Appendix A

Geological Setting

Narrabeen Group

Selected extracts from NSW DMR (2000) - p3, p10, p14, p49-70.

GHD

SOUTHERN COALFIELD

By R. S. Moffitt

Notes to accompany the Southern Coalfield Geology Map

MINERAL RESOURCES NEW SOUTH WALES

GHD

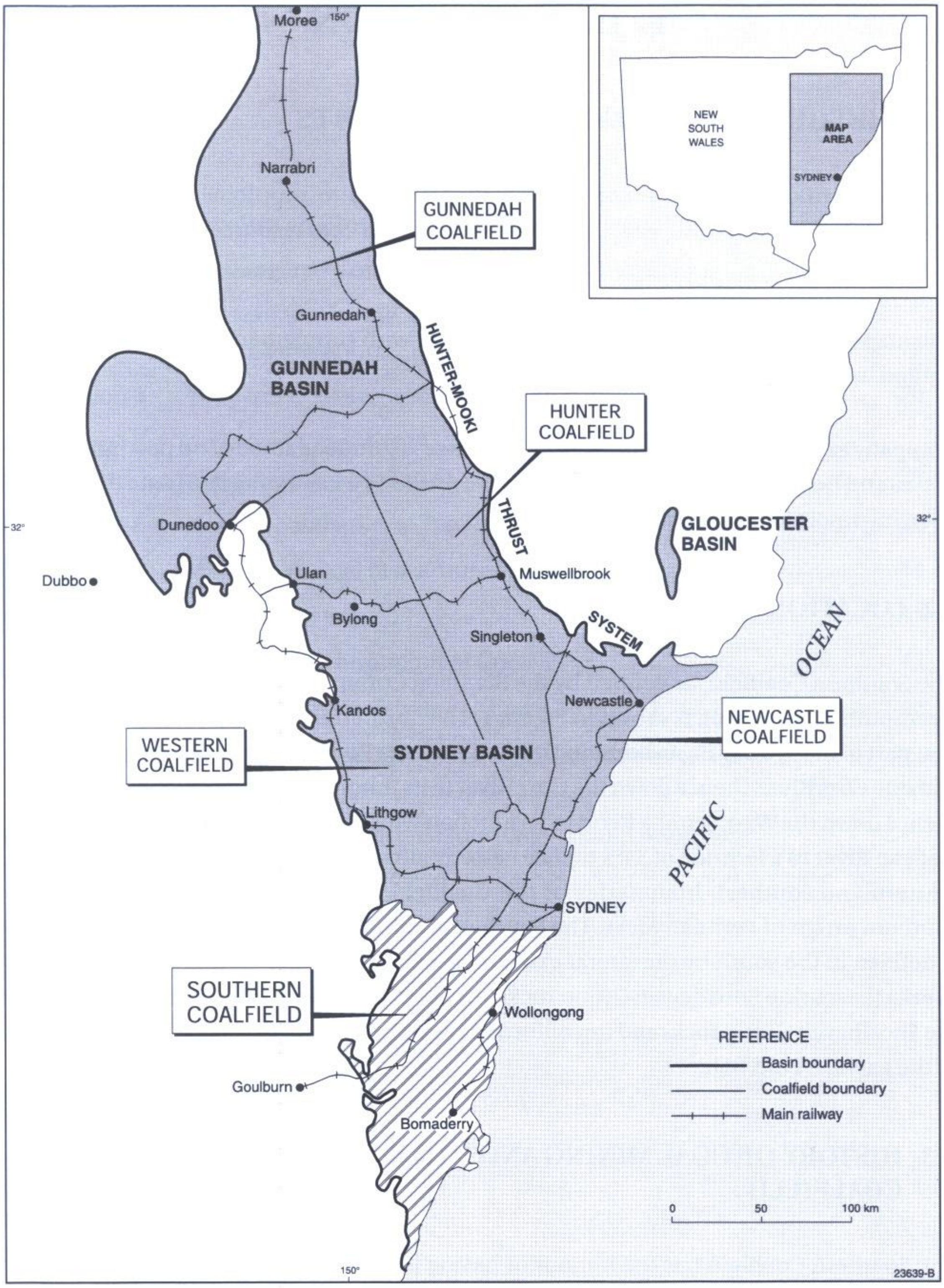

Figure 1. The Southern Coalfield of New South Wales (as defined by the Standing Committee on Coalfield Geology,1986).

