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Chapter 3

Land Resources

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Roper Bar Iron Ore Project



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3 Existing Environment – Land Resources

3.1 Introduction

This chapter describes the land resources of the Roper Bar Project Area (i.e. the MLA and immediate surrounds) and proposed Haul Road route. This includes the topography, geomorphology, land systems, regional and local geology, mineral resources and target ore body characteristics (including acid mine drainage potential), soils, land capability, land use, and also scenic and recreational values.

Land resources described for the Roper Bar Project Area encompass the MLA area totalling approximately 5000 ha. This includes the mining pits and associated support infrastructure (camp, airstrip, access roads, waste dumps, processing plant, etc). Land resources are also described for the proposed 165 km Haul Road route between the Project Area and the Port of Bing Bong. This includes at a broad scale, the coastal area at the proposed location of the Stockyard and Barge Loading Facility at the Port of Bing Bong. However, for more specific detail on this coastal area, please refer to Chapter 4 Terrestrial and Aquatic Biodiversity and Chapter 5 Marine Environment.

Vegetation types existing within the Project Area and along the Haul Road, although strongly influenced by land system types, are not described here. For results of detailed vegetation surveys conducted within the Project Area and along the Haul Road please refer to Chapter 4 Terrestrial and Aquatic Biodiversity. Also refer to Chapter 6 Surface and Ground Water for a detailed discussion on surface and groundwater resources.

3.2 Topography and Geomorphology

3.2.1 General Description

The Roper Bar Project Area and 165 km-long proposed Haul Road to the Port of Bing Bong are located within the broad-scale drainage system known as the “Gulf Fall” (Aldrick & Wilson 1992). All rivers and creeks within this system flow towards the Gulf of Carpentaria, with the Roper Bar Project Area located on the Towns River, approximately 46 km upstream of where it flows into the Gulf (Figure 3-1). The Towns River for most of its distance downstream of the Project Area, flows across a broad, flat, coastal floodplain, and there is very little rise in elevation between the Gulf coastline and the Project Area. The Project Area is only between 20 m and 60 m above sea level (see Figure 3-1 and 3-2).

At a broad scale, the Roper Bar Project Area and first two thirds of the Haul Road are located within undulating terrain comprising scattered low, steep hills on Proterozoic and Palaeozoic sedimentary rocks, in places overlain by lateritized Tertiary material (as defined for the “Gulf Falls and Uplands” bioregion by Woinarski 2001, and in the *Interim Biogeographic Regionalisation for Australia* or IBRA; see IBRA version 6.1, DSEWPAC 2011). Soils across the region are mostly skeletal or shallow sands.

The last third of the Haul Road to Bing Bong traverses across gently undulating to flat coastal plains, with scattered rugged areas of Proterozoic sandstones and Tertiary sediments (i.e. the IBRA “Gulf Coastal” bioregion). Soils are predominantly sandy red earths and shallow gravelly sands.

The Port of Bing Bong is located on the Gulf coast within an area of coastal sand dunes, sand sheets, and chenier plains adjacent to tidal mud flats, tidal creeks, and mangroves. See Chapter 4 Terrestrial and Aquatic Biodiversity and Chapter 5 Marine Environment for more detail on this area.

Present-day landform features of the Gulf Fall region predominantly result from differential weathering and erosion of the underlying rock strata, where resistant sandstones form narrow, linear ridges, and less resistant siltstones, mudstones, shales, and carbonates underlie broad valley floors. The drainage system is largely inherited from post-Mesozoic times (probably Miocene), when much of the region was

covered by a lateritised erosion surface (Paine 1963, Smith 1972). Subsequent down-warping to create the Gulf of Carpentaria (Christian *et al.* 1954) significantly increased rates of landscape erosion and resulted in the etching out of underlying Proterozoic rocks, which in turn imposed structural constraints on the drainage pattern of rivers and streams in the region (for example the upper Limmen Bight River; as detailed below).

A major sea-level rise in the Pleistocene completed flooding of the Gulf. This was followed by a more recent fall in sea level, which further modified drainage landform patterns, especially those close to the coast where extensive levees and alluvial plains now flank most major streams.

Lateritised surfaces are a prominent present-day feature throughout the Gulf region and have been important historically in development of the landscape. Isolated, laterite-capped, flat-topped hills occur at intervals across many parts of the area, and an extensive low level laterite sheet occurs along the coast and hinterland.

Based on the present-day rate and nature of geomorphological processes acting across the landscape, Aldrick and Wilson (1990, 1992) divided the Gulf Fall region into six geomorphic provinces; where a geomorphic province is defined as “an area of land having attributes of landform and/or soil and/or vegetation that differ consistently from those of other terrain, because of the direct influence of geomorphological landscape forming processes operating there but not operating elsewhere at the same rate”. Dividing the landscape up in this way provides a basis for predicting the susceptibility of land to degradation. Table 3-1 below outlines the attributes of the geomorphic provinces encompassing the Project Area and the Haul Road route.

The topography and geomorphology of the Roper Bar Project Area and Haul Road are described separately in further detail below.

3.2.2 Roper Bar Project Area

The main topographic features within the Roper Bar Project Area are narrow, linear, rocky, quartz sandstone ridges that are relatively low, only rising up to 30 m above the surrounding alluvial plains (Figure 3-2). These ridges are made up of relatively resistant Proterozoic sandstones (belonging to the Roper Group) and are steep sided in places, occasionally forming small precipices. These ridges mainly run east-west across the Project Area (predominantly in the vicinity of Area F and also in the south-eastern corner of the MLA), with the exception of the far eastern portion (Area E East, Pit 1), where the main sandstone ridge turns sharply and has a north-south orientation.

The highest elevation within the Project Area is around 55 m AHD, which occurs on top of the large east-west trending ridge in the south-eastern corner of the MLA, as well as on top of the smaller linear ridge on the far western boundary of the Project Area (see Figure 3-2). The steepest slopes within the Project Area also occur near these locations (i.e. on the eastern and southern sides of the large ridgeline in the south-eastern corner of the MLA) and the southern side of the east-west trending ridgeline in the western portion of the Project Area. All areas away from ridgelines are predominantly broad, flat, alluvial plains (slopes <1%; see Figure 3-2).

The Towns River flows in a north-easterly direction across the Project Area, and crosses through a gap in the east-west trending ridgeline near Area F (Figure 3-2). A small tributary located south of the Towns River also flows in a north-easterly direction across the Project Area and joins the Towns River downstream of the MLA boundary. The majority of surface water runoff across the Project Area flows into either the Towns River or its smaller tributary, except for the far south-eastern portion of the MLA, where several small drainage lines flow into the Magaranyi River (Figure 3-2), which is a major tributary of the Towns River (green catchment in Figure 3-1). The Little Towns River (orange catchment in Figure 3-1) flows north of the Project Area, however, no mining or infrastructure will be developed in this catchment.

The Project Area is located within the “G4” geomorphic province, where drainage is strongly controlled by the underlying geology, expressed as linear, mainly sandstone ridges that are resistant to erosion, inhibit the normal down-cutting of streams, and often lie across the direction of drainage. Erosion rates are slow to moderate and sediment accumulation has led to broad, shallow valleys, with only the upper parts of relief being subject to strong erosive force. However, these higher areas mostly comprise erosion-resistant rocks, with little sediment left to erode. Erosion-susceptibility of individual land systems within the Project Area are discussed in more detail in the sections below.

In regards to the location of proposed mining pits and associated infrastructure, the four Area F pits are located along a low, linear, east-west trending ridgeline across the northern portion of the Project Area (see Figure 3-2) with the Towns River running parallel along this ridgeline and then cutting through it between Area F Pit 3 and Pit 2. The Area E Pit is located on the north-south trending ridgeline in the eastern portion of the Project Area. The processing plant, waste dumps, and low grade stockpile, as well as all access roads linking this infrastructure to the mining pits and Camp, are located on the broad, flat alluvial plains between the higher ridgelines.

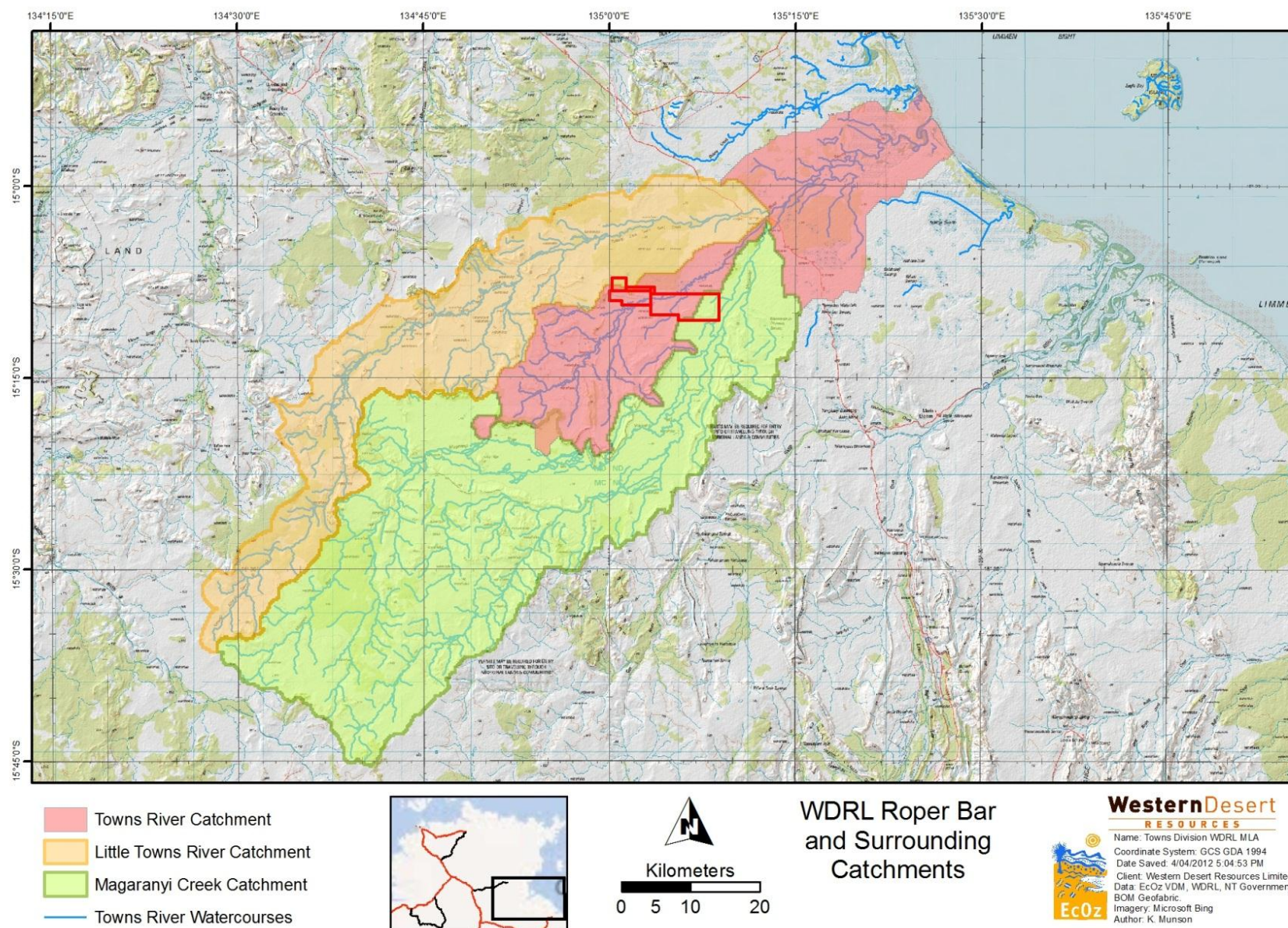
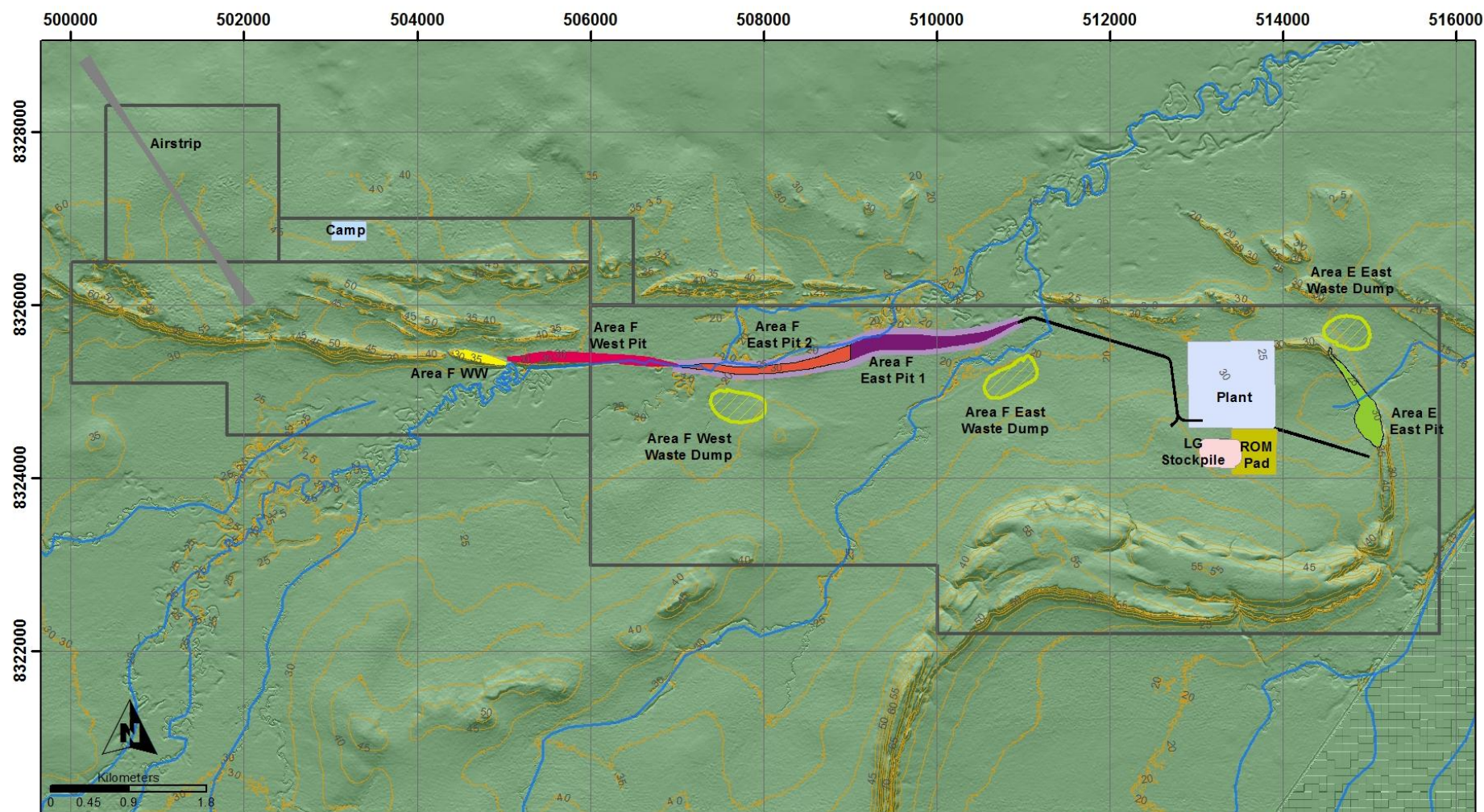


Figure 3-1 Location of Roper Bar Project Area within Towns River catchment.



- | | | | |
|-----------------------|-------------------|--------------|----------------------------|
| Infrastructure | Area F East Pit 1 | Camp | ROM Pad |
| Airstrip | Area F East Pit 2 | LG Stockpile | Airstrip |
| Area E East Pit | Area F WW Pit | Levee Bank | Watercourses |
| Waste Dumps | Area F West Pit | Plant | WDRL Proposed Mining Lease |
| | | | 5m Contours |

Roper Bar Topography

WesternDesert RESOURCES



Name: Roper Bar DEM
Coordinate System: GEOCENTRIC DATUM of AUSTRALIA UTM Zone 53S
Date Saved: 13/06/2012 11:08:48 AM
Client: Western Desert Resources Limited
Data: EcOz, WDRL
Imagery: National Geographic, ESRI
Author: K. Munson

Figure 3-2 Topography of the Roper Bar Project Area

3.2.3 Haul Road Route

The proposed Haul Road, linking the Project Area to the Port of Bing Bong, is approximately 165 km long. It traverses across low, gently undulating country for the first two thirds, and for the last third, across a relatively flat coastal plain as it approaches Bing Bong and the Gulf coast (Figure 3-3). Elevation along the road is very low and varies little, typically remaining between 10 m and 50 m AHD for most of its length; rising to between 50 m and 100 m for a small section when passing through the foothills of the Yiyintyi Range. The route crosses seven major water courses and approximate chainages of these features along the route (starting from mine site) are as follows:

- Magaranyi River (5 km);
- Cox River (25 km);
- Limmen Bight River (50 km);
- Nathan River (68 km);
- Yiyintyi Range (98 km);
- Rosie Creek (120 km);
- Pine Creek (138 km); and
- Bing Bong Creek (150 km).

Slopes are very gentle or flat (< 3%) along most of the Haul Road route (see Figure 3-3), except for a few isolated areas of greater relief located at approximate chainages 17km (between Magaranyi and Cox Rivers), 50 km (on either side of the Limmen Bight River, especially the eastern side), and chainage 80 – 105 km (foothills of Yiyintyi Range). Slopes on either side of most river and creek crossings are also steep in places. See Chapter 6 Surface and Ground Water for further details regarding the features of each river crossing and the design of bridges and causeways at these locations. Chapter 6 also contains further detail on catchment sizes and river flows relevant to the design of these crossings.

Rivers and streams in the region are generally controlled by the underlying geology in their upper reaches. However, once these systems reach the flat coastal floodplain they invariably flow in a north-easterly direction towards the Gulf of Carpentaria coastline (Figure 3-3). The Limmen Bight River is a good example, where upstream of the Cox River confluence, the river channel is confined within the variously resistant north-south trending Proterozoic rock strata (see geology map in Figure 3-7); whereas downstream, the river flows north-east across the flat, coastal floodplain (Figure 3-3).

The broad-scale geomorphology of the region traversed by the Haul Road can be characterised using the geomorphologic provinces defined by Aldrick and Wilson (1990, 1992). The Haul Road begins in the “G4” geomorphic province (as described in above section) and then moves into the “G5” geomorphic province after crossing the Cox River. The G5 province occurs on the coastward side of the prominent ridgelines of G4 province. Here, there is no restriction to coastward sediment transport, and low relief, gentle erosional slopes, and competent, low gradient streams are characteristic. The Haul Road remains within this G5 province until the Yiyintyi Range, after which it crosses into the “G6” geomorphic province. The G6 province occurs adjacent to the coast and is predominantly influenced by coastal-related depositional and erosional processes. The coastal strip comprises beaches, berms, chenier plains, and dunes, and inland exist almost flat coastal terraces (old sea floor materials). Rates of landscape denudation are slow due to the low relief, high soil permeability, and juvenile disintegrated drainage patterns. Further details of these geomorphic provinces are provided in Table 3-1 below.

Rates of natural erosion are slow to moderate in all geomorphic provinces crossed by the Haul Road route (Table 3-1). This is because of the low relief and permeable soils across much of the region and where relief is greater, the substrate comprises mainly erosion-resistant sandstone with little sediment cover available to be eroded. The susceptibility of individual land systems within these geomorphic provinces along the Haul Road route are discussed in more detail below.

