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Heavy minerals in modern sediments of the Minnamurra estuary and shelf environment, NSW, Australia

Rabea Haredy
rah99@uow.edu.au

Brian G. Jones
University of Wollongong, briangj@uow.edu.au

Adrian C. Hutton
University of Wollongong, ahutton@uow.edu.au

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Abstract

Provenance and sediment distribution have been investigated in the Minnamurra estuary and the adjacent shelf in NSW, Australia. Heavy mineral assemblages in the sand fractions (63-250 f.lm) of 110 surficial sediment samples were assessed using microscopic and microprobe analyses. In addition to the dominant opaque minerals, twelve translucent heavy mineral species were identified. The translucent assemblage is dominated by pyroxene, zircon, tourmaline and hornblende. Statistical cluster analysis of heavy mineral percentages in the surficial sediments revealed the existence of five mineralogical facies: the upper fluvial part of the estuary, the Minnamurra spit and elevated inner sand terrace, the estuary inlet and inner part of the inner-shelf, a combined group consisting of the outer part of the iriner-shelf and the midestuary (Rocklow Creek), and the mid-shelf facies. The main factors that control the distribution of the surficial sediments and their contained heavy minerals are transport and hydraulic sorting processes, together with minor coastal erosion. This can be seen clearly on the shelf area with denser heavy minerals concentrated in shallow water deposits whereas the lighter platy heavy minerals become more prominent in the deeper water lower energy areas. The mid-estuary facies is a mixed zone that has a similar heavy mineral assemblage to the outer part of the inner-shelf; possibly resulting from reworking of marine-influenced sand sheets in the Rocklow Creek catchment. The Minnamurra spit (aeolian dune) and elevated inner sand terrace facies is distinctive with its high concentration of total heavy minerals, resulting from winnowing by wind and storm wave influences. The heavy mineral assemblage also identifies multiple sources. The occurrence of heavy minerals from non-local source rocks reflects reworking of quartz sand from the outer-shelf to the inner-shelf and coastal environments during the post-glacial marine transgression. These minerals were originally derived from the Precambrian craton in southeastern and central Australia, and from the Lachlan Fold Belt. The fold belt would have contributed both reworked older grains of ultrastable heavy minerals as well as some primary minerals from the igneous rock units. Fluvial and coastal erosion of the locallatite units and their associated volcaniclastic sedimentary succession has liberated pyroxene and epidote to the Minnamurra estuary and shelf. Fluvial erosion of a Mesozoic tinguaite (containing aegerine augite) and the Tertiary basalts at Robertson (containing titanaugite) have added to the mineralogical complexity, especially in the upper fluvial portion of the estuary.

Keywords

nsw, environment, shelf, australia, estuary, heavy, minnamurra, sediments, modern, minerals, GeoQuest

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HEAVY MINERALS IN MODERN SEDIMENTS OF THE MINNAMURRA ESTUARY AND SHELF ENVIRONMENT, NSW, AUSTRALIA

R.A. Haredy, B.G. Jones and A.C. Hutton

School of Geosciences, University of Wollongong, NSW 2522, Australia

ABSTRACT

Provenance and sediment distribution have been investigated in the Minnamurra estuary and the adjacent shelf in NSW, Australia. Heavy mineral assemblages in the sand fractions (63-250 μm) of 110 surficial sediment samples were assessed using microscopic and microprobe analyses. In addition to the dominant opaque minerals, twelve translucent heavy mineral species were identified. The translucent assemblage is dominated by pyroxene, zircon, tourmaline and hornblende. Statistical cluster analysis of heavy mineral percentages in the surficial sediments revealed the existence of five mineralogical facies: the upper fluvial part of the estuary, the Minnamurra spit and elevated inner sand terrace, the estuary inlet and inner part of the inner-shelf, a combined group consisting of the outer part of the inner-shelf and the mid-estuary (Rocklow Creek), and the mid-shelf facies.

