# Rock Units, Structure and Metamorphism of the Port Macquarie Block, eastern New England Fold Belt

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The presence of syn- and late-orogenic rocks, relationships between recrystallization and imposed structures, and contrasts between units separated by large faults, has allowed reconstruction of a detailed structural and metamorphic history of the Port Macquarie Block.

Three units of stratified rocks are recognized: the Watonga Formation mainly composed of chert and slate of pre-Devonian age, the Middle Palaeozoic Touchwood Formation consisting of volcanogenic clastic sedimentary rocks and andesite, and the Thrumster Slate comprising slate and meta-sandstone of Early Permian (?) age. These units have been intruded by dolerite dykes collectively grouped in the Karikeree Metadolerite, by serpentinite bodies, and by felsic dykes, and are unconformably overlain by Early Triassic conglomerate of the Camden Haven Group.

The Watonga Formation and Thrumster Slate together with early members of the Karikeree Metadolerite were cleaved and recrystallized under greenschist facies conditions at an early stage during Late Permian orogenesis. Later dolerite bodies emplaced in the cleaved rocks are massive but also show greenschist facies mineral assemblages. Touchwood Formation rocks and associated Karikeree Metadolerite dykes lack cleavage and suffered only burial metamorphism, under prehnite-pumpellyite metagreywacke facies conditions. They were brought into contact with the more intensely deformed rocks by transcurrent movements along a system of northnorthwest-trending faults that slice the block. Subsequently serpentinite masses rose along some of these fractures as well as along a somewhat younger northwest striking fault. Isolated glaucophane schist blocks in soil at one locality have probably weathered out of a serpentinite lens.

A small thermal high in which static recrystallization produced biotite post-dates most deformation and may be associated with a buried intrusive body. Here the serpentinite contains antigorite, in contrast with the chrysotile-lizardite serpentinites elsewhere in the block, and is associated with lenses of talc and chlorite-tremolite rocks.

Fault movements continued into post-Early Triassic times, juxtaposing Camden Haven rocks and both serpentinite and earlier Palaeozoic rocks.

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## INTRODUCTION

The meridional trend of major tectonic units that characterizes most of the Tasman Orogenic Zone cannot be recognized in the eastern part of the New England Fold Belt. Instead, stratified rocks of diverse facies, structural history, and metamorphic character, are juxtaposed across a complex series of faults that divide the region into irregular blocks, of which the 150 km$^2$ Port Macquarie Block is the smallest (Fig. 1; Leitch, 1974). The only accessible contact of this block with other Palaeozoic rocks is on its west, where it abuts Carboniferous and Early Permian sedimentary rocks of the Hastings Block along the Cowarra Fault. To the south the block is faulted against Early Triassic strata of the Lorne Basin, and to the north it disappears beneath Quaternary sediment. The eastern edge of the block lies beyond the coastline except perhaps north of Tacking Point where coastline and a northwest-bounding fault may coincide.

No systematic account of the nature of the block has been published previously, although Voisey (1939) described some of the constituent rocks. Carne (1896), Quodling (1964) and Barron, Scheibner and Slansky (1976) have provided data concerning serpentinite and associated rocks that occur along the coast north of Tacking Point, and in view of these reports, and forthcoming accounts by Samuels (*in prep.*) and Leitch (*in press*) the geology of this complex zone is not treated here.

Recent investigations by the author confirm the distinctive character of the Port Macquarie Block but indicate that it is more geologically diverse than has previously been recognized. Northnortheast-trending faults divide the predominantly Palaeozoic mass into domains of differing rock sequences, structural character, and metamorphic history, and its unity derives principally from a persistent structural grain and the presence in each domain of members of a suite of metadolerites.

## Rock Units

Most of the Palaeozoic rocks of the Port Macquarie Block are placed in lithostratigraphic units of formational status that are defined here for the first time. Distribution of the various units is shown on Fig. 1.

### *Watonga Formation*

The Watonga Formation comprises abundant chert and slate, uncommon meta-sandstone, and rare metabasalt, found east of the Lake Innes Fault. The name is derived from Watonga Rock (932171*) designated the type locality for the unit. Irregular folds and numerous faults throughout the formation prevent designation of a meaningful type section.

Chert is typically thin-bedded with stratification defined by colour changes and the presence of thin slate beds and argillaceous partings. Massive chert found particularly adjacent to faults and in some fold hinges has resulted, at least in part, from intense deformation and partial recrystallization of originally thin-bedded units, for in some mesoscopic folds massive chert in the hinge area passes into stratified material in the fold limbs. The cherts are composed of anhedral interlocking quartz grains 0.01-0.02 mm across cut by several generations of quartz veins; traces of radiolaria remain in some samples. A few small mica flakes are scattered through the rocks, which contain tiny hematite grains that impart a progressively more intense red colour as their amount increases. At several localities (876144, 837095) hematite has been concentrated sufficiently to yield impure ironstone intercalations in the cherts. Slate forms units up to several tens of metres thick. It ranges from green chloritic quartz-poor varieties to dark grey micaceous types in which discontinuous quartz segregations occur parallel to cleavage. Stratification is indicated by colour changes and thin fine-grained meta-sandstone laminae. The rocks are texturally reconstituted, detrital relics are absent and cleavage is defined by parallel phyllosilicate films. Meta-sandstone is interstratified with slate at 873140. Little primary structure is preserved and relic detrital grains of plagioclase and less abundant quartz are scattered through a groundmass rich in white mica.

Exposures of igneous rocks of the Watonga Formation (904197, 904191, 905185) are extremely weathered; abundant chloritic material suggests a mafic composition, and relic textural features indicated fine to medium grainsize.

Although no stratigraphic divisions have been recognized within the formation several chert-dominated units each probably originally in excess of 100 m thick, are shown on Fig. 1. It is unclear whether the units comprise different stratigraphic levels,

*Localities are specified by 6-digit grid references read from 1: 25,000 sheets Port Macquarie and Grants Head (1st edition, 9434-I-N and 9435-II-S) published by the New South Wales Department of Lands.