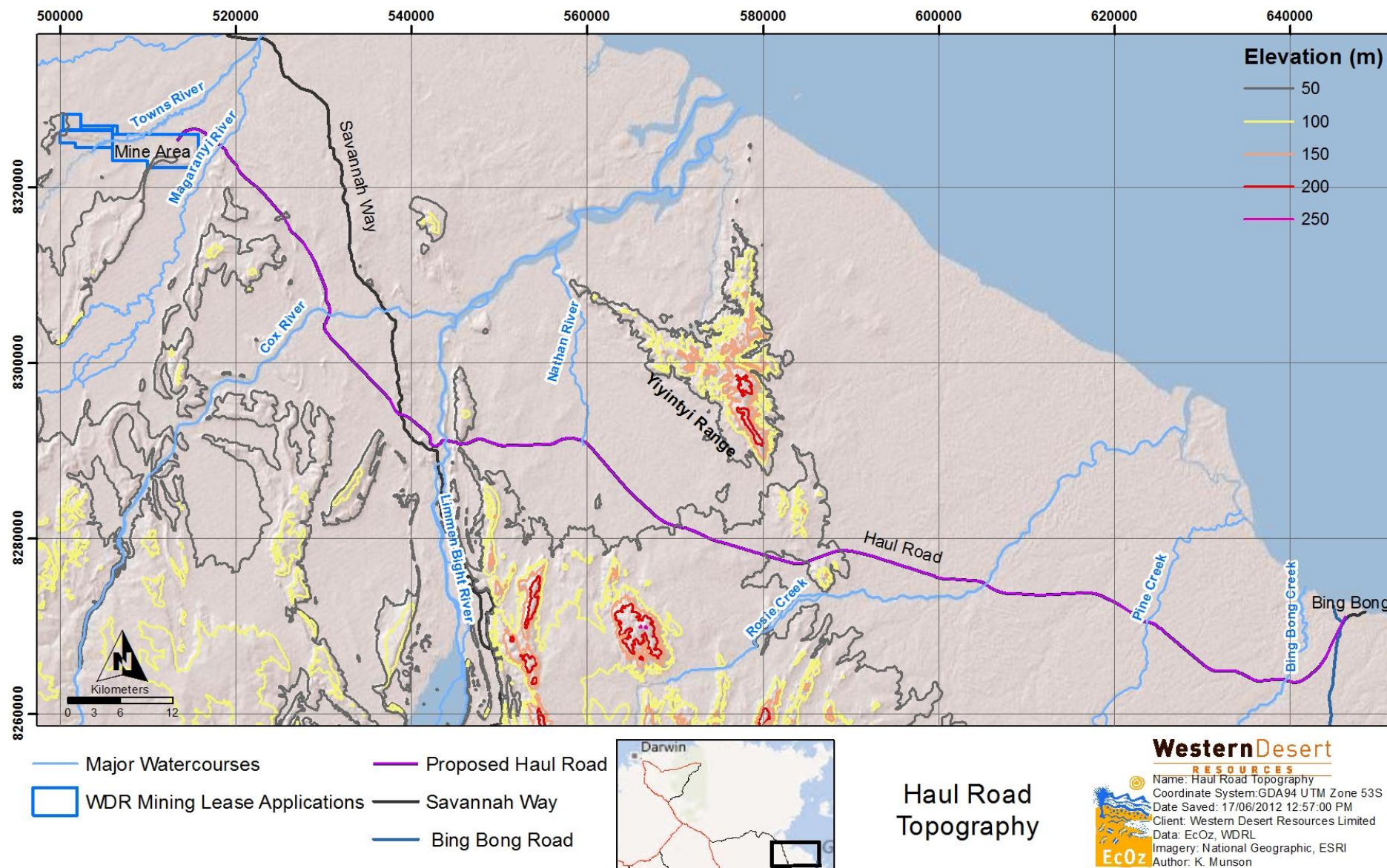


Figure 3-3 Topography along the Haul Road route.

Table 3-1 Geomorphic Provinces along the Haul Road route.

Province characteristics taken from Aldrick and Wilson (1990, 1992).

Haul Road Section & Geomorphic Province	Characteristics of the Geomorphic Province	Rate of Natural Erosion
Project Area – Cox River “G4” Geomorphic Province	Flat to gently undulating plains, rises, and hills; linear rocky ridges, broad and narrow fluvial corridors, channels, levees, floodplains, back-plains and associated swamps, billabongs, and springs.	Slow to moderate. Local base levels and sediment accumulation lead to broad, shallow valleys. Only upper parts of relief are subject to strong erosion, but these are mostly erosion-resistant rocks. Drainage is strongly controlled by underlying geological structure. A series of linear, mainly sandstone ridges lie across the direction of drainage, and have inhibited the normal down-cutting of streams.
Cox River – Yiyintyi Range “G5” Geomorphic Province	Low relief. Level to gently undulating plains; broad and narrow fluvial corridors; swamps and low-lying areas; and undulating rises and low hills.	Slow to moderate due to low relief. Gentle erosional slopes on the coastward side of the sandstone ridges that characterise G4.
Yiyintyi Range “G3” Geomorphic Province	High relief. High rocky sandstone plateaux and ridges.	Slow due to erosion resistant sandstone. Rate of sediment removal is rapid due to high relief and stream competence, however little sediment available for transport.
Yiyintyi Range – Bing Bong “G6” Geomorphic Province	Very low relief. Almost flat coastal terraces. Level to very gently undulating plains; broad or narrow fluvial corridors, swamps and low-lying areas; broad depositional floodplains; tidal mud flats with channels and estuaries; coastal sand sheets, dunes and cheniers. Some undulating rises to low hills.	Very slow due to the very low relief and a very young, immature, weakly developed drainage pattern, and permeable soils. This geomorphic province occurs near the coast and coastal erosional influences are prominent.

3.3 Land Systems

A “land system” is an area, or group of areas, throughout which there is a recurring pattern of topography, vegetation, and soils (Christian & Stewart 1953). Land systems mapping for the Roper River and Southern Gulf regions is provided by Aldrick and Wilson (1990, 1992). The land systems occurring within the Roper Bar Project Area and along the Haul Road route are each described in detail below.

3.3.1 Roper Bar Project Area

A total of 7 different land systems occur within the MLA boundary of the Roper Bar Project Area. These are shown in Figure 3-4 and described in Table 3-2. Two land systems dominate the Project Area; Frog (Taf), which covers 1866 ha or 37% of the Project Area (i.e the area within the MLA boundary shown in Figure 3-4), and Bukalara (Asb), covering 1634 ha or 32 % of the Project MLA Area.

The Frog (Taf) land system describes most of the low-lying areas within the Project Area, comprising broad sandy floodplains, terraces, swamps, drainage depressions (seasonally inundated) and colluvial slopes. Soils are deep siliceous, earthy sands and solodic soils. This land system has moderate flooding and soil drainage risk and moderate erosion risk. A large proportion of the Area F mining pits (Pits 1, 2, and 3) are within this land system; with the remainder of Area F Pit 3 and Pit 4 within the Bukalara (Asb) land system, and a proportion of Pits 2 and 1 within the McArthur (Tam) land system (see

below). Mining infrastructure planned for areas within the Frog (Taf) land system include the processing plant, waste dumps, and the low grade stockpile. Most roads accessing these facilities from the Camp and mining pits are also within this land system.

The Bukalara (Asb) land system describes the sandstone ridges that run predominantly east-west across the Project Area (i.e. those running parallel to Area F and also the large ridge in the south-east corner of the MLA), as well as the eastern-most ridge (Area E East), which runs north-south. This land system comprises rugged rocky plateau and steep linear ridges on massive sandstones with lithosols and shallow siliceous soils. However, it should be noted that this description suggests far more topographic relief than actually exists on site (maximum relief around 35 m). The Bukalara (Asb) land system has high erosion hazard but low soil drainage and flood risk. All proposed mining in Area E is within this land system as well a small proportion of Area F (Pit 3 and Pit 4). Most of the Area E waste dump is within this land system and road access between the mining areas and the Camp also passes through this land system.

The McArthur (Tam) land system comprises about 275 ha or 5.4 % of the Project Area. This land system includes the Towns River channel and immediate surrounds, and is described as broad or narrow fluvial corridors that conduct regional drainage towards the coast, on grey and brown clays, red and yellow earths, and siliceous sands. It has a high flooding risk and moderate soil drainage and erosion risk. Much of the proposed mining in Area F (Pits 2 and 1) is within this land system.

A further four land systems occur within the Project Area, although these only cover a small proportion of the area. The Horse Creek (Alh) land system comprising gently undulating plains on sandstone, occurs in the north-western portion of the Project Area where the proposed mining camp and road to the airstrip are located. This land system has high erosion risk but low soil drainage and flooding risk. The airstrip itself is located in the north-western portion of the Project Area mainly within the Lansen (All) land system comprising long, low, often terraced rises with linear outcrop on prominently bedded sandstones. This land system has moderate soil erosion risk and low soil drainage and flood risk. A small area of Munyi (Asm) land system comprising steep to gentle slopes on the Sherwin Ironstone occurs in the western portion of the Project Area (Area F West), although no immediate mining or infrastructure is proposed for this area. This land system has a high soil erosion risk and low drainage and flood risk. The Patterson (Alp) land system occurs in the central southern part of the Project Area; but no mining or infrastructure is proposed for this area.

In summary, a large proportion of the Project Area is subject to either high erosion risk (i.e. Bukalara (Asb), Horse Creek (Alh), and Munyi (Asm) land systems) or high flooding and soil drainage risk (i.e. McArthur (Tam) and to a lesser extent Frog (Taf) land systems). Areas planned for mining are predominantly located within the Frog (Taf), Bukalara (Asb), and McArthur (Tam) land systems, therefore development of the mining pits will incorporate measures for minimising the respective erosion and flooding risks associated with these land systems. The mining camp and associated access roads are located on the Horse Creek (Alh) land system, with high erosion risk but low soil drainage and flooding risk, whereas the airstrip is very well located on the Lansen (All) land system that has only a moderate erosion risk and low soil drainage and flooding risk. Similarly, the processing plant, waste dumps, and stockpile areas are predominantly located in the moderate erosion and flood risk Frog (Taf) land system. Roads to and from the camp to the mining pits and processing plant areas are also mainly located within the Frog (Taf) land system.

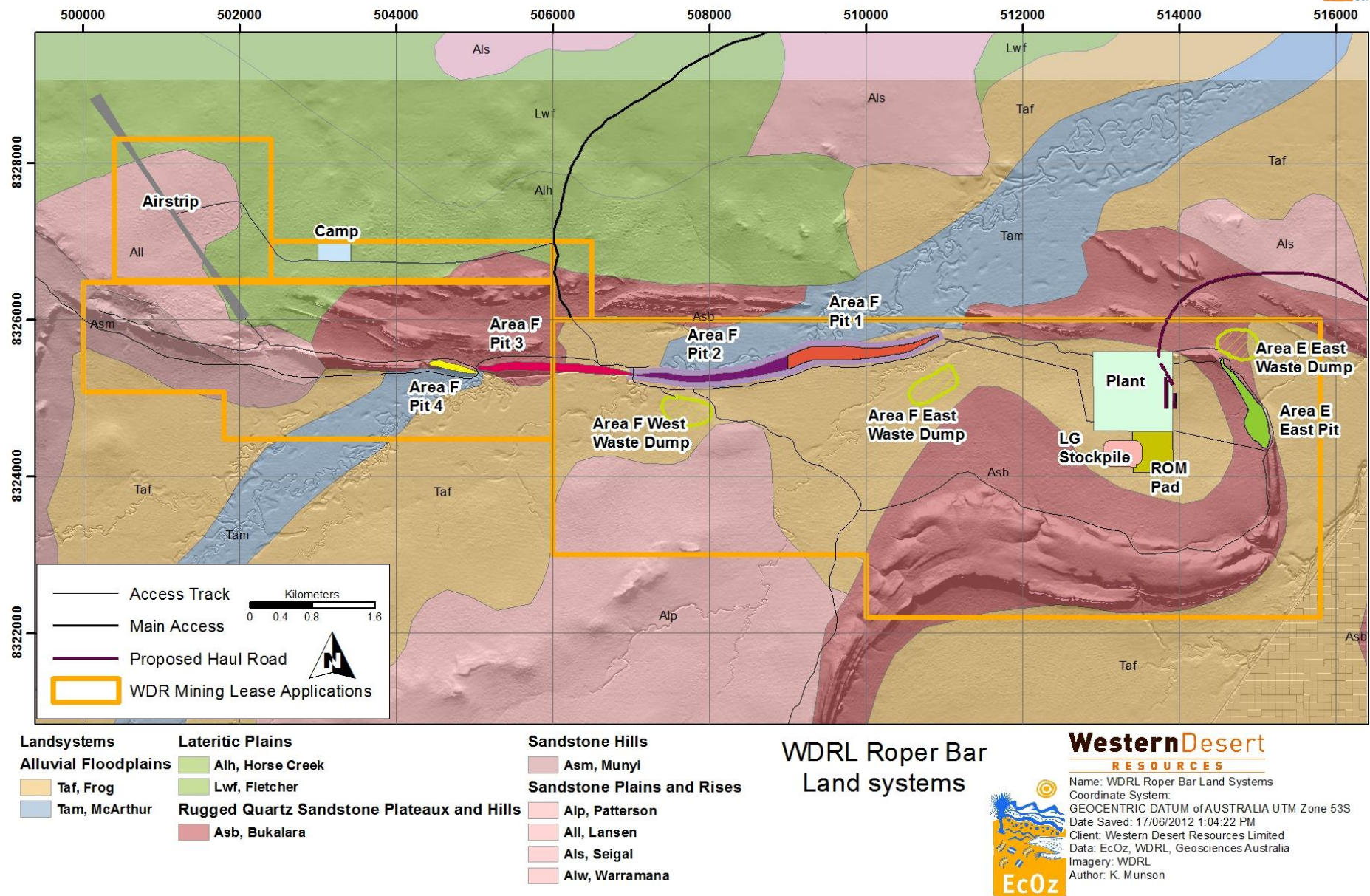


Figure 3-4 Land systems of the Roper Bar Project Area.

Adapted from Aldrick & Wilson (1992).

3.3.2 Haul Road Route

A total of 18 different land systems occur along the Haul Road route and a further 5 occur within 5 km of the Haul Road but not directly along it. These are mapped in Figure 3-5 and described in Table 3-2. The complexity and diversity of land systems is much greater between the Project Area and Limmen Bight River than between the Limmen Bight River and Bing Bong. Land system types comprising the greatest length of road are the Horse Creek land system (occupying a total combined road length of 26.7 km), Fletcher (23.1 km), Rosie (20.3 km), Running (16.1 km), and McArthur (15.6 km) land systems (Figure 3-5 and Table 3-2). These 5 land systems make up the majority of terrain crossed by the Haul Road between the Limmen Bight River and Bing Bong and are characteristic of the “G5” and “G6” geomorphic provinces, as defined for the region by Aldrick and Wilson (1990, 1992; see Table 3-1 above, also Figure 3-5).

The Horse Creek (Alh), Fletcher (Lwf), Rosie (Tor), and Running (Twr) land systems occur on the very level to gently undulating rises and terraces of the coastal plain. The Fletcher (Lwf) land system occurs on the seaward part of the coastal plain underlain by laterite, some of which was previously inundated by the sea. The Rosie (Tor) land system also occurs on this laterite sheet, which is overlain by a system of low, sandy, parallel, dunes and intervening shallow, linear swales, which are sub-parallel to the coastline. Inland, the laterite rises gently and is mapped as the Running (Twr) land system. Further inland, the laterite sheet ends and is replaced by the Horse Creek (Alh) land system, which occurs on sandstones.

The McArthur (Tam) land system encompasses all rivers, creeks, and drainages, which flow across the coastal plain in a north-easterly direction to the coastline. Other land systems occurring along smaller stretches of road between the Limmen Bight River and Bing Bong include the Kangaroo (Rlk) and October (Alo) land systems, which are associated with the greater relief and rockier areas where the road crosses the foothills of the Yiyintyi Range. Also, the Coolibah (Tac) land system is situated on flatter ground on the western side of this range. The Bing Bong (Lwb) land system occurs where creeks cut down into the hard lateritic surface of the Fletcher (Lwf) land system, and the Haul Road crosses this land system where it flanks Bing Bong Creek and other nearby creeks. The marine-influenced land systems of Spillen (Tos) and Littoral (Tol) comprising sand dunes, sand plains, cheniers, tidal mud flats and estuarine environments occur where the road ends on the coast at Bing Bong.

The diversity of land systems between the Project Area and Limmen Bight River are characteristic of those within the “G4” and “G5” geomorphic provinces. The most common land system is Seigal (Als), which occurs along a total of 13.2 km of Haul Road, followed by Bukalara (Asb; 8.4 km), Emmerugga (Rle; 6.8 km), Frog (Taf; 6.2 km), and Wearyan (Tcw; 4.6 km). The McArthur (Tam) land system also encompasses all rivers, creeks, and drainages. The Seigal (Als) and Bukalara (Asb) land systems comprise mainly undulating rises and linear rocky sandstone ridges. These higher relief land systems alternate along the road with broad sandy floodplains, and lower colluvial slopes of the Frog (Taf) land system, as well as gently undulating plains and low hills on argillaceous (silt and clay) sediments of the Wearyan (Tcw) and Emmerugga (Rle) land systems (see map in Figure 3-5 and Table 3-2 for detailed descriptions). The Downs (Ald) land system comprises gently undulating plains and rises on fine-grained sandstones also occurs close to this section of road.

Terrain on the immediate eastern side of the Limmen Bight River crossing is the most rugged along the Haul Road route consisting of steep, rocky sandstone ridges of the Bukalara (Asb) land system, which are aligned north-south, parallel to the river channel. The only occurrence of the Nathan (Tcn) land system also occurs on the eastern side of the Limmen Bight River, comprising pediments and side slopes on detritus and argillaceous sediments.

The nearest occurrence of the O’Keefe (Aso) land system to the Haul Road occurs about 5 km south of where the route crosses the Limmen Bight River (Figure 3-5). This land system comprises dissected structural plateau on sub-horizontally bedded sandstones of the Roper Group. Some rock units, in particular, the Hodgson Sandstone often forms spectacular columns (referred to as “lost city”) formations

due to the etching along intersecting joints. The scenic and conservation values of these rock formations are discussed below.

The Wulkulyi (TpW) land system is defined for seasonal and perennial swamps and poorly drained, low-lying areas. Although the route does not cross any of these, swamps and poorly drained depressions mapped as Wulkulyi do occur nearby, namely, Nawamalayu (Wanawu) Swamp, located just south of the Magaranyi River, and Nyamulumulu Swamp, just west of the Yiyintyi Range. These are further discussed in Section 3.8 below and shown in Figure 3 -21.

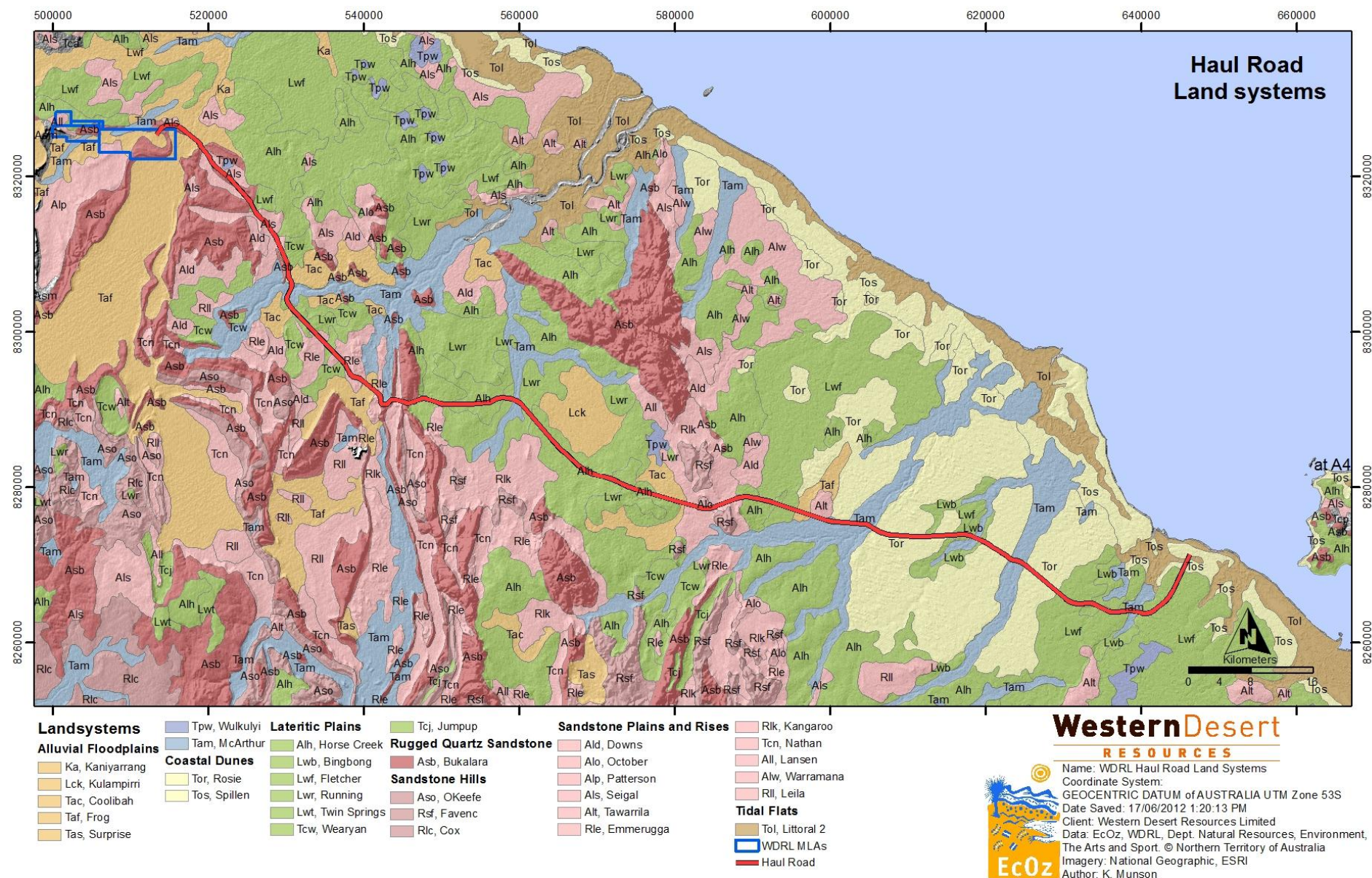


Figure 3-5 Land systems along the Haul Road route

Adapted from Aldrick & Wilson (1990, 1992).