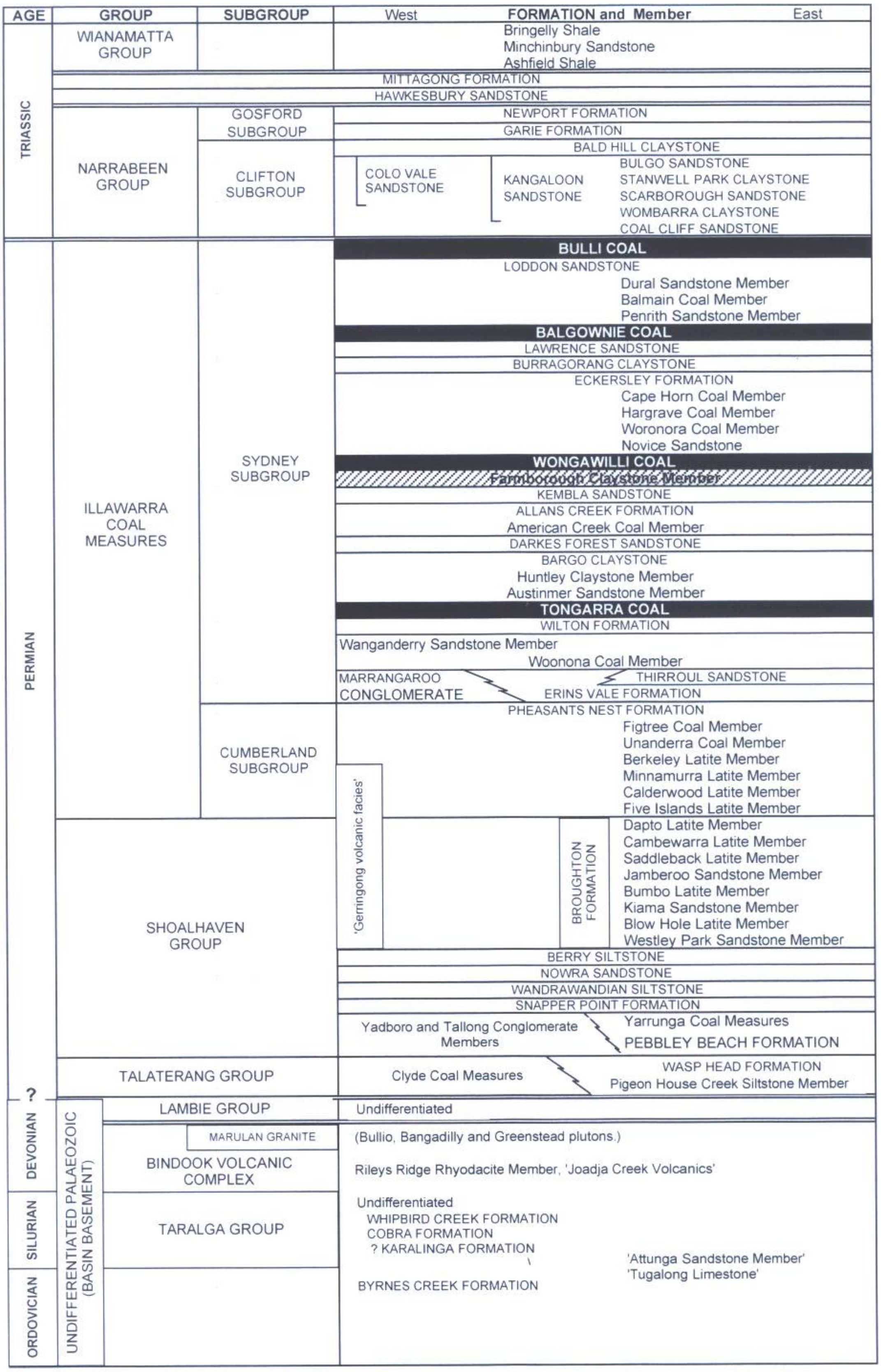

Figure 2. The stratigraphy of the southern Sydney Basin region.

Three major stratigraphic sub-divisions are recognised in the rocks above the Illawarra Coal Measures. These are:

» The Late Permian to Middle Triassic Narrabeen Group

» The Middle Triassic Hawkesbury Sandstone, and

» The Middle Triassic Wianamatta Group.

The correlation of the Narrabeen Group units in the Southern and the Western Coalfields is shown in figure 8.