The main factors that control the distribution of the surficial sediments and their contained heavy minerals are transport and hydraulic sorting processes, together with minor coastal erosion. This can be seen clearly on the shelf area with denser heavy minerals concentrated in shallow water deposits whereas the lighter platy heavy minerals become more prominent in the deeper water lower energy areas. The mid-estuary facies is a mixed zone that has a similar heavy mineral assemblage to the outer part of the inner-shelf; possibly resulting from reworking of marine-influenced sand sheets in the Rocklow Creek catchment. The Minnamurra spit (aeolian dune) and elevated inner sand terrace facies is distinctive with its high concentration of total heavy minerals, resulting from winnowing by wind and storm wave influences.

The heavy mineral assemblage also identifies multiple sources. The occurrence of heavy minerals from non-local source rocks reflects reworking of quartz sand from the outer-shelf to the inner-shelf and coastal environments during the post-glacial marine transgression. These minerals were originally derived from the Precambrian craton in southeastern and central Australia, and from the Lachlan Fold Belt. The fold belt would have contributed both reworked older grains of ultrastable heavy minerals as well as some primary minerals from the igneous rock units. Fluvial and coastal erosion of the local latite units and their associated volcaniclastic sedimentary succession has liberated pyroxene and epidote to the Minnamurra estuary and shelf. Fluvial erosion of a Mesozoic tinguaite (containing aegerine augite) and the Tertiary basalts at Robertson (containing titanaugite) have added to the mineralogical complexity, especially in the upper fluvial portion of the estuary.

INTRODUCTION

The study site is located on the mid-south coast of the New South Wales (Illawarra region), 20 km south of Wollongong City and is centered around longitude 150° 53 E and latitude 34° 38 S, eastern Australia. The study site includes the Minnamurra estuary and the adjacent shelf (Figure 1). Sediments collected from these two areas are considered to be of Holocene age and predominantly of marine origin, rather than fluvial. The Minnamurra estuary meanders between its sand barriers and extends westward upstream to Minnamurra falls at the Jamberoo escarpment, giving a total length of 24 k. The inlet of the Minnamurra estuary has a 170 m wide opening between the Minnamurra Point headland and the southern end of Minnamurra spit. Furthermore, the Minnamurra inlet receives some protection from high-energy wave attack by Stack Island, which is situated approximately 250 m east of the inlet. The tidal influence persists from the inlet to around 7 k upstream. This paper discusses the distribution of the mineralogical facies within the Minnamurra estuary and shelf environments, as well as the provenance of the heavy minerals.

