

THE PIGNA BARNEY OPHIOLITIC COMPLEX
AND ASSOCIATED BASALTIC ROCKS,
NORTHEASTERN NEW SOUTH WALES,
AUSTRALIA

by

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I certify that the substance of this thesis has not already been submitted for any degree and is not being currently submitted for any other degree.

I certify that any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

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K.C. Cross

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Approximate dimensions of items used to indicate the respective scales of most field photographs:

Camera lens cap	: diameter	5.5cm.
Brunton compass	: diameter	7cm.
Artline marking pen	: diameter	1.5cm; overall length 14.5cm.
Geological pick	: length (head)	16.5cm; overall length 29cm.
Sledge hammer	: length (head)	16.5cm; overall length 73cm.

SUMMARY

The Pigna Barney Ophiolitic Complex (PBOC) is a lithologically and chemically distinctive ultramafic-mafic melange which is largely confined to major fault zones in the Pigna Barney-Curricabark area, southern New England Orogen (NEO), northeastern New South Wales.

For the most part, the PBOC lies along the arcuate, southern-most section of the Peel Fault System. This major steeply-dipping fault system marks the line of contact between a complex accretionary terrane (Zone B) lying to the east and north, and a significantly less-deformed volcanic arc-related basin (Tamworth Belt) lying to the west and south. Fragments of the PBOC also lie within Zone B, especially along the Curricabark Fault Zone and along faulted contacts between the ? pre-Devonian, largely hemipelagic Myra beds and Permian epiclastics of the Nambucca Association. The PBOC is everywhere in contact with adjacent stratigraphic associations, and non-tectonic contacts between its various component lithologies are exceedingly rare.

The PBOC consists of: (i) a highly disrupted and incompletely preserved ophiolitic assemblage whose members consistently display atypically low abundances of 'incompatible' elements (e.g. Ti, Zr, P); and (ii) a diverse range of igneous, sedimentary and metamorphic lithologies which generally occur as tectonic blocks in serpentinite-matrix melange (highly sheared tectonized harzburgite). In its type area the PBOC displays a crude internal ophiolitic stratigraphy which, at least on present orientation, consistently faces the Tamworth Belt to the southwest.

Seven distinct lithological groups comprise the ophiolitic members of the PBOC. All groups are altered to varying degrees. In order of general structural position and inferred stratigraphic sequence these groups are: (1) depleted tectonized harzburgite - Fo_{92-91} , $Al_2O_3 < 1.2wt\%$, modal diopside $< 1\%$, the lowest in the sequence, followed by: (2) cumulate harzburgites and rare olivine orthopyroxenite cumulates - Fo_{92-90} ; (3) 'plagioclase'-bearing peridotite cumulates - Fo_{88-84} ; (4) cumulate olivine (mela-)norites - Fo_{87-80} , An_{90-85} ; (5) cumulate quartz-bearing gabbros/gabbronorites - *mg* 77-61; (6) dolerites and quartz 'dolerites' - *mg* 56-45; and (7) pillowed and massive basaltic extrusives and related shallow intrusives - *mg* 69-56.

Tectonized harzburgite is the dominant and most widespread member of the PBOC. Although it is typically highly serpentinized and, for the most part, highly sheared, primary phases and relict metamorphic (porphyroclastic/neoblastic) textures still persist. However, any original mesoscopic and larger-scale tectonite fabrics are not preserved. In this respect, and also in its unusually abundant modal and normative orthopyroxene (30-40%) the PBOC tectonized harzburgite differs from most metamorphic peridotites in ophiolites elsewhere.

Most PBOC cumulates are also remarkably orthopyroxene-rich and clinopyroxene-poor, especially the relatively abundant olivine-bearing types (modal opx 85-20%, modal cpx \leq 20%). The generalized crystallization sequence in the PBOC cumulates - Cr-Al spinel \rightarrow olivine \rightarrow opx \rightarrow plag. \rightarrow cpx \rightarrow quartz - is extremely unusual in lithologies of this type. The persistent crystallization of significant Cr-Al spinel in place of Fe-Ti oxides in all but the most evolved quartz-bearing variants, and the late appearance of atypically Cr-rich clinopyroxene (0.6-1.1% Cr₂O₃) are other unusual but nevertheless distinctive characteristics.

Although the PBOC olivine-bearing intrusives all display well-developed adcumulus textures, cumulus phases are typically unzoned. Furthermore, any chemical variation between coexisting cumulus and postcumulus phases of the same species is almost invariably negligible. Most variants display some diffuse layering, but almost all lack definitive evidence for gravity-controlled crystal accumulation. These characteristics suggest that cumulate formation was, in effect, rapid relative to overall changes in the compositions of successive melts. The PBOC cumulates may have crystallized *in situ* on the bounding surfaces of magma chambers or conduits while their parental melts were actively convecting or 'in transit'.

