CHAPTER 2

REGIONAL GEOLOGY

2.1 INTRODUCTION

The New England Fold Belt (Leitch, 1974) is one of the major structural elements within the extensive Tasman Orogenic Province, which comprises the eastern part of the Australian continent. The fold belt is composite and consists of a northern part which is separated from the relatively large southern part by arms of the Mesozoic Clarence-Morton and Great Artesian Basins (Figure 2.1). The rocks studied in this thesis are restricted to the southern part and further reference to the New England Fold Belt will henceforth ignore the northern portion.

2.2 STRATIGRAPHIC FRAMEWORK

Recent summaries on the plate tectonic interpretations and development of the New England Fold Belt have been presented by Leitch (1974), Runnegar (1974) and Scheibner (1976). Leitch (1974) divided the New England Fold Belt into two major structural and lithostratigraphic zones, A and B. Zone A [synonymous with the Western Belt of Folds and Thrusts (Voisey, 1958), Tamworth Trough (Crook, 1961) and Tamworth Shelf (McKelvey, 1974)] is a narrow, more-or-less meridional belt characterized by moderate folding, low-angle thrusting and zeolite-facies metamorphism. The rocks within Zone A are composed predominantly of volcanogenic detritus derived mainly from a western source, presumably a volcanic arc, situated along the western margin of this zone. Widespread ash-fall tuffs and continuous but relatively thin ash-flows provide convincing evidence that volcanism was contemporaneous with sedimentation during the Devonian and Carboniferous. The sedimentary rocks in this zone change upward and westward from older marine sandstones with minor intercalated coralline limestones in the east, through littoral and paralic sediments, to terrestrial conglomerates and alluvial sediments in the west. In the Woolomin district, 25 km southeast of Tamworth, the above regressive marine sequence unconformably overlies Cambrian and Ordovician strata. These underlying rocks (mainly argillites), estimated to be 1330 m thick (Cawood, 1976), contain limestone blocks yielding the trilobites *Ptychagnostus* and *Glyptagnostus*, brachiopods, and the conodonts *Prioniodina macrodentata* and *Periodonaculeatus*. Leitch (1979) estimated that the total stratigraphic thickness of Zone A approaches 12 km.