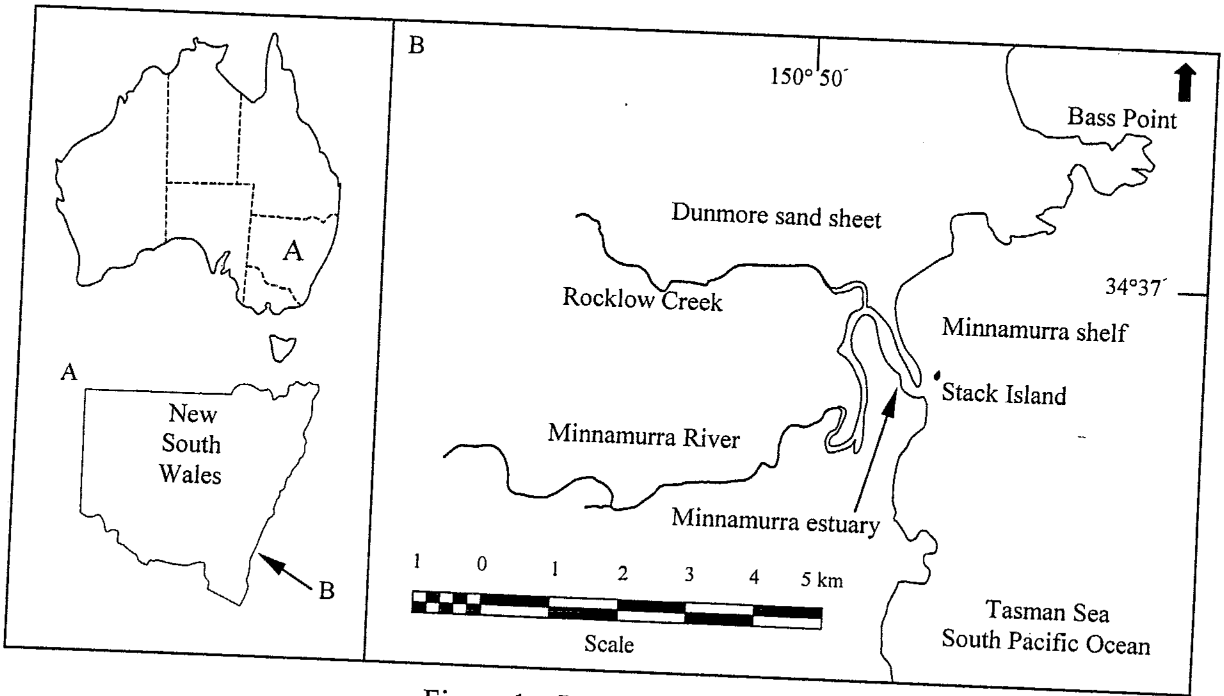


Figure 1 – Location of the study area.

REGIONAL GEOLOGY

The local catchments and the adjacent outcrops of the study area include the Shoalhaven Group, Illawarra Coal Measures, Narrabeen Group, Hawkesbury Sandstone and Wianamatta Group of the southern Sydney Basin. The Broughton Formation of the Shoalhaven Group surrounds the study area and includes eight members including five latite lava members and three sandstone members. The latite members of this formation are shoshonitic types (Carr *et al.*, 1999). The sedimentary rocks mainly consist of immature lithic sandstone, pebble conglomerate and mudstone derived from a volcanic source (Doyle, 2000). The Bumbo Latite Member outcrops along the coast of the study area. The overall mineralogy of the Bumbo Latite Member includes plagioclase, K-feldspar, clinopyroxene (augite), titanomagnetite, and a variety of secondary minerals such as epidote and chlorite that occur in the hydrothermal phases (Carr *et al.*, 1999).

PREVIOUS WORK IN THE STUDY AREA

The study of heavy minerals in sediments along the east coast of Australia began in the early thirties during exploration for placer and/or economic heavy mineral deposits. Furthermore, several studies have discussed the nature, occurrence and provenance of heavy minerals in marine sediments on the continental shelf and coastal environments along the east coast (see Haredy, 2003). A study by Hudson (1985) involved the analysis of heavy minerals from some beach sediment samples along the east coast south of Sydney. This study included the area between Wollongong and Shoalhaven Bight (Killalea and Minnamurra beaches are involved) and revealed that heavy mineral assemblages are variable and thus difficult to classify. Moreover, the persistent occurrence of hornblende and epidote in the heavy mineral suite (e.g. Minnamurra) is unrelated to the local sources. An investigation of the bedrock and Quaternary geology of the shelf between Minnamurra and Bass Point was carried out by Davey (1992) and involved petrographic examination of the sediments. It showed that heavy mineral assemblages contain an unstable suite, rather than an ultrastable suite, over the shelf. Generally, opaque minerals have a high concentration in both shelf and estuarine sediments, especially adjacent to the latite outcrops. Moreover, the occurrence of these minerals and volcanic rock fragments within the shelf sediments indicates that erosion of the bedrock is associated with local sediment input (Davey, 1992).