Compared with ocean-floor cumulates and practically all of their ophiolitic or stratiform analogues, for a given M value the PBOC cumulates are significantly depleted in incompatible elements (typically, TiO₂ \ll 0.1%, Zr and Y \ll 5 μ g/g, Σ REE \leq 1 μ g/g), enriched in Cr (1000-5000 μ g/g) and Ni (200-1600 μ g/g), and have lower original Fe₂O₃/FeO ratios (significantly $<$ 0.1). Hence, melts parental to the PBOC cumulates appear to have been essentially 'dry', atypically enriched in *en*, Cr and Ni, and highly depleted in the incompatible elements.

The PBOC doleritic intrusives form a disrupted series of sills and low-angle dykes lying between the cumulate sequence and the overlying basaltic extrusives. All are devoid of orthopyroxene and some appear to be intrusive equivalents of the basaltic extrusives. However, the quartz-bearing types contain more *qz* (5-15%) and incompatible elements (e.g. 0.4-0.5% TiO_2 , 20-40 $\mu\text{g/g}$ Zr) than would be expected if they were to be interpreted as more evolved variants of the basaltic extrusives. Their precise petrological relationships to other ophiolitic members of the PBOC remain enigmatic.

The PBOC extrusives bear the general geochemical stamp of low-Ti ophiolitic basalts (e.g. $\text{TiO}_2 < 0.25\%$, $\text{P}_2\text{O}_5 \leq 0.05\%$, $\text{Zr} \leq 10 \mu\text{g/g}$). However, in most aspects of their major element chemistry they resemble normal K-poor tholeiites. Furthermore, they may be contrasted with boninites, high-Mg andesites, and related Ti-poor types in that ; (i) they are devoid of modal orthopyroxene and amphibole; (ii) their spinels are comparatively Cr-poor ($\text{Cr} < 60$, *cf.* $\text{Cr} \sim 70-90$); and (iii) they typically contain less Ni and Cr, and more V and Sc, and have significantly lower Zr/Y and Zr/Nb ratios (<1 and 2-?4 respectively). Furthermore, highly calcic plagioclase is a major near-liquidus phase in the PBOC low-Ti basaltic extrusives, and it crystallized relatively early as a cumulus phase in the PBOC intrusives where it closely followed orthopyroxene (which in turn contains significant Ca, i.e. Wo_{1-3}). These characteristics suggest that the PBOC parental melts were significantly enriched in Al and Ca (? $\sim 16\% \text{Al}_2\text{O}_3$, 10-12% CaO) relative to typical boninitic types (from which plagioclase is a late-crystallizing phase).

First order similarities in chemistry between PBOC intrusives and extrusives are sufficient to strongly suggest that they derived from a common upper mantle source region(s), and retained communal chemical characteristics during any subsequent evolution. However, chemical (and petrographic) evidence for any direct links between PBOC intrusives and extrusives *via* fractional crystallization controls is not compelling.

Overall chemical variations displayed by the basaltic extrusives as a whole do not reflect their derivation from a communal magma reservoir *via* reasonable fractional crystallization controls. Rather, it is envisaged that most or all PBOC basaltic units represent discrete, relatively low-pressure (? $\sim 8-10 \text{ kb}$) anhydrous partial melts of highly depleted, but not necessarily highly refractory (in terms of *M* value, Al and Ca), clinopyroxene-bearing upper mantle source rocks. These melts could have experienced some fraction-

ation of Cr-Al spinel + olivine ± orthopyroxene prior to eruption/emplacement, if the PBOC tectonized harzburgite ($M \sim 92$) is assigned the role of depleted upper mantle residuum. However, the data available do not establish any direct links between envisaged PBOC melts and the PBOC tectonized harzburgites *via* partial melting controls. Indeed, if any relatively *en*-rich melts had been extracted from the PBOC tectonized harzburgites, the comparatively fertile mantle precursor(s) would of necessity have been significantly more orthopyroxene-rich than commonly envisaged model upper mantle source rocks.

The mechanism whereby PBOC source rocks attained the elevated temperatures necessary for anhydrous partial melting remains uncertain. However, the initiation of partial melting might have been facilitated at geologically reasonable temperatures (?1200-1300°C) if the source rocks were not highly refractory and/or they experienced significant decompression following (?)diapiric rise.

The essential character of the PBOC is that of a highly disrupted and incompletely preserved remnant of what could well be termed a 'depleted'- or 'Ti-poor ophiolite'. Compared with ophiolitic assemblages elsewhere it is distinctive in that all its ophiolitic members display pronounced 'Ti-poor' characteristics. Moreover, some characteristics of the suite appear to be unique (e.g. $Zr/Y < 1$).

Exotic members of the PBOC include a range of relatively Cr- and Mg-rich greenschists and amphibolites (whose histories remain enigmatic), and rare blocks of blueschist-facies metabasalts. In many aspects of their chemistry the latter resemble E-type MORB. Conceivably, they might represent 'recycled' fragments of subducted oceanic (Myra) layer 1 or layer 2 basaltic rocks. Other exotic blocks in the PBOC serpentinite-matrix melange include a range of relatively little-altered basaltic-silicic volcanics, tonalitic intrusives, and sedimentary lithologies which appear to have been plucked from the adjacent Myra beds and Tamworth Belt sequences during minor tectonic movements.

The principal lithologies in the Myra beds are chert, impure chert, jasper, siliceous argillite, argillite, and relatively minor altered basaltic rocks. These most probably represent an accreted oceanic layer 1 assemblage. In gross structural terms the Myra beds are a tectonic melange which largely consists of steeply-dipping mesoscopic- to kilometre-sized blocks and slabs of the more resistant lithologies arranged in a more-or-less imbricate fashion

in a variably-sheared matrix. This melange is largely autoclastic in origin and is dominated more by bedding-parallel shear than by chaotic mixing. It forms the oldest recognizable tectonostratigraphic unit in the complex Zone B accretionary terrane.

Basaltic rocks in the Myra beds are of three principal types:

(*Type 1*) discrete cooling units of aphyric to fine-grained pillowed and massive extrusives and medium-grained intrusives; (*Type 2*) composite associations of conspicuously plagioclase-phyric, often moderately vesicular, pillowed and massive extrusives and medium to coarse-grained intrusives; and (*Type 3*) distinctive highly vesicular pillowed and massive extrusives and breccias. All three types consist almost entirely of plagioclase + Ca-rich pyroxene + lesser Fe-Ti oxides, or low-grade alteration products of these phases. Only *Type 3* appears to have been originally olivine-bearing.

On the basis of their pyroxene and bulk chemistries all three Myra basaltic types display subalkaline or, on occasion, transitional magmatic affinities. They appear to reflect within-plate or 'off-axis' oceanic volcanism and, in particular, types 2 and 3 might represent fragments of submarine volcanic complexes disrupted during accretion.

The (?) Lower-Upper Palaeozoic Tamworth Belt succession largely consists of moderately deformed volcanic arc-derived epiclastics and argillites, limestones, and towards the base, voluminous altered basaltic rocks and lesser keratophyric volcanics. Most of the basaltic rocks are relatively Fe-rich (8-18% FeO, $1 < \Sigma\text{FeO/MgO} < 3.5$) and olivine or its alteration products is exceedingly rare. They display a broad spectrum of pyroxene- and bulk chemical compositions ranging from: (i) variants in the Glen Ward beds which resemble evolved island-arc tholeiites ($\text{TiO}_2 < 1\%$, $\Sigma\text{FeO/MgO} \sim 1-3$, low Ni and Cr); to (ii) more-or-less stratigraphically equivalent variants lying to the north of the Pigna Barney-Curricabark area which resemble E-type MORB ($\text{TiO}_2 \sim 2-3\%$, $\Sigma\text{FeO/MgO} \sim 1.5-3.5$, low Cr and Ni). Many basaltic units were intruded/extruded penecontemporaneously with the deposition of voluminous proximal arc-derived epiclastics and, on occasion, the eruption/emplacement of calc-alkaline extrusives/intrusives.

On the basis of similarities between Tamworth Belt basaltic rocks and basalts which occur in: (i) juvenile oceanic rifts; and (ii) some modern and (?) ancient back-arc settings - and in view of their close association in space

and time with various volcanic-arc-related lithologies, it is suggested that the Tamworth Belt may have been the site of an actively-opening inter-arc or back-arc basin in the Early-Mid Devonian. Subsequent deformation appears to have been insufficient to expose any 'back-arc' crust which might have formed by 'normal' spreading mechanisms once the proposed rift basin became well-established, and which now might underlie much of the Tamworth Belt. Significant accretion in Zone B possibly post-dates initial rifting in the proto-Tamworth Belt.

It is conceivable, therefore, that the PBOC formed as a 'basin margin ophiolite' during initial stages in the rifting of a pre-Mid Devonian volcanic arc in the proto-NEO.

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