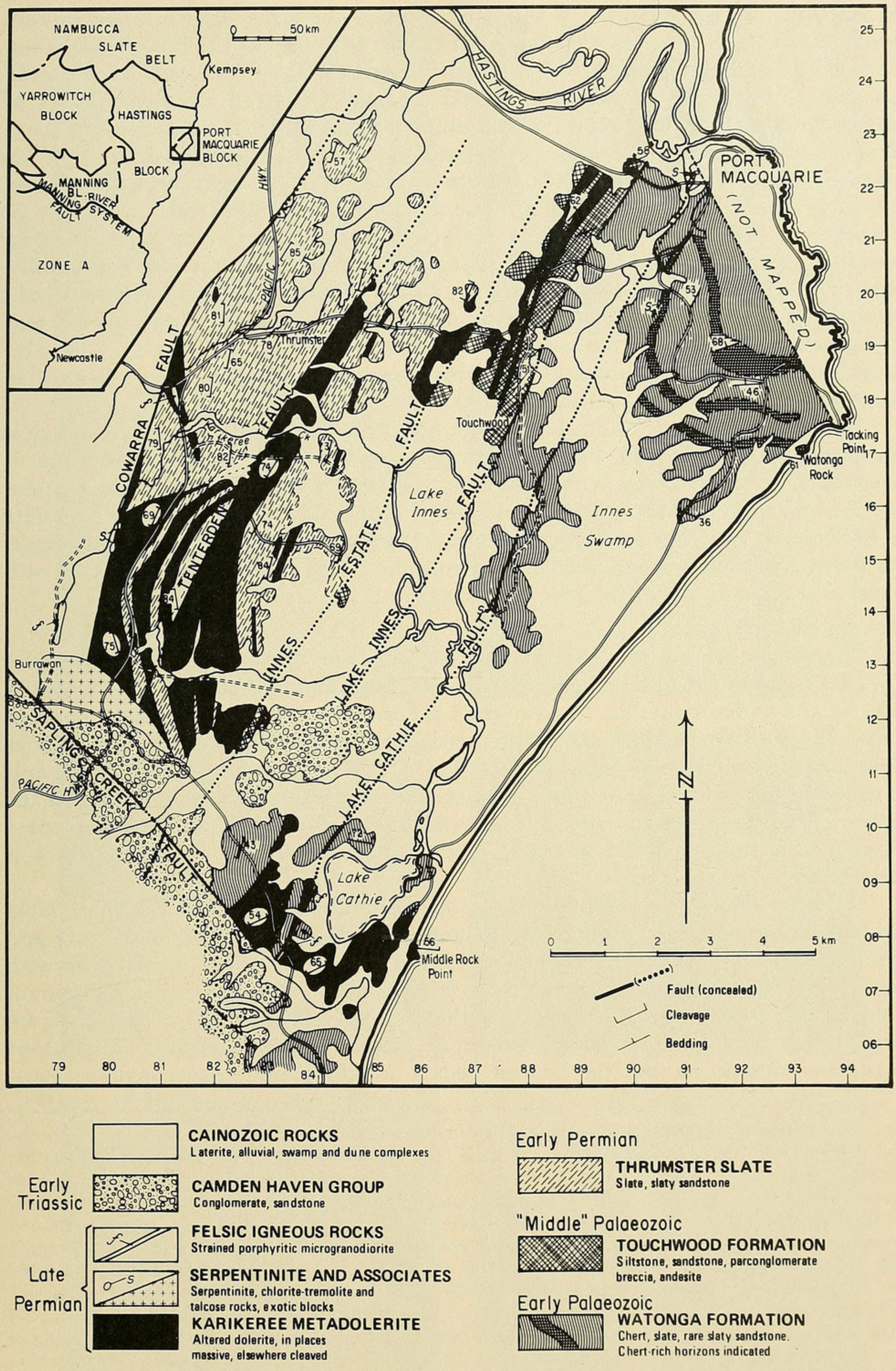



*Fig. 1.* Geological map of the Port Macquarie Block. (Note an arrow head on the bedding symbol denotes direction of younging.)

or whether they are tectonically repeated slices of the same horizon. The western contacts of two of the units are exposed (913207, 905197). At the first locality thin-bedded chert adjoins slate along a near vertical surface slightly oblique to the overall attitude of stratification in the chert and along which small weathered lenses of serpentinous material are found. Relationships at the second locality are less clear, but again an abrupt boundary is indicated. Several small serpentinite pods occur some 30-50 m to the west of the contact, elongate parallel to it. At both localities isolated blocks of chert several metres long are imbedded in the slates and, especially at 905197, the structure of the slates is characterized by sudden along-strike changes, irregular sheared contacts and abrupt changes in degree of deformation. It is possible that many chert contacts in the Watonga Formation are complex shears that have largely remained unrecognized because of poor exposure. Elsewhere in the unit disruption is suggested by the presence of blocks of chert floating in clay (904191), and steeply-dipping chert zones 2-20 m wide alternating with clay zones 1-50 m wide across contacts oblique to stratification (905185).

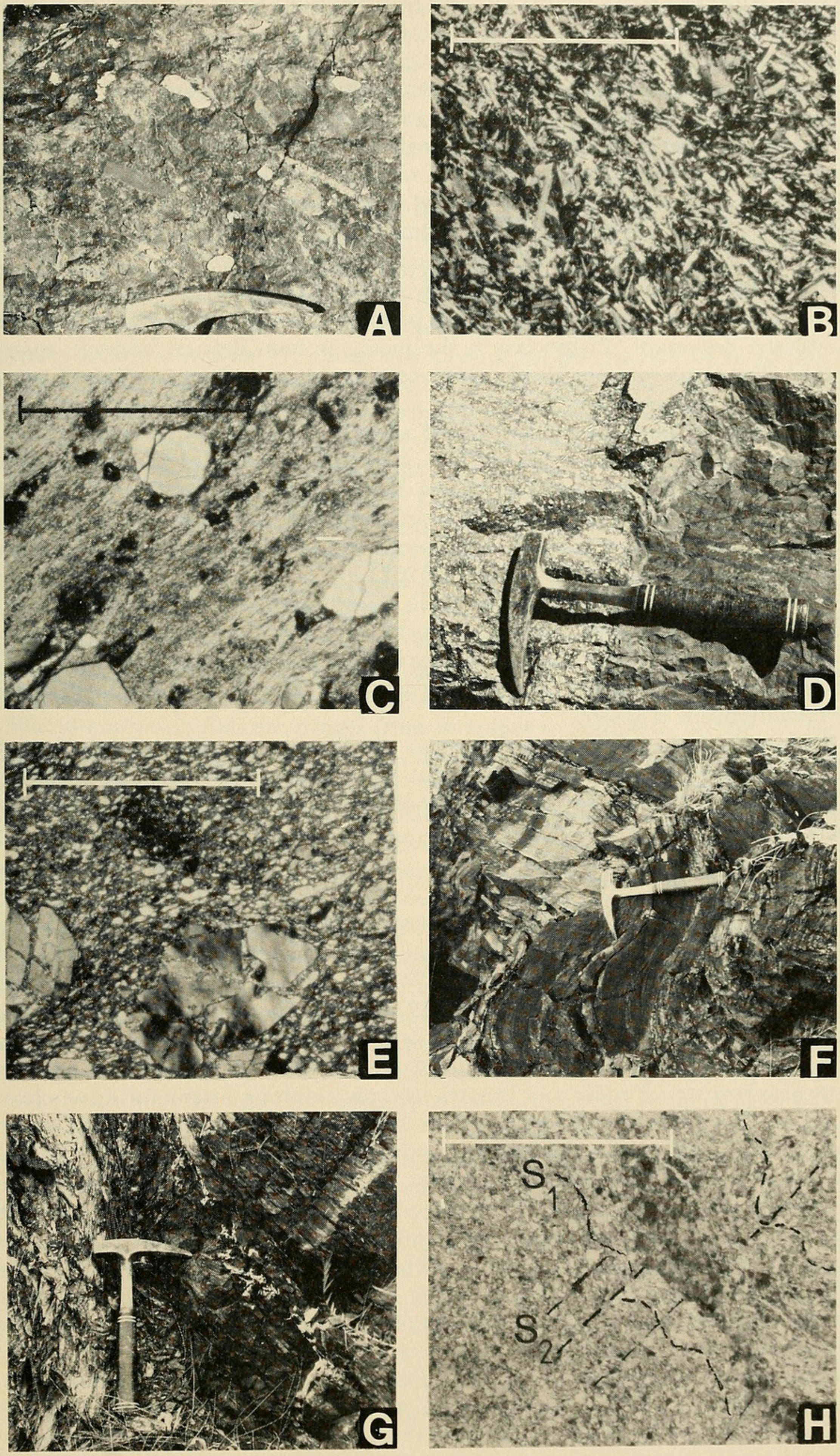
Biostratigraphically useful fossils have not been found in the unit and its age is uncertain. It is intruded by Late Permian metadolerite in the south and is lithologically similar to the Woolomin Beds as defined by Crook (1961) which are of pre-Devonian age (Leitch and Cawood, 1980). Interbedded meta-sandstone and slate at 873140 may belong to a different (? younger) sequence from the rocks further east, for they occur close to the Lake Cathie Fault and are not clearly interstratified with chert-slate sequences typical of the Watonga Formation.

*Touchwood Formation*

The name Touchwood Formation, derived from the property of that name (877177), is applied to a sequence of siltstone, sandstone, paraconglomerate, basalt breccia and andesite that lies between the Lake Innes and Innes Estate faults north of Lake Innes. Two small areas further south that lack outcrop are mapped as Touchwood Formation by extrapolation (Fig. 1). Neither top nor bottom of the unit is exposed, but it forms a west-younging sequence at least 600 m thick of which the upper 250 m comprises andesite. Typical epiclastic rocks of the formation are exposed in a 40 m section in an old quarry in western Port Macquarie (889224), which is designated the type section.

Siltstone, dark grey to black in colour with a subconchoidal fracture, lacks primary structures apart from horizontal lamination defined by changes in colour and grain size; it characteristically occurs in beds less than 0.1 m thick interstratified with sandstone. The latter are indurated, grey, feldspatholithic rocks containing abundant volcanic debris that form units ranging in thickness from 0.01 to 1.0 m. Many beds are simply graded, a few show small-scale cross lamination, intraformational siltstone clasts are widespread, but the base of beds is usually planar. Paraconglomerate is

*Fig. 2.* **A.** Paraconglomerate of the Touchwood Formation with fragments of limestone (white), siltstone and volcanic rock fragments (889224). **B.** Andesite from the upper part of the Touchwood Formation (882205). Scale bar = 2 mm. Crossed polars. **C.** Scattered quartz and plagioclase grains in a micaceous groundmass. Meta-sandstone of the Thrumster Slate (824171). Scale bar = 2 mm. Crossed polars. **D.** Highly porphyritic Karikeree Metadolerite (beneath hammer head) in contact with Touchwood Formation rocks (beneath handle) (889224). **E.** Mylonitic groundmass containing strained and fractured relic quartz and plagioclase phenocrysts. From felsic dyke adjacent to Lake Cathie fault (838087). Scale bar = 2 mm. Crossed polars. **F.** Rounded folds affecting $S_1$ with incipient axial plane crenulation. Slates of Watonga Formation (873140). **G.** Tremolite-chlorite rocks to left of hammer contain small folds with axial plane cleavage dipping vertically and parallel to the contact of these rocks with cleaved slates to the right of hammer. Cleavage within the slates is oblique to the contact. Margin of Lake Innes mass (873140). **H.** Lenticular biotite aggregate cutting across crenulations in $S_1$ and their associated axial surface structure ($S_2$). Same locality as F. Scale bar = 0.8 mm. Plane polarized light.


