TRIASSIC PALAEOSOLS IN THE UPPER NARRABEEN GROUP OF NEW SOUTH WALES. PART II: CLASSIFICATION AND RECONSTRUCTION

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(With 1 Table and 10 Figures)

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ABSTRACT

Detailed study of palaeosols in the sea cliffs between Long Reef and Palm Beach, north of Sydney, has given a much clearer idea of the environment and climate of the area during the late Scythian to early Anisian portion of Triassic time.

At the base of the exposed succession, kaolinitic clayey soils with red *B* horizons were formed on volcanogenic sediments derived from the old Gerringong volcanic ridge to the east. The red Bald Hill Claystone consists largely of soil material, both in place and resorted. These were grey-brown podzolic soils (ferrods) formed on well-drained sites under coniferous forest. Humic gleys (fibrists) within the overlying Garie Formation were probably lowland catenary equivalents formed under *Dicroidium, Voltziopsis*, and equisetalean swamp woodland.

These soils were drowned by the relative rise of the Narrabeen lagoonal complex and the concomitant southward growth of sediments of the Gosford Delta. These sediments formed the lower Newport Formation, of clean quartz-lithic sandstone and grey kaolinite-illite shale, derived from an extensive source land to the north and west. The most widespread soils in the delta were gleyed podzolic soils (aquods) under *Dicroidium* heath. Younger soils of a similar type (alluvial soils or aquents) also supported *Dicroidium* heath in low-lying areas and *Pleuromeia* meadows in interdistributary bays. On slightly more elevated areas a more oxidized gleyed podzolic soil (ochrept) developed. On clayey levees, grey clay soils (fluvents) formed under a *Dicroidium* flora locally dominated by *Taeniopteris lentriculiformis*.

Few palaeosols are preserved in the upper Newport Formation and Hawkesbury Sandstone because of the more frequent channel reworking of the floodplain during their deposition.

The dominance of podzols is compatible with a cool temperate climate.

INTRODUCTION

A uniformitarian approach to palaeosol studies may be very helpful in reconstructing the past. Each recognizable palaeosol type and its associated fossil flora, when classified and reconstructed, may furnish a clear and detailed impression of past environments.

Brewer, Crook & Speight (1970) have made several recommendations for the stratigraphic use of palaeosols. However, my principle aim here is to classify palaeosol types for environmental interpretation. The Working Group on the Origin and Nature of Palaeosols (1971) has recommended that palaeosol nomenclature parallel that of modern science as closely as possible. I have here followed their philosophy in an unorthodox way by using the USDA soil-mapping groupings into associations, series, types, phases, and variants (Buol, Hole & McCracken, 1973). These names should be clearly indicated as palaeosols wherever there is any possibility of confusion with rock units or modern soils.

This system has several advantages. The palaeosols may be interpreted at various conceptual levels within the hierarchy. A separate name may be given to any individual palaeosol. The names are not interpretative and not dependent on modern soil classifications, whose criteria may not always be applied to palaeosols or be unequivocally distinguished from diagenetic modifications. The units of classification are already defined and accepted by modern soil scientists.

Here I apply this system to the palaeosols in sea-cliff exposures of the upper Narrabeen Group between Long Reef and Palm Beach, north of Sydney, whose various features I described in a previous paper (Retallack, 1977). The descriptions of the palaeosols are based on terminology from various sources. Brewer (1964) was used for soil micromorphology, but USDA Handbook 18 (Soil Survey Staff, 1951, 1962) for macroscopic descriptions of mottling, soil horizons, and peds. Palaeosol names follow the textural classes of USDA Handbook 18,

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TABLE

Grain size distributions of upper Narrabeen Group palaeosols by point counting of thin sections

	sand	silt	clay
Long Reef Clay			
A_2	2	5	93
B_{11r}	16	10	74
B_{31r}	2	5	93
Turimetta clay			
O	21*	6†	73
A_2	13**	1†	86
B & A	27**	4†	69
C	2**	37	61
Turimetta clay sandy variant			
O	0	8	92
Avalon silt loam			
A_2	6	69	25
B_{2t}	0	14	86
B_{3hir}	0	5	95
C	0	8	92
C	2	23	75
Avalon silt loam thick surface phase			
A_2	0	74	26
Avalon silty clay loam			
A_2	14	52	34
Warriewood clay loam			
A_2	27	35	38
B_t	20	13	67
Warriewood silty clay loam			
A_2	1	61	38
St Michaels silty clay loam			
A_2	1	71	28
B_{2t}	12**	41	47
St Michaels sandy loam			
A_2	63	18	19
St Michaels clay			
A_2	0	9	91
South Head clay			
AC (upper)	0	6	94
AC (lower)	0	9	91
C	0	4	96

Symbols: **sphaerosiderite only, † some siderite crystals, * some faecal pellets.

but otherwise standard rock names and Wentworth size grades (Folk, 1968) are used. All percentage estimates of rock components are based on point counting of thin sections (*e.g.* Table). Colours of fresh rock were taken from the Munsell Soil Colour Charts (Munsell Colour Co. Inc., 1954). Fossil locality numbers registered in the Geology Department, University of New England, Armidale, are prefixed by UNEL, and rock specimens and thin sections are stored under the numbers UNER 27987 to UNER28032 and UNER35270 to UNER35357. Military grid references of localities, prefixed by BB, are from the 1:63 360 'Broken Bay' map.

Detailed descriptions of the type profiles of the various palaeosols named here may be obtained by writing to the Geology Department, University of New England.

LONG REEF PALAEOSOL ASSOCIATION

Definition. Palaeosols with clayey hematite and kaolinite, red-coloured *B* horizons. In the Pittwater area they occur in the Bald Hill Claystone and Garie Formation.

Palaeotopography. The petrography of clasts, mineralogy, palaeocurrents, isopachs, and heavy minerals of the Bald Hill Claystone and the Garie Formation, indicate that they were derived from a highly weathered basic to intermediate volcanic terrain to the east (Loughnan, 1963; Goldbery & Holland, 1973; Loughnan, Ko Ko & Bayliss, 1964; Culey, 1938). This was probably a northern extension of the Gerringong Volcanics (Leitch, 1969; Raam, 1969), which can be traced northeast of Wollongong in offshore magnetic anomalies (Ringis, Hawkins & Seedsman, 1970; Mayne *et al.*, 1974). The Gerringong Volcanics have yielded isotopic dates of 240 to 252 m.y. (Mayne *et al.*, 1974, p. 86). The Bald Hill Claystone and Garie Formation are late Scythian to early Anisian in age (Helby, 1969), and contain a fossil flora older than that found near Nymboida, N.S.W., dated at 211 m.y. (Retallack, Gould & Runnegar, in press). So the old volcanic ridge was probably about 20 m.y. old when the Bald Hill Claystone was deposited. This ridge was the source area for most of the middle Narrabeen Group sediments (Ward, 1972), but was never an active eastern source area after the deposition of the Garie Formation. This and the pronounced magnetic anomalies (Ringis *et al.*, 1970), suggest that the source area was a low undulating ridge with scattered tall plugs. The Long Reef Palaeosol Association was probably formed on its lower western flanks.

Acritarchs, forams, and holothurian sclerites in the middle Narrabeen Group (Mayne *et al.*, 1974, p. 207) suggest that the Eopacific Ocean (of Carey, 1970) was probably only a short distance east of the volcanic ridge and intermittently connected with the depositional basin.

Parent material. The Gerringong Volcanics south of Wollongong consist largely of volcanic sandstones containing Permian marine fossils and latite flows which thin westward. This material, relatively unmodified by chemical weathering, provided the grey-green lithic sandstone found within the Bald Hill Claystone, the Garie Formation, and much of the middle Narrabeen Group. Red sandstone in the Gerringong Volcanics indicates subaerial weathering of this material even in the Permian (Bowman, 1970). Red clay pedoliths in the upper Bulgo Sandstone also suggest that some of the parent material of the Long Reef Palaeosol Association was resorted soil.