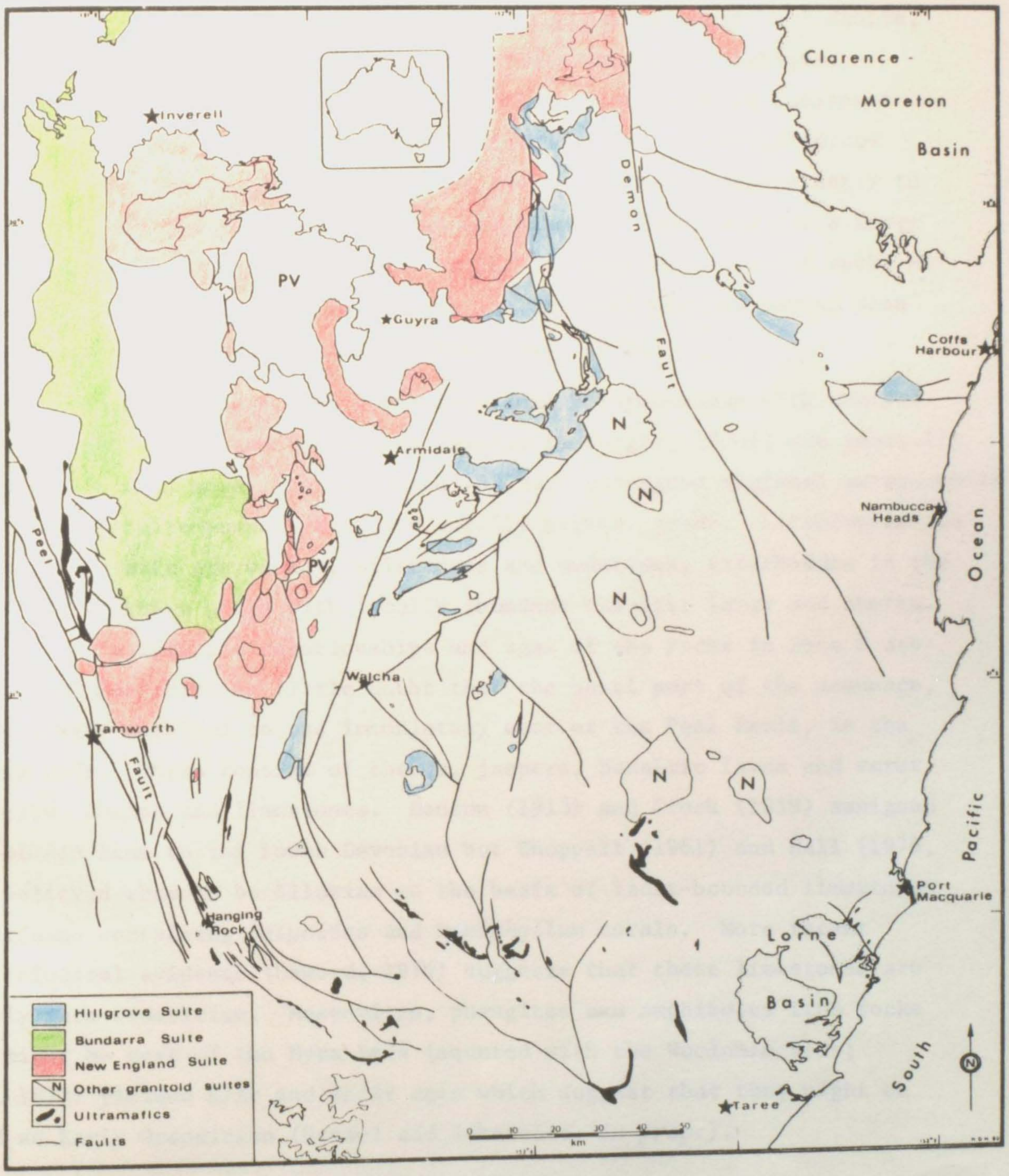

Figure 2.1 Distribution of granitoid suites and associated intrusives in the southern portion of the New England Batholith.

Zone B is separated from Zone A by an arcuate fault zone, the Peel Fault, which is characterized by large fault-bounded lenses and smaller pods of massive and schistose serpentinites (dominantly harzburgite and dunite, with minor lherzolite and wehrlite), mafic rocks (eucrites, gabbros, rodingites, dolerites, diorites), and a complex association of sediments enclosing exotic blocks of conglomerate and Ordovician to Carboniferous limestones. The actual (eastern) line of the thrust fault dips steeply to the east at ~ 65° (Price, 1970; Ramsay and Stanley, 1976) and has a large positive magnetic anomaly, presumably reflecting substantial mafic rocks at depth. South of Tamworth the fault line is less well-defined having been itself displaced and multiply folded (Scheibner, 1976).

Compared with Zone A, the rocks from Zone B [synonymous with Central Complex (Voisey, 1958) and Tablelands Complex (Runnegar, 1974)] are generally much more deformed, more tightly folded and have undergone regional metamorphism of at least prehnite-pumpellyite, and locally higher, grade. Lithologies are mainly volcanogenic greywackes, siltstones and mudstones, interbedded in the central and southern parts with locally abundant basaltic lavas and cherts. At present stratigraphic relationships and ages of the rocks in Zone B are poorly known but there is little doubt that the basal part of the sequence, forming a belt parallel to and immediately east of the Peel Fault, is the Woolomin Beds. These consist of cherts, jaspers, basaltic lavas and rarer greywackes, shales and limestones. Benson (1913) and Crook (1959) assigned the Woolomin Beds to the Lower Devonian but Chappell (1961) and Hall (1970, 1975) believed them to be Silurian on the basis of fault-bounded limestones near Attunga containing *Halysites* and *Maxiphyllum* corals. More recent paleontological evidence (Cawood, 1976) suggests that these limestones are probably Late Ordovician. Muscovites, phengites and amphiboles from rocks which might be part of the Myra Beds (equated with the Woolomin Beds; Mayer, 1972) yielded K/Ar and Rb/Sr ages which suggest that they might be as old as Early Ordovician (Hensel and Roksandic, *in prep.*).

