NSW DPI

Quarterly Notes

Geological Survey of New South Wales

October 2007 No 126

# Geological units of the Port Macquarie–Tacking Point tract, north-eastern Port Macquarie Block, Mid North Coast region of New South Wales

## ABSTRACT

The Point Macquarie–Tacking Point coastline provides excellent exposures of the accretionary subduction complex and younger magmatic arc rocks that make up much of the New England Fold Belt (also known as the New England Orogen) in north-eastern New South Wales. Nine geological units, including six formally defined here (Port Macquarie Serpentinite, Rocky Beach Metamorphic Mélange, Tacking Point Gabbro, Town Beach Diorite, Nobbys Beach Lamprophyre and Sea Acres Dolerite), have been identified along this coastal tract. The Karikeree Metadolerite has been redefined. The oldest rocks are prograde lawsonite eclogite and retrograde blueschist blocks embedded in the chlorite–actinolite schist matrix of the Rocky Beach Metamorphic Mélange that occurs as a slab within the Port Macquarie Serpentinite. The Port Macquarie Serpentinite is a product of alteration of cumulate ultramafic rocks of a c.530 Ma forearc ophiolite. The Watonga Formation is a mostly broken formation that consists of Middle–Late Ordovician pelagic rocks, the mafic oceanic substrate on which these were deposited; younger basalt and olistostromes of probable ocean island origin; and tuff, siltstone and sandstone inferred to be trench fill accreted in the Late Ordovician–Carboniferous interval. Later intrusive rocks of probable Permian age are the geochemically similar Tacking Point Gabbro, Town Beach Diorite, Karikeree Metadolerite and Nobbys Beach Lamprophyre that are possibly related to the Clarence River Supersuite of the New England Batholith. Uncommon felsic dykes are considered minor components of the Middle Triassic leucoadamellite suite of the New England Batholith. Little-altered dykes of Sea Acres Dolerite, characterised by high Ti, Fe and Zr, are Late Triassic or younger.

***KEYWORDS: Port Macquarie, Port Macquarie Serpentinite, Rocky Beach Metamorphic Mélange, Watonga Formation, Tacking Point Gabbro, Town Beach Diorite, Karikeree Metadolerite, Nobbys Beach Lamprophyre, Sea Acres Dolerite, New England Fold Belt, New England Orogen, accretionary complex, high-pressure metamorphism***

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***Papers in* Quarterly Notes *are subject to external review. External reviewer for this issue was Paul Lennox. His assistance is appreciated.***

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**ISSN 0155-3410**

## Editorial Note

This paper provides a fresh look at one of the state's most geologically significant regions, where the action of plate tectonic, convergent margin processes is apparent. Igneous rocks were subducted to depths of ~60 km, where they were metamorphosed to high pressures and relatively low temperatures, and subsequently exhumed and returned to the surface in a complex major fault zone. Port Macquarie is the first reported locality of lawsonite eclogite in Australia, and one of few worldwide. Blocks of blueschist are more common and host the remnants of the retrograde eclogite. The association of blocks of high pressure–low temperature metamorphic rocks with serpentinite, basalt, chert and other sedimentary rocks — all indicative of plate tectonic, subduction-related processes — has generated much scientific interest in the Port Macquarie area. The Ordovician ages of the blueschists and cherts provide a tantalising insight into the older parts of the southern New England Fold Belt/Orogen, that is elsewhere dominated in outcrop by Devonian to Triassic rocks.

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## INTRODUCTION

The Port Macquarie Block is a small structural element of the eastern New England Fold Belt (also known as the New England Orogen) located in the Mid North Coast region of New South Wales (Figure 1). The block is very largely composed of deformed Palaeozoic sedimentary and igneous rocks that have undergone low-grade metamorphism (Leitch 1980a). The eastern third of the block is mostly slate, chert, mudstone, sandstone and basalt — part of the Palaeozoic accretionary subduction complex that occupies much of the eastern New England Fold Belt. Additionally, along the coastal tract extending 5 km south-southeast from the Port Macquarie township to Tacking Point, there are serpentinised ultramafic rocks, small gabbro and diorite plutons, mafic and felsic dykes, and mélange containing blocks of blueschist and eclogite. These rock units are unknown or only poorly outcropping in inland areas. The variety, excellent exposure, and ready accessibility of the coastal outcrops have attracted numerous geological visitors, especially since the advent of plate tectonics has placed particular emphasis on such rock assemblages.

The complex geology of the coastal tract, with its widespread serpentinite bodies and close spatial association of rocks of differing metamorphic grade and structural complexity, led to its interpretation as coinciding with a north-northwest to south-southeast fault zone (e.g. Brunker et al. 1970; Barron et al. 1976; Leitch 1980b; Gilligan et al. 1987; Scheibner & Basden 1998; Aitchison et al. 1994). However, detailed investigation along the coastal tract between Port Macquarie township and Tacking Point indicates that the rocks are a continuation of those found in the south, in the eastern third of the Port Macquarie Block. The seemingly greater geological complexity of the coastal tract is a reflection of the much better coastal exposure.

In this paper formal names are proposed for most of the igneous components and a revised definition of the Karikeree Metadolerite, previously defined by Leitch (1980a) is given. In addition, the Watonga Formation is shown to incorporate a wider variety of rocks than described by Leitch (1980a). The Rocky Beach Metamorphic Mélange (Och et al. 2003) is more completely defined, and the nature of the widespread serpentinite bodies of the Port Macquarie Block is discussed.

The Port Macquarie–Tacking Point area is a rapidly evolving urban area. This paper provides an indication of the range of rock types and, by implication, the geotechnical conditions likely to be encountered during major development. It is also a general guide to exposures along the coastline, and provides a common reference frame for the discussion of the tectonic significance of these important rocks in the broader setting of the geological development of the New England Fold Belt.

## PREVIOUS INVESTIGATIONS

Earlier descriptions of the geology of the Port Macquarie–Tacking Point district have generally been brief records indicating rock types and commonly concentrating on economically significant mineral occurrences. Carne (1897) reported 'altered sedimentary rock occurring in contact with serpentine and dolerite' between Port Macquarie and Tacking Point. He noted the presence of small amounts of colluvial gold, cobaltiferous manganese oxide, and magnetite and hematite. Lateritic iron, nickel and cobalt deposits were subsequently identified in Port Macquarie (Jaquet 1898), initially exploited for cobalt but later a source of iron ore utilised for gas purification (Pittman 1913; MacNevin 1975). Minor copper mineralisation was noted in the coastal section just south of Nobby Head as early as 1880 (MacNevin 1975).

Benson (1918) mapped several meridional serpentinite lenses surrounded by 'Permo-Carboniferous' rocks south of Port Macquarie. Voisey (1939) noted the presence of serpentinite, green tuffaceous rocks and greenish grey mudstone, phyllite and intrusions of basic rock from the Port Macquarie area. Quodling (1964) reported native iron from a rock she considered a metamorphosed impure chert and first recorded the assemblage quartz–garnet–glaucophane–lawsonite from Port Macquarie. Wilkinson (1969) recorded harzburgite, lherzolite and orthopyroxenite as the protoliths of the serpentinite at Port Macquarie.

Brunker et al. (1970) mapped (?)lower Palaeozoic 'schist, phyllite, greywacke and slate' containing lenses of serpentinite and dolerite in an area extending 20 km southwest from Port Macquarie. They showed the Port Macquarie–Tacking Point coastal strip as composed entirely of serpentinite.

A comprehensive account of the petrography and rock types exposed along the coastline was published by Barron et al. (1976), who presented a sketch map and described the rocks under the headings ultramafic complex, basic plutonic complex, mafic dykes, mafic volcanic complex, glaucophane-bearing rocks and sediments. They were the first to record lamprophyres, the possible presence of altered eclogite and the presence of omphacite-rich rocks.

Ishiga et al. (1988) described conodonts and radiolarians from chert from Tacking Point and Watonga Rocks but the middle Palaeozoic ages they ascribed to the rocks have been questioned by Och et al. (2007), who extracted middle to late Ordovician conodonts from chert from three localities between Port Macquarie and Tacking Point.

Leitch (1980b) largely accepted the division of rocks by Barron et al. (1976) of the Port Macquarie–Tacking Point area, which he regarded as a fault complex.

Fukui (1991) determined K–Ar ages of 467±10 Ma and 471±10 Ma for muscovite from a metabasite block from mélange at Port Macquarie. Watanabe et al. (1993) and Fukui et al. (1995) concluded that the middle Ordovician date probably closely accorded with that of blueschist facies metamorphism. Watanabe et al. (1997) identified lawsonite eclogite blocks from Port Macquarie and Och et al. (2003) determined the polymetamorphic character of the rocks and their likely P–T history.

Aitchison et al. (1994) described the coastal rocks as 'In a broad sense … a serpentinite matrix mélange'. They agreed with Barron et al. (1976) on the presence of many elements of an ophiolite sequence, but noted that no large-scale ophiolitic sequence is present and that various 'blocks' are not necessarily related. Aitchison et al. (1994) speculated that the present coastal tract rocks are products of an oceanic island-arc subduction complex that was later invaded by serpentinite and a range of mafic dykes, including some of boninitic character (lamprophyres of Barron et al. (1976)). SHRIMP ages for zircons from felsic dykes at Town Beach and Tacking Point indicate that these are no older than Triassic, according to Aitchison & Ireland (1995).