A
B
C
D
E
F
G
$S_1$
$S_2$
H

composed of subrounded clasts of limestone, basalt, and andesite, and angular siltstone and interbedded sandstone-siltstone fragments similar to adjacent finer-grained rocks, set in a poorly sorted feldspatholithic sandstone matrix (Fig. 2A). Most conglomerate-grade material is in the size range 0.02-0.1 m diameter, but includes infrequent clasts of limestone up to 0.6 m and bedded sedimentary rocks up to 1.5 m. Clast to matrix ratio is about 1:2. Paraconglomerate forms beds ranging in thickness from 1.5-20+m. Internally the rocks are massive, although there is some preferred orientation of the long axes of clasts parallel to bedding, and in a thick bed at the base of the type section local concentrations of limestone pebbles are found. The top 1 m of this bed is graded from granule conglomerate to sandstone.

All of the clastic rocks are characterized by their quartz-poor character and volcanic provenance. Lithic volcanic debris ranges from basalt to dacite with basalt and andesite dominant. Plagioclase is the most common detrital mineral, quartz is rare, and clinopyroxene is nearly always present in at least accessory amounts.

A massive volcanic breccia horizon at least 50 m thick intercalated between bedded sandstone and siltstone below and coarse sandstone above, is exposed in an abandoned quarry (876183). The rock is composed of vesicular basalt fragments 5-50 mm in diameter together with a few larger clasts (up to 0.1 m) of bedded sedimentary rocks comparable with those underlying the breccia, set in a coarse ill-sorted sandstone matrix. A coarse basalt breccia lacking sedimentary fragments occurs on the north side of the Hastings River (915252).

Poorly exposed andesitic (keratophyric) rocks comprise the upper part of the formation. They are slightly porphyritic rocks, in which small phenocrysts of altered plagioclase occur scattered through a groundmass of aligned plagioclase laths and secondary minerals replacing intersertal glass (Fig. 2B). In contrast to the basaltic rocks clinopyroxene is absent.

Tabulate and rugose corals occur in limestone blocks in the thick paraconglomerate of the type section but these are too altered to allow specific identification. Attempts to obtain conodonts from the limestone blocks were unsuccessful.

*Thrumster Slate*

Slate, meta-sandstone, and meta-granule conglomerate that outcrop between the Innes Estate and Cowarra faults are termed Thrumster Slate, after the parish of Thrumster in the northwestern part of the Port Macquarie Block. Scattered exposures along Lake Innes Drive (817171 to 824171) comprise the type section. Here, as elsewhere, outcrops are discontinuous and usually deeply weathered, and an estimated thickness of 650 m for this section, which provides a minimum for the unit, assumes no structural repetition of rocks and ignores tectonic thinning attendant upon cleavage formation. The stratigraphic limits of the Thrumster Slate have not been observed and no internal stratigraphy has been recognized.

Slate, the dominant rock type, is of dark blue-grey to black colour when unweathered and has a distinct micaceous sheen. A single planar cleavage is ubiquitous and in some outcrops stratification is indicated by thin beds of poorly cleaved siliceous slate, and fine-grained meta-sandstone laminae. The slate is almost totally recrystallized with cleavage resulting from the parallel growth of white mica films that separate similarly aligned lenses of small quartz and albite grains. Coarse meta-sandstone and granule meta-conglomerate occur together in intervals several tens of metres thick accompanied by little finer-grained material. Individual beds are often simply graded and contain rip-up clasts of siltstone, some over 1 m long. These rocks are dominated by detrital quartz, with lesser relic detrital grains of plagioclase and felsic volcanic rock fragments scattered through a groundmass of white mica (Fig. 2C).

No fossils have been found in the slate and the only signs of organic activity are faecal pellets found at one locality (830497). The unit closely resembles rocks of the Nambucca Slate Belt and on this basis is tentatively assigned an Early Permian age (Runnegar, 1970).

*Karikeree Metadolerite*

Altered dolerite bodies emplaced within all three stratified Palaeozoic units are grouped in the Karikeree Metadolerite, named from Karikeree Creek that cuts several of the bodies along its course across the western part of the block. Outcrops along Lake Innes Drive (832168 to 827160) constitute the type section.

The doleritic rocks are holocrystalline, of medium grain-size, and at least incipiently altered. Some are crammed with plagioclase phenocrysts up to 20 mm long (Fig. 2D) or contain large clinopyroxene plates, but most are approximately equigranular. Those relatively rich in clinopyroxene have an ophitic texture, whereas more felsic varieties tend to be hypidiomorphic-granular aggregates of equant clinopyroxene grains and plagioclase laths. Plagioclase of intermediate composition was the most common magmatic phase. Although it has been partially replaced by albite, relic labradorite, sometimes normally zoned, occurs in a number of specimens and even some quite highly reconstituted rocks retain feldspar of this composition. Magmatic calcic clinopyroxene is preserved in many metadolerites; colourless, very pale green and distinctly pink varieties are found in different rocks. Coarsely crystalline brown hornblende found in several metadolerites, either as discrete grains or mantling clinopyroxene, is a late-magmatic phase. Apatite rods and angular irregular opaque oxide grains are also magmatic relics.

The alteration of dolerite ranges from incipient to complete. Albite, actinolite, chlorite, epidote and sphene are widespread secondary phases, white mica, clinozoisite, calcite and quartz are less widespread, and garnet is rare. Pseudomorphous replacement characterizes the massive metadolerites, but foliated bodies show a marked preferred orientation of secondary phases and the start of metamorphic differentiation. Planar zones of an exclusively metamorphic character up to a metre wide and containing restricted mineral assemblages, usually dominated by epidote, mark sites of extensive metasomatic alteration and were probably major hydrothermal passageways during metamorphism.

Chemical composition and C.I.P.W. norms for a selection of metadolerites are given in Table 1. On present composition three samples, those with normative nepheline, would be considered alkalic, six samples are olivine-hypersthene normative, and one sample quartz normative and hence apparently tholeiitic. However the norm of the latter is much affected by a high $Fe_2O_3/FeO$ ratio (0.58) and when recalculated for a value of 0.20, normative quartz virtually disappears (qz = 0.01). As expected porphyritic samples contain high normative plagioclase and ophitic rocks have relatively large amounts of normative pyroxene plus olivine.

The total alkali versus silica relationship (Fig. 3A, Macdonald and Katsura, 1964) would indicate that both tholeiitic and alkalic rocks are present, with a tendency for more highly metamorphosed rocks to appear more tholeiitic. However, when plotted on Miyashiro's (1975) $Na_2O/K_2O$ versus $Na_2O + K_2O$ diagram some samples fall outside the field occupied by fresh volcanic rocks and the others occur in tholeiitic rather than alkali basalt fields (Fig. 3B). Changes in the amount of $Na_2O$ and $K_2O$ during metamorphism are indicated, and the magmatic affinities of the metadolerites cannot be unambiguously determined from their major element composition.