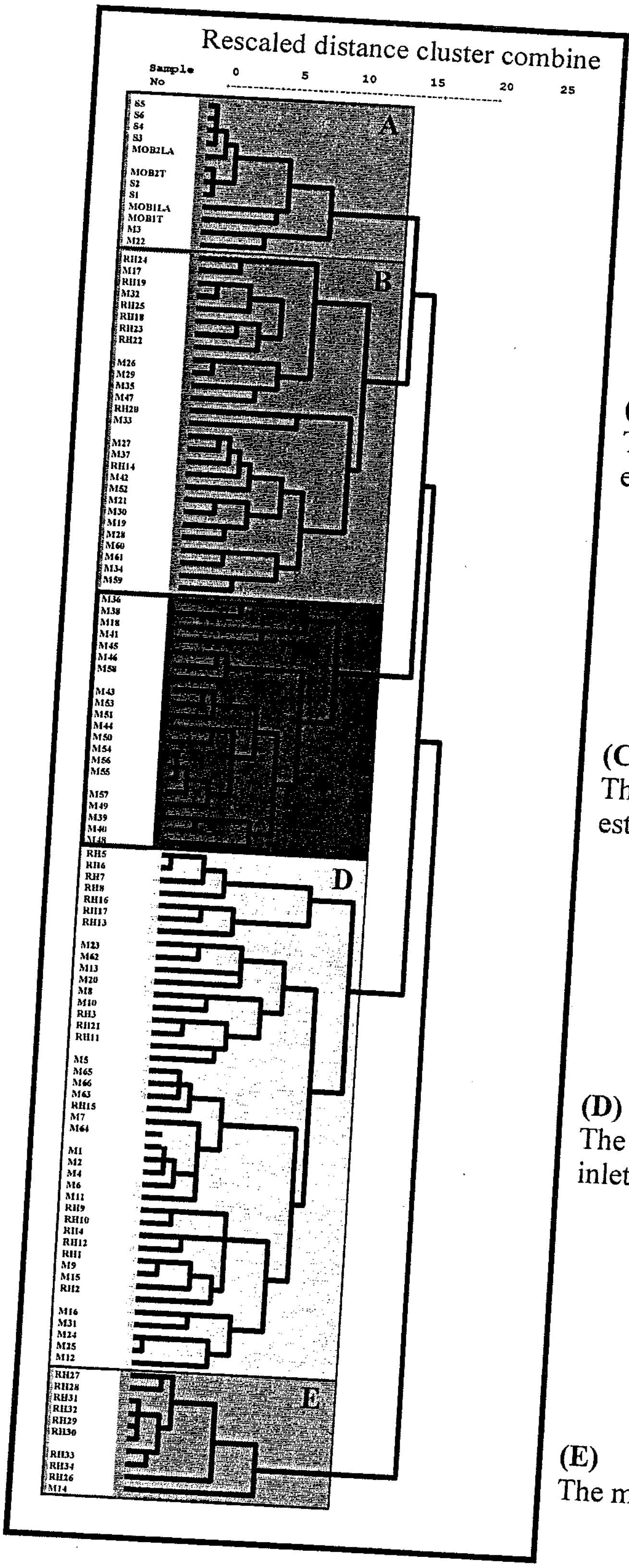
METHODOLOGY

A total of 110 surficial sediment samples were collected from the study area (Figure 1; Haredy, 2003). Heavy mineral assemblages (63-250μm) were identified and point counted, using standard petrographic examination and microprobe analyses. Mineral compositions of heavy mineral grains were determined on polished thin sections, using a CAMEBAX Cameca electron microprobe housed in the Research School of Earth Sciences, Australian National University (Haredy, 2003). Grain size distributions were performed, using Malvern Mastersizer 2000 instrument on a representative bulk sediment sample that had been treated with HCL for the shelf samples and H_2O_2 for the estuary samples (Haredy, 2003). Total carbonate contents were determined volumetrically using the weight difference technique after treatment with 10% HCL. Between-group average-linkage Q-mode Hierarchical cluster analysis was applied to all data (Table 1; Figure 2; Haredy, 2003), in order to identify mineralogical facies within the Minnamurra estuary and adjacent shelf.

RESULTS

Cluster analysis of the mineralogical and sedimentological data revealed the existence of five mineralogical facies (five cluster) in the study area (Figures 2; Table 1). These facies are the upper fluvial part of the Minnamurra estuary, the Minnamurra spit and river terrace facies, the estuary inlet and inner part of the inner-shelf, the outer part of the inner-shelf (with Rocklow Creek or mid estuary) and the mid-shelf (see Table 1 for facies characteristics).