## LITHOSTRATIGRAPHIC UNITS

### Port Macquarie Serpentinite

The several bodies of serpentinite exposed along the coastal strip south from Port Macquarie are collectively referred to here as the Port Macquarie Serpentinite and it is proposed that this name be extended to the other serpentinite bodies known from the Port Macquarie Block including those referred to as the 'Burrawan serpentinite' and the 'Lake Innes mass' by Leitch (1980a). The Port Macquarie Serpentinite is a mélange with a matrix of schistose serpentinite, native blocks of massive serpentinite, blocks of highly altered mafic rock (rodingite) that may originally have been dykes in the serpentinite protolith, rare exotic blocks of high-pressure metamorphic rocks, and rocks derived from the adjacent Watonga Formation. Extensive exposures of the large northern body between Town Beach and Rocky Beach (GR 492110E 6522700N to GR 492800E 6521730N (AMG)) constitute the type area for the unit.


**Figure 1.** Geological map of the Port Macquarie Block

## REFERENCE

### Cainozoic

*Laterite and alluvial, swamp and dune complexes*

### Early Triassic

Camden Haven Group:

Grants Head Formation
*Sandstone and shale*

Laurieton Conglomerate
*Chert conglomerate*

Jolly Nose Conglomerate
*Lithic conglomerate*

### Early Permian–Late Triassic

*Undifferentiated* Karikeree Metadolerite *and* Sea Acres Dolerite *variably altered dolerite, in places cleaved. (Coastal tract dykes shown on the map as wider bodies rather than symbols represent Shelly Beach dolerites)*

Tacking Point Gabbro *and* Town Beach Dolerite
*Gabbro, pyroxenite, diorite, pegmatite*

### Permian

Thrumster Slate
*Slate, slaty sandstone, rare limestone*

### Devonian–Permian

'Undifferentiated Hastings Block'
*Conglomerate, sandstone and siltstone*

### Devonian

Touchwood Formation
*Siltstone, sandstone, paraconglomerate, breccia, andesite*

### Middle Ordovician–late Carboniferous

Watonga Formation:

*Dominantly pillow and massive basalt, rare dolerite dykes, but also contains mudstone, sandstone and stratabound metalliferous rocks. Not separately mappable away from coastal exposure*

*Dominantly chert*

*Undifferentiated rocks; slate, chert, mudstone, sandstone, conglomerate, and minor basalt and stratabound metalliferous rocks*

### (?) Early Cambrian

Port Macquarie Serpentinite
*Massive, schistose serpentinite, rodingite, serpentinised peridotite, and orthopyroxenite*

Port Macquarie Serpentinite
*'Inferred from drilling'*

### (?)Neoproterozoic–Middle Ordovician

Rocky Beach Metamorphic Mélange
*Eclogite, omphacitite, blueschist, glaucophane–phengite schist, tremolite marble and rare slate*

Bedding
Clevage
Dykes
Fault
Fault, approximate
Fault, inferred
Geological boundary
Geological boundary approximate
Geological boundary concealed
Dyke
Seawall
Road
Drainage
Grid: AMG Zone 56

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Eight masses of Port Macquarie Serpentinite have been mapped along the coastal tract (Figure 2). They range from large linear masses, as exposed in the immediate vicinity of Port Macquarie township, to narrow lenses of limited lateral extent, as at north Miners Beach and the isolated small exposures north and south of Nobby Head. At the headland separating Shelly Beach from Miners Beach serpentinite forms a highly irregular body, in part a result of incorporation of several large blocks of Watonga Formation. Away from the coastline, exposure of all rock types is very poor, and the serpentinite bodies shown on Figure 2, north and south of Rosendahl Reservoir, have been identified very largely on the basis of temporary excavations and drillhole data, and their total extent and shape are incompletely constrained. Most outcrops consist of serpentinite mélange as defined by Raymond (1984) and are referred to by some writers as 'broken formation' (Hsu 1968), and they do not necessarily contain exotic blocks. Typical serpentinite blocks that range up to 3 m in longest dimension are ellipsoidal and vary from prolate spheroidal to discoidal in shape (Photograph 1(a) and (b)), although there are rare concentrations of small angular blocks. The blocks have polished and occasionally slickensided surfaces. Except adjacent to younger intrusive bodies, both blocks and matrix are composed of a lizardite–chrysotile assemblage.


**Photograph 1(a).** Serpentinised harzburgite block preserving cumulate texture and magmatic layering imbedded in Port Macquarie Serpentinite Mélange. Schistose serpentinite visible in upper right and in extreme left. View is northward at GR 492510E 6522550N (AMG).

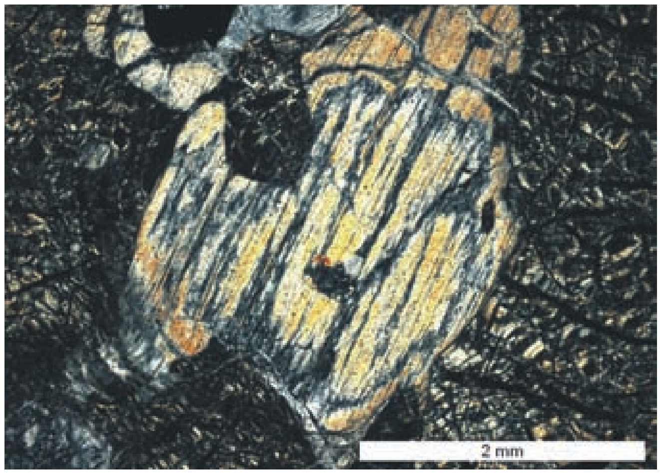

**Photograph 1(b).** Massive serpentinite blocks embedded in schistose serpentinite matrix, Port Macquarie Serpentinite, viewed southward at GR 492510E 6522550N (AMG).

Uncommon blocks within the serpentinite mélange include incompletely altered ultramafic rocks and rodingite slabs. Blocks of Watonga Formation up to 200 m in longest dimension are common, especially south of Oxley Beach. Some consist largely of thin-bedded, grey–green and dark blue–grey siltstone, sandstone and fine conglomerate, whereas others are dominated by chert and/or massive basalt.

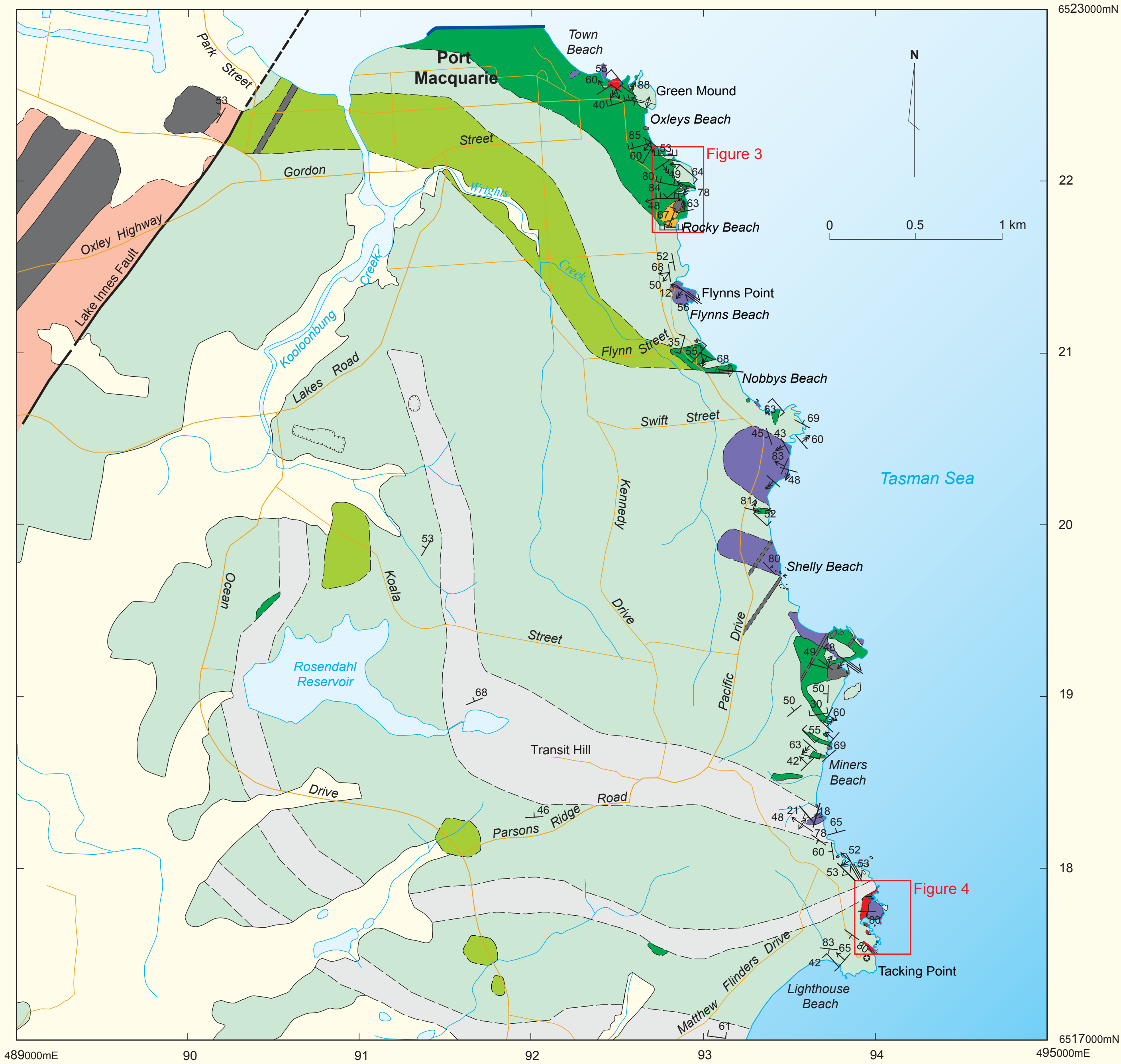
Wilkinson (1969) recorded harzburgite, lherzolite and orthopyroxenite as the protoliths of the serpentinites at Port Macquarie, and Barron et al. (1976) additionally recorded clinopyroxenite. Relic igneous textures preserved in massive serpentinite indicate that the protolith was of cumulate character. Chrome spinel mostly retains its original crystal shape and bastites commonly reflect the form of the original pyroxene crystals including marginal embayments and are indicative of crystals undeformed prior to serpentinisation (O'Hanley 1996; Li et al. 2004). Olivine crystal shape is suggested by rim concentrations of magnetite but relic olivine has not been identified.