TABLE 1

*Chemical Data*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 49.09 | 48.13 | 47.99 | 47.90 | 47.75 | 47.01 | 46.92 | 47.04 | 46.94 | 44.83 |
| $TiO_2$ | 1.69 | 2.97 | 2.66 | 2.46 | 1.54 | 1.99 | 1.29 | 2.19 | 2.98 | 2.29 |
| $Al_2O_3$ | 18.73 | 14.36 | 14.73 | 14.16 | 18.53 | 15.05 | 15.81 | 14.90 | 14.61 | 13.37 |
| $Fe_2O_3$ | 0.84 | 2.28 | 2.34 | 1.56 | 1.72 | 1.63 | 1.30 | 4.29 | 4.99 | 3.14 |
| FeO | 7.69 | 10.86 | 9.97 | 10.68 | 7.22 | 8.98 | 7.50 | 7.79 | 8.54 | 9.32 |
| MnO | 0.15 | 0.23 | 0.21 | 0.23 | 0.16 | 0.19 | 0.16 | 0.22 | 0.23 | 0.20 |
| MgO | 5.31 | 5.46 | 5.75 | 6.65 | 6.16 | 7.44 | 9.08 | 7.16 | 6.20 | 11.76 |
| CaO | 10.38 | 8.76 | 8.50 | 9.90 | 11.84 | 10.48 | 10.20 | 9.84 | 9.29 | 7.97 |
| $Na_2O$ | 3.90 | 3.27 | 4.01 | 3.13 | 2.42 | 3.74 | 3.77 | 2.92 | 2.51 | 1.68 |
| $K_2O$ | 0.26 | 0.39 | 0.16 | 0.12 | 0.09 | 0.08 | 0.14 | 0.50 | 0.32 | 0.06 |
| $H_2O^+$ | 2.08 | 2.39 | 3.88 | 2.85 | 2.49 | 3.85 | 3.41 | 2.82 | 2.79 | 5.63 |
| $H_2O^-$ | 0.09 | 0.16 | 0.14 | 0.12 | 0.12 | 0.13 | 0.18 | 0.14 | 0.14 | 0.39 |
| $P_2O_5$ | 0.19 | 0.32 | 0.27 | 0.25 | 0.18 | 0.20 | 0.11 | 0.20 | 0.30 | 0.25 |
| Total | 100.40 | 99.58 | 100.61 | 100.01 | 100.22 | 100.77 | 99.87 | 100.01 | 99.84 | 100.89 |

C.I.P.W. NORMS

(anhydrous)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| qz | | | | | | | | | 3.25 | |
| or | 1.56 | 2.38 | 0.98 | 0.73 | 0.54 | 0.49 | 0.86 | 3.04 | 1.95 | 0.37 |
| ab | 31.68 | 28.51 | 35.13 | 27.29 | 20.98 | 27.30 | 24.67 | 25.46 | 21.92 | 14.98 |
| an | 33.43 | 24.07 | 22.49 | 24.99 | 40.40 | 24.85 | 26.80 | 26.87 | 28.54 | 30.32 |
| ne | 1.04 | | | | | 2.92 | 4.59 | | | |
| di | 14.57 | 15.35 | 15.92 | 19.73 | 15.13 | 22.46 | 20.22 | 17.80 | 13.72 | 7.74 |
| hy | | 17.71 | 5.88 | 11.37 | 13.74 | | | 10.66 | 16.59 | 30.72 |
| ol | 12.76 | 1.98 | 10.20 | 8.14 | 3.22 | 15.15 | 18.09 | 4.99 | | 5.87 |
| mt | 1.24 | 3.41 | 3.51 | 2.33 | 2.55 | 2.44 | 1.96 | 6.41 | 7.46 | 4.80 |
| il | 3.27 | 5.81 | 5.23 | 4.81 | 3.00 | 3.90 | 2.54 | 4.28 | 5.84 | 4.58 |
| ap | 0.46 | 0.78 | 0.66 | 0.61 | 0.44 | 0.49 | 0.27 | 0.49 | 0.73 | 0.62 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

1 — 57518 Little-altered porphyritic dolerite (898224)
2 — 57519 Moderately altered metadolerite (812163).
3 — 57520 Moderately altered metadolerite (811160).
4 — 57521 Moderately altered ophitic metadolerite (815140).
5 — 57522 Moderately altered porphyritic metadolerite (817137).
6 — 57523 Little-altered ophitic dolerite (812183).
7 — 57524 Moderately altered ophitic metadolerite (834153).
8 — 57525 Moderately altered metadolerite (858077).
9 — 57526 Moderately altered ophitic metadolerite (826083).
10 — 57527 Highly altered metadolerite (832168).

Analyses by X-ray fluorescence spectrometry except for FeO (titrimetry), $H_2O$ (gravimetry). R. Beck, analyst.

The metadolerite masses comprise mainly tabular bodies that range in width from 1 m to more than 30 m. Many of the larger masses shown on Fig. 1 are composite, formed of several parallel bodies often separated by thin (1-10 m) screens of country rock. Where intrusive relationships have been determined the massive, little altered and sometimes porphyritic bodies post-date more altered foliated dykes. The latter tend to lie parallel to cleavage in adjacent rocks, whereas the former though

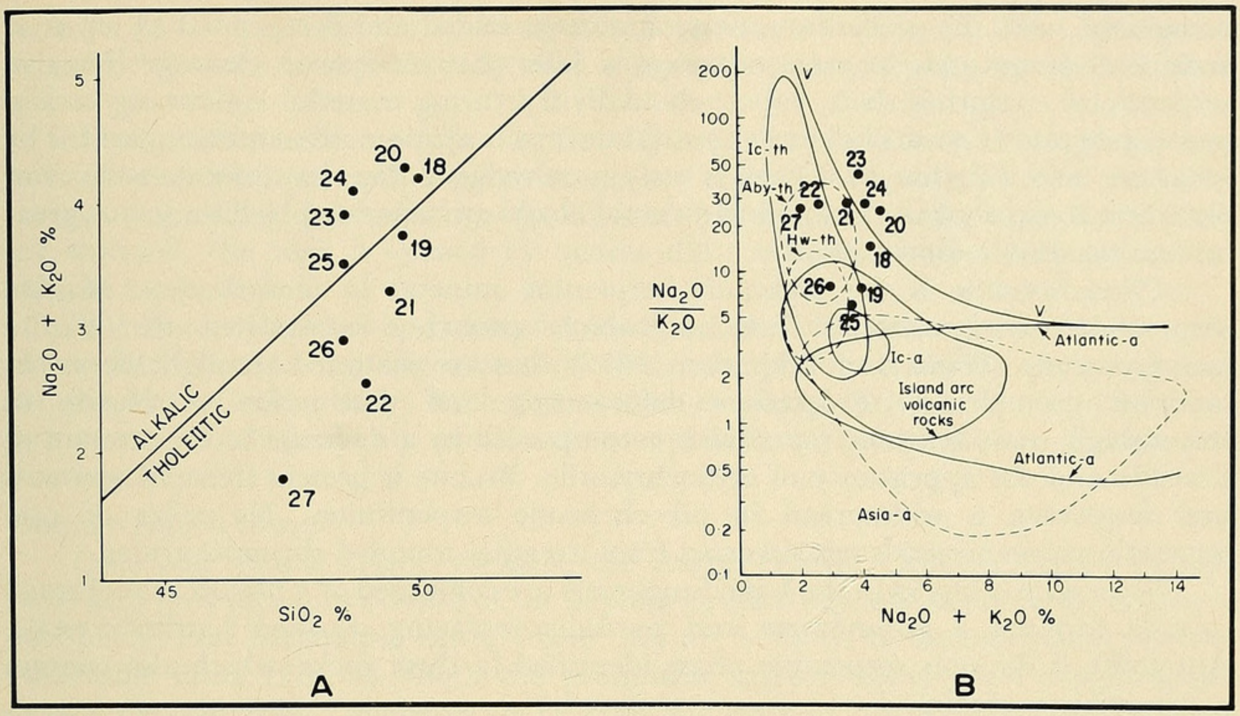



*Fig. 3.* **A.** $SiO_2$ versus $Na_2O$ + $K_2O$ for Karikeree Metadolerite. Alkalic-tholeiitic division from Macdonald and Katsura (1964). **B.** $Na_2O$ / $K_2O$ versus $Na_2O$ + $K_2O$ for Karikeree Metadolerite with fields of Cainozoic volcanic rocks indicated (after Miyashiro, 1975). Abyssal tholeiites (Aby-th), Hawaiian tholeiites (Hw-th), Icelandic tholeiites (Ic-th), Icelandic alkalic rocks (Ic-a), alkalic rocks from other Atlantic Islands (Atlantic-a) and from eastern Asia (Asia-a), and common arc volcanic rocks. Numbers are last two digits of University of Sydney numbers indicated on Table 1.

maintaining this orientation in places elsewhere cut obliquely across structural surfaces in the surrounding formations. Cleavage within the metadolerites is variably developed; some bodies are uniformly cleaved, others contain narrow zones of enhanced cleavage, and some otherwise massive dykes have narrow cleaved margins. Contact effects adjacent to the bodies are restricted to a zone from 0.1 to 0.4 m wide wherein the country rocks have been partially silicified and cleavage is less conspicuous.