Electron microprobe analyses of pyroxene correspond to four types: augite, diopside (treated as augite in point counts; Mange and Maurer, 1992), titanaugite and aegirine-augite. The chemical



(A)
Minnamurra spit and river terraces facies.

(B)
The outer part of the inner-shelf and mid-estuary (Rocklow Creek) facies.

(C)
The upper fluvial part of the Minnamurra estuary facies.

(D)
The inner part of the inner-shelf and estuary inlet facies.

(E)
The mid-shelf facies.

Figure 2 – Dendrogram illustrates the classification of the mineralogical facies.

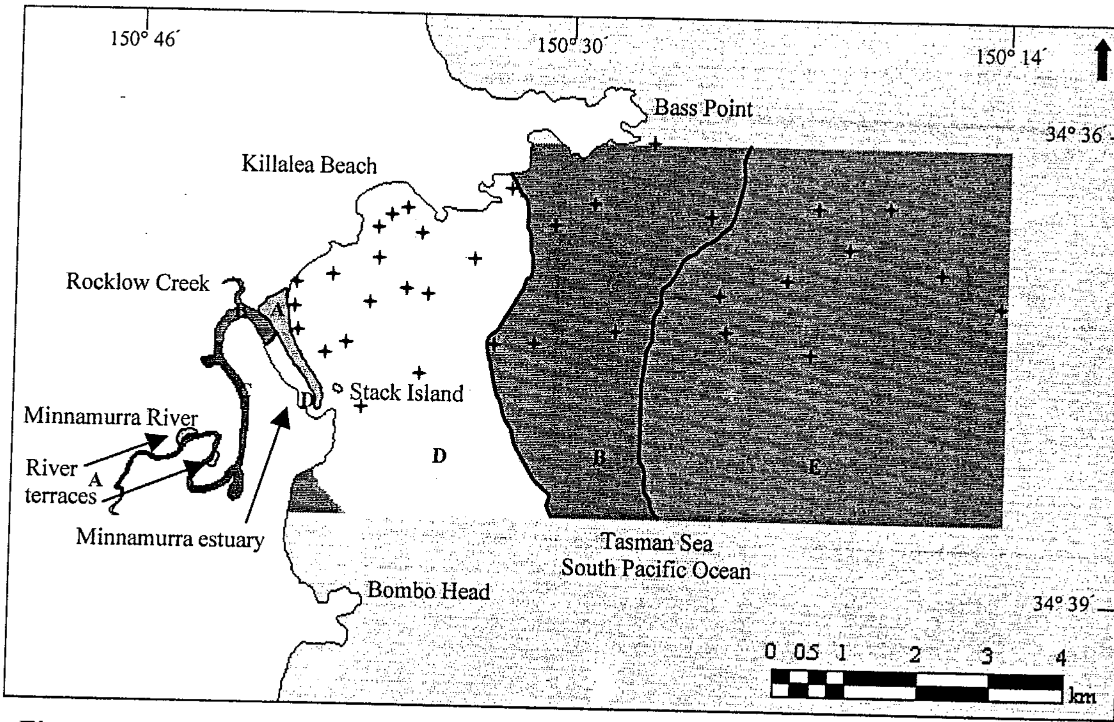


Figure 3 – Cluster map showing the distribution of mineralogical facies in the study area. Note that the facies matche the dendrogram in Figure 2.

Table 1 – Mean values as percentages, except where noted, for variables in each facies.

Facies	$CaCo_3$	Zircon	Rutile	Tourmaline	Augite	Titanaugite	Aegirine-augite	Hornblende	Minor heavier heavy minerals (epidote+andalusite+garnet)
A	9.3	29.7	13.4	13.1	32.1	1.1	1.2	5.7	3.4
B	8.3	32.7	3.6	19.7	25.8	1.4	2.5	7.2	6.2
C	5.1	18	1.7	15.8	33	4.1	17.7	5.9	3.3
D	26.5	18.2	3.3	18.5	39.3	1.6	1.2	11.7	4.4
E	29	11.1	1.5	23.2	23.3	1.6	0.5	20.8	3.6

