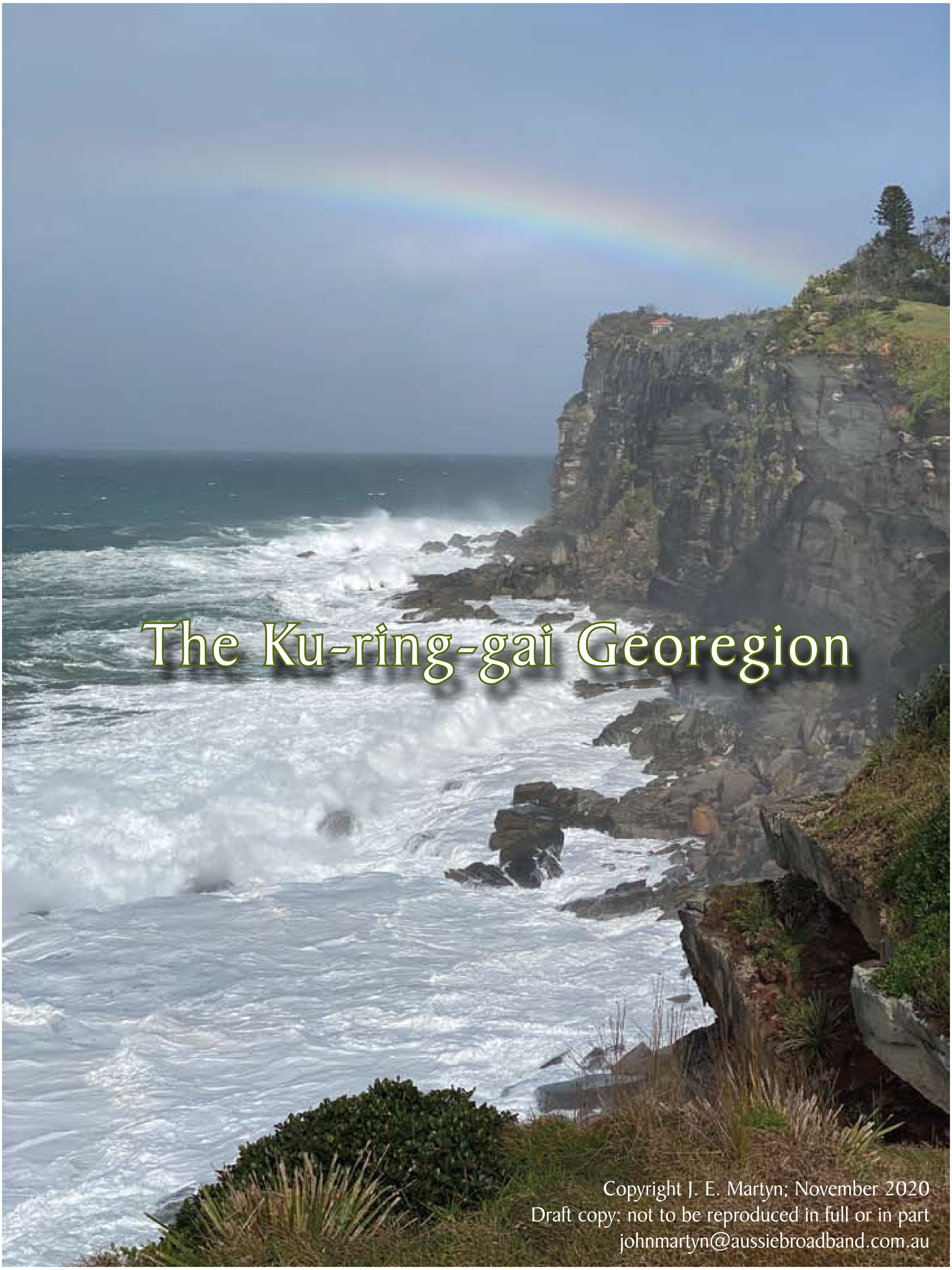

The Ku-ring-gai Georegion

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