Karikeree Metadolerite intrudes the Early Permian (?) Thrumster Slate and is truncated by the Late Permian Burrawan serpentinite. The rocks were emplaced during and perhaps immediately after orogenesis, and a Late Permian age is favoured.

*Serpentinite bodies and related rocks*

Serpentinite bodies occur both within and at the margin of the Port Macquarie Block. The largest mass is that at the southwest corner of the block in the parish of Burrawan, here referred to as the Burrawan serpentinite. A lens of tremolite-chlorite rock containing talc-rich areas and serpentinite blocks on the eastern shore of Lake Innes (873140) is referred to as the Lake Innes mass. Small serpentinite lenses occur along the Cowarra Fault (153800, 157801) and in quarries near Port Macquarie (913207, 905197). Serpentinite mapped in the vicinity of the Lake Cathie Road (827083) and on the Pacific Highway (811160) by Brunker, Offenberg and Cameron (1970) were not located; only outcrops of Karikeree Metadolerite were found at these localities.

Both massive and schistose serpentinite are present, the former variety being more common in the Burrawan mass and the latter forming the bulk of the smaller bodies. In the schistose rocks several generations of structural surfaces can be recognized, with the earliest and dominant often folded and overprinted by an axial surface cleavage and, in some outcrops, a later discrete spaced cleavage. Massive serpentinite comprises dark, subconchoidally-fracturing material containing bastite pseudomorphs. It occurs in blocks up to a metre in maximum dimension separated by schistose material that in places is only a selvedge a few centimetres wide, but elsewhere forms a matrix in which individual blocks are separated by distances as great as their maximum dimension.

Clinochrysotile is the dominant serpentine mineral in most bodies. Massive serpentinite also contains lizardite which probably constitutes the bastite pseudomorphs (Wicks and Whittaker, 1977) that are scattered through the mesh-textured groundmass. Progressive deformation and destruction of bastite in increasingly more schistose material is accompanied by a decrease in the amount of lizardite and the appearance of orthochrysotile. Brucite is present in small amounts and magnetite is widespread in all chrysotile serpentinites. No relics of pre-serpentinization minerals remain apart from irregular rounded chromite grains.

Serpentinite blocks in the Lake Innes mass are composed of a bladed mat of small crystals forming a groundmass and partially replacing strained bastite crystals. Antigorite is the only serpentine phase identified in these rocks, which also contain small amounts of talc.

Magnesite is present as a weathering product of the serpentinites, and chalcedonic silica occurs in the southern part of the Burrawan body.

Tectonic inclusions that are scattered throughout the Burrawan serpentinite are mostly chert identical with that in the Watonga Formation, and highly altered dolerite and amphibolite, in which prehnite is a common phase. Inclusions of massive siltstone similar to that in the Hastings Block are restricted to the western part of this body.

Several blocks of glaucophane schist up to a metre long are associated with metadolerite and a highly foliated quartz-albite rock, along the trace of the Innes Estate Fault (826117). None of this material is *in situ,* but it is almost certainly of local derivation. The blocks are probably tectonic inclusions weathered out of a recessive serpentinite lens.

The serpentinite bodies are intrusive with respect to the stratified Palaeozoic rocks and the Karikeree Metadolerite, and have been emplaced as cold masses along faults. Voisey (1939) reported that the Burrawan serpentinite is unconformably overlain by Triassic strata, and although I have not located an exposure of this contact, his interpretation is accepted and a Late Permian age for emplacement of the body favoured. However, movement on the Sapling Creek Fault subsequent to deposition of the Triassic rocks has locally brought these into tectonic contact with the serpentinite (Fig. 1). Along this section the southern margin of the mass is silicified, probably as a result of these late movements.

*Felsic dykes*

Two narrow felsic dykes have been mapped within the Port Macquarie Block, one trending just west of north adjacent to the Pacific Highway (813183-814177), and the other striking northeast west of Lake Cathie (833076-839090). The rocks of both bodies are strained and altered. Their general composition is granodioritic, with quartz and plagioclase the dominant constituents; potassic feldspar is uncommon and primary mafic minerals are not preserved.

The Lake Cathie body, which lies adjacent to the Lake Cathie Fault, has been converted to a blastomylonite; plagioclase and quartz phenocrysts remain in a fine groundmass of albite grains, highly strained and marginally recrystallized elongate quartz grains, and slightly wavy white mica films (Fig. 2E). The phenocrysts have been fractured, bent, and rotated during deformation as is indicated by the disruption of twin lamellae in formerly contiguous fragments of feldspar. That they were originally igneous is indicated by relic magmatic embayments preserved in some quartz grains.

The igneous texture of the Pacific Highway dyke is clearer; rare plagioclase microphenocrysts and graphically intergrown quartz-feldspar clots are scattered through a granular quartz-feldspar groundmass. Both quartz and plagioclase crystals are strained, the rock is crossed by quartz-albite veins, and secondary pyrite and chlorite are present.

The Pacific Highway body intrudes Karikeree Metadolerite and hence is probably of post-Early Permian age. Because of its similar composition a similar age is suggested for the Lake Cathie body. Both dykes were emplaced prior to the end of fault movements which probably continued into post-Early Triassic times (Leitch and Bocking, *in press*).

*Camden Haven Group*

Quartzose coarse clastic rocks of the Early Triassic Camden Haven Group, previously only recognized south of the Sapling Creek Fault, also occur in the southern part of the Port Macquarie Block where they are believed to unconformably overlie Palaeozoic units (Fig. 1). Both the prominent scarp-forming chert conglomerate termed the Laurieton Conglomerate by Pratt and Herbert (1973), and an older lithic conglomerate unit (Leitch and Bocking, *in press*) have been recognized.

*Tertiary and Quaternary rocks*

Very deep weathered zones, laterite, and extensive Quaternary alluvial, swamp, and dune complexes mask much of the Palaeozoic basement. A metre-wide camptonite dyke cutting Karikeree Metadolerite at Middle Rock Point (857076) probably belongs to the Tertiary alkaline province more voluminously represented west and southwest of the Port Macquarie Block (McDougall and Wilkinson, 1967).

## STRUCTURE

*Faults*

The structure of the Port Macquarie Block is dominated by a set of northnortheast-striking faults which juxtapose stratified rocks belonging to different formations and of contrasting metamorphic grade and structural character. Large but unestablished strike-slip movements are indicated, for no relationship exists between metamorphic grade and the age of rock units, a relationship which might be anticipated if vertical movements had led to the exposure of different levels of a stratified sequence. Major fault surfaces have not been seen, but steep dips are suggested by approximately straight fault traces, the vertical attitude of serpentinite bodies emplaced along the faults, and the steep inclination of small-scale shear fractures within the Block.

The *Cowarra Fault* bounds the Block to the northwest, its position marked by an abrupt change in rock types, from uncleaved conglomerate sandstone and siltstone of the Hastings Block to metadolerite and slate. Small serpentinite lenses occur along the southern part of the fault and further north (819202) highly irregular folds in the Thrumster Slate indicate its proximity. A sliver of Hastings Block rocks is surrounded by slate where the fault cuts the Pacific Highway (832212), suggesting the fracture here is of more complex structure than elsewhere.

The presence of the *Tenterden Fault* is inferred from the distribution of Thrumster Slate and Karikeree Metadolerite south of Karikeree Creek. The *Innes Estate Fault* marks the western limit of the Touchwood Formation and is a major structural and metamorphic discontinuity: cleavage, ubiquitous in pelitic rocks west of the fault, is absent on its eastern side, and metamorphic grade changes from greenschist in the west to prehnite-pumpellyite in the east. Close to its trace Thrumster Slate shows numerous kink bands and associated less regular small folds.

The eastern extent of the Touchwood Formation is determined by the *Lake Innes Fault* east of which cleaved rocks of greenschist grade are again found. Pits from which lateritic iron was once quarried (876173, 894212 and 896215) occur along the trace of the fault and Harrison (1955) recorded serpentinite, not now visible, in the pit at the last locality. The *Lake Cathie Fault* is mapped on the basis of the presence and shape of the Lake Innes serpentinite mass, the abrupt termination of a prominent hematite chert horizon in the Watonga Formation northwest of Lake Cathie, and the mylonitic structure of the granodiorite dyke west of Lake Cathie. The northern continuation of the fault passes through a body of serpentinite in the grounds of the Catholic Church in Port Macquarie (913223).