Chemical analyses of massive serpentinite samples reveal compositions that are Ca-poor and Mg-rich (Table 1). Normative mineralogy, based on anhydrous oxide abundances, is olivine (37.8–64.5%), orthopyroxene (32.7–54.7%), magnetite (1.4–2.5%), and chrome spinel (0.2–1.0%), with little or no calcic clinopyroxene (Table 1). Thus the peridotite protolith was probably mostly harzburgite, although any loss of calcium during serpentinisation will have reduced indicated clinopyroxene abundances (Shervais et al. 2005).

The distribution of bastite pseudomorphs in some massive serpentinite reflects the former presence of igneous layering (Photograph 2). Bastite abundances range from 66% to 87% in former pyroxenite layers 5 mm to 500 mm wide, whereas intervening altered peridotite layers contain no more than 47% bastite. The absence of bastite pseudomorphs from some massive serpentinite suggests the original presence of dunite.




**Photograph 2.** Photomicrograph showing bastite pseudomorph consisting of fibrous lizardite and surrounded by mesh-rim texture lizardite in harzburgite block from Port Macquarie Serpentinite Mélange. The embayment in the top left corner of the bastite is probably after olivine. Note absence of deformation. Crossed polars, Sample Ptme 187.




## REFERENCE

**Cainozoic**

*Laterite, and alluvial, swamp, and dune complexes*

**(?) Permian–Late Triassic**

Sea Acres Dolerite: *variably altered diorite, in places cleaved*

Tacking Point Gabbro *and* Town Beach Diorite: *gabbro, pyroxenite, diorite, pegmatite*

**Devonian**

Touchwood Formation: *siltstone, sandstone, paraconglomerate, breccia, andesite*

**Middle Ordovician–late Carboniferous**

*Dominantly pillow and massive basalt, rare dolerite dykes, but also contains mudstone, sandstone and stratabound metalliferous rocks (Not separately mappable away from coastal exposure.)*

*Dominantly chert*

*Undifferentiated rocks: slate, chert, mudstone, sandstone, conglomerate, and minor basalt and stratabound metalliferous rocks*

Watonga Formation

**(?) Early Cambrian**

Port Macquarie Serpentinite
*Massive, schistose serpentinite, rodingite, serpentinised peridotite, and orthopyroxenite*

Port Macquarie Serpentinite
*'Inferred from drilling'*

**(?) Neoproterozoic – Middle Ordovician**

Rocky Beach Metamorphic Mélange:
*eclogite, omphacitite, blueschist, glaucophane–phengite schist, tremolite marble and rare slate*

Bedding
Cleavage
Dyke inclined; vertical
Antiform with plunge
Strike slip movement on fault

Road
River, creek, dam
Quarry
Seawall
Lighthouse

Grid : AMG Zone 56

**Figure 2.** Geological map of the Port Macquarie–Tacking Point coastal tract

**Table 1. Whole rock analyses* of serpentinised ultramafic rocks**

| Sample | Ptme187 | Ptme188 | Ptmb111 |
|---|---|---|---|
| Coordinates | E 492512 N 6522590 | E 492532 N 6522580 | E 492880 N 6521815 |
| Rock | serpentinised harzburgite | serpentinised harzburgite | serpentinised pyroxenite |
| $SiO_2$ | 39.81 | 39.25 | 43.92 |
| $TiO_2$ | 0.01 | 0.01 | 0.10 |
| $Al_2O_3$ | 0.43 | 2.18 | 1.16 |
| $Fe_2O_3^T$ | 6.84 | 5.38 | 10.15 |
| MnO | 0.10 | 0.16 | 0.11 |
| MgO | 39.02 | 38.28 | 33.30 |
| CaO | 0.01 | 0.02 | 0.57 |
| $Na_2O$ | 0.18 | 0.16 | 0.20 |
| $K_2O$ | 0.01 | 0.01 | 0.02 |
| $P_2O_5$ | 0.01 | 0.00 | 0.00 |
| $SO_3$ | 0.16 | 0.10 | 0.07 |
| LOI | 12.70 | 12.77 | 9.90 |
| Total | 99.27 | 98.32 | 99.50 |
| Mg# | 0.93 | 0.94 | 0.88 |
| **Trace element (ppm)** | | | |
| Zr | 4 | 4 | 5 |
| Nb | <1 | <1 | <1 |
| Y | <1 | <1 | 2 |
| Sr | 3 | 3 | 11 |
| Rb | <1 | <1 | 1 |
| U | <1 | <1 | <1 |
| Th | 0 | <1 | <1 |
| Pb | 2 | 1 | 3 |
| Ga | 1 | 2 | <1 |
| Cu | 3 | 1 | 4 |
| Zn | 38 | 56 | 55 |
| Ni | 2682 | 1144 | 504 |
| Ba | 1 | 3 | 13 |
| Sc | 3 | 11 | 59 |
| Co | 82 | 73 | 76 |
| V | 11 | 41 | 176 |
| Cr | 727 | 4752 | 2401 |
| La | <1 | <1 | <1 |
| Ce | <1 | <1 | <1 |
| Nd | 2 | 5 | 4 |
| **Recalculated CIPW normative values (wt%)**** | | | |
| ol | 64.5 | 60.6 | 37.8 |
| opx | 32.7 | 34.3 | 54.7 |
| cpx | 0.0 | 0.0 | 0.3 |
| chr | 0.2 | 1.0 | 0.5 |
| mag | 1.7 | 1.4 | 2.5 |
| ilm | 0.0 | 0.0 | 0.2 |
| crn | 0.4 | 2.4 | 0.0 |
| pl | 0.5 | 0.9 | 4.2 |

*See Appendix 1 for analytical information. **CIPW NORM values calculated on an anhydrous basis using Excel spreadsheet calculator developed by Kurt Hollocher, Geology Department, Union College, Schenectady, NY, 12308, hollochk@union.edu.

Aitchison & Ireland (1995) determined ages of around 530 Ma (early Cambrian) for zircons in plagiogranite associated with serpentinised ultramafic rocks in the western New England Fold Belt. These are probable correlatives of the Port Macquarie Serpentinite, sharing its structural and compositional characters, and the date is assumed to be that of the protolith of the Port Macquarie Serpentinite. Emplacement in the Port Macquarie Serpentinite of dykes of Nobbys Beach Lamprophyre (GR 493160E 6520910N (AMG)), Karikeree Metadolerite (GR 493860E 6519360N (AMG)) and the formation of antigorite as a result of local thermal metamorphism by the Town Beach Diorite (GR 492450E 6522570N (AMG)) indicate that formation of the serpentinite was completed before the onset of Permian to (?)Lower Triassic magmatism. By the earliest Permian serpentinite mélange had been exposed at the surface elsewhere in the New England Fold Belt (Cross et al. 1987; Sharp 1995) but its presence in piercement-like structures formed in Early Triassic rocks in the southern part of the Port Macquarie Block indicates significantly later movement of some bodies (Leitch & Bocking 1980).

## Rocky Beach Metamorphic Mélange

Near the northern end of Rocky Beach two bodies of chlorite–actinolite schist, surrounded by highly schistose Port Macquarie Serpentinite, contain blocks of blueschist, lawsonite eclogite, omphacitite and tremolite marble (Figure 3). Although high-pressure metamorphic rocks are known from serpentinite bodies elsewhere in the southern New England Fold Belt this occurrence is unique in the abundance and lithological range of blocks and the nature of the matrix. Thus, in spite of its limited extent, the formal name Rocky Beach Metamorphic Mélange was introduced for these rocks (Och et al. 2003). The type area is around GR 492820E 6521740N (AMG) at the northern end of Rocky Beach. The unit consists of two lenses separated by a narrow strip of Port Macquarie Serpentinite. Blocks of multiply deformed, polymetamorphosed, high-pressure metamorphic rocks of mafic igneous parentage; low-grade blocks of sedimentary and basaltic rocks derived from the Watonga Formation; and a narrow slice of antigorite serpentinite, are set in a multiply deformed chlorite–actinolite schist matrix.