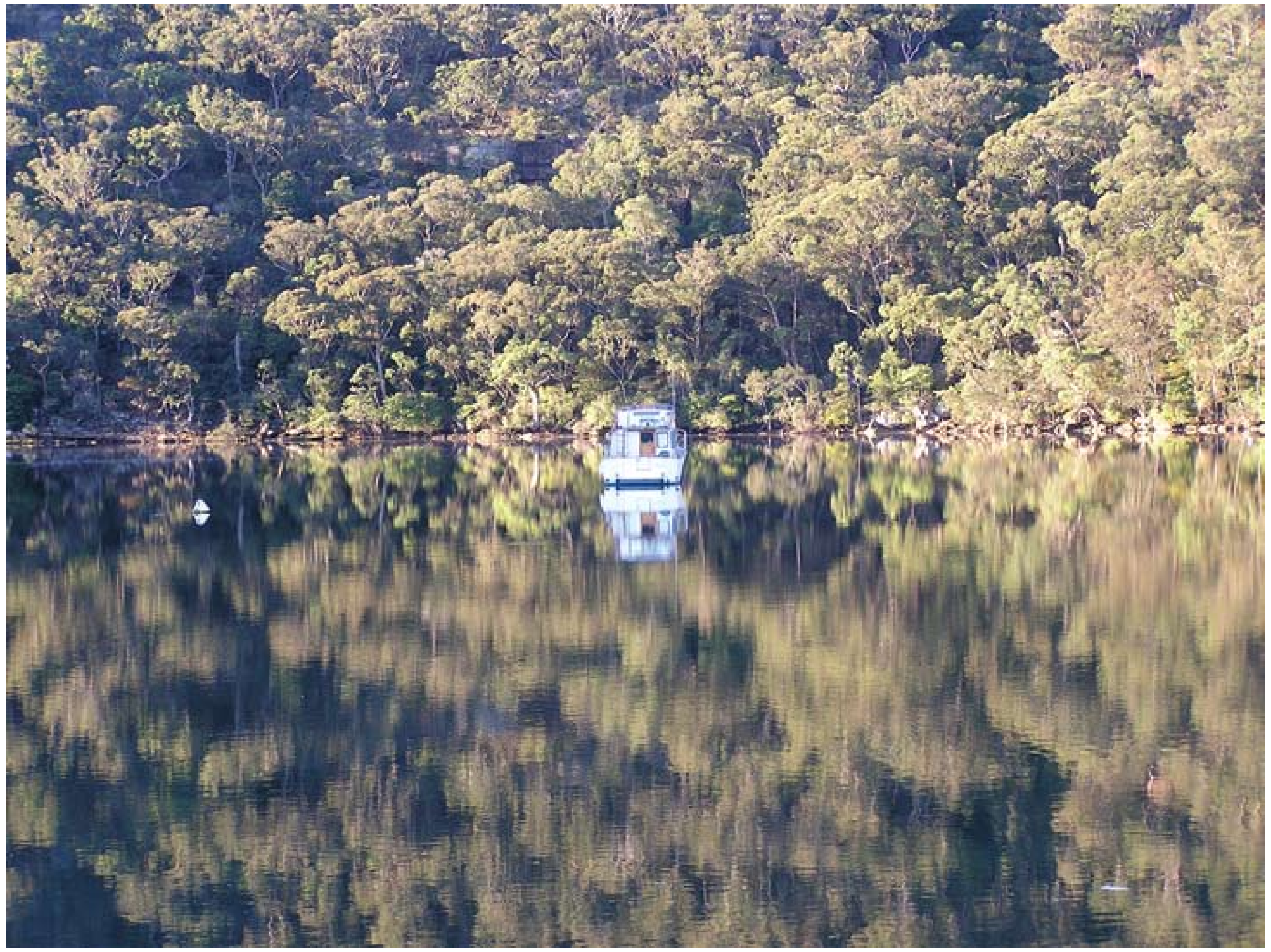
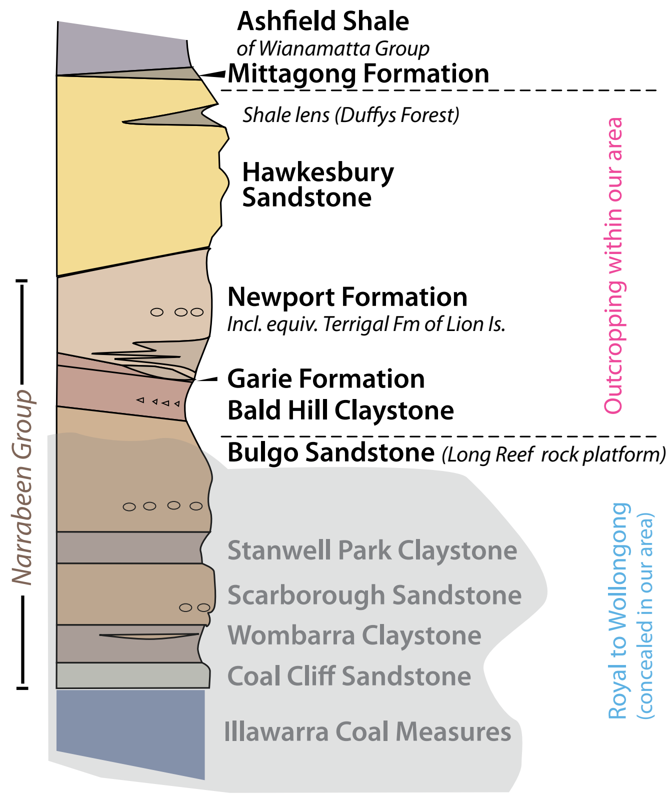
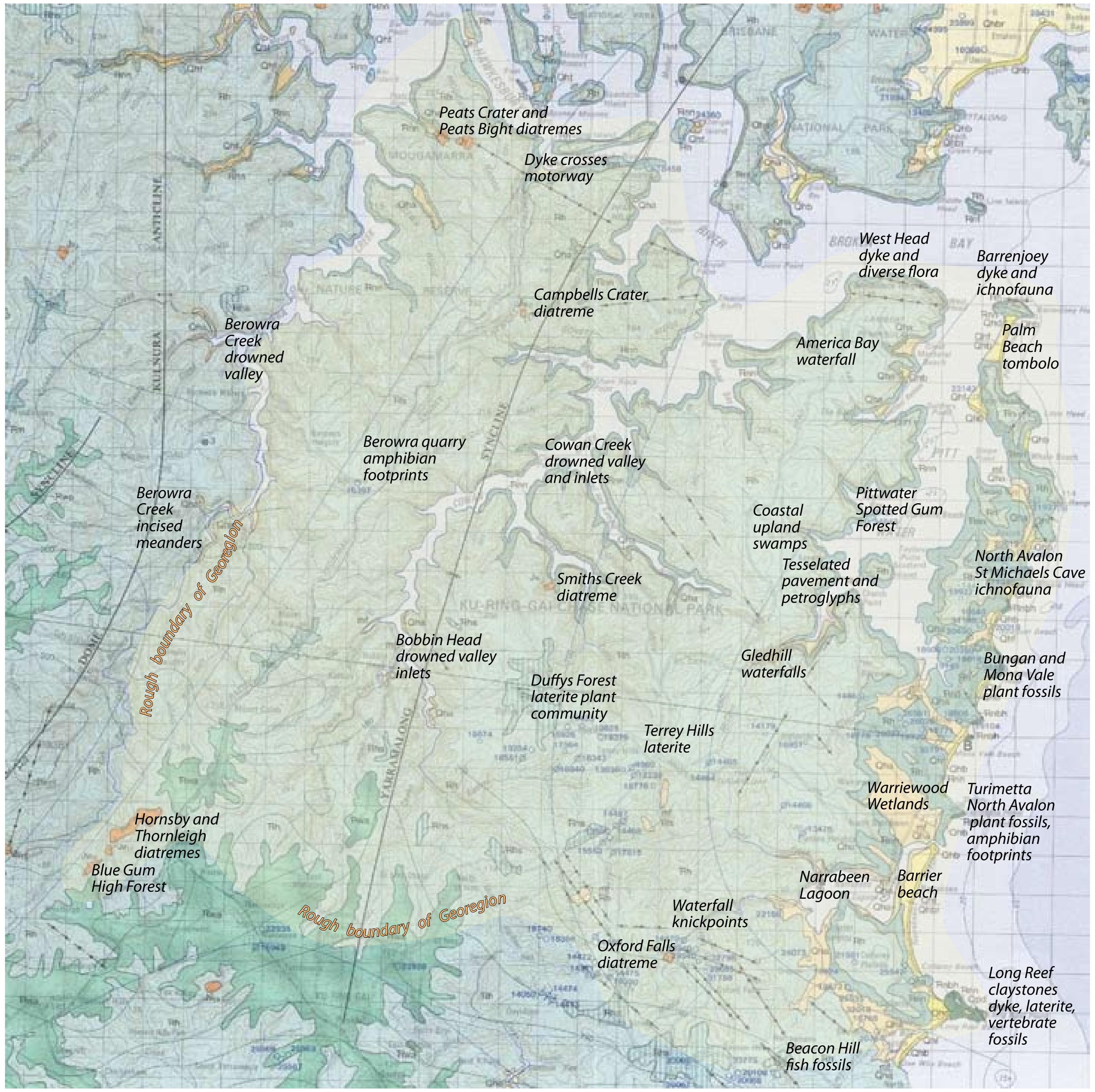