Facies	Biotite	Chlorite	Weathered	HM	Mean(phi)	ISD (phi)	Sand	Silt	Clay
A	0.1	0.1	6.4	25	1.7	0.5	100	0	0
B	0.3	0.7	9.7	5.3	1.5	0.5	100	0	0
C	0.2	0.3	14.5	4	1.6	0.9	95.3	3.7	1
D	0.7	1	9.2	3.1	1.8	0.6	99.9	0.1	0
E	10.2	4.2	16.1	1.6	4.1	1.8	58.8	33	8.2

Epidote composition ranges between metaluminous (approximately 83%) to peraluminous (approximately 17%; Loiselle and Wones, 1979 cited in Sial, 1990). Microprobe analyses of the opaque heavy mineral grains revealed the dominance of ilmenite among the opaque assemblages, with a subordinate amount of other iron oxides.

compositions of tourmaline cover a considerable range but show a decrease in abundance from schorl to dravite within the solid solution series (Haredy, 2003).

DISCUSSION

The immaturity of the mid-shelf facies indicates that the sediments have faced a minimal rate of reworking and reflect less subaerial exposure influence (Hudson, 1985). Also this facies contains a higher proportion of the heavy mineral assemblage that is related to a provenance in the Lachlan Fold Belt. Major rivers that drain the Lachlan Fold Belt (e.g. Shoalhaven River; Clyde River) supplied sediments to the continental shelf during the sea level low stand and these sediments were transported northward and seaward on the shelf (Roy and Thom, 1981; Colwell, 1982; Hudson, 1985; Roy; 1999).

The maturity of the Minnamurra spit and river terraces facies is attributed to several processes: winnowing and abrasive effects of wind and storms, and subaerial weathering associated with wetting and drying processes. The mineralogical similarities between the river terraces, which occur along the northwest bank in the upper fluvial part of the estuary and the Minnamurra spit could be referred to the following theories. The river terraces could represent relict deposits of an inner-barrier that formed during the early stages of the Minnamurra estuary evolution in the Holocene (Carne, 1991). Alternatively, the similarity in heavy mineral assemblage between the Minnamurra spit and the river terraces could be referred to large marine incursions in the late Holocene. Switzer (1999) and Pucillo (2000) suggested that the Dunmore sand sheets were deposited by the action of two tsunami events in the late Holocene. Sediment from the inner-shelf and the top part of the Minnamurra spit would have been transported landward and deposited in the current Dunmore embayment. Finally, the river terraces were possibly deposited by strong wind and storm actions that could have carried some of the dune sediment from the Minnamurra spit and dumped them into the upper fluvial part of the estuary. In each case, sediments from the Minnamurra spit and river terraces would show a similarity in their heavy mineral assemblages.

The similarity in facies between the outer part of the inner-shelf and mid-estuary (Rocklow Creek) is attributed to two possible mechanisms. (1) As the lower part of the estuary is characterised by a high energy regime, hydraulic sorting processes transported less dense, larger and platy minerals (augite and hornblende) downstream. Therefore, ultrastable heavy minerals were concentrated as lag deposits in the mid-estuary (Rocklow Creek). Sorting processes during the transgression also concentrated the ultrastable heavy minerals in the outer part of the inner-shelf. (2) Earlier work in the Minnamurra embayment by Switzer (1999) and Pucillo (2000) illustrated that the Dunmore sand sheets were deposited by the action of two tsunami events in the late Holocene. As a result, marine sediments from the shelf were dumped into the Dunmore area to form the sand sheets, which are located northwest of the Minnamurra estuary. On the basis of this theory, Rocklow Creek, which drains the Dunmore sand sheet, supplies the mid-estuary with shelf sediment including a heavy mineral assemblage typical of the inner shelf.

The formation of the upper fluvial part of the Minnamurra estuary facies is attributed mainly to the local provenance, as the Minnamurra River is transporting detritus from rocks that occur in the escarpment (Minnamurra falls and Robertson highland area) to the upper fluvial part of the estuary. The igneous rocks in this area mainly produce pyroxene minerals. In contrast, the absence of most other heavy minerals from the local lithologies has resulted in a lower abundance of these minerals in this upper fluvial facies. Apart from flood events, the upper fluvial part of the estuary is characterised by a low energy regime, mud content starts to appear at the uppermost end of this facies, and fluvial sediments are dominant > 6500 m from the inlet.