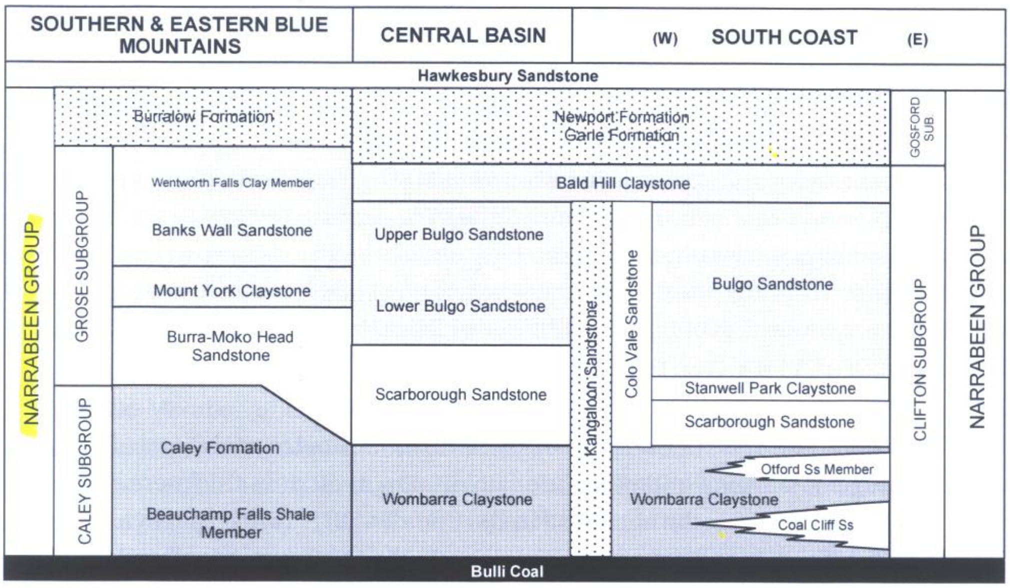

Figure 8. Correlation of the Narrabeen Group across the Western and Southern Coalfields (modified from Galloway & Hamilton 1988, table 1).

Narrabeen Group

The Narrabeen Group consists of two main subgroups, the basal Clifton Subgroup and the upper Gosford Subgroup (figures 2 and 8 herein). The Clifton Subgroup contains the basal Coal Cliff Sandstone with, in ascending order, the overlying Wombarra Claystone, Scarborough Sandstone, Stanwell Park Claystone, Bulgo Sandstone and Bald Hill Claystone. Facies changes within the Clifton Subgroup have resulted in the inclusions of the Kangaloon Sandstone and the Colo Vale Sandstone. The Gosford Subgroup contains the Garie and the Newport Formations.

The Coal Cliff Sandstone variably underlies and interdigitates with the Wombarra Claystone over most of the eastern part of the Southern Coalfield. In the central and southern parts of the Coalfield the sandstone is absent. South of Macquarie Pass, the sandstone becomes part of the Kangaloon Sandstone when the overlying Wombarra Claystone lenses out. The Coal Cliff Sandstone cannot be readily recognised in the west and southwest near Yerrinbool because of the considerable variation in thickness and persistent splitting by claystone bands.

The Coal Cliff Sandstone is a cliff-forming light grey, well sorted to moderately sorted quartz-lithic sandstone. It crops out from Coalcliff in the north where it is 10 m thick in the type section, and extends to Macquarie Pass in the south. The Coal Cliff Sandstone has been interpreted as fluvial channel deposits.

The Wombarra Claystone consists of up to 30 m of mid-green to green-grey to chocolate claystones with interbedded sandstone units. The sandstone content of the Wombarra Claystone increases towards the south and the west, ranging from less than 20% to greater than 60% at Burragorang, 70% at Yerrinbool and more than 90% at Avondale. With the increasing sandstone content the formation becomes increasingly difficult to recognise. Locally correlatable palaeosols also exist towards the top of the Wombarra Claystone.

The Wombarra Claystone crops out from Coalcliff in the north to as far as Macquarie Pass in the south, though is not developed south of Macquarie Pass. The Wombarra Claystone lenses out, or becomes more sandy, south of Avon Dam, becoming part of the Kangaloon Sandstone.

Rocks of the Wombarra Claystone record deposition in the lacustrine environment on the underlying subsiding Illawarra Coal Measures floodplain and coal swamps.

The Scarborough Sandstone, which is transitional from the underlying Wombarra Claystone, consists mainly of coarse, upward-fining volcanolithic channel deposits of sandstone and conglomerate interbedded with some siltstone bands. Fine-grained floodplain sedimentary units with minor coal bands cap some major channel facies. Planar crossbeds, trough crossbeds and graded bedding are common throughout the formation.

The Scarborough Sandstone crops out from Stanwell Park in the northeast to Avon Dam in the south and averages about 24 m in thickness. It is measured at 25.9 m in the type section at Clifton. [NSW DMR (2000) notes that to the south, and possibly west of Avon Dam, the Scarborough Sandstone cannot be recognised because the overlying Stanwell Park Claystone does not occur. Hence the Scarborough Sandstone and the Bulgo Sandstone cannot be separated, and the combined Scarborough Sandstone and the Bulgo Sandstone are termed the Colo Vale Sandstone. This is not the case within Dendrobium Area 3, in that the Stanwell Park Claystone has been recognised consistently in lithological logging of recovered core].

The overlying Stanwell Park Claystone crops out from Undola in the north to Avon Dam in the south but does not extend as far west as Yerrinbool or Camden. It consists of three main claystone intervals interbedded with two sandstone intervals. The claystone intervals, ranging from chocolate to mottled chocolate to olive green claystone and interbedded grey-green lithic sandstones derived from the east, are believed to be floodplain or lacustrine in origin. The degree of oxidation and palaeosol development suggests a significant deposition hiatus. The Claystone lenses out towards the south and west as the westerly derived alluvial plain sands from the Lachlan Fold Belt become dominant. The maximum thickness of the Stanwell Park Claystone is 79 m in the Sutherland area.