The source area soils may have been similar to the Long Reef Palaeosol Association or perhaps were krasnozems and red and yellow prairie soils similar to those developing on the Gerringong Volcanics today (Walker, 1960). The upper portion of a modern soil developing on the Bumbo Latite of the Gerringong Volcanics (Craig & Loughnan, 1964), is chemically and mineralogically similar to palaeosols of the Long Reef Palaeosol Association. Loughnan (1963) maintains that there were laterites in the source area. This is possible, but the evidence of dominantly kaolinitic mineralogy and sporadic oolites, pisolites, and boehmite is insuffi-

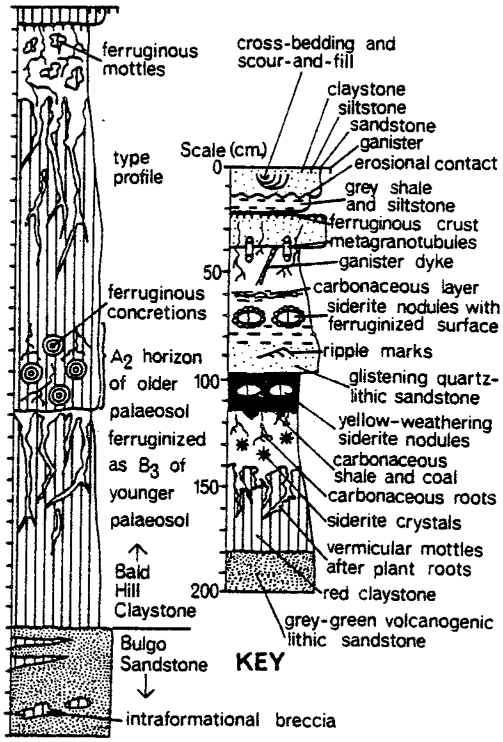

Fig. 1. Profiles of Long Reef Palaeosol Series and key to this and ensuing profiles.

Fig. 2. Superimposed palaeosols of Long Reef Reef Palaeosol Series in Long Reef southeast wall (faint figure on top of cliff gives scale).

cient. These features may be found in a variety of different soil types (see Grim, 1968, p. 515; Millot, 1970; Stace *et al.*, 1968).

Long Reef Palaeosol Series (Uf2, grey-brown podzolic, ferrod)

Diagnosis. Predominantly red clayey palaeosols with a sporadically bleached grey clay A_2 horizon.

Type example. The Long Reef clay palaeosol, 2 m above the rock platform, 200 m southwest of the easternmost littoral talus on the point at Long Reef (BB322319, Fig. 1). This is the second profile above the grey-green sandstone of the rock platform. It has the most conspicuous and thickest leached *A* horizon of the palaeosols at Long Reef. It is truncated by a fault to the southeast and eroded away and covered by sand and littoral talus to the north.

The distriubtion of sand in the profile (Table) is probably a relict of an upward-fining point-bar or crevasse splay deposit over an earlier soil. The micromorphology of the $B_{3ir,o}$ indicates that it was the A_2 of an older soil oxidized in the formation of the type profile.

Further examples. The Bald Hill Claystone north of Garie beach and at Long Reef contains at least eight superimposed palaeosols of this type (see Hanlon, 1956). The exact number of palaeosols is difficult to assess as the upper horizons are usually eroded away and the palaeosols overlap to a varying extent. The palaeosols weather out in steps (Fig. 2). The upper portions weather to a low-angled ledge of pebble-size interlayered claystone pillows overlying progressively more resistant lower portions and strongly outcropping red pedolith or grey-green lithic sandstone *C* horizons. Claystone from the A_2 horizon of the type example placed in tap water for 12 hours disintegrates to clay and fine aggregate up to 5 mm in size. Similar treatment of lower horizons gives progressively larger aggregates down the profile. This behaviour is not nearly as marked in other palaeosols of the Pittwater area, which have a generally higher organic content (a relationship also found in modern soils by Marshall, 1962).

The Long Reef clay nodular variant palaeosol, low in the middle of Long Reef southeast wall, is possibly equivalent to the type example although separated by faulting. It has a similar A_2 horizon but with a prominent irregular network of lamellar ferri-argillans and common hard irregular ferric mottles and round concretions up to 3 cm in diameter. In thin section highly sinuous neoferri-organans, as well as the argillans, are set in a porphyroskelic vomasepic plasmic fabric.

Jointing and tessellated pavements may give the false impression of prismatic beds in the *B* horizons of Long Reef clay palaeosols. No subcutans or cutans could be seen in thin sections across the joints. One joint, and a small boxwork system of associated fissures, were filled with a white mineral quite different from soil material. This prismatic structure is probably tectonic jointing, as suggested by Roeschmann (1971) for German Wurzelböden.

Reconstructed soil. The original soil had a weak texture contrast. There was no or little A_0. The A_1 was a thin sandy surface crust with shallow cracks into the A_2. The A_2 was greyish with subangular blocky peds, low organic content and ferric mottles and concretions. The *B* horizons had a relict sandy texture. They were apedal and heavily ferruginized, but probably only light brownish in colour (since inverted to hematite).

Stratigraphic distribution. Eroded palaeosols of this type form much of the Bald Hill Claystone at Long Reef and also in the road cuttings and sea cliffs between Garie beach and Stanwell Park on the south coast. The lowest palaeosol in the Bald Hill Claystone north of Garie beach also shows a well developed A_2 horizon like the type example at Long Reef. I have not seen palaeosols of this type in the laterally equivalent Wentworth Falls Claystone Member of the Banks Wall Sandstone (Bembrick & Holland, 1972; Goldbery & Holland, 1973; Mayne *et al.*, 1974), either beside the track near Wentworth Falls or near the car park at Mt Piddington.

Parent material. The parent material is the grey-green sandstone interbedded with the palaeosols, which consists of clastic grains similar in thin section to those within the profiles. The lowest sandstone of this type in the platform at Long Reef is probably the top of the Bulgo Sandstone (Ward, 1972), of which several petrographic descriptions are available (Loughnan, 1963; David, 1889). At Long Reef these are medium to coarse sandstones, largely of rounded, variably devitrified, volcanic and cryptotonstein grains, many with oxidized surfaces.

However, many of the palaeosols have developed on older soils and resorted soil material. The type Long Reef clay formed partly over an older soil, whose *A* horizon is within its lower *B* horizon. Some contribution of resorted soil material is indicated by the large epsilon cross-set (*sensu* Allen, 1963) low in the cliff and on the rock platform below the type Long Reef clay, in which there are alternating layers of grey-green lithic sandstone and red pedogenic claystone.

Palaeobotany. Palaeosols and sedimentary rocks of the Bald Hill Claystone are marked by an almost total lack of recognizable macroscopic fossil plant remains. The *Dicroidium*-dominated taphoflora (Walkom, 1925; Burges, 1935; Retallack, 1973) thrived both before and after the deposition of the Bald Hill Claystone with no perceptible modification. It is abundantly preserved in a grey claystone near the base of the Bald Hill Claystone north of Garie beach (UNEL1566; see Ward, 1972, pl. 24, fig. 3) and in the Garie and Newport Formations at many localities (UNEL 1376 to UNEL1469) between Long Reef and Palm Beach; and was also reported above and below the Bald Hill Claystone in the second Cremorne bore (Pittman, 1894; Etheridge, 1893) and the Birthday Shaft (Dun, 1908).

However, Helby (1973) records remarkably low amounts of *Falcisporites* (*Dicroidium* pollen) but relatively abundant *Lunatisporites* and *Protohaploxypinus* (coniferous pollen) from within the Bald Hill Claystone. This indicates that the Long Reef clays were developed under coniferous forest producing pollen similar to that found in the middle Narrabeen Group. The foliage of these conifers was probably of the *Voltziopsis* and *'Brachyphyllum' s.l.* type and the wood of the type described by Baker (1931) and Burges (1935).

Fragmentary shoots of the *'Brachyphyllum' s.l.* type are similar to Sydney Basin Permian *Walkomiella australis* (Feistmantel) Florin 1944, but have broader and almost mucronate leaves. They have been found in the middle Narrabeen Group at Thelma Head, south of Garie beach (UNEL 1567), ELECOM Wyong DDH4 (Australian Museum specimen AMF51456), second Cremorne bore (Etheridge, 1893), and possibly also from the Garie Formation at Turimetta Head (Helby & Martin, 1965, fig. 6). *Voltziopsis* (Townrow, 1967) occurs in the lowest Narrabeen Group of Late Permian age and not far above the Bald Hill Claystone at Bungan (UNEL1417) and Turimetta Heads (UNEL1449).