In the south the Cowarra and Tenterden faults abut the Burrawan serpentinite and the three fractures situated further east are cut off by the northwest striking *Sapling Creek Fault.* This structure brings Palaeozoic rocks in the northeast in contact with Triassic strata to the southwest. A small mass of serpentinite, mapped by Leitch and Bocking (*in press*) at 813046 (see their fig. 1), possibly marks the position of the Cowarra Fault south of the Sapling Creek Fault (Fig. 1), suggesting sinistral strike-slip movement of about 4 km on the latter.

*Structural domains*

The major northnortheast faults bound domains of differing structural character (Fig. 4). Within these domains bedding ($S_0$) and slaty cleavage ($S_1$) are the dominant surfaces, the latter forming the axial surface to folds in the former ($B_0^1$). A lineation produced by the intersection of the two surfaces (L(0x1)) is occasionally discernible. The internal structure of the domains is discussed below.

*Domain I:* $S_1$, the dominant structural surface in Domain I, occurring both in the Thrumster Slate and in early members of the Karikeree Metadolerite, parallels the axial surface of small, rather angular tight to isoclinal folds in $S_0$, but is unaffected by later mesoscopic structures apart from kink-bands and less regular folds close to the Innes Estate Fault. The stereographic projection of poles to $S_1$ (Fig. 4A) shows a slightly elongate point maximum suggesting an average orientation of 015/75/W but with slight flexure about an axis plunging approximately 75 to 196, a flexure also indicated by the curve of metadolerite bodies in the southwest of the domain (Fig. 1).

Stratification is not common in this domain and is most readily observed where it is at a high angle to $S_1$. Hence in spite of the narrow hinges and near-parallel limbs of mesoscopic $B_0^1$ structures, the distribution of $S_0$ differs from that of $S_1$ (Fig. 4B). Insufficient readings are available to allow a detailed study of the geometry of this surface, and the absence of mappable marker horizons and a dearth of younging structures inhibit recognition of major $B_0^1$ folds. Most mesoscopic $B_0^1$ folds and L(0x1) lineations plunge very steeply (Fig. 4B) and probably maintain a coherence because of the steep plunge of the axis about which $S_1$ flexure occurred. The two readings that plunge moderately southwest come from within 1 km of the Burrawan serpentinite and may have been rotated during emplacement of this mass. $S_1$ in this area strikes west of north and may also have been so affected.

*Domain II:* $S_0$ in the Touchwood Formation strikes approximately northeast and dips about the vertical, younging consistently northwest (Fig. 4C). No mesoscopic folds are present and cleavage is absent both from these rocks and Karikeree Metadolerite dykes emplaced within them.

*Domain III:* $S_1$, the only widely developed structural marker in the rocks of domain III, has an average strike of about northeast and generally dips at a moderate angle northwest (Fig. 4D). Slate and meta-sandstone adjacent to the Lake Innes mass

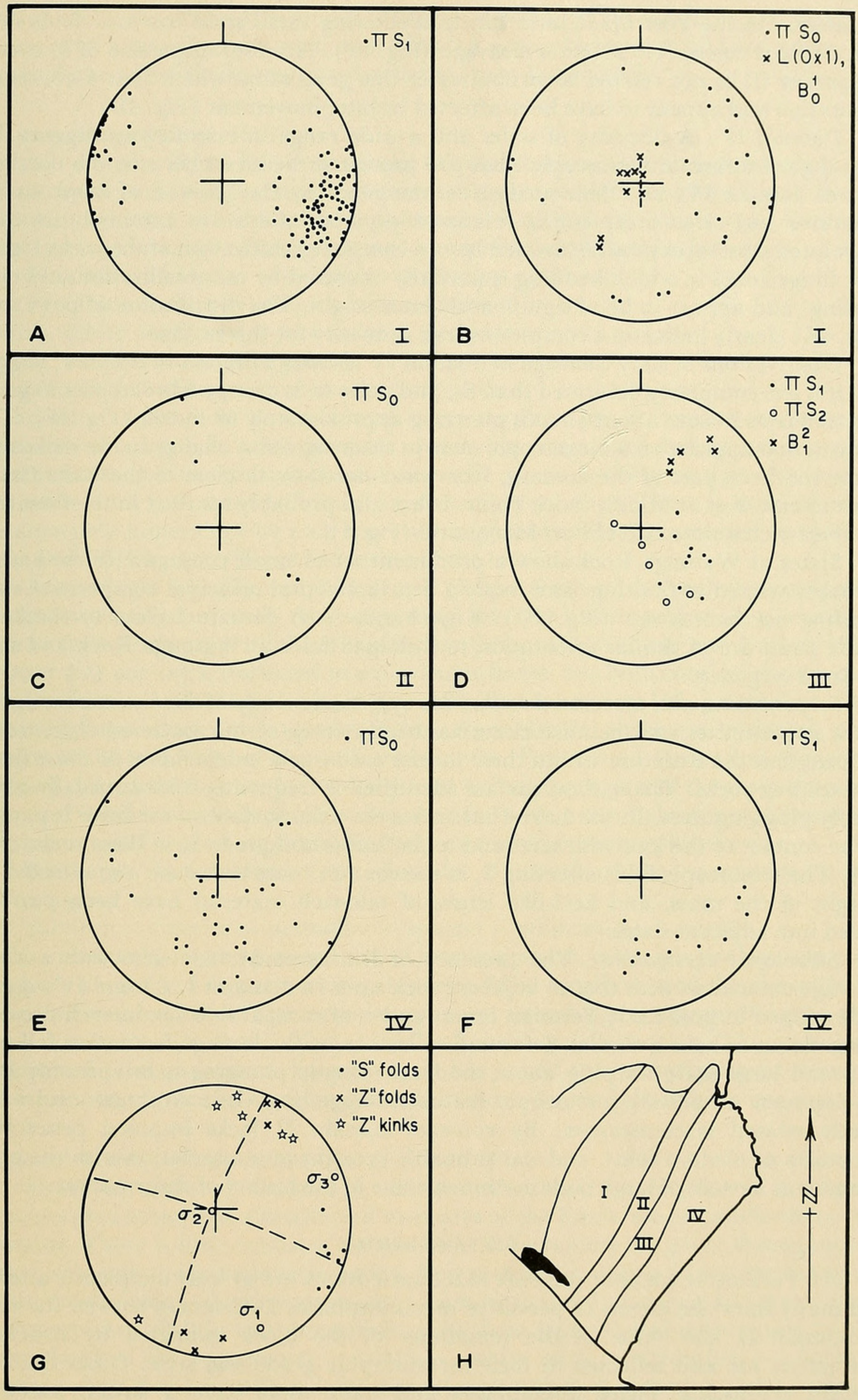



*Fig. 4.* Structural data for the Port Macquarie Block. Plots are equal angle stereographic projections and roman numerals refer to the domains indicated in H. See text for detailed descriptions.

are unique in the Port Macquarie Block in showing small-scale rounded folds in $S_1$ with an axial surface crenulation cleavage (Fig. 2F). However dispersion of $S_1$ overall in domain III is not related to structures of this generation which lack a consistent orientation and appear to have been affected by later movement (Fig. 4D).

*Domain IV:* A diversity of styles and a wide range in orientations suggest that several generations of mesoscopic folds are present in bedded cherts in the northern part of domain IV, but their analysis is hampered by the absence of axial surface structures and clear overprinting relationships. Some folds are extremely intricate convoluted structures possibly formed before complete lithification of the rocks, others have hinge zones in which bedding is partially obscured by recrystallization and close jointing, and appear to be of significantly later origin. The distribution of poles to $S_0$ (Fig. 4E) clearly indicates a complex overall geometry for this surface.

Observations of slaty cleavage in domain IV although limited in number, suggest that it is less complexly deformed than $S_0$, and poles to $S_1$ occupy a broad partial girdle that indicates flexure about an axis plunging approximately 60 to 335 (Fig. 4F). This deformation appears on a megascopic scale in the progressive change in the strike of $S_1$ in the southern part of the domain, from near north-south close to the Lake Cathie Fault to east-west at Middle Rock Point. It has also probably resulted in the flexure of the chert-rich units south of Port Macquarie (Fig. 1).

Slates at Watonga Rock show a prominent set of small conjugate folds that are probably related to faulting, and imply a near horizontal principal compressive stress trending northnorthwest (Fig. 4G). Kink bands from domain I close to the Innes Estate Fault are of similar orientation to Z-shaped folds at Watonga Rock and show the same vergence.