Contacts with the Rocky Beach Metamorphic Mélange are discrete faults lacking kinematic indicators. However, the presence of several small blueschist blocks within the Port Macquarie Serpentinite immediately adjacent to the north-western margin of the larger lens of Rocky Beach Metamorphic Mélange (GR 492840E 6521890N (AMG)) suggests local mixing of material adjacent to this contact.

The schistose matrix of the Rocky Beach Metamorphic Mélange is chlorite-rich with variable amounts of actinolite. The schistosity is commonly folded on a small scale, particularly close to contacts, and overprinted by a later set of shears with associated slickenfibres of actinolite. Contacts between the matrix and the high-pressure blocks are gradational, with the margin of some blueschist blocks showing progressive replacement by matrix leading to isolation of small, apparently unrotated, remnants. Omphacitite masses pass gradationally into the matrix through a chlorite-rich zone.

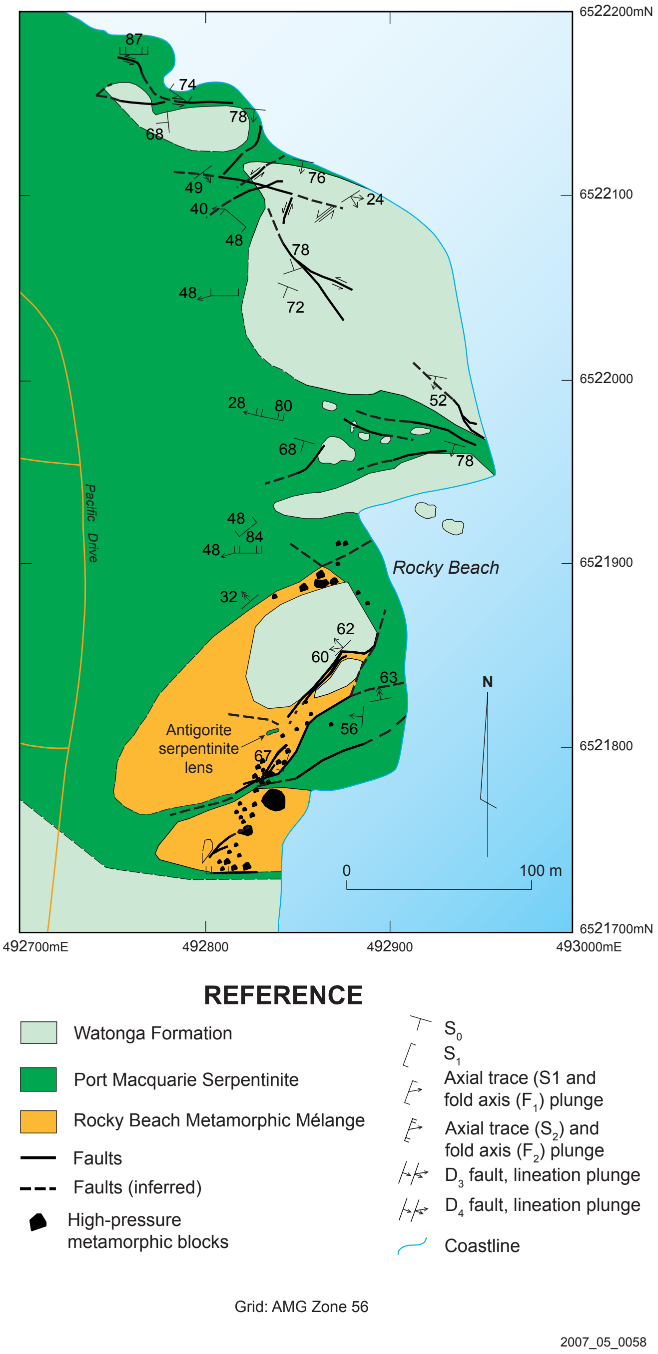
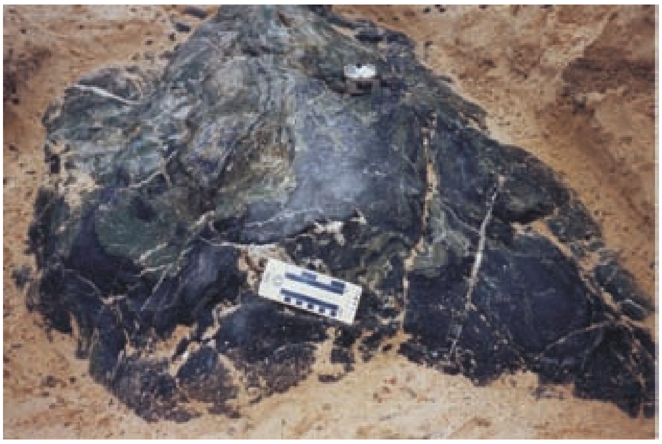



**Figure 3.** Detailed geological map of northern Rocky Beach showing blocks of Watonga Formation and lenses of Rocky Beach Metamorphic Mélange enclosed in Port Macquarie Serpentinite

Blocks make up about 20% of the Rocky Beach Metamorphic Mélange. Blueschist blocks range up to at least 6 m in longest dimension and have a strong foliation that ranges from planar to intensely folded. Irregular vein-like masses composed mainly of glaucophane and phengite lacking any obvious preferred orientation have formed late in block development. Rounded eclogite and omphacitite inclusions range up to 2 m in diameter, with the former characterised by the presence of almandine crystals set in a green-lawsonite–omphacite aggregate that has been extensively replaced by glaucophane and phengite (Photograph 3). Omphacitite forms monomineralic unfoliated emerald green masses. Discoid tremolite marble blocks attain 1.5 m in longest dimension and are locally concentrated in areas where disrupted calcite veins occur in the matrix. Watonga Formation blocks, that closely resemble the formation as found elsewhere along the coastal tract, range up to 20 m in longest dimension and are of irregular shape with, contacts that are abrupt and angular.



**Photograph 3.** Multiply deformed polymetamorphosed block of lawsonite eclogite containing abundant glaucophane and phengite. From Rocky Beach Metamorphic Mélange, north Rocky Beach (GR 492790E 6521780N (AMG)).

The presence of chlorite–actinolite rinds formed from metasomatic interaction between mafic blocks and ultramafic rock during serpentinisation has been widely reported from serpentinite bodies (e.g. Coleman 1971; Cloos 1986). Samples were collected in a traverse from an omphacitite block, across the chlorite–actinolite matrix and into the surrounding serpentinite. Chemical analyses of these samples (Table 2) indicate that, in general, the chlorite–actinolite rock has a composition intermediate between omphacitite and serpentinite, and support a similar origin for the matrix of the Rocky Beach Metamorphic Mélange. The rather anomalous composition of the rind arises from its chlorite-rich character and is, relative to the matrix, enriched in elements abundant in chlorite (e.g. $Al_2O_3$, $Fe_2O_3$) and impoverished in elements more abundant in actinolite (e.g. CaO, MgO).

**Table 2. Whole rock analyses of samples* from the omphacitite phacoid to the adjacent Port Macquarie Serpentinite**

| Sample | Ptmc153 | Ptme218 | Ptme219 | Ptmc156 |
|---|---|---|---|---|
| Coordinates | E 492822 N 6521785 | E 492822 N 6521785 | E 492822 N 6521785 | E 492822 N 6521785 |
| Rock | omphacitite | rind | chl–act matrix | serpentinised harzburgite |
| $SiO_2$ | 49.78 | 28.56 | 45.75 | 39.72 |
| $TiO_2$ | 2.05 | 2.12 | 1.09 | 0.01 |
| $Al_2O_3$ | 10.03 | 17.67 | 7.69 | 0.64 |
| $Fe_2O_3^T$ | 7.70 | 17.64 | 9.49 | 7.39 |
| MnO | 0.09 | 0.21 | 0.15 | 0.07 |
| MgO | 8.33 | 21.98 | 20.64 | 38.43 |
| CaO | 11.86 | 1.77 | 6.37 | 0.02 |
| $Na_2O$ | 3.73 | 0.06 | 0.32 | 0.17 |
| $K_2O$ | 1.10 | 0.00 | 0.04 | 0.01 |
| $P_2O_5$ | 0.48 | 0.10 | 0.16 | 0.01 |
| $SO_3$ | 0.18 | 0.06 | 0.19 | 0.14 |
| LOI | 4.70 | 9.55 | 7.57 | 12.42 |
| Total | 100.03 | 99.72 | 99.46 | 99.02 |
| Mg# | 0.72 | 0.74 | 0.84 | 0.92 |
| Trace element (ppm) | | | | |
| Zr | 250 | 133 | 116 | 4 |
| Nb | 36 | 27 | 29 | <1 |
| Y | 48 | 47 | 22 | <1 |
| Sr | 224 | 17 | 48 | 3 |
| Rb | 20 | <1 | <1 | <1 |
| U | 2 | <1 | 2 | <1 |
| Th | 5 | 3 | 2 | <1 |
| Pb | 6 | 2 | 3 | 2 |
| Ga | 11 | 19 | 10 | <1 |
| Cu | 28 | 8 | 26 | 3 |
| Zn | 64 | 237 | 83 | 34 |
| Ni | 25 | 527 | 1210 | 2523 |
| Ba | 452 | <1 | <1 | <1 |
| Sc | 34 | 3 | 15 | 6 |
| Co | 13 | 88 | 69 | 95 |
| V | 305 | 132 | 163 | 21 |
| Cr | 106 | 572 | 1715 | 2147 |
| La | 38 | 16 | 4 | <1 |
| Ce | 82 | 40 | 14 | <1 |
| Nd | 39 | 21 | 11 | 2 |

*The samples range from the omphacitite phacoid, across its chlorite rind to the chlorite–actinolite matrix and the adjacent serpentinite. See Appendix 1 for analytical information.