So the Long Reef Palaeosol Series supported coniferous forest fringed and only partly mixed with *Dicroidium* vegetation in more poorly drained areas.

Palaeotopography. The sepic plasmic fabrics, surface crust and cracking, granular and blocky peds, collapsed clay illuviated root channels, and predominance of iron as ferric minerals suggest that these soils were well drained. They probably formed on low undulating country.

The eight closely superimposed palaeosols forming the Bald Hill Claystone, suggest that base level remained relatively low for a long time. Taking 2000 years as a conservative estimate for the formation of a mature podzolic soil (Buol *et al.*, 1973, p. 254), the Bald Hill Claystone probably took at least 16 000 years to form.

Classification. The Long Reef Series palaeosols have a Uf2 PPF (of Northcote, 1974). There is not sufficient evidence for seasonal cracking.

In the classification of Stace *et al.* (1968), they are a marginal variety of grey-brown podzolic, with a weak texture contrast, grey *A* and brown *B* horizons. Ferric nodules in the *A* horizon are common in soils of this type (*e.g.* Hendricks *et al.*, 1962). They are distinguished from the red and yellow podzolic soils, solonetz, solod, and soloth by lacking a strongly differentiated clayey *B* horizon. The solonetz, solod, and soloth also have a more abrupt boundary between *A* and *B* horizons, a more bleached A_2 and domed columnar peds in the *B* horizon. Red and yellow podzolics are ferruginized throughout the solum.

In the USDA system (Soil Survey Staff, 1960; Buol *et al.*, 1973) these palaeosols have a diagnostic ochric epipedon and spodic horizon and a non-diagnostic paralithic contact and albic horizon. As they have up to 14.49% Fe_2O_3 + FeO (Retallack, 1977, table I) they are ferrods.

Modern soils of this type are developed under coniferous and deciduous broadleaf forest in cool temperate climates of the northern hemisphere (McFee & Stone, 1965; Moss & St Arnaud, 1955) and under sclerophyll woodland in cool temperate Australia (Stace *et al.*, 1968). They form on hilly

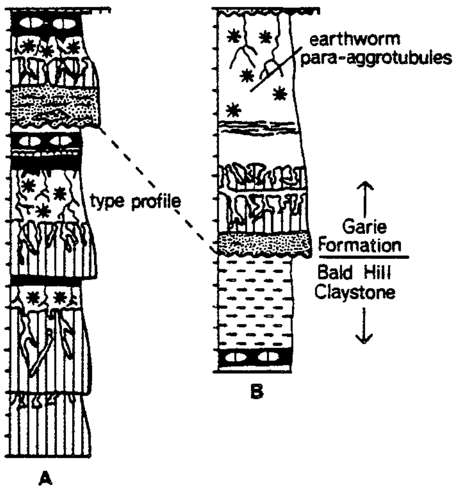

Fig. 3. Profiles of Turimetta Palaeosol Series. A, type Turimetta clay palaeosol overlain by Turimetta clay sandy variant palaeosol near sewer outlet at Turimetta Head. B, Turimetta clay slightly eroded phase south of Bilgola beach.

upland sites with well drained moderate to gentle slopes. About 2000 years seems to be a reasonable time for such a soil to form (Buol *et al.*, 1973).

Turimetta Palaeosol Series (O, humic gley, fibrist)

Diagnosis. Sideritic clay palaeosols with thick organic horizon, grey A_2 and red vermicular mottled *B* horizons.

Type example. The Turimetta clay, the second palaeosol above the more massive red claystone, 3.1 to 3.9 m above the rock platform in the eastern end of Turimetta Head southeast wall. The type profile is taken from the low cliff above the cement and rubble over the sewer outflow pipe at BB320365 (Fig. 3A). The Turimetta clay palaeosol is traceable throughout the southeast wall of Turimetta Head. Its organic horizon is well exposed on the rock platform 100 m south of the type profile and its lower horizons farther south. Near the centre of the southeast wall the mottled *B* horizon contains a large, grey (N5), sideritic-clay nodule 25 cm in diameter, with a distinct reduced halo, possibly infilling a cradle knoll, burrow, tree trunk or root cast. The palaeosol may be laterally equivalent to that near the top of the Bald Hill Claystone north of Mona Vale beach and perhaps with part of the palaeosols low in the cliffs south of Bilgola and north of Avalon beach.

Further examples. Immediately above the type example, the sandy variant of the Turimetta clay palaeosol (Fig. 3A) is developed on a ripple-drift cross-laminated lithic sandstone, the base of which is taken as the base of the Garie Formation (Retallack, 1973). The profile has two thin purple mottled horizons in the centre of the southeast wall. The lower mottled horizon contains a grey, sideritic-clay nodule, measuring 7.2 by 12 by 38 cm, similar to the one in the type Turimetta clay palaeosol there.

Three more very thin and poorly differentiated palaeosols or pedoliths of this type overlie the sandy variant near Turimetta point. South of the centre of the southeast wall they have been eroded away and replaced by grey kaolinitic claystone and shale with a brecciated base.

The slightly eroded phase of the Turimetta clay palaeosol south of Bilgola beach (BB333423) is a very thick palaeosol of this type (Fig. 3B). It is largely inundulic clay, but some sedimentary relict sandy layers have skelinsepic and vomasepic porphyroskelic plasmic fabric. Some carbonaceous layers in the profile are probably also sedimentary relicts. Red para-aggrotubules (earthworm burrows) occur in the upper layers of this palaeosol. The lower red mottled horizon is probably a pedorelict of an older soil forming level.

Reconstructed soil. The original soil probably had a thick peaty organic horizon of plant material, fine sand, and faecal pellets, attesting a rich soil fauna, overlying heavy clay mineral horizons. A blue-green A_2 graded down into an increasingly mottled *B* horizon away from plant roots. The red mottles were probably yellow or brown before diagenesis. The siderite mineralization is probably not entirely original but formed when the palaeosol was the *C* horizon of the overlying soil.

Stratigraphic distribution. These palaeosols are characteristic of the Garie Formation and upper Bald Hill Claystone in the Pittwater area. However, the Garie Formation north of Garie beach (Hanlon, 1956; Loughnan, 1962, 1969, 1970) does not contain palaeosols of this type, but is largely composed of graded pedoliths, in 50-80 cm upward-fining sets of cryptotonstein breccia and cutanized, fine, granular peds ('oolites' of Loughnan, 1970).

Parent material. The bright red siltstone *C* horizon of the type example is the only red pedolith associated with Turimetta Series palaesols. They were probably largely formed on drab sandstones and shales similar to those common below the Bald Hill Claystone.

Palaeobotany. The organic horizon of the type example contains contains much amorphous and finely fragmented plant material. In a rock platform exposure of this horizon (UNEL1440) there are some identifiable fragments of *Dicroidium zuberi* (Szajnocha) Archangelsky 1968, large seeds of a type commonly associated with this species, further seeds of a different type and a log, tapering from 6.11 to 1.17 cm over a length of 4.17 m and showing a single branch base near the top. The lower clayey layers of the organic horizon contain abundant *Neocalamites* in places. A kaolinitic claystone above the Turimetta clay sandy variant at the southern end of Turimetta Head southeast wall (UNEL1449) contains lycopod leaves, *Neocalamites*, *Lepidopteris*, *Voltziopsis*, *Dicroidium*, and woody axes. In the cliff face here there is a dichotomously forked log 2 m long, embedded in low-angle scour-and-fill grey-green siltstone. South of

Bilgola resorted palaeosol material overlying the slightly eroded phase of the Turimetta clay palaeosol (UNEL1410) contains naturally macerated *Dicroidium zuberi* leaves and its supposed pollen organ, *Neocalamites*, roots, and woody axes.

So the flora contained a mixture of conifers and *Dicroidium*, with possibly hydroseral (see Ashby, 1969) equisetaleans (*Neocalamites*). Judging by the size of the fossil logs, soil type, and abundance of equisetaleans, it was probably a swamp woodland association.