The Bulgo Sandstone, which disconformably overlies the Stanwell Park Claystone, is the thickest unit in the Narrabeen Group on the South Coast. It crops out from Garie Beach in the north to Avon Dam in the south and extends to Camden and Yerrinbool in the west. In type section at Clifton, it is about 119 m thick and at Avon Dam it is about 90 m in thickness.

The lower part of the Bulgo Sandstone is dominated by large braided channel and channel-fill deposits principally derived from the Lachlan Fold Belt. Those channel deposits generally fine upwards from coarse to very coarse pebbly sandstone (predominantly quartzose) and polymictic conglomerate to occasional claystone channel-fill tops. The upper part of the Bulgo Sandstone is dominated by green sand-rich alluvial plain deposits, which are overlain by an upper unit of thinly interbedded sandstone, siltstone and mudstone laid down as floodplain/lacustrine deposits. The sandstone units in the top two thirds of the sequence are characteristically green, uniformly fine to medium-grained, and were derived from altered intermediate to basic volcanic rocks.

The Bald Hill Claystone, which conformably overlies the Bulgo Sandstone, is the uppermost unit of the Clifton Subgroup of the Narrabeen Group. It consists mainly of massive chocolate-coloured and cream pelletal claystones and mudstones, and occasional fine-grained channel sand units towards the base. Chocolate-coloured units are dominant in the sequence and show best development in the eastern-central and southern parts of the Southern Coalfield. They are believed to be interchannel floodplain, basin-centre mudflats and muddy channel-fill deposits laid down by easterly and south-easterly flowing mixed-load fluvial systems.

The Bald Hill Claystone ranges in thickness from 6 m in the Yerrinbool area to over 67 m in the Sutherland area. At its type section in the Bald Hill area, it is about 15 m thick. It varies to less than a metre near Budgong gap, finally lensing out to the west of Barrengarry Mountain. At its western limit, where the Bald Hill Claystone cannot be recognised, the underlying Kangaloon Sandstone is indistinguishable from the overlying Hawkesbury Sandstone.

The Garie Formation, which is the lower unit of the Gosford Subgroup, gradationally overlies the Bald Hill Claystone. It is one of the most characteristic, and best, marker horizons in the southern Sydney basin. It consists of cream, massive, kaolinite-rich pelletal claystone, which grades upwards to grey, slightly carbonaceous claystone containing plant fossils. It is present over all but the very marginal outcrops where it has been eroded prior to deposition of the Hawkesbury Sandstone. It is present in exposures from Mount Ousley to Otford. It thickens to the north, ranging from 0.6 m to 3 m.

Both the Bald Hill Claystone and the Garie Formation were deposited in the same or similar depositional setting.

The Newport Formation is the uppermost unit of the Narrabeen Group and overlies the Garie Formation. It consists dominantly of fine-grained sandstones, siltstone and minor claystones. The claystone and mudstone interbeds vary in colour from dark grey to cream to purple. The dark grey interbeds contain abundant plant fossils. The laminate towards the top of the sequence consists mainly of very fine sandstone and mudstone. The Formation attains a thickness of 50 m near Sutherland and is 18.4 m thick in the type section north of Garie beach. It lenses out near Macquarie Pass and is not recognised in the west at Yerrinbool.

TRIASSIC

Hawkesbury Sandstone

The Hawkesbury Sandstone crops out over much of the Illawarra area and forms cliffs along the Illawarra escarpment and around the Kangaroo Valley, and further west.

The Hawkesbury Sandstone is overlain by the Wianamatta Group and, in the Robertson-Kangaloon and Sutton Forest areas, by the Robertson Basalt and associated flows. To the north of Mount Kembla, the basal Hawkesbury Sandstone interfingers with the Newport Formation. To the south, where the Newport Formation is not present, it disconformably overlies the Garie Formation, the Bald Hill Claystone, the Colo Vale Sandstone, or the Kangaloon Sandstone. In the southwestern part of the Sydney basin it disconformably overlies the Illawarra Coal Measures.

In the Southern Coalfield, the Hawkesbury Sandstone ranges in thickness from 120m at Fitzroy Falls to 180 m at Stanwell Park and 120 m at Macquarie Pass. In DM Campbelltown DDH 4, near Minto, it is 230 m thick.

Two major facies are identified in the Hawkesbury Sandstone - a sheet facies and a massive facies. The sheet facies is characterised by small to large-scale, planar to trough, crossbeds that range from a few centimetres to 5 m or more. The massive facies characteristically exhibits massive bedding and is internally homogeneous in grainsize. The massive facies has grossly discordant lower surfaces (scour surfaces containing rip-up clasts) and planar, concordant upper surfaces.