Overview

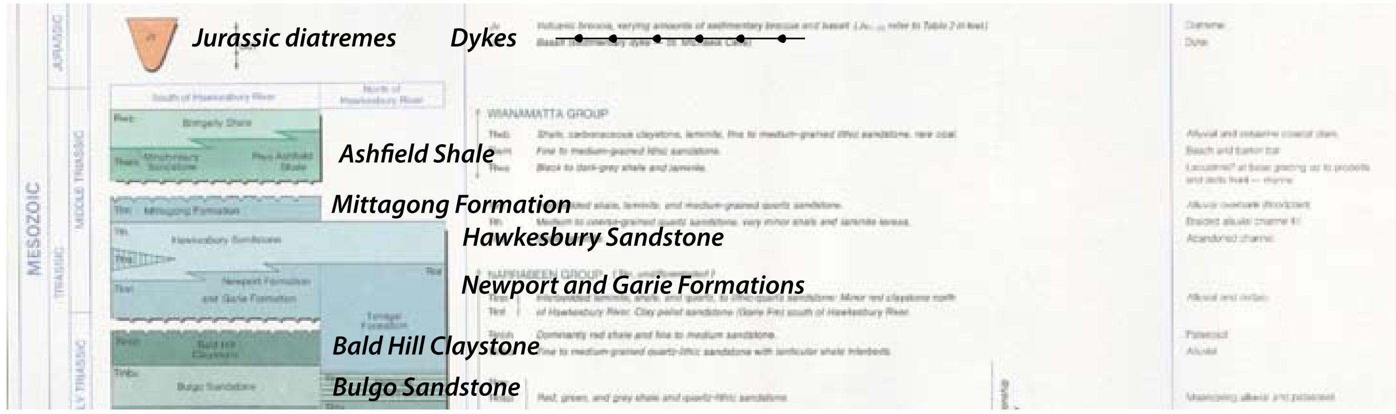
The geology of the broad sweep of country from the Northern Beaches via Ku-ring-gai Chase to the Berowra Valley is dominated by rocks of lower to Middle Triassic age (right) belonging to the Narrabeen Group and the Hawkesbury Sandstone. Our boundaries for this area are broadly outlined (opposite) but very much constrained and guidedby physical features such as the ocean, Pittwater and Hawkesbury estuary coastlines and the deep Berowra Valley. The country rock coverage extends to include thin cappings of Mittagong Formation and the lower part of the Ashfield Shale of the Wianamatta Group.

The main geological framework is punctuated by igneous bodies, notably dykes of dolerite, and related diatremes, of Early Middle Jurassic age. The best available age dates on a dyke strongly linked to diatremes are K-Ar ages of 171 and 173[23] for the Barrenjoey-West Head system that extrapolates westwards to the Peats and Campbells Crater diatremes.





A portion of the Sydney 1:100,000 scale published geological map[30] covering the area in question, with key units annotated over the legend for more clarity.



The area has classic examples of laterite formation, as at Terrey Hills and Long Reef, plus notable post glacial geomorphic features like the sand spit or tombolo linking the tied island of Barrenjoey to the Northern Beaches peninsula, plus the coastal lagoons of Narrabeen and Dee Why. The serene and peaceful rias or drowned inlets branching from the Hawkesbury are classic examples of their kind and reflect sea level rise following the most recent glacial peak of 21,000 years ago.

Inextricably linked to the geology are the numerous petroglyphs carved into the case-hardened surface shells of bare sandstone pavements: Aboriginal engravings of animals, shields and mythological figures – Ku-ring-gai Chase is regarded as one of the seven best areas for Aboriginal rock art in Australia.

The Hawkesbury Sandstone pavements themselves are the best of their kind in the Sydney region, and case hardening plus long exposure to shrinkage related to temperature and moisture extremes has generated patchy mosaic or tesselated patterns in a quite a few of them. Some of these are quite striking in appearence and have led to many opinions as to their origin: some of them bizarre and unlikely.

The area has an enormously diverse flora well illustrating the inverse relationship between soil nutrient levels and floral richness. The range of elevations from sea level to 230 m creates numerous pockets of habitat, from exposed heathland to rainforest filled ravines, and rocky crevices bursting with shrubs, ferns, orchids and even sizeable trees. There are interesting, sometimes subtle, sometimes strong relationships between geology and flora.

There follows a series of highlights of the geology and related features. These are illustrated where possible in following pages.

Highlights of the georegion

• The Bald Hill Claystone, best exposed at Long Reef Point but also forming many broad rock platforms to the north, has been researched as a classic encapsulation of Triassic soil formation processes that postdated the great end-Permian extinction event[65] (which upended our planet's climate – a mega global warming event that affected even the Sydney Basin despite its then sub-Antarctic location). The hematite-stained kaolinite claystones evolved from multiple protracted weathering periods acting on volcaniclastics washed by streams and rivers from an eroding volcanic range to the east.

• The Garie Formation, a thin, mottled grey to purple-red claystone less than 2 metres thick, exposed notably at Bilgola and Turimetta headlands, has been shown to be an accretionary lapilli tuff[18] formed from multiple nucleations of dust and ash in a volcanic cloud in a similar manner to hailstone formation. Such rocks are uncommon, even in purely volcanic terrains.

• The Newport Formation began its life as the sandy and silty deposits of freshwater lagoons and meandering streams on a broad coastal plain.[64] Estuarine to deltaic surges of sands, silts and gravels came from directions other than the volcanic range, and especially from the continental north-west. Concurrently the New England Fold Belt had reared up to the east and north supplying pulses of sand and polymictic gravel. But a sand source from the south-west, the key direction supplying the overlying Hawkesbury Sandstone, also became apparent at younger levels.[14,31,72]

• Estuarine and lagoonal siltstone and laminite beds in the lower part of the Newport Formation, have proven a rich source of fossil plants and ichnofauna remains. Various suites of plant species grew on swampy flats and neighbouring rises.[66] You will commonly find the broken stem fragments of large horsetails or *equisetales*[32] covering bedding plains of slabs smashed in rockfalls. These may be accompanied by fossils of seed ferns, true ferns or early cycads, or peppered with the cones of lycopods like club moss, which were of small tree size in the Triassic. The slabs suffer a constant turnover by storm waves and you should carry a smartphone or camera to picture them – they may not survive the next storm.

The word ichnofossil refers to tracks or traces of animals or plants often of unknown type. These may be burrows, casts, trails etc., and they are abundant in the lower Newport Formation.[48] Large vertebrates roamed the swamps,and the fossil jawbone of the amphibian *Bulgosuchus gargantua*[16] found at Long Reef measured a metre in length.