Palaeotopography. The predominantly drab A_2 horizon and weakly mottled *B* horizon, abundance of humic material, inundulic plasmic fabric, and siderite suggest that these palaeosols were wet for most of the year. The preservation of entire profiles and doubled mottled horizon (in the Turimetta clay sandy variant) suggests a subsidence rate of at least 5 cm per century. These palaeosols are intimately associated with lenticular grey-green lithic sandstone channel and levee deposits (Retallack, 1973). They probably developed in a slowly subsiding swampy alluvial plain.

Classification. The Turimetta Series palaeosols are 0 in the Northcote (1974) key. Organic soils have not yet been further subdivided.

In the classification of Stace *et al.* (1968) they are humic gleys; with a grey clay subsoil, mottled *B* horizon, and gley features extending into a permanently waterlogged zone below.

In the USDA system they are fibrists. They consist, by pure count, of mineral matter (52%), fibre (31%) and amorphous organic material (13%). Their histic epipedon is diagnostic; the paralithic contact is not.

Modern soils of this type are azonal but favoured by maritime climates, slowly permeable parent material, coastal or subcoastal lows, estuarine plains, and concave positions on hilly slopes that are wet for a part of the year (Buol *et al.*, 1973; Stace *et al.*, 1968). A soil of this type and thickness could take 1000 to 2000 years to form (Buol *et al.*, 1973, p. 292).

AVALON PALAEOSOL ASSOCIATION

Definition. Silty palaeosols with grey, clayey *B* horizons, sometimes weathered pink. Most commonly they also have a conspicuously bleached A_2 horizon and siderite nodules in the *B* horizon. In the Pittwater area they occur within the Newport Formation, and there are eight well-exposed profiles at North Avalon (Fig. 4).

Palaeotopography. Mineralogy, conglomerate pebble types, heavy minerals, and palaeocurrents indicate that the Newport Formation sediments were derived from an extensive drainage basin extending several hundred kilometres into hilly country of the Lachlan Fold Belt to the west and the New England Fold Belt to the north (Culey, 1938; Ward, 1972). McDonnell (1974) has reconstructed a part of this broad floodplain from the rocks now exposed north of Broken Bay. However, in the Pittwater area the streams fed into the 'Gosford Delta' (Conolly, 1969) building southwards into a large freshwater lake (Retallack, 1975). The Avalon Palaeosol Association developed on a patchwork of sandy point bar ridges, levees, and silty floodplains within this delta. The palaeosols are not so well preserved in the active delta lobes (at Turimetta Head) as in delta plain and interdistributary areas (at North Avalon; Retallack,

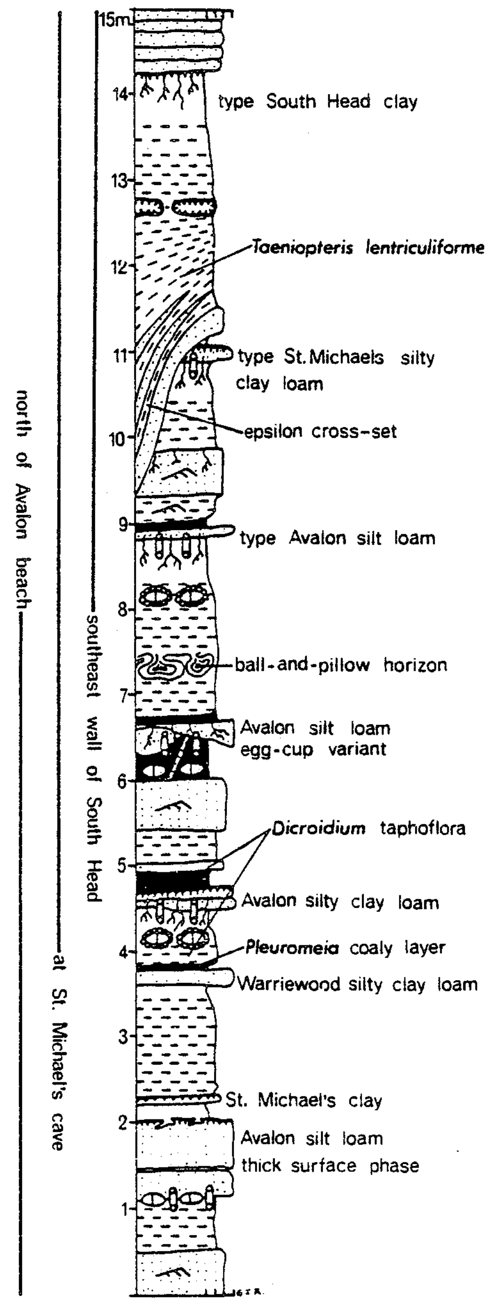

Fig. 4. Succession of palaeosols exposed in sea-cliffs from Avalon beach to South Head.

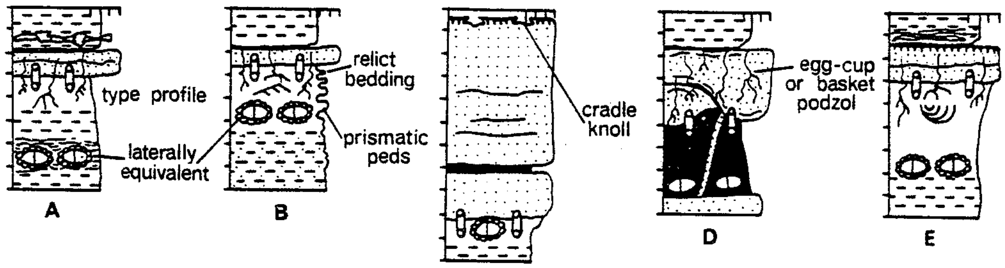

Fig. 5. Profiles of Avalon Palaeosol Series. A, type Avalon silt loam palaeosol 200 m south of St. Michaels cave. B, type Avalon silt loam palaeosol on rock platform near South Head. C, Avalon silt loam thick surface phase palaeasol north of Avalon beach. D, Avalon silt loam egg-cup variant palaeosol near St. Michaels cave. E, Avalon silty clay loam palaeosol 200 m south of St. Michaels cave.

1977, fig. 2). Some grey-green lithic sandstone channels at Turimetta Head are interbedded with the prodelta shales. The channels represent the last traces of sediment derived from the old volcanic ridge, probably deposited on clay flats east of the delta.

Parent material. In the Triassic, the New England Fold Belt to the north probably revealed a variety of acid volcanics and plutons, flysch, shallow marine sediments, and coal measures. The Lachlan Fold Belt to the west consisted of a variety of Palaeozoic sediments, volcanics, and granites, probably more extensively covered by red weathering Upper Devonian sandstones than at present (Brown, Campbell & Crook, 1968).

A considerable component of resorted soil material from the source area is also indicated by the geochemical maturity of Newport Formation rocks (Retallack, 1977, table I).

The sediments, on which the Avalon Palaeosol Association developed, include clean quartz-lithic sandstone with 38 to 60% quartz (Loughnan, 1963; Retallack, 1973; Ward, 1971) and siltstone and shale largely of kaolinite (40 to 50%) and quartz (25 to 35%), with some illite (10 to 15%), mixed layer clay (5 to 10%) and siderite (5%) (Loughnan, 1963).

Avalon Palaeosol Series (Dg3.41, gleyed podzolic, aquod)

Diagnosis. Palaeosols with a light coloured ganister A_2 and a clayey *B* horizon with a layer of siderite nodules.

Type example. The Avalon silt loam palaeosol 8.84 m above the rock platform 200 m south of St Michaels Cave at BB345445 (Fig. 5A). This palaeosol thins to the south where it disappears into interbedded sandstone and shale. Northwards it can be traced until it runs below sea level near South Head. At its northern end (Fig. 5B) it has developed on more sandy parent material with more conspicuous relict bedding and ripple marks throughout the profile. Here the siderite-nodule horizon is exposed in plan (Retallack, 1976, fig. 17) and there are also some prismatic peds, best expressed in a 3 cm sandy layer above the nodules (Retallack, 1977, fig. 14A).