About 90% of the Hawkesbury Sandstone is quartzose sandstone, with the remainder consisting of siltstone/fine sandstone laminate, siltstone, and claystone interbeds. The sandstone varies from moderately to poorly sorted, very fine to very coarse in grainsize, with the major part being medium-grained. Smooth quartz pebbles and rare lithic pebbles up to 40mm are present throughout the sequence, having accumulated especially as bed-lag deposits. Within the massive facies, mudstone clasts vary in size from flakes to 10 m long blocks. The interbedded laminate, siltstone and claystone generally occur in the top half of the sequence. They are lensoid, ranging in thickness from a few millimetres to more than 10 m, and are commonly several kilometres in length.

A strong uni-modal trend in crossbed directions in the Hawkesbury Sandstone indicates a predominant current direction towards the north or northeast. A fluvial environment of deposition is suggested for the Hawkesbury Sandstone, with the internal fabric of the sandstone being consistent with rising and falling flood cycles (comparable to the current depositional environment of the Brahmaputra River in India).

Mittagong Formation

The Mittagong Formation consists of the fine-grained quartzose sandstone interbedded with dark grey siltstone and laminate in beds up to 1 m thick. It conformably overlies the Hawkesbury Sandstone and in places appears to grade into it. It varies in thickness up to 6 m but averages about 2 m. The Mittagong Formation has not been identified within Dendrobium Area 3.

Wianamatta Group

The Wianamatta Group is the topmost unit of the Permo-Triassic sequence in the Southern Coalfield and represents the last phase of sedimentation directly related to the development of the Sydney Basin.

The Wianamatta Group occupies the central part of the Sydney Basin. It crops out in the Bringelly-Cobbitty-Camden-Campbelltown-Picton area and in the Moss Vale-Kangaloon area, with the thickest section of Wianamatta group reaching 304 m at Razorback, near Picton. Only about 15 m of the Wianamatta Group has been preserved in the Illawarra area and has not been mapped within Dendrobium Area 3.

Depositional history of the Permo-Triassic

Following abandonment of the Kembla depositional system, the thick Wongawilli Coal was deposited as a dominant fluvial system.

Renewed uplift in the New England Fold Belt and the resulting increase in the supply of detritus from the north, terminated coal formation in the Wongawilli Coal. Deposition then passed up-sequence into a generally basin-wide fluvial system dominated by braided fluvial system deposits in the north-eastern part of the Southern Coalfield (near Picton) and blanket-like, basin-wide coal deposition. The first appearance of the northerly sourced detritus in the Southern Coalfield is the braided channel deposits in the north near Picton and the floodplain / lacustrine deposits of the Eckersly Formation to the south of Stanwell Park.

Ongoing episodic detritus supply and the intervening periods of basin stability resulted in the deposition of the Burragorang Claystone (floodplain/lacustrine) and the Lawrence Sandstone (braidplain channel-fill). During the following period of stability the Balgownie Coal formed on the old braidplain surface. The next major period (pulse) of detritus supply deposited the Loddon Sandstone in the northern part of the Southern Coalfield, terminating the formation of the Balgownie Coal in the north. Following the cessation of detritus supply and during the ensuring period of renewed basin stability, the Bulli Coal and the Wombarra Claystone formed basin-wide.

Rapid climate change, more so than renewed uplift in the New England and the Lachlan Fold Belt, marked the drowning and therefore the termination of coal-forming environments in the Late Permian coal measures, and the deposition of the Wombarra Claystone interval. The mainly non-coal fluvial sediments of the Narrabeen Group, which were gradationally deposited across the upper parts of the Illawarra Coal Measures and the Wombarra Claystone, were derived from southerly prograding alluvial systems from the New England Fold Belt. These systems consisted mainly of alluvial fans which grade into extensive braided fluvial systems.

Volcanic centres (Cape Banks volcanic apron (?'Gerringong volcanic ridge')) off the present coastline immediately to the east supplied distinctive green volcanolithic sediment to the southern Sydney Basin. The Lachlan Fold Belt became a major contributor of detritus to the basin as sediment supply from the New England Fold Belt waned. During this major late Permian to Early Triassic episode, sediment was supplied from the east, the north and the west. At any one time there were two depositional systems commonly interdigitating across the basin. During this period a gross upward gradation from estuarine, meandering alluvial to braided alluvial and alluvial fan depositional environments, to well-drained alluvial plain deposits (green and reddish shales) formed the sediments of the Narrabeen Group.

Sedimentation patterns in the southern part of the Sydney Basin were markedly affected by continual uplift of the Lachlan Fold Belt during the mid-Triassic. This tectonic event led to erosion of Late Permian and Early Triassic sedimentary units in this part of the basin and resulted in deposition of the coarse-grained massively bedded quartzose Hawkesbury Sandstone over most of the basin.

