than with Victorian.

The Symposium has continued the Society's policy of providing a forum for such topics, and similar arrangements to deal with other districts are currently in train.

J. W. Warren
Hon. Editor

THE ABORIGINES OF THE OTWAY REGION

By N. H. Scarlett*

Abstract: Local groups belonging to three distinct "tribes" (language units) occupied the Otway Region: *Djargurd*, west of Cape Otway and Pirron Yaloak, *Gulidjan*, around Colac, and *Wadjawuru*, east of Birregurra. These languages belong to three different sub-groups of the Kulinic Language Group, but *Gulidjan* and *Wadjawuru* are more closely related to each other than to *Djargurd*. Paradoxically, the *Djargurd* and *Gulidjan* were organised into matri-moieties, in contrast to the *Wadjawuru* with patri-moieties. There was some degree of marriage across linguistic and social-system boundaries.

The bulk of the small population probably occupied the coast, relying on marine and estuarine protein resources. The main inland population centres were around the lakes and swamps of the Basalt Plains region, but swamps and river-flats within the foothill forests of the Otway Region may have provided limited food resources for seasonal occupation. The forest areas were also a source of raw materials for important trade items.

The occupation of aboriginal territory by European pastoral interests between 1836 and 1847 shattered the indigenous socio-economic system. Massacres, introduced diseases and the forcible abduction of aboriginal women quickly decimated the aboriginal people of both the Otway and Basalt Plains regions.

INTRODUCTION

The aboriginal people of the Otway Region were linked by social and cultural bonds to the population of an area extending from the Upper Goulburn district to the Glenelg River. In order to understand the pre-European situation in context a consideration of the wider picture is necessary.

LINGUISTIC CLASSIFICATION, 'TRIBES' AND LOCAL ORGANISATION

The 'tribes' of most early investigators prior to A. W. Howitt (1904) correspond to the 'local groups' of modern anthropologists, or to limited aggregations of local groups which habitually camped and hunted together (vide Stanner 1965). The various local groups occupying the Otway Region can be classified into named language units on the basis of the work of Tuckfield (in Cary 1898), Dawson (1881) and Mathews (1904a,b). The units correspond roughly to the 'tribes' of modern anthropology, but they did not operate as single cultural-political entities.

The author's conclusions, derived from the original sources cited above, differ from the surveys of Tindale (1940, 1974) and Oates and Oates (1970). A detailed discussion of these differences cannot be presented here, but the most important points of disagreement are noted below. In this paper aboriginal terms in italics are transcribed in conformity with the 'A.I.A.S. Convention for Representation of Tribal and Language Names'. Terms in quotation marks are quoted in the spelling of the original source material.

Three distinct languages were represented in the region: *Djargurd*, west of Pirron Yaloak and Cape Otway, *Gulidjan* (Gulag-ngad), east of Pirron Yaloak to near Birregurra; and *Wadjawuru* (Wadhawurung), east of Birregurra and along the east coast toward Cape Otway. These languages belonged to three different sub-groups of the Kulinic Language Group: Drual, Gulyan and Kulin, respectively (Wurm 1971). Although structurally similar, there were important grammatical and lexical differences, and the languages were not readily inter-intelligible (Dawson 1881). *Wadjawuru* and *Gulidjan* were more closely related in vocabulary than either was to *Djargurd*.

The term *Djargurd*, although derived from the name of a small aggregation of local groups centred at Camperdown (Robinson in Kenyon 1928, Tuckfield in Cary 1898) was applied in a general sense to the various dialects of the 'Mara Nation' of Howitt (1904), spoken between Cape Otway and Portland. Mathews' 'Dhauhurtwurru' is a variant form used in the Portland-Lake Condah area (Mathews 1904a). Tindale's division of these people into the 'Gunditjmara' and 'Kirrae' tribes is not accepted by the present writer

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(Tindale 1940, 1974). Dawson (loc. cit.) noted seven dialects of *Djargurd* type, of which three were found in the Otway Region: *Warn-dhalanj* 'Rough speech' in the Camperdown area, *Wirngilngad-dhalinanung* 'Koala language' in the forest country east of the Hopkins River, and *Gadabanud* 'King Parrot langauge' at Cape Otway. The relevant local groups and their dialect affiliations are listed in Table 1. (See also Fig. 1).

The *Gulidjan* (Gulag-ngad) people occupied the area around Colac and south into the foothills of the Otway Ranges. 'The extent of their country was a radius of 10 miles from Lake Colac except on the south, where in the extensive Cape Otway Ranges there was no other tribe'. (Murray 1853). Unfortunately no information on the *Gulidjan* local groups has been recorded. Tindale (1974) assigns part of the Otway coast to the *Gulidjan*, but Dawson and Goodall's data do not support this conclusion.

The *Wadjawuru* (Wadhawurung) langauge was spoken in the country between the Werribee River, Mt. Emu, the northern shores of Lake Corangamite and Birregurra, including the coast east of Cape Otway (Howitt 1904, Mathews 1904) and included the Barrabool, Leigh, Buninyong and Wardy Yaloak 'tribes' of the early settlers (Murray 1853, Addis 1841). Of the fifteen recorded local groups (Parker 1844, Robinson in Kenyon 1928, Thomson 1836), two may have occupied the Otway Region: *Djeraldjur* to the west of Lake Modewarre, and *Wadiwaru (Barabil)* in the Barrabool Hills and south to the coast.

SOCIAL ORGANISATION

The nature of the kinship 'network' linking the Otway Region groups together cannot be reconstructed with any accuracy. However, according to Dawson, dialect exogamy was the norm, at least among the *Djargurd*; this has parallels in some other parts of Australia e.g. north-east Arnhem Land. From a wider perspective, both *Djargurd* and *Gulidjan* groups were organised into two intermarrying matrilineal moieties: *Gabadj* (Black Cockatoo: *Calyptorhynchus funereus*) and *Guragidj* (White Cockatoo: *Kakatoë tenuirostris*). This type of social system extended west to Mt. Gambier and north to Lake Hindmarsh (Howitt 1904). Patrimoieties, termed *Bundjil* (Eaglehawk: *Aquila audax*) and *Waang* (Crow: *Corvus coronoides*) prevailed among the *Wadjawuru*, in common with the other Central Victorian 'Kulin' tribes, extending in the east to Western Port and the Upper Goulburn River, and in the west to the Avoca River.

Women from as far as Lake Bolac and the Shaw River to the west came as wives to the *Djargurd* and *Gulidjan* men (Dawson 1881, Hebb 1970). In turn the *Gulidjan* intermarried with some families of the *Wadjawuru* despite the different descent system (Tuckfield 1840). The 'constant war' reported as existing between the different 'tribes' appears to have been a matter of

TABLE 1
LOCAL GROUPS AND DIALECTS, DJARGURD LANGUAGE

Local Group	*Localities*	*Dialect*	*Source*
Liwura or Gurngulag	Mt. Leura, Lake Bullenmerri and Gnotuk; Lake Corangamite	Warn	Goodall, Robinson
? possibly including Yelinggamadj	Lake Elingamite	Warn	Robinson
Malanggil	South of Lake Purrumbete, including Mt. Pordon	Warn	Goodall
? possibly including Barambidj	Lake Purrumbete	Warn	Robinson
Duram	West of Curdies River (to the Hopkins)	Wirngil	Goodall
Naragurd	East of Curdies River	Wirngil	Goodall
Baradh	Sherbrooke Creek, including Browns Hill (near Princetown)	Wirngil	Goodall
Two unnamed groups	One group at the Aire River, locality of the other unknown	Gada	Hebb, Osburne

Local groups and localities from Robinson in Kenyon (1928), Goodall in Brough-Smythe (1972), Hebb (1970) and Osburne (1937). Dialect affiliation from Dawson (1881).

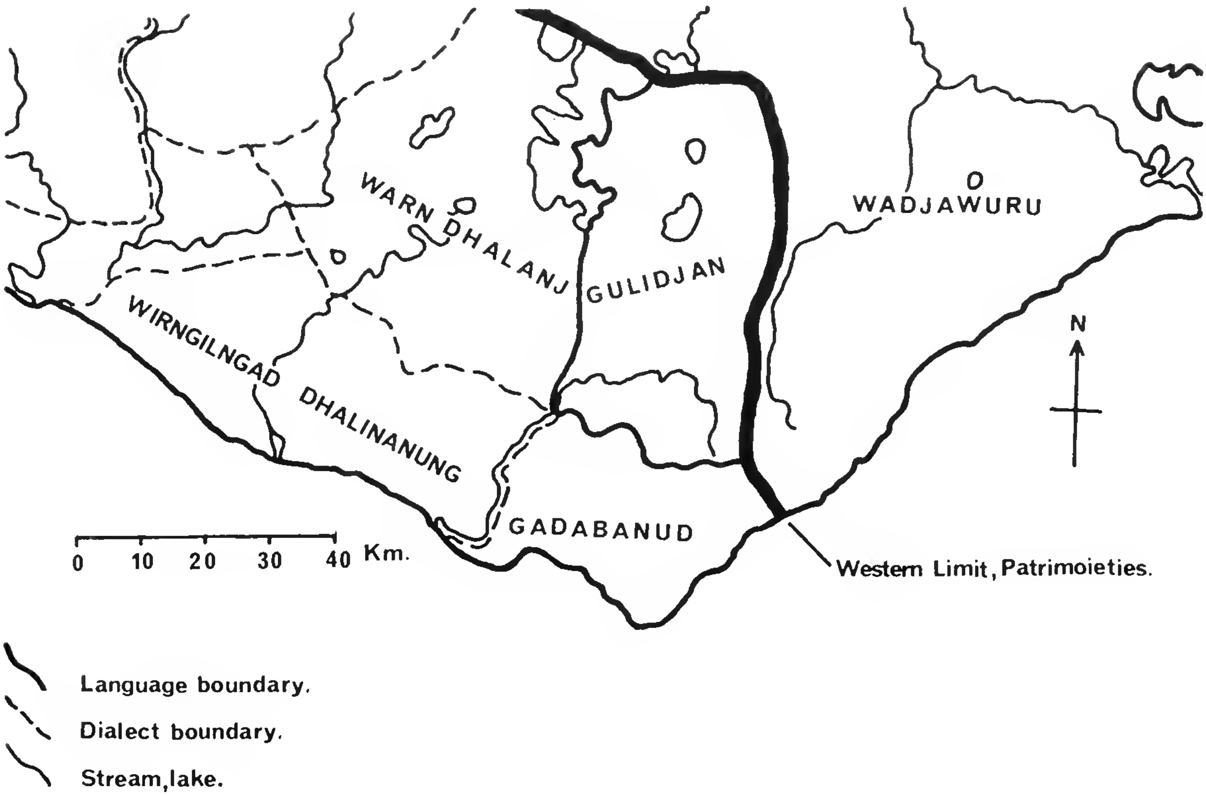

FIG. 1—Distribution of Aboriginal Groups in the Otway Region.

continuing disputes concerning marriage arrangements.

Djargurd and *Wadjawuru* men competed for wives from the *Gulidjan* — such rivalry was also a frequent source of feuds in north-east Arnhem Land (Warner 1937). Hugh Murray (1853) states that the 'Colac tribe' suffered considerably in these conflicts, and the details of skirmishes at the Buntingdale Mission (q.v.) recorded by Tuckfield (1840) tend to support his comments.

USE OF NATURAL RESOURCES

A wide range of natural resources was available within the Otway Region, although it was not a rich area in comparison to the Basalt Plains Region to the west and north.

The economy of the coastal groups was based on shellfish collection and fishing in the tidal estuaries, supplemented by plant foods collected from the land, particularly on the river flats and swamps: e.g. The tubers of Water-ribbons *(Triglochin procera)*, the rhizomes of the Tall spike-rush *(Eleocharis sphacelata)*, and the tubers of the Club-rush *(Scirpus maritimus* sensu lato).

There is little doubt that the bulk of the permanent population of the region would have been found along the coast, particularly around the Hopkins and Curdies River estuaries (*Duram* and *Naragurd* local groups). No early census material is available, but there were apparently two groups at Cape Otway numbering 13 and 20 people (Hebb 1970, Osburne 1937). Assuming similar numbers for the other coastal groups the population would have been in the order of 100 to 120 people between Breamlea and Warrnambool. Seasonal visitors may have increased the numbers at times. William Buckley's accounts of his travels along the coast between Aireys Inlet and Barwon Heads certainly do not indicate a large permanent population (Morgan 1967, Wedge 1835).

The inland forest areas were probably occupied on a seasonal basis by families which spent the bulk of the year at the larger population centres, either on the coast or in the Basalt Plains Region. The more open forests and the heaths would be used most intensively, particularly around river flats and swamps e.g. Gherangamete, Irrewillipe and Chapple Vale. Massola (1966) reports archaeological evidence for such occupation. Lakes Modewarre, Colac, Corangamite and Purrumbete were centres for large gatherings of up to 150 people (Manifold 1853) but these sites are, strictly speaking, outside the region. It is difficult to estimate the actual numbers exploiting the forest areas. Robinson (in Kenyon 1928) states that the *Barambidy* group numbered 58 people, and the number of *Gulidjan* was only about 40 (Murray 1853), so that the numbers in the forest would be less than 100, at least in the northern section. Within the forest koala, possum and wallaby were hunted, the latter with 'dogs and spears' (Dawson 1881), and probably with the aid of extensive fires. Vegetable food was derived mainly from species from wet places, as for the coastal areas (q.v.). The main staple root foods of the plains dwellers, Yam-daisy *(Microseris scapigera)* and Pink Bindweed *(Convolvulus erubescens)* were probably of less importance.

The relatively low animal populations and difficulty of movement probably restricted utilization of the tall open forests in the wetter parts of the Ranges. However the utilization of the pith of tree ferns as a carbohydrate source is reported from other areas of Victoria, and aboriginal groups may have deliberately penetrated the forests to exploit stands of these species. Camp sites at Gellibrand and a burial cave near Barramunga (Massola 1966) support this possibility.

The forests also supplied raw materials for important implements. James Dawson (1881) mentions the rare and valuable *bandid* spears (probably from *Phebalium squameum*), which were exchanged for fancy *malin* spears from the interior (NW. Victoria). Grass-tree *(Xanthorrhoea)* flower stalks utilized to make *narmal*, light spears, were also traded. Seashells and red ochre were obtained from the coast. These articles were exchanged for others at the great meetings at Mt. Noorat. Buckley stated that *dealwark* firesticks were used by the *Wadjawuru* (Morgan 1970); these were made of Austral Mulberry *(Hedycarya angustifolia)*, a species of the mountain fern gullies. The relatively recent discovery of a dolerite axe quarry at Gellibrand is additional evidence for the economic importance of the Otway Region in aboriginal times. (Massola 1966).

Despite penetration of the fringe of the Otway Ranges, the denser forests seem to have been regarded as 'dangerous places'. Dawson mentions that *Burdgurug*, a 'female devil' as tall as a gumtree, inhabited the top of the Cape Otway mountains, and was held in great dread by the Aborigines.

THE EUROPEAN INVASION

European pastoralists moved swiftly into the Otway Region from the initial bridgehead in the Melbourne-Geelong area. By August 1837 settlement had extended along the Barwon to the western boundary of the *Wadjawuru* (Rickett's Station near Birregurra) and by 1838 the best of the *Gulidjan* territory was fully occupied. The main centres of the *Djargurd* in the Pirron Yaloak, Purrumbete and Allansford areas were settled between 1839 and 1840. Stations had extended along the coast to Port Campbell from the west, and to Aireys Inlet from the east by 1842. In subsequent years stations were established further into the inland foothills, reaching Forrest by 1847 (Billis & Kenyon 1932).

The initial reaction of the aboriginal people was to try to obtain as much of the novel material wealth of the Europeans as possible — iron tomahawks, food, clothing and livestock. Local groups were gathered together by messengers to share in the expected bounty (Morgan 1967, Corris 1968). Thus Aborigines well beyond the limits of settlement became involved in clashes with the advancing Europeans. The majority of the *Wadjawuru* of the Otway Region probably gathered at the embryonic town of Geelong between 1836 and 1837, while *Gulidjan* and *Djargurd* groups began to raid the new stations, initially in the Birregurra area, and later at Colac (Lloyd 1862, Murray 1853, McLeod 1853). Armed parties of settlers pursued the raiding parties and violent clashes followed. Inevitably the Aborigines were defeated and their weapons, rugs and huts destroyed. The Stony Rises at Pirron Yaloak were used as refuge following such raids, as it was difficult terrain for the mounted settlers. Initially the settlers exercised a degree of restraint, but in 1839 a new phase began, involving brutal massacres of entire camps. A desperate struggle developed on the Basalt Plains west of Lake Corangamite. Doubtless the *Djargurd* people of the Otway Region were drawn into the fighting, but information on this point is lacking. In the east, as the squatters pushed along the Barwon south of Birregurra, Aborigines from the Otway coast began to raid the stations. In 1841, after the killing of some surveyors, one group was pursued and massacred. As late as 1847 another group from the coast was exterminated at the mouth of the Aire River in retaliation for the death of a shepherd south of Colac (Hebb 1970, Osburne 1937).

Their attempts forcibly to dispossess the settlers defeated, the Aborigines found their hunting-and-gathering curtailed by both direct intervention and the alteration of the environment by grazing stock. Rev. Joseph Orton (1839) commented at Colac: 'Poor creatures the settlers have driven them to a state of starvation so far as their natural food goes. The kangaroo has abandoned the spot — the root on which they feed has been destroyed by the sheep and placed in this destitute state the settlers (as one did today) call them a great nuisance.' The Wesleyan Mission at Buntingdale south of Birregurra, established in 1839, failed to halt the destruction of the aboriginal people. There was fighting between the disparate groups gathered together there, and the Aborigines refused to adopt the settled and orderly life-style required of them by Rev.

Tuckfield. On surrounding stations the Aborigines were harassed: '. . . they are driven from this favoured haunt and from that other favoured haunt and threatened if they do not leave immediately they will be lodged in gaol or shot.' (Tuckfield 1840). Aboriginal women were abducted and prostituted (Tuckfield 1841), and venereal disease spread rapidly resulting in death or sterility (Hurst 1841, Corris 1968). The same pattern of depopulation doubtless applied to the western part of the Otway Region, but specific information is lacking.

By 1857 only 16 *Gulidjan* survived (Corris 1968), and a census five years later showed 51 *Djargurd* living west of the Hopkins at Allansford ('Tooram') and Camperdown (Osburne 1937). Framlingham Mission Station (est. 1864) finally became the home of many of the remaining aboriginal people, particularly after 1879, although a number of old people refused to abandon their traditional country. At present Framlingham is the only part of Western Victoria remaining in the hands of the original inhabitants.

REFERENCES

ADDIS, E. B., 1841. Letter to the Superintendent of Port Phillip, in *Votes* and *Proc. N.S.W. Legislative Assembly*, 1843.

BILLIS, R. V. & KENYON, A. S., 1932. *Pastoral Pioneers of Port Phillip*. 1st ed., Macmillan, Melbourne.

CORRIS, P., 1968. Aborigines and Europeans in Western Victoria. *Occ. Pap. in Ab. Stud. 12*. A.I.A.S., Canberra.

DAWSON, J., 1881. *Australian Aborigines, etc.* George Robertson, Melbourne.

GOODALL, W., in BROUGH-SMYTHE, R., 1972. *The Aborigines of Victoria*. Vol. 1, 2nd ed., Currey and O'Neil, Melbourne.

HEBB, I., 1970. *The History of Colac and District*. Hawthorne Press, Melbourne.

HOWITT, A. W., 1904. *The Native Tribes* of *South-East Australia*. Macmillan, London.

HURST, B., 1841. Report of the Wesleyan Society's Mission to the Aborigines of Port Phillip, in *Votes and Proc. N.S.W. Legislative Assembly*, 1843.

LLOYD, G. T., 1862. *Thirty-three years in Tasmania and Victoria*. Houlston & Wright, London.

MANIFOLD, T., 1853, in BRIDE, T. F., 1969. *Letters from Victorian Pioneers*. 2nd ed., Heinemann, Melbourne.

MASSOLA, A., 1966. Notes on the Aboriginal antiquities of the Colac District. *Vict. Nat.* 83: 125-136.

MATHEWS, R. H., 1904a. The Native Tribes of Victoria, their languages and customs. *Proc. Am. Philos. Soc.* 43: 54-65.

————, 1904b. Language of the Wuddyawurru Tribe, Victoria. *Zeit. für Ethn. Berlin*. 36: 729-734.

MORGAN, J., 1967. *The Life and Adventures of William Buckley*, 2nd ed., Heinemann, Melbourne.

McLEOD, J. N., 1853, in BRIDE, T. F., 1969. See Manifold, T. above.

MURRAY, H., 1853, in BRIDE, T. F. *(ibid.)*.

OATES, W. J. & OATES, L. F., 1970. A Revised Linguistic Survey of Australia. *Aust. Ab. Stud.* 33. A.I.A.S., Canberra.

ORTON, J. R., 1839. *The Journal of Rev. J. Orton*. Photoprint copy, La Trobe Library.

OSBURNE, R., 1937. *The History of Warrnambool, etc.* Chronicle Printing Co. Ltd., Prahran.

PARKER, E. S., 1844. *Great Britain Parliamentary Papers*, 34: 312-316.

ROBINSON, G. A., in KENYON, A. S., 1928. The Aboriginal Protectorate of Port Phillip. *Vict. Hist. Mag.* 12: 134-171.

STANNER, W. E. H., 1965. Aboriginal Territorial Organisation: Estate, Range, Domain and Regime. *Oceania* 36: 1-26.

THOMSON, A., 1836. Questions submitted by Mr. Stewart for Bourke, Governor-General, in CROLL, R. H. and WETTENHALL, R. R., 1937. *Doctor Alexander Thomson*. Roberton & Mullens, Melbourne.

TINDALE, N. B., 1940. Results of the Harvard-Adelaide Universities' Anthropological Expedition; 1938-39: Distribution of Australian Aboriginal Tribes: A Field Survey. *Trans. R. Soc. S.Aust.* 64: 140-231.

————, 1974. *Aboriginal Tribes of Australia*, 2 vols. A.N.U. Press, Canberra.

TUCKFIELD, F., in CARY, J. C., 1898. Vocabularies of the Geelong and Colac Tribes, collected in 1840. *A.A.A.S. Rpt.* 7: 840-872.

————, 1840, *The Journal of F. Tuckfield*. Photoprint copy. La Trobe Library.

————, 1841. Letter from the Superintendent of the Wesleyan Mission at Geelong, to his Honor the Superintendent of Port Phillip, in *Votes and Proc. N.S.W. Legislative Assembly*, 1843.

WARNER, W. L., 1937. *A Black Civilisation*. Harper, New York.

WEDGE, J. H., 1835. *The Field Book of J. H. Wedge*. Xerox copy, La Trobe Library.

WURM, S. A., 1971. Classifications of Australian Languages, including Tasmanian. *Current Trends in Linguistics* 8: 721-778.

2

EVOLUTION OF THE OTWAY COAST, AUSTRALIA, FROM THE LAST INTERGLACIAL TO THE PRESENT

by EDMUND D. GILL*

ABSTRACT: The Otway Ranges consist of uplifted non-marine Lower Cretaceous arkoses (greywackes) and siltstones. The Southern Ocean swell supplies a strong energy input, which is concentrated within a tidal range of 1.52-1.75 m. The Last Interglacial sea cut platforms and built boulder beds, which were covered with colluvium when the sea retreated during the Last Glacial. The return of the sea in the Holocene cut the platforms existing now, and produced the modern generation of boulder beds. Some quantified data are provided for the rocks and their rates of erosion. These have engineering applications. When the sea cuts away the toe of the steep coastal slope, it creates instability and slips occur. The same happens when the toe is removed in roadmaking. The history of a slip at Eastern View from the Last Interglacial to the present is outlined.

ORIGIN OF OTWAY ROCKS

'A study of change as opposed to a description . . . . . . events of change rather than events in change'.
(A. R. H. Baker, 1972)

Events that occurred over 100 million years ago when Australia was still attached to Antarctica (Gill 1975) have determined important aspects of the geochemistry, lithology and structure of the Otway rocks, influencing how they react in the present shoreline situation. In the Lower Cretaceous over 2 km thickness of sediments were laid down rapidly in a basin or rift valley to which the sea had no access. These sediments are highly feldspathic because: (i) Derived from feldspar-rich rocks, e.g. granodiorite, pieces of which occur in the sediments. (ii) Buried rapidly in the sinking basin, so permitting but minimal weathering, as also did (iii). The low ambient temperatures (probably seasonal freezing).

The flatland ecology was dominated by lakes and swamps. No paleosol has been found in the Otways. The sediments were of two main types:

1. Sand-sized, yielding the present arkose or greywacke (the classification depends on the definition accepted for these terms). The amount of arkose falls off northwards, suggesting a source to the south.
2. Silt-sized, giving the present siltstone, which on the present coast reacts quite differently from the arkose.

These two lithic types represent two energy levels. Both are stratified, with the higher energy beds having current bedding. Fern-conifer forests covered land surfaces and swamps, yielding a rich record of fossil plants, which in places form coal. Animal fossils are rare, especially vertebrates, which reflects the nature of the environment (Waldman 1971, Gill 1972a). According to the geochemistry of the environment, concentrations of calcium carbonates, iron carbonates and such occurred while the rocks were still horizontal. These produced the characteristic concretions of the Otway Group that presently influence the course of marine erosion on parts of the coast.

This Otway Basin system was terminated by the uplift of the rocks into a massive elongate dome (Medwell 1971) with marginal folds and faults accompanied by much jointing (Pl. 2, fig. 1), except where large lenses of arkose proved too competent to allow these to develop very far. The earth movements concerned appear to be part of a series that led to the separation of Australia from Antarctica.

A journey along the coast gives the impression that the arkose completely dominates the stratigraphic succession, but bores have proved otherwise (Edwards & Baker, 1943). The reason is that the siltstone is eroded at twice the rate of the arkose (Gill 1973a), so that the former occupies the negative geomorphic structures such as the valleys and bays, and is therefore largely out of sight. A siltstone quite different from the usual one occurs at Cape Otway. It is darker, harder, and does not decrepitate, forming coastal platforms more like those of arkose. Dr. E. R. Segnit kindly examined slides of this rock, and pointed out that it is predominantly quartzose, and has 'feldspar (near albite) and

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PLATE 1

Aerial view of Otway coast from Big Hill Creek (top) north-east towards Point Castries (Grassy Creek). The Great Ocean Road follows high ground to Big Hill Creek, then continues along beach in front of Cathedral Rock (top of photo) towards Cross Springs and Lorne. The view spans about 1.5 km of coast. Note shore platforms, often with beaches. (Keith Cecil photo.)

chlorite, with some calcite and mica'. It lacks cleavage. The formation is separated from the normal Otway rocks by a fault; it is considerably faulted, jointed, and secondarily infilled with calcite. Fossils to check its age were sought but only fossil wood too decomposed for identification and a seam of coal about 1 cm thick were found.

PALAEOECOLOGY

The extensive flatland, with its accumulation of km^3 of sediments in the sinking basin, infers an extensive highland as source. The abundant feldspar infers considerable outcrops within that highland of feldspar-rich rocks, such as granodiorite. To provide transport of such great quantities of sediment from the highland to the lowland, and to form such extensive lakes, a high effective rainfall must have existed along with large rivers.

Australia was then still attached to Antarctica, and the palaeomagnetic measurements show that the south pole was south-east of Tasmania (Wellman, McElhinney & McDougall 1969). Palaeontologic and oxygen isotope evidence show that the temperature gradient moved from very cold in the south-east to tropical in the north-west of Australia (Gill 1972a). The presence of extensive forests is consistent with a cold but not frigid climate. The occurrence of drop pebbles, of masses of unsorted gravel, of rock slabs up to many metres in diameter with sharp edges and broken pieces floating in a matrix of different rock, indicate ice transport from seasonal freezing followed by thawing. Waldman (1971) has so interpreted varves at Koonwarra in South Gippsland which have plants, insects and fish but without bioturbation. A climate with seasonal freezing would reduce weathering, and so help to preserve the high percentage of feldspar; it would also depress evaporation and so make the rainfall more effective.

I have seen no paleosols in the Otways, no stumps in position of growth (except one in a transported block, which is not relevant here) and no tree trunks, although all of these occur in rocks of the same age in Gippsland. These facts are consistent with a greater development of lakes in the Otway region of the Lower Cretaceous, and of swamps in the South Gippsland region. This could account for the development of coal in economic quantities in South Gippsland but not in the Otways.

The widespread occurrence of siderite in the Otway region, but not (as far as I know) in the Gippsland region, is of ecologic significance in that this mineral occurs only where the pH is about neutral and the Eh just below 0.0. Probably the greater amount of vegetal matter (as shown by the coal) in South Gippsland kept the pH too low for siderite to form.

PRESENT OTWAY COAST

'The problem of reconciling both aspects of time – as setting and as sequence'. (A. R. H. Baker, 1972)

As the Otway Range is a horst, the hills come down to the sea, forming cliffed headlands and extensive shore platforms (Pl. 1). Sandy beaches occur in bay heads where the larger rivers debouch. The spring tidal range increases from west to east, viz. 1.52 m at Apollo Bay to 1.75 m at Lorne. Siltstone shore platforms consist of a low ramp graded to L.W.L. Arkose platforms consist of intertidal and supratidal planated areas with irregularities caused by ramparts (Gill 1972b) and 'islands' of higher rock often steep-sided or stepped (Jutson 1949, 1954). Shore platforms are well developed because:

1. The south-west swell provides a high energy input.
2. The energy is concentrated in a small tidal range.
3. The Flandrian Transgression reached its peak about 6,000 years ago in Australia (Thom & Chappell 1975) thus providing a greater time for formation than in some other areas which had the Holocene sea level peak at 3,500 years or even later.

Where the spurs transect the coast, two-storied cliffs usually occur. Indeed the hinterland is an important aspect of coastal organization because its elevation can determine whether cliffing occurs or not, and so affect

(a) The rate of coastal retrogradation

(b) The degree of weathering of the rocks sectioned by the sea, i.e. if the sea is below the weathered zone. On a low coastline the sea sections the weathered zone. But on the Otway coast most of the platforms are in unweathered rocks with oxidation only in the large joint planes. Local weathering is usually due to the oxidation of pyrite, which occurs both as nodules and as plates in open joint planes.

(c) The amount of rainfall. The Otway Ranges are a rain trap, with much water available to erode sediments and to transport them.

Four unusual features of the Otway coast are:

1. *Tafoni*, both honeycomb weathering (on sloping to vertical and overhang surfaces usually), and cavitation weathering (recesses in cliffs and such). Honeycomb formation can occur with exceptional rapidity in Otway arkose in that it has developed in sea walls built of this rock in 1943 and 1949 respectively.

2. *Concretions:* These are cemented by calcite, siderite and siderite/ankerite. Some occur in heavy mineral bands (which oxidise to limonite). Nodules of pyrite (which oxidises to goethite) also occur. See Gill, Segnit and McNeill 1977.

3. *Boulder formations:* Significant accumulations of boulders occur at many places. There is some correlation between the occurrence of rivers and the incidence

of boulder beds, showing that the rivers are a source of supply. Boulder ramps occur in the following situations: (a) At the back of present beaches and platforms, usually in a trap consisting of a jutting headland or smaller rock mass (Gill 1973b, Pl. 6).
(b) In back beach locations, where they are covered with sand capped by a thin soil and vegetation (Gill 1972b, Fig. 3). (c) In ramps now emerged and vegetated, but containing shells (Gill 1972d, Figs. 10-11). (d) In Last Interglacial boulder ramps on emerged shore platforms, sometimes weathered, and often covered with colluvium capped by soil (Gill 1972d, Figs. 13-14, Plates 2-3).
4. *Ramparts:* These are explained as a function of marine differential erosion (Gill 1972b).

LAST INTERGLACIAL COAST

The shaping of the coast during the Last Interglacial appreciably influences the development of the present coast, since in all coastal evolution there are marked inheritance factors. The best recorded past shoreline in Australia (and indeed in the world) is that of about 125,000 years ago, which in stable areas stands at about 7.5 m above the present. On the exceptionally stable coast to the west at Warrnambool, where even the Miocene marine strata are still horizontal, this shoreline stands at 7.5 m, and can be traced for long distances along the coast of Western Victoria. It has been traced through to the Otways where there are numerous emerged shore platforms and boulder beds at approximately this elevation. On the Otway coast from Eastern View to Apollo Bay 19 such sites are listed (Gill 1974) and others are known to the author, e.g. from the Parker River, Cape Otway and Point Flinders areas.

The platforms on the Bass Strait part of the Otway coast are usually covered with colluvium which can be as much as 20 m thick. The colluvium is capped by a dark grey to black sandy loam up to 0.5 m thick. The colluvium is Last Glacial because it accumulated after the retreat of the Last Interglacial sea.

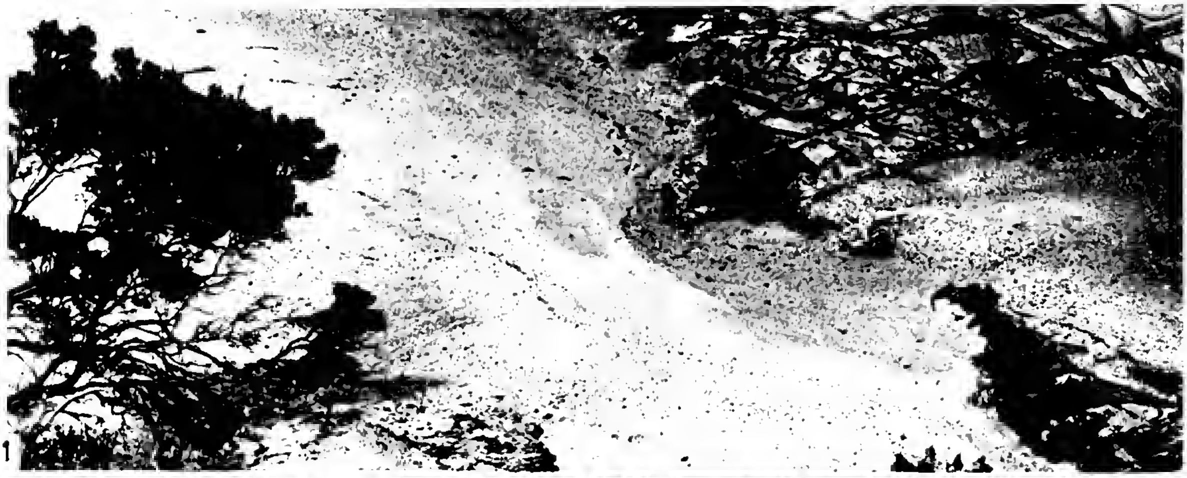
An example of emerged platform, boulder bed and colluvium is now described from the long roadcut on the Ocean Road on the north-east side of the Cumberland River (Pl. 2 and 3). Part of this section fronts the ocean and part the small estuary of the Cumberland River. The roadcut is 3 to 21 m high, and descends slowly from the Lorne end to the river end, so that the section progressively passes through the fossil pebble bed, and then the platform with pebble bed above. The surveyed section is about 366 m long and finishes at the edge of the concrete ford where the old road crossed the river. In the middle of the section the road turns into the estuary, and at this point bedrock rises through the section; it is a small headland or a former rock stack. The total fall of the section line is 21.5 m. As the energies on the river front are less than those on the ocean front, the boulders there do not reach so large a diameter. The Cumberland River boulder bed is the longest seen so far, and as it covers various lithologies (arkose in thin and thick beds, and siltstone) and two environments (open coast and estuary), it can be deduced that the Last Interglacial sea made its impress on the shore in much the same way as does the modern sea. There is variation of platform height and lithology as on the existing coast. Taking this into account, the emerged platform is of the order of 7.5 m above the present ones. Numerous platforms occur at about 4 m and some near Warrnambool have *Ninella torquata*, showing they are Last Interglacial (Baker & Gill 1957, Gill & Amin 1975). Since the platforms were formed, river channels have been incised below sea level, showing that these platforms are older than Last Glacial. Gill and Amin (1975) dated such platforms at Sandy Bay as about 110,000 years old, and interpreted

PLATE 2

FIG. 1—Coast south-west of Boggaley Creek, south-west of Lorne. Note strong jointing of arkose shore platform and its effect on geomorphology. The platform continues under the beach. On the left, at the foot of the cliff is a miniature embayment with vegetated deposits of boulders, shells and calcarenite. The deposit is a few hundred years old, but is now being eroded by the sea.

FIG. 2—Road cut facing sea on north-east side of mouth of Cumberland River. Note (a) 3 m of Last Interglacial shoreline boulder bed covered by (b), over 1 m of fine colluvium with angular rock fragments, and covered in turn by (c) a thick bed of colluvium with large angular blocks. At the top is fine colluvium (d) and again with some rounded boulders, apparently derived from a higher shoreline. A uniform sandy loam (e) covers the colluvium. Height of section above road is 21 m.

FIG. 3—Close up view of boulder bed at foot of section shown in Fig. 2. The seaward facing section has boulders up to 1 m diameter, which is much larger than the maximum size for the bed facing the estuary, because of higher energy status.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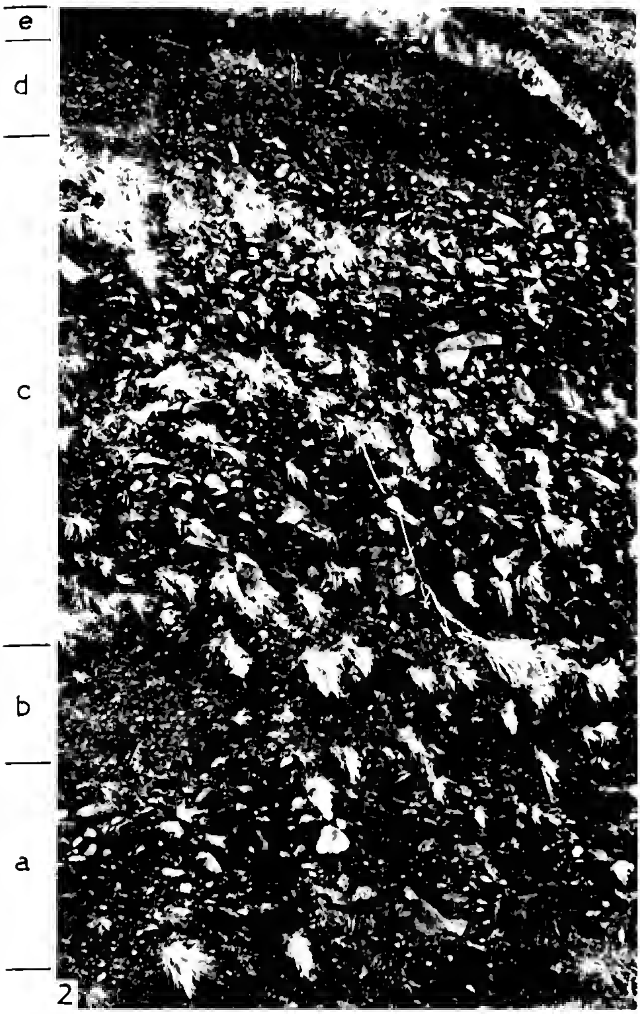
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them as a stage in the retreat of the Last Interglacial sea.

CHRONOLOGY

The chronology of the platforms has been investigated by three approaches:

1. *Eustasy:* The platforms and associated deposits are emerged beyond reach of the present waves, yet are related to the present coast and constitute the previous major cycle. After this shoreline was established, the sea retreated below the present level, so that river channels were cut deep below it.

2. *Stratigraphy:* The Holocene shorelines contain carbonate shells whereby they can be dated. They are considerably younger than the emerged platforms and boulder beds from which all carbonate has been leached, except in the Cape Otway area where they are covered with aeolianite. It is hoped eventually that shells suitable for U/Th assay will be found under this formation. The aeolianite is immature, but with a mature terra rossa at the surface, now commonly eroded to reveal the calcrete B horizon. The immaturity of the aeolianite capped with a mature terra rossa are the characteristics of the Last Interglacial aeolianite at Warrnambool (Dennington Sand) which has been dated at 125,000 years (Gill 1967).

3. *Extrapolated chronometry:* The series of emerged platforms under discussion can be traced from Port Fairy near Warrnambool round the Otway coast to Eastern View at approximately the same level. At Port Fairy this platform has been dated by U/Th at 125,000 years (Gill 1967), and also proved to be beyond the range of radiocarbon dating. The continuity of this shoreline at about the same level round the Otway coast shows that little or no tectonic movement has occurred in that period of time.

EVOLUTION OF THE OTWAY COAST

The Great Ocean Road (Pl. 1) provides an excellent, more or less continuous section of the coastal rocks from Eastern View to Apollo Bay. This reveals the great quantity of Last Glacial colluvium covering this emerged shoreline and filling in old gullies (Pl. 2, fig. 2). From this section three processes in the evolution of this coast since the Last Interglacial can be inferred:

1. The terracing of the steep terrain by the Last Interglacial sea at about 7.5 m above present sea level, and its retreat (probably through a 4 m stage) leaving elatforms and boulder beds.

2. The retreat of the sea far out on the relatively flat continental shelf during the Last Glacial, leaving the old shorelines as part of the terrestrial terrain. The emerged shore face had been weakened because the toe of the steep slopes was cut away. Sub-aerial agencies operated to re-establish stability by combing down the coastal face, so that colluvium covered platforms and boulder beds, filling in also the coastal gullies.

3. From 20,000 to 6,000 years ago the sea was advancing back over the plain of the emerged continental shelf (the Flandrian Transgression), and in the subsequent comparative stillstand has cut the present platforms and cliffs. At the same time a soil was forming on the colluvial slopes. In the past 6,000 years platforms and cliffs have been cut, channels have dissected the platforms and new boulder beds have accumulated. Work has also been done on the boulder budget. The rivers have delivered new boulders to the coast. Erosion has caused some to be inherited from the Last Interglacial deposits (Pl. 2 and 3). Some have come as concretions eroded out of the cliffs, and some have been carried below sea level where they become covered with marine growth and are no longer active.

QUANTIFICATION OF COASTAL PROCESSES

'To a considerable extent, advances in the understanding of processes shaping spatial patterns depend upon our being able to measure these processes.' (A. R. H. Baker, 1972).

Quantification has done more to increase understanding of coastal processes than any other study method. It makes thinking precise, narrows the range of possible interpretations, and itself prompts new ideas.

1. *Rates of retrogradation:* In the common environment of west Victorian climate and marine regime, the mean rates of retrogradation achieved in four different rock types during the past 6,000 years since the sea came to its present level are (Gill 1973a): Lower Cretaceous arkose 0.9 cm/yr; Lower Cretaceous siltstone 1.8 cm/yr; Last Interglacial aeolianite 4.0 cm/yr; Penultimate Glacial basalt 0.

These figures show that we deal with quite different kinds of coast, and quite different profile ages. An Otway siltstone profile changes 100 per cent faster than an arkose one. On the other hand, the profile on the basalt is the same as for the Last Interglacial: erosion has occurred in channels and other high energy areas, but the overall geometry is unchanged because the original basalt flow profile is still there and surface features of the flow (such as tumuli) are still preserved. Last Interglacial fossils lie in many vertical and horizontal joints in the supratidal zone. By contrast, if the average aeolianite platform is 20 m wide, then in the past 6,000 years twelve such platforms have been formed and all destroyed except the existing one, and this is only 500 years old. Present platforms are of course in all stages of evolution, but the foregoing figures give the scale of change. No ancient features are retained on existing aeolianite platforms; they are too young. However, it may transpire that the small differences that do remain are significant, i.e. they may record recent small oscillations of sea level.

2. *Erosion rates:* On March 8, 1971, the arkose ramparts on the south-west side of the mouth of St. George River were surveyed, and yellow oil paint discs about 5 cm in diameter were painted for control on three high points, viz. the top of the highest rampart at 4.7 m above L.W.L. [*x*], the top of a lower rampart behind it at 3.9 m [*y*], and the top of a large boulder on the ramp of debris from roadmaking at 4.1 m [*z*]. This section was published (Gill 1972b, Fig. 5). A year later (March 11) I was surprised to discover that while discs *y* and *z* showed no change, there was a noticeable reduction of the arkose surface at disc *x* on the south side, although this was the highest outcrop and so presumably the most resistant bed. By November 6, 1973, disc *x* was reduced to a series of patches, and reduction of rock surface had occurred all round the disc. By this time there was also some rock reduction on one side of disc *y*. By May 19, 1975, disc *x* was reduced to one irregular patch 2 x 1.2 cm, and the maximum reduction of surface was 3 mm. No site would receive maximum erosion all the time since the Flandrian peak 6,000 years ago, but if it did, the reduction would be of the order of 4.5 m! This is sufficient to show that a considerable reduction of rock surfaces has occurred. At the end of this four years of observation disc *z* was still bright. This indicates that the reduction of the paint and surrounding rock was essentially a function of erosion and not weathering.

In 1961 a cut was made through the supratidal platform north-east of Stony Creek, Lorne, to insert a sewer outlet. It was concreted over level with the platform. A pool with boulders in it beside the outlet but behind the rampart was cemented over, but has now been broken up, and pieces of rock and concrete widely distributed. In the vicinity of the cut, and also near Stony Creek where access was gained by trucks to the platform, blobs of concrete were left. Erosion since 1961 has reduced the surrounding platform so that the concrete stands up like miniature mesas. In this instance wear has increased by the constriction of swash between the mesas. The amount of wear varies, but the maximum is the surprising amount of 2.5 cm. Also survey marks cut in the platform were considerably diminished after one year, so much so that they were difficult to find.

These results show that on exposed sites arkose abrasion is considerable, but very variable. Thus it would be imprudent to propose that existing exposed Otway supratidal platforms preserve the height of a mid-Holocene sea level, unless specific evidence had proved it. Nevertheless, they could be relics of such platforms now reduced in height.

3. *Rate of honeycomb formation:* That this process can take place more rapidly than previously known is demonstrated by two arkose sea walls built in different areas (but in the splash zone) in 1943 and 1949, and now having quite extensive honeycomb (tafoni) on them (Pl. 4, Fig. 3).

4. *Lithology:* Edwards and Baker (1943) record that 60-70 per cent of the Otway rocks are arkose, and although thick beds are rare, the thickest known is 122 m. The mineral grains are mostly 0.25-0.5 mm diameter. The arkose consists of 10-15 per cent quartz, and 23-35 per cent feldspar, i.e. 2-2.5 times more abundant. This is one reason why the rock has a high erosion rate. The porosity is 2 per cent when fresh, 10 per cent when weathered. The calcareous concretions are 25-49.3 per cent carbonate, but the matrix has only a few per cent. The siltstones have about 33 per cent kaolinite.

5. *Rates of marine quarrying and plucking:* The degree to which this occurs depends on the energy of the sea at the site of the process, and the frequency of the bedding planes, joints and faults that facilitate removal. Quarried blocks fall into channels, over the platform edge clifflet, or are thrown on to the platform and moved to the back, whence they usually find their way into a channel. Plucked blocks are lifted out of the surface of the platform, and therefore follow a similar route. These blocks in transit erode the platform, and sometimes the cliff also. During storms, blocks from the intertidal zone are thrown up on to platforms from time to time. These 'rocks out of place' can be recognised by their biota, e.g. calcareous worm tubes (Gill 1972c). Blocks with abraded honeycomb and worm tubes originated in the spray zone, lay between M.S.L. and L.W.L., then were hurled up to the platform. Oxidation/reduction patterns assist tracing the journey of such blocks; also they can be labelled with concretions when they come from a bed with such structures. Blocks from roadmaking are usually fully oxidised, and are unmistakable when they have marks pierced by a jackhammer!

On the platform south-west of Point Sturt, plucked blocks were weighed and it was estimated that since the Flandrian Transgression 300 tons of such material had been removed from that platform (Gill 1971). The weight of quarried rocks would be many times larger because the blocks are usually much heavier. On January 21, 1972, I observed that a block had been quarried from the south-west edge of the supratidal platform south-west of Point Sturt, and had been carried 2 m into an intertidal position. The volume of this arkose was about 0.5 m^3 and so weighed about a


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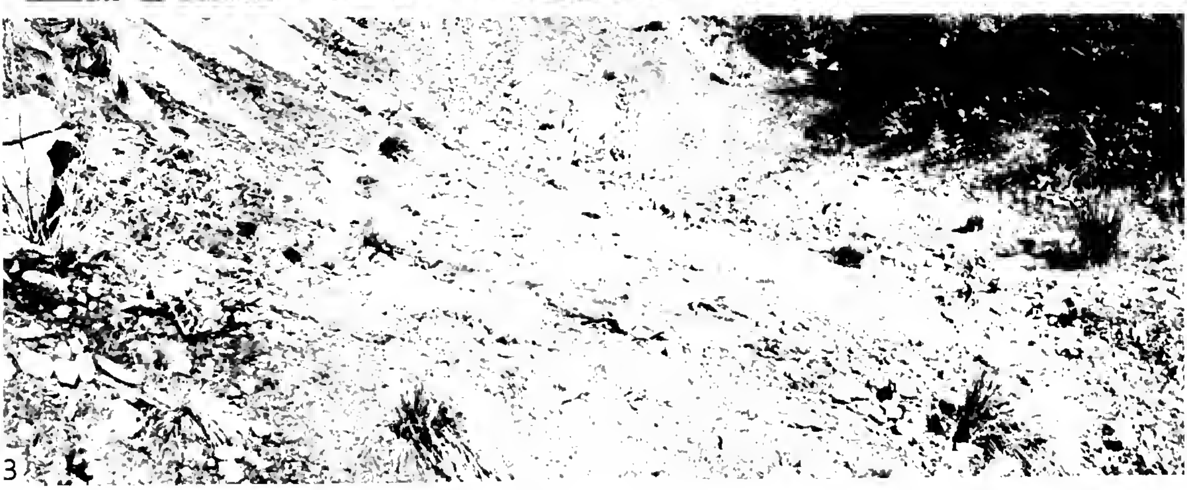
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tonne. On November 6, 1973, the block was in the channel, abrading and being abraded. The freshly exposed area from which the block came was occupied by young limpets at an intensity of about 300 per m^2. If for the 6,000 years since the Flandrian Transgression one such block on the average was quarried each year, then 6,000 tonnes of rock that had occupied 3,000 m^3 would have been removed.

Many rocks are cast ashore each year from M.L.W. or below, attached to kelp (*Durvillea potatorum*) holdfasts (Gill 1971, Pl. 1, Fig. 1).

6. *Energy of waves:* One of the most important quantifications awaiting achievement is the measurement of the flux of energy from the open ocean to the shore. A method has been devised, but the instrumentation is expensive. At Lorne on May 16, 1975, big seas were running due to an extra strong south-west swell. A local storm was running at the same time, but was coming offshore and so blew spindrift seaward from the tops of the waves. At the supratidal platform north-east of Stony Creek, huge waves were crashing on the seaward side of the ramparts, then hurling masses of highly turbulent water shorewards. As the platform had been surveyed it was possible to calculate that each large wave loaded the platform with some 12,000 tonnes (12,000 m^3 of water) travelling at over 20 km/hr. When the sea subsided, it could be seen that large blocks of arkose up to a tonne in weight had been ripped from the rampart and hurled to the back of the platform. This energy from a subantarctic storm conveyed by swell modified the coast at Lorne on that day.

ENGINEERING GEOLOGY

1. *Coastal roads:* Limited success with shoreline installations will continue until shoreline processes are understood, in particular until coasts can be mapped in terms of energy. Engineers have asked how close the Great Ocean Road can be built to the shore so as to give maximum views, yet protect the investment. As Otway siltstone has only half the resistance as arkose on the coast, it is an obvious source of weakness. Thus arkose forms all headlands; there is no headland of siltstone (with the special exception of Cape Otway already mentioned). Where the two occur in alternate strata, the arkose has not its usual strength because it has a weak support. Where bedding planes, faults, crush zones, joints and such structural weaknesses occur, the resistance of arkose is decreased; where concretions exist, the resistance is increased (Gill & McNeill 1973). On the other hand, in a roadcut, siltstone decrepitates as a heap of small pieces, while arkose tends to break away in large pieces which are a danger when falling, and a hazard on the roadway.

It was mentioned earlier that colluvium infilling old gullies occupies a great number of roadcuts. But there are two kinds of colluvia. One is sandy, oxidised, contains masses of angular arkose of a great range of size, and is liable to slip when charged with water. The other kind is grey to faintly mottled, i.e. little oxidized, and clayey. The two types are of the same age, and their differences are due to being derived from the two lithic types — arkose and siltstone respectively. Thus the latter is usually in the valleys and the former around the headlands. The sandy colluvium may have seepage issuing from it, but the clayey colluvium is an aquaclude. It can be used for inferring the presence of unseen siltstone bands in the bedrock.

2. *Coastal slips:* Each transgression of the sea has cut away the toe of the coastal slopes and caused slips. Slippage can be slow, in the form of colluvium, or sudden. The cutting of the Ocean Road has removed the toe of coastal slopes in the same way, and so caused slips (Pl. 4). At the same time the clearing of the hillsides has in many areas caused increased instability by increasing rate of water runoff and removing root anchorages. Slips may be in the bedrock (as at Windy Hill between the Sheoak and Cumberland Rivers), or limited to the unconsolidated Cainozoic rocks above (Evans & Joyce 1974, Joyce & Evans 1976). Comment will be limited here to one example of the second type of Eastern View.

In December 1973 the Ocean Road east of Spout Creek was widened and straightened. This work revealed a Last Interglacial shore platform cut in unoxidized Lower Cretaceous arkose, and covered by a boulder bed (Pl. 4, fig. 1). Above this was up to 2 m of thin layers of sediments (the top one with a dip of 15° seaward) which were interpreted as layers of hillwash. Above was some 5 m of slip material, covered with a

PLATE 3

FIG. 1—Ocean Road cutting facing estuary of the Cumberland River. Emerged shore platform with well rounded boulders and pebbles on it. This arkose platform varies in height as modern ones do, but part of it was surveyed as 7.5 m above L.W.L. Scale: 1 m rule with top at platform level.

FIG. 2—Close up view of boulders on platform. Scale: 1 m rule.

FIG. 3—Same roadcut, but near river end on old road. The boulder bed has been quarried for road works. The quarry shows that the platform and boulder bed extend in to a former cliff.

grey juvenile soil such as commonly occurs on Holocene deposits. This section later collapsed, revealing that a number of small slips was involved, i.e. separate unstratified masses of clean running sand, clayey sand, sandy clay, and carbonaceous clay. In the slip material further east are many large pieces of silcrete; five were noted over 1 m in diameter and one about 5 m. This silcrete comes from a lateritic profile at the top of the range 120-200 m high and 3-5 km away (which means a declivity of about 1 in 25).

The history of the slip at the old shoreline is as follows:

(i) The Last Interglacial sea cut a cliff in the competent Lower Cretaceous arkose, and the incompetent Tertiary beds. Slips that occurred while the sea was there were washed away. The large quantity of heavy mineral sand associated with the boulder bed on the shore platform came in part from such sediments.

(ii) When the sea withdrew, hillwash covered the platform and boulder bed. By the time the sea had withdrawn to south of its present position, the area was a terrestrial environment, no longer influenced by the sea. Slips occurred from time to time in a long train from the range capped with a lateritic profile down to the coastal plain formed by the exposed continental shelf. Pieces of silcrete broken away from the ridge capping were rafted seawards by the slips.

(iii) The sea rose in the Flandrian Transgression during the period 20,000 to 6,000 years ago and at its peak it was near the old shoreline. From that level the sea retreated in a series of oscillations to its present level, leaving a narrow sandy Holocene terrace along which the Ocean Road now runs. This rise of the sea once more caused coastal instability. During the succeeding period of comparative stability, the juvenile soil was formed on the surface of the old slips. This stability lasted until the toe of the slope was once more removed, this time by the roadmakers. A more detailed study of this area could greatly improve this history with respect to both space and time.

ACKNOWLEDGMENTS

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REFERENCES

Baker, A. R. H., 1972. *Progress in Historical Geography*. David and Charles, London.

Baker, G. & Gill, E. D., 1957. Pleistocene emerged marine platform, Port Campbell, Victoria. *Quaternaria* 4: 1-14.

Edwards, A. B. & Baker, G., 1943. Jurassic arkose in Victoria. *Proc. R. Soc. Vict.* 55: 195-228.

Evans, R. S. & Joyce, E. B., 1974. Landslides in Victoria. *Vict. Naturalist* 91: 240-245.

Gill, E. D., 1967. Evolution of the Warrnambool-Port Fairy coast, Western Victoria. In *Landform Studies in Australia and New Guinea*. Ed. J. N. Jennings & J. A. Mabbutt. A.N.U. Press, Canberra.

————, 1971. Rocks plucked by the sea. *Vict. Naturalist* 88: 287-290.

Plate 4

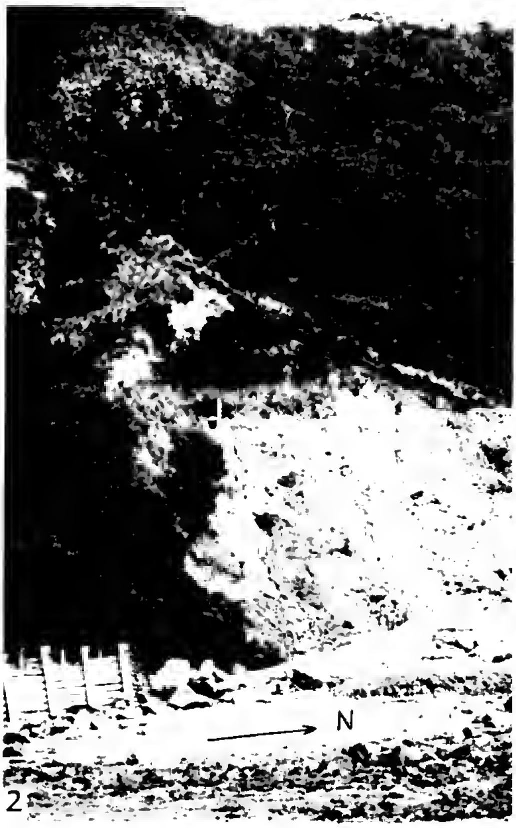
Fig. 1—December 1973 roadworks for widening the Ocean Road at Eastern View east of Spout Creek. The base of the section is Lower Cretaceous freshwater arkose in which is cut a Last Interglacial shore platform, on which is a boulder bed with pebbles and sand (with heavy minerals). Over this is about 1 m of thin layers dipping towards the shore (other side of road), interpreted as hillwash. The remainder of the thick section of Lower Tertiary sediments is a series of slips of varying lithology. Since the roadcut was made the section has slipped badly, revealing the nature of the materials. The marks on the batter are bulldozer scours and not bedding.

Fig. 2—View south of the above locality from the shore platform. In the middle of the photo is (a) the Ocean Road (marked by road posts) in jeopardy from 'Clarke's Slip'. On the left at H.W.L. is (b) a row of piles set in deep concrete and backed by logs, behind which is rock fill. At the north (right) end a stone wall (Fig. 3) extends from the wooden construction to the cliff. This work was done in 1949 to protect the toe of a slip from erosion by the sea, which it has done, and the slip is now vegetated. The large blocks of stone at the north end were placed there recently because of marine attack on the stone wall. On the right side of the photo is the latest slip. On the hillside above is evidence of a long history of slipping. The basic cause is a wide belt of siltstone, which as usual has eroded to give a platform graded to L.W.L. The siltstone suffers wet/dry decrepitation and results in unstable slopes. The road cutting has aggravated a natural instability. There is no Tertiary formation present here.

Fig. 3—Close up of arkose wall built in 1949, but now weakened by a 'nip' eroded by the sea at its base, and by tafoni in the rock. Only walls in the marine spray zone suffer this rapid development of honeycomb weathering.

(a)

(b)



———, 1972a. Palaeoclimatology and dinosaurs in south-east Australia. *Search* 3: 444-445.
———, 1972b. Ramparts on shore platforms. *Pacific Geol.* 4: 121-133.
———, 1972c. Seaside rocks out of place. *Vict. Naturalist* 89: 225-226.
———, 1972d. The relationship of present shore platforms to past sea levels. *Boreas* 1: 1-25.
———, 1973a. Rate and mode of retrogradation on rocky coasts in Victoria, Australia, and their relationship to sea level change. *Boreas* 2: 143-171.
———, 1973b. Application of recent hypotheses to changes of sea-level in Bass Strait. *Proc. R. Soc. Vict.* 85: 117-124.
———, 1974. Victoria. In ANZAAS Quaternary Shorelines Committee Report. *Quat. Newsletter* 3: 14-15.
———, 1975. Evolution of Australia's Unique Flora and Fauna in Relation to the Plate Tectonics Theory. *Proc. R. Soc. Vict.* 87: 215-234.
GILL, E. D. & AMIN, B. S., 1975. Interpretation of 7.5 and 4 metre Last Interglacial shore platforms in Southeast Australia. *Search* 6: 394-396.
GILL, E. D. & MCNEILL, N. H., 1973. The Otway coast of Victoria. *Vict. Naturalist* 90: 12-16.
GILL, E. D., SEGNIT, E. R. & MCNEILL, N. H., 1977. Concretions in Otway Group Sediments. *Proc. R. Soc. Vict.* 89: 51-55.
JOYCE, E. B. & EVANS, R. S., 1976. Some areas of landslide activity in Victoria. *Ibid.* 88: 95-108.
JUTSON, J. T., 1949. The shore platforms of Lorne, Victoria. *Ibid.* 61: 43-59.
———, 1954. The shore platforms of Lorne, Victoria, and the processes of erosion operating thereon. *Ibid.* 65: 125-134.
MEDWELL, G. J., 1971. Structures of the Otway Ranges. *Spec. Bull. Geol. Surv. S. Aust. Vict.*, pp. 339-359.
THOM, B. G. & CHAPPELL, J., 1975. Holocene sea levels relative to Australia. *Search* 6: 90-93.
WALDMAN, M., 1971. Fish from the freshwater Lower Cretaceous of Victoria, Australia, with comments on the palaeo-environment. *Spec. Pap. Palaeont.* 9.
WELLMAN, P., MCELHINNEY, M. W. & MCDOUGALL, I., 1969. On the polar-wander path for Australia during the Cenozoic. *Geophys. J. R. astron. Soc.* 18: 371-395.

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THE GEOLOGY OF THE OTWAY REGION, SOUTHERN VICTORIA

by J. G. Douglas*

Abstract: The physiography of the Otway Region, and its geological history following the mid-Mesozoic initiation of basinal deposition are outlined. Figures and Tables indicate details of stratigraphical relationships and biostratigraphical zonation. Some comments on palaeontology, structure and economic deposits are included.

PHYSIOGRAPHY

The Otway Region is physiographically divided into two major units, the Otway Ranges and the Coastal Plains. Their boundaries are relatively clearly defined, and the geology is readily observable from a fine road network, notably the Great Ocean Road which crosses the coastal segment.

The Coastal Plains extend up to 50 km inland and are bounded on the north by the Volcanic Plains (see Symposium 'The Basalt Plains of Victoria', Proc. R. Soc. Vict. Vol. 77, Pt. 2, 1964). Jenkin (1976) refers to two divisions of the plains: the Port Campbell Coastal Plains on the west and north of the Otway Ranges and the Torquay Coastal Plains to the east.

The flat or gently undulating Port Campbell Coastal Plains slope gently to the west with a steepening near the ranges and the Volcanic Plains. Height above sea level is usually below 100 m in the west, reaching to over 200 m at prominences on the east (e.g. Fergusons Hill). A prominent north-west to south-east drainage pattern south-east of Cobden on the Curdies River-Scotts Creek area has deep, steep valleys. There is semi karst topography with sink-holes near the northern margin of this area, and on the coast near Peterborough. Barred streams, for example the Gellibrand, Sherbrook and Curdies Rivers, are a feature of the Coastal Plains west of the ranges.

Abele (1971) regarded much of the Torquay Coastal Plains as the remnants of a plateau. This surface rises to the west to a maximum elevation of about 210 m near Wensleydale.

The most prominent feature of the Region is the Otway Ranges. A main north-east to south-west trending ridge runs for almost 100 km from Moonlight Head to north of Aireys Inlet in the east. Highest point is Mount Cowley (670 m) and the height of the main ridge is about 500 m for much of its length. Dissection is deep, with streams running off the ridge into the major Gellibrand and Barwon Rivers on the northern slopes, and short swift streams draining into the sea on the south. Waterfalls (e.g. Margaret, Melba, Erskine and Cumberland Falls) are prominent where these streams cross the strike of hard sandstone bands or where faulting has resulted in prominent scarps. Dissection is particularly marked near Apollo Bay along the Skenes Creek and Wild Dog Creek roads.

Shoreline profiles have been principally determined by lithology. Lower Cretaceous feldspathic sandstone and mudstone form broad shore platforms and cliffs of varying heights from Eastern View to Moonlight Head with some interruption by Tertiary sequences west of Cape Otway. Tertiary sand forms vertical cliffs at Anglesea. Older basalt forms a shore platform at Aireys Inlet. Tertiary limestone forms the famous rock stacks and indented coastline about Port Campbell. Quaternary aeolianite has a characteristic narrow shore platform and ramp of debris at Princetown and Hordern Vale. Recent dunes with shifting sandy areas back on to long beaches in several low-lying stretches.

GEOLOGY

Introduction

C. S. Wilkinson made one of the first exploratory journeys (1864) through the Otway Ranges, traversing the coast from Cape Otway to Peterborough. His report, with geological map, was published in 1865. Other early accounts of the geology of the ranges were by Krausé (1874) and Murray (1877). Sterling published several papers late last century, but little more was published until the major lithological study of Edwards and Baker (1943). Baker, in a series of stratigraphical papers (1944, 1950), mapped the westernmost Otway Ranges coastline and some of the Coastal Plains. Edwards (1962) in his final contribution

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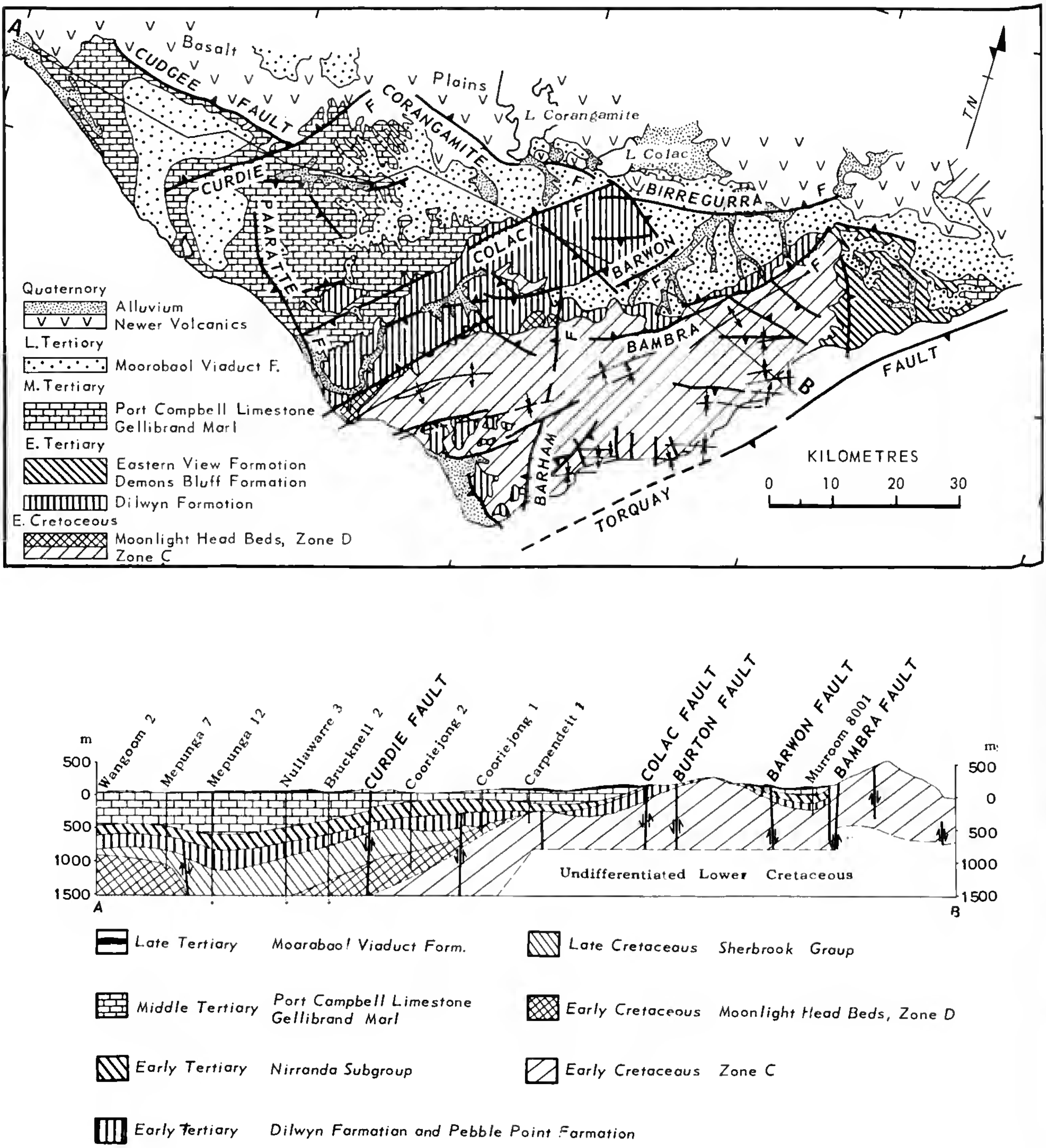

Fig. 1—Geological map Otway Region, and cross section.

Note: Cross section runs east-west, and is based on information from deep bores shown, and Otway Ranges outcrop geology. Western end A (see map) is near Warrnambool, eastern end B is at Lorne.

detailed the geology of the Lorne area, and Singleton (1967) reviewed the geology of the region. The most recent major paper on the ranges was a structural study by Medwell (1971).

Hall (1910) and others mapped the Anglesea coast, whilst Raggatt and Crespin (1955), Stach (1964) and Abele (1971) worked on the stratigraphy of this east coastal section.

In recent years there have been many palaeontological and biostratigraphical contributions, often based on studies of bore cores from the Coastal Plains. These include Singleton (1943), Cookson (1954), Cookson and Dettmann (1958), Carter (1958), Douglas (1960, 1969), Evans (1961), Dettmann (1963), Taylor (1964, 1971), Bock and Glenie (1965), Cookson and Eisenack (1965), Harris (1965), Glenie (1971). In addition there is much information in unpublished private company reports. Papers on economic geology are briefly discussed below.

Geological History

Little is known of the pre-Mesozoic rocks in the region, but schists in the Fergusons Hill No. 1 bore at about 3,500 m are believed to represent basement of possible Cambro-Ordovician age. Current theories of continental movements postulate that a drifting apart of the Gondwana or 'Southern Continent' which began in the Late Jurassic induced rifting in southern Australia. East-west grabens or troughs appeared (the Gippsland and Otway Basins in southern Victoria), and sediments from the northern Palaeozoic hinterland and uplands fringing the still adjacent Antarctica accumulated in a non-marine environment.

During the ensuing 30,000,000 years of *Early Cretaceous* time, sufficent sediment was supplied to produce feldspathic sandstone, mudstone and shale up to 3,000 m thick in places. In the Otway Basin these beds, the Otway Group, are present from the Mornington Peninsula to Robe (South Australia) and seaward, and have been intersected in many deep bores. However they outcrop only in the Casterton-Merino area and the Otway Ranges, and peripheral areas such as the Barrabool Hills. These outcrop areas are parts of the basin which have been subsequently uplifted and dissected.

A variety of non-marine depositional environments has been suggested for these Lower Cretaceous beds with the accent on alluvial and fluviatile conditions involving much re-working of sediment. The fossil flora is extensive and in places well preserved. The rocks and these fossils suggest braided streams and accompanying sandy areas, with vegetated swamps, fringing marshes, extensive more elevated areas with heavy fern and pteridosperms giving thick multistoried ground cover and coniferous forests on the higher country. Chains of small lakes and deltaic conditions are indicated elsewhere (Douglas 1969). The animal kingdom may have been dominated by the dinosaurs, although no remains have been found closer than Cape Paterson in the Gippsland Basin (also Lower Cretaceous). There were fish similar to present day non-marine species, although again these are better known from Lower Cretaceous beds to the west and in Gippsland, as well as mussel-like shellfish and crabs, and a variety of insects including cicadas, bees, fleas, beetles and dragonflies. The birds recorded from feathers at Koonwarra in South Gippsland surely had their counterparts in the Otway area.

Accompanying volcanism has been postulated (Darragh & Bowen 1965), but basalt flows similar to those interbedded subsurface in the Otway Group further west have not been recorded here. Lower Cretaceous rocks are now well exposed along the Great Ocean Road from Eastern View on the east to Moonlight Head in the west, and in inland road cuttings. Cuttings inland are almost always of rock highly weathered to a buff colour, and the feldspathic sandstone on the ridges often weathers to an amorphous face, with bedding difficult to distinguish except where plant 'chaff' is prominently aligned. Coal bands usually a few cm in thickness are also useful as bedding indicators.

Little or no attempt has been made to define lithological units, although the fine grained sandstones and mudstones of the Moonlight Head Beds in the western flanks described by Baker (1950) contain a plant fossil assemblage (Zone 'D', see Table 3) readily distinguishable from the older assemblage on the ridge and other flanks of the Ranges.

There have been also only sporadic attempts to lithologically subdivide the subsurface section to the west, but the name Eumeralla Formation has gained some acceptance (see Benedek & Douglas 1976 and Table 1). Hence subdivision of both outcrop and subsurface is principally based on biostratigraphic evidence, viz. plant reproductive and vegetative remains. Spores and pollen assemblages have been used for the subsurface section, supplemented by megaplants in the Otway Ranges High. Several zones or assemblages with characteristic fossils have been delineated (see Table 3).

At the commencement of *Late Cretaceous* time, with the continental movement gathering momentum (Veevers & Evans 1973) shallow marginal marine conditions signalled the beginning of a new sedimentary regime. The Early Cenomanian Waarre Sandstone is the oldest formation in a transgressive-regressive series (Sherbrook Group) continuing into the Early Tertiary (see Table 1).

These Late Cretaceous beds do not now outcrop, but underlie Tertiary beds, in the Port Campbell Embay-

			Port Campbell area	Aire coast area	Anglesea area	
TERTIARY	PLIOCENE	Heytesbury Group	Moorabool Viaduct Formation	Moorabool Viaduct Formation	Moorabool Viaduct Formation	Torquay Group
	MIOCENE		Port Campbell Limestone		Puebla Formation Zeally Limestone Member	
			Gellibrand Marl	Sentinel Rock Clay Fishing Point Marl		
	OLIGOCENE	Nirranda Subgroup	Clifton Formation	Calder River Limestone	Waurn Ponds Ls.Mem., Jan Juc Formation Point Addis Ls.Mem.	
			Older Volcanics		Older Volcanics	
	EOCENE	Wangerrip Group	Narrawaturk Marl	Glen Aire Clay Castle Cove Limestone Browns Creek Clay	Angahook Member	
			Mepunga Formation		Demons Bluff Formation Anglesea Member	
			Older Volcanics			
	PALAEOCENE		Dilwyn Formation Pember Mudstone Member	Johanna River Sand	Eastern View Formation	
			Pebble Point Formation	Rotten Point Sand		
CRETACEOUS	UPPER	Sherbrook Group	Timboon Sand Member Paaratte Formation Nullawarre Greensand Member Belfast Mudstone Member			
			Flaxman Formation			
			Waarre Sandstone			
	LOWER	Otway Group	Moonlight Head Beds	Moonlight Head Beds		Otway Group
			Eumeralla Formation			

Table 1.
Tertiary and Cretaceous Stratigraphic Units, Otway Region

Unit	Lithology	Key Fossils	Biostratigraphic Assemblages**	
Zeally Limestone Member	Marine calcarenite	Foraminifera, echinoids, molluscs	P.tuberculatus	G 7
Puebla Formation	Marine calcareous silt, limestone, clay, marl	Foraminifera, gastropods, molluscs, bryozoans	T.bellus P.tuberculatus	E-H 6-8
Waurn Ponds Limestone Member	Marine bryozoal calcarenite, marl, clay	Foraminifera, bryozoans	P.tuberculatus	H 5
Point Addis Limestone Member	Marine marl, silt, limestone, bryozoal calcarenite, calcirudite	Foraminifera, echinoids, molluscs	P.tuberculatus	I-H 5
Jan Juc Formation	Marine marl, glauconitic calcarenite	Foraminifera, molluscs, echinoids	P.tuberculatus	I 4-5
Angahook Member	Tuff, basalt, breccia, sand, gravel, clay	Gastropods	P.tuberculatus	I-J 4
Demons Bluff Formation Anglesea Member	Marine carbonaceous silt, claystone, clay, sand, coal, pyritic and glauconitic shale	Foraminifera, ostracods, gastropods, echinoids, sporomorphs, microplankton	N.asperus	J-N 1-3
Eastern View Formation	Non-marine estuarine sand, gravel, silt, carbonaceous clay, brown coal	Plants (angiosperms), molluscs, sporomorphs	N.asperus Nothofagidites	N-Y?
Sentinel Rock Clay	Non-marine clay	Plants (angiosperms)		
Fishing Point Marl	Marine marl, clay, limestone	Foraminifera		F-H 6-8
Calder River Limestone	Marine calcarenite, quartz pebbles	Foraminifera	T.bellus P.tuberculatus	H-I 5
Glen Aire Clay	Marine bryozoal and sandy clay, carbonaceous clay	Foraminifera, bryozoans	N.asperus	K 3
Castle Cove Limestone	Marine limestone, sandy limestone, clay, marl	Foraminifera, shelly fossils	N.asperus	K-L 2-3
Browns Creek Clay	Marine marl, clay, glauconitic sand, carbonaceous silt	Foraminifera, molluscs, corals, echinoids, microplankton, sporomorphs	N.asperus	L-N 1-2
Johanna River Sand	Paralic sandstone, silt, conglomerate, sand, clay	Foraminifera	M.diversus N.asperus	N-U
Rotten Point Sand	Marine pebbly silty sandstone	Foraminifera, sporomorphs	L.balmei	
Moorabool Viaduct Formation	Sand, silt, ironstone, laterite, grit, limestone	Foraminifera, molluscs, plants (angiosperms)		
Port Campbell Limestone	Marine limestone, marl, chert	Foraminifera, bryozoans, brachiopods, echinoids, crustacea	T.bellus	C-E 8-12
Gellibrand Marl	Marine marl, limestone	Foraminifera, corals, molluscs, crustacea, microplankton	P.tuberculatus	F-H 6-8
Clifton Formation	Marine limonitic limestone, quartz sand, bryozoal sand	Foraminifera, bryozoans, molluscs, echinoids, fish	P.tuberculatus	H-I 5
Narrawaturk Marl	Marine marl	Foraminifera, bryozoans, brachiopods, molluscs	P.tuberculatus N.asperus	I-K 3-4
Mepunga Formation	Marine limonitic calcareous sandstone, limestone, gravel	Foraminifera, molluscs, microplankton, sporomorphs		
Older Volcanics	Olivine basalt, titanaugite basalt, associated dykes, dolerits			
Dilwyn Formation	Paralic clay, shale, sandy dolomitic siltstone, sand, coal	Foraminifera, molluscs, fish, microplankton, sporomorphs	N.asperus P.asperopolus	L-Q 1-2
Pember Mudstone Member	Marine mudstone	Foraminifera, corals, molluscs, microplankton, sporomorphs	M.diversus L.balmei	R-U
Pebble Point Formation	Marine pebbly limestone, siltstone, silt, dolomitic sand, conglomerate, gravel	Foraminifera, corals, molluscs, fish, ostracods, microplankton, sporomorphs	L.balmei	U
Timboon Sand Member	Non-marine quartz sand, mudstone, coal			
Paaratte Formation	Paralic, deltaic, quartz sandstone, sand, shale, coal	Foraminifera, microplankton, molluscs, sporomorphs	T.lilliei to T.pachyexinus Paaratte Flora	D.pellucida to D.cretacea Y-XA
Nullawarre Greensand Member	Marine glauconitic and limonitic sandstone	Foraminifera, microplankton	T.pachyexinus to P.pannosus	N.aceras to A.parvum XA-XD
Belfast Mudstone Member	Marine, glauconitic mudstone	Foraminifera, gastropods, ammonites, belemnites, fish, microplankton, plants, (angiosperms, gymnosperms), sporomorphs	T.pachyexinus to P.pannosus	N.aceras to A.parvum XA-XD
Flaxman Formation	Marine and paralic glauconitic sandstone, sandy mudstone	Foraminifera, microplankton, sporomorphs	C.triplex to P.pannosus	A.parvum XB, XC, XD
Waarre Sandstone	Paralic and non-marine quartz sandstone, mudstone, carbonaceous siltstone	Microplankton, plants (coniferales, angiosperms, ginkgoales)	A.distocarinatus P.pannosus Waarre Flora	A.parvum XC, XD
Moonlight Head Beds	Non-marine light friable mudstone, feldspathic sandstone, carbonaceous bands	Plants (pteridosperms, filicales, liverworts, coniferales, angiosperms?), sporomorphs, insects	C.paradoxa Zone 'D'	
Eumeralla Formation	Non-marine alternating grey feldspathic sandstone, dark mudstone, thin coal seams	Plants (pteridosperms, filicales, coniferales), sporomorphs, fish	D.speciosus Zone 'C'	

TABLE 2. OUTLINE OF LITHOLOGIES, FOSSIL CONTENT AND BIOSTRATIGRAPHY OF UNITS SHOWN IN TABLE 1*.

* . Units of the Port Campbell area are listed, in stratigraphic sequence, below those of the Aire coast area, which in turn are below those of the Anglesea area.

** . See also Table 3. Largely based on Abele (1976).

ment (see Fig. 1.1 Wopfner & Douglas 1971) where they are over 1,700 m thick, and in deeper parts of the Otway Basin to the west. They contain foraminifera, microplankton and pollens used for stratigraphical distinction, and much rarer molluscs, ammonites, belemnites, fish scales, and plant remains.

The initial *Tertiary* unit was the Pebble Point Formation, a transgressive marine phase of the Wangerrip Group, with small outcrop areas on the coast near Princetown and present in bore sections west of the ranges. The most extensive outcrop is the Dilwyn Formation, a predominantly sandy unit which comprises the sands and gravel on the western flanks of the Ranges down to and across the Gellibrand River, and less important formation deposits north of Johanna and Cape Otway. The Dilwyn Formation conformably overlies the Pebble Point Formation and in its type section is calcareous sandy clay and silt, micaceous and pyritic, and conspicuously burrowed. Subsurface the formation is widespread, and generally thicker than the Pebble Point Formation. Both formations contain characteristic faunas. McGowran (1965) monographed the foraminifera. Spores and pollens and microplankton were studied by Harris (1965) and Stover (1973). Shelly fossils, particularly molluscs, are prevalent in the Pebble Point Formation but much rarer in the Dilwyn Formation.

There has been much confusion in stratigraphic nomenclature in this part of the Tertiary section. Suggested clarifications and detailed discussion are included in Abele (1976). Volcanic activity during the Eocene and Oligocene is represented by olivine basalt and dykes near Gellibrand, and several flows up to 200 m thick have been penetrated in bores.

The Nirranda Subgroup forms an important intermediate phase in Middle Tertiary sedimentation in the Port Campbell Embayment, but thickness is generally less than 200 m. The Mepunga Formation, essentially quartz sand, often calcareous and limonitic, but unfossiliferous, and the Narrawaturk Marl, richly fossiliferous, have been distinguished as units of this Subgroup.

The nomenclature of the Heytesbury Group with its constituent units and their stratigraphic limits is also confused, but consists predominantly of two transgressive marine units, the Gellibrand Marl, and the Port Campbell Limestone. These are almost 1,000 m thick in the Mepunga area, and contain extensive marine faunas including foraminifera. The Port Campbell Limestone forms the prominent and scenic coastal cliffs westwards from Princetown. Glenie (1971) included also in the Heytesbury Group the unconsolidated sands, gravels etc. of the Moorabool Viaduct Formation. These fringe the north central part of the Ranges.

In the Torquay Coastal Plains Tertiary sedimentation proceeded under a somewhat different regime, and a separate nomenclature has developed. Hence reconciliation with the areas adjoining the Port Campbell Embayment around the northeast of the ranges is difficult. The Torquay Tertiary sequence commences with the continental Eastern View Formation, which includes the brown coal measures at Anglesea (see below). This conformably underlies the Demons Bluff Formation and contains pollen assemblages (see Zonal scheme, Table 3).

The Demons Bluff Formation was subdivided by Raggatt and Crespin (1955) into three members of varied lithologies best exposed in coastal localities. Abele (1968) regrouped these in the Anglesea and Angahook Members. The Anglesea Member contains abundant foraminifera and rich pollen assemblages.

The Torquay Group, of marine origin, is represented by several units, the oldest of which, the Jan Juc Formation, conformably overlies the Demons Bluff Formation.

The Newer Volcanics of the *Quaternary* Volcanic Plains which abut the Otway region are not represented in the area. However consolidated Quaternary sediment is represented by highly cross-bedded dune limestones prominent at the mouth of the Gellibrand River at Princetown and the mouth of the Aire River at Hordern Vale and Glenaire. Unconsolidated Quaternary sands form extensive dune systems prominent east and west of the Gellibrand River mouth at Princetown and west of the Aire River mouth.

STRUCTURE

Elevation of the Ranges above the surrounding part of the basin seems to have begun in mid-Cretaceous time, and they have remained as a structural high. Although the postulation that they were an island throughout Tertiary time has been questioned (Hills 1940, Edwards 1962), some degree of pre-Tertiary uplift has gained considerable acceptance. See also Medwell 1977.

Medwell discusses the structure of the ranges in detail. He considers the basic structure to be a complex, flat-lying, block-faulted dome somewhat modifying his (1971) picture of a broad north-east trending anticline, with associated syncline on the south-east. Gunn (1974), using geophysical data, postulated three prominent structural trends in the region. A north-east trend in the ranges and to the west is most evident, and shown on geological maps of the area (e.g. Mines Dept. Vict., 1973), where major faults such as the Chapple Vale Fault delimit outcrop area and have great topographical expression. North-west faults, with less obvious, but still marked topographic expression are typified by the Benwerrin Fault, and the Barham Fault

(Medwell 1971) may be an example of Gunn's major north, north-east faults.

Economic Geology

Brown coal of Palaeocene-Eocene age is at present the most economically important mineral, and occurs on the periphery of the Ranges, although the Benwerrin brown coal deposit is on the main ridge in the north-east. The coal has been extracted at Wensleydale, Benwerrin, Deans Marsh-Bambra and Anglesea principally by open cut method. The only deposit currently worked is the Anglesea coalfield which supplies the ALCOA power station at Anglesea. This is the highest grade large brown coal deposit in Victoria and part of the Eastern View Formation which rests uncomfortably on Mesozoic beds. There are 8 coal seams more than 3 m thick, but most of the coal is produced from two groups of seams. Total reserves are nearly 500 million tonnes, with about 100 million recoverable under present day economics. Of the other areas, Deans Marsh-Bambra probably represents the best future prospect with possible large reserves south-west of Deans Marsh.

The Waurn Ponds Limestone Member of the Jan Juc Formation outcrops south-west of Geelong but not within the Otway Region. These beds, which are quarried for limestone a little to the north may extend subsurface into the region beneath Newer Volcanics. There are other limestone deposits at Kawarren and at Curdies River, both of which have been worked for agricultural lime, and east along the coast from Bells Beach.

Clay pits are worked for brickmaking at Eliminyt, and bentonite at Gellibrand was discussed and assessed by Darragh and Bowen (1965) and Bowen (1970).

Natural gas, but in uneconomic quantity, was encountered on the Port Campbell Coastal Plain and in the same area underground water is present in significant quantity in several aquifers (e.g. Port Campbell Limestone). This is used for local supply, as well as to supplement the Otways-Warrnambool pipeline supply when necessary.

Black coal is exposed in thin seams in many road cuttings throughout the Ranges and along the coastline. An extensive drilling programme for black coal last century showed that the deposits do not attain the thickness of the similar coals at Wonthaggi in Gippsland, and that faulting had disrupted the seams. No extraction was therefore attempted.

Gold was discovered in reefs at Wangerrip on the north-west flanks of the Ranges in 1899. This is one of the few records of *in situ* reef gold in post Palaeozoic sediments in Victoria and hence of considerable interest. It was suggested (Stirling 1900) that the gold was associated with a dyke, but recent investigations have failed to re-locate the reef.

Where the Lower Cretaceous beds have been locally hardened they are quarried and used for road construction. The fringing Tertiary beds with heavy gravels and sands are the principal source of materials for local roads.

REFERENCES

Abele, C., 1968. Explanatory notes on the Anglesea 1: 63 360 geological map. *Rept. Geol. Surv. Vict., 1968/1.*

————, 1971. Resources Survey, Barwon Region. *Cent. Plan. Auth., Vict.*

————, 1976. *Geology of Victoria.* Chap. 8. Tertiary. *Geol. Soc. Aust. Spec. Pub.* 5.

Baker, G., 1944. The geology of the Port Campbell District. *Proc. R. Soc. Vict.* 56: 56-108.

————, 1950. The geology and physiography of the Moonlight Head District. *Ibid.* 60: 17-44.

Benedek, S. & Douglas, J. G., 1976. *Geology of Victoria,* Chap. 7. Mesozoic. *Geol. Soc. Aust. Spec. Pub.* 5.

Bock, P. E. & Glenie, R. C., 1965. Late Cretaceous and Tertiary depositional cycles in southwestern Victoria. *Proc. R. Soc. Vict.* 79: 153-163.

Bowen, K. G., 1970. Further report on bentonite at Gellibrand. *Min. Geol. Jour: Vict.* 6 (6): 33-39.

Carter, A. N., 1958. Tertiary foraminifera from the Aire district, Victoria. *Bull. Geol. Surv. Vict.* 55.

Cookson, Isabel C., 1954. A palynological examination of No. 1 bore, Birregurra, Victoria. *Proc. R. Soc. Vict.* 66: 119-128.

———— & Dettmann, Mary E, 1958. Some trilete spores from Upper Mesozoic deposits in the Eastern Australian region. *Ibid.* 70: 95-128.

———— & Eisenack, A., 1965. Microplankton from the Palaeocene Pebble Point Formation, southwestern Victoria. *Ibid.* 79: 139-146.

Darragh, P. J. & Bowen, K. G., 1965. The occurrence of bentonite at Gellibrand. *Min. Geol. Jour. Vict.* 6 (5): 32-36.

Dettmann, Mary E., 1963. Upper Mesozoic microfloras from southeastern Australia. *Proc. R. Soc. Vict.* 77: 1-148.

Douglas, J. G., 1960. Microplankton from the Deflandreidae group in Western District sediments. *Min. Geol. Jour. Vict.* 6 (4): 17-32.

————, 1969. The Mesozoic floras of Victoria, Parts 1 & 2. *Mem. Geol. Surv. Vict.* 28.

Edwards, A. B., 1962. Notes on the geology of the Lorne District, Victoria. *Proc. R. Soc. Vict.* 75: 101-119.

Edwards, A. B. & Baker, G., 1943. Jurassic arkose in southern Victoria. *Ibid.* 55: 195-228.

Evans, P. R., 1961. Mesozoic stratigraphic palynology in Australia. *Aust. Oil & Gas Jour.* 12: 58-63.

Glenie, R. C., 1971. Upper Cretaceous and Tertiary rock stratigraphic units in the Central Otway Basin. *The Otway Basin of Southeastern Australia.* Eds. Wopfner, H. & Douglas, J. G. *Spec. Bull. Geol. Survs. S.A. & Vict.* pp. 193-215.

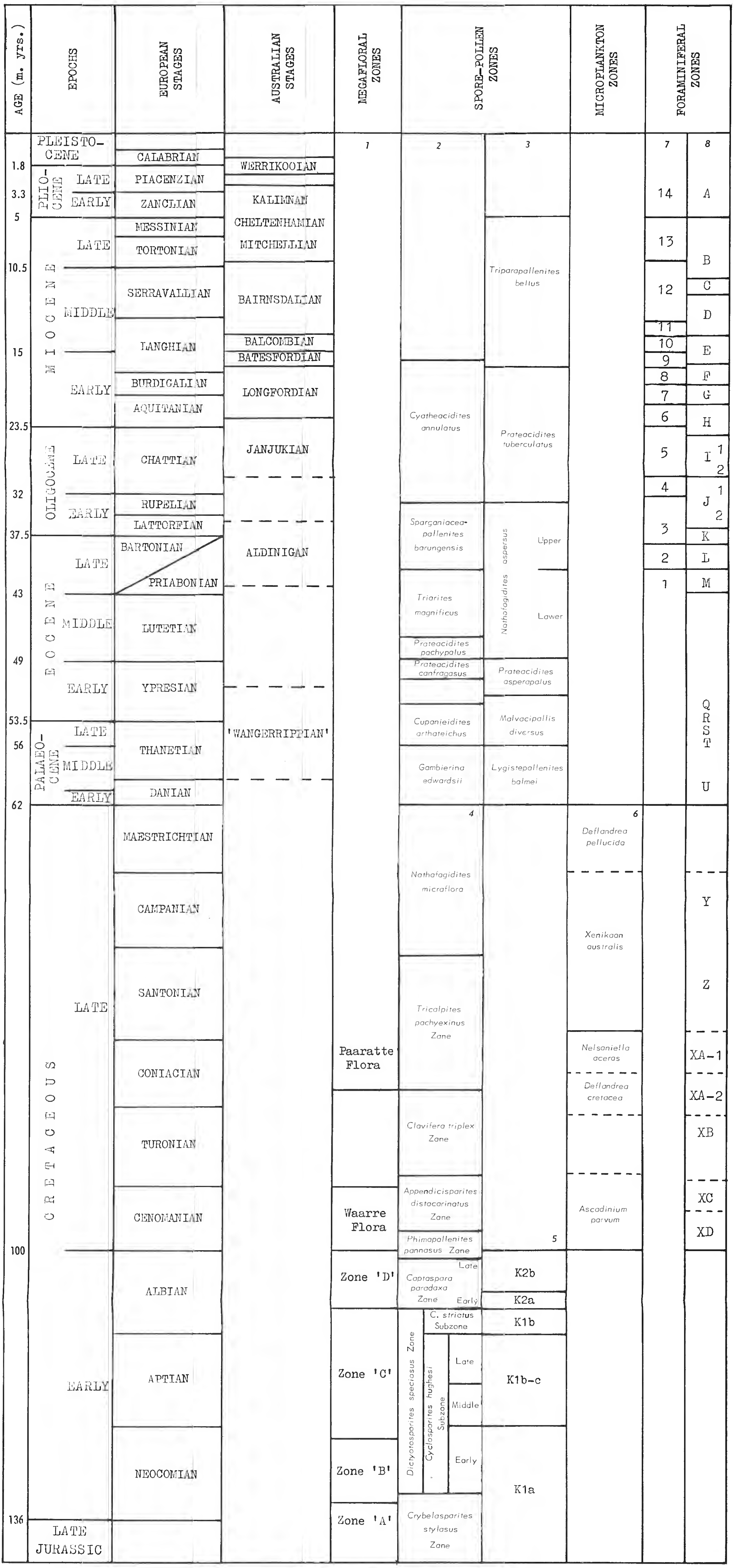

TABLE 3. CORRELATION CHART OF BIOSTRATIGRAPHIC ZONAL SCHEMES USED IN OTWAY REGION

Modified from Abele (1976), and Douglas (1976), using data of 1. Douglas (1972); 2. Harris (1971, etc.); 3. Stover & Patridge (1973); 4. Dettmann & Playford (1969); 5., 6. Evans (1971); 7. Carter (1958), Nichols (1968); 8. Taylor (1971).