A slab approximately 2 m wide of bright green antigorite serpentinite is present within the Rocky Beach Metamorphic Mélange at GR 492830E 6521810N (AMG). It lacks the internal structural character of the Port Macquarie Serpentinite, as well as possessing a distinctive mineralogy.

The eclogite component in the Rocky Beach Metamorphic Mélange may be as old as c.570 Ma, if it is the same age as eclogite from Attunga, also found associated with serpentinite (Watanabe et al. 1998). K–Ar ages of c.469 Ma for phengite introduced during retrograde blueschist metamorphism of the eclogite blocks at Rocky Beach indicates that substantial exhumation of these rocks had occurred by the Middle Ordovician (Fukui et al. 1995; Offler 1999). The chlorite–actinolite matrix is probably significantly younger, having resulted from the reaction of blocks with the Port Macquarie Serpentinite under the very low-grade metamorphic conditions under which chrysotile is stable (O'Hanley 1996).

## Watonga Formation

Leitch (1980a) named the chert–slate–sandstone–metabasalt assemblage that characterises the eastern part of the Port Macquarie Block the Watonga Formation. Chert-rich zones and the intervening, more recessive rocks, include chert, siltstone, volcaniclastic sandstone and altered basalt, extend into the Miners Beach–Tacking Point tract (figures 2 and 4). Similar rocks occupy much of the coastline north from Miners Beach to Rocky Beach and occur further north (Rocky Beach to Town Beach), mostly as large blocks surrounded by serpentinite (figures 2 and 3). All these rocks are now mapped as Watonga Formation. The better exposure along the coast has led to a more detailed knowledge of this unit, especially the more recessive mafic volcanic rocks.

The Watonga Formation consists of sedimentary and igneous rocks that have undergone low-grade metamorphism. The unit has been subject to several episodes of deformation, with the earliest episode pre-dating complete sediment consolidation. In the case of chert and some conglomeratic rocks, it is uncertain whether some characters are of depositional origin or whether they are the result of soft-sediment deformation and diagenesis. Other deposits are inferred products of syn-depositional mass movement of variably consolidated materials. The disrupted character of the Watonga Formation has previously been noted (Leitch 1980a; Aitchison et al. 1994) and the coastal outcrops reveal that much of it consists of typical broken formation (Hsu 1968) with a lack of stratal continuity, common pinch-and-swell structure and widespread boudinage producing mélange similar to that described from elsewhere in the eastern New England Fold Belt (Fergusson 1984). Blocks, particularly of chert and basalt up to several metres in longest dimension, occur isolated in a variably foliated inhomogeneous siltstone–mudstone matrix.

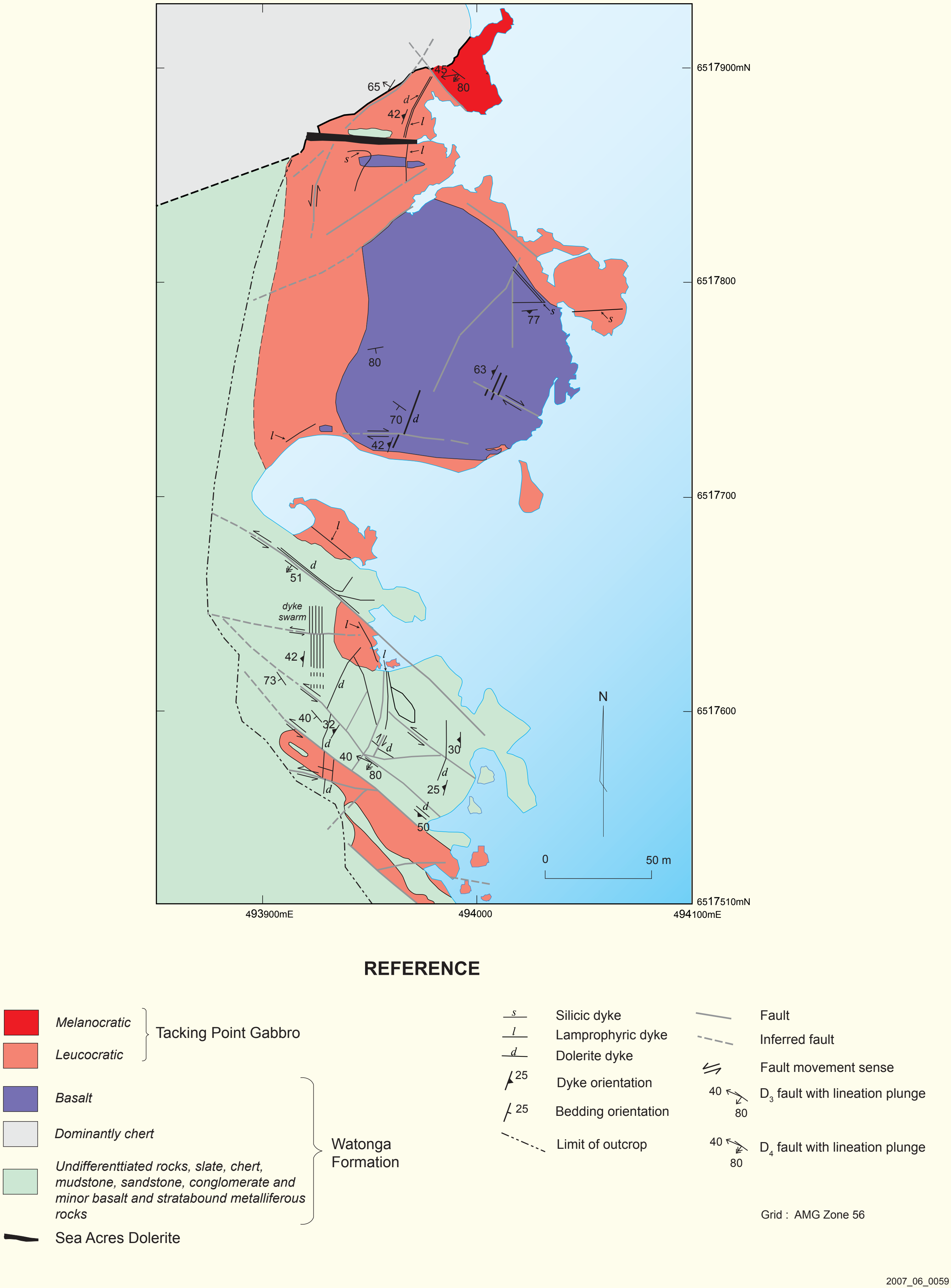



**Figure 4.** Detailed geological map of the area immediately north of Tacking Point. Dykes not otherwise labelled are of Karikeree Metadolerite.

Chert occurs widely in the Watonga Formation, in beds ranging from 10 mm to 1 m thick intercalated with thinner recessive dark mudstone units, some mere films. It is of highly variable colour, white and grey predominating but including red, green and black. Most can be described as 'ribbon chert', characterised by highly discontinuous stratification with individual beds 5 mm to 200 mm in maximum thickness forming irregular flat lenses rarely exceeding 0.5 m in length. Mesoscopic disharmonic folds lacking signs of any axial surface structure, of variable orientation and style ranging from chevron to box-shaped, are common in chert units and interpreted as syn-sedimentary slump structures. Small pods of rhodonite and black manganese oxide minerals are present within the chert sequences, elongate parallel to stratification. North of Tacking Point, at Miners Beach (GR 493950E 6517860N (AMG)) (Figure 2), and in the surf zone at Flynns Point (GR 492890E 6521420N (AMG)), quartzose beds in sequences up to 5 m thick include magnetite–pyrite laminae and uncommon associated chalcopyrite of probable exhalative origin (Barron et al. 1976). These mineralised beds, near Tacking Point form a block 10 m by 2.5 m elongate parallel to bedding and surrounded by basalt, and as xenoliths in gabbro. At Miners Beach these beds occur in a lens 30 m long associated with interbedded siliceous mudstone and chert and contain a lens of massive chert. At Flynns Point, they occur surrounded by basalt.

Isolated coherent intervals of clastic rocks consist of up to about 5 m of thin-bedded simply graded tuffaceous sandstone, siltstone and mudstone, although Green Mound (GR 492690E 6522490N (AMG)) consists mostly of cleaved siltstone interstratified with less common chert in a sequence apparently at least several tens of metres thick. The clastic rocks are green or dark grey, and finer-grained varieties are commonly internally laminated. Fecal pellets occur in a few siltstone beds.

Tuffaceous sandstones range from fine-grained to very coarse and locally grade into granule conglomerate. They are composed mostly of feldspar and volcanic detritus, including pumiceous fragments accompanied by uncommon relic pyroxene and quartz crystals. Grains are mostly angular and have low sphericity—feldspar grains preserve euhedral shapes in some samples. The matrix of the rocks is vitroclastic, composed mostly of tiny glass shards pseudomorphed by chlorite and quartz. Rare thin ash-fall lenses consist of curved angular altered glass shards, pumice fragments and minor discrete angular fragments of quartz and feldspar.