*Serpentinites and associated rocks:* No systematic study of the internal structure of the serpentinites and their associates has been attempted but scattered observations indicate that the structure within these masses are largely independent of those in the surrounding rocks. The earliest surface identified is frequently folded, usually about steeply plunging axes. In the Lake Innes mass the axial surface of the folds is parallel to the contact of the lens with surround rocks, but is oblique to $S_1$ in these rocks (Fig. 2G). The mesoscopic folds affecting $S_1$ in the country rocks here have also affected the margin of the mass, and keel-like lenses of talc-rich material have been partially folded into adjacent slates.

*Structural correlation:* The presence of Karikeree Metadolerite with a single cleavage coincident with that in adjacent rock units in domains I, III and IV suggests $S_1$ developed in post-Early Permian times, and is of comparable age in each domain. These domains have a similar deformation history, with cleavage formation followed by broad large-scale warping about moderate-steeply plunging axes and only local development of post-$S_1$ mesoscopic features, suggesting their structure evolved in closely related circumstances. By contrast domain II lacks imposed penetrative structures or obvious folds, and was probably brought into association with the other domains as a result of large fault movements late in the history of deformation.

## METAMORPHISM

All Palaeozoic rocks of the Port Macquarie Block are at least incipiently altered, and many show the effects of pervasive metamorphism. Differences betwen the rocks of domain II and those of the remainder of the block indicated by structural characters, are also reflected in their metamorphic grade and style. Other domains contain greenschist facies assemblages and most rocks have a strong preferred orientation of metamorphic phases, but the rocks of domain II are of subgreenschist grade and new minerals have grown pseudomorphously or in irregular replacement patches and veins. These two groups of rocks are discussed separately below, as are the products of a late thermal event that affected a small area east of Lake Innes, and glaucophane schist blocks associated with the Innes Estate Fault.

*Metamorphism in domain II*

All domain II rocks retain their original texture and much of their pre-metamorphic mineralogy; secondary minerals are patchily developed and there is abundant evidence of incomplete replacement. Rocks of the Touchwood Formation have developed a range of low-grade metamorphic assemblages including:

(i) albite — chlorite — epidote — prehnite — pumpellyite
(ii) albite — chlorite — epidote — prehnite
(iii) albite — chlorite — actinolite — prehnite
(iv) albite — chlorite — epidote
(v) albite — chlorite — actinolite — epidote

In addition sphene is a ubiquitous metamorphic phase, calcite is frequently encountered but only in small amounts, quartz has crystallized during metamorphism in some rocks and in others is present as a relic phase showing no sign of alteration, and white mica is a common but minor secondary mineral. There is little control of metamorphic mineralogy by rock type, although white mica is restricted to epiclastic rocks and (iv) characterizes the andesites of the formation.

Assemblages (i), (ii) and (iii) are all characteristic of the prehnite-pumpellyite metagreywacke facies, with (iii) suggesting the rocks were subjected to conditions close to those at the upper limit of this facies (Coombs, Horodyski and Naylor, 1970). Neither (iv) nor (v) is restricted to a particular facies, but both confirm the low grade of alteration. Assemblage (v) is probably more typical of greenschist facies metamorphism than lower grade facies, especially in rocks reconstituted under conditions of low $fCO_2$ as are indicated for the Touchwood Formation. Specimens showing this assemblage are known only from the southern part of the main outcrop of domain II rocks, and it is possible that they fall within the Lake Innes thermal high (see below) and hence have been affected by a second metamorphic event.

Karikeree Metadolerite from domain II contains the secondary mineral asemblage:

(albite) — chlorite — actinolite — sphene — white mica — calcite

and is noteworthy for the preservation of most magmatic calcic plagioclase, alteration of which is restricted to narrow irregular veins filled by albite, and the crystallization of tiny white mica flakes. The secondary mineral assemblage is not specific as to grade but is consistent with that indicated by the Touchwood Formation. The retention of plagioclase (and also calcic clinopyroxene) has meant that components necessary for the formation of calcium aluminosilicate minerals were not released in these rocks.

*Regional metamorphism in domains I, III and IV*

Stratified rocks of domains I, III and IV show the imprint of a regional metamorphic event that also affected members of the Karikeree Metadolerite in these domains. There is little evidence for variation in metamorphic grade throughout the rocks, although the metadolerite bodies show a range in degree of reconstitution and fabric development which suggests some were introduced at only a late stage during metamorphism. Pelitic and psammitic rocks show typical sub-biotite grade mineral assemblages of the type quartz — albite — white mica — (chlorite) — (epidote) whereas chert has reconstituted to assemblages including quartz — white mica — hematite, quartz — stilpnomelane — hematite and quartz — chlorite — stilpnomelane — hematite.

Metamorphic assemblages recognized in the Karikeree Metadolerite are:

(i) albite — actinolite — chlorite — epidote — sphene — (white mica) — (quartz) — (calcite)
(ii) actinolite — chlorite — epidote — sphene — white mica — (quartz) — (calcite)
(iii) albite — actinolite — epidote — sphene — (quartz)
(iv) albite — chlorite — epidote — sphene
(v) albite — chlorite — quartz
(vi) epidote — garnet — calcite

Of a total of 31 specimens examined, 18 contained assemblage (i), 5 contained (ii), 4 contained (iii)), 2 contained (iv), 1 contained (v) and 1 contained (vi). Assemblages (i) and (ii) include the least altered and texturally restructured metadolerites but there is no systematic difference in degree of alteration between the two assemblages. In particular the failure of albite to form at the expense of calcic plagioclase in (ii) is not related to an overall low degree of alteration. Rocks characterized by (ii) contain abundant epidote, and it is likely that the absence of albite is related to a very high $Ca^{2+}/Na^{+}$ ratio in the local fluid phase during metamorphism, which both enhanced the stability of calcic plagioclase relative to albite, and supplied the calcium necessary for epidote crystallization. The ubiquitous presence of small amounts of white mica in assemblage (ii) rocks is possibly a result of the failure of albite to form. Small amounts of potassium in the rocks, that could have been accommodated in albite had it formed, instead gave rise to a potassic phase. It is noteworthy that white mica occurs in all rocks of assemblage (ii) but occurs in only 3 of the assemblage (i) samples, in each of which much magmatic calcic plagioclase remains and albite is present in only small amounts. White mica also occurs in all domain II metadolerites which are characterized by little or no albite.

Assemblages (iii) - (vi) occur in highly altered rocks believed to have suffered metasomatic changes involving increase in Ca ( (iii) and (vi) ), relative increase in Al (iv), and loss of Ca (v).

The mineral assemblages found in domains I, III and IV indicate regional metamorphism took place under low greenschist facies conditions. Neither prehnite nor pumpellyite is present and biotite has not formed in the pelitic or psammitic rocks. Assemblage (i) in the Karikeree Metadolerite is typical of the lower part of the greenschist facies. Similar assemblages occur a little to the north of the Port Macquarie Block in the Nambucca Slate Belt (Leitch, 1976a).

*The Lakes Innes thermal high*

Rocks that outcrop in the southern part of the promontory separating Lake Innes from Innes Swamp show the impress of a static thermal metamorphic event on the earlier regional metamorphic fabric. Mineral assemblages identified in stratified rocks here are:

(i) quartz — albite — white mica — biotite — chlorite — epidote — tourmaline
(ii) quartz — albite — white mica — chlorite — epidote
(iii) quartz — hematite — (white mica) — (chlorite) — (garnet)

Assemblage (i) is confined to pelitic rocks, (ii) typifies psammites and (iii) occurs in metamorphosed chert. The pelitic and psammitic rocks are those of domain III that possess both $S_1$ and a crenulation cleavage $S_2$ axial plane to folds in $S_1$. Textural relationships indicate that the assemblages are the result of recrystallization both during the formation of $S_1$ and $S_2$, as well as subsequent to the development of the latter surface. $S_1$ is defined by the parallel orientation of white mica and chlorite flakes which are bent and have polygonized in the hinges of the post-$S_1$ folds. Some white mica has grown along $S_2$ in pelitic rocks and irregular patches of chlorite are concentrated in the hinge zone of microfolds in psammites.

Biotite in the pelites is pleochroic in drab shades of green and brown. It occurs in decussate aggregates cutting across $S_1$ and $S_2$ (Fig. 2H), and in randomly oriented grains concentrated along chlorite-rich layers parallel to $S_1$. Biotite is nowhere deformed and it clearly has formed subsequent to the development of $S_2$. Tourmaline also crystallized in these rocks after deformation, for prisms of this phase grow across $S_1$ and $S_2$ but are neither bent nor fractured.