Table 3-2 Land systems within the Roper Bar Project Area and along Haul Road route

Includes all land systems within 5 km either side of Haul Road route but not necessarily directly on it. Land systems mapping taken from Aldrick & Wilson (1990, 1992).

*Soil erosion and drainage hazard rated for crop production.

Land System		Landform	Soils	Occurrence	Road (km) & Project Area (ha) within Land System	Land Capability and Susceptibility*
Ald	Downs	Gently undulating plains and rises on mainly fine-grained sandstones	Sandy yellow earths and siliceous sands	Haul Rd – 2 small occurrences near road, but not on road, in area around Cox River. Project Area - none	0 km 0 ha	High soil erosion hazard Low soil drainage hazard Low flood risk
Alh	Horse Creek	Gently undulating plains on sandstone with deep sandy soils and isolated swampy depressions	Siliceous sands and earthy sands	Haul Rd – common between the Limmen Bight River and Rosie Creek Project Area – small area in north-western portion (airstrip and road to airstrip)	26.7 km 389 ha	High soil erosion hazard Low soil drainage hazard Low flood risk
All	Lansen	Long, low, often terraced rises with linear outcrop on prominently bedded sandstones	Lithosols	Haul Rd - none Project Area – small area in western portion (airstrip)	0 km 362 ha	Mod soil erosion hazard Low soil drainage hazard Low flood risk
Alo	October	Very rocky gently undulating rises on massive sandstones	Lithosols	Haul Rd – 1 small occurrence where road crosses Yiyintyi Range Project Area - none	1.3 km 0 ha	Mod soil erosion hazard Low soil drainage hazard Low flood risk
Alp	Patterson	Low hills, rises and undulating areas on reddish platy sandstones and siltstones, often micaceous, of the Kyalla Member.	Lithosols, earthy sands and shallow red and brown earths	Haul Rd - none Project Area – central southern portion	0 km 376 ha	Mod soil erosion hazard Low soil drainage hazard Low flood risk
Als	Seigal	Gently undulating to undulating rises with abundant, often linear rocky outcrops and shallow sandy soils	Lithosols, minor siliceous and earthy sands.	Haul Rd – common between Project Area and Cox River Project Area – outside northern boundary	13.2 km 0 ha	High soil erosion hazard Low soil drainage hazard Low flood risk
Alt	Tawarrila	Undulating rises to low hills with some rocky outcrops on sandstone	Lithosols and siliceous sands	Haul Rd – 1 small occurrence west of Rosie Creek crossing Project Area - none	1.8 km 0 ha	High soil erosion hazard Low soil drainage hazard Low flood risk
Asb	Bukalara	Rugged rocky plateaux and steep, linear ridges on massive sandstones	Lithosols and shallow siliceous sands	Haul Rd – occurs between Project Area and Cox River and also around Limmen Bight River Project Area – central northern and eastern portion	8.4 km 1634 ha	High soil erosion hazard Low soil drainage hazard Low flood risk

Asm	Munyi	Steep to gentle slopes on the Sherwin Ironstone	Lithosols	Haul Rd – none Project Area – small area in western portion	0 km 184 ha	High soil erosion hazard Low soil drainage hazard Low flood risk
Aso	O'Keefe	Broad breached anticlines and dissected structural plateaux on sub-horizontally bedded sandstones of the Roper Group with sandstone columns	Shallow siliceous sands	Haul Rd – occurs south of Limmen Bight River crossing, but not on actual road Project Area - none	0 km 0 ha	High soil erosion hazard Low soil drainage hazard Low flood risk
Lck	Kulampirri	Gently undulating plains on the Kulampirri Travertine Beds comprising lacustrine or spring-related calcrete deposits	Solodic	Haul Rd – one large occurrence on north-eastern side of road between Nathan River crossing and Yiyintyi Range; road does not cross this land system Project Area - none	0 km 0 ha	Mod soil erosion hazard Mod soil drainage hazard Low flood risk
Lwb	Bingbong	Incised, undulating rises flanking streams which are eroding into the laterite carapace of Lwf (Fletcher)	Ferruginous lithosols and earthy sands	Haul Rd – occurs along Bing Bong Creek and also a small creek between the Rosie and Pine Creek crossings Project Area - none	3.6 km 0 ha	High soil erosion hazard Low soil drainage hazard Low flood risk
Lwf	Fletcher	Level to very gently undulating plains on ferruginous material (laterite) that has been re-exposed from a sub-marine position, with swales in a sub-coastal orientation.	Earthy sands and yellow podzolic soils	Haul Rd – common between Yiyintyi Range and Bing Bong Project Area – occurs north of the area but not within it	23.1 km 0 ha	Mod soil erosion hazard Mod soil drainage hazard Low flood risk
Lwr	Running	Gently undulating plains and rises on ferruginised, mainly arenaceous sediments	Lateritic podzolics and lithosols	Haul Rd – scattered along road between Project Area and Yiyintyi Range Project Area - none	16.1 km 0 ha	High soil erosion hazard Low soil drainage hazard Low flood risk
Rle	Emmerugga	Undulating to rolling low hills on mainly argillaceous sediments	Lithosols and brown earths	Haul Rd – mainly between Cox and Limmen Bight River crossings Project Area - none	6.8 km 0 ha	High soil erosion hazard Low soil drainage hazard Low flood risk
Rlk	Kangaroo	Gently undulating to undulating rises on mainly argillaceous sediments	Shallow yellow earths and yellow podzolics	Haul Rd – occurs either side of Yiyintyi Range Project Area - none	5.9 km 0 ha	High soil erosion hazard Mod soil drainage hazard Low flood risk
Rsf	Favenc	Steep hills on mainly argillaceous sediments	Lithosols and brown earths	Haul Rd – north and south of the road where it crosses through Yiyintyi Range; but road does not actually cross this land system Project Area - none	0 km 0 ha	High soil erosion hazard Low soil drainage hazard Low flood risk
Tac	Coolibah	Level to gently undulating plains on unconsolidated transported materials, rarely sedentary	Grey and brown clays, minor black earths	Haul Rd – around Cox River crossing and west of Yiyintyi Range	6.5 km 0 ha	Mod soil erosion hazard Mod soil drainage hazard High flood risk

Taf	Frog	Broad sandy floodplains, terraces and lower colluvial slopes	Deep siliceous and earthy sands, sandy yellow earths and sandy solodic soils	Haul Rd – west of Limmen Bight River crossing and west of Rosie Creek crossing Project Area – common throughout	6.2 km 1866 ha	Mod soil erosion hazard Mod soil drainage hazard Mod flood risk
Tam	McArthur	Broad or narrow fluvial corridors conducting regional drainage across various land systems towards the coast	Grey and brown clays, red and yellow earths and siliceous sands	Haul Rd – at all river and creek crossings Project Area – along the Towns River	15.6 km 275 ha	Mod soil erosion hazard Low soil drainage hazard High flood risk
Tcn	Nathan	Pediments and side slopes of broad valleys on detritus and argillaceous sediments	Yellow earths, siliceous sands and brown clays	Haul Rd – only on east side of Limmen Bight River crossing Project Area - none	2 km 0 ha	High soil erosion hazard Mod soil drainage hazard Low flood risk
Tcw	Wearyan	Gently undulating plains and pediplains on transported material or argillaceous sediments	Yellow podzolics and solodic soils	Haul Rd – east and west of Cox River crossing Project Area - none	4.6 km 0 ha	Mod soil erosion hazard High soil drainage hazard Low flood risk
Tol	Littoral	Tidal mud flats with channels and estuaries	Laterite sheets commonly exposed, undifferentiated marine deposits	Haul Rd – only at Bing Bong Project Area - none	0.5 km 0 ha	Mod soil erosion hazard High soil drainage hazard High acid sulfate soil risk High flood risk
Tor	Rosie	Almost level plains on old sea-floor deposits with regular dune swale systems or isolated sand dunes, in a sub-coastal orientation	Earthy sands and yellow podzolic soils	Haul Rd – common between Yiyintyi Range and Bing Bong Creek Project Area - none	20.3 km 0 ha	High soil erosion hazard Mod soil drainage hazard Low flood risk
Tos	Spillen	Coastal sand sheets, dunes and cheniers with minor intervening tidal flats	Siliceous sands and yellow podzolic soils	Haul Rd – Bing Bong only Project Area - none	1.6 km 0 ha	High soil erosion hazard Mod soil drainage hazard High acid sulfate soil risk Mod wind erosion hazard Low flood risk
Tpw	Wulkulyi	Seasonal and perennial swamps and poorly drained, low-lying areas	Humic gleys, yellow podzolic soils and undifferentiated clay soils	Haul Rd – 2 isolated occurrences north of road but none actually on the road Project Area - none	0 km 0 ha	Low soil erosion hazard High soil drainage hazard Mod flood risk

3.4 Geology

3.4.1 Regional Geology

The Roper Bar Iron Ore Project is located within the geological province known as the McArthur Basin. This is a large intracratonic sedimentary basin with an exposed area of about 180 000 km² and a thickness ranging between 4 and 12 km (Rawlings 1999, Scott *et al.* 2000). It extends across most of the Gulf Fall region of north-eastern Northern Territory and across the border into Queensland. The Basin contains a series sedimentary rocks, which were deposited between the late Paleoproterozoic to the early Mesoproterozoic (1800-1430 Ma). The basin also contains volcanic rocks and related intrusive igneous rocks however these are a relatively minor component.

The stratigraphy of the McArthur Basin is dominated by a succession of siliclastic and carbonate sediments deposited in shallow marine, marginal marine, fluvial, aeolian, and lacustrine environments (Rawlings 1999, Scott *et al.* 2000). These make up the rock units of the Roper, Nathan, McArthur, and Tawallah Groups (see stratigraphy in Figure 3-6). Despite a long history, rock strata within the Basin are relatively undeformed and non-metamorphosed.

In spite of a long structural history, McArthur Basin strata are generally only gently folded with shallow dips. Some exceptions exist near faults, where bedding often steepens to 20–40°, and occasionally up to 70° (Pietsch *et al.* 1991). North-south trending faults of the Batten Fault Zone (or Batten Trough); one of the major fault zones of the McArthur Basin, are shown in Figure 3-7. Within this zone, the four recognised stratigraphic groups (Tawallah, McArthur, Nathan, and Roper Groups) attain a maximum collective thickness of 12 km; which is the maximum thickness attained within the McArthur Basin. This fault zone is between 50 and 80 km wide and hundreds of kilometres long. It is flanked to the west by the relatively flat lying and undeformed strata of the Bauhinia Shelf and to the east by the similarly flat and undeformed Wearyan Shelf. It is believed these tectonic features were inherited from the underlying orogenic and transitional domains.

The Roper Bar Project Area is located west of the Batten Fault Zone on the Bauhinia Shelf, whereas the Haul Road route traverses approximately at right angles across the Batten Fault Zone. The east-west trending Urapunga Fault Zone is located north of the Roper Bar Project Area; roughly aligned along the Roper River. An extension of this fault zone, referred to as the “Hells Gate Hinge Line”, strikes east-west through the northern section of the Project Area aligned along the Area F deposit (see below in Figure 3-10 and Figure 3-11). This fault is associated with the high grade hematitic iron ore mineralisation and is discussed in more detail in the sections below.

Figure 3-6 outlines the stratigraphy and lithology of rock units outcropping within the Roper Bar Project Area and along the Haul Road route. These rock units, located within the southern section of the McArthur Basin, correspond to the rock units mapped in and Figure 3-9 (note that rock units exposed within other parts of the McArthur Basin but not within the Project Area or along the Haul Road are not included or discussed). Further detailed stratigraphy and lithology of the target iron ore unit (i.e. the Sherwin Formation) is given in Figure 3-8 and its occurrence underlying the Project Area shown in Figure 3-10 and Figure 3-11.

The Early Proterozoic Scrutton Volcanics are the oldest rock unit exposed in the area mapped in Figure 3-7 and comprise base layers of the McArthur Basin in this region (see stratigraphy in Figure 3-6). These only outcrop in a small area to the south shown on Figure 3-7.

The basal Tawallah Group overlies the Scrutton Volcanics, and comprises the lower 7 km of southern McArthur Basin stratigraphy. This group outcrops extensively on the eastern side of the Limmen Bight River. The dominant rock type is white to pink, flaggy, medium grained quartz sandstone, for example, the Yiyintyi Sandstone, which forms the Yiyintyi Range, and also the Sly Creek Sandstone, which forms the large, linear, north-south trending rocky range on the eastern side of the Limmen Bight River. There

are also minor mafic igneous units (Seigal Volcanics and Settlement Creek Dolerite) with small areas of outcrop shown in the southern portion of Figure 3-7.

The Tawallah Group is conformably overlain by the McArthur Group, which is a mostly carbonate series of rocks. This series includes dolomite, limey dolomite, conglomerate, sandstone, siltstone, shale, dolomitic sandstone, dolomitic siltstone, dolomitic shale, chert, chert breccia and tuff, outcrops in the upper catchments of Rosie and Pine Creeks (Figure 3-7).

The Nathan Group unconformably overlies the McArthur Group and mainly comprises coarse-grained evaporitic-stromatolitic-oidal dolostone, sandstone, siltstone; minor conglomerate; basaltic sills, sandstone, and mudstone. This sequence outcrops along the Limmen Bight River (Figure 3-7).

The base of the Roper Group is marked by a regional unconformity that overlies both the Nathan and McArthur Groups. The Roper Group is an almost entirely siliclastic succession characterised by alternating units of quartz sandstone and mica-rich siltstones. Minor lithologies include calcareous siltstone, limestone, conglomerate and ironstone. This group dominates rock outcrop west of the Limmen Bight River (Figure 3-7) and continues north, where it comprises the majority of rock outcrop within the Roper River catchment. The target iron ore unit (Sherwin Formation) is one of the main units within the Maiwok Subgroup of the Roper Group (see Figure 3-6 and Figure 3-8). This is described in more detail in the sections below.

Many dolerites intrude the Roper Group, either as sills or dykes that have filled fault zones. The dolerites are uniform in composition and mineralogy and are collectively known as the Derim Derim Dolerite. Outcrops of this dolerite are common in the central McArthur Basin northwest of the area shown in Figure 3-7, however, only one outcrop appears in Figure 3-7, located in the far western portion.

Age		Strat Group	Map ID	Unit Name	Broad Rock Type	Rock Type	Lithological Description
Cainozoic	Quaternary		Qa	alluvium	regolith	alluvial sediment	Channel and flood plain alluvium: sand, silt, clay; alluvial terrace deposits; some black soil and sandy soil
			Qdc	coastal dunes	regolith	sand, aeolian	Quaternary coastal dunes, beach ridge, barrier beach, foredune and shoreface sands
			Qe	estuarine and delta deposits	regolith	mud	Estuarine, tidal delta deposits; coastal mud flats; may contain older vegetated black soils
			Qrc	colluvium	regolith	sand, gravel	Colluvium and/or residual deposits, talus, scree, sheet wash; boulder, gravel, sand; may include minor alluvial or sand plain deposits
			Qib	Beatrice Island Limestone	sedimentary carbonate	limestone	Fossiliferous, large-scale cross-bedded limestone; finely oolitic limestone
	Cz		sediments	regolith	sand, soil	Undifferentiated unconsolidated alluvial, colluvial and residual deposits: sand, soil, silt, gravel, sheetwash, talus, duricrust	
	Czk		calcrete	regolith	calcrete	Calcrete, travertine; calcareous cementing of bedrock and transported materials (Kulampirri Beds)	
	Czl		ferruginous duricrust	regolith	lateritic duricrust	Ferruginous duricrust, laterite, may include massive to pisolithic ferruginous subsoil, mottled clays	
	Czs		sand plain	regolith	sand	Sand plain, may include some residual alluvium; sand dominant, gravel, clay	
Cretaceous - Late Jurassic			Ksm	sediments	sedimentary siliciclastic	sandstone	Undifferentiated sediments, largely previously mapped as Mullaman beds (now discontinued); quartzose to lithic and micaceous sandstone, siltstone, claystone, conglomerate, minor breccia; commonly ferruginised or silicified; locally fossiliferous
Early Cambrian - Neoproterozoic		Kiana Group	Nskc	Cox Formation	sedimentary siliciclastic	sandstone	Fine grained, usually micaceous sandstone, siltstone and shale
Neoproterozoic			Nskb	Bukalara Sandstone	sedimentary siliciclastic	sandstone	Fine to very coarse grained, cross bedded, friable quartz to lithic sandstone with minor shale beds and basal pebbly sandstone to conglomerate; trace fossils
Mesoproterozoic	Ectasian	Roper Group	Mdd	Derim Derim Dolerite	igneous mafic	dolerite	Fine to coarse grained dolerite and gabbro sills
	Ectasian - Calymmian		Msr2	Maiwok Subgroup	sedimentary siliciclastic	sandstone	Mudstone, shale (+/- carbonaceous), lithic-glaucinitic sandstone, ooidal ironstone, quartzose sandstone
			Msr1	Collara Subgroup	sedimentary siliciclastic	sandstone	Quartzose sandstone, lithic-glaucinitic-ferruginous sandstone, mudstone, shale (+/- carbonaceous)
	Calymmian	Nathan Group	Msn	Nathan Group	sedimentary carbonate,	dolostone, sandstone	Cyclic coarse-grained evaporitic-stromatolitic-ooidal dolostone, sandstone, siltstone; minor conglomerate; synsedimentary basaltic sills, sandstone, mudstone
Paleoproterozoic	Statherian	McArthur Group	Lsm3	Batten Subgroup	sedimentary carbonate	dolostone, siltstone	Chertified evaporitic-stromatolitic dolostone, dolomitic siltstone, sandstone, pyritic-carbonaceous shale; minor pink chert beds (tuff?)
			Lsm1	McArthur Group, Lower	sedimentary carbonate	dolostone, siltstone	Masterton Sandstone to Emmerugga Dolomite: Evaporitic-stromatolitic dolostone, dolomitic siltstone and sandstone, quartzose sandstone; minor basal conglomerate
		Tawallah Group	Lst2	Tawallah Group, Upper	sedimentary siliciclastic	sandstone, mudstone	Wununmantyala Sandstone to Echo Sandstone: Quartzose and lithic sandstone, mudstone, evaporitic-stromatolitic dolostone, carbonaceous shale
			Lst1	Tawallah Group, Lower	sedimentary siliciclastic	sandstone	Yiyintyi Sandstone to McDermott Formation: Quartzose sandstone; subordinate conglomerate, ferruginous sandstone, dolostone, mudstone
			Lsts	Sly Creek Sandstone	sedimentary siliciclastic	sandstone	Lithic and quartz sandstone, minor siltstone and conglomerate
			Lbts	Seigal Volcanics	igneous mafic	basalt	Vesicular and amygdaloidal basalt; massive non-vesicular basalt; thin siltstone, sandstone and tuff interbeds
			Ldte	Settlement Creek Dolerite	igneous mafic	dolerite	Black to orange equigranular dolerite; local hornfels enclaves
			Lsty	Yiyintyi Sandstone	sedimentary siliciclastic	sandstone	Quartz arenite and lesser sublitharenite and litharenite; fine to coarse grained with scattered quartz pebbles and minor conglomerate
			Orosirian		Lfsc	Scrutton Volcanics	igneous felsic

Figure 3-6 Stratigraphy and description of rock units shown in geological maps of Haul Road and Project Area (see Figure 3-7 and Figure 3-9).

Unconformities shown as a shaded line. The Maiwok Subgroup hosting the target iron ore unit (Sherwin Formation) is highlighted. See Figure 3-8 for further subdivision of the Maiwok Subgroup. Stratigraphy adapted from Liu *et al.* (2006), Abbott *et al.* (2001), and Plumb *et al.* (1964).