The formation of the estuary inlet and the inner part of the inner-shelf facies is mainly related to the provenance, coastal erosion, morphology, and physical sorting. As the local latite units contain abundant augite, subaerial and coastal erosion, associated with longshore drift, have

concentrated augite within the inner part of the inner-shelf, especially at the front of the estuary inlet between Minnamurra Point and Stack Island. Moreover, the high energy tide regime in the lower part of the estuary has transported augite and hornblende downstream from the mid-estuary, resulting in high abundance of these minerals within the inlet area. The high content of carbonate is attributed to marine biogenic production by molluscs and various biota.

In terms of mineral provenance, augite was derived mainly from two sources: the adjacent Permian basalt and basaltic-andesite (Bumbo and Blow-Hole Latite Members; Carr, 1984) in the southern Sydney Basin, and the Tertiary basaltic rocks near Robertson. Diopside was also derived from the alkaline olivine basalt located above the escarpment northwest of the Minnamurra falls (Robertson Basalt, Bowman, 1974). Aegirine-augite was probably derived from the post-Late Triassic Minnamurra Tinguaite and Dhruwalgha Tinguaite in the escarpment near and southwest of the Minnamurra River, respectively (Harper, 1915; Bowman, 1974). The major source of the aegirine-augite is most likely the Minnamurra Tinguaite since the detrital aegirine-augite grains are weathered and dark green, which is very similar to the Minnamurra Tinguaite unit described by Harper (1915) and located near the head of the Minnamurra River. The potential source for the titanaugite is the Tertiary basalts (Cordeaux Flow) and the post-Late Triassic Wallaya Olivine-Dolerite that is exposed in the bed of the Minnamurra River on the Robertson highland (Harper, 1915; Bowman, 1974). The latter conclusion was based on a comparison between the current TiO_2 content in the detrital pyroxenes and the three rock units (Bumbo Latite Member; Cordeaux Flow and Wallaya Olivine-Dolerite; Harper, 1915; Carr, 1984; see Haredy, 2003 for more details).

Detrital epidote has two possible sources: igneous rocks (granites) in the Lachlan Fold Belt and the hydrothermal alteration phases that occur in the mafic basalt lavas of the Permian Broughton Formation in the southern Sydney Basin (e.g. Bumbo Latite Member; Carr *et al.*, 1999). The metaluminous epidote is most likely derived from the local latite members. Chemical compositions of epidote in the alteration phases of Bumbo and Dapto Latite Members show a similarity to the detrital epidote in the surficial sediments of the Minnamurra estuary and shelf. This latter finding contrasts with the earlier suggestion by Hudson (1985) that epidote in the Minnamurra beach did not reflect a local source. However, some nearby granites in the Lachlan Fold Belt may also produce some metaluminous epidote. The peraluminous epidote is probably a product of the Lachlan peraluminous granites.

The iron-rich varieties of schorl tourmaline were possibly derived from the Lachlan Fold Belt granites, and their pegmatites, and granodiorites. In contrast, the magnesian tourmaline (dravite) could be derived from metamorphic gneisses and schists in the Precambrian rocks of central Australia and/or from the quartz-tourmaline rocks in the Lachlan Fold Belt. An example of the latter rocks, which contain >90% of dravite tourmaline, are found near Bungonia adjacent to the Marulan Batholith (Jones *et al.*, 1981).

CONCLUSIONS

The classification of mineralogical facies within the Minnamurra estuary and shelf environments was controlled by spatial variability of heavy mineral assemblages rather than the textural characteristics of the sediment. The spatial variability of heavy minerals is controlled by the following factors: marine transgression during the Late Quaternary, northward littoral transport, a low rate of local fluvial supply, coastal erosion of headlands, embayment morphology and hydraulic sorting processes. The heavy mineral assemblage also identifies multiple sources.

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