In addition to the presence of small amounts of garnet in some samples, a somewhat higher metamorphic grade for the cherts of this area compared with those elsewhere in the Block is indicated by their coarser grain size. Cherts in the Lake Innes thermal high have average quartz grain diameter of about 0.05 mm compared with 0.01-0.02 mm elsewhere.

Additional evidence for a late-stage thermal metamorphism in this region is furnished by the serpentinite in the Lakes Innes mass. Although emplacement of these rocks post-dated regional metamorphism, blocks within the mass are composed of antigorite, rather than lizardite and chrysotile that characterize the other serpentinite bodies of the Port Macquarie Block. Antigorite serpentinites are generally considered to result from alteration at significantly higher temperatures than are lizardite-chrysotile serpentinites (e.g. Coleman, 1971) and the antigorite has probably resulted from the metamorphism of lizardite-chrysotile material during late-stage heating. Talc-rich lenses on the margins of this mass, and widespread tremolite-chlorite rocks, probably also result from reactions during the thermal event.

Post-tectonic metamorphic highs similar to that at Lake Innes occur elsewhere in the New England Fold Belt (e.g. Gunthorpe, 1970; Leitch, 1972; Korsch, 1978), in places associated with abundant silicic dykes suggesting a subjacent granite pluton. Although no dykes have been discovered at Lake Innes a buried plutonic body is considered to be the most likely heat source. Late stage crystallization of tourmaline might be construed as evidence of boron addition to the rocks from a granite body, but the amount of tourmaline present is not large, and the required boron may have been inherited from the precursor sedimentary parents of the metamorphic rocks (cf. Reed, 1958).

*Glaucophane schist blocks*

The glaucophane schist blocks along the Innes Estate Fault consist of dark blue fine-grained, schistose rock characterized by the presence of lavender blue to colourless amphibole prisms. The amphibole forms a nematoblastic mat enclosing lenses and clots of fine-grained chlorite and pumpellyite, and tabular clinozoisite crystals. Small murky sphene grains are concentrated along fine seams roughly parallel to cleavage. Calcic clinopyroxene crystals, fractured and partially replaced by glaucophane, are pre-metamorphic relics. The rocks are cut by veins of glaucophane and clinozoisite and by later irregular calcite or calcite-albite patches. The metamorphic mineralogy, and the presence of relic calcic clinopyroxene suggests the schists were derived from basic igneous rocks.

The metamorphic mineral assemblage in these rocks, glaucophane — chlorite — clinozoisite — pumpellyite — sphene — calcite — (albite) is that characteristic of rocks transitional between greenschist and blueschist facies. Absence of lawsonite, jadeite and aragonite indicates metamorphic pressures not greatly above those attained in the greenschist facies, and the presence of pumpellyite suggests relatively low temperatures, less than those of the greenschist facies.

The relationship between the metamorphism giving rise to the glaucophane schists and that responsible for the greenschist facies rocks of the Port Macquarie block is not known. Schistosity in the glaucophanitic rocks is strongly crenulated, perhaps indicating a more complex deformation history than that suffered by the greenschist facies rocks. Although it has been suggested that the blocks are tectonic inclusions within a serpentinite lens (p. 282), an origin as accidental fragments derived from beneath the associated greenschist rocks appears unlikely.

## Geological History

Three phases can be recognized in the geological development of the Port Macquarie Block: a pre-orogenic phase during which the stratified Palaeozoic rocks accumulated, an orogenic phase that commenced with the onset of penetrative deformation and regional metamorphism of many of the stratified rocks and ended with the juxtaposition of the various fault slices that comprise the block, and a late-orogenic phase with faulting on a more restricted scale, probably involving mainly vertical movements and perhaps associated with local plutonic igneous activity.

*Pre-orogenic phase*

The Watonga Formation is a member of an Early Palaeozoic chert-siliceous argillite-basalt association, widely distributed in the southern part of the New England Fold Belt, and believed to comprise mostly ocean-floor deposits scraped from downgoing lithosphere at a consuming plate margin (Leitch, 1974). The dominance of fine-grained terrigenous detritus, the absence of limestone or massive sandstone, and the presence of widespread bedded radiolarian chert, accord with a deep marine depositional environment. Progressive detachment of the rocks from basaltic ocean floor along a system of imbricate thrust faults could give rise to the repetition of beds suggested by the several chert units, and the disrupted character of the formation with occasional basic igneous intercalations would be anticipated in the rocks of a subduction zone.

The Touchwood Formation clearly belongs to a quite different setting, having accumulated close to a volcanic region comprising rocks ranging from basalt to dacite, but in which subsilicic material was most common. Clastic sedimentary rocks of the formation are mostly turbidite and debris-flow deposits, suggesting accumulation in a relatively steep-sided basin fed by material swept from unstable shelf or delta-front environments. The oligomictic nature of some volcanic-derived units indicates rapid remobilization of debris the initial accumulation of which may have closely followed eruption. Coralline limestone blocks in some paraconglomerates suggest erosion of newly-deposited shelf material and channelling of the basin floor is indicated by abundant intraformational siltstone fragments in many of the coarser rocks. Lateral migration of volcanic activity gave rise to the thick andesite mass that caps the exposed sedimentary sequence.

The parent material of the Thrumster Slate accumulated in a region dominated by siltstone deposition but into which coarse clastic debris derived from silicic volcanic rocks was periodically carried by turbidity currents. The Slate is closely related to the Watonga Formation in its orogenic history, and it is possible that it accumulated in a basin developed on Watonga rocks.

All three formations can be envisaged as fragments of a Palaeozoic active margin. Subduction zone rocks of the Watonga Formation formed a basement for the Thrumster Slate that accumulated either in a slope basin on the accreting face of the zone, or, more likely in view of the probable age difference between the two units, in the outer part of an evolved fore-arc basin above the subsiding older part of the subduction zone. Touchwood rocks are representative of the magmatic arc — inner fore-arc basin realm that were juxtaposed with the other rocks by transcurrent faulting that sliced the margin obliquely at a late stage in orogenesis.

*Orogenic phase*

Orogenesis affected the Port Macquarie Block in the Late Permian, in the interval between deposition of the Thrumster Slate and the Camden Haven Group. The earliest and most intense deformation, and accompanying greenschist facies metamorphism, affected the Thrumster Slate, the Watonga Formation and the oldest members of the Karikeree Metadolerite. It resulted in the production of near-isoclinal steeply plunging folds and a steeply dipping slaty cleavage. Emplacement of dolerite dykes continued through this period and the presence of little-deformed dykes showing greenschist facies metamorphism suggests that elevated temperatures continued for a period after the relaxation of pervasive stresses.

This relaxation may have followed inception of movement on the northnorthwest-trending faults. Although little control is available, contrasts across the Cowarra, Innes Estate and Lake Innes faults point to large amounts of transcurrent displacement, most of which was completed before emplacement of the serpentinite masses. Thus the Burrawan body truncates several of these fractures and was probably emplaced during movement on the Sapling Creek Fault. By this time temperatures had fallen to sub-greenschist values as indicated by the presence of chrysotile and lizardite and the replacement of plagioclase by prehnite in dolerite blocks. The conditions under which mobilization of the serpentinite bodies occurred are unclear, but it is likely that their rise was initiated under relatively low temperatures and perhaps was accompanied by some re-equilibration of the surrounding metamorphic rocks producing glaucophane schists.

Local folding and the formation of crenulation cleavage post-dated emplacement of the Lake Innes mass indicating minor coherent deformation took place later in orogenic history.

*Late-orogenic phase*

Although the main orogenic phase was relatively short-lived, structural adjustments continued until after deposition of the Camden Haven Group. Vertical movement on the Sapling Creek Fault disrupted these strata and several faults with northnortheast trends have affected Camden Haven rocks northwest of Grants Head. Abrupt changes in the thickness of formations within the Camden Haven Group take place across northnortheast-trending faults in the Palaeozoic rocks suggesting fault control of sedimentation in the Early Triassic (Leitch and Bocking, *in press*). Emplacement of Triassic granitic rocks elsewhere in the eastern part of the New England Fold Belt was accompanied by vertical faulting (Leitch, 1976b), and the inferred plutonic mass beneath the Lake Innes thermal high was possibly intruded at this time. Further south in the Lorne Basin several large granitic plutons yield Late Triassic K-Ar ages (McDougall and Wellman, 1976). It is unclear whether the felsic dykes of the Port Macquarie block are related to this activity, and owe their strained character to proximity to faults on which there was significant late movement or whether they are representatives of an earlier episode of granitic magmatism.

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