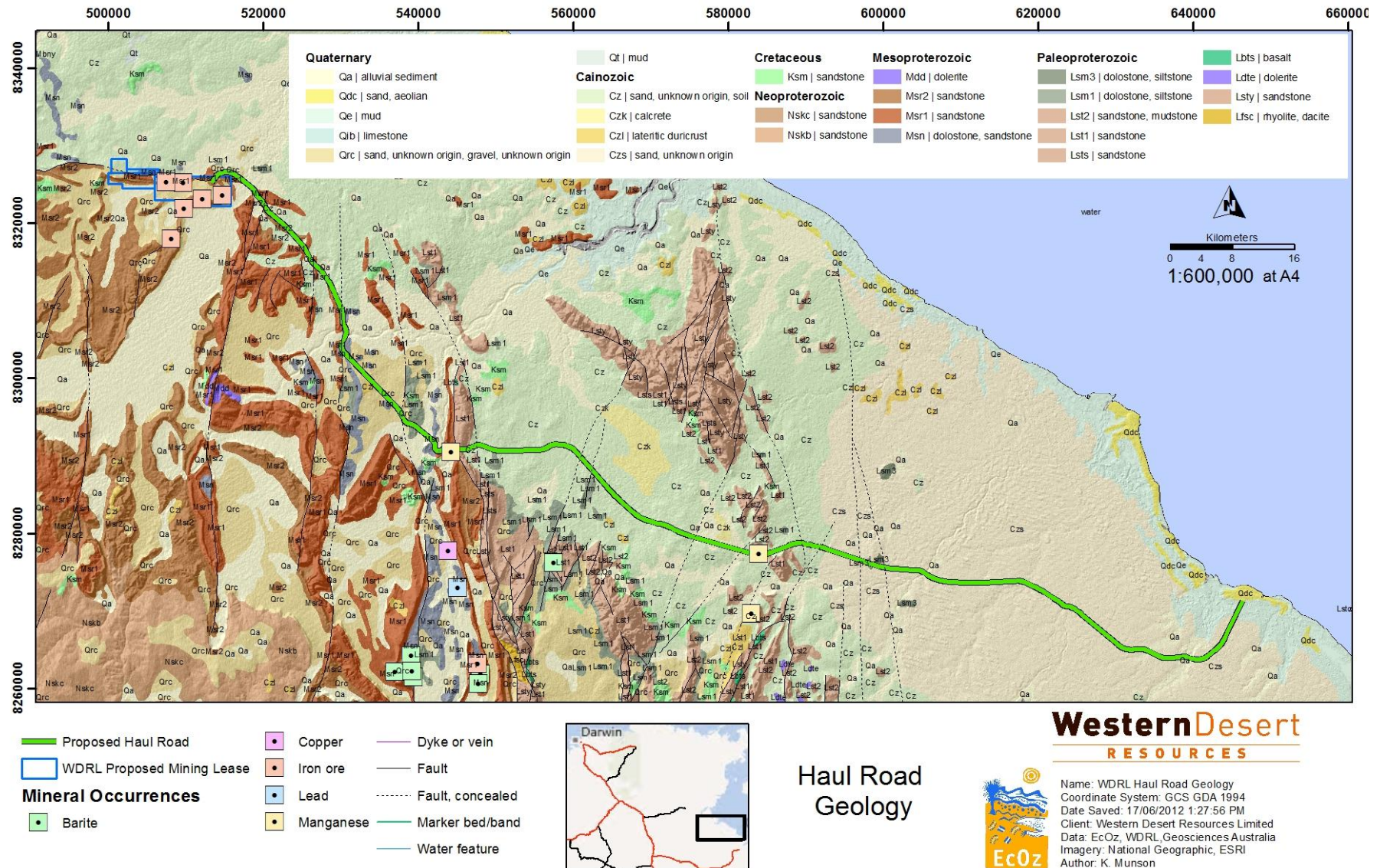


Figure 3-7 Geology along Haul Road; see Figure 3-6 for rock unit descriptions. Known mineral occurrences also shown.

Geology from Geoscience Australia's Geology of Australia 1:1 000 000 map (Liu *et al.* 2006); mineral occurrences from NT Geological Survey's MODAT Database (NTGS 2012).

3.4.2 Geology along the Haul Road Route

The 165km long Haul Road route traverses across a large portion of the southern McArthur Basin; the stratigraphy and lithology of which was described above in the previous section. Notably, the northwest-southeast alignment of the Road, in general, cuts across the north-south trending rock strata. The Road starts in the upper McArthur Basin sequence (Roper Group; see Figure 3-6 and Figure 3-7) at the Project Area, then moves into older units between the Cox and Limmen Bight Rivers (Nathan and McArthur Groups), and subsequently into the basal Tawallah Group after crossing the Limmen Bight River (Figure 3-6, Figure 3-7). The Road, which starts on the western edge of the Batten Fault Zone, also crosses a large number of north-south trending fault lines belonging to this Zone as it moves from west to east.

Rock outcrop between the Project Area and Cox River typically comprises linear ridgelines of the more resistant sandstone units of the Roper Group (e.g. Moroak, Bessie Creek, Jalboi, Hodgson, and Limmen Sandstones) aligned along the strike of sedimentary bedding whereas the less resistant siltstones and finer-grained units (e.g. Kyalla and Mainoru Formations) underlie the intervening valleys.

Following the Cox River crossing the road then traverses across the older units of the Nathan and McArthur Groups (see Figure 3-6). These commonly comprise carbonate-rich (dolomitic) sandstones, siltstones, and cherts. Finally, after crossing the Limmen Bight River, the Road crosses into the underlying rock units of the Tawallah Group comprising quartz sandstones that form many of the large rugged, sandstone ridges and ranges in the region, for example the Yiyintyi Range and the steep range on the eastern side of the Limmen Bight River.

Lateritized Lower Cretaceous sandstones occur as isolated flat topped mesas scattered throughout the region (i.e. rock unit "Ksm" in Figure 3-6 and Figure 3-7), however, none of these mesas are crossed by the Road. This unit also underlies the coastal plain. Cainozoic deposits (sands, calcrete, and lateritic duricrusts) blanket most low-lying areas as well as relatively recent Quaternary alluvial, colluvial, marine, and wind-blown deposits. A smaller outcrop of the travertine (calcrete) Kulampirri Beds also occurs alongside the Road. Notably, other carbonate-rich rocks outcrop near the Road where it crosses Rosie Creek (Batten Subgroup "Lsm3", in Figure 3-6 and Figure 3-7), and also west of the Limmen Bight River and near the Nathan River crossing (i.e. units of the Lower McArthur Group, "Lsm1").

3.4.3 Geology of the Roper Bar Project Area

The Roper Bar Project Area comprises rock units of the upper McArthur Basin sequence; namely, the Maiwok Subgroup of the Mesoproterozoic Roper Group (Figure 3-6 and Figure 3-8). The target iron ore mineralisation occurs within the Sherwin Formation, which outcrops in several areas within the central part of the McArthur Basin, mainly in the region north-west of the Project Area, between the Project Area and the Roper River, for example the type locality at Sherwin Creek. Stratigraphically, the Formation occurs between the Moroak Sandstone (older) and Kyalla Formation (younger). The Sherwin Formation is characterised by the presence of oolitic ironstone layers. However, these layers tend to be laterally discontinuous and the formation as a whole is dominated volumetrically by interbedded sandstone, siltstone, and mudstone (Abbott *et al.* 2001).

Locally within the Project Area, ironstone layers within the Sherwin Formation contain significant zones of iron enrichment; enough to be viable to mine. Most of this occurs as the mineral hematite (iron oxide; Fe_2O_3), with a small but significant contribution from siderite (iron carbonate; FeCO_3). The highest grade layers are dominated by earthy, red, hematitic oolite; where the "ooids", which are spherical grains <2 mm diameter, are composed of concentric layers of hematite. Iron-ore deposits of this type are best classified as a *sandy, clayey, and oolitic, shallow-inland-sea iron formation*, or SCOS-IFs (Kimberley 1978), but they are also known as Clinton-type oolitic ironstones. These are believed to have formed within an agitated, shallow marine depositional environment.

Figure 3-8 shows the stratigraphic relationship of the Sherwin Formation within the Roper Group and also outlines the lithology of the various different layers within the Sherwin Formation where it occurs

within the Roper Bar Project Area. The highest grade iron layers comprising hematitic oolite often include disseminated fine crystalline hematite in the matrix between the ooids. The highest grade ore contains the greatest amount of this crystalline hematite. These hematitic oolite layers are thinly interbedded with siltstones and fine grained sandstones. Oolitic sandstone with variable siderite cement between the ooids occurs towards the base of the Sherwin Formation, whereas sideritic oolite (where the ooids are composed of siderite) occurs at the top of the Formation and sometimes beneath the hematitic oolite (see Figure 3-8) for detailed descriptions of the various layers). The target ore body and its occurrence within the Project Area, including resource estimates of tonnage and grade are given in Table 3-4 and outlined in the Sections below.

The Kyalla Formation, which overlies the Sherwin Formation ((Figure 3-8), comprises thinly interbedded mudstone, siltstone, very fine-grained silty sandstone, and fine-grained sandstone. This unit is readily erodible and outcropping is rare. Within the Project Area, it mostly underlies the broad, flat alluvial plains (for example, the Kyalla Formation most commonly underlies the Frog (Taf) land system in the Project Area; see Figure 3-4 and Figure 3-10).

The Moroak Sandstone underlies the Sherwin Formation (Figure 3-8) and comprises mainly fine-grained sandstone, in places ferruginous, thin-bedded to flaggy with some interbedded coarse-grained sandstone and minor conglomerate. This Sandstone is relatively more resistant to erosion compared to the Sherwin and Kyalla Formations and forms most of the ridges in the Project Area, which also comprise the Bukalara (Asb) land system (see Figure 3-9, Figure 3-4, and Figure 3-1). Other than rare dolerite sills, there are no volcanics in or around the Project Area.

In regards to geological structure, a major east-west trending fault zone called the Hells Gate Hinge Line transects across the north of the Project Area parallel to Area F (see Figure 3-10). North-south striking faults are also common in the wider region around the Project Area. A cross section of Area F and Area E (South) show the two outcrops of Sherwin Formation are linked; forming a broad syncline (Figure 3-11). Rock strata dip very steeply to almost vertical in Area F, where they abut against the Hells Gate Hinge Line; whereas rock strata dips gently to the north in Area E (South). Rock strata outcropping at Area E (East) strikes north-south and dips towards the west at greater than 45 degrees. Together, the Sherwin Formation at Areas F, E (South), and E (East) forms a basin; where the Kyalla Formation is in the centre and the Moroak Sandstone around the outer edge.

Notably, in regards to considerations for mining pit development within Area F, local-scale structural analysis has identified that the bedding and it's interaction with jointing will govern the slope angles of mining pits. Rock unit layering (bedding) across the area is almost vertical and is therefore prone to toppling. Moderately dipping joints at about 30 degrees act as a failure plane allowing the steeply dipping bedding to release once excavation has taken place. Failure of this nature will affect the north or south walls depending on the orientation of bedding. A near vertical joint set has also been identified. Geotechnical analysis and investigation will continue as the project progresses, and further data is obtained, to further refine the geotechnical parameters used in the pit designs.

North of the Hells Gate Hinge Line, in the vicinity of the present exploration camp location (Figure 3-10), older rocks of the Nathan Group (see stratigraphy in Figure 3-6) comprising dolomitic sandstones occur. These east-west trending outcrops of older Nathan Group units are immediately north of and parallel to the Moroak Sandstone and Sherwin Formation ridgelines of Area F and have been juxtaposed against these younger Roper Group units by vertical movement on the fault.

Further structural information regarding the exploration areas within the MLA (i.e. Areas F and E), as well as those outside the MLA (i.e. Areas A, B, C, D, and G), is given in Table 3-4 and discussed in the Sections below.

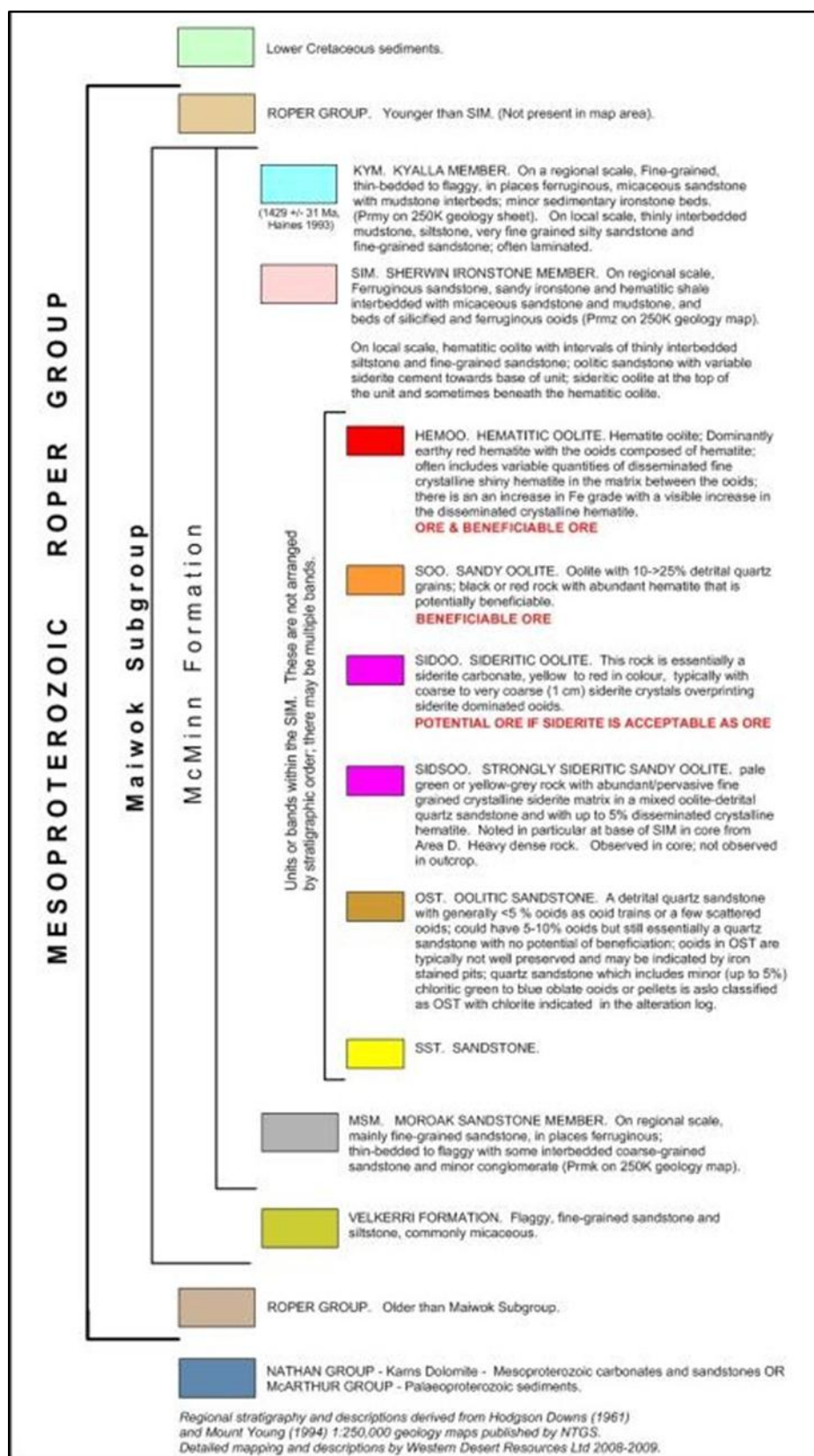
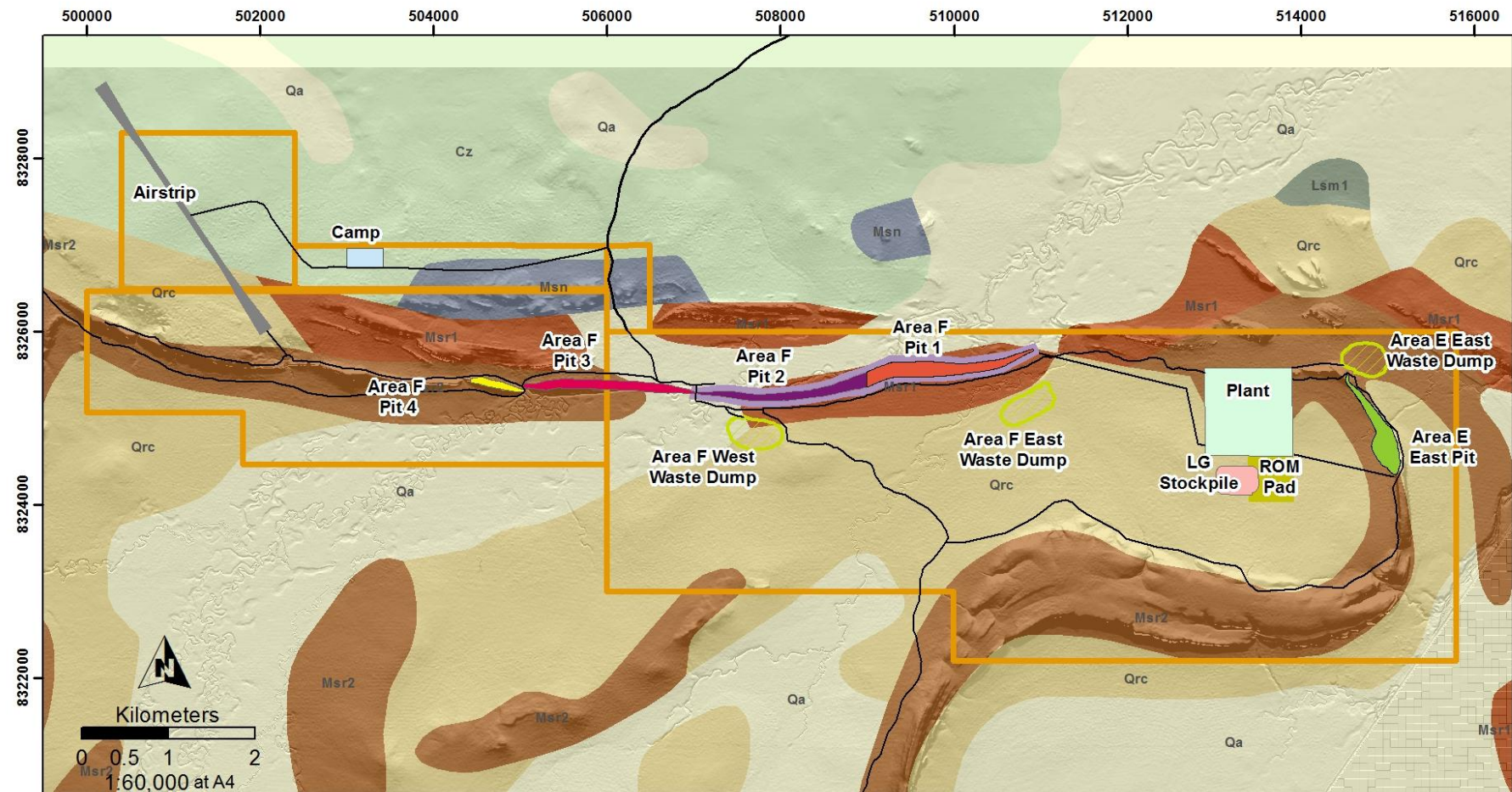


Figure 3-8 Stratigraphic relationship and rock unit descriptions (specific to the Roper Bar area) of the Sherwin Formation within the Roper Group. Source: WDRL

Note the Sherwin Formation was originally known as the "Sherwin Ironstone Member" (SIM) of the McMinn Formation in the original stratigraphy as defined by Dunn (1963). Abbott and Sweet (2001) have since raised the SIM to "Formation" status and abandoned the McMinn Formation. However, the McMinn Formation and SIM nomenclature is still useful in mapping within the Project Area and as such are used by WDRL in ore body definition.



Geology

Quaternary

Qa | alluvial sediment

Qrc | sand, unknown origin, gravel, unknown origin

Cainozoic

Cz | sand, unknown origin, soil

Mesoproterozoic

Msr2 | sandstone

Msr1 | sandstone

Msn | dolostone, sandstone

Paleoproterozoic

Lsm1 | dolostone, siltstone

Roper Bar
Geology

Western Desert RESOURCES

Name: WDRL Roper Bar Geology
Coordinate System:
GEOCENTRIC DATUM of AUSTRALIA UTM Zone 53S
Date Saved: 18/06/2012 2:58:17 PM
Client: Western Desert Resources Limited
Data: EcOz, WDRL, Geosciences Australia
Imagery: National Geographic, ESRI
Author: K. Munson



Figure 3-9 Geology of the Roper Bar Project Area; see Figure 3-6 for rock unit descriptions.