Most of the bedded clastic rocks in the Watonga Formation show evidence of early disruption and individual thin beds are rarely continuous over distances of more than 0.5 m. Sedimentary breccias consisting of angular siltstone clasts set in a sandstone matrix are present in thin-bedded intervals and jumbled siltstone blocks are locally concentrated in thicker sandstones. Mudstone injections in sandstone and chert, and cutting obliquely across laminated fine-grained rocks, retain remnant lamination. Small faults, at least some showing extensional offset, disrupt bedded sequences that are also affected by stretching and boudinage yielding a flaser-like structure. Convolute lamination and associated small disharmonic folds are confined to just a few laminae in otherwise planar sequences. None of these structures are associated with foliation or cleavage, nor with mineral veins. Contacts between lithologies are welded and grain-scale deformation is absent. Thus, disruption pre-dated complete consolidation of the rocks and much of it was probably syn-depositional.

Although much of the Watonga Formation is clearly mélange, in a few rocks the clast-in-matrix structure appears to have been inherited from deposition and is not the result of subsequent deformation. These rocks include examples with a foliation and here this interpretation is more equivocal, as at GR 493750E 6518110N (AMG), where it is unclear if rocks with sandstone and chert inclusions in a mudstone matrix are conglomerate or pseudoconglomerate (cf. Fergusson et al. 1993). Most conglomeratic rocks consist of sub-angular to rounded spherical or ellipsoidal clasts of chert, basalt, sandstone and rare limestone set in a green volcaniclastic sandstone matrix. The rocks are poorly sorted, lack internal ordering and have a high matrix to clast ratio.

Basalt occurs widely within the Watonga Formation along the coastal tract. Pillowed and massive sheetflows are present associated with autoclastic breccias. Narrow dolerite intrusions grade into the basaltic rocks in the more extensive outcrops and are probable feeders. The basaltic rocks have undergone extensive low-grade metamorphism and are mostly green–grey due to the presence of widespread chlorite, actinolite and epidote. Although at Miners Beach (GR 493690E 6518280N (AMG)), red basalt dusted with hematite forms breccia and is associated with red mudstone, possibly resulting from the weathering of the oxidised basalt. Some chert beds overlie basaltic rocks depositionally but elsewhere basalt has invaded the chert or seemingly overlies it. In a large broken formation block at GR 493940E 6517590N (AMG) small pockets of peperite have formed where basalt has flowed over unconsolidated siltstone.

Extensive outcrops of little-disrupted basalt occur at Flynns Point (GR 492850E 6521420N to GR 492850N 6521280E (AMG)); south of Nobby Head; at Shelly Beach (GR 493550E 6519490N and GR 493690E 6519330N (AMG)); at Miners Beach (GR 493660E 6518270N (AMG)); and near Tacking Point (GR 494000E 6517810N to GR 494000E 6517690N (AMG)) (Figure 2). Sequences are up to 400 m thick and consist very largely of basaltic rocks lacking associated interstratified sedimentary rocks although large rafted blocks of chert are locally present (e.g. south of Nobby Head GR 493400E 6520500N (AMG)). Pillow basalt is most common but massive rocks and autoclastic breccias are also widespread. Pillows range up to 0.8 m in longest dimension. They range from irregularly ellipsoidal to near spherical and most are closely packed. Alignment of the long axes of pillows defines stratification in the pillow piles and downward protuberances indicate younging direction (Barron et al. 1976, plate 6). Interpillow interstices are occupied by altered spalled basaltic debris, structureless jasper or, rarely, dark grey recrystallised limestone (e.g. Flynns Beach, GR 492960E 6521030N (AMG)). Basalt lacking preserved magmatic structures apart from uncommon irregular lenses of autoclastic breccia are interpreted as the product of sheetflows. Some occur associated with pillowed flows and others form extensive massive outcrops. Widespread tectonic fractures have obscured cooling joints. Breccias consist of basaltic clasts, including pillow fragments and in rare cases complete detached pillows, dark once-glassy pillow rind and massive basalt. They are poorly sorted, mostly less than 0.25 mm in longest dimension, near equidimensional and closely packed with interstices filled by altered fine basaltic debris or, less commonly jasper or limestone. Most breccias are considered autoclastic rocks formed at flow margins. However, at Miners Beach (GR 493660E 6518310N (AMG)), blocks of ribbon chert up to 10 m in longest dimension are isolated in a matrix of pebble- to cobble-grade red basaltic breccia and red slaty mudstone. The breccia also contains variolitic red and green massive basalt blocks and detached pillows. Although some contacts between the larger blocks and the matrix are late faults many lack any signs of shear, polishing, or tectonic brecciation. This, and the irregular distribution of the matrix lithologies, strongly suggest that these rocks collectively constitute an incompletely mixed olistostrome.

Although conodonts from near Tacking Point and radiolarians from Watonga Rock suggested a Devonian age for chert of the Watonga Formation (Ishiga et al. 1988), recent detailed study of conodonts from three localities along the coastal tract reveal that they are of Upper Ordovician age (Och et al. 2007). The basalts that are overlain by chert are inferred to be of a similar Ordovician age. The age of the volcaniclastic sedimentary rocks and ash-fall tuff inferred to overlie the chert has not been established but may be only slightly younger.

## Tacking Point Gabbro

The name Tacking Point Gabbro is introduced for a small pluton composed of rocks ranging from pyroxene-rich melanocratic gabbro to plagioclase-dominated leucocratic gabbro, gabbroic pegmatite and aplite. The pluton is only exposed on the shore platform and in the intertidal area about 200 m north of Tacking Point, the source of the name (Figure 4, Photograph 4). Included in the unit are irregular gabbro dykes emplaced in the Watonga Formation between the pluton and Tacking Point, at the south end of Miners Beach.

**Photograph 4.** View northward over the type area of the Tacking Point Gabbro from GR 493930E 6517840N (AMG). Cliffs in shade are composed largely of chert of the Watonga Formation that is intruded by the gabbroic rocks.

The pluton preserves intrusive contacts with cherty broken formation of the Watonga Formation to the west and south although locally its western contact lies along a narrow shear zone. Xenoliths of Watonga Formation are present within the pluton. A roof pendant of Watonga Formation basalt is exposed as an approximately circular mass about 100 m in diameter within the pluton (Figure 4). The gabbro has mainly intrusive contacts with this mass.

The Tacking Point Gabbro is coarse-grained and ranges in colour from near-black (melanocratic gabbro) to pale grey (leucocratic gabbro). At least locally, the darker variant has invaded the leucocratic gabbro. The pluton shows well-developed magmatic layering and contains schlieren of pyroxenite, coarse pegmatitic segregations, and uncommon narrow aplite dykes. Some dykes extend into the basalt roof pendant. All gabbro is extensively altered, with primary ferromagnesian silicates replaced principally by actinolite and chlorite and almost complete replacement of plagioclase. Discrete faults cut the gabbro and a narrow zone of mylonitic gabbro (GR 493930E 6517840N (AMG)) indicates faulting occurred prior to complete cooling.

The Watonga Formation roof pendant, the presence of small satellite gabbro bodies, the inhomogeneous nature of the rocks and their highly altered state, and the presence of pegmatitic segregations and aplite dykes, collectively suggest that the exposures at Tacking Point represent the top of a more extensive, but largely buried, gabbro pluton.

The Tacking Point Gabbro post-dates the generation of the broken formation of the Watonga Formation and has been intruded by dykes of Karikeree Metadolerite, Nobbys Beach Lamprophyre and felsic rocks. Geochemical data (Och 2007) indicate that the Tacking Point Gabbro is similar to the Permian (251 to 290 Ma) Clarence River Supersuite of the New England Batholith (Bryant et al. 1997). Many Clarence River Supersuite bodies are deformed, as is the Tacking Point Gabbro, and they are concentrated in the eastern part of the New England Fold Belt, as is the Port Macquarie unit. Mafic rocks are more common in the Clarence River Supersuite than in other New England Batholith suites. The Tacking Point Gabbro is thus tentatively accorded a Permian age.

## Town Beach Diorite

The name Town Beach Diorite is introduced for a small hornblende diorite pluton and associated irregular dykes and segregations of gabbro, dolerite, hornblende pegmatite and tonalite aplite that occur surrounded by Port Macquarie Serpentinite in the inter-tidal zone at the eastern end of Town Beach. The type area of the unit is at Town Beach (GR 492460E 6522530N (AMG)) where exposure varies according to the amount of surficial sand that mantles the low shore platform.

The Town Beach Diorite is texturally inhomogeneous and includes a highly pegmatitic variant that has invaded an earlier darker phase. Although considered blocks by Aitchison et al. (1994) the dioritic body is here regarded as intrusive for it contains xenoliths of talcose serpentinite that are cut by hornblende-rich veins that can be traced back into the diorite without offset. In addition, adjacent to the diorite the dominant serpentine mineral is antigorite rather than the lizardite–chrysotile assemblage found in serpentinite distant from the body.

The Town Beach Diorite is geochemically similar to the Tacking Point Gabbro — with which it is correlated (Och 2007). Like the latter it shares attributes with the Clarence River Supersuite of the New England Batholith and is considered to be of possible Permian age.