GUNN, P. J., 1974. Fault patterns in the Colac Trough. *Rept. Geol. Surv. Vict.* 1974/18 (unpub.).

HALL, T. S., 1910. Notes on the geology of the country around Anglesea. *Proc. R. Soc. Vict.* 23: 44-53.

HARRIS, W. K., 1965. Basal Tertiary microfloras from the Princetown area, Victoria, Australia, *Palaeontographica*. B. 115: 75-106.

HILLS, E. S., 1940. *The Physiography of Victoria*. 1st Ed. Whitcombe and Tombs.

JENKIN, J. J., 1976. *Geology of Victoria*, Chap. 10. Geomorphology. *Geol. Soc. Aust. Spec. Pub.* 5.

KRAUSE, F. M., 1874. Report on the Cape Otway country. *Rept. Prog. Geol. Surv. Vict.* 1: 99-109.

MCGOWRAN, B., 1965. Two Palaeocene foraminiferal faunas from Wangerrip Group, Pebble Point coastal section, Western Victoria. *Proc. R. Soc. Vict.* 79: 9-74.

MEDWELL, G. J., 1971. Structures of the Otway Ranges. *The Otway Basin of Southeastern Australia*. Eds. H. Wopfner & J. G. Douglas. *Spec. Bull. Geol. Survs. S.A. & Vict.* pp. 339-362.

————, 1977. Palaeocurrent Directions in Otway Group Sediments, Otway Ranges, Southeastern Australia. *Proc. R. Soc. Vict.* 89: 27-50.

MINES DEPT. VICT., 1973. Colac 1:250000 Geological Map.

MURRAY, R. A. F., 1877. Report on the geology of portions of the Cape Otway district. *Rept. Prog. Geol. Surv. Vict.* 4: 11-12.

RAGGATT, H. C. & CRESPIN, I., 1955. Stratigraphy of Tertiary rocks between Torquay and Eastern View, Victoria. *Proc. R. Soc. Vict.* 67: 75-142.

SINGLETON, F. A., 1953. An Eocene molluscan fauna from Victoria. *Ibid.* 55: 266-281.

SINGLETON, O. P., 1967. Otway Region. *ANZAAS 39th Congress Sect. C. Excursions Handbook*. Ed. McAndrew, J., & Marsden, M. A. H., pp. 117-131.

STACH, L. W., 1964. Subsurface geology of the Torquay embayment, Port Phillip Basin, Victoria. *Aust. Petrol. Explor. Assocn.* 1961. Conf. Papers pp. 89-94.

STIRLING, J., 1900. Report on gold discoveries, Wangerrip, Gellibrand River, *Prog. Rept. Geol. Surv., Vict.* 8 & 9: 3.

STOVER, L. E., 1973. Palaeocene and Eocene species of *Deflandrea* (Dynophyceae) in Victorian coastal and offshore basins. Australia. *Spec. Pub. Geol. Soc. Aust.* 4, pp. 167-188.

TAYLOR, D. J., 1964. Foraminifera and the stratigraphy of the western Victorian Cretaceous sediments. *Proc. R. Soc. Vict.* 77: 535-602.

————, 1971. Foraminiferal biostratigraphy of a marginal area of the Otway Basin. *The Otway Basin of Southeastern Australia*, Eds. Wopfner, H. & Douglas, J. G. *Spec. Bull. Geol. Survs. S.A. & Vict.* pp. 235-239.

VEEVERS, J. J. & EVANS, P. R., 1973. Sedimentary and magmatic events in Australia and the mechanism of world wide Cretaceous transgressions. *Nature Phys. Sci.* 245: 33-36.

WILKINSON, C. S., 1865. Report on the Cape Otway country (from Parl. Papers 1864-65). *Rep. Geol. Surv. Vict.*

WOPFNER, H. & DOUGLAS, J. G. (Eds.), 1971. The Otway Basin of Southeastern Australia. *Spec. Bull. Geol. Survs. S.A. & Vict.*

4.

PALAEOCURRENT DIRECTIONS IN OTWAY GROUP SEDIMENTS, OTWAY RANGES, SOUTHEASTERN AUSTRALIA

By G. J. Medwell*

Abstract: Along the eastern coastline of the Otway Ranges, southern Victoria, Lower Cretaceous arkoses and mudstones of dominantly braided fluviatile origin contain five common primary structures of directional significance. These are filled channel-forms, planar and trough cross-bedding in arkose units, ripple mark, longitudinal erosion hollows and oriented cylindrical concretions. They have been used to derive a palaeogeographic reconstruction for Zone C (Albian) times in this part of the Otway Basin, showing drainage from north and south to join a central river system flowing westerly between Lorne and Cape Patton. The westerly-flowing trend has not previously been demonstrated.

Deposits of black coal are most likely to be found in the central area of the Ranges which was topographically the lowest part of the drainage basin.

INTRODUCTION

Douglas (1971, 1977) has discussed the Mesozoic and Tertiary setting of the Ranges. They are one of four outcrops of Lower Cretaceous sediments which lie en echelon in the latitudinal 'Great Valley of Victoria'. This is a major intracratonic rift system associated with the breakup of the Antarctic-Australian continent, beginning in the Jurassic and completed by the late Palaeocene (Boeuf & Doust 1975, Falvey 1974, Griffiths 1971).

The Otway Ranges consist of Lower Cretaceous braided fluviatile, paludal and lacustrine sediments, and constitute a High marginal to the Tertiary Otway Basin of south-west Victoria.

The main structural features of the Ranges (Fig. 2) were described by Medwell (1971), based on reconnaissance mapping of dips and strikes and a compilation of the work of several authors. The Ranges comprise a broad north-east trending anticline, possibly axially faulted, which plunges north-east into the Torquay Embayment and south-west into Bass Strait. An associated syncline, complicated by faulting and minor folding occurs on the southeastern side of the anticline. There are many monoclines, the largest of which are the Skenes Creek Monocline and the Devils Elbow Monocline. These two throw down in opposite directions from the elevated central part of the Ranges, which is thought to be essentially a flatlying and block-faulted area (Fig. 11).

Inland the Ranges are rugged and difficult of access, with poor exposures limited to tracks and creek beds. Good exposures are restricted to the shore platforms between Moonlight Head and Eastern View.

A survey has been made of part of this coastline, from Cape Otway to Eastern View, along most of the eastern flank of the Otway Ranges dome. Primary sedimentary structures which indicate palaeocurrent directions were recorded, and the sedimentation pattern inferred. The lack of detailed stratigraphic knowledge and the incomplete cover of the exposed section should however be noted.

DIRECTIONAL STRUCTURES

1. Filled Channel-forms (Allen 1968, Reineck & Singh 1973)

Small scour-and-fill structures almost always contain a dominantly mudstone lithology. Hence they occupy topographic lows on shore platforms, have a characteristic lensoid shape and show distinctive internal features (Pl. 7). More-or-less planar thin mudstones interbedded with arkose are rarer, and indicate channel-ways of the braided stream environment.

The commonly-found mudstone lenses have erosional bases which are sharply curved and cut into cross-stratified arkose. Maximum thickness is about 2-4 m, most being about 1-2 m. They frequently taper out over a distance of 10 to 100 m to meet the planar or undulose bedding surfaces of adjacent arkose beds.

The usual fill material is a sedimentary breccia of darker grey mudstone clasts in a grey mudstone matrix

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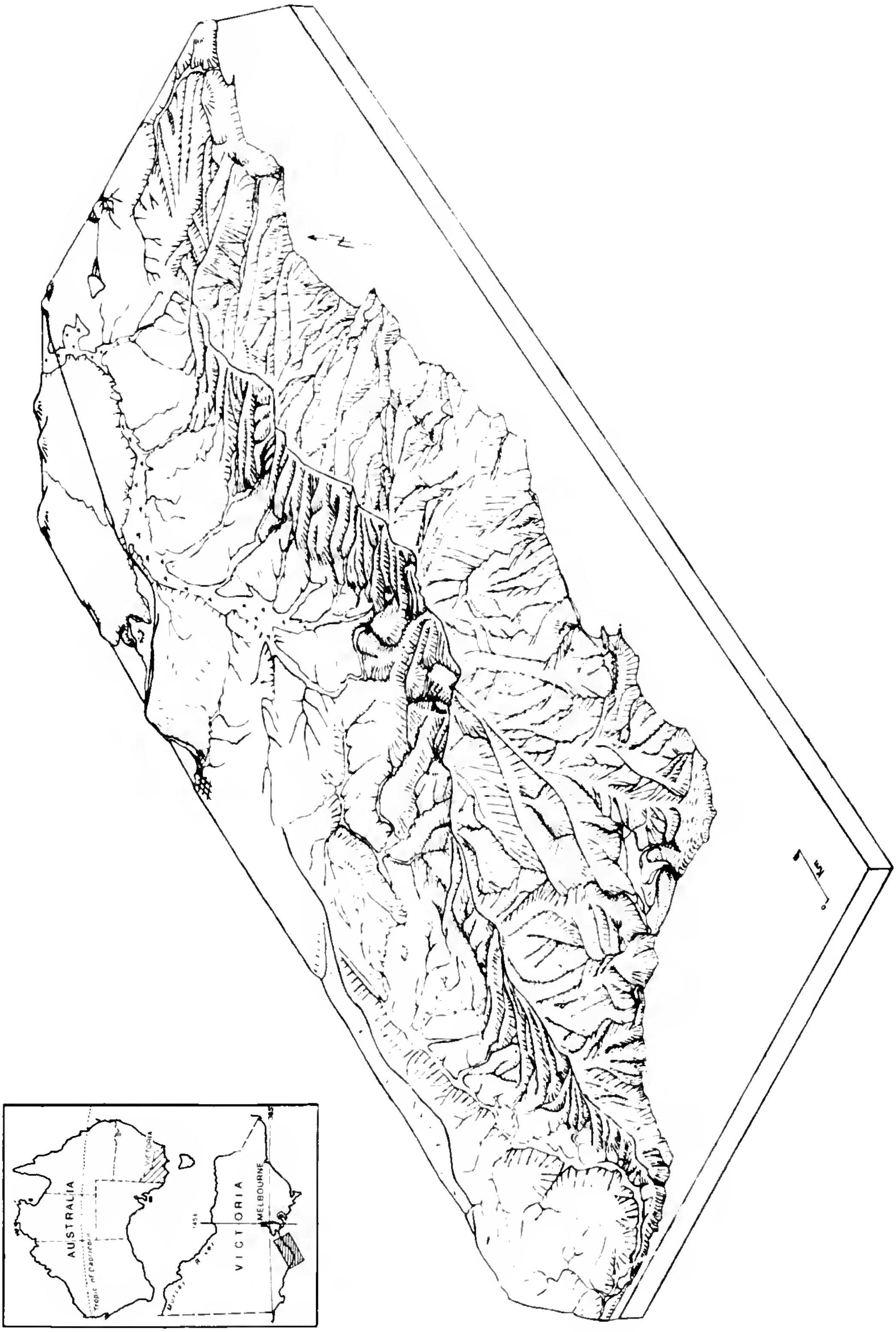


FIG. 1—Locality Map and Block Diagram of the Otway Ranges. Looking north-west from Cape Otway (foreground) towards Colac. Based on contours from Colac 1:250,000 Sheet, Mines Dept. Victoria, 1973.

(e.g. Boggaley Creek). Other fills are laminites of sandstone and mudstone (Grassy Creek), thinly-bedded sand and mud lenses (Skenes Creek), sandstone thinly bedded parallel to the scour base (Addis Bay), and massive mudstone.

The lenses represent cutoffs and abandoned channels in a braided fluvial system of deposition, filled with overbank fines and bank-collapse material during waning flood stage and low stage deposition.

In palaeocurrent analysis, the scoured channels were found to be the directional structures showing least dispersion at all localities where they are abundant, and thus the most reliable estimator of current direction. They are given code A — the innermost position — in the circle diagrams used below.

2. Cross-bedding

Most arkose beds and some mudstones show well developed internal cross-bedding of planar or trough types. On each shore platform 10-20 readings of maximum foreset inclination in arkose beds more than 0.5 m thick were easily obtained. Traces of cross-bedding planes are usually clearly visible as darker lines on sections of exposed beds, and are readily excavated where weathering is advanced. The dark lines are concentrations of coalified plant remains. Sometimes cross-bedding planes are marked by small rounded clasts of mudstone, by iron oxide cement, and rarely by calcite of secondary origin. Some show ferruginisation due to weathering.

Cross-bedding marked by coal fragments: Three oriented slabs with abundant coal fragments lying on foreset planes were sampled at Skenes Creek. The orientations of fragment long axes were plotted, as percentages in 30-degree sectors, to determine if preferred orientation of linear coal could be demonstrated. Bimodal distribution (with and normal to current) became evident in the plots (Fig. 3), though not always readily apparent in hand specimen. One correction for tectonic tilt was made stereographically, ignoring regional plunge and initial dip. Results agreed well with the overall palaeocurrent vector mean for the locality.

This technique may be useful in the hinterland of the Ranges where good exposures are limited and statistically reliable palaeocurrent directions are more difficult to obtain.

Results must be interpreted with caution. The coal fragments are oriented by local currents sweeping over the top and down the avalanche face of braid bars of various types. Sometimes the avalanche face is skewed at a large angle across the stream bed (see Allen 1968) and the local current is strongly divergent from the overall downstream direction. Further, currents may flow along and not down the avalanche face, as when generating 'reverse cross-bedded cross-beds' (Williams 1971). Provided these limitations are recognised, oriented coal may be a useful current indicator.

Examples of other cross-bedding: Cross-bedding may be marked by rounded clasts of mudstone and sandstone. Examples of sigmoidal cross-stratification showing this occur in a road cutting on the Barham road at the west end of Noel St., Apollo Bay, and in sea cliffs south-west of the mouth of the Elliott River.

In sea cliffs under Cinema Point Lookout, intersections of bedding planes with cross-bedding topsets and upper foresets of the bed below are preserved in the internal structure of a spheroidal calcified concretion approx. 10 cm in diameter. A similar structure can be seen at Artillery Rocks, in a large concretion forming a pedestal rock 1 m high (Pl. 8).

Ferruginised cross-beds are exposed in road cuttings north of the mouth of Skenes Creek on the Forrest road.

Interpretation of cross-bedding: Initially, cross-bedding which did not accord with the range of current directions and the mean palaeocurrent vector for a locality was regarded as probable hindsets. Later an alternative explanation became evident.

The shore platforms commonly expose strike sections (b-c sedimentary plane of Allen 1968) up to 100 m long, in bedding which dips seawards at low to moderate angle. The cross-stratification exposed is undulose and often in restricted zones, not permeating the full thickness of the bed. At intervals, vertical-sided gulches cut in the shore platform by marine erosion expose dip sections (a-c plane). Here the cross-stratification is seen to be generally pervasive, with traces usually sigmoidal or flexed. This relationship is illustrated in Fig. 4, which sketches beds at the Grey River mouth. It is also evident at the Mt. Defiance seawall, where almost vertical beds show strike sections in the shore platform and dip sections in the road cutting above.

The structures are interpreted as internal cross-stratification due to migratory sandwaves, with sinusoidal crests over a length of several metres in plan and about 1-2 m high. They resemble the delta-cross-stratification of Allen (1963) but occur at larger scale. Modern aeolian analogues have been observed at Sandy Point, Waratah Bay. Bed forms of a size capable of producing such internal features are well known from several modern river systems (see for example, Coleman 1969, Harms & Fahnestock 1965, Williams 1971).

As a palaeocurrent direction indicator, the cross-bedding can be measured in two ways:

• by estimating the trend of the troughs and/or crests evident in the strike sections. Multiple dip readings taken on a curved stratification surface are plotted

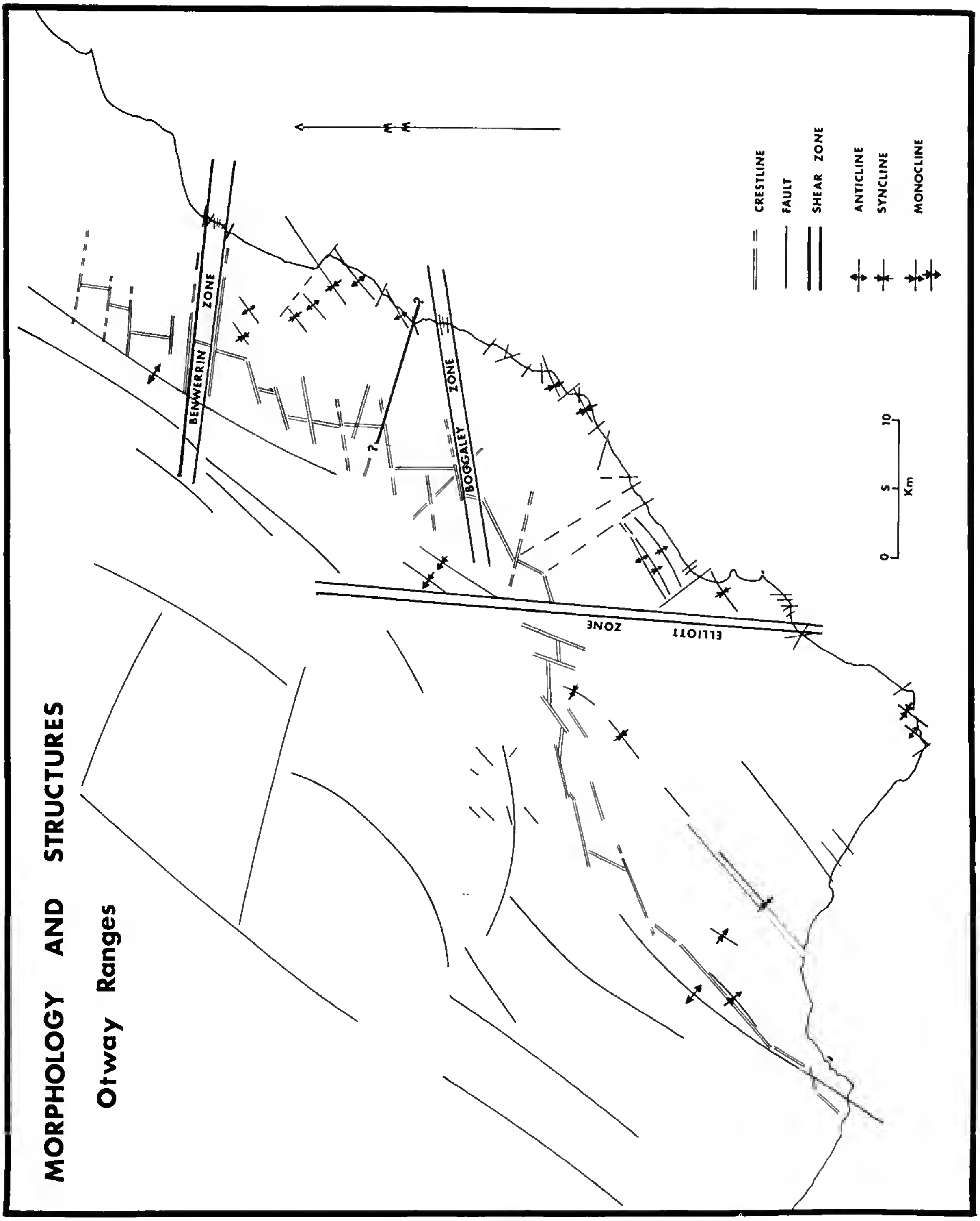


FIG. 2—Morphology and Structures, Otway Ranges. (After Medwell 1971, Mines Department Victoria 1973). Note the regular right-lateral offsetting of the crestline of the Ranges, especially in the northern end, and the alignment of shear zones between prominent crestline lows and shatter belts on the coastline. The Elliott Zone is marked by linear stream valleys, including the Barwon River (see Fig. 1) and appears to terminate the major monoclines at Devils Elbow and Skenes Creek. The Benwerrin Zone contains downfaulted Tertiaries including brown coals (Edwards 1962).

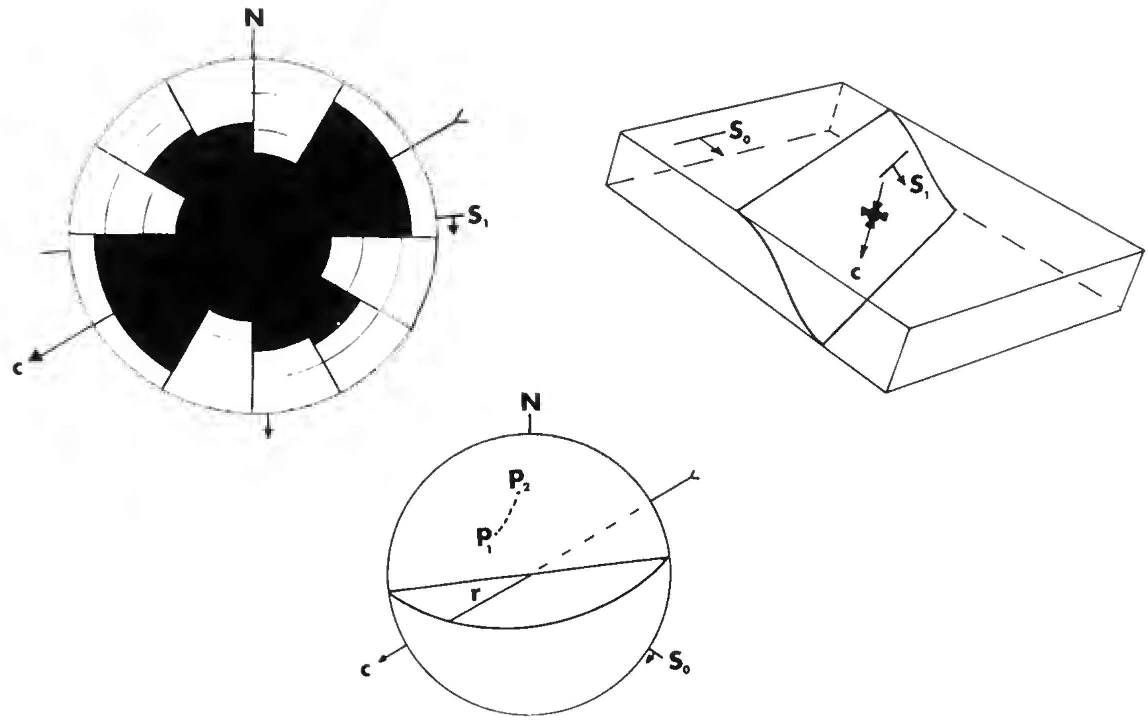


FIG. 3—Interpretation of Oriented Coal Fragments on Foresets. Rosette from oriented slab shows bimodal preferred orientation. Strongest mode is most likely along-current. Scale interval 5%. S_0 Bedding. S_1 Foresets. C Current direction angled across bedform. P_1 Pole of foresets. P_2 Pole of foresets after correction for dip of S_0, corresponding plane shown, r Rake of C in plane of S_1.

stereographically, and the trend of the structure obtained from a π or β diagram.

- by measuring the maximum dip of the planar surfaces exposed in the dip sections. These must be expected to show considerable dispersion at any locality.

Cross-bedding current directions are shown as Structure Code B below (Fig. 5).

3. Small-Scale Ripple Mark

Small-scale ripple mark (Structure C) is found only in thin-bedded facies of restricted distribution.

Asymmetric current ripples (X = 5 cm, h = 1 cm) tend to occur in fine-grained sediments wherever thin-bedded sequences are well developed. Such sequences are predominantly mudstones, but may contain arkose bands up to 2 m thick. They are not common, having been found only at Cape Otway Lighthouse, south-west of Parker River mouth, between Elliott River and Storm Point, near Cape Patton, in Addis Bay, at 'Flatrock' south-west of Wye River (Picnic Point), at The Brothers near Lorne, and at Point Grey.

The thin-bedded sequences thus occur in occasional belts, commonly 500 to 1000 m in strike width and about 100 m in thickness. They are probably natural levee or overbank deposits formed along major channels during mainly low stage periods, and preserved in part during succeeding floods, possibly by channel avulsion.

The tops of some of the more sandy strata are ripple-marked, and yield a current sense. Where constant direction of asymmetry is observed, a current direction can be obtained for fine material.

Ripple mark is also found occasionally in the thin beds filling the erosional channel-forms described above (Structure A).

4. 'Crests and Troughs'

Larger-scale undulations resembling ripple mark were noted at the base of thick arkose beds which overlie the mudstone fill of several small scours. Best examples are in the roadcutting at the Cape Patton Lookout, and in the Skenes Creek north-east shore platform near the end of the camping reserve (Pl. 5). In each case λ = 1 m, and h = 0.3-1 m.

These crests and troughs were first thought to be current megaripples (Allen 1968) but were later found to lie mostly parallel to the estimated local current direction. They are possibly too large and regular for load casts. True load casts are generally absent from the sections examined, and bedding surfaces between arkose and mudstone are planar or gently undulose.

The crests and troughs are tentatively regarded as

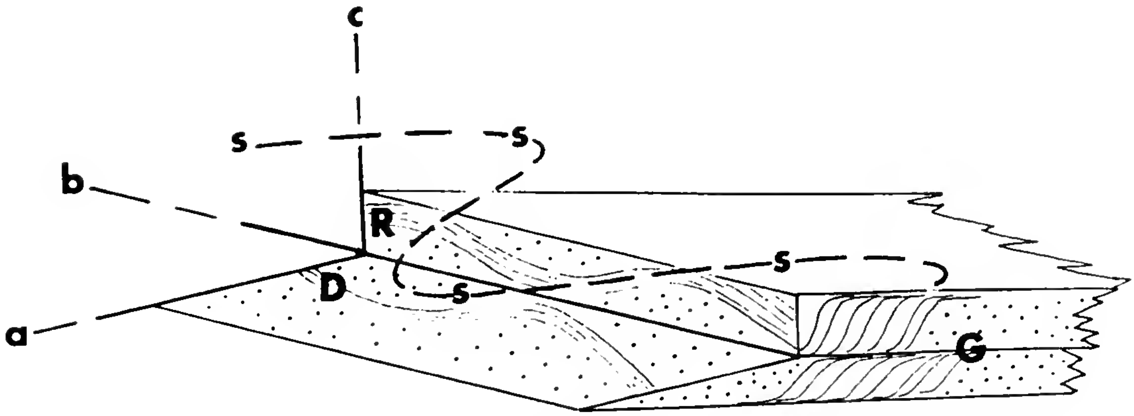


FIG. 4—Interpretation of Crossbedding in Arkose, Grey River Mouth, Otway Coast. a,b,c = Sedimentary axes (Allen, 1968), a = Current, b = Right bank, c = Vertical, R = Rampart, D =Depression of shore platform, G = Gulch, -s-s-s-s-s = Sinuous crest of bedform.

DESCRIPTION OF PLATES 5-8

PLATE 5

Primary Directional Structures in Otway Group Sediments.

Upper and Centre: Oriented cylindrical concretions, Cleary River mouth, south-west side. Concretions lie in plane of bedding. *Upper:* Small-scale. For section, see Plate 6B. *Centre:* Large-scale. *Lower:* 'Crests and troughs', Skenes Creek mouth, north-east side. Arkose moulds of longitudinal (down-current) grooves, scoured by a succeeding flood in the soft mudstone fill of an erosion channel. For scale, note hammer in centre foreground.

PLATE 6

Internal Structures in Small-Scale, Homogeneous Concretions of Calcified Arkose, Otway Coast. Actual size.

Left — Photographs showing apparent homogeneous nature of sectioned concretions.
Right — Corresponding X-radiation prints. X-radiopaque laminations become visible (mica, secondary oxides of iron, etc.). After Hamblin (1962).

A. Small-scale planar bedding, probably mica layers.
B. Homogeneous arkose, rim of secondary iron oxides.
C. Small-scale crossbedding internally, rim of iron oxides.
D. Homogeneous arkose.

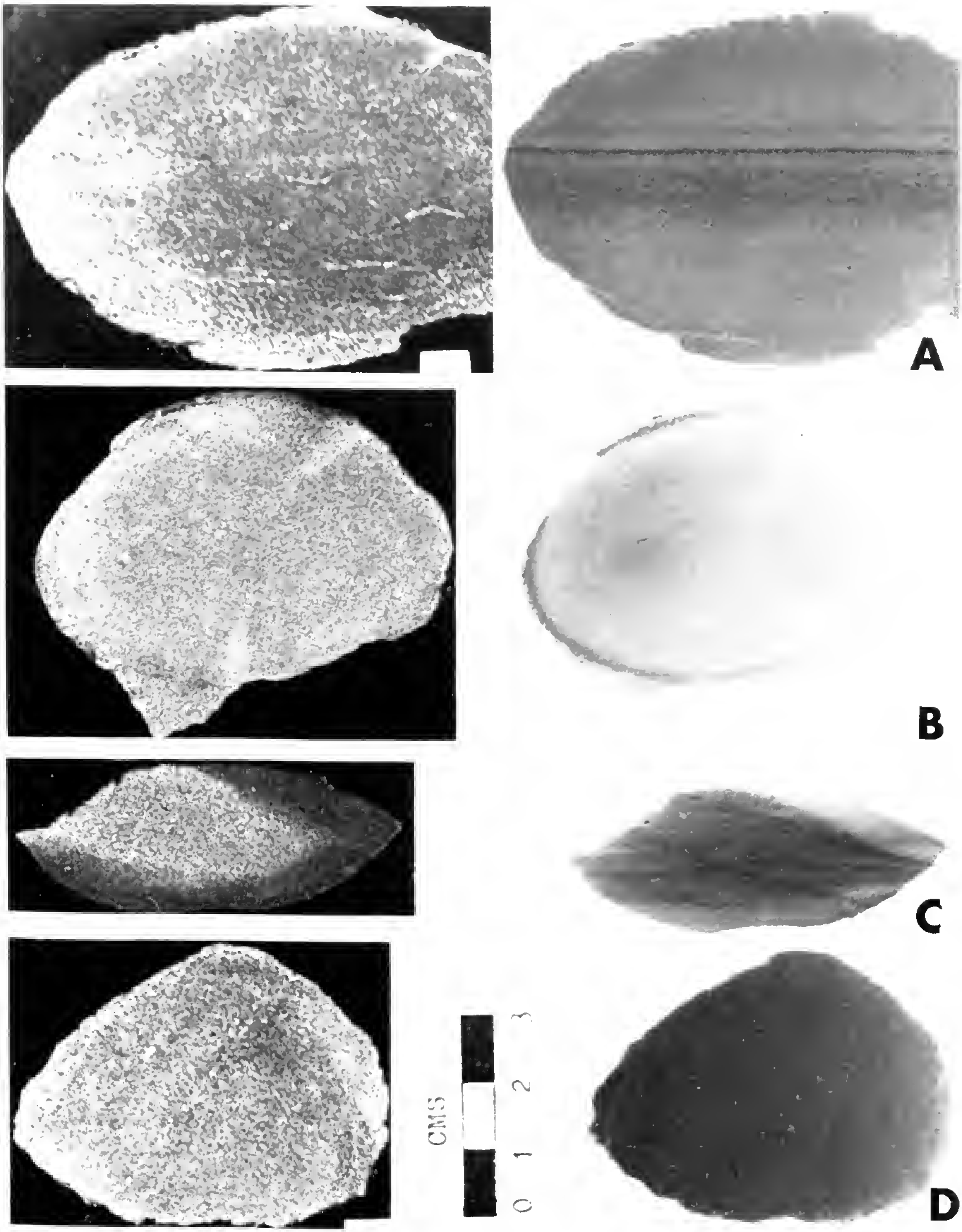
PLATE 7

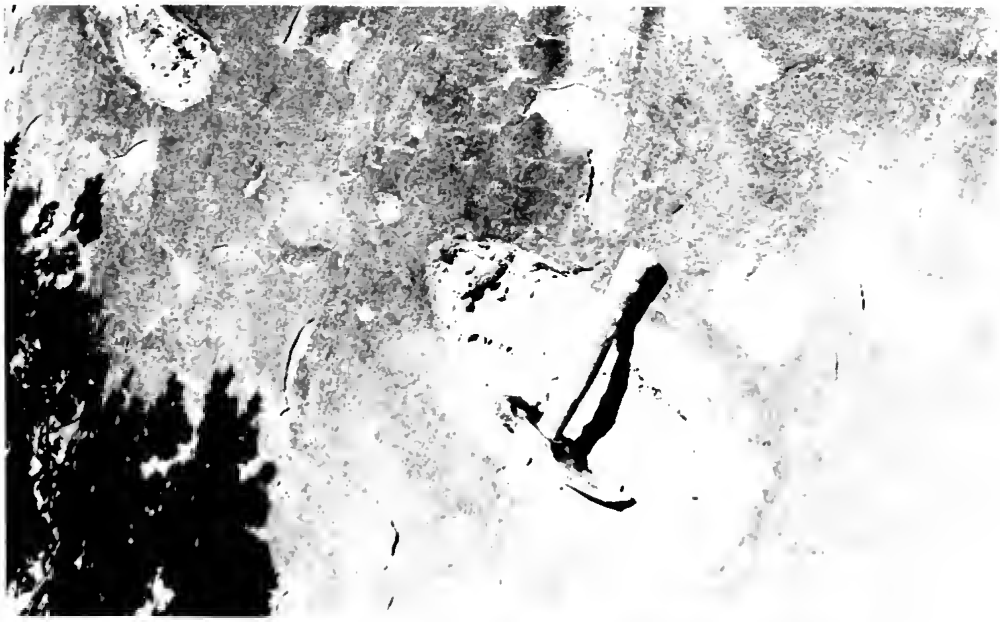
Filled Channel-Form, Wild Dog Creek. Near north-east end of shore platform, opposite 'The Falls'. Small channel-form with two lobes in the erosional base. Lobes yield slightly different current directions, indicating channel migration during scour. Fill is sedimentary breccia (angular mudstone clasts in a mudstone matrix). Minor fault transects scour, offsetting planar base of overlying arkose beds by approx. 30 cm. Note hammer on boulder along fault trace. Maximum thickness of scour, approx. 2 m.

PLATE 8

Concretions in Otway Group Arkoses.

Upper: Sandball type. Smythes Creek Quarry, east wall.
Lower: Calcified arkose type. Pedestal rock, Artillery Rocks, showing bedding dipping south-east (right) and crossbedding dipping flatly north-east (left).


A
B
C
CMS
0 1 2 3
D



longitudinal scour structures, formed in the soft muds of abandoned-channel fill during early overbank period of the next flood stage, and preserved by advance of braid bars during full flood and subsequent waning. Rapid rise of stage without prolonged erosion is indicated.

Because of their uncertain origin they were treated initially as D // and D ⊥ — meaning Structure Code D, parallel to current if scours and normal to current if megaripple. D // is usually more in agreement with the locality vector mean.

5. Cylindrical Concretions

Calcareous concretions are abundant in arkose beds, and on weathering and marine erosion stand out in relief on the cliffs and shore platforms (Pl. 8). Two types are present — calcified arkose type (probably secondary in origin) and 'sand-ball' or pod type, which consist of coarse sand, heavy minerals and pyrite (Stirling 1901), often within a ferruginised shell. At Mt. Defiance the latter show a fining-up sequence of spheres, becoming progressively smaller in a succession of arkose beds. Some concretions are cylindrical with diameters of 20-100 cm and more, and lengths of 0.5 to 2 or 3 m. Others are spheroidal, up to 50 cm diameter.

The cylinders tend to occur in groups or sets and commonly are aligned either normal or parallel to the estimated current direction (Pl. 5). In some places, dual sets are seen (both normal and parallel to current) and occasionally individual concretions may be bent twice at right angles into a U-shape. They are called Structure Code G (G // and G ⊥) in the analysis since it is usually not possible to know independently whether they are locally parallel or normal to current.

Possibly they are due to rolling of sand-rich pods during flood stage, forming cylindrical zones when entrained in channel-bar deposits, which are then favoured as a locus of deposition for circulating solutions during diagenesis, lithification and weathering.

Sets of unusually large cylinders occur south-west from the mouth of the Elliott River (Pl. 5). A few are found on most shore platforms.

P. Conaghan (1975, pers. comm.) has suggested that some may be in fact calcified logs, the decomposing woody tissue setting up chemical gradients in the lithifying sediments which promote local calcification. A search has been made for internal tree ring structures, by X-radiation and thin section, but these are generally absent (Pl. 6).

J. Douglas (1975, pers. comm.) suggests that they may be of algal origin, having noted similar structures in the Grampians sandstones (Early Devonian or older), formed before trees existed.

Treatment of Structures Code D & G: Each example of Structures Code D or G was first plotted as four equivalent possible current source directions. Then using other structures which are more current-sensitive to indicate the likely source quadrant, one of the four values was subjectively selected for statistical treatment and inclusion in the grouped data for the locality.

6. Lineations

Linear features on bedding planes are sometimes useful. These include entrained coalified logs and preferred orientation of coal fragments (Structure Code E).

Coalified logs are rare except north of Lorne at Cathedral Rock. Here several were found in the shore platform, ranging up to 1 m in length.

Preferred orientation of linear coal fragments on bedding planes and cross-stratification planes was demonstrated to be potentially useful, but only one example was in fact included (see limitations, above).

7. Small-scale Structures

Small-scale foresets (Structure Code F) were found in overbank thin-bedded sequences and in the fill of channel forms, mostly in the thin sandstones. They were measured at Addis Bay and Point Grey and included in the overall data for current direction determination at those localities.

PALAEOCURRENT DIRECTION MEASUREMENT

Methods

The most consistent indicator of current directions proved to be the scoured channel forms, filled with mudstone, arkose bands and sedimentary breccia. Several occur on most shore platforms, especially between Lorne and Cape Patton, where eight or ten per km of coastline may be found.

Five or six readings of the attitude of the erosional contact at the scour base were made, together with that of the bedding nearby, and plotted on the stereographic projection.

The poles of each dip measurement fall on a girdle on the projection, which defines the section-plane normal to the axis of the channel-form. The pole to this plane is the axis of the channel, and after correction for tectonic tilt indicates the local current vector as an azimuth and plunge angle.

Foresets in a-b or a-c planes (Allen 1968) were measured as often as encountered, together with foreset troughs (see Fig. 4), ripple mark, longitudinal erosion scours, and linear features such as entrained logs and cylindrical concretions.

Because individual primary structures are not abundant, every available structure was measured in the field. Structures occurring in groups (e.g. foresets) were measured at 2 or 3 places and the arithmetic mean used.

Sampling

No formal pre-designed sampling plan was employed. However, an hierarchical grouping structure was developed, consisting of

(i) *Exposures* — usually about 100 m of shore platform, sea cliff and adjacent road cuttings, identified by a fieldbook number.

(ii) *Localities* — groups of several adjacent exposures, showing consistent trends, containing about 10 measurements, and identified by a locality name.

(iii) *Sectors* — for computing moving-average trends, the coastline was divided into 5 km sectors, measured north-east from Cape Otway and identified by the letters A-M. Each sector contained up to 3 or 4 localities.

(iv) *Areas* — three Areas, or groups of many Localities and Sectors were outlined, defining discrete parts of the former basin of deposition.

(v) *Region* — the whole coast sampled, from Cape Otway to Eastern View.

Statistical Procedure

Data was analysed using the procedures advocated by High and Picard (1971). These are set out in their Fig. 6, and involve

- Correction for tectonic tilt and plunge
- Demonstration that directional data for different structures are statistically equivalent and capable of being grouped (Kolmogorov-Smirnov test)
- Use of the Tukey Chi-square statistic to demonstrate nonrandom orientation from the grouped data at each locality

The Rayleigh statistic, as advocated by Curray (1956) was also computed, and found generally more sensitive. Where a preferred unimodal distribution was not evident, Tanner's (1955) procedure for polymodal distributions was followed

- Calculation of measures of central tendency and dispersion, namely vector resultant, mean for grouped data, vector magnitude, variance and standard deviation. Where mean and vector resultant differ significantly due to choice of origin, data was transformed linearly (+180°) and the mean and variance recalculated
- Moving-average analysis of the region divided into 5 km sectors
- Map representation, compass diagram and circular histogram construction; identification of sub-areas within the basin
- Reconstruction of palaeogeographic trends.

Selection and Grouping of Measurements at Outcrop Level

Scours, troughs and crests, foresets, and linear features were first plotted on the stereographic projection (Wulff net) and tilt due to dip of bedding removed. Minor secondary tilt due to plunge of nearby folds was ignored as statistically insignificant. Following Ramsay (1961, Fig. 5, p. 89) and Potter and Pettijohn (1963, p. 261), the angular error in azimuth from neglecting plunge is less than 5° in the following cases: plunge ⟨ 10° : S_0 dips up to 63°; plunge ⟨ 20° : S_0 dips up to 35°; plunge ⟨ 30° : S_0 dips up to 42°. Plunges in the Otways appear to be shallow (⟨ 10°) and dips are rarely over 45°.

Using the reduced data, a circular diagram (Fig. 5) was constructed showing palaeocurrent directions for every type of structure present.

The most significant vectorial structures were placed in the centre; other scalar and possibly ambiguous structures were placed towards the periphery. Then the range of readings to be accepted was marked in the eye of the diagram.

The diagrams thus gave a visual subjective estimate of the possible range of current directions, and readings from scalar structures were selected accordingly to be grouped with vectorial data (scours and foresets) as input to the computer. Nearly always the selected reading was found to *parallel* the observed attitude of the scalar structure (e.g. logs parallel to current); much more rarely were normals to observed attitudes included.

Grouping of Outcrops into Localities, and Naming Localities

By comparing the ranges of acceptable readings for adjacent outcrops, groupings of 3-4 outcrops with similar trends into localities were made. These are the units used in the summary (Table 1), assembled in sequence north-east from Cape Otway. Each is a shore platform (or part of one) and has little other geological significance. Localities may therefore be grouped or regrouped as desired. The localities used were selected to contain about 10 measurements each, as suggested by High and Picard (1971, p. 34) and Potter and Pettijohn (1963, p. 256).

Locality names in Table 1 were usually chosen from the mouth of the nearest named river (indicating on which side, north-east or south-west): thus 'Grey River S.P. SW' means 'Grey River shore platform, south-west from river mouth'.

Hence localities are groups of adjacent outcrops, from 2 to 4 or 5 in number, which show consistent palaeocurrent directional trends, and which contain approx. 10 measurements. They have been grouped from inspection of the circular outcrop-group diagrams

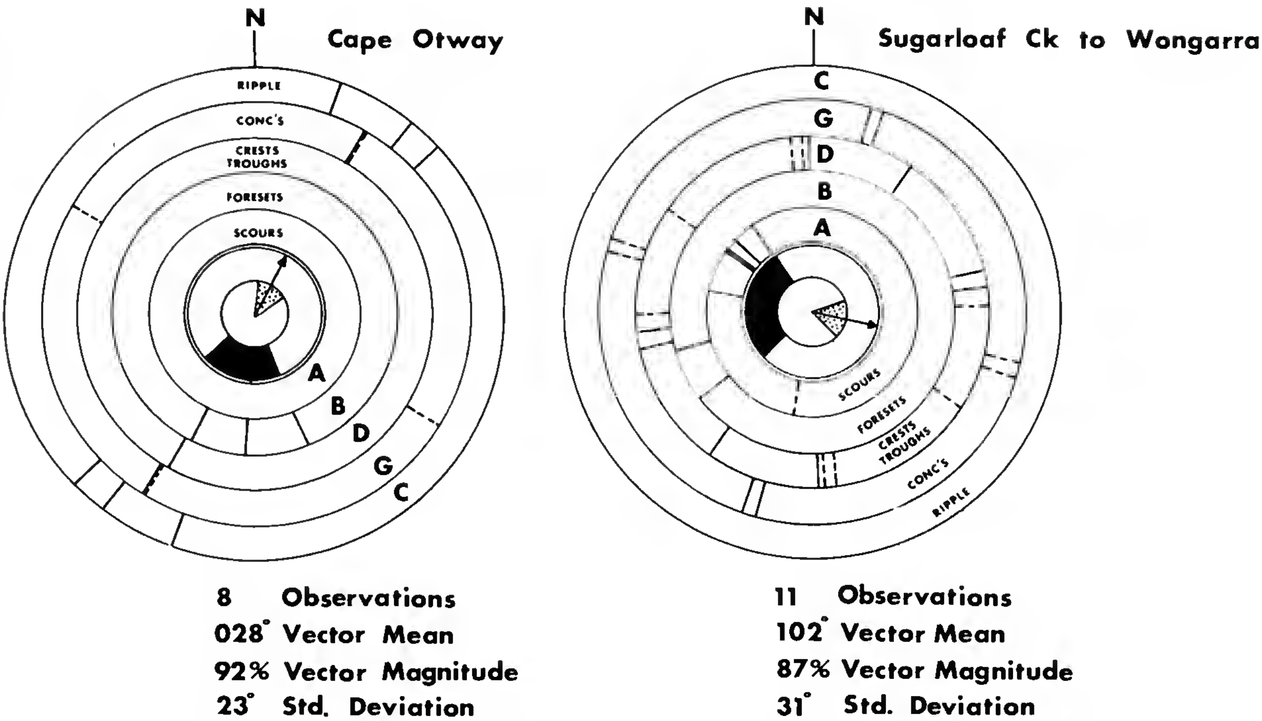


FIG. 5—Two Examples of the Circular Diagrams used in the Selection of Directional Structures. Central Part: Current Vector Mean; arc subtends one standard deviation each side. Range of likely current sources (shown in black). Peripheral Part: Directional structures measured at this locality.

as having essentially similar overall ranges of palaeocurrent source directions.

Computer Processing

A computer program was written in ICL 1900 Fortran to increase flexibility of ordering of data groups and to ensure mathematical accuracy. The computer calculated for each locality (and then for data grouped in various manners) a variety of statistics:

- Vector mean and significance using the Tukey Chi-square test (High & Picard, 1971 p. 33).
- Vector mean and vector magnitude ('consistency ratio') after the method of Reiche (1938).
- Mean, variance and standard deviation for classed (grouped) data (Koch & Link 1970).
- Probability that the calculated value of x_2 is not the product of random orientations, using tables of Dixon and Massey (1951, p. 308).
- Rayleigh test of significance (Curray 1956, p. 175 and Fig. 4).

Since grouping of localities would tend to produce polymodal distributions, the data needed for the compass diagrams and rose diagrams of the Tanner procedure were produced, namely mean number of observations per interval with associated standard deviation and variance. Results appear in the format of a worksheet, allowing manual checking, following High and Picard (1971 p. 34, after Harrison, 1957). At the end of each set of localities there is a summary by class interval of all observations submitted, which can be used to repeat the computations for sectors, sub-areas and for the region as a whole. A summary table listing all results is produced at end-of-run (Tables 1 to 4).

ANALYSIS OF PALAEOCURRENT RESULTS

Recognition of Areas

Inspection of the compass diagram (Fig. 7) representing the polymodal distribution for the whole region reveals three modes. The three sub-areas are respectively Cape Otway to Point Sturt (near Wye River), Point Sturt to Point Grey (Lorne), and north-east of Lorne. Each shows a well-developed preferred orientation when all palaeocurrent data are plotted as a circular histogram, indicating sources to the south, east and north-west this is consistent with accepted ideas on the regional structure of the basin of deposition (Wopfner & Douglas, 1971).

Detailed Palaeocurrent Trends

For a more precise estimate of current trends, vector mean (V.M.) and vector strength (L½) are shown in Table I as computed at locality level, and are plotted on Figs. 8 and 9. Readings have been grouped into 30°

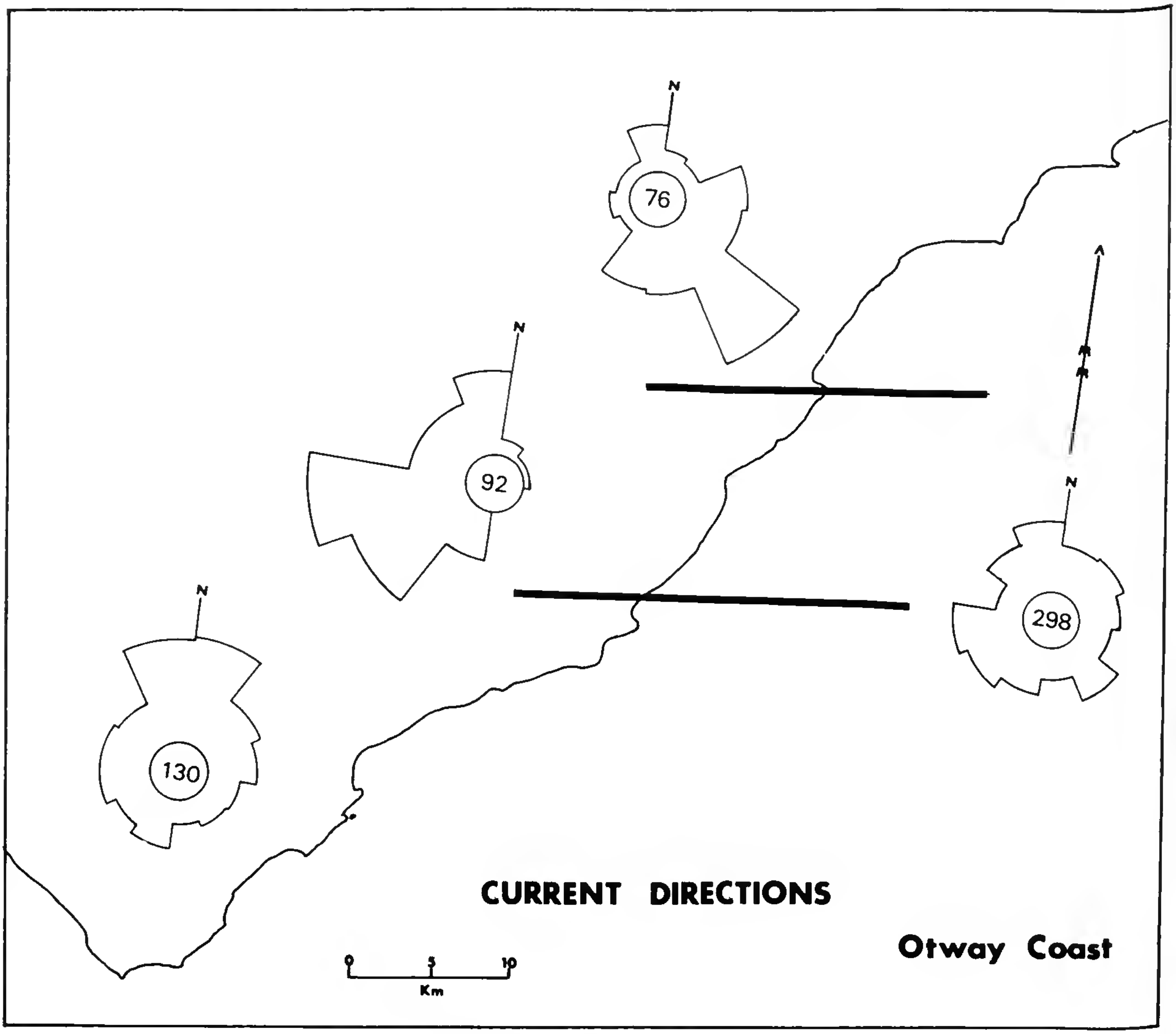


FIG. 6—Current Directions, Otway Coast: Roses.

classes as suggested by High and Picard (1971, p. 35). Inspection of each vector mean direction in Fig. 8 shows a general uniformity of overall trend within each area, but considerable local variance, and occasional gross divergence. The gross divergencies are all near major faults or monoclines (Elliott River coastline, Skenes Creek Monocline, Carisbrook Creek and Reedy Creek).

Dispersion around the vector mean is shown in Fig. 9 by vector magnitude (L% — Curray 1956). The vector magnitude shows appreciably lower values in the central area, compared with northern and southern areas where it commonly exceeds 85%. This decline in vector strength reflects a greater dispersion of values around the mean (Potter & Pettijohn 1963), presumably due to the lower gradients of the central part of the basin. The dispersion was noticed in the field before any knowledge of the palaeocurrent directions was available, from the larger range of current source directions.

At Lorne, the change in source direction from north-west (northern area) to east (central area) is abrupt. It occurs at Point Grey where a fault zone is evident in the shore platform, trending north-west, and a small synclinal structure recorded by A. B. Edwards (unpub. field notes) is exposed at low tide. The syncline is probably caused by drag on the fault zone.

In contrast, the change in source direction from east to south at Point Sturt is more gradual, occurring over about 5 km of coastline in sector H.

TABLE 1.
CURRENT SOURCE DIRECTIONS. LOCALITIES — CAPE OTWAY TO EASTERN VIEW.

VECTOR RESULTANT	VECTOR MAGNIT.%	SIGNIFICANCE TUKEY	RAYLEIGH	NO. OBS	MEAN	VARIANCE	STD.DEV'N	LOC.NO.
208.3	92.9	0.995	0.0023678	7	207.9	557	23.60	745 CAPE OTWAY
77.4	86.2	0.995	0.0000301	14	77.1	1034	32.15	746 PARKER RIVER SW
325.1	81.5	0.995	0.0001781	13	268.8	13592	116.59	748-52 ELLIOTT R. COASTLINE
285.0	100.0	0.950	0.0497871	3	285.0	0	0.00	753 ELLIOTT RIVER NE (MUDSTONES)
126.2	89.4	0.995	0.0003410	10	126.0	810	28.46	754-758 STORM POINT
166.7	83.6	0.995	0.0004553	11	165.0	1260	35.50	734-9 SWELL PT TO CAPE MARENGO
156.2	59.9	-0.900	0.2385889	4	157.5	3825	61.85	747 CUTTING, NOEL ST. APOLLO BAY
113.8	54.5	0.950	0.0282861	12	115.0	3655	60.45	741-2 WILD DOG CREEK
24.9	97.0	0.995	0.0002109	9	25.0	225	15.00	740 SKENES CREEK SW
174.4	88.4	0.990	0.0092107	6	175.0	960	30.98	733 & 732 SKENES CREEK NE
282.8	87.0	0.995	0.0002425	11	282.3	982	31.33	716B WONGARA TO SUGARLOAF
218.3	60.0	0.950	0.0390068	9	205.0	4050	63.64	715-6A SUGARLOAF-CARISBROOK CK.
191.6	83.5	0.995	0.009452	10	192.0	1290	35.92	711-2 CAPE PATTON-GREY R.
215.1	65.2	0.990	0.0093533	11	205.9	3289	57.35	706,713 GREY R. TO ADDIS BAY NE
76.5	52.3	0.900	0.0646200	10	93.0	4640	68.12	710,717-8 KENNETT R. TO PICNIC PT
103.7	57.0	0.950	0.0389136	10	108.0	3890	62.37	719-21 PICNIC PT TO PT STURT
137.3	88.1	0.995	0.0000189	14	137.1	895	29.92	722 WYE R. TO BOGGALEY CK.
93.8	59.6	0.990	0.0099130	13	98.1	3323	57.65	725-8 BOGGALEY CK.
142.9	90.8	0.950	0.0369187	4	142.5	825	28.72	729-31 GODFREYS CK-ARTILL. ROCKS
116.6	43.2	-0.900	0.1547372	10	126.0	5210	72.18	767-9 JAMIESON R. TO MT DEFIANCE
81.2	84.6	0.995	0.0032404	8	82.5	1221	34.95	770-2 CUMBERLAND R - SHEOAK CK.
69.9	74.9	0.995	0.0006826	13	72.7	2019	44.94	765-6 TEDDYS LOOKOUT S.P.
65.1	79.5	0.995	0.0018041	10	66.0	1610	40.12	701 POINT GREY SW
328.3	87.0	0.995	0.0005187	10	291.0	10160	100.80	773,763,764 POINT GREY, LORNE
320.1	90.2	0.995	0.0000001	20	267.0	11975	109.43	774-6 STONY CK TO REEDY CK.
179.6	78.3	0.995	0.0006334	12	187.5	2148	46.34	777-8 REEDY CK - CATHEDRAL ROCK
264.9	79.3	0.995	0.0009827	11	246.8	3436	58.62	760,761 BIG HILL CREEK, NE & SW
55.6	72.4	0.995	0.0006488	14	83.6	7398	86.01	779-80 CINEMA PT - BALL HOUSE SP
345.0	82.9	0.995	0.0020492	9	268.3	16450	128.26	762,779 GRASSY CREEK

TABLE 2.
CURRENT SOURCE DIRECTIONS. SECTORS.

VECTOR RESULTANT	VECTOR MAGNIT.%	SIGNIFICANCE TUKEY	RAYLEIGH	NUMBER OBS.	MEAN	VARIANCE	STD.DEV'N	LOC.NO.
109.6	43.9	0.975	0.0173767	21	120.7	4826	69.47	SECTOR A CAPE OTWAY
337.4	17.5	-0.900	0.4526653	26	215.8	12079	109.91	SECTOR C ELLIOT R.
160.0	69.4	0.995	0.0004500	16	155.6	2486	49.86	SECTOR D MARENGO
90.0	37.7	0.975	0.0215819	27	98.3	5146	71.74	SECTOR E WILD DOG
282.8	87.0	0.995	0.0002425	11	282.3	982	31.33	SECTOR F SUGARLOAF
202.0	70.5	0.995	0.0000793	19	198.2	2489	49.89	SECTOR G CAPE PATTON
173.0	35.3	0.900	0.0735559	21	166.4	5533	74.38	SECTOR H KENNETT
126.8	72.4	0.995	0.0000035	24	125.0	2243	47.37	SECTOR I WYE NE
111.2	54.8	0.995	0.0003054	27	115.0	3738	61.14	SECTOR J JAMIESON
71.5	78.4	0.995	0.0000000	31	73.1	1616	40.20	SECTOR K CUMBERLAND
306.4	47.5	0.995	0.0000760	42	250.0	10050	100.25	SECTOR L LORNE
349.5	36.4	0.975	0.0111216	34	185.3	15476	124.40	SECTOR M CINEMA PT

TABLE 3.
CURRENT SOURCE DIRECTIONS. MOVING AVERAGES OF ADJACENT SECTORS.

VECTOR RESULTANT	VECTOR MAGNIT.%	SIGNIFICANCE TUKEY	RAYLEIGH	NUMBER OBS.	MEAN	VARIANCE	STD.DEV'N	LOC.NO.
109.6	43.9	0.975	0.0173767	21	120.7	4826	69.47	SECTOR AB
337.4	17.5	-0.900	0.4526653	26	215.8	12079	109.91	SECTOR BC
169.0	17.3	-0.900	0.2944790	41	196.5	8818	93.90	SECTOR CD
130.0	41.2	0.995	0.0007886	42	121.4	4838	69.56	SECTOR DE
4.6	10.2	-0.900	0.6614004	40	161.2	12286	110.84	SECTOR EF
234.3	58.9	0.995	0.0000305	30	229.0	3583	59.86	SECTOR FG
191.8	50.5	0.995	0.0000374	40	181.5	4244	65.14	SECTOR GH
140.2	51.4	0.995	0.0000069	45	144.3	4125	64.22	SECTOR HI
119.7	62.5	0.995	0.0000000	51	119.7	3001	54.79	SECTOR IJ
86.3	63.6	0.995	0.0000000	58	92.6	3001	54.78	SECTOR JK
19.6	28.4	0.995	0.0027238	73	174.9	14151	118.96	SECTOR KL
322.6	39.7	0.995	0.0000063	76	221.1	13352	115.55	SECTOR LM

TABLE 4.
CURRENT SOURCE DIRECTIONS. AREAS AND REGION SUMMARIES.

Number Obs.	Mean	Variance (Transformed)	Std. Dev'n	Locality
298	148.2	5544	74.46	Summary: Region
130	159.7	6034	77.68	Summary: Cape Otway to Pt. Sturt
92	101.1	3110	55.77	Summary: Pt. Sturt to Pt. Grey
76	185.5	3437	58.63	Summary: North-east of Lorne

PALAEOGEOGRAPHIC RECONSTRUCTION

At sector level, moving averages of vector means and vector strengths were computed to smooth local variations and distribute current symbols evenly across the map without regard to outcrop control. These are shown in Fig. 10. Vector strengths as expected are considerably lower.

The tripartite nature of current trends along the coastline is again seen, but emphasis is given to the radial pattern of current directions in the central area, converging into the region west of Wye River.

The east-to-west trend of currents in the central sector may reflect the general slope of the rift valley of southern Australia in Albian times (I. McPhee 1975, pers. comm.), including the Strzelecki Basin (Hocking 1972) and the Bass Basin. Alternatively, the Mornington Peninsula — King Island ridge may have been topographically high during the Albian, dividing the rift valley into separate basins of deposition in the Early Cretaceous. Lower Cretaceous sediments at Inverloch are regarded as estuarine (A. Link 1975, pers. comm.) rather than fluviatile so that the latter suggestion seems more likely at present.

Fig. 10 suggests the pattern of sedimentation for the Otway Coast. North-south ridges, probably of low relief, divide piedmont slopes into broad open valleys with braided channel systems, flowing inwards and then westerly along the rift valley. Overbank facies are scarce, suggesting largely emphemeral streams such as those of eastern Central Australia today.

Areas of swamp and lake deposition are indicated by thin-bedded sequences such as at Skenes Creek, and by some thick mudstones, such as at Cape Otway and Elliott River.

ECONOMIC SIGNIFICANCE

The palaeocurrent trends have considerable economic significance. Mesozoic rocks contain Victoria's only major deposit of bituminous black steaming coal, at Wonthaggi (Knight 1975, Edwards and others 1944). The Otway Ranges were investigated for further deposits in 1900 (Strling 1901), by means of several drill holes near Apollo Bay and Skenes Creek, where 12-inch (0.3 m) coal seams were being worked along the valley of Wild Dog Creek within the Skenes Creek Monocline belt.

With a better understanding of original deposition and later tectonic modification, the search for a black coal field in the Otways might be resumed. Exploration in the low-lying regions of the basin offers best hope of locating coal swamps, and as shown in Fig. 10, this means initially in the Ranges to the west of Wye River. Basin analysis should be extended to the rest of the Ranges, as sedimentation trends inland from the coast are unknown.

The area of interest is triangular and lies between Cape Patton, Point Grey, and Forrest. Reconnaissance mapping (Edwards 1962, Medwell 1971) suggests that the central part of this region is a plateau dipping flatly north-east (10°-20°), which is ringed by structurally disturbed belts — the Devils Elbow Monocline, Lorne Syncline, Mt. Defiance Anticline and fault, Kennett and Patton Synclines, and Skenes Creek Monocline. It is also transected by many small faults and two major fault zones (Fig. 11).

HIGH REGIONAL VARIANCE

When total readings from all localities are accumulated and grouped into classes, to compute a grand vector mean and a regional variance (Table 4), the resulting variance (5544) is unusually high. Potter and Pettijohn (1963) quote 4000-6000 as being characteristic of fluviatile deposits generally. Casshyap and Qidwai (1971) obtained figures of 2045 and 4178 for formations from environments dominated by braided streams and meandering streams respectively. McDonnell (1974) obtained a total variance of 2049 for the Gosford Group (Triassic) of the Sydney Basin, commenting that this reflected measurements on pi-cross-bedded sandstones identified as channel bars in a 'low sinuosity low-braiding' fluvial system.

When total variance is computed for each area (northern, central, southern) and transformed data is used where necessary to obviate the effect of choice of origin, respective figures of 3437, 3110 and 6034 are obtained (Table 4). These are still somewhat higher than might be expected in a braided stream environment. They may reflect the combining of readings

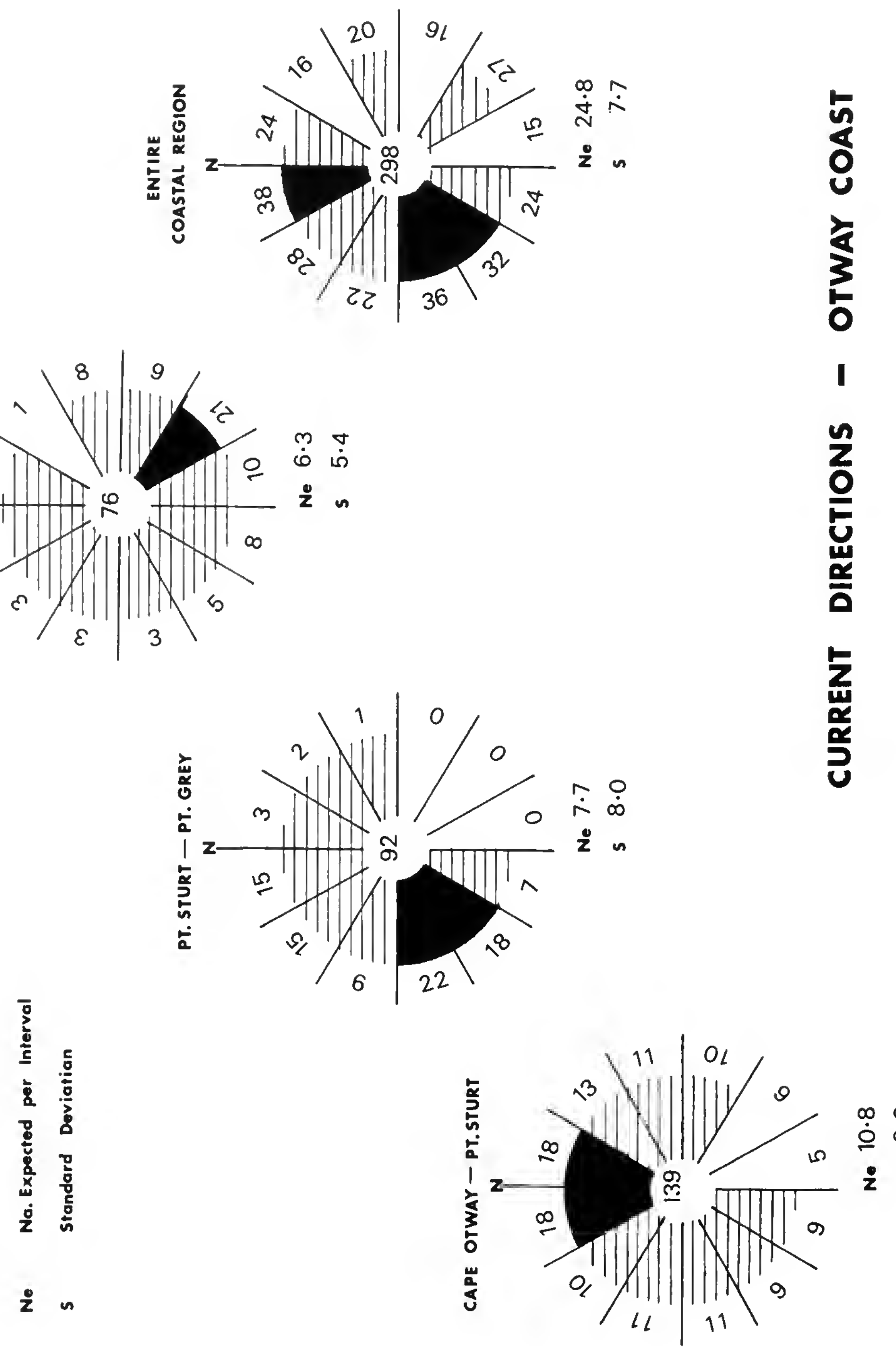


FIG. 7—Current Directions, Otway Coast: Compass Diagrams.

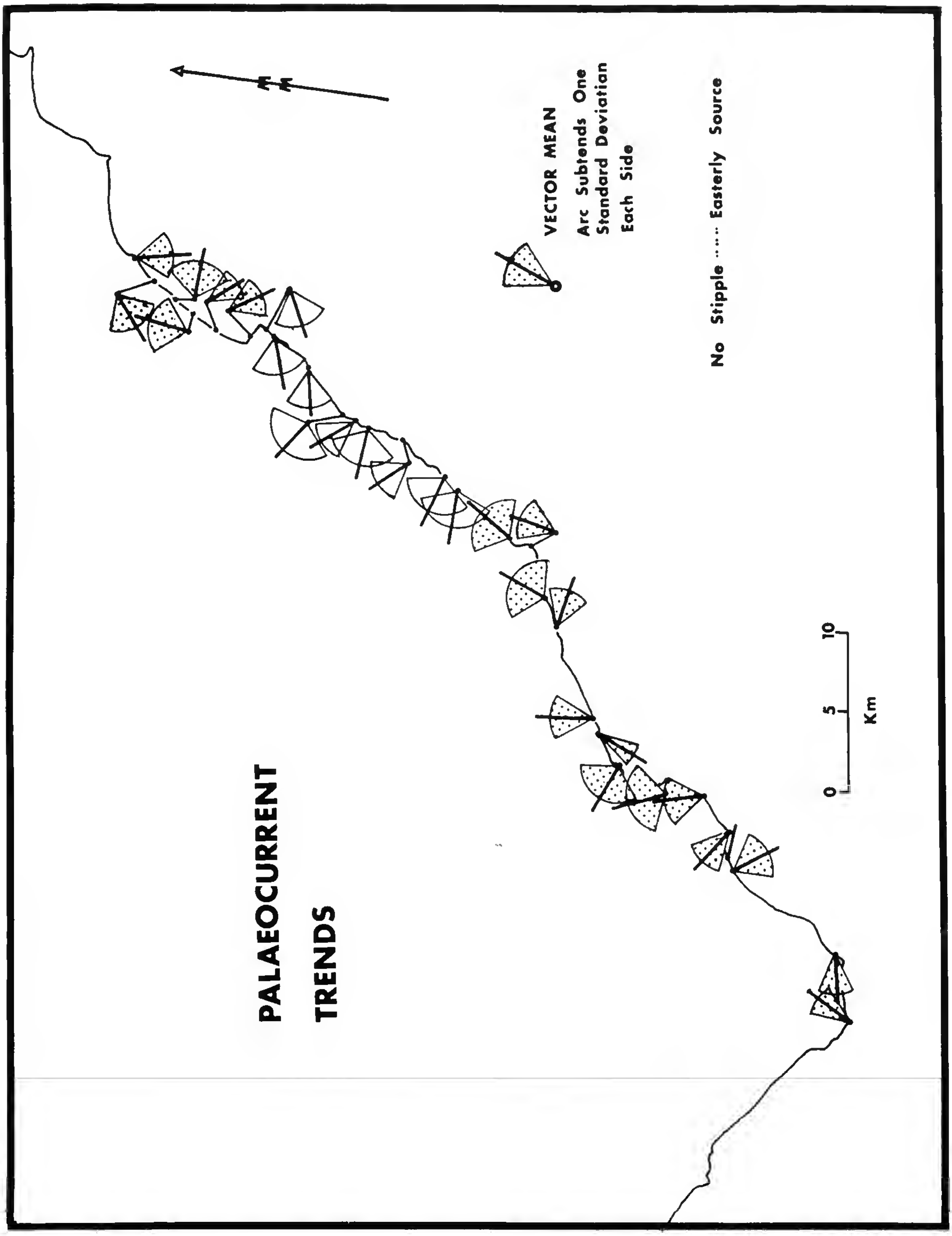
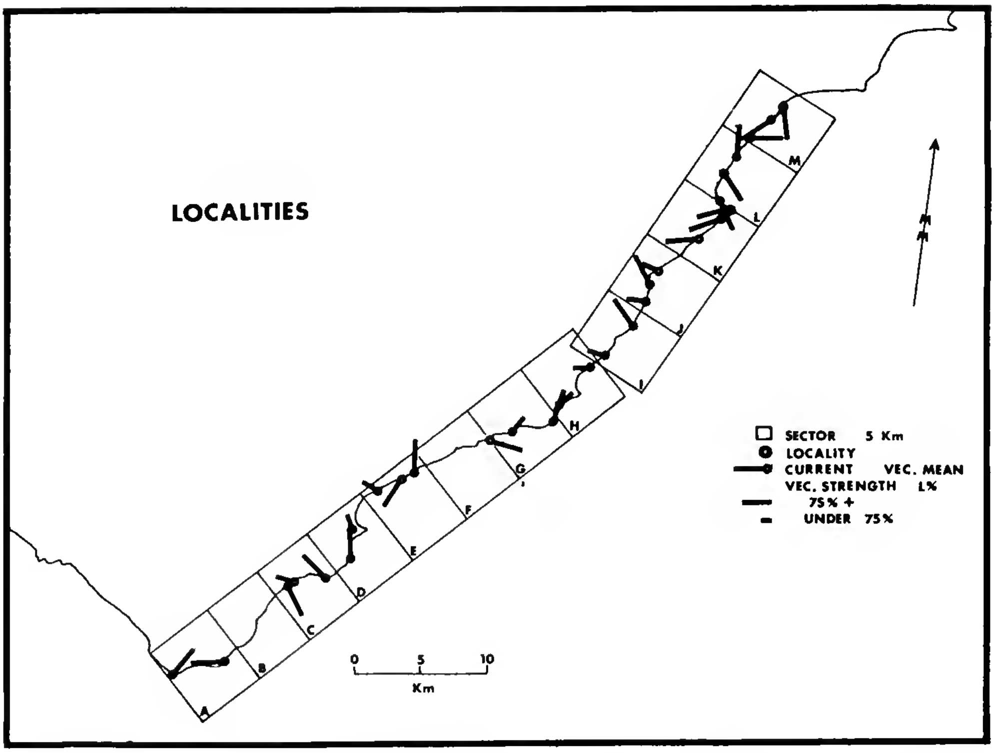


FIG. 8—Palaeocurrent Trends at Coastal Localities Sampled.



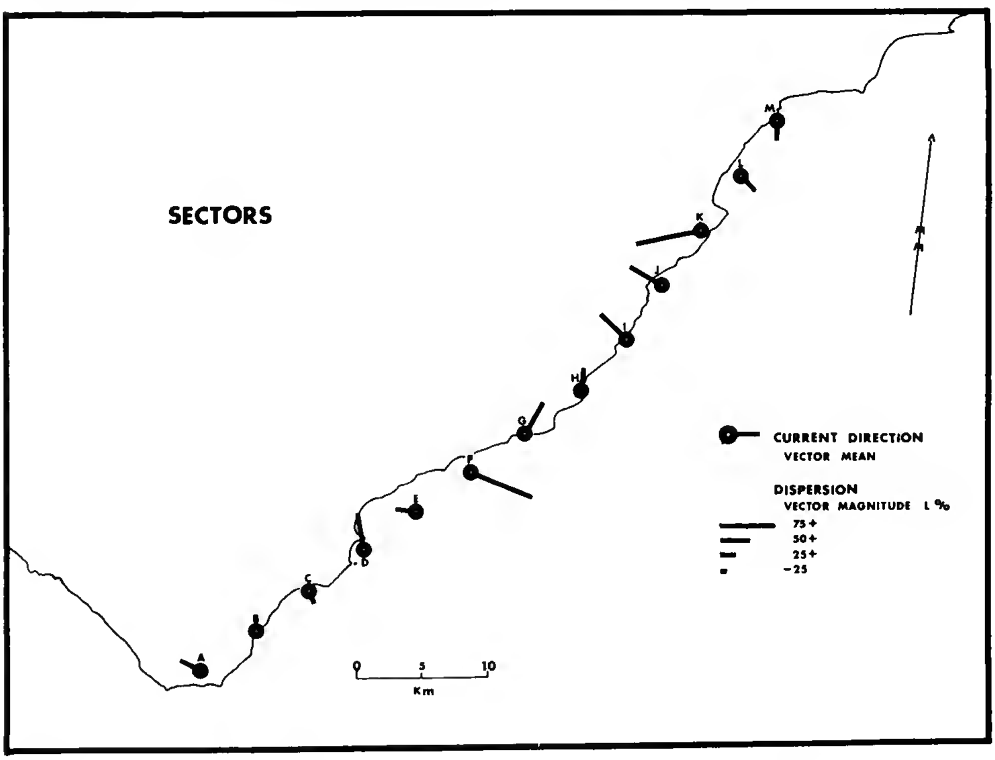


FIG. 9—Palaeocurrent Trends by Locality and Sector.

from five sets of different structures. Certainly they reflect the generally marked angular difference between source directions inferred from cross-bedding and from filled channel-forms at most localities.

Four localities were noted where gross divergence from the inferred regional trends occurs. These are the localities termed Elliott River Coastline, Skenes Creek south-west to Wild Dog Creek, Carisbrook Creek south-west, and Reedy Creek.

Each is near a major fault or monocline whose effects are not adequately known. Elliott River Coastline lies south-west from the mouth of the Elliott River, where an abrupt change in strike occurs and faulting is inferred ('Elliott Zone', Fig. 11).

At Wild Dog Creek, the beds in the shore platform increase in dip southwesterly (from 46° to near vertical) over a strike length of about 1 km at the foot of the Skenes Creek Monocline. Carisbrook Creek and Reedy Creek are each the site of faults inferred by Edwards (1962) from linear valleys and dislocation of beds in the shore platforms. At Reedy Creek a basin structure interpreted as dragged bedding on a major fault is visible.

If the discrepancies are not of later tectonic origin, they represent flow directions in the basin of deposition generally opposite to the overall trends and suggest local topographic highs, as marked on Fig. 10 by dashed lines. These may have been intermittently formed by syndepositional tectonism with north to south trends, resulting in defeat of streams and the periodic formation of swamps, lakes and coal measures.

A third possible explanation might stem from inability to distinguish separate stratigraphic horizons along the coast. The anomalous localities may be younger deposits (Zone D) preserved in local grabens. If so, they suggest by their northerly source-indication that the axis of the basin (Central Area of this study) migrated south through the Early Cretaceous. This would accord both with Kenley's suggestion (in Wopfner & Douglas 1971, Fig. 21.11) that the early (Zone B) 'axis of greatest shaliness' was located nearer the northern margin of the rift valley, and the observation here presented, that the basin axis was south of Lorne by Zone C time.

SUMMARY

The coastline of the Otway Ranges, between Cape Otway and Eastern View, exposes 65 km of Lower Cretaceous sediments, thought to be essentially of the same stratigraphic position (Zone C of Douglas 1971, that is, Albian) because of the domed structure of the Ranges.

Five directional primary structures were found to be abundant. These are filled channel-forms ('scours'), foresets in arkose units, crests and troughs aligned downcurrent by penecontemporaneous erosion, ripple mark, and alignment of cylindrical (pod-shaped) concretions.

Filled channel-forms are most abundant along the central coast between Lorne and Cape Patton. They contain easily-erodible mudstone, sedimentary breccia and thinly-bedded sandstones and hence are topographically low. The axis of the structure (plotted stereographically) was used, and commonly showed small dispersion about the local mean palaeocurrent trend.

The maximum inclination of foreset beds in thick arkose units showed considerable dispersion. This structure is best measured in the a-c sedimentary plane, which is usually in the vertical wall of gulches in the shore platforms. The shore platforms commonly expose the a-b plane, in which the foresets are seen to be sinuous and non-penetrative.

Cross-bedding is often marked by coalified plant remains, which are oriented normal and parallel to strictly local current directions down or along the avalanche face of the bedform.

Ripple mark was restricted to the mudstones of thin-bedded sequences, which occur only at a limited number of outcrops. These represent the levee and overbank suites of palaeochannel deposits and are not abundant.

Crests and troughs of longitudinal (with-current) hollows in mudstones filling channel-forms were also used. These were grouped with other undulose structures in arkose beds, whose orientation (with-or across-current) is less certain.

Finally, use was made of oriented calcareous concretions. Two types of concretion occur in these rocks — calcified arkose spheres and cylinders, and 'sandballs' which may be spherical or pod-shaped.

When cylindrical they are commonly oriented approximately down-current, and were probably rolled up by flood-stage currents and entrained in braid bars during waning stage deposition.

These structures were shown to have statistically equivalent distributions and were grouped to give a minimum of ten observations per locality, wherever possible. The grouped data was computer processed providing tables from which Figs. 6-10 were constructed. These show current direction and dispersion (as vector mean and vector magnitude L %) for localities and sectors (5 km of coastline), and moving averages for adjacent sectors.

A palaeogeographic reconstruction was made for Zone C times, showing well-defined southerly-flowing streams in the northern Ranges, turning to

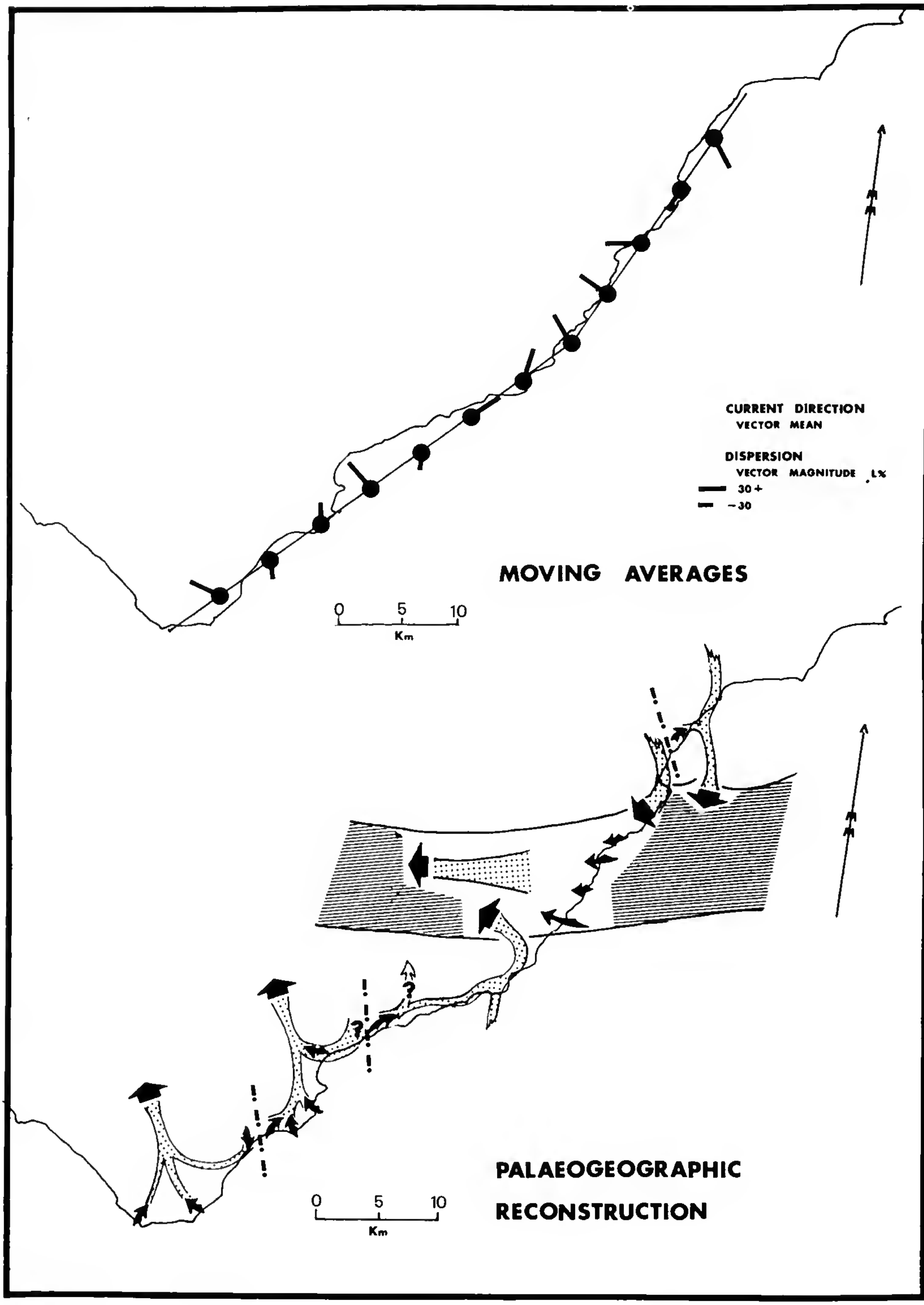


FIG. 10—Moving Averages and Palaeogeographic Reconstruction.

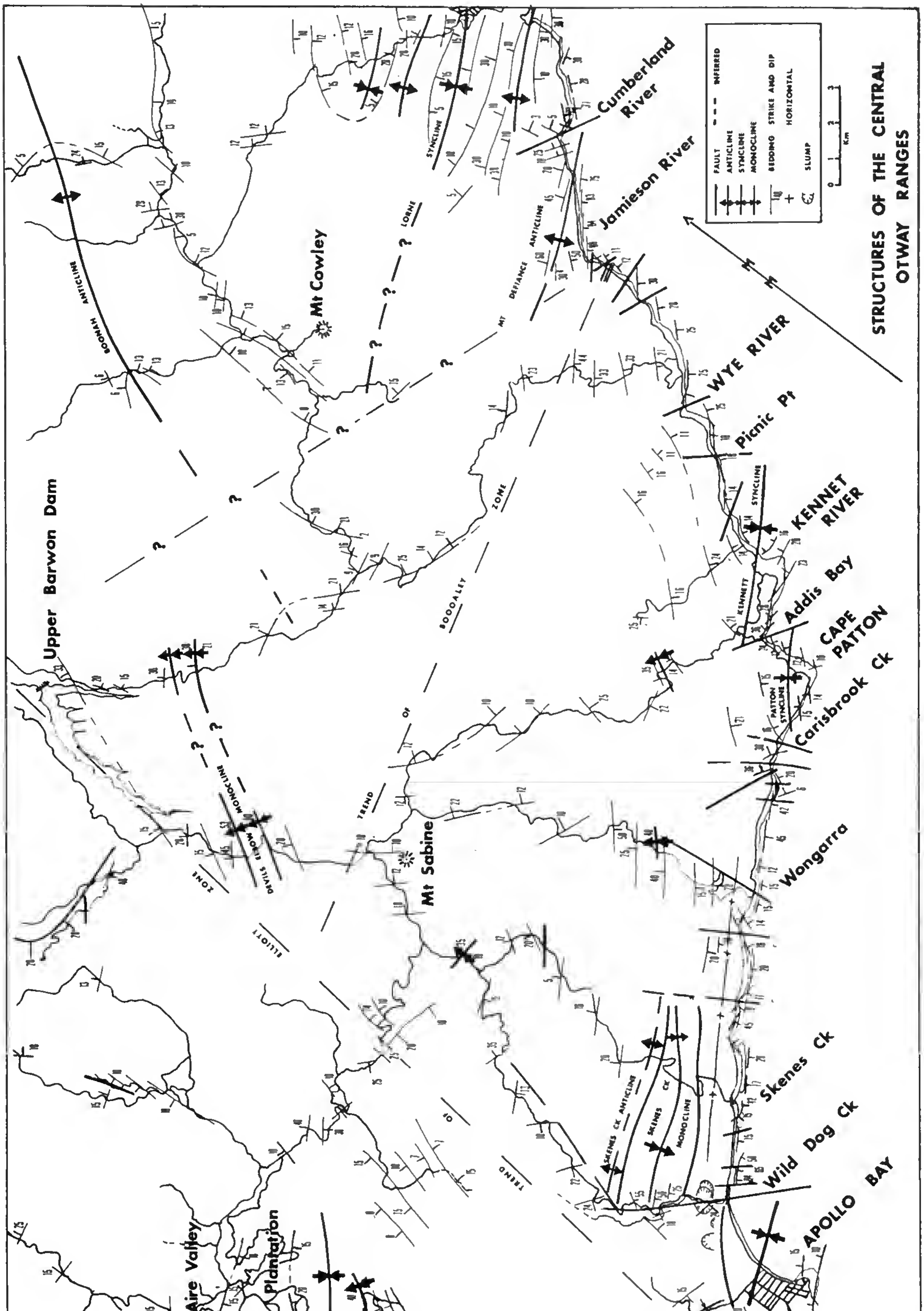


FIG. 11—Structures of the Central Otway Ranges.

westerly-flowing in the region south of Lorne and then to northerly-flowing south of Kennett River.

These trends generally confirm previous ideas on the basin sedimentation pattern derived from oil bores (see Kenley in Wopfner & Douglas 1971). However, the westerly-flowing trend in the central area has not previously been noted.

An eastern source area for the central part of the ancient Otway Basin may imply that the Mornington Peninsular-King Island ridge was a high in Albian times, and hence probably throughout the Early Cretaceous. It therefore separated the Otway Basin from the Strzelecki Basin during the early stages, continuing to do so until the present. It may thus be a feature of considerable permanence, astride the rift valley.

Alternatively, the region of westerly-flowing streams may indicate that the whole of the Early Cretaceous rift valley, from Gippsland to South Australia, drained westerly. Probable estuarine conditions of sedimentation at Inverloch would seem to preclude this.

Some of the palaeocurrent directions obtained imply that north to south trending divides may have existed between adjacent drainage basins. They suggest an environment of shallow wide valleys with braided streams in which high flow regimes were rarely attained (contrast the Hawkesbury Sandstone environment described by Conaghan & Jones 1975). In these valleys the distribution of lakes and swamps was irregular, with no apparent control which can be identified as yet. The central part of the Otway Ranges is the most likely area to contain black coal seams of economic significance. This is an elevated flat-lying region surrounded by major faults, folds and monoclines, and transected by many faults.

The palaeocurrent directions show a high variance which is considerably in excess of published data for other deposits of braided streams. The factors causing this include great variability in cross-bedding measurements, grouping of different primary structures, tripartite division of source regions, low gradients in the central area, possible local tectonic disturbance, and perhaps the inclusion of unrecognised beds from higher stratigraphic positions. In the region of the Skenes Creek Monocline, almost 1000 m of sediments dip steeply towards the sea, so that the stratigraphic position of the present coast is uncertain.

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REFERENCES

ALLEN, J. R. L., 1968. *Current Ripples*, North Holland Pub. Co., Amsterdam.

————, 1963. The classification of cross-stratified units, with notes on their origin. *Sedimentology* 2 : 93-114.

BOEUF, N. G., & DOUST, H., 1975. Structure and development of the southern margin of Australia. *APEA Jour.* 15, Pt. 1 : 33-43.

CASSHYAP, S. M., & QIDWAI, H. A., 1971. Paleocurrent analysis of Gondwana sedimentary rocks, Pench Valley Coalfield, Madhya Pradesh (India). *Sediment. Geol.* 5: 135-145.

CONAGHAN, P., & JONES, J. G., 1975. The Hawkesbury Sandstone and the Brahmaputra: A depositional model for continental sheet standstones. *J. geol. Soc. Aust.* 22, Pt. 3: 275-283.

CURRAY, J. R., 1956. The analysis of two-dimensional orientation data. *J. Geol.* 64: 117-131.

COLEMAN, J. M., 1969. Brahmaputra River: channel processes and sedimentation. *Sediment. Geol.* 3: 129-239.

DOUGLAS, J. G., 1971. Biostratigraphical subdivision of Otway Basin Lower Cretaceous sediments. In Wopfner and Douglas, (Eds), The Otway Basin of Southeastern Australia, *Spec. Bull. geol. Survs S. Aust. and Vict.*: 187-192.

————, 1977. The Geology of the Otway Region, Southern Victoria. *Proc. R. Soc. Vict.* 89: 19-25.

DIXON, W. J., & MASSEY, F. J. Jr., 1951. *Introduction to Statistical Analysis*. McGraw-Hill Book Co., 370 pp.

EDWARDS, A. B., 1962. Notes on the geology of the Lorne district, Victoria. *Proc. R. Soc. Vict.* 75 (1): 101-118.

EDWARDS, A. B., BAKER, G., & KNIGHT, J. L., 1944. The geology of the Wonthaggi coalfield, Victoria. *Proc. Aus. I.M.M.* 134: 1-54.

EDWARDS, A. B. & BAKER, G., 1943. Jurassic arkose in Southern Victoria. *Proc. R. Soc. Vict.* 55 (2): 195-228.

FALVEY, D. A., 1974. The development of continental margins in plate tectonic theory, *APEA Jour.* 14, Pt. 1: 95-106.

GRIFFITHS, J. R., 1971. Continental margin tectonics and the evolution of South East Australia, *Ibid.* 11, Pt. 1: 75-79.

HARRISON, P. W., 1957. New techniques for three-dimensional fabric analysis of till and englacial debris containing particles from 3 to 40 mm in size. *J. Geol.* 65: 98-105.

HAMBLIN, W. K., 1962. X-ray radiography in the study of structures in homogeneous sediments. *J. Sed. Pet.* 32, No. 2: 201-210.

HARMS, J. C., & FAHNESTOCK, R. K., 1965. Stratification, bedforms, and flow phenomena (with an example from the Rio Grande). In G. V. Middleton (Ed), Primary Sedimentary Structures and their Hydrodynamic Interpretation. *Soc. Econ. Palaeontologist & Mineralogists Spec. Publ.* 12: 84-115.

HIGH, L. R., & PICARD, M. D., 1971. Mathematical treatment of orientation data. In Carver, R. E. (Ed). *Procedures in Sedimentary Petrology*, Wiley-Interscience, New York.

HOCKING, J. B., 1972. Geologic evolution and hydrocarbon habitat, Gippsland Basin. *APEA Jour.* 12, pt. 1: 132-137.

KENLEY, P. L., 1971. Hydrocarbon Occurrences and Potential of the Otway Basin (Wopfner, Kenley and Thornton). In Wopfner, H., and Douglas, J. G., (Eds) The Otway Basin of Southeastern Australia. *Spec. Bull. geol. Survs S. Aust. and Vict.*: 385-435.

KOCH, C. S., & LINK, R. F., 1970. *Statistical Analysis of Geological Data*. Wiley, New York: 2 v.

KNIGHT, J. L., 1975. Wonthaggi and other Cretaceous Black Coal Fields, Victoria. *Monograph No. 6., Aus. I.M.M.*: 334-338.

McDONNELL, K. L., 1974. Depositional environments of the Triassic Gosford Formation, Sydney Basin. *J. Geol. Soc. Aust.*, 21, Pt. 1: 107-132.

MEDWELL, G. J., 1971. Structures of the Otway Ranges. In Wopfner, H., and Douglas, J. G., (Eds) The Otway Basin of Southeastern Australia. *Spec. Bull. geol. Survs. S. Aust. and Vict.*: 339-362.

MIDDLETON, G. V., 1965. The Tukey Chi-square test. *J. Geol.*, 73: 547-549.

————, 1967. The Tukey Chi-square test: a correction, *Ibid.* 75: 640.

POTTER, P. E., & PETTIJOHN, F. J., 1963. *Palaeocurrents and Basin Analysis*. Springer-Verlag, Berlin.

RAMSAY, J. G., 1961. The effects of folding upon the orientation of sedimentation structures. *J. Geol.* 69: 84-100.

REICHE, P., 1938. An analysis of cross-lamination — the Coconino Sandstone. *Ibid.*, 46: 905-932.

REINECK, H., & SINGH, I., 1973. *Depositional Sedimentary Environments*. Springer-Verlag, New York.

STIRLING, V. R., 1901. Report on Geological Sheet No. A[1] 47 (Apollo Bay). *Vict. Mines Dept. Spec. Rept.* with map.

TANNER, W. F., 1955. Paleogeographic reconstructions from cross-bedding studies, *Bull. Am. Assoc. Petrol. Geol.* 39: 2471-2483.

VICTORIA, MINES DEPT., 1973. 1:250,000 Geol. col. series, Sheet SJ 54-12 Colac.

WILLIAMS, G. E., 1968. Formation of large-scale trough cross-stratification in a fluvial environment. *J. Sed. Pet.* 38: 136-140.

————, 1971. Flood deposits of the sand-bed ephemeral streams of Central Australia. *Sedimentology*, 17: 1-40.

WOPFNER, H., & DOUGLAS, J. G., (Eds), 1971. The Otway Basin of Southeastern Australia. *Spec. Bull. geol. Survs. S. Aust. and Vict.*

5

CONCRETIONS IN OTWAY GROUP SEDIMENTS, SOUTH-EAST AUSTRALIA

By Edmund D. Gill*, E. R. Segnit** and N. H. McNeill†

Abstract: Concretions are characteristic of the Otway strata and are best seen along the coast. They are cemented by carbonates, viz. calcite (by far the most common), siderite and ankerite. The concretions are stratified; they are not derived but were formed in the sediments before compaction and while the strata were still horizontal. They were jointed and faulted by the tectonic movements that updomed these rocks. Post-tectonic calcite, pyrite, aragonite and barite (in order of abundance) occupy joints and fault planes.

INTRODUCTION

'No one can do effective research in any field unless he enthusiastically enjoys doing it.'
(Professor Sir MacFarlane Burnet)

The highly feldspathic Lower Cretaceous sandstones (arkose or greywacke according to the definition used) of the Otway Group (especially the Otway Ranges) are characterized by concretions. These accretionary growths all have carbonate cements, and so the term *concretion* (Latin *con* + *creta* = cemented with carbonate) is apt. They are particularly in evidence on the extensive shore platforms of the Otway coast, where they stand out because of differential erosion. All occur in arkose, a function of arkose porosity, and none in siltstone. NHMcN studied their occurrence from Eastern View to Point Flinders west of Cape Otway. EDG investigated their geology (including x-rays of rock slabs) and chronology, and ERS the petrography and mineralogy.

MORPHOLOGY

The commonest shape in calcite, siderite and siderite-ankerite concentrations is a spheroid (Pls. 9-10, 11, fig. 2). This suggests radial growth, which in some instances can be proved by concentric structures (Pl. 10, figs. 3-4); also some concretions break away in shells (Gill & McNeill 1973, Pl. 2). Occasionally the sideritic types form a string. Calcite spheroids are not usually so jointed, but more elongate ones may so occur, being known locally as 'sausages'. Calcite spheroids occur in a great range of sizes, but the majority have a diameter of 0.1-0.3 m. The siderite and siderite-ankerite types are usually in the lower part of this range.

Other concretions are platey. The largest concretionary masses cover a range of shapes from platey to pillar-shaped. The Artillery Rocks get their name from the presence of pillar-shaped (cannon) and spheroidal (shot) concretions. Platey forms also occur there. Some of the pillar type flatten to become 'pillows'. The longest measured was about 6 m. The large concretions of whatever shape have joints through them, even when no or few joints occur in the matrix. This is interpreted as a function of a rigid material in a less rigid matrix. Occasionally a close reticulate jointing occurs, wherein a secondary mineral may be deposited to give a septarian appearance. In others, the joints are more or less normal to one another, and when excavated by erosion, the concretion looks like a tray of large loaves. Such can be seen at the north-east end of the shore platform north of Stony Creek, Lorne, and also west of Eagles Nest in South Gippsland on a shore platform. Sometimes the points are infilled with iron oxide. When the joints cross obliquely the effect is that of Tudor house panelling.

The Artillery Rocks site is a virtual museum of calcite concretions, which are present in large numbers and great variety (Pl. 9, fig. 1). Quite remarkable shapes occur. It has been recommended that the place be preserved as a monument.

STRATIGRAPHY

The Otway coast concretions are stratified, i.e. they are limited to particular beds. Therefore one of the

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factors controlling the number appearing on a given platform, and so the degree of resistance to erosion, is the dip of those beds. At North Lorne on the north-east side of Stony Creek is an extensive flat supratidal platform (locally called Jump Rock) 58 m wide and 213 m long. The strata are unoxidized, as the sea has cut deeply into a large spur. The dip is 10° seaward. Calcite concretions there range from 1 cm to 1 m in diameter, and can best be seen at the north-east end of the platform. Three lines of concretions project from its surface: one of the platey type, one of average size spheroids, and the third of small spheroids. This range at such close intervals indicates a range of geochemical conditions in beds lithologically the same. The lines follow the strike, and at the end of the platform where it drops 2.5 m to a siltstone platform below, they can be seen to follow the dip. The platey type is oriented to the containing stratum.

Nodules of pyrite occur on this and many other platforms, but are not stratified. Nevertheless these nodules are limited to particular areas and so must be a function of a suitable geochemical environment not present everywhere. The mineral is pyrite, not marcasite, so the conditions were neutral or alkaline, in spite of the common occurrence of plant material. In their distribution across the beds and their independence of the presence of plants (suggesting that decomposition was finished), the pyrite occurrences seem to be related to post-tectonic conditions and not to the time when the beds in which the concretions were formed were still horizontal. Other evidence in this connection will be discussed later in the paper. The pyrite fills joints as plates of plain or fibrous mineral, while many nodules have been found (e.g. north-east of Big Hill Creek) which have numerous cubic system faces.

Calcite is common in two roles. The first is as concretions limited to particular strata, and the second is an infill mineral in joints and fault planes. Edwards and Baker (1943) record 'veins up to several feet thick'. They analysed calcite concretions and found they contained 25-49.3% of that mineral, while their matrices possessed only a few per cent. The ultimate source of the calcium is no doubt weathered feldspar from the Victorian/Tasmanian granodiorites, but the more immediate source may be the weathering of older shales or the greywackes (arkoses) themselves.

Fresh rock breaks across the grains due to the presence of cement, the commonest of which is calcite. The concretions apparently grew from centres of crystallization till the free carbonate was used up. However, there are places with plenty of carbonate but not concretions, which could indicate a second generation of carbonate. This is discussed later. Other rock cements are chlorite (Edwards & Baker 1943) and laumontite (determined by D. S. Coombs). Laumontite rosettes are not uncommon in rocks of this age in South Gippsland (Gill 1957). Some were found in fossil wood in the shore platform below Cinema Point by NHMcN — the first record from the Otways.

On the Mt. Defiance coast between the Cumberland and Jamieson Rivers, siderite-ankerite concretions occur in great numbers. The matrix is unusual in colour in that it is grey instead of greenish grey, although an occasional bed of the latter colour may be found. This block is bounded by strong faults, and the dips are exceptionally high for Lower Cretaceous beds in this region, reaching 90° at Mt. Defiance. This particular type of concretion is found only on this part of the coast, and is present in such numbers as to assist definition of the lithology (Pl. 9, fig. 3). Thus the concretions could be used along with the grey colour to define this block as a new formation.

As the calcite concretions (and indeed all the concretions as here defined) are limited to particular strata, they can be used for measuring the throw of faults. Thus the fault on the right bank of St. George River at its mouth is covered in the roadcut by a cone of talus and colluvium. However, on the seaward side is a concretion bed dipping at 20° and on the landward side the same bed can be recognized dipping at 28° from which the throw of the fault can be measured at about 7.3 m. Judging by the slickensides, and the crush zones in the shore platform at the mouth of the river, a good deal of movement has occurred. The fault has a strike of 65° magnetic.

The first concretion studied was a calcitic oblate spheroid from the intertidal shore platform on the south-west side of Stony Creek at Lorne (Pl. 10, figs. 1-2). This specimen belongs to a group that is unusual since instead of a hard resistant surface it has a soft oxidation zone, thin underneath, thick (17 mm) on the sides, but thin on top due to erosion. Its external colour is dark reddish brown (Munsell 5YR 2/2). The concretion came away from its matrix neatly, showing that a distinct interface existed between concretion and surrounding rock. The white zone in Pl. 10, fig. 1 is salt (NaCl), and has a maximum thickness of 4 mm. A slide of the rock was x-rayed in the Faxitron machine at the National Museum of Victoria (cf. Bridgman 1973), and part is reproduced in Pl. 10, fig. 2. This reveals very fine horizontal layers with little bifurcation or lensing. Heavy minerals are common, causing the dark lines in the x-ray. From an enlargement it was possible to count 100 clear layers in 103 mm. There are probably a total of 175 layers in the whole section. Lenses of heavy minerals (including magnetite) are found occasionally in the Otway rocks, but the common occurrence of black sands on the existing beaches shows that it is a common component of the sediments. Heavy minerals caused the unusual oxidation in this concretion. South-west of Boggaley Creek there is an area of strongly oxidized platform unusual for this coast. Heavy minerals occurred as bun-shaped concretions and also in the bedrock, thus causing the high degree of oxidation.

On a cliff re-entrant at the south-west end of the supratidal platform that extends from Cinema Point towards Lorne, fine bedding is picked out by differences in carbon content, and these are seen to pass through the concretions without interruption (Pl. 11, fig. 1). This same stratigraphic relationship can be demonstrated for all the types of concretions, e.g. a polished medial section through a siderite-ankerite concretion from the Mt. Defiance shore platform shows a thin layer of breccia with numerous shale chips which passes through both the concretion and the adhering matrix. This was confirmed by x-ray of the concretion using a thin slab from the middle of the specimen.

Thus the continuity from matrix through concretion to matrix again of specific layers and of sedimentary structures such as current bedding proves that the concretions are younger than the sediments, i.e. they are not derived. The question is how much later were the concretions formed? This will be discussed in the section on chronology.

WEATHERING

Calcite concretions are the dominant type, and where exposed on the shoreline have suffered no obvious weathering except for occasional pitting. They are denser than the matrix, i.e. their porosity is lower. Because of the susceptibility of black sands to weathering, concretions formed in sediments rich in this component have a weathered cortex (Pl. 10, fig. 1). This cortex is porous, and hence the salt layer at the interface of the cortex and the unweathered part of the concretion. Salt is often credited with causing decrepitation of the rock face, but here anyway it is concentrated without any visible effect. Both the siderite and the siderite-ankerite concretions have a cortex of weathered rock.

As siderite weathers readily, it may be possible to utilize it for measuring the weathering rate. At Mt. Defiance there are plenty of concretions exposed in the cuttings in the Ocean Road, but none are oxidised except for some soft porous ones. The road was opened in 1932 and the work commenced about 1930, so the concretions have been exposed for about 45 years. Taking into account the retrogradation rate of the arkose of 0.9 cm/yr (Gill 1973), 100 yr should be significant. At the north-east end of the Mt. Defiance platform in March 1973, an undercut mass of arkose was seen to have broken into three units, two of which moved north-east along the strike parallel to the shore so that the three were separated. The largest gap was 1.75 m between the north-east (4.9 m long) and middle (5 m long) blocks. The rock faces in this gap are about 2.7 m wide, 1.4 m high on the landward margin (which is up the vertical bedding plane) and 0.2 m on the seaward margin (less because of undercut). When first viewed these faces were fresh and without epifauna, and so the fractures were new. It is interesting to note that the breaks did not sever the concretions, but one face or other contained the whole concretion, while the opposite face contained the mold. This means that the secondary mineralization during concretion formation strengthened the rock, and that there is a definite concretion/matrix interface. By November 1974 two species of limpets, probably three of *Melarapha*, and a green seaweed had colonized the rock faces. Check in 1975 showed more epifauna but no change in oxidation. So an oxidation cortex of 0.5-1 cm in specimens examined must require considerable time. A closer examination of concretions in the newer and older parts of the platform, and a search for them below sea level may assist quantification.

It is significant that honeycomb weathering (tafoni) does not develop on concretions, but may be excellently developed in the matrix right up to the concretion surface (Pl. 9, fig. 1). Concretions on pedestals at Artillery Rocks have their pedestals appreciably weakened by deep honeycomb in the supratidal zone. However as already noted, pittings, usually well separated, are found on the concretions.

EROSION

Concretions project from the rock surface in all zones of the shore. As they are denser and heavier, they resist erosion more successfully than does their matrix, and so stand out from platform and cliff as a function of differential erosion. In the higher energy zones the concretions are dislodged earlier than in the lower energy areas of shore and cliff. When dislodged before the base is eroded away, they leave craters (Gill 1967, Pl. 33, fig. 2; Gill & McNeill 1973, Pl. 1).

An assessment of the rate of concretion removal can be made by studying old dated photographs. For example, Jutson (1954, Pl. 7) figured a row of calcite concretions on the shore platform south-west of Point Grey, Lorne (about 0.5 km north-east of the St. George River mouth). The concretions are grey (10 YR 5/1), the matrix greenish grey (5 GY 6/1), and the joints dark reddish grey (5 YR 4/2) — all colours dry. The seven concretions are in a single bedding plane normal to the shore, and they are here (below) numbered from the seaward end. Since 1954 two concretions have been removed and could not be found, the two in the vicinity being of the wrong size; also the top half of concretion one had been removed. All are in the *Melarapha* zone, i.e. supratidal.

Jutson's concretions are actually the first seven of 27 running along the strike from an incipient channel at the seaward end to a steep ramp at the base of the cliff:

1. Diameter 0.47 m but 10-20 cm eroded away on the south-west side, and the top removed; 10.7 cm above the platform on the landward side and 20.5 cm on the seaward.

2. Diameter 40.5 cm, height 20.2. Pitted on top. Largest concretions at this end of the row. For concretions 2-7 see Pl. 11, fig. 2.

3. Double concretions (a) diameter 39 cm x 10.9 high, joined by neck 14 cm wide to (b) 26 x 5 cm. (a) pitted on top.

4. Removed, but ferruginous concave base 34 cm wide.

5. 33 x 8 cm.

6. Removed, but base 27 x 6 cm.

7. 25 x 4 cm. Not fully exposed. From this point to the ramp, the platform surface is covered with sand, shells and pebbles.

8-27. Beyond Jutson's photograph. Of this series 14-15, 17, 20-21 and 26 have been removed, leaving craters.

These observations and photographs, taken March 1973, can be used for a further check in years to come.

Light is thrown on the process of shore platform erosion by pedestal and mushroom rocks. An example is found on the siltstone platform on the small headland south-west of Point Sturt (north-east side). The caprock is arkose, the pedestal siltstone. The site is intertidal as shown by *Hormosira* seaweed and *Galeolaria* calcareous worm tubes. As is usual, more vertical than lateral wear has taken place. The passing sea-water armed with sand, shells and pebbles is the same cutting compound that erodes the platform. The caprock must in some way afford protection. The siltstone surface is rough, so the rock must be plucked by the sea and/or fretted by wet/dry decrepitation. By contrast, a pair of arkose pedestals in the supratidal zone at Artillery Rocks have relatively smooth stems, although there is differential erosion. In the supratidal zone there are many pedestal rocks (concretions) with their stems covered with honeycomb (Pl. 9, fig. 1). One on the north-east side of the deep gulch stands more than 0.5 m above the platform. It is remarkable that the downwear has been many times greater than the sidewear. Where the paired pedestals stand in the lower part of the supratidal zone, storm waters spurt between them with considerable force, yet the downwear still far exceeds the sidewear. In the higher part of the supratidal zone honeycomb weathering covers the stems and the higher parts of the platform, but the rest is worn smooth by the swash surges.

On the north-east side of the gulch the erosion is complex, but on the south-east side where it is more homogeneous, there are two distinct levels of platform. The lower is cut in strata without concretions, while the higher one is essentially a dip slope due to the resistance offered to the sea by the many concretions. The strike is parallel to the shore and, as elsewhere, the concretions are stratified, as can be seen neatly in the gulch walls. When the platey concretions (Pl. 11, fig. 3) are pulled away from the platform by storm waves, they cause much wear before they are disposed of down a channel or into some other negative part of the coastal morphology.

MINERALOGY

Calcite concretions: Those figured (Pl. 12, figs. 1-2) are from the intertidal arkose shore platform south-west of Little Stony Creek, Lorne. They are greywacke-type arenites of quartz grains, finely granular quartz particles, feldspar grains (both plagioclase and microcline, fresh and weathered), coarse muscovite flakes and chlorite particles, and abundant fragments of shale. The particles tend to be well separated, and cemented by finely crystalline calcite. Apart from a slight variation in grain size, a 6 cm section across the bedding of the concretion does not show the banding recorded by the x-ray. This is because the x-ray slab was about 2 mm thick whereas the microscope slide was 0.1-0.01 mm.

Siderite concretions: Those figured (Pl. 12, figs. 3-4) are from the shore platform north-east of Big Hill Creek, north-east of Lorne. The sectioned one is a grey concretion with a red-brown outer zone 10-15 mm thick. This again is a typical greywacke composed of abundant small shale particles, quartz and feldspar, but cemented with siderite. It is poorly crystalline and so does not give an x-ray diffraction pattern, but the colour suggests haematite rather than goethite. These concretions are quite different in appearance from those with siderite-ankerite cement in the Mt. Defiance area (cf. Pl. 9, fig. 2 and Pl. 9, fig. 3). The siderite concretions are comparatively rare.

Siderite-ankerite concretions: These occur in great numbers in the shore platform below Mt. Defiance between the Cumberland and Jamieson Rivers (Pl. 9, fig. 3). The siderite forms a zone round the detrital grains, while the ankerite fills the interstitial spaces with a clear, more coarsely crystalline carbonate. Some specimens contain a fine seam of breccia with particles of shale up to 10 mm diameter. Cementation probably began by deposition of carbonate at discrete points, from which growth has continued from carbonate brought in by percolating waters. The Fe^{2+} of the siderite could have been derived from alteration of pyrite, or by reduction of iron compounds by carbonaceous material or anaerobic bacteria. The presence of two carbonates, deposited sequentially, indicates changes in groundwater conditions.

CHRONOLOGY

In that the carbonate concretions are all strictly related to the bedding, they must have formed while the beds were horizontal. Because the mineral grains on the whole are well separated, and the cement or cements fill the spaces, compaction was not well advanced when they formed. No seams of siderite or ankerite fill joints. Later carbonate and sulphate which did fill joints and occupy fault planes are calcite, aragonite and barite (found at Cross Springs by NHMcN). Moreover, the concretions are involved in the faulting and jointing. For example, there is a long open cave (unnamed) at about the level of the top of the first high waterfall on the Sheoak River about 0.5 km from the sea. Numerous jointed concretions are in the wall of the cave and some have been displaced on faults but the greatest throw was only 3 cm. Of 35 concretions in the cave, 17 had joints while 18 showed movement, and so technically are faults. In all instances, the breaks were filled with crystalline calcite. Further upstream is a second cave called Swallow Cave. A short distance upstream from it are joints filled with calcite 1 cm or more wide, with crystals of calcite down each side of the joint, and crystals of pyrite in the middle.

The updoming of the Otway rocks created tension which probably accounts for the open joints often filled with calcite. The uplift would bring about active weathering of these highly feldspathic strata and so yield much carbonate in addition to the sources mentioned earlier, e.g. bedrock shale. There appear to be two generations of carbonate, that which formed the penecontemporaneous concretions, and that which followed uplift and filled the opened joints. Pyrite nodules are found, and pyrite filling joints. This mineral, the aragonite, and the barite, appear to belong to this second generation of minerals. The pyrite is not related to the bedding so much as to the jointing. The concretions were formed after the sediments were emplaced, while they were still horizontal, before compaction had proceeded far, and before the tectonic movements began. They are probably Cretaceous in age. The folding, faulting and jointing were caused by tectonic movements, probably during the breaking away of Australia from Antarctica (Gill 1975). If so, the pyrite, barite and second generation calcite are Tertiary in age. The aragonite, being comparatively unstable, suggests a younger date for the joint fillings.

REFERENCES

BRIDGMAN, C. F., 1973. The radiography of museum objects. *Expedition* 15: 2-14.

EDWARDS, A. B. & BAKER, G., 1943. Jurassic arkose in Victoria. *Proc. R. Soc. Vict.* 55: 195-228.

GILL, E. D., 1957. Fossil wood replaced by laumontite. *Ibid.* 69: 33-35.

———, 1967. Dynamics of the shore platform process, and its relation to changes in sealevel. *Ibid.* 80: 183-192.

———, 1972. Palaeoclimatology and dinosaurs in south-east Australia. *Search* 3: 444-445.

———, 1973. Rate and mode of retrogradation on rocky coasts in Victoria, Australia, and their relationship to sea level change. *Boreas* 2: 143-171.

———, 1975. Evolution of Australia's unique flora and fauna in relation to the Plate Tectonics Theory. *Proc. R. Soc. Vict.* 87: 215-234.

GILL, E. D. & MCNEILL, N. H., 1973. The Otway coast of Victoria. *Vict. Naturalist* 90: 12-16.

JUTSON, J. T., 1954. The shore platforms of Lorne, Victoria, and the processes of erosion operating thereon. *Proc. R. Soc. Vict.* 65: 125-134.

WALDMAN, 1971. Fish from the freshwater Lower Cretaceous of Victoria, Australia, with comments on the palaeo-environment. *Spec. Pap. Palaeont.* 9.

EXPLANATION OF PLATES 9-12

Plate 9

FIG. 1—Grey calcitic concretions in supratidal shore platform at Artillery Rocks, south-west of Lorne. The concretions follow a seaward dip slope. The coast is of high energy and swash circulates among the concretions, so producing a smooth surface. Above this, tafoni occupies the surface of arkose pedestals, but ceases at the concretion, on which some pitting may be found.

FIG. 2—Reddish-brown sideritic concretions on shore platform north-east of Big Hill Creek, north-east of Lorne.

FIG. 3—Reddish siderite-ankerite concretions in grey arkose (greywacke) on the supratidal shore platform and cliff at Mt. Defiance, south-west of Lorne.

Plate 10

FIG. 1—Polished section of calcitic concretion from arkose with fine layers of heavy minerals (Fig. 2), supratidal shore platform, south-west of Little Stony Creek, North Lorne. The outer crust is brown (oxidized) with a layer of salt (white) at the base. The rest of the section is grey.

FIG. 2—Same concretion. Part of x-ray of median slab to show heavy mineral layers, which continue through to the matrix.

FIG. 3—X-ray of a calcite concretion showing concentric structures.

FIG. 4—Brown weathered (oxidized) concretion in arkose (greywacke) with heavy minerals, producing ?haematite. Note concentric structures.

Plate 11

FIG. 1—Calcitic concretions in cliff above supratidal platform south-west of Grassy Creek (Cinema Point). Fine carbonaceous bands in the matrix continue through the concretions, showing that the concretions are secondary.

FIG. 2—Present state of Jutson's 1954 concretions on shore platform south-west of Point Grey. No. 1 is out of sight (top half removed). Nos. 2-3, 5 and 7 are still in place, but erosion has removed 4 and 6.

FIG. 3—Horizontally oriented concretion (calcitic) at Artillery Rocks, south-west of Lorne, stratified in arkose.

Plate 12

The short graphic scale at foot of Fig. 6 applies to Figs. 1 and 3, while the long scale applies to the remainder of the figures.

FIGS. 1 and 2—A calcitic concretion from shore platform south-west of Little Stony Creek, North Lorne; shows typical greywacke texture. Dark shale particles, clear quartz and unaltered feldspar, with grains separated by calcite cement.

FIGS. 3 and 4—Siderite concretion from shore platform north-east of Big Hill Creek, north-east of Lorne. Particles cemented by siderite on right. On left, siderite oxidised to ferric oxide.

FIGS. 5 and 6—A siderite-ankerite concretion from the shore platform at Mount Defiance, south-west of Lorne.


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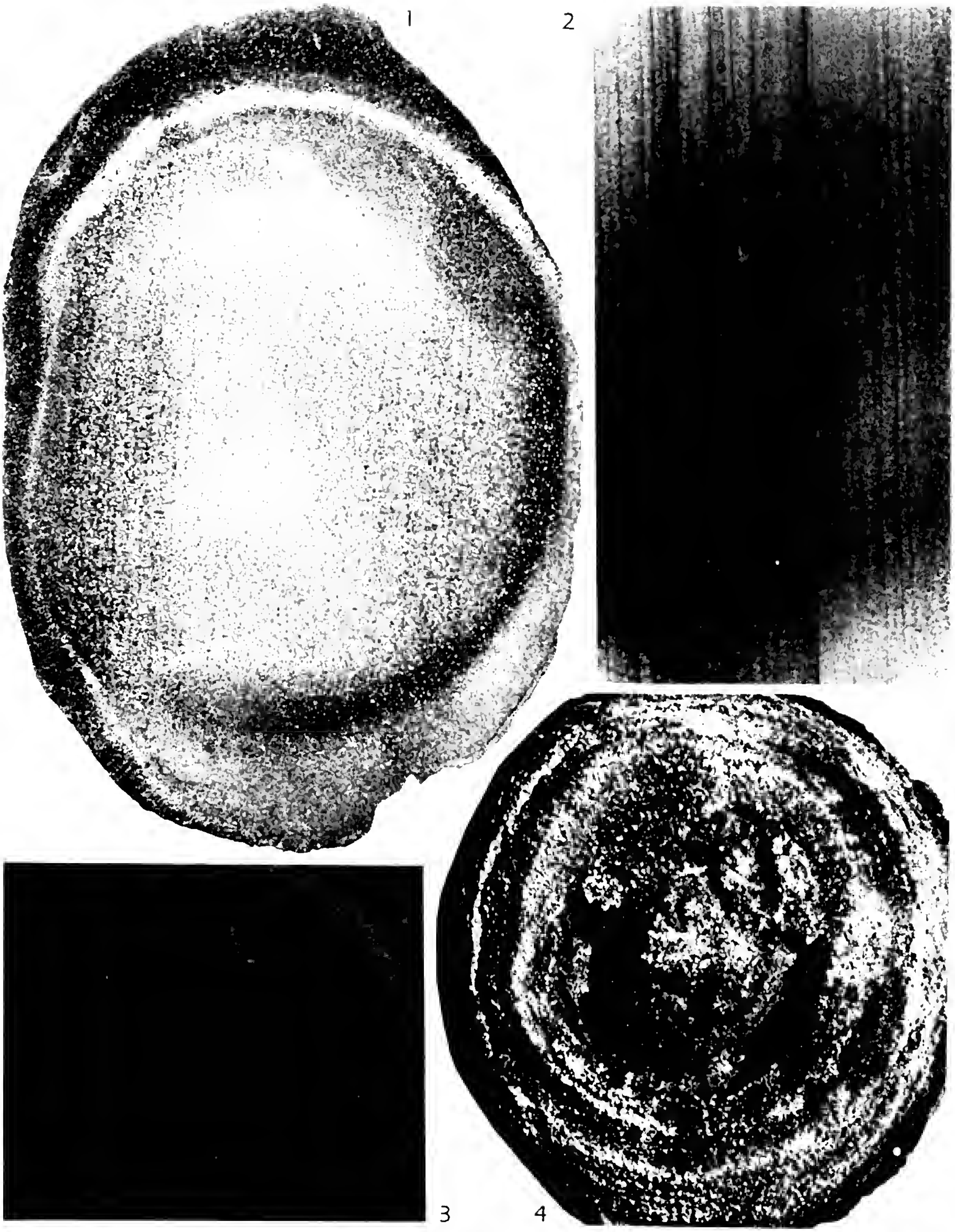
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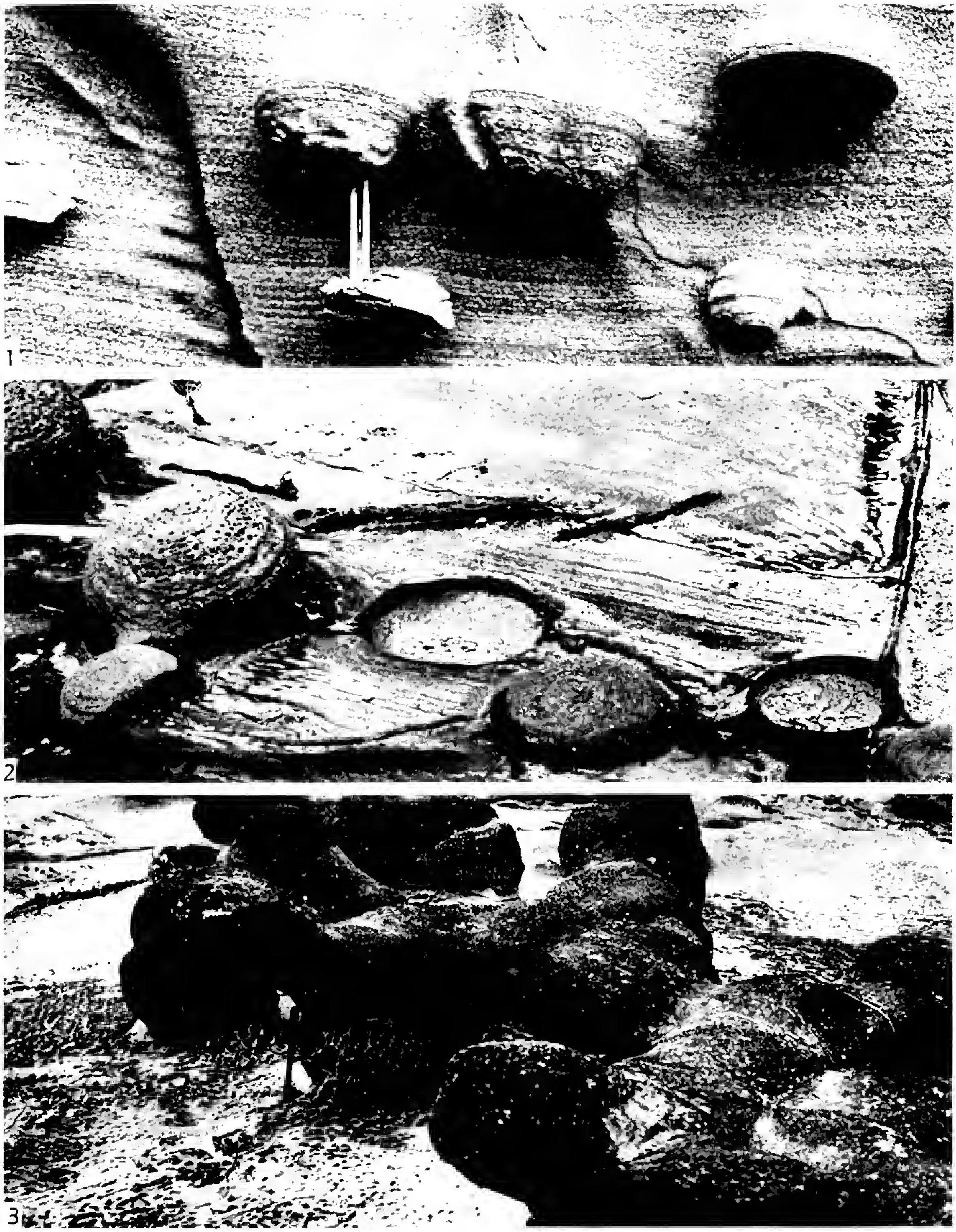

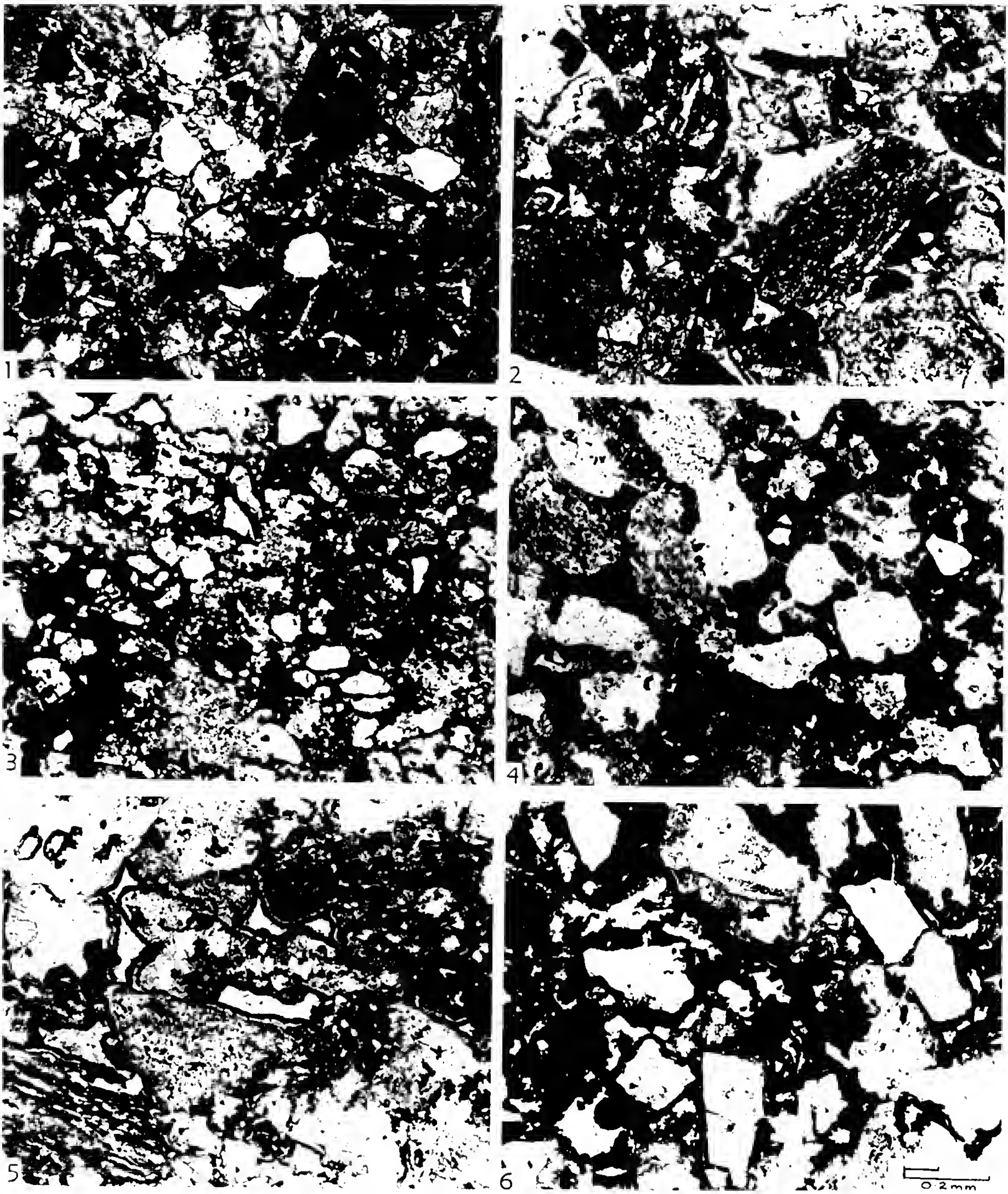
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THE CLIMATE OF THE OTWAY REGION

By D. J. Linforth

INTRODUCTION

The Otway Region for this meteorological survey is defined as the area south of the Princes Highway and extending from Warrnambool to Torquay. Most of the area is hilly, with the main Otway Ranges reaching an elevation of 600 metres.

METEOROLOGICAL DATA

Daily rainfall records for at least 30 years are available for 47 stations in the area, while records extend beyond 50 years at 34 of these. There are currently four pluviographs in the area, but only two of them have records for more than two years.

Observations of temperature, humidity and cloud are available for eight stations, four at towns on the Princes Highway, two on the coast and two in the northern foothills of the Otway Ranges. There are no records of these elements on the high country. At some of these stations observations have not been made on all seven days of the week.

Wind observations are made at these eight stations, but at only two is there an instrument; at the others wind speed is estimated by the observer.

METEOROLOGICAL CONTROLS

The general weather of southeastern Australia is determined primarily by the behaviour of pressure systems, which move from west to east on a more or less latitudinal track. The mean track of anticyclones is centred south of the continent from November to April but is located between latitude 30°S and 35°S from May to October.

Anticyclones are separated by low pressure areas, which usually contain active frontal surfaces separating air masses of different characteristics. These low pressure areas are rain bearing systems and have most influence in winter and spring. Rainfall in the Otway Region is frequent and often heavy in these seasons.

In summer, the southern location of the anticyclonic belt brings an easterly wind flow over the district. When anticyclones move into the Tasman Sea, where they sometimes stagnate for several days, winds tend northerly. This situation results in heatwave conditions which persist until relieved by the west to southwest winds associated with the next oncoming depression. At places on the coast, however, the heat is tempered by sea breezes except on the last day of a heatwave when the northerly wind is usually strongest.

The Otways are usually beyond the reach of moist air of tropical origin, which, in summer, can be responsible for heavy rain over eastern and northern Victoria. Occasionally, however, warm moist air from the Tasman Sea penetrates far enough westward over the colder waters of Bass Strait to produce sea fog off the Otway coast.

The climate of the Otway Region follows, in a general way, a pattern which has been described as Mediterranean, i.e. hot dry summers and cool wet winters.

RAINFALL

The effect of elevation on rainfall is very marked in this Region, and can be seen in Figs. 1-3. The wettest part is along the main ridge of the Otway Ranges, where the average annual rainfall is in excess of 1800 mm. This ranks among the wettest areas in Victoria. To the northeast of the Region is a marked rain shadow, which extends over much of the inland plains of the Western District. Northeast of Winchelsea-Torquay, the average annual rainfall is less than 600 mm.

Average rainfall in January and July is shown in Figs. 2 and 3 respectively. These show the markedly seasonal nature of the rainfall, rainfall in July being about 2½ times that in January. On the average, about 60% to 65% of the rain falls in the May-October period.

The rainfall is very reliable, the coefficient of variation (standard deviation of the annual rainfall divided by the average annual rainfall) for the West Coast rainfall district is 0.16, which with West Gippsland, is the lowest in Victoria.

Although the average summer rainfall is much lower than in winter, heavy rain can fall in summer, on rare

Bureau of Meteorology, P.O. Box 1289K, Melbourne, Victoria, 3001.

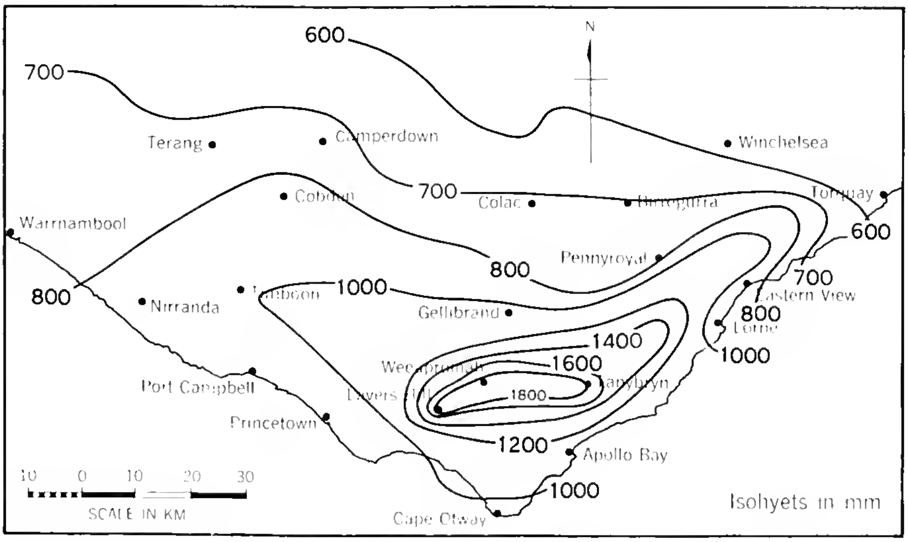


FIG. 1—Average Annual Rainfall.

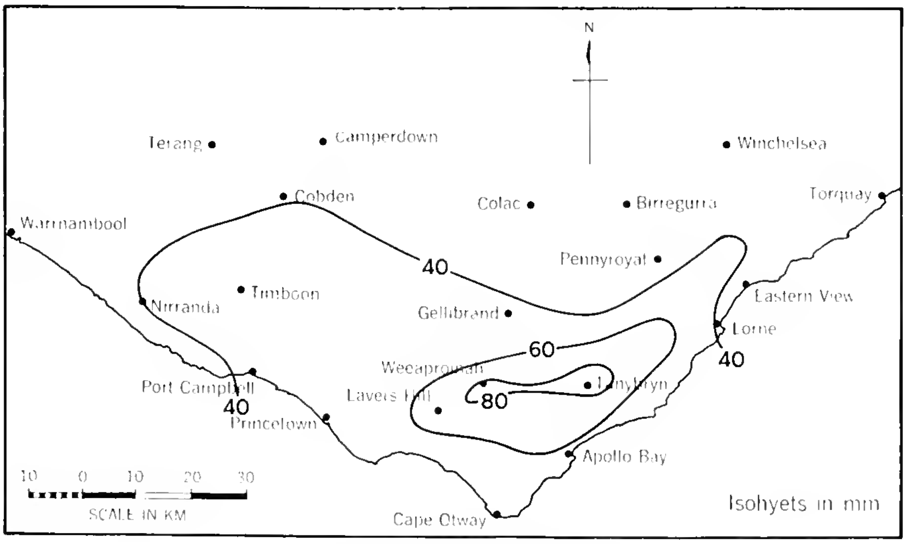


FIG. 2—Average Rainfall—January.

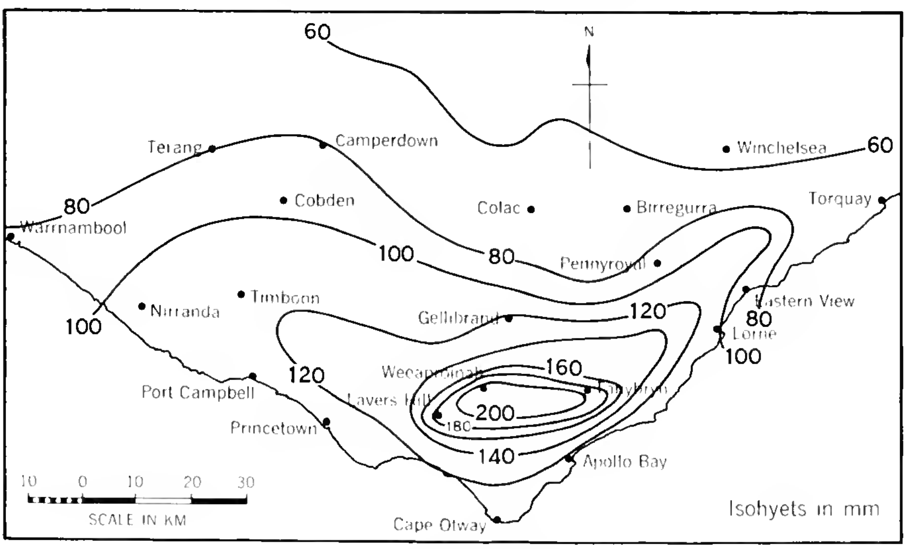


FIG. 3—Average Rainfall—July.

TABLE 1
HIGHEST RAINFALL ON RECORD FOR 1, 2 AND 3 DAYS

Station	1 Day Rain-fall (mm)	Month of Occurrence	2 Day Rain-fall (mm)	Month of Occurrence	3 Day Rain-fall (mm)	Month of Occurrence
Birregurra	86	Feb.73	98	Dec.33	104	Dec.33
Winchelsea	101	Feb.73	135	Dec.33	142	Dec.33
Colac	103	Feb.73	123	Feb.46	124	Feb.46
Eastern View	170	Feb.54	200	Dec.33	204	Dec.33
Lorne	180	Feb.54	231	Dec.33	238	Dec.33
Pennyroyal Ck.	123	Jun.52	220	Jun.52	242	Jun.52
Tanybryn	233	Jun.52	461	Jun.52	587	Jun.52
Weeaproinah	154	Mar.19	244	Apr.60	270	Apr.60
Cape Otway	93	Mar.32	134	Mar.32	145	Mar.32
Apollo Bay	*	-	281	Mar.32	305	Mar.32
Port Campbell	114	Jan.52	118	Mar.32	125	Mar.32
Princeton	102	Jan.52	145	Mar.32	150	Mar.32
Nirranda	118	Mar.46	148	Mar.46	157	Mar.46
Warrnambool	167	Mar.46	217	Mar.46	229	Mar.46
Terang	90	Jan.37	118	Feb.46	126	Mar.10
Cobden	90	Feb.57	102	Feb.57	129	Feb.11
Camperdown	88	Jan.41	114	Jan.41	121	Jan.41

*Rainfall measured for only 2 days at Easter 1932.

occasions. Table 1 shows the highest one, two and three day falls at a number of stations. It can be seen that most of these high falls have occurred in the warmer months from December to March. The warmer atmosphere at this season can hold more moisture, and when a rain-producing mechanism does occur, heavy rain results.

TEMPERATURE

Monthly temperature data are shown in Table 2. The 14 percentile of maximum temperature is that temperature which is not reached on 14 per cent of days, the 86 percentile is that temperature which is not reached on 86 per cent of days, i.e. which *is* reached on 14 per cent of days. Fourteen per cent of days represents one day in seven. Similarly, temperature falls below the 14 percentile of minimum temperature on 14 per cent of days or remains above the 86 percentile on 14 per cent of days.

Mean maxima are higher inland than on the coast in summer, but the coast has marginally higher maxima in winter. The range of maximum temperature, as shown by the 14 and 86 percentiles is much higher in summer than in winter. The extreme maxima are practically the same at all these lower level places, i.e. on occasions, unusually warm air spreads over the entire Region and sea breezes have no effect. Mean minima are lower inland than on the coast in all seasons, and the extreme minima follow this pattern also.

Data on frost are given in Table 3. Frost is rare right on the coast. The station at Warrnambool is at the Post Office, about 3 km from the open beach, and here light frosts occur on a few days per year, but heavy frosts are rare.

TABLE 2
TEMPERATURE DATA (°C)

Station	Altitude (metres)	Data	No. of Years of Record	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Lorne	15	Mean Max. Temp.	70	23.0	22.8	21.6	19.0	16.1	13.8	13.2	14.4	16.3	18.2	19.9	21.5
		14 percentile	4	18.9	19.8	18.4	17.5	14.0	12.5	12.2	11.9	13.1	15.1	16.5	17.5
		86 percentile	4	25.6	29.6	25.3	23.5	19.4	16.1	16.0	16.7	19.3	21.5	21.7	25.0
		Extreme Temp.	55	43.6	41.7	40.9	31.7	26.1	18.6	21.6	25.1	30.8	38.3	37.8	40.7
		Year of Extreme		1939	1919	1942	1922	1921	1940	1975	1940	1928	1914	1927	1941
		Mean Min. Temp.	70	12.2	12.9	12.0	10.2	8.6	7.0	6.2	6.9	7.2	8.3	9.5	10.9
		14 percentile	4	11.7	12.5	11.5	10.3	7.8	6.2	5.8	5.6	6.1	7.2	8.3	10.0
		86 percentile	4	17.0	18.3	16.4	15.3	12.2	10.7	9.4	9.4	11.2	12.5	12.8	15.0
		Extreme Temp.		4.4	5.0	2.8	0.6	1.5	0.6	-0.6	1.3	0.0	1.7	3.9	4.4
		Year of Extreme		1930	1905	1935	1917	1928	1949	1929	1944	1938	1926	1926	1924
Cape Otway	91	Mean Max. Temp.	106	21.5	21.5	20.4	17.6	15.2	12.5	12.9	13.8	15.2	16.9	18.4	19.6
		14 percentile	17	17.2	17.2	16.4	14.4	12.8	11.7	10.8	11.1	11.7	12.8	13.9	15.6
		86 percentile	17	26.1	27.2	24.4	22.5	17.4	15.6	13.9	15.1	17.4	20.9	22.2	24.4
		Extreme Temp.	68	42.8	40.6	38.9	32.8	25.6	21.7	21.8	23.9	30.0	34.2	38.1	39.2
		Year of Extreme		1908	1919	1934	1958	1921	1957	1975	1940	1928	1914	1921	1920
		Mean Min. Temp.	106	13.1	13.6	13.0	11.5	9.8	8.0	7.3	7.7	8.3	9.5	10.5	11.9
		14 percentile	17	11.1	11.7	10.6	8.9	7.3	6.3	5.6	5.6	5.6	7.1	7.8	9.4
		86 percentile	17	15.6	16.4	15.6	14.0	11.7	10.6	9.3	9.4	10.0	11.7	12.2	14.1
		Extreme Temp.	68	6.1	5.0	4.4	3.3	1.7	1.7	0.0	1.1	1.7	1.1	3.9	4.4
		Year of Extreme		1951	1945	1964	1965	1963	1922	1966	1935	1908	1962	1935	1955
Warrnambool	21	Mean Max. Temp.	77	22.0	22.0	20.9	18.5	15.9	13.8	13.2	13.9	15.6	17.2	18.8	20.5
		14 percentile	17	18.8	18.4	18.0	16.1	13.7	12.5	11.7	12.2	13.3	14.5	15.6	16.8
		86 percentile	17	30.1	29.3	27.7	24.7	18.9	16.7	15.6	17.2	19.4	22.8	25.3	26.1
		Extreme Temp.	78	46.1	43.9	41.7	34.2	30.0	23.1	22.5	23.9	30.6	36.9	39.4	43.3
		Year of Extreme		1908	1901	1934	1958	1905	1957	1975	1911	1928	1914	1921	1897
		Mean Min. Temp.	77	12.7	13.2	12.1	10.3	8.5	6.8	6.1	6.6	7.6	8.9	10.0	11.5
		14 percentile	17	10.0	10.6	9.0	7.2	5.6	2.8	3.0	3.3	5.0	5.7	6.7	8.5
		86 percentile	17	16.1	16.1	15.0	13.3	11.2	9.4	8.3	8.9	10.0	11.7	12.8	14.4
		Extreme Temp.	78	4.4	3.4	3.3	1.1	-1.1	-1.1	-1.9	-1.6	0.3	1.1	1.7	3.2
		Year of Extreme		1919	1949	1907	1942	1910	1949	1960	1966	1908	1939	1965	1949
Terang	132	Mean Max. Temp.	60	24.9	25.2	22.7	18.5	15.3	12.7	12.2	13.2	15.5	17.7	20.1	22.9
		14 percentile	9	18.4	18.9	17.5	15.6	12.8	11.1	10.6	11.1	12.2	13.3	14.4	16.1
		86 percentile	9	33.3	33.3	30.9	25.9	19.4	15.6	14.9	16.1	18.3	23.3	25.6	28.9
		Extreme Temp.	69	45.0	42.8	41.1	33.3	28.3	21.1	20.5	22.2	30.0	35.6	38.9	41.1
		Year of Extreme		1939	1912	1940	1958	1905	1957	1975	1969	1961	1914	1962	1960

TABLE 2 (Continued)

Station	Altitude (metres)	Data	No. of Years of Record	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
		Mean Min. Temp.	60	10.7	11.5	10.3	8.2	6.6	4.7	4.1	4.6	5.8	6.9	8.3	9.6
		14 percentile	9	7.4	8.9	6.7	5.6	3.3	0.9	1.7	2.2	2.8	3.9	5.0	6.7
		86 percentile	9	16.1	17.2	14.4	12.2	10.0	7.3	6.7	7.2	8.3	11.1	11.7	13.0
		Extreme Temp.	61	0.0	1.1	1.1	-0.6	-2.2	-2.8	-2.8	-3.3	-2.2	-1.1	0.6	2.2
		Year of Extreme		1950	1908	1921	1947	1946	1949	1963	1929	1940	1924	1963	1955
Camperdown	165	Mean Max. Temp.	70	26.1	26.0	23,6	18.9	15.4	12.6	12.1	13.7	15.9	18.2	20.4	23.9
		14 percentile	9	20.0	20.1	18.2	15.6	12.8	11.1	10.9	11.1	12.7	14.0	15.1	17.1
		86 percentile	9	34.1	34.2	30.6	25.9	18.9	15.0	14.4	16.1	19.0	24.8	26.0	30.4
		Extreme Temp.	67	45.3	43.3	41.7	34.4	28.9	21.7	21.0	24.4	30.8	37.2	38.0	41.9
		Year of Extreme		1939	1912	1940	1938	1905	1957	1975	1914	1928	1914	1966	1920
		Mean Min. Temp.	70	11.5	12.2	10.9	8.6	6.7	4.7	4.0	4.8	6.1	7.3	8.6	18.3
		14 percentile	9	8.9	9.9	8.2	15.8	4.4	1.8	1.9	2.4	3.4	4.5	6.0	7.2
		86 percentile	9	16.2	17.1	14.4	12.2	9.5	6.8	6.7	7.1	8.9	10.6	11.7	13.3
		Extreme Temp.	67	1.1	0.0	1.7	-1.7	-1.1	-2.2	5.0	-2.8	-1.1	-1.1	-0.6	0.6
		Year of Extreme		1902	1945	1917	1901	1927	1940	1929	1938	1907	1918	1917	1907
Colac	134	Mean Max. Temp.	72	25.6	25.8	23.4	19.8	15.7	13.0	12.3	13.6	15.7	18.1	20.7	23.4
		14 percentile	16	20.0	19.6	18.3	15.0	12.2	11.1	10.0	11.1	12.8	13.9	15.0	16.7
		86 percentile	16	34.4	32.8	29.4	23.9	18.3	15.6	13.9	16.1	18.3	22.8	25.9	30.6
		Extreme Temp.	74	44.4	41.1	41.1	33.3	29.4	21.7	21.2	23.3	29.4	35.6	37.8	41.1
		Year of Extreme		1939	1914	1940	1938	1905	1957	1975	1940	1926	1914	1927	1920
		Mean Min. Temp.	72	10.6	11.1	9.9	7.9	6.1	4.4	3.9	4.4	5.7	6.8	8.2	9.3
		14 percentile	16	3.9	5.0	3.9	1.7	0.6	0	-0.6	0.6	1.1	1.7	3.3	3.3
		86 percentile	16	13.9	13.9	13.9	11.1	8.9	8.3	6.7	7.2	8.3	10.0	11.7	13.3
		Extreme Temp.	74	0.6	0.6	0.0	-3.9	-3.3	-4.4	-5.0	-3.3	-3.9	-3.3	-2.8	-0.6
		Year of Extreme		1957	1931	1965	1963	1957	1965	1960	1963	1959	1967	1967	1967
Gellibrand	84	Mean Max. Temp.	9	24.5	25.4	22.5	19.5	15.3	13.1	12.6	13.6	14.8	17.6	19.5	21.8
		14 percentile	9	18.3	18.9	17.0	15.0	12.6	11.1	10.6	11.1	11.2	13.3	14.4	16.2
		86 percentile	9	31.9	32.9	29.8	24.7	18.9	15.0	14.4	16.1	18.9	23.3	25.4	28.4
		Extreme Temp.	20	43.3	40.6	38.9	31.7	25.1	21.1	20.5	22.2	31.7	29.4	37.2	38.2
		Year of Extreme		1959	1967	1966	1968	1967	1957	1975	1969	1965	1965	1966	1960
		Mean Min. Temp.	9	10.0	10.9	8.8	7.6	5.1	3.0	3.4	3.7	5.0	6.2	7.7	9.0
		14 percentile	9	5.6	6.7	5.0	3.9	1.6	-0.6	0	0	1.6	2.2	4.0	5.4
		86 percentile	9	14.4	15.6	13.0	11.1	9.4	7.2	6.7	6.9	8.5	10.0	11.1	12.8
		Extreme Temp.	20	0.0	1.1	0.0	-2.2	-1.7	-4.4	-6.5	-3.9	-1.7	-3.1	0.0	1.1
		Year of Extreme		1958	1963	1965	1967	1969	1969	1974	1957	1966	1967	1960	1967

TABLE 3(a)
AVERAGE NUMBER OF DAYS OF LIGHT FROST
(temperature ≤ 2.5°C)

Station	No. of Years	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Colac	12	1.5	0.8	1.2	4.8	8.3	10.9	13.2	10.8	8.0	6.1	2.7	2.9	72
Gellibrand	10	0.3	0.1	1.0	2.2	7.6	14.0	10.4	10.8	6.9	4.4	1.1	0.4	55
Warrnambool	10	-	-	-	0.1	0.3	3.3	2.6	1.5	0.2	0.1	0.2	-	8

TABLE 3(b)
AVERAGE NUMBER OF DAYS OF SEVERE FROST
(temperature ≤ 0°C)

Colac	12	-	-	0.2	0.8	3.0	5.3	6.4	4.0	2.9	1.0	0.2	0.2	25
Gellibrand	10	-	-	0.2	0.4	2.1	8.2	5.8	5.7	1.9	1.0	0.1	-	23
Warrnambool	10	-	-	-	-	-	0.4	0.1	0.2	-	-	-	-	0.7

TABLE 3(c)
FIRST AND LAST DATES OF FROST

Station	Years	First Dates				Last Dates			
		Earliest 2.2°C	Median 2.2°C	Earliest 0°C	Median 0°C	Median 0°C	Latest 0°C	Median 2.2°C	Latest 2.2°C
Colac	1957-68	2 Jan.	25 Jan	25 Mar	27 Apr	15 Oct	19 Dec	21 Dec	31 Dec
Gellibrand	1965-74	10 Jan.	5 Apr	25 Mar	15 Apr	15 Sep	26 Oct	22 Nov	8 Dec
Warrnambool	1957-74	17 Apr.	1 Jun	6 May	18 Jun	11 Jul	17 Aug	27 Aug	25 Nov

Colac seems to be unusually prone to frost, but this may be due to the observing station over this period of record being in a 'frost hollow'. Frost can be very localized and is more liable to occur in hollows where cold air can accumulate on clear, calm nights.

WIND

Wind shows the seasonal nature arising from the meteorological controls described above.

Fig. 4 comprises wind diagrams for January and July for three stations. The diagrams are compiled from wind observations at 9 a.m. and 3 p.m., isopleths being drawn of frequency of various wind speeds and directions.

At Cape Otway in July the most frequent wind is northwest at 25 km/h, while in January, easterly and westerly winds of 25 km/h are equally frequent. At Warrnambool Post Office southwesterly winds of 12 km/h are most common in January and northwest winds of 5 km/h most common in July.

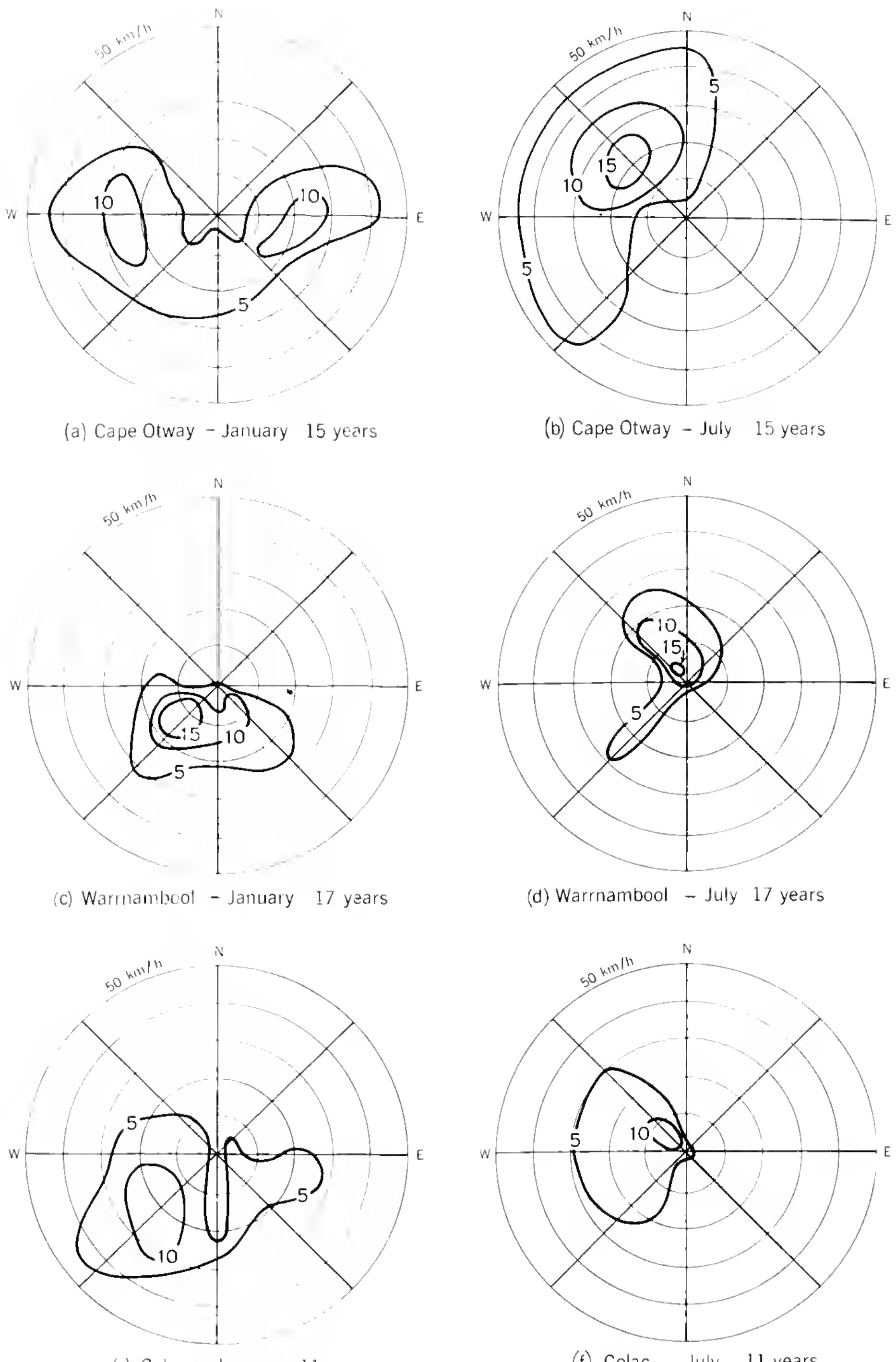
Strong winds are most frequent on the coast. Cape Otway has a far higher frequency of wind speed over 40 km/h than the inland stations.

PHENOMENA

Fog inland is most common in winter, forming overnight due to radiational cooling of moist air, and dissipating a few hours after sunrise on most occasions. At Colac it occurs on about 20 days per year. Along the coast, fog is more common in summer, when warm moist air from the Tasman Sea is brought over the cooler waters of Bass Strait. At Cape Otway it occurs on about five days per year. The seaward slopes of the Otways may be shrouded in fog while the landward side is enjoying a warm and sunny day.

Thunder is heard on 10 to 14 days per year, about the same frequency as most places in Victoria.

Hail occurs on one or two days per year, mostly



(a) Cape Otway – January 15 years

(b) Cape Otway – July 15 years

(c) Warrnambool – January 17 years

(d) Warrnambool – July 17 years

(e) Colac – January 11 years

(f) Colac – July 11 years

FIG. 4—Relative Frequency of Wind Speed (km/h) and Direction—Daytime Isopleths are percentage frequency of occurence.

during very cold weather in winter. Large and damaging hail tends to be associated with violent thunderstorms, which affect only a small area, and its occurrence at a given spot is very rare.

Snow occurs on the high country on two or three days per year, and has fallen to depths of five to ten centimetres. It is very rare over the lower country, two memorable occasions being 28 July 1901 and 4 August 1943 when most of the Western District was covered in snow.

7

SOILS OF THE OTWAY RANGES AND SURROUNDING COASTAL PLAIN

By A. Pitt*

INTRODUCTION

The information presented in this paper has been collected by the Soil Conservation Authority of Victoria during a land system survey of the catchments of the Gellibrand River, Barwon River downstream from Winchelsea, Thompsons Creek and the numerous smaller catchments on the south side of the ranges. The part of these catchments which lies inside the area of the Otway Region as defined for the Symposium forms the present area of study (Fig. 1). Work is still in progress on this survey and this paper presents an interim report on the soils.

Previous published discussions of the soils of the area are confined to two reports: by Skene (1957) and Walbran (1971). Generalised maps of the soils have been published by CSIRO (Northcote 1960, 1962).

The distribution of the major soil groups is described in terms of land zones (Fig. 2). Land zones are groups of similar land systems (Gibbons & Downes, 1964). For each land zone, the major soil groups identified in the field are classified in descriptive terms and discussed according to their profile characteristics, possible genesis, indigenous vegetation and their significant attributes for land use (Table 1). Alternative soil classifications by Northcote (1974) and Stace et al. (1968) are included for comparison (Table 1).

There are also many soil groups of only minor occurrence. Three of these groups assume relatively high importance despite their restricted occurrence, because of their intensive use for agriculture and, in one case, for recreation. These three soil groups are discussed briefly, according to their profile characteristics and land use (Table 1).

MAJOR SOIL GROUPS

Zone 1

This zone covers the area of Lower Cretaceous sediments. The topography consists mainly of steep hills with a few restricted remnants of an undulating peneplain on the crests of these hills. The soils fall into three groups:

Dark yellowish brown gradational soils: These are found in the rainfall range 1000-2000 mm in most topographic positions including broad crests and steep slopes. The equivalent soil group from Stace et al. (1968) is the brown podzolic soils and they key out as Gn 3.94 in Northcote's factual key (1974).

They are well structured and medium to heavily textured, grading from a loam or clay loam at the surface to a silty clay or clay in the subsoil. Colluvial rock is common throughout the profile and the subsoil overlies freshly weathering sandstones and mudstones at about 1 m depth. From the limited chemical analyses available (Leslie, pers. comm.) the soil reaction is quite acid with the pH grading from about 4.5 at the surface to about 5.0 in the subsoil. Fertility appears to be comparatively high for Australian soils. Edwards and Baker (1942) have shown the Lower Cretaceous sediments to contain moderate levels of most elements essential for plant growth. Most of the soil profiles are too young for extensive leaching to have occurred, so concentration of these nutrients at the surface by root absorption and litter decay have resulted in this moderately high fertility.

These soils support some of the tallest and most productive forests in Victoria, a good indication of their natural fertility. The main species are mountain ash (*Eucalyptus regnans*), mountain grey gum (*E. cypellocarpa*), blue gum (*E. globulus*) and messmate (*E. obliqua*). The first three of these are almost completely confined to the soils of the Lower Cretaceous sediments in this part of Victoria.

The main limitation to the productive potential is the precipitous topography: many areas are too steep for mechanical equipment to operate. Where the soils occur on flatter areas such as on the remnants of the uplifted peneplain around Beech Forest and Wyelangta, their productive potential is very high. High acidity of these soils presents problems in establishing produc-

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TABLE 1

Land Zone	*Soil Group*	*Stace et al. (1968)*	*Northcote (1974)*	*Vegetarian Structure Specht (1972)*	*Important Attributes for Land Use*
1	Dark Yellowish Brown Gradational Soils	Brown Podzolic Soils	Gn 3.94	Tall Open Forest	Prone to Landslips, Highly Acidic, Often Found on Very Steep Slopes
1	Friable Brown Gradational Soils	Brown Podzolic Soils	Gn 4.31	Tall Open Forest	Highly Acidic
1	Yellowish Brown Duplex Soils	Yellow Podzolic Soils	Db 3.31	Open Forest	Acidic, Low Water Holding Capacity, High Erosion Hazard
2	Deep Leached Sands with Coffee Rock	Podzols, Humus Podzols	Uc 2.36	Low Woodland, Closed Heath	Low Levels of Most Plant Nutrients, Moisture Stress, Sheet Erosion
2	Sandy Yellow Gradational Soils	Yellow Podzolic Soils	Gn 3.84	Open Forest, Woodland	Some Nutrient Deficiencies, Sheet Erosion
3	Mottled Duplex Soils with Ironstone	Lateritic Podzolic Soils	Dr 3.31	Open Forest	Nutrient Deficiencies
3	Yellow Sodic Duplex Soils with Coarse Structured Subsoils	Gleyed Podzolic Soils	Dy 3.41	Open Forest	Soil Salting (for Water Supply) Some Nutrient Deficiencies, Landslips, Gully and Sheet Erosion
Minor Soil Groups	Calcareous Sands	Calcareous Sands	Uc 1.11	Open Grassland	Vegetation Unstable — Wind Erosion
Minor Soil Groups	Grey Gradational Soils	—	Gn 2.92	Open Woodland	Highly Productive
Minor Soil Groups	Reddish Brown Gradational Soils	Terra Rossa	Gc 2.21	Open Woodland	Production of Crops Dependent on Free Lime in the Soil. Example — Grapes

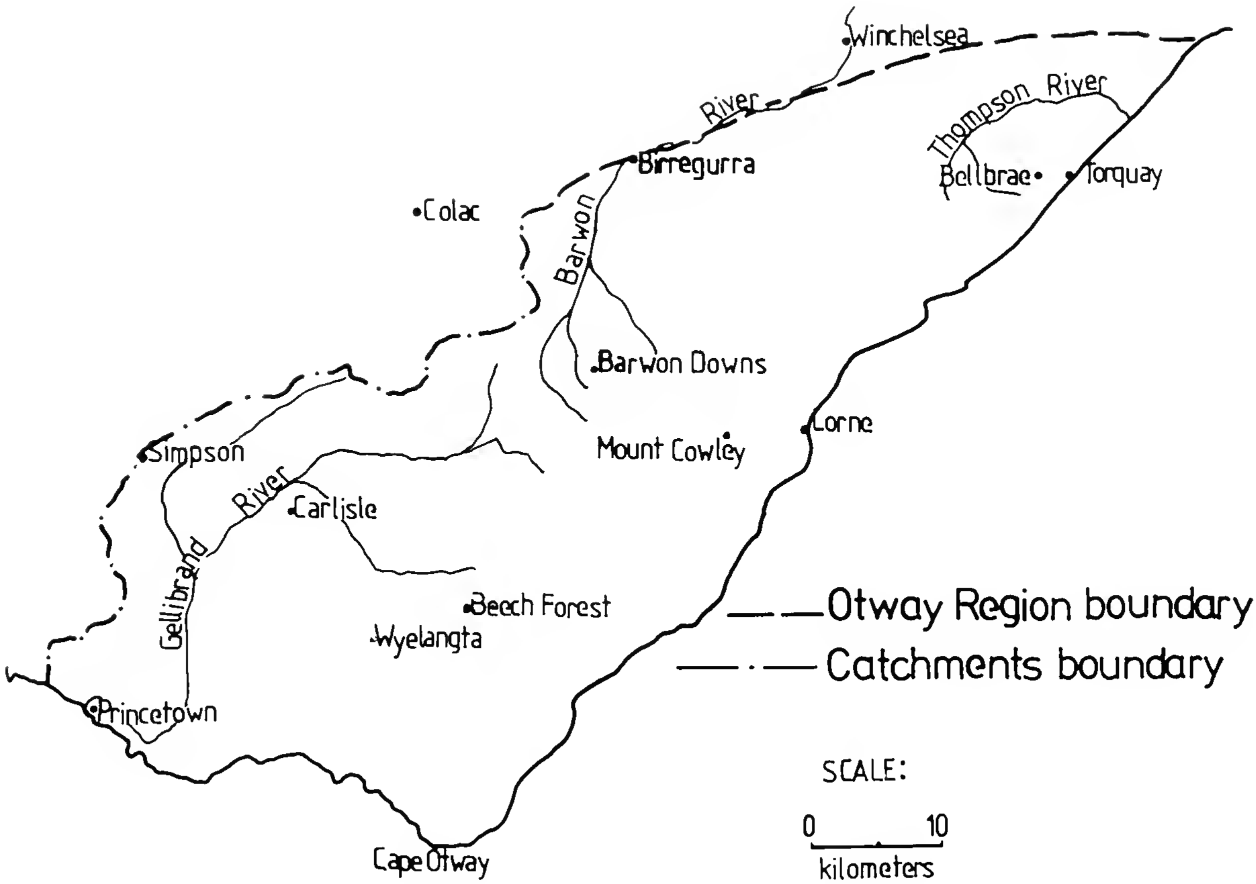

FIG. 1—The Study Area

tive pastures of introduced grasses. The ability of deep-rooted forest vegetation to extract nutrients from freshly weathering rock may give hardwood and softwood forestry a potential advantage over agricultural uses of the land. The other major form of land use on these soils is water supply and here the high organic content of the surface layers of the soil is important in aiding retention of large quantities of water during rainstorms and then slowly releasing it to streams during subsequent dry periods. Loss of these surface layers of soil leads to a loss of the degree of perenniality of streams.

Landslides, slumping and sheet erosion are the major forms of soil deterioration to be contended with. Both landslides and sheet erosion occur under natural conditions but appear to increase in incidence following clearing of the native timber.

Road batters around the Great Ocean Road are very prone to slumping. Proximity to the sea and exposure to on-shore salt-laden winds has most probably resulted in replacement of the adsorption sites on the clay with sodium ions. This leads to a decreased attraction of the clay particles and increases the proneness of the clay to dispersion and hence to rilling and slumping of the road batters.

Friable brown gradational soils: Outlying remnants of the uplifted peneplain around Mt. Cowley still have the yellow gradational soils (above) as the dominant soil group, but also have very deeply weathered friable brown gradational soils as a sub-dominant group. They are also referred to as brown mountain soils or acid brown earths and key out to Gn 4.31 from Northcote (1974).

Most commonly the profile consists of a black loam or clay loam overlying a brown light clay at 60 cm. The light clay continues to about 2 m before weathered sandstones are encountered. Their occurrence is probably due to a change in the nature of the parent material but the mineralogical and chemical differences of the rocks have not been determined.

The depth of the soils indicates that these geological beds are more prone to weathering than those where the dark yellowish brown gradational soils are found.

Major forms of land use on these soils are hardwood

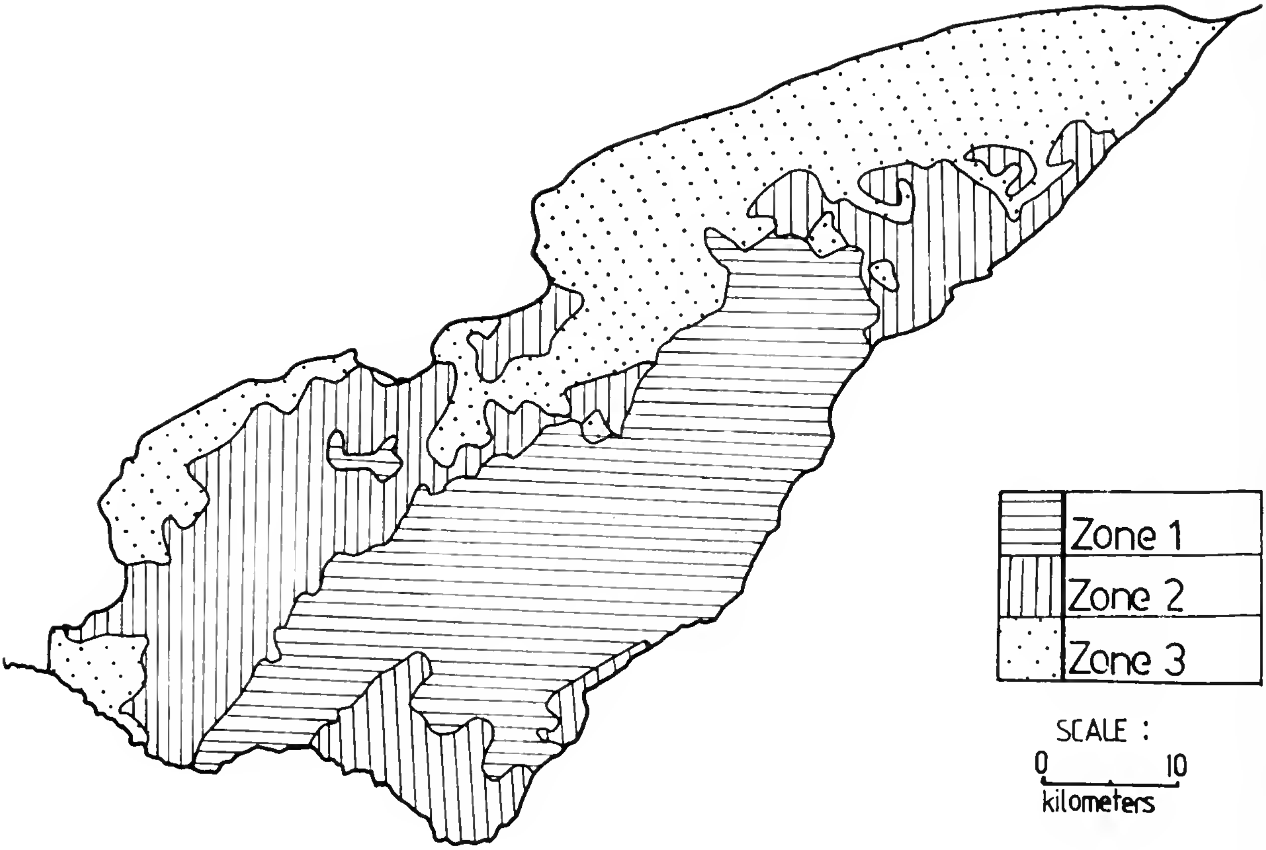

FIG. 2—Land Zones

forestry and water supply. The high organic content and depth of the soil makes them well suited to these uses.

Yellowish-brown duplex soils: Also known as yellow podzolic soils according to Stace et al. (1968) and as Db 3.31 from Northcote (1974) these soils are found in those parts of the Ranges where rainfall is less than 1000 mm per annum.

The surface texture is commonly a loam and this is underlain by a weakly bleached A_2 horizon of similar texture and weak structure. At about 40 cm there is a comparatively sharp change to a yellow silty clay frequently interspersed with weathering sandstones. Thus these soils have duplex profiles, that is, a marked and sudden texture contrast between the A and the B horizons.

Open forests of messmate (*E. obliqua*), narrow leaf peppermint (*E. radiata*) and blue gum (*E. globulus*) are the major vegetative associations. Both forestry and agricultural potential are lower than in the abovementioned areas because of the lower annual rainfall. Water supply potential is also lower, and this is partly due to the influence of the duplex profile. The sharp decrease in permeability across the A/B horizon boundary tends to produce rapid overland or subsurface flow. Thus the amount of water retained for slower release to streams is reduced.

The duplex profile has other influences on the potential uses of these soils. For example, pines have difficulty growing where there is a water-impeding layer within 50 cm of the surface, as is often the case in duplex soils. Also some forms of erosion such as gullying and tunnelling are more likely to occur on duplex soils.

ZONE 2

Surrounding the Lower Cretaceous sediments on all but the seaward side are the unconsolidated sediments of the Dillwyn Formation. Here the soils are extremely variable, their profile characteristics depending to a large extent on the proportions of sand and clay in the parent material. Thus, many different soil groups occur and only the two major groups are discussed:

Deep leached sands with coffee rock: These soils are common on the immediate periphery of the Lower Cretaceous sediments towards Carlisle and also in the north-east near Anglesea. Their classification from Northcote's (1974) key is Uc 2.36 and they belong to both the podzols and the humic podzols of Stace et al. (1968).

The soils have a dark A_1 horizon high in organic matter, a bleached, almost white A_2 horizon, a cemented and often impermeable horizon of coffee rock at about 50 cm, frequently with ferruginous nodules inside a cemented mass, and then a structureless coarse clayey sand horizon.

The soils of this group have very low levels of most plant nutrients and this is reflected by the stunted nature of the vegetation with its structure ranging from low woodlands to heathlands. The structure seems to be also determined by the moisture regime of the soils. In areas where the coffee-rock is discontinuous or found to exist in columns, the soils are more permeable and low woodlands of narrow-leaf peppermint (*E. radiata*), shining peppermint (*E. nitida*) and brown stringybark (*E. baxteri*) dominate. However when the coffee-rock is thick and continuous the soils are badly drained, with seasonal perched water-tables. In these areas heathlands and low open woodlands of shining peppermint (*E. nitida*), prickly tea-tree (*Leptospermum juniperinum*) and scented paperbark (*Melaleuca squarrosa*) are most common. Thus it appears that some eucalypts can survive the low level of fertility and extreme moisture stresses found on the well drained soils but when these conditions are combined with waterlogging in winter, only heathland vegetation can develop. A further development of this effect is the increase in the occurrence of heathland vegetation with increasing rainfall: soils with intermediate permeability become more extensively waterlogged as one moves closer to the ranges and the rainfall increases.

Sandy yellow gradational soils: Where the parent material has at least a moderate amount of clay, these soils tend to develop. They are classified as Gn 3.84 from Northcote (1974) and as yellow podzolic soils from Stace et al. (1968).

Typically shallow light-textured A_1 and A_2 horizons overlie a yellow sandy clay loam horizon at about 25 cm. This horizon may or may not contain ferruginous nodules and usually continues to about 75 cm. Beneath this horizon is a strongly structured clay or silty clay with shiny ped faces and yellow, grey and occasionally red mottles.

In most areas, varying depths of iron-rich sands have been washed over the top of the soil profiles, apparently in previous drier climatic periods. The thickness of these sand sheets varies from a few centimetres to many metres, but in most places it seems to be about 40 cm thick. During subsequent weathering and leaching, the iron has been washed out of the surface horizons of sand into the top of the older soil profile, usually the yellow sandy clay loam horizon. This has led to cementation and formation of large areas of coffee rock.

Permeability is quite variable depending on the extent of development of the coffee rock. This is reflected in the native vegetation: open forests of messmate (*E. obliqua*) and brown stringybark (*E. baxteri*), dominated by the former, are found on the more permeable soils without coffee rock. These are replaced by woodlands of brown stringybark (*E. baxteri*) and narrow-leaf peppermint (*E. radiata*) as the coffee rock develops underneath the sand sheets, resulting in impeded drainage.

Sheet erosion by water and possibly by wind can be a problem on these sandy, weak structured soils. Damage can be severe on areas clear of vegetation. Other forms of soil deterioration are not as important.

Zone 3

Further away from the Ranges again are exposures of the more clayey Tertiary sediments known as the Gellibrand Marl which roughly coincide with the third land zone. This area is widely used for agriculture. There are two major soil groups to be found:

Mottled duplex soils with ironstone: Classified as Dr 3.31 from Northcote (1974) and as a variation of the lateritic podzolic soils from Stace et al. (1968), these soils are found on flat or very gentle plateau remnants over most of this area.

Surface textures are loams, frequently with an organic A_1 and a bleached A_2 horizon changing fairly sharply to a silty clay at about 40 cm. This clay has an extremely strong structure and is dominated by red and white mottles on shiny angular peds. This horizon is underlain by large ferruginous concretions or a continuous indurated horizon at about one m. Typical mottled zones and pallid zones commonly found in most lateritic profiles in Victoria are usually present.

In places the strong structured clay horizon continues to greater depths with only minor iron cementation and directly overlies the clayey marls of the parent material. These sediments are also deeply weathered and strongly kaolinised.

These soils are thought to have been formed during a previous climate, when conditions were conducive to the synthesis of lateritic soils. They have survived subsequent erosional cycles to remain as lateritic soils today with only minor modifications.

Most of the native forests have been cleared for agriculture, some areas just recently for the Heytesbury settlement around Simpson. They originally supported open forests with the major species being messmate (*E. obliqua*) and swamp gum (*E. ovata*). Plant nutrient levels are commonly low with deficiencies in phosphorous, potassium, copper and molybdenum common (Phillips, pers. comm.). Intensive leaching during formation and subsequent fixation by adsorption onto sesquioxides could be the main factor responsible for these deficiencies.

Yellow sodic duplex soils with coarse structured subsoils: These soils have developed where stream dissection has cut deeply into the ancient plateaux exposing the lower lateritic horizons and Tertiary unconsolidated marls and clays. These are classified as Dy 3.41 from Northcote (1974) and belong to the gleyed podzolic soils of Stace et al. (1968).

The surface horizon is usually a loam with a dark A_1 and a bleached A_2 horizon and this sharply overlies a pale yellow (or off-white if developed on the pallid zone) heavy clay. Mottles are common in this clay horizon but are relatively dull and the structure comprises large coarse blocky peds frequently 10 cm across. These clays are quite dispersible and are probably sodic.

In some areas, such as between Barwon Downs and Winchelsea, dissection of the plateaux has been only minor. However, where dissection has been deep and extensive, for example just to the south of Birregurra, severe salting and gullying have led to widespread deterioration of the productive potential of the land. Other regions of Australia which have an almost identical catenary relationship between the soils have similar problems. The Dundas Tablelands in Victoria (Gibbons & Downes 1964) and the Darling Ranges in Western Australia (Dimmock et al. 1974) are two examples. It is postulated that the underlying pallid zones of the lateritic profile contain relatively high proportions of salt, most probably of cyclic origin. When the native vegetation is cleared the rising groundwater table and increased activity of springs brings this salt to the surface.

In the Heytesbury settlement, dissection of the lateritic plateaux has again been extensive. However most of the land has only just recently been cleared and insufficient time has elapsed for these problems to fully develop. As the severity of salting is generally observed to decrease with increasing annual rainfall, particularly when this is above 650 mm, it is anticipated that salting problems will not be as severe here as near Birregurra. However, leaching of salt from the landscape may have important consequences for proposals to use parts of the Heytesbury district for domestic water supply.

MINOR SOIL GROUPS

Three other soil groups of minor occurrence are worthy of mention because of their importance for land use.

Calcareous sands: Found on recently formed sand dunes at the river mouths and on other parts of the coastline, these soils are classified as Uc 1.11 from Northcote (1960).

The soil profile is usually an undifferentiated mixture of sand and weathering shell particles. There is sometimes a slight darkening near the surface due to organic matter build-up. The indigenous vegetation is a grassland of hairy spinifex (*Spinifex hirsutus*) but this is extremely susceptible to trampling from people travelling over the dunes and it has completely disappeared from many of the dunes in the area. When bare of vegetation these dunes are highly susceptible to wind erosion, and it is often necessary to stabilise them by hand planting the introduced marram grass (*Ammophila arenaria*) which is more tolerant of trampling.

Further inland on older dunes these calcareous sands give way to more leached siliceous sands with a woodland vegetation which is more tolerant to trampling and disturbance.

Grey gradational soils: Classified most often as Gn 2.92 from Northcote (1974), these soils exhibit wide degrees of variation. They are found on alluvial flats throughout the area, and are noted for their productive capacity, particularly around Carlisle and Barwon Downs.

Profiles are quite variable as mentioned, but generally have a deep sandy loam topsoil rich in organic matter merging gradually into a light coloured sandy clay loam or sandy clay. The soils are quite porous, well drained and fertile.

Reddish brown gradational soils: These soils are found on the well drained slopes where limestone is outcropping, as at Bellbrae in the north east of the area. They are known as Terra Rossa's from Stace et al. (1968) and are classified as Gn 2.21 from Northcote (1974).

Textures are usually clay loams or light clays grading to medium clays with depth. Weathering limestone is found at about 60 cm to 1 m below the surface. Their structure is strong and these soils are quite stable to most forms of erosion. Fertility is relatively high.

They are also highly productive agriculturally and where they occur are intensively used for grazing and cropping.

ACKNOWLEDGMENTS

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BIBLIOGRAPHY

DIMMOCK, et al., 1974. Salt content of lateritic profiles in the Darling Range, Western Australia. *Aust. J. Soil Res.* 12: 63-69.

EDWARDS, A. B. & BAKER, G., 1943. Jurassic arkose in southern Victoria. *Proc. R. Soc. Vic.* 55: 195-225.

GIBBONS, F. R. & DOWNES, R. G., 1964. A study of the land in south-western Victoria. *Soil Cons. Auth. Vic.* T.C.3.

NORTHCOTE, K. H., 1960. *Atlas of Australian soils. Explanatory data for sheet 1, Port Augusta–Adelaide–Hamilton area.* CSIRO Aust. and Melb. Univ. Press C2.

————, 1962. *Atlas of Australian soils. Explanatory data for sheet 2, Melbourne–Tasmania area.* CSIRO Aust. and Melb. Univ. Press C2.

————, 1974. *A factual key for the recognition of Australian soils.* Rellim Technical Publications, 4th edition.

SKENE, J. K. M., 1956. Soil map of Victoria. Vic. Dep. Ag.

————, 1957. Soils, Corangamite regional resources survey. *Central Planning Authority* pp. 70-73.

SPECHT, R. L., 1972. *The vegetation of South Australia.* A. B. Jones Publications 28.

STACE, H. C. T. et al., 1968. *A handbook of Australian soils.* Rellim Technical Publications.

WALBRAM, W. I., 1971. Soils, Barwon regional resources survey. *Central Planning Authority* pp. 63-65.

8

NATIVE VEGETATION OF THE OTWAY REGION, VICTORIA

By R. F. Parsons*, J. B. Kirkpatrick** and G. W. Carr*

Abstract: A general account of the vegetation of the Otway Region is presented with emphasis on *Eucalyptus* species, for which most data are available. Detailed maps are given of the distribution of *E. globulus* in the region and of the eucalypts in the Parker River area. The vegetation contrasts between the relatively fertile soils on Cretaceous rocks and the infertile soils of Tertiary sediments are emphasized, and the similarities between the Otways and the South Gippslands hills indicated. Serious problems affecting the native vegetation include invasion by weeds and by the fungal die-back disease *Phytophthora cinnamomi*.

INTRODUCTION

The Otway Ranges are isolated from other mountain areas both by the Cainozoic basalts of the Basalt Plains to the north, and by the drowning of Bass Strait by rising sea-levels in the Quaternary to the south. In addition they are an island of wetness, being roughly contained within the 89 cm (35 in.) mean annual rainfall isohyet and surrounded by drier country on all sides. The acidic, sandy, infertile country surrounding the Ranges is also cut off from similar country by the Basalt Plains and Bass Strait. This isolation of the region has caused some distinctive vegetation characteristics.

The region includes some of the wettest country in Victoria (up to 198 cm (78 in.) mean annual rainfall) and is the furthest west in the State where recorded rainfall exceeds 119 cm (47 in.). Accordingly, it marks the western-most limit of the distribution of a number of plant species and communities. Part of the distinctiveness of the Otway Ranges in Victoria lies in the occurrence of high rainfall country at lower altitudes and closer to the coast than elsewhere (D. H. Ashton, unpublished).

The present paper deals with the whole area of Cretaceous rocks making up the Otway Ranges themselves. It includes also all areas of Tertiary and Quaternary sediments between the inland boundary of the Cretaceous rocks and the coast, plus the flanking Tertiary sediments both around the north-east end of the ranges and as far west as the Gellibrand River.

The Cretaceous rocks are felspathic sandstones, siltstones and mudstones and weather to give moderately fertile soils with loamy topsoils. The Tertiary sediments usually produce highly infertile soils with sandy topsoils (including both deep sands and duplex soils with shallow sandy topsoils over clayey subsoils). The Quaternary sediments include aeolian calcarenites and calcareous and siliceous coastal sands of varying fertility.

This paper attempts to review what is known of the plant communities in the area. Nomenclature for plant names follows Willis (1970, 1972) unless otherwise stated and for vegetation forms follows Specht (1970) as modified by Victoria: Land Conservation Council 1976 (abbreviated here to VLCC 1976).

The vegetation is poorly known; VLCC (1973, 1976) provides some description and mapping in broad structural categories. Block names and boundaries within the area follow VLCC (1973, 1976). Throughout this paper, areas, sites, soils and slopes found on geological deposits of a given age (as Cretaceous or Tertiary) will, for the sake of conciseness, be referred to by phrases like 'Cretaceous sites' or 'Tertiary slopes'.

CLOSED-FORESTS

Tall closed-forests dominated by *Nothofagus cunninghamii* (often including trees of *Acacia melanoxylon*) occur in sheltered gullies where mean annual rainfall (MAR) exceeds 127 cm (50 in.), and extend onto broad valleys and saddles where MAR exceeds 178 cm (70 in.) on the Beech Forest plateau. Howard and Ashton (1973) give an account of their ecology and floristics, including mosses and liverworts, although the exact distribution of these forests has not been mapped. Common understorey species include

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Hedycarya angustifolia, Clematis aristata, Australina muelleri, Dicksonia antarctica and *Blechnum wattsii* Tindale (formerly called *B. procerum*) as well as a profusion of epiphytes including mosses, liverworts and filmy ferns. Despite the surprising absence of *Atherosperma moschatum* which is so common in such forests in the rest of Victoria and Tasmania, the Otways *Nothofagus* forests are not greatly different floristically from those of other low altitude areas in Victoria (Howard & Ashton 1973). The Otway Ranges are thought to be especially vulnerable to fire because they are exposed to dry country on their whole north-west flank. *A. moschatum* may have been eliminated by widespread past fires (Howard & Ashton 1973).

From apparently reliable measurements, it is claimed that *N. cunninghamii* formerly reached heights of 61 m (200 ft.) and girths of 4.6 m (15 ft.) in the upper Elliott River Valley (Hardy 1905).

OPEN-FORESTS WITH HEIGHTS EXCEEDING 40 METRES.

Such forests occur where MAR exceeds 152 cm (60 in.) on northern slopes and 114 cm (45 in.) on southern slopes (VLCC 1976). *Eucalyptus regnans* is commonly dominant on the wettest sites (MAR higher than 127 cm (50 in.)) and a tree at Olangalah last century was 100 m (329 ft.) high with 20 m (63 ft.) girth. The species forms pure stands especially above altitudes of 488 m (1600 ft.), but in the southern Otways below 488 m it commonly forms mixed stands with one or more of *E. cypellocarpa, E. obliqua* and *E. viminalis*. Near the lower limit of *E. regnans* between 122 and 274 m (400 to 900 ft.), *E. globulus* enters the mixture as in the Parker and Kennett River areas (see Fig. 3). Elsewhere in Victoria, *E. regnans* forms mixed stands only in narrow ecotones.

Where *E. regnans* and *E. obliqua* occur together, trees intermediate between these species are common and are locally called 'Otways messmate'. There is good evidence that these trees are hybrids between the two species, and such hybrids are common wherever the two species meet elsewhere (Ashton 1958).

Major understorey species in the *E. regnans* forests are *Hedycarya angustifolia, Olearia argophylla, Phebalium squameum* and to a lesser extent *Pomaderris aspera* and *Bedfordia arborescens* Hochr. (formerly called *B. salicina*). *H. angustifolia* is much more predominant in the Otways than in Central Victoria and the importance of this species and *O. argophylla* may be an expression of the very high rainfalls in the south central Otways (D. H. Ashton, unpublished). *P. squameum* subsp. *squameum* occurs in Tasmania, New South Wales, Queensland and the Otways, but nowhere else in Victoria.

In areas drier than the *E. regnans* forests, *E. cypellocarpa, E. globulus, E. obliqua, E. viminalis* and *Acacia melanoxylon* 40-70 m high occur over *P. aspera, O. argophylla, B. arborescens, Pimelea axiflora, Tetrarrhena juncea* and other understorey species. The understorey types above will be referred to collectively as broad-leaved shrub understories.

Large areas where *E. regnans* has been cleared now support secondary scrub of *A. melanoxylon* with *O. argophylla, H. angustifolia, Phebalium squameum* and *Pomaderris aspera* with *Polystichum proliferum* dominant among other ferns in the generally sparse understorey. On similar sites subjected to greater or more persistent disturbance, dense stands of *Pteridium esculentum*, introduced *Rubus* spp. and of the introduced noxious weeds *Hypericum androsaemum* and *Senecio jacobaea* can be found (Parsons 1973, D. H. Ashton, unpublished). The tragic economic and social consequences of the destruction of much of the original wet forest are discussed by Webb (1968).

OPEN-FORESTS WITH HEIGHTS LESS THAN 40 METRES.

These forests are highly variable in structure and floristics and are poorly known. The available data, summarized in Table 1, are generalized and far from comprehensive. Categories are based on dominant species. Most of the available ecological data relate to tree species and these are discussed in turn below.

(1) *E. globulus* (blue gum)

This is ecologically the best-known tree species following intensive work (Kirkpatrick 1970, 1975a, this paper). Despite previous uncertainty about the exact identity of the Otways populations of blue gum (Hall, Johnston & Chippendale 1970, Willis 1972) it is now clear that they are part of a cline between *E. globulus* subsp. *globulus* and *E. globulus* subsp. *pseudoglobulus* (Naudin ex Maiden) Kirkpatrick (see Kirkpatrick 1974). The Otways stands are not typical 'core populations' of either subspecies. They are most like typical subsp. *globulus* within 0.5 km of the coast (especially all such coastal stands seen north-east of Apollo Bay), while the more inland stands vary from these in the direction of subsp. *pseudoglobulus* (Kirkpatrick 1971, 1974, 1975a). The Otways populations then are transitional between the typical subsp. *globulus* of Tasmania and King Is. and the typical subsp. *pseudoglobulus* found to the north at Lerderderg Gorge.

The altitudinal range for *E. globulus* in the Otways is from just above sea level to 442 m (1450 ft.) and MAR varies from 69 cm (27 in.) to 140 cm (55 in.), but is typically between 76 cm and 114 cm. The higher rainfall areas are, with the western Tasmanian

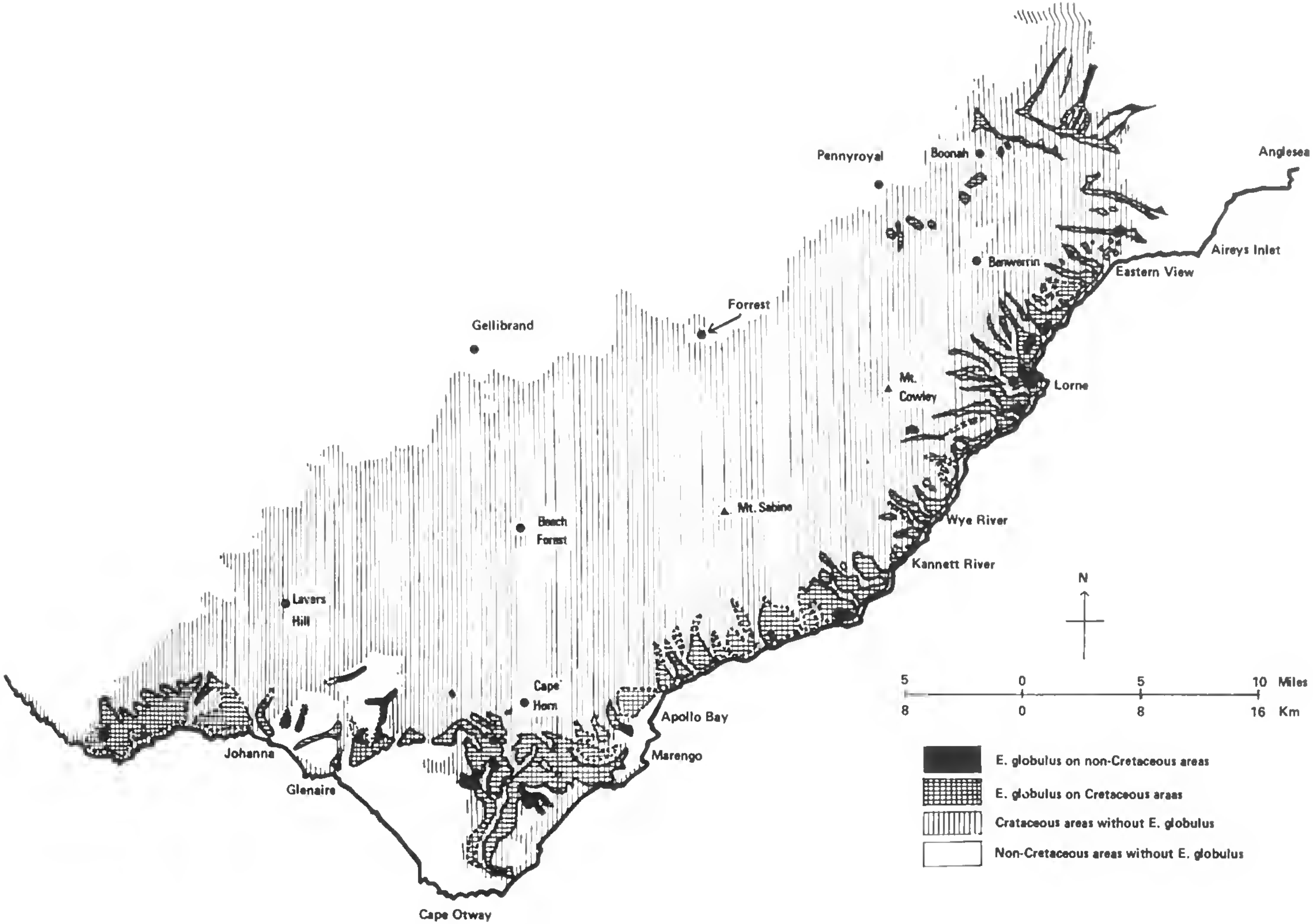

FIG. 1—Distribution of *Eucalyptus globulus* in the Otway Region mapped from ground traverse of all available roads and vehicle tracks. Dashed lines show extrapolated boundaries in cleared areas. In the *E. globulus* area shown in the extreme NE., the species follows watercourses. Geological boundaries from Victoria: Geological Survey 1971, 1973. The *E. globulus* occurrences shown on non-Cretaceous are virtually all on areas mapped as Tertiary. Some inland slope records from P. Denham (personal communication).

occurrences, the wettest sites from which *E. globulus* is known (Kirkpatrick 1975a). The species occurs as a dissected fringe around the seaward edge of the Otways (Fig. 1).

Most of its range is on soils on Cretaceous rocks, but it occurs occasionally in areas mapped as Tertiary (Victoria: Geological Survey 1971, 1973) on diverse soils ranging from heavy alluvial soil near streams (as along Breakfast Creek) to deep acidic sands (as on the Wait-a-While and Calder ridges). The records known to be on deep sands are from sites wetter than those typical for *E. globulus* in the Otways, which may partly reflect the low water storage capacity of the sands.

Although most typically a ridge-top species in the Otways, *E. globulus* is confined to south-facing slopes and stream margins in the driest parts of its range there, and becomes increasingly concentrated on ridges and north-facing slopes as rainfall increases. It is less common on the slopes inland from the main ridge (Fig. 1), being seen there only as far to the south-west as Dunse Track south of Pennyroyal; but it occurs also on Norman Track nearby to the west (P. Denham, personal communication).

The understorey beneath *E. globulus* varies with rainfall from grassy to the broad-leaved shrubs of the *E. regnans* understorey type. *Themeda australis* dominates in some near-coastal areas but further inland *Poa sieberana* Spreng. and *P. labillardieri* Steud. are the dominant grasses with a sparse shrub layer of *Acacia stricta* and *Helichrysum dendroideum*. Elsewhere, more sclerophyllous understories are dominated by *Pultenaea daphnoides*, *A. verticillata* and/or *A. mucronata* over *Tetrarrhena juncea*. All the above types are from Cretaceous areas.

(2) *E. cypellocarpa*

This species has a similar general range to *E. globulus* in the Otways, but is also common on the inland slopes. There is good evidence that the two species hybridize elsewhere (Kirkpatrick, Simmons & Parsons 1973). Despite widespread co-existence in the Otways, presumed hybrids are rare, being seen on Wye River Track, the T.W. Spur, near Johanna Vale and near the St. Georges River reservoir.

E. cypellocarpa typically occurs in a zone separating *E. globulus* from *E. regnans* forest, often replacing *E. globulus* as altitude exceeds about 305 m (1000 ft.) on steep slopes. On more gradual slopes, the two species are often intermixed, frequently along with *E. obliqua*. *E. cypellocarpa*, however, also occurs in a variety of other situations and mixtures. The understories of communities dominated by this species are similar to those found under *E. globulus*, except that grassy understories are comparatively rarer and never dominated by *Themeda*.

The species is most common on soils on Cretaceous

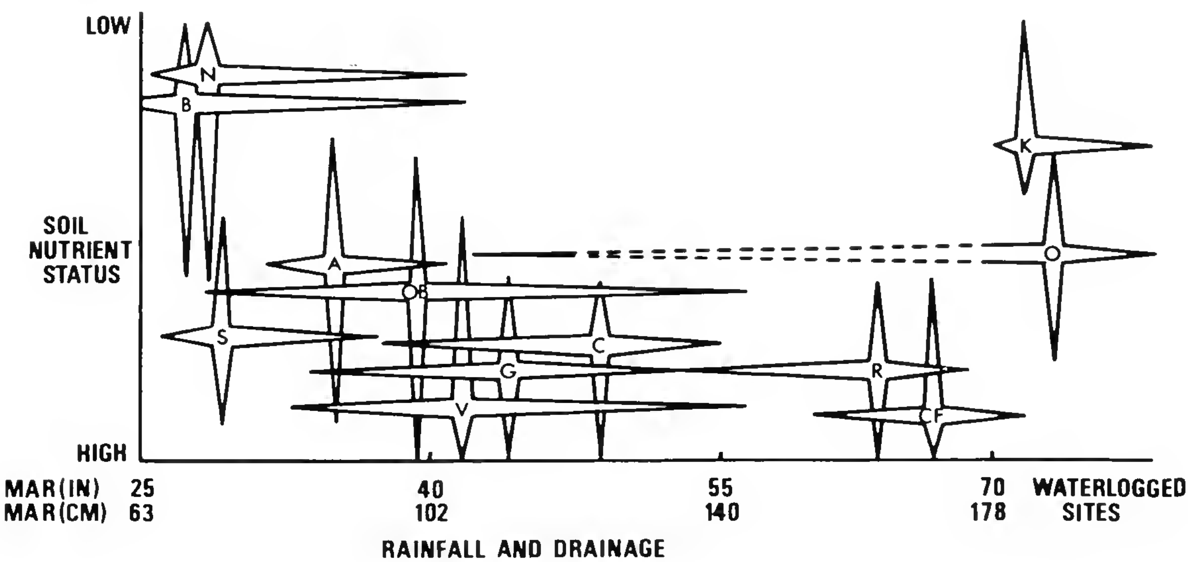

FIG. 2—Approximate relationships between the distribution of *Eucalyptus* species in the Otway Region and soil nutrient status, rainfall and drainage. Horizontal axis is mean annual rainfall (MAR) except for righthand side which shows waterlogged sites. **A** = *E. aromaphloia*, **B** = *E. baxteri*, **C** = *E. cypellocarpa*, **CF** = closed-forest including *Nothofagus*, **G** = *E. globulus*, **K** = *E. kitsoniana*, **N** = *E. nitida*, **O** = *E. ovata*, **OB** = *E. obliqua*, **R** = *E. regnans*, **S** = *E. sideroxylon*, **V** = *E. viminalis*. *E. radiata* not shown but its range on this diagram would be closely similar to that of *E. aromaphloia*.
Soil nutrient status inferred from profile descriptions and limited chemical analyses.

rocks, but is known from Tertiary areas (e.g. inland from Cape Otway, east of Johanna), although not in the north-east of the area. Here, populations morphologically intermediate between *E. cypellocarpa* and *E. goniocalyx* occur on at least four Tertiary sites (Distillery Creek, Urquharts Bluff and two sites near Anglesea). It is possible that these stands are of hybrid origin, even though *E. goniocalyx* is almost certainly absent from the whole region (Parsons & Kirkpatrick 1972), despite earlier reports (Hall, Johnston & Chippendale 1970). The stands are in drier areas than those typical for *E. cypellocarpa*.

(3) *E. ovata*

This species is widespread in the Otways, typically on poorly-drained sites in valleys and flats on a wide variety of soils as elsewhere. However, it also occurs occasionally on well-drained ridges and slopes as on Peters Hill ridge and the Elliott River area where it is mixed with *E. globulus* as well as near Wattle Hill (Hooke 1960) and near Cape Otway on the Lighthouse road. *E. ovata* more than 28 m high is common between Benwerrin and Mt. Sabine (VLCC 1976). Understories to *E. ovata* include dense thickets of *Leptospermum juniperinum* and/or *Melaleuca squarrosa*, especially on badly drained Tertiary sites, and shrubby understories like those described for *E. globulus* on well-drained Cretaceous sites.

(4) *E. viminalis*

In the Otway Ranges this is typically a species of river banks (e.g. upper Parker River valley; see Fig. 3) and flood plains and so is partly independent of direct rainfall. It is also found on slopes mixed with a variety of species (e.g. with *E. globulus* around Elliott River). Where Cretaceous rocks reach the coast, *E. viminalis* commonly occurs in a narrow salt spray-pruned band, being the first eucalypt encountered passing inland.

Around the Tertiary flanks of the northern half of the Otways from north of Anglesea to at least as far south-west as Barongarook, *E. viminalis* was formerly dominant over large areas on the Pliocene Moorabool Viaduct Formation (mapped in Victoria: Geological Survey 1971, 1973). Almost all of this community has been cleared. In the remnants, wetter sites can have sub-dominant *E. obliqua* and *E. radiata* with scattered shrubs of *Acacia mucronata* and *Leptospermum juniperinum* and a dense ground layer of *Lomandra longifolia* and *Pteridium esculentum*. Drier sites, possibly of woodland structure, have scattered shrubs of *Bursaria spinosa* and *Acacia armata* and a grassy understorey of *Poa labillardieri, Themeda australis* and *L. longifolia*.

Other habitats for *E. viminalis* include Quaternary sands with acidic topsoils near Cape Otway and the steep sides of the Cumberland River Gorge.

(5) *E. aromaphloia*

This species is extensive on Tertiary inland slopes with *E. obliqua* and *E. radiata* and forms a narrow fringe on dry Cretaceous sites along the coast especially where MAR is less than 102 cm (40 in.). As well it appears on dry inland Cretaceous areas. The understorey is dominated by sclerophyllous shrubs and bracken on the Tertiary and by *Poa* and *Acacia* on the Cretaceous.

(6) *E. sideroxylon*

The exact Otways distribution has been mapped and is all in the north-east within an area 13 km (8 miles) across (Kirkpatrick 1970). The nearest stands to this interesting outlying coastal occurrence are to the north-east at Point Addis (VLCC 1973) and inland in the Brisbane Ranges to the north. The species rainfall range in the Otways is 69 cm (27 in.) to 84 cm (33 in.) MAR on both Cretaceous and Tertiary areas (on relatively fertile duplex soils on the Tertiary rather than deep sands).

E. sideroxylon forms almost pure stands over much of its range here but also forms mixed stands with *E. cypellocarpa-E. goniocalyx* intermediates (Parsons & Kirkpatrick 1972), *E. obliqua* and to a lesser extent *E. globulus*. *Acacia verniciflua* and *Pultenaea daphnoides* are the main shrubs found under *E. sideroxylon*, often occurring in patches interspersed by an herbaceous cover dominated by *Poa sieberana*. In some areas the taller shrubs are largely absent and the herbs occur in a patchwork with bare ground.

E. sideroxylon generally occupies exposed sites that appear drier than nearby ones carrying *E. globulus*. Following the 1967/68 drought, in an even-aged mixed stand of the two species, *E. globulus* trees were more severely drought damaged than *E. sideroxylon* (which were smaller in this area), suggesting that drought tolerance is greater in the latter. Nearby, suppressed *E. sideroxylon* can be found under *E. globulus*, suggesting that *E. globulus* may suppress *E. sideroxylon* if moisture is adequate (Kirkpatrick 1970).

(7) *E. obliqua*

This is the most widely distributed tree species in the Otways and ranges from low woodlands (described in a later section) on very infertile soils on Tertiary areas with MAR 61 cm (25 in.) to fertile soils on Cretaceous areas with MAR more than 127 cm (50 in.). It is the most common tree associated with *E. globulus* and usually extends upslope into wetter areas than this species, where it associates commonly with *E. cypellocarpa* before finally adjoining or mixing with *E. regnans* in even wetter sites. In addition it extends into drier and more infertile sites than those occupied by any of the above species where it associates with *E. radiata, E. nitida, E. aromaphloia, E. baxteri* and *E.*

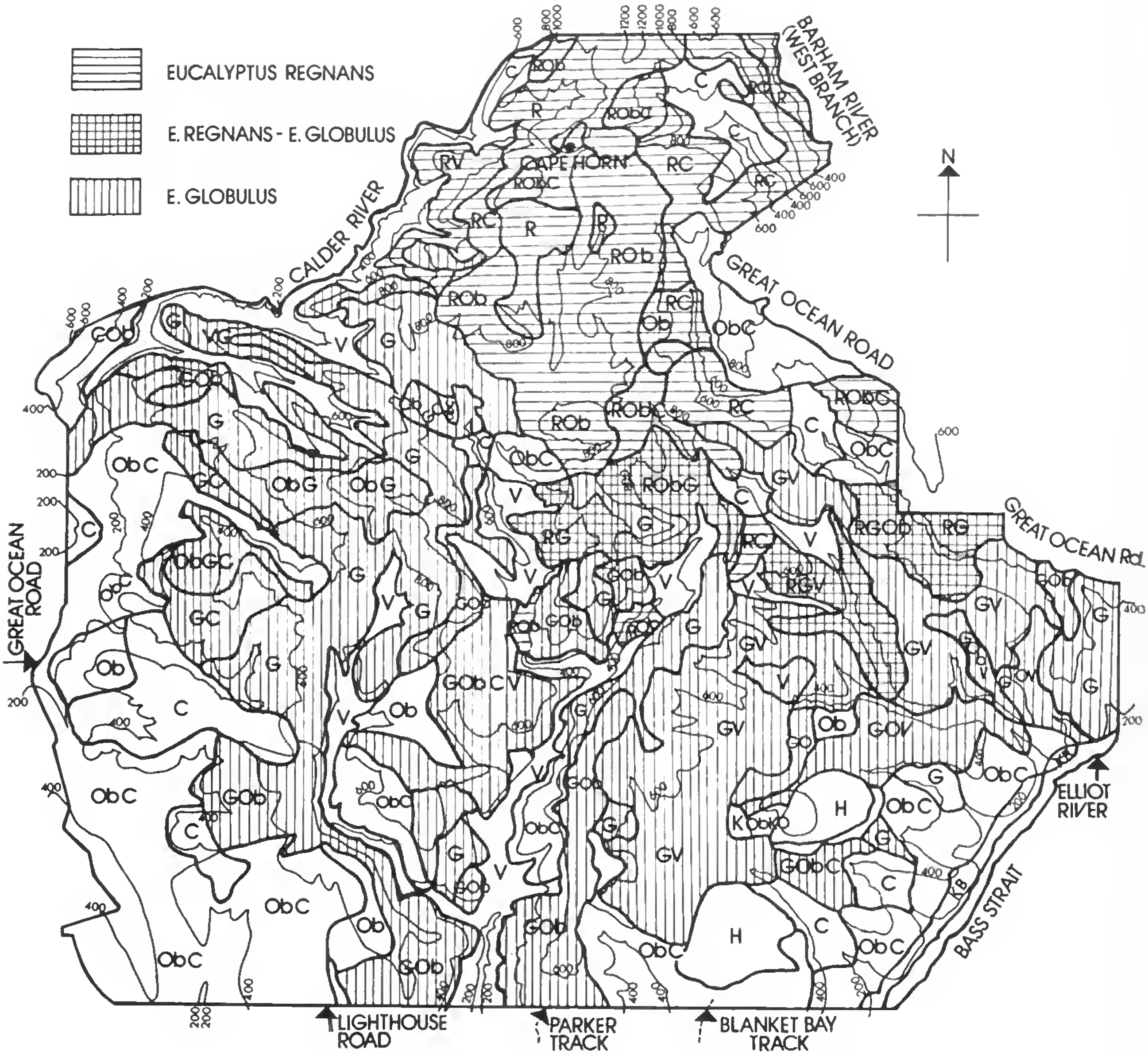

FIG. 3—Distribution of *Eucalyptus* species in relation to altitude in part of the Cape Otway Block. *E. regnans* and *E. globulus* hatched as in legend on map. **B** = *E. baxteri*, **C** = *E. cypellocarpa*, **G** = *E. globulus*, **K** = *E. kitsoniana*, **O** = *E. ovata*, **Ob** = *E. obliqua*, **R** = *E. regnans*, **V** = *E. viminalis*, **H** = heath. Species listed in order of abundance in each type. All contours in feet. Mean annual rainfall increases from south to north (very approximately from 94 cm (37 in.) to 140 cm (55 in.)). Mostly Cretaceous, but Victoria: Geological Survey (1973) maps some Tertiary sediments in the SW and SE corners. Both heath areas shown are on Tertiary. Source is Victoria: Forests Commission (1936) 'Forest contour and type map of Otway' (unpublished). Mapping from field traverses. Distribution of *E. viminalis* closely related to creek-lines. Arrowheads show position where named features cross study area boundary.

viminalis. Unlike *E. globulus* it is widespread on both the inland and coastal flanks of the Otways.

E. obliqua is found with a wide variety of understorey types including all the types found under *E. cypellocarpa* as well as bracken and sclerophyll shrub understories typical of the well-drained Tertiary sites.

(8) *E. radiata*

Found particularly on the inland slopes sometimes as pure stands and known mainly from Tertiary areas where the understorey is dominated by bracken and sclerophyll shrubs, the most important of which are *Leptospermum juniperinum, Banksia marginata, L. myrsinoides* and *Aotus ericoides*. Occurrences on Cretaceous areas are confined largely to the dry north-east.

(9) *E. dives*

Although a few isolated records exist of this species (e.g. Hooke 1960), it has not been seen during extensive field work by the present authors or by Beauglehole or Thornley, unpublished. Detailed field checking is required, especially of the inland slopes. Isolated records could refer to occasional *E. obliqua-E. radiata* hybrids, or even to forms of *E. nitida*.

(10) *E. baxteri*

More typically a woodland tree in this area, but occurs in forest in the Cape Otway Block. It is common on Tertiary areas and is either very rare or absent from Cretaceous ones. Anomalous trees in the Cape Otway Block are almost certainly hybrid swarms between this species and *E. obliqua* (D. H. Ashton, unpublished).

WOODLAND

Woodlands in this area are virtually confined to areas where MAR is less than 102 cm (40 in.) and are closely associated with highly acidic infertile soils on Tertiary sediments, often with an impeding horizon which can cause waterlogging of the topsoil in winter and increased evaporation and drought in summer (VLCC 1976). Of the forest eucalypts, *E. obliqua* and *E. baxteri* both occur commonly in woodlands as well, where the latter often appears to occupy more infertile soils than the former (e.g. the pure stands of *E. baxteri* in the Cape Otway Block).

In the north-east south of Wurdiboluc Reservoir, there is a sharp change in geology from Pliocene to Palaeocene sediments across the Bambra Fault (Victoria: Geological Survey 1971). This coincides with a sharp change in vegetation from *E. viminalis* to *E. obliqua* woodland (A. Thornley, personal communication) and probably correlates with a decrease in soil fertility.

In the wetter areas of the Cape Otway Block, eucalypts can form woodlands up to 21 m (70 ft.) high over dense understories of *Leptospermum juniperinum* from 3 m (10 ft.) to 12 m (40 ft.) high. (D. H. Ashton, unpublished).

E. ovata can also occur in woodland on Tertiary areas, especially in swamp margins. In addition, the following eucalypts usually absent from forest are found:

(1) *E. kitsoniana*

This rare species is only found in the Cape Otway Block up to 5 km (3 miles) inland and north-westerly from Blanket Bay (Hooke 1960 and see Fig. 3), and elsewhere is known only from Wilsons Promontory and nearby areas (Parsons 1963) and far south-west Victoria (Gibbons & Downes 1964). It is a species of infertile, badly-drained sites and is uniquely well-developed in the Otways, single-stemmed trees sometimes reaching heights of about 18 m (60 ft.).

(2) *E. nitida*

This species is very common on Tertiary areas on the inland flanks of the Otways between Gellibrand and Chapple Vale and on the Bald Hills near Anglesea, often with *E. baxteri* (VLCC 1976), and often on very infertile soils which appear to have the lowest water storage capacities or the driest topographic positions of those seen. On more favourable sites carrying forest (e.g. around Karwarren), populations intermediate between *E. nitida* and *E. radiata* can be found. The inland flanks of the Otways would be ideal sites to study the ecological and taxonomic relationships of these two closely related species.

E. nitida and all the other species mentioned above are components of woodlands with understories dominated by sclerophyllous shrubs.

(3) *E. pauciflora*

Three very small outlying populations of this species have been recorded on north-east Tertiary areas. Three trees occurred at Anglesea rubbish tip, on the east side of Camp Road 1 km from its southern end; these have already been destroyed by clearing (A. Thornley, personal communication). A second population is found from the junction of Gundries Road and Vickery Road up to 0.5 km north along Vickery Road (8 km north-east of Anglesea). About 20 trees remain as roadside remnants with an understorey including *Poa sieberana, Pteridium esculentum* and *Themeda australis*. Finally, a remnant of about 20 trees occurs south-east of Lake Modewarre at grid reference 205780 on the Anglesea 1:63,360 military survey map (A. Pitt, personal communication).

Conservation is urgently needed of these disjunct stands, as along the coast to the west stands do not recur until the vicinity of Heywood in far south-west Victoria (Gibbons & Downes 1964).

(4) *E. leucoxylon*

Scattered trees of this species have been recorded in roadside remnants near the Henty Main Road north of Anglesea (A. Thornley, personal communication) on the Pliocene Moorabool Viaduct Formation which carries soils comparatively fertile for Tertiary areas. Woodlands of *E. viminalis* and to a lesser extent *Casuarina stricta* were formerly widespread on this Formation before clearing.

Some general topographic and soil nutrient and water relations of the main tree species of both forests and woodlands are shown in Figs. 2 and 3.

HEATH

These completely treeless communities dominated by sclerophyllous shrubs are much less common than woodlands. They are found principally on very infertile highly acidic soils of Tertiary areas. Coastal heaths are common in the Anglesea area and have been mapped there (Turner, Ashton & Bird 1968). *Leptospermum juniperinum* and *L. myrsinoides* are often co-dominant and occur with *Casuarina pusilla*, *Gahnia radula* and many other species. The reasons for the treelessness of such coastal heaths are poorly understood. Salt spray damage to adjacent eucalypts suggests that this factor is often important but extreme infertility, periodic waterlogging, fire history or some combination of these and other factors may also be important.

Inland heaths are most common in the Carlisle Block. Dominants include *Melaleuca squarrosa*, *L. juniperinum*, and *Gymnoschoenus sphaerocephalus* which occur with *Sprengelia incarnata*, *Gahnia sieberana*, *Empodisma minus* (Hook.f.) L. A. S. Johnson & Cutler (formerly *Calorophus lateriflorus*) and many others. These heaths occupy swampy valley bottoms and elevated areas of strongly impeded drainage. Treelessness may be related to soil waterlogging, extreme infertility and other factors but salt spray is clearly not important. MAR is around 109 cm (43 in.) here compared to 66 cm (26 in.) at Anglesea.

In contrast to these two extreme situations are the heaths at Cape Otway. These are in exposed coastal locations but are floristically much more similar to the Carlisle heaths than to the Anglesea ones, with 'wet' elements like *M. squarrosa* and *S. incarnata* important. MAR here is 86 cm (34 in.), so it appears that increasing rainfall has an important effect on heath floristics, presumably partly by increasing the severity of waterlogging and thus favouring the 'wet' heath elements. However, detailed soil comparisons are badly needed to clarify the situation.

As examples of these important floristic differences, *Epacris lanuginosa*, *Gymnoschoenus sphaerocephalus* and *Hibbertia procumbens* are completely absent from the Anglesea Block, but are common at Cape Otway and Carlisle, while the reverse is true for *Casuarina pusilla*, *Spyridium vexilliferum*, *Thysanotus dichotomus* and *Goodenia geniculata*. *C. paludosa*, *Sprengelia incarnata* and *E. obtusifolia* are all very rare at Anglesea, but common at Cape Otway and Carlisle. There are also some important differences between the Cape Otway and Carlisle heaths, *Melaleuca squamea* and *Hibbertia acicularis* being recorded only from Carlisle. The 'wet' heaths often grade into closed-scrubs dominated by *M. squarrosa* and *L. juniperinum* often 3-4 m up to 6 m high.

Coastal heaths at Marengo, (MAR of 112 cm (44 in.)) superficially similar to those at Cape Otway, are being increasingly disturbed and destroyed and urgently need detailed study.

Both the woodlands and heaths usually have very high plant species diversity. The sclerophyllous vegetation of the Tertiary area around Anglesea includes interesting disjunct occurrences of species otherwise known in Victoria only from much further west (notably the Grampians and the far south-west). These include *Conospermum mitchellii*, *Schoenus breviculmis* and *Thysanotus dichotomus* (Willis 1962). Within a 13 km (8 miles) radius of Anglesea, no less than 86 species and 3 varieties of native orchids can be found, out of the Victorian total of about 169 species and 19 varieties, excluding presumed hybrid taxa in all cases (Beauglehole, Carr & Parsons 1977). Willis (1962) has emphasized the paucity of *Grevillea* species in the Otway region: only one highly localized species is known. In this respect, the region is similar to Wilsons Promontory, the Holey Plains or the heathy coastal country south-west of Mallacoota (one *Grevillea* species in each area).

COASTAL COMPLEX

On seaward coastal dunes the grasses *Spinifex hirsutus*, *Ammophila arenaria* and *Festuca littoralis* are common, with herbs like *Tetragonia implexicoma* and *Swainsona lessertiifolia*. On landward dunes, the shrubs *Leucopogon parviflorus* and *Acacia longifolia* var. *sophorae* are more or less frequent throughout. *Melaleuca lanceolata* is very important through the Anglesea-Aireys Inlet area; we have not re-located the record from Lorne (Willis 1948). The species does not re-appear west of Lorne until near Warrnambool (Willis 1948), being generally absent at the coast where MAR exceeds about 89 cm (35 in.).

The distribution and status of the widely planted *Leptospermum laevigatum* is puzzling. It is widespread as dense scrub and clearly indigenous north-east of the study area at Ocean Grove and is common around Torquay. It occurs on dunes at Anglesea and Eastern View, but as scattered patches rather than widespread stands, suggesting the possibility that it is a garden escape in these areas. Even the stand of old trees at the Erskine River mouth at Lorne could be planted rather than indigenous. It is also known from Cape Otway. The absolute western limit of indigenous stands must fall somewhere within the areas mentioned and historical research may help to resolve this problem. Spasmodic occurrences along the coast from Cape Otway to Nelson are apparently all escapes from gardens or hedges planted as wind breaks (A. C. Beauglehole, personal communication).

L. laevigatum has not been seen anywhere in the coastal fringe where the Cretaceous rocks come to the coast, but *Leucopogon parviflorus* is widespread in such sites. The tree *Casuarina stricta* is important on exposed coastal cliffs and slopes, particularly before the eucalypt zone is reached passing inland. Carr (1970) gives further details on the coastal vegetation.

The only Victorian record of *Correa reflexa* var. *nummulariifolia* is from the mouth of the Parker River around the coast to Cape Otway, at the base of aeolian calcarenite slopes often just above high tide level on shallow calcareous sand over calcarenite (this study). This is the only mainland occurrence of a variety known elsewhere only from Kangaroo Island and islands in Bass Strait. Some species more or less characteristic of soils on calcarenite and rare or absent elsewhere in the area are also found here, viz. *Acrotriche affinis*, *Beyeria leschenaultii*, *Exocarpos syrticola* and *Olearia glutinosa*.

OTHER COMMUNITIES

Salt marsh was examined at the mouth of Anglesea River, where *Salicornia quinqueflora* and *Juncus kraussii* Hochst. (formerly called *J. maritimus*) are important dominants and associated species include *Disphyma blackii*, *Hemichroa pentandra* and *Sebaea albidiflora*. On low-lying estuarine flats at the mouth of the Aire River, *J. kraussii*, *Phragmites australis* (Cav.) Trin. ex Steud., *Scirpus pungens* Vahl (formerly called *S. americanus*) and *S. validus* are important.

Melaleuca ericifolia, which occurs throughout eastern Victoria on low-lying sub-saline sites inland from salt marsh, does not extend as far west as the Otway region. At the mouth of the Anglesea River, such sites are occupied, surprisingly, by *M. lanceolata* which throughout the rest of its range is a species of elevated, well-drained, non-saline sites. *M. halmaturorum* is characteristic of swampy saline sites in South Australia and Western Victoria, but is not known further east than Cope Cope near Donald (J. H. Willis, personal communication).

In non-saline swamps, closed-scrubs are usually dominated by *M. squarrosa* and, especially in the west Otways, *Leptospermum lanigerum*. The nature and ecology of all the swamp communities are very poorly known and need further work.

CONSERVATION

State-owned plantations of introduced softwoods (mainly *Pinus radiata*) in the Otways zone at present occupy 3400 ha. Current scheduled planting is 200 ha per year and the planned plantation area for the zone is 8000 ha (Williams 1975). Presumably much of the future increase will be at the expense of native vegetation. Private companies own a further 8000 ha, all of which is intended for softwood plantations (A. Pitt, personal communication). Probably at least half of this will be at the expense of native forest rather than formerly cleared land.

Death of native vegetation from fungal die-back disease caused by *Phytophthora cinnamomi* Rands has been recorded in heath and woodland vegetation on Tertiary areas in the Great Ocean Road Flora Reserve near Anglesea, in Angahook Forest Park (Weste & Marks 1975) and near Point Addis (Weste 1975). The eastern Otways and Gellibrand are said to have 'small pockets of infection and very few die-back patches' (Marks, Fagg & Kassaby 1975). No work whatever is being done on the disease in the Otways region at present. Clearly, information is urgently needed on exact distribution, and whether the disease is likely to cause damage on Cretaceous areas as well as Tertiary ones. Such data may help to avert disastrous epidemics like those in Western Australia and East Gippsland. Certainly, compulsory testing of road gravel supplies and nursery stock and proper cleaning of road-making equipment as suggested by Weste and Marks (1975) should be implemented in the area immediately.

The most serious weed problem affecting native vegetation is *Chrysanthemoides monilifera* both because it is already widespread, especially along the whole coast north-east of Cape Otway and because it frequently invades both disturbed and completely undisturbed native communities. Gravel carting from infested areas should be strictly avoided (Parsons 1973). Introduced *Rubus* spp. are widespread and serious weeds and *Pittosporum undulatum* is already an important weed in some areas (e.g. coastal vegetation at Eastern View). The latter is also causing concern in Nine Mile Reserve (Heathmere) and Bolwarra Quarry Reserve north of Portland (A. C. Beauglehole, personal communication).

DISCUSSION

The most striking features in the macrovariation pattern of vegetation in the Otway Ranges are the ecological shifts and terminations occasioned by the Tertiary-Lower Cretaceous boundary, and the gradual changes in species dominance and vegetation structure within each geological unit responding to degrees of availability or excess of soil moisture. The set of eucalypt species found on the Cretaceous overlaps with the set found on the Tertiary, differences being due in part to the frequently drier climates experienced on the latter. However, the general absence of species such as *E. baxteri* and *E. nitida* from the Cretaceous and the rarity of *E. cypellocarpa* from the Tertiary probably reflect differences in nutrient status more than differences in moisture status. Marked structural shifts occur along the geological boundary. Most commonly there is a shift from heath or woodland with a sclerophyll shrub understorey on the Tertiary to open-forest with a grassy understorey on the Cretaceous. Where drainage is impeded in soils on the Tertiary, heaths and scrubs can directly adjoin tall open-forest on the well-drained soils on the Cretaceous. Grassy understories are more characteristic of the Cretaceous than the Tertiary on which sclerophyllous shrub understories or communities dominate. However, soils on the Tertiary Moorabool Viaduct Formation support grassy woodlands, possibly as a synergistic result of lower rainfall and higher fertility of the soil parent material. These compare with some Tertiary areas dominated by *E. sideroxylon* near Aireys Inlet

TABLE 1

MAJOR FOREST AND WOODLAND COMMUNITIES OF THE OTWAY REGION VLCC (1976)
D. H. Ashton (unpublished) and The Present Study.

Structural forms	Dominant species with associated tree species in brackets. VP=varying proportions	Geology	Common understorey species
Closed-forest	*Nothofagus cunninghamii (Acacia melanoxylon)*	Cretaceous	*Hedycarya angustifolia, Dicksonia antarctica, Blechnum procerum*
Open-forest 40m high	*Eucalyptus regnans* (see text)	Cretaceous	*H. angustifolia, Olearia argophylla, Phebalium squameum*
	E. cypellocarpa, E. globulus, E. obliqua, E. viminalis VP	Cretaceous	*Pomaderris aspera, O. argophylla, Bedfordia arborescens*
Open-forest 28-40m high	*E. obliqua (E. cypellocarpa)*	Cretaceous	*Acacia mucronata, A. melanoxylon, Pimelea axiflora*
	E. globulus (E. obliqua, E. cypellocarpa)	Cretaceous	as above
	E. ovata (E. obliqua, E. cypellocarpa)	Cretaceous	as above
Open-forest 15-28m high	*E. obliqua, E. globulus, E. cypellocarpa* VP	Cretaceous	*A. mucronata, A. verticellata, A. verniciflua*
	E. baxteri, E. obliqua, E. radiata VP	Tertiary	*Banksia marginata, Leptospermum juniperinum, A. verticellata*
Open-forest 15m high	*E. globulus* E. sideroxylon* VP	Cretaceous	*A. verniciflua, Pultenaea daphnoides, Goodenia ovata*
	E. aromaphloia, E. obliqua, E. radiata VP	Cretaceous and Tertiary	various
	E. sideroxylon, E. obliqua, E. cypellocarpa* VP	Tertiary	*A. verniciflua, P. daphnoides, Poa sieberana*
	E. obliqua (E. baxteri)	Tertiary	*B. marginata, Epacris impressa, Xanthorrhoea australis*
	E. viminalis (E. obliqua)	Quaternary sands	*Pteridium esculentum, Poa* spp., *Lomandra longifolia*
Woodland	*E. baxteri, E. nitida, E. obliqua* VP	Tertiary	*Leptospermum juniperinum, L. myrsinoides, B. marginata*
	E. kitsoniana (E. ovata, E. baxteri)	Tertiary	*Leptospermum juniperinum, Melaleuca squarrosa*

* = can form pure stands

and *E. ovata* near Anglesea, where some facies of the Tertiary deposits appear to be of higher fertility than normal or to accumulate nutrients through downslope movement.

Sclerophyllous shrub understories do occur on the Cretaceous but have a distinctly taller and more diffuse character than the heath-like understories on the Tertiary, this character being imparted by species such as *Acacia verticillata, Pultenaea daphnoides* and *Acacia mucronata*. The herbaceous component of the sclerophyll understories on the Cretaceous is also more prominent than in sclerophyll understories on the Tertiary, where, however, bracken is considerably more common. Broad-leaved shrub understories may be found on both substrates, but are naturally more extensive on the Cretaceous which includes most of the high rainfall country.

The Cretaceous core of the Otways exhibits an apparently moisture-related continuum of eucalypt communities. The set of eucalypts confined to the driest Cretaceous areas is *E. sideroxylon, E. radiata* and *E. aromaphloia* with *E. sideroxylon* generally in drier areas than the other two. *E. viminalis, E. globulus, E. cypellocarpa* and *E. obliqua* form a central set in putative order from dry to wet. *E. regnans* occupies the wettest areas, and the middle set overlaps with both extreme sets. Changes from one community to another are usually gradual, and recognized communities are probably points on a continuum. However, the three broad understorey types of grassy, sclerophyll shrub and broad-leaved shrub are often sharply distinct and jaggedly contiguous, suggesting that fire history may be of considerable importance in setting their boundaries. The *Poa*- and *Themeda*-dominated grassy understories are usually replaced by sclerophyll shrub understories with sparse suppressed grasses where the eucalypt canopy is opened and shrub germination encouraged by severe fire. However, a succession of ground fires will tend to reinforce the grassiness of the understorey, as will a lack of fire for a period greater than the relatively short lifespan of the understorey shrub species. Some shrub establishment that might occur even under the reduced light intensities of a mid-dense eucalypt canopy may be suppressed by the activity of both native and introduced herbivores who often produce a low, evenly-grazed, herbaceous sward.

Local inhabitants tell of much more extensive grassy forests in the past in areas where *Acacia verticillata* and *Goodenia ovata* now dominate the understorey. Grassy forest floors are now most common around holiday settlements and grazing lands where accidental and deliberate fires are still frequent.

There appears to be much more variation in the fertility of the soils on Tertiary deposits than in the soils on Cretaceous rocks, so generalizations on the sequence of eucalypts are not so easily related to precipitation. Well-drained sites on the Tertiary support low open *E. nitida* woodland in the driest situations, *E. nitida-E. baxteri* woodland in slightly wetter situations and *E. obliqua-E. aromaphloia-E. radiata* open-forests as moisture becomes even more abundant. Tall open-forests of *E. obliqua, E. globulus* and *E. viminalis* are found in the wettest areas. *E. sideroxylon* woodland is spatially restricted and difficult to fit within this sequence, its occurrence possibly being related to particular nutrient conditions as much as moisture availability. *E. ovata* and *E. kitsoniana* occur on the fringes of wet heaths in areas of impeded drainage, the latter possibly only where drought does not greatly inhibit growth in the dry season.

An interesting feature of the Otways vegetation is the widespread occurrence of mixed stands of eucalypts known to be capable of inter-breeding, such as *E. regnans-E. obliqua, E. cypellocarpa-E. globulus* and *E. obliqua-E. radiata*, whereas Pryor (1953) suggests that eucalypt species capable of interbreeding occur together only in ecotones or severely disturbed areas. One of the major problems raised by the present data is the width of range overlap that can still be considered ecotonal (Kirkpatrick 1975a) and further work is clearly needed.

The Otway Ranges and the South Gippsland Hills have identical Cretaceous geology and show other marked similarities. Although the South Gippsland vegetation is now largely destroyed, the remnants show the same relationships between eucalypts on the Cretaceous (only *E. sideroxylon* is absent), the same marked shifts and terminations on contact with the surrounding Tertiary deposits, and even the same pattern of geographic variation in *E. globulus* (Kirkpatrick 1975b). *Nothofagus cunninghamii* closed-forest occurs in both areas, as do communities dominated by *E. kitsoniana* on the Tertiary. However, the vegetation on the Tertiary areas surrounding the South Gippsland Hills differs in many respects from that found in the Otways (VLCC 1972) and there are interesting floristic differences in the closed-forest; most notably the lack of *Atherosperma* in the Otways and the absence of *Phebalium squameum* subsp. *squameum* in the South Gippsland Hills.

In general, the Otway Ranges are not strongly distinguished by floristic peculiarities. The only plant species endemic to the area is the little-known *Leptorhynchos gatesii*, of which the only collection is from 'dry hillsides at Lorne' (Willis 1957b). However, many species reach their extreme eastern or western limits in the Otways (see Beauglehole, Carr & Parsons 1977). One such species is *Acacia nanodealbata* whose range was significantly extended in the present work when it was found at low altitudes (less than 70 m) in the western Otways (e.g. at junction of Caroline Creek with Gellibrand River road). This south-central Victorian species was thought to be montane or sub-alpine except for the only previous Otways record at Lorne (Willis 1957a). Apart from the Lorne record, the species is apparently centred in the south-west Otways, where the closely related and otherwise widespread *A. dealbata* is apparently absent. The *A. nanodealbata* seen in the Otways differs from the type description (Willis 1957a) in its longer leaves (up to 15 cm), much more distant pinnae and non-glaucous stems. Clearly more work on its distribution and taxonomy is needed.

The Otways deserve strong consideration for a much extended system of reserves. The magnificent variety of the heaths, scrubs and forests, the lack of gross disturbance of much of the vegetation of the ranges and the scenic amenity of the juxtaposition of mountains, sea, heath, woodland and forest deserve more than accelerating extension of pine plantations, ugly coastal shack development and clearing of marginal land for farming.

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REFERENCES

ASHTON, D. H., 1958. The ecology of *Eucalyptus regnans* F. Muell.: the species and its frost resistance. *Aust. J. Bot.* 6: 154-176.

BEAUGLEHOLE, A. C., CARR, G. W. & PARSONS, R. F., 1977. A floristic check list of the Otways Region. *Proc. R. Soc. Vict.* 89:

CARR, G., 1970. Vegetation of the Parker River, Cape Otway region. Part 1. *Geelong Nat.* 7: 66-106.

GIBBONS, F. R. & DOWNES, R. G., 1964. A study of the land in south-western Victoria. *Victoria: Soil Conservation Authority Tech. Comm.* No. 3.

HALL, N., JOHNSTON, R. D. & CHIPPENDALE, G. M., 1970. *Forest Trees of Australia.* 3rd ed. Aust. Govt. Publishing Service, Canberra.

HARDY, A. D., 1905. Excursion to the Otway forest. *Vict. Nat.* 21: 149-156.

HOOKE, A. G., 1960. Excursion to Apollo Bay. Trees. *Ibid.* 76: 319.

HOWARD, T. M. & ASHTON, D. H., 1973. The distribution of *Nothofagus cunninghamii* rainforest. *Proc. R. Soc. Vict.*, 86: 47-76.

KIRKPATRICK, J. B., 1970. Some observations on the relative drought resistance of two eucalypt species near Aireys Inlet. *Vict. Nat.* 87: 184-185.

————, 1971. A probable hybrid swarm in *Eucalyptus. Silvae Genet.* 20: 157-159.

————, 1974. The numerical intraspecific taxonomy of *Eucalyptus globulus* Labill. (Myrtaceae). *Bot. J. Linn. Soc.* 69: 89-104.

————, 1975a. Natural distribution of *Eucalyptus globulus* Labill. *Aust. Geog.* 13: 22-35.

————, 1975b. Geographic variation in *Eucalyptus globulus* Labill. *Australia: Forestry & Timber Bureau Bull.* No. 47.

————, SIMMONS, D. & PARSONS, R. F., 1973. The relationship of some populations involving *Eucalyptus cypellocarpa* and *E. globulus* to the problem of phantom hybrids. *New Phytol.* 72: 867-876.

MARKS, G. C., FAGG, P. C. & KASSABY, F. Y., 1975. The distribution of *Phytophthora cinnamomi* in forests of Eastern Gippsland, Victoria. *Aust. J. Bot.* 23: 263-275.

PARSONS, R. F., 1966. Soils and vegetation at Tidal River, Wilsons Promontory. *Proc. R. Soc. Vict.* 79: 319-354.

————, & KIRKPATRICK, J. B., 1972. Possible phantom hybrids in *Eucalyptus. New Phytol.* 71: 1213-1219.

PARSONS, W. T., 1973. *Noxious Weeds of Victoria.* Inkata Press, Melbourne.

PRYOR, L. D., 1953. Genetic control in *Eucalyptus* distribution. *Proc. Linn. Soc. N.S.W.* 78: 8-18.

SPECHT, R. L., 1970. Vegetation. In *The Australian Environment.* Ed. G. W. Leeper. 4th Ed. CSIRO, Melbourne.

TURNER, J. S., ASHTON, D. H. & BIRD, E. C. F., 1968. The plant ecology of the coast. *Victorian Year Book.* 82: 1-7.

VICTORIA: GEOLOGICAL SURVEY, 1971. Queenscliff 1:250,000 geological map. Geological Survey of Victoria, Melbourne.

————, 1973. Colac 1:250,000 geological map. Geological Survey of Victoria, Melbourne.

VICTORIA: LAND CONSERVATION COUNCIL, 1972. Report on the South Gippsland Study Area (district 1). Land Conservation Council, Melbourne.

————, 1973. Report on the Melbourne Study Area. Land Conservation Council, Melbourne.

————, 1976. Report on the Corangamite Study Area. Land Conservation Council, Melbourne.

WEBB, L., 1968. The rape of the forests. In: *The Great Extermination.* Ed. A. J. Marshall. Panther Books, London.

WESTE, G., 1975. Coastal reserves. Their value and vulnerability. *Victoria's Resources.* 17. No. 2: 29-31.

———— & MARKS, G., 1974. Conservation of our landscape. Invasion by disease. *Ibid.* 16. No. 4: 13-15.

WILLIAMS, L. B., 1975. Why pines? *Ibid.* 17. No. 1: 6-10.

WILLIS, J. H., 1948. On the nature and distribution of "Moonah" (*Melaleuca pubescens* Schauer). *Vict. Nat.* 65: 76-84.

————, 1957a. Vascular flora of Victoria and South Australia. *Ibid.* 73: 149-160.

————, 1957b. Vascular flora of Victoria and South Australia. *Ibid.* 73: 188-202.

————, 1962. Land flora of Victoria. *Victorian Year Book.* 76: 1-36.

————, 1970. *A Handbook to Plants in Victoria.* Vol. I. 2nd ed. Melbourne Univ. Press, Melbourne.

————, 1972. *A Handbook to Plants in Victoria.* Vol. II. Melbourne Univ. Press, Melbourne.

9

TIMBER PRODUCTION IN THE OTWAY REGION

By L. B. Williams*

Abstract: The paper describes the native hardwood forests and the softwood plantations of the Otway Ranges. It traces the history of timber utilisation and discusses the present and potential significance of the region for timber production.

INTRODUCTION

The area of significance for commercial timber production comprises State Forest and associated forested freehold land in and adjacent to the main Otway Ranges between Anglesea and Princetown.

Approximately 100,500 ha have been dedicated as Reserved Forest and a further 27,700 ha are designated as Protected Forest. The Forests Commission is responsible for the control, management and protection of Reserved Forest. In Protected Forest the Commission's responsibilities relate mainly to the management and protection of the vegetation, although the land itself is under the control of the Department of Crown Lands and Survey.

Reserved Forest and Protected Forest together comprise State Forest as defined in the Forests Act 1958.

STATE FOREST MANAGEMENT OBJECTIVES

The management objectives for the Otway State Forest include:

(1) Protection of the forests and their associated vegetation and fauna from damage by wildfire and from injury from biological agencies.
(2) Provision of a continuing supply of hardwood sawlogs, pulpwood and other forest products at a level which is consistent with the growth of the forests.
(3) Protection of water catchments.
(4) Conservation of landscape values, wildlife habitat, flora and other environmental values.
(5) Provision of facilities for public recreation and education.
(6) Establishment of softwood plantations to augment wood supplies from the hardwood forests and to support a viable forest products industry based largely within the locality.

THE NATIVE HARDWOOD FORESTS

Eucalyptus species occurring naturally in the area are:

**E. regnans* F. Muell.—mountain ash
**E. obliqua* L'Hérit.—messmate.
**E. baxteri* (Benth.) Maiden and Blakely—brown stringybark.
**E. globulus* Labill.—southern blue gum.
E. st. johnii R. T. Baker—Victorian blue gum.
**E. cypellocarpa* L. Johnson—mountain grey gum.
**E. viminalis* Labill.—manna gum.
**E. sideroxylon* A. Cunn. ex Woolls—red ironbark.
E. radiata Sieber—narrow leaf peppermint.
E. nitida Hook—shining peppermint.
E. aromaphloia L. D. Prior and J. H. Willis—scent bark.
E. ovata Labill.—swamp gum.
E. goniocalyx F. Muell. ex. Miq.—long leaf box.
E. kitsoniana Maiden—bog gum.
**Species of significance for timber production.*

Other native species which have some potential for specialised timber products include:
Acacia melanoxylon R. Br.—blackwood.
Nothofagus cunninghamii (Hook) Oerst.—myrtle beech.
Phebalium squameum (Labill.) Engl.—satin box.

FOREST TYPES

Three broad vegetation types based on potential timber productivity have been recognised for wood production planning purposes. The locations of these types are shown in Fig. 1.

(1) *Mountain forest:*

This is defined as all mountain ash forest and forests of other species having a mature stand height exceeding 40 m. This forest type coincides closely with the

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boundary of understorey species such as *Olearia argophylla* (Labill.) Benth. (musk) which are favoured by high rainfall, and it corresponds roughly with the 1,500 mm rainfall isohyet on the northern slopes of the ranges and the 1,150 mm isohyet on the southern slopes.

The main eucalypt species are mountain ash, messmate, manna gum, swamp gum, southern blue gum and mountain grey gum.

The trees in the virgin mountain forests were very large and early photographs of Beech Forest show trees with girths well in excess of 10 m. Record exists of one mountain ash tree which was over 100 m tall.

About 41,000 ha of mountain forest are within State Forest (Reserved Forest 37,000 ha and Protected Forest 4,000 ha), and this area includes some 11,000 ha of dense regrowth forest which resulted mainly from the extensive 1919 forest fires. This regrowth is of considerable importance for future timber production. The area of mountain forest in private ownership is not large; however there are some 2,600 ha in areas controlled by water supply authorities in the headwaters of Gellibrand River and Olangolah Creek (Colac water supply) and Arkins Creek (Warrnambool water supply).

(2) *Foothill forest:*

This is defined as all forest with a mature stand height from 15 m to 40 m.

The main eucalypt species are messmate, mountain grey gum (mainly on the northern side of the main Otway ridge), southern blue gum (mainly on the southern side of the ridge), brown stringybark, manna gum and narrow leaf peppermint. A limited occurrence of red ironbark occurs in the relatively dry forest adjacent to Aireys Inlet.

There are about 61,000 ha of foothill forest type in State Forest in the area, and there are also substantial areas under private ownership.

(3) *Low forest and heathland:*

This is defined as all areas in which the mature stand height is less than 15 m.

Although this type covers about 22,000 ha of State

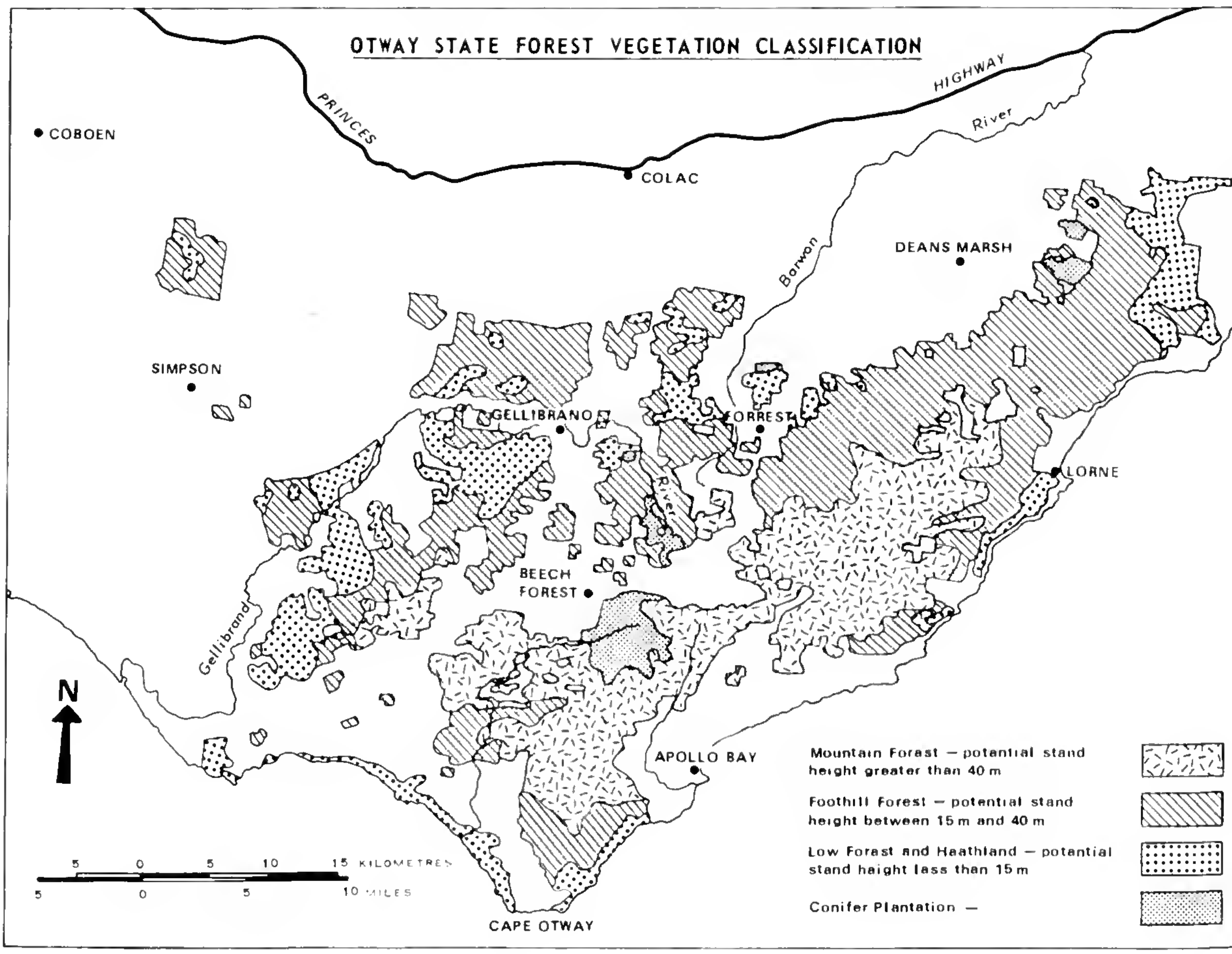

FIG. 1

Forest it is of little value for timber production. It falls into two main categories:
(i) dense but stunted tree cover on exposed coastal situations, and
(ii) predominantly heathland with a relatively open cover of stunted trees on poor soils which have developed in many areas on Tertiary sediments.

HISTORY

The present hardwood forests are the remnants of magnificent forests which, prior to settlement, covered practically the whole of the Otway area. They originally comprised some 35,000 ha distributed as 230,000 ha in the County of Polwarth and 120,000 ha in the County of Heytesbury (Forests Commission 1963).

Timber utilisation has been an important element in the history of the Otways, and the production of blue gum sleepers for Victorian Railways from Apollo Bay and Loutit Bay was recorded as early as 1850 (Thornley 1974). The timber was transported by sea, which was the only link with the outside world.

Lack of access presented a problem for both settlement and timber utilisation right from the earliest days of development. In winter access was particularly difficult due to the high rainfall and the intractable nature of the Otway mud, characteristics which have made the development of wet weather land transport links both difficult and costly to the present time.

By 1858 a steam-powered sawmill had been constructed at Apollo Bay, and several boom years of timber production in the area followed. However by 1865 production had declined due to the completion of the railway contracts.

The timber industry in the Otways has been characterised by periods of boom and depression, and it was not until the 1880s that there was a resurgence of sawmilling activity. In 1882 a large sawmill commenced operations at the Elliott River, to the south-west of Apollo Bay, and continued operating until the 1920s. On the inland side of the ranges sawmills were established at Barramunga, to the south of Forrest. The opening in 1891 of the broad gauge Birregurra to Forrest railway gave a great boost to sawmilling in this area, and extensive networks of forest tramlines were developed which linked with the Forrest railhead (Light Railway Research Society 1974). Sawmilling development also took place at Barwon Downs.

In the latter part of the nineteenth century there was considerable emphasis on opening up the Otways for settlement, and much prime forest land was alienated. An example of this was the Beech Forest area, made available for settlement in 1886.

The policy was deplored by a number of officials who recognised the value of these areas for timber production. Thus, in a report for the Government on the Cape Otway forests F. D'A. Vincent (1887) was critical of the release of forested land for settlement. He reported: 'The country is unsuitable for cultivation being extremely hilly and broken' and 'There is every reason to suppose that much of the land has been taken up for the sake of the timber . . . .

Despite strong recommendations in 1897 by the then Surveyor-General (S. K. Vickery) and the Inspector of Forests (J. Blackburne) 'that all unalienated lands in the Otway district, as indicated, together with any allotments relinquished or forfeited, should be incorporated in this forest' further alienation was permitted, and during the period 1899 to 1904 the Benwerrin and Wymboliel lands were thrown open for selection in the Parish of Lorne.

The narrow gauge railway which was completed from Colac to Beech Forest in 1902 and extended to Crowes in 1911 marked the intensification of sawmilling and paling splitting in the western part of the Otway Ranges. Where previously the produce had been carted over tracks to Colac or shipped from Apollo Bay, the railway in the ranges now provided an outlet for larger volumes of timber.

Under the Forests Act of 1907 a Forests Department was constituted on 4 February 1908. The new Department commenced a long term campaign to halt the unwise alienation of forested Crown land, and in its Annual Report of 1910 it stated: 'It will be an ill day for Victoria if the partially denuded forest lands of Central and Eastern Otway are permitted to be sacrificed to a few families of selectors who do not now improve properly or till successfully the lands they occupy. Indeed a marked feature of this district is the wilderness of inferior growth and scrub, the result of partial clearing by fire, which is taking the place of the great forest of blue gum and ash which once occupied it'.

The Forests Act of 1907 defined areas of permanent forest in the Otways with a total area of 78,700 ha, but the Act made provision for revision of the area where any of this land was required for settlement during the ensuing five years. 35,150 ha were so excised by 1911. The Department then reported: 'Although officers of Lands and Forests Departments who are charged with the duty of recommending excisions and additions listed large areas of valuable timber to take the place of those excised, nothing has been done to proclaim any new reserves.'

In the Forests Department's Annual Report of 1911 it was stated: 'Attempts have been made during the year past, and successfully resisted, to secure further alienation of the scattered remnants of the one time magnificent Otway Forest which when bounded by the Gellibrand River and Bass Strait was by far the finest reserve in Victoria. A great deal of employment is now being given to timber cutters on the central tableland and the returns from timber there as a rule are much better than from root crops or grazing.'

In February 1919 devastating fires swept the Otways and further decimated the forests. These caused property losses from which many settlers were unable to recover, and so they left their farms. A direct result of the holocaust of 1919 was the prolific regeneration of the high quality forests of the area, and abandoned farmland carrying belts of this regeneration was purchased by the Forest Commission.

Substantial areas of abandoned farmland were also purchased for reforestation by the Commission during the 1920s in the Parish of Olangolah. It is noteworthy that, despite agitation for further excisions in 1924, approximately 4,000 ha of previously alienated land were re-dedicated as permanent forest so that nearly 90% of the original 1907 reservation was by 1926 retained as forest reserve.

However, after the first World War, settlement in the western portion of the County of Heytesbury was intensified and the area of forested Crown land was reduced from 120,000 ha to 36,000 ha.

The post-war period also coincided with a timber boom and in 1922 twelve sawmills were working full time along the Beech Forest to Crowes railway. The boom was shortlived, however, and by 1931 shortage of accessible timber combined with the general economic depression forced the closing of most of the mills.

Some forestry projects of lasting benefit were undertaken during the 1930s using unemployment relief labour. These included the cutting of forest access tracks, thinning and timber stand improvement works in the native forests, and the commencement of the Aire Valley softwood plantation.

In 1939 the forests of the area were again swept by major fires which were largely confined to the northerly aspects of the ranges. These destroyed some of the young age classes and caused deterioration of the older trees on the areas burnt.

After the second World War the housing boom caused a great demand for timber, and the Commission embarked on a major road construction programme in the Otways to make prime stands of milling timber accessible for utilisation by modern tractor and motor truck harvesting methods in place of the earlier winch and tramline. The last timber tramway, which closed in 1948, was Henry's Mt. Sabine line which carried timber from bush sawmills to the Forrest-Apollo Bay road.

Most of the major road construction to tap timber supplies was completed by 1959. The roads constructed included the Seaview, Aire Valley, Old Bay, Binns, Calder Ridge and Parker Ridge roads in the western Otways, and the Grey River, Kaanglang and Mt. Sabine-Benwerrin roads in the eastern Otways.

The annual cut of hardwood sawlogs from State Forest was approximately 110,000 m³ during the late 1950s.

In 1952 some 28,000 ha of forested land in the County of Heytesbury was assigned to the Soldier Settlement Commission for the development of farming lands. An estimated 8,000 ha of this was considered suitable for retention as permanent forest reserve. However representations for such reservation were not successful.

The late 1950s also saw emphasis being given to the environmental and recreational values of the forests and a number of scenic reserves were set aside, including those at the Grey River (48 ha), Calder River (37 ha) and Maits Rest (74 ha). Further extensive reservations for scenic and reercational purposes were made in 1970 and 1972 with the declaration of the Angahook and Lorne Forest Parks, of some 2,900 ha and 3,680 ha respectively.

PRESENT MANAGEMENT

Present hardwood timber harvesting is aimed at using as much as possible of the old growth forests outside Forest Parks and special reservations, and then harvesting the second growth forests which have resulted from earlier timber extraction and from fires, especially the 1919 fires.

The annual authorised cut of 50,000 m³ of hardwood sawlogs from State Forest provides supplies to 12 sawmills at Colac, Apollo Bay, Gellibrand, Barwon Downs, Birregurra and Geelong.

A similar quantity of pulpwood is also estimated to be available, and Smorgons Consolidated Industries Pty. Ltd. is currently taking a substantial part of the available pulpwood for its packaging paper and paperboard plant in Melbourne.

The development of this pulpwood market has led to more efficient forest management. The utilisation of pulpwood facilitates the economic procurement of sawlogs from defective trees, as the parts of the trees which are unsuitable for sawlogs usually contain material suitable for pulpwood. This reduces the volume of forest residue left after logging, and enables cheaper and more effective regeneration operations.

The continued supply of optimum quantities of timber from the hardwood forests of the Otways depends on the transfer of harvesting operations from the rapidly dwindling areas of old growth forest to the younger regrowth forests, and especially to those which resulted from the 1919 fires.

The young trees, saplings and regeneration already on site form the basis of timber utilisation for at least the next 60 years, and the regeneration developed

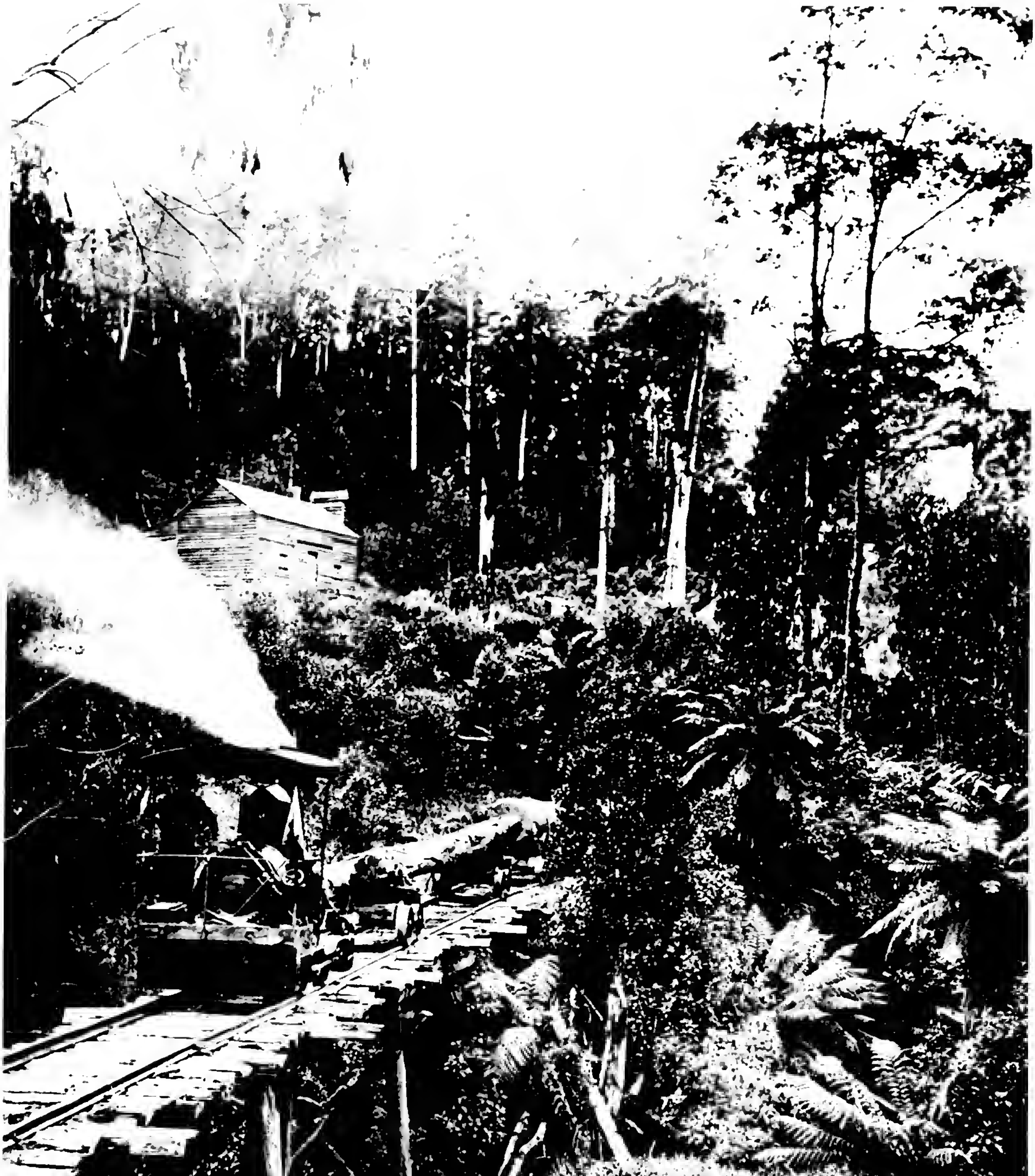

PLATE 13
Tramways were the main means of transporting logs and timber from the forest prior to the Second World War. The one shown was part of J. H. Henry's 3′ 6″ gauge line south of Forrest.

following the future harvesting of these trees, and from the reforestation of non-productive areas, will provide the basis for timber production thereafter.

The main requirements for successful seedling establishment are a receptive seed bed, which favours germination and promotes rapid growth, and an adequate seed supply.

In the mountain forest harvesting and regeneration is normally achieved by the clear felling of defined cutting areas, so that operations are concentrated and the new forest is established in conditions of suitable seed bed with maximum sunlight and without competition from an overstorey. This method is essential for such species as mountain ash where intense burning of the site is necessary to stimulate the natural regeneration process of the species.

Rapid re-establishment of understorey species following logging is a feature of the Otway mountain forests and this has often precluded satisfactory regeneration operations. Acceptable chemical techniques have now been developed to suppress the invading scrub species and thus facilitate the burning and subsequent seeding operations.

As well as mountain ash, a local provenance of messmate known as 'Otway messmate' has proved to be a particularly fast growing variety (Pederick 1974), and is used in reforestation operations in the mountain forest zone.

The regeneration of the foothill forests is more easily achieved, and harvesting is normally carried out with the retention of regulated numbers of overwood trees which supplement the seed source on the ground. This method results in adequate regeneration in this forest type. This system of management also enables selected trees to be retained for further growth, or for fauna habitat, and to soften the visual effect of harvesting operations.

POTENTIAL PRODUCTION

Due to the effects of early unregulated timber exploitation, abortive settlement schemes, wildfires, and the difficulty of establishment of regeneration in the mountain forests, the Otway hardwood forests are not yielding anywhere near their high potential for timber production.

The mountain forests are potentially capable of producing wood fibre at a mean annual increment rate of the order of 15 to 20 m^3 per ha, and such yields could eventually be expected from the gentler slopes of the main Otway ridge and its associated spurs, and the catchment of the Aire River, where development of intensively managed forests for timber production is a practicable strategy.

The foothill forests are less productive and a mean annual increment of the order of 3 to 4 m^3 per hectare is expected from the better-class managed forests.

SOFTWOOD PLANTATIONS

General

Commercial softwood plantation projects in the Otways have been a mixture of successes and failures. The early coastal plantation projects by the Commission at Waarre, near Port Campbell (1919 to 1936), and at Anglesea (1924 to 1934) were planned in accordance with the philosophy of the day, whereby only land which was unfit for settlement and unsuitable for hardwoods was considered for plantations. Unfortunately these areas, by and large, also proved unsuitable for softwoods.

However the plantings commencing 1930 on abandoned farmlands at Aire Valley were on high quality forest sites with high rainfall, and outstanding plantations have developed in this area.

The more recent plantings in the Gellibrand locality, and in the eastern Otways have been on satisfactory sites and overall in the Otway area there are now over 4,000 ha nett of successful State softwood plantations, and this area is planned for continued expansion to build up a total plantation resource of some 8,000 ha. This is designed to provide sawlogs for the local sawmilling industry, and veneer logs, pulpwood and round posts and poles for preservation.

In recent years there has also been an increasing interest in plantation development by private wood-based industries and the area of young private plantations in the Otways is currently about 1,400 ha.

Species

The main species used in the State plantation programme were:

Pinus radiata D. Don—radiata pine
P. nigra Arnold—Corsican pine
P. pinaster Ait.—maritime pine
P. muricata D. Don—bishop pine
P. ponderosa Dougl.—western yellow pine
Pseudotsuga menziesii (Mirb.) Franco—douglas fir
Picea sitchensis (Bong.) Carr—sitka spruce
Sequoia sempervirens (D. Don) Endl.—Californian redwood

History

(1) *Waarre Plantation:* Plantating commenced in 1919. However a fire destroyed most of the pre-1926 plantings. The effective area of the plantation in 1955 was 570 ha comprising maritime pine (310 ha), radiata pine (209 ha), bishop pine (34 ha), and Corsican pine (17 ha).

Growth over most of the plantation was unsatisfactory due to soil deficiencies, drainage problems and coastal exposure. A marked exception to this, how-

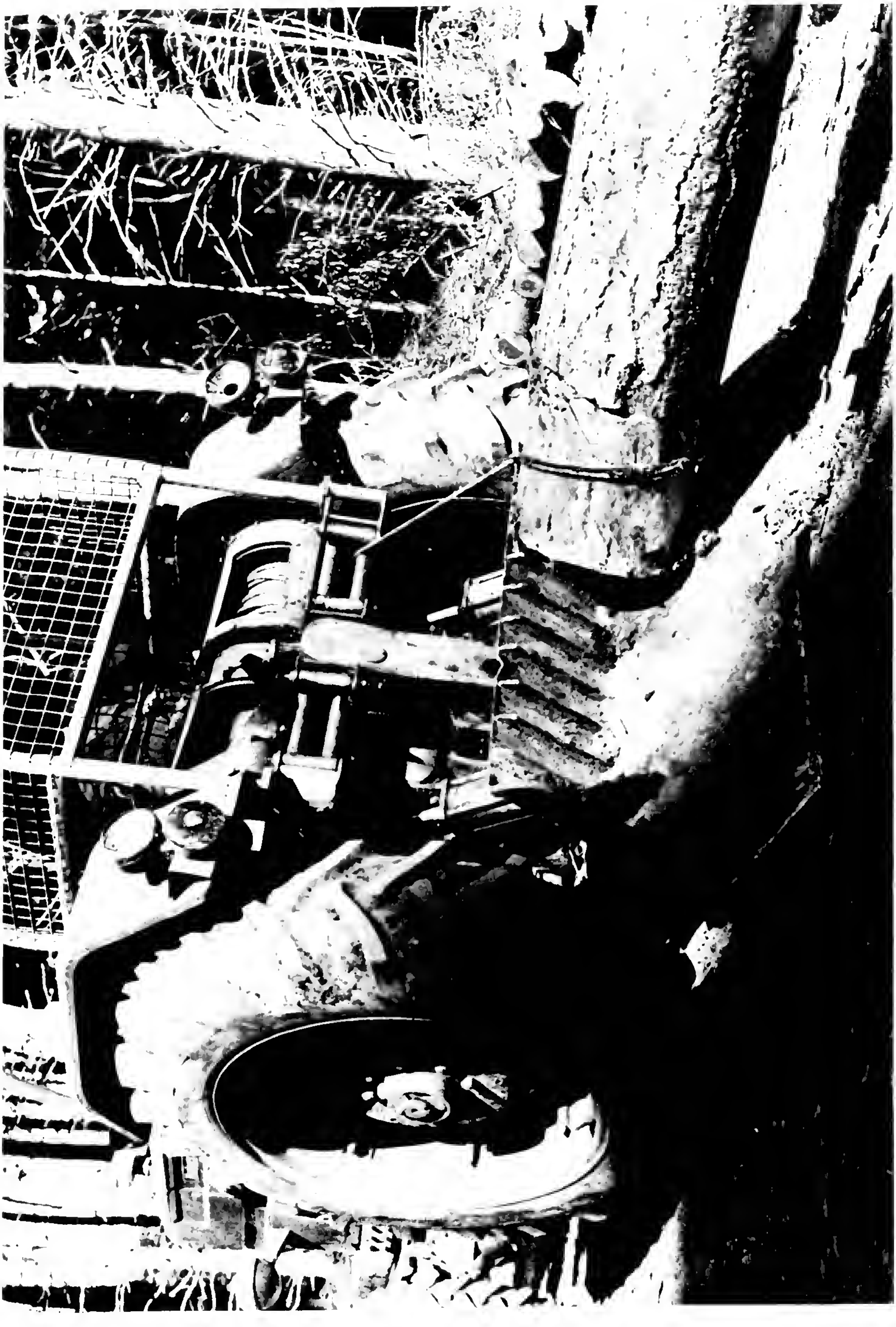

PLATE 14
Modern machinery is now essential for economical timber harvesting and transport. This tractor, fitted with winch and skid pan, is hauling logs from the Aire Valley plantation.

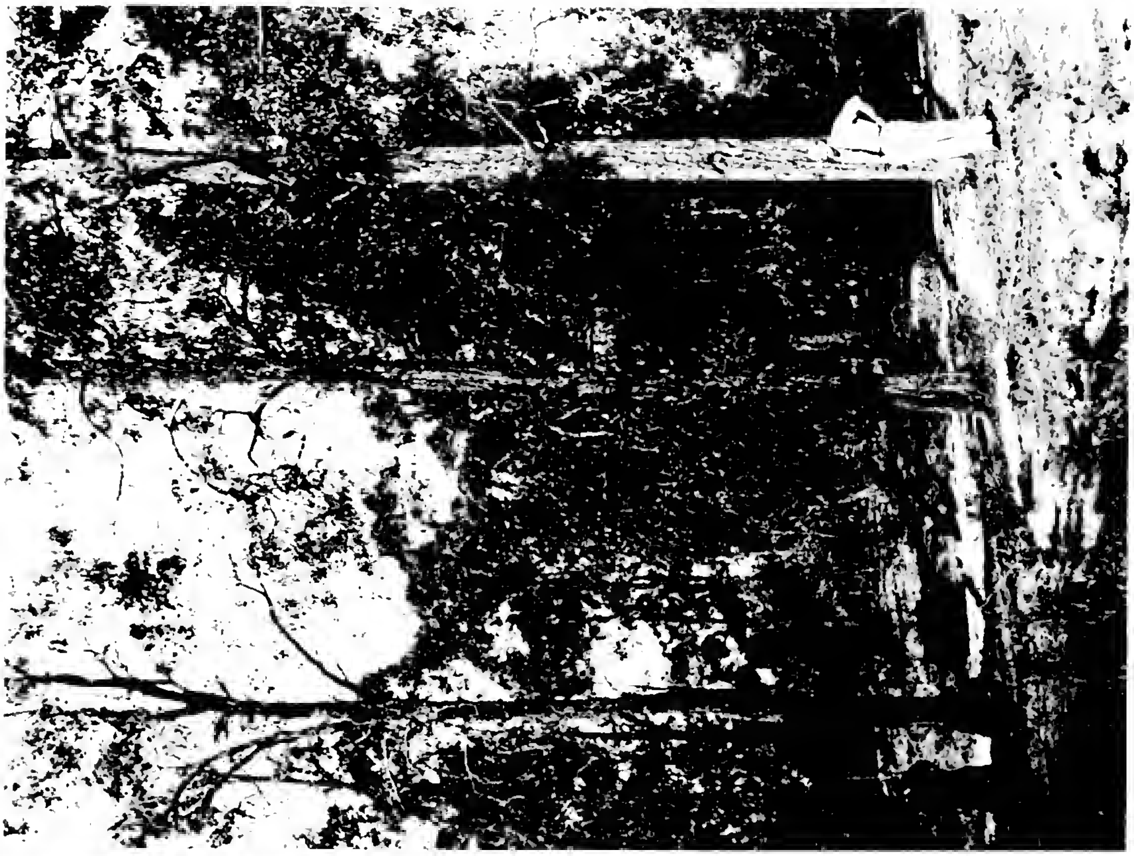

PLATE 15

(*Left*) Mountain ash reaches optimum development in the high rainfall mountain forest on and adjacent to the main Otway ridge.

(*Right*) Fine stands of red ironbark occur in the drier areas near Aircys Inlet.

ever, was some 25 ha of radiata pine growing on limestone on the north side of the Sherbrook River.

In 1963 it was decided to abandon the area as a commercial plantation, to salvage most of the merchantable produce over a ten year period, and to leave a park-like area of the better quality pines for shelter and recreational use adjacent to the Sherbrook River. This program has now been carried out.

(2) *Anglesea Plantation:* Planting commenced in 1924 and continued until 1933. At this time the plantation was over 1,760 ha nett area and comprised mainly radiata pine (1,340 ha) and maritime pine (360 ha).

By 1929 it was realised that there were serious growth problems and in 1934 it was decided to cease further plantings in all coastal plantations, including Anglesea.

In the late summer of 1936 fires swept a considerable portion of the plantation and virtually destroyed the area as a viable plantation unit.

Subsequent research work has shown that commercial timber could be grown on much of the area if appropriate site preparation and phosphate fertilisers are used. However the area is no longer State Forest.

(3) *Aire Valley and Websters Hill Plantations:* Planting at Aire Valley commenced in 1930 on former farm land which had been acquired by the Commission.

In line with Commission policy at the time, the most favoured parts of this 1,800 mm rainfall site were planted with douglas fir, sitka spruce, bishop pine, western yellow pine, and Californian redwood, with a protective fringe of radiata pine, which at the time was regarded as an inferior species, on the upper slopes and ridges. Planting was largely completed by 1939. The current nett planted area is about 2,000 ha, mainly of radiata pine (47%), douglas fir (23%), and Corsican pine (15%).

Clear felling commenced on a moderately large scale in 1966 and currently averages about 40 ha per year. Clear felled areas are replanted with radiata pine almost exclusively, as this is by far the most productive species, achieving a mean annual increment on the better sites of over 30 m^3 per ha.

The nearby Websters Hill plantation was commenced in 1963 and now has a nett area of 530 ha, mainly of radiata pine.

At Aire Valley thinning operations in radiata pine, which have been carried out intermittently since the early 1940s, have been frustrated by the broken topography and difficult access and weather conditions, and even the clear felling proved difficult until the introduction of a high lead cable system of logging.

The current authorised cut from the plantation is 34,000 m^3 of sawlogs and peeler logs, together with additional pulpwood and preservation material.

(4) *Eastern Otways Plantation:* Plantation development has been taking place since 1968 in two locations, one near Forrest and the other near Bambra. Over 1,000 ha have been established and planting is planned to continue at 120 ha annually. Utilisation has not yet commenced.

Potential Production

The mean annual increment of potentially merchantable wood from existing radiata plantations in the Otways is of the order of 20 m^3 per hectare. Yields of at least 140,000 m^3 of sawlogs, veneer logs, pulpwood, and round posts and poles for preservation can be expected from a balanced series of age classes in the completed plantation resource of 8,000 ha.

FUTURE TIMBER PRODUCTION FROM THE OTWAY FORESTS

The Otway forests are of importance for supplying many community needs, and particularly water, recreation and timber. The timber production is important from both the overall Victorian and the local points of view.

In the Victorian context the Otway State Forest includes about 4% of the State hardwood reserves and over 6% of the State softwood plantations. On the local scene it provides the basis for the important and growing timber-based industries in the area.

Forest management practices have been developed to enable timber production to take place in a manner which is compatible with most other uses of the forest, and it is anticipated that timber production will continue to be a legitimate and important use of much of the land within the Otway Ranges.

ACKNOWLEDGMENTS

I am indebted to a number of my colleagues in the Forests Commission's Division of Forest Management for assistance in preparing this paper.

REFERENCES

Carr, G. W., 1971. *Vegetation of the Cape Otway-Parker area.* Supplement to *Geelong Naturalist* Vol. 8, No. 1.

Cowley, R. D., 1971. *The Otway forest land use report.* Victorian Forests Commission report, 69/1885, (unpubl.).

Department of State Forests (Victoria). Annual reports from 1909 to 1918. Government Printer, Melbourne.

Light Railway Research Society of Australia, 1974. *Tall timber and tramlines.* Booklet published March 1974, 60 pp.

Forests Commission (Victoria), 1963. *Statement of forest history of Otways hill country.* Departmental report 63/299 (unpubl.).

FORESTS COMMISSION (Victoria). Annual reports from 1919 to 1974. Government Printer, Melbourne.

PEDERICK, L. A., 1974. Genetic variation in *Eucalyptus obliqua* with special reference to Otway messmate. *Forests Commission, Victoria, Research Report No. 53* (unpubl.).

THORNLEY, A., 1974. Otway settlement. *Investigator*, Sept. 1974.

10

A FLORISTIC CHECK-LIST OF THE OTWAY REGION, VICTORIA

By A. C. Beauglehole*, G. W. Carr** and R. F. Parsons**

This paper presents a check-list of the vascular plant species found in the Otway Region. It is based largely on previously unpublished field work, supplemented by reliable published and unpublished records as shown in the check-list heading and includes also Beauglehole and Finck (1967) and Carr (1971) updated where necessary in the light of more recent knowledge. As a number of records in Adcock (1895) appear certain to be from the Basalt Plains and elsewhere, his list has not been used here.

The area covered is made up of 8 Descriptive Blocks from the Corangamite Study Area (see check-list heading) plus part of the Torquay Block of the Melbourne Study Area as far to the north-east as a line joining Bells Beach with Wurdiboluc Reservoir (see Victoria: Land Conservation Council 1973, 1976 for definition of Blocks). Thus the study area stretches from Port Campbell National Park and its surroundings in the west to just past the Anglesea River in the east. No Basalt Plains country is included.

The field work was concentrated mainly on Public Land and records are presented partly in terms of the Descriptive Blocks mentioned above. To indicate as accurately as possible the conservation status of every species, care has been taken to distinguish those species at present known only from private property in the area. Very broad abundance categories indicating approximately how many plants of the species were seen in total in any given Block during the course of the work are as follows: *very common* = seen in thousands, *common* = seen in hundreds, *rare* = seen in dozens, *very rare* = less than two dozen. Certain abundant species are nevertheless confined to restricted colonies of a few square metres. Where no entry has been made in any of the Block columns, the species is known from the study area without precise locality.

Nomenclature follows Wakefield (1975) for Pteridophyta, Vickery (1970) for *Poa*, Amor and Miles (1974) for introduced *Rubus* spp., Aston (1973) for aquatics and Willis (1970, 1972) for all other species unless species authors are given. *Thelymitra* sp. and *Prasophyllum* sp. (from Anglesea) are the taxa formerly incorrectly referred to as *T. aristata* and *P. nigricans* respectively (George 1971). *Eucalyptus* aff. *cypellocarpa* refers to intermediates between this species and *E. goniocalyx* (see Parsons, Kirkpatrick & Carr 1977). Since the list was prepared it has been realized that the name *Montia australasica* should be replaced by *Neopaxia australasica* (Hook.f.) O. Nilss. and the name *Marianthus procumbens* should be replaced by *Rhytidosporum procumbens* (Hook.) F. Muell. (McGillivray 1975).

For groups where nomenclature in general follows Willis (1970, 1972), more recent taxonomic revisions necessitate some name changes. These are listed here in pairs with the name used by Willis (1970, 1972) listed second: *Acacia genistifolia* — *A. diffusa*, *Acetosella vulgaris* — *Rumex acetosella*, *Arthrochilus huntianus* — *Spiculaea huntiana*, *Bedfordia arborescens* — *B. salicina*, *Calochilus herbaceus* — *C. saprophyticus*, *Centaurium tenuiflorum* — *C. pulchellum*, *Empodisma minus* — *Calorophus lateriflorus*, *Gnaphalium gymnocephalum* — *G. japonicum*, *G. sphaericum* — *G. involucratum* (in part), *Hibbertia empetrifolia* — *H. astrotricha*, *Juncus kraussii* — *J. maritimus*, *Leporella fimbriata* — *Leptoceras fimbriatum*, *Luzula meridionalis* — *L. campestris* (in part), *Microlepidium pilosulum* — *Capsella pilosula*, *Paracaleana minor* — *Caleana minor*, *Parahebe derwentiana* — *Veronica derwentiana*, *P. perfoliata* — *V. perfoliata*, *Paspalum paspalodes* — *P. distichum*, *Patersonia occidentalis* — *P. longiscapa*, *Phalaris aquatica* — *P. tuberosa*, *Phragmites australis* — *P. communis*, *Pterostylis plumosa* — *P. barbata*, *Scirpus marginatus* — *S. antarcticus*, *S. pungens* — *S. americanus*, *Sisyrinchium pulchellum* — *Libertia pulchella*, *Solanum opacum* — *S. nodiflorum*. In some cases these changes only necessarily apply to material from within the present study area. The species listed here as *Thelymitra* sp. (formerly called *T. aristata*) is now known to be *T. megcalyptra* Fitz.

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Through space limitations only a few plant community categories could be shown. However, some attempt is made to separate records in areas geologically Tertiary where soils are usually infertile, highly acidic and sandy, from records in Cretaceous areas where soils are generally more fertile and heavier-textured. These soil differences are associated with floristic differences, Tertiary areas usually having more sclerophyllous species than Cretaceous ones. However, community T (see check-list heading) includes some non-sclerophyllous, more or less grassy understories from both *Eucalyptus sideroxylon* stands on relatively fertile Tertiary areas and from *E. viminalis* stands on Quaternary sands (see Parsons, Kirkpatrick & Carr 1977). Communities H and S are both from Tertiary areas.

From the study, more detailed distributional and community data are available for each species than can be printed here. Complete floristic lists were made from about 35 separate areas, each subdivided into component plant communities. If finance were available the data could at least be presented in terms of grid areas bounded by 10 minutes of latitude and longitude, and this would be highly desirable in terms of conservation and land utilization strategy (Churchill and de Corona 1972).

The check-list records 1099 vascular plant species; 844 native and 257 naturalized aliens* (presumed hybrid taxa excluded in all cases). This survey records as new for Victoria *Deyeuxia decipiens* (F. Muell.) J. W. Vickery, previously known from New South Wales and Queensland, *Stipa tenuiglumis* Hughes previously known from South Australia, as well as the South American *Plantago australis* Lam. as a naturalized alien (representative specimens held at the National Herbarium of Victoria are A. C. Beauglehole Nos. 43909 and 21412 and G. W. Carr No. 1097 respectively). *P. australis* is also known as recent collections from both Wilsons Promontory and Tasmania (Dr. B. G. Briggs personal communication). Four garden escapes are also recorded as naturalized for the first time.

In all, 47 species of native plants reach the absolute western-most limit of their distribution in the area. 27 of these (including 12 ferns) are species characteristic of wet forest (*Nothofagus* closed-forest or tall open-forests of the *Eucalyptus regnans* type); this is in keeping with the fact that the Otways region is the furthest west in the state where recorded mean annual rainfall exceeds 119 cm (47 in.). In contrast, only 18 species reach their easternmost limits in the area, including 6 coastal species and 7 heath species.

It can be seen from the check-list that specimens were collected of *Poa, Deyeuxia* (two separate taxa), *Caladenia, Galium* and *Olearia* which cannot at present be determined to species level; some at least represent undescribed taxa. In addition an unresolved, robust grass species has been found near Cape Otway. Clearly much more study is needed before the floristics of the Otway region are clearly understood.

We gratefully acknowledge Dr. L. A. S. Johnson and staff of the New South Wales National Herbarium for identification of difficult taxa within the families Poaceae, Cyperaceae, Juncaceae, Plantaginaceae and Rubiaceae, Mr. R. J. Chinnock, Herbarium of South Australia, for identification of some ferns and Dr. J. H. Willis for assistance over a long period. We are grateful to the following for valuable orchid data: Mr. G. A. Barfoot, Mr. and Mrs. W. Mathieson and family, Mr. B. McDonald, Mrs. F. Negredo, Mr. I. Whytcross and Mr. G. R. Young. A.C.B. thanks the Land Conservation Council of Victoria for financial support.

*Since the list was prepared, *Toxanthes muelleri* (Block O, vr) and *Scirpus subtilissimus* (Block C,r) have been recorded.

REFERENCES

Adcock, G. H., 1895. Census of plants from the Cape Otway forest. *Geelong Nat.* 5.

Amor, R. L. & Miles, B. A., 1974. Taxonomy and distribution of *Rubus fruticosus* L. agg. (Rosaceae) naturalized in Victoria. *Muelleria* 3: 37-62.

Aston, H. I., 1973. *Aquatic Plants of Australia*. Melbourne Univ. Press, Melbourne.

Beauglehole, A. C. & Finck, E. W., 1967. Indigenous vascular flora of Port Campbell National Park. Victoria: National Parks Authority (mimeo.)

Carr, G. W., 1971. Vegetation of the Cape Otway-Parker River region — Part 3. *Geelong Nat.* 8 (Suppl.): 1-9.

Churchill, D. M. & De Corona, A., 1972. *The Distribution of Victorian Plants*. Royal Botanic Gardens, Melbourne.

George, A. S., 1971. A check-list of the Orchidaceae of Western Australia. *Nuytsia* 1: 166-196.

Henderson, R. J. F., 1974. *Solanum nigrum* L. (Solanaceae) and related species in Australia. *Contrib. Qld. Herb.* No. 16.

McGillivray, D. J., 1975. *Billardiera* Sm. and *Rhytidosporum* F. Muell. (Pittosporaceae) in New South Wales. *Telopea* 1: 55-57.

Nicholls, W. H., 1933. Orchid notes and new records. *Vict. Nat.* 49: 229-230.

————, 1940. Some orchid notes. *Ibid.* 57: 83-84.

————, 1942. An interesting *Caladenia*. *Ibid.* 58: 178-180.

Parsons, W. T., 1973. *Noxious Weeds of Victoria*. Inkata Press, Melbourne.

Parsons, R. F., Kirkpatrick, J. B. & Carr, G. W., 1977. Native Vegetation of the Otways Region. *Proc. R. Soc. Vict.* 89:

Specht, R. L., 1970. Vegetation. In *The Australian Environment*. Ed. G. W. Leeper. 4th ed. CSIRO, Melbourne.

Vickery, J. W., 1970. A taxonomic study of the genus *Poa* L. in Australia. *Contrib. N.S.W. Nat. Herb.* 4: 145-243.

VICTORIA: LAND CONSERVATION COUNCIL, 1973. Report on the Melbourne Study Area. Land Conservation Council, Melbourne.

———, 1976. Report on the Corangamite Study Area. Land Conservation Council, Melbourne.

WAKEFIELD, N. A., 1975. *Ferns of Victoria and Tasmania*. 2nd ed. revised by J. H. Willis. Field Naturalists Club of Victoria, Melbourne.

WILLIAMSON, H. B., 1928. Easter camp-out, excursion to Forrest. *Vict. Nat.* 45: 11-13.

WILLIS, J. H., 1948. On the nature and distribution of 'Moonah'' (*Melaleuca pubescens* Schauer). *Ibid.* 65: 76-84.

———, 1957. Vascular flora of Victoria and South Australia. *Ibid.* 73: 149-160, 188-202.

———, 1970. *A Handbook to Plants in Victoria.* Vol. I, 2nd ed. Melbourne Univ. Press, Melbourne.

———, 1972. *A Handbook to Plants in Victoria.* Vol. II, Melbourne Univ. Press, Melbourne.

THE CHECK-LIST (pp. 102-121)

vc = very common, **c** = common, **r** = rare, **vr** = very rare, **+**= record for which abundance not known. Abundance symbols underlined = known only from private property, abundance symbols in brackets = not known whether record from public land or private property.

* = naturalized alien, **W** = species reaches westernmost limit in area, **E** = species reaches easternmost limit in area, **N** = noteworthy record; either isolated or rare in Victoria or unusual form, **A** = first record of species as naturalized alien in Victoria, **X** = presumed hybrid.

Block symbols: **H** = Heytesbury, **C** = Carlisle, **R** = Aire River, **O** = Cape Otway, **T** = Tanybryn, **P** = Pennyroyal, **B** = Birregurra, **S** = Salt Creek, **A** = Anglesea (Torquay Block).

Community symbols: **N** = *Nothofagus* closed forest and *Eucalyptus* open-forest more than 40 m high, **F** = open-forest less than 40 m high on Cretaceous, **T** = open-forest less than 40 m high on Tertiary sediments or Quaternary sands, **H** = shrubby woodland or heath, **C** = coastal complex, **M** = salt marsh, **W** = swamps, ponds, watercourses, rivers, soaks, **S** = *Leptospermum juniperinum* — *Melaleuca squarrosa* closed-scrub (records from Aire River and Cape Otway Blocks only), **D** = disturbed; roadsides, clearings, etc.

Data sources other than present authors: **1 = J. Agar,** personal communication (p.c.), 2 = Amor and Miles (1974), 3 = Aston (1973), 4 = E. Bound p.c., 5 = J. Burgess p.c., 6 = R. J. Chinnock p.c., 7 = Henderson (1974), 8 = B. A. Fuhrer p.c., 9a,b,c = Nicholls (1933, 1940, 1942), 10 = Parsons (1973), 11 = A. Thornley p.c., 12 = Wakefield (1975), 13 = Williamson (1928), 14a,b,c,d = Willis (1948, 1957, 1970, 1972), 15 = F. Poole p.c.

Floristic Check-list of the Otway Region

	BLOCK									COMMUNITY							
SPECIES	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
Acacia aculeatissima								r					H					
A. armata								vr	vc			T	H	C				
*A. baileyana									r				H					D
A. dealbata					r	c	vr		vc		F		H					
*A. decurrens									r				H					D
*A. floribunda									vr									D
A. genistifolia Link	r	c							vc			T	H					
A. gunnii N									vr			T						
*A. longifolia									c			T	H					
A. longifolia var. sophorae	r			vc	vc				vc					C				
A. mearnsii					vr	r	vr	vr	c			T	H					
A. melanoxylon	c	vc	c	vc	vc	c	vr		vc	N	F	T	H					
A. mitchellii									vr				H					
A. mucronata	vc	vc	vc	vr	vc	vc	vc	vc	vc	N	F						S	
A. myrtifolia	vc	c		vc		c	r	vc	vc			T	H	C				
A. nanodealbata N W 14b		vc	vc		vc	vc	vc					T						
A. oxycedrus									r			T						
A. pycnantha							vr	c	vc			T	H	C				
*A. saligna	vr								c				H	C				D
A. stricta	vc	vc		vc	vc	c	vc	vc	vc		F	T	H				S	
A. suaveolens		vc					vr	c	vc				H					
*A. terminalis									vr				H					D
A. verniciflua		vc	vc	vr	vc	vc			vc	N	F	T	H					
A. verticillata	vc	vc	vc	vc	vc	vc	vc	vc	vc	N	F	T	H	C			S	
A. verticillata var. latifolia N W					c	c								C				
A. verticillata var. ovoidea	c				c	vc			vc				H	C				
Acaena anserinifolia	vc	vc	vc	vc	vc	vc	vc	vc	vc	N	F	T	H	C				D
A. echinata	r			vc	c	r		r	vc			T	H	C				
*Acetosella vulgaris Fourr.	r	c	r	vc	r	r		vr	vc				H	C				D
*Achillea millefolium					r													D
Acianthus caudatus	c	r					vr		vc				H					
A. exsertus	c			c			c	c	vc			T	H	C				
A. reniformis	r			vc			c	c	vc				H	C				
Acrotriche affinis	r			c					c					C				
A. prostrata	c			r			r		r		F	T						
A. serrulata	vc	r		c		r	vc	vc	vc			T	H					
Adiantum aethiopicum	c			vc	vc		c	vc	vc		F	T	H	C				
Adriana klotzschii	vr													C				
*Agapanthus orientalis					r													D
*X Agropogon littoralis				r												W		
Agropyron scabrum	r			r										C				
Agrostis avenacea	c	vr	r	c	c	c	r	r	vc		F	T	H	C				D
A. billardieri				c					c					C			S	
*A. gigantea				vr										C				
A. hiemalis N W							c									W		
A. rudis	r	c		r	vc	vc				N	F	T						
*A. semiverticillata 14c				r					(+)					C				
*A. stolonifera				vc														D
*A. tenuis	c	vc		c	vc	vc	r	vr	vc									D
*Aira caryophyllea	vc	vc		vc	c	c	r	vc	vc				H	C				D
*A. praecox	r	r					r					T						
Ajuga australis	r			vc					vc			T	H	C				
*Albizia lophantha	vr		r	r	c				vc				H	C				
*Allium triquetrum	vr	vc			vc		vc											D
Alyxia buxifolia	r			r	vr				vc					C				

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
***Amaranthus albus**		vr																
***Ammophila arenaria**	vc			vc	vc				vc					C				
Amperea xiphoclada	vc	vc	vc	vc		vc	vc	vc	vc			T	H					
Amphibolis antarctica				r				Marine										
Amphibromus neesii	r						vc		c							W		
A. recurvatus	vr						c		vc							W		
Amphipogon strictus								vc	vc				H					
Amyema pendulum	r	vc	c	c	r	r	vr	vr	c	N	F	T	H					
*Anagallis arvensis	c	r	r	vc	r	r		r	vc									D
Angianthus preissianus	r								c						M			
Anguillaria dioica	r			r					c				H	C				
*Anthemis nobilis	r																	
*Anthoxanthum odoratum	vc	vc	r	vc	vc	vc	r	r	vc			T	H	C				D
Aotus ericoides	vc	vc					vc	vc	vc			T	H					
Apalochlamys spectabilis	vr													C				
*Aphanes arvensis		vc	vr		r	vr				N	F							
Aphelia gracilis	c							vc					H					
A. pumilio	r							vc				T	H					
Apium prostratum	c			vc	r				vc					C		W		
*Aponogeton distachyon					vc											W		
*Araujia hortorum					vr													D
*Arctotheca calendula	r		vr	vr	vr		vc	vr	vc					C				D
*Arctotis stoechadifolia								r						C				D
*Arenaria leptoclados				c										C				
Arthrochilus huntianus (F.Muell.)D.Blaxell 11		vr				(+)		vr				T	H					
Arthropodium milleflorum				c	c	vc		c	r		F	T	H					
*Asparagus asparagoides									vr					C				
Asperula conferta	vc			r	r	c	vc	r	r			T	H					
A. gunnii		c		c	c	vc						T						
A. scoparia	r			r					r					C				
A. subsimplex N	r															W		
*Asphodelus fistulosus									r									D
Asplenium bulbiferum		c	vc	vc	vc		vc			N								
A. flabellifolium		vc	vc	vc			r		vr	N	F	T						
A. flaccidum N W			r	r	vc					N								
*Aster subulatus	vr			vc	vc				vc					C				D
Astroloma humifusum	c			c			r	vc	vc			T	H	C				
Athyrium australe			r	r	r					N								
Atriplex cinerea	vr													C				
*A. hastata	r			vc					vc					C				
Australina muelleri	vc	vc	vc	vc	vc	c				N								
A. pusilla N W				vr							F							
*Avellinia michelii				vc										C				
*Avena sativa									vr					C				D
Azolla filiculoides						vc	vc									W		
Baeckea ramosissima	r							c	c				H					
Banksia marginata	vc	vc		vc		c	vc	vc	vc			T	H	C				
Bauera rubioides	vc	vc		vc	vc											W	S	
Baumea acuta	vc	vc		vc	vc			vc	vc				H			W		
B. gunnii	c						r									W		
B. juncea	vc	vc		r					c				H					
B. laxa N E	r															W		
B. rubiginosa	vc						vc									W		
B. tetragona		vc		c												W		
Bedfordia arborescens Hochr. W	r	vc	vc	vc	vc	vc		c	r	N	F							

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
*Bellis perennis		c	vr	vc	c													D
Beyeria leschenaultii	c			vc										C				
Billardiera longiflora		vr	c	vc	c	r				N	F							
B. scandens	r	vr		c	r	vr	r	r	vc			T	H					
Blechnum cartilagineum W 14b																		
B. chambersii	r	c	r	c	c				vr	N	F					W		
B. fluviatile W		vc	c	c	vc	c				N	F							
B. minus		vc	c	r	c	r	r			N	F							
B. nudum	vc	vc	vc	vc	vc	vc	vc	vc	vc	N	F					W		
B. patersonii W 14c																		
B. wattsii	c	vc	vc	vc	vc	vc	r			N	F					W		
Boronia muelleri N W			vc	vr								T					S	
B. nana	c	c				r		vr	vr				H					
B. parviflora	vc	c		vc									H			W		
Bossiaea cinerea	vc	vc	vc	vc					r				H				S	
B. cordigera						c						T						
B. prostrata	vc			vc			vc	c	vc				H	C				
Brachycome cardiocarpa	vr							r	vr							W		
B. diversifolia				r										C				
B. graminea				vr					vr							W		
B. multifida	r							c	vc			T	H					
B. parvula	r			c					c					C				
B. perpusilla	vr													C				
B. uliginosa								vc	vc				H			W		
Brachyloma ciliatum	vc	vc		r		c		vc					H			W		
*Briza maxima	r			r					vc			T		C				D
*B. minor	vc	vr	r	vc	c	r		c	c					C				D
*Bromus diandrus				r										C				D
*B. mollis				r	r			vr						C				
*B. sterilis				vc	r			vr						C				
*B. unioloides	vr			c	c			vr	c					C				D
Brunonia australis	vc			c		r	c	vc	vc			T	H					
Bulbine bulbosa	r			r	r				r			T						
B. semibarbata	r													C				
Burchardia umbellata	vc	vc		vc	r	c	vc	vc	vc			T	H	C		W		
Burnettia cuneata 8		r														W		
Bursaria spinosa	r	r		vc	vc	vr	r	vr	vc			T	H	C				
Caesia parviflora	c							r	r				H					
*Cakile edentula				vr	r									C				
*C. maritima				vc	vc				vc					C				
Caladenia angustata	vr	r						r	r			T	H					
C. caerulea								vr	r				H					
C. carnea	vc	vc		c	r	vr	c	c	vc	N		T	H					
C. carnea var. pygmaea		r						vr					H					
C. clavigera	vr								r				H					
C. clavigera X C. dilatata									vr				H					
C. congesta	r	vr							vr			T						
C. deformis	r	c							vc				H					
C. dilatata	r	c		r			r	c	vc			T	H					
C. dilatata X C. patersonii									vr				H					
C. filamentosa	r	r							(vr)				H					
C. iridescens	vr	vr						r	r			T	H					
C. latifolia	vc			r					vc					C				
C. menziesii	vc	r		r			r	vc	vc			T	H					
C. pallida 9c					(+)							T						
C. patersonii	r							vr	c				H					

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
C. patersonii var. *concolor*									vr				H					
C. patersonii X *C. reticulata* 11									(vr)				H					
C. patersonii X *C. tessellata*									vr				H					
C. reticulata	vc	c		vr				vr	r				H					
C. sp. 5									vr				H					
C. tessellata									c				H					
C. X *tutelata*									vr				H					
Calandrinia calyptrata									vr				H					
Caleana major	r	c						r	c			T	H					
**Callistemon rigidus* R.Br., A									c				H					
Callitriche brachycarpa				r			vr									W		
C. muelleri 3																W		
**C. stagnalis*	r	r		r	c	r										W		
Calocephalus brownii	c			vc	vc				vc					C				
C. lacteus	r								vr					C				
Calochilus campestris	r	r							r				H					
C. herbaceus Lindl. 14									vr				H					
C. imberbis									vr				H					
C. paludosus	r	r		vr					r				H			W		
C. robertsonii	r	r		vr		vr		vr	c			T	H					
Calystegia marginata			r	vr	vr	r				N	F							
C. sepium	r	vr		r					r							W		D
Calytrix tetragona								c					H					
Cardamine dictyosperma				r						N	F							
C. hirsuta	r			vr	c	vr			c									D
C. stylosa N W				vr		vr				N								
C. tenuifolia	vr				vr							T						
**Cardaria draba* 10																		
**Carduus pycnocephalus*				vr														D
**C. tenuiflorus*	r			c	r				r					C				D
Carex appressa	r	c	c	c	r	c		r	r	N	F					W		
C. bichenoviana				r												W		
C. breviculmis	c			vc										C		W		
C. brownii	vr													C				
C. fascicularis				vr	vr	r				N	F					W		
C. gaudichaudiana	r							vc								W		
C. gunniana	vr			vr												W		
C. inversa 14c	(+)			vr	r									C				
C. inyx N				vr												W		
C. pumila				c	c									C				
**Carpobrotus edulis*								vr	r					C				D
C. rossii	c			c	c				vc					C				
Cassinia aculeata	vc	r			vr			vr	r				H					
C. arcuata N									vr			T						
Cassytha glabella	c	c		c		r	vr	c	vc			T	H					
C. melantha	vr	vr		r	r		vr	vr	c			T	H	C				
C. pubescens	c	c		r		c	vr	r	c			T	H					
Casuarina littoralis							vr	vc				T						
C. paludosa	vc	vc		vc			vc	vc	vr				H			W		
C. pusilla								c	vc				H					
C. stricta	r			vc	r				c					C				
**Catapodium rigidum*				vc	vr				c					C				
Caustis flexuosa W 14c																		
C. pentandra				c	c				c			T	H					
C. restiacea		vc						c	vc				H					
**Centaurium minus*	vc	r	vc	vc	c	r	c	r	vc	N	F	T	H	C	M			D

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
*C. tenuiflorum(Hoffm.et Link)Fitsch	c	r		c					c						M	W		D
Centella cordifolia	vc			c			r	r	r			T				W		
Centipeda cunninghamii	r					r			r				H			W		D
Centrolepis aristata	c	c		c		c	r	vc	vc				H			W		
C. fascicularis	vc	c	r	r		r	r	r	c			T	H			W		
C. glabra								c								W		
C. polygyna	c			r										C				
C. strigosa	vc	vc		r	vr	c	r	c	vc			T	H			W		D
*Centunculus minimus	r				vr			r					H					
*Cerastium glomeratum	c	r	r	vc	c	vr		r	c			T	H	C				D
*Chamaecytisus proliferus			vr		r		r	vr	r									D
Chamaescilla corymbosa	vc			r			r	vc	vc				H					
Cheilanthes tenuifolia									vr			T						
Cheiranthera linearis N 4									vr			T						
*Chenopodium album			r						r					C				D
C. glaucum			r						r					C				D
*C. murale									r									D
C. pumilio		vr														W		
Chiloglottis cornuta N			r	vr	r	r				N								
C. gunnii				vr		vr						T	H					
C. reflexa	c	c		c			vc	c	vc				H					
Chorizandra enodis	r															W		
*Chrysanthemoides monilifera					vc		c	vc	vc			T	H					D
*Chrysanthemum leucanthemum					r					N								D
*Cicendia filiformis	c			r				vc	r							W		D
*Cichorium intybus							vr											D
*Cirsium vulgare	vc	r	c	c	c	c	vr	vr	c	N	F	T	H					D
Cladium procerum 14c				(+)														
Clematis aristata	c	vc	c	vc	vc	c	r	c	r	N	F	T						
C. microphylla	r			c	r				vc				H	C				
Colobanthus apetalus	c			vc					r					C				
Comesperma calymega	r	c		r		vr		c	c				H					
C. defoliatum	r	vc		c			vr						H			W		
C. ericinum					r	vr		c	c				H			W		
C. retusum N	vr	c				r							H			W		
C. volubile	r	r		vr	r	vr	vr	r	vc			T	H	C				
*Conium maculatum						vr		c										D
Conospermum mitchellii E								vc	vc				H					
Convolvulus erubescens	r			r					r					C				
*Conyza bonariensis	r		r	r					vc			T	H	C				D
*C. canadensis	r	vr		r	vr									C				
Coprosma hirtella	r	r	c	c	c	c	r			N	F	T						
C. quadrifida	r	vc	vc	vc	vc	vc		c	c	N	F	T						
*C. repens	vr				r				r					C				
Correa alba				c	r									C				
C. lawrenciana		r	c	c	c	c				N	F							
C. reflexa	vc	c							c				H					
C. reflexa var. nummularifolia N				c										C				
Corybas diemenicus	r			r					vc				H	C				
C. dilatatus	c			vr	r				vr	N			H					
C. fordhamii N		c																
C. unguiculatus	c			r					vr				H					
Cotula australis	r			vr					c			T	H	C				D
C. coronopifolia	vr	r		vc	vc	c	r		vc					C		W		
C. reptans	r	c	c	vc	vc	vc	r	r	r	N	F					W		
Craspedia glauca	c							c	r				H					
Crassula helmsii	c			c					vc							W		

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
C. macrantha	r			c	vr			vc	c					C				
C. pedicellosa N								c				T	H					
C. peduncularis	r															W		
C. sieberana	c			vc	r				c			T	H	C				
**Crataegus* sp. (see 10)				vr	vr		vr	vr	vr									D
**Crepis capillaris*		r	r	r	r	r	r			N	F	T						D
**Crocosmia aurea*					r				r									D
Cryptandra tomentosa									c				H					
Cryptostylis subulata	c	r			r		r		c							W		
Ctenopteris heterophylla W		c	vc	vc	c	c			r	N	F							
Culcita dubia	vc	c	r	c	c	vr	vc		c		F	T						
**Cupressus macrocarpa*					c				r					C				
Cyathea australis	r	c	vc	vc	vc	vc		vr	c	N	F	T						
C. cunninghamii N W			vr	r						N								
C. marcescens N W			vr	vr						N								
Cyclosorus nymphalis N W 12,14c																W		
C. penniger N 12, 14c																W		
Cymbonotus preissianus	c			c	r	c	c	c	c			T	H	C				
Cynodon dactylon	r			c					c					C				D
Cynoglossum australe	c			r					r					C				
C. latifolium			c	vc	r	c			c	N	F	T				W		
C. suaveolens	r			c	vr				c				H	C				
**Cynosurus cristatus*	vr			r					r	N			H					D
**C. echinatus*				r					r									D
**Cyperus eragrostis*	vr		c	vr	vr	vr			vc							W		D
C. lucidus				c					r							W		
C. tenellus	vc	r		c	r	r		vc	vc				H			W		
**Dactylis glomerata*	r	vc		vc	r	vr			c			T	H					D
Danthonia caespitosa		r		vc								T		C				
D. eriantha	r													C				
D. geniculata	r					r	r		c			T	H	C				
D. laevis						r							H					
D. longifolia N				r		c					F		H	C				
D. pallida								c					H					
D. penicillata	c			vc	c	vc		vc	c	N	F	T	H					
D. pilosa	c						c					T						
D. procera	vc			c		r						T	H					
D. racemosa	r								r					C				
D. semiannularis	vc			c	c	r	r	r	r				H					
D. setacea	r	c		c		r		vc	c			T						
**Datura* sp. 10																		
**Daucus carota*	vr																	D
D. glochidiatus	r			vc	vr				r					C				
Daviesia brevifolia								c	vc				H					
D. latifolia	r											T						
D. ulicifolia	r					r			c			T	H					
D. virgata						vr		c	vr			T						
Dennstaedtia davallioides W 15			r	r	c			+		N								
**Desmazeria acutiflora*	r													C				
Desmodium varians N					c				r			T		C				
Deyeuxia brachyathera N						c				N								
D. contracta N W		r				vr						T	H					
D. decipiens (F.Muell.) J. Vickery N						r							H					
D. densa	c	r		vc		r	c					T	H			W		
D. minor		vr														W		

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
D. quadriseta	vc	c		c	r	c	vc	c	vc				H					
D. scaberula N W					c	vc				N	F							
D. sp. N		vr		vr								T				W		
D. sp. N						c				N								
Dianella revoluta	vc	vc	c	vc	vc	r	c	vc	vc			T	H	C				
D. tasmanica	c	vc	vc	vc	vc	vc	c		r	N	F	T						
Dichelachne crinita	c	vr		c			vr	vr	r			T	H					
D. sciurea	vc	r		vc	c	vc		vr	c			T						
Dichondra repens	c			vc	c	c	r	c	vc	N	F	T	H	C				
Dichopogon strictus	vc			r									H					
Dicksonia antarctica	c	vc	vc	vc	vc	vc	r			N	F							
**Digitalis purpurea*		vr	<u>vr</u>	vr	vr	r												D
Dillwynia cinerascens									r				H					
D. glaberrima	vc	vc		vc		vc	r	vc	vc			T	H			W	S	
D. sericea				vr				vc	vc			T	H					
Diplarrena moraea	c											T						
**Diplotaxis tenuifolia*									vr					C				D
Dipodium punctatum	vc	vc		r		vc	c	c	c		F	T						
Disphyma blackii									vc					C	M			
Distichlis distichophylla	c			r	r				c					C	M			
Diuris brevissima (doubtful species)	11								vr			T						
D. longifolia	vc	c		c		vr	r	c	vc			T	H					
D. maculata									r				H					
D. palustris	vc												H	C				
D. pedunculata	c								<u>vr</u>				H					
D. sulphurea				<u>c</u>					vr				H					
**Dolichos lignosus*					r				r			T		C				
Doodia caudata 14c																		
D. media				r	r		r	r	r		F							
Drimys lanceolata			c	vr	r					N								
Drosera auriculata	vc	vc		vc	vc	c	vc	vc	vc			T	H			W		
D. binata	r	vc		vr					vr							W	S	
D. glanduligera		vr						c	c				H			W		
D. peltata	c	c		vr					r				H					
D. planchonii	r	r						r	c				H	C				
D. pygmaea	vc	vc		vc	vc	c	c	vc	vc				H			W		
D. spathulata		vc														W		
D. whittakeri		c		r		r	vc	vc	vc			T	H	C				
Drymophila cyanocarpa		c		c			vr		vr		F	T					S	
Echinopogon ovatus	c		c	vc	c	vc		c	r	N	F	T						
**Echium* sp. 10																		
**Egeria densa* 3									(+)							W		
**Ehrharta calycina*				r										C				
**E. erecta*					c				vc					C				D
**E. longiflora*	r						vr							C				D
Elatine gratioloides									r							W		
Eleocharis acuta	r			vc	r				c							W		
E. atricha N								c								W		
E. gracilis				r					r				H			W		
E. sphacelata				c	r											W		
Empodisma minus (Hook.f.) L.A.S.Johnson & Cutler	vc	vc		vc		vc	vc	r	vc				H			W	S	
Enchylaena tomentosa				vr					r					C				
Epacris impressa	vc	vc	vc	vc	c	vc	vc	vc	vc		F	T	H	C				
E. lanuginosa	vc	vc		c			vc						H			W		
E. microphylla N W 14d																		

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
Epacris obtusifolia		vc		vr					vr				H			W		
Epilobium billardierianum	r		r	c	c	r			vc					C		W		
E. cinereum	c	vr	r	vc	r	r		vr	vr					C		W		D
E. hirtigerum				vr	r	vr		vr						C				
E. pallidiflorum				r												W		
Eragrostis brownii	vc	r		r		c	c	r	c				H			W		
*Erica lusitanica	r	c	c			vc	vc											D
Eriochilus cucullatus	c	r					r	r	c				H	C				
*Erodium cicutarium	c		c						c									D
Eryngium vesciculosum	r															W		
Eucalyptus aromaphloia	vc	vc	r	c	vc	vc	c	vc	vc		F	T	H					
E. baxteri	vc	vc	vc	vc		c		vc	vc			T	H					
E. cypellocarpa	vc	c	c	vc	vc	vc	vc	vc	vc	N	F	T						
E. aff. cypellocarpa									vc			T						
E. globulus	vc	vc	vc	vc	vc	vc		vc	vc	N	F	T						
E kitsoniana N				vc									H					
E. leucoxylon 11									vr				H					
E. nitida	vc	vc				vc	vc	vc	vc			T	H					
E. obliqua	vc	vc	vc	vc	vc	vc	vc	vc	vc	N	F	T						
E. ovata	vc	vc	vc	vc	vc	r	c	vc	vc		F	T	H					
E. pauciflora N								(vr)	vr				H					
E. radiata	vc	vc		r		vc	vc	vc	vc		F	T						
E. regnans W		vc	vc	vc	vc	vc				N								
E. sideroxylon								vc	vc		F	T						
E. viminalis	vc	c	vc	vc	vc	vc	r	vc	vc	N	F	T	H	C				
*Euphorbia peplus	vr				vc			vr	c									D
Euphrasia collina	r								vc				H					
*Euryops abrotanifolius (L.) DC. A									vr				H					D
Exocarpos cupressiformis	vc		r		vr	vr	vr	vr	c			T	H					
E. strictus	r											T	H					
E. syrticola	r			c	r									C				
*Festuca arundinacea	vr			r										C				
F. hookerana N	r															W		
F. littoralis	c			vc					c					C				
*Foeniculum vulgare									c									D
*Freesia refracta					vc		vc		vc				H					D
*Fumaria bastardii									r									D
Gahnia clarkei	vc	c	r	c			r		r				H			W	S	
G. filum									c							W		
G. radula	vc			c		c		vc	vc				H					
G. sieberana	vc	c	vc	vc	vc	vc	c		vc		F		H			W	S	
G. trifida	vc								vc					C		W		
*Galenia pubescens					r				r									D
*Galium aparine				vr	vr		r											D
G. australe					vr								H					
G. ciliare N				r			r					T						
G. sp. N	c			vc										C				
*G. murale	vc			vc										C				
G. propinquum	r			r		r				N	F							
Gastrodia sesamoides	r	vr	r	r	vr	r	r	vr	vr	N	F	T	H			W	S	
*Gazania ringens					vr				vr									D
*Genista linifolia					c				c			T	H					D
*G. monspessulana	vr				c		r	r	c			T	H					D
Gentianella diemensis N 14d																		
*Geranium dissectum				vr									H					
G. homeanum N W				r						N								

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
**Geranium molle*				vc	vr													D
G. potentilloides	c	vc	c	c	vc	vc	c			N	F	T		C				
G. eolanderi			r	vc	vc	r					F	T		C				
Gleichenia dicarpa	vc	vc	r	r	c	vc	c		c	N			H			W	S	
G. microphylla			r	c	c	vr	vr	vr	c	N			H			W	S	
Gloseodia major	vc	vc		r			c	c	vc			T	H					
Glyceria australis	c			c	c	c			c				H			W		
Glycine clandestina				r	r				c			T	H	C				
G. latrobeana	r													C				
**Gnaphalium candidissimum*	vc	c	r	vr		r	vr	vr	vc				H					D
G. gymnocephalum DC.	vc	c	c	c	vc	c	vc	vc	c	N	F	T	H					
G. indutum	c			vr										C				
G. luteoalbum	vr	vr	r	r	r	vr	vr		vc		F	T	H	C				D
**G. purpureum*	r	r	r	r	r	r	r	r	r	N	F	T	H					
G. sphaericum Willd.	c	r		c	c	r		vr			F	T	H					
**G. spicatum*		vr														W		
Gompholobium ecostatum	r	c		vr		r		c	c			T	H					
G. huegelii	r	c						r	(vr)				H					
Goodenia geniculata				r				vc	c			T	H					
G. humilis	vc						c	c	c				H			W		
G. lanata	vc	vc	vc	vc	c	c	vc	vc	vc			T	H					
G. ovata	vc	vc	vc	vc	vc	vc	c	vc	vc	N	F	T	H	C				
Goodia lotifolia		vr		c	r	c		c	vr		F	T						
Grammitis billardieri			vc	c	c				r	N								
Gratiola peduncelata	r							r								W		
G. peruviana	c			vr	r	r	r	r	c							W		
Grevillea aquifolium N E								c	c			T	H					
Gymnoschoenus sphaerocephalus	vc	vc		vc									H			W		
Gynatrix pulchella	vr	vr	r	r	vr	r			r		F	T						
**Hakea laurina* R.Br. A									r									D
H. sericea	r	c							($\bar{c}$)				H					
H. ulicina	vc	vc		r		c	c	vc	vc			T	H					
Haloragis brownii	vr															W		
H. exalata N E	r													C				
H. micrantha	vc	c	c	c		r	vc	r	vc				H			W	S	
H. tetragyna	vc	vc	vc	vc	vc	vc	vc	vc	vc			T	H					
H. teucrioides	vc	vc	vc	vc	vc	vc		r	vc		F	T	H					
**Hedera helix*				vr	vr													D
Hedycarya angustifolia	r	vc	vc	vc	vc	vc				N	F							
Helichrysum apiculatum	c			vc					r				H	C				
H. blandowskianum E		vc											H					
H. dendroideum	vc	vc	vc	vc	vc	vc	c	vc	vc	N	F	T	H	C				
H. leucopsideum	c			vr	r				r					C				
H. obcordatum									vr				H					
H. obtusifolium	r	c						vc	vc			T	H					
H. paralium	c			vc	c				vc					vc				
H. rogersianum N W		c	r								F							
H. rosmarinifolium	r	r		vr			r		vr							W		
H. scorpioides	vc	vc	c	c	c		vc	vc	vc			T	H					
H. semipapposum				c	vc	r		vr	r		F	T						
Hemarthria uncinata	vc	r		vc			vc	c	vc							W		
Hemichroa pentandra									c						M			
Heterozostera tasmanica 3													marine					
Hibbertia acicularis W		c											H					
H. aspera	c			r										C				
H. empetrifolia (DC.)Hoogland	vc	vc										T	H					

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
Hibbertia fasciculata	vc	vc		c				vc	vc				H			W		
H. procumbens	c	c		c	r	c	r						H					
H. sericea		r		c					vc			T	H					
H. stricta	vc	c		c			c	vc	vc			T	H					
Histiopteris incisa	vr	vc	c	vc	vc	vc		vr	vr	N	F							
**Holcus lanatus*	r	vc	c	vc	vc	vc	c	c	vc					C		W		D
**Homeria breyniana* 10																		
**Hordeum hystrix* 14c									(+)									
**H. leporinum*	r			r	r									C				
Hovea heterophylla								c	c				H					
Hydrocotyle callicarpa	c					vr		vc					H					
H. capillaris	c			r										C				
H. foveolata	c			r	r			vc					H					
H. hirta	r	vc	c	vc	vc	c			c	N	F							
H. laxiflora				vc	vc			c	c			T						
H. muscosa	r															W		
H. pterocarpa	r											T						
H. sibthorpioides	r			r		r	r	r	vc	N				C		W		
Hymenolobus procumbens	r													C				
Hymenophyllum australe			vc	vc	vc					N								
H. cupressiforme		c	vc	vc	vc	vc				N	F							D
H. flabellatum			vc	vc	vc					N								
H. rarum		r	r	c						N								
**Hypericum androsaemum*	r	r	c	c	r					N	F							D
H. gramineum	vc	r	r	r	vc	r	r	vc	vc		F	T	H	C				
H. japonicum				r	vr	vr		r								W	S	
**Hypochoeris glabra*				vc	vc													D
**H. radicata*	vc	vc	c	vc	vc	c	c	vc	vc					C				D
Hypolaena fastigiata	vc	vc		c				vc	vc				H					
Hypolepis australis N W 15		+	+	+	+				+	N								
H. punctata		+	+	+	+					N								
H. rugosula 6 15		+	+	+	+					N								
Hypoxis glabella	r							c	c			T						
H. hygrometrica	r			c									H	C				
H. pusilla									r				H					
Imperata cylindrica	r			c	r			r	vc					C				
Indigofera australis	vr			vr	vr	r	vr	r	c			T	H					
**Inula graveolens*									vc									D
**Iris germanica*					vr													D
Isachne globosa N 14c	(+)			c												W		
Isoetes drummondii	r							r								W		
Isopogon ceratophyllus	vc	vc					r	vc	vc			T	H					
Isotoma fluviatilis	r							r	r							W		
**Ixia maculata*									c									D
Ixodia achilleoides									vc			T	H	C				
Juncus amabilis Edgar	r			r												W		
**J. articulatus*	c	r	r	c	c	r	r		c							W		D
J. bufonius	c	vc	r	vc	vc	c	r	c	vc				H			W		D
**J. bulbosus*	vc					vr	c	c	r					C		W		D
J. caespiticius	c			c								T		C		W		
**J. capitatus*	r	r		vc	r	r		vc	vc				H					D
J. gregiflorus					r						F							
J. holoschoenus	r		r	c	r	r	r	c	c							W		D
J. homalocaulis						vr							H					
J. kraussii Hochst.	vc			vc	c				vc					C	M			
J. pallidus	c	r	vr	r	r	r	vr	r	vc	N	F	T	H			W		D

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
Juncus pauciflorus	c	r	r	c	r	r	vr		vc			T	H	C				
J. planifolius	vc	vc	r	c	c	r	c	vc	vc			T	H	C		W		
J. procerus	c	c		r	c	r	c		vc							W		
J. sarophorus	r	r		r	vr	r												D
J. subsecundus				r	r			vr										
Kennedia prostrata	r			vc		c	r	c	vc			T	H	C				
*Kickxia spuria				r														D
*Koeleria phleoides				vc										C				
Lagenophora gracilis	c			vc			vc	c	c		F	T						
L. stipitata	c			vc	r	r			r		F	T	H					
*Lagurus ovatus				vc		r			vc					C				D
Lasiopetalum baueri	vc								vc					C				
L. schulzenii N E	vr													C				
Lastreopsis hispida W			r	vc						N								
L. shepherdii				vc	vc					N								
*Lavatera arborea	vr				r									C				D
Lawrencia spicata	vr								vr						M			
Laxmannia sessiliflora	r	c		r		vr		vc	vc				H					
Lemna minor				(vc)		vc	vc									W		
L. trisulca 13																W		
*Leontodon taraxacoides	vc	r		vc	r	r	c	r	vc									D
Lepidosperma concavum	vc	vc		c		c		vc	vc				H					
L. congestum N	r								r				H					
L. elatius	Distribution uncertain because of confusion with L. laterale																	
L. filiforme	vc	vc		vc			vc	vc	vc				H					
L. gladiatum	vc			vc	vc				vc				H	C				
L. laterale	vc	c	vc	vc	vc	c	vc	r	vc				H			W		
L. lineare	vc						r	vr	vc				H			W		
L. longitudinale	vc			vc			vc	vc	vc							W		
L. neesii N	c							c					H					
L. semiteres	c					c		vc	vc				H					
Lepilaena bilocularis				c												W		
Leporella fimbriata (Lindl.)A.S. George									c				H					
Leptocarpus brownii	c								c				H			W		
Leptorhynchos gatesii N 14b					(+)													
L. linearis								vr	c				H					
L. squamatus	c			vc					c				H	C				
L. tenuifolius	c												H					
Leptospermum glabrescens N	r	c					c									W		
L. juniperinum	vc	vc	c	vc	vc	vc	vc	vc	vc			T	H			W	S	
L. laevigatum				r	r				vc					C				
L. lanigerum	c			vc					vc							W		
L. myrsinoides	vc	vc		c		vc	c	vc	vc				H					
L. scoparium	vc			vc	vc						F	T						
Lepyrodia muelleri								r								W		
*Leucojum aestivum		c	c		vc		c											D
Leucopogon australis	c	c		vc									H			W	S	
L. ericoides	r	vc											H					
L. glacialis E								vc	vc			T	H					
L. lanceolatus	vr															W		
L. parviflorus	c			vc	vc				vc			T		C				
L. virgatus	c	vc		r		c	c	vc	vc			T	H					
Levenhookia dubia									vr							W		
*Leycesteria formosa			r															D
*Ligustrum vulgare				vr														D
Lilaeopsis polyantha	r															W		

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
Limosella australis	c															W		
Lindsaea linearis	vc	vc		vc		vc	vc	vc	vc			T	H					
Linum marginale	r			vr	vr				vr					C				
Lissanthe strigosa N									c			T						
Lobelia alata	c	vr	r	c	vr				c					C		W		
L. gibbosa	r	r		c	r	r	vr		vr		F	T	H					
L. pratioides				r				r						C				
L. rhombifolia								vr	vr			T	H					
Logania ovata N E	r													C				
*Lolium perenne	r	c		c	r	vr		vr	vc									D
Lomandra filiformis	vc	c		r	r	r	c	vc	vc			T	H					
L. glauca	r								r				H					
L. longifolia	vc	vc	vc	vc	vc	vc	vc	vc	vc		F	T	H					
L micrantha	r								c				H					
L. multiflora				r				r	vc			T	H					
Lomatia fraseri W			r	r	r	vr				N	F							
L. ilicifolia W						c		vc	c			T	H					
Lonicera japonica					vr													D
Lotus australis	r			vr										C				
*L. hispidus	c	c	r	vc	r	c					F	T						D
*L. pedunculatus	c	c	r	vc	c	r	vr	vr	vc									D
Luzula meridionalis Nordenskiold	r	r	r	c	vc	c	r	c	vc		F	T	H					
*Lycium ferocissimum				vr	r				r					C				D
Lycopodium deuterodensum	c	c				r							H					
L. laterale		vc														W		
L. varium N 14b			+	vr						N								
Lycopus australis				vc												W		
Lyperanthus nigricans								c	vc			T	H					
L. suaveolens N W									vr				H					
*Lythrum flexuosum	vr													C				
L. hyssopifolia	r	c		r	r	vr		vr	vc							W		D
L. salicaria				vr												W		
*Malus sylvestris		vr		vr	vr		vr		vr	N	F	T						D
*Malva nicaeensis	vr			vr	vr							T						
*M. parviflora				vr														D
Marianthus procumbens		c						c	c			T	H					
*Marrubium vulgare	vr			vr									H					
*Mattiola incana				vr										C				
Mazus pumilio	r			c				r	r							W		
*Medicago arabica					vr			vr						C				
*M. lupulina	vc			vc	vc									C				
*M. polymorpha				r	vr													D
Melaleuca lanceolata 14a					(+)				c					C	M			
M. squamea N E	vc	c							vr							W		
M. squarrosa	vc	vc	c	vc			vc		vc			T	H			W	S	
*Melilotus indica	vc			vc	r				c					C				D
Mentha diemenica				(vr)										C				
M. laxiflora	c	c		vc	vc	vc		c	c	N	F							
*M. rotundifolia				r														D
*M. spicata		vr		r														D
Microlaena stipoides	vc	r		c	c	c	c	vc	vc		F	T	H					
Microlepidium pilosulum F.Muell. N E				r										C				D
Microseris scapigera	c							c	vc				H					
Microsorium diversifolium		vc	vc	vc	c	c			c	N	F	T						
Microtis oblonga	c	c		(vr)												W		
M. parviflora	c	r							r				H					

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
Microtis unifolia	vc	c		vc	vr	vr			vc			T	H					
Mimulus repens	r			c					r					C		W		
**Minuartia hybrida*				r										C				
Mitrasacme distylis	c							r								W		
M. paradoxa	r													C				
M. pilosa	r	vc		vr		r	vr	vr	vr				H	C				
M. pilosa var. stuartii N		r		vr									H					
**Modiola caroliniana*					vr		vr		c									D
**Moenchia erecta*	c			r										C				
Monotoca elliptica (?W)	c	c	c	vc			vr						H				S	
M. scoparia	r	c				c		vc	vc			T						
Montia australasica	r								c							W		
M. fontana	r		vr		vr											W		
Muehlenbeckia adpressa	vr			vr					vc					C				
Muellerina eucalyptoides	vr			r		r	r		r			T	H					
Myoporum insulare	r			c	vr				c					C				
M. viscosum	c				r				c					C				
Myosotis australis				c		r			r					C				
**M. sylvatica*			r		r													D
Myriophyllum amphibium N									r							W		
M. elatinoides				r												W		
M. integrifolium	r							r								W		
M. pedunculatum N							vc									W		
M. propinquum	vc			r		r	r	r	vc							W		
**Nasturtium officinale*		r	r	c	vr	r								C		W		D
Nertera reptans	c			r			c						H					
Notelaea ligustrina	c	vc	c	vc	vc	c				N	F							
Nothofagus cunninghamii W			c	c	c					N								
**Oenothera stricta*									c					C				D
Olearia argophylla	r	vc	vc	vc	vc	vc			vr	N	F							
O. axillaris	r			c					vc					C				
O. ciliata N		r							vr				H					
O. erubescens	r		vr			r			r			T	H					
O. glandulosa				vr			vr									W		
O. glutinosa				vc										C				
O. lanuginosa - O. lepidophylla complex N				r										C				
O. lirata	c	c	c	vc	vc	vc	vr	vr	c	N	F	T						
O. myrsinoides							vr	c	c			T						
O. pannosa									vr			T						
O. phlogopappa	c	vc	c	vc	vc	c	r	r	r		F	T	H					
O. ramulosa	vc	vr		c	vr	vr	vr	vc	vc			T	H	C				
O. speciosa	c			r	c		r					T						
O. teretifolia N								c	vc				H					
Opercularia ovata								r	r				H					
O. varia	r	r		r		vr	r	c	vc			T	H					
Ophioglossum coriaceum									vr				H					
Orthoceras strictum	c	r			vr				r				H			W		
Orthrosanthus multiflorus N E	vr													C				
Ottelia ovalifolia 13							+									W		
Oxalis corniculata	c	r	r	c	c	r	vr	r	vc			T	H					
**O. incarnata*							vc											D
**O. pescaprae*					vc		vc		vc									D
**O. purpurea*							vc		c									D
Paracaleana minor (R.Br.)D.Blaxell		vr							vr				H					
Parahebe derwentiana (Andr.) B.Briggs et Ehrend.	r			c	vc	vr	c		c		F	T						

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
Parahebe perfoliata (R.Br.) B.Briggs et Ehrend.									vr				H					
**Parapholis incurva*				vc	r				c					C				
**P. strigosa*				r					r						M			
**Parentucellia latifolia*	vr			c	vr			r	c				H	C				D
**P. viscosa*	vc	c	c	r	c	r			c	N	F	T	H					D
Parietaria debilis				vc										C				
Parsonsia brownii W			vr	vr						N								
**Paspalum dilatatum*	r	vr	r	r	vr	r		vr	c									D
P. paspalodes (Michx.) Scribn.				c												W		
Patersonia fragilis	vc	vc		vc	vc	c	vc	v	vc				H			W	S	
P. occidentalis R.Br.	vc			vc	c				r				H					
**Pelargonium* X *asperum*			r						vr									D
P. australe	r	r		r	vr	vr		vr	c			T		C				
P. inodorum	vr			r	r	vr				N								
P. littorale N	vr			vr	vr									C				
P. rodneyanum									vr				H					
Pellaea falcata				c	vc		r		c	N	F							
**Pennisetum clandestinum*	r			c					vc									D
Pentapogon quadrifidus	vc			r			r	r				T						
Persoonia juniperina	r	r				r	vr	vc	c			T	H					
**Petrorhagia prolifera*				vc														D
**P. velutina*				vc														D
**Phalaris minor*	c			r	r				r									D
**P. aquatica* L.					r		vc		r									D
Phebalium squameum N W	vr	vc	vc	vc	vc	vc				N	F							
**Phormium tenax*				vr	vr				vr									D
Phragmites australis (Cav.) Trin. ex Steud.	vc	vc		vc	r		vc	vc	vc				H	C		W		
Phyllanthus gunnii N									vr		F							
P. hirtellus									c				H					
Phylloglossum drummondii	c	r						r	c				H			W		
**Physalis peruviana*				r							F							
**P. viscosa*				vr														D
**Picris echioides*	c			r	r													D
**P. hieracioides*				c										C				D
Pimelea axiflora		c	vc	vc	vc	vc				N	F							
P. flava		vr			vr	vr					F							
P. glauca	c	r		vc					c			T	H	C				
P. humilis	vc	c		c		vr	vr	vc	vc				H	C				
P. ligustrina	r	r	c	r	c	vc	c				F							
P. linifolia	r	c		c		r		c	c			T	H					
P. octophylla	r							r	c				H					
P. phylicoides						r		vc	c				H					
P. serpyllifolia									vc					C				
**Pinus pinaster*						vr			vc				H					D
**P. radiata*	vc		c	vr	c		c	c	vc			T	H					D
Pittosporum bicolor W		c	c	r	r	c				N	F							
**P. undulatum*					r				vc				H	C				D
**Plantago coronopus*	vc			vc	r	r		vr	vc						M			D
P. debilis				vr	r						F							
**P. lanceolata*	c	r	c	vc	vc	r	vr	r	vc									D
**P. major*		r	c	c	c	vr			vc									D
**P. australis* Lam. A				r														D
P. varia	r			c		vc		vc	vc			T	H	C				
Platylobium formosum		vc	c									T						
P. obtusangulum	c	c		vc		c	c	vc	vc			T	H					

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
Platylobium obtusangulum var. *spinulosum* N								vr	vr				H					
Platysace heterophylla								c	r				H					
Pleurosorus rutifolius									vr			T						
**Poa annua*	r	c	r	c	vc	r		r	vc					C				D
P. labillardieri	vc	r		vc	vc	vc	r	vc	vc		F	T	H					
P. poiformis	vc			vc	vc									C				
P. sieberana	vc	r		vc	c	vc	vc	vc	vc		F	T	H					
P. sp.aff.*morrisii*	c	c					c	vc					H					
P. tenera	vc		c	vc	vc	vc	c		vc							W		
Podolepis jaceoides N					vr				vr				H	C				
**Polycarpon tetraphyllum*	c			vc				r	vc					C				D
**Polygala myrtifolia*				vr	c				vc					C				
**Polygonum aviculare*		vr		vr	vr				r									D
P. hydropiper			r	r		c										W		
P. minus	r		c	r		c			c							W		
P. strigosum			r	r		r										W		
Polyphlebium venosum			vc	vc	vc					N	F							
**Polypogon monspeliensis*	vr			vc	vr				vc									D
Polypompholyx tenella	c				r				r							W		
Polystichum proliferum	vc	vc	vc	vc	vc	vc	c	c	c	N	F					W		
Pomaderris aspera	c	c	vc	vc	vc	vc			vc	N	F							
P. elachophylla		vr			r	vr			r			T						
P. ferruginea W									c			T	H					
P. oraria				c					vc					C				
P. racemosa	vr					vr		vr	r			T				W		
Poranthera microphylla	c	r		c	r	c	r	c	c		F	T	H					
Potamogeton crispus				(+)												W		
P. ochreatus			vr	vr					r							W		
P. pectinatus	c															W		
P. perfoliatus 14c				(+)												W		
P. tricarinatus	r						c									W		
Prasophyllum archeri 11							vr		(vr)				H			W		
P. australe	c	r		c	r		vr		vr							W		
P. beaugleholei N			vr				vr				F							
P. brainei 11				vr					vr									
P. brevilabre	r	c							vr			T						
P. despectans	r	c							vr				H			W		
P. elatum	r	r						r	c				H					
P. flavum N				vr									H					
P. frenchii 14c									(+)				H					
P. gracile 9a									(+)				H					
P. morrisii		r				vr			c				H					
P. odoratum	r			r					c				H					
P. odoratum var. *album*									r				H					
P. patens 14c																		
P. sp. (formerly called *P. nigricans*)									r				H					
Pratia pedunculata	vc	vc	r	vc	vc	vc	vc	c	c	N	F	T				W		
P. platycalyx	r			c					r						M	W		
P. sp. aff. *purpurascens*	r	c			r						F							
Prostanthera lasianthos	c	vc	vc	vc	vc	c	c		vc	N	F	T						
P. melissifolia W		r	c		vc	c	c			N	F							
P. nivea N									vr			T						
Prunella vulgaris	c	c	r	c	c	c	vr	vr	c	N	F	T	H			W	S	D
**Prunus cerasifera*		r			vr	vr	vr	vr										D
**Psoralea pinnata*				r					r									D

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
Pteridium esculentum	vc	vc	vc	vc	vc	vc	vc	vc	vc	N	F	T	H	C			S	D
Pteris comans W 12 14c			(+)		(+)													
P. tremula					vr				vr		F							
Pterostylis alata	r	r		vr					vr				H					
P. alpina					vr	vr			vr		F	T						
P. concinna									c				H	C				
P. cucullata N				r								T		C				
P. curta									c				H					
P. falcata	vc			c					c							W		
P. falcata X *P. nutans* N									vr							W		
P. foliata	r	r							vr			T		C				
P. longifolia	vc	c		vr	vr	vr	c	c	vc		F	T	H					
P. nana	c	c		r			c		vc			T	H	C				
P. nutans	vc	c		c			r	c	vc			T	H					
P. obtusa			vr	vr	vr	vr		vr		N	F	T						
P. parviflora	r	r	r	r		r	vr	r	vc			T	H					
P. pedunculata	c	c	r	vr					r	N			H	C				
P. plumosa L. Cady	c	c		vr			r	vr	c				H					
P. tenuissima E	c								vr							W		
P. vittata									c				H					
Ptilotus macrocephalus N									vr				H					
Puccinellia stricta	vr			r					r					C	M			
Pultenaea canaliculata N	r			c										C				
P. daphnoides	vc	vc	c	vc	vc	vc		vc	vc		F	T	H	C			S	
P. dentata	c			c			r		c							W		
P. gunnii						r		vc	r			T	H					
P. humilis				r				vc	vc			T	H					
P. juniperina var. *planifolia*	vc				vc	vc	c		vc		F	T				W		
P. mollis		r							vc				H					
P. muelleri W	c	r	c										H				S	
P. muelleri var. *reflexifolia* N W 14d					(+)													
P. prolifera	vc	vc						vc					H					
P. scabra								vc	r			T	H					
P. stricta	vc	r		r			c		c							W		
P. subumbellata		vc														W		
P. tenuifolia	c			vc					c					C				
Ranunculus inundatus	r															W		
R. lappaceus	c			c		c								C				
**R. muricatus*		r		c														D
R. papulentus	vr					r		r								W		
R. plebeius			r	c	c	c			c		F	T	H					
R. pumilio				c		vr		vr				T	H					
**R. repens*		c	c	c	c	c				N	F							
R. rivularis	r		r	c	r	r			r							W		
R. sessiliflorus	r				vr	vr					F			C				
**Raphanus raphanistrum*					vc	c	c		vc									D
Restio tetraphyllus 14b		c	+	r					r							W		
Rhagodia baccata	c			c					c					C				
R. hastata									r					C				
R. nutans									c					C				
**Romulea longifolia*	r				vc		vc	vc	vc									D
**Rosa rubiginosa*				vr					r									D
**Rubus cissburiensis* 2																		D
**R. laciniatus*				r	vr	vr			vr	N	F	T						D
R. parvifolius	c	c	vc	c	c	vc	vr	c	vc			T	H	C				
**R. polyanthemus* 2																		

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
**Rubus procerus* 2																		
**R. rosaceus* 2		(+)	(+)															
**R. selmeri* 2					(+)													
**R. ulmifolius* 2																		
**R. vestitus* 2			(+)				(+)											
Rumex bidens 3									(+)							W		
R. brownii	r	vr	r	r	r	r			r					C		W		
**R. conglomeratus*				r	r				c							W		D
**R. crispus*	r	r	r	vc	r	vr	vr		c									D
**R. obtusifolius*		r				r												D
**R. pulcher*				c												W		
**R. sagittatus*									r					C				
Rumohra adiantiformis			vc	vc	c					N	F							
Ruppia maritima				r												W		
Rutidosis multiflora	c							vc					H					
Sagina apetala	r			r				r						C				
S. procumbens		vr		r	r	r	r		c									D
Salicornia blackiana	r														M			
S. quinqueflora	r			vc	vc				vc					C	M			
**Salix alba* X *S. fragilis*		r					<u>c</u>											D
**Salpichroa origanifolia* 10																		
Sambucus gaudichaudiana	vr	r	r	vr	r	vr			vr	N	F			C			S	
Samolus repens	c			vr	vc				vc					C			S	
Sarcochilus australis N W			vr	r						N								
**Sarothamnus scoparius*			r				r											D
**Scabiosa atropurpurea*									<u>c</u>									D
Scaevola albida N				vr										C				
S. pallida	c			c	vc				vc					C				
Schizaea asperula 14c					vr				+				H			W		
S. bifida	r	r						r					H			W		
S. fistulosa		c			vr				r				H			W		
Schoenus apogon	vc	c	r	c	c	r	c	vc	vc			T	H					D
S. breviculmis N E								vc	vc				H					
S. brevifolius 14c									(+)									
S. maschalinus	c	vc	c	c	c		vr	r	r		F	T	H					
S. nitens	c			vc					vc					C	M	W		
S. tenuissimus	vc	vc		vc		vc	vc	vc	r				H			W		
S. tesquorum	vc						vc	c	c							W		
S. turbinatus N								r	r				H					
Scirpus cernuus	c		r	c					r					C		W		
S. fluitans	c						r	r	r							W		
S. fluviatilis				c												W		
S. hookeranus					vr	vr		r		N			H					
**S. hystrix*	r							r								W		
S. inundatus	c	c	r	r	r	r	c		r				H			W	S	
S. marginatus Thunb.	c			vc				r	c			T	H			W		
S. maritimus	r													C		W		
S. nodosus	vc			vc	vc				vc			T		C				
S. platycarpus				r	vr									C		W		
S. productus	r															W		
S. pungens Vahl	c			r	vr				r					C		W		
S. validus				c					c					C		W		
Scleranthus biflorus N				vr										C				
Scutellaria humilis				r									H	C				
Sebaea albidiflora	c								c						M			

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
Sebaea ovata	c			vc	r	r		r	c				H					D
Selaginella gracillima	vc							r								W		
S. uliginosa	vc	vc		vc	vc	vc	c	r	vc				H			W		
Selliera radicans	r			r					c					C	M	W		
**Senecio elegans*				c					c					C				D
S. glomeratus	c	r		vr	c	r		vr	vc			T	H	C				
S. hispidulus	c	vr	r	r		vr	r	r	vc			T	H	C				
**S. jacobaea*	c	c	c	c	r	r	r	vr	c		F	T						D
S. lautus	c	vr	r	vc	vc	vc			vc		F	T	H	C				
S. linearifolius	vc	vc	vc	vc	vc	vc			c	N	F	T		C				
**S. mikanioides*	vr	vr							r									D
S. minimus	r	vc	c	vc	vc	vc		c	vc		F	T	H	C				
S. odoratus	c		c	vc	vc	c			vc		F	T		C				
S. quadridentatus	vr	vr			r		c	c	c			T	H	C				
S. squarrosus	r													C				
S. velleioides	vr	r	c	c	c	vc			c	N	F						S	
**Setaria geniculata*	vr																	D
**Sherardia arvensis*				c										C				D
Sigesbeckia orientalis			c	c	c	c			c	N	F			C				
**Silene gallica*				c														D
**S. nocturna*	r																	D
**Silybum marianum* 10																		
**Sisymbrium officinale*	vr					vr							H					
**Sisyrinchium iridifolium*	vr	vr		r	r	vr			c									D
S. pulchellum (R.Br.)F.Muell. N W			vr							N								
Solanum aviculare W				r	vr						F			C				
S. laciniatum	r		r	r		vr			r	N	F			C				D
S. linearifolium N W						vr				N								
**S. nigrum*	vr	vr	r	vr	vr	r	vr		c									D
S. opacum A.Br. & Bouché 7			(+)															
**S. sodomaeum* 10																		
Solenogyne bellioides	c							c	c			T	H					
**Soliva pterosperma*					vr									C				
**Sonchus asper*	r	r		r	vr	r		vr	c		F	T		C				D
S. hydrophilus Boulos	r														M			
S. megalocarpus	c			c	r				c					C				
**S. oleraceus*	r	c	r	r	vr	vr		vr	c			T		C				D
**Sparaxis tricolor*									c									D
Spergularia media	r								r								S	
Sphaerolobium vimineum	vc	r		vc		r		vc	vc				H					
Spinifex hirsutus	c			c	r				c					C				
Spiranthes sinensis 1									vr							W		
Spirodela oligorrhiza							vc									W		
**Sporobolus africanus*				c	c		c	c	vc					C				D
S. virginicus	c														M			
Sprengelia incarnata	vc	vc		vc			r		c				H			W		
Spyridium parvifolium	vc	c		c	vc	vc			vc		F	T	H					
S. vexilliferum E	r								c				H	C				
Stackhousia monogyna	r			vc	r	r		c	vc		F	T	H	C				
S. spathulata	c			c										C				
Stellaria filiformis	r			r										C				
S. flaccida	c	vc	vc	vc	vc	vc			c	N	F	T		C				
**S. media*		vr	r	r	vr									C				D
S. pungens	vc			vc	vc	c		c	vc	N	F	T						
**Stenotaphrum secundatum*				vc					vc					C				D
Sticherus lobatus N W			r		r					N	F							

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
Sticherus tener		r	c	vr	c				vr	N	F							
Stipa compacta				vc										C				
S. elatior	c			c					(+)				H	C				
S. hemipogon	c								(+)				H	C				
S. nervosa W									c			T	H					
S. pubescens	vc			vc			c	vc	c									
S. tenuiglumis Hughes E	r													C				
S. variabilis									c				H					
Stuartina muelleri	c																	
Stylidium beauglaholei N	vc			c									H					
S. graminifolium	c	vc		c	vc	c	vr	vc	vc			T	H	C				
S. inundatum	vc							c					H					
S. perpusillum	vc												H					
Stypandra caespitosa	c	c		r		r	c	vr	vr				H			W		
Swainsona lessertiifolia	c			vc					c					C				
**Taraxacum officinale*		c	vc	c	c	r		vr	c									D
Tetragonia implexicoma	c			c	c				vc					C				
Tetraria capillaris	vc			vc					c				H			W		
Tetrarrhena acuminata		c														W		
T. distichophylla	vc	vc	vc	vc	vc	vc	vc	vc	vc			T	H			W		
T. juncea	vc	vc	vc	vc	vc	vc	vc	vc	vc	N	F	T	H			W		
Tetratheca ciliata	vc	vc		c		c	vc	vc	c			T	H					
Thelymitra antennifera	r	r						c	vc			T	H					
T. aristata (formerly called *T. grandiflora*)	r	c		r			r	r	r				H					
T. carnea									vr				H					
T. epipactoides N	vr								(vr)				H					
T. flexuosa	vc	c		r				c	c			T	H					
T. fuscolutea N		c						vr				T	H					
T. holmesii N E	r								r							W		
T. ixioides	c	c		vr			r	r	c			T	H					
T. luteocilium N 5									(vr)				H					
T. X *macmillanii* N 11									(vr)				H					
T. matthewsii N 9									(vr)									
T. media									vr			T	H					
T. mucida N E									r							W		
T. pauciflora	vc	c		c		vr		c	c	N	F	T	H					
T. rubra		r						c	vc			T	H					
T. sp.(formerly called *T. aristata*)									r				H					
T. venosa N		r														W		
Themeda australis	vc			vc	vc		vc	vc	vc			T	H	C				
Thomasia petalocalyx N	c								vc				H	C				
Threlkeldia diffusa	c			vr					r					C				
Thysanotus dichotomus N E									c				H					
T. patersonii	r			r				vc	vc			T	H	C				
T. tuberosus	c			c		c		r	c			T	H					
Tieghemopanax sambucifolius N W		r										T						
Tmesipteris billardieri N			vr	vr						N								
T. elongata N W 6										N								
Todea barbara		vr		r	vr				vr	N						W		
Tricoryne elatior									c			T	H	C				
Tricostularia pauciflora		c						vc	c				H					
**Trifolium campestre*		r		vc	vr													D
**T. cernuum*	vr				vr	vr												D
**T. dubium*	c	vc		vc	vc	c		vr										D
**T. fragiferum*				c														D
**T. glomeratum*				vr		r												D

Floristic Check-list of the Otway Region (continued)

SPECIES	BLOCK									COMMUNITY								
	H	C	R	O	T	P	B	S	A	N	F	T	H	C	M	W	S	D
**Trifolium repens*	c	r	vc	c	c	c	vr	vr	vc									D
**T. subterraneum*	vr			r	vr	vr			vc									D
**T. tomentosum*	r																	D
Triglochin centrocarpa	c			r					(+)					C				
T. minutissima	r														M			
T. procera	r		r	vc			r		c					/		W		
T. striata	c			vc			c		vc					C	M	W		
**Trigonella ornithopodioides*					vr	vr		vr						C				
**Tropaeolum majus* L. A					r				c									D
Typha sp. (see 3)	c			c	c	c		vc	vc							W		
**Ulex europaeus*	r	r	c	c	c	c	c	c	c									D
Uncinia tenella W	vc	c	vc	c						N	F							
Urtica incisa		c	c	vc	vc	c			c	N	F			C				
**U. urens*									vc					C				D
Utricularia dichotoma	c	vc		c			c	r	r							W		
U. lateriflora		vc		r	r				r				H			W		
Velleia paradoxa									(vr)				H					
**Verbascum thapsus* 10																		
**V. virgatum*	r			r	r	r												D
**Veronica arvensis*				c				vr						C				D
V. calycina	vc			c	vr			r	c			T	H					
V. gracilis	c			vc					c			T	H	C		W		
V. notabilis N W			vr							N								
**V. persica*								vr	c									D
V. serpyllifolia N		r			r					N								
**Vicia angustifolia*				vr	vr	r			r									D
**V. hirsuta*				vr														D
**V. sativa*				vr	r	vr												D
**V. tetrasperma*				vr														D
Villarsia reniformis	vc						c	r	c							W		
Viminaria juncea	r							vr	r							W		
**Vinca major*	r	r		r	r		r	vr	r									D
Viola hederacea	vc	vc	vc	vc	vc	vc	vc	vc	vc	N	F	T	H				S	
**V. odorata*	r				vr													D
V. sieberana	r			vc	r	r	c	vc	c			T	H					
**Vulpia bromoides*	r	c		r	r			vr						C				
**V. ciliata*				r														D
**V. membranacea*				r										C				
**V. myuros*				c										C				D
Wahlenbergia gracilenta	r	r		c		r		vc	c		F	T	H	C				
W. gymnoclada	vc			vc		c		vr					H					
W. quadrifida	r	r		r	c	r		r	c			T	H	C				
W. stricta				r		r	vr	c	c				H					
W. tadgellii	r			r	r			r	r				H					
**Watsonia bulbillifera*		c	c		c	vc	c	c	c									D
**W. pyramidata*									c									D
Wilsonia backhousei	c								vr						M			
W. humilis	r														M			
W. rotundifolia	r														M			
Wolffia australiana						vc	vc									W		
Xanthorrhoea australis	vc	vc		vc		vc	vc	vc	vc			T	H					
X. minor	vc	vr		r				vc	c			T	H					
Xanthosia dissecta	c	c		r		r	c		c				H				S	
X. pusilla	c	c		c				r	c				H					
Xyris gracilis	vc	vc														W		
X. operculata	c	vc		r	c				r				H			W		
**Zantedeschia aethiopica*		r	r	vr	vc	r	r	vr	vr							W		D
Zieria arborescens			vc	r	c	r											S	
Zostera muelleri	c												marine					
Zygophyllum billardieri				c					c					C				

11

Drosophila (DIPTERA: INSECTA) IN THE OTWAY REGION OF VICTORIA: SPECIES DIVERSITY

By P. A. Parsons[1] and I. R. Bock[2]

ABSTRACT: In the Otway Region as in other suitable sites west of Melbourne, there is a western extension of the adaptive radiation of the typically Australian subgenus *Scaptodrosophila*. Flies are found in permanently damp habitats characterized by tree ferns and/or sedges.

Four *Scaptodrosophila* species belonging to the same species group occur in the Otways. This species group dominates the whole of Victoria, but in eastern Victoria and southern New South Wales, many other *Scaptodrosophila* species belonging to other species groups are found also. In these regions the higher diversity of *Drosophila* is expected, since floral diversity is higher and *Drosophila* as a genus is dependent upon the vegetation as a resource.

D. (Sophophora) dispar, a widespread species, is the only other endemic Australian species found in the Otway Region.

INTRODUCTION

Carson (1971), an eminent American evolutionary biologist working in Southeastern Australia in 1961, commented that 'this part of Australia is notably depauperate in its *Drosophila*' fauna by comparison with other parts of the world where *a priori* suitable habitats for species of the genus appear to occur. Recently, following intensive field work (Bock & Parsons 1975, Parsons 1975), it has become apparent that in the rain forest/wet sclerophyll forests of Southeastern Australia there are many endemic *Drosophila* species.

Previously, as assessed from a survey of museum collections by Bock (1976), rare occurrences of *Drosophila* were reported throughout the east coast region of Australia (including Tasmania and Victoria). Bock's study comprised 81 species, including 40 that are new. Forty-five of the species belong to the subgenus *Scaptodrosophila* which is rare on a world basis (Bock & Parsons 1975). In addition, four more *Scaptodrosophila* species have been found during recent field work in Southeastern Australia, and some species previously represented by very few specimens can now be regarded as common (Parsons & Bock unpublished).

The southern Australian situation is unique in that the well-known Hawaiian adaptive radiation is in the subgenus *Drosophila* and not the typically Australian subgenus *Scaptodrosophila* (Bock & Parsons 1975). There are in fact no known species in subgenus *Drosophila* endemic to Australia. The number of Australian species now known is about one-fifth of those described in Hawaii although many Hawaiian species have yet to be described (Hardy 1974).

In this paper we relate the Otway Region *Drosophila* collections to those elsewhere in Victoria.

COLLECTING METHODS AND SITE ECOLOGIES

With rare exceptions, southern Australian flies are not attracted to conventional baits of fermented fruit or rotting mushroom. Indeed all the Otway Region flies were obtained simply by sweeping with a deep net (39 cm diam.). Many of the Otway Region habitats are characterized by tree ferns (*Dicksonia*) and other ferns. In such habitats, which are generally in sheltered locations in mountainside gullies, the highest canopy is *Eucalyptus*, though tall *Acacia* and *Nothofagus cunninghamii* may occur also (sites 1-5, and 8 in Fig. 1 and Table 1). The fern gullies yielding flies are characterized by permanent water or wet rotting on the ground. In addition, *Drosophila* has been found in permanently damp habitats characterized by sedges often at the edge of freshwater swamps and small lakes (sites 6 and 7 in Fig. 1 and Table 1).

Habitats in the Otway Region and elsewhere in Victoria which are disturbed by fire, flood, logging, or introduced plant species such as blackberries, normally have a depauperate *Drosophila* fauna. Presumably these disturbances upset the life cycle of the flies, which from evidence so far involves the larvae as

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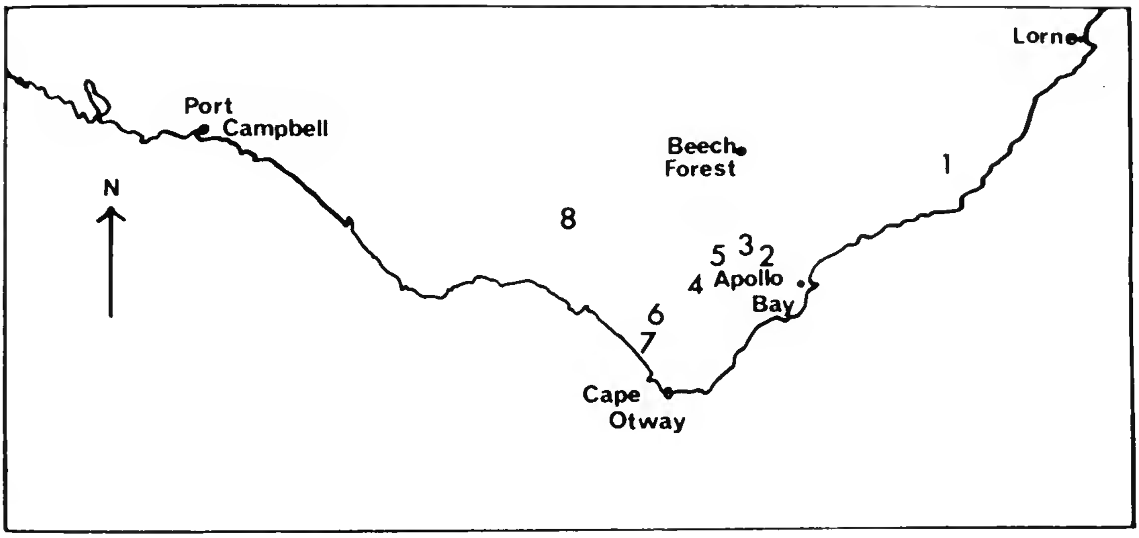

FIG. 1—Map of the Otway Region indicating the eight collection sites listed in Table 1.

miners of decomposing leaf litter followed by pupation in the soil. In other words the flies are intimately dependent on the flora as a resource, which is a feature of the genus on a world-wide basis (Carson 1971).

All species mentioned in this paper are described in Bock (1976), some for the first time. These include *D. collessi*, *D. rhabdote*, *D. barkeri*, *D. exemplar*, *D. megagenys* and *D. parsonsi*.

RESULTS

An initial late winter Otway Region collection made in September 1974 by Grossfield and Parsons (1975) consisted of four *D. (Scaptodrosophila) inornata* (1 ♂, 3 ♀♀) from Paradise Valley (site 2, Fig. 1). Subsequent summer collection records are in Table 1.

Four *Scaptodrosophila* species are listed in Table 1. Of these *D. inornata* is the commonest by far. The only exception is for site 7 which is a sedge habitat, where *D. rhabdote* predominates. It is a general feature of western Victorian collections that *D. inornata* predominates in tree fern habitats and *D. rhabdote* in sedge habitats. Table 2 gives comparative data for other western Victorian sites. *D. rhabdote* predominates in the sedge habitats of Mt. Eccles National Park

TABLE 1

SUMMED COLLECTIONS OF OTWAY REGION *Drosophila* FROM LATE 1974 TO LATE 1975

Subgenus	Sophophora		Scaptodrosophila								
Species	dispar		inornata		collessi		fuscithorax		rhabdote		Total
Site	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	
1. Grey River Scenic Reserve			3	6							9
2. Paradise		2	113	57	6	7	1		1	6	193
3. Killala			10	42	1						53
4. Mait s Rest		1	73	82	1			1	3		161
5. Cape Horn			3	10							13
6. Hordern Vale Road about 1 km from Aire River.	2		1		1	1					5
7. Hordern Vale Road at Aire River.	1	2	1				1		6	18	29
8. Beauty Spot	1			1		1					3
Total	4	5	204	198	9	9	2	1	10	24	466

TABLE 2

SUMMED COLLECTIONS OF WESTERN VICTORIAN *Drosophila* FROM LATE 1974 TO LATE 1975

Subgenus	Sophophora	Scaptodrosophila					Total
Species	dispar	inornata	collessi	fuscithorax	rhabdote	parsonsi	
Mt. Eccles National Park) Tower Hill)		8			50		58
Mt. Cole Forest) Grampian Ranges)		329	10			1	340
Lerderderg Gorge) Mt. Macedon) Brisbane Ranges)		85	6		4		95
Otway Region	9	402	18	3	34		466
Total	9	824	34	3	88	1	959

and Tower Hill, *D. inornata* in the remaining sites where tree ferns are common. In Table 2, out of 959 flies collected only one, *D. parsonsi*, does not belong to the four *Scaptodrosophila* species listed in Table 1. Taxonomically, the latter four species are closely related, forming a species group (Bock 1976).

D. (Sophophora) dispar is a fifth Otway Region species not belonging to subgenus *Scaptodrosophila*. This species has not been found elsewhere in western Victoria, but is common in east coast rain forests as far north as Cairns. It is therefore the only exception to the total domination of *Scaptodrosophila* in western Victoria.

Turning to eastern Victoria (Wilson's Promontory and East Gippsland), all of the six species so far mentioned have been found in tree fern and/or sedge habitats. *D. inornata* remains dominant, but less completely so, since a number of other *Scaptodrosophila* species appear. These are *D. obsoleta, D. barkeri, D. exemplar, D. megagenys* and four species as yet undescribed, as well as *D. (Hirtodrosophila) polypori*. Of these only *D. obsoleta* belongs to the same species group as the Otway Region species. Species diversity therefore increases in eastern, as compared with western, Victoria. This appears to parallel the appearance of plant species such as the lilly-pilly, *Eugenia smithii*, which are characteristic of the rain forests of the east coast of Australia (Francis 1970). Indeed the East Gippsland flora is unique through its diversity and the presence of species not found elsewhere in Victoria (Ashton 1969). Further north, *Drosophila* species diversity from both recent collections and museum surveys (Bock 1976) is even higher. The empirical generalization that species diversities of plants and animals usually decrease with increasing latitude appears therefore to be applicable to Australian *Drosophila* (*vide* Emlen 1973). Additionally, and as already stressed, on a world-wide basis *Drosophila* as a genus is dependent upon the vegetation as a resource (Carson 1971).

DISCUSSION

The Otway Region species represent one section of an Australian adaptive radiation of the subgenus *Scaptodrosophila*. The number of species is very low compared with coastal forests to the east and north. This is almost certainly associated with greater and changing floral diversity in these latter regions. The major feature determining survival appears to be a suitable temperature/humidity regime, as found in permanently damp areas (Parsons 1975). Given the environment of Southeastern Australia, many of these suitable habitats are necessarily isolated by considerable distances (Bock & Parsons 1975), as exemplified by the Otway Region. This affords opportunity to study the *Drosophila* of 'insular islands of vegetation' on a continent as determined by suitable temperature/humidity parameters. In many cases these are marked by the presence of tree ferns in moist gullies. The 'insular islands' have probably been separated for at least 6,000 years, or since the end of an era of high precipitation, high temperature, and high rainfall (Rawlinson 1974).

There is a parallel with the populations of the Hawaiian Islands, which are isolated both between, and within islands by unsuitable climates and/or by factors such as lava flows. Suitable habitats in the Hawaiian Islands often have many *Drosophila* species, but each habitat has to some extent its own unique fauna. Temperature and humidity extremes are less frequently limiting in Hawaii in regions where flies occur than in Australia. However, there is a parallel between Hawaii and Australia, since the Hawaiian species avoid temperatures above 21°C and relative humidities below 90% (Carson et al. 1970). In Southeastern Australia it is normally these physieal boundary eonditions that determine isolation given the need for permanent moisture (Parsons 1975), while in many regions in the Hawaiian Islands there is permanent moisture, but geographie features such as lava flows are important in determining isolation.

The end result in both eases is the same: an adaptive radiation in a subgenus of *Drosophila*. The Hawaiian speeies (subgenus *Drosophila*) are easily charaeterized by simply observed morphologieal traits; thus their taxonomy is simple. Many species, espeeially the large patterned/winged speeies are sexually highly dimorphie, with eomplex mating patterns. The Australian *Scaptodrosophila* are frequently diffieult to separate taxonomieally, since relianee on the internal male genitalia is often neeessary to separate some speeies. Furthermore sexual dimorphism is slight or absent. The flies are mainly small, the largest so far found being about four times as large as the eosmopolitan speeies *D. melanogaster* though several are smaller. The Otway Region speeies are about the size of *D. melanogaster*.

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REFERENCES

ASHTON, D. H., 1969. Botany of East Gippsland. *Proc. R. Soc. Vict.* 82: 69-76.

BOCK, I. R., 1976. Drosophilidae of Australia I. *Drosophila* (Insecta: Diptera). *Aust. J. Zool.* Suppl. Ser. No. 40, 1-105.

————, & PARSONS, P. A., 1975. Adaptive radiation in the subgenus *Scaptodrosophila* of Australian *Drosophila*. *Nature*, 258: 602.

CARSON, H. L., 1971. The ecology of *Drosophila* breeding sites. Harold L. Lyon Arboretum Lecture Number Two. 27pp. University of Hawaii.

————, HARDY, D. E., SPIETH, H. T. & STONE, W.S., 1970. The evolutionary biology of the Hawaiian Drosophilidae. In: *Essays in evolution and genetics in honor of Theodosius Dobzhansky* (Eds. M. K. Hecht & W. C. Steere), pp. 437-543. Appleton-Century-Crofts, New York.

EMLEN, J. M., 1973. *Ecology: an Evolutionary Approach*. Addison-Wesley, Reading.

FRANCIS, W. D., 1970. *Australian Rain/forest Trees*. Australian Govt. Publ. Serviee, Canberra.

GROSSFIELD, J. & PARSONS, P. A., 1975. Loeality reeords for some endemie Australian Drosophilidae based on winter eolleetions. *Proc. R. Soc. Vict.*, 87: 235-237.

HARDY, D. E., 1974. Evolution in the Hawaiian Drosophilidae. Introduction and background Information. In: *Genetic Mechanisms of Speciation in Insects* (Ed. M. J. D. White), pp. 71-80. Australia and New Zealand Book Company, Sydney.

PARSONS, P. A., 1975. The effect of temperature and humidity on the distribution patterns of *Drosophila inornata* in Victoria, Australia. *Environ. Entomol.* 4: 961-964.

RAWLINSON, P. A., 1974. Biogeography and eeology of the reptiles of Tasmania and the Bass Strait area. In: *Biogeography and Ecology in Tasmania* (Ed. W. D. Williams), pp. 291-338. W. Junk, The Hague.

12

A COMPARISON OF THE INVERTEBRATE FAUNA UNDER *Eucalyptus* AND *Pinus* FORESTS IN THE OTWAY RANGES, VICTORIA

By L. D. Ahern* and A. L. Yen†

ABSTRACT: The invertebrates under a mature *Eucalyptus regnans* forest and a mature *Pinus radiata* plantation were sampled in May 1975. When the invertebrates from these sites were compared, marked differences were found in most groups.

INTRODUCTION

Plantations of exotic softwoods (predominantly *Pinus radiata* D. Don) have replaced native forests in many parts of Australia, and there has been considerable discussion about the extent to which the establishment of such plantations affects native fauna.

Studies on invertebrates associated with introduced conifers in Australia have been few, and have taken a predominantly pest management approach (Campbell 1971, Minko 1961, Moore 1963, 1972).

Unlike vertebrates, which are often highly vagile, many invertebrates depend closely upon components of native vegetation for their survival. Little attention has been paid to invertebrates associated with pine plantations, to the detailed reasons for elimination of particular taxa, or to the ecological consequences of such elimination. The presence of an animal in pine forest does not necessarily imply permanent occupancy, nor ability to survive and reproduce in that habitat. Many of the vertebrates and flying insects may be transient in pines, while other species may survive in pines but require continual repopulation from adjacent native areas, e.g. Forster and Wilton (1973).

METHODS

During 18-19 May 1975, the invertebrate fauna in mature, unlogged *Eucalyptus regnans* F. Muell. forests and mature *Pinus radiata* plantations in the central Otway Ranges was sampled. Only the invertebrate macrofauna and mesofauna as defined by Murphy (1955) were studied.

Four study sites, each of approximately two ha were selected; the *P. radiata* sites were located 6 km SSW. of Beech Forest in the Aire Valley Plantation and the *E. regnans* sites were 2-3 km S. and SW. of the pine sites. Two different aspects (NW. and SW.) were chosen in pines (May 18) and duplicated in eucalyptus (May 19).

One 50 m transect containing three equidistant circular quadrats of 3 m radius was established along the contour at each site. Within each quadrat the understorey vegetation between the substrate and the 2 m level was sampled by beating; a 10 x 10 cm litter sample and a 10 x 10 x 10 cm soil sample were also taken. One 20 x 20 cm bark sample was taken from each of four individuals of the dominant tree species near the transect, each sample being at a different aspect (N., S., E. and W.) and at a height of 0-30 cm from ground level. At each site, a random search was made for macrofauna within 25 m on either side of the transect and 10 litter depth measurements were recorded. The same time was spent in random searching at each site.

The soil, litter and bark invertebrates were extracted using Tullgren funnels. Most animals were sorted into apparent species, but for a number of taxa (Oligochaeta, Pseudoscorpionida, Acarina, Pauropoda, Diplopoda, Symphyla and Lepidoptera) representatives were only counted, due to the difficulty involved in their identification. Numbers of individuals in all groups and/or species were tallied and these results were pooled for the two eucalypt sites and for the two pine sites. A complete list of animals and the numbers collected is given in Appendix 1. All tallies for Orders represented by 10 or more individuals were statistically analyzed (Simpson, Roe & Lewontin, 1960) whilst random search values shown in Appendix 1 were excluded from analysis.

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RESULTS

Eucalypts supported significantly more individuals (8868) than pines (3179) (Table 1). Similarly, eucalypts contained more species (169) than pines (65). The following taxa showed significant numerical dominance favouring eucalypts: Oligochaeta, Acarina, Araneae, Ostracoda, Isopoda, Pauropoda, Diplopoda, Collembola, Hemiptera, Coleoptera, Diptera, Lepidoptera and Hymenoptera. Only four taxa of the 18 analyzed were not significantly different: Pseudo-scorpionida, Amphipoda, Chilopoda and Symphyla. Ostracoda and Paurapoda were absent from the pines, and Oligochaeta, Isopoda, Diplopoda, Diptera and Hymenoptera were poorly represented (Table 1).

The eucalypt understorey vegetation, soil and bark samples contributed significantly more individuals than the corresponding pine layers, whilst the litter contained more individuals per unit area under pines than under eucalypts (Table 2). The relative distribution of individuals and of species numbers throughout all eucalypt layers is significantly different from that of pine layers (Table 2).

DISCUSSION

At the time of sampling, marked differences were found in numbers of both individuals and species occurring under eucalypts and pines, and this may be considered in the light of the greater heterogeneity of the understorey vegetation, soil, litter and bark components of the eucalypts. Results of random search (Appendix 1) show that 26 additional species were found in eucalypts and 35 in pines, possibly because the more open, homogeneous pine habitat permitted a more thorough search to be made.

The higher number and diversity of invertebrates in eucalypt understorey vegetation may be explained by the greater floristic density and diversity in the eucalypts (G. W. Carr, pers. comm.). Many phytophagous insects are host plant dependent and thus are eliminated from habitats lacking suitable hosts. The reduced spider fauna in pines, especially species requiring suitable structures upon which to suspend webs (e.g. Argiopidae), reflect the inadequacy of pine understorey in providing microhabitats. This factor would be limiting in pines regardless of prey availability.

The influence of soils upon the soil fauna, which was markedly reduced in pines when compared to eucalypts, was not ascertained.

The small numbers of both individuals and species in the pine bark are associated with the persistent nature of the *P. radiata* bark, which offers fewer microhabitats than does the sub-persistent bark sampled on *E. regnans*.

Although litter under pines had fewer invertebrate

TABLE 1

TOTAL NUMBERS OF INDIVIDUALS COLLECTED IN *Eucalyptus* AND *Pinus* SITES. IN ORDERS WITH MORE THAN 10 SPECIES COLLECTED. THE NUMBER OF SPECIES IS IN PARENTHESIS.
χ^2 SIGNIFICANCE LEVELS (*) 0.05; (**) 0.01; (***) 0.005.

Taxa	No. Individuals *Eucalyptus*	No. Individuals *Pinus*	χ^2
Oligochaeta	25	4	15.20***
Pseudoscorpionida	26	21	0.54 n.s.
Acarina	5739	2454	1317.13 ***
Araneae	145 (37)	48 (19)	48.76 ***
Ostracoda	664	0	664.00 ***
Amphipoda	18	12	1.20 n.s.
Isopoda	113	2	107.14 ***
Pauropoda	90	0	90.00 ***
Diplopoda	77	3	68.46 ***
Chilopoda	9	5	1.14 n.s.
Symphyla	3	7	2.28 n.s.
Collembola	1131 (7)	518 (8)	227.88 ***
Hemiptera	33 (13)	15 (5)	6.76 **
Coleoptera	312 (47)	44 (14)	201.76 ***
Diptera Larvae	114 (20)	11 (6)	84.88 ***
Adults	34 (14)	3 (5)	8.34 ***
Lepidoptera	24	3	16.34 ***
Hymenoptera	288 (24)	4 (4)	276.22 ***
Total	8868 (169)	3179 (65)	

TABLE 2

TOTAL NUMBERS OF INDIVIDUALS AND SPECIES IN DIFFERENT SAMPLING LAYERS IN *Eucalyptus* AND *Pinus* SITES. χ^2 SIGNIFICANCE LEVELS (*) 0.05; (***) 0.005.

	Eucalyptus		*Pinus*		χ^2	
	Individuals	Species	Individuals	Species	Individuals	Species
Understorey vegetation	1156	87	160	36	753.81***	10.57***
Soil	1720	62	757	11	374.39***	17.82***
Litter	1579	47	2028	28	55.89***	4.81*
Bark	4413	57	234	21	3758.13***	5.68*
					χ^2_3=2686.54***	χ^2_3=46.22***

species than under eucalypts, the number of individuals per unit area in the pine litter is greater than that in the eucalypt. Taking into account the litter depths in pines (5.8 cm) and eucalypts (2.6 cm), the actual density of invertebrates was higher in eucalpts. The reduced species richness of the pine litter may be due partly to the homogeneous composition of the litter and partly to the chemical nature of the pine needles (e.g. Etherington 1975).

The invertebrate fauna of the understorey vegetation, soil, litter and bark layers under the eucalypts showed greater species richness and higher numbers of individuals than under the pines, at the time of sampling. This is probably due to the greater structural complexity of the eucalypt habitat. However, further studies are necessary to ascertain whether similar trends are found at other times of the year and at other sites. It is also necessary to ascertain the importance of the history of the pine site prior to planting, the ability of invertebrates to recolonize after plantation establishment, and the ability to utilize pine habitat.

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REFERENCES

CAMPBELL, K. G., 1971. Disease and insect problems in exotic *Pinus* spp. plantations in south-eastern Australia, with particular reference to *P. radiata* D. Don. In: *Pinus radiata Symposium Aust. Nat. Univ. Canberra, Aug. 1970. 1.* Paper 1F. 5pp.

ETHERINGTON, J. R., 1975. *Environment and Ecology*. J. Wiley and Sons, New York.

FORSTER, R. R. & WILTON, C. L., 1973. The spiders of New Zealand. Part IV. *Otago Museum Bull. 4.* Dunedin.

MINKO, G., 1961. The insects of *Pinus radiata* plantations in north-eastern Victoria. *Bull. No. 13, For. Comm. Vict.*

MOORE, K. M., 1963. Observations on some Australian forest insects. 14. A preliminary list of insects attacking *Pinus* species in New South Wales. *Aust. Zool.* 13: 69-77.

———, 1972. Observations on some Australian forest insects. 30. A supplementary list of insects attacking *Pinus* species in New South Wales. *Ibid.* 17: 59-64.

MURPHY, P. W., 1955. Ecology of the fauna of forest soils. In: *Soil Zoology* (Ed. D. K. McE. Kevan): 99-124. Proceeding of the University of Nottingham Second Easter School in Agricultural Science, 1955. London.

SIMPSON, G. G., ROE, A. & LEWONTIN, R. C., 1960. *Quantitative Zoology*. Harcourt, Brace and Co., New York.

APPENDIX 1

Numbers of Individuals Taken in Understorey Vegetation, Soil, Litter and Bark Samples in *E. regnans* and *P. radiata* Sites.

V Understorey vegetation; numbers/169.65 m² (6 x 28.27 m² samples). **S** Soil; numbers/6000 cm² (6 x 1000 cm² samples). **L** Litter; numbers/600 cm² (6 x 100 cm² samples). **B** Bark; numbers/3200 cm² (8 x 400 cm² samples). **R** Random search. * Individuals not differentiated beyond taxon shown. ** Immature stages for insects.

	Eucalyptus sites					Pinus sites				
	V	S.	L	B.	R.	V.	S.	L.	B.	R.
ANNELIDA										
*Oligochaeta		5	18	2		2	1	1		
*Hirudinea					2					3
ARTHRDPODA										
Arachnida										
*Pseudoscorpionida	3	2		21		1		1	19	
Dpiliones sp. A			4	1				1		
B			1	1						
*Acarina	765	995	B23	3156		29	6B3	15B5	157	
Araneae										
Dipluridae sp. A				2	6					
Oonopidae sp. A							1			
Dysderidae sp A									2	
Decobiidae sp. A				1						
Dictynidae sp. A					2					
B					1					
C	3									
Salticidae sp. A	6			2						
B			1						3	3
C								1		6
D										2
E										1
Clubionidae sp. A						1				5
B	2					1				1
C	1									
Symphytognathidae sp. A		2	2			1		3	1	
B								1		
Mimetidae sp A								1		
Gnaphasidae sp. A					3					
B					1					
Thomisidae sp. A	4									1
B										1
C				1						
D			1							
E	1									
Theridiidae sp. A	1									
B	4					1		1	2	
C	2								1	
D						3			2	
E	2									

Appendix 1 (continued)

	Eucalyptus sites					Pinus sites				
	V	S.	L	B.	R.	V.	S.	L.	B	R.
F	6					1				
G	1									
H	1									
I	1									
Linyphiidae sp. A			1					1		
B										1
C		3								
D	1									
Argiopidae sp. A	3									1
B	11									1
C	46					10				10
D	13					6				
E	1									
F	6									
G	2									
H	1					1				1
I						1				
J					1					
K	1									
L	1									
Agelenidae sp. A					1					
B			1							
C										1
D				4				1	1	
Pisauridae sp. A					1					301
B										
Lycosidae sp. A		1								
B		2								
Crustacea										
Ostracoda										
Cyprididae sp. A		239	424	1						
Amphipoda										
Tallitridae sp. A	7	2	7	2		7		5		
Isopoda										
Oniscidae sp. A	46	4	6	56				2		
Armadillidae sp. A			1							
*Pauropoda				90						
*Diplopoda		43	16	18		2			1	
Chilopoda										
Geophilidae sp. A		1	2	3				1	1	
8		1		1						
Lithobiidae sp. A				1	2			3		
Crytopidae sp. A					2					
Symphyla										
*Scutigerellidae			1	2			7	1		
Insecta										
Collembola										
Poduridae sp. A	8	26	56	811		2	47	166	24	
B	8	35	10	83			1	208	2	
C		1		3				2	1	

Appendix 1 (continued)

	Eucalyptus sites					*Pinus* sites				
	V	S.	L	B.	R.	V.	S.	L.	B	R.
D								4		
Isotomidae sp. A	2	1		20		6	1		2	
Entomobryidae sp. A	40	2	8	10		12	3	13	1	
B	2							2		
Sminthuridae sp. A	3		1	1		21				
Diplura										
Campodeidae sp. A				1						
Japygidae sp. A		1	1				4			
Archagocnatha										
Meinertellidae sp. A							1			
Blattodea										
Blatellidae sp. A	1			1	5					
B					1					
Isoptera										
*Termitidae					6					
Plecoptera										
Nemouridae sp. A					1					1
Orthoptera										
Gryllacrididae sp. A										2
Tetrigidae sp. A								1		
Phasmatodea										
Phasmatidae sp. A	1									
Embioptera										
Oligotomidae sp. A									1	
Psocoptera										
Liposcelidae sp. A		1	1							
Philotarsidae sp. A										1
B	1									
C	1									
Peripsocidae sp. A	2									
Ectopsocidae sp. A										1
Caeciliidae sp. A						1				1
B						1				1
Psocidae sp. A	1									
Hemiptera-Homoptera										
Cixiidae sp. A	1									
Delphacidae sp. A						2				
Cicadellidae sp. A	1									
B										1
C	1									
Membracidae sp. A	1**									
Psyllidae sp. A	1									
B						1				
C		3**						4**		
Aphididae sp. A					1					1**
Coccidae sp. A		4					3	1	2	
Hemiptera-Heteroptera										
Nabidae sp. A										1
Reduviidae sp. A		1		3						
Saldidae sp. A	1									
Lygaeidae sp. A		2	6	1			2			
B		1								

Appendix 1 (continued)

	Eucalyptus sites					*Pinus* sites				
	V	S.	L	B.	R.	V.	S.	L.	B.	R.
C		1	4							
Gelastocoridae sp. A		1								
Thysanoptera										
Phlaeothripidae sp. A	1									
B	1									
Neuroptera										
Hemerobiidae sp. A	1									1
Coleoptera										
Sphaeriidae sp. A		9**							2**	
Carabidae sp. A			1**			2(1**)				
B	1**	2**	1**							
C				1						
Ptiliidae sp. A				9						
Scydmaenidae sp. A	2	1		1		4				
B				1		1				
Scaphidiidae sp. A	7									
B				2						
Staphylinidae sp. A						1			1**	
B	1		1	3						
C		5		3						
D		9								
E		45								
F		4	1	2				1		
G		1								
Pselaphidae sp. A				16						1
B				1						
Scarabaeidae sp. A		2**		1**						
Elateridae sp. A				1**						
B						1**				
C		11**								
D	1**	1**								
E		1**								
F					1**					
G		1**		1**						
H				1**						
I				1**						
Eucmenidae sp. A		3**	1**	21**					2**	
Anobiidae sp. A						1**				
Cleridae sp. A				2**						
Corylophidae sp. A	6									1
Coccinellidae sp. A									1	
Lathridiidae sp. A	1								3	
B										1
Ciidae sp. A					1					
Tenebrionidae sp. A		1								
B				1						
C				1						
Lagriidae sp. A		5**		6**						
Melandryidae sp. A	3			1						
Chrysomelidae sp. A		1**								
Curculionidae sp. A	39	5	4	7		12				
B	5									

Appendix 1 (continued)

	Eucalyptus sites					Pinus sites				
	V	S.	L	B.	R.	V.	S.	L	B	R.
C	5									
D	5			2						
E	1									
F	1	1		1		2				
G		11	1							
H			1	2						
I					1					
J		1								
K		1		4						
L				1						
M	2	2				4		6		
Diptera, larvae										
Nematocera sp A		1								
B		1								
C		10	7					1		
D		3								
E		1	24							
F		2	1							
G		1								
H		1								
I			1							
J			2							
K			1							
L			1							
M			2							
N								1		
O					1					
Brachycera sp. A		2					2	2		
B		24						3		
C								1		
D							1			
E		1	16	1						
F			5							
G			3							
H				1						
I					1					
J			2							
Diptera, adults										
Tipulidae sp. A	9					10				
B	2									
C			1							
Psychodidae sp. A	1									
Chironomidae sp. A	1					1				1
B					1					
C					1					
D	1									
Simuliidae sp. A						1				
Bibionidae sp. A					1					
Cecidomyiidae sp. A	1					1				
B										1
Sciaridae sp. A	3									1
B	1			1						1

Appendix 1 (continued)

	Eucalyptus sites					*Pinus* sites				
	V	S.	L	B.	R.	V.	S.	L.	B	R.
C	1									
D	8		1							
Rhagionidae sp. A					1					
Empididae sp. A										2
Dolichopodidae sp. A	1				1	1				
Syrphidae sp. A										1
Sphaeroceridae sp. A			1							
Chloropidae sp. A	1									
*Lepidoptera										
Eriocraniidae	1									1
Tortricidae			1**	1**						
Psychidae	1**									
?Phyllocnistidae	1**									
Glyphipterygidae	1									
Oecophoridae		1**	9**	5**						
Geometridae		1**								
Lasiocampidae									1**	
Notodontidae						2**				
Arctiidae	1**									1**
Noctuidae	1**									1**
Hymenoptera										
Ichneumonidae sp. A										1
B	1									
Braconidae sp. A										1
B	1									
C			1							
Proctotrupidae sp. A										1
B	3									
C		1								
Platygasteridae sp. A				5						
Scelionidae sp. A	1									
B				3						
C				1						
D				1						
E	1									
Diapriidae sp. A									1	
B	1	1								
C						1				
D	2									
E			1							
Eulophidae sp. A						1				
Mymaridae sp. A	1									
B	1									
Pteromalidae sp. A	1					1				
Formicidae sp. A			1							
B		1	1							1
C		160	90		13					1
D				1						1
E	3									
F				1						
G	3									

Appendix 1 (continued)

	Eucalyptus sites					*Pinus* sites				
	V	S.	L	B.	R.	V.	S.	L.	B	R.
MOLLUSCA										
Choropidae										
Pernagera tamarensis					1					
Pillomera meroia					1					
Pillomera sp.								1		
Helicorionidae										
Heliocarion niger					1					
Cystopeltidae										
Cystopelta purpura					1					
Rhytididae										
Victaphanta compacta					2					4
Rhytida ? gawleri					1					

13

TERRESTRIAL PLANARIANS AND NEMERTEANS OF THE OTWAY REGION

By L. Winsor*

Abstract: Terrestrial planarians and nemerteans are cryptozoic animals found in microhabitats of forests, plantations and agricultural land of the Otway Region. Their distribution is primarily restricted in the terrestrial environment by the availability of moisture.

The ecological distribution of terrestrial planarians and nemerteans within Victoria is best explained in terms of moisture availability. There is a tentative correlation between the occurrence of these taxa and zoogeographic regions of Victoria which can be recognised as distinctly moist.

Of the thirty species of terrestrial planarians that occur in Victoria, eleven have been recorded from the Otway Region. The only terrestrial nemertean species known from Victoria is also recorded from the Otway Region.

Two Victorian zoogeographic regions were recognised in the study area: Cool Temperate Bassian and Warm Temperate Bassian. Taxa considered characteristic of the Cool Temperate Bassian predominate, with elements typical of Warm Temperate Bassian impinging on the north-eastern end of the study area. The terrestrial planarian and nemertean faunas of the Otway Region most closely resemble those of the Macedon Range in Victoria, but differ from the faunas of wet forest to the east of Melbourne mainly through the absence of common Eastern Highland wet forest species. Inadequacies in taxonomic data permit discussion of the affinities and origins of the terrestrial planarian and nemertean faunas of the Otway Region only in terms of the distribution and ecology of these taxa.

INTRODUCTION

Terrestrial planarians (Phylum Platyhelminthes) and terrestrial nemerteans (Phylum Nemertea) are two common and characteristic invertebrate groups of the Cryptozoa. Dendy (1895) defines Cryptozoa as 'the assemblage of small terrestrial animals found dwelling in darkness beneath stones, rotten logs, and the bark of trees, and in other similar situations.'

This paper is part of a continuing investigation into the taxonomy, ecology and distribution of the terrestrial planarians of Australasia undertaken by the author. Previous work on Australian terrestrial planarians was largely confined to descriptions of new taxa, most of which were recorded from only a few localities in each state. Data on the terrestrial nemerteans of this region are also included in this paper because of the close phylogenetic relationships between nemerteans and planarians, and also to augment the recent review of the group by Moore (1975).

The Otway Region is defined as that area south of a line passing through Warrnambool, Naringal, Ecklin South, 4 km north of Timboon, Elingamite, Tandarook, Purrumbete South, Stoneyford, Colac, Birregurra, Modewarre and Breamlea. Distribution surveys for terrestrial planarians and nemerteans within the Otway Region are incomplete and confined to wet forest, conifer plantations and adjacent farmlands within the Otway Ranges. The south-west of the region, near Warrnambool, was not surveyed.

ECOLOGY

Of the five categories of animals inhabiting the cryptozoic niche recognised by Cole (1946) terrestrial planarians and nemerteans can be placed with those forms regarded as transitional between aquatic and terrestrial habitats. They are primarily restricted in the terrestrial environment by the availability of moisture. The majority of species possess no water-saving adaptations and depend upon the micro-environment for their moisture requirements. However, they are sensitive to liquid water and ecologically can be regarded as stenohygric hygrocoeles (Froehlich 1955b).

Typical microhabitats of terrestrial planarians include soil cracks and fallen fence posts in cleared agricultural land, or leaf litter, stones, rotten logs,

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treebark and leaf bases of some densely foliated plants in forests areas. Under adverse conditions, some species burrow deep into the soil where they ensheath themselves with mucus secretion. The physical conditions that exist in these microhabitats and the way in which they affect the behaviour of planarians are at present ill defined and poorly understood.

Except in overcast or waterlogged conditions, terrestrial planarians remain hidden by day and emerge only at night to feed, when the relative humidity of the air is high, and, in dry areas, they congregate on the mud bordering any surface moisture. They are carnivores and feed upon a wide variety of animals occupying the cryptozoic niche. Some species are cannibalistic and others necrophagic.

Terrestrial nemerteans have similar ecological requirements to terrestrial planarians, but many habitats which support planarians are apparently unsuitable for nemerteans (Moore 1975).

DISTRIBUTION

Low mobility and stenotopy of terrestrial planarians and nemerteans account for fairly stable distribution patterns with a high degree of species endemicity. Minor changes in species distribution appear to have resulted from the activities of man in Australia. Anthropochore dispersal in soil and on vegetation and other carriers seems the most likely explanation for some species that occur in both urban and rural areas. These are always associated with man and are often far from natural populations of the same species, ('man-followers' or adventives).

The distribution of natural populations of terrestrial planarians and nemerteans within Victoria cannot be adequately explained solely in terms of single environmental factors such as vegetation, rainfall, temperature and altitude, or by habitat type preferences.

Variations in these combined environmental factors permits the recognition of climatic regions within Victoria. Terrestrial planarians and nemerteans are primarily restricted in the environment by the availability of moisture and their distribution may best be explained in terms of moisture regions.

Davidson (1954) defined Bioclimatic Zones for Australia based upon the monthly ratio of rainfall to evaporation, and Gentilli (1972) related moisture to effective plant growth in Climatic Moisture Regions. These zones and regions do not correspond adequately to planarian distributions. Rawlinson (1969) defined Thermal Zones of the Bassian zoogeographical subregion within Victoria based on reptile distribution patterns. There is a tentative correlation between these thermal zones and the distribution of terrestrial planarian and nemertean species in Victoria. A summary of these zones defined by Rawlinson (1971) follows:

The Bassian area in Victoria includes the Eastern Highlands, South Gippsland Highlands and the Otway Ranges, as well as the western coastal and volcanic plains and the East and West Gippsland coastal plains. The topography and vegetation vary greatly within the Bassian, and rainfall is spread more or less evenly throughout the year. Temperatures of the Bassian are the coldest of the four Australian zoogeographic sub-regions, reflecting the high latitudes and altitudes of the area.

The Warm Temperate Zone includes the coastal plains of south-eastern Victoria, the volcanic and coastal plains of south-western Victoria, the inland margins of the Eastern Highlands and the Kilmore Gap. The low moisture availability in this zone is due to an annual rainfall of less than 800 mm and high surface temperatures resulting from the low altitudes of the area (less than 300 m). The open nature of the vegetation permits intense solar radiation to reach the ground and consequently affords little protection of microhabitat.

The Cool Temperate Zone covers the Eastern Highlands below 1200 m and includes the Macedon and Otway Ranges, and the South Gippsland Highlands. The high moisture availability in this zone is due to high average rainfalls (over 800 mm) and low surface temperatures due to the high elevations. Dense climactic vegetation allows little solar radiation to reach the ground and buffers the microhahitat against the high summer temperatures encountered in warm temperate zones.

The Cold Temperate Zone includes alpine and sub-alpine areas above 1200 m altitude in the Eastern Highlands. Average rainfalls of over 1400 mm and low environmental temperatures due to the high elevation result in microhabitats possessing high moisture availahility. Dense forests occur in the lower altitudes but are limited by the severity of the cold to near 1300 m. At altitudes above this, vegetation changes to that of open alpine woodlands, herbfields, swamps and grasslands. At these altitudes, suitable microhabitat for terrestrial planarians and nemerteans is scarce and mostly limited to the open alpine woodlands. This situation is analogous to that observed in the warm temperate zone. Microhabitats in these cold temperate zones are subjected to snow in winter and intense solar radiation during the summer periods.

The Bassian Thermal Zones and the Eyrean subregion comprise the zoogeographic regions of Victoria (Rawlinson 1971). The distribution of terrestrial planarians and nemerteans in Victoria are best expressed in terms of these regions and extensive distribution studies in Victoria indicate that each of these regions may have a characteristic terrestrial planarian fauna (Winsor unpublished).

Terrestrial planarians and nemerteans in the Australian Region are largely confined to the Torresian, Bassian and South Western zoogeographic sub-regions of Spencer, as modified by Serventy and Whittell (1951). There is insufficient distributional data available for other states to permit the recognition of characteristic terrestrial planarian and nemertean faunas for these sub-regions.

TAXONOMY

The taxonomy of Australian terrestrial planarians is primarily based upon the anatomy of the reproductive organs. All species recorded from the Otway Region belong to the family Geoplanidae, the Australian genera of which are *Geoplana* and *Artioposthia*. Graff (1899) defined two groups within the genus *Geoplana* according to the position of the testes: those species with dorsal testes, exclusively Neotropical and those with ventral testes, chiefly Oriental and Australasian. Froehlich (1955a) restricted the genus *Geoplana* to species with dorsal testes and either the Type 'a' musculature of Graff (very strong supepidermal bundles, absent parenchymal bundles), or at least close to it. He suggested that the genus *Coenoplana* Moseley 1877, originally proposed for Australian species but at present unoccupied, might be emended for those species with ventral testes which can no longer remain in the genus *Geoplana*. An examination of Moseley's original specimens and the emendation of *Coenoplana* is at present under consideration.

Taxa from the Otway Region have been referred to the genus *Geoplana* Fr. Mueller *sensu lato* pending their revision.

The anatomy and distribution of Australian terrestrial nemerteans has been reviewed by Moore (1975); their classification, as used in this paper is given by Gibson (1972).

Data for the faunas are presented under the following headings:

1. *Specimens examined:* This includes specimens in the author's collection (Ge), the National Museum of Victoria (NMV) or the Australian Museum (AM), that were collected within the Otway Region.
2. *Specimens observed:* This refers to specimens observed but not collected and specimens that decomposed following their collection in the Otway Region.
3. *Literature records:* Reliable literature records of taxa recorded in the Otway Region.
4. *Ecology:* Notes on general habitat, feeding, reproductive state, associations and status. Most of these data come from the author's unpublished information, based on Australia-wide observations. Nomenclature of vegetation is after Sprecht (1970).
5. *Distribution:* Records of the species within Australasia and the distribution within zoogeographic regions of Victoria. Terrestrial planarian and nemertean distributions are surveyed and recorded on the Degree by Degree and a half (DDHG) biological grid, used for marine molluscs by Smith and Long (1970) and for Anuran Amphibians by Brook (1975). Most of these distributional data are based on extensive collections made by the author in Australian states. These are supplemented by data obtained from the collections of the National Museum of Victoria, the Ausralian Museum Sydney, and specimens collected by the acknowledged naturalist groups. The taxonomy and distribution of the Australasian terrestrial planarians will be published elsewhere. All identifications were made by the author with reference to type and other named material.

PLATYHELMINTHES

Tricladida, Terricola

Geoplanidae

Geoplana Fr. Mueller 1857

Geoplana hoggii Dendy, 1891

Specimens Examined: Ge 99, 5 km NW. Benwerrin, six specimens and one cocoon; Ge 313 Aireys Inlet, three mature specimens.

Specimens Observed: Nil.

Literature Records: Nil.

Ecology: This large, yellow-striped species is found mainly beneath rotting logs in Tall Open and Open Forests, often in relatively dry situations such as slopes. Sexually mature specimens have frequently been found from January to March, with juveniles emerging from cocoons in late March; specimens collected in April were immature. In the Otway Region *G. hoggii* was found in association with *G. howitti*; elsewhere it was associated with *G. mediolineata*, *G. m'mahoni*, *G. munda* and *G. sanguinea*. This species differs from the lowlands form of *G. sulphurea* by the presence of paired median green stripes. *G. hoggii* is a common species.

Distribution: This species is endemic to Victoria and extends east from the Blackwood Ranges to Mt. Baw Baw, and south to the Otway Region which is the most westerly occurrence of the species. *G. hoggii* occurs predominantly in the Cool Temperate Bassian and less commonly in the Warm Temperate Bassian of south central Victoria.

Geoplana howitti Dendy, 1891.

Specimens Examined: Ge 132, 200, 5 km NW. Benwerrin, two mature specimens; Ge 230, 7 km SW. Benwerrin on Mt. Sabine road, single mature specimen with cocoon; Ge 321,

near falls, Cumberland River in Lorne Forest Park, single immature specimens.
SPECIMENS OBSERVED: Nil.
LITERATURE RECORDS: Nil.
ECOLOGY: Abundant in the microhabitat of the Alpine complex and Tall Open Forest in which the species was first recorded. Also found in lesser numbers in dry Coast complex in Gippsland, Open forest, conifer plantations and rarely on cleared land. It is a medium sized yellow and brown striped planarian, capable of rapid movement, and has been observed to prey upon other planarian species, particularly *G. sanguinea*.

Sexually mature specimens were obtained during January, February, July and October, and cocoons in March; immature specimens were collected in November. The genitalia of this species possess adenodactyli, characteristic of *Artioposthia* to which *G. howitti* may be referred on revision of the Australasian Geoplanidae.

This species has been found in association with *G. hoggii*, in the Otway Region; elsewhere with *G. dendyi*, *G. lucasi*, *G. mediolineata*, *G. spenceri*, *G. sulphurea*, *G. varigata*, *G. walhallae* and *Geonemertes australiensis*. It is synonymous with *G. robusta* Steel and may be synonymous with *G. warragulensis* Graff and *Artioposthia harrisoni* Wood. Its status is common in the sub-alpine regions, uncommon elsewhere.
DISTRIBUTION: Otway Region, Eastern Highlands, Cape Liptrap, Wilsons Promontory Victoria and Bundanoon, New South Wales. Its occurrence in the Otway Region is the most westerly record for this species.

G. howitti occurs mainly in the Cool and Temperate Bassian with marginal extension into the Warm Temperate Bassian in north-eastern Victoria.

Geoplana mediolineata Dendy, 1891
SPECIMENS EXAMINED: Ge 133, Anglesea, single immature specimen; Ge 314, 6.5 km NE. Anglesea, single immature specimen; NMV, Apollo Bay, multiple specimens.
SPECIMENS OBSERVED: Boundary road, 9.5 km S. Anglesea.
LITERATURE RECORDS: Nil.
ECOLOGY: This medium sized yellow planarian is common in the microhabitat of Open Forest, less common in Tall Open Forest, Coastal complex, and cleared agricultural land.

Mature specimens have been recorded in November and April, immature specimens in March.

G. mediolineata was not found associated with any other species of planarian in the Otway Region; associations observed elsewhere are *G. adae*, *G. dubia*, *G. hoggii*, *G. munda*, *G. quinquelineata*, *G. sanguinea* and *G. sugdeni*.

There is great variation in the dorsal stripe pattern of this species which may vary from one to five stripes, making it difficult to distinguish from similarly striped species *G. m'mahoni* and *G. quinquelineata*. *G. mediolineata* is a common species.
DISTRIBUTION: Otway Region, Mt. Ararat, Macedon Range in Victoria, and near Adelaide, South Australia. This species occurs mainly in the Cool Temperate Bassian with some marginal extension into the Warm Temperate Bassian of mid-western Victoria.

Geoplana m'mahoni Dendy, 1891
SPECIMENS EXAMINED: Ge 201, 1.5 km S. Benwerrin, single immature specimen; NMV, 3 km S. Lavers Hill, single specimen.
SPECIMENS OBSERVED: Nil.
LITERATURE RECORDS: Nil.
ECOLOGY: A long slender bright yellow planarian found in Tall Open Forest, Open Forest and agricultural land. Specimens collected in March and May were immature. In the Otway Region, *G. m'mahoni* was associated with *Peripatoides*; elsewhere with *G. hoggii* and *G. munda*. It is an uncommon species, but can be distinguished from similarly striped species by its greater length.
DISTRIBUTION: This species is endemic to Victoria and found in the Otway Ranges and Eastern Highlands. A similar but as yet unidentified species has been found near Portland and Koroit, Victoria. *G. m'mahoni* occurs predominantly in the Cool Temperate Bassian in the ranges east of Melbourne.

Geoplana munda Fletcher and Hamilton, 1888
SPECIMENS EXAMINED: Ge 141, Bellbrae, Torquay, two mature specimens; NMV Apollo Bay, multiple specimens.
SPECIMENS OBSERVED: Near Stoneyford.
LITERATURE RECORDS: Otway forest, Dendy (1891, 1892).
ECOLOGY: This small brown and cream species is a natural inhabitant of basalt plains and is also a 'man follower'. It occurs as an adventive confined to agricultural land and urban gardens, naturally along stream banks on basaltic plains. Its natural microhabitat is usually in mudcracks or beneath earth clods. It emerges at dusk and feeds on earthworms and carrion stranded on muddy banks. The species has been frequently found feeding in large aggregations similar to the feeding behaviour seen in certain fresh water planarians (Winsor, unpublished). *G. munda* has an unusually high liquid water tolerance for a terrestrial planarian and is often found in waterlogged conditions. Ecologically it may be best regarded as a euryhygric species.

Sexually mature specimens have been recorded in March and April, cocoons in early May and juveniles in May and October. Immature specimens were recorded in June, October, November and December.

G. munda was associated with *G. quinquelineata* and *G. sugdeni* in the Otway Region; elsewhere with *G. atrata*, *G. ventrolineata* and *Rhynchodemus simulans* Winsor (1973a), *G. hoggii*, *G. mediolineata* and *G. sanguinea*. Its status is very common.
DISTRIBUTION: The Victorian distribution of this species is predominantly central and south-west. It also occurs in New South Wales, SE. South Australia and in Tasmania where it is associated with man. Apart from isolated records on agricultural land in Cool Temperate Bassian, *G. munda* is confined to the Warm Temperate Bassian regions.

Geoplana quadrangulata Dendy, 1891
SPECIMENS EXAMINED: Ge 44, Love Creek near Kawarren, single immature specimen.
SPECIMENS OBSERVED: Nil.
LITERATURE RECORDS: Nil.
ECOLOGY: This small brown mottled species was first re-

corded in Tall Open Forest and on stream and dam banks within agricultural land. Immature specimens were recorded in November, mature specimens in December. Little is known of this uncommon to rare species recorded from only four localities all west of Melbourne. It has not been associated with any other planarian species.
DISTRIBUTION: This species is endemic to Victoria and has been recorded from the Otway Region, Macedon Ranges and near Creswick in Victoria. It occurs only in the Cool Temperate Bassian region, and its occurrence in the Otway Region is the most westerly record for the species.

Geoplana quinquelineata Fletcher and Hamilton, 1888
SPECIMENS EXAMINED: Ge 131, 12 km NE. Deans Marsh, single mature specimen; Ge 142, Bellbrae, Torquay, multiple mature specimens with cocoon; Ge 144 Gnarwarre, single mature specimen.
SPECIMENS OSERVED: Nil.
LITERATURE RECORDS: Otway Forest, Dendy (1891, 1892).
ECOLOGY: This medium sized yellow and brown striped species is found in Open Forest and agricultural land. It is a 'man-follower' and occurs on agricultural land in cool areas. This is the only terrestrial planarian as yet found in Grassy Open Scrub (Mallee).

Sexually mature specimens were recorded in January and March, juveniles early April, and immature specimens in October and November. It has been associated with *G. munda* and *G. sugdeni* in the Otway region; elsewhere with *G. hoggii*, *G. mediolineata*, *G. munda* and *G. sanguinea*. Of these species, *G. munda* is the most common associate of *G. quinquelineata*. This is a very common species.
DISTRIBUTION: Eastern New South Wales, Northern Tasmania, South Australia, South Western Australia and introduced into New Zealand.

In Victoria the distribution of this species is almost exclusively Warm Temperate Bassian with marginal extension into the Eyrean sub-region in the Bealiba and Little Desert areas of Victoria, and near Kingston, South Australia. The few isolated records of this species in Cool Temperate Bassian areas in Victoria and Tasmania were always associated with agricultural land.

Geoplana sanguinea (Moseley *sensu* Fyfe 1948)
SPECIMENS EXAMINED: Ge 202, on the bank of Charleys Creek, 1.5 km S. Gellibrand, single mature specimen; NMV G 747, 748, Apollo Bay.
SPECIMENS OBSERVED: Cumberland River near falls, upstream from camping ground; 7 km SW. Benwerrin on Mt. Sabine road.
LITERATURE RECORDS: Nil.
ECOLOGY: This white to red coloured species is found over a wide range of habitat from Alpine complex to Tussock grassland. It is a 'man-follower' and is commonly encountered in urban gardens. Sexually mature specimens have been recorded for each month of the year, and juveniles in early April. The species is not gregarious and usually only single specimens are found. It has, however, been associated with nearly every known species of terrestrial planarian found in Victoria. It is a common form.
DISTRIBUTION: This species has the widest distribution of any Australian terrestrial planarian, extending from north of Ingham, Queensland, New South Wales, Victoria and Tasmania and South Australia. It has been introduced into New Zealand. In Victoria, *G. sanguinea* is widespread throughout the Bassian subregion, with the only record in the Eyrean associated with man in Mildura. It is rare in South Australia and this may be the limit of its westerly distribution.

Geoplana sugdeni Dendy, 1891
SPECIMENS EXAMINED: Ge 159, Bellbrae, Torquay, single mature specimen, AM, W1541, Forrest.
SPECIMENS OBSERVED: State school grounds, Barramunga, Pirron Yalloak Creek near Swan Marsh.
LITERATURE RECORDS: Nil.
ECOLOGY: A medium sized yellow planarian, *G. sugdeni* frequents Open Forest and agricultural land mainly in coastal regions. It is one of the few terrestrial planarians found crawling about in daylight. Sexually mature specimens have been recorded in late November. This species was associated with *G. munda* and *G. quinquelineata* in the Otway Region; elsewhere with *G. hoggii* and *G. munda*. This is a common species in coastal areas.
DISTRIBUTION: Mainly southern coastal areas of Victoria and northern coastal areas of Tasmania. In Victoria this species occurs in both the Warm and Cool Temperate Bassian.

Geoplana sulphurea Fletcher and Hamilton, 1888
SPECIMENS EXAMINED: Nil.
SPECIMENS OBSERVED: Nil.
LITERATURE RECORDS: Otway Forest, Dendy (1892).
ECOLOGY: Two forms of this species exist, a lowland form which closely resembles *G. hoggii* and an alpine form, smaller and with a more pronounced dorsal stripe pattern. Sexually mature specimens of the lowland from have been recorded in January, October and November. The associations of this species are similar to *G. hoggii* with which the lowland form is probably synonymous.
DISTRIBUTION: The lowland form occurs in the Otway Region and central Victoria, Mt. Wilson and Hartley Vale, New South Wales and introduced into New Zealand. In Victoria this form occurs in both the Warm and Cool Temperate Bassian.

Geoplana sp.
SPECIMENS EXAMINED: Ge 232, Benwerrin.
SPECIMENS OBSERVED: State school grounds, Barramunga; 7 km S. Benwerrin on Mt. Sabine road; camping area Cumberland River, Lorne Forest Park.
LITERATURE RECORDS: Nil.
ECOLOGY: This medium sized yellow planarian with three ill defined green dorsal stripes was found in wet conditions under logs in Tall Open Forest, near a farm dam and in a camping ground. Specimens collected in May and November were sexually mature, and were associated with *G. howitti*, *G. sanguinea* and *G. sugdeni*. The species is uncommon, and unlike any other species in this Region.
DISTRIBUTION: Otway Region, Cape Liptrap, Stony Rises and Rosebud, Victoria; Montague, Tasmania. In Victoria the few records are all within the Cool Temperate Bassian.

NEMERTEA
HOPLONEMERTEA
PROSORHOCHMIDAE
Geonemertes Semper 1863
Geonemertes australiensis Dendy, 1892

SPECIMENS EXAMINED: Ankerhook Forest, Anglesea, Single specimen.

SPECIMENS OBSERVED: Near Cumberland River, Lorne Forest Park.

LITERATURE RECORDS: Otway Forest, Dendy (1892b).

ECOLOGY: This terrestrial nemertean was found under logs and within rotting timber in Tall Open Forest. Hickman (1963) provides an account of the ecology of the species in Tasmania, which is similar to that observed in Victoria. This nemertean was not associated with any terrestrial planarians in the Otway Region; elsewhere it has been found together with *G. adae*, *G. mediolineata*, *G. sanguinea* and *G. spenceri* in Tall Open Forest and with *G. howitti*, *G. lucasi*, *G. sanguinea* and *G. spenceri* in Alpine complex (Winsor 1973b). It is an uncommon species.

DISTRIBUTION: The distribution of the terrestrial nemertean *Geonemertes australiensis* in Australia has been recently reviewed by Moore (1975). In Victoria, the most westerly record indicated for this species was Healesville, east of Melbourne. The three records for the Otway Region extend its known most westerly occurrence in Australia; it is also recorded from the Lamington Plateau, Queensland, the Brindabellas and from Pretty Point on the Mt. Kosciusko Plateau, New South Wales, and from numerous localities in Tasmania. The distribution of this species in Victoria is mainly restricted to the Cool and Cold Temperate Bassian regions with extension into Warm Temperate Bassian in the Otways.

Specimens were identified by external characters, and distinguished from terrestrial planarians by stimulating eversion of the proboscis. Although the taxonomy of the Australian land Nemerteans is soundly based (Moore 1975), the distributions of taxa other than *Geonemertes australiensis* are poorly known, and further distributional and ecological studies are required to clarify the interrelationships between nemertean species.

The habitat types, status and Victorian zoogeographic distribution of these foregoing terrestrial planarian and nemertean taxa are presented in Table 1.

DISCUSSION

Thirty species of terrestrial planarians are known in Victoria. In this paper twelve species are recorded from the Otway Region. Eight species, including one possibly new form, are recorded in this area for the first time. The terrestrial nemertean *Geonemertes australiensis* was first recorded in the Otway Region by Dendy (1892b) and subsequently by the present author.

The habitat types and status of taxa recorded in the study area were similar to those of the same species elsewhere in Victoria, (Winsor 1973c). The majority of species were found in Open Forest, Tall Open Forest and agricultural land. Planarians were encountered only close to the periphery of conifer plantations. Similar situations have been observed in plantations in the Macedon Ranges, Victoria and near Mt. Gambier, South Australia. Overall status of species in the Otway Region showed seven common species, four uncommon species and one species considered rare.

Within the Otway Region, two zoogeographic regions are recognised: Cool Temperate Bassian which characterizes the area and a small region of Warm Temperate Bassian that impinges upon the northeastern corner of the study area. From the distribution of the taxa within the Otway Region, two species occur only in the Warm Temperate Bassian, six species occur only in the Cool Temperate Bassian and five species, including the nemertean, occur in both regions. This analysis of the taxa in the study area, with the exception of the nemertean, agrees with their distribution in Warm and Cool Temperate Bassian regions elsewhere in Victoria.

The occurrence of two typically Warm Temperate Bassian planarian species, *Geoplana munda* and *G. quinquelineata* deep within the Cool Temperate Bassian was recorded in the Otway Region. This situation has been observed elsewhere in Victoria, where both species have been recorded from cleared and agricultural lands in Cool Temperate Bassian regions. They are considered adventive species in these regions, as geographically they occur in localized, remote areas, discontinuous with the species' main areas of distribution. Collector artefact cannot account for the large gaps in distribution. Ecologically, the species are restricted to cultivated and agricultural lands, and have not been recorded from adjacent natural forest. These findings fulfil two of the five possible criteria proposed by Lindroth (1957) for the recognition of adventive species, and militate against the possibility of relict populations.

The low mobility and stenotopy exhibited by terrestrial planarians make it highly improbable that these 'anomolous' distribution patterns in Cool Temperate Bassian areas are the result of active dispersal. Biochore dispersal, particularly via domestic stock (e.g. in mud in hooves), cannot be excluded, but is considered remote. It is suggested that passive dispersal by man, via soil, vegetation, timber and masonry, all of which have been found by the author to be carriers, is the most likely explanation of these distribution patterns.

Records of terrestrial planarians considered introduced in various countries are frequently encountered in the literature. Most of these reports do not indicate whether the introduced species are endemic or nonendemic, and few indicate possible modes of dispersal. Froehlich (1955b) discussed 'man follower'' species of Brazil, but did not mention likely modes of dispersal, nor whether the occurrence of endemic forms in

TABLE 1.

THE HABITAT TYPE, STATUS, AND DISTRIBUTION IN THE VICTORIAN ZOOGEOGRAPHIC REGIONS OF TERRESTRIAL PLANARIANS AND NEMERTEANS OF THE OTWAY REGION.

Negative records in this table do not imply absence of a species from a particular habitat or zoogeographic region. Status: **C** = Common. **U**= Uncommon. **R** = Rare. Distribution: **A** = Considered Adventive in this region.

TAXA	HABITAT TYPE								STATUS	VICTORIAN ZOOGEOGRAPHICAL REGION					
	OPEN FOREST	TALL OPEN FOREST	TEMPERATE RAINFOREST	SUB-ALPINE COMPLEX	COASTAL COMPLEX	WETLANDS	AGRICULTURAL LAND	URBAN		WARM TEMPERATE BASSIAN ONLY	WARM AND COOL TEMPERATE BASSIAN	COOL TEMPERATE BASSIAN ONLY	COOL AND COLD TEMPERATE BASSIAN	COLD TEMPERATE BASSIAN	EYREAN
PLATYHELMINTHES															
TRICLADIDA, TERRICOLA															
GEOPLANIDAE															
Geoplana hoggii	+	+	-	-	-	-	+	-	C	-	+	-	-	-	-
Geoplana howitti	+	+	-	+	+	-	+	-	U	-	-	-	+	-	-
Geoplana mediolineata	+	+	-	-	-	-	+	-	C	-	-	+	-	-	-
Geoplana m'mahoni	+	+	-	-	-	-	-	-	U	-	-	+	-	-	-
Geoplana munda	+	-	-	-	-	+	+	+	C	+	-	A	-	-	-
Geoplana quadrangulata	-	+	-	-	-	+	+	-	R	-	-	+	-	-	-
Geoplana quinquelineata	+	-	-	-	-	-	+	-	C	+	-	A	-	-	+
Geoplana sanguinea	+	+	+	+	-	+	+	+	C	-	+	-	+	-	A
Geoplana sugdeni	+	-	-	-	-	-	+	-	C	-	+	-	-	-	-
Geoplana sulphurea	+	+	-	-	-	+	+	-	C	-	+	-	-	-	-
Geoplana sp.	-	+	-	-	-	-	+	-	U	-	-	+	-	-	-
NEMERTEA															
HOPLONEMERTEA, PROSORHOCHMIDAE															
Geonemertes australiensis	+	+	+	+	-	-	-	-	U	-	+	-	+	-	-
	10	9	2	3	1	4	10 ·	2	-	2	5	4	3	-	1

TABLE 2.

DISTRIBUTION OF TERRESTRIAL PLANARIAN AND NEMERTEAN TAXA OF TALL OPEN FOREST AND TEMPERATE RAINFOREST, IN THE EASTERN HIGHLANDS, MACEDON RANGES, OTWAY REGION AND TASMANIA. (**A** = considered adventive in the area).

Taxa	Eastern Highlands	Macedon Ranges	Otway Region	Tasmania
Platyhelminthes				
Geoplanidae				
Artioposthia fletcheri	–	+	–	–
Geoplana adae	+	+	–	+
Geoplana caerulea	+	–	–	–
Geoplana dendyi	+	–	–	–
Geoplana dubia	+	–	–	–
Geoplana hoggii	+	+	+	–
Geoplana howitti	+	–	+	–
Geoplana lucasi	+	–	–	–
Geoplana mediolineata	+	+	+	–
Geoplana m'mahoni	+	–	+	–
Geoplana munda	A	+	+	A
Geoplana quadrangulata	–	+	+	–
Geoplana quinquelineata	A	+	+	A
Geoplana sanguinea	+	+	+	+
Geoplana spenceri	+	–	–	–
Geoplana sugdeni	–	+	+	+
Geoplana sulphurea	+	–	+	–
Geoplana varigata	+	–	–	+
Geoplana ventropunctata	+	–	–	–
Geoplana walhallae	+	–	–	+
Geoplana species	–	–	+	+
Rhynchodemidae				
Rhynchodemus victoriae	+	–	–	–
Rhynchodemus guttatus	+	–	–	–
Rhynchodemus simulans	–	+	–	–
Nemertea				
Prosorhochmidae				
Geonemertes australiensis	+	+	+	+
	18	11	12	7

man-disturbed areas was at variance with the known distributions and habitats of the various species involved.

Knowledge of the distributions and habitats of many terrestrial planarians has been largely based on isolated records. Hitherto, no systematic distribution studies have been carried out. These present studies facilitated the recognition of adventives, particularly endemic forms, in relation to their normal distribution patterns.

The survival of these adventives in cool regions may be due to the similarity between the micro-environment of cleared land and that of Warm Temperate Bassion regions. The reduction in micro-habitat and loss of protective vegetation with increased exposure of the ground to solar radiation may favour those planarians that normally occur in warm temperate areas rather than those sensitive forms restricted to cool temperate regions. These distribution patterns and the tentative explanation for adventive survival require further investigation.

The terrestrial planarian and nemertean faunas of the Otway Region (twelve species) closely resemble those of the Macedon Ranges of Central Victoria (eleven species); eight species are shared between these regions (Table 2.) and the most significant difference between the faunas is the absence of *Rhynchodemus* (Rhynchodemidae) in the Otway Region, but present in the Macedon area. This uncommon genus has been recorded west of Warrnambool and its presence in the Otway Region is highly probable. The nemertean *Geonemertes australiensis* has been recorded by the author in the Macedon Ranges.

Of the eighteen species found in the Eastern Highlands, five are shared with the Macedon Ranges and seven with the Otway Region. Tasmania shares five species with the Eastern Highlands, four with the Macedon Ranges and four taxa with the Otway Region.

Examination of the south-eastern Australian distribution of the land planarian and nemertean taxa of the Otway Region, provides evidence on the possible origins of these faunas.

The nemertean *Geonemertes australiensis* occurs mainly in wet forest on mainland south-eastern Australia and shows disjunct distribution between the Eastern Highlands, the Macedon Ranges and its most westerly occurrence in the Otway Ranges; there is also a major disjunction across Bass Strait to Tasmania. Two terrestrial planarians, *Geoplana sanguinea* and *G. sugdeni* show major disjunctions only in their ranges to Tasmania across Bass Strait. A third species, *Geoplana sp.*, first recorded in the Otway Ranges has also been found in northern Tasmania, but its distribution is otherwise poorly known. The natural occurrence of these four taxa in Tasmania suggests that they are Glacial relicts, having traversed the Bassian isthmus from the mainland to Tasmania during the last Ice Age. However, it is uncertain as to whether these taxa colonized the Otway Region during the last Glacial period, or whether they expanded their ranges from the Eastern Highlands region (and ?Central Victoria *G. sugdeni*) to the Otways during the Post-glacial pluvial period. The wet forest disjunctions of *Geonemertes australiensis* indicate possible expansion of range previous to more recent arid periods when the range may have contracted to present distributions.

Three land planarians, *Geoplana howitti*, *G. hoggii* and *G. sulphurea*, show disjunct distributions similar to those of *Geonemertes australiensis*, but are all absent from Tasmania. It is suggested that these taxa are Post-glacial intrusives that probably expanded their ranges in the Post-glacial pluvial period, perhaps accompanying the spread and development of Post-glacial forests. The subsequent arid period resulted in the contraction of their ranges giving rise to present distribution patterns.

The distributions of the foregoing taxa, considered Glacial relicts and Post-glacial intrusives, are very close to those of reptiles (group c) considered Glacial relicts, and those (group b) reptiles considered Post-glacial intrusives by Rawlinson (1974).

Two species, *Geoplana munda* and *G. quinquelineata* show fairly continuous south-west to north-east distribution (apart from isolates considered adventives, as previously discussed) through Central Victoria, extending into South Australia and New South Wales. These distributions in the drier regions of south-eastern Australia, and the absence of natural populations in wet forests of Victoria and Tasmania suggest recent speciation, possibly in response to the Post-glacial arid period environment. The peripheral natural occurrence of these two taxa in the Otway Region may indicate recent expansion of their ranges, utilizing the dry forest and plain habitats.

There is insufficent distribution data for *Geoplana m'mahoni* and *G. quadrangulata* to allow discussion of their origins. *Geoplana mediolineata* appears to have close affinities with three West Australian and South Australian taxa, and the distribution of this species is thus confused. The origin and affinities of *G. mediolineata* can only be discussed when its relationships with the other similar taxa are clarified.

From the foregoing discussion, the land planarian and nemertean faunas of the Cool Temperate Bassian regions to the west of Melbourne (Otway and Macedon areas), compared to those east of Melbourne, differ significantly by the absence of some typical Eastern Highland wet forest forms. In particular, the common and widespread blue-green species, *Geoplana caerulea*, *G. dendyi* and *G. spenceri* have not been recorded west of Mt. Disappointment, Victoria, nor in Tasmania, although suitable wet forest habitats occur in these regions.

Recent evidence indicates that the present Otway vegetation is Post-glacial in origin, and that there has been no continuity of habitat between the Eastern Highlands and the Otway Region (Rawlinson, unpublished). This discontinuous forest habitat probably acted as a filter, possibly limiting strictly wet forest forms, such as the blue-green land planarians of the Eastern Highlands, to continuous wet forest habitat. However, species able to survive in and colonize habitats other than those of wet forests were able to radiate to the Otway Region. Differences between the terrestrial planarian and nemertean faunas of the Macedon Ranges and the Otway Region may reflect more favourable habitat between the Otways and the Eastern Highlands than between the latter area and the Macedon Ranges.

This discussion of the origins and affinities of the land planarians and nemertean faunas of the Otway Region has been primarily based upon distributional and ecological data. The phylogenetic relationships between the various terrestrial planarian taxa are poorly understood due to inadequacies in the present taxonomy of the group.

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REFERENCES

Brook, A., 1975. The distribution of Anuran Amphibians in Victoria. *Vict. Nat.* 92: 104-120.

Cole, L. C., 1946. A study of the Cryptozoa of an Illinois Woodland. *Ecol. Monogr.* 16: 49-86.

Davidson, J., 1954. Bioclimatic Zones of Australia. In: Andrewartha, H. G. & Birch, L. C., *The Distribution and abundance of animals*. University of Chicago Press.

Dendy, A., 1891. On the Victorian Land Planarians. *Trans. R. Soc. Vict.* 2: 65-80.

————, 1892a. Additional observations on the Victorian Land Planarians. *Ibid.* 2: 25-41.

————, 1892b. On the Australian Land Nemertine (*Geonemertes australiensis*, n. sp.). *Proc. R. Soc. Vict.* 4: 85-112.

————, 1895. The Cryptozoic Fauna of Australasia. *Rep. Australas. Ass. Advmt. Sci.* 6: 99-119.

Froehlich, C. G., 1955a. Sobre morfologia e taxonomia das Geoplanidae. *Bol. Fac. Fil. Cien. Letr., Zool.* 19: 195-279.

————, 1955b. On the biology of land planarians. *Ibid.* 20: 263-272.

Gentilli, J., 1972. *Australian Climate Patterns.* Thomas Nelson (Australia) Ltd.

Gibson, R., 1972. *Nemerteans.* Hutchinson and Co. Ltd., London.

Graff, L. von., 1899. *Monographie der Turbellarien* II. *Tricladida Terricola,* Endelmann, Leipzig.

Hickman, V. V., 1963. The occurrence in Tasmania of the land nemertine, *Geonemertes australiensis* Dendy, with some account of its distribution, habits, variations and development. *Pap. Proc. R. Soc. Tasm.*, 97: 63-75.

Lindroth, C. H., 1957. *The faunal connections between Europe and America,* Almqvist and Wiksell/Gebers, Stockholm; and Wiley, New York.

————, In M.D.F. Udvardy, 1969. *Dynamic Zoogeography with special reference to land animals.* Van Nostrand Reinhold Co., New York. p.344 (not sighted)

Moore, J., 1975. Land Nemertines of Australia. *Zool. J. Linn. Soc.*, 56: 23-43.

Rawlinson, P. A., 1969. The Reptiles of East Gippsland. *Proc. R. Soc. Vict.* 82: 113-118.

————, 1971. Reptiles of Victoria.

————, 1974. Biogeography and Ecology of the Reptiles of Tasmania and the Bass Strait Area. in: W. D. Williams (ed.) *Biogeography and Ecology in Tasmania.* Junk, The Hague.

Serventy, D. L. & Whittell, H. M., 1951. *Handbook of Birds of Western Australia.* Paterson Brokensha, Perth. pp. 44-48.

Smith, B. J., & Long, D. C., 1970. Plans for a proposed census of Non-Marine Molluscs in Victoria. *Vict. Nat.* 87: 169-170.

Sprecht, R. L., 1970. Vegetation. In: G. W. Leeper (ed.). *The Australian Environment.* CSIRO & Melbourne University Press.

Winsor, L., 1973a. *Geoplana atrata* Steel, 1897 — A new land planarian record for Victoria. *Vict. Nat.* 90: 101-102.

————, 1973b. *Geoplana varigata* Fletcher and Hamilton, 1887 — A new land planarian record for Victoria. *Ibid.* 90: 264-265.

————, 1973c. Land Planarians. In: *Land Conservation Council, Victoria, Report on the Melbourne Study Area.* Government Printer, Melbourne.

14

THE NON-MARINE MOLLUSC FAUNA OF THE OTWAY REGION OF VICTORIA

By Brian J. Smith

Abstract: This study forms part of a wider survey of non-marine molluscs of Southeastern Australia and the fauna of the Otway Region is typical of this faunal zone. The fauna consists of 25 families and approximately 70 species of molluscs. Several have their type localities in the Otway Region: examples are *Victaphanta compacta; Geminoropa scindocataracta; Pillomena (Oreomava) otwayensis*. However, very few species are endemic and unique to the area and, after further survey and systematic work, several now thought to be confined to the area could prove to have wider distributions.

Five main habitat-faunal associations are recognised for the non-marine molluscs of the Region: marine influence zone; freshwater; wet sclerophyll and rain forest; dry sclerophyll forest and woodland scrub; areas modified by man. Each of these habitats has its own faunal association and very few species are found in more than two habitat types.

The non-marine mollusc fauna of the Otway Region is in general similar to that of central and eastern Victoria, though with a smaller species diversity: several species are conspicuous by their absence. For a number of species the Otway Region is the western extremity of their distribution range. The relationships of the molluscan fauna of the area are compared with neighbouring regions in Victoria, South Australia and Tasmania.

INTRODUCTION

Compared with other parts of Australia, the non-marine mollusc fauna of Victoria is fairly well documented. Several early records of Victorian molluscs were made by Cox (1868) and later general work by Cox and Hedley (1912) and Gabriel (1930, 1939, 1947) provided much valuable data, while Iredale (1933, 1937, 1938) erected many new genera. However the only detailed description of the non-marine mollusc fauna of any area of Victoria, as opposed to a purely systematic work, remains the work on the molluscs of the Snowy River Area by Gabriel and Macpherson (1947).

The Otway Region of south-western Victoria, south of the basalt plains of central western Victoria, is a discrete area for faunal studies. Dominated by the Otway Ranges, the area has been separated from the topographically similar areas of eastern Victoria several times during recent geological history (Gregory 1912, Hills 1940) and is now separated from it by the cleared and developed Melbourne-Geelong corridor. This study of the non-marine molluscs of the Otway Region is part of a wider study of the non-marine molluscs of Southeastern Australia. It is a distributional survey into which systematic and ecological data of the fauna are also collated.

The molluscan fauna of the Otways is essentially similar to that of the remainder of southern Victoria. This study is intended to give current knowledge of the fauna, to show how the distribution of the molluscs of the area is closely related to the major habitat types, and to compare the fauna of the Otways with that of the remainder of Southeastern Australia. A significant part of the distributional and ecological data used was provided by Mr. and Mrs. F. W. Aslin of Mt. Gambier and Mr. D. C. Long, now of Cheltenham, U.K., to whom thanks are due.

FAUNAL REVIEW

A complete systematic list of the non-marine mollusc fauna of the Otways Region is given in the Appendix. The taxonomy of many of the groups is much in need of revision and many of the generic and specific names used in this listing should be regarded as provisional, subject to full revisionary studies being carried out. A systematic revision is not being undertaken here, but in several families radical changes have occurred in the taxonomy of many species since the last works on the groups were published. Where this has

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occurred, brief notes to the major directions of these changes are given.

To typify the molluscan fauna of the area, distribution maps are given for several of the most important species (Figs. 1-8). The maps are based on a five minute grid, a subdivision of the basic ten minute grid being used for the survey of the molluscs of Southeastern Australia.

FAMILY HYDROBIIDAE

This family of small aquatic operculate snails contains a large number of species endemic to Southeastern Australia. This complex is the subject of current taxonomic revision and the final status of the generic and specific names used here will have to await the results of this revision.

Five species are recognised from the Otway Region. *Tatea rufilabris* which is confined to the estuarine reaches of most of the major creeks and rivers has a shell length extending to 10-12 mm with a very acute pointed spire. *Potamopyrgus nigra* and *Hydrobia buccinoides* are both found in some localities which from time to time receive saline waters. However they are basically freshwater species with a wide saline tolerance rather than estuarine species, and are most abundant in the coastal streams, well above the regions of tidal influence. These two species have a basically similar appearance being 2-5 mm in length with a short spire. *Angrobia angasi* and *Pupiphrix grampianensis* are somewhat smaller than the preceding species with a shorter spire. These are usually found in small freshwater creeks and occur both in the upper reaches of the coastal streams and in the creeks high up in the Ranges. Generic and specific differences depend upon detailed anatomical studies, with shell characters playing only a minor role.

FAMILY LYMNAEIDAE

Following the works of Hubendick (1951) and Boray and McMichael (1961), only two species of this family are recognised for Australia and both occur in the Otway Region. The most common, *Lymnaea tomentosa*, is a small to medium sized dextral species found in streams, ponds and dams throughout the area. *Lymnaea lessoni* is a large, inflated species with a discontinuous distribution throughout Victoria. It is recorded from several ponds in the northern part of the study area adjacent to cleared land.

FAMILY PLANORBIDAE

This family of sinistral snails is the dominant freshwater gastropod group in Southeastern Australia, with many specific and generic names appearing in the literature. Two major shell forms are present: large shells with a high spire and small planispiral shells. Within these groups are a wide variety of shell forms and shapes, most of which at some time have attracted new specific and generic names. A comprehensive revision of this family is long overdue and should include anatomical studies.

Six species are tentatively recognised from the area, three with a high spire and three planispiral. *Physastra gibbosa* is a medium to large species with a smooth, high spired shell found mainly in stagnant or very slow moving water. *Gyraulus* sp., the largest planispiral species with an acute baso-peripheral keel is found in similar habitats.

Bulinus (Isidorella) hainesii and *Glyptophysa aliciae*, the two other high spired species occur in flowing freshwater. The latter is known from only one or two localities in the northern part of the area. These species have fine spiral striae on the shell and fine periostracal hairs. In *G. aliciae* the striae are greatly enlarged to form spiral ridges.

The two other planispiral species found in the area are *Plananisus tasmanicus* and *Pygmanisus scottianus*. These have small shells with peripheral keels either less marked or absent and are found in flowing fresh water.

FAMILY FERRISSIIDAE

The two closely related species of freshwater limpets found in the area are referred to this family following Zilch (1959), and to species after a revision of the group by Huberdick (1967). The species are *Ferrissia (Pettancylus) petterdi* and *F. (P.) tasmanica*. Both appear to be found in both stagnant and flowing water throughout the area with *F. (P.) tasmanica* the commoner and more wide spread. Further work is needed on the ecological preferences of these two species.

'ENDODONTOIDS' — FAMILIES PUNCTIDAE and CHAROPIDAE

The dominant group of snails in the Southeastern Australian non-marine mollusc fauna is the 'endodontoids'. They are small to minute species, with an average shell diameter of 1-2 mm. Over 80 species are present in this faunal region (Southeastern Australia) and 17 in the study area. Until recently it has been generally considered that all these species belonged to a single family the Endodontidae. However recent work (principally by Solem, as yet unpublished) foreshadowed in Solem (1973) and Climo (1969) suggests that this is an artificial group and should be divided into a number of families based on anatomical characters.

The two families to which most or all the endodontoids in the Otway region should be referred are the Punctidae and the Charopidae. Full revisions of this fauna are being undertaken at present and while no firm results have emerged, it is possible tentatively to assign most of the species to families and to give some idea of their relationships. Whether all the species recognised in this study will emerge as accepted species after the revisionary work has been completed is not yet known.

Several of the species in these families were first described from within the Otway Region and are thought to be endemic to this area. These include *Pernagera gatliffi*, *Geminoropa scindocataracta*, and *Allocharopa erskinensis*, all of which come from the wet sclerophyll forest areas of the Otway Ranges.

Family Arionidae

This family of introduced slugs was only recently confirmed as being well established in Australia (Long 1970) and *Arion intermedius* has a widespread distribution within the Otway Region (Fig. 1). The species is small with a yellow foot and mucus, and a prominent caudal gland. It is found in forest areas adjacent to man-modified habitat and probably penetrates the farthest into native bush areas of all the introduced species.

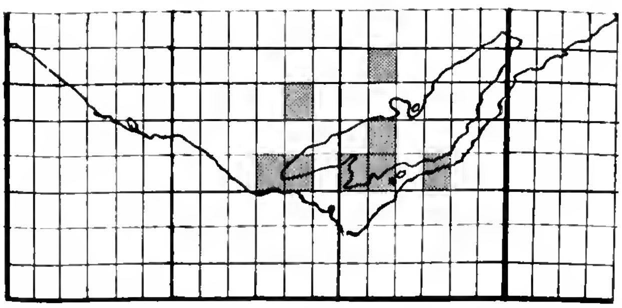

Fig. 1. Distribution of *Arion intermedius*. The study area overlaid with a 5 minute grid. The irregular outline is the 1000 m contour denoting the Otway Ranges.

Families Milacidae and Limacidae

These are two more families of introduced slugs, the Australian species of which have recently been revised (Altena & Smith 1975). All six of the species known from Australia occur in the study area, mainly confined to cleared and other areas modified by man. The distribution of one of the species, *Lehmannia (Lehmannia) nyctelia*, only recently recognised in Australia, is given in Fig. 2.

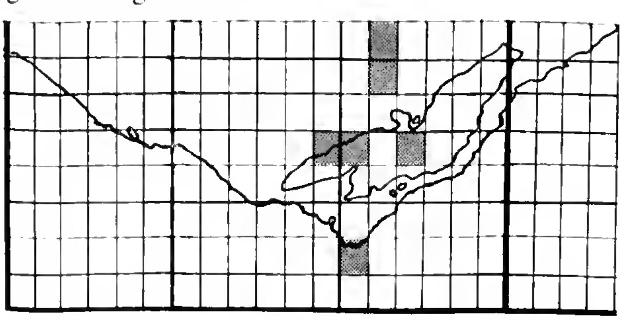

Fig. 2. Distribution of *Lehmannia (Lehmannia) nyctelia*.

Family Helicarionidae

Two closely related species of this family occur in the Otway Region. *Helicarion niger* typically has a dark horn-brown shell, is a dark to black animal, and is mainly found in dry sclerophyll forest and coastal scrub areas (Fig. 3). *Helicarion cuvieri* is a larger, more lightly coloured animal with a light yellowish-green shell. This species is much less common and appears to prefer wetter forest areas.

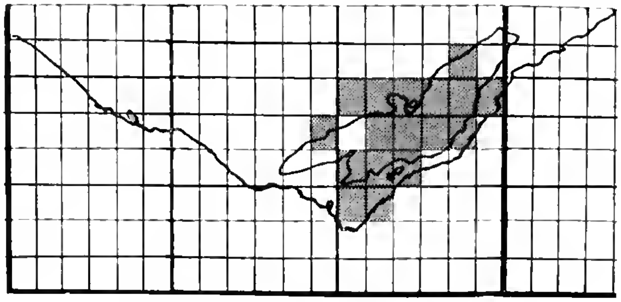

Fig. 3. Distribution of *Helicarion niger*.

A revision of this family is being undertaken at present and a clearer idea of the status of these two species will emerge from this study.

Family Cystopeltidae

This is the only family of native slugs present in Southeastern Australia and, due mainly to the lack of anatomical studies, the status of the various species referred to the family is in doubt. The distribution of *Cystopelta purpurea* is given in Fig. 4. It is found in both wet and dry sclerophyll forests.

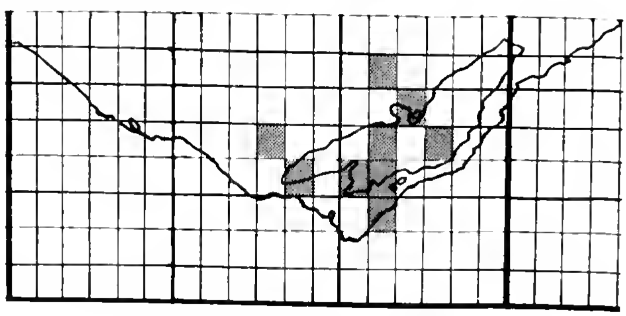

Fig. 4. Distribution of *Cystopelta purpurea*

Family Ferussaciidae

This small, horn-coloured pupoid introduced snail, *Ferussacia* sp., not previously recorded from Victoria, has recently been found in a suburban garden on the southern outskirts of Colac. The only other record of this species in Australia is from Linden Park, Adelaide (Cotton 1954). Work is under way at the moment to confirm this record as an established population.

Family Rhytididae (Paryphantidae)

This family of carnivorous snails is widespread and common in eastern Australia with many species with restricted distributions. It is currently the subject of taxonomic revision by the author. Five species are present in the Otway Region, of which one species is endemic. External characteristics of the family, adaptations to the carnivorous habit, are the thin, lightweight shell and very long head which contains the large muscular buccal mass.

The largest native snail in the Otway Region, *Victaphanta compacta*, is endemic to the rainforest areas of the Otway Ranges (Fig. 5). The genus *Victaphanta* was the subject of recent studies (Smith 1970, Smith & Kershaw 1972) and is endemic to the Southeastern Australian faunal region.

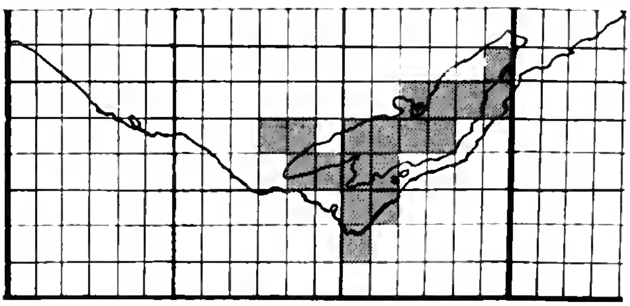

FIG. 5. Distribution of *Victaphanta compacta*

The smallest member of the family, *Prolesophanta dyeri*, is also found mainly in the wet forest areas and is confined to Victoria and Tasmania. The other three species listed as occurring in the study area are tentatively referred to the genus *Rhytida*. Current work (Smith, unpublished data) has shown that the genus *Strangesta*, to which Iredale (1938) referred these species, is incorrect and they should probably be tentatively assigned to the New Zealand genus *Rhytida sensu lato*. *Rhytida* (?) *capillacea* is a large flat species with fine transverse shell sculpture and the Otway Region constitutes its south-westerly distribution limit. It is found in both wet and dry forest areas. *Rhytida* (?) *gawleri* has a large globose shell with fine sculpture and a narrow umbilicus and the Otway Region is its easterly distribution limit. It is found in open dry forest situations. *Rhytida* (?) *ruga* is a small species with a coarsely irregular transversely sculptured shell. This species is found mainly in wet forest situations in Tasmania and southern Victoria.

FAMILY CAMAENIDAE

This large, diverse family, dominant in the non-marine moluscan fauna of northern and central Australia, is represented by a single species in the study area. *Chloritobadistes victoriae* is a medium sized snail found commonly in dry forests and scrub throughout the area (Fig. 6). It is characterized by the fine periostracal hairs on the shell.

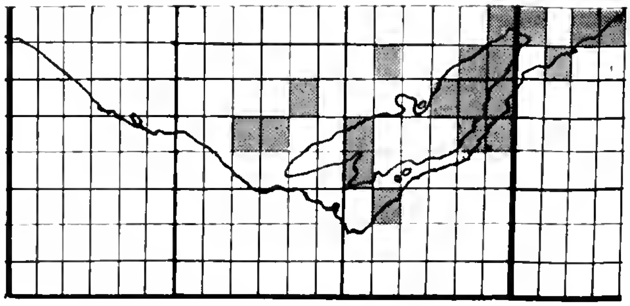

FIG. 6. Distribution of *Chloritobadistes victoriae*

FAMILY HELICIDAE

This is the major family of introduced snails in Australia and five species are present within the study area. The largest and most widespread species is *Helix (Cryptomphalus) aspersa*, the common garden snail, which is commonly found adjacent to permanent dwellings of man (Fig. 7). Another commonly occurring

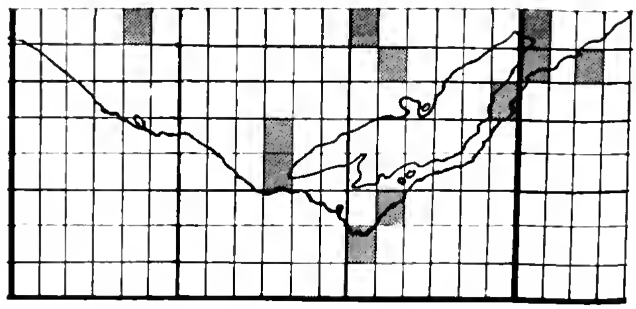

FIG. 7. Distribution of *Helix (Cryptomphalus) aspersa*

snail along the coastal dune and heathland of the area (Fig. 8) is the white shell with the brown concentric bands, *Theba pisana*. This has been recorded in very large population densities in coastal areas closely associated with human activity (Smith 1967) and has more recently been observed to be spreading into areas away from the coasts (Smith & Plant 1973).

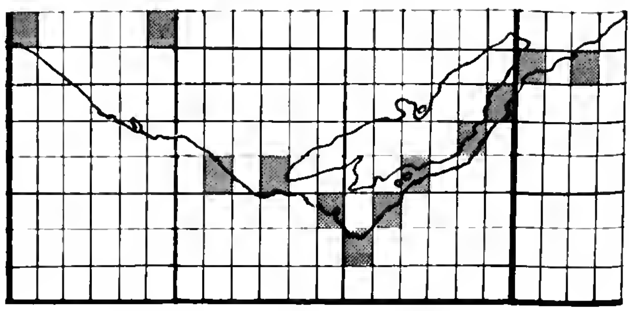

FIG. 8. Distribution of *Theba pisana*.

The small conical snail, *Cochlicella ventrosa* is very widespread and abundant in pasture and marginal cleared land. Small populations of the white snail *Cernuella (Cernuella) virgata* have been reported in the north-west of the study area. This is a very common pest species in South Australia. A small white species with brown concentric bands found associated with *Theba pisana* on the coasts has recently been re-identified as *Candidula intersecta* by Folco Guisti of Siena (pers. comm.). This species has previously been referred to as *Helicella caperata*.

FAMILY HYRIIDAE

There are two species of large freshwater mussels recorded in the area. The taxonomy of this family was revised by McMichael and Hiscock (1958) and the species adequately described. *Velesunio ambiguus* is a large black mussel found in many of the coastal rivers throughout the area. *Hyridella (Hyridella) drapeta* with a brown, thin shell is found in one or two rivers in the north-eastern part of the area, these records constituting the south westerly limit of the species.

FAMILY SPHAERIIDAE

The small pea-mussels are very widespread in all types of freshwater habitat in the Otway Region. Three species are tentatively recognised, though a full revision of the sphaeriid fauna of the Region is needed. The small cosmopolitan species, *Pisidium casertanum*, is found in flowing and standing water. The large spherical *Sphaerium tasmanica* occurs in several ponds and dams in the northern part of the area, while the smaller *Sphaerium problematicum* has tentatively been identified from still water in the eastern part.

HABITAT-FAUNAL ASSOCIATIONS

The non-marine mollusc fauna of the Otway Region can best be understood if considered as a series of habitat-faunal associations. Each major habitat type in the area, as characterised by physical and vegetation factors, has its own molluscan fauna which is unique to that habitat type. Only a few species occur in more than one habitat-faunal association. Each of the habitat types is described in detail below and the molluscan fauna of each given. Abbreviations in the association faunal lists: (I) — introduced species; (E) — endemic to the Otway Region.

1. MARINE INFLUENCE ZONE

This is the strip of land along the coast and beside the tidal reaches of the creeks and rivers, which, although above the regular daily tidal range, receives occasional inundation with sea water. The fauna is largely typical of salt-marshes along the southern coast or, in the aquatic habitat, is a brackish estuarine fauna. Also falling into this general definition is the coastal dune system which is within the range of wind-borne spray from the surf.

MOLLUSC FAUNA OF THE MARINE INFLUENCE ZONE

Tatea rufilabris	Brackish
Hydrobia buccinoides	Estuarine
Truncatella scarlarina	Salt-marsh
Assiminia tasmanica	
Marinula meridionalis	
Marinula zanthostoma	
Ophicardelus ornatus	
Salinator solida	
Omegapilla sp.	Coastal dunes
Austrosuccinea australis	
Magilaoma penolensis	
(I) *Theba pisana*	
(I) *Candidula intersecta*	

The fauna of these three habitat types under the general heading of the marine influence zone is the same as that found in similar habitats in other parts of the Victorian coast. The salt-marsh species require inundation by seawater several times a year and are regarded by some as supra-littoral marine species. However they are found in close association with non-marine flora and fauna and can be found separated from the sea by some distance when near a tidal river.

All the coastal dune species can also be found away from the area of marine influence, but form an interesting faunal association in this area.

2. FRESHWATER

The freshwater habitats of the study area are many and varied, from the clear, shallow, fast flowing creeks and rivers of the Ranges to the sluggish drainage streams of the north and the dams and ponds on the cleared land. Unlike the many bodies of enclosed water on the basalt plains of western Victoria there are no highly saline lakes in the study area. Except where the inflow of sea water elevates the salinity, all aquatic habitats are freshwater.

MOLLUSC FAUNA OF THE FRESHWATER

Potamopyrgus niger
Angrobia angasi
Pupiphyrx grampianensis
'Hydrobia' buccinoides
Lymnaea tomentosa
Lymnaea lessoni
Physastra gibbosa
Bulinus (Isidorella) hainesii
Glyptophysa aliciae
Gyraulus sp.
Plananisus tasmanicus
Pygmanisus scottianus
Ferrissia (Pettancylus) tasmanicus
Ferrissia (Pettancylus) petterdi
Velesunio ambiguus
Hyridella (Hyridella) drapeta
Corbiculina angasi

Pisidium casertanum
Sphaerium tasmanica
Sphaerium problematicum

The freshwater fauna of the Otway Region is a rich one, with 20 species present. Of particular interest is the presence of four species of freshwater hydrobiids and six species of planorbids. This reflects the diversity and species composition of the freshwater mollusc fauna of the Southeastern Australian faunal region and all the species listed above occur generally throughout the Region. The fast clear mountain rivers are characterized by the two freshwater limpet species, *Bulinus (Isidorella) hainesii* either *Plananisus tasmanicus*, *Pygmanisus scottianus* or both, two or three species of hydrobiid, a large mussel and a sphaeriid. By contrast many of the ponds within the area contain one or two species of Lymnaeid, *Physastra gibbosa*, *Gyraulus* sp. and one or two large sphaeriid species.

3. Wet Sclerophyll and Rain Forest

This is a restricted habitat confined, in the study area, to the Otway Ranges, where the rainfall is very high throughout the year. These wet forests occur on the steep slopes of the Ranges on the Cretaceous rocks and soils and are dominated by *Eucalyptus regnans* and *Nothofagus cunninghamii* with a dense under story and deep fern tree gullies. The ground surface is covered by a rich deep leaf litter with many fallen trees and a permanently wet surface with a rich fungal growth.

This habitat is very similar to the wet sclerophyll forest areas of the Great Dividing Range and parts of Western Tasmania and very different from all the surrounding areas.

Mollusc Fauna of the Wet Sclerophyll and Rain Forests

Excellaoma retipora
Thyrasona elenescens
(E) *Pernagera gatliffi*
Pernagera tamarensis
Pillomena (Pillomena) meraca
(E) *Geminoropa scindocataracta*
(E) *Allocharopa erskinensis*
Robinella subdepressa
Helicarion cuvieri
Cystopelta purpurea
(E) *Victaphanta compacta*
Prolesophanta dyeri
Rhytida (?) *gawleri*
Rhytida (?) *ruga*
Chloritobadistes victoriae

The wet sclerophyll forest contains all four of the species of molluscs considered endemic to the study area. These species have close relatives in similar habitats in the faunal region but are considered specifically distinct. It is of interest to note that the fauna of this habitat type is relatively restricted compared to similar habitats of the Great Dividing Range. One notable absent species is the charopid *Mulathena fordei*, a comparatively large species, common in Central Victoria and Tasmania (Smith 1975). A wider range of punctid and charopid species would be expected in these other rain forest areas.

4. Dry Sclerophyll Forest and Woodland Scrub

On the lower slopes of the Ranges and the surrounding hills, on Tertiary rocks and soils, is an open dry sclerophyll forest and woodland scrub. This is typified by mixed *Eucalyptus* spp. and *Acacia* spp. with either little understory and ground cover, or a thick scrub and well drained slopes. There is little leaf-litter and the ground cover and litter is mainly dry. The main habitat for molluscs is underneath fallen logs and bark and the species present can withstand a much drier habitat than the rain forest species.

Mollusc Fauna of Dry Sclerophyll Forest and Woodland Scrub

Austrosuccinea australis
Paralaoma morti
Paralaoma mucoides
Paralaoma halli
Magilaoma penolensis
Trocholaoma (Laomavix) collisi
Pernagera stanleyensis
Pillomena (Oreomava) otwayensis
Elsothera funera
(I) *Arion intermedius*
(I) *Deroceras reticulatus*
(I) *Lehmannia (Lehmannia) nyctelia*
Cystopelta purpurea
Helicarion niger
Rhytida (?) *capillacea*
Chloritobadistes victoriae

Several of the species, such as *Cystopelta purpurea*, *Rhytida* (?) *capillacea* and *Chloritobadistes victoriae*, occur only in the wetter parts of this habitat type. Three species of introduced slugs are commonly found invading this habitat through the activities of man. Much of the dry forest has been cleared and most of the habitat now occurs in restricted stands surrounded by a man-modified environment.

5. Areas Modified by Man

Much of the land in the Otway Region has been cleared over the past 100-150 years of settlement by European man. This has happened mainly on the Tertiary rock areas, but some large areas of Cretaceous soils in the Ranges can be included. The cleared land, with all the original forest vegetation and litter burnt, has been used either for human habitation, for putting down to pasture or crops, or for forest planting, principally of a monoculture of introduced softwoods. All these activities have resulted in an initial denudation of the original native vegetation and its replacement, either deliberately or accidentally, by introduced plants. This has resulted in an almost total replacement of the native molluscan fauna by an introduced one, principally of pest species.

Mollusc Fauna of Areas Modified by Man

Paralaoma morti
Trochokaoma (Laomavix) collisi
(I) *Arion intermedius*
(I) *Oxychilus alliarius*
(I) *Oxychilus cellarius*
(I) *Milax gagates*
(I) *Limax maximus*
(I) *Deroceras caruanae*
(I) *Deroceras reticulatus*
(I) *Lehmannia (Lehmannia) nyctelia*
(I) *Lehmannia (Limacus) flavus*
(I) *Ferussacia* sp.
(I) *Helix (Cryptomphalus) aspersa*
(I) *Theba pisana*
(I) *Cochlicella ventrosa*
(I) *Cernuella (Cernuella) virgata*
(I) *Candidula intersecta*

Altogether 15 species of introduced molluscs are known from the area, many of which are very abundant and widespread. These include 7 species of slugs and eight species of snails. Only two species of punctids are commonly found in this environment although pockets of native woodland may contain relict populations of that habitat association in an otherwise modified area.

DISCUSSION

The non-marine mollusc fauna of the Otway Region is similar to that of the remainder of the Southeastern Australian faunal region. This includes the whole of Victoria and Tasmania and the southern parts of New South Wales and South Australia. This fauna is dominated, both in numbers of species and numbers of individuals, by the endodontoid snails. Many of the species in the fauna have a widespread distribution throughout the faunal region though the level of endemism is also high due to local habitat isolation.

Four species are considered here endemic to the Otway Region and all these are to be found exclusively in the wet sclerophyll and rain foreest area of the Otway Ranges. These are:

Victaphanta compacta
Pernagera gatliffi
Geminoropa scindocataracta
Allocharopa erskinensis

It is thought that this endemism was brought about by the early isolation of the Otway Ranges. This also brought about the somewhat restricted nature of the wet forest fauna with the absence from it of species widespread throughout similar habitats in the Southeastern Australian faunal region.

Of the five habitat associations recognised, only one, the wet sclerophyll and rain forests, can be said to be unique to the Otway Region. All the others are to be found in similar habitats in other parts of Victoria. The Otway Region is the south-westerly limit of distribution of a number of east coast species.

However, because of the widespread land clearing carried out in the area and the establishment of large areas of introduced vegetation, the most noticeable elements of the fauna are the introduced species of snails and slugs.

ACKNOWLEDGMENTS

This work was partially supported by a grant from the Australian Biological Resources Study and thanks are due to Elaine Johns who is employed under this grant. Thanks are also due to Rhyllis Plant of the Invertebrate Department, National Museum of Victoria, for assisting with the data extraction.

REFERENCES

Altena, C. O. van Regteren & Smith, B. J., 1975. Notes on introduced slugs of the families Limaeidae and Milaeidae in Australia, with two new records. *J. Malac. Soc. Aust.* 3 (2): 63-80.

Boray, J. C. & McMichael, D. F., 1961. The identity of the Australian Lymnaeid snail host of *Fasciola hepatica* L. and its response to environment. *Aust J. mar. freshw. Res.* 12 (2): 150-163.

Climo, F. M., 1969. Classification of New Zealand Arionacea (Mollusca Pulmonata). 1. The higher classification. *Rec. Dom. Mus. Wellington.* 6 (12): 145-158.

Cotton, B. C., 1954. A catalogue of introduced snails and slugs in Australia. *Rec. S. Aust. Mus.*, 11 (2): 177-187.

Cox, J. C., 1868. *A Monograph of Australian Land Shells.* Sydney.

————, & Hedley, C., 1912. An index of the land shells of Victoria. *Mem. natn. Mus. Vict.*, 4: 1-11.

Gabriel, C. J., 1930. Catalogue of the land shells of Victoria. *Proc. R. Soc. Vict.* 43: 62-88.

————, 1939. The freshwater Mollusca of Victoria. *Mem. natn. Mus. Vict.*, 11: 100-139.

————, 1947. Additions to and alterations in the catalogue of the land shells of Victoria (including descriptions of new species). *Ibid.*, 15: 109-125.

————, & MacPherson, J. H., 1947. Mollusca. in *A preliminary report on the biology and ecology of the Snowy River area in North Eastern Victoria. Ibid.*, 15: 146-171.

Gregory, J. S., 1912. *The geography of Victoria: Historical, physical and political.* Melbourne.

Hills, E. S., 1940. *The physiography of Victoria.* Whitcombe & Tombs, Melbourne.

Hubendick, B., 1951. Recent Lymnaeidae, their variation, morphology, taxonomy, nomenclature and distribution. *K. svenska Vetensk-Akad. Handl.*, 3 (1): 5-223.

————, 1967. Studies on Ancylidae. The Australian, Pacific and Neotropical form groups. *Acta. R. Soc. scient. litt. Gothoburg. (Zoologica)*, 1: 5-52.

IREDALE, T., 1933. Systematic notes on Australian land shells. *Rec. Aust. Mus.*, 19 (1): 37-59.

————, 1937. A basic list of Land Mollusca of Australia. Pt. I. *Aust. Zool.*, 8 (4): 287-333. Pt. II. *Aust. Zool.*, 9 (1): 1-39.

————, 1938. A basic list of Land Mollusca of Australia. Pt. III. *Ibid.*, 9 (2): 83-124.

LONG, D. C., 1970. *Arion intermedius* (Normand), an introduced slug in Victoria. *Victorian Nat.*, 87 (6): 170-172.

McMICHAEL, D. F. & HISCOCK, I. D., 1958. A monograph of the freshwater mussels (Mollusca: Pelecypoda) of the Australian region. *Aust. J. mar. freshwat. Res.* 9 (3): 372-508.

SMITH, B. J., 1967. Notes on the distribution of the dune-snail *Theba pisana* Müller at Portsea Back Beach, Victoria. *Victorian Nat.*, 84 (9): 267-270.

————, 1970. Notes on the anatomy of *Victaphanta atramentaria* (Shuttleworth) and *V. compacta* (Cox and Hedley), and the designation of a neotype for *V. atramentaria*. *J. Malac. Soc. Aust.*, 2 (1): 13-21.

————, 1975. Victorian non-marine molluscs No. 14. *Victorian Nat.*, 92 (3): 47-48.

———— & KERSHAW, R. C., 1972. Tasmanian snail referred to the genus *Victaphanta* (Stylommatophora: Paryphantidae). *Mem. natn. Mus. Vict.*, 33: 111-114.

———— & PLANT, R. J. 1973. Preliminary results of non-marine mollusc census. *Victorian Nat.* 90 (9): 259-263.

SOLEM, A., 1973. Convergence in Pulmonate radulae. *Veliger*, 15 (3): 165-171.

ZILCH, A., 1959-60. Gastropoda-Euthyneura. *Handbuch der Paläozoologie*, 6: 1-834. Borntraeger, Berlin.

APPENDIX

SYSTEMATIC LIST OF THE NON-MARINE MOLLUSC FAUNA OF THE OTWAY REGION.

Abbreviations: (I) = introduced species; (E) = endemic to the Otway Region.

Family HYDROBIIDAE
- *Tatea rufilabris* (A. Adams, 1862).
- *Potamopyrgus nigra* (Quoy and Gaimard, 1835).
- *Angrobia angasi* (Smith, 1882).
- *Pupiphryx grampianensis* (Gabriel, 1939).
- *'Hydrobia' buccinoides* (Quoy and Gaimard, 1835).

Family TRUNCATELLIDAE
- *Truncatella scarlarina* (Cox, 1867).

Family ASSIMINEIDAE
- *Assiminia tasmanica* (Tenison-Woods, 1875).

Family ELLOBIIDAE
- *Marinula meridionalis* (Brazier, 1877)
- *Marinula zanthostoma* H. and A. Adams, 1854.
- *Ophicardelus ornatus* (Ferussac, 1821).

Family AMPHIBOLIDAE
- *Salinator solida* (von Martens, 1878).

Family LYMNAEIDAE
- *Lymnaea tomentosa* (Pfeiffer, 1855).
- *Lymnaea lessoni* (Deshayes, 1831).

Family PLANORBIDAE
- *Physastra gibbosa* (Gould, 1847).
- *Bulinus (Isidorella) hainesii* (Tryon, 1866).
- *Glyptophysa aliciae* (Reeve, 1862).
- *Gyraulus* sp.
- *Plananisus tasmanicus* (Tenison-Woods, 1876).
- *Pygmanisus scottianus* (Johnston, 1879).

Family FERRISSIIDAE
- *Ferrissia (Pettancylus) tasmanicus* (Tenison-Woods, 1876).
- *Ferrissia (Pettancylus) petterdi* (Johnston, 1879).

Family PUPILLIDAE
- *Omegapilla* sp.

Family SUCCINEIDAE
- *Austrosuccinea australis* (Férussac, 1821).

Family PUNCTIDAE
- *Paralaoma morti* (Cox, 1864).
- *Paralaoma mucoides* (Tenison-Woods, 1879).
- *Paralaoma halli* (Legrand, 1871).
- *Excellaoma retipora* (Cox, 1867).
- *Magilaoma penolensis* (Cox, 1868).
- *Trocholaoma (Laomavix) collisi* (Brazier, 1877).

Family CHAROPIDAE
- *Pernagera stanleyensis* (Petterd, 1879).
- (E) *Pernagera gatliffi* (Gabriel, 1930).
- *Pernagera tamarensis* (Petterd, 1879).
- *Pillomena (Pillomena) meraca* (Cox and Hedley, 1912).
- *Pillomena (Oreomava) otwayensis* (Petterd, 1879).
- (E) *Geminoropa scindocataracta* (Gabriel, 1930).
- (E) *Allocharopa erskinensis* (Gabriel, 1930).
- *Roblinella subdepressa* (Brazier, 1871).
- *Elsothera funerea* (Cox, 1868).
- *Thryasona elenescens* (Cox and Hedley, 1912).

Family ARIONIDAE
- (I) *Arion intermedius* (Normand, 1852).

Family ZONITIDAE
- (I) *Oxychilus alliarius* (Millar, 1822).
- (I) *Oxychilus cellarius* (Muller, 1774).

Family MILACIDAE
- (I) *Milax gagates* (Draparnaud, 1801).

Family LIMACIDAE
- (I) *Limax maximus* (Linnaeus, 1758).
- (I) *Deroceras caruanae* (Pollonera, 1891).
- (i) *Deroceras reticulatus* (Muller, 1774).
- (I) *Lehmannia (Lehmannia) nyctelia* (Bourguignat, 1861).
- (I) *Lehmannia (Limacus) flavus* (Linnaeus, 1758).

Family HELICARIONIDAE
- *Helicarion niger* (Quoy and Gaimard, 1832).
- *Helicarion cuvieri* Férussac, 1821.

Family CYSTOPELTIDAE
- *Cystopelta purpurea* Davies, 1912.

Family FERUSSACIIDAE
- (I) *Ferussacia* sp.

Family RHYTIDIDAE (PARYPHANTIDAE)
- (E) *Victaphanta compacta* (Cox and Hedley, 1912).
- *Prolesophanta dyeri* (Petterd, 1879).
- *Rhytida* (?) *capillacea* (Férussac, 1822).
- *Rhytida* (?) *gawleri* (Brazier, 1872).
- *Rhytida* (?) *ruga* (Legrand, 1871).

Family CAMAENIDAE
Chloritobadistes victoriae (Cox, 1868).
Family HELICIDAE
(I) *Helix (Cryptomphalus) aspersa* (Born, 1778).
(I) *Theba pisana* (Muller, 1774).
(I) *Cochlicella ventrosa* (Férussac, 1819).
(I) *Cernuella (Cernuella) virgata* (Da Costa, 1779).
(I) *Candidula intersecta* (Poiret, 1801).

Family HYRIIDAE
Velesunio ambiguus (Philippi, 1847)
Hyridella (Hyridella) drapeta (Iredale, 1934).
Family CORBICULINIDAE
Corbiculina angasi (Prine, 1864).
Family SPHAERIIDAE
Pisidium casertanum (Poli, 1795).
Sphaerium tasmanica (Tenison-Woods, 1876).
Sphaerium problematicum (Gabriel, 1939).

PROCEEDINGS

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CONTENTS OF VOLUME 89 PART 2

15

AGE-RELATIONSHIPS OF NEWER BASALTS IN THE GEELONG DISTRICT, VICTORIA

By ALAN COULSON*†

ABSTRACT: In the Geelong District four types of Newer Basalt occur, viz. Trentham, Malmsbury, Footscray and Ballan types, ranging in age from Middle or Upper Pliocene to Lower Pleistocene. This paper is concerned with a confined flow of Trentham type along the north bank of the Barwon River, and its relation to the other types.

INTRODUCTION

The Geelong Geological Sheet No. 857 (1:63,360) published by the Geological Survey of Victoria in 1963, shows a confined basalt flow marked Nv2, Newer Volcanic 'Valley basalt', along the Barwon River from Pollocksford to St. Albans. Seven further exposures have been found between Pollocksford and Inverleigh, two east of Winchelsea, and one near the Avalon Overpass on the Geelong-Melbourne Road. The age of this Nv2 basalt, which is of Trentham type (Edwards 1938) is discussed in relation to the adjacent flows of Nv1 'Sheet' basalts, not differentiated on the official map, but here distinguished as Ballan, Footscray and Malmsbury types (Fig. 1).

The method of investigation was field observation and optical petrography. About 400 thin sections were prepared, and are now deposited at the Geology School of the University of Melbourne. Some slides were made at the Gordon Institute of Technology by courtesy of Mr. S. E. Rowe, Lecturer in Geology. Dr. D. Spencer-Jones, Director of the Geological Survey of Victoria, assisted with information and criticism. Much help was received from Dr. A. Cundari and Dr. O. P. Singleton (Melbourne University), and Dr. J. M. Bowler (A.N.U., Canberra). Dr. Bowler kindly allowed the use of his unpublished manuscript on the formation of iddingsite. The co-operation of quarry managers and property owners was also appreciated.

PETROGRAPHY OF THE Nv2 TRENTHAM-TYPE BASALT

Fresh specimens from the interior of the flows are black, greenish-black or dark grey, non-vesicular, with short glittering plagioclase crystals. Thin sections reveal corroded or partly rounded clear olivine crystals, not iddingsitized, sub-hedral pyroxenes, short laths of labradorite (Ab_{32} to Ab_{38}) and a dark groundmass of felspar laths, pyroxene prisms and black glass containing microliths of ilmenite and magnetite. Green felspathic material occurs in some slides from lower portions of flows.

The upper flow units yield specimens which have the olivine crystals lightly margined with yellow or red-brown iddingsite, with less glass, thin rods or blebs of iron ore, but the texture and other minerals remain as in the Trentham basalt.

The virtual absence of iddingsite from the margins of the olivine phenocrysts in the Nv2 valley basalt enables it to be readily recognized in hand specimens as well as in thin sections. The presence of iddingsitized olivine in the upper zones of Nv2, and uniformly throughout the thin sheet flows of Nv1 basalt has been explained (Gay & Le Maitre 1961) as occurring at the deuteric stage, after the flow had come to rest but before the consolidation of the magma, at intermediate temperatures and in a strong oxidizing atmosphere. 'Iddingsite is not a mineral with a definite structure and chemical composition, neither is it a simple sub-microscopic intergrowth of two or more well-characterized minerals' (Gay & Le Maitre 1961). These were thought to be goethite and smectite-chlorite.

According to Bowler (1961), 'the mechanism of iddingsite formation is that the olivine is rich in MgO (Fa_{13},Fo_{87}) and after crystallization some olivine sinks through the fluid centre, causing the residual liquid and volatiles to begin to rise towards the top. Falling temperatures increase the viscosity at top and bottom, pyroxenes crystallize and olivines are partially redissolved with preferential resorption of MgO and SiO_2, leaving the depleted lattices in a disordered state. Near the top of the flow, the remaining FeO is oxidized *in situ* to goethite whilst the remaining SiO_2 takes up CaO

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and Al_2O_3 from the residual liquid to form a layered silicate strueture alongside fibrous lamellae of goethite. Deeper in the flow, at higher temperatures, the olivine lattice, with rims depleted in MgO, exsolves excessive iron as magnetite, or incorporates iron into the depleted lattice, resulting in an iron-rich rim.'

Dr. Bowler has supplied the following chemical evidence (Tables 1-3) in support of his theory. (Analysts V. Biskupsky and J. M. Bowler.)

TABLE 1

A. Nv2 VALLEY FLOW, DOG ROCKS, BATESFORD.
B. Nv1 PLAINS FLOW, EAST BATESFORD

	A	B
SiO_2	50.65	51.57
Al_2O_3	13.97	15.51
Fe_2O_3	2.20	6.59
FeO	8.42	4.20
CaO	8.61	8.42
MgO	8.70	4.60
Na_2O	2.10	2.20
K_2O	1.30	0.98
Ti O_2	1.75	1.75
H_2O-110°	0.94	1.65
H_2O+110°	0.50	1.71
	99.14	99.18

It will be noted that 1. the degree of alteration of olivine to iddingsite decreases with depth. 2. the modal percentage of olivine increases with depth. 3. the percentages of Ca and Mg increase with depth. 4. the percentages of SiO_2 and Al_2O_3 decrease slightly with depth.

Weathered specimens and deep bore cores often contain secondary calcite or aragonite, zeolites, reddish limonite, some siderite and occasional serpentine.

TABLE 3

PARTIAL ANALYSIS OF AVERAGE Nv2 SAMPLES REPRESENTING UPPER, MIDDLE AND LOWER ZONES IN BORE 13, GHERINGHAP, 1 KM WEST OF FYANSFORD.

	Upper Zone	Middle Zone	Lower Zone
Ca O	6.96	7.80	6.06
Mg O	6.73	7.23	8.28
Fe O	5.58	5.57	6.80
Fe_2O_3	4.00	2.75	2.64

AGE OF THE Nv2 FLOW

Near Pollocksford the Nv2 rests on Moorabool Viaduct Sands, usually regarded as Lower Pliocene, but possibly Upper Miocene in age (T. A. Darragh quoted in Aziz-ur-Rahman & McDougall 1972). Between Pollocksford and Fyansford the Nv2 rests on Moorabool Viaduct Sands on the north bank of the Barwon River and on Lower Cretaceous sediments on the south bank. From Fyansford through Newtown the Nv2 fills a valley cut in Lower Cretaceous sandstone and conglomerate. Near Kardinia Park in Latrobe Terrace, Chilwell, the sub-basaltic formation is Moorabool Viaduct Sands (as proved by borings of the Geelong Waterworks and Sewerage Trust). Between Fyansford and Batesford the Nv2 rests on eroded Fyansford Clay (Bairnsdalian) or on Devonian granite at the Dog Rocks.

Thin Quaternary gravels and sands cover the Nv2 in places between Batesford and Fyansford, also at Breakwater and St. Albans. At Batesford Australian Portland Cement Ltd. quarry there was a capping, now removed, of 1 m of sandy limestone chemically deposited in surface depressions on the Nv2; it resembled the Lara limestone of Pleistocene age (Pritchard 1895) but contained no fossils.

TABLE 2

ANALYSES OF Nv2 BASALT AT VARIOUS DEPTHS IN GHERINGHAP BORE 15, 1 KM WEST OF FYANSFORD, ON HAMILTON HIGHWAY.

Depth	3.0 m	16.4 m	24.3 m	32.3 m	38.1 m	40.8 m	45.1 m
Si O_2	51.08		48.57	50.95		49.74	49.65
Al_2O_3	15.10		13.35	14.04		13.50	12.95
Fe_2 O_3	4.33	4.49	3.44	3.95	3.08	1.60	4.49
Fe O	5.38	6.08	7.00	6.50	7.60	9.36	6.24
Ca O	8.34	6.48	7.40	7.80	7.33	8.38	8.17
Mg O	6.10	8.66	9.52	4.95	9.63	9.79	7.50
Na_2 O	3.68		3.69	4.38		3.68	3.84
K_2 O	1.32		1.31	2.42		1.75	1.75
Ti O_2	1.65		1.60	2.40		1.80	1.78
H_2O-110°	1.11		1.95	1.21		0.19	0.97
H_2O + 110°	1.25		1.50	1.40		0.15	1.75
	99.41		99.33	100.07		99.94	99.19

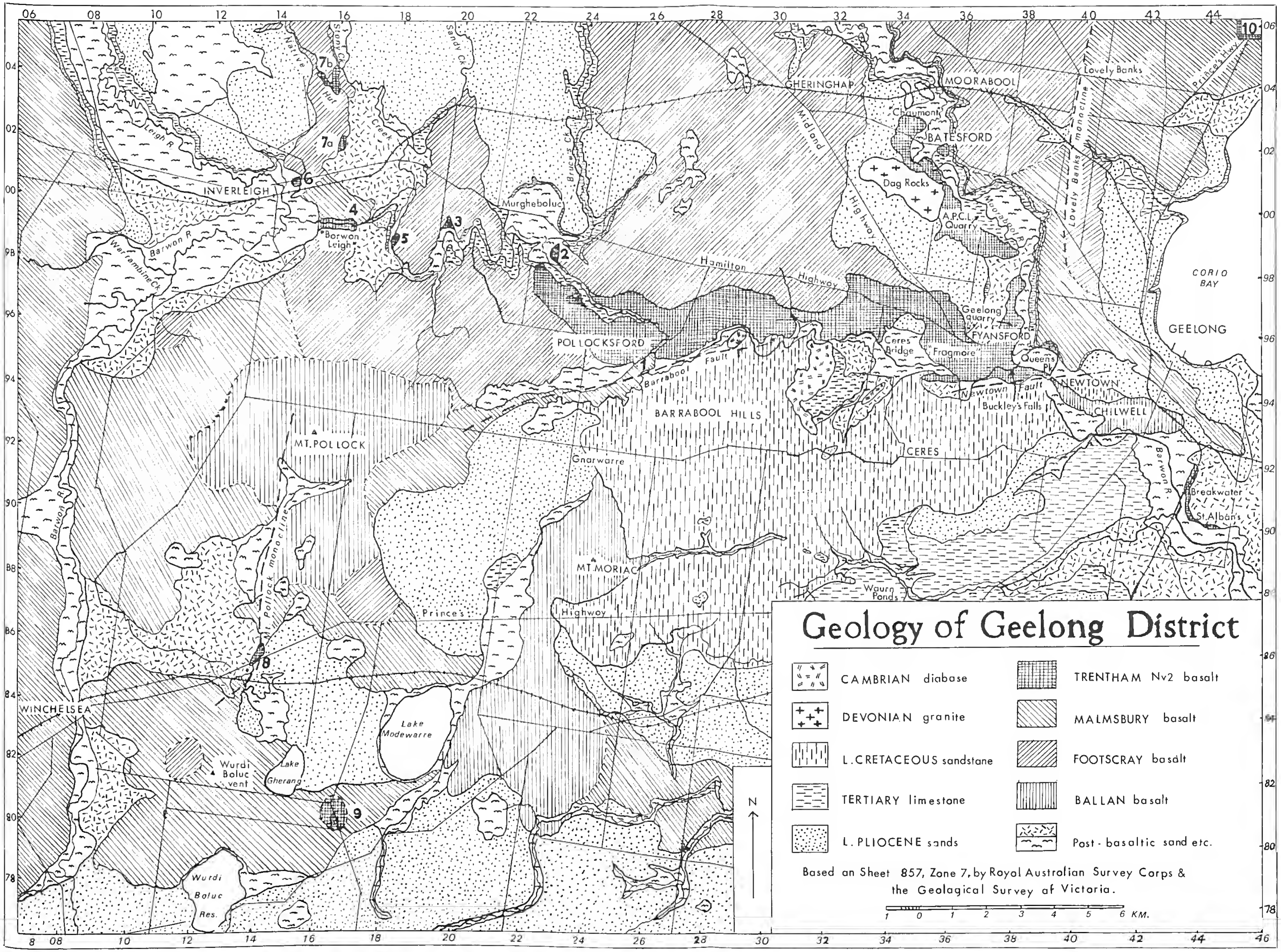

FIG. 1. Geology of Geelong District.

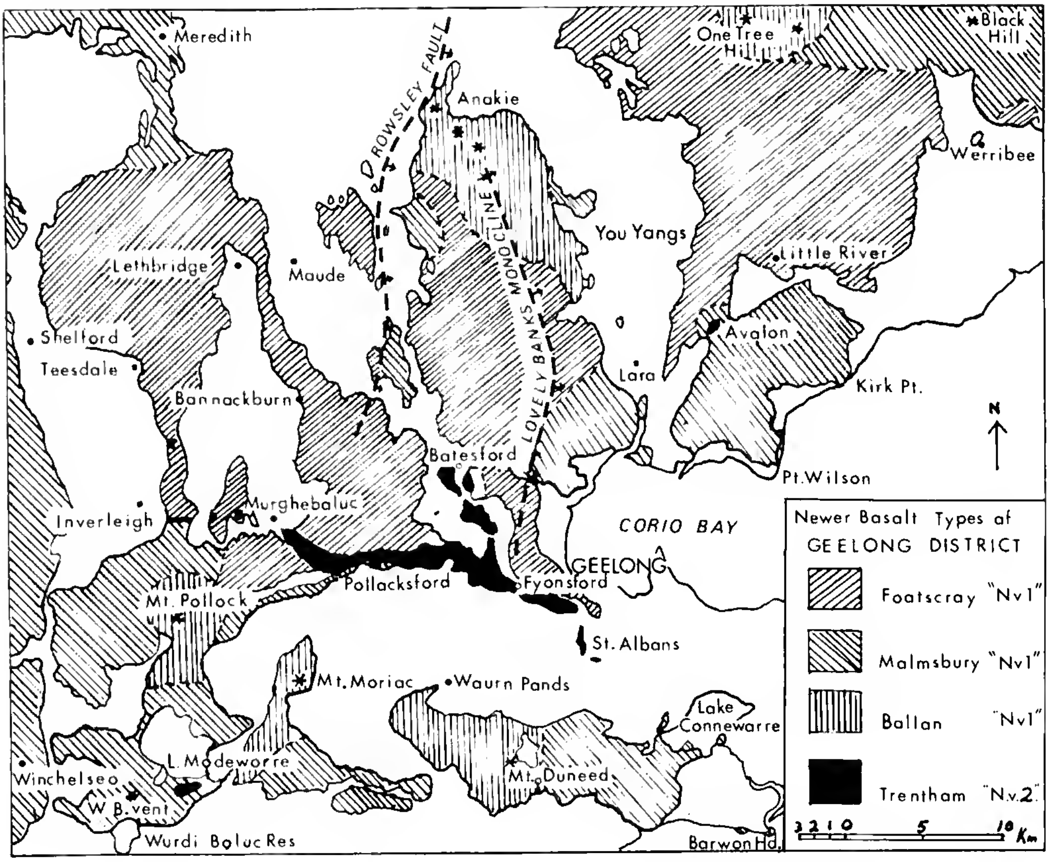

FIG. 2.—Distribution of Newer Volcanic types in Geelong District.

If the suggested Upper Miocene age of the Moorabool Viaduct sands is accepted, it provides a longer time-interval for the extrusion of the Newer Volcanic flows, say from Middle Pliocene to Lower Pleistocene. The K-Ar radiometric age of 2.1 million years (Aziz-ur-Rahman & McDougall 1972) on Nv2 samples from Pollocksford and Fyansford would place it in the Upper Pliocene at the latest; its stratigraphic position could be Middle or Upper Pliocene.

EXTENT OF THE Nv2 FLOW

The Nv2 flow as mapped (Fig. 1) extends from 5 km west of Pollocksford (altitude 60 m) along the Barwon River to Fyansford (altitude 45 m) through Newtown (altitude 36 m) and Chilwell (altitude 20 m) to Breakwater and St. Albans (altitude 8 m), a distance of 19 km (Fig. 1). A flow of Nv2 runs north from Fyansford to Batesford, a distance of 6 km, but has been severely eroded by the Moorabool River into four residuals overlain in places by gravel and sands.

The thickness of the Nv2 varies considerably, being 35 m at Pollocksford, 20 m near Ceres Bridge, 46 m in Gheringhap Bore 20 at Fyansford, 30 m in Geelong Quarry at North Fyansford, 15 m at the Dog Rocks, and 10 to 15 m at the Australian Portland Cement Ltd. quarry at Batesford. The Nv2 basalt forms the river bed at Pollocksford Bridge, the property 'Barwon Leigh', and at Buckleys Falls, Fyansford.

Three flow units can be discerned in Geelong Quarry, three at Buckleys Falls, two in Fyansford and Newtown quarries, and three in the Gheringhap bores in 'Frogmore' west of Fyansford (Fig. 3). Each unit consists of an upper vesicular zone about 2 m thick, columnar basalt 5 to 12 m thick, and a thin glassy base. The vesicular zone about 2 m thick, columnar basalt 5 to 12 m thick, and a thin glassy base. The vesicular zone is usually marked by partially iddingsitized olivines resulting in a more brownish colour in the rock.

FURTHER EXPOSURES OF Nv2 BASALT

The following exposures have been located; numbers correspond to Fig. 1.

Locality 1. 50 m W. of Pollocksford Bridge, in cutting on S. side of Gnarwarre Road. Corestones in 'onion structures' are Nv2., overlain by Footscray type. Military Co-ordinates (hereafter M.C.) 262951. Altitude (hereafter Alt.) 33 m.

Locality 2. 2 km SE. of Murgheboluc, on spur near junction of Bruces Creek and Barwon River. Upper flow is Malmsbury type. M.C. 219986. Alt. 60 m.

Locality 3. 2 km SW. of Murgheboluc, in gully on 'View Bank' farm, N. bank of Barwon River. M.C. 195993. Alt. 45 m. Upper flow is Malmsbury, probably from Mt. Pollock.

Locality 4. 'Barwon Leigh,' 2 km SE. of Inverleigh, basalt bar 1 km wide in Barwon River. M.C. 165992. Alt. 56 m.

Locality 5. E. bank of Barwon River opposite 'Barwon Leigh'. M.C. 181993. Alt. 50 m. Upper flow is Footscray type.

Locality 6. Inverleigh Picnic Reserve, E. bank of Leigh River in road cutting. M.C. 144006. Alt. 59 m. Upper flow is Footscray type from Stony Creek flow.

Locality 7. (a) Inverleigh, E. of Golf Course. M.C. 152023. Alt. 53 m.

(b) Inverleigh, junction of Stony Creek and Native Hut Creek, in bed of creek, overlain by Footscray type. M.C. 158033. Alt. 57 m.

Locality 8. Prince's Highway, 1 km E. of road bridge over railway E. of Winchelsea. M.C. 139852. Alt. 105 m. Mt. Pollock Monocline crosses the road at this point, tilting lava to W. Corestones in onion structures; associated with fine Malmsbury type.

Locality 9. Between Lake Modewarre and Wurdi Boluc Reservoir. M.C. 162802. Alt. 126 m. About 1 sq. km of Nv2 is exposed here, and may be an early flow from the Wurdi Boluc vent about 3 km to the W.

Locality 10. (a) Prince's Highway, disused quarry at W. end of Avalon Overpass. M.C. 531117. Alt. 17 m. Upper flow is Malmsbury type. Radiometric age of upper flow is 1.6 million years, (Aziz-ur-Rahman & McDougall 1972).

(b) Same locality, Woornyalook Bores 2,3. Nv2 below 20 m depth. Upper flows are Footscray and Malmsbury types, probably from the Balliang group of vents to the N.

Superposition is demonstrable at localities 3, 5 and 7, where in each case the Nv2 is overlain by Footscray or Malmsbury type sheet-flows. Other instances of superposition occur at (i) Stonehaven, in a gully running south through the property 'Springdale' to the Barwon River. M.C. 307963. Here Footscray type overlies Nv2. (ii) in a gully north of Pollocksford Bridge. M.C. 267958. Here a similar relation exists. (iii) Breakwater Railway Crossing. M.C. 437917. Malmsbury type overlies the Nv2.

The width of the exposed Nv2 between Murgheboluc and Fyansford varies between 1 and 2 km, the junction between Nv1 and Nv2 is irregular, and the surface of the Nv2 is usually several metres lower than the Nv1.

It is necessary to explain why the Nv1 does not overlap the Nv2 right up to the Barwon River. One reason is that in many places the Nv1 did not extend further than its present limits. The other is that erosion has removed the thin southern edges of the Nv1 flows.

A more serious difficulty is that the upper flow-units of Nv2 are often iddingsite-bearing, thus resembling Footscray type. This makes it necessary to examine the basalt underlying the surface type to decide if it is Nv2 or Nv1. If both surface and underlying rock is Nv1, then the whole is mapped as Nv1. If the under-rock is Nv2, and the surface rock is apparently Nv1 but thin, it is mapped as Nv2. For this reason the official mapping has been followed in classifying as Nv2 rather than Footscray, the surface basalt near the south end of Dears Lane, the low ridge 50 m east of Stonehaven Primary School, and near the north end of Pollocksford Road.

It will be realized from the foregoing that, at least in the area between Inverleigh and Fyansford, the Nv2 is older than the Footscray and Malmsbury types there. Does the same age-relationship hold for the Nv2 of the Batesford-Fyansford tongue flow? East of Batesford Bridge the lower flow is a residual of an Nv2 flow which filled a valley of the ancestral Moorabool River. Its surface level is 46 m, whilst the upper level Nv1 sheet flow is at 61 m, and the bank has receded 300 to 350 m east of the river (Fig. 3). Just after extrusion the Nv1 must have extended to the east flank of the Dog Rocks. Erosion by the Moorabool River has removed the upper basalt from the western edge of the flow, and exposed the Moorabool Viaduct Sands and the Fyansford Clay.

The upper level Nv1 sheet-flows at Batesford probably came from eruption centres near Anakie, and as they ante-date the Nv2 there, must be older than 2.1 million years, i.e. they must have been extruded in Lower or Middle Pliocene times, and would thus be the earliest of the 'Newer' basalts (cf. Spencer-Jones 1970). They are overlain by freshwater limestone of Pleistocene age at Lara, and in general are more weathered than the Nv1 types to the west of the Moorabool River.

There is no evidence of Nv2 in the valleys of the upper Moorabool River or Sutherlands Creek, nor in the valley of Cowie's Creek; the Nv2 terminates at the property 'Chaumont' 1 km north-west of Batesford. At the east end of the Moorabool Viaduct there is a quarry (Bowler 1963) at a level 15 m below the surface of the upper Nv1 flows, but the rock is Footscray type filling a small valley on the pre-basaltic surface. No connection has been found between the Batesford Nv2 and the Avalon Nv2 despite search in the valleys of Cowies Creek, and Hovells Creek. An alternative source of the Batesford Nv2 is that it came upstream from Fyansford, a distance of 6 km. The maximum

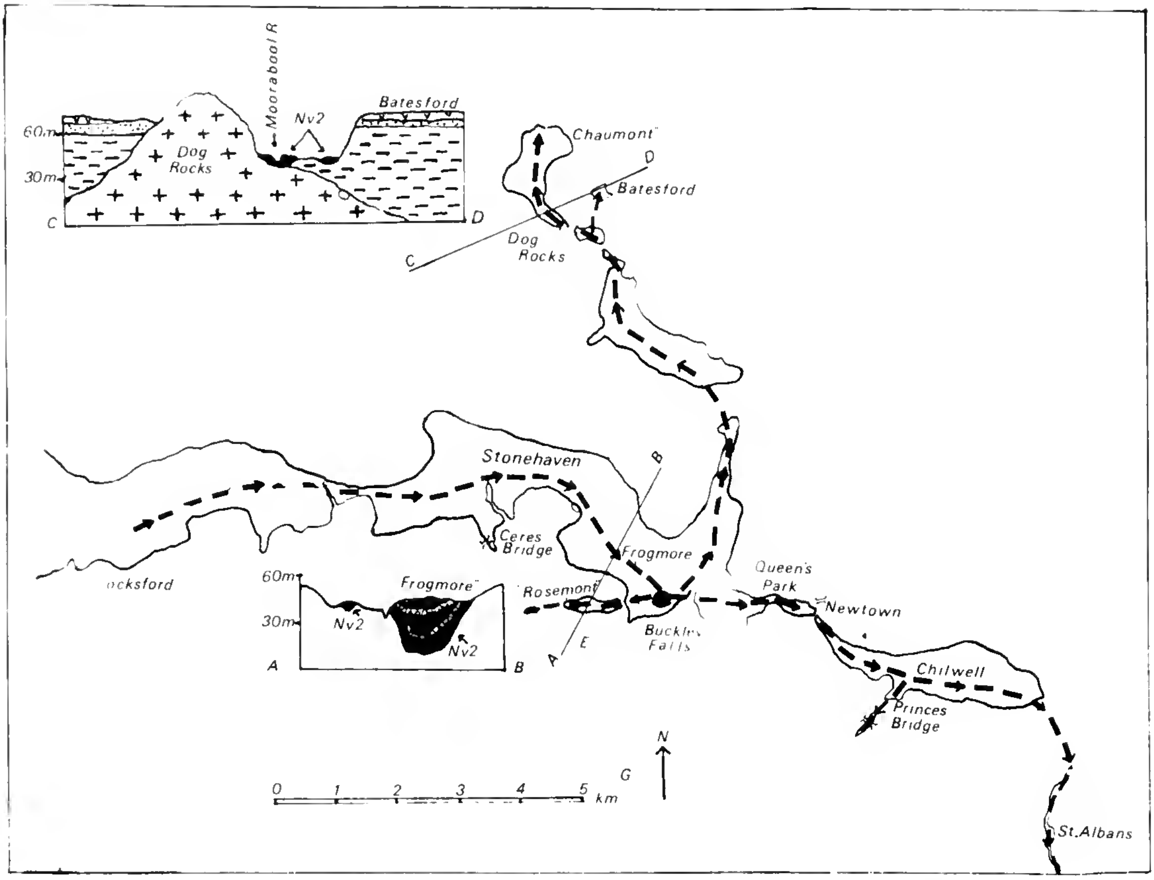

FIG. 3.—Possible course of Nv2 lava filling valley of ancestral Barwon River.

thickness of Nv2 at Fyansford (Gheringhap Bore 20) is 46 m and at Batesford 33 m. It is suggested that the early Nv2 flow units from Pollocksford partly filled, to say 34 m, a deep hole at Buckleys Falls, Fyansford, then occupied the former Barwon River valley (Fig. 3) through Newtown and Chilwell to St. Albans. Further flows of Nv2 on reaching Fyansford were diverted northwards, filling the valley of the ancestral Moorabool River to about 46 m altitude, and terminating at North Batesford. Some support for this theory is that there are three flow units visible in the east face of Buckleys Falls, each approximately 15 m thick. The upper flow shows crudely columnar structure, and it was possibly part of this flow which reached Batesford.

ORIGIN AND EMPLACEMENT OF THE Nv2 FLOWS

The source of the Pollocksford Nv2 has not been definitely located. Two localities that suggest themselves are (i) Locality 7(b), just north of the junction of Native Hut and Stony Creeks. This exposure is covered by a very young flow of Footscray type from the Teesdale area. (ii) Locality 9, between Wurdi Boluc Reservoir and Lake Modewarre. This outcrop is surrounded and partly covered by the fine Malmsbury type from the Wurdi Boluc lava dome 3 km to the west. This locality is 14 km south of the Inverleigh exposures, but no connection can be traced between them except for the limited exposure at Locality 8.

The Nv2 is pictured as emanating north of Inverleigh, flowing south to 'Barwon Leigh', then turning east along the valley of the ancestral Barwon at the foot of the Barrabool Fault scarp and the Newtown Fault scarp to Fyansford. The main flow continued through Newtown to St. Albans, whilst a shorter flow moved north up the Moorabool valley to Batesford. The Barwon River was displaced further south as a result of the infilling of its former valley by the Nv2, and cut its present valley, causing recession of the northern face of the horst. Some of the infilled tributaries, e.g. south of 'Frogmore' near Ceres Bridge, and east of Princes Bridge at Marnock Vale, formed temporary barrier lakes until cut by the rejuvenated Barwon River. Similarly Queens Park was a lake until breached by the Barwon at Newtown (Fig. 3).

After the Nv2 had solidified, the Nv1 flows began to appear. One of these filled a former valley between Lethbridge and Fyansford, roughly along the present Midland Highway. This flow, of Footscray type, is 5 m thick at Nashs Quarry, Lethbridge, and 14 m thick at Bannockburn (Bore 1, Wabdallah). A more westerly sheet-flow of Footscray type, 12 km wide, west of Lethbridge, narrows to 1 or 2 km north of Inverleigh, and partly covers the Nv2 in that vicinity.

Early flows of Footscray type from Mt. Pollock travelled north-east towards Pollocksford and Inverleigh, partly covering the Nv2. The most interesting flows east of Mt. Pollock are the Malmsbury type basalts which coat the hillslopes between Mt. Pollock, Gnarwarre and Pollocksford Bridge. These patches of Nv1 reach an altitude of 136 m and descend to 50 m at river level; the basalt is apparently continuous down the slopes. The question arises as to how the basalt managed to clothe the slopes, which are the fault scarp of the western end of the Barrabool Fault, which possibly extends west to the Mt. Pollock monocline. Possibly the faulting movements and the volcanicity were contemporaneous. There has been a series of movements on the Barrabool Fault, beginning in the Lower Miocene (Coulson 1960), and the one under discussion took place probably in the Upper Pliocene or Lower Pleistocene.

The Newtown Fault scarp along Queens Park road east and south of Buckleys Falls is partly coated with Nv2 basalt, descending from 46 m to 34 m surface level with thicknesses ranging from 12 m at the top to 25 m at the bottom, as recorded in Barrabool Bores 1-6. The problem here is that the Nv2 in the bed of the river at Buckleys Falls is at altitude 10 m, but the base of the Nv2 in the infilled valley between Buckleys Falls and Newtown Hill (Fyans Park) is at altitude 18 m. This difference of level may be due to relative uplift along the Queens Road strip, or it may indicate that the pre-basaltic river bed was uneven, with a relatively deep hole at Buckleys Falls, say to altitude 10 m. Actually there are pre-basaltic grits showing just above river level at the base of the east face of Buckleys Falls, and of course the Mesozoic bedrock close under; this contributed to the undermining of the cliffs there, and caused large blocks of basalt to fall into the pond.

Possibly a combination of uplift and ponding occurred; the Newtown Fault has been active several times. Borings by the Geelong Waterworks and Sewerage Trust in the Central part of Geelong in Villamanta Street reveal that an easterly extension of the Newtown Fault has lowered the Nv1 Malmsbury type basalt about 30 m along an east-west line. One effect of this was to expose Malmsbury basalt at low tide a few metres east of the swimming pool on the Eastern Beach.

The age of the latest movements on the Barrabool and Newtown Faults is Upper Pliocene or Lower Pleistocene; this is somewhat later than those on the Rowsley Fault and the Lovely Banks Monocline. The Rowsley Fault has raised four small patches of Anakie Nv1 flows on its western upthrow side (Fig. 2). The Lovely Banks Monocline has lowered Anakie flows on its eastern downthrow side by about 20 m, increasing to 70 m near 'Elcho' farm, and dwindling to a few metres south of the Ballarat-Geelong road. The displaced Anakie flows are of Middle to Upper Pliocene age; probably the movements took place in the Upper Pliocene.

CONCLUSIONS

1. The Trentham Nv2 type basalt originated possibly in the Inverleigh district, and flowed east filling a valley of the ancestral Barwon River from Pollocksford to Fyansford. The main flow continued through Newtown and Chilwell to Breakwater and St. Albans.

2. A northern branch of Nv2 flowed from Fyansford up the lower Moorabool valley to Batesford.

3. The age of the flows of Nv2 is 2.1 million years, i.e. Upper Pliocene.

4. The sheet-flows of Nv1 west of Fyansford are younger than the Nv2 though probably still Upper Pliocene or Lower Pleistocene.

5. At Batesford the Nv1 upper level flows are older than the Nv2 there. They could be Middle Pliocene.

REFERENCES

Aziz-ur-Rahman & McDougall, I., 1972. Potassium-Argon ages on the Newer Volcanics of Victoria. *Proc. R. Soc. Vict.* 85: 61-69.

Bowler, J. M., 1961. 'Iddingsite' formation in Olivine Basalt from Victoria. Unpub. MS.

———, 1963. Tertiary Stratigraphy and Sedimentation in the Geelong-Maude Area, Victoria. *Proc. R. Soc. Vict.* 76: 69-137.

Condon, M. A., 1951. The Geology of the Lower Werribee River, Victoria. *Ibid.* 63: 1-24.

Coulson, A., 1938. The Basalts of the Geelong District. *Ibid.* 50: 251-257.

———, 1960. Some structural features of the Barrabool Hills. *Ibid.* 72: 45-52.

Edwards, A. B., 1938. The Tertiary Volcanic Rocks of Central Victoria. *Quart. Journ. Geol. Soc.* 94: 243-320.

Gay, P. & Le Maitre, R. W., 1961. Some Observations on Iddingsite. *Amer. Min.* 46: 92-111.

Pritchard, G. B. , 1895. Notes on the Freshwater limestones of the Geelong District. *Geelong Nat.* 4(3): 37-40.

Spencer-Jones, D., 1970. Explanatory Notes on the Geelong (1:63,360) Geological Map. *Victorian Mines Dept.*

APPENDIX

PETROGRAPHIC DESCRIPTIONS OF NEWER BASALT Nv1 TYPES (after Edwards 1938)

BALLAN TYPE Olivine Andesine Basalt ('Olivine Basalt' Condon 1951).

Macro: light grey, very fine grained, slaggy or platy structures common, contains occasional masses of olivine and rare 'anorthoclase'.

Micro: numerous small olivines partly or completely iddingsitized, abundant short laths (5.5 mm) of andesine Ab_{55}, very small granular pyroxenes colourless and diopsidic, abundant minute dots of iron ore, fine needles of apatite.

FOOTSCRAY TYPE. Olivine Labradorite Basalt ('Augite Basalt' Condon 1951).

Macro: dark grey with bluish tinge, abundant minute vesicles, fine texture.

Micro: abundant olivine phenocrysts rimmed with iddingsite, medium to long (1 mm) laths of plagioclase labradorite-bytownite, much intersertal plagioclase with undulose extinction, ophitic augite and some pale titanaugite, much black or brown glass containing microliths and globules of iron ore.

MALMSBURY TYPE. Olivine-Iddingsite-Labradorite Basalt.

Macro: light grey, matted sub-doleritic texture, spotted with reddish iddingsite, finely vesicular.

Micro: olivines usually corroded and heavily rimmed with red-brown iddingsite, matted laths of labradorite, ophitic colourless to greenish prisms of pyroxene, thin rods of titano-magnetite, rare glass, secondary calcitic zeolites.

16

A STUDY OF SOME COASTAL DUNE LAKES IN WESTERN VICTORIA

By B. V. Timms*

ABSTRACT: To the west of Portland, there are several small lakes lying on coastal calcareous dunes. Their water is clear, hard, alkaline and dominated by Na+ and Cl^- ions. Zooplankton in most is sparse or dominated by the copepods *Gladioferens spinosus* and *Sulcanus conflictus*. The benthos of two lakes includes the polychaete *Boccardia limnicola*. The presence of these three species, together with geomorphological evidence, suggests a marine origin for nearly all lakes. The main exception, Swan Lake, contains the copepod *Calamoecia tasmanica* and is similar to dune lakes on the east coast of Australia.

INTRODUCTION

There are a number of coastal lagoons of fresh water in the south and east of Australia. East of Bass Strait these lie on siliceous sands and have characteristic features (pH ⟨ 5, TDS ⟨ 100 ppm, *Calamoecia tasmanica* the typical planktonic crustacean) as described by Bayly (1964). To the west of Bass Strait, coastal sands are calcareous (Bird 1967) and hence lakes of different character might be expected. On King Island, where there is a mixture of the two sand types (Jennings 1957), dune lakes are heterogenous but essentially similar to the siliceous dune type (Brand 1967).

The only coastal freshwater lakes of any note in south-west Victoria lie to the west of Portland, between Bridgewater and Nelson. Bayly (1963) has recorded the copepods *Sulcanus conflictus* and *Gladioferens spinosus* from the Bridgewater Lakes; the presence of the latter species is significant for it indicates the lake had a past marine contact (Timms 1973). Hence, the Bridgewater Lakes, and possibly the others near them are basically different from those on the siliceous dunes which developed independently of direct marine contact.

This paper explores this possibility by analysing the modes of origin, water chemistry, some other physico-chemical features, and the major animal communities, especially the zooplankton, of these coastal lagoons.

THE LAKES

Between the Glenelg River mouth (near Nelson) and Cape Bridgewater there are 10 lakes and several swamps (Fig. 1). Most lie in a swale between a low, outer Pleistocene dune, incompletely covered with recent dunes, and a higher mass of Pleistocene dune limestone. The outer dunes are composed of calcareous sand of high (90 - 100%) lime content (Boutakoff 1963). Lake Bong Bong, part of the Glenelg estuary, and Long Swamp, lie in the western end of the swale. To the south-east of Bong Bong the swale is divided by recent dunes into compartments in which Sheepwash Lagoon and Cains Hut Swamp lie. The south-eastern extremity of the swale contains the four Bridgewater Lakes (the largest is here termed the Main Bridgewater Lake).

The centre region and much of the southern part of the long swale is largely obscured by advancing Recent dunes. Thirteen kilometres south-east of Cains Hut Swamp, Malseed Lake lies in a hollow, closed in on three sides by advancing dunes. Swan Lake occupies the lower portion of a valley cut into a scarp of consolidated Pleistocene dunes by Johnstons Creek and is bounded at the seaward end by Recent dunes. In addition to these lakes there is a small unnamed lagoon (here termed Lagoon No. 4) in a depression in the inner consolidated dunes.

The seven lakes studied are small and shallow (Appendix 1). Only Bong Bong and the Main Bridgewater Lake are of any size (*c.* 60 and 40 ha) and depth (7 and 9 m respectively). Not surprisingly much of the lake bottoms are weeded, except for isolated areas on Bong Bong, Main Bridgewater and Swan Lakes. All lakes are no more than 10 m as l, probably much less. Water levels are variable (Appendix 1), particularly in Swan

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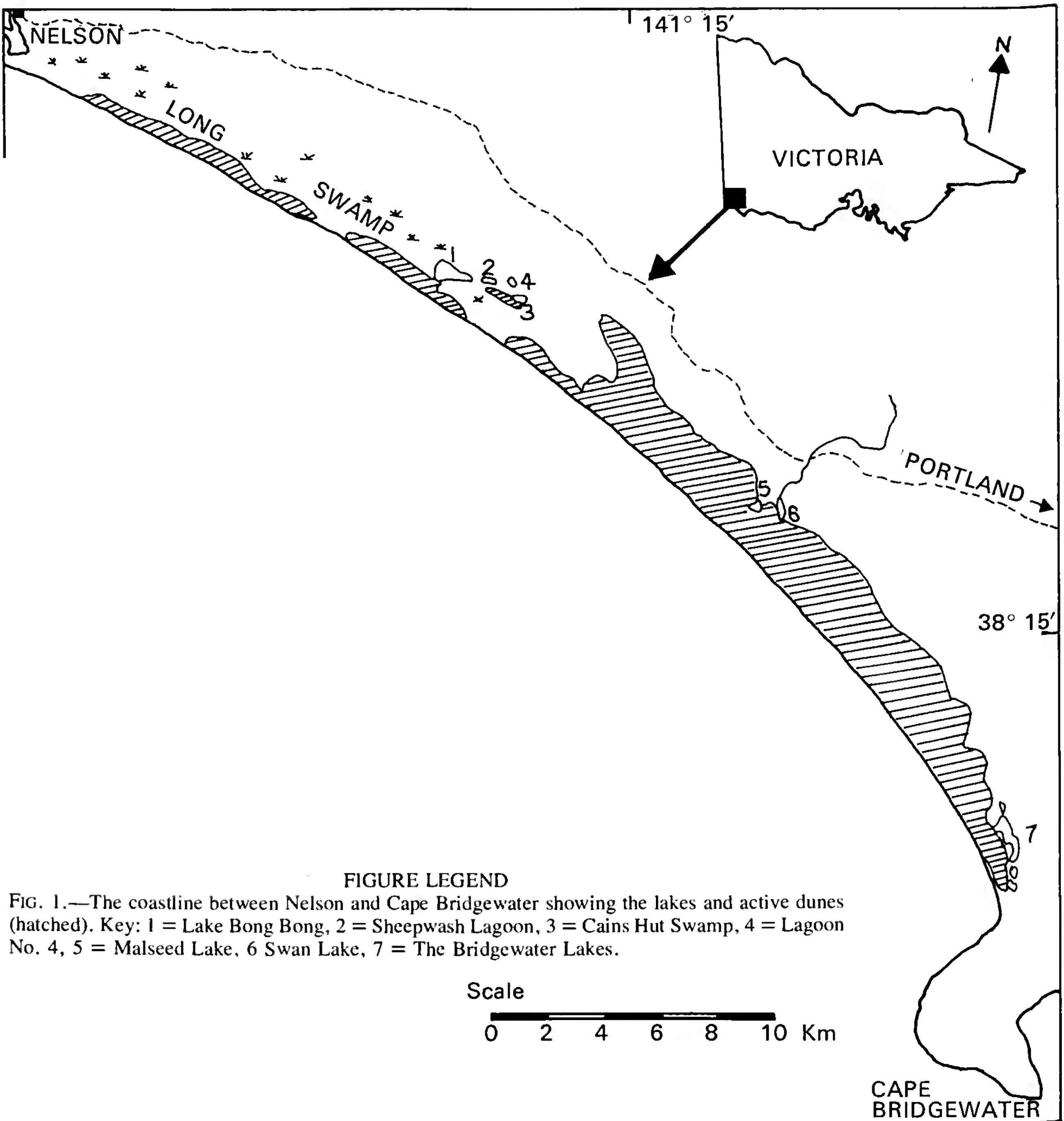

FIGURE LEGEND

FIG. 1.—The coastline between Nelson and Cape Bridgewater showing the lakes and active dunes (hatched). Key: 1 = Lake Bong Bong, 2 = Sheepwash Lagoon, 3 = Cains Hut Swamp, 4 = Lagoon No. 4, 5 = Malseed Lake, 6 Swan Lake, 7 = The Bridgewater Lakes.

Scale

0 2 4 6 8 10 Km

Lake, the only lake with an inflow and outflow. The latter has breached the dune barrier but flows only when lake level is exceptionally high. In wet years the Bridgewater Lakes merge to form a continuous body of water.

METHODS

The Lakes were visited on three occasions: in March and November, 1970 and in August 1972.

Light penetration was determined by Secchi disc and water colour was measured against methyl orange standards and expressed in Pt units on the basis of 0.01 mg/l methyl orange being equivalent by 2.8 Pt units (see Hutchinson 1957 p. 413).

Total Dissolved Solids (hereafter TDS) were determined by evaporation at 105°C and pH with a Metrohm portable pH meter. Water samples, collected in November 1970, were analysed for sodium, potassium, calcium, magnesium, chloride, bicarbonate, and sulphate according to the methods reported by Timms (1973).

Limnetic zooplankton was collected by oblique tows with a conical net of mesh size 159 μm from the deepest part of each lake. In addition to daytime collections, night samples were taken in Lake Bong Bong, Sheepwash Lagoon, Cains Hut Swamp and Lagoon No. 4. A Birge cone net of mesh size 159 μm, and brass cone mesh size 2.5 mm was used to sample microinvertebrates in littoral weedbeds. In Swan Lake macroinvertebrates were collected by hand from rocks along the shoreline. Benthos was collected with a Birge-Ekman grab of 200 cm^2 gape in Bong Bong (9 samples), Swan (3 samples) and Main Bridgewater Lake (6 samples).

TABLE 1

SOME PHYSICOCHEMICAL FEATURES OF THE LAKES

Lake	Mean Secchi disc transparency (cm)*	Water colour in Pt units	Mean TDS (ppm)*	Mean pH*
Bong Bong	445⁺	8	340	8.2
Sheepwash	212⁺	11	363	8.0
Cains Hut	324⁺	14	482	8.1
Lagoon No. 4	68⁺	24	357	7.6
Malseed	-	8	415	8.5
Swan	154	56	363	7.8
Bridgewater	507	8	629	8.5

⁺bottom visible
*for range of values measured, see Appendix 1

RESULTS

(a) Some physico-chemical features

Water in each lake, except Swan is transparent (Table 1) so that the bottom is visible everywhere in some, and in most places in others. In Swan Lake, water is light humic brown and relatively opaque.

The mean TDS values for the series range from 340 to 629 ppm (Table 1). The concentrations of major ions in the lakes are presented in Table 2. Cationic dominance orders are Na⟩Ca⟩Mg⟩K in all except the Bridgewater group where the order is Na⟩Mg⟩Ca⟩K. For anions the common order of dominance is Cl⟩HCO_3⟩SO_4 but in Lagoon No. 4 it is HCO_3⟩Cl⟩SO_4 and in Swan Lake Cl⟩SO_4⟩HCO_3.

Water is distinctly alkaline in each lake, the means ranging from 7.6 to 8.5 (Table 1). Lowest values were recorded in November and August (Appendix 1), following abundant rainfall and presumed acidic inflows (Timms 1973). Changes were most marked in Swan Lake.

(b) Some biological features

Zooplankton is both sparse and of low diversity (Table 3) with nine species represented and an average momentary species richness of 1.7 per lake. There is little uniformity in species composition: Lakes Bong Bong and Bridgewater share two species; there are some species common to Lake Bong Bong, Sheepwash Lagoon, Cains Hut Swamp and Lagoon No. 4, while Swan Lake's fauna is the most divergent with 4 out of 6 species peculiar to it (Table 3). The record of *Boeckella nyoraensis* in Swan Lake is the first since its description in 1912 from Nyora, near Westernport.

There is a distinct difference between daytime and night-time collections from Lake Bong Bong, Sheepwash Lagoon, Cains Hut Swamp and Lagoon No. 4. No plankton could be caught in the latter three by day while at night small numbers representing two species per lake (see Table 3) were captured. In Bong Bong *Sulcanus conflictus, Mesocyclops leuckarti,* and *Daphnia lumholtzi* were usually present by day while at night large numbers of *Gladioferens spinosus* joined them. This species probably behaves similarly in the Main Bridgewater Lake but no nightime collections were taken to prove it.

Thirty-five species of littoral crustaceans were collected (Table 3). Most are restricted to one or a few lakes, so that species lists for individual lakes are much shorter (8-13 species). The fauna of Swan Lake is the most divergent with 35% of species not found elsewhere in the series (cf. values of 12-20% for the other lakes). Most species in the series are known from a few sites elsewhere, or are widely distributed in southern Australia. (D. Morton, personal communication; Smirnov & Timms, unpublished data).

TABLE 2

CONCENTRATIONS OF MAJOR IONS (m-equiv/l) IN THE SEVEN LAKES

Lake	Na^+	K^+	Ca^{++}	Mg^{++}	Sum of cations	Sum of anions	Cl^-	HCO_3^-	$SO_4^=$
Bong Bong	2.91	0.08	1.99	0.91	5.89	5.88	3.18	2.35	0.35
Sheepwash	2.43	0.04	2.67	0.73	5.87	5.85	2.78	2.65	0.42
Cains Hut	3.91	0.08	1.95	1.05	6.99	6.89	4.10	2.12	0.67
Lagoon No. 4	2.04	0.03	2.94	0.64	5.65	5.79	2.31	3.08	0.40
Malseed	3.48	0.04	1.76	1.17	6.45	6.56	3.80	2.23	0.53
Swan	2.30	0.05	1.31	0.62	4.28	4.31	2.65	0.29	1.37
Bridgewater (west)	6.67	0.17	1.67	2.46	10.97	11.08	6.17	4.54	0.37
Bridgewater (main)	5.87	0.10	1.31	2.03	9.31	9.27	5.80	3.01	0.46
Bridgewater (near east)	7.20	0.14	1.44	2.27	11.05	11.08	7.07	3.37	0.64
Bridgewater (far east)	9.02	0.20	1.48	2.72	13.42	13.32	9.66	2.83	0.83

TABLE 3

LIMNETIC AND LITTORAL CRUSTACEA OF THE LAKES

TAXON	LAKES
LIMNETIC SPECIES	
Cladocera	
Daphnia lumholtzi Sars	1, 6
Eubosmina meridionalis (Sars)	S
Alona rectangula Sars	3
Copepoda	
Boeckella symmetrica Sars	S
Boeckella nyoraensis Searle	5
Calamoecia tasmanica (Smith)	S
Gladioferens spinosus Henry	1, 2, 3
Sulcanus conflictus Nicholls	1, 6
Acanthocyclops australis (Sars)	S
Mesocyclops leuckarti (Claus)	1, 2, 4, S
Paracyclops fimbriatus (Fischer)	5
LITTORAL SPECIES	
Ostracoda	
Candonocypris assimilis Sars	2
Cypretta viridis King	2
Cypridopsis sp.	3
cypridid "Bridgewater species"	4, 6
Gomphocythere australica Hussainy	2
Mytilocypris mytiloides (Brady)	1, 2, 4
Cladocera	
Ceriodaphnia sp.	S
Simocephalus elizabethae (King)	S, 6
Echinisca pectinata Smirnov	6
Neothrix armata Gurney	5
Streblocercus serricaudatus (Fischer)	4
Alona davidi Richard	S
Alona rectangula Sars	4
Alonella excisa (Fischer)	1, 3
Biapertura kendallensis (Henry)	5
Biapertura rigidicaudis Smirnov	4, 5, 6
Biapertura setigera (Brehm)	S, 6
Camptocercus australis Sars	2, 3, 5
Chydorus eurynotus Sars	S
Chydorus sphaericus (Muller)	1, 2, 5, 6
Graptoleberis testinaria (Fischer)	S, 6
Oxyurella tenuicaudis Sars	1, 2, 3
Pleuroxus aduncus (Jurine)	1, 2, 3
Copepoda	
Bœckella nyoraensis Searle	5
Gladioferens spinosus Henry	1, 6
Ectocyclops phaleratus (Koch)	2, 3, 4
Eucyclops euacanthus (Sars)	1, 4, 6
Eucyclops serratulus (Fischer)	1
Macrocyclops albidus (Jurine)	1, 2
Microcyclops varicans (Sars)	1, 2, 3, 4
Paracyclops fimbriatus (Fischer)	3, S
Attheyella (Chappuisiella) australica (Sars)	2, 6
Attheyella (Delachauxiella) sp.	6
Malacostraca	
Austrochiltonia subtenuis Sayce)	1, 6

Key to lakes: 1 = L. Bong Bong, 2 = Sheepwash Lagoon, 3 = Cains Hut Swamp, 4 = Lagoon No. 4, 5 = Swan Lake 6 = Main Bridgewater Lake.

Rock substrates occur in limited areas of Swan Lake; on 18 August 1972 they harboured ten species of macroinvertebrates of which the mayfly *Atalophlebia* cf. *australis* was the most common. Other species were the odonate *Hemicordulia tau* Selys, the corixid *Agraptocorixa euryuome* Kirk., the naucorid *Naucorix congrex* Stal., the dytiscids *Antiporus femoralis* Boh., *Lancetes lanceolatus* Clark, *Platynectes* nr *decempunctatus* and an unidentified species, the hydrophilid *Limnoxenus zelandicus* Brown, and the snail *Phyastra cf. gibbosa*.

Few benthic species were collected from Bong Bong (7 species) and Bridgewater (9 species) while none were found in Swan Lake. The polychaete *Boccardia limnicola* Blake and Woodwick, a tubificid *Tubifex tubifex tubifex*, the crab *Halicarcinus lacustris* (Chilton), the amphipod *Paracorphium* cf. *excavatum*, and the chironomid *Cryptochironomus* sp. occurred in both lakes, while the amphipods *Paracalliope* cf. *fluviatilis* and '*Gammarus*' sp. were also collected from Bong Bong, and the chironomids *Procladius villosimanus* Kieffer, *Chironomus oppositus* Walker and *Tanytarsus* sp., and an unidentified psychomyiid trichopteran from the Main Bridgewater Lake. The polychaete, crab and amphipods were most common at shallow stations while the oligochaete and chironomids dominated at greater depths.

DISCUSSION

The Nelson-Bridgewater Lakes owe their origin to sea level changes and coastal dune formation during the Quaternary. Most lie in a long swale between calcareous Pleistocene dunes which in late Pleistocene-Early Recent times were invaded by the sea (Boutakoff 1963). As the sea retreated a series of relictual sea lagoons remained, some to the present day.

The continued presence of these and the formation of others has been made possible by (a) an impervious clay seal and/or buried fossil soils formed in wetter periods of the Plcistocene climatic cycle and (b) by water percolating through the inland dunes by karst processes and surfacing in the interdune trough (Boutakoff 1963).

Since there are marine relictual species in Lake Bong Bong and the Main Bridgewater Lake (see later), it is suggested that these lakes have remained intact since their origin, sea water being gradually replaced by fresh water. The same history probably applies to Sheepwash Lagoon and Cains Hut Swamp. Swan and Malseed Lakes lack a direct marine origin and exist because a Recent dune has blocked a valley and a swamp respectively. Locality No. 4 lies isolated from the swale in a depression of the inner Pleistocene dunes. It has possibly been enlarged by karst processes.

Some of the physiochemical features measured are atypical of lakes in coastal dune regions. Transparencies and TDS values are relatively high and the concentrations of all ions, particularly Ca, Mg and HCO_3, much higher than are usual in dune lakes on siliceous sands (Bayly 1964, Timms 1973). The latter condition is due to the calcareous environment, but despite this, Na and Cl ions dominate in all lakes, save one, indicating the importance of the aerial supply of ions.

The most notable feature of the fauna of the lakes is the presence of three species with marine affinities: *Boccardia limnicola*, *Gladioferens spinosus*, and *Sulcanus conflictus*. *Boccardia limnicola* is the only freshwater species in the family Spionidae (Blake & Woodwick 1976); its other known occurrence is in Lake Barracoota, a marine relictual lake (Timms 1973). *Gladioferens spinosus* is an estuarine species capable of living in closed freshwaters (Bayly 1963), but it can reach them only via water (Timms 1973). The presence of *Sulcanus conflictus*, another estuarine copepod (Bayly 1963), is the only occurrence known for closed freshwater lakes. It is suggested it reached such lakes via past estuarine contact.

Based on a similar mode of origin, Lake Bong Bong, Sheepwash Lagoon, Cains Hut Swamp and the Bridgewater Lakes form a group of homogenous lakes — the Bridgewater series — which contrast with lakes on siliceous dunes in eastern Australia.

The two groups differ in their genesis, water chemistry and fauna:

(i) The marine relictual origin of the Bridgewater series contrasts with that of siliceous dune lakes, which have never had oceanic contact (Bayly & Williams 1973). Further the calcareous dune series lack the typical accumulation of organic matter, induration of the base to form a seal, and perched nature of most of the siliceous dune lakes.

(ii) While water in both lake series is dominated by Na and Cl ions, the presence of large amounts of Ca, Mg and HCO_3 in the Bridgewater series contrasts with their virtual absence in the siliceous dune lakes (Bayly 1964). In addition, water in the former is alkaline and hard, whereas in the latter it is acid and soft (Bayly 1964).

(iii) *Calamoecia tasmanica*, the characteristic siliceous dune lake zooplankter (Bayly 1964), is absent in the Bridgewater series; instead widespread zooplankters (*Daphnia lumholtzi*, *Mesocyclops leuckarti*) or those characteristic of estuarine waters (*Gladioferens spinosus*, *Sulcanus conflictus*) are present. The presence of a polychaete and a crab further characterizes the Bridgewater Lakes.

It is clear that there is little relationship between lakes in the two series, despite their common position in coastal dunes. Some of the distinctive features of the Bridgewater series are associated with a calcareous environment, but it is their marine ancestry which is outstanding.

Swan Lake does not share the characteristics of the Bridgewater series, neither are many of its features typical of siliceous dune lakes. Of the latter the humic water and the presence of *Calamoecia tasmanica* are significant. These, together with other features, such as genesis by valley or depression damming, hard alkaline water, relatively large amounts of Ca, Mg and HCO_3 ions, and the presence of *Boeckella symmetrica*, *Mesocyclops leuckarti*, various other cyclopoids and *Eubosmina* sp. are typical of dune lakes on King Island (Brand 1967). This suggests that lakes developing on calcareous dunes independently of oceanic contact (e.g. Swan Lake and those on King Island) are a distinct lake type, but somewhat similar to siliceous dune lakes.

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REFERENCES

Bayly, I. A. E., 1963. A revision of the coastal water genus

(*Gladioferens* (Copepoda: Calanoida). *Aust. J. mar. Freshwat. Res.* 14: 194-217.

———, 1964. Chemical and biological studies on some acidic lakes of east Australian sandy coastal lowlands. *Ibid.* 14: 56-72.

BAYLY, I. A. E. & WILLIAMS, W. D., 1973. *Inland Waters and Their Ecology*. Longman, Melbourne.

BIRD, E. C. F., 1967. Coastal lagoons of south-eastern Australia, in *Landform Studies from Australia and New Guinea*, Ed. Jennings, J. N. and Mabbutt, J. A. A.N.U. Press, Canberra.

BLAKE, J. A. & WOODWICK, K. H., 1976. A new species of *Boccardia* (Polychaeta: Spionidae) from two freshwater lakes in south-eastern Australia. *Rec. Aust. Mus.* 30: 123-128.

BOUTAKOFF, N., 1963. The geology and geomorphology of the Portland Area. *Geol. Surv. Vic. Mem. No. 22*.

BRAND, G. W., 1967. Studies on some south-east Australian dune lakes with special reference to the distribution of *Calamoecia tasmanica* Smith (Copepoda: Calanoida). B.Sc. Honours Thesis, Monash University.

HUTCHINSON, G. E., 1957. *A Treatise of Limnology*. Vol. I. Wiley, New York.

JENNINGS, J. N., 1957. Coastal dune lakes as exemplified from King Island, Tasmania. *Geogrl. J.* 123: 59-70.

TIMMS, B. V., 1973. A limnological survey of the freshwater coastal lakes of East Gippsland, Victoria. *Aust. J. mar. Freshwat. Res.* 24: 1-20.

APPENDIX 1

THE LAKES: DATES OF VISITS, LOCATION, AND PHYSICOCHEMICAL DATA RECORDED ON EACH VISIT

Lake	Dates of visits		Location		Morphometry		Fluctuation of water level between visits (m)	Physicochemical parameters		
	1970	1972	Lat. (S.)	Long. (E.)	Approx area (ha)	Approx max. depth (m)		Secchi disk transparency (cm)	TDS ppm	pH
Lake Bong Bong	30-iii, 17-xi	12-viii	38° 08'	141° 11'	50	7	1	426, 210, 700+	370, 404, 345	8.5, 8.2, 8.0
Sheepwash Lagoon	30-iii, 17-xi	12-viii	38° 08'	141° 11'	5	2.5	0.5	210+, 205+, 220+	354, 407, 328	8.2, 7.9, 8.0
Cains hut Swamp	30-iii, 17-xi	12-viii	38° 08'	141° 12'	8	4.5	0.5	257, 305, 410+	555, 457, 435	8.3, 7.8, 8.1
Lagoon No. 4	17-xi	12-viii	38° 08'	141° 12'	5	1	0.2	70+, 67+	407, 307	7.8, 7.5
Malseed Lake	17-xi	12-viii	38° 13'	141° 17'	18	1	0.5	-------	445, 385	8.4, 8.6
Swan Lake	30-iii, 17-xi	18-viii	38° 13'	141° 17'	12	4	3	120, 255, 88	557, 317, 214	8.2, 7.7, 7.4
Main Bridge-water Lake	30-iii, 18-xi	18-viii	38° 19'	141° 24'	40	9	2	500, 490, 530	636, 728, 522	8.8, 8.4, 8.4

+bottom visible

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STUDIES IN VICTORIAN VEGETATION, II

A FLORISTIC SURVEY OF THE VEGETATION ASSOCIATED WITH *Nothofagus cunninghamii* (HOOK.) OERST. IN VICTORIA AND TASMANIA

By John R. Busby†* and P. B. Bridgewater†**

Abstract: A floristic analysis of the vegetation associated with *Nothofagus cunninghamii* shows that considerably greater vegetation variation exists than has been revealed by previous structural and dominance studies. Two major Associations have been identified, one restricted to Tasmania, the other occurring in both Victoria and Tasmania, and consisting of numerous variants. The variants are described and discussed with respect to other vegetation studies and the species which are characteristic of these groups have been used in the production of a floristic 'key' to the vegetation. This should be useful in the understanding of the relationships of particular stands to the vegetation as a whole. The major gradient in the vegetation is correlated strongly with altitude, a finding which agrees with previous studies.

INTRODUCTION

Nothofagus cunninghamii is distributed over much of Tasmania and occurs sporadically in the southern central region of Victoria (Howard & Ashton 1973). It is found in vegetation variously described as 'temperate rainforest' (e.g. Beadle & Costin 1952, Gilbert 1958, Wood & Williams 1960); 'microphyll moss forest' and 'microphyll moss thicket' (Webb 1959); and, more recently 'nanophyll moss forest' and 'nanophyll moss thicket' (Webb 1968). The Victorian forests were recently described by Howard and Ashton (1973) as 'Tall Closed Forest', 'Closed Forest', and 'Low Closed Forest' based on a scheme proposed by Specht (1970). Their study included an analysis of floristic data from seventeen stands in Vietoria but the major emphasis was on the forest structure.

It has been claimed that vegetation classifications based on physiognomy or 'dominant species' are less precise than those based on floristics (Goodall 1953, Moore et al. 1970). Obviously it cannot be assumed *a priori* that classifications based on physiognomy or 'dominant species' are less precise than those based on floristies (Goodall 1953, Moore et al. 1970). Obviously it cannot be assumed *a priori* that classifications based on physiognomy will also represent the main floristic differences (Moore 1962, Noy-Meir 1972), so this study was undertaken to examine the floristic variation in these forests and to compare the results with those of previous studies.

METHODS

Data Collection: Some 100 vegetation samples (10m x 10m) were taken from sites eontaining *N. cunninghamii* over its known altitudinal range in Victoria, and over as much of its range as practical in Tasmania during the time available for sampling. Samples were not taken in sites of obvious disturbanee, or in elear eeotones between distinet plant communities. Presenee, rather than dominance, of *N. cunninghamii* was used as the sampling criterion. Victorian samples were numbered from 1 to 55 and the Tasmanian samples from 101 to 145.

A total of 178 vascular plant species were recorded, ferns in the family Hymenophyllaceae and non-vascular plants being excluded. Their small size should reflect only microenvironmental factors and so should contribute little useful information to a primary survey. Eaeh species record was accompanied by a cover/abundance symbol (Braun-Blanquet 1964) to provide additional descriptive information of the stand and these data were transferred to computer cards for analysis. Species occurring in less than 5% of the

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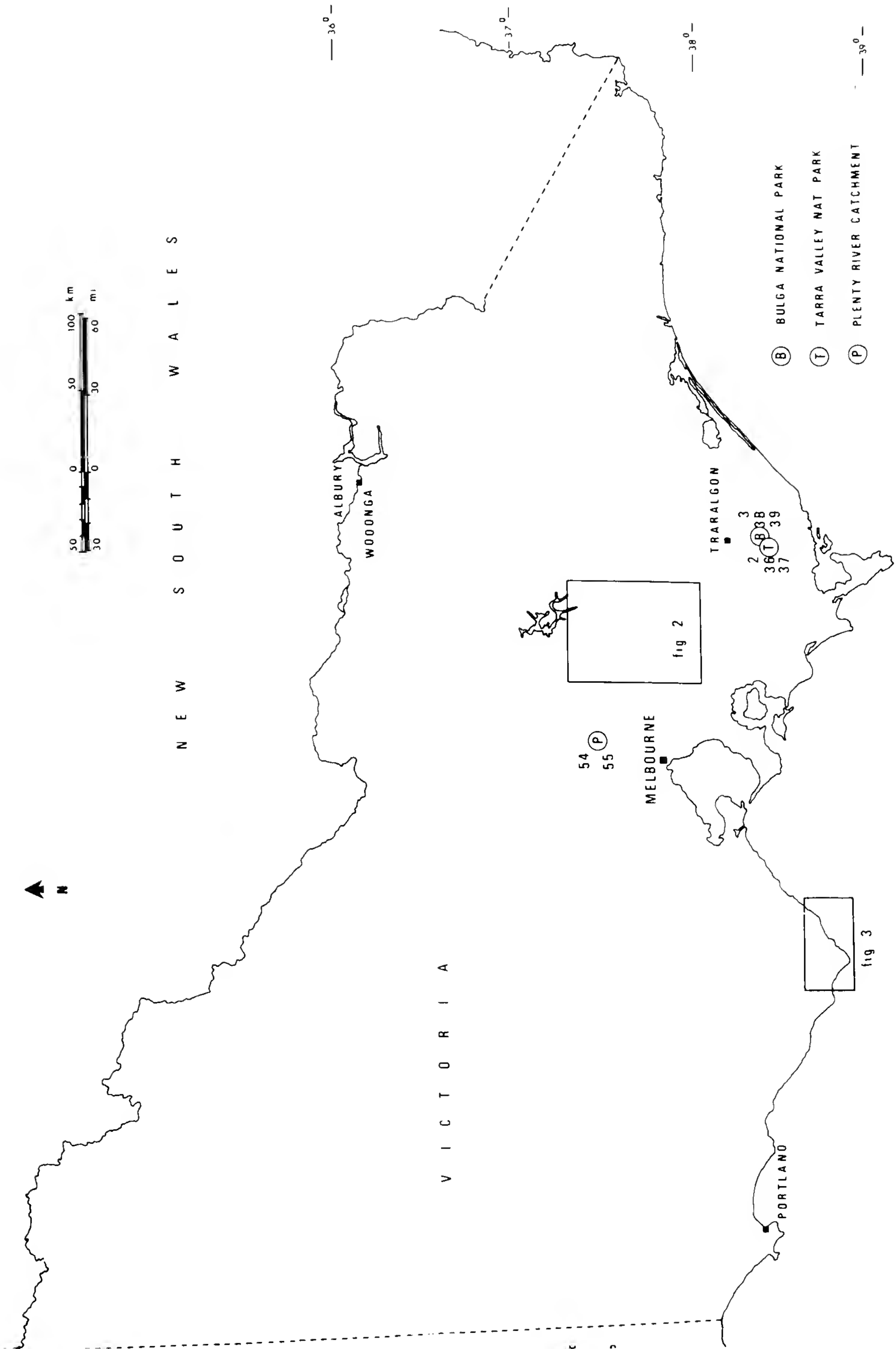

FIG. 1—Location of sample sites in Victoria.

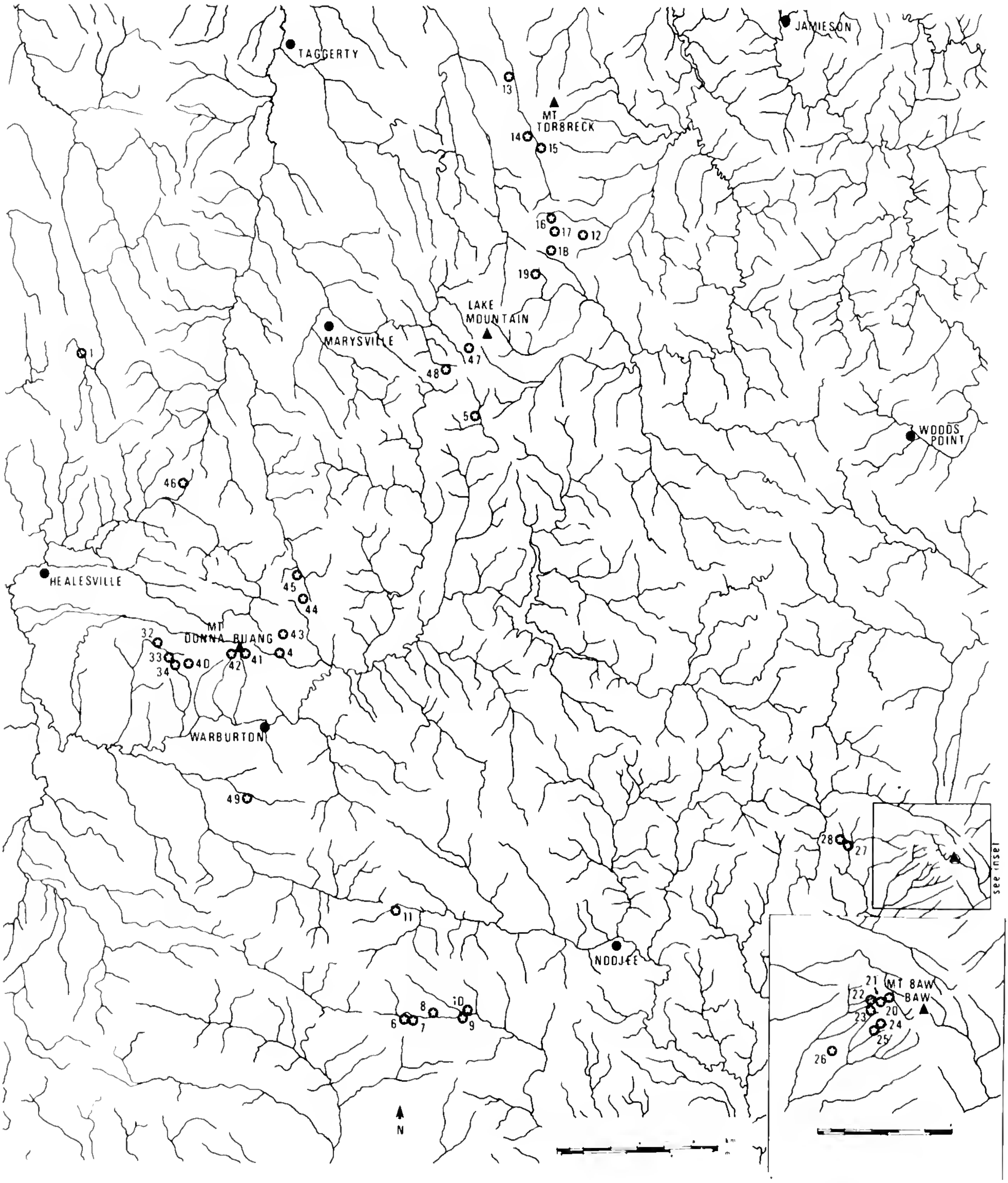

FIG. 2—Location of sample sites in the Central Highlands region of Victoria.

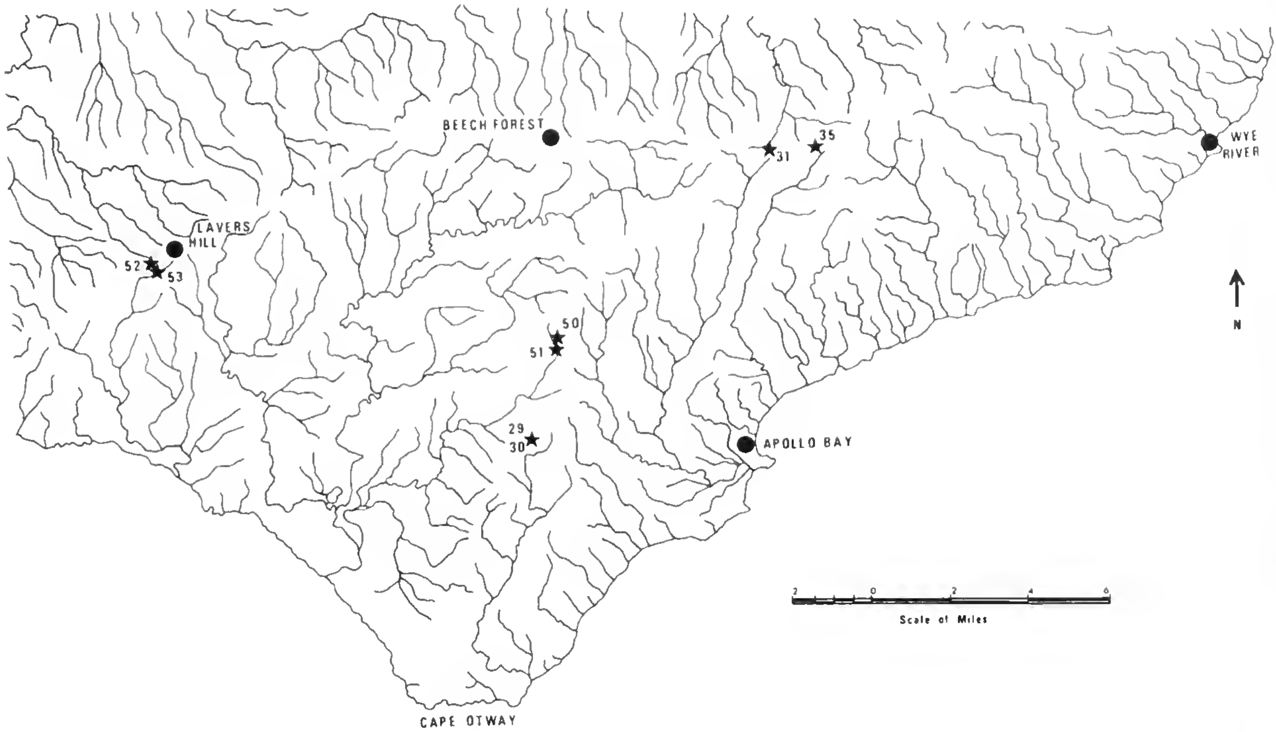

FIG. 3—Location of sample sites in the Otway Ranges, Victoria.

samples were excluded from subsequent analysis.

Data analysis: After being checked for accuracy, the data were arranged in a two-way table by the Fortran IV Program ZUMONT/PRINT, written for the Monash University Burroughs B6700 computer. Species and samples form the rows and columns respectively of this table (Fig. 5) and the analysis of the data involved the repeated visual sorting of the species and samples until the species records were highly concentrated at the top of the table (c.f. Bridgewater 1971). The computer program was used to print out new tables at various stages in this process until it was decided that further sorting was unnecessary.

The Zurich-Montpelier (Z-M) type of analysis, though simple in concept, is frequently difficult and tedious in practice. The process can, however, be accelerated by the use of numerical methods to give preliminary sample and/or species groups (e.g. Ceska & Roemer 1971, Lieth & Moore 1971).

This method has been criticised because it is 'subjective', in that the order of samples and species is determined by the investigator (e.g. Dale & Anderson 1972). Moore et al. (1970), on the other hand, state that the order of species and samples is determined by the data, and that the sorting process is, in reality, a polythetic divisive method based on visual ranking of correlated species and sites rather than operating via a particular statistic. The sorting process described above attempts to ensure that samples which are most similar to each other lie side by side in the table.

A comparison of the results of this process (Fig. 5) with the results of an association analysis (Williams & Lambert 1959) and a cluster analysis (Carlson 1972) performed on the same data showed no significant differences between them (Table 1). (For additional information see Busby 1973, pp. 70-71, also Appendix VI).

The classifications were compared, in pairs, using a method devised by Kullback et al. (1962). Information statistic values were calculated for each comparison and these values (multiplied by two) were assessed for significance against the theoretical probability distribution x^2 at P=0.0005 with the relevant degrees of freedom under the null hypothesis that, in each com-

TABLE 1

PERCENTAGE INCREASE OF INFORMATION STATISTIC VALUE (X 2) OVER x^2 (P=0.0005).

	Analysis		
	Z-M	Association (x^2, P=0.05)	Cluster
Z-M analysis	—	157.9	110.7
Association analysis		—	161.3
Cluster analysis			—

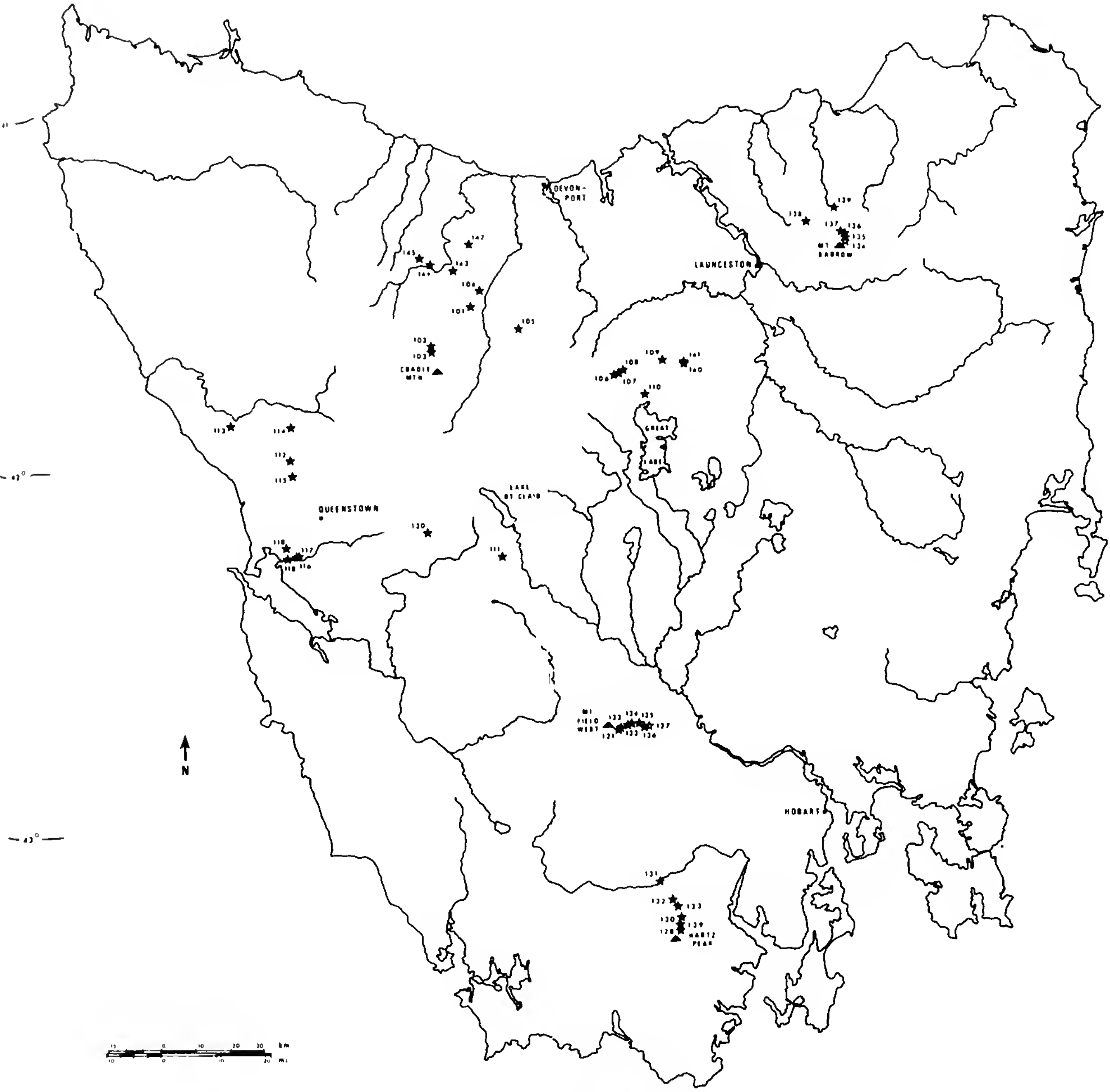

FIG. 4—Location of sample sites in Tasmania.

parison, the two classifications were unrelated. The values shown in Table 1 are the percentage increase of the information statistic value (x 2) over the value of x^2 at P=0.0005 and indicate that, in each comparison, the probability that the classifications are unrelated is less than 0.0005.

SPECIES GROUPS ASSOCIATED WITH *Nothofagus cunninghamii*

An examination of the sorted data in Fig. 5 show them to be concentrated into 'blocks' of species records. This feature has been noted in many such tables, recent examples including Webb et al. (1970) and Walker (1972). Most of these blocks (or 'noda' *sensu* Poore 1955) show internal variation and grade into each other. Despite this, twelve distinct sample groups and four fragmentary groups can be detected.

It is apparent that two quite distinct plant communities are present. These two communities are called, for the purposes of the following discussion, Association A and B. (Association A includes groups A.1 through A.4 in Fig. 5). Although there is no need for noda to be hierarchically related (Noy-Meir 1972), groups A.1 to A.4 can be considered to be Sub-

Associations of Association A, and two of these groups, A.2 and A.3, contain sub-groups or Variants.

The term Association is taken in this context to mean a plant community of uncertain status in the vegetation as a whole but which is considerably different from other communities under consideration. Associations defined in this way are based entirely on floristics and may or may not correspond to 'Associations' based on structural features of the vegetation. This confusion is unfortunate but it illustrates the necessity of deriving a standard system for establishing the status and nomenclature of different types of vegetation.

Association A is characterized by the presence of *Blechnum procerum*, *Dicksonia antarctica* and *Polystichum proliferum*. Association B is characterized by the presence of *Bauera rubioides*, *Coprosma nitida*, *Cyathodes parvifolia*, *Eucalyptus coccifera*, *Orites diversifolia*, *Telopea truncata*, and *Trochocarpa gunnii*.

Association B is completely restricted to Tasmania and most of its characteristic species are endemic to that State. Samples of this vegetation type were collected on Mt. Barrow, Mt. Field Plateau, and Hartz Mountains. (Fig. 4). This Association corresponds to the 'nanophyll moss thicket' of Webb (1968) and appears to consist mainly of the 'Small Eucalyptus Scrub Association' with elements of the 'Low Mountain Forest Association' of Gibbs (1920). It also appears to correspond to the '*Eucalyptus-Nothofagus*' forest recorded by Sutton (1928) on Cradle Mountain and the '*Eucalyptus coccifera* consociation' and '*E. coccifera-urnigera* association' described by Martin (1940) on Mt. Wellington. From descriptions by these workers it is evident that there is greater variation in this vegetation than has been demonstrated in this survey. This is due to the fact that this Association is restricted to exposed mountain tops, particularly in south-west Tasmania, and most of these locations were inaccessible to this primary survey. This vegetation is quite different from the other vegetation containing *Nothofagus cunninghamii* and further work is necessary to describe it fully. The relative paucity of species in sample 134 from Mt. Barrow (see Fig. 4) perhaps indicates that this represents an outlying occurrence of a type which is concentrated in the south-west of the State.

Association A consists of four 'Sub-Associations' and is found in both Victoria and Tasmania. The numbering system (outlined above) enables one to scan the top line of the sample numbers in Fig. 5 (the sample numbers are printed vertically) and readily distinguish the Tasmanian samples (1) from the Victorian samples (0). This group appears to correspond with the 'microphyll moss forest' of Webb (1968).

Sub-Association A.1 is characterized by *Acacia dealbata*, *Cyathea australis*, *Tetrarrhena juncea*, and *Tieghemopanax sambucifolius*. Other conspicuous species include *Acacia melanoxylon*, *Blechnum nudum*, *Clematis aristata*, *Todea barbara*, and *Viola hederacea*. *Polystichum proliferum*, one of the differential species of Association A, is not common in this group. This vegetation may be a part of the 'Tall Closed Forest' of Howard and Ashton (1973) but was apparently not surveyed in their study. It appears to occur mainly at the limits of *Nothofagus cunninghamii* distribution and perhaps represents a region of overlap between forest dominated by this species and that dominated by eucalypts. *Eucalyptus regnans*, for example, is more conspicuous in this than in any other group.

Sub-Association A.2 is found in both Victoria and Tasmania and is characterized by the presence of *Atherosperma moschatum* and *Grammitis billardieri*. This group appears to correspond to 'Temperate Rain Forest' as defined by Gilbert (1958), viz. an association of *Nothofagus cunninghamii* and *Atherosperma moschatum*. The group also appears to correspond to the 'Tall Closed Forest' and 'Closed Forest' of Howard and Ashton (1973) and it is in this vegetation that *Nothofagus cunninghamii* reaches its greatest physiognomic development. This can be seen in the consistently high cover/abundance values in Fig. 5. Eucalypts are less conspicuous in this than any other group.

Six variants can be distinguished within this group: A.2.1 through A.2.6. Variant A.2.1 is characterized by the presence of *Clematis aristata*, *Hedycarya angustifolia*, *Microsorium diversifolium*, *Pittosporum bicolor*, and *Rumohra adiantiformis*. Variant A.2.2 is characterised by the presence of the above species with the addition of *Asplenium bulbiferum*, *Athyrium australe*, and *Blechnum aggregatum*. Variant A.2.3 is characterized by *Asplenium bulbiferum*, *Blechnum aggregatum*, and *Microsorium diversifolium*. The last of these species is the only differential species for A.2.4. Variant A.2.5 is a quite different group, consisting almost entirely of species endemic to Tasmania, viz. *Anodopetalum biglandulosum*, *Anopterus glandulosus*, *Eucryphia lucida*, *Gahnia grandis*, and *Phyllocladus aspleniifolius*. *Microsorium diversifolium* is absent and two of the differential species for the Association, i.e. *Dicksonia antarctica* and *Polystichum proliferum*, are not conspicuous. Variant A.2.6 contains no differential species in addition to *Atherosperma moschatum* and *Grammitis billardieri* which are are differential species for the Sub-Association.

Species lists in various published works sometimes enable the identification of the plant groups present in these forests. Variants A.2.1 to A.2.4 (the exact group depending on certain species which may not have been recorded) can be identified in the work of Gibbs

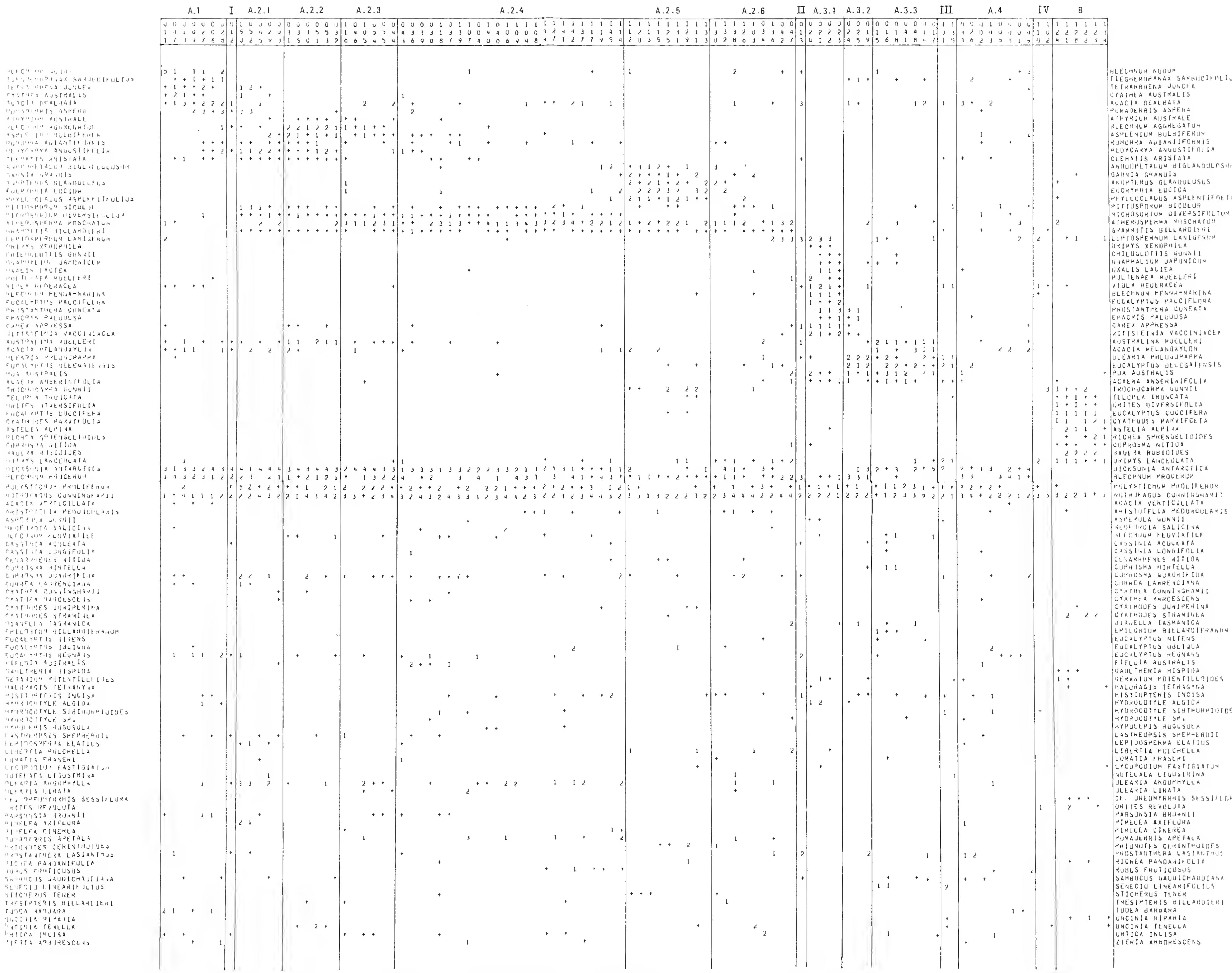

FIG. 5.—Two-way table of vegetation data from all Victorian and Tasmanian sites. The table was produced by the computer program ZUMONT/PRINT. Sample numbers should be read downwards.

(1920), Morris (1929), Peric et al. (1929), Martin (1940), Howard and Hope (1969) and Howard and Ashton (1973). Variant A.2.5, being fairly distinct, can be clearly detected in work published by Davis (1940) and Gilbert (1958), and perhaps also Gibbs (1920).

The absence of *Atherosperma moschatum* from eight of the samples in A.2.1 and A.2.2 is an interesting feature of this Sub-Association. The samples concerned are all from the Otway Ranges (Fig. 3) where this species has never been recorded. The table strongly suggests that this species is not absent for ecological reasons, although Howard and Ashton (1973) suggest that it might have been eliminated by fire and could not re-establish itself because of the isolation of this region from other seed sources. An alternative suggestion is that it was never present in the Otways due to the lack of suitable habitats between this region and areas further east where it may have originated (N. A. Wakefield, pers. comm).

Sub-Association A.3 appears to be confined to Victoria and is mainly a sub-alpine plant community. In this community *Nothofagus cunninghamii* is generally found as a large shrub under a canopy of eucalypts and the vegetation type appears to correspond to the 'Low Closed Forest' of Howard and Ashton (1973). The differential species are *Acaena anserinifolia* and *Poa australis* and three variants can be distinguished, A.3.1 through A.3.3.

Variant A.3.1 consists of samples taken on Mt. Baw Baw, Victoria and this vegetation appears to be confined to that locality. A study by Morris (1929) indicated that similar vegetation may occur on Echo Flat, Lake Mountain (Fig. 2), but a superficial survey failed to locate it. This vegetation is characterized by *Blechnum penna-marina*, *Carex appressa*, *Eucalyptus pauciflora*, *Viola hederacea*, and *Wittsteinia vaccinacea*. An additional eight species are conspicuous in this vegetation and these can be seen in Fig. 5. An interesting feature is the absence of *Dicksonia antarctica*. The group, however, contains only four samples so further work is necessary to clearly define it. However, it is apparent that it is quite distinct from the others and further sampling would be expected to enhance this difference.

Variant A.3.2 is also incompletely defined, consisting of only three samples. Further work is needed in this vegetation also to properly define it. Possible differential species are *Eucalyptus delegatensis*, *Olearia phlogopappa*, and *Tieghemopanax sambucifolius* and perhaps some of the following: *Acacia dealbata*, *Epacris paludosa*, *Histiopteris incisa*, *Prostanthera cuneata* and *Wittsteinia vaccinacea*.

It should be noted that *Tieghemopanax sambucifolius* is also a differential species of Sub-Association A.1. This suggests that this species may, in fact, be composed of more than one 'ecotype'. Willis (1972) notes for this species that 'invariably in the subalps and often also in the lowlands, leaflets are linear and obtuse . . . In moist lowland forests the leaflets bay be lanceolate to broadly ovate and acute or obtuse . . . Autecological work in this species is needed to clarify the situation.'

An examination of Fig. 5 will show other species which have distributional patterns which could prompt similar questions, e.g. *Acacia melanoxylon*, *Australina muelleri*, and *Viola hederacea*.

Variant A.3.2, in fact, appears to be intermediate between A.3.1 and A.3.3. Variant A.3.3 is characterised by *Acacia melanoxylon*, *Australina muelleri*, *Eucalyptus delegatensis*, and *Olearia phlogopappa*. An interesting feature of this group is the virtual absence of *Blechnum procerum*, a species which is characteristic of every other group in Association A.

Sub-Association A.4 is the 'typicum' for Association A in that it contains no characteristic species in addition to the ones which characterize the Association.

The main groups in the table are all linked by intermediate samples. Fragments I to III occur between the Sub-Associations in Association A and Fragment IV is intermediate between Associations A and B. Further work will be necessary to establish the status of these fragments. The '*Athrotaxis-Nothofagus*' forest described by Sutton (1928), for example, appears to be intermediate between these Associations, and the status of Fragment IV may be clarified by further work in this forest type.

FLORISTIC KEY TO THE VEGETATION

Since the vegetation in which *Nothofagus cunninghamii* occurs can be classified into a number of species groups, it was possible to devise a floristic 'key' to this forest (Appendix I). The main uses of this key would be to allow new vegetation samples to be rapidly allocated to the existing classification, and to enable other workers to identify the vegetation type under study so that they can establish the status of their particular stand of vegetation relative to the forest as a whole. This information is essential in determining the limits of extrapolation for detailed work in any part of the forest (c.f. Austin 1972). In other words, ecological observations must be specified in terms of the community in which they are made (Poore 1962) and results of investigations into one type are not necessarily applicable to another (Moore 1962).

DISCUSSION

The main vegetation groups, as indicated above, appear to correspond closely with previously published structural classifications. It is also apparent, however, that this floristic analysis has detected the presence of vegetation categories which have not been previously described. Further work, of course, is necessary to clarify the status of some of these groups and to determine reasons for the differences between them. Because of the repeated disturbance of this forest by fire and man, many of these groups may well represent successional stages, but this remains to be confirmed.

Re-analysis of the floristic data presented by Howard and Ashton (1973), using the floristic key presented in Appendix 1, showed that their 'Tall Closed Forest' corresponds to groups A.2.1 (three of their stands), A.2.2 (two stands), A.2.3. (two stands) and A.2.6 (one stand). The 'Closed Forest' corresponds to groups A.2.2. (one stand), A.2.6 (four stands) and A.4 (one stand). The two structural types appear to reflect floristic differences to a certain extent but the distinction between them requires further clarification.

The strong altitudinal zonation recorded by Howard and Ashton (1973) is also reflected in this analysis. The average altitude in each of the 12 sample groups was calculated and is shown in Table 2. In sample groups which contained both Victorian and Tasmanian samples (A.2.3, A.2.4, and A.4), the averages for the Victorian samples (V), and Tasmanian samples (T), were calculated separately. It can be noted that, within the sample group, the Victorian samples consistently have a higher average altitude than the Tasmanian samples, the average difference being 370 metres. This difference in altitude is attributed to environmental differences which are correlated with latitude differences, Tasmanian forests being, on average, 4° further south. An interesting point about two of the samples in Association B (128 and 134) which are separated by 2° of latitude, is that the southern sample (128) is 410 m lower in altitude than the northern one (134). It is suggested that Sub-Association A.1 (average altitude 330 m), which is recorded from Victoria only, will not be found in Tasmania because of this factor, except possibly in some restricted areas. It should also be noted that no Tasmanian samples were classified into groups A.2.1 and A.2.2.

If the altitude of the Tasmanian samples is 'corrected' for this latitude difference by the addition of 370 m to the altitude of each sample, then these 'corrected' altitudes show a sequence of increasing values from one group to the next (Table 2).

There is, however, considerable variation in altitude within each group so that the averages are rather poor estimates of the true means. This implies, of course, that the 'average' altitude difference between Victoria and Tasmania is only an approximation and further studies will be necessary. The variation, after all, is only to be expected since other factors such as exposure are almost certainly involved.

TABLE 2

RELATIONSHIPS BETWEEN SAMPLE GROUPS AND ALTITUDE (M). See text for description of 'corrected' altitude.

Sample Group	Average Altitude	Altitude Difference	'Corrected' Altitude
A.1	330	—	330
A.2.1	440	—	440
A.2.2	420	—	420
A.2.3	580(V) 180(T)	400	570
A.2.4	630(V) 410(T)	220	730
A.2.5	390	—	760
A.2.6	1140(V) 520(T)	620	970
A.3.3	1060	—	1060
A.3.2	1070	—	1070
A.3.1	1320	—	1320
A.4	660(V) 430(T)	230	650
B	1350	—	1350

It can be noted that Sub-Association A.4 is an exception to the gradient. This group, as discussed above, is the 'typicum' for Association A and the lack of character species in addition to the ones defining the Association makes its status in the vegetation a little obscure. Its position in the altitude gradient appears to indicate that it has been misplaced in Fig. 5 but perhaps its species composition is controlled by factors which are not correlated with the main gradient.

Another point is that Variants A.3.1 and A.3.3 have been reversed in Table 2. This was done on the basis of their average altitudes and re-examination of Fig. 5 which indicates that the floristic picture would not be disrupted if they were also to be reversed in the two-way table. Variant A.3.1 was located next to A.2.6 in Fig. 5 because they both contained *Leptospermum lanigerum*. This name was used *sensu lato* as in Ewart (1931) on the basis of an identification by the National Herbarium early in the sampling program. This name includes *L. glabrescens* N. A. Wakefield and *L. grandifolium* Sm. (Willis 1972, p.449) and both species were probably encountered in this survey. The altitude differences between A.3.1 and A.2.6 suggests that the former may contain *L. grandifolium* and the latter *L. glabrescens*. If this is so then the analysis has been useful in pointing out taxonomic differences which were not recognised in the field (see also the case of *Tieghemopanax sambucifolius* discussed above).

An interesting feature of the analysis is the quite strong floristic links between Victorian and Tasmanian vegetation, three Variants in one Sub-Association and another Sub-Association being represented in both States. The vegetation in the Otway Ranges in Victoria (Fig. 3) also shows strong similarities with other forests by its location in Sub-Association A.2. These links persist despite the fact that this forest has been isolated from the other forests for a considerable period of time.

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REFERENCES

AUSTIN, M. P., 1972. Models and analysis of descriptive vegetation data. pp.61-86 *In Mathematical Models in Ecology*. J. N. R. Jeffers (Ed.). Blackwell.

BEADLE, N. C. W. & COSTIN, A. B., 1952. Ecological classification and nomenclature. *Proc. Linn. Soc. N.S.W.* 77: 61-82.

BRAUN-BLANQUET, J., 1964. *Pflanzensoziologie*. Berlin.

BRIDGEWATER, P., 1971. Practical application of the Zurich-Montpellier system of phytosociology. *Proc. R. Soc. Vict.* 84: 255-262.

BUSBY, J. R., 1973. The Phytosociology of *Nothofagus cunninghamii* (Hook) Oerst. Unpublished M.Sc. thesis, Monash University.

CARLSON, K. A., 1972. A method for identifying homogenous classes. *Multivariate Behavioral Research* 7: 483-488.

CESKA, A. & ROEMER, H., 1971. A computer program for identifying species-releve groups in vegetation studies. *Vegetatio* 23: 255-277.

DALE, M. B. & ANDERSON, D. J., 1972. Qualitative and quantitative information analysis. *J. Ecol.* 60: 639-655.

DAVIS, C., 1940. Preliminary survey of the vegetation near New Harbour, S.W. Tasmania. *Pap. Proc. R. Soc. Tas.* pp.1-9.

EWART, A. J., 1931. *Flora of Victoria*. Govt. Printer, Melbourne.

GIBBS, L. S., 1920. Notes on the phytogeography and flora of the mountain summit plateaux of Tasmania. *J. Ecol.* 8(1): 1-17, (2): 89-117.

GILBERT, J. M., 1958. Forest succession in the Florentine Valley, Tasmania. *Pap. Proc. R. Soc. Tas.* 93: 129-151.

GOODALL, D. W., 1953. Objective methods for the classification of vegetation. I. The use of positive interspecific correlation. *Aust. J. Bot.* 1(1): 39-63.

HOWARD, T. M. & ASHTON, D. H., 1973. The distribution of *Nothofagus cunninghamii* rainforest. *Proc. R. Soc. Vict.* 86: 47-75.

HOWARD, T. M. & HOPE, G. S., 1969. The present and past occurrence of beech (*Nothofagus cunninghamii* Oerst.) at Wilsons Promontory, Victoria, Australia. *Ibid.* 83: 199-209.

KULLBACK, S. & KUPPERMAN, M. & KU, H. H., 1962. Test for contingency tables and Markov chains. *Technometrics* 4(4): 573-595.

LIETH, H. & MOORE, G. W., 1971. Computerized clustering of species in phytosociological tables and its application to field work. pp. 403-422. *In Statistical Ecology 1. Spatial Pattern and Statistical Distribution*. G. P. Patil, E. C. Pielou, and W. D. Waters (Eds.). Pennsylvania State University Press; London.

MARTIN, D., 1940. The vegetation of Mt. Wellington, Tasmania. The plant communities and a census of the plants. *Pap. Proc. R. Soc. Tas.* pp. 97-124.

MOORE, J. J. FITZSIMMONS, P., LAMBE, E. & WHITE, J., 1970. A comparison and evaluation of some phytosociological techniques. *Vegetatio* 20: 1-20.

MORRIS, P. E., 1929. Ecology of Marysville and Lake Mountain. *Vict. Nat.* 46: 34-42.

NOY-MEIR, I., 1972. Multivariate analyses of the semi-arid vegetation in South-Eastern Australia: Nodal ordination by component analysis. *Quantifying Ecology: Proceedings of the Ecological Society of Australia*. 6: 159-194.

PETRIE, A. H. K., JARRET, P. H. & PATTON, R. T., 1929. The vegetation of the Black Spur Region. I. The mature plant communities. *J. Ecol.* 17: 223-248.

POORE, M. E. D., 1955. The use of phytosociological methods in ecological investigations. II. Practical issues involved in an attempt to apply the Braun-Blanquet system. *Ibid.* 43: 245-269.

————, 1962. The method of successive approximation in descriptive ecology. *Adv. Ecol. Res.* 1: 35-68.

SPECHT, R. L., 1970. Vegetation. pp. 44-67 *In The Australian Environment*. G. W. Leeper (Ed.). C.S.I.R.O. and Melbourne University Press.

SUTTON, C. S., 1928. A sketch of the vegetation of the Cradle Mountain, Tasmania and a census of its plants. *Pap. Proc. R. Soc. Tas.* pp. 132-159.

WALKER, D., 1972. Vegetation of the Lake Ipea Region, New Guinea Highlands, II. Kayamandra swamp. *J. Ecol.* 60: 479-504.

WEBB, L. J., 1959. A physiognomic classification of Australian rain forests. *Ibid.* 47: 551-570.

————, 1968. Environmental relationships of the structural types of Australian rainforest vegetation. *Ecology* 49: 296-311.

WEBB, L. J., TRACEY, J. G., WILLIAMS, W. T. & LANCE, G. N., 1970. Studies in the numerical analysis of complex rain-forest communities. V. A. comparison of the properties of floristic and physiognomic-structural data. *J. Ecol.* 58: 203-232.

WILLIAMS, W. T. & LAMBERT, J. M., 1959. Multivariate methods in plant ecology. I. Association analysis in plant communities. *Ibid.* 47: 83-101.

WILLIS, J. H., 1972. *A Handbook to Plants in Victoria*. Vol. 2. Melbourne University Press.

WOOD, J. G. & WILLIAMS, R. J., 1960. Vegetation, in *The Australian Environment*. 3rd edn. Melbourne.

NOTES: (1) A full set of specimens for the vascular plants named in this survey are housed in the Monash University Botany Department Herbarium. (2) Species nomenclature used for Victoria is that of Churchill, D. M. and de Corona, A. (1972). *The distribution of Victorian plants,* Dominion Press, Melbourne, and for Tasmanian endemics Curtis, W. M. (1956-67) *Students flora of Tasmania*, Hobart. (3) Details of computer programs, or details of site locations are available on application to the authors.

APPENDIX

FLORISTIC 'KEY' TO *Nothofagus cunninghamii* FOREST

In allocating a vegetation stand to one of the groups described in this study enter the key at 1. and compare the species in the stand with the differential species in the key. Any stand examined should be approximately 10 m x 10 m. A number in the right hand column means go to that number in the key, a letter in this column means that the stand has been allocated to one of the plant groups discussed in the text.

1. Two of the following present: *Coprosma nitida, Cyathodes parvifolia, Orites diversifolia.*	— B
Not as above.	— 2
2. *Acaena anserinifolia* and/or *Poa australis* present.	— 3
Not as above.	— 6
3. *Tieghemopanax sambucifolius* and *Blechnum procerum* present, *Acacia melanoxylon* absent.	— A.3.2
Not as above.	— 4
4. *Eucalyptus pauciflora* present.	A.3.1
Not as above.	— 5
5. *Atherosperma moschatum* and *Grammitis billardieri* present.	— 6
Australina muelleri present.	— A.3.3
Not as above.	— 6
6. At least three of the following present: *Anodopetalum biglandulosum, Anopterus glandulosus, Eucryphia lucida, Gahnia grandis, Phyllocladus aspleniifolius.*	— A.2.5
Not as above.	— 7
7. Two of the following present: *Atherosperma moschatum, Grammitis billardieri, Pittosporum bicolor.*	— 9
Otway stands.	— 9
Not as above.	— 8
8. *Asplenium bulbiferum* present.	— 9
Not as above.	— 13
9. *Microsorium diversifolium* present.	— 10
Not as above.	— A.2.6
10. *Clematis aristata* and *Hedycarya angustifolia* present.	— 11
Not as above.	— 12
11. *Asplenium bulbiferum* and *Blechnum aggregatum* present.	— A.2.2
Not as above.	— A.2.1
12. Two of the following present: *Asplenium bulbiferum, Athyrium australe, Blechnum aggregatum.*	— A.2.3
Not as above.	— A.2.4
13. At least three of the following present: *Acacia dealbata, Cyathea australis, Tetrarrhena juncea, Tieghemopanax sambucifolius.*	— A.1
Not as above.	— 14
14. At least two of the following present: *Blechnum procerum, Dicksonia antarctica, Polystichum proliferum.*	— A.4
Not as above.	Unclassified

This key is based on the results of the floristic analysis of the data collected. It is, at this stage, provisional and the classification will no doubt be modified by the addition of more data. The authors will welcome any comments or revisions and species lists (preferably with some type of cover/abundance value for each species) from any vegetation which appears to be anomalous.

18

UPPER SILURIAN CONODONTS FROM THE YARRANGOBILLY LIMESTONE, SOUTHEASTERN NEW SOUTH WALES

By Barry J. Cooper*

ABSTRACT: Conodonts from the Upper Silurian Yarrangobilly Limestone are described, using multielement taxonomy. The specimens are correlated with the *siluricus* and *crispa* Zones of Walliser (1964), which indicate a middle to late Ludlow age. It follows that the Yarrangobilly Limestone is equivalent to the Hume Limestone, Black Bog Shale and probably parts of the Rosebank Shale in the well-known Yass Basin succession.

INTRODUCTION

Yarrangobilly is situated about 65 km south of Tumut and 20 km north of Kiandra in south-eastern New South Wales. The area was first investigated geologically by Anderson (1886), who described the caves that had been discovered in the limestone. A geological map of the limestone was produced in a subsequent cave report by Trickett (1897). The entire Yarrangobilly area, including the limestone, was mapped by Adamson (1958) as part of the Snowy Mountains Hydroelectric Scheme.

Fossils were collected from the Yarrangobilly Limestone soon after a Caves Superintendent was appointed and were forwarded to the Geological Survey in Sydney. Etheridge (1893-4) and Andrews (1901) record the brachiopod, 'Pentamerus Knightii' as well as seven genera of gasteropods and bivalves from this collection. Rugose and tabulate corals have been described by Hill (1954) with revisions by Hamada (1957, 1958).

The present report considers a conodont collection from the Yarrangobilly Limestone which makes possible a correlation with other Silurian successions.

STRATIGRAPHY

In the Yarrangobilly area, Silurian sediments may be divided into two widespread stratigraphic units: the Tumut Ponds Group overlain by the Ravine Beds. This succession was first recognised near Kiandra (Moye, Sharp & Stapleton in Packham, 1969) and was extended into the Yarrangobilly area by Labutis (1969). The latter worker also demonstrated that the lenticular mass of the Yarrangobilly Limestone is equivalent to sediments close to the boundary of the Tumut Group and the Ravine Beds. The Goobarrangandra Porphyry, which outcrops just east of the Yarrangobilly Limestone, has been little studied. Adamson (1960) believes that it correlates with sediments within the Tumut Ponds Group. Strusz (1971) suggests that a fault separates the porphyry from the Silurian sediments.

PROCEDURE

Some 50 samples were collected for conodonts from two measured sections and several isolated localities in the Yarrangobilly Limestone. These are shown on the sketch map (Fig. 1) and the stratigraphic columns (Fig. 2) and described in the locality register at the end of the paper.

Approximately 1 kg of each sample was processed initially, using standard acetic acid techniques, and those samples yielding reasonable conodont abundances were subject to bulk recollection and further disaggregation. Overall, 120 kg of limestone were processed and about 800 identifiable conodonts were recovered. Table 1 summarises conodont occurrences in the Yarrangobilly Limestone. Barren samples are excluded.

BIOSTRATIGRAPHY

The establishment of a succession of conodont zones through most of the Silurian by Walliser (1964) permits ready age determination of the Yarrangobilly conodonts. Near the base of the Yarrangobilly Limestone, multielement species *Kockelella variabilis* and *Ozarkodina confluens* occur together. *K. variabilis* is restricted to the *crassa, ploeckensis* and *siluricus* Zones of Walliser, while *O. confluens* was not recorded below the *siluricus* Zone by Walliser. This suggests that the lower beds of the Yarrangobilly Limestone can be correlated best with the *siluricus* Zone even though the zonal name-giver is absent in the collections.

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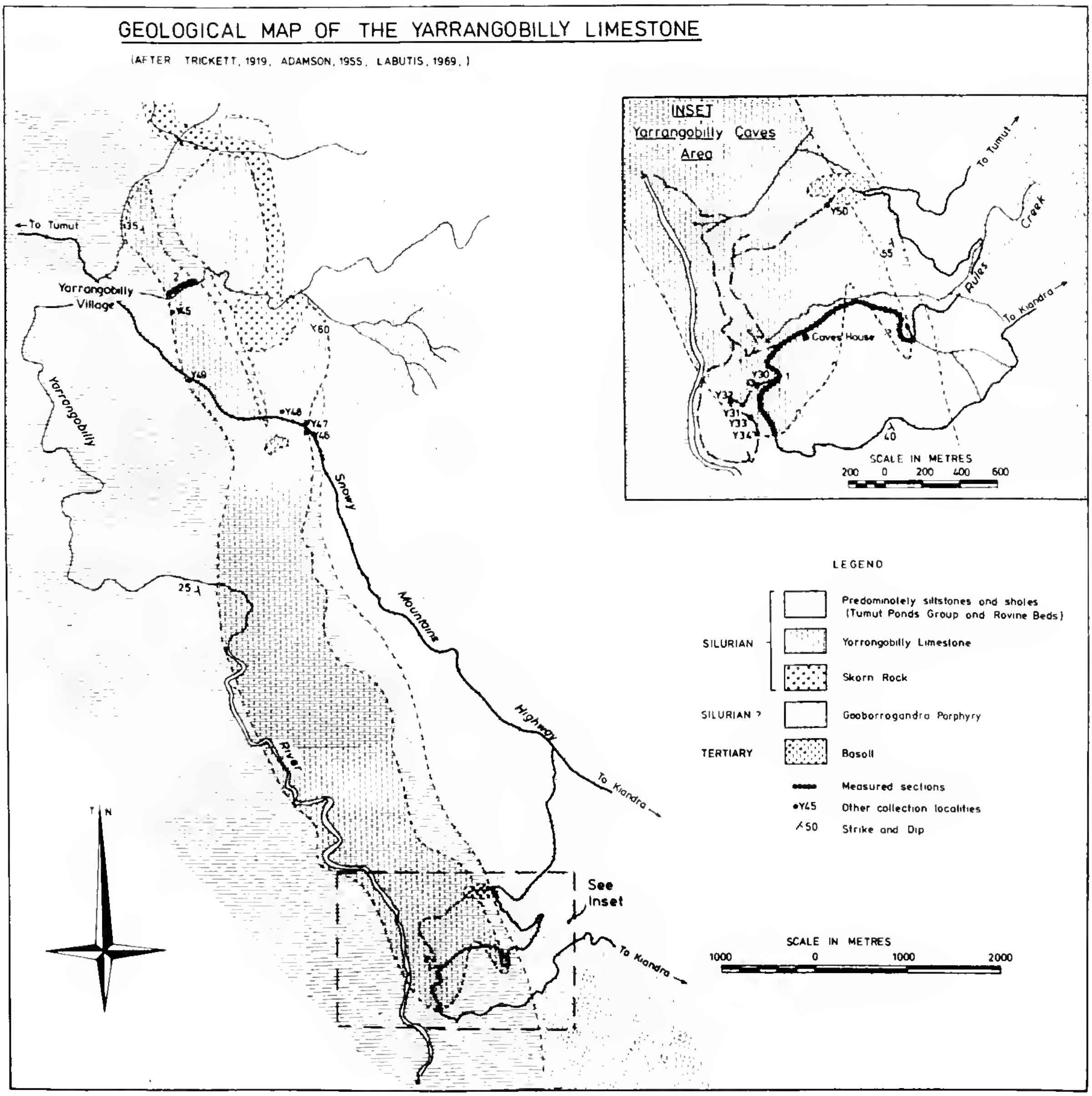


FIG. 1

The topmost beds of the Yarrangobilly Limestone contain the distinctive Pa skeletal component of the apparatus of *Ozarkodina crispa*. This is the index fossil for another of Walliser's (1964) zones, so a direct correlation can be made.