Geology from Geoscience Australia's Geology of Australia, 1:1 000 000 map (Liu *et al.* 2006).

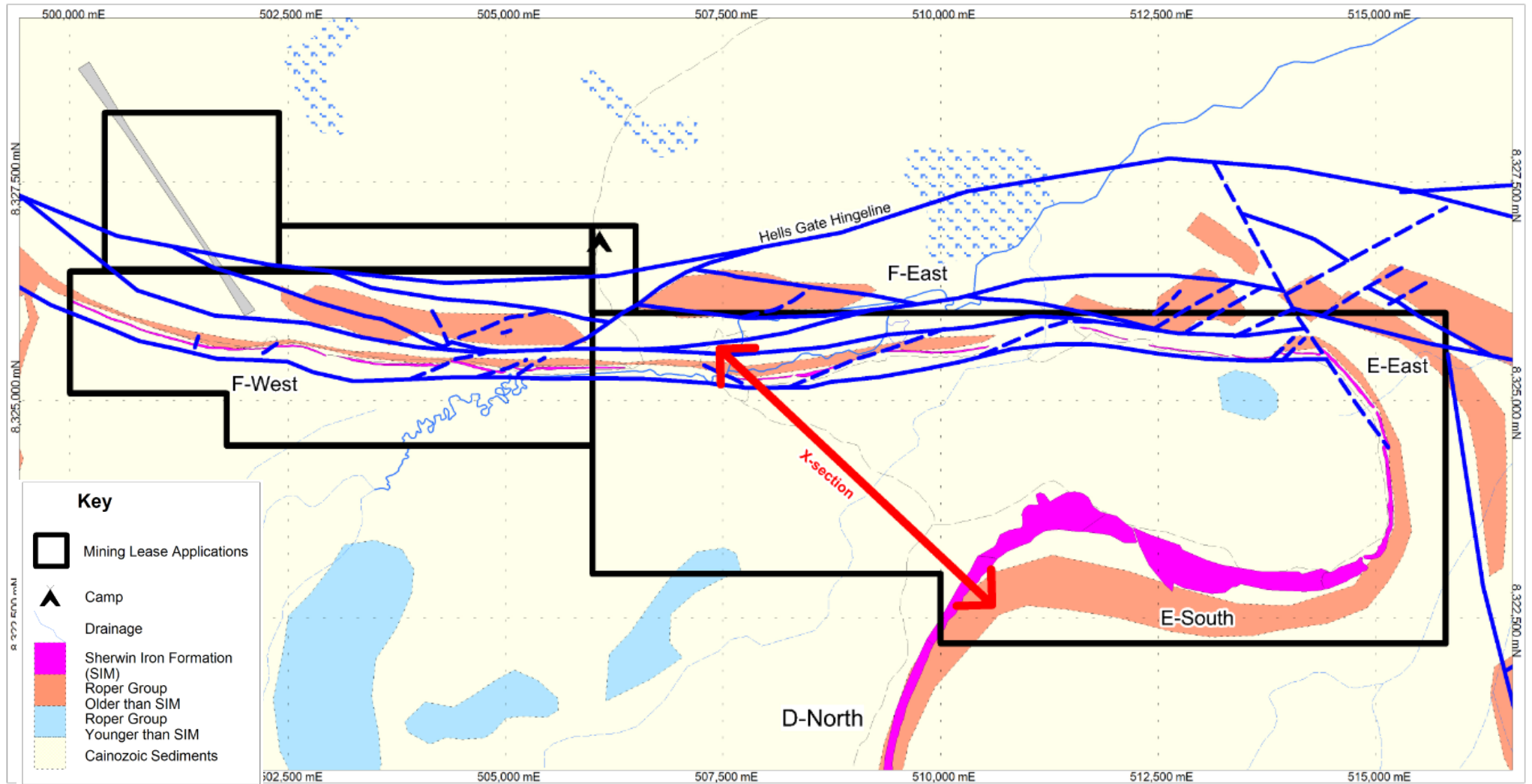


Figure 3-10 Structural geology and detailed mapping of Sherwin Ironstone Member within the Roper Bar Project Area.

For geological cross section indicated on this map see Figure 3-11. Source: WDRL.

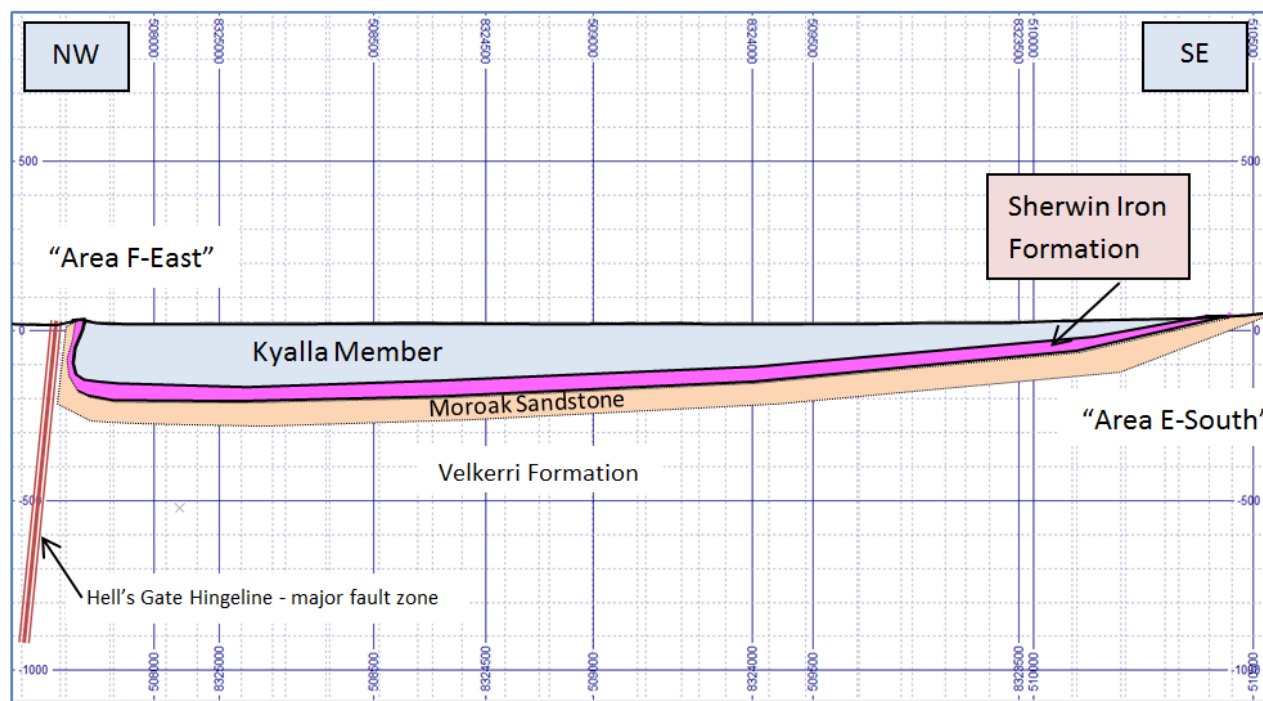


Figure 3-11 Geological cross section between Area F and Area E.

Cross section location shown in Figure 3-10. Source: WDRL.

3.4.4 Mineral Resources in the Region around the Project Area and along the Haul Road route

The McArthur Basin hosts a number of mineral resources in addition to iron ore. These include significant base metal (Cu, Pb, Zn, Fe) occurrences and resources such as the world-class zinc-lead-silver deposit at McArthur River mine (Abbot *et al.* 2001), diamond-bearing kimberlites, such as those present at Merlin, and copper at Redbank (Rawlings 1999, Scott *et al.* 2000). The basin also contains numerous manganese deposits (Ferenczi 2001) and surficial ilmenite mineralisation occurs in places associated with dolerite sills. Minor uranium mineralisation occurs within basal units. The region has also been explored for petroleum and geothermal potential. Figure 3-12 shows previous exploration around the Project Area and shows known mineral occurrences along the Haul Road route.

Iron ore deposits within the McArthur Basin are typically of high tonnage and low to moderate grade and are present at several stratigraphic levels within the Mesoproterozoic Roper Group; in particular, the Sherwin Formation (Ferenczi 2001). As mentioned above, mineralisation occurs as massive stratiform oolitic ironstones within marine terrigenous clastic sediments. This style of mineralisation is known as *sandy, clayey, and oolitic, shallow-inland-sea iron formations*, or SCOS-IFs (Kimberley 1978), but they are also known as Clinton-type oolitic ironstones. The ironstones are interbedded with shale and quartz sandstone, which were deposited in an agitated, shallow marine depositional environment. The main iron minerals present are variously goethite, hematite, limonite, siderite, chamosite, greenalite, and traces of magnetite. Gangue minerals include detrital quartz and authigenic chert. The oolitic ironstones form beds between 0.5 m and 4 m thick that are commonly continuous over tens of kilometres. The iron ore deposits targeted for mining within the Roper Bar Iron Ore Project Area were described in the sections above and also below in Table 3-4.

3.5 Previous and Current Exploration in the Region and Known Mineral Occurrences

The McArthur Basin has significant exploration potential given the number of known mineral occurrences and resources and the potential for the discovery of further base metal deposits, diamonds, and iron ore (NTGS 2012). Large areas in the north of the basin are effectively unexplored.

Ferenczi (1997, 2001) provides a review of iron ore deposit geology, previous exploration and ore resource potential in the region. The first significant iron ore discovery in the Northern Territory was in 1911 at Murphy's prospect near Roper Bar. This later drew BHP (now BHP-Billiton) to the area in 1955, leading to the discovery of the Roper River oolitic iron ore deposits. Between 1955 and 1961, BHP investigated some 27 iron ore prospects to the west and southwest of Roper Bar. This included geological mapping, drilling, bulk sampling and considerable metallurgical test work. Estimated iron ore resources at Sherwin Creek were 200 Mt grading 27-33% Fe and 40-45% SiO₂, and at Hodgson Downs 200 Mt grading 37-52% Fe and 7-16% SiO₂. At this time, the Roper River deposits were not developed, and investigations were abandoned in favour of the higher quality and larger Pilbara iron ore deposits in Western Australia that were discovered in the late 1950s. These very large deposits also meant that very little iron ore exploration was carried out in the Northern Territory in the 70s, 80s, and 90s.

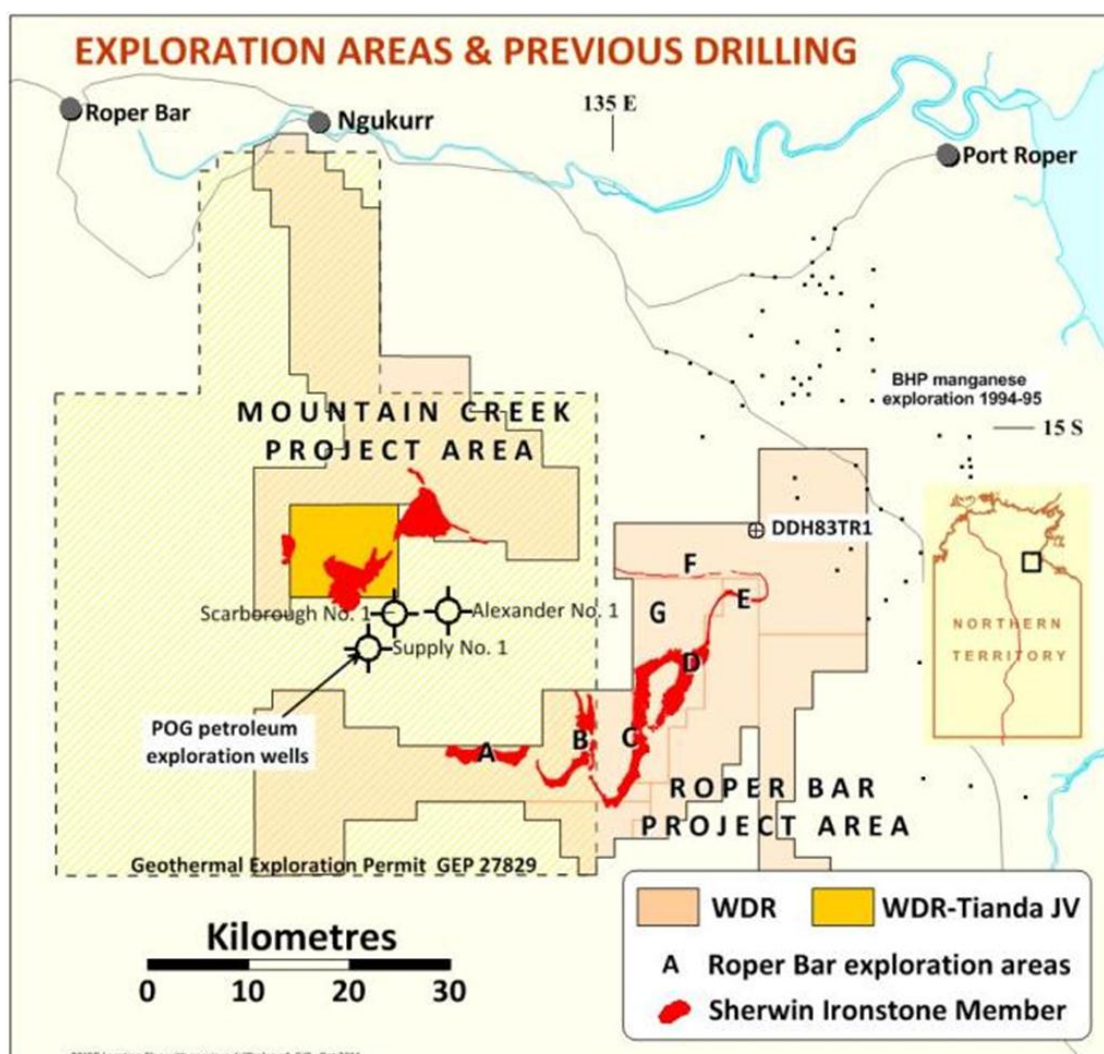


Figure 3-12 Previous exploration and drilling in the region of the Roper Bar Project Area.

Source: WDRL.

In later years, interest in iron ore deposits in the region has increased in response to increasing demand and price for iron ore. Presently, Sherwin Iron Limited (ASX:SHD) are exploring the old BHP deposits, under an agreement with the tenement holder and SHD majority shareholder Xiao Feng (Jerry) Ren.

In 1996, Geoff Fanning pegged EL9041, which generally coincides with WDRL's EL25672; located south of WDRL's presently proposed (in this EIS) Mining Lease Applications. Geoff Orridge, a consulting Geologist, completed reconnaissance exploration of the area and took 16 samples. Only three samples assayed above 50% Fe; maximum 56.6%. These results were not of commercial interest and the EL was relinquished.

Since this time, WDRL has taken an interest in the area and were granted exploration licences in July 2005. Extensive exploration work has defined an economically minable resource (see details in Sections below) and in September 2010, applications were lodged for three Mining Leases, with a further two Mining Lease Applications (MLAs) lodged in August 2011. This EIS forms part of the approvals process for granting of these MLAs for mining to proceed.

In regards to other commodities, the wider region has been explored for base metals, particularly shale-hosted zinc-lead deposits of the McArthur River type. Drilling has been carried out for manganese by BHP in 1994-95 (locations shown in Figure 3-12), and numerous sampling programs for diamonds have also been completed.

There are no records of any previous drilling on the Sherwin Formation in the Roper Bar Project Area. The nearest documented deep drill hole is 4 km north of WDRL's Area E (shown as DD83TR1 in Figure 3-12). This hole was drilled to a depth of 500 m by CRA Exploration in 1983 to test a gravity anomaly for base metal mineralisation.

In the region between the Roper Bar Project and Mountain Creek Project, Pacific Oil and Gas Pty Ltd ("POG") in 1987 drilled three exploration petroleum wells to maximum depth 700 m (locations shown in Figure 3-12). Extrapolation of bottom-hole temperatures from these holes, plus the presence of a shale horizon acting as a thermal insulator show the area has potential for geothermal energy exploration.

Known mineral occurrences along the Haul Road route recorded in the NT Geological Survey's MODAT Database (NTGS 2012) are shown in Figure 3-7.

These comprise occurrences of iron ore (i.e. mainly those of the Roper Bar Project Area), manganese, lead, barite, and copper. Only two records occur directly along the Haul Road route; both manganese. These are referred to in the MODAT Database as "L4" and "Yiyintyi", where the L4 deposit occurs on the eastern side of the Limmen Bight River, and the Yiyintyi deposit occurs in the foothills of the Yiyinti Range. Neither of these deposits are of significant size.

A number of mineral occurrences occur south of the Road, along the Limmen Bight River associated with the carbonate-rich sedimentary rocks of the Nathan Group, and faults of the Batten Fault Zone. These include deposits of barite, copper, lead and iron, however to date, none of these have been identified as significant in size.

The Haul Road route intersects 9 different exploration leases not including those of WDRL (see Table 3-3 and also the map in Figure 2-11 in Chapter 2). Sandfire Resources hold a significant area of granted tenements in the region with the aim of exploring for significant manganese and base metal deposits. Sandfire's exploration leases enclose a significant proportion of the Batten Fault Zone, which also hosts the giant McArthur River (Pb-Zn-Ag) deposit (located south of where the Haul Road crosses the Batten Fault Zone). Sandfire's leases also cover near-coastal areas of Cretaceous rocks considered to be highly prospective for sedimentary manganese mineralisation, similar to the world-class Groote Eylandt manganese deposits in the Gulf of Carpentaria.

Sandfire's primary exploration targets within the Batten Fault Zone are sedimentary zinc and lead deposits similar to the McArthur River Mine deposit. Previous reconnaissance exploration by Sandfire

for manganese has identified several extensive zones of manganese mineralisation in the Rosie Creek catchment area and elsewhere within its tenement holdings.

Sandfire is also undertaking exploration for uranium and has identified prospective mineralisation along a 40km strike length of the basal unit (Yiyintyi Sandstone) of the McArthur Basin (rock unit “Lsty” in Figure 3-7).

Similar to Sandfire, Brumby Resources hold tenements within the Batten Fault Zone aiming to identify mineralisation similar to that which occurs at the McArthur River mine. Brumby have identified several prospective areas with elevated Zn and Mn levels, both near-surface and at depth, and interpretation of the geophysics provided Brumby with promising drill targets. Exploration and drilling will continue in 2012.

The status of exploration undertaken within the exploration leases held by Australian Manganese Resources and Natural Resources Exploration were not known at the time of writing.

Table 3-3 Mining tenement interests intersected by the Haul Road to Bing Bong.

Granted Tenements*	Licence Holder
MLA 28264	WDRL Iron Ore Pty Ltd
EL24307	WDRL Iron Ore Pty Ltd
EL24665	WDRL Iron Ore Pty Ltd
EL28587	Australian Manganese Resources Pty Ltd
EL28605	Australian Manganese Resources Pty Ltd
EL26939	Sandfire Resources NL
EL26837	Sandfire Resources NL
EL26835	Sandfire Resources NL
EL29021	Brumby Resources Limited
EL29022	Sandfire Resources NL
EL24401	Sandfire Resources NL
EL28319	Natural Resources Exploration PTY Ltd

*See Figure 2-11 in Chapter 2 for map showing these mining tenements.

3.5.1 Mineral Resources in the Roper Bar Project Area

WDRL is currently exploring two prospective iron ore areas in the region; the Roper Bar Project Area (the subject of this EIS), and the Mountain Creek Project Area, which is located about 30 km west of the Roper Bar Project Area (Figure 3-12). Exploration of the Roper Bar Project Area began in 2008, with broad scale reconnaissance mapping, also sampling and analysis of surface material. Exploration drilling then started in the Roper Bar Project Area in late 2008, and has continued each dry season during 2009, 2010, and 2011. Mapping and rock chip sampling has now been completed over most of the Sherwin Formation outcrop in the Roper Bar Project Area. More targeted and deeper drilling is planned for the 2012 season to further define the resource. To date, only limited mapping, sampling, and reconnaissance drilling has been completed on the Mountain Creek Project Area.

Iron ore within the Roper Bar Project Area within Areas F and E, has been found to be economically minable for several reasons: significant tonnages of high grade (DSO) and medium grade (BFO) ore, and mineralised layers are laterally extensive, flat-lying, and close to the surface. Also, the ore is quite low in

contaminants, for example phosphorus is usually less than 0.01%; where too much phosphorus can detract from the saleability of iron ore since it can result in the steel being too brittle. A further favourable aspect is the significant potential for mining to continue into the other nearby exploration areas to the south and west of the MLA (Areas A, B, C, D, G, and Mountain Creek) once the operation is established using the already identified resources in Areas F and E.