Further examples. The Avalon silt loam thick surface phase (Fig. 5C) has a prominent cream weathering ganister up to 0.61 m thick. North of Avalon beach its wavy surface and vertical jointing are strongly ferruginized. On the rock platform south of St Michael's Cave its surface shows probable cradle knolls.

The Avalon silt loam egg-cup variant (Fig. 5D; Retallack, 1977, fig 9) is readily distinguished by its common egg-cup podzols and very carbonaceous *B* horizon containing thin ganister dykes (Retallack, 1977, fig. 11). The locally carbonaceous *B* horizon is largely amorphous and fragmentary organic matter, with some recognizable equisetalean, lycopod, and *Dicroidium* leaf remains.

The Avalon silty clay loam (Fig. 5E; Packham, 1976, fig. 5) outcrops from north of Avalon beach to near St Michaels Cave. It has developed on an upward coarsening sequence interpreted by Retallack (1975) as a crevasse splay. There is some relict cross bedding and scour-and-fill in the upper portion of the palaeosol. Unlike other Avalon Series palaeosols it has a cracked and ferruginized surface (Retallack, 1977, fig. 8B) and the *B* horizon is more orange coloured. I regard it as an end member of the Avalon Palaeosol Series close to the St Michaels Palaeosol Series.

Reconstructed soil. The original soil probably had a thin, at least intermittently dry, mor humus (see Buol *et al.*, 1973, p. 149) and a loose clean sandy A_2 horizon with an acid reaction. The *B* horizon was more clayey, though still showing sedimentary relicts and incipient prismatic peds. It was penetrated by numerous insect krotovinas and contained a layer of siderite nodules in the zone of water table oscillation.

Stratigraphic distribution. The Avalon Palaeosol Series occurs in the lower Newport Formation of the sea cliffs north of Avalon, and also probably in the stratigraphically equivalent Gosford Formation, north of Broken Bay (McDonnell, 1974).

Parent material. Most of the Avalon Palaeosol Series show some relict sedimentary bedding or structures, and so appear to have formed on low-lying floodplain and crevasse splay deposits of siltstone and shale.

Palaeobotany. I have collected good assemblages of plant fossils from the leaf litter, from within the profile and from underlying sedimentary rocks of the Avalon silty clay loam in a large fallen block north of Avalon beach (UNEL1386): *Neocalamites, Asterotheca, Cladophlebis, Gleichenites, Chiropteris, Taeniopteris* spp., several leaf species of *Dicroidium* (including *Dicroidium zuberi* (Szajnocha) Archangelsky 1968 and its reproductive organs), rhizomes, roots, and woody axes. These are typical of the *Dicroidium* taphoflora found throughout the lower Newport Formation in the coastal cliffs of the Pittwater area (Walkom, 1925; Burges, 1935; Retallack, 1973).

Several lines of evidence incline me to agree with Tenison-Woods (1883) that this was a 'heathy stunted vegetation such as even now grows on poor sandy soil'.

1. No logs or trunks wider than 11 cm have been seen associated with the Series.

2. Egg-cup podzols, cradle knolls and radiating root systems indicate that the central root system of the plants was less than 50 cm across.

3. Associated *Dicroidium* leaves have a thicker cuticle and more fleshy leaf which does not show the venation as clearly as the same species, associated with identical reproductive structures, in the western equivalent of the Bald Hill Claystone at Mt Piddington (UNEL1467).

4. The Avalon Series palaeosols were probably clean sandy soils with acid reaction and high water table, similar to soils of modern heaths (Small, 1931; Godwin, 1932; Specht & Rayson, 1957).

Although *Dicroidium zuberi* formed a heath association here, it, and especially other species, probably formed broadleaf forest associations elsewhere. Archangelsky (1968) and Brett (1968) argue that *Dicroidium* leaves were born on huge trunks of the *Rhexoxylon* type.

Palaeotopography. The shallow siderite nodule layer and thin texturally mature ganister indicate an almost permanently high water-table. So they were probably soils of low-lying areas. On the other hand, the clean sandy ganisters, ferruginized surface crust, and insect krotovinas suggest a quite dry surface soil.

Classification. These palaeosols are described by Dg3.41 in the Northcote (1974) key. The *B* horizon has a V/C of 2, but is nevertheless very close to V/C3 and a gley colour. The sandy A_2 is assumed to be acid and usually not hard setting (the Avalon silty clay loam palaeosol may be an exception). Peds are only rarely seen in the *B* horizon but may have been more marked before compaction.

According to the classification of Stace *et al.* (1968, p. 359), they are gleyed podzolic soils.

In the USDA system these palaeosols are immature aquods; they have a diagnostic ochric epipedon and argillic and spodic (siderite) horizons, non-diagnostic albic horizon and paralithic contact, and considerable sedimentary relicts.

Modern soils of this type are formed on low-lying sites waterlogged at least intermittently. They are common in mixed clay-sand colluvium and alluvium. Podzolic soils support heath and coniferous forest in cooler humid areas, but also some broadleaf forest. These soils form relatively quickly and incompletely developed examples may be formed in a few hundred to 100 years (Buol *et al.*, 1973; Stace *et al.*, 1968).

Warriewood Palaeosol Series (Uc2.21, alluvial soil, aquent)

Diagnosis. Poorly developed palaeosols with a ganister A_2 and a very thin leached *B* horizon.

Type example. The Warriewood clay loam palaeosol on a ledge where the fisherman's track meets a short rock-climb down to the rock platform, due north of Turimetta trig, at BB316368 (Fig. 6A). This palaeosol can be followed for about 1 km from the easternmost point of Turimetta Head to Warriewood beach. Its low-angle discordance with the sandstone channel deposits of these cliffs illustrates clearly the difficulties of using individual channel sandstones as stratigraphic markers.

Further examples. The Warriewood clay-loam thick surface-phase palaeosol forms a 25 cm cap to the lowest epsilon cross-set exposed in the northeast wall of Bilgola Head (Fig. 6B).

The Warriewood silty-clay loam outcrops for about 1 km from north of Avalon beach to near St Michaels Cave (Figs 6C, D). Near the beach the whole profile is only 10 cm thick and the ganister is poorly differentiated, with a more gradational lower contact, no phytoliths and conspicuous clay matrix to silt-sized grains. On the rock platform near St Michaels Cave the whole profile is 30 cm thick with a clearly differentiated ganister, a leached *B* horizon and rare ganister metagranotubules and thin dykes.

Reconstructed soil. The original soil probably had a thin sandy A_2 horizon over barely modified, possibly waterlogged, sediment.

Stratigraphic distribution. The Warriewood Palaeosol Series is found in the lower Newport Formation of the Pittwater area and possibly also in the Gosford Formation north of Broken Bay (McDonnell, 1974).

Parent material. These palaeosols developed on predominantly silty material, similar to the parent material of the Avalon Palaeosol Series.

Palaeobotany. Fossil localities close to the type Warriewood clay loam (UNEL1426, UNEL1430, UNEL1431) contain the *Dicroidium* taphoflora typical of the Pittwater area. The vegetation of the Warriewood Palaeosol Series was probably mostly the same as that of the Avalon Palaeoson Series.

By contrast, the organic horizon of the Warriewood silty clay loam at North Avalon contains an almost monospecific assemblage of compressed and strata-transgressive logs, rhizophores, elongate leaves, and leaf bases of *Pleuromeia longicaulis* (Burges) Retallack 1975. These lycopods probably formed monodominant stands in interdistributary

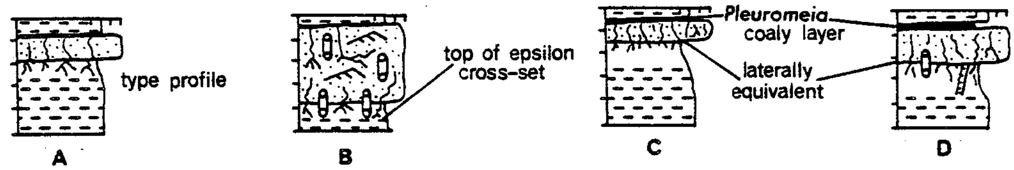

Fig. 6. Profiles of Warriewood Palaeosol Series. A, type Warriewood clay loam palaeosol on ledge by track north of Turimetta trig. B, Warriewood clay loam thick-surface phase palaeosol low in northeast wall of Bilgola Head. C, Warriewood silty clay loam palaeosol north of Avalon beach. D, Warriewood silty clay loam palaeosol near St. Michaels cave.

bays and released their supposed cones (*Cylostrobus sydneyensis* (Walkom) Helby & Martin 1965 *s.l.*) and leaves (*Sigillariophyllum* sp.) to be fossilized within large areas of prodelta shale (Retallack, 1975).

Palaeotopography. The type example was probably not in equilibrium with its environment before burial. However, the Warriewood clay loam thick surface phase palaeosol has a texturally mature ganister with a sharp lower boundary, possibly indicating a high water-table (Daniels *et al.*, 1967).

The better differentiation of the Warriewood silty clay loam palaeosol along strike suggests it was a hydrologic soil catena (see Bird, 1957). This is compatible with the lycopod flora it supported, which was perhaps partly submerged at the southern end and graded into drier *Dicroidium* heath at the northern end.

Classification. By the Northcote (1974) key these palaeosols are described as Uc2.21. This has a mottled *B* horizon with background V/C rating of 2 and no carbonate pan. Soils of the Uc2.2 type are non-sodic, non-alkaline, and non-saline (Northcote & Skene, 1972).

According to the classification of Stace *et al.* (1968), these are alluvial soils, showing minimal profile development beyond some differentiation of the *A* horizon and the accumulation of organic matter.

By the USDA system they are aquents, shallow gleyed soils with sporadic mottling. They have a diagnostic ochric epipedon and cambic horizon, and non-diagnostic paralithic contact and albic horizon.

Similar modern soils are common on the younger features around lakes and rivers and in deltas and alluvial fans. In river systems aquents are common in backwater lowlands, fluvents (*e.g.* South Head Palaeosol Series) on clayey levees and psamments on sandy islands, bars and river banks (Buol *et al.*, 1973). All these are young poorly developed soils. Given more time before burial, Warriewood Series palaeosols probably would have developed into soils similar to the Avalon Palaeosol Series.

St Michaels Palaeosol Series (Dy3.41, gleyed podzolic, ochrept)

Diagnosis. Palaeosols with a prominently ferruginized A_2 horizon, a grey clayey *B* horizon, weathering orange and yellow, and containing ferruginized insect krotovinas.

Type example. The St Michaels silty clay loam 8.5 m above the rock platform near St Michaels Cave at BB345445 (Fig. 7A). This palaeosol outcrops from south of St Michaels Cave to South Head (Fig. 4). Near the track down the cliff from the car park off Marine Parade, the palaeosol is locally scoured out by a large epsilon cross-set (*sensu* Allen, 1963).

Further examples. The St Michaels clay palaeosol has a thin ferruginized shale *A* horizon (Fig. 7C). It directly overlies the Avalon silt loam thick surface phase palaeosol from Avalon beach to south of St Michaels Cave. It thickens from 15 to 45 cm northwards along strike.

The St Michael's sandy loam palaeosol (Fig. 7B) crops out on the rock platform and low in the cliff at North Narrabeen. It has a mamillated ferruginous surface crust (Retallack, 1977, fig. 8A) and a sphaerosideritic clayey *B* horizon, also described by Culey (1932).

Reconstructed soil. The original soil probably had a poorly developed mull humus and a hardsetting oxidized surface crust which cracked on drying. The original crust was probably less red than it appears today. Beneath it was either loose

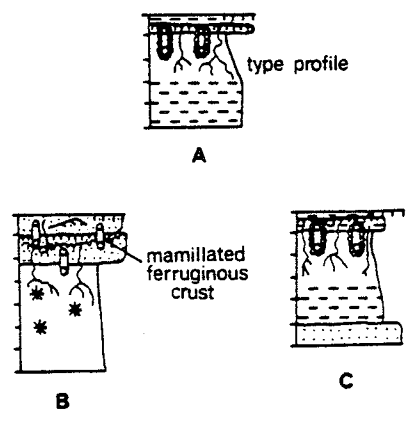

Fig. 7. Profiles of St Michaels Palaeosol Series. A, type St Michaels silty clay loam palaeosol near St Michaels cave. B. St Michaels sandy loam palaeosol north of Narrabeen beach. C. St. Michaels clay palaeosol 200 m south of St Michaels cave.

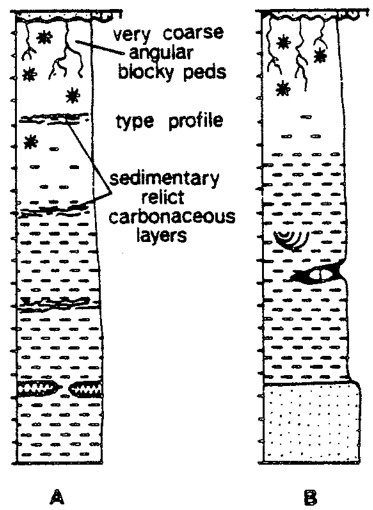

Fig. 8. Profiles of South Head Palaeosol Series. A, type South Head clay palaeosol low in southeast wall of South Head. B, South Head clay nodular variant palaeosol south of Warriewood beach.

clean sand or silty clay, over a heavy clay yellow-grey *B* horizon containing strongly oxidized insect krotovinas.

Stratigraphic distribution. These palaeosols occur in the lower Newport Formation of the Pittwater area and probably also the Gosford Formation, north of Broken Bay (McDonnell, 1974, fig. 14).

Parent material. Predominantly silty sediments as for the Warriewood and Avalon Palaeosol Series.

Palaeobotany. Associated fossil localities (UNEL1453) contain a diverse *Dicroidium*-dominated taphoflora similar to that thought to have grown in the Warriewood and Avalon Palaeosol Series.

Palaeotopography. The stronger ferric iron stain and lack of siderite nodules indicates that these soils were better drained than the Avalon and Warriewood Palaeosol Series. They probably developed on higher features of the area such as levees, point bar ridges, and proximal crevasse splays.

Classification. These palaeosols are described by Dy3.41 in the Northcote (1974) key. The *B* horizon has a V/C rating of 2 but is faintly mottled and more yellow and brown than Munsell gley. The apparently hard-setting ferruginized A_2 is taken to be acid like that of the Avalon Series palaeosols. Soils of this form may be sodic and non-saline, but grade into normal forms usually classed as gley podzolic (Northcote & Skene, 1972).

According to the USDA system, these palaeosols have a diagnostic ochric epipedon and argillic horizon and non-diagnostic albic horizon and paralithic contact. The prominent argillic horizon, at least in the type example, is probably a sedimentary relict, as bedding can still be made out in these palaeosols. Thus they are unlikely to be argids or ultisols, and are perhaps best classed as ochrepts.

By the classification of Stace *et al.* (1968, p. 359), these are gleyed podzolic soils.

The ochrepts are azonal immature soils, which often show the direction of soil development, in this case possibly towards ultisols or yellow podzolic soils. These latter modern soils are common on intermediate to lower slopes in hilly country under temperate sclerophyll woodland or conifer and broadleaf forest (Stace *et al.*, 1968; Buol *et al.*, 1973).

South Head Palaeosol Series (Uf4.2, grey clay, fluvent)

Diagnosis. Poorly differentiated, grey to pink weathering, clay palaeosols, with some evidence of peds, carbonaceous roots, relict bedding and deep gleying.

Type example. The South Head clay palaeosol 6 m above the rock platform in the southeast wall of South Head, under a cave forming, cross-bedded sandstone at BB346452 (Fig. 8A). This palaeosol rises to crop out above sea level north of South Head, and can be traced as far south as St Michaels Cave where it is completely eroded by channel sandstone.

Further examples. Possible palaeosols of this type are common high in the cliffs at Turimetta Head, south of Bilgola beach, and capping the two upper large-scale epsilon cross sets which dominate Bilgola Head northeast wall. These are pink weathering claystone grading downwards into unaltered sedimentary rock. I have not examined them in detail.

A more certain example is the South Head clay nodule variant palaeosol cropping out beneath the cliff-top sandstone south of Warriewood beach (Fig 8B). This consists of 91 cm of leached, pink weathered claystone containing carbonaceous roots, overlying 76 cm of light grey siltstone and a carbonaceous shale, containing plant fossils and siderite nodules. This palaeosol does not crop out to the north and is probably a better drained and more clayey, catenary equivalent of an unnamed Avalon Series palaeosol 4.6 m above the rock platform due north of Turimetta trig.

Reconstructed soil. The original soil was probably a poorly differentiated firm clay with blocky peds. The deep gley or siderite horizon was probably dependent on suitable parent material, such as a carbonaceous layer.

Stratigraphic distribution. These palaeosols are found through most of the Newport Formation, rather higher than the other Avalon Association palaeosols, and possibly also in the Gosford Formation north of Broken Bay (McDonnell, 1974, fig. 15).

Parent material. Fine siltstones and shales.

Palaeobotany. Fossil floras found near the type example at North Avalon (UNEL1389, UNEL1390, UNEL1393, UNEF13972-5) contain some elements of the usual *Dicroidium*-dominated taphoflora: *Neocalamites, Asterotheca, Chiropteris, Taeniopteris undulata* Burges 1935 and *Dicroidium.* However, there is a marked dominance of *Taeniopteris lentriculiformis* (Etheridge) Walkom 1917, which is also characteristic of the uppermost Narrabeen Group taphofloras at Harbord (Etheridge, 1894; Dunstan, 1894) and Gosford (Etheridge, 1894; David, 1890). *T. lentriculiformis* has been found associated with and attached to slender branching axes at North Avalon (UNEF 13893, UNEL1393, UNEL1390). It was probably a diffuse, many-branched tree or shrub, which locally dominated the *Dicroidium* flora.

Palaeotopography. These palaeosols are usually found on the more clayey upper members of point-bar sequences and the tops of large-scale epsilon cross-sets.

They also cap the three impressive epsilon cross sets up to 10.7 m thick, exposed in section and in plan in the rock platform and cliffs on the north side of Bilgola Head (Packham, 1976, fig. 12). These are compounded from similarly oriented huge trough cross beds, formed of sigmoid cross-strata of alternating sandstone and shale dipping at 5° to 4° but curving to concordance with the base of the set. These compounded sets grade laterally in the cross-stratal down-dip direction into horizontally-bedded shale and in an up-dip direction into thick-bedded sandstone. They are probably at least in part levee complexes built up by interfingering proximal crevasse splays (*cf.* Hatch *et al.*, 1971, fig. 119). The well-developed peds and comparison with modern soils also suggest that these palaeosols formed on levees.

Classification. These palaeosols are described by Uf4.2 in the Northcote (1974) key. They have an unbleached pedologically organic A_2 horizon over a dry coherent porous apedal *B* horizon. There is no evidence of seasonal cracking.

Within the classification of Stace *et al.* (1968, p. 79) they are a variety of 'grey, brown and red clays', composed of grey heavy clay (94%) with some rust spotting, angular blocky peds, and well disseminated carbonate.

In the USDA system they have a diagnostic ochric epipedon and a non-diagnostic paralithic contact. So they are fluvents, clayey textured entisols with irregular organic profiles and commonly with limited iron accumulation at about 1 m.

In modern river systems, fluvents are common on more clayey levees, aquents on backwater lowlands (e.g. Warriewood Palaeosol Series) and psamments on sandy islands, bars, and river banks (Buol *et al.*, 1973). The grey, brown and red clays are more usually desert soils, but are also found in humid rainfall zones (up to 175 cm). The lack of profile differentiation is probably due to high clay content (Stace *et al.*, 1968).

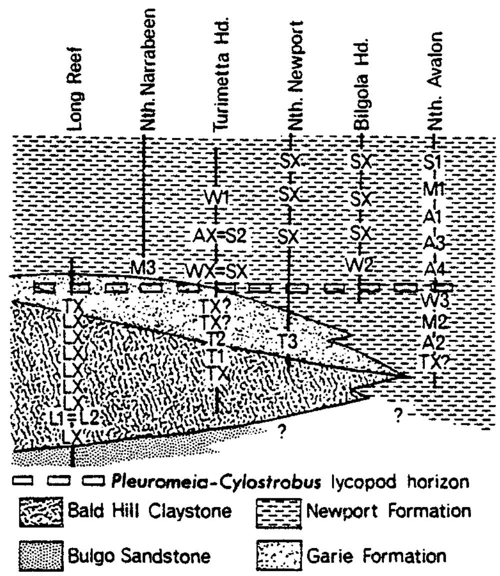

Fig. 9. Palaeosol distribution at selected localities and within formations. A1, type Avalon silt loam; A2, Avalon silt loam, thick surface phase; A3, Avalon silt loam, egg-cup variant; A4, Avalon silty clay loam; AX, unnamed Avalon Series; L1, type Long Reef clay; L2, Long Reef clay, nodular variant; LX, unnamed Long Reef Series; M1, type St Michaels silty clay loam; M2, St Michaels clay; M3, St Michaels sandy loam; S1, type South Head clay; S2, South Head clay, nodular variant; SX, unnamed South Head Series; T1, type Turimetta clay; T2, Turimetta clay, sandy variant; T3, Turimetta clay, slightly eroded phase; TX, unnamed Turimetta Series; W1, type Warriewood clay loam; W2, Warriewood clay loam, thick surface phase; W3, Warriewood silty clay loam; WX, unnamed Warriewood Series.

STRATIGRAPHIC DISTRIBUTION

The mapping and correlation of these palaeosols is very uncertain because Triassic bedrock is extensively mantled by Tertiary palaeosols and pedoliths, and Holocene alluvium, beaches and soils. In addition, several of the palaeosols show catenary changes along strike (*e.g.* Warriewood silty clay loam palaeosol at North Avalon). Most are scoured out locally by channel sandstone deposits and thin and interdigitate into point bar and levee deposits. The best geological datum in the area remains the *Pleuromeia-Cylostrobus* lycopod horizon (Retallack, 1975), which marks the base of a lobe of the Gosford Delta. Comparison of individual successions of palaeosols at individual localities (Fig. 9) suggests the following general sequence: Long Reef Series, then Turimetta Series, then the Avalon-St

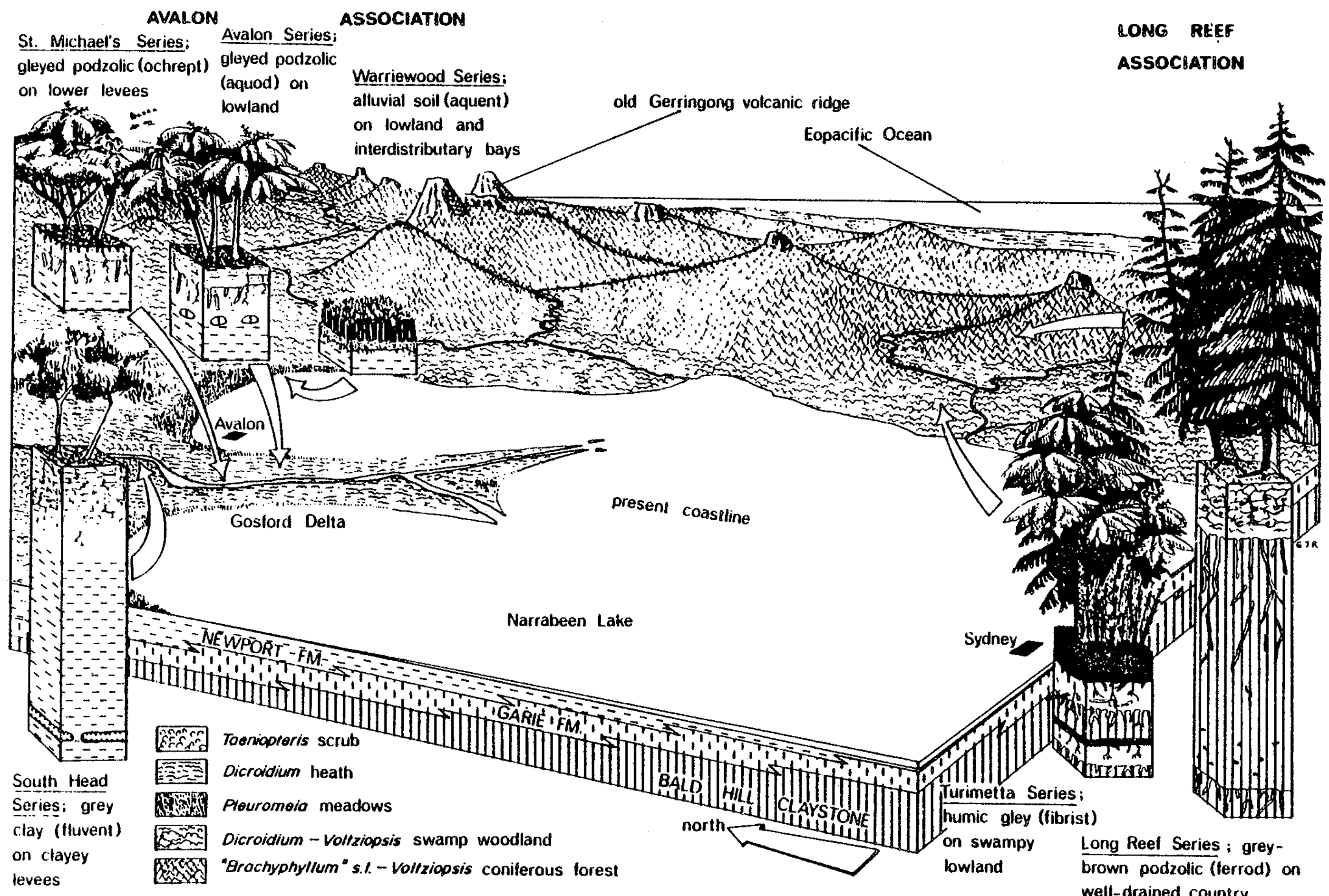

Fig. 10. Reconstructed soils, vegetation, topography of Pittwater area during deposition of lower Newport Formation.

Michaels-South Head group of Series. However, the lycopod horizon, observable palaeocatenary relations and the close relation between palaeosol type, parent material, and palaeodrainage, suggests that all of the described palaeosols could have formed the ground surface at one time (Fig. 10).

THE TRIASSIC ENVIRONMENT

Figure 10 is a reconstruction of the Pittwater area for a time within the late Scythian to early Anisian, when the cliff-forming quartzose sandstone of Turimetta Head southeast wall was a sandy stream bed. I have modelled the peaks of the old Gerringong ridge on the magnetic map of Mayne *et al.* (1974). However, some of the magnetic anomalies are central to radial swarms of alkali dolerite dykes, intruding the Triassic sedimentary rocks onshore (David, 1950). Only *Pleuromeia* is accurately reconstructed (Retallack, 1975), the others being more or less diagrammatic.

The following section describes the possible panorama in this region during Triassic times.

From a position high in the sky west of Sydney, the extensive waters of Narrabeen Lake can be seen to be the freshwater northern portion of a lobate lagoonal system intermittently open to the sea in the south (for similar modern examples, see Bird, 1962, 1968).

To the east, low rolling land rises slowly to scattered well-dissected plugs of the 20-m.y.-old Gerringong volcanic ridge, which separates the lake from the glistening waters of the Eopacific (*sensu* Carey, 1970) in the far distance. Sluggish streams drain down towards the lake from the low crest of the old volcanic ridge. Their meandering and branching is marked by deep linear shadows through the tall coniferous forest of the low hills and the *Dicroidium-Voltziopsis* swamp woodland of the lake margins.

These streams are floored by unaltered grey-green volcanogenic sandstones. However, when exposed, these sandstones weather quickly to give the predominantly kaolinitic clay soils of the Long Reef Association. In better drained areas the clay is strongly oxidized to grey-brown podzolic soils (ferrods) of the Long Reef Series under coniferous forest. Well-drained conditions prevailed for at least 16 000 years, with very slow subsidence, to form the Bald Hill Claystone.

In lowland areas around the lake, the soft lithic sandstones form clayey gley soils, accumulating small thicknesses of peat under *Dicroidium-Voltziopsis* swamp woodland. Local thickets of *Neocalamites* are probably trapping sediment as an early stage in the hydrosere towards a woodland climax. The mature soils are humic gleys (fibrists) of the Turimetta Series. With the slow relative rise of the Narrabeen Lake drab clayey sediments and soils of this type come to overlie continuously the Bald Hill Claystone, forming the Garie Formation.

At the northern end of the lake, the Gosford Delta (of Conolly, 1969) is imperceptibly building southwards concomitant with the slow relative rise of lake level. The delta channels drain a broad river plain extending far to the northwest. A few hundred kilometres to the north and west, hilly country is barely visible on the horizon. This large source area supplied quartzose sand and silt and kaolinite-illite clay to the delta.

From the air, the Gosford Delta is an interesting patchwork of dark *Pleuromeia* meadows in marshy interdistributary bays, light drab green *Dicroidium* heath on sandy surfaced soils, bright green islands of pteridophytes around small lakes and billabongs, and bushy *Taeniopteris* scrub on levees, dissected by sinuous ribbons of shining water in clean sandy channels. Beneath the still waters, the lake floor is predominantly grey clay with finely comminuted plant fragments, but there are lighter-coloured sand bars at the distributary mouths (Retallack, 1975).

Within the low-lying and sedimentologically active delta only gleyed and immature soils are formed. Alluvial soils (aquents) of the Warriewood Series are found under *Dicroidium* heath in lowlands recently covered by flood deposits and also under partly submerged *Pleuromeia* meadows in interdistributary bays. On better drained clayey levees, grey clays (fluvents) of the South Head Series support *Taeniopteris lentriculiformis* scrub. On older lowlands *Dicroidium* heath grows on more differentiated gleyed podzolic soils (aquods). These had a dry acid surface but the water table is almost permanently within a metre of the surface. On slightly more elevated ground under *Dicroidium* heath there are relatively drier gleyed podzolic soils (ochrepts) of the St Michaels Series. These are immature but indicate that yellow podzolic soils (ultisols) may have developed on these parent materials in more inland and better drained sites.

The southward growth of the Gosford Delta lobes and bay shorelines eventually filled in much of the Narrabeen Lake to form the Newport Formation. Slow but steady relative subsidence of less than a metre every 2000 years prevailed during the progradation of the Gosford Delta and the final drowning of the old Gerringong volcanic ridge. After a time the base level rose more slowly. As a result the river channels more frequently reworked the floodplain by lateral meandering. So only young grey clays (fluvents) of the South Head Series are preserved in the geological record. Base level was almost stable when the Hawkesbury Sandstone was deposited by powerful braided streams, deeply eroding into older sediments and reworking the floodplain to such an extent that few clayey sediments and no palaeosols are preserved.

Many of the palaeosols described are azonal; but, as in the modern world (Bridges, 1970), the dominance of podzols probably indicates a cool temperate climate for the Sydney area during the late Scythian to early Anisian. Similarly, the palaeosols and petrography of Triassic rocks in the Bowen Basin of Queensland suggest 'siallitic and podsolic weathering . . . under humid temperate conditions' (Jensen, 1975, p. 142). Colder climates are suggested by Sydney's Triassic latitude of 75°S (estimated from the palaeomagnetic pole of McElhinny, 1973). However, palaeolatitude is a relatively weak indicator of palaeoclimate. Notwithstanding continental drift, global climatic zones have fluctuated greatly in the past (Meyerhoff, 1973). The climate of southeastern Australia seems to have remained cool temperate from the later Permian (Dickins, 1973; Rigby, 1971; Gould, 1972) to the later Triassic (Townrow, 1964) and ameliorated to warm temperate in the Jurassic (Bowen, 1961; Stevens, 1971; Stevens & Clayton, 1971).

It is unlikely that the appearance of redbeds in the Triassic of the Sydney-Bowen Basin is due to tropical palaeoclimates (as suggested by Dickins, 1973; Loughnan *et al.*, 1964; Loughnan, 1963, 1970). Redbeds occur even in the supposedly cool temperate Gerringong Volcanics (Bowman, 1970). As I have already indicated, there is no conclusive evidence of laterites in the source areas of the Bald Hill Claystone. Even if they were there, lateritic podzolics are no longer believed to be strictly zonal soils of the tropics (Paton & Williams, 1970).

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