Many fossils found in the georegion are classed as holotypes, or the original of a genus, species or subspecies, and are thus of global significance.

• The Hawkesbury Sandstone is one of Australia's great landscape-forming rocks. It was deposited on the vast braid plain of a continental scale river which had sources in Antarctica when the latter was fused with Australia. Scattered zircon grains have been matched in age to source rocks now located in the Transantarctic Mountains.[77]

• The Hawkesbury Sandstone ridgetops and plateaus feature scattered duricrusted or case-hardened pavements: areas of bare rock separated by florally-rich heathland, shrubland, woodland or upland swamp and many of these pavements were canvases for Aboriginal petroglyph artists.

• Both Hawkesbury Sandstone and Newport Formation sandstones have been weathered and leached to tens of metres depth. Their iron carbonate cement has been oxidised, dissolved, recycled and reprecipitated in iron oxide seams and onion-ring "liesegang" bands. Case hardened, duricrust surface shells have been breached, etched and weathered by rain creating honeycomb patterns and bizarre and sometimes beautiful shapes.

• Hawkesbury Sandstone is alternatingly thickly and thinly bedded and some horizons are pebbly. It also incorporates occasional lenses of mudrocks, siltstone and laminite. The latter were the deposits of stranded flood plain lagoons and oxbows, the largest known in the Sydney Basin being at Duffys Forest where a maximum total thickness of 35 m was recorded[30] and the weathered shales were quarried for ceramic products. The Beacon Hill shale lens was also quarried and proved a rich source of plant, freshwater fish,[75] amphibian and insect fossils, many of them holotypes. Flaggy, fine-grained sandstone at a Berowra quarry yielded the tracks of an amphibian.[24]

• Compared with sandstones, igneous rocks have a subtle presence, containing silicates which are unstable to weathering and rot down to fertile clays. The igneous bodies often occupy low ground and may best be recognised on satellite images from lineaments or vegetation anomalies. Our area is notable for a clear relationship between an east-west dyke system that has been dated at 171and 173 Ma,[23] and diatremes of the same Early Middle Jurassic age. The separate Smiths Creek diatreme may be linked to subtle north-south or north-east dyke-related lineaments and a diatreme at Oxford Falls lies within a swarm of north-west trending dykes. But principal in the area is the world class quarry exposures of a basalt breccia diatreme complex more than 2 km long running from Hornsby Valley to Thornleigh.[3, 29,30]

Where igneous outcrop is absent, the main interest in dykes and diatremes lies in their vegetation, which is isolated and surrounded by contrasting communities. Each locality has unique features and is worthy of study. Visible outcrop or no outcrop, accessible or difficult to reach, each one is regarded as a geosite.

• Laterites, both in-situ and detrital, on the south side of Long Reef Point, are very rich in hematite: hence their red colour. The reason is likely to be hematite rich Bald Hill Claystone in the subsurface. The partially overgrown exposures of laterite in the abandoned laterite quarry faces on the aestern edge of the Terrey Hills sportsfield are largely detrital and dominated by brown and yellow-brown iron hydroxides. Such laterites cover significant areas in the Terrey Hills district.

Geology and related vegetation

Highlighting threatened and endemic communities and species and their relationship to geology and geomorphology.

Littoral Rainforest and Coastal Vine Thicket community: status – critically endangered. Includes tree species like Coast Banksia *Banksia integrifolia*, Lillypilly *Acmena* (*Syzygium*) *smithii*, Cabbage Tree Palms *Livistona australis*, Port Jackson Figs *Ficus rubiginosa* overtopped by Bangalay *Eucalyptus botryoides* Vine thickets include *Cissus* and *Smilax* species and *Marsdenia rostrata*. **Occurrence** – in moist, sheltered coastal pockets on Newport Formation, e.g. Angophora Reserve, Bilgola Headland and the lower western side of Barrenjoey Headland.

Themeda Grassland on Seacliffs and Coastal Headlands: status – endangered. Remnant pockets dominated by Kangaroo Grass on grey clay soils[52,59] on Newport Formation quartz lithic sandstones and laminites. Narrabeen, Turimetta, Bilgola, and Mona Vale headlands.

Pittwater Spotted Gum Forest: status – endangered.[53] Confined mainly to the western shores of Pittwater plus McKay and Angophora reserves. Dominant tree is Spotted Gum *Corymbia maculata* variously accompanied by *Angophora costata*, *A. floribunda*, *Eucalyptus paniculata* and *E. botryoides*. Open grassy forest merging into littoral rainforest understory; on quartz lithic sandstones of the Newport Formation.

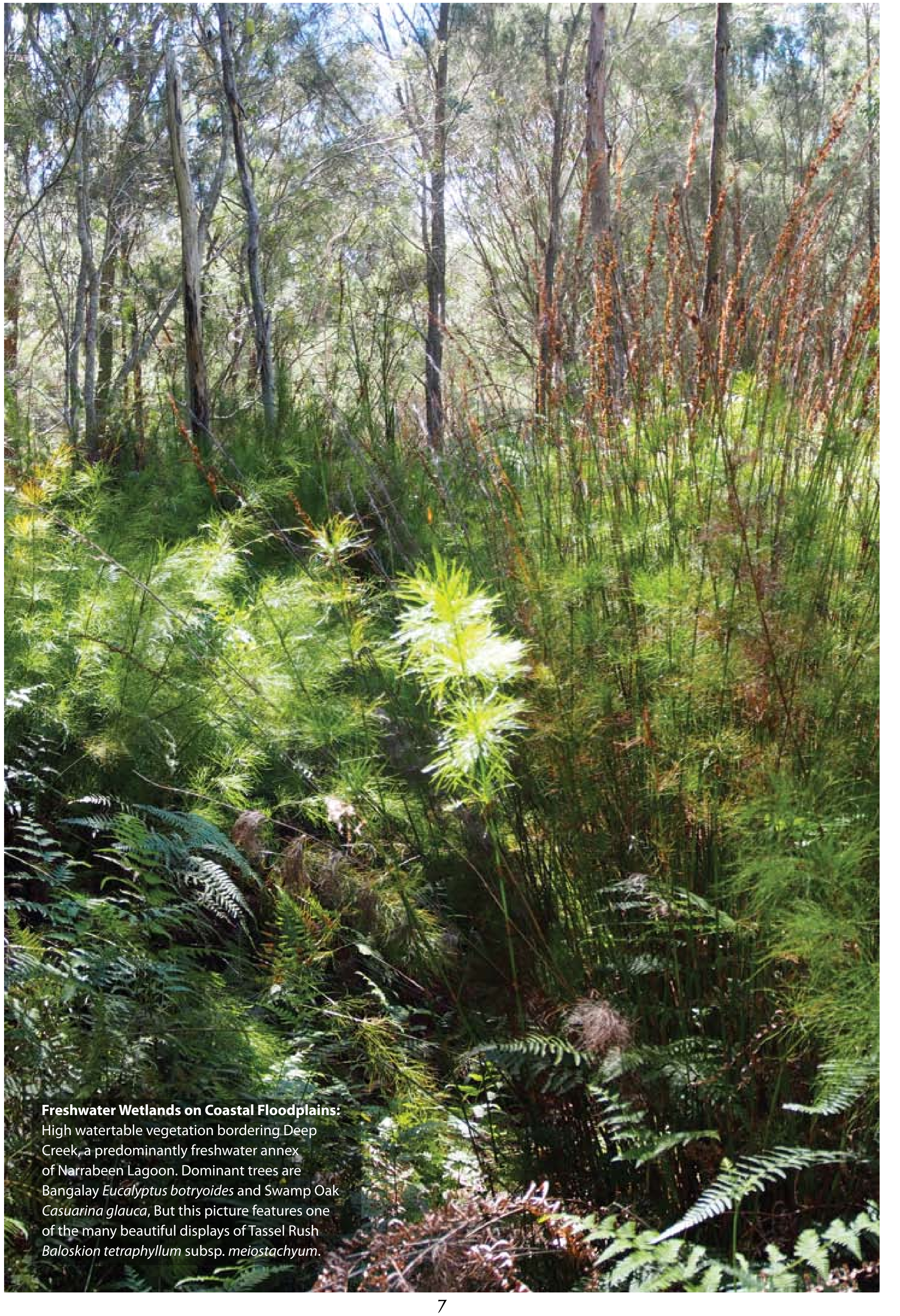
Duffys Forest Ecological Community – status endangered.[51,67] Favours lateritised ridgetops where capped by Mittagong Formation and shale lenses. Key tree species is Brown Stringybark *Eucalyptus capitellata* though *E. oblonga* more common. *Grevillea caleyi* a key endemic species. The community is rich in Proteaceae species including Waratah.

