Geology and mineral resources of the Northern Territory

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Chapter 39: Carpentaria Basin


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Chapter 39: CARPENTARIA BASIN

INTRODUCTION

The Jurassic–Cretaceous intracratonic Carpentaria Basin (Smart et al. 1980) lies beneath the Gulf of Carpentaria in offshore northern Australia and extends onshore into Queensland and the Northern Territory. It is overlain by Cenozoic sediments of the Karumba Basin (in Queensland) and extends over a total area of about 680 000 km². Approximately 20% of the offshore basin is in Northern Territory waters. The basin was formed as a gentle intracratonic downwarp in the Jurassic and Cretaceous, and contains a typically thin, but laterally extensive sedimentary succession with a maximum thickness of about 1760 m in the offshore Carpentaria Depression (Weipa Sub-basin), which constitutes the basin's major depocentre (Burgess 1984). The Carpentaria, Eromanga and Surat basins together form the bulk of the Great Australian Basin (Green 1997, Draper 2002) of central and northeastern Australia. Other interconnected eastern Australian basins (e.g. Clarence-Moreton, Nambour and Laura basins) could also be considered to be a part of this vast depositional system.

McConachie et al. (1990) subdivided the Carpentaria Basin into four sub-basins (Western Gulf, Weipa, Staaten and Boomarra) that are recognised by the characteristics of the basal Mesozoic sandstone or the basement they overlie (Figure 39.1). Onshore in the Northern Territory, a condensed succession of the Western Gulf Sub-basin onlaps an erosional surface of deformed Proterozoic rocks of the Arnhem Province, and sedimentary rocks of the McArthur, Georgina, Wiso and Daly basins. The former ‘Dunmarra Basin’ in the NT is here reinterpreted as a westerly extension of the Western Gulf Sub-basin across the northern part of the Territory as a result of a major marine transgression in Aptian to early Albian time.

Basement highs separate the Carpentaria Basin from adjacent contemporaneous basins. To the east, the basin is bounded by Proterozoic rocks of the Coen, Yambo and Georgetown inliers and by Carboniferous rocks of the Cape York-Oriomo Ridge, although there were probable connections in the vicinity of the Coen Inlier across basement highs (Bramwell and Kimba arches) with contemporary basins in northeastern Queensland, including the Papuan and Laura basins. Lithological continuity is probable between these depositional areas (Krassay 1994b). To the north, the boundary with the Morehead Basin (Papua New Guinea) is poorly defined. The Money Shoal Basin in the northwest is separated from the Carpentaria Basin by the ill-defined offshore Wessel Rise and by the onshore Kombolgie palaeohigh (new informal name, Figure 39.1), which consists of Proterozoic Katherine River Group rocks that form the southwestern part of the Arnhem Land Plateau. The northern margin, to the south of Darwin, is here taken to be a line enveloping the eroded Cretaceous outcrops. To the southeast in Queensland, the Carpentaria Basin is separated from the Eromanga Basin by the Eureka Arch and, although there is probable stratigraphic continuity between the two basins, depositional environments to the south of the arch are interpreted to have been more restricted and lower energy (Krassay 1994b). Within the Northern Territory, the southern margins of the basin correspond to the mapped limits of the main Cretaceous outcrops within the Territory, but also incorporate areas of subcrop beneath Cenozoic sediments, as determined from waterbores (unpublished NTGS data). Note that the mapped boundaries of the basin in the Northern Territory do not necessarily coincide with the depositional margins, which have been eroded or covered by Cenozoic sediments in many places.

Figure 39.1. Schematic map showing extent of Carpentaria Basin and sub-basins (modified after McConachie et al. 1994, 1997). Maximum extent of Cretaceous deposition (Aptian) derived from NTGS GIS database and unpublished waterbore data compiled by NTGS. Approximate late Albian regional shoreline after Krassay (1994b). Overlying Cenozoic Karumba Basin (Queensland) not shown for clarity.

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Middle to Late Jurassic sediments within the basin were sourced from the east and consisted of fluvial clastic rocks in a series of basement depressions, mostly within the Weipa and Staaten sub-basins (McConachie et al 1990). A marine transgression affected the north of the basin in the latest Jurassic–earliest Cretaceous and gradually became more widespread (Frakes et al 1987). Marine deltaic to fluvio-lacustrine environments at this time were replaced by widespread shallow-marine to marine conditions, which reached their maximum extent during the Aptian to early Albian, when much of the northern part of Australia was inundated. This late Early Cretaceous transgression resulted in a thick mudstone succession over much of the basin. Psisolic manganese was also precipitated in protected coastal areas along the west coast of Groote Eylandt at about this time (Ferenczi 2001). By late Albian times, shorelines had retreated from much of the Northern Territory, but shallow-marine conditions persisted in eastern and offshore areas, and in Queensland (Figure 39.1). Albian to later Cretaceous deposits indicate a continuing regression, with depositional environments gradually shallowing from shallow marine to paralic. During Late Cretaceous time, the margins of the basin were locally faulted, uplifted and eroded prior to the commencement of sedimentation in the overlying Karumba Basin.

LATE EARLY–EARLY LATE CRETACEOUS

The stratigraphic succession of the Carpentaria Basin and its sub-basins has been established from onshore exposures, stratigraphic drillholes, onshore and offshore petroleum wells, several deep water bores, and marine seismic data. It has been summarised in a number of publications, including Skwarko (1966), Smart et al (1980), Burgess (1984), McConachie et al (1990, 1994, 1997), Krassay (1994a, b) and Ferenczi (2001). The following discussion is focused on the Western Gulf Sub-basin in the Northern Territory.

Onshore Western Gulf Sub-basin

The Western Gulf Sub-basin occupies much of the Gulf of Carpentaria and extends onshore across much of the north of the Northern Territory (Figure 39.1). Smart et al (1980) conservatively located the western boundary of the sub-basin offshore, to the east of Groote Eylandt. This boundary was subsequently extended onshore (Krassay 1994a, b) to include Cretaceous marine facies of the 'Coastal Belt' of Skwarko (1966). It is here extended further westward to include strata previously referred to the 'Inland Belt' of Skwarko (1966), later informally named the 'Dunmarra Basin' by NTGS geologists in 1990. The thin, flat-lying, relatively undeformed onshore succession forms tablelands, mesas, buttes and isolated rounded exposures, mantling Proterozoic and early Palaeozoic basement rocks from eastern Arnhem Land southwards along the Northern Territory coastline towards the Queensland border, and westward as an extensive outcrop tract across the central northern part of the Northern Territory to the vicinity of the Joseph Bonaparte Gulf. The scattered exposures are remnants of a once much more continuous outcrop tract that has been eroded and dissected by coastal peneplanation (Figure 39.2).

In the main depocentres of the Carpentaria Basin to the east, the relatively thick (up to 1760 m) succession has been divided into seven principle units (Figure 39.3), consisting of quartzic sandstone at the base, overlain by thick intervals of quartzitic glauconitic sandstone, lithic glauconitic sandstone and shale. Krassay (1994b) referred a much thinner onshore succession (maximum composite thickness 50–60 m, but generally less than 20 m) in the Arnhem Land area to two units, the Walker River and Yirrkala formations (previously Mullaman Beds of Skwarko 1966). These have been broadly correlated with the Gilbert River Formation and Rolling Downs Group equivalent (Smart et al 1980) of the central Carpentaria Basin. The two formations have been recognised throughout much of the 'Coastal Belt' of Skwarko (1966), but their distribution to the west is unclear.

The Walker River Formation (Krassay 1994b, Rawlings et al 1997) consists of moderately to well sorted, typically cross-bedded, fine- to coarse-grained quartzic sandstone, which is interbedded with laminated clayey siltstone and chert granule and pebble conglomerate. The unit forms both upward-finining and -coarsening cycles that are typically 5 to 10 m thick. Where the base of the formation is exposed, it consists of thick, normally graded, chert cobble to pebble conglomerate that grades upward into sandstone containing molluscan macrofossils and marine trace fossils. Krassay (1994b) equated the formation with informal units 2–7 of the 'coastal belt' of Skwarko (1966) and tentatively correlated it with units B and C of Skwarko's 'inland belt' ('Dunmarra Basin'). The Walker River Formation contains a range of sedimentary structures, including hummocky cross-stratification, planar cross-bedding, wave and current ripples, convolute lamination, slump structures and sole markings that indicate deposition in a predominantly shallow-marine shelf setting mostly above storm wave base. Krassay (1994b) determined a range of palaeoenvironments, including foreshore, offshore shallow marine, and distal deltaic to deltaic marine.

The Yirrkala Formation (Krassay 1994b, Rawlings et al 1997) is massive to thickly planar-bedded and consists of friable, kaolinised arkosic sandstone and poorly sorted, fine- to very coarse-grained, matrix-poor quartzic sandstone that are interbedded with minor claystone. The unit contains large-scale cross-beds, dispersed chert pebbles and rare, moderately to poorly preserved plant fossils, particularly in upper, finer-grained parts of the unit. It unconformably overlies the Walker River Formation, or is unconformable on Proterozoic sedimentary and metasedimentary rocks, or is nonconformable on Proterozoic granite. The formation was interpreted by Krassay (1994b) to represent sandy bedform, channel and gravel bar deposits, deposited as fluvial, high-energy channel deposits and valley fills. Krassay remarked that, in places, the formation resembled unit 1 of the 'coastal belt' and unit A of the 'inland belt' of Skwarko (1966), but the stratigraphic position of these units beneath interpreted Aptian shallow-marine intervals (Walker River Formation and equivalents) suggests that they are not correlatives. Non-marine, restricted-marine and shallow-marine rocks in the uppermost part of the onshore succession, including the Yirrkala Formation, are correlated with the offshore Normanton Formation equivalent at the top of the Rolling Downs Group equivalent (Rawlings et al 1997).

The thin Cretaceous sedimentary succession of the 'Inland Belt' of Skwarko (1966) or former 'Dunmarra
Figure 39.2. (a) Distribution of Cretaceous outcrops in Northern Territory portion of Carpentaria Basin and major watercourses (compiled from GA 1:1M GIS database). (b) Generalised Cretaceous outcrop map overlaid on digital elevation model, with approximate boundaries of Cretaceous basins and sub-basins. Headward erosion from coastlines has resulted in extensive peneplanation, leaving scattered remnant exposures of Cretaceous strata on coastal plains. Kombolgie palaeohigh separates Carpentaria Basin from Money Shoal Basin and may or may not have been emergent. Arbitrary northwestern boundary of Carpentaria Basin and southern boundary of Money Shoal Basin correspond to lines enveloping Cretaceous outcrops, but it is likely that these depositional areas were connected at time of maximum flooding (Aptian–early or middle Albian).
Carpentaria Basin forms a widespread outcrop tract that covers an area of about 200,000 km² over the central northern part of the Northern Territory, extending from the Joseph Bonaparte Gulf towards the Queensland border (Figure 39.1). All of these strata are here included within the Western Gulf Sub-basin, because the relatively thin 'Dunmarra Basin' succession is interpreted to be merely a condensed version of the coastal succession with few significant lithological differences, there is no separate depocentre within the 'Dunmarra Basin', and the two depositional areas are interpreted to have been directly connected at the time of deposition. The 'Dunmarra Basin' is therefore considered to be a westward extension of the Carpentaria Basin across the Northern Territory at the time of maximum transgression of the Cretaceous sea. For descriptive purposes, this outcrop tract is here informally referred to as the 'Dunmarra region'.

Strata of the Dunmarra region have not been affected by tectonic activity and are near-horizontal, except for rare local faulting that has possibly resulted from the rejuvenation of earlier basement faults. Skwarko (1966) used the blanket term Mullaman Beds for all the onshore Cretaceous strata of the Northern Territory, but this name has since been abandoned (Hughes 1978, Krassay 1994b) and the succession has not otherwise been formally named. Skwarko divided the 'Mullaman Beds' of the 'Inland Belt' into three informal units (A–C), which can be distinguished across most of this region (Figure 39.4). Unit A is the lowermost of these and comprises plant fossil-bearing, massive, cross-bedded quartz sandstone and rare siltstone. The unit is of variable thickness, but is usually in the range 3–25 m. Browne and Randal (1969) reported a maximum thickness of about 37 m from a borehole in BEETALOO. The flora does not allow accurate dating, but is generally indicative of the late Mesozoic. Unit B conformably overlies unit A and comprises a lower layer of siltstone overlain by fine-grained sandstone. Both the siltstone and sandstone contain some plant fossils, which as for unit A, do not provide a basis for accurate dating. Skwarko (1966) reported a thickness of up to 5 m for each of the two intervals, but the extent of variation in both thickness and

![Figure 39.3](A09-013.ai)

**Figure 39.3.** Age and possible correlation of onshore stratigraphic units in Northern Territory portion of Carpentaria Basin, with reference to generalised succession in main offshore depocentres of the basin. Note that Rolling Downs Group is defined in Eromanga Basin.
composition within the unit across the region has not been documented. Unit C comprises claystone and silty claystone with small lenses of sand and, in places, small gypsic concretions (Figures 39.5, 39.6). It contains marine fossils and disconformably overlies the older non-marine units A and B. Unit C is usually greater than 20 m in thickness and in many areas, is much thicker; Brown (1969) reported a thickness of 60 m in DALY WATERS and combined thicknesses for units B and C of greater than 60 m have been reported from a number of areas, e.g., WALLHALLOW (Plumb and Rhodes 1964), BEETALOO (Brown and Randal 1969), TANUMBIRINI (Paine 1963) and elsewhere. Several arenaceous foraminifera fossil species have been recorded from unit C, but they have only a limited value in establishing a precise date.

The age of units within the onshore Western Gulf Sub-basin has been broadly established from biostratigraphic age determinations and correlations. Krassay (1994a, b) reported an age of late Aptian to early Cenomanian for the Walker River Formation, but indicated that the base may be as old as early Aptian. The Yirrkala Formation is estimated from lithostratigraphic correlations to be in the age range Albian to Cenomanian. Lignitic coal partings from within the unit (Dodson 1967) have yielded a Late Albian microflora (Evans 1967). Strata from the Dunmarra region are regarded as being Aptian to early or possibly middle Albian age, based on a broad correlation with the Walker River Formation and on the reported Aptian to early Albian age of the maximum marine incursion across the Northern Territory (Frakes et al. 1987). Hughes (1978) correlated units A–C in the northwestern part of the Dunmarra region with plant fossil-bearing arenaceous sediments of the ‘Petrel Formation’ (now ?Plover Formation equivalent; see Money Shoal Basin) and the overlying shallow-marine mudstone-dominated Darwin Formation of the Money Shoal Basin. The correlative Darwin Formation is regionally extensive and is also recognised in the Petrel Sub-basin of the Bonaparte Basin in the Joseph Bonaparte Gulf. The onshore succession in the Dunmarra region also possibly correlates with the terrestrial Unit I of the ‘Coastal Belt’ succession of Skwarko (1966) and at least part of the overlying marine Walker River Formation. However, note that lithologically similar rocks at apparently similar stratigraphic positions, but from widely separated localities, may be diachronous in a transgressive–regressive setting. Thus, the basal terrestrial rocks of the Dunmarra region are likely to be age-equivalents of marine strata in deeper areas of the basin to the east.

In general, the onshore Western Gulf Sub-basin succession records a large-scale marine transgression—

![Figure 39.4](https://example.com/figure4.png) **Figure 39.4.** Simplified stratigraphic column showing Units A–C of ‘Inland Belt’ of Skwarko (1966). Not to scale.

![Figure 39.5](https://example.com/figure5.png) **Figure 39.5.** Thinly to medium bedded, planar bedded, medium-grained, marine sandstone probably of Unit C. Cap on prominent Hill in Daly Basin area (0774116mE 8406136mN).

![Figure 39.6](https://example.com/figure6.png) **Figure 39.6.** Trails or burrows on bedding plane from same locality as Figure 39.5.)
Carpentaria Basin

Regression that resulted in the inundation of much of the northern part of the Northern Territory. Basal terrestrial strata can probably be referred to a variety of fluvial and possibly lacustrine settings (Krassay 1994b), including high-energy channel deposits and valley fills, deposited on a basement topography of low to moderate relief. Krassay indicated that palaeocurrent directions in fluvial rocks at the base of the Walker River Formation are to the east-southeast and southeast, consistent with a westerly provenance at this time. Marine transgression resulted in the drowning of these areas and the development of estuarine facies, represented by mixed coarser and finer units, followed by predominantly shallow-marine conditions, represented by the Walker River Formation and equivalents. Finer-grained marine sediments are widespread across the Dunmarra region indicating that relatively deep shallow-marine conditions prevailed across much of this region at the time of maximum flooding during the Aptian to early Albian (Frakes et al 1987). The onshore marine succession along the western edge of the Gulf of Carpentaria has been interpreted as representing an oblique transect across an exhumed, broad, low-gradient, epeiric Cretaceous shelf system (Rawlings et al 1997), from proximal, coastal plain to inner shelf environments in the north to progressively more distal marine environments in the south. Krassay (1994b) interpreted this shelf to have been wide and gently sloping, with a low sediment supply and low rates of subsidence. Following the withdrawal of the sea in late Aptian–early Albian times, exposed Cretaceous rocks of the Dunmarra region were eroded and subjected to lateritisation in many areas. The Yirrkala Formation represents a return to terrestrial conditions in the east, as relative sea level continued to drop in the late Albian.

MINERAL RESOURCES

The Carpentaria Basin hosts occurrences of a number of mineral commodities including bauxite, manganese, oil shale, heavy minerals, limestone, salt and coal (Smart et al 1980). In the Northern Territory, bauxite and manganese are the only commodities found in commercial quantities within the succession and these are currently being mined by open cut operations at Groote Eylandt and Gove, respectively. The location of some important occurrences is shown in Figure 39.7.

Bauxite

The Carpentaria Basin hosts a number of major bauxite deposits. The main resources are on the west coast of Cape York Peninsula in northern Queensland (Weipa deposit) and the Gove Peninsula in the Northern Territory. Ferenczi (2001) has reviewed the Northern Territory occurrences and the following description is largely based on this publication. For discussions on the bauxite occurrences in

Figure 39.7. Main mineral occurrences of Carpentaria Basin, Northern Territory, on simplified geological regions map slightly modified from NTGS 1:2.5M geological regions GIS dataset. Note that all occurrences are within Mesozoic strata, small outliers of which are omitted. Box shows location of Figure 39.8.
Cape York Peninsula, reference could be made to Smart et al (1980), McConachie et al (1990) and Eggleton and Taylor (2008). Total resources in the Weipa region are of the order of 1212 Mt at 45–50% Al₂O₃ (Taylor et al 2008). In the Gove region, total existing reserves are 226 Mt at 49.4% Al₂O₃ at the main Gove deposits (Rio Tinto 2010).

**Main Gove Plateau**

The Gove Plateau bauxite deposit was discovered when the Northern Territory Coastal Patrol Service collected a specimen of pisolitic bauxite from near Gove airstrip that assayed 52.6% Al₂O₃. This led to a more detailed reconnaissance and assessment of the Gove deposit by a Bureau of Mineral Resources (BMR) geologist, HB Owen, in August 1952. Extensive exploration followed and in 1965, Nabalco Ltd was given an opportunity to explore and develop the deposits. In 1968, Nabalco proposed a $1.5B bauxite-alumina project that was subsequently approved by the Federal Government. The project involved the establishment of a 6Mt/yr open cut mine, an 18.7 km ore conveyor system, an alumina refinery, a modern town (Nhulunbuy) and a port. Mining commenced in 1971 and the alumina plant was commissioned in 1972. About 221 Mt of bauxite averaging 50.5% Al₂O₃ has been produced to July 2012.

The main plateau hosting the Gove deposit is gently undulating and is typically 30–60 m ASL. The deposit developed over the Yirrkala Formation and is divided into three separate orebodies (Figure 39.8); these are referred to as the Main Gove Plateau (mainly in SML 1), Rocky Bay (SML 4) and Eldo Road (SML 2 and 3) deposits.

The thickness of the bauxite sheet in the Main Gove Plateau deposit averages about 3.7 m, and ranges from absent at plateau edges and on hill crests to 10 m in

![Figure 39.8. Simplified geology of Gove bauxite deposits after Ferenczi (2001). Location shown in Figure 39.7.](image-url)
topographic swales (Figure 39.9). Up to eight layers are recognised in the normal or complete laterite profile (Figure 39.10), these are from top to bottom: topsoil; loose pisolitic bauxite; cemented pisolitic bauxite; tubular bauxite; lower nodular bauxite; nodular ironstone; mottled zone; and saprolite (Figure 39.11). Details of these layers are provided in Ferenczi (2001).

The bauxite is mainly composed of gibbsite and minor boehmite, particularly in the upper levels of the profile. Haematite and goethite are the iron oxide constituents of ore-grade material. Silica is present as quartz (average 0.8%) and in kaolinite (average 3.3%). Titanium oxides average about 3.2% and are present in the form of anatase, although there are also trace amounts of zircon and ilmenite.

**Rocky Bay**

The Rocky Bay deposit covers an area of 9 km² and, after a 1966 drilling program on a 200 m square grid, was estimated to contain about 18.7 Mt of bauxite averaging 50.5% Al₂O₃ and 5.1% SiO₂, at an average thickness of 2.61 m (Nabalco 1968 as quoted in Ferenczi 2001). The average free silica content of the ore is about 2.5%. This reserve estimate included a resource with a lower silica content of 10 Mt at 51.7% Al₂O₃ and 3.8% SiO₂. Mining of the deposit commenced in January 1996 and a 20 year mine life has been estimated. Ore is hauled to a stockpile, which is located 10 km to the west of the deposit, from where it is transported by conveyor to the Gove refinery.

![Figure 39.9. Schematic cross-section of bauxite deposits on Main Gove Plateau after Ferenczi (2001).](A07-240.ai)

![Figure 39.10. Generalised bauxite profile at Gove after Ferenczi (2001). Relative proportions of minerals with respect to depth on right.](A07-241.ai)
Eldo Road

Eldo Road is divided into northern and southern orebodies. After a 1966 drilling program on a 200 m square grid, Eldo Road North was estimated to contain up to 6.2 Mt at 50.4% Al₂O₃ and 7.0% SiO₂. The deposit has an average thickness of 2.77 m and includes a low silica resource of 0.75 Mt at 52.2% Al₂O₃ and 4.2% SiO₂. Eldo Road South contains 20.4 Mt at 50.9% Al₂O₃ and 6.4% SiO₂ and has an average ore thickness of 4.42 m. It includes a low silica resource of 7.9 Mt at 51.9% Al₂O₃ and 4.1% SiO₂ (Nabalco 1968).

Dhupuma

Grubb (1970) outlined a bauxite deposit on the Dhupuma Plateau that covers an area of 11 km² but geological mapping by NTGS (Rawlings et al 1997) indicated that about 5 km² of bauxite material is present. The bauxite layer ranges between 3.5 and 11 m in thickness and is developed over a sandstone and claystone succession (Yirrkala Formation overlying granite basement of the Bradshaw Complex) at 97 m depth. Ferenczi (2001) estimated that 35–70 Mt of bauxite-bearing material exists at Dhupuma.

Other bauxite occurrences

Bauxite profiles have developed at several other places, but investigations so far have indicated that they are uneconomic. At the Cato Plateau, located 32 km to the southwest of Nhulunbuy, bauxitic laterite overlies friable sandstone and shale of the Yirrkala Formation. The coarse pisolitic and tubular bauxitic laterite averages 3 m in thickness. Best sample (0–1.8 m on the cliff section) returned 32.0% Av.Al₂O₃ (available alumina) and 12.3% Re.SiO₂ (reactive silica). Similar results were reported by Gardner (1957) and Chesnut et al (1966). At Umbakumba some low-grade, sandy pisolitic and tubular bauxite is partly exposed along cliff sections and in a creek between Umbakumba and Thompsons Bay on Groote Eylandt. This occurrence was briefly investigated by government geologists (Shields 1968, Dodson 1969, Watts 1970). The thickness of the bauxite interval varies from 1–6 m and averages 2–3 m. Grab samples averaged 35.0% Al₂O₃, 30.1% SiO₂ and 26.0% Fe₂O₃. Loose sand was present in some of the assayed samples. The highest assay obtained was 41.4% Al₂O₃, 21.6% SiO₂ and 16.0% Fe₂O₃. Watts (1970) sampled five shallow exploratory pits in order to determine the quality of subsurface material. The highest assay from 0.65 m depth in pit 2 returned 41.6% Al₂O₃, 13.9% SiO₂, and 19.4% Fe₂O₃ over 1.2 m.

Manganese

A number of manganese occurrences are known from the Carpentaria Basin succession. The world-class deposit at Groote Eylandt (Figure 39.12) is the largest of these and is currently being mined. Ferenczi (2001) has reviewed these occurrences and the following description is largely based on this publication.

Figure 39.11. Bauxite ore from Main Gove Plateau laterite profile. (a) Loose pisolitic bauxite (NTGS collection). (b) Cemented pisolitic bauxite (J Dunster collection). (c) Tubular bauxite (NTGS collection).
Figure 39.12. Simplified geology of Groote Eylandt after Ferenczi (2001).
Manganese was discovered at Groote Eylandt in 1960, when PR Dunn assayed four samples from a site near the Groote Eylandt airstrip that yielded >50% Mn. Follow up mapping and test pit work by BMR identified significant deposits of high-grade manganese between the Angurugu and Emerald rivers (Crohn 1962). Between 1963 and 1967, BHP Ltd carried out extensive exploration drilling and test pitting which outlined a reserve of 64 Mt averaging 30–50% Mn (GEMCO 1967). Mining of the deposits commenced in 1965. The current resource estimate is 116 Mt at 46.2% Mn (measured, indicated) and 39 Mt at 43.3% Mn (inferred), for a total of 161 Mt at 45.9% Mn (BHP-Billiton 2012). The Groote Eylandt Mining Company Ltd (GEMCO) is a wholly owned subsidiary of Samancor Ltd (60% BHP-Billiton, 40% Anglo American Corp).

The manganese deposits are hosted within the Walker River Formation. The mineralization is in a stratiform, massive to disseminated sheet-like body averaging 3 m in thickness, which thins and dips gently (<5°) to the west (Figure 39.12). Four separate deposits (Deposits F, A, D and J) are outlined (Figure 39.13). These deposits occupy a series of west-northwest-trending depressions between elongate ridges of the Palaeoproterozoic Dalumbu Sandstone (Figure 39.14) and together form an ore zone 22 km long and up to 6 km wide. This orebody varies in thickness from 0.1–11.5 m and the thickest portions of the ore interval (>6 m) are confined to discrete pods along the eastern basement terraces. Thinner parts occur over west-northwest-trending basement ridges.

The main manganese minerals are pyrolusite and cryptomelane with minor amounts of romanechite, todorokite, verandite, braunite, liithiophorite, birnessits and chalcopyhanite (Ostwald 1988). Gangue minerals include kaolinite, detrital quartz and iron oxides. The ore minerals are present in a variety of textural types but oolitic/pisolitic textures are predominant with local concretionary textures (Figure 39.15). The ooliths and pisoliths are variably cemented. Most pisoliths and ooliths do not contain distinct nuclei. When present, nuclei may include silt- to fine sand-sized quartz grains, abraded pisolith or oolith fragments, or aggregates of detrital quartz and clay material. The cortex is accretionary in nature and consists of alternating laminae of romanechite (often altered to cryptomelane) and pyrolusite. Ostwald (1990) identified filamentous and cocoid bodies, wavy and wrinkled lamination (oncolite microstructures), and columnar structures (stromatolites), all of which suggest a biogenic origin for the pisoliths and ooliths. Physical reworking is indicated by the presence of flattened or irregularly shaped grains, and by fractured pisolith and oolith fragments. Pisolitic facies ore is generally best developed on palaeo-seafloor terraces adjacent to palaeo-highs. A number of manganese ore types are recognised, based on texture, ore/gangue ratio, grade attributes, mineralogy, degree of cementation and laterisation (Pracejus et al 1988). Post-depositional diagenetic supergene and pedogenic processes have produced a complex vertical and lateral distribution of Mn ore units or facies (Pracejus et al 1988) and include massive textureless ores, leached ores, siliceous ores, Mn-concretions, Mn-spherulites, Mn-impregnations/cements, replaced ooliths and pisoliths (eg ferruginised), mangcrete and clay pipe structures.

Manganese oxides were originally precipitated as pisoliths and ooliths in a shallow-marine nearshore environment. This interpretation is supported by the occurrences of well documented sedimentary structures, accretionary pisoliths/ooliths and foraminifera at levels below, above and in the ore interval (Pracejus et al 1988, Dammer et al 1996). Varentsov (1982) suggested that “primary pisolithic ores” resulted from reworking of a pre-existing weathered crust that developed on the underlying manganiferous marl unit. However, this model would infer that the pisoliths were concretionary in origin, and this is inconsistent with interpretations from pisolith studies (Ostwald 1988, 1990, Bolton et al 1988). Bolton et al proposed an inorganic catalytic oxidation process for Mn oxide pisolith formation in an oxidised, agitated, shoaling nearshore marine environment. Ostwald (1990) proposed a biogenic origin for the pisoliths, based on the identification of microscopic algal structures and suggested that pyrolusite, which forms the ‘primary pisoliths’, may not represent the original mineralogy. Dammer et al (1996) carried out K-Ar dating of romanechite (43.7 ± 1.2 Ma), and cryptomelane and Ba todorokite (6 Ma and 18 Ma); these dates are much younger than the host sequence and it has been proposed that the present mineralogy of the Groote Eylandt ore is entirely the product of intense chemical weathering cycles from the Early Cenozoic to the present.

The ultimate source of manganese is considered to be the subaerial weathering and erosion of the underlying marl unit (Slee 1980). Manganese carbonate in the marl was leached and the Mn transported as a bicarbonate complex in west-flowing streams into oxidising, nearshore marine environments where it precipitated to form Mn oxide pisoliths. However, Frakes and Bolton (1984) suggested that manganese concentration occurred during an Albian marine transgression in anoxic, organic-rich basin waters. They suggested that manganese oxides were later precipitated during an early Cenomanian marine regression on coastal terraces. Precipitation of Mn oxide is thought to occur, initially, via catalytic oxidation onto mainly organic particles and membranes, and then via autocatalytic processes (Bolton et al 1988).

Other occurrences

Shallow offshore areas adjacent to Groote Eylandt may contain down-dip extensions of onshore manganese deposits currently being mined by GEMCO. A number of sea-based exploration titles covering these prospective areas were applied for in 2009. However, in 2012, the Northern Territory Government placed a three-year moratorium on seabed exploration and mining in this region.

The Rosie Creek South prospect is located about 75 km to the northwest of Borroloola and was discovered by BHP Ltd (Berents 1994). Manganese mineralisation is within claystone and minor conglomerate at the base of the Cretaceous Walker River Formation, at the unconformity with the underlying Yiyintyi Sandstone. Berents (1994) suggested that the deposit may contain 4.5–5.5 Mt at 25% Mn. Details on the methodology for these estimates are unknown. Moderate to high levels of phosphorus (0.08–0.14%) and silica (14.0–31.4%) are present in intercepts containing >30% Mn.
Figure 39.13. Location of main manganese deposits at Groote Eylandt after Ferenczi (2001).
Regional exploration by BHP Ltd between 1964 and 1967 in the East Arnhem Land region led to the discovery of the Caledon 1 prospect, which is located in the Caledon Bay area, about 70 km to the southwest of Nhulunbuy. Four prospecting pits were sunk adjacent to a creek that contained exposures of Cretaceous manganiferous sandstone (BHP 1964a). These pits indicated the existence of at least two sandy Mn lenses within a 2 m-thick interval. At the Peter John prospect, which is located 31 km to the west-southwest of Nhulunbuy (BHP 1964a, b, Chesnut et al 1967), a sample from a 0.45 m-thick sandy Mn lens assayed 31.7% Mn, 21.4% SiO₂ and 10.3% Fe (BHP 1964a). Follow-up pit sinking and RC drilling indicated that the mineralisation was largely surficial. Two Mn lenses are located at the northern end of Probable Island (Probable Island prospect). A 30 m-thick interval of siltstone and sandstone (Walker River Formation?) separates the two lenses, which are 1.5 m and 2.1 m thick (BHP 1964a, b). A chip sample from the thinner lens assayed 41% Mn, 12.5% SiO₂ and 7.5% Fe.

Other significant discoveries in the Gulf region include Yiyintyi, Batten Creek and Caledon 2. At Yiyintyi, initial RC drilling by BHP Ltd intersected 2 m at 39.2% Mn and 9.2% Fe (Berents et al 1994). Follow-up drilling indicated that the mineralisation has limited lateral continuity (Rennison et al 1995). At Batten Creek, patchy Mn mineralisation was intersected in an RC drillhole (6 m at 15.1% Mn, unwashed) beneath a TEM anomaly (Paterson 1996). There is very little information on Caledon 2 other than a reference to outcropping pisolitic manganese material in excess of 2 m in thickness within Cretaceous sediments (Frakes 1990).

**Dunmarra region**

There are few known mineral occurrences in Cretaceous strata from the Dunmarra region. In the last two decades, extensive exploration for diamonds has been undertaken by various explorers, but although several microdiamonds have been recovered, no kimberlite pipes have been located. On the basis of correlations with the Walker River Formation, there is some chance of locating Groote Eylandt-type manganese occurrences. Manganese mineralisation is present in lithologies mapped as Cretaceous 10 km southwest of Renner.
Carpentaria Basin

Springs. The occurrence is termed Renner Spring No 5 and is characterised by manganese oxides partially replacing siltstone and chert. It essentially contains low-grade ore with less than 22% Mn and pockets of medium-grade ore containing 22–38% Mn (Hussey et al 2001).

Petroleum

In 1978, The Shell Company of Australia Ltd reviewed the hydrocarbon potential of the Carpentaria Basin and concluded that Proterozoic and/or Palaeozoic source rocks could charge overlying Mesozoic traps. They acquired offshore permits in the Gulf of Carpentaria in 1980 and a regional seismic survey program at relatively wide spacing (50 km) was shot in the early 1980s. In 1984, the dry well, Duyken-1 (Figure 39.16), was drilled and all exploration leases were subsequently relinquished. In the late 1980s, a Comalco Ltd / Bridge Oil Ltd JV collected over 3000 line km of multifold seismic data and drilled four petroleum wells (McConachie et al 1990), which failed to intersect substantial hydrocarbon accumulations. The Geological Survey of Queensland also drilled four cored stratigraphic wells in deeper parts of the basin. Since that time, there has been little petroleum exploration activity in the basin.

In the offshore Western Gulf Sub-basin, which constitutes all of the Northern Territory portion of the Carpentaria Basin, sandstones within the 50–150 m-thick Gilbert River Formation constitute good potential reservoirs. This formation is sealed by Wallumbilla Formation equivalent shale throughout much of the offshore basin (Burgess 1984). The effectiveness of this reservoir/seal pair has been demonstrated by oil shows in the south of the basin and good flows of water have been recorded in onshore drillholes from the sandstones (Thomas et al 1991), although no commercial hydrocarbons have yet been discovered.

Good potential source rocks occur in sedimentary successions underlying the Carpentaria Basin. These include Proterozoic organic-rich shale within the McArthur and Roper groups in the relatively unmetamorphosed McArthur Basin and possibly pre-Jurassic sedimentary rocks of the little-known Bamaga Basin, which is a small sag basin identified from seismic data in the offshore northeastern Gulf of Carpentaria, west of the northern tip of Cape York Peninsula (Passmore et al 1993). Under conditions of late migration or remigration, Carpentarian Basin reservoirs could have received a hydrocarbon charge from these source rocks. Possible source rocks from within the Carpentaria Basin succession include intervals within the Garraway

Figure 39.16. Structure contour map (two-way time) of base Mesozoic unconformity showing rugged, irregular topography in Western Gulf Sub-basin as opposed to more regular flatter topography in eastern and southern parts of basin. Petroleum wells also shown (after Thomas et al from early 1980s seismic data).
Sandstone and Gilbert River Formation, and organic-rich shale of the Wallumbilla Formation equivalent (Burgess 1984, McConachie et al. 1990, Thomas et al. 1991). Although the Mesozoic succession is thin onshore and, offshore, is less than 1800 m at its maximum depth, oil shows have been reported onshore wells, showing that hydrocarbon generation is occurring within the basin. The deeper offshore portion of the basin may be within the oil window (Burgess 1984) and there is potential for significant petroleum accumulations in the vicinity of the Weipa Sub-basin (McConachie et al. 1994).

In Northern Territory waters, any hydrocarbon accumulations are likely to be controlled by the nature of the underlying basement and by the distribution of potential fluvial sandstone reservoirs of the Gilbert River Formation. The base Mesozoic unconformity is rugged, and irregular in the offshore Western Gulf Sub-basin, but is smoother and flatter in the eastern and southern parts of the basin (Figure 39.16). The irregular unconformity surface in the west was interpreted as karstic topography or reefal buildups by Burgess (1984), who suggested that the offshore basement rocks were carbonates of Middle Proterozoic or Cambrian age. Alternatively, this basement might be an eroded terrane of well bedded sediments or metasediments of the Proterozoic McArthur Basin (Thomas et al. 1991), or possibly older rocks of the Arnhem Province, or possibly younger Neoproterozoic–early Palaeozoic equivalents of the Georgina/Arafura basins. The smoother topography in the east and south was interpreted by Thomas et al. (1991) as possibly representing a northerly extension of the Isa Superbasin.

Basal Carpentaria Basin sediments include quartzic sandstone of the aerially restricted Eulo Queen Group in the south of the basin, overlain by more widespread fluvial quartzic sandstones of the Gilbert River Formation. In the western part of the basin, these basal fluvial sediments were deposited in valleys and troughs between prominent basement highs (Thomas et al. 1991). This geometry would be compatible with possible stratigraphic traps in basal channel sandstones of the offshore Carpentaria Basin succession, top sealed by Wallumbilla Formation equivalent shale. Isolated distributary or tributary incisions could potentially create numerous hydrocarbon-filled pinch-out traps and compactional drape traps on palaeohighs are another possible play type (McConachie et al. 1990). However, rapid variations in palaeotopographic relief suggest that individual hydrocarbon accumulations would be small (Thomas et al. 1991). Seismic data indicate that the western Carpentaria Basin is relatively unstructured, so there appears to be limited potential for conventional structural traps. Fault traps juxtaposing Wallumbilla Formation equivalent top seal against pre-Mesozoic reservoir rocks are possible in the Western Gulf Sub-basin, but suitable fault systems are unlikely to be extensive and large hydrocarbon accumulations are therefore unlikely (Thomas et al. 1991). More closely spaced infill seismic data would be useful to better delineate targets in the western parts of the offshore basin.

REFERENCES


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