## Karikeree Metadolerite

Leitch (1980a) introduced the name Karikeree Metadolerite for variably altered dolerite bodies emplaced in the stratified rocks of the Port Macquarie Block, with a type section along Innes Estate Drive about 10 km southeast of Port Macquarie township. In the type section the intrusive bodies have been emplaced into the early Permian Thrumster Slate but dykes mapped as Karikeree Metadolerite were also recognised as having been emplaced into the Touchwood Formation and the Watonga Formation (Leitch 1980a). During the present work two distinct groups of dolerite bodies, included in the Karikeree Metadolerite by Leitch (1980a), were identified, based on field relations, geochemical, metamorphic and structural grounds. The older group, intruded by dykes of Nobbys Beach Lamprophyre, are distinguished by relatively low $TiO_2$ (0.58–0.75%) and total Fe (9.12–10.91%), and Zr (45–94ppm) (10 analyses, Och 2007 and Table 3), intense alteration and the presence of at least two generations of fractures. Younger, little-altered, simply fractured dykes with relatively high $TiO_2$ and total Fe make up the Sea Acres Dolerite described below. Examination of the type section of the Karikeree Metadolerite specified by Leitch (1980a) indicates that most of the dykes there are deformed and significantly metamorphosed and it is maintained as the type section pending investigation of the geochemical composition of the rocks.

Karikeree Metadolerite dykes are composed of grey–green rocks, some of which preserve a finely porphyritic texture with scattered small phenocrysts of much-altered plagioclase and pyroxene. Marginal chilling of the dykes is marked by the development of noticeably darker zones up to 0.1 m wide. Moderate to steep dips predominate but the dykes show no obvious preferred orientation. They are offset by small faults invaded by quartz–epidote–calcite veins; are commonly intensely jointed; and not foliated.

Cross-cutting relationships demonstrate that intrusion of the Karikeree Metadolerite dykes post-dated emplacement of the Tacking Point Gabbro and Town Beach Diorite but pre-dated injection of the Nobbys Beach Lamprophyre and Sea Acres

## Table 3. Average analyses* of dolerite samples

| Rock unit | Karikeree Metadolerite | | Sea Acres Dolerite | |
|---|---|---|---|---|
| Number of representative analyses | n=10 | SD | n=8 | SD |
| $SiO_2$ | 49.93 | 1.66 | 46.98 | 0.61 |
| $TiO_2$ | 0.83 | 0.09 | 2.53 | 0.35 |
| $Al_2O_3$ | 16.22 | 2.08 | 15.02 | 0.74 |
| $Fe_2O_3^T$ | 10.04 | 0.64 | 13.30 | 1.16 |
| MnO | 0.18 | 0.04 | 0.22 | 0.02 |
| MgO | 6.97 | 2.24 | 6.76 | 0.36 |
| CaO | 8.45 | 1.38 | 9.66 | 0.99 |
| $Na_2O$ | 3.28 | 1.13 | 3.19 | 0.38 |
| $K_2O$ | 1.33 | 0.93 | 0.43 | 0.29 |
| $P_2O_5$ | 0.15 | 0.03 | 0.24 | 0.07 |
| $SO_3$ | 0.07 | 0.06 | 0.13 | 0.09 |
| LOI | 2.67 | 1.64 | 1.61 | 0.71 |
| Total | 100.03 | | 100.08 | |
| Mg# | 0.59 | 0.07 | 0.54 | 0.03 |
| Trace element (ppm) | | | | |
| Zr | 77 | 16 | 176 | 38 |
| Nb | 2 | 1 | 5 | 8 |
| Y | 17 | 3 | 45 | 5 |
| Sr | 478 | 285 | 229 | 71 |
| Rb | 28 | 17 | 12 | 8 |
| U | <1 | <1 | <1 | <1 |
| Th | 1 | <1 | <1 | <1 |
| Pb | 4 | 1 | 2 | 2 |
| Ga | 15 | 2 | 21 | 2 |
| Cu | 83 | 44 | 50 | 21 |
| Zn | 74 | 14 | 89 | 11 |
| Ni | 86 | 85 | 66 | 23 |
| Ba | 233 | 199 | 82 | 75 |
| Sc | 35 | 6 | 39 | 6 |
| V | 323 | 43 | 356 | 77 |
| Co | 41 | 7 | 48 | <1 |
| Cr | 178 | 303 | 100 | 53 |
| Hf | 1.38 | 0.27 | 4.79 | 0.76 |
| Rare earth elements (ppm) | n=5 | SD | n=4 | SD |
| La | 21.10 | 4.31 | 17.53 | 6.66 |
| Ce | 20.69 | 3.82 | 24.07 | 6.38 |
| Nd | 18.80 | 3.39 | 28.42 | 5.11 |
| Sm | 15.20 | 2.86 | 29.00 | 3.83 |
| Eu | 11.56 | 2.53 | 23.91 | 4.02 |
| Tb | 12.19 | 2.25 | 25.00 | 3.32 |
| Ho | 10.56 | 2.18 | 21.69 | 2.90 |
| Yb | 8.01 | 2.00 | 16.97 | 1.84 |
| Lu | 7.45 | 2.00 | 16.07 | 2.22 |

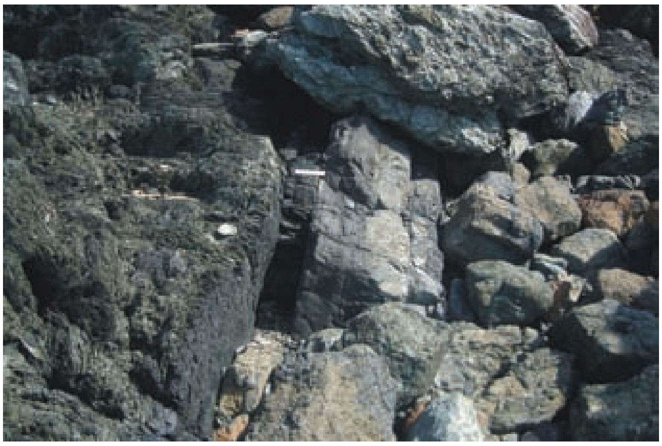
REE values represent normalisation to chondite after Boynton (1984). Italicised REE and trace element analyses derived from INAA.

*See Appendix 1 for analytical information

Dolerite. Leitch (1980a) showed that deformed and altered Karikeree Metadolerite dykes were emplaced in early Permian strata a few kilometres southwest of Port Macquarie prior to the end of Hunter–Bowen deformation at about 251 Ma, indicating a middle to late Permian age for the unit.

## Nobbys Beach Lamprophyre

The formal name Nobbys Beach Lamprophyre is introduced for narrow lamprophyre dykes, first recognised by Barron et al. (1976), that are a widespread, albeit minor, component of the coastal section. The name is derived from Nobbys Beach and the type area is the small headland at the north end of the beach (GR 493180E 6520900N (AMG)) where a lamprophyre dyke about a metre wide emplaced into the Port Macquarie Serpentinite is well exposed (Photograph 5). Nobbys Beach Lamprophyre dykes have only been identified south of Flynns Beach along the coastal tract. Between the type area and Tacking Point some 20 bodies have been documented.



**Photograph 5.** Nobbys Beach Lamprophyre dyke emplaced in Port Macquarie Serpentinite to immediate right of 200mm scale, showing darker chilled margins and greenish grey interior. Nobbys Beach Lamprophyre type area, GR 493180E 6520900N (AMG).

The lamprophyre dykes are composed of fine-grained dark green to almost black rocks that show dark chilled margins rarely exceeding 30 mm wide. Some have an internal zoning resulting from variations in the abundance of small (<4 mm) spherical ocelli and a few show subtle flow layering. Small phenocrysts of mafic minerals are present but rarely prominent. The dykes range from 50 mm to 1 m wide although most are less than 0.3 m and are on average notably less wide than those of either the Karikeree Metadolerite or the Sea Acres Dolerite. Most are planar. The dykes have a wide range in strike and have low to moderate dips. Some are gently sinuous and others split and rejoin, show small angular jogs or small en echelon offsets. They are simply jointed, offset by small faults but are otherwise little deformed.

Nobbys Beach Lamprophyre dykes have intruded the Port Macquarie Serpentinite at Nobbys Beach (GR 493280E 6520700N (AMG)) and Shelly Beach (GR 493910E 6519260N

(AMG)); the Watonga Formation, especially around Tacking Point; the Tacking Point Gabbro; and the Karikeree Metadolerite (e.g. GR 493810E 6518050N (AMG)). They are cut by a prominent dyke of Sea Acres Dolerite north of Tacking Point and by a small aplite dyke near Tacking Point (GR 493970E 6517830N (AMG)). The Nobbys Beach Lamprophyre shows geochemical similarities with the Tacking Point Gabbro, the Town Beach Diorite and the Karikeree Metadolerite (Och 2007) and is considered to be only a little younger and hence also of probable Permian age. They are geochemically distinct from other lamprophyres recorded from the southern New England Fold Belt including those associated with the New England Batholith (Henley 1991; Ashley et al. 1993).

## Felsic dykes

Although uncommon and volumetrically insignificant, several dykes of intermediate to silicic composition with predominantly felsic minerals occur along the coastal tract. No formal name is given to these bodies that are restricted to two localities. Several narrow (<2 m) intermediate and silicic dykes have been emplaced into the Tacking Point Gabbro and Watonga Formation on the coast near Tacking Point. They range from planar to irregular bodies, steeply dipping but of widely variable strike. The felsic dykes include a 50 mm wide quartz diorite aplite and several steeply inclined microdiorite intrusions. At Town Beach irregular quartz diorite dykes form a localised network in the Town Beach Diorite (Aitchison & Ireland 1995, figure 2b). The rocks are pale grey to white, fine-grained but with scattered plagioclase phenocrysts. Most lack inclusions although one at Tacking Point is crowded with small angular basalt xenoliths derived from the adjacent wallrocks.