Defining the Resource

To date, most drilling at Roper Bar has been RC (reverse circulation), with some targeted diamond drilling to obtain cores for metallurgical test work. Figure 3-12 shows the location of the seven defined exploration areas (Areas A through to G) within the Roper Bar Project (note this is the EL area; a wider area than the MLA area subject of this EIS), and Table 3-4 outlines the details of drilling completed in each of these Areas since drilling began in 2008. Note that only drilling completed up to the end of 2010 is included for Areas A, B, C, D, E and G, as results of the 2011 drilling season for these Areas are not yet finalised. Drilling completed in Area F in Table 3-4 includes all drilling up to the end of the 2011 season, since these were used to calculate the latest mineral resource estimation contained within Area F; published in February 2012.

Airborne and ground-based geophysical surveys measuring magnetic, radiometric, gravity, and electromagnetic response have also been conducted across the Project Area.

Resource calculations have been carried out for prospective areas (Areas D, E, and F) within the Roper Bar Project Area by AMC Consultants Pty Ltd. These mineral resource estimates comply with the Joint Ore Reserves Committee Code; or JORC Code (see JORC 2004). This code of practice sets out the minimum standards for public reporting in Australia and New Zealand of “Exploration Results”, “Mineral Resources”, and “Ore Reserves” by providing a mandatory system for classification of tonnage/grade estimates according to geological confidence and technical/economic considerations.

Table 3-4 sets out the results of AMC Pty Ltd’s resource estimates for Area D (South) published in October 2009, Area E (South and North) published in October/November 2010, and Area D (North) published in February 2011. It also includes the most recent resource estimate for Area F published in February 2012; noting that Area F has been identified as the most resource-rich.

An “indicated” resource has been calculated for Area E (East) and most of Area F (the eastern section); which are the two areas planned for immediate mining, and the subject of this EIS. An “inferred” mineral resource has been calculated for Areas D, E (South), and the western part of Area F. The JORC term “indicated” mineral resource implies a greater degree of confidence based on more extensive drilling and survey information than an “inferred” mineral resource.

The indicated mineral resource within Area F is 24.6 Mt at 49.3% Fe and the inferred mineral resource is 5.5 Mt at 46.6% Fe. This includes 15.5 Mt at a high grade of 59.5% Fe. This is significant, given that ore which is greater than 58% Fe is regarded as Direct Shipping Ore (DSO), which requires minimal beneficiation (only gravity separation) to produce a saleable product. Ore with less than 58% Fe is defined as Beneficiation Feed Ore (BFO), which requires more processing before it can be sold for smelting. Area F contains the most DSO identified to date.

Other areas show good prospects for future mining providing saleable product through beneficiation. Area E (East) contains less iron ore than Area F with an indicated mineral resource of 12.1 Mt at 46.1% Fe, including 4.7 Mt at 55.6% Fe. Whereas Area E (South) has lower grade ore but more of it with an inferred mineral resource of 72.1 Mt at 39% Fe. Area D (South) and Area D (North) also have moderate grades but high tonnages with inferred mineral resources of 90.7 Mt at 37.2% Fe and 116.5 Mt at 40.3% Fe respectively.

JORC resource estimates have not been commissioned for Areas A, B, C, and G, given the greater focus on firming-up the resources contained within Areas E and F, and to a lesser extent Area D. Significant drilling and survey work has however been completed across these areas (see Table 3-4),

and results have indicated laterally extensive and shallow haematitic oolite of reasonably good grade warranting further investigation and drilling.

The Mountain Creek Project Area, although still in the early stages of exploration, further adds to the prospective future resources. Recent drilling (81 drill holes totalling 2360 m) has intersected significant DSO mineralisation in the 50% Fe range which is laterally extensive and close to the surface (reported in ASX announcement 3rd March 2012).

Table 3-4 Exploration results for the Roper Bar Project Area.

Note that only Areas E and F are within the proposed MLA; the other Areas are within WDRL's Exploration Leases but outside the MLA. *Drilling completed up to the end of 2010, ^JORC Estimate based on drilling results up to the end of 2010 with 30% Fe Cut-off; note that drilling has continued since this time. JORC: The Joint Ore Reserves Committee Code (JORC 2004), see Glossary for definitions of "Inferred" and "Indicated" mineral resource etc.

Area	Drilling Completed*	Fe Grade and mineralised thickness encountered	JORC [^] Estimate	Comments
Area A	None – only mapped and surface samples	Surface rock chip samples up to 46%	None	Reconnaissance work has identified outcrop of Sherwin Formation with some areas of hematitic oolite. Significant further work is required to assess this area.
Area B	RC drilling : 90 holes totalling 4262 m in late 2010	Typically 40-45% and 1-4 m thick	None	Worthy of further drilling given lateral extent (8 km) of outcropping, shallow, high grade hematitic oolite. Central area of high grade outcrop still remains essentially untested.
Area C	RC drilling: 29 holes totalling 626 m in late 2010	Average 40% and 1-2 m thick	None	Thickness and quality of hematitic mineralisation relatively lower grade. However, the shallowness (0-9 m depth) and broad lateral extent (14 km) of mineralisation warrants further work to determine resource potential.
Area D South	RC Drilling: 124 holes totalling 2728 m in 2009 Infill RC Drilling: 38 holes totalling 989 m in late 2010	Mostly 30-45% occasionally up to 45-58% Typically 1-4 m thick, up to 8 m thick	<u>Inferred</u> Mineral Resource: 90.7 Mt @ 37.2% Fe Published Oct 09	There are up to four laterally extensive mineralised oolitic horizons of varying grade and thickness (generally 1-4 m thick) and close to the surface (0-16 m depth). Shows good prospects for future mining provided saleable product produced through beneficiation.
Area D North	RC Drilling: 27 holes totalling 2258 m in 2008 Diamond Drilling: 5 holes totalling 426 m in 2008 RC Drilling: 43 holes totalling 1486 m in late 2010	Average 45% commonly up to 50% Two main mineralised horizons, each 2-8 m thick	<u>Inferred</u> Mineral Resource: 116.5 Mt @ 40.3% Fe Published Feb 11	Hematite enrichment is very reliably laterally extensive (4.2 km) and occurs between 0 and 60 m depth. With a large proportion close to the surface. Shows good prospects for future mining provided saleable product produced through beneficiation. Is in close proximity to other identified economic deposits to the north (Areas E and F).

Area E South	RC Drilling: > 290 holes in late 2010	Typically between 45 and 50% and 10 m thick	<u>Inferred</u> Mineral Resource: 72.1 Mt @ 39% Fe Published Nov 10	Mineralised zone strikes east-west and dips gently to the north. Has significant strike extent and surface mineralisation. Shows good prospects for future mining provided saleable product produced through beneficiation. Is in close proximity to other identified economic deposits (Areas D North, E East and F).
Area E East	RC Drilling: 35 holes totalling 1655 m in 2009 RC Drilling: >40 holes in late 2010	Variable between 40 and 60%, commonly between 50-60% Variable thickness between 7-20 m	<u>Indicated</u> Mineral Resource: 12.1 Mt @ 46.1% Fe Incl. DSO of 4.7 Mt @ 55.6% Fe Published Dec 10	Mineralised zone strikes north-south and dips to the west at greater than 45°. Thickness of DSO is 5-10 m, enveloped in a halo of BFO. Has significant strike extent and is close to the surface. Has considerable mining potential and is planned for mining as part of the present mining lease application.
Area F East & West	Extensive RC Drilling: 290+ holes totalling 19,715 m between 2009 - 2011 Diamond Drilling: 20+ holes totalling 832 m between 2009 - 2011		<u>Inferred</u> Mineral Resource: 5.5 Mt @ 46.6% Fe Published Feb 12 <u>Indicated</u> Mineral Resource: 24.6 Mt @ 49.3% Fe Incl. DSO of 15.5 Mt @ 59.5% Fe Published Feb 12	Mineralised zone dips steeply to the north and is almost vertical in places. Recumbent folding of the Sherwin Formation has resulted in increased near-surface volumes of high grade mineralisation. This is to date, the most prospective area within the Roper Bar Project and is planned for immediate mining as part of the present mining lease application.
Area G	Only limited preliminary drilling completed to date	N/A	None	This Area comprises the western extension of Area D and recent drilling confirms the ironstone unit is continuous at depth. More drilling is required to determine ore depth, thickness, and grade.

3.6 Acid Mine Drainage (AMD) Potential

This section summarises the results of geochemical studies undertaken and details the management procedures that will be implemented to prevent any environmental impacts from Acid Metalliferous/Mine Drainage (AMD). A detailed report including a number of standard acronyms and terms that are used in the assessment of AMD potential is provided in Appendix K.

AMD refers to the process whereby rock materials containing sulfides are exposed to the atmosphere and microbial activity; causing the oxidation of these sulfides resulting in the production of sulphuric acid. At Roper Bar, the dominant sulfide mineral is pyrite (FeS_2), which is visible in variable quantities in the rocks that will be disturbed during open cut mining.

The potential acid forming (PAF) properties of rock materials (both waste and ore) have been characterised in order to gain an understanding of the potential for AMD at the Roper Bar Project Area.

3.6.1 Terminology

A number of standard acronyms and terms are used in the assessment of AMD potential. The main acronyms and terms used in this particular study and their meanings are:

- AMD Acid Metalliferous/Mine Drainage – the outflow of acidic and usually highly metal-rich water from excavated and exposed (oxidised) material from mining operations.
- ABA Acid-Base Accounting - is the analysis used to assess the potential of a material to produce acidity from sulfide oxidation taking into account its ability to also neutralize any acid formed. Determinations involved in this analysis include pH and electrical conductivities (EC) of paste solutions, Total-S and $\text{SO}_4\text{-S}$, maximum potential acidity (MPA), and acid-neutralisation capacity (ANC).
- NAPP Net Acid Producing Potential is a measure used in ABA analysis. It is given as $\text{kgH}_2\text{SO}_4/\text{ton}$ and determined by subtracting the ANC from the MPA (see definitions below): i.e $\text{NAPP} = \text{MPA} - \text{ANC}$. Conceptually, a negative NAPP indicates all acid produced is neutralised and a positive NAPP indicates the material is net acid producing.
- NNP – Net Neutralising Potential is the opposite of NAPP described above. It is given as $\text{kgH}_2\text{SO}_4/\text{ton}$ and determined by subtracting the MPA from the ANC (see definitions below): i.e $\text{NNP} = \text{ANC} - \text{MPA}$. Conceptually, a positive NNP indicates all acid produced is neutralised and a negative NNP indicates the material is net acid producing.
- MPA Maximum Potential Acidity – is the maximum amount of sulfuric acid produced from complete oxidation of sulfide minerals in the rock material. It is given as $\text{kgH}_2\text{SO}_4/\text{ton}$ and determined by multiplying the Sulfide-S values (in %) by 30.6 which accounts for the reaction stoichiometry for the complete oxidation of pyrrhotite and pyrite by O_2 to $\text{Fe}(\text{OH})_3$ and H_2SO_4 .
- ANC Acid Neutralising Capacity – is the measure of acid neutralising compounds (usually carbonates and exchangeable bases) in rock material able to neutralise any acid produced.
- APR Acid Potential Ratio – is ANC/MPA and is used (combined with other measures such as NAPP) to classify the material as either:
 - NAF Non-Acid Forming – for example where $\text{ANC}/\text{MPA} \geq 2$ and NAPP is negative
 - PAF Potentially Acid Forming – for example where $\text{ANC}/\text{MPA} < 2$ and NAPP is positive

3.6.2 Scope of Activities

The specific scope of activities included:

- Characterise selected drill-core rock samples in terms of their potential for acid forming (PAF) properties and enrichment and/or release of available metals to the environment.
- Analyse the sulfur distribution among the waste rock and ore materials.
- Evaluate results and assess the implications for mine operations with regards to waste rock management.

3.6.3 Sampling

A total of 204 samples were selected from 58 exploration drill holes located within Area F (West and East) and Area E (East and South). Sample locations are shown in Figure 3-13.

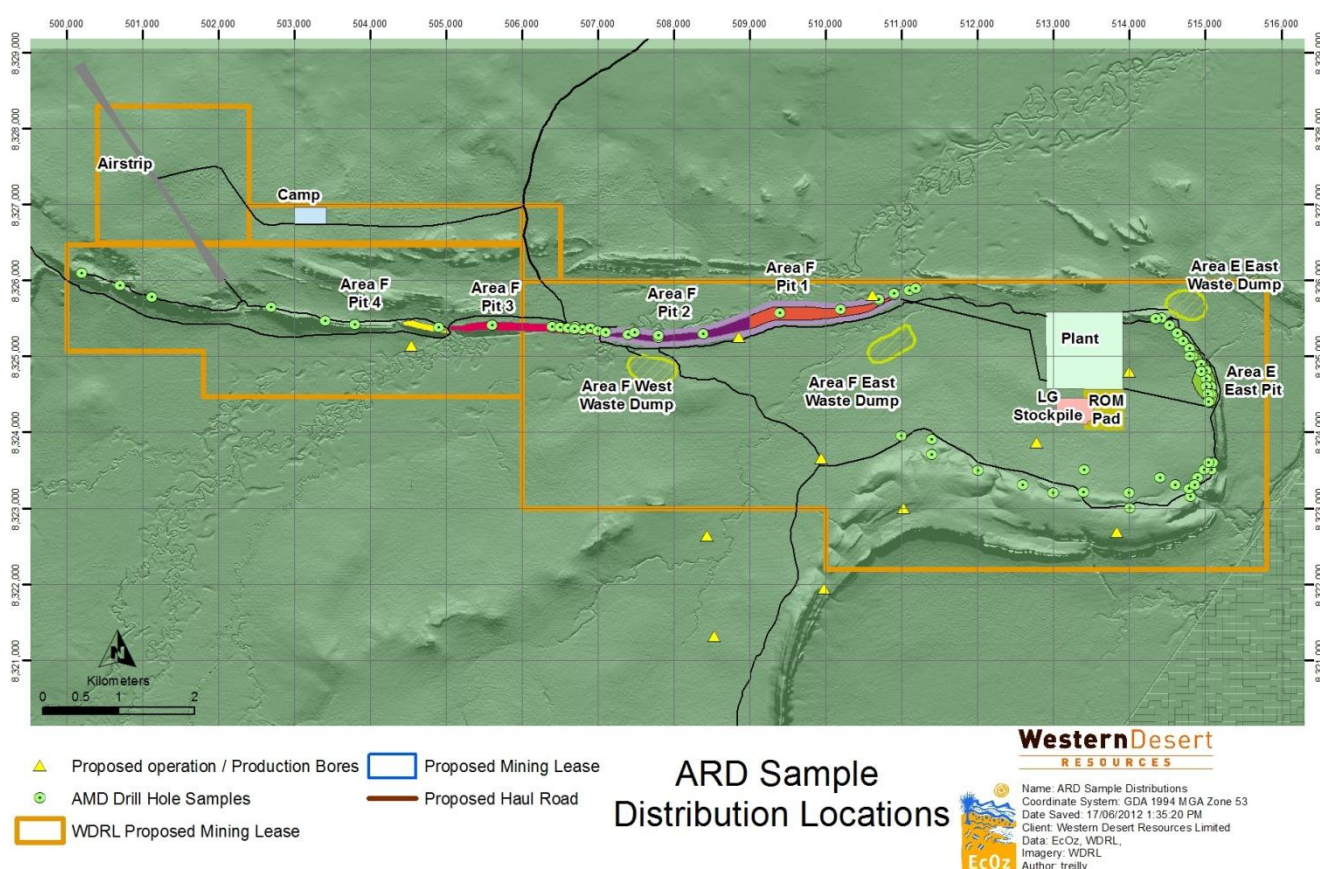


Figure 3-13 Location of drill holes from which samples were collected for potential acid forming (PAF) analysis.

3.6.4 Sample Analysis and Data Processing

Sample analysis and data processing on these 204 samples included:

- Mineralogical assessment using X-ray powder diffraction (XRD) followed by scanning electron microscopy and energy-dispersive micro-analysis (SEM-EDS) techniques. A geochemical abundance index (GAI) was used to assess enrichment of the samples for major elements.

- Acid Base Accounting (ABA) and Net Acid Generation (NAG) tests including pH and electrical conductivity (EC) of paste solutions, oxidation pH, Total-S and SO₄-S, acid-neutralization capacity (ANC), carbonate alkalinity as CaCO₃ and net-acid generation (NAG).
- Hydro-geochemical assessment of laboratory leachates produced to estimate the potential quality of mine drainage as a first indicator of sulfide mineral oxidation.

In addition, an analysis of sulfur (%S) distribution within the ore and waste was also undertaken on a total of 6,385 XRF sulfur assays or handheld Niton XRF readings at one metre down hole intervals from exploration drill holes within the proposed pits.

3.6.5 Classification Criteria

Currently no standard criteria exists for classifying mine wastes in terms of their acid forming potential (AFP). This is because of the complexity of specific mineral assemblages and ore deposit specific characteristics. However, on the basis of laboratory and field experiences, several AMD practitioners and researchers have indicated that calculated Net Acid Producing Potential (NAPP) and Acid Potential Ratio (APR) present a starting point for classifying the AFP of mine waste materials. Others use net acid generation (NAG)-pH in association with the NAPP to classify the acid generating potential of a sample. Table 3-5 lists the most accepted AFP criteria used for classifying the particular mine waste materials being assessed.

Table 3-5 Acid Forming Potential (AFP) Classification Criteria

Category	Campbell, 2005 and DITR, 2007	Lei and Watkins, 2005	OSS-ACMRR*-DITR
Non-Acid Forming (NAF):	Sulfide-S < 0.3% For Sulfide-S ≥ 0.3%, a negative NAPP value and APR ≥ 2.0	NAPP < -20 APR >3	NAG-pH > 4.5 NAG <5-10
Potentially Acid Forming (PAF):	For Sulfide-S ≥ 0.3%, any positive NAPP value, negative NAPP value with an APR < 2.0	NAPP > 20 APR < 1	NAG-pH <4.5 NAG > 10
Zone of Uncertainty	NAPP: between -20 and +20; APR: between 1 and 3		
*Office of the Supervising Scientist and the Australian Centre for Mine Rehabilitation Research.			

3.6.6 Findings and Implications for AMD Management

Sulfur Distribution

The distribution of sulfur analysed on the 6,385 XRF sulfur assays or handheld Niton XRF readings at one metre down hole intervals indicates an overall low level of sulfur concentration in each mining area (see Table 3-6). The average sulfur concentration for most lithotypes is less than 0.3 %, except for fresh Moroak Sandstone in Area E East and fresh Kyalla Member in Area E South. Sporadic high sulfur concentrations (greater than 0.3%) are found in fresh rock in all proposed mining areas.

The distribution of sulfur within the Roper Bar iron deposits has been further examined in cross section. Representative cross sections displaying the down hole sulfur distributions are shown in Figure 3-14, Figure 3-15, and Figure 3-16. This data also indicates an average low level of sulfur, with sporadically high concentrations in each mining area, particularly in Areas E East and F East. An important observation from this assessment is that the upper levels of waste rock (which represents the early stages of mining) consist of oxidised rock, with lower levels of sulfur compared to concentrations in deeper fresh rocks. From a waste management perspective, these oxidised rocks have the potential to be used to assist in the management of any issues that may arise from high sulfur zones encountered in the fresh rock.

Table 3-6 Summary of sulfur distribution in different lithotypes from XRF sulfur assays or handheld XRF readings taken at 1 m down hole intervals.