Coastal Upland Swamps – status endangered.[49] Confined to drainage headwaters on Hawkesbury Sandstone plateaus and benches.[8] Florally diverse with many species of family Ericaceae plus *Banksia robur*; Proteaceae species in wet heath fringe; rushes, sedges, coral ferns and grasses. Examples on source tributaries of Salvation Creek on West Head draining to Lovett Bay on Pittwater.

Other swamps, wetlands and riparian vegetation communities – statuses various but most are in "threatened" categories. These vary from dune swales to swampy fringes and annexes of coastal lagoons plus the forests of high water table alluvial flats bordering the larger creeks and tidal inlets. Such communities in our area include **River-flat Eucalypt Forest – status endangered:** examples on Berowra Creek in the vicinity of Crosslands, and Cowan Creek in Ku-ring-gai Chase. **Freshwater Wetlands on Coastal Floodplains – status endangered:**[50] examples – Deep Creek bordering Narrabeen Lagoon (see opposite). **Swamp Sclerophyll Forest on Coastal Floodplains – status endangered:** best example the Swamp Mahogany *Eucalyptus robusta* forest of Warriewood Wetlands.

Blue Gum High Forest – status critically endangered. This tall forest community is dominated by Sydney Blue Gum *Eucalyptus saligna* with subordinate Blackbutt *E. pilularis*, Grey Ironbark *E. paniculata*, *Angophora floribunda* and other eucalypt species. generally hosted by Ashfield Shale but notably for our Georegion the fertile soils of the basaltic volcaniclastics of the Hornsby and Thornleigh diatremes.

Last but not least, the wonderfully diverse heaths, shrublands, woodlands and forests growing on Hawkesbury Sandstone. The thin, dominantly gritty, sandy skeletal soils of the Hawkesbury Sandstone are noted not only for the species diversity of their flora but also for the beautiful wildflower displays they host, most notably in August to October.



Freshwater Wetlands on Coastal Floodplains: High watertable vegetation bordering Deep Creek, a predominantly freshwater annex of Narrabeen Lagoon. Dominant trees are Bangalay *Eucalyptus botryoides* and Swamp Oak *Casuarina glauca*, But this picture features one of the many beautiful displays of Tassel Rush *Baloskion tetraphyllum* subsp. *meiostachyum*.

Geology outline

Narrabeen Group

The Narrabeen Group is the suite of sand, pebble, silt and clay rich rocks sandwiched between the coal measures below and the Hawkesbury Sandstone. You will sometimes hear the term "Narrabeen shales"[26] but in reality the group is dominated by sandstones, with lesser conglomerates, siltstones, laminites, mudstones, claystones, tuffs and paleosols and with true shale as a variant of mudstone, claystone and laminite.

At its base, the Narrabeen Group encapsulated the end-Permian mass extinction event at 252 Ma.[66] The plant ecosystems that created the earlier coal seams were terminally disrupted and pteridosperms, lycopods or lycophytes and equisetales dominated land vegetation for a while, in a paleolatitude that was borderline Antarctic. However the extinction event had led to a drastic warming of the climate that extended to such latitudes.[63-66]

The complete sequence of Narrabeen Group strata that reaches the coast at Sea Cliff Bridge north of Wollongong is dominated by three thick sandstones separated and overlain by mudrock-rich suites. The youngest and thickest of these, the Bulgo Sandstone, submerges northwards then rises above the waves at the outer tip of Long Reef Point (and probably also Little Reef offshore from Bungan Head). It's overlain by the Bald Hill Claystone, a redbed, and a remarkable rock by any definition consisting of successive weathering horizons developed on bedded volcaniclastics af alkali andesite affinity.[63-65] This suite, of 18 m thickness at Long Reef but much thicker at depth offshore,[57] is followed by estuarine and deltaic sands, gravels, silts and clays forming the Newport Formation. A thin intervening Garie Formation, an airfall tuff,[18] missing at Long Reef, reappears further north in cliffs and rock platforms from Turimetta to Mona Vale and Bilgola headlands.

1: Part of a cliff section at Turimetta Headland that touches on three formations of the Narrabeen Group. A little of the red-brown Bald Hill Claystone sneaks in bottom right, followed by a thin representation of the purple-grey Garie Formation. This passes upwards into well bedded purple and grey Newport Formation claystones, laminites and thin sandstones.

2: Planed-off curvilinear bedding traces of uppermost Bulgo Sandstone cross Long Reef to disappear under wave-cast blocks thrown from sub-sea outcrops of the same formation.

Hawkesbury Sandstone

In stratigraphic name terms, the Hawkesbury Sandstone[14,31,72,77] is a stand-alone rock unit and not part of any group like the Narrabeen, though in the Hawkesbury Valley its base intergrades and interfingers with the underlying sandstones of that group,[31] a transition commonly marked by a break in slope. It is Middle Triassic in age, about 235 Ma, and up to 280 m thick though usually less.

More than 90% of the Hawkesbury Sandstone is medium to coarse grained sandstone, sometimes with small vein-quartz pebbles or granules. It is of fluvial origin, deposited on a vast Triassic braid plain.[31] Quartz is the dominant mineral of the sand grains, with subordinate grains of claystone cemented by a variable combination of clays, the iron carbonate mineral siderite, iron oxides both primary and secondary plus secondary silica.

The sandstone takes two broadly defined forms: massive and sheeted. Massive sandstones have a higher content of lithic grains and occur in thick units often with irregular, erosional bases. They tend to form bluffs, buttresses and extensive, distinctive and physiographically important flat rock platforms and benches with case-hardened crusts. The sheeted sandstone is strongly layered and features multiple sets of cross beds.

Ferrous carbonate cement is most apparent where recycled as hydroxide, forming multiple, overlapping sets of liesegang rings. The younger process of case hardening is apparent in almost all smooth-capped outcrops and may appear as a hard, biscuity shell where caved, undercut or honeycombed.[76] Fragile "drum caves" may occur.

Lenses of mudstone, shale, siltstone and laminite make up a small part of the sandstone's thickness mostly towards its top. They are usually less than 5 m thick though a large lens at Duffys Forest was recorded up to 35 m. The up to 8 m thick lens of mudrocks formerly quarried for ceramics at Beacon Hill yielded a large range of fossil fish species[30,31,75] and represents a stranded lagoon in what must have been a large river system to carry such a diverse aquatic fauna.

Hawkesbury Sandstone and Newport Formation

1: One of the many striking sandstone cliffs and cuttings along the M1 Motorway north of Berowra. The sharp change of light colour over dark may be the Hawkesbury Sandstone/Newport Formation contact though that is not confirmed.

2: Hawkesbury Sandstone cliff face at West Head viewed from Pittwater. It's extraordinary how big and strong Sydney Red Gums can grow in such a barren, rocky setting.

3: View across the water from Brooklyn. Though north of our area, it illustrates the sandstone on sandstone setting of the lower Hawkesbury estuary. The wooded lower cliff face is massive sandstone of the Newport Formation. Hawkesbury Sandstone forms the hill perched above the distinct break in slope.

Soils and laterites

Soils are important in governing the growth of plants and the distribution of vegetation communities. In a geologically simple landscape dominated by sandstones, shale, and small areas of volcanic rock a great deal of soil variation would not be expected but that simplicity enabled researchers at Macquarie University to focus on factors other than rock weathering and to revise conventional models of soil genesis[56].

In the past soils were described and explained with reference to the vertical relationship between soil horizons (a 'soil profile'). The Macquarie researchers found that it was more meaningful to consider discrete bodies of identifiably different soil materials distributed as 3-D entities across the landscape. Such patterns demanded different explanations and involved recognition of soil forming processes that had not previously been fully considered. Discrete soil bodies could be dealt with using an approach that had more affinity with the geological concept of stratigraphy than conventional pedology and this approach was successfully adopted by the Soil Conservation Service of NSW in mapping Soil Landscapes.[12]

In the Ku-ring-gai area Hawkesbury Sandstone is the most common rock and soil mapping recognized that it was the parent material to the soils in seven different soil landscapes. The most important of these was the Hawkesbury Soil Landscape which consists of steep, benched hills, broken by sandstone outcrop. Surveyors found five different bodies of soil material occurring in particular landscape positions, of which the topsoil (A1-horizon) was loose quartz sand, with a single grained structure, a high porosity, and which was often water repellent. Stratigraphically this topsoil overlay the four other materials and little weathered bedrock, and it could be shown to be an extensive blanket or soil mantle distributed almost all over the landscape. Different vertical combinations of layers created more than eight identifiable soil profiles.

Hawkesbury Sandstone is the main parent material in six other Soil Landscapes on plateau tops, ridge crests, slopes, and on valley floors and in these a total of 15 different profile types were recognized.

How can a single rock type which weathers to sand and a little clay produce such variety? The answer lies in considering two sets of process that have largely been ignored in the past. These are to consider erosion processes as an essential part of soil formation, and to take greater account of the role of plants and animals in soil formation.

Setting aside landslides and rock falls, the most common erosion process on local hill slopes is sheet erosion driven by overland flow during rainstorms. The rate of erosion varies with storm intensity and effective ground cover. It is greatest in the first storms after bushfires when the surface of an entire hillslope can be mobilized and moved down slope until the soil is held back by litter dams and/or regenerating ground cover vegetation.[45] But sheet erosion can occur at any time that bare mineral soil is exposed at the surface and this is where biological interactions need to be considered. The most important of these are actions by plants or animals that disturb surface soil and expose loose material to the effects of rainsplash and rainwash. Burrowing organisms such as ants, termites, worms and cicada do this very effectively. Falling trees are also important, and some of the highest rates of soil disturbance have been recorded for lyrebirds in another sandstone landscape in the Blue Mountains where they turned over 45 tonnes of mineral soil per hectare per year.

Soil mixing by organisms can operate from the surface to many metres depth (termites) but generally is in the range of 200-300mm. This is typically the thickness of the topsoil (biomantle) and the combination of soil mixing and surface erosion provides an explanation of why the biomantle can be identified as a discrete layer.

A majority of the soils in the Ku-ring-gai area, and in fact over much of Australia are described as having either a texture contrast or a fabric contrast profile in which a biomantle overlies a different material which is most often created by rock weathering in situ. Recognition of this relationship has been internationally significant.[6,56]

Another soil type that is of limited extent but reasonably common within Ku-ring-gai has a quite a different profile and a very close relationship with the plant communities that grow on it. This is a podzol (podsol), a profile type which is globally well known and found in older coastal sand dunes from Cape York to Tasmania. It had not been recorded in Ku-ring-gai as it is confined to deep deposits of alluvial sand in relatively closed basins, or on the margins of hanging swamps. It always has a distinctive vegetation community growing on it.[9] Common species include *Angophora costata*, *Banksia serrata*, and *Ceratopetalum apetalum*, which do grow elsewhere, but are known to be active podzol formers when growing on sterile sand.

The characteristics of a podzol are that the lower parts of the A-horizon are intensely bleached and lie over a complex soil pan where the accumulated sand is cemented by iron oxides. We now understand that these features are created when leaf leachates from particular plants react with the thin iron oxide coating present on the grains of yellow sand. The oxides are dissolved converting yellow sand to white sand, then this solution moves deeper into the profile where it breaks down precipitating an iron/organic complex to form the pan. The process first becomes apparent in the profile after about 2-3,000 years and as it continues the profile becomes deeper and the pans more complex.