Aitchison & Ireland (1995) determined Archaean to Triassic (240 Ma, SHRIMP) ages for inherited zircons from two felsic dykes which they accordingly considered to be no older than Triassic. The dykes are probably related to the magmatism that gave rise to young leucoadamellite plutons of the New England Batholith and comagmatic volcanic rocks which are widespread to the north, south and west of Port Macquarie, and have an age about 230 Ma (Leitch & McDougall 1979; Shaw et al. 1991).

## Sea Acres Dolerite

Dolerite dykes previously included in the Karikeree Metadolerite but distinguished from bodies typical of that unit by their comparative lack of alteration and a distinctive geochemistry, are here grouped in a new unit, the Sea Acres Dolerite. These chemical differences include notably elevated abundances of $TiO_2$ (2.13–2.93%), total Fe (12.07–15.50%) and Zr (133–243ppm) (8 analyses, Och 2007 and Table 3). The name is derived from the Sea Acres Nature Reserve, which includes the headland between Shelly Beach and Miners Beach where the rocks are typically exposed (GR 493840E 6519130N (AMG)) (Photograph 6). The dykes have only been identified along the coastal tract between Shelly Beach (GR 493380E 6519890N (AMG)) and Tacking Point (GR 493960E 6517840N (AMG)) where 14 intrusions have been mapped (Figure 2 and Figure 4).

**Photograph 6.** Sea Acres Dolerite (dark colour), part of a 10 m wide dyke at the type area, southern end of Shelly Beach at GR 493840E 6519130N (AMG). Scale is 20 mm.

Sea Acres Dolerite bodies are composed of fine- to medium-grained dark green plagioclase-phyric dolerite, undeformed and with alteration confined to narrow quartz–epidote veins and pseudomorphous replacement of some mafic minerals (olivine and/or orthopyroxene). The dykes range in width from 0.15 m to 10 m, are mostly planar (although infrequently show en echelon offsets and bulbous projections), are moderately to steeply dipping, and have a weak preferred orientation with a modal strike 010° and dip of 60° to the west. Most dykes have fine-grained chilled margins up to several centimetres wide. The Sea Acres Dolerite has intruded all other units exposed along the coastal tract except the Town Beach Diorite and the Rocky Beach Metamorphic Mélange. As Sea Acres Dolerite is found to cross-cut felsic dykes at Tacking Point, a Late Triassic age is inferred.

## Basalt dykes of uncertain affinity

Two narrow undeformed dykes emplaced in the Watonga Formation are composed of dark green–black basalt. They differ from Sea Acres Dolerite dykes in having a dark devitrified glassy groundmass containing scattered microphenocrysts of clinopyroxene and plagioclase and in their trace and REE geochemistry (Och 2007). One dyke is a poorly exposed body 0.5 m wide that outcrops in the inter-tidal area at Town Beach (GR 492530E 6522590N (AMG)). The other, about 0.15 m wide and continuous for at least 6 m, cuts cherty rocks near Tacking Point (GR 493960E 6517620N (AMG)).The age of these rocks is uncertain. Their relatively little-altered appearance suggests they are no older than the Sea Acres Dolerite and they may be a product of the basaltic magmatism widespread in north-eastern New South Wales during the Tertiary.

## DISCUSSION AND CONCLUSIONS

Rock units of the coastal tract between Port Macquarie and Tacking Point are better exposed, but include representatives, of those found further inland. There is no indication that the tract coincides with a major fault. This paper describes rocks equivalent to the Watonga Formation; the first formal description of the Port Macquarie Serpentinite; and a modified description of the Karikeree Metadolerite. Several other new units have been defined: the Rocky Beach Metamorphic Mélange, the Town Beach Diorite, the Tacking Point Gabbro, the Nobbys Beach Lamprophyre and the Sea Acres Dolerite. Uncommon felsic and basaltic dykes have been identified but not formally named.

The Port Macquarie Serpentinite and the Rocky Beach Metamorphic Mélange are inferred to be the oldest rocks in the Port Macquarie Block, largely dated by analogy with rocks from elsewhere in the New England Fold Belt. They contain a fragmentary late Neoproterozoic to early Palaeozoic history that includes subduction of mafic rocks to depths of 50+ km and associated metamorphism under high-pressure/low-temperature conditions (Och et al. 2003), possibly around 571 Ma (Watanabe et al. 1998), as well as during subsequent exhumation in the Middle Ordovician (Fukui et al. 1995). They were subsequently juxtaposed against ultramafic cumulates of possible forearc origin (Aitchison et al. 1994). Later serpentinisation of the ultramafic rocks was accompanied by metasomatic reaction with the high-pressure rocks producing remnant eclogite and blueschist facies blocks embedded in a chlorite–actinolite schist matrix.

The Watonga Formation consists of ribbon chert, mudstone, siltstone, tuffaceous sandstone, tuff, conglomerate, olistostromal rocks and basalt, that are inferred to have accumulated on an oceanic plate during its passage from spreading ridge to trench. The chert was deposited during the Middle to Late Ordovician. Deformation of the Watonga Formation commenced prior to consolidation of the clastic rocks but was most intense during frontal accretion of the formation, during which they underwent stratal disruption, several episodes of folding and local cleavage formation and possible diapirism. The broken formation character of the unit was established during this progressive accretionary deformation. The age of the inferred trench-fill Watonga Formation clastic rocks has not been established and hence the age of accretion of the formation can only be very broadly constrained between Middle Ordovician and late Carboniferous. Subsequent to accretion, the Port Macquarie Serpentinite and the entrained Rocky Beach Metamorphic Mélange were emplaced into the Watonga Formation.

The Town Beach Diorite and the Tacking Point Gabbro, the Karikeree Metadolerite and the Nobbys Beach Lamprophyre were emplaced (in that order) mostly into previously deformed Watonga Formation. All show the geochemical characteristics of magmatic arc rocks, and the Town Beach Diorite and Tacking Point Gabbro show similarities to members of the Permian Clarence River Supersuite of the New England Batholith, with which they are tentatively correlated. Several minor felsic dykes, two of which have yielded Early Triassic zircon xenocrysts, are considered correlatives of the late leucoadamellite bodies of the New England Batholith emplaced elsewhere in the eastern New England Fold Belt and are of probable Middle Triassic age. The Sea Acres Dolerite has intruded these rocks and hence is Middle Triassic or younger.

Overall, the rocks of the Port Macquarie Block reveal a protracted geological history but nearly all show some imprint of convergent margin tectonics. The high-pressure metamorphic blocks in the Rocky Beach Metamorphic Mélange were underplated at subcrustal depths, presumably beneath an associated over-riding plate. In contrast, the Watonga Formation, being mildly metamorphosed and subjected to widespread soft-sediment deformation, was probably the product of frontal accretion. The Permian and Triassic igneous rocks mark the establishment of a magmatic arc within this older subduction complex, resulting from the relative oceanward movement of the plate boundary.

Although the geological history of the north-eastern Port Macquarie Block is consistent with that recognised for other parts of the eastern New England Fold Belt, it has provided important new information. The relationship of the high-pressure metamorphic rocks is much clearer than elsewhere in the New England region; the age of chert from the Watonga Formation — Ordovician — is greater than that of chert from elsewhere in the accretionary complex; and the range of mafic igneous rocks is greater than recorded from elsewhere along the Permian–Triassic magmatic arc.

## ACKNOWLEDGEMENTS

David Och acknowledges support from a University of Technology, Sydney, Faculty of Science PhD Research Scholarship. The work was supported in part by ARC Large Grant A39601646. We are grateful to John Watkins, Paul Lennox, and Richard Glen for constructive reviews that much improved the original manuscript. Detailed editorial suggestions from Richard Facer and Simone Meakin are gratefully acknowledged. The geotechnical database of Douglas Partners Pty Ltd and drilling carried out by Jervois Mining N.L. in the late 1990s provided information on unexposed serpentinite bodies in the Port Macquarie Block.

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# APPENDIX 1

## Geochemical analytical techniques

Geochemical samples were crushed and powdered at the University of Technology, Sydney, using a Tema tungsten carbide mill. Major element abundances were measured on fused discs prepared from the rock powders, using a Philips PW1480 XRF spectrometer at the Discipline of Geology and Geophysics of The University of Adelaide. Relative accuracy was better than 1% of the amount present. Trace element abundances were measured using pressed pellets with a reported accuracy of ±5% of the amount present. Nineteen samples were analysed by Instrumental Neutron Activation Analysis (INAA) at the Béquerèl Laboratories, Australian Nuclear Science and Technology Organisation, Lucas Heights, New South Wales. Approximately 1g of rock powder for each sample was used to determine rare earth element (REE) and Hf, Th, U and Sc abundances. Detection limits in ppm are: Sm, Lu = 0.01; Yb = 0.03; La, Eu, Sc = 0.05; Ho = 0.10; Hf, Th = 0.20; Ce = 0.50; Nd, U = 1.00.