KYM = Kyalla Member; SIM = Sherwin Ironstone Member; MSM = Moroak Sandstone Member
(see

Figure 3-8 for stratigraphic and lithographic description of these units.
OX = oxidised; FR = Fresh

Lithotype	Number of Samples	Average S%	Maximum S%
Area F-West			
KYM_OX	11	0.04	0.19
KYM_FR	32	0.16	0.55
SIM_OX	140	0.03	0.49
SIM_FR	176	0.09	1.65
MSM_OX	117	0.08	1.04
MSM_FR	30	0.15	0.35
Area F-East			
KYM_OX	202	0.01	0.22
KYM_FR	423	0.18	5.66
SIM_OX	513	0.03	1.50
SIM_FR	2044	0.08	5.00
MSM_OX	586	0.04	3.68
MSM_FR	817	0.11	1.76
Area E-East			
KYM_OX	11	0.20	0.40
SIM_OX	135	0.03	0.27
SIM_FR	30	0.05	0.24
MSM_OX	8	0.12	0.54
MSM_FR	9	0.80	4.03
Area E-South			
KYM_OX	233	0.02	0.77
KYM_FR	37	0.31	1.03
SIM_OX	574	0.02	0.26
SIM_FR	177	0.09	1.58
MSM_OX	8	0.02	0.04

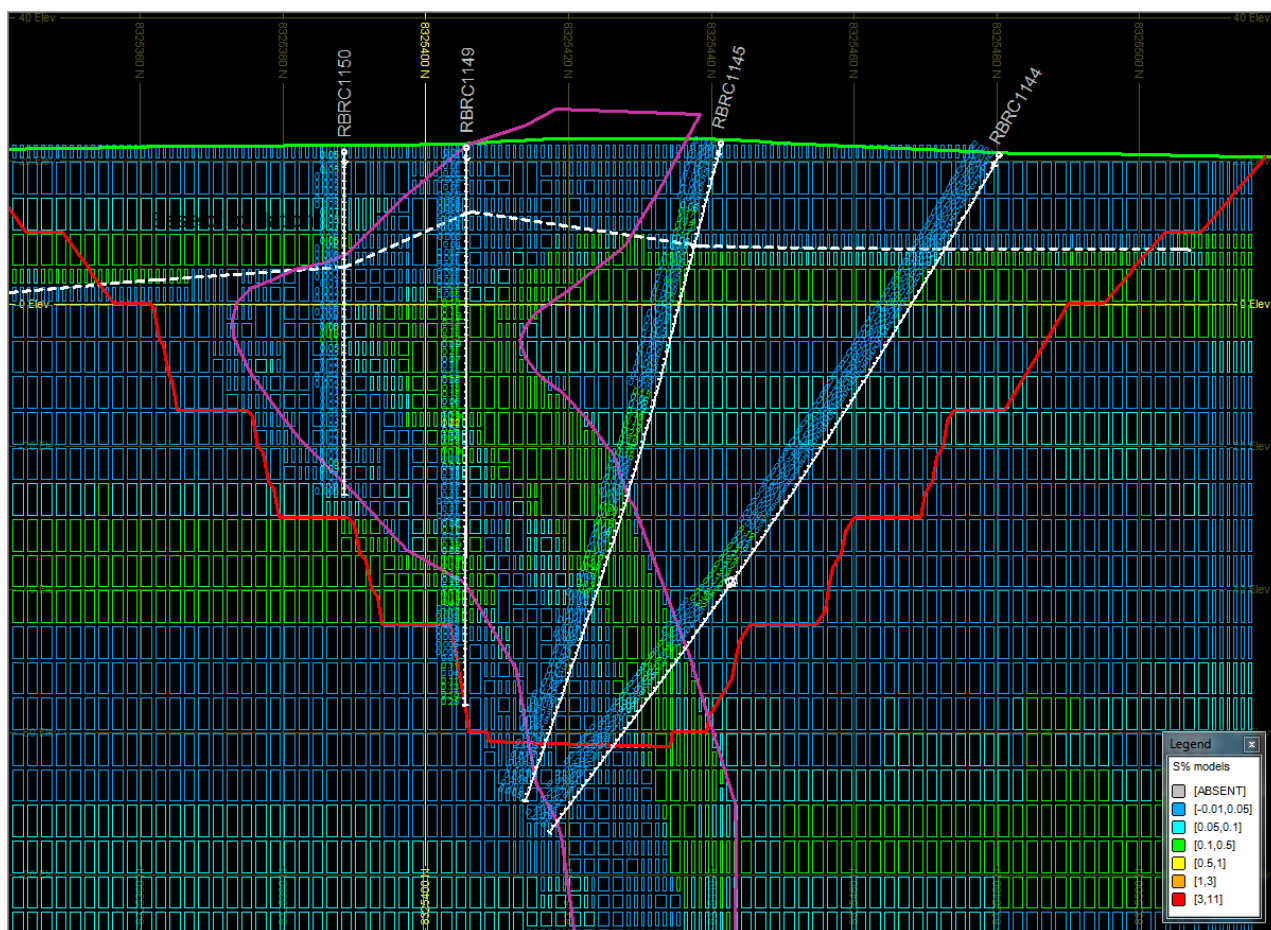


Figure 3-14 Area F-East Cross Section 508900E (S-N) showing sulfur distribution.

Note for Figure 3-14 Figure 3-15 and Figure 3-16 area between pink lines is the Sherwin Iron Formation (SIF), with the Kyalla Member to the left and the Moroak Sandstone to the right. Area above the white-dashed line is the Oxidation Zone.

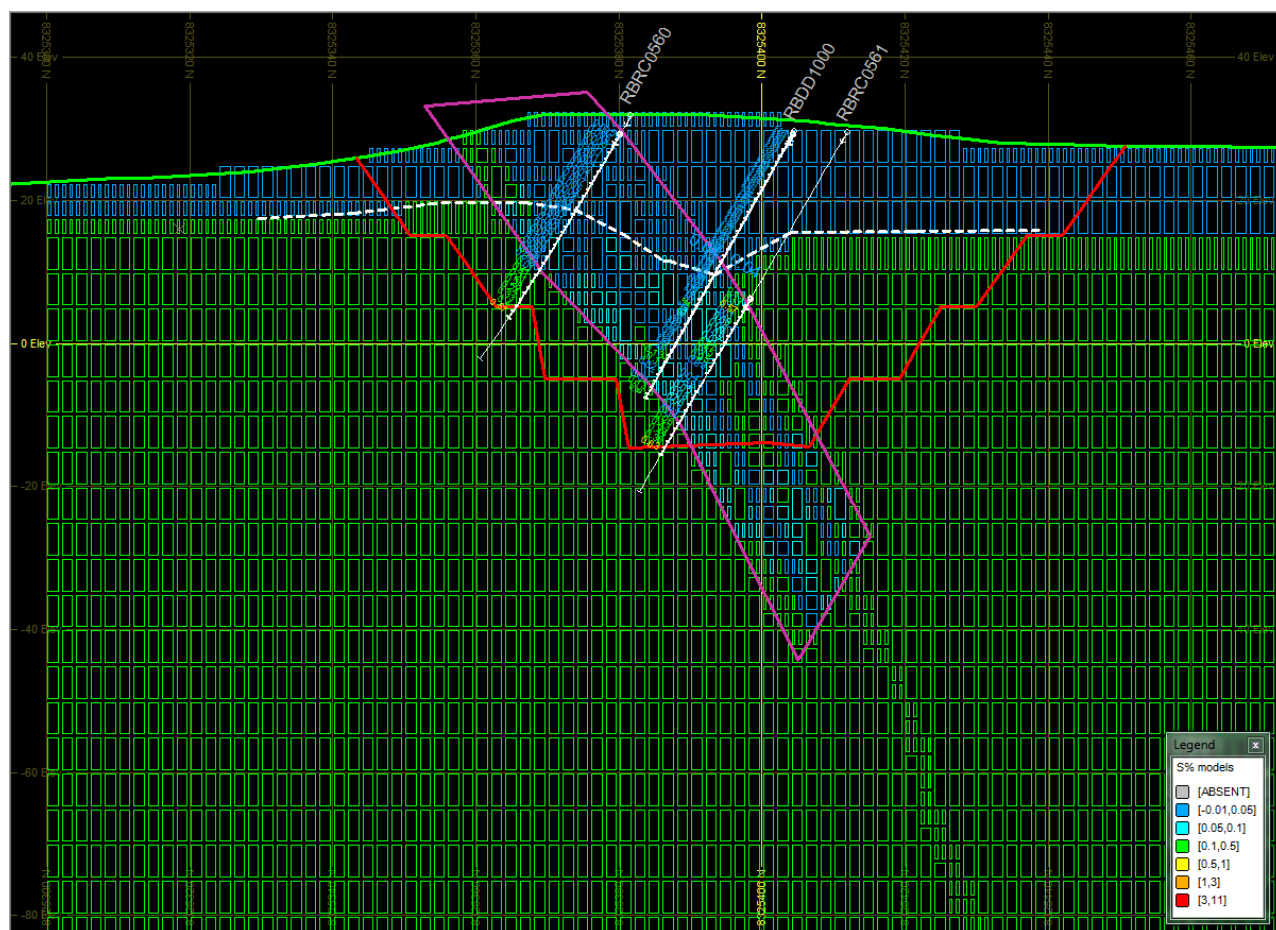


Figure 3-15 Area F-West Cross Section 505700E (S-N) showing sulfur distribution.

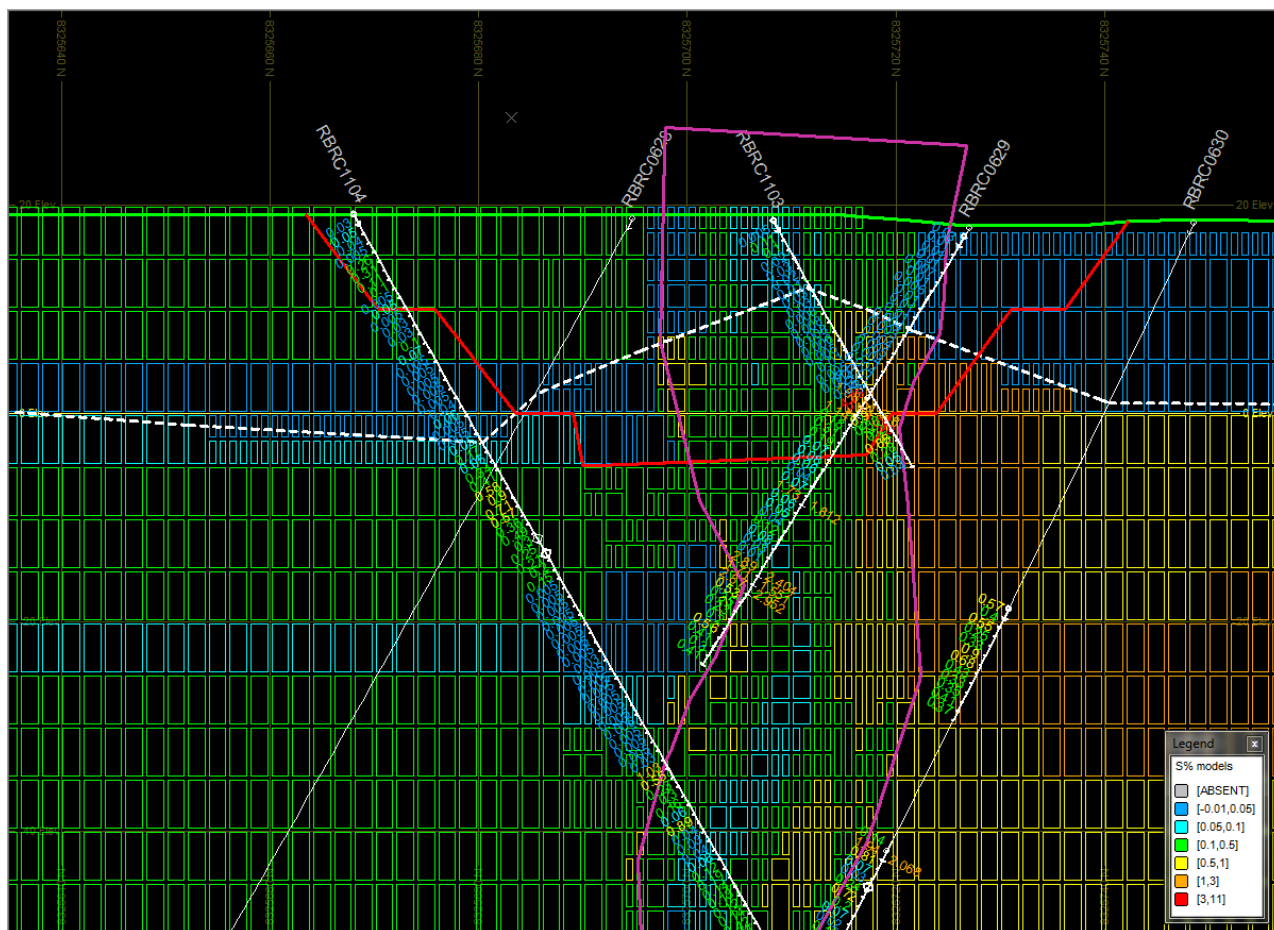


Figure 3-16 Area E-East Cross Section 510500E (S-N) showing sulfur distribution.

Acid Base Accounting (ABA) Analysis

The Acid Base Accounting (ABA) assessment classified materials proposed for excavation as either potentially acid forming (PAF) or non-acid forming (NAF) based on the criteria in Table 3-5 above. The result of this analysis is summarised in Table 3-7. In addition, a preliminary mass balance of acid- and alkaline-producing material is presented in Table 3-8 based on a block model developed by Smith and Brady (1990) and average thicknesses of about 12 m for the proposed benches to be excavated during mining. Note this analysis is based on several assumptions and will require ongoing validation during further exploration, construction, and mining. For more details refer to Appendix K.

Table 3-7 Distribution of PAF materials.

SST = sandstone; CY = Clay; OST = oolitic sandstone; OO = haematitic oolite; SOO = sandy oolite;
SLT = siltstone; SIDOO = sideritic oolite; SIDSOO = sideritic sandy oolite.

See Figure 3-8 for lithotype descriptions.

Depth (mbgl)		Prospect Code	Lithotype	Proportion of Lithotype	% PAF Lithotype	% each PAF Lithotype	% of NAF Lithotype	% of Lithotype (uncertain)
From	To							
0	50	Area E East	SST	36%	29%	81%	19%	0%
			OO	31%	24%	79%	21%	0%
			CY	2%	0%	0%	100%	0%
			OST	2%	2%	100%	0%	0%
			SOO	16%	9%	57%	29%	14%
			SLT	11%	11%	100%	0%	0%
			SIDOO	2%	0%	0%	0%	100%
			Total PAF Samples 76%					
50	100	Area E East	SST	30%	20%	67%	0%	33%
			OO	30%	10%	33%	67%	0%
			SOO	20%	0%	0%	50%	50%
			SLT	10%	10%	100%	0%	0%
			SIDOO	10%	0%	0%	100%	0%
			Total PAF Samples 40%					
100	130	Area E East	SST	40%	0%	0%	100%	0%
			OO	20%	0%	0%	100%	0%
			SLT	40%	0%	0%	100%	0%
			Total PAF Samples 0%					
0	50	Area E South	SST	33%	3%	9%	73%	18%
			OO	24%	0%	0%	88%	13%
			OST	12%	6%	50%	50%	0%
			SOO	12%	0%	0%	100%	0%
			SLT	9%	0%	0%	100%	0%
			SIDOO	3%	0%	0%	100%	0%
			SIDSOO	6%	0%	0%	100%	0%
			Total PAF Samples 9%					
50	70	Area E South	SLT	100%	0%	0%	50%	50%
			Total PAF Samples 0%					
0	50	Area F East Pit 1	SST	50%	29%	57%	29%	14%
			OO	43%	14%	33%	17%	50%
			OST	7%	0%	0%	100%	0%
			Total PAF Samples 43%					
50	70	Area F East Pit 1	SST	50%	0%	0%	100%	0%
			OO	50%	0%	0%	100%	0%
			Total PAF Samples 0%					
0	50	Area F East Pit 2	SST	67%	25%	38%	50%	13%
			OO	8%	4%	50%	0%	50%
			OST	8%	4%	50%	50%	0%
			CY	13%	0%	0%	100%	0%
			SOO	4%	0%	0%	100%	0%
			Total PAF Samples 33%					
50	80	Area F East Pit 2	SST	100%	0%	0%	100%	0%
			Total PAF Samples 0%					
0	50	Area F East Pit 3	SST	16%	4%	25%	50%	25%
			OO	12%	4%	33%	67%	0%
			SLT	56%	40%	71%	0%	29%
			CY	12%	0%	0%	100%	0%
			SOO	4%	0%	0%	100%	0%
			Total PAF Samples 48%					
50	80	Area F East Pit 3	SLT	100%	75%	75%	0%	25%
			Total PAF Samples 75%					
0	50	Area F West	SST	37%	5%	14%	71%	14%
			OO	32%	0%	0%	83%	17%
			OST	5%	0%	0%	0%	100%
			SOO	11%	5%	50%	50%	0%
			SLT	11%	0%	0%	100%	0%
			SIDOO	5%	0%	0%	0%	100%
			Total PAF Samples 11%					
50	60	Area F West	SST	25%	0%	0%	100%	0%
			OO	75%	25%	33%	33%	33%
			Total PAF Samples 25%					

Table 3-8 Mass Acid Base Accounting (ABA) results.

Activity	Unit	Depth (m)		Thickness	Unit WT	Fraction	Volume	Ton (Rock/Ore)	Sulfide	ANC	Tons	Tons	NNP
		From	To	(m)	kg/m³	Spoiled	(m³)	materials	%		MPA	ANC	Tons
Area E East													
Pit	MSM (90%), SIM (10%)	0	15	15	2,800	1	3,931,947	12,135,843.24	0.13	45.60	48,276	553,394	505,118
	SIM (80%), MSM (10%), KYM (10%)	15	27	12	2,675	0.5	2,831,002	8,347,726.46	1.97	32.00	251,098	133,564	-117,534
	SIM (30%), MSM (35%), KYM (35%)	27	39	12	2,675	0.6	2,673,724	7,883,963.88	1.73	33.70	250,127	159,414	-90,714
	SIM (70%), KYM (30%)	39	51	12	2,675	0.5	2,123,251	6,260,794.84	2.00	22.40	191,772	70,121	-121,651
Totals						2.6	11,559,924.4	34,628,328.4		133.7	741,273.5	916,492.7	175,219.2
Area E South													
Pit	SIM (90%), KYM (10%)	0	15	15	2,800	1	61,473,958	189,737,631	0.02	4.47	110,313	848,393	738,079
	SIM (60%), MSM (30%), KYM (10%)	15	27	12	2,675	0.75	37,157,593	109,565,953	0.37	25.21	917,807	2,071,380	1,153,573
	SIM (90%), MSM (10%)	27	39	12	2,800	0.75	29,507,500	91,074,063	0.12	33.05	250,818	2,257,498	2,006,680
	MSM (90%), SIM (10%)	39	51	12	2,800	0.9	21,857,407	67,462,269	0.11	25.55	30.38	1,551,295	1,551,264
Totals						3.4	149,996,458.3	457,839,915.0		88.3	1,278,968.4	6,728,566.0	5,449,597.6
Area F East Pit 1													
Pit	MSM (90%), SIM (10%)	0.0	15.0	15.0	5,335	0.95	4,671,153	27,470,261.34	0.01	1.40	10,621	36,535	25,915
	SIM (90%), KYM (10%)	15.0	27.0	12.0	2,675	0.30	3,529,316	10,406,832.32	1.87	5.30	178,650	16,547	-162,103
	KYM (90%), SIM (10%)	27.0	39.0	12.0	2,675	0.50	2,802,692	8,264,249.19	1.42	2.30	179,865	9,504	-170,361
	MSM (90%), SIM (10%)	39.0	51.0	12.0	2,800	0.75	2,076,068	6,407,725.23	0.15	16.38	22,059	78,695	56,636
Totals						2.50	13,079,228.73	52,549,068.08		25.38	391,194.56	141,281.07	-249,913.49
Area F East Pit 2													
Pit	KYM (45%), SIM (40%), MSM (15%)	0.0	15.0	15.0	2,675	0.60	4,406,338	12,992,892	0.01	11.01	2,624	85,831	83,207
	KYM (70%), SIM (30%)	15.0	27.0	12.0	2,675	0.70	3,329,233	9,816,851	0.59	18.13	123,012	124,608	1,596
	KYM	27.0	39.0	12.0	2,800	0.75	2,643,803	8,160,022	0.73	31.70	136,334	194,005	57,670
	KYM	39.0	51.0	12.0	2,800	1.00	1,958,372	6,044,460	0.11	21.70	19,883	131,165	111,282
Totals						3	12,337,745	37,014,225		83	281,854	535,609	253,755
Area F East Pit 3													
Pit	TC (Clay) (60%), SIM (20%), MSM (20%)	0.0	15.0	15.0	2,800	1.00	3,672,325	11,334,528	0.02	6.3	5,946	71,408	65,462
	MSM	15	27	12.0	2,650	0.60	2,774,646	8,105,087	0.24	21.2	35,491	103,097	67,606
	SIM	27	39	12.0	2,650	0.50	2,203,395	6,436,392	0.39	14.00	38,209	45,055	6,846
	SIM (70%), KYM (30%)	39	51	12.0	2,650	0.50	1,632,145	4,767,698	1.00	10.30	73,165	24,554	-48,611
Totals						2.60	10,282,510.40	30,643,704.75		51.80	152,810.48	244,112.62	91,302.14
Area F West													
Pit	MSM	0	15	15	2,800	1.00	30,845,392	95,203,428	0.02	1.80	58,264	171,366	113,102
	SIM (90%), MSM (10%)	15	27	12	2,675	0.90	23,305,407	68,720,252	0.28	21.00	537,486	1,298,813	761,327
	SIM (90%), KYM (10%)	27	39	12	2,650	0.80	18,507,235	54,061,947	0.07	26.90	97,008	1,163,413	1,066,405
	SIM	39	51	12	5,335	0.75	13,709,063	80,620,681	0.01	12.90	18,502	780,005	761,503
Totals						3	86,367,097	298,606,308		62.6	711,261	3,413,597	2,702,336
Grand Totals						18	283,622,964	911,281,549		444.3	3,557,361	11,979,658	8,422,297

The salient findings of this testing program were:

Mineralogical assessment:

- The characteristic mineralogical composition in all prospect areas is Quartz > Hematite > Siderite > Pyrite > Kaolinite > Muscovite > Goethite > Iron. Sulfides, principally in the form of pyrite, are contained as minor or trace concentrations. These are more significant in prospect Area E East sample materials.
- XRF analysis defines the samples as having elemental composition in the order of Si > Fe > Al > Mg > Mn > K > Ca > Na. Sporadic presence of sulfides, principally pyrite, are also significant.
- Sample enrichment, defined by the values of the Geochemical-Abundance Index (GAI), occurs by iron, sulfur and manganese only. Significant enrichment with sulfur, by about 96-fold, was observed in samples from prospect Area E East, particularly among the oolites, sandstones and oolite sandstones at depths between 19 and 24 m below ground level.
- SEM and EDS analysis also shows that elemental concentration is in the order oxygen > carbon > iron > silicon, with varying minor and trace amounts of aluminium, calcium, magnesium and sulfur. About 95% of samples assessed, particularly the oolites, sandstones, sandstone oolites and the sandy oolites, contain minor to trace quantities of sulfur.