Hence the Yarrangobilly Limestone can be shown to correlate with the *siluricus* and *crispa* Zones of Walliser (1964), which suggests in terms of the presently recognised division of the Silurian (cf. Berry & Boucot, 1970, p. 9-19) a middle to late Ludlow age,

The recent study of conodonts from the classic Australian Silurian succession in the Yass Basin by Link (1970) and Link and Druce (1972) also allows a more accurate correlation than previously possible between the Yarrangobilly Limestone and the Yass succession. In the Yass Basin, the Hume Limestone and the base of the Black Bog Shale contains typical *siluricus* Zone conodonts that can be related to the conodont collection from near the base of the limestone at Yarrangobilly. The uppermost horizons of the Yarrangobilly Limestone are probably equivalent to beds within the Rosebank Shale in the Yass Basin. The failure of Link and Druce (1972) to find conodonts within this formation seems to account for the absence of *latialata* and *crispa* Zone conodonts at Yass in an otherwise complete succession of Walliser's (1964) late Silurian and early Devonian conodont zones.

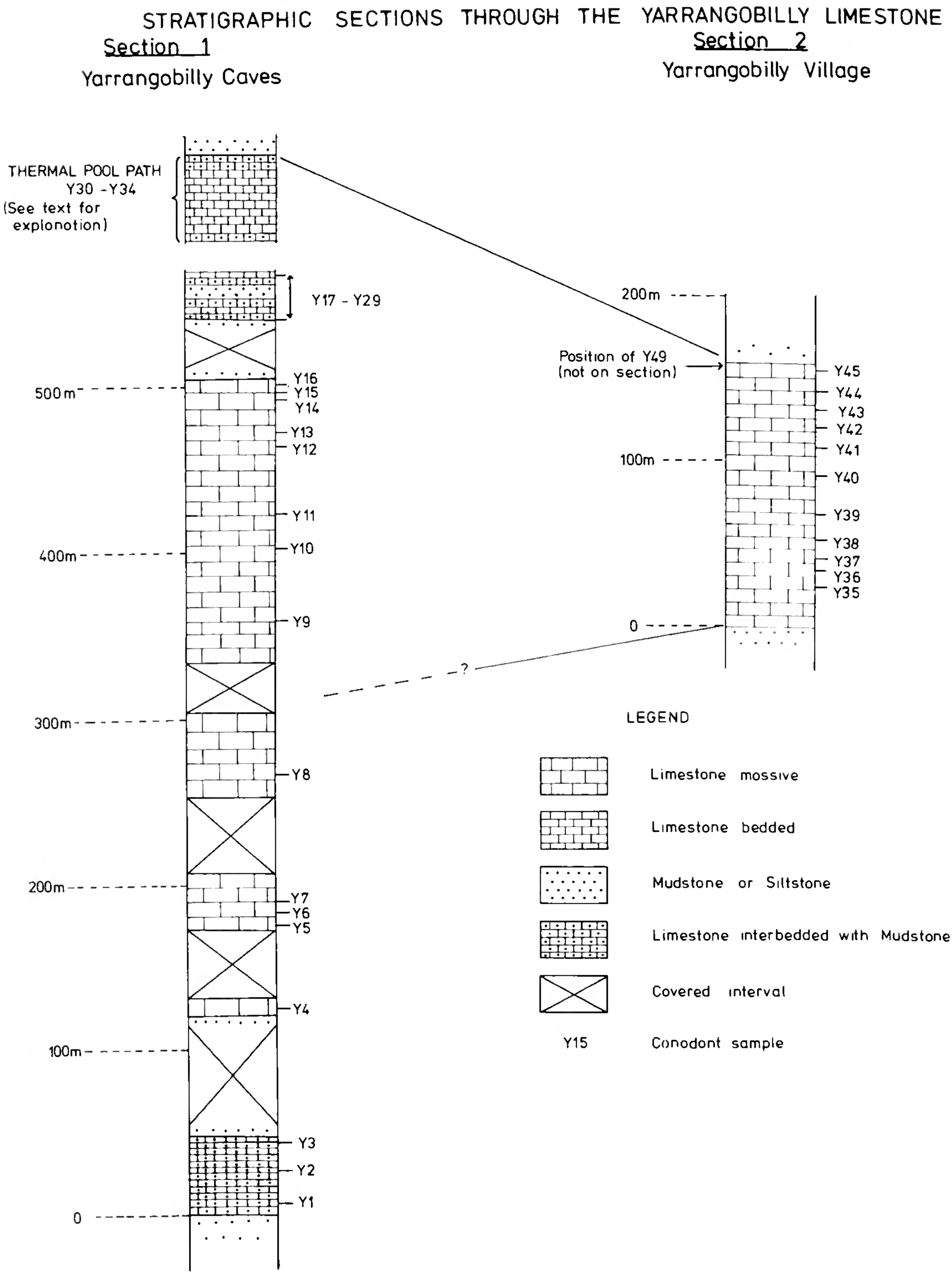

STRATIGRAPHIC SECTIONS THROUGH THE YARRANGOBILLY LIMESTONE
Section 1
Yarrangobilly Caves
Section 2
Yarrangobilly Village
THERMAL POOL PATH
Y30 -Y34
(See text for
explonotion)
Y17 - Y29
Y16
Y15
Y14
Y13
Y12
Y11
Y10
Y9
Y8
Y7
Y6
Y5
Y4
Y3
Y2
Y1
500m
400m
300m
200m
100m
0
200m
Position of Y49
(not on section)
100m
0
Y45
Y44
Y43
Y42
Y41
Y40
Y39
Y38
Y37
Y36
Y35
?
LEGEND
Limestone mossive
Limestone bedded
Mudstone or Siltstone
Limestone interbedded with Mudstone
Covered interval
Y15
Conodont sample

FIG. 2

TABLE 1

DISTRIBUTION OF CONODONTS IN THE YARRANGOBILLY LIMESTONE

SPECIES	SAMPLE NUMBERS																								
	Y5	Y6	Y7	Y9	Y11	Y18	Y19	Y21	Y23	Y24	Y25	Y26	Y27	Y28	Y31	Y32	Y34	Y35	Y36	Y37	Y38	Y41	Y43	Y44	Y49	Y50
Beladella anamalis																										
lenticular																				r		r		r	r	
triangular							r			r						r	r					r	r	r	r	
Kackelella variabilis																										
Pa		r	r																							
Pb			c																							
Sa			r																							
Sb			r																							
Sc			c																							
Ozarkadina confluens																										
Pa			r				c			r	r				c		r	c	r	c	r	r		r	r	
Pb			r				r			r							r	r		r	r	r			r	
M			r				r												r							
Sa			r				r										r			r					r	
Sb										r	r					r	r		r							
Sc											r	r													r	
Ozarkadina crispa																										
Pa																	r								r	
Ozarkadina excavata																										
Pa			c				r			r	r	r	r		r		r	r	r						c	
Pb			r				r			r	r			r				r							r	
M			r						r		r				r		r			r					c	
Sa			r				r										r			r					r	
Sb			r							r	r							r					r		c	
Sc			r				r				r						r			r					a	
Panderodus unicastatus																										
simplexifarm			r	c	r		r	r		r	c	r	c	r			c	c	c	r	r	c	c	r	a	r
castate	r			c	r	r	r		r	c	r	r	r	r	r	c	c	c	c	c		c	r	c	a	
Walliseradus n.s.p.																										
acodontiform																					r		r	r	c	
costate																									r	

r = rare (1 – 3 specimens) c = common (4 – 10) a = abundant (< 10)

SYSTEMATIC PALAEONTOLOGY

The Yarrangobilly conodonts are described, using multielement taxonomy. In recent years this approach has gained widespread acceptance by conodont workers and can be applied easily to the Yarrangobilly collection. Following the lead of Klapper and Philip (1972), Walliser (1972) and Klapper and Murphy (1975), familial categories are also used. The skeletal element notation that is used to describe representatives of the family Polygnathidae in this paper is described by Sweet and Schönlaub (1975).

All illustrated specimens are stored in the University of Melbourne, Department of Geology Fossil Slide Collection (MUGD.FS). Bulk limestone collections from Yarrangobilly are also stored in the above institution.

Family PANDERODONTIDAE Lindström, 1970

TYPE GENUS: *Panderodus* Ethington, 1959.

REMARKS: The conodonts belonging to this family have been discussed in detail by Lindström (1970), Lindström and Ziegler (1971) and Barnes, Sass and Poplawski (1973).

Genus **Panderodus** Ethington, 1959

Panderodus ETHINGTON, 1959, p. 284.

TYPE SPECIES: *Paltodus unicostatus* Branson and Mehl, 1933.

REMARKS: Multielement *Panderodus* is considered here, according to the interpretation of Cooper (1975, 1976).

Panderodus unicostatus (Branson & Mehl)
(Pl. 17, figs. 9, 11, 13, 14)

Simplexiform element.

Paltodus simplex BRANSON & MEHL, 1953, p. 42, Pl. 3, Fig. 4.

Panderodus simplex (Branson & Mehl). REXROAD & CRAIG, 1971, p. 697, Pl. 81, figs. 35-40; LINK & DRUCE, 1972, p. 75, Pl. 7, figs. 13-16.
Costate elements
Paltodus unicostatus BRANSON & MEHL, 1933, p. 42, Pl. 3, fig. 3.
Panderodus gracilis (Branson & Mehl). REXROAD & CRAIG, 1971, p. 695, Pl. 81, figs. 28, 29; LINK & DRUCE, 1972, p. 72, Pl. 7, figs. 23, 24.
Panderodus unicostatus (Branson & Mehl). REXROAD & CRAIG, 1971, p. 697, Pl. 81, figs. 30-34; LINK & DRUCE, 1972, p. 77, Pl. 7, figs. 19-20, Pl. 11, figs. 13, 15. (Refer Cooper, 1976 for a comprehensive synonymy).

REMARKS: Cooper (1976) has discussed this species, so few details are supplied here. Some specimens of the simplexiform element from Yarrangobilly show the development of a second longitudinal furrow on the inner side just below the first. This feature was also noticed by Lindström and Ziegler (1971) in Devonian representatives of *Panderodus*.

The costate components exhibit great variation in the development of fine ridges adjacent to the longitudinal furrow and along the upper margin. In some costate elements, this ornament is absent altogether. As in other representatives of *Panderodus*, the costate elements form a morphologic series not unlike the symmetry transition series that is found in conodonts having a ramiform element apparatus.

REPOSITORY: Simplexiform elements MUGD.FS 2109-2121; Costate elements MUGD.FS 2122-2128.

Family POLYGNATHIDAE Bassler, 1925

TYPE GENUS: *Polygnathus* Hinde, 1879.

REMARKS: Lindström (1970) and Klapper and Philip (1972) have emended the Polygnathidae with regard to multielement taxonomy.

Representative Silurian genera include *Ancoradella*, *Kockelella* and *Ozarkodina*. *Ancoradella* and *Kockelella* have not been placed in this family by Klapper and Murphy (1975), despite the demonstration of a close relationship between the Pa skeletal element of all three genera as well as the overall apparatus similarity between *Kockelella* and *Ozarkodina* (Walliser, 1964, 1972).

Genus **Ozarkodina** Branson & Mehl, 1933

Ozarkodina BRANSON & MEHL, 1933, p. 51; LINDSTROM, 1970, p. 439-440; KLAPPER & MURPHY, 1975, p. 29 (Refer Klapper & Murphy, 1975 for additional synonymy).

TYPE SPECIES: *Ozarkodina confluens* (Branson & Mehl, 1933) (= *Ozarkodina typica* Branson & Mehl, 1933).

REMARKS: *Ozarkodina* is the best known Silurian multielement conodont genus. Research over the last decade, especially by Walliser (1964) and Helfrich (1975) has demonstrated that several long-ranging and distinct lineages can be recognised within *Ozarkodina*, which could be separated at the subgeneric level by future workers.

Most conservative is the lineage of *Ozarkodina excavata*. In this group, the elements in both P positions may show arching and appear to be ozarkodiniform. The lineage probably extends throughout the Silurian. Representative species include *O. excavata* (Branson & Mehl, 1933), *O. hamata* (Walliser, 1964), *O. posthamata* (Walliser, 1964) and *O. protexcavata* Cooper, 1975.

A second lineage is that of *Ozarkodina confluens*. Species of this group generally have an apparatus containing large, robust skeletal elements with small basal cavities. The lineage is well documented in the Ludlow, but extends back at least into the Llandovery. Representative species include *O. confluens* (Branson & Mehl, 1933), *O. hadra* (Nicoll & Rexroad, 1969) and *O. gulletensis* (Aldridge, 1972).

Helfrich (1975) has recognised an *Ozarkodina sagitta* lineage which includes *O. sagitta*, *O. snajdri* and *O. crispa*, all of Walliser (1964) and *O. bicornutus* and *O. tillmani* of Helfrich. Most skeletal elements in the Pa position of these species are distinguished by partial fusion of the denticles.

Representatives of each of the above lineages are present in the Yarrangobilly collection. A fourth lineage is known from the Upper Silurian and Lower Devonian and is commonly called the *Ozarkodina steinhornensis* group.

Important recent studies of these conodonts are provided by Bultynck (1971), Mashkova (1972) and Fåhraeus (1974). Future research should confirm the presence of additional long-ranging *Ozarkodina* lineages in the Silurian and confirm the close relationship of *Ancoradella* and *Kockelella* to *Ozarkodina*.

Ozarkodina confluens (Branson & Mehl, 1933)
(Pl. 16, figs. 1-7)

Pa element
Spathodus primus BRANSON & MEHL, 1933, p. 46, Pl. 3, figs. 25-30.
Pb element
Ozarkodina typica BRANSON & MEHL, 1933, p. 51, Pl. 3, figs. 43-45.
M element
Prioniodus bicurvatus BRANSON & MEHL, 1933, p. 44, Pl. 3, figs. 9-12.
Sa element
Trichognathus symmetrica BRANSON & MEHL, 1933, p. 50, Pl. 3, figs. 33, 34.
Sb element
Plectospathodus flexuosus BRANSON & MEHL, 1933, p. 47, Pl. 3, figs. 31, 32.
Sc element
Hindeodella confluens BRANSON & MEHL, 1933, p. 45, Pl. 3, figs. 21-23.
Complete Apparatus.
Hindeodella confluens Branson & Mehl, JEPPSSON, 1969, p. 15, figs. 1A-F, 2A-F; JEPPSSON, 1974, p. 31-35, Pl. 5, figs. 1-9D, Pl. 6, figs. 1-3G, Pl. 7, figs. 1-14C, Pl. 8, figs. 1-3.
Ozarkodina confluens (Branson & Mehl). KLAPPER & MURPHY, 1975, p. 30, Pl. 3, figs. 1-23, Pl. 4, figs. 1-27, Pl. 8, figs. 11-15.
(Refer to Jeppsson, 1974 for a comprehensive synonymy).

REMARKS: The skeletal elements of this species are well known, especially as a result of work by Jeppsson (1969, 1974), and Klapper and Murphy (1975). The skeletal element in the Pa position is most variable and Walliser (1964, Text fig. 8) documented the form variation of this element from the *siluricus* Zone to the Lower Devonian. The Yarrangobilly representatives of the Pa components of *Ozarkodina* *confluens* correspond to variants found in the *siluricus, latialata* and *crispa* Zones by Walliser (1964).

Klapper and Murphy (1975) recognise five informal morphotypes of *Ozarkodina confluens* based also on the morphology of the Pa element. Yarrangobilly specimens of the Pa element are identical to the α morphototype of Klapper and Murphy that occurs in strata correlative with the *siluricus, latialata* and *crispa* Zones of Walliser (1964).

REPOSITORY: Pa elements MUGD.FS 2137-2139; Pb element MUGD.FS 2103; M elements MUGD.FS 2095, 2096; Sa element MUGD.FS 2141; Sb element MUGD.FS 2131; Sc elements MUGD.FS 2084, 2085.

Ozarkodina crispa (Walliser, 1964)
(Pl. 16, figs. 16, 17)

Pa element

Spathognathodus crispus WALLISER, 1964, p. 74, Pl. 9, fig. 3, Pl. 21, figs. 7-13; FEIST & SCHÖNLAUB, 1974, Pl. 7, figs. 8, 9, 11, 12, 14, 15; HELFRICH, 1975, Appendix 1, p. 55, Pl. 14, figs. 1-4, 9, 14, 19, 21, 24, 27.

Ozarkodina crispa (Walliser). KLAPPER & MURPHY, 1975, p. 33, Pl. 8, fig. 10.

Complete Apparatus

Multielement Conodont Species, Group X. HELFRICH, 1975, p. 40.

REMARKS: Three specimens conforming to the distinctive Pa skeletal element of this conodont apparatus were identified from Yarrangobilly.

REPOSITORY: Pa element MUGD.FS 2132, 2133.

Ozarkodina excavata (Branson & Mehl, 1933)
(Pl. 16, figs. 8-15)

Pa element

Ozarkodina simplex BRANSON & MEHL, 1933, p. 52, Pl. 3, figs. 46, 57.

Prioniodella inclinata RHODES, 1953, p. 324, Pl. 23, figs. 233-235.

Pb element

Ozarkodina media WALLISER, 1957, p. 40, Pl. 1, figs. 21-25.

M element

Prioniodus excavata BRANSON & MEHL, 1933, p. 45, Pl. 3, figs. 7, 8.

Sa element

Trichognathus excavata BRANSON & MEHL, 1933, p. 51, Pl. 3, figs. 35, 36.

Sb element

Plectospathodus extensus RHODES, 1953, p. 323, Pl. 21, figs. 236-240.

Sc element

Hindeodella equidentata RHODES, 1953, p. 303, Pl. 23, figs. 248, 252-254.

Complete Apparatus

Conodonten-Apparat H WALLISER, 1964, p. 14.

Hindeodella excavata (Branson & Mehl). JEPPSSON, 1969, p. 18, figs. 1G-L, 3A-F; JEPPSSON, 1974, p. 25-31, Pl. 4, figs. 1-17.

Ozarkodina excavata excavata (Branson & Mehl). KLAPPER & MURPHY, 1975, p. 34-37, Pl. 6, figs. 1-20.

(Refer Jeppsson, 1974 for a comprehensive synonymy).

REMARKS: *Ozarkodina excavata* is the most convincing of all Silurian multielement conodont reconstructions. Illustrated specimens from the Yarrangobilly collection include arched, as well as bar-like representatives of the Pa skeletal component.

REPOSITORY: Pa elements MUGD.FS 2134-2136; Pb elements MUGD.FS 2100-2102; M elements MUGD.FS 2097, 2098; Sa element MUGD.FS 2140; Sb element MUGD.FS 2129, 2130; Sc element MUGD.FS 2086, 2087.

Genus **Kockelella** Walliser, 1957

TYPE SPECIES: *Kockelella variabilis* Walliser, 1957.

Kockelella variabilis Walliser, 1957
(Pl. 17, figs. 1-7)

Pa element

Kockelella variabilis WALLISER, 1957, p. 35, Pl. 1, figs. 3-10; WALLISER, 1964, p. 40, Pl. 8, fig. 12, Pl. 16, figs. 1-15.

Complete apparatus

Conodonten-Apparat G. WALLISER, 1964, P. 14 (non Pb element = *Ozarkodina ziegleri ziegleri*).

Kockelella variabilis Walliser. KLAPPER & MURPHY, 1975, p. 53, Pl. 9, figs. 5-11, Pl. 10, figs. 1-16. (Refer Klapper and Murphy, 1975, for a comprehensive synonymy).

REMARKS: The skeletal elements of *Kockelella variabilis* are rare in the author's collections and no M components were recognised. Nevertheless the restricted occurrence of the distinctive Pa element and other apparatus constituents confirm the presence of this multielement species.

REPOSITORY: Pa element MUGD.FS 2089-2090; Pb element MUGD.FS 2099; Sa element MUGD.FS 2094; Sc element MUGD.FS 2091-2092.

Family Uncertain

REMARKS: Under this heading are included conodonts that have a simple-cone skeletal apparatus and cannot yet be placed with confidence in the Family Panderodontidae. Definite familial placement of these genera awaits comprehensive studies of Ordovician ancestors.

Genus **Belodella** Ethington, 1959

Belodella ETHINGTON, 1959, p. 271.

TYPE SPECIES: *Belodus devonicus* Stauffer, 1940.

REMARKS: Cooper (1974, 1976) provides a discussion of this genus.

Belodella anomalis Cooper, 1974

Belodella anomalis COOPER, 1974, p. 1121, Pl. 1, figs. 1-10. Text fig. 1.

REMARKS: This species has, until now, been recorded only from the Yarrangobilly Limestone. A description has been provided elsewhere (Cooper, 1974).

REPOSITORY: MUGD.FS 2075-2083.

Genus **Walliserodus** Serpagli, 1967

Walliserodus SERPAGLI, 1967, p. 104.

TYPE SPECIES: *Acodus curvatus* Branson & Branson, 1947.

REMARKS: *Walliserodus* was revised as a multielement conodont genus by Cooper (1975), and his interpretation is followed in this paper. The two conodont skeletal elements that are described here are sparsely represented in the Yarrangobilly collection, but are referred to *Walliserodus* on the basis of comparison with the type species.

Walliserodus n. sp.
(Pl. 17, figs. 8, 10, 12)

DESCRIPTION: The known skeletal elements of *Walliserodus* n. sp. can best be compared with the acodontiform and one of the asymmetrical costate components in the apparatus of *W. curvatus*.

Acodontiform Element

This is a simple uniformly curved biconvex cone, almost symmetrical in cross-section. The upper and lower margins are generally sharp, but the lower margin is flattened towards the base. A deep basal cavity that constricts to a tip near the lower margin is present. The lateral sides are smooth except for fine striations slightly oblique to the length of the unit.

Costate Element

This is a gently curved paltodontiform element. On one side, near the lower margin, a strong costa is apparent that extends almost the full length of the element. Around the upper margin, a series of longitudinal costae of varying length occur, most obvious about the mid-length. A narrow, sharply defined, wrinkled zone is present around the basal margin.

REMARKS: The acodontiform element of *Walliserodus* n. sp. differs from its counterpart in *W. curvatus* in the lack of a lateral costa. The costate component can be best compared in *W. curvatus* with the costate element previously described as the form-species *Paltodus debolti* by Rexroad (1967). However in *W. curvatus*, this element has lateral costae near the lower margin on both sides of the unit.

REPOSITORY: Acodontiform elements MUGD.FS 2105-2107; Costate element, MUGD.FS 2108.

ACKNOWLEDGEMENTS

This study forms part of a M.Sc. thesis supervised by Dr. G. A. Thomas at the University of Melbourne and completed in 1972. Financial support was provided by a Commonwealth Post Graduate Research Award and permission to collect in the Kosciusko National Park was granted by the New South Wales National Parks Service. D. Campbell drafted the illustrations and the late Mr. R. Britton supervised Scanning Electron Microscope studies. The views expressed here have been greatly influenced by study (1972-1974) under the guidance of W. C. Sweet and S. M. Bergström at The Ohio State University, Columbus. Publication is authorised by the Director of Mines, Geological Survey of South Australia.

REFERENCES

ADAMSON, C. V., 1958. Reconnaissance Geology of the Snowy Mountains — Progress Report No. 11, Yarrangobilly. *Tech. Rep. Dep. Mines N.S.W.* 3 (1955): 34-42.

———, 1960. Reconnaissance Geology of the Snowy Mountains — Progress Report No. 16, Tumut. *Ibid.* 5 (1957): 138-142.

ALDRIDGE, R. J., 1972. Llandovery Conodonts from the Welsh Borderland. *Bull. Br. Mus. Nat. Hist. (Geol.)* 22: 125-231.

ANDERSON, W., 1886. Report on Yarrangobilly caves. *A. Rep. Dep. Mines N.S.W.* p. 163-165.

ANDREWS, E. C., 1901. Report on the Kiandra lead. *Mineral. Resour. N.S.W.* No. 10.

BARNES, C. R., SASS, D. B. & POPLAWSKI, M. L. S., 1973. Conodont Ultrastructure: The Family Panderodontidae. *Life Sci. Contr., R. Ont. Mus.* 90: 1-36.

BASSLER, R. S., 1925. Classification and Stratigraphic use of conodonts. (Abstract). *Bull. geol. Soc. Amer.* 36: 218-220.

BERRY, W. B. N. & BOUCOT, A. J., 1970. Correlation of the North American Silurian rocks. *Spec. Pap. geol. Amer.* 102: 1-289.

BRANSON, E. B. & BRANSON, C. C., 1947. Lower Silurian Conodonts from Kentucky. *J. Paleont.* 21: 549-556.

BRANSON, E. B. & MEHL, M. G., 1933. Conodont Studies I and II. *Univ. Mo. Stud.* 8: 1-156.

BULTYNCK, P., 1971. Le Silurien Supérieur et le Dévonien Inférieur de la Sierra de Guadarrama (Éspagne centrale) II — Assemblages de conodontes á *Spathognathodus*. *Bull. Int. r. Sci. nat. Belg.* 47 (3): 1-43.

COOPER, B. J., 1974. New Forms of *Belodella* (Conodonta) from the Silurian of Australia. *J. Paleont.* 48: 1120-1125.

———, 1975. Multielement Conodonts from the Brassfield Limestone (Silurian) of southern Ohio. *Ibid.* 49: 984-1008.

———, 1976. Multielement Conodonts from the St. Clair Limestone (Silurian) of southern Illinois. *Ibid.* 50: 205-217.

ETHERIDGE, R., 1893-4. The Pentameridae of New South Wales. *Rec. geol. Surv. N.S.W.* 3: 49-60.

ETHINGTON, R. L., 1959. Conodonts from the Ordovician Galena Formation. *J. Paleont.* 33: 257-292.

FÅHRAEUS, L. E., 1974. Taxonomy and Evolution of *Ozarkodina steinhornensis* and *Ozarkodina optima* (Conodontophorida). *Geologica et Palaeontologica* 8: 29-37.

FEIST, R. & SCHÖNLAUB, H. P., 1974. Zur Silur/Devon-Grenze in der Östlichen Montagne Noire Süd-Frankreichs. *N. Jb. Geol. Paläont. Mh.* 4: 200-219.

HAMADA, T., 1957. On the Classification of Halysitidae I. *J. Fac. Sci. Toyko Univ.* (2) 10: 393-405.

———, 1958. Japanese Halysitidae. *Ibid.* (2) 11: 91-114.

HELFRICH, C. H., 1975. Silurian Conodonts from the Wills Mountain anticline, Virginia, West Virginia and Maryland. *Spec. Pap. geol. Soc. Amer.* 161: 1-82.

HILL, D., 1954. Coral Faunas from the Silurian of New South Wales and Devonian of Western Australia. *Bull. Bur. Miner. Resour. Geol. and Geophys. Aust.* 23: 1-51.

HINDE, G. J., 1879. On Conodonts from the Chazy and Cincinnati group of the Cambro-Silurian and from the Hamilton and Genesee Shale divisions of the Devonian in Canada and the United States. *Quart. J. geol. Soc. Lond.* 35: 351-369.

JEPPSSON, L., 1969. Notes on some Upper Silurian multielement conodonts. *Geol. Fören. Stockh. Förh.* 91: 12-24.

———, 1974. Aspects of Late Silurian Conodonts. *Fossils and Strata* 6: 1-54.

KLAPPER, G. & MURPHY, M. A., 1975. Silurian and Lower Devonian conodont sequence in the Roberts Mountains Formation of central Nevada. *Univ. of California, Publ. in Geol. Sci.* 3: 1-62.

KLAPPER, G. & PHILIP, G., 1972. Familial Classification of reconstructed Devonian conodont apparatuses. *Geologica et Palaeontologica* SBI: 97-114.

LABUTIS, V., 1969. The Geology of the Yarrangobilly area, N.S.W. Unpublished B.Sc. (Hons.) Thesis, Australian National University.

LINDSTRÖM, M., 1970. A suprageneric taxonomy of the conodonts. *Lethaia* 3: 427-445.

LINDSTRÖM, M. & ZEIGLER, W., 1971. Feinstrukturelle Untersuchungen an Conodonten 1. Die. Überfamilie Panderodontacea. *Geologica et Palaeontologica* 5: 9-34.

LINK, A. G., 1970. Age and Correlation of the Siluro-Devonian strata in the Yass Basin, New South Wales. *J. geol. Soc. Aust.* 16: 711-722.

LINK, A. G. & DRUCE, 1972. Ludlovian and Gedinnian conodont stratigraphy of the Yass Basin, New South Wales. *Bull. Bur. Miner. Resour. Geol. and Geophys. Aust.* 134: 1-136.

MASHKOVA, T. V., 1972. *Ozarkodina steinhornensis* (Ziegler) Apparatus, its conodonts and biozone. *Geologica et Palaeontologica* SB-1: 81-90.

NICOLL, R. S. & REXROAD, C. B., 1969. Stratigraphy and Conodont paleontology of the Salamonie Dolomite and Lee Ck. Member of the Brassfield Limestone (Silurian) in south-eastern Indiana and adjacent Kentucky. *Bull. geol. Surv. Indiana* 40: 1-73 (Date of imprint 1968).

PACKHAM, G. H. (Ed.), 1969. The Geology of New South Wales. *J. geol. Soc. Aust,* 16: 1-654.

REXROAD, C. B., 1967. Stratigraphy and Conodont paleontology of the Brassfield (Silurian) in the Cincinnati areh area. *Bull. geol. Surv. Indiana* 36: 1-64.

REXROAD, C. B. & CRAIG, W. W., 1971. Restudy of Conodonts from the Bainbridge Formation (Silurian) at Lithium, Missouri. *J. Paleont.* 45: 684-703.

RHODES, F. H. T., 1953. Some British Lower Palaeozoic conodont faunas. *Phil. Trans. Roy. Soc. Lond.* B237: 261-334.

SERPAGLI, E., 1967. I conodonti dell'Ordoviciano Superiore (Ashgillinao) delle Alpi Carniche. *Boll. Soc. Palaeontol. Italiana* 6: 30-111.

STAUFFER, C. R., 1940. Conodonts from the Devonian and associated clays of Minnesota. *J. Paleont.* 14: 417-435.

STRUSZ, D. L., 1971. 1:250,000 Geological Series — Explanatory notes. Canberra, Australian Capital Territory and New South Wales. *Bur. Miner. Resour. Geol. Geophys. Aust. 1:250,000 Geol. Expl. Notes* 1-47.

SWEET, W. C. & SCHÖNLAUB, H. P., 1975. Conodonts of the Genus *Oulodus* Branson and Mehl, 1933. *Geologica et Palaeontologica* 9: 41-59.

TRICKETT, O., 1897. *A. Rep. Dept. Mines N.S.W.* p. 221.

WALLISER, O. H., 1957. Conodonten aus dem oberen Gotlandium Deutschlands und der Karnischen Alpen. *Notizbl. hess Landesamt Bodenforsch.* 85: 28-52.

———, 1964. Conodonten des Silurs. *Abh. hess. Landesamt Bodenforsch.* 41: 1-106.

———, 1972. Conodont Apparatuses in the Silurian. *Geologica et Palaeontologica* SB-1: 75-80.

APPENDIX

LOCALITY REGISTER

All Grid. References (G. R.) refer to the Yarrangobilly (1 inch = 1 mile) map sheet.

MEASURED SECTION 1: Yarrangobilly Caves. Tops of Section G. R. 29941806, Base of Section G. R. 29981808.

This section misses the youngest horizons of the Yarrangobilly Limestone because of rapid lensing of the formation, south of Caves House. The youngest beds of the Yarrangobilly Limestone were collected in the caves area along the Thermal Pool Path. This is illustrated by the addition shown at the top of the first column in Fig. 2.

MEASURED SECTION 2: Yarrangobilly Village. Top of Section G. R. 29811859, Base of Section G. R. 29841859.

The main belt of limestone, just east of Yarrangobilly Village has split into two parts. This measured section is across the westernmost limestone band only. Isolated samples Y45 and Y49 can be accurately fixed on this section.

ISOLATED SAMPLES: Y30, Y31, Y32, Y33, Y34, samples collected progressively down Thermal Pool Path (G. R. 29931807); Y45 (G. R. 29811858); Y46 (G. R. 29911846); Y47 (G. R. 29911848); Y48 (G. R. 29891849); Y49 (G. R. 29821854); Y50 (G. R. 29961813).

EXPLANATION OF PLATES 16 & 17

All specimens in Plates 16 and 17 (which follow) were photographed, using a Graflex camera having a SM3-CS1 attachment on a J.E.O.L. Scanning Electron Microscope.

Plate 16

Figs. 1-7—*Ozarkodina confluens* (Branson & Mehl). (1) Lateral view of Pa element, MUGD.FS 2138, ×60, Y49. (2) Basal view of Pa element, MUGD.FS 2138, ×60, Y49. (3) Lateral view of M element MUGD.FS 2095. ×120, Y19. (4) Lateral view of Pb element MUGD.FS 2103, ×60, Y49. (5) Posterior view of Sa element, MUGD.FS 2141, ×60, Y41. (6) Lateral view of Sc element, MUGD.FS 2084, ×60, Y49. (7) Lateral view of Sb element, MUGD.FS 2131, ×60, Y49.

Figs. 8-15—*Ozarkodina excavata* (Branson & Mehl). (8) Lateral view of Pb element, MUGD.FS 2101, ×60, Y49. (9) Lateral view of Pa element with prominent apical denticle, MUGD.FS 2136, ×60, Y31. (10) Lateral view of Pa element showing arching, MUGD.FS 2135, ×40, Y7. (11) Lateral view of Pa element, MUGD.FS 2134, ×60, Y49. (12) Lateral view of Sb element, MUGD.FS 2129, ×60, Y49. (13) Posterior view of Sa element, MUGD.FS 2140, ×120, Y49. (14) Lateral view of Sc element MUGD.FS 2087, ×60, Y49. (15) Lateral view of M element, MUGD.FS 2097, ×60, Y49.

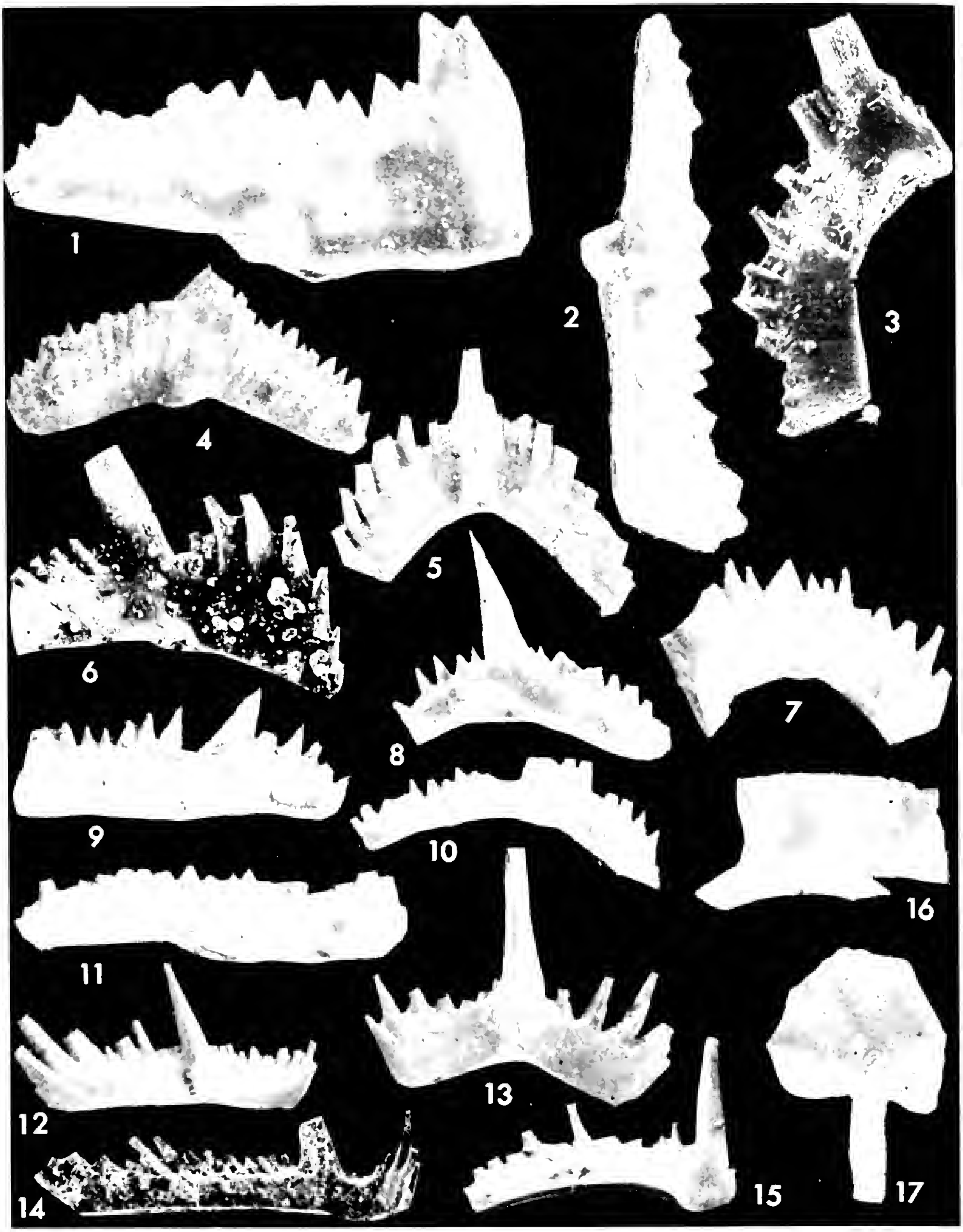
Figs. 16, 17—*Ozarkodina crispa* (Walliser). (16) Lateral view of Pa element, MUGD.FS 2132, ×100, Y49. (17) Basal view of Pa element, MUGD.FS 2132, ×100, Y49.

Plate 17

Figs. 1-7—*Kockelella variabilis* (Walliser). (1) Basal view of Pa element, MUGD.FS 2089, ×60, Y7. (2) Lateral view of Pa element, MUGD.FS 2090, ×100, Y7. (3) Posterior view of Sa element, MUGD.FS 2094, ×100, Y7. (4) Lateral view of Sc element, MUGD.FS 2091, ×60, Y7. (5) Top view of Pa element, MUGD.FS 2089, ×60, Y7. (6) Lateral view of Sb element, MUGD.FS 2104, ×100, Y6. (7) Lateral view of Pb element, MUGD.FS 2099, ×100, Y7.

Figs. 8, 10, 12—*Walliserodus* n. sp. (8) Lateral view of possible costate element MUGD.FS 2108, ×200, Y49. (10) Other lateral view of costate element, MUGD.FS 2108, ×200, Y49. (12) Lateral view of possible acodontiform element, MUGD.FS 2105, ×200, Y49.

Figs. 9, 11, 13, 14—*Panderodus unicostatus* (Branson & Mehl). (9) Outer lateral view of costate element, ×60, Y49. (11) Inner lateral view of costate element, MUGD.FS 2112, ×60, Y49. (13) Inner lateral view of simplexiform element MUGD.FS 2122, ×60, Y49. (14) Inner lateral view of costate element, MUGD.FS 2111, ×400, Y49.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DIRECTIONAL SEDIMENTARY STRUCTURES IN RECENT TUFFS, TOWER HILL, AUSTRALIA.

By Brian Marshall*

Abstract: Differences in movement-directions of climbing-ripple cross-lamination relative to initial dip orientation are used to demonstrate that the Tower Hill tuffs were deposited by wind action rather than from a slurry. The dominant wind trend is shown to have been north-east to south-west, while the dominant wind direction was south-west, a direction in accordance with contemporary prevailing wind records.

INTRODUCTION

Tower Hill is a volcanogenic landform near Warrnambool, Western Victoria, which has been called a nested caldera (Gill 1950, 1967, 1972), and a maar (Ollier & Joyce, 1964, Ollier 1967), and assigned an age 7300 ± 150 years B. P. (Gill 1972). It comprises an ash and lapilli rim encompassing a lake and several scoria cones. The rim is well defined in all but a small south-west portion and attains its highest development east-north-east of the ovoid main crater, which is elongated north-east to south-west and has long and short axes approximating 3.4 km and 2.6 km (Fig. 1). The rim extends outwards into a tuff apron, the areal asymmetry of which has been interpreted by Gill (1950, 1972) in terms of a prevailing south-west wind during the period of eruption. Ollier and Joyce (1964) have questioned this on the basis that the areal distribution of the tuff ring is not easily defined and asymmetry could reflect unusual winds engendered by the eruption.

The friable porous tuffs are extremely well bedded (e.g. Ollier 1967, figure 5), and display directional sedimentary structures. These comprise common climbing-ripple cross-lamination type B (Allen, 1973, figure 1) in ash horizons, and less common type A (op. cit.) in some small lapilli horizons. As defined by Allen, type A cross-lamination is characterized by an erosional relationship between sets, such that mainly lee-side laminae are preserved and the angle of climb is generally less than 10^2. In contrast, type B involves a gradational relationship between sets with preservation of stoss- and lee-side laminae, moderate to strong asymmetry of ripple profile, and angles of climb between 10^2 and 60^2.

Singleton and Joyce (1968) have suggested that foreset bedding in the tuffs is evidence of deposition from a slurry. They therefore disagree with wind-controlled asymmetry of the tuff ring (Gill 1950, 1972), and prior suggestions that the sedimentary structures are aeolian (Ollier & Joyce 1964, Marshall 1967).

This paper will present evidence for the aeolian origin of directional sedimentary structures at Tower Hill, and will examine Gill's proposal that the prevailing wind determined the asymmetric ash distribution.

STRUCTURAL ANALYSIS

Exposures from which meaningful structural data can be obtained are restricted to road metal quarries at five peripheral localities (Fig. 1). Bedding was systematically measured in each quarry and plotted as the plunge of the dip on a Lambert equal-area projection (Fig. 2). The radially outward initial dip (within the range 3^2 to 10^2) of the tuffs is readily apparent, despite lack of data from the south-west portion of the crater.

Directional sedimentary structures are common at locality 1, infrequent at locality 5 and sparse at localities 2, 3 and 4. This restricted the analysis to locality 1 where, for climbing-ripple cross-lamination types A and B, the dip of the lee- and stoss-sides, the angle of climb where the stoss-side was eroded, and the plunge of the crest (terminology after Allen 1973) were recorded. Resulting data were plotted on Lambert projections, and the most common orientations of measured elements were determined by visual assessment of point-distribution densities, since the relatively few readings did not merit contouring procedures. Monoclinic symmetry planes (or mirror planes) for cross-

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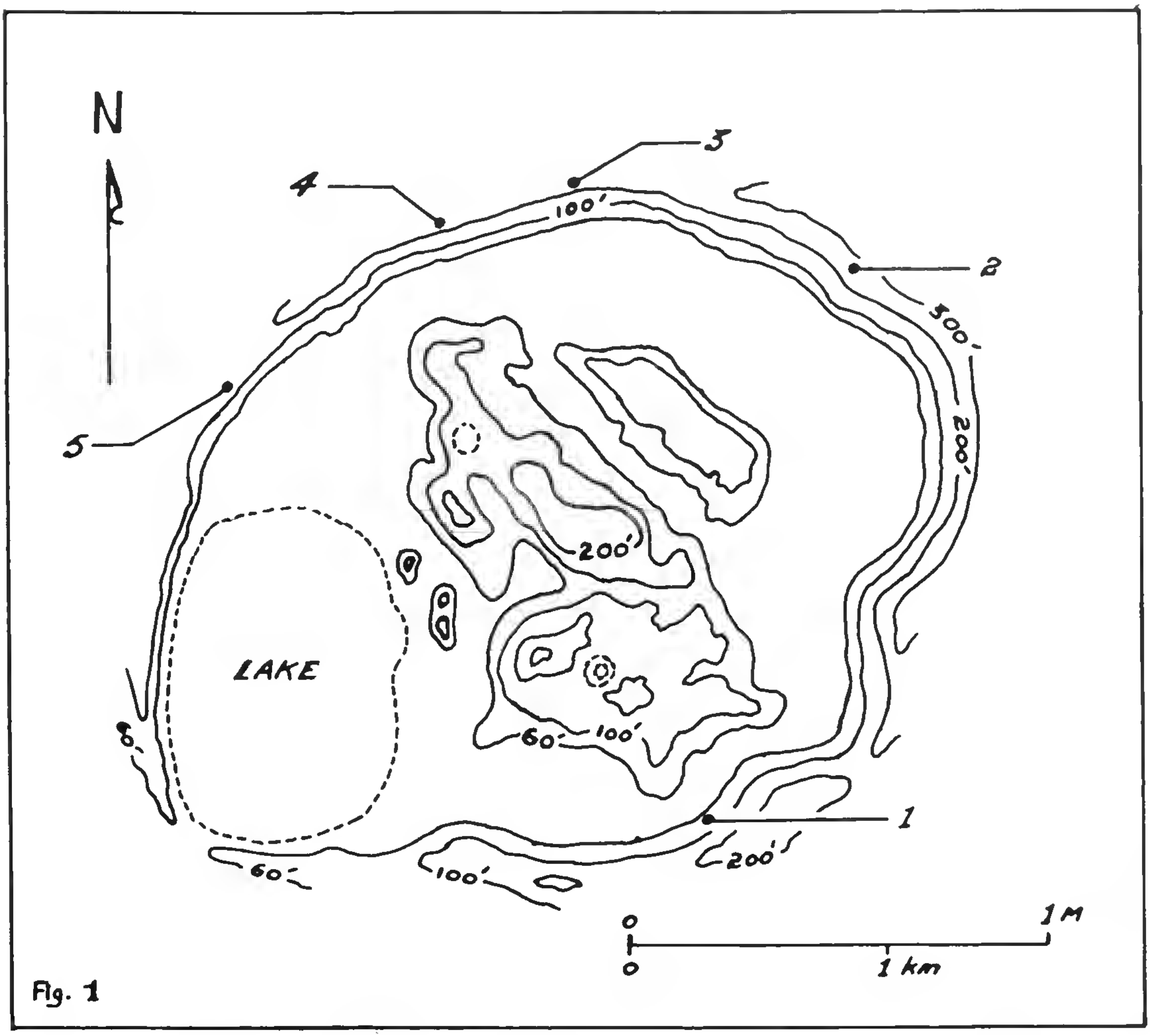


FIG. 1—Tower Hill: topographic contours and quarry localities (Nos. 1 to 5).

lamination types A and B were then constructed by finding which great circles of the projections were common to the lee- and stoss-side maxima.

The significance of determining the symmetry plane for climbing-ripple cross-lamination is that its strike is the trend of the aeolian or aqueous traction current which produced the structure. Further, the true movement-direction of the current may be obtained from the facing of lee-side laminae which are identified from ripple asymmetry.

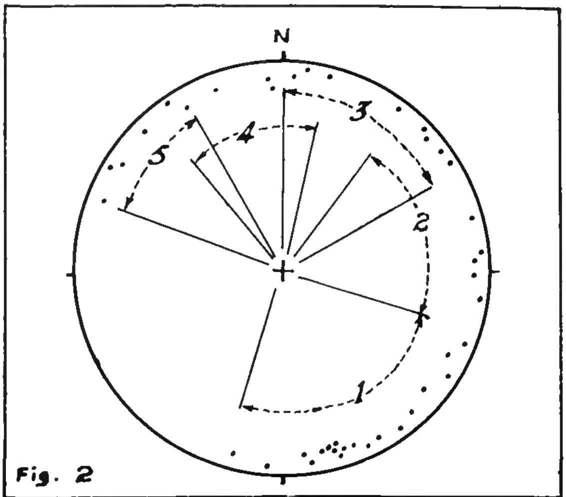
Excluding the plunge of ripple crests, which were measured to check the orientations of the symmetry planes and sensibly formed small peripheral concentrations about the poles to the symmetry planes, salient results are presented in Figs. 3A and 3B and Table 1.

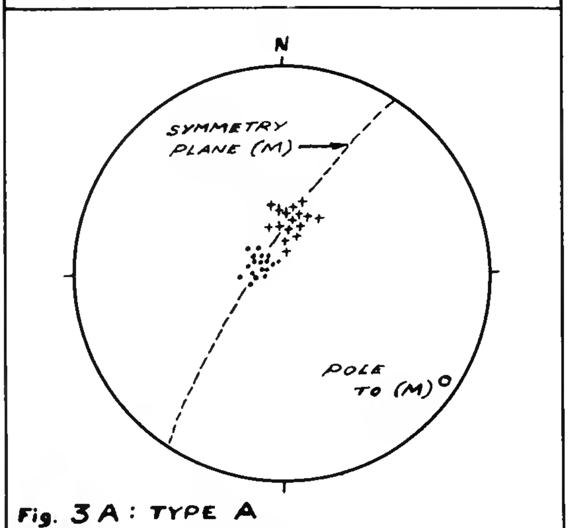
DISCUSSION

Despite the limited exposure and the small number of measurements, the analysis is considered meaningful because all exposed structures were recorded, the results are consistent, and the structural geometry is simple.

In Table 1 and Figs. 3A and 3B, the trend of the traction current producing the structures is the strike of the monoclinic symmetry plane, and the movement-direction within the trend is indicated by the facing of the lee-side element. For locality 1 where the tuffs dip south-south-eastward, the trend of climbing-ripple cross-lamination type A is 213^{2}-33^{2} and the movement-direction towards 213^{2}; for type B the trend is 222^{2}-42^{2} and the movement-direction towards 42^{2}. The trends of traction currents forming cross-lamination types A and B are therefore closer to the strike (approximately 045^{2}) than to the initial dip (135^{2}) of the tuffs, and the movement-vectors within the trends are very obliquely down the initial dip for type A, and very obliquely up the initial dip for type B.

These data are incompatible with the Singleton and





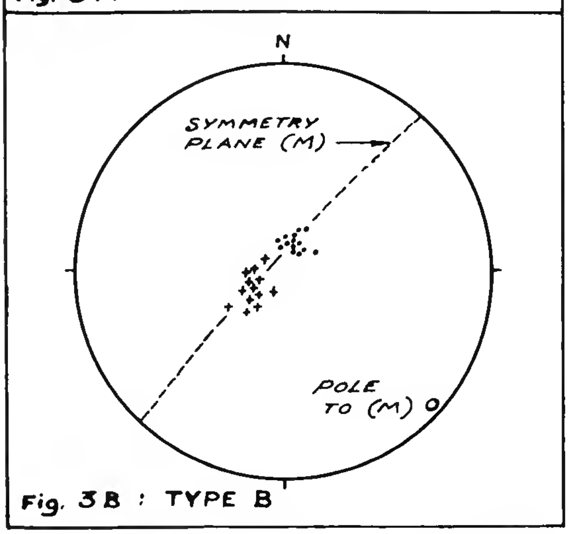


FIG. 2—Bedding plane orientations plotted as the plunge of the dip: the angular spread of data from each quarry is shown. FIG. 3A—Climbing-ripple cross-lamination type A: poles to lee (+) and stoss (.) sides. FIG. 3B—Climbing-ripple cross-lamination type B: poles to lee (+) and stoss (.) sides.

TABLE 1

THE MOST COMMON ORIENTATION OF STRUCTURAL ELEMENTS EXPRESSED AS:

Structural Element	Fig. 3A Strike	Fig. 3A Dip	Fig. 3B Strike	Fig. 3B Dip
Lee-side	279^2	19^{2}S	147^2	15^{2}NE
Stoss-side *or* angle of climb	202^2	8^{2}E	280^2	7^{2}S
Monoclinic symmetry plane (M)	033^2	82^{2}NW	042^2	86^{2}NW

Joyce suggestion that deposition was from a slurry, which would require the traction current vector to be down the initial dip of the tuffs, but support an aeolian genesis for the directional sedimentary structures.

Accepting an aeolian origin for the structures, climbing-ripple cross-lamination type B (the commonly observed form in this area) reflects a south-west wind from 22^2, whilst Type A was caused by a north-north-east wind from 33^2. The dominant wind trend therefore approximated north-east to south-west and, based on relative abundance of types A and B, the predominant wind direction during eruption was south-west. This direction is in accordance with the long axis of the elliptical crater, the build-up of substantial thicknesses of ash and tuff around the north-east sector, and, as noted by Gill (1950), the wider dispersion of the tuff and ash apron around the same sector. The results therefore support Gill's contention (1950, 1972) that the asymmetric tuff ring formed under the influence of a prevalent south-west wind, and accord with contemporary records (Hounam & Powell 1964) that the prevailing summer wind direction in the Warrnambool district is south-west.

ACKNOWLEDGMENTS

The data were collected whilst I was an Academic Staff member at Melbourne University. The facilities of the Geology Department and the co-operation of its staff are acknowledged.

REFERENCES

ALLEN, J. R. L., 1973. A classification of climbing-ripple cross-lamination. *Jl. geol. Soc. Lond.* 129: 537-541.

GILL, E. D., 1950. An hypothesis relative to the age of some Western District volcanoes. *Proc. R. Soc. Vict.* 60: 45-56.

———, 1967. Evolution of the Warrnambool-Port Fairy coast and the Tower Hill eruption, western Victoria. *Landform Studies from Australia and New Guinea*, Ed. J. N. Jennings and J. A. Mabbutt. Aust. Nat. Univ., Canberra. pp. 340-364.

———, 1972. Eruption date of Tower Hill volcano. *Vict. Naturalist,* 89: 188-192.

Hounam, C. E. & Powell, F. A., 1964. Climate of the basaltic plains of western Victoria. *Bureau of Meteorology Working Paper 63/3 14, January.*

Marshall, B., 1967. Kink Bands and other syndepositional structures in Recent Tuffs, Tower Hill, Victoria. *Summary papers for Section C*, Ed. J. McAndrew, M. A. H. Marsden and B. Marshall. *ANZAAS 39th. Congress, Melbourne.*

Ollier, C. D., 1967. Maars, the characteristics, varieties, and definition. *Bulletin Volcanologique*, 31: 45-73.

Ollier, C. D. & Joyce, E. B., 1964. Volcanic physiography of the western plains of Victoria. *Proc. R. Soc. Vict.* 77: 357-376.

Singleton, O. P. & Joyce, E. B., 1968. Cainozoic Volcanicity in Victoria. Geol. Soc. Aust. Specialists' Meeting, Canberra.

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STUDIES ON SOME PRESUMED HYBRID POPULATIONS IN *Eucalyptus*

By J. B. Kirkpatrick*

Abstract: Three morphologically similar but disjunct populations of *Eucalyptus*, generally morphologically intermediate between *Eucalyptus globulus* ssp. *bicostata* and *E. glaucescens*, are found in northeastern Victoria. A progeny test revealed that the seedlings of the three populations were no more variable than the seedlings of nearby populations of *E. globulus* ssp. *bicostata* and *E. glaucescens*, and less variable than the seedlings of an apparent hybrid between *E.* aff. *smithii* and one of the three populations. Thus it is concluded that, although there may be several reasonable alternative explanations for the origin of the three populations, they have not resulted from recent hybridization between *E. globulus* and *E. glaucescens* as had been proposed earlier, and are best regarded as component populations of an undescribed species.

INTRODUCTION

In previous papers (Parsons & Kirkpatrick 1972, Kirkpatrick, Simmons & Parsons 1973) attempts were made, through analysis of the morphology of adult populations and progeny tests, to establish the validity of the term 'phantom hybrid' in relation to several populations of *Eucalyptus*. In the case of *E. cypellocarpa* L. Johnson and *E. goniocalyx* F. Muell. ex. Miq. the presumed hybrid populations were disjunct from populations of both supposed parents. In the case of *E. globulus* Labill. and *E. cypellocarpa* one parent was found contiguous to the supposed hybrids. In this paper I attempt to discover the evolutionary and taxonomic status of three populations identified in part by Willis (1972, p. 420) as presumed hybrids of *E. glaucescens* Maiden & Blakely and *E. globulus* Labill. ssp. *pseudoglobulus* (Naudin ex Maiden) Kirkpatrick (*E. pseudoglobulus* of Willis). Only one of these three populations is contiguous with the supposed parent species, thus presenting an interesting situation for comparison.

The three populations consist of glaucous-leaved mallees similar in habit to *E. glaucescens*, but differ most markedly from *E. glaucescens* in the shape and size of the fruits, which approximate those of some populations of *E. globulus*. Population NS is situated on steep rocky slopes below Stradbroke Chasm in northeastern Victoria (Fig. 1). *E. viminalis* Labill. and *E. globulus* Labill. ssp. *bicostata* (Maiden *et al.*) Kirkpatrick are found immediately adjacent to this population in a more mesic situation, and *E. glaucescens* is found on Mt. Stradbroke above the scarp cliff which separates it from population NS. These three species are from the same section of the same subgenus and thus are likely to be capable of hybridization (Pryor & Johnson 1971). The only other species in the same subgenus growing adjacent to population NS is *E. albens* Benth. which is in the section Adnataria and is thus less likely to be capable of hybridization with the other three species. Population LR is separated from population NS by a disjunction of 14 km, and is found on the rocky edge of the Little River Gorge around the lookout. The only other eucalypt in the same section as those mentioned previously and found in close vicinity to population LR is a mallee resembling *E. smithii* R.T. Bak., although glaucous-leaved populations of mallees observed on the precipitous walls of the gorge may be either *E. glaucescens* or similar to population LR. Population MW is found on steep rocky slopes around the summit of Mt. Wheeler, intermingled with *E.* aff. *smithii*, and with a small stand of *E. viminalis* in the near vicinity. A disjunction of 2½ km separates MW and LR (Fig. 1). Thus, none of the four species which could be suspected to have some role in their genesis are found near all of the three populations (Table 1).

E. viminalis, a species found in many hybrid combinations, is believed on the basis of field, morphological and progeny evidence to cross with both *E. glaucescens* and *E. globulus* (Pryor 1951, 1962). There seems to be no similarly substantiated reports of any other combinations of the four species (including *E.* aff. *smithii*) in the literature.

Careful field examination of the form, leaves, in-

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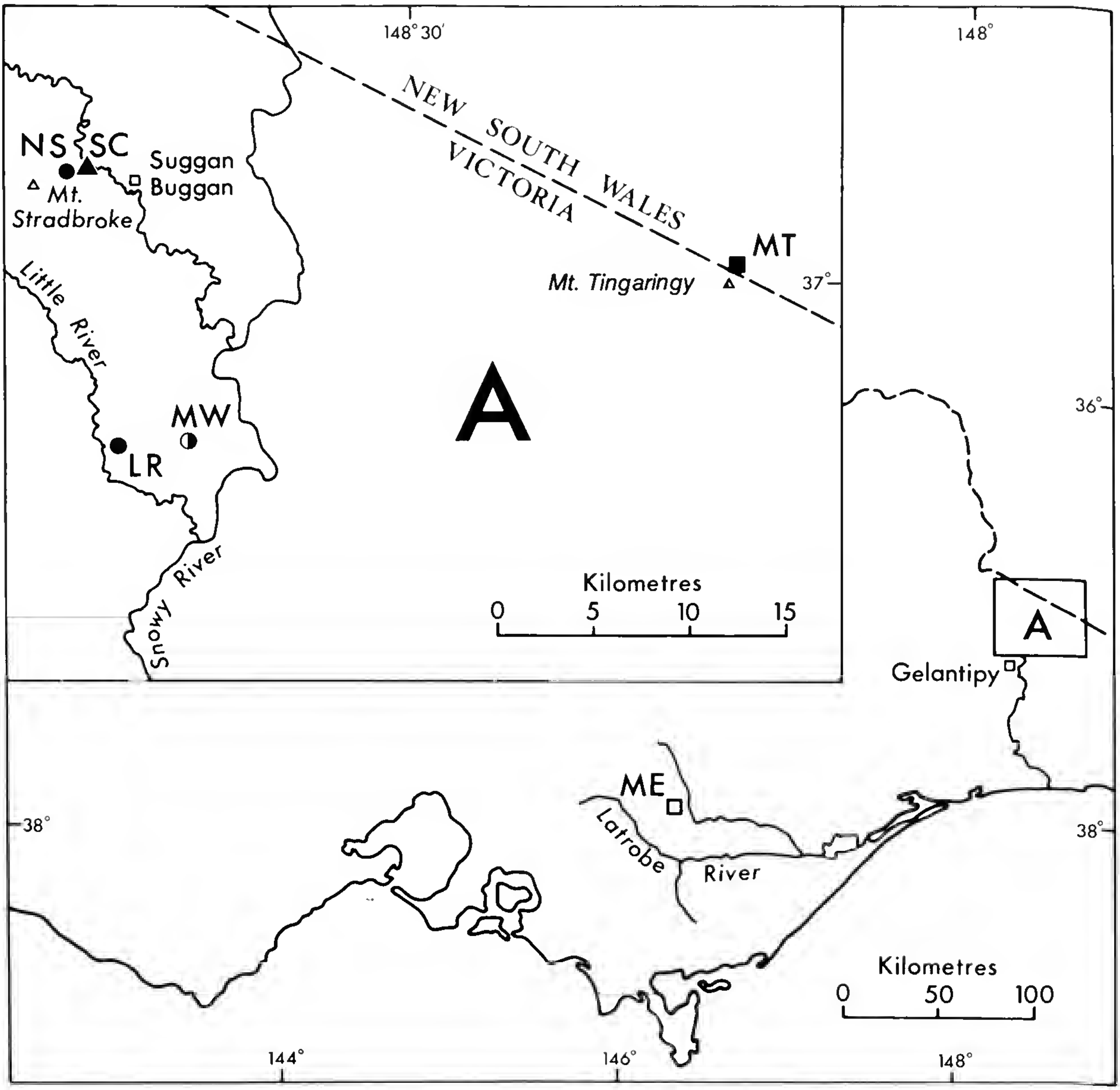

Fig. 1. The location of the sampled populations.

florescences, buds and fruits of populations NS, LR and MW, revealed *E. viminalis* and *E.* aff. *smithii* to be unlikely parents. The main piece of evidence that led to this conclusion was fruit size, as the fruits of trees in the three populations are invariably larger than those found on either *E. viminalis* or *E.* aff. *smithii*, and are also larger than all except the southern Victorian populations of *E. glaucescens*. To produce the buds and adult leaves found in the three populations *E. glaucescens* would be necessarily involved, thus necessitating another parent species with fruits larger than both *E. glaucescens* and the three populations. *E. globulus* ssp. *bicostata* fulfils this requirement. The nearest stand of *E. globulus* ssp. *pseudoglobulus* is at Gelantipy (Fig. 1) and as this taxon is generally confined to more equable climates than those found in the study area (Kirkpatrick 1975) and as its fruits are generally no larger than those of the three populations, it seemed a less likely parent than *E. globulus* ssp. *bicostata*. Thus, subsequent work was designed to test whether the three populations resulted from hybridization between *E. glaucescens* and *E. globulus* ssp. *bicostata*. Also considered was the role of *E.* aff. *smithii* in contributing to the variability of populations

TABLE 1

THE POPULATIONS SAMPLED

Symbol	*Taxon*	*Location*	*Associated taxa in same section*
NS	—	On steep slopes below Stradbroke Chasm	*E. glaucescens* (adjacent, not mixed), *E. viminalis, E. globulus* ssp. *bicostata*
MW	—	Rocky slopes near summit of Mt. Wheeler	*E.* aff. *smithii, E. viminalis* (adjacent, not mixed
LR	—	Southern edge of Little River Gorge near lookout	*E.* aff. *smithii*
ME	*E. glaucescens*	Southeastern slopes of Mt. Erica	*E. nitens* Maiden
MT	*E glaucescens*	Mt. Tingaringy	—
SC	*Eucalyptus globulus* ssp. *bicostata*	Alongside stream below Stradbroke Chasm	*E. viminalis*, population NS

LR and MW, as a few trees in these populations exhibited some intermediacy in the adult phenotype with this species.

METHODS

Adult Morphology: Collections of leaves, fruits, seed and buds when available were made from a variable number of trees (Table 2) from two populations of *E. glaucescens* (ME, MT), one population of *E. globulus* ssp. *bicostata* (SC) and populations NS, LR and MW. One tree of *E.* aff. *smithii* (SM) was sampled along with an apparent hybrid (LR2) between it and population LR. Sampling of all populations took place within areas less than 0.5 km in diameter.

To assess the range of variation within *E. glaucescens* specimens were obtained from the National Herbaria of New South Wales and Victoria, the Forest Research Institute Herbarium, and the Herbarium of the University of Tasmania, patterns of geographic variation in *E. globulus* having been already investigated (Kirkpatrick 1975). Twenty measurements per sampled tree or herbarium specimen were made of maximum fruit diameter, diameter at the calycine ring, fruit height, height of the fruit above the calycine ring, number of valves per fruit, and pedicel and peduncle length. The trees were classified using the polythetic agglomerative computer program HGROUP which groups on the basis of a generalized distance function (Vendman 1967). The attributes used were those shown in Table 2 with the exception of seed weight. The figures for each attribute were normalized prior to the classificatory process to ensure that each variable was equally weighted in the analysis.

The weight of fifty seeds from each collected specimen was measured on an electric balance. Population

TABLE 2

POPULATION MEANS AND COEFFICIENTS OF VARIATION FOR ADULT MORPHOLOGY

Character	SC(8)***		NS(11)		MW(13)		LR(10)		ME(9)		MT(10)	
	M*	CV**	M	CV	M	CV	M	CV	M	CV	M	CV
Maximum fruit diameter (mm)	16.2	7.7	12.1	7.3	10.3	10.9	9.5	7.75	8.9	6.6	7.0	5.8
Fruit height/maximum diameter	0.85	6.4	0.82	7.2	0.90	8.8	0.96	10.2	1.09	6.4	1.14	5.3
Maximum diameter/diameter at the calycine ring	1.00	0.0	1.00	0.0	1.00	0.0	1.00	0.0	1.13	5.3	1.05	2.6
Height of the fruit above the calycine ring (mm)	3.65	22.8	1.22	45.1	1.84	26.7	1.16	43.5	0.05	94.6	0.45	63.4
Pedicel height (mm)	0.0	0.0	0.32	57.0	0.60	41.1	0.33	118.5	0.25	67.4	0.24	28.4
No. of valves per fruit	3.91	4.1	3.89	6.9	4.01	3.8	3.93	5.8	3.29	5.3	3.21	5.1
Peduncle length (mm)	2.88	32.6	4.15	21.4	3.43	21.9	3.88	23.1	2.88	22.7	2.59	16.2
Weight of 50 seeds (g)	0.105	15.9	0.069	20.8	0.056	20.2	0.050	25.4	0.092	17.8	0.067	18.3

* Mean
** Coefficient of variation (%)
***Number of individuals in sample

means and coefficients of variation were calculated for seed weight and the characters used in the classificatory analysis.

Progeny Test: Seed from eight trees each of populations ME, MT, NS, LR, MW and SC and from one tree of *E.* aff. *smithii* and the apparent hybrid of *E.* aff. *smithii* and population LR were stratified for four weeks then placed in germinating dishes. The seed from most trees of ME and one tree of MT failed to germinate. Sixteen newly germinated seedlings per tree were planted in an equal mixture of sand and *Sphagnum* (one seedling per pot) in three totally randomized blocks in a heated glasshouse. Water and nutrients were held near optimum amounts at all times. After 12 weeks, seedling height, seedling length (many seedlings were prostrate), the number of leaf pairs, the number of secondary growth nodes, and the length and maximum breadth of one of the first, third and fifth leaf pairs above the cotyledons were measured. Tree means and coefficients of variation were calculated for the characters shown in Table 3.

RESULTS

Adult Morphology: The anomalous populations (NS, MW and LR) were completely intermediate between SC and the *E. glaucescens* populations (ME and MT) in maximum fruit diameter and height of the fruit above the calycine ring. In all other measured characters intermediacy was at least partially lacking (Table 2). Only in the ratio fruit height/maximum fruit diameter and in seed weight were the coefficients of variation for all three anomalous populations greater than those for both SC and the *E. glaucescens* populations (Table 2). Although tree means of *E. globulus, E. glaucescens* and the anomalous populations overlapped in most measured adult characters, a combination of characters could easily be used to separate the three groups of populations (Table 2).

The classificatory analysis placed all trees of *E. glaucescens* in a distinct group, in which the southern Victorian trees including population ME were concentrated in two of the groups at the ten group level of agglomeration (Fig. 3). The anomalous populations were fused into a small group which included the single specimen of *E.* aff. *smithii* and the supposed hybrid (LR2) of this species with population LR, and a larger group which included the single relatively small-fruited specimen of *E. globulus* ssp. *bicostata* apparent in Fig. 2. The remaining seven specimens of *E. globulus* formed a distinct group which amalgamated with the anomalous population group in the next to last fusion (Fig. 3).

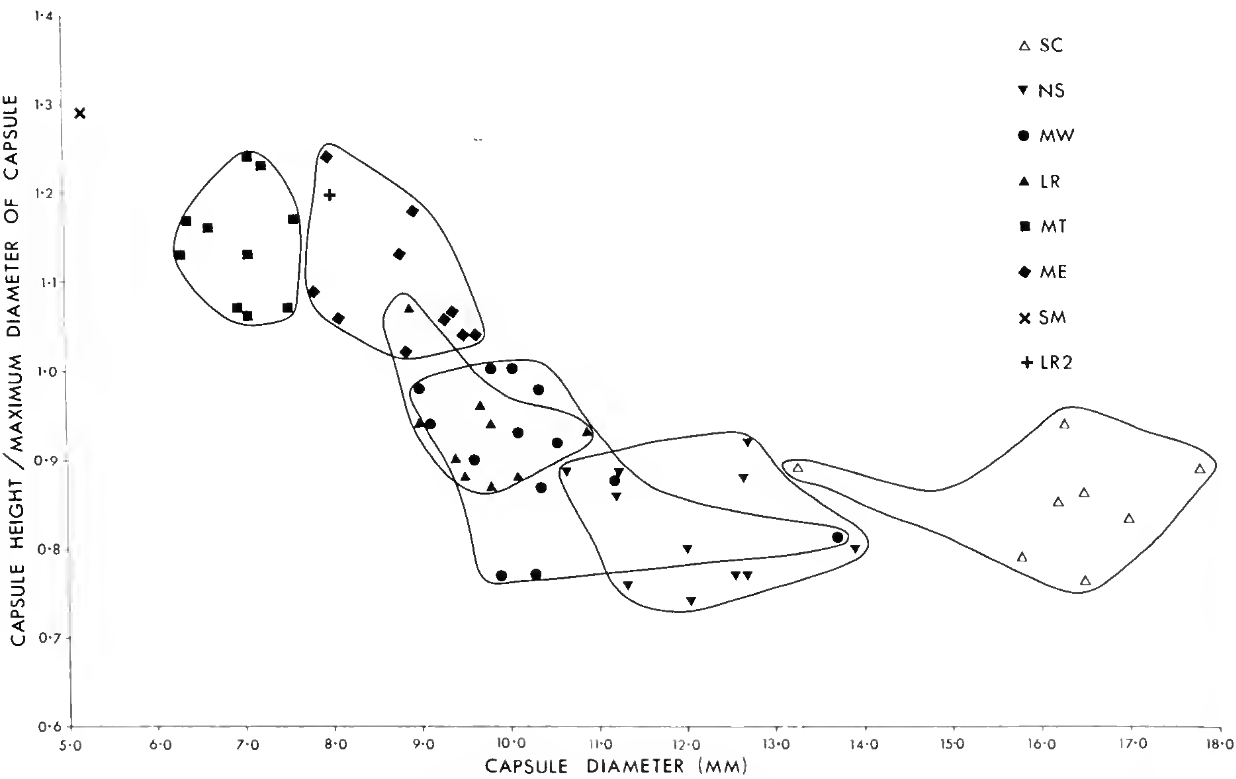

Fig. 2. Scatter diagram of tree means of maximum fruit diameter and fruit height/maximum fruit diameter.

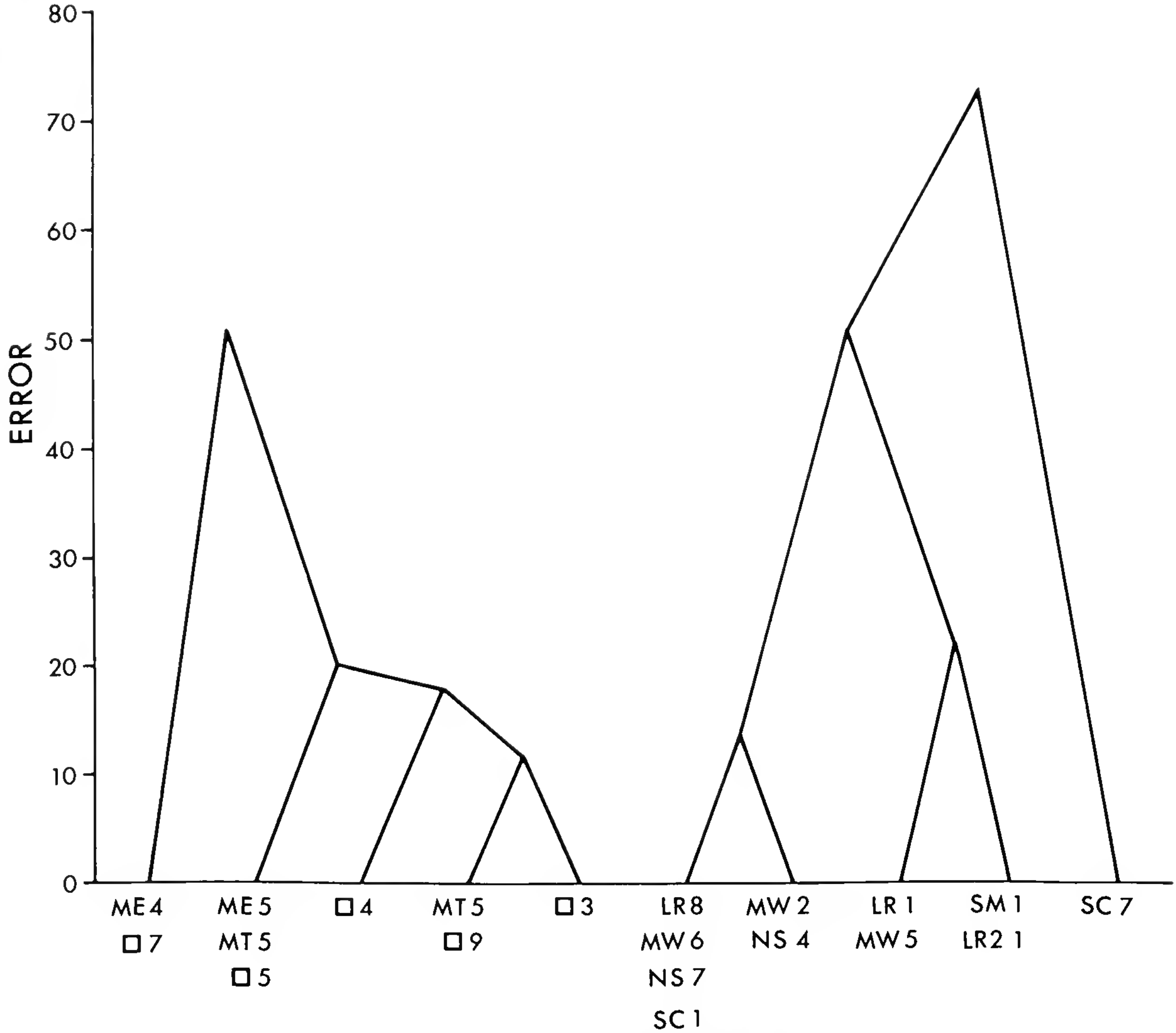

Fig. 3. Dendrogram from HGROUP analysis. Agglomeration is shown from the ten group level upward, the composition of each group being shown below the dendrogram. Empty squares symbolize herbarium specimens of *E. glaucescens*.

Progeny Test: The progeny of the anomalous populations proved to be intermediate between the progeny of population MT and the progeny of population SC in all but three growth characters (Table 3, Figs. 4, 5). The lack of intermediacy in these characters may be due to the experimental conditions being more suitable for these populations than for either MT or SC, and other experimental conditions could give different results.

The progeny of the supposed hybrid (LR2) between population LR and *E.* aff. *smithii* was intermediate between its putative parents in all characters except leaf length in the first pair above the cotyledons and the angle of the main stem with the ground surface (Table 3). The supposed hybrid progeny had higher coefficients of variation than either putative parents in all except four characters. In contrast, in only one character were the coefficients of variation of all three anomalous populations higher than those of both populations SC and MT, and in three characters the progeny of the three populations had coefficients of variation lower than both SC and MT (Table 3).

DISCUSSION

Although the anomalous populations are generally intermediate between *E. globulus* ssp. *bicostata* and *E. glaucescens* in their seedling characteristics, they are only partially intermediate between these two taxa in their adult morphology. NS, MW and LR are no more variable in adult and juvenile characteristics than

TABLE 3

CHARACTER MEANS AND MEAN COEFFICIENTS OF VARIATION FOR FIVE POPULATIONS AND THE PROGENY OF TWO TREES

Character	SC(8)*		NS(8)		MW(8)		LR(8)		MT(7)		LR2(1)		SM(1)	
	M**	CV***	M	CV	M	CV	M	CV	M	CV	M	CV	M	CV
Seedling length (cm)	16.5	*18.0*	23.4	*17.1*	26.1	*15.7*	25.3	*14.6*	17.3	*20.5*	25.2	*26.2*	22.0	*18.6*
Angle of main stem with ground surface (°)	87.8	*7.3*	44.4	*51.6*	48.4	*51.7*	43.7	*55.3*	32.8	*62.1*	65.8	*45.4*	56.3	*51.8*
No. of open leaf pairs	7.1	*13.3*	10.1	*10.8*	9.9	*12.2*	10.5	*12.0*	9.9	*14.1*	8.7	*14.4*	8.4	*9.0*
No. of secondary growth shoots	0.3	*199.3*	4.5	*46.9*	5.0	*49.1*	5.9	*48.0*	5.5	*42.4*	8.9	*35.9*	9.4	*40.3*
Leaf length 1st pair	3.9	*15.85*	2.3	*16.6*	2.6	*16.1*	2.5	*15.8*	2.0	*17.6*	2.9	*30.6*	2.4	*24.1*
Leaf length 3rd pair	7.1	*13.3*	3.0	*12.9*	3.3	*12.7*	3.1	*12.1*	2.8	*17.4*	4.0	*12.8*	4.3	*12.4*
Leaf length 5th pair	6.3	*17.4*	2.5	*14.6*	2.7	*15.5*	2.6	*19.7*	2.2	*20.8*	3.8	*17.3*	4.5	*21.8*
Leaf length/breadth 1st pr	3.4	*17.4*	1.9	*24.9*	2.1	*24.7*	2.4	*28.4*	1.9	*23.5*	3.0	*19.3*	3.5	*15.2*
Leaf length/breadth 3rd pr	2.6	*11.7*	1.1	*14.7*	1.2	*13.9*	1.4	*16.5*	1.0	*22.8*	2.2	*24.8*	2.8	*22.4*
Leaf length/breadth 5th pr	2.2	*15.2*	0.9	*11.6*	0.9	*10.3*	1.0	*14.7*	0.7	*19.7*	2.1	*29.0*	2.6	*24.3*

* No. of parent trees
** Mean
***Mean of coefficients of variation (%)

SC and MT. In fact, in juvenile characteristics, MT, the type population of *E. glaucescens,* was clearly the most variable of all populations included in the experiment.

LR2 was clearly intermediate between population LR and *E.* aff. *smithii,* and in most juvenile characters measured was more variable than either of its supposed parents. This intermediacy and high variability was also evident in characters not recorded in the results of this study. For instance, LR2 varied between 3 and 7 in flower number per inflorescence. Population LR has consistently three flowers per inflorescence and *E.* aff. *smithii* has seven flowers per inflorescence. Also, the progeny of *E.* aff. *smithii* was non-glaucous, that of LR was glaucous, and that of LR2 was mixed. Thus, there is extremely strong evidence that population LR and *E.* aff. *smithii* hybridize.

The contrast between the relatively high coefficients of variation found for LR2 and the relatively low coefficients of variation found for populations NS, MW and LR, and the lack of intermediacy in these populations recorded above, suggest that recent active hybridization is not occurring between *E. globulus* ssp. *bicostata* and *E. glaucescens* to produce the anomalous populations. However, there is some evidence to suggest that gene-exchange with contiguously occurring species has influenced the morphological characteristics of the three populations. Population NS is closer in most characteristics to *E. globulus* ssp. *bicostata* than MW or LR. Population LR is closer in most characteristics to *E.* aff. *smithii* than NS or MW. Population MW tends to be closer to *E.* aff. *smithii* than population NS, but its *E.* aff. *smithii* tendencies may have been tempered somewhat by gene-exchange with *E. viminalis*. Thus, the similarities of each of the three populations reflect the relative distributions of *E. globulus* ssp. *bicostata, E.* aff. *smithii* and *E. viminalis* (Table 1).

The mode of origin of the anomalous populations is uncertain. The likelihood that the three populations evolved through selection from *E. glaucescens* seems low, given the overall similarity of their environments. However, they may be the remnants of a stabilized hybrid swarm of *E. globulus* and *E. glaucescens* further influenced by gene-exchange with *E. viminalis* and *E.* aff. *smithii*. Alternatively, NW, MW and LR may be relic stands of a formerly more extensively distributed species, stranded on a few steep rocky slopes in the course of climatic change.

Although the three populations differ somewhat in their morphological characteristics, they can be easily distinguished as a group from all closely related populations, they breed true, and each population has a spatial reality. Thus, taxonomically they are best re-

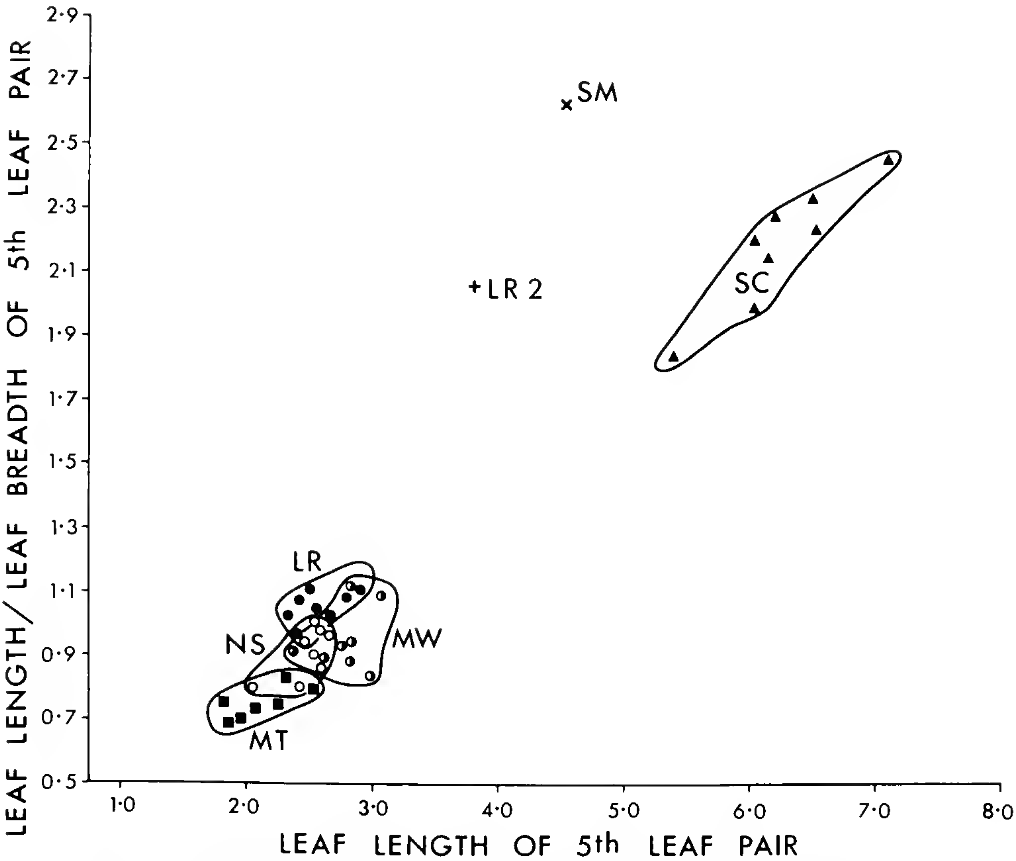

Fig. 4. Scatter diagram of means of leaf length in the fifth leaf pair above the cotyledon and leaf length/leaf breadth in the fifth leaf pair.

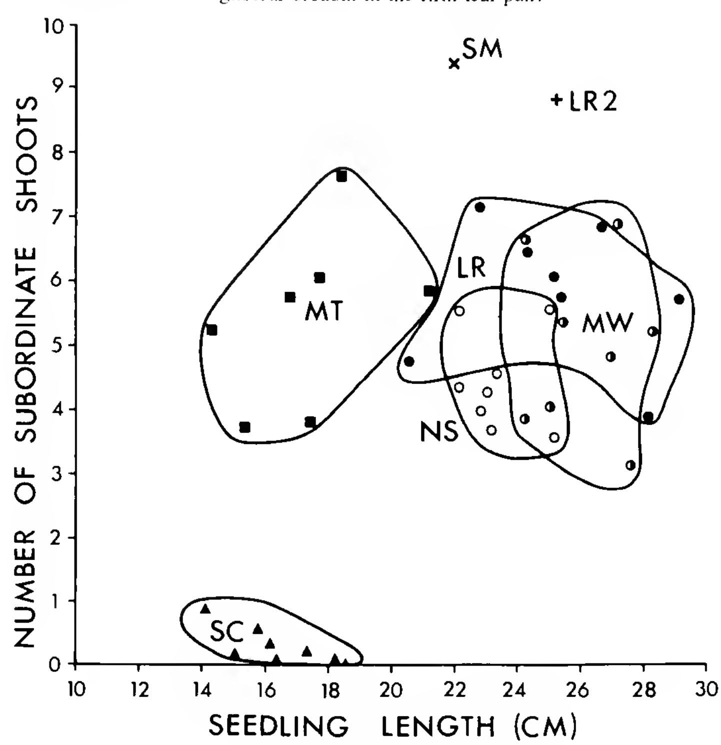

Fig. 5. Scatter diagram of means of number of subordinate shoots and seedling length.

garded as three populations of an undescribed species. This species is to be formally described elsewhere (Kirkpatrick & Brooker 1977).

ACKNOWLEDGEMENTS

I gratefully acknowledge the help of Bob Parsons, Trevor Whiffin, Lou Costello in the collection of material, and the Forest Research Institute (now the CSIRO Division of Forest Research) for botanical specimens, seed collection and glasshouse facilities at Hobart.

REFERENCES

KIRKPATRICK, J. B. 1975 *Geographical variation in* Eucalyptus globulus *Labill. Australia Forestry and Timber Bureau Bulletin No. 47.*

KIRKPATRICK, J. B. & BROOKER, M. I. H., 1977. A new species of *Eucalyptus* from north-eastern Victoria. *Aust. For. Res.* (in press).

KIRKPATRICK, J. B., SIMMONS, D. & PARSONS, R. F., 1973. The relationship of some populations involving *Eucalyptus cypellocarpa* and *E. globulus* to the problem of phantom hybrids. *New Phytol.* 72: 867-876.

PARSONS, R. F. & KIRKPATRICK, J. B., 1972. Possible phantom hybrids in *Eucalyptus*. *Ibid.*, 71: 1213-1219.

PRYOR, L. D., 1951. A genetic analysis of some *Eucalyptus* species. *Proc. Linn. Soc. N.S.W.* 76: 140-147.

————, 1962. The validity of taxonomic categories in the assessment of evolutionary trends within the genus *Eucalyptus*. In *The evolution of living organisms*. A symposium of the Royal Society of Victoria held in Melbourne, December, 1959, 446-455.

PRYOR, L. D. & JOHNSON, L.A.S., 1971. *A classification of the eucalypts*. Australian National University, Canberra.

VELDMAN, D. J., 1967. *Fortran programming for the behavioural sciences*. Holt, Rinehard and Winston, New York.

WILLIS, J. H. 1972. *A handbook to plants in Victoria. Volume II Dicotyledons*. Melbourne University Press, Carlton.

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1976

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ABRIDGED REPORT OF THE COUNCIL

FOR THE YEAR ENDING 11 MARCH, 1976

MEETINGS AND LECTURES

During the year, ten Ordinary and one Special Meeting were held.

MARCH 13—Following the Annual General Meeting, the retiring President Sir Robert Blackwood delivered his Presidential Address, *'Ankor Wat and associated archaeological sites in Thailand'*.

APRIL 10—Medal Lecture: *'The Nature of Leukaemia'*. Dr. D. Metcalf.

MAY 8—Medal Lecture: *'Animal Photoreceptor Optics'*. Dr. A. W. Snyder.

JUNE 12—Joint Meeting with the Australian Institute of International Affairs, Victorian Branch: *'International Aspects of Atomic Energy'*. Mr. K. S. Alder.

JULY 10—*'Opal–and Opal'*. Dr. E. R. Segnit.

AUGUST 14—*'Energy Conservation in Buildings'*. Mr. E. R. Ballantyne.

SEPTEMBER 11—*'The Formation of the Broken Hill Orebody'*. Professor B. E. Hobbs.

OCTOBER 9—Symposium: *The Otway Region*. J. G. Douglas, G. J. Medwell, E. D. Gill, D. J. Linforth, A. Pitt, R. F. Parsons, B. D. Williams, R. D. Cowley, A. Thornley, B. J. Smith, K. Norris and P. A. Rawlinson.

OCTOBER 28—Special Meeting: *Alfred Russel Wallace*. Professor R. E. Bernstein of the South African Institute for Medical Research.

NOVEMBER 13—Soiree: Film, *A Bay in the Balance*. Exhibits were provided by the National Museum of Victoria, the Westernport Bay Environmental Study Group, the School of Earth Sciences, University of Melbourne, the Department of Physical Chemistry, La Trobe University, CSIRO, Division of Chemical Physics and ICI Australia Ltd.

DECEMBER 4—*'Climate–The Atmosphere as a Heat Engine'*. Dr. J. S. A. Green.

MEMBERSHIP *at 1st January 1976:*

Honorary Life Members 5, Life Members 40, Members 539, Associates 65. Total, 649.

Council recorded with regret the deaths of Dr. G. Baker (Life Member), Dr. R. A. Dungan, Mr. D. G. Moye, Mr. J. A. Ritchie and Mrs. K. M. Sherrard (Life Member).

GEORGE BAKER, D.Sc., was born in Coventry, England, on October 10, 1908 and died at Mount Eliza, Victoria, on August 29, 1975.

His scientific career began when he was selected as junior assistant at the Geology School, University of Melbourne, where he was to work for the next 43 years (April 1925-August 1968), although from 1948 he was an employee of CSIRO. He published some 135 papers and monographs on mineralogy and related subjects. His M.Sc. was granted for his research on the petrology of the You Yangs, and his D.Sc. for his outstanding investigation of Tektites (1956). His monograph on Australites was published as Memoir 23 of the National Museum of Victoria where he was Honorary Associate in Mineralogy. He shared the Syme Prize in 1944 and received this Society's first Research Medal (established at the Society's Centenary, 1959). In 1967 he was awarded a Nuffield Special Grant to study tektites in England.

Dr. Baker was a Fellow of the Mineralogical Society of America and of the Meteoritical Society, a Life Member of the American Geophysical Union, of the Mineralogical Society of Great Britain and of this Society. He was Commissioner for Australia of the Internation Committee on Meteorites.

KATHLEEN SHERRARD, M.Sc., died in Sydney on 21st August, 1975 at the age of 77. The only daughter of Dr. and Mrs. John McInerny of North Carlton, she graduated at the University of Melbourne, B.Sc. in 1918 and M.Sc. in 1921, majoring in Chemistry and Geology. She joined the staff of the Geology School under Professor Skeats as Demonstrator and later as Assistant Lecturer in Petrology. In 1928 she married Howard Sherrard and went to Sydney to live. She became interested in palaeontology and undertook research on graptolites. She published 15 scientific papers including 4 in the Society's *Proceedings*. At Cambridge in 1926 she studied crystallography under Professor Hutchinson and in 1950 she worked on graptolites under Miss Ellis. In Moscow in 1963 she discussed graptolites with Dr. Galino Lyaschenko. In 1967 she studied fossil collections in Pekin, and 1968 she attended the International Geological Congress in Prague.

She joined the Society 1918 and became a Life Member 1972. She was a member of the Palaeontological Society of London, of the Linnaean Society and the Royal Society of New South Wales and of the Geological Society of Australia. She was closely associated with women's activities, her interest being in disabilities, status and independence of women.

Congratulations. Council congratulates the following Members who were honoured during the year: Sir Lindesay Clark, Companion, Order of Australia; Dr. P. G. Law, Officer, Order of Australia; Mr. G. M. Pizzey, Member, Order of Australia; Dr. R. Southby, Officer, Order of the British Empire; Mr. Neil Douglas, Member, Order of the British Empire; Dr. D. W. Connell, who was awarded a Churchill Fellowship.

PROCEEDINGS

During the year the Society published Volume 87 (Parts 1 and 2 in one cover) at a net cost of $10,505 after receipt by the printer of $3247 Book Bounty. Council acknowledges with gratitude an increased grant from the Victorian Government and a grant from the University of Melbourne towards the cost of publication.

LIBRARY

2567 volumes and parts were received during the year, mainly from exchanges with 62 Australian and 267 overseas organizations. Members contributed $184 towards the cost of binding, and 83 volumes were bound at a cost of $595. 546 items were borrowed from the Library (565 in 1974).

HALL

In addition to the Society and the Royal College of Obstetricians and Gynaecologists, 22 professional and other bodies held 113 meetings on the premises, compared with 92 meetings by 16 bodies in 1974.

Plasterwork at the southern end of the Lecture Hall and Library was repaired at a cost of $582.

FINANCIAL STATEMENT

The form of the *Statement of Income and Expenditure* has been modified to indicate the cost of operation of the Library, which is built up almost entirely from publications received in exchange for 335 copies of each issue of *Proceedings*. The Cudmore Bequest was made specifically to enable the Society to retain the services of a professional librarian.

ACKNOWLEDGEMENTS

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J. D. MORRISON,
President.

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