2.3 SUBDIVISIONS OF ZONE B

Despite severe limitations imposed by paucity of data, severe deformation, poor exposure and absence of marker horizons, Leitch (1974) and Korsch (1977) recognized several major lithological associations within

Zone B. One of these is the Sandon Association [synonymous with the Middle-Upper Paleozoic greywacke-argillite-chert association (Leitch, 1974)], consisting predominantly of deep-water, intermediate, volcanoclastic greywackes, mudstones and minor cherts, jaspers, basaltic lavas and rare limestones. According to Korsch (1977) the distribution of this association is extensive and includes:

1. the majority of stratified rocks exposed between the granitoids from the Bundarra and New England Suites,
2. large fault-bounded blocks in the southern part of Zone B, and
3. the area around Armidale immediately east of the New England Suite.

The age of this association is debatable. The occurrence of *Lepidodendron* in these beds near Uralla and Armidale was interpreted by Crook (1958) to indicate an Early Carboniferous age; however, on the basis of additional plants (some of which may be allochthonous) Gould (*pers. comm.*) recommended a Late Devonian age, the age originally suggested by Voisey (1942). A fossiliferous limestone from the western part of this association was interpreted by Lusk (1963) to be Silurian; however, Korsch (1977) considered this limestone to be a possible fault sliver and therefore not related to this association.

The Coffs Harbour Association [synonymous with the Upper Paleozoic greywacke-argillite association of Leitch (1974)] is best developed north of the Bellinger Fault and consists of thick monotonous sequences of greywacke, siltstone and argillite. Although the greywackes are quartz-poor and largely featureless,Korsch (*op.cit.*) maintained that they were deposited by turbidity currents from a northwesterly, acid to intermediate volcanic provenance. He also claimed that this association forms the main stratigraphic sequence into which the granitoids from the Hillgrove Suite were emplaced, and argued that the regional metamorphic rocks from the Wongwibinda Complex (Binns, 1966) and Brackendale Metamorphics (Gunthorpe, 1970) are the metamorphic equivalents of this association.

The presence of cherts, sedimentary manganese and iron deposits, and basaltic lavas in close association with quartz-rich greywackes at Wongwibinda (and also with abundant orthoconglomerate at Moona Plains), strongly suggests that Korsch's assignation of these sediments to the Coffs Harbour Association is incorrect. This interpretation is supported by radiometric data (Chapter 3) which indicates that the quartz-rich sediments from these fault-bounded blocks (Figure 2.1) are at least of Devonian age.

The correlation between sediments near Rockvale, Enmore, Winterbourne and Tia with the Coffs Harbour Association, as suggested by Korsch (*op.cit.*), cannot at present be ascertained with any certainty; however, it is suggested that the lithological resemblance between these sediments and those near the eastern 'margin' of the Sandon Association [particularly east of Armidale (Traise, 1973)] is sufficiently close to imply that they may represent facies variations of the Sandon Association.

Despite comprehensive structural, sedimentological and metamorphic studies of the Nambucca Slate Belt (Leitch, 1972, 1974, 1975, 1976; Leitch and McDougall, 1979) the precise relationship between the sediments belonging to the Nambucca Association [synonymous with the Upper Paleozoic greywacke-argillite-paraconglomerate association (Leitch, 1974)] and those of the previous two associations is not known. In many instances, the relationship between the Nambucca and other associations is fault-bounded. For example, at Moona Plains, rocks of the Parrabel Beds (a rudaceous Permian unit within the Nambucca Slate Belt) have been clearly faulted against the Late Devonian Agnes Greywackes.

Although Korsch (*loc.cit.*) emphasised that plutons of the Hillgrove Suite do not intrude this association, pronounced contact metamorphic effects can be demonstrated across the Chandler Fault, separating the Abroi Granodiorite (Hillgrove Suite) from the undifferentiated sediments adjacent to the Styx River Beds (Collerson, 1967).

Sporadic occurrences of sediments, containing Early Permian (Allandale) marine fossils, at a number of localities west of the Nambucca Slate Belt was accepted by previous authors to imply a Permian age for these sediments (Voisey, 1950; Binns *et al.*, 1967; Runnegar, 1970, 1974; Leitch *et al.*, 1971; Pogson and Hitchins, 1973; Leitch, 1974; Scheibner, 1976; Leitch and McDougall, 1979). In Chapter 3 it is shown that the Permian age previously assigned to the sediments from the western part of the Nambucca Slate Belt is too young and that in fact they range in age from Early to Late Devonian. This age is more realistic in terms of observed granite-sediment field relationships and the proposed genetic relationship between these sediments and the generation of the Hillgrove Suite granitoids (cf. Binns, 1966). It implies however that major unconformities occur throughout this block, separating the fossiliferous Early Permian beds from the underlying Devonian strata. Degeling and Runnegàr (1979) recently speculated on the presence of such an unconformable relationship between some proximal, shallow-water sediments of the Halls Peak volcanogenic sequence and the underlying intensely deformed sediments of the Nambucca Slate Belt.

2.4 STRUCTURE

Although the underlying rocks are at times intensely deformed, the recognition of these unconformities in the Nambucca Slate Belt has been made exceedingly difficult because the most intense deformation in the New England region probably occurred during the mid-Permian (Leitch and McDougall, 1979) and thus affected both strata. Unfortunately, structural data on the rocks of Zone B are limited and any detailed information is then available only on a local basis. In summarizing the more important structural characteristics of this zone, Leitch (1974) noted many contrasts between the various blocks of this zone but found the following aspects particularly significant:

1. tight to isoclinal upright folds,
2. steeply plunging fold axes,
3. widespread axial plane slaty cleavage,
4. conglomerate pebbles commonly flattened parallel to cleavage and elongated parallel to fold axes,
5. changes in tectonic grain from easterly near the coast to more-or-less N-S in the Hillgrove Block.

2.5 IGNEOUS ACTIVITY

Although the Peel Fault, with its associated serpentinized ultramafics, mafic complexes and juxtaposed slivers of sediments of differing ages, is a very prominent and regionally significant structural feature there would probably be little debate that the most outstanding and impressive aspect of New England geology is its granitoid associations. Three major suites of granitoids, namely the Hillgrove, New England and Bundarra Suites, essentially comprise the New England Batholith *sensu lato*. Salient characteristics of the granitoids belonging to the Hillgrove and New England Suites have already been outlined in Chapter 1. The third group of granitoids, collectively termed the Bundarra Suite, flanks the western margin of the New England Batholith and is composed of massive, coarsely porphyritic, cordierite-bearing adamellites. Despite its 220 km extent along strike only five separate intrusions have been recognized in the Bundarra Suite (Flood, 1971; Morrow, 1974; Chappell, 1978). Radiometric ages of the Suite range from Mid-Carboniferous (Runnegar, *pers. comm.*) to Early Permian (Bofinger, 1969; this work; Flood and Shaw, 1977) and thus they compare closely with the age for the Hillgrove Suite. On the basis of its chemistry and mineralogy the Bundarra Suite has most probably been derived by partial melting of pelitic parent rocks and is thus also an 'S-type' granitoid as defined by Chappell and White (1974).

Korsch (1977) suggested that a fourth group of granitoids, occurring mainly between the majority of Hillgrove Suite granitoids and the coast, but also near Tenterfield, northern New South Wales, be termed the Stanthorpe Suite. However, the distribution of these granitoids is extremely wide and therefore the intrusions are unlikely to represent a genetically related suite of granitoids. Hence, a non-genetic collective is preferred, e.g. the New England post-orogenic granitoid association (NEPOGA). Outcrop patterns of these granitoids are characteristically circular, and with the exception of the Carrai and Botumburra Granodiorites, the granitoids are felsic, Ca-poor types. As the preferred name for this association implies, these granitoids provide a minimum age of orogenesis in the New England region. Leitch and McDougall (1979) dated some of these granitoids in the Nambucca Slate Belt and showed that the thermal effects from these plutons clearly overprinted many of the D_1 - D_4 structures formed during the last main orogenic (mid-Permian) period in New England. In addition, some of these post-orogenic granitoids (e.g. Botumburra Range Granodiorite) truncate post-orogenic faults which Leitch (1976) considered to be associated with granite emplacement.

A very distinctive and previously undocumented series of tholeiitic intrusives, characterized by olivine gabbros, diorites and to a lesser extent granophyres, occurs along the entire eastern margin of the New England Batholith. Their close spatial relationship with the Hillgrove Suite has been erroneously interpreted by previous authors (e.g. Binns *et al.*, 1967; Pogson and Hitchins, 1973; Scheibner, 1976) as evidence in favour of a genetic relationship. However, the intimate occurrence of these mafic rocks with the Hillgrove Suite is a function of deep crustal fractures, presumably created during the Early to Mid-Permian orogeny which uplifted and deformed the granitoids of the Hillgrove Suite. Although these mafic rocks are not volumetrically impressive at the present level of exposure, their relative abundance at depth is suggested by the laterally uniform chemical and isotopic compositions (Chapter 7).

Several smaller intrusive complexes, also occurring along this eastern margin of the Batholith, display calc-alkaline affinities and are interpreted as tholeiitic intrusives which were contaminated at depth by small amounts of hydrous, felsic melts. H.K. Herbert (*pers.comm.*) has also mapped and described numerous small mafic complexes in a N-S trending belt east of Tenterfield (northern New England). These mafic complexes generally closely resemble those associated with the Hillgrove Suite; however, some of the complexes appear to have mildly alkaline affinities.

As noted earlier, mafic intrusives are commonly associated with serpentinites along the Peel Fault. To date, the genetic relationship of these intrusives with the serpentinized ultramafics has not been convincingly established. Despite this, the occurrence of gabbros, dolerites, basalts, cherts and serpentinites in close proximity to each other at Snake Gully, Nundle and at Port Macquarie have been interpreted respectively by Cross (1974) and Scheibner *et al.* (1976) as representing partial or dismembered ophiolite sequences. Crook and Felton (1975) also suggested ophiolitic affinities for similar rocks from the Pigna Barney (Mayer, 1972) and Barry Complexes (Heugh, 1971).

The age of these mafic intrusives is not known, largely because contacts with country rock are generally obscured by either extensive weathering or by posthumous faulting. The absence of thermal metamorphism adjacent to the serpentinites strongly suggests that emplacement of the ultramafic rocks along the Peel Fault was strictly tectonic and post-serpentinization. Lanphere and Hockley (1976) suggested that the emplacement age of the serpentinites was close to 275 m.y., based on K/Ar determinations on nephrites resulting from low-temperature reaction between serpentinite and phyllitic country rock.

Additional manifestations of intrusive activity which are possibly related to the development of the Peel Fault are a suite of trondhjemites and granodiorites (Chapter 6). These granitoids are characterized by high SiO_2,

Al_2O_3, Na_2O and Sr but low K_2O, Rb, Ba and Y and are therefore readily distinguished from granitoids belonging to any of the major granitoid suites. Their characteristically low initial $^{87}Sr/^{86}Sr$ ratios ($\sim$0.7035 - 0.7040) are typical of granitoids derived from an isotopically primitive source.

Covering some of the granitoids of the New England Batholith west of Guyra is a relatively extensive veneer of felsic and intermediate extrusives comprising mainly ignimbrites, pyroclastics and rhyolitic to dacitic lava flows (Langham, 1973). Compositionally similar volcanic extrusives, known as the Emmaville Volcanics, also blanket many granitoids north and northwest of Glen Innes (Godden, 1980). In addition, Herbert (*pers.comm.*) described andesitic lavas of the Drake Volcanics interdigitated with more felsic extrusives in the northern part of the batholith. Although chemical data for many of these volcanics are sparse they might represent extrusive equivalents of the New England Suite. Unfortunately their precise (total rock) age has not been established. Leitch (1974) considered these volcanics to be Early Permian, based on the suggestion by Bunker *et al.* (1969) that they unconformably overlie sediments of the Sandon and Nambucca Associations, but show a conformable relationship to terrestrial Permian sediments north of Armidale (McKelvey and Gutsche, 1969). Assuming this is correct it implies that these terrestrial volcanic sediments predate the intrusions of the New England Suite, for which a crystallization age of ~ 265 m.y. has been inferred (Chapter 4).

Almost 200 m.y. separates the above igneous activity from the Tertiary basaltic activity which covered much if not all of New England with predominantly mafic alkaline lavas and olivine tholeiites in a number of areas. The alkaline rocks are characterized by high-pressure phases such as olivine, orthopyroxene, clinopyroxene, anorthoclase, kaersutite and spinel megacrysts, and Cr-diopside lherzolite xenoliths may be locally abundant. Dunite, harzburgite and rare pyroxenite xenoliths are also known. Binns (1969), Binns *et al.* (1970) and Wilkinson (1974) have summarized the germane aspects of the mafic extrusives in relation to certain provinces.

2.6 METAMORPHISM

All pre-orogenic stratified rocks from New England display mineralogies indicating that they have been at least incipiently metamorphosed. In Zone A the most obvious mineralogical changes are recorded in volcanic sediments containing a significant volcanic glass component (Packham and Crook, 1960;

Wilkinson and Whetten, 1964; White, 1966; McKelvey, 1966). Metamorphic assemblages range from those appropriate to zeolite to prehnite-pumpellyite facies and are largely a direct response to deep burial.

In contrast, many of the pre-orogenic sediments from Zone B have been metamorphosed at conditions indicating higher pressure and/or temperatures than Zone A. For example, between Tia and Port Macquarie basaltic lavas have developed a crossite-stilpnomelane-pumpellyite assemblage suggesting pressures of at least 4-5 kb (Gunthorpe, 1970). At Port Macquarie grossular-glaucophane-lawsonite-omphacite-epidote-phengite assemblages imply high-pressure but low-temperature metamorphism and are therefore similar to the glaucophane-lawsonite-bearing rocks from the Franciscan and Sanbagawa Belts (Banno, 1964; Ernst, 1965; Essene *et al.*, 1965; Turner, 1968). Intense faulting at Port Macquarie has juxtaposed the Silurian glaucophane-lawsonite schists against Permian greenschists (Hensel and Roksandic, *in prep.*). At Pigna Barney the Early Ordovician glaucophane-phengite blueschists are lawsonite-free. This suggests either lower-pressure conditions of metamorphism than at Port Macquarie, or more likely, a calcium-poor rock composition.

The original parent rock to both the Port Macquarie and Pigna Barney blueschists cannot be ascertained with certainty. Whole-rock chemistries and mineral assemblages suggest that the parent rocks were probably basaltic. The very high initial $^{87}Sr/^{86}Sr$ ratios of these blueschists (~ 0.7100) may seem anomalous; however, in the absence of any rock type in New England with such a high initial $^{87}Sr/^{86}Sr$ ratio, it is suggested that these original basaltic rocks may have equilibrated with sea-water. K/Ar and Rb/Sr ages of the blueschist rocks from Pigna Barney and Port Macquarie are the oldest crystalline rocks yet dated in the New England Fold Belt and hence implies a lengthy orogenic history for this region.

Metamorphism at low pressures but high temperatures on both contact and regional scales is widespread in the central parts of New England where the concentration of granitoids is particularly high. Most New England Suite granitoids show distinct thermal effects on the country rocks. Albite-epidote hornfelses give way to hornblende hornfels assemblages close to the contacts (Chappell, 1961; Binns, 1965) and wollastonite marbles, diopside hornfelses and skarns are well developed in calcareous rocks adjacent to quartz monzodioritic plutons (e.g. Horse Arm Creek, Attunga). In contrast, plutons belonging to the Hillgrove Suite display a dichotomy of metamorphic aureoles:

one type resembling a high-grade regional metamorphic terrane and the other showing only very mild thermal effects on the adjacent sediments.

Apart from xenoliths of country rock in the Kentucky mafic diorites, the highest grade of metamorphism developed in the stratified rocks is uppermost amphibolite facies. Rocks appropriate to this facies occur in the Wongwibinda, Tia and Moona Plains Complexes (Binns, 1966; Gunthorpe, 1970; Hensel, 1972, 1973) where pelitic and basic rocks have been transformed into high-grade schists and amphibolites respectively. The schists contain sillimanite, almandine-rich garnet, orthoclase and cordierite whereas the amphibolites collectively contain complex mineral assemblages including olivine, spinel, orthopyroxene, diopside, cordierite, anthophyllite and garnet in addition to amphibole and plagioclase. Stephenson and Hensel (1979) estimated P/T conditions of metamorphism at Wongwibinda to be in the range 2-4 kb and 650° - 700° C, based on coexisting cummingtonite-actinolite pairs, the absence of muscovite, and incipient melting in pelitic and psammitic schists.