A transition from braidplain sedimentation to predominantly alluvial floodplain sedimentation resulted from the cessation of uplift. The Mittagong Formation is a preserved remnant of the waning 'Hawkesbury Depositional Episode' The Wianamatta Group, which crops out over the northern half of the Southern Coalfield, is the uppermost unit of the southern Sydney Basin. It consists of a conformable sequence exhibiting a continuous succession of environments, grading upwards from marine to near-marine to predominantly alluvial floodplain.

IGNEOUS ROCKS

A large number of igneous bodies, which vary in age, form, lithology and stratigraphic emplacement, occur in the Southern Coalfield. Emplacement of igneous bodies into the coal measures has variably affected coal quality in many areas.

The oldest volcanic rocks in the Southern Coalfield are the Late Permian latite flows in the Broughton Formation (Shoalhaven Group) and the overlying Pheasants Nest Formation.

Syenite, diorite and gabbroic plugs, intrusive complexes and associated sills occur in the southern half of the Coalfield. They are considered to be part of the Late Triassic to Jurassic intrusive province associated with crustal extension in the Sydney basin and are probably derived from the same primary igneous source. These include Mount Jellore and Mount Flora (192 Ma), Mount Gibraltar (187 Ma), Mount Misery (from 48 Ma to 175 Ma) and Mount Gingenbullen (164 Ma to 184 Ma), and the Sutton Forest gabbro/dolerite. The thick syenite sill in the middle of the Wongawilli Coal at Mount Alexandra could also be of Jurassic age.

A series of alkaline intrusions were emplaced during the Tertiary in the eastern central portion of the Southern Coalfield. These plugs, sills, lopoliths and flows are known to adversely affect the coal measures at various localities throughout the Coalfield. Major intrusions, which are dated between 57 Ma and 26 Ma, include the Nolan Dolerite; Rixons Pass Teschenite, which crops out as a series of sills west of Woonona; Mount Nebo Monchiquite and O'Briens Monchiquite, which occur as sills at Mount Nebo where they were called the 'Nebo Sills') and the Cordeaux Teschenite which crops out near the Cordeaux dam (referred to as the "Cordeaux Crinanite" adjacent to Area 2). Many more smaller intrusions and flow remnants are present throughout the Coalfield.

A large number of dykes occurs in the Southern Coalfield, either separately or in swarms. Some are up to 5 km in length. Although the majority are less than 3 m in width, some, such as the Luddenham Dyke (olivine basalt), to the east of Wallacia, are up to 15 m. The dykes have approximately the same strike direction as most of the faults, and are along most of the dominant joint directions – that is, west-northwest to north-northwest. Most dykes are not obvious on the surface as they are strongly weathered, but they are commonly encountered in most underground coal mine workings. The majority of the dykes are considered to be Tertiary in age. Some silling within the coal seams associated with those dykes is also present in the Southern Coalfield. Columnar jointing in Hawkesbury Sandstone, south of Tugalong, suggests it has been affected either by an overlying extrusive igneous body which as been removed by erosion or by a nearby subsurface intrusion.

STRUCTURE OF THE SOUTHERN COALFIELD

The Sydney Basin is the southern part of the structural Sydney-Bowen Basin, a major structural basin extending from Batemans Bay in the south northwards to the central coastal region of Queensland. It is bounded by the Lachlan Fold Belt to the west, the New England Fold Belt to the north and northeast, and the 'Offshore Uplift' and possible volcanic ridges (including the Gerringong volcanic facies') to the east and to the southeast.

Historically, the southern Sydney basin was thought to have formed as a result of short-duration rifting in the Late Carboniferous to Early Permian and evolved as a foredeep to the New England Fold Belt. Structural domains and sedimentation patterns in this part of the Sydney Bain are bounded by major magnetic lineaments. These reflect the depositional processes within the Sydney Basin.

The Tomah and the Lapstone Monoclines and the Nepean Fault Zone are believed to have had a significant influence on sedimentation during the late Permian to mid-Triassic. Flexure on these structures during deposition and basin loading resulted in the thickening of sedimentation over those structures. The Lapstone Monocline, as well as the Coastal lineament, controlled the distribution of the Wianamatta group, delineating a fairly sharp western boundary, with only thin, elevated, erosional remnants to the west of this structure.

The major structure of the Southern Coalfield is an essentially linear zone trending north-northeast and south-southwest forming a prominent physiographic feature. Within this zone are the Lapstone Monocline and Fault System; the Nepean Fault Zone; the Glenbrook Fault (and monoclines and associated faults); the Oakdale Fault System and the Bargo Fault further to the south; and the small-scale Thirlmere Monocline. These are a series of sub-parallel, high-angle, discontinuous, *en echelon*, reverse faults resulting from both compression and wrenching (convergent wrenching) during the late Triassic - see Southern Coalfields geological sheet.