Acid-base chemistry:

- The highest oxidation-pH occurs at depths between 23 to 25 m below ground level among oolites and strongly sideritic sandy oolites in prospect Area E South, indicating significant concentrations of readily available alkaline materials. The lower oxidation pH values were in samples from prospect Areas E East, F East Pit 1 and F East Pit 3. See Appendix K for presentation of oxidation-pH results.
- Total sulfur distribution and concentration varies with depth and lithological composition. Of the 204 samples analysed for ABA analysis (as opposed to the XRF readings of the 6835 samples presented in Table 3-6), 55% contained Total-S lower than 0.3%, with a maximum concentration of 5.97% in the sandstones of the Kyalla Member (KYM) within prospect Area E East.
- The highest average concentration of sulfur (1.58%) was observed in prospect Area E East, whilst the lowest (0.21%) was observed in prospect Area E South. Prospect Area F East Pit 1 has significant average sulfur concentration (0.86%) ranging from 0.01 to 2.7%.
- Sulfur concentration in a total of 18,866 readings in samples from exploration drill holes indicate an overall low level, with sporadic high sulfur concentrations in each mining area, particularly at prospect E East and F East.
- ANC assessment of samples indicates that most of the samples in all prospect areas contain low ANC values with an average of ~15 kgH₂SO₄/ton. However, sporadic sandstones and oolites in all prospect areas (particularly those located at near surface) presented relatively high ANC concentrations.
- The highest average ANC (22.75 kgH₂SO₄/ton) concentrations were found in the lithotypes within prospect Area E South, indicating that from a waste management perspective, this Area contains significant ANC hosting materials.
- The majority of PAF samples in prospect Area E East (~76%) are located between 0 and 50 m below ground level (Table 3-7). Sandstones, Oolites, Sandy Oolites and Siltstones are those with the highest PAF sample concentrations. Clays in this sequence are all NAF materials. Concentrations of PAF materials decrease with depth to about 40%.

- A total of 9% of samples in prospect Area E South are classified as PAF, all of which were localised near-surface. All samples below 50 m depth was classified as NAF, with only one SLT sample (~57 m depth) presenting uncertain characteristics (Table 3-7).
- Prospect Area F East includes Areas F East Pit 1, Pit 2 and Pit 3. About 41% of near-surface samples to a depth of about 50 m below ground level are classified as PAF materials, with significant concentrations of PAF sandstones and oolites at depths between 15 to 36 m below ground level (Table 3-7). Significant concentrations of NAF materials are at near-surface, between 0.0 to 15 m below ground level.
- A lower amount of PAF materials (~ 18%) were observed in prospect Area F West. Most of the samples are scattered across the stratigraphical sequence, with particular concentration at between 40 to 50 m below ground level. Sandstones and sandstone oolites, which compose about 50% of lithotypes within this horizon, present the highest concentrations of PAF materials.
- Siltstones, oolites and deep-bedded sandstones are predominantly NAF materials within the prospect Area F West. All siderite oolites and oolite sandstones, which are encountered at shallow domains, are “uncertain to be classified” samples.
- NAG values range from less 0.1 kgH₂SO₄/ton to a maximum of 154 kgH₂SO₄/ton and strongly correlate with the highest NAPP values.
- In general, using the proposed criteria:
 - 52% of the samples can be classified as Non-Acid Forming (NAF).
 - 34% are classified as Potentially Acid forming (PAF).
 - 14% of samples fall within a zone of uncertainty (UC), which require further assessment.

Hydro-geochemical Assessment:

- Average pH values of leachates from 83 samples are slightly acidic (pH 6.3) and range from 3.0 to 8.2. The low average pH values are associated with samples from Area E East, whilst the highest average pH (pH 7.3) was observed in sample solutions from Area F East Pit 2, indicating these samples have available alkaline materials.
- Despite the low pH observed in samples from prospect Area E East and as compared with the results from samples in the other prospect areas, average calcium and magnesium concentrations are relatively high. Potassium and aluminium are also relatively high, indicating that these samples have readily available carbonates and aluminosilicate minerals to buffer potential acid environments in the short term.
- Generally, the highest concentrations of sulfate, iron, aluminium and manganese and most other metals were associated with low-pH samples.
- According to their hardness the majority of leachates can be classified as being very soft, with only five samples ranging from moderately soft to very hard waters.
- Most of the samples from Areas E East and E South produced sodium-potassium-bicarbonate type waters, whilst a significant number of samples from Areas F East Pit 2 and Pit 3 produced sodium-potassium-sulfate-chloride leachate types.

It does not appear that one particular lithology is PAF but some generalisations can be made:

- The siltstones (SLT) in Area E (East) and Area F (East) are PAF materials, whereas the siltstones in Area E (South) and Area F (West) are non-acid forming.
- Clay (CY) units are always non-acid forming.

- The hematitic oolite (i.e. the main target ore) within the Sherwin Formation is low to moderately PAF, with the highest proportion of PAF material in Area E (East) and Area F (East) and lower proportions of PAF in Area E (South) and Area F (West).
- Layers within the Sherwin Formation containing siderite tend to be non-acid forming. That is the strongly sideritic sandy oolite (SIDSOO), and sideritic oolite (SIDOO).
- The sandy oolite (SOO) layers within the Sherwin Formation are moderately PAF in Area E (East and South) and non-acid forming in Area F (East and West).
- The oolitic sandstone (OST) layers within the Sherwin Formation are quite variable in regards to PAF. They are highly PAF in Area E (East) and Area F (West), moderately PAF in Area E (South) and non-acid forming in Area F (East).
- Sandstones are quite variable ranging from moderately to highly PAF. They are highly PAF in Area E (East) and moderately PAF in the other Areas. At depth, sandstones are NAF, particularly below 90 m.

The overall mass balance (Table 3-8) for all pits combined indicates that Acid Neutralizing Capacity (ANC) materials will be higher by about 70% as compared to the Maximum Potential Acidity (MPA) materials. Most of the near surface materials to a depth of about 20 m across all proposed pits rendered a desirable positive net neutralising potential (NNP) value indicating dominance of ANC materials.

Other key observations are:

- The top 51 m in prospect Area F West render positive NNP values with high ANC materials at depths between 15 and 37 m below ground level.
- Although a positive NNP was calculated for prospect Area E East, MPA materials are significant, particularly at depths between 15 m to 23 m and 25 m to 77 m below ground level. Lithotypes with significant ANC characteristics are located below 77 m.
- With the exception of Area F East Pit 1, ANC materials are higher than MPA materials in all other pits indicating lower AMD potential for these pits.
- MPA materials in Area F East Pit 1 are significant at depths between 15 to 39 m below ground level whilst in prospect Area F East Pit 3 MPA material are located between 39 to 51 m extending to about 87 m below ground level.

The key conclusion of the study is that AMD is not likely to be an issue with major implications for the Roper Bar Project. However, further more detailed studies are required to understand the extent and distribution of high sulfur zones which pose the greatest risk for acid mine drainage.

3.6.7 Acid Mine Drainage (AMD) Management

Based on the assessment outlined above and detailed in Appendix K, and by applying a conservative approach, the implications for mine waste materials management indicates that careful management of ores and waste rocks will be required. With regard to the management of PAF materials during mining, a preliminary risk assessment framework (Appendix K) was developed to promote better environmental practice and continuous environmental improvement and awareness of AMD issues.

A comprehensive waste management procedure will include:

- Since current predictions reveal that about 70% of materials contain higher ANC values, waste rocks to be managed and disposed of undergo;
 - Site control and monitoring of excavated materials whilst developing the pit structures which will also be carefully engineered and monitored.

- Upfront engineering/scientific approaches to identify/predict, prevent, remediate and monitor potential AMD formation.
- Assessment and performance evaluation of selected methodologies for the on-going identification/prediction, prevention, treatment and remediation of AMD. Rehabilitation and closure of the mine will be the driver for this assessment.
- On-going risk assessment to define impacts on the local ecosystems and downstream environments.

Specific approaches selected to adequately manage the potential for AMD formation during the construction phase includes;

1. Continuous and detailed waste/ore body materials geochemical characterisation and this will include:

- Identification and review of available site collated data.
- Targeted drilling at narrower spacing to define whether predicted and identified PAF materials, particularly those defined as highly localised, are extent across the bulk and ore body and waste rock materials. Findings will assist in improving delineation of both PAF/NAF waste and ore materials and define further management processes.
- Refine geochemical characterisation plan. A refined geochemical characterisation plan may include;
 - Refine block model to improve waste rock/ore body delineation on regards to NAF/PAF characterisation.
 - Define NAF/PAF characterisation in exposed and properly delineated low grade ore bodies.
 - Define selective and targeted sampling procedures for NAF/PAF characterisation.
 - In-field characterisation/screening for PAF of both waste and ore body. The in-situ paste pH is a simple method for determining readily available acidity and alkalinity and indicates the immediate reactivity of sulphides and acid neutralising minerals present in the samples and this shall be the principal screening test. In this context;
 - A paste pH > 5.0 suggest the presence of reactive carbonates.
 - A paste pH < 5.0 suggests that the materials contain acidity from prior acid generation.
 - Specific paste pH screening methodology and steps will be defined and implemented before mine operations starts.
 - Where feasible and practical water sampling in the excavated area would be carried out to define natural weathering features.
 - Where materials show low paste-pHs, representative samples will be sent to the laboratory for full ABA assessment and results will be used for the overall mass waste rock ABA evaluation.
 - Where PAF materials are encountered, materials will be segregated and where possible prevent wider interaction with the atmosphere, particularly by rainfall. If disposal of these materials due to operational activities is postponed, materials will be provisionally encapsulated with NAF materials to then adequately be disposed of.
 - Implementation of kinetic tests to investigate SoRs and potential quality of drainage from mine waste structures, and this will entail;
 - Short term tests pre-mining kinetic tests. Although a detailed methodology to implement the test is in progress, a preferred kinetic test approach will include the implementation of field test columns and pads for each material of concern.

- Monitoring of weathering conditions, drainage chemistry and loadings.
- Long term kinetic tests. Investigation phase.
- Refine the overall Waste Rock Management Plan.

2. During-mining PAF waste rock management activities:

- Implement long term kinetic tests. This will include:
 - Continuing pre-mine field kinetic tests and setting up new field test pads and monitoring sites on project components to study materials of concern.
 - Monthly basis monitoring of weathering conditions, drainage chemistry and loadings.
 - Prediction of post-closure drainage chemistry which will be periodically repeated.
- Refine waste management approaches and included conceptual models to suit new observations and findings.
- Initial conceptual model for the disposal of PAF waste/low grade ore materials include:
 - Initial excavated NAF materials will be used to construct engineered beds and/or cells for the disposal by encapsulation of PAF materials. Encapsulation of PAF materials with high NAF materials will be accomplished as shown in the conceptual model below (Figure 3-17).
 - Mine engineered waste rock dump (Figure 3-17) will include drainage systems, sediment traps, seepage diversion barriers and collection ponds, and embankments to prevent surface waters entering the waste rock dumps containing PAF materials.
 - Identification of clay and highly weathered NAF materials to be used to construct an impermeable base for the Waste Rock Dump and for providing a landscaped cap during rehabilitation with the view to minimize ingress of oxygen and infiltration of rain. Significant weathered NAF rock materials, excluding those that are potentially acid forming, would be considered to be used for constructing pads and walls.
 - Inhibition of oxygen and water into PAF materials is to be achieved by engineered dry covers (Figure 3-17 and Figure 3-18). The applicability of store-release cover types as an option is being currently investigated.
 - Monitoring will include surface water structures conveying and containing waters from ore and waste rock dumps. Shallow and deep bores for ground water monitoring will be constructed up and downstream of these facilities.

If ongoing waste characterisation identifies increased concentrations of PAF materials, a further approach of PAF management will include an updated PAF encapsulation model (Figure 3-18). However, this approach will need to be further investigated and engineered.

3. Post-mining, closure and rehabilitation:

- Mine waste handling will include processes and methodologies to prevent or minimize exposure of PAF materials to the atmosphere. Processes and methodologies which may include pit back filling, subaqueous disposal of reactive waste in mine voids and/or in-pit disposal of waste rocks with alkaline materials addition will be described and developed as necessary and consulted with the relevant authorities.

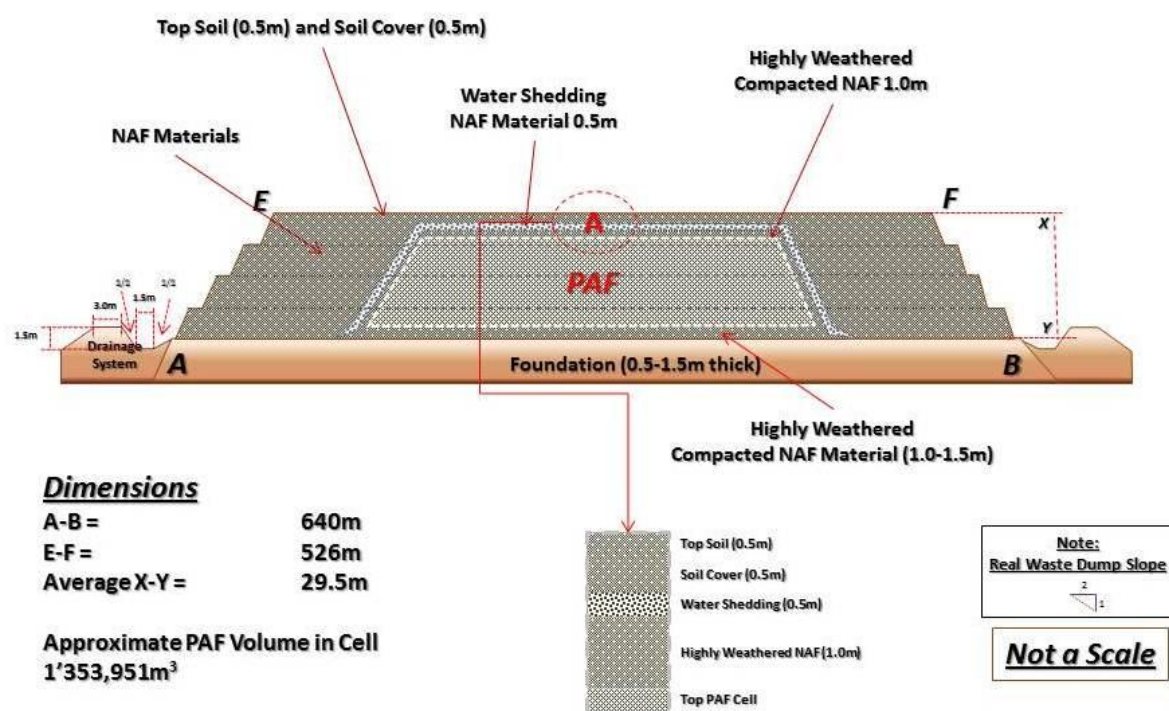


Figure 3-17 Option I; Schematic Proposed Waste Rock Dump Arrangement

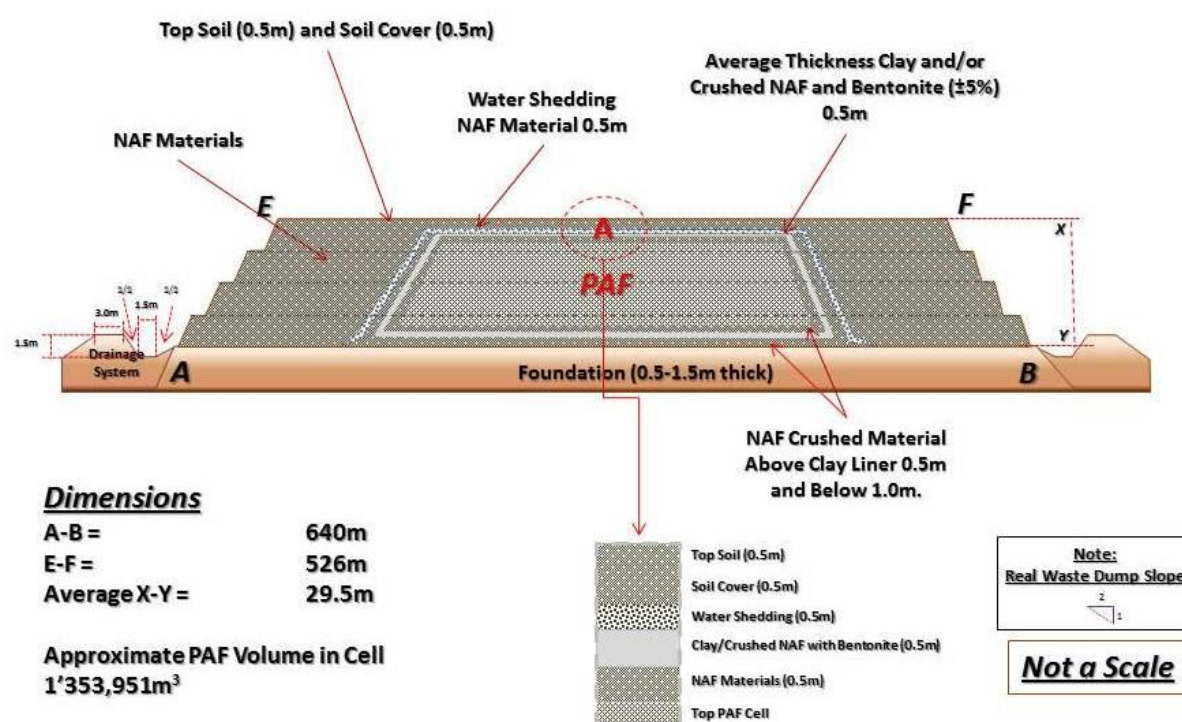


Figure 3-18 Option II; Schematic Proposed Waste Rock Dump Arrangement

Note: Waste Rock Dumps will be constructed with adequately engineered drainage systems, sediment traps, seepage diversion barriers and collection ponds, lysimeters to quantify infiltration rates, and embankments. Crushed NAF materials will be mixed with clays to prevent ingress of oxygen and water into the PAF materials.

3.7 Soils and Land Capability

Regional soil surveys have previously been conducted as a component of land system mapping of the Southern Gulf and Roper regions (Aldrick & Wilson 1990, 1992) and the analysis provided here is based on this regional land system data. More detailed soil survey data across the Project Area and along the Haul Road has been completed for this Project and is detailed in Appendix N2 – see Geotechnical Investigation by Golder, also Appendix P – Rehabilitation Plan.

Table 3-2 gives the soil types that predominate in each land system and the area and kilometre length of each of these land systems within the Project Area and along the Haul Road. In the Project Area, soils in the lower lying areas (Frog [Taf] land system) are predominantly deep siliceous and earthy sands, sandy yellow earths and sandy solodic soils. Mining infrastructure planned for these areas include the processing plant, waste dumps, and low-grade stockpiles, as well as most of the access roads to these areas and the mining pits. A large proportion of the Area F mining pits are also within this soil type. On the ridges (Bukalara [Asb] land system) soils are predominantly lithosols and siliceous sands. The Area E (East) mining pit is located on these soils as well as a proