Evaluation of mineral resources of the continental shelf, New South Wales

ABSTRACT
This paper discusses the mineral resource potential of the New South Wales segment of the continental shelf of eastern Australia. That portion of the shelf extends over 2000 km but is generally less than 50 km wide. Average water depths range from over 160 m in the north to less than 100 m in the south. Eastward-draining river valleys transect the coast at various places and their palaeovalleys extend across much of the shelf. The catalyst for this paper was the Australian Offshore Minerals Locations Map, a joint project between CSIRO’s Wealth From Oceans National Flagship Project; Geoscience Australia; CSIRO Exploration and Mining; and state/NT Geological Surveys. The New South Wales continental shelf has a diverse range of mineral resources that justify additional evaluation.

Marine aggregate (mainly quartz-rich sands) occurs in large deposits (>100 Mt) up to 40 m thick in shelf sand bodies at various places, notably near Sydney, that extend over many kilometres parallel to the shore, and as inner shelf sand sheets. These deposits contain sand suitable for such construction uses as concrete aggregate; for industrial applications, including glass manufacture; and for beach nourishment. The inner continental shelf hosts submerged coastal barriers formed during periods of lower sea levels that are variably preserved owing to extensive reworking by high-energy storm waves. Although submerged barriers have moderate potential for heavy minerals, principally rutile and zircon, their economic viability remains largely untested.

The continental shelf intersects the Sydney Basin and Clarence-Moreton Basin, as well as Palaeozoic orogens. The Sydney Basin, which is one of the most important sources of black coal in Australia and supplies large quantities of coal from mines near the coast, is also a growing source of coal seam methane. Seismic exploration in the offshore extensions of the Sydney Basin and the Clarence-Moreton Basin has identified areas with significant potential for petroleum or coal seam methane. No exploration wells, however, have been drilled in either region. The offshore Sydney Basin, particularly between Sydney and Newcastle, is highly prospective for petroleum, coal seam methane and coal. In the offshore part of the Clarence-Moreton Basin, Tertiary rocks may provide seals to underlying coal measures that are inferred to include source rocks and reservoir sequences with comparable petroleum and coal seam methane resource potential to equivalent formations onshore. Near Bermagui and Narooma, and possibly sections of northern New South Wales, small amounts of fine-grained gold derived from alluvial and lode gold deposits in Palaeozoic rocks have been transported by streams to the coast to accumulate in marine sands.

KEY WORDS
Gold, sand, body, heavy, minerals, rutile, zircon, petroleum, methane, body, phosphates, Sydney, marine, offshore, discontinuities, aggregate, placer, shelf, continental, coal, seam, ilmenite, barrier, coast, erosional
INTRODUCTION

The world’s oceans have a diverse range of mineral deposits of potential economic interest, including such detrital minerals (along the continental shelf) as rutile, zircon, gold, cassiterite and diamonds; and large deposits of sand and gravel. Deeper oceanic regions have extensive occurrences of manganese nodules and cobalt-rich manganese crusts, and polymetallic sulphides associated with hydrothermal discharge from vents from mid-ocean ridges, backarc basins and submarine volcanic arcs. The potential importance of the mineral deposits of Australia’s surrounding oceans, which form about 70% of its sovereign territory, has been the subject of a recent major initiative between the CSIRO’s Wealth from Oceans National Flagship Program and Geoscience Australia — with the CSIRO Exploration and Mining. That initiative was completed in 2006. The Geological Survey of New South Wales, along with other state and territory geological surveys, played major geological roles in the program. This investigation of the mineral potential of Australia’s marine jurisdiction produced the world’s first map (CSIRO–Geoscience Australia 2006) showing a detailed summary of the known offshore mineral occurrences of a national region.

The southeastern Australian continental shelf, which extends from Bass Strait to the Great Barrier Reef, is comparatively shallow, mostly less than 200 m deep (Roy & Boyd 1996). In contrast with Atlantic-type passive margins, the southeastern Australian continental shelf is relatively old, narrow and has an anomalously thin cover of (young) sediments, perhaps less than 500 m thick (Roberts & Boyd 2004). The New South Wales part of the continental shelf (Figure 1) is generally less than 50 km wide, being narrowest offshore from Jervis Bay (16 km) and widest offshore from Newcastle (53 km) (Boyd et al. 2004).

The continental shelf (or eastern margin to the Australian continent) developed in response to continental break-up and sea-floor spreading that formed the Tasman Sea in the Cretaceous period (Hayes & Ringis 1973). Plate separation was apparently asymmetrical through a process of detachment faulting with little seismic evidence for rifting on the Australian (upper) plate. This largely accounts for the narrowness, by world standards, of the southeastern Australian continental shelf and steep continental slope, and is one of the main causes of its high-energy wave regime.

Along the New South Wales coast, the continental shelf is a wave-dominated environment characterised by an overall northward dispersal of shelf sands, upon which are superimposed shore-normal sediment fluxes caused by repeated transgression/regression cycles throughout the Quaternary period (Roy & Hudson 1986). Quaternary marine surface sediments on the continental shelf are subdivided into
Figure 1. Locality map showing limit of the continental shelf, New South Wales
nearshore and inner shelf sands; mid-shelf sands and muddy sands; and outer shelf calcareous sands (Roy 1998, 2001). The principal geological features of the inner shelf sediments include regressive submerged shelf barriers on gently sloping, sediment-rich parts of the shelf and headland-attached shelf sand bodies off protruding coastlines where the substrate is steeply sloping (Ferland 1990).

The present coastal morphology of New South Wales is largely the product of a relatively recent (18 000 to 6500 years ago) sea level rise that inundated an older sub-aerial landscape to produce a classic ‘drowned embayment coast’ (Roy 1998). This period of rapid sea level rise is referred to as the ‘Post-Glacial Marine Transgression’. About 18 000 years ago, the sea level was some 120 m below the present sea level, which meant that the coastline near Sydney, for example, was 10 to 15 km east of its present position. Between 18 000 and 6500 years ago, the sea level rose on average of about one metre each century in response to significant contraction of continental and polar ice sheets and general warming of sea waters. During the last 6500 years, a period commonly known as a ‘stillstand’, there have been comparatively minor fluctuations — in the order of one metre — of sea level.

At the coast, mainly Quaternary valley-fills are dominated by barrier sand bodies with estuarine and lagoon deposits that extend to the inner shelf. With the exception of riverine sediments, deposits on the coast and in estuary entrances comprise sediments derived from the continental shelf during the Post-Glacial Marine Transgression. These sediments, which have been intensely reworked before being deposited in their present location, are commonly referred to as ‘marine sands’, comprising well-sorted and rounded quartzose sands with highly variable proportions of shells and shell fragments.

GEeLOGY OF MARINE MINERAL DEPOSITS
The mineral resource potential of the continental shelf of New South Wales was intermittently investigated between 1965 and 1994, mainly for heavy minerals and construction sand, as well as phosphates, coal seam methane and petroleum (Whitehouse 2006). The search for offshore heavy minerals has primarily involved rutile and zircon but there has been some exploration for gold in southern New South Wales. Much of the earlier heavy mineral exploration drilling, however, has been inadequately documented in relevant exploration reports. Although the continental shelf is believed to have significant potential for coal seam methane and petroleum, no offshore exploratory wells have been drilled. Moreover, specific investigations of the geology of the Quaternary sequences principally occurred between 1985 and 1993, although some more recent work has become available (Boyd et al. 2004; Roberts & Boyd 2004). The spasmodic nature of these earlier investigations, combined with limited studies over the past decade, indicates that a detailed reappraisal of the geological setting and mineral resource potential of the continental shelf is strongly justified.

The Geological Survey of New South Wales has played a leading role in developing mineral exploration models for the Quaternary sequences of the continental shelf. This article outlines the significance of this work. Roy & Hudson (1986) concluded that four main types of fluvial and marine deposits, with potentially economic quantities of construction sand and disseminated heavy minerals, may occur on the continental shelf of New South Wales: shelf sand bodies and inner shelf sand sheets; placer deposits; erosional lags and buried (filled) valleys. The following discussion is primarily based on that work. Shelf sand bodies, and inner shelf sand sheets perhaps to a lesser extent, are of major commercial interest owing to their large quantities of quartz sand. They also contain low-grade disseminations of such heavy minerals as rutile and zircon. Erosional lags on the sea bed, and other potential traps in the marine environment, have been proposed as possible sites for high-grade heavy mineral deposits. Geological studies of coastal barrier building based on exploration drilling (vibracoring) and computer modelling, however, have substantially diminished their potential for placer heavy mineral deposits.

**Shelf sand bodies and inner shelf sand sheets**
There are vast quantities of sand on the inner continental shelf of New South Wales in water depths ranging from 20 m to 70 m. The sand is mostly quartzose, fine- to medium-grained, less commonly coarse-grained and, because of the energetic wave regime, contains almost no mud. Occurrences of gravel are rare. Two main types of sand deposits (Figure 2) have been recognised (Roy & Hudson 1986; Roy et al. 1997; Roy 2001).

1. Inner shelf sand sheets form thin (generally less than 1.5 m thick) deposits over about 70% of the inner shelf.
2. Shelf sand bodies, which are much thicker and containing large quantities of sand, are less common.

Shelf sand bodies are typically 20 m to 30 m thick, 5 km to 40 km long, 2 km to 4 km wide and are mostly less than 5 km from the coast (Ferland 1990). The largest shelf sand bodies occur at Montague Island, Sydney (Cape Banks–Providential
Figure 2. Representative stratigraphic cross-sections showing morphology of shelf sand bodies, inner shelves and sheets and submerged barriers of the (Section A) Tuncurry embayment, (Section B) Wallis Lake embayment and (Section C) Cape Hawke shelves and body. (After Roy et al. 1997).
Figure 3. Shelf sand bodies, continental shelf, New South Wales. Although shelf sand bodies have been identified at many places on the continental shelf, the most important deposits occur near Sydney, Montague Island and Tweed Heads.
Regression of shelf barriers, which form tabular bodies in the subsurface in front of coastal embayments, are potentially much less important sources of sand.

The various sand deposits are characteristically distinct with potentially useful properties (R.W. Corkery Pty Ltd 1993; Roy 2001). Shelf sand bodies and regressive shelf barriers contain fine- to medium-grained quartz sand that is well-suited to concrete manufacture and industrial applications (including glass manufacture). In contrast, inner shelf sand bodies contain coarser sand sizes and grains tend to be iron-stained, which makes them suitable for beach nourishment. They could, perhaps, be processed in some circumstances to produce construction and industrial grade sand.

Shelf sand bodies (Figure 4) are typically associated with headlands and consist of linear, shore-parallel deposits of fine- to medium-grained, moderately sorted to well-sorted, quartz sand; disseminated heavy minerals (mainly rutile and zircon); moderate (10% to 15%) biogenic carbonate, and usually less than 1% mud (Roy 2001). They began as transgressive sand sheets in areas where variations in continental shelf relief near prominent headlands disrupted coast-parallel sand movement towards the north during lower sea levels. Shelf sand bodies in northern New South Wales are connected to contemporary littoral drift, involving the supply of large quantities of sand, and occur in shallower water depths. Along the south coast, shelf sand bodies are transacted by rock reefs.

The Sydney (Cape Banks–Providential Head) shelf sand body (Figure 3) is probably the most important sand resource because of its proximity to the Sydney region, which uses 6 Mt to 7 Mt of construction (and industrial) sand annually (Pienmunne & Whitehouse 2001), and the quality and size of the potential sand resource. That deposit, which occurs in water depths of 30 m to 70 m about 0.5 km to 2.5 km off the coast, contains sand in the order of hundreds of millions of tonnes (R.W. Corkery Pty Ltd 1993). The Sydney (Cape Banks–Providential Head) shelf sand body consists of two units. The first is a lower, fine-grained transgressive sequence, similar to the lower shoreface sand in the adjacent barriers, which is more than 6500 years old and was deposited during the Post-Glacial Marine Transgression. The second unit is an upper regressive sequence that is often coarse-grained, contains shell fragments and rock fragments from adjacent cliffs and is less than 6500 years old (Fedland 1990; Roy 2001). The Sydney (Cape Banks–Providential Head) shelf sand body experienced variable sand input. This resulted in the development of a northern, deeper water section that experienced declining rates of alongshore sediment transport (total sediment thickness of less than 20 m), and a southern section that experienced comparatively high rates of alongshore sand transport (sediment thickness up to 30 m).

Placer deposits

Submerged beaches (Figure 5) are unlikely to be preserved intact on high-energy continental shelves, like those found along southeastern Australia. However, they may be preserved to some extent under restricted conditions (Roy & Hudson 1986). Preservation of beaches (or strandlines) on the continental shelf depends largely on the extent and rate of reworking by marine transgressions. During rising sea levels, coastal sand barriers are constantly being destroyed, reworked or reformed, and there is a mass landward transfer of sand, including most of its heavy minerals. Thus preservation, to any significant extent, of former beach placer deposits on the continental shelf is unlikely to occur. Seismic
sequence analysis of offshore sediments near Tweed Heads and Newcastle (Browne 1994) identified several drowned coastal deposits showing various degrees of preservation. Only small occurrences of generally low-grade heavy mineral concentrations, however, have been located in these deposits.

**Erosional lags**

Erosional lags (Figure 6) consist of thin layers of potentially heavy mineral-bearing sediment remaining after much of a sand deposit has been removed (winnowed) by erosional processes (Roy & Hudson 1986). Complex depositional processes are involved in the formation of placers in coastal barriers (e.g. Roy 1999; Roy & Whitehouse 2003). In general, lighter (especially sandy) material may be preferentially removed leaving the heavier and larger grains to form a lag concentrate. Thus, lags characterise places that are fundamentally erosional in nature rather than depositional. Erosional surfaces or discontinuities on which lags could develop appear to occur in a complex range of fluvial, estuarine and marine sediments and depositional settings ranging in age from Tertiary to Quaternary. Potential exploration targets may include places where the Post-Glacial Marine Transgression has reworked mineral-bearing river channels on the shelf and submarine rock reefs that, at lower sea level periods, could have allowed heavy mineral-bearing sediments to accumulate.

![Figure 6. Diagrammatic section showing an erosional lag (after Roy & Hudson 1987).](image)

**Buried valleys**

Buried valleys (Figure 7) on the continental shelf are of interest as a potential source of heavy minerals that may have been reworked by marine processes and redeposited as erosional lags on the sea bed (Roy & Hudson 1986). However, they are not high priority targets on the continental shelf because of the expected difficulties in exploring (and exploiting) these types of deposits. In contrast, buried valleys are major sources of sand and gravel in the United Kingdom (UK) for concrete aggregate and for beach nourishment owing to their large size and low clay and silt content (British Marine Aggregate Producers Association 2005). These deposits are highly variable relict Quaternary sequences formed by fluvial or glaciofluvial processes but modified by the rise of sea level associated with the Post-Glacial Marine Transgression and subsequently reworked by tidal currents.

**MARINE MINERAL RESOURCE POTENTIAL**

Shelf sand bodies and inner shelf sands along the New South Wales coast contain major resources of high-quality marine aggregate (mainly quartz sands) that can be processed to suit numerous construction applications, principally concrete manufacture. Another use for the (raw) sand is beach nourishment. Large quantities of marine aggregate are extracted in such places as Japan, the UK and Europe. In a typical year, the UK requires over 230 Mt of aggregates (British Marine Aggregate Producers Association 2005). The UK marine aggregate industry provides almost 20% of the sand and gravel used in England and Wales, and some of the aggregate needs of several nearby European countries. In some places, notably London and nearby areas, marine aggregate provides as much as 50% of the sand and gravel requirements.

Apart from limited quantities of sand intended primarily for beach nourishment, offshore deposits of sand in New South Wales have yet to be systematically extracted. Small quantities of sand are extracted from beach deposits at the entrance
to South West Rocks Creek, northern New South Wales, for concrete manufacture (Kempsey Council, pers. comm. 2006). Minor quantities of medium- and coarse-grained gravel have reportedly been extracted (in the 1950s) from shoreface deposits at beaches near Norah Head and Wybung Head, near Gosford (G. McNally, pers. comm. 2006).

In New South Wales, the only beach nourishment project involving the exploitation of a specific offshore source is the Tweed River Entrance Sand Bypassing Project (Patterson Britton & Partners Pty Ltd 2006) near Tweed Heads. The Tweed River Entrance Sand Bypassing Project is subject to a Deed of Agreement between the states of New South Wales and Queensland under the *Tweed River Sand Bypassing Act 1995*.

Marine sand is also periodically extracted from the entrance to Narrabeen Lagoon, northern Sydney, for beach nourishment at nearby Collaroy Beach to mitigate extensive erosion of the shoreface that periodically takes place during severe storms. This has the complementary advantage of preventing Narrabeen Lagoon from being infilled with fluvial and estuarine sediments (Warringah Council, pers. comm. 2006).

Other beach nourishment projects that have been implemented in New South Wales include Park Beach (Coffs Harbour), Bate Bay (Cronulla, southern Sydney), Lady Robertson Beach and Towra Point (Botany Bay, Sydney) and Shoal Bay and Jimmys Beach (Port Stephens) (Patterson Britton & Partners Pty Ltd 2006). A proposal to extract sand from the Cape Byron–Ballina shelf sand body (Figure 3) for the control of beach erosion is being developed by Patterson Britton & Partners Pty Ltd (2006) on behalf of Byron Bay Council. This proposal, which involves beach nourishment, along with the development of control structures and a seawall, is designed to reduce erosion hazards at Byron Bay/Belongil Beach and New Brighton Beach.

**Photograph 1.** Extracting marine sand from the entrance to Narrabeen Lagoon in 2006. The sand was then used to nourish Collaroy Beach, a few kilometres south of the source (Photographer: J. Whitehouse).
Photograph 2. Heavy minerals mining on Stockton Bight, Port Stephens. Coastal sand deposits in New South Wales have been major sources of rutile and zircon. Further investigation is needed to assess the potential for offshore occurrences of these minerals in commercial quantities (Photographer: D. Barnes).
**Shelf sand deposits**

Offshore exploration for construction sand deposits in the Sydney area first took place in the late 1970s, under Exploration Licence 1194, when a proposal to extract fine to coarse sand from inner shelf sand deposits within the entrance of Broken Bay (north of Sydney) was developed by a consortium of Consolidated Gold Fields Australia Ltd and ARC Marine Ltd (1980). At this time, seismic reflection studies defined a sand resource at a depth of 20 m to 40 m over an area of about 10 km² with an average thickness of 10 m (Australian Marine Resources Pty Ltd 1979). Wallace and Roy (1980) subsequently defined a potential sand resource in Broken Bay of about 12 Mt (extraction depth of one metre assumed) although the overall resource is probably much larger. Sand extraction at this locality has yet to occur.

In 1985 Hooker Mining Pty Ltd lodged applications for two mining leases within Botany Bay in areas potentially requiring sand extraction for berths associated with the development of Botany Bay. These applications were unsuccessful. In February 1986, Hooker Mining Pty Ltd lodged three exploration licence applications for marine aggregate over much of the Sydney (Cape Banks–Providential Head) shelf sand body, and the Bass Point shelf sand body (Figure 3). In 1988, the state government issued four exploration licences (ELs 3217, 3218, 3219 and 3221) over parts of the shelf between Nowra and Port Jackson to several companies, including Hooker Mining Pty Ltd. By late 1989, Hooker Mining Pty Ltd sold its titles to Ready Mixed Industries Pty Ltd, trading as Metromix.

In 1993, Metromix developed a proposal (R.W. Corkery Pty Ltd 1993) to extract a sand resource (pre JORC) of about 100 Mt from the Sydney (Cape Banks–Providential Head) shelf sand body, consisting of 50 Mt of sand near Cape Banks (EL 3221) (Figure 8) and about 50 Mt of sand near Providential Head (EL 3219) (Figure 8). Although the Sydney (Cape Banks–Providential Head) shelf sand body contains an estimated 1200 Mt of sand, the Metromix proposal involved sand removal to a maximum depth of 5 m only. The Bass Point shelf sand body was not considered for extraction. The Sydney (Cape Banks–Providential Head) shelf sand body is composed mainly of fine- to medium-grained quartz with variable quantities of shell fragments. The minus 75 micron fraction is mainly clay (kaolinite, illite and illite-smectites). That sand is suitable for uses that include concrete aggregate, fill, horticulture, bedding sand, or industrial applications that include mixing with cement in plaster, render or grout, and possibly glass manufacture (R.W. Corkery Pty Ltd 1993).

**Submerged beaches, erosional lags and buried valleys**

Placer deposits of heavy minerals with high concentrations of rutile, zircon, ilmenite and minor monazite have been mined from beach barrier and dune deposits from the Central Coast to southern Queensland (Roy 1998). These deposits are usually found at erosional discontinuities between barriers of different ages, most commonly Pleistocene/Holocene contacts (Roy 1999). Until recently, the New South Wales coast was a major source of placer concentrates of rutile, zircon, ilmenite and minor monazite in barrier beach deposits. These deposits have largely been extracted or are unavailable for exploitation. In eastern Australia (New South Wales and Queensland) between 1933 and 1980, about 11.4 Mt of valuable heavy minerals (5.8 Mt of rutile and about 5.6 Mt of zircon) were extracted from coastal dune deposits (Morley 1981). Heavy minerals mining continues in Queensland, but extraction in New South Wales coastal deposits peaked during the 1980s and then steadily declined before ceasing in 2003.

The large deposits of premium-grade rutile and zircon in coastal barriers soon encouraged exploration for these minerals on the continental shelf. Exploration for offshore rutile and zircon in New South Wales first occurred between 1966 and 1972 (Browne 1992). This involved work by Ausminda (during 1966), NSW Rutile Mining Company (from 1966 to 1967), Planet Metals Ltd (from 1966 to 1972), United Uranium NL (from 1971 to 1972) and Wyong Minerals Ltd and Associated Minerals Consolidated Ltd (from 1966 to 1969). Those exploration titles covered most of the continental shelf between Sydney and Tweed Heads. Exploration included drilling; sporadic seismic reflection profiling; heavy mineral assemblage determinations; and mineral resource estimations (Browne 1992, 1993). Many of the drillholes were poorly targeted because of the unavailability of seismic reflection data and inadequate exploration models. Variable depths of penetration were achieved during drilling (typically 2–4 m but as much as 12 m in some places) in the shelf sediments. Sample recovery was commonly poor, in places only 20% to 30% of the drilled section.

The most comprehensive investigations along the New South Wales continental shelf were undertaken by Planet Metals Ltd, which found low-grade (0.2% heavy minerals) deposits near Tweed Heads and near Forster (Brown 1971a,b). A series of relatively shallow (<40 m) barriers on the continental shelf were evaluated. Near Tweed Heads and Forster, these barriers are associated with peat and organic layers (likely back barrier depositional setting), and gravel. Several types of (coarse-grained) heavy mineral deposits were recognised, including beach placers with sporadic drill intersections up to several metres thick, with a wide range (20–60%) of heavy mineral grades, and disseminated deposits of generally low-grade (<0.5% total) heavy minerals. Brown (1971a) inferred that the low-grade deposits represented either dune components of the submerged barriers or, more likely, formed in response to intense reworking by high energy storm waves on the continental shelf.
Figure 8. Proposed sand resource extraction areas, Sydney (Cape Banks–Providential Head) shelf sand body. (From R.W. Corkery Pty Ltd 1993, for Metromix Pty Ltd.) This shelf sand body, considered the most important in New South Wales primarily because of its proximity to the Sydney construction sand market, has large resources of fine- to medium-grained quartz sand that are suitable for many construction applications, principally concrete aggregate.
In 1991 Cable Sands Holdings Pty Ltd investigated the heavy mineral potential of the continental shelf between Gosford and Tweed Heads (Browne 1992, 1993). Seismic profiling was extensively used to find submerged barriers for drill testing. In particular, the Tweed Heads, Swansea and Forster areas (Cape Hawke) were extensively re-evaluated. Cable Sands concentrated primarily on these areas partly because they had difficulty using the poorly documented geological data obtained in the earlier regional investigations (C. Ricketts, pers. comm. 2006). Exploration near Tweed Heads and Swansea defined several low-grade deposits of heavy minerals that contain only minor quantities of zircon and rutile, in the order of several thousand tonnes at each location (Figure 9). In contrast to adjacent coastal barriers and the offshore deposit near Swansea, the offshore heavy mineral assemblage at Tweed Heads contains more ilmenite and less rutile and zircon (Sircombe 1999). Ilmenite was probably derived from eroded volcanic rocks in the Tweed River area and then transported to the coast by alluvial processes and deposited in marine sands on the adjacent shelf.

Jones and Davies (1979) reported that visible (probably very fine-grained) gold was recovered off Port Macquarie during the nineteenth century during hand lead depth soundings conducted by HMS Herald. No specific locality for this occurrence, however, was provided. Significant quantities of fine-grained gold have been extracted from coastal deposits near Bermagui in southern New South Wales. In 1879 a high-grade deposit of placer gold was briefly worked from heavy mineral-bearing beach sand in the entrance to Lake Corunna, near Bermagui (Figure 10) (Chalker & Bembrick 1977). The onshore area from Bermagui to Narooma contains scattered heavy mineral concentrations in addition to large quantities of mainly quartz sand. The investigations by Roy and Hudson (1987), and a later offshore study in the Forster region (Roy et al. 1997), however, found only minor (<1.0%) heavy mineral accumulations in marine sands. No enrichment of heavy minerals in inner shelf sand sheets or depositional terraces was observed at either locality. This confirmed earlier (1980) detailed studies of heavy mineral occurrences in shelf sediments on the Australian east coast undertaken during a joint Australian–German project using the German research vessel SONNE (Riech et al. 1982). In four offshore localities between Newcastle and Fraser Island (southern Queensland) heavy mineral concentrations were extremely low (0.01% to 1.6% by volume).

Submerged barrier complexes on the continental shelf of southeastern Australia are potentially widespread, but the only areas of possible commercial interest are barriers that survived the Post-Glacial Marine Transgression, and subsequent storm activity, and have been variably preserved. During the Quaternary, the eastern Australian continental shelf experienced intense reworking involving marine transgressions that eroded sand from the offshore sea bed, bringing heavy mineral occurrences in shelf sediments on the Australian east coast undertakings of complex stratigraphic and structural setting.
Figure 9. Heavy minerals placer deposits, continental shelf, New South Wales. Heavy mineral-bearing sediments have been identified at many places on the continental shelf. However, the only occurrences of significance are small, low-grade deposits associated with submerged relict beaches near Newcastle and Tweed Heads (Whitehouse 2006).
Figure 10. Offshore gold occurrences, continental shelf and its margins, New South Wales. Scattered offshore occurrences of fine-grained gold near Narooma and Bermagui were probably derived from hinterland gold deposits and transported to the coast by alluvial processes to accumulate in marine sands (Whitehouse 2006).
mineral-rich sediment shoreward and adding it to the coast in the form of successive shoreface deposits (Roy 1990; Roy et al. 1997; Roy 1999). Computer modelling of barrier formation indicates that accumulation of heavy minerals on erosional discontinuities between inner shelf sand units and older sediments or bedrock surfaces is unlikely. Consequently, the only depositional environment in which heavy minerals are significantly concentrated is on the beach face. Shelf sand bodies, however, are still potential sources of large quantities of low-grade disseminated heavy minerals.

**Phosphates**

The eastern Australian continental shelf is not regarded as an area of strong oceanic upwelling and associated high organic productivity, where the world’s major offshore phosphate deposits traditionally occur (Kudrass 1999). Iron- and phosphorous-rich nodules of late Quaternary age, ranging in size from very coarse sand to boulders, have been identified on the outer continental shelf and upper slope in northern New South Wales (Figure 11) (von der Borch 1970; Cook & Marshall 1981). The shelf is relatively narrow (25–40 km) and the slope considered unusually steep, the major shelf break occurs at depths between 210 m and 450 m (O’Brien et al. 1986). The nodules have highly variable phosphate (P$_2$O$_5$) contents, ranging from about 5% for poorly consolidated sediments to as much as 15% for strongly lithified sediments (von der Borch 1970; Cook & Marshall 1981). Most of the pellets within the nodules are glauconitic and are composed mainly of SiO$_2$, FeO and minor P$_2$O$_5$ (<0.5%). In contrast, the matrix ranges between cellophane (cryptocrystalline carbonate–fluorapatite, average 29% P$_2$O$_5$) and goethite (average 4% P$_2$O$_5$).

Given their relatively low P$_2$O$_5$ contents, eastern Australian nodules are more appropriately described as being ‘phosphatic’ rather than as phosphorites and are unlikely to have commercial potential (Global Marine Australasia Pty Ltd 1971). Although the origin of the iron-rich nature of the eastern Australian phosphorites is not clearly understood, the most likely source of the iron (and phosphorous) is the ocean (Cook & Marshall 1981; O’Brien et al. 1986).

**Other minerals**

Roy and Hudson (1987) noted that the continental shelf between Narooma and the Tuross Estuary, about 20 km north of Narooma, has a geological setting broadly comparable to the (near-shore) diamond provinces of southwest Africa. The potential for offshore deposits of diamonds on the New South Wales continental shelf is probably very low. Beside gold, the Mount Dromedary intrusion is known to contain other precious metals (e.g. platinum), which are likely to occur in alluvial deposits and rare grains of osmiridium have apparently been found in beach sand near Mystery Bay, near Narooma (Roy & Hudson 1987). Cassiterite from alluvial workings at Tanja and Cathcart, near Bega, may also have been transported to the coast and incorporated in marine deposits on the continental shelf (e.g. Chalker & Bembrick 1977). Since the potential for erosional lags to form detrital heavy mineral accumulations on the continental shelf is no longer believed to be significant, the possibility of these minerals forming economic accumulations offshore appears correspondingly poor.

**COAL, PETROLEUM AND COAL SEAM METHANE**

The Sydney Basin is a major source of black coal suitable for thermal (steaming) and metallurgical (coking) use whilst the Clarence-Moreton Basin has lower rank thermal coal. The offshore parts of the Sydney Basin and the Clarence-Moreton Basin contain sequences that are highly prospective for petroleum (Figures 12 and 13) (Alder et al. 1998; Shaw et al. 2001). It is unclear if ‘offshore’ coal seam methane would be economically viable unless the gas accumulated in significant quantities within ‘conventional’ traps. Numerous petroleum and methane-rich gas occurrences have been detected during onshore exploration and mining in these basins. No petroleum wells, however, have been drilled on the continental shelf and there is limited modern seismic coverage. Any extraction of the coal, petroleum or coal seam methane resources is likely to involve directional drilling (and mining) from onshore locations (S. Cozens, pers. comm. 2006). Although commercial occurrences of (conventional) petroleum remain to be found in the Sydney Basin or the Clarence-Moreton Basin, coal seam methane is extracted in significant quantities in the southern Sydney Basin. The Sydney Basin and Clarence-Moreton Basin are geologically favourable for coal seam methane occurrences because of their thick coal measures sequences and high vitrinite, bituminous coals with seam gas enriched in methane (Ingram et al. 1996), and for petroleum resources because of their suitable source rocks, reservoir seals and known structural traps.

**Clarence-Moreton Basin**

The Walloon Coal Measures of the Clarence-Moreton Basin have significant potential for petroleum and coal seam methane. The potential for offshore coal resources is unknown, but unlikely to be significant. Metgasco Limited (PEL 13 and PEL 16) has identified commercial reserves of coal seam methane at its South Casino Coal Seam Gas Field near Casino, which is planned for use in a proposed 30 megawatt electricity generating plant in Casino (PESA News 2006). Reprocessed seismic reflection
Figure 11. Phosphate occurrences of the continental shelf, New South Wales. Although phosphates have been identified at various locations in northern New South Wales, the main occurrences are near Coffs Harbour. There, the phosphates are of mostly poor quality and are not likely to prove commercially viable (Whitehouse 2006).
Figure 12. Coal, petroleum and coal seam methane potential, continental shelf, New South Wales (from NSWDPI unpublished brochure ‘Petroleum projects and exploration highlights in New South Wales’, October 2006.)
Figure 13. Coal, petroleum and coal seam methane potential, continental shelf, Sydney Basin, New South Wales (from NSWDPI unpublished brochure ‘Petroleum projects and exploration highlights in New South Wales’, October 2006.)
data indicate that offshore sequences are in the order of 2500 m thick, which are comparable to, or exceed, seismically defined sequence thicknesses in the onshore part of the basin (Stewart & Alder 1995; Ingram et al. 1996; Shaw et al. 2001). Although the source rock and reservoir potentials of the offshore sequences are unknown, the Permian coal measures sequences and overlying Triassic rocks are promising exploration targets. The reprocessed seismic reflection data for the offshore part of the basin show considerable faulting that may provide stratigraphic and structural traps amenable to petroleum accumulation.

**Sydney Basin**

Coal has been extracted in comparatively small quantities from the offshore part of the Sydney Basin near Newcastle during the 1880s and to about 1915, and again from the late 1940s to the mid-1980s (R. Rigby, pers. comm. 2006). Coal has also been extracted offshore from Coalcliff, near Wollongong. The high cost of the more recent underground offshore mining compared with open cut coal mining in the nearby Hunter Valley, and geological constraints (including igneous intrusions intersected during offshore extraction), rendered offshore coal mining uncompetitive. The offshore Sydney Basin, however, has potentially large resources of coal. Bowman (1981) estimated that thermal and metallurgical grade coal resources at depths to 600 m below the seabed present in seams greater than 1.5 m thick may be in the order of several billion tonnes. This estimate is highly provisional given that offshore coal seams of the Sydney Basin have not been drilled, with the exception of limited exploration associated with underground coal mine workings near Newcastle and Wollongong.

The Sydney Basin is gas-prone, and numerous seeping oil occurrences and gas flows indicate that the basin contains an ‘active’ petroleum system. A joint venture between Sydney Gas Limited and AGL Energy Limited produces coal seam methane from the Camden area (the Camden Gas Project) and significant production is planned in the Hunter Valley. Although a number of petroleum exploration wells have been drilled in the onshore Sydney Basin, no petroleum exploration wells have been drilled on the offshore Sydney Basin. Alder et al. (1998) reported that a number of structurally controlled reservoirs with the potential to contain significant gas reserves occur in the offshore Sydney Basin. The more important prospects are the Sealion Lead (Figure 13) (ESP Pty Ltd 1982), and the South Baleen Lead (Figure 13) (Bradley 1993). The South Baleen Lead, now called the Biggus Lead, is situated in an area considered to have particularly high potential for petroleum known as the ‘Offshore Uplift’ (Figure 13) (Bradley 1992, 1993). The South Baleen Lead, which is believed to contain up to 1.2 trillion cubic feet (about 34 billion cubic metres) of gas, is largely covered by Petroleum Exploration Permit (PEP) 11 (held by Bounty Oil & Gas NL).

**CONCLUSIONS**

The New South Wales continental shelf has extensive occurrences of sand in shelf sand bodies and inner shelf sand sheets. Shelf sand bodies contain major resources of high-quality marine aggregate (mainly quartz sands) that can be processed to suit numerous construction applications, notably concrete production. Uses of unprocessed sand include beach nourishment. These deposits are typically 20 m to 30 m thick, extend over many kilometres parallel to the shore, and contain large amounts of sand (in the order of hundreds of million of tonnes in places). The most important deposit, which occurs near Sydney in water depths of 30 m to 70 m about 0.5 km to 2.5 km off the coast, could become a major source of sand for the construction sand requirements of the Sydney region (currently 6–7 Mt annually). Other sand deposits of possible commercial interest, mainly for beach nourishment, occur in inner shelf sand sheets at Broken Bay, north of Sydney, and other parts of the inner continental shelf. These deposits also contain low-grade disseminations of rutile and zircon.

Until 2003, the New South Wales coast was a major source of placer concentrates of rutile, zircon and ilmenite in onshore barrier beaches. These deposits, which were also minor, intermittent sources of gold many years ago, have been largely mined-out or are unavailable for exploitation. The inner continental shelf hosts submerged coastal barriers formed during periods of lower sea levels that are variably preserved owing to extensive reworking by high-energy storm waves. Although submerged barriers have low potential for heavy mineral deposits, their economic viability remains largely untested.

The continental shelf of New South Wales was previously considered to have possible accumulations of heavy mineral in lag deposits (lags) on erosional surfaces or discontinuities on the sea floor. It was also assumed that there may be some possibility for mineral placer deposits in barrier complexes associated with shelf sand bodies, and depositional terraces (beaches) developed on submerged bedrock highs. Offshore investigations in the Narooma–Bermagui area, southern New South Wales, and the Forster–Tuncurry area, central New South Wales, however, found only minor (<1.0%) heavy mineral accumulations in marine sands and that there was no enrichment of heavy minerals in inner shelf sand sheets or depositional terraces at either locality.

During the Quaternary period, the eastern Australian continental shelf experienced intense reworking involving
multiple marine transgressions that eroded sand from the offshore sea bed, bringing heavy mineral-rich sand shoreward and adding it to the coast as successive shoreface deposits in which beach placers developed. The accumulation of heavy minerals on erosional surfaces between inner shelf sand units and older sediments is now considered unlikely and the only depositional environment in which heavy minerals are significantly concentrated is on the beach face. Near Bermagui and Narooma, and possibly parts of northern New South Wales, fine-grained gold derived from small alluvial and lode gold deposits in Palaeozoic rocks were transported by streams to the coast to accumulate in marine sands. The potential for offshore gold deposits, or other such detrital minerals as cassiterite (tin) of commercial interest, however, has not yet been established and is presently not considered to be significant.

The Sydney Basin is one of the most important sources of black coal in Australia, supplying large quantities of coal and is a growing source of coal seam methane. The offshore Sydney Basin has potentially very large resources of black coal to depths of 600 m or more below the sea floor. Coal has been extracted in comparatively small quantities from the offshore part of the Sydney Basin near Newcastle and near Wollongong. The high cost of the (relatively) more recent offshore (underground) mining compared with modern open cut mining in the nearby Hunter Valley, however, renders offshore coal extraction uncompetitive. Although seismic exploration in offshore extensions of the Sydney Basin and the Clarence-Moreton Basin has identified areas with potential for petroleum and/or coal seam methane, no exploration wells have been drilled. The offshore Sydney Basin, especially in a large, structurally complex area between Sydney and Newcastle, is prospective for petroleum and coal seam methane. In the offshore part of the Clarence-Moreton Basin, Tertiary rocks may provide seals to underlying coal measures that are inferred to have source rocks and reservoir sequences of comparable potential to those being evaluated onshore.

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**REFERENCES**


**BOUNTY OIL & GAS NL.** 2006. Exploration announcement. PEP 11 offshore Sydney Basin. (www.bountyoil.com)


**BRITISH MARINE AGGREGATE PRODUCERS ASSOCIATION**. 2005. Aggregates from the sea drawing strength from the depths, 16 pp. (www.bmapa.org)


Cordero-Geoscience Australia 2006. Australian Offshore Minerals Location First Edition (1:000 000 scale map) Geoscience Australia, Canberra, Australia.


Patterson Britton & Partners Pty Ltd 2006. Scoping study on the feasibility to access the Cape Byron sand lobe for sand extraction for beach nourishment. Report prepared for Byron Bay Council. (unpubl.).


New South Wales’ by G R Burton, S J Trigg & L P Black.

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‘New and revised lithostratigraphic units from the Port Macquarie Block, northeastern New South Wales’ by D Och & E Leitch

‘A Middle Triassic age for felsic intrusions and associated mineralisation at the Doradilla Prospect, New South Wales’ by G R Burton, S J Trigg & L P Black.