At the mine-scale, the area is dominated by normal faulting. The majority of these normal faults trend north-northwest - south-southeast and are generally parallel to the fold axes in the eastern section of the Southern Coalfield. The throws on these faults range up to 95 m (in Bulli Colliery) and can vary markedly along strike. The throw on some faults also increases with depth, suggesting that faulting was contemporaneous with sediment deposition. A set of west-northwest - east-southeast strike-slip faults has also been identified within the eastern sector of the Coalfield. These faults, which are thought to be reactivated normal faults, are a common phenomenon in the Coalfield, and are often associated with gas outbursts within collieries.

The most predominant regional structure identified in the Coalfield is the 'Lapstone Structural Complex'. This complex incorporates the Nepean Fault Zone in the south and the Lapstone Monocline in the north. This fault zone trends north-south and extends as far south as Tahmoor Colliery. It is a sinistral shear couple of a series of *en echelon* high angle reverse and normal faults.

JOINTING

Four sets of prominent joints occur in the Southern Coalfield. Their strike directions are 005^0, 055^0, 105^0 and 155^0. These sets are parallel to, and at right angles to, the principal fold axes in the region. The joint sets are probably tensional features resulting from stress relief after folding.

DOMING

There are at least ten structural domes in the central southern part of the Southern Coalfield. These are the Mount Lindsay, Mount Burke and the Mount Flora domes, Gap Creek Dome, Kells Creek Dome, Nattai Dome (Mount Alexandra) and the Mittagong Dome, the Bulli Dome, the Dural Dome near Albion Park and the Kemira Dome. Most of the doming in these parts of the Southern Coalfield appears to have resulted from emplacement of igneous bodies at depth. The Bulli Dome, however, appears to be associated with the termination of the Bulli Anticline and the Kemira Dome with the termination of the Kemira Anticline.

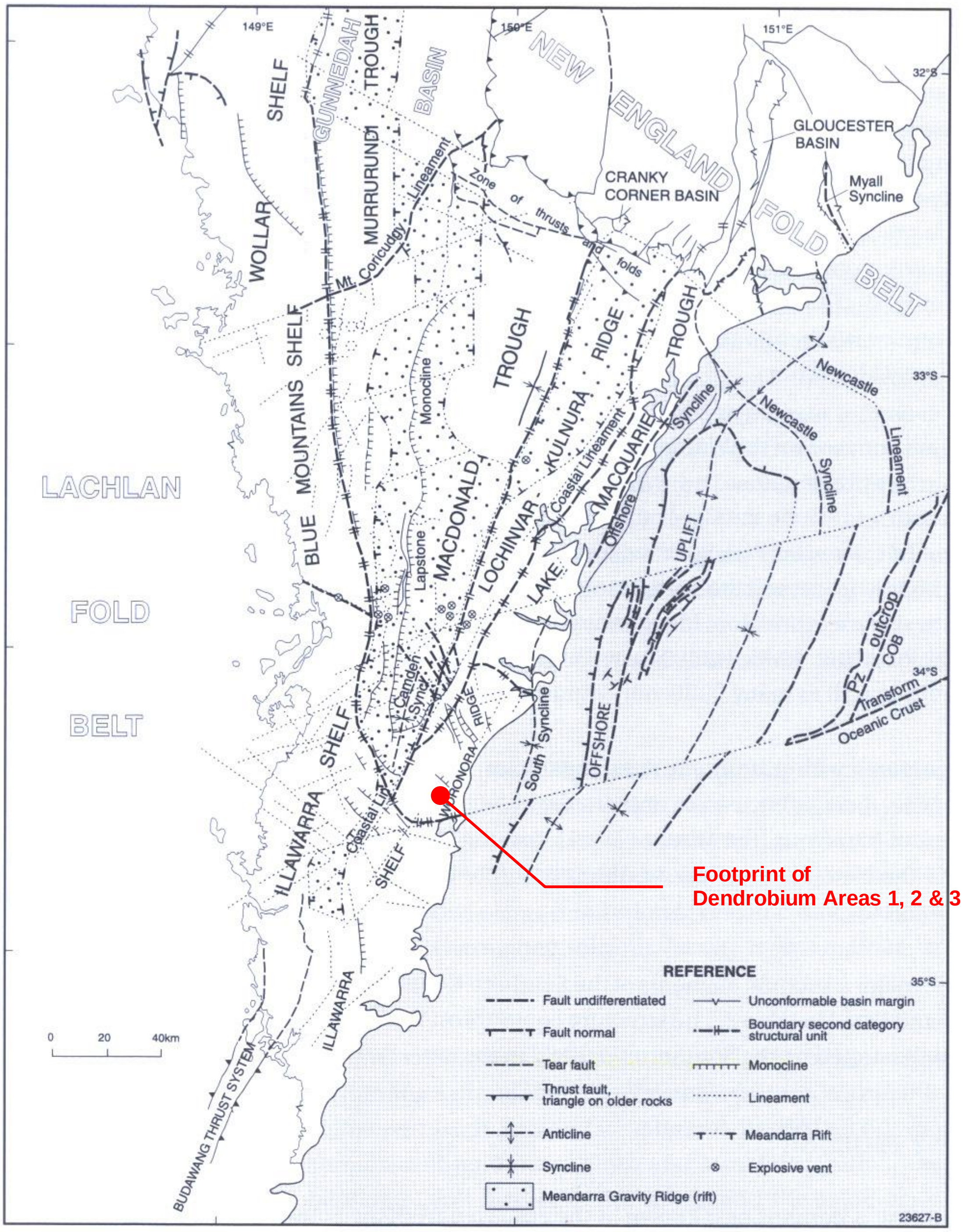

Figure 11. Schematic structural map of the Sydney Basin (after Scheibner & Basden (ed) 1996, figure 6.4A).

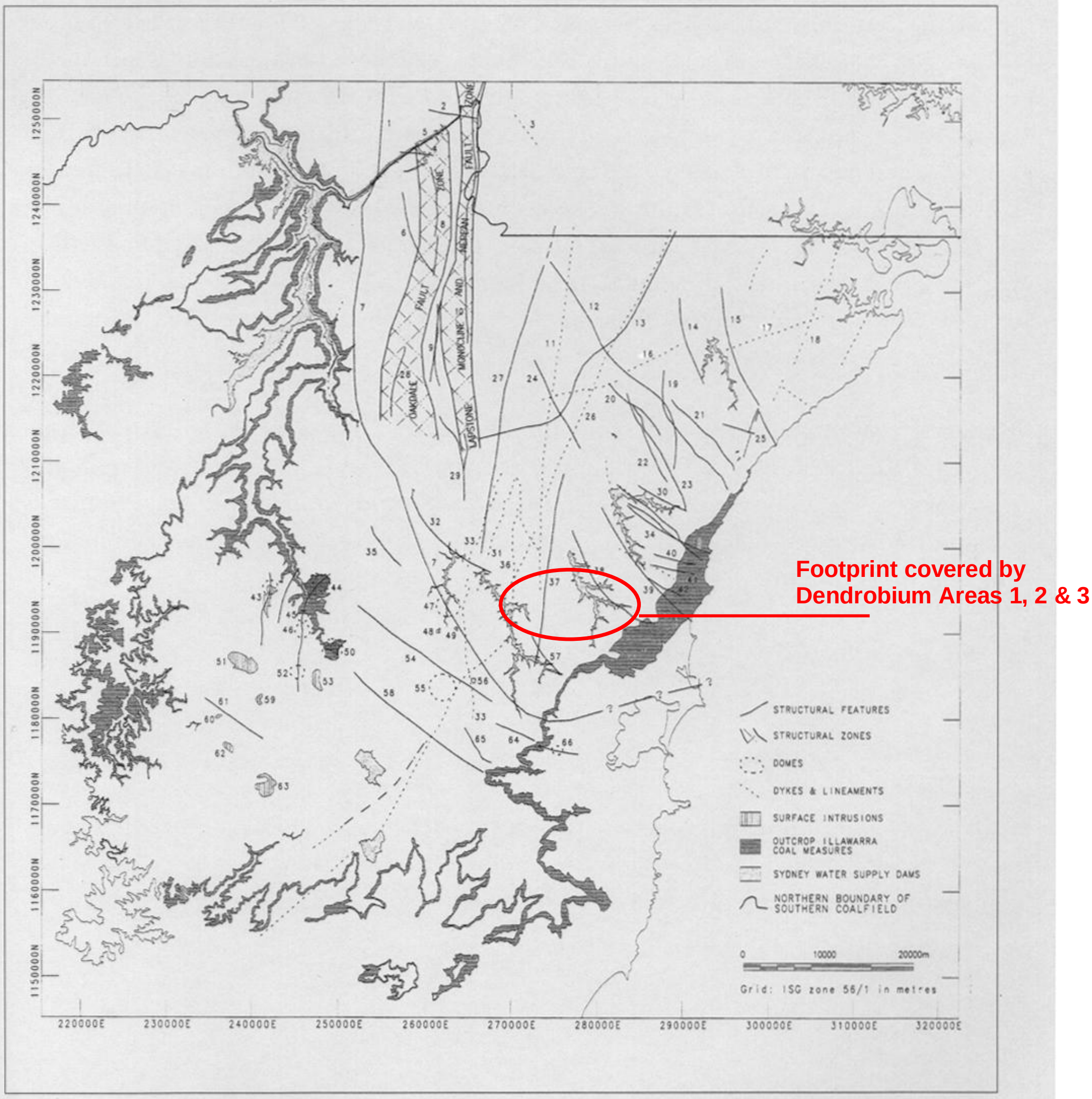

Figure 12. Major structural elements and intrusions in the Southern Coalfield.