The process is so effective that it can even occur in solid sandstone rock where thin bleached layers form above mini-pans. This raises the fascinating question of when is a soil a soil?

There are many answers to that question depending on the interests of the inquirer, a geologist will see soil quite differently from an engineer, a farmer, or an academic and these different perspectives often show up in the concept of 'fossil soils' or palaeosols.

The Ku-ring-gai area is well known for two types of 'fossil soil' that require some comment. The first are the laterites found on plateau remnants such as at Terrey Hills. Geologists don't have much issue with them but pedologists (academic soil scientists) have long regarded them as mature soil profiles now found well outside the environment where they were believed to have formed. In the late 19th Century laterites were defined as zonal soils resulting from intense tropical weathering. In the early 20th Century this model was extended to claim that they formed on tropical peneplains – a worn down landscape where chemical weathering was dominant and where erosion processes were reduced to practically nothing. Add the supposed presence of a fluctuating water table and you have a model that clearly did not apply to places like Terrey Hills therefore the laterite profiles had to be relics from a geological past (fossil soils) formed when the environment was seasonally tropical and the landscape was reduced to a plane surface near sea level.

That argument was extended to claim that if complete profiles were found intact on sandstone crests, then evidence of their former distribution could be seen in the abundance of ironstone clasts found in other parts of the landscape.

This genesis model generated a number of scientific papers and PhD theses. The problem of course is that the evidence does not stack up and the arguments supporting it are circular and untestable.

Never-the-less laterites exist in the Ku-ring-gai area. Are they ancient remnants or contemporary rock weathering features? Is there something unusual about the rock on which they are found? And is there any relationship between the laterites and the widespread occurrence of ironstones elsewhere in the landscape? These questions were addressed and it was found that laterites are contemporary, they are formed from sandstone beds that happen to have an iron oxide content up to 20%, and that the great majority of ironstone clasts are residual products of the contemporary weathering of other iron rich beds in sandstone or shale. These stone layer clasts can usually be traced to a local source.[33] The movement of iron oxides in solution in the Ku-ring-gai environment can be seen in numerous places where soil water or shallow groundwater reaches the surface in springs, seepages, and swamp discharge zones. Precipitation of iron rich slime is common with the processes presumably being mediated by organic chemicals from plants and bacteria.

The second oft-quoted example of fossil soils in the Ku-ring-gai area are the descriptions of middle-Triassic 'soils' and hypothesized vegetated landscapes described in the Narrabeen Group of rocks exposed in the coastal cliffs north of Long Reef.[62,63] The rocks in question contain numerous trace fossils of burrows, feeding trails and possibly plant root patterns, and they are associated with fragmentary plant fossils. A reasonable interpretation of the origin of some of these beds is that they represent sediments on the margins of streams or swampy estuarine flats that supported plants. They are however clearly sediments with preserved bedding planes and a complex assemblage of trace fossils. To call them soils or fossil soils depends on the investigator's idea of what a soil is and in this case it seems to be any deposit of sediment that supports plants. This minimal definition that would not be supported by most observers but to take the argument to another level where the palaeosols were named using modern soil profile nomenclature and to support their identification by applying specialized soil fabric descriptors leaves the reader wondering about the merits of the case.

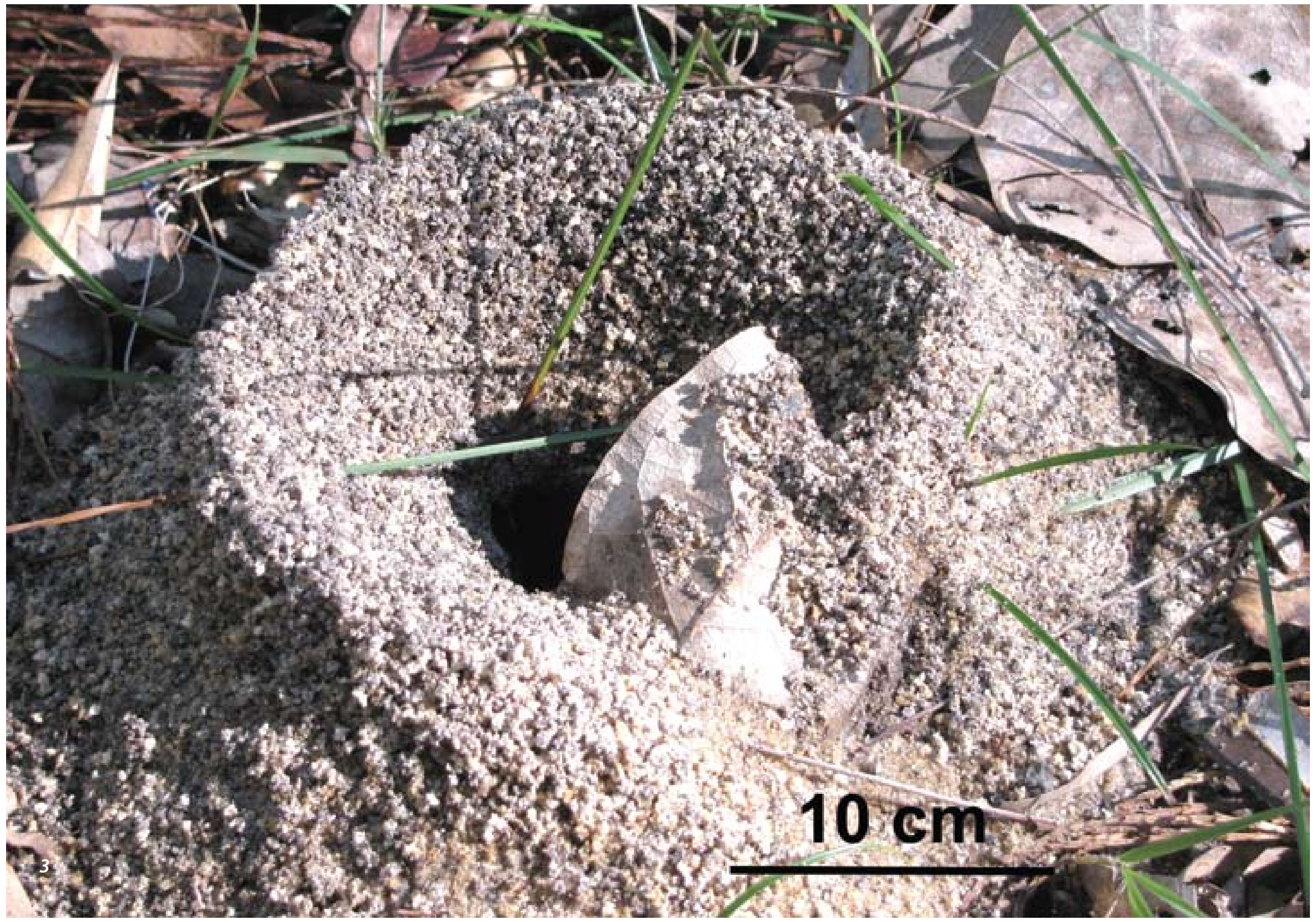
Soils and laterites

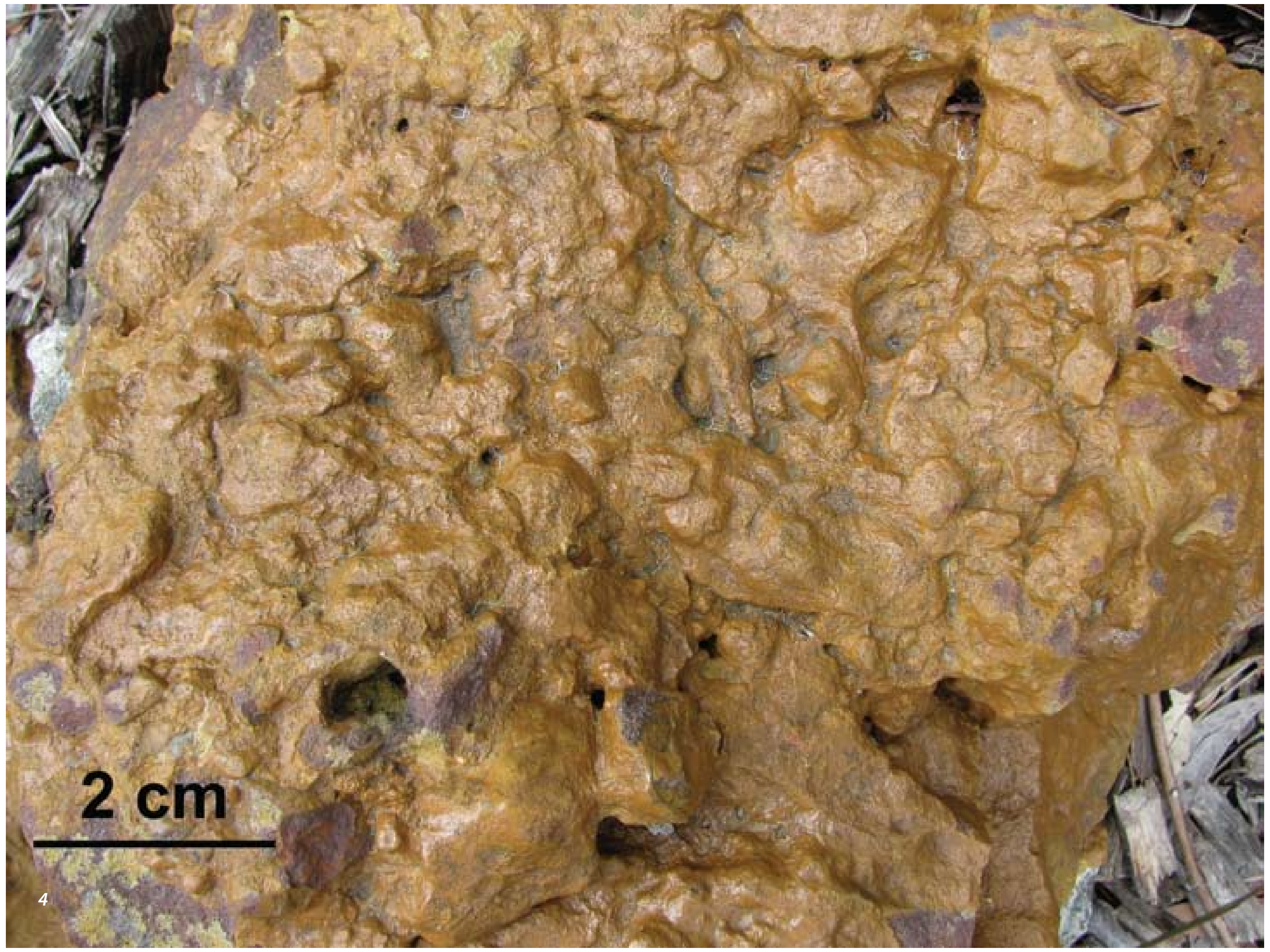
1: A strongly developed texture contrast profile in which the surface biomantle is derived from sandstone upslope and the subsoil (B-horizon) is weathered *in situ* from volcanic breccia.

2: Eroding soil held by litter dams formed by surface flow after a bushfire.

3: An ant nest bringing subsoil material to the surface and placing it on the litter layer. With the next rainfall most will be destroyed with finer particles moving further than coarser sand.

4: Goethite and limonite crust on a block of laterite.





Drowned valley of upper Cowan Creek viewed from the Centre Trail. The uniform summit level remnants of the Hornsby Plateau define the skyline.

Geologically young geomorphic features

The evolution of the landscape of our georegion is long and complex and, like most coastal regions globally, much influenced in its later history by sea level rise following the last glaciation. Most of the main body of the Ku-ring-gai area belongs to the southernmost sweep of the Hornsby Plateau, an old land surface that gradually rises in an arc north-westwards beyond our area, skipping across the northward-waning Lapstone Structural Complex and merging with the Lower Blue Mountains. The uplift of this surface was progressive and its early history dates back to the mid to late Cretaceous and a long period of weathering and softening of the landscape. Subsequent uplifts took place in the Miocene and Pliocene and even as late as Quaternary.[26] Rivers that meandered across the old land surface became entrenched as winding gorges, the technical term for which is incised meanders, and this includes most of the larger streams in the Ku-ring-gai Georegion. Smaller tributary streams were stranded in shallow valleys on the tableland surfaces, their larger parents cutting down at a faster rate. They now flow to them via

precipitous drops, either as tumbling rapids, a progression of small waterfalls or a single drop of several tens of metres, guided by the particular local character of the sandstone strata. These sharp breaks in slope marking the upstream progression of valley deepening are known as knickpoints.

Sea levels rose and fell many times during the Quaternary glacial era, peaking in the previous interglacial period 125,000 years ago when the sea was 4 to 6 metres higher than today's. Sea level again peaked around 1.75 metres above present around 6000 years ago[28] but the critical factor is how low it went in geologically recent times – actually around 125 metres below present roughly 20,000 years ago. The rise from that extreme low is what drowned the winding gorges and created the calm, dreamy, meandering waterways of our georegion.

The 6000 year ago peak sea level was also the benchmark for the sculpting and building of our present coastline, with the evolution of beaches, sandbars, tombolos, dunes and coastal lagoons and the carving of our current, still-retreating clifflines and our extensive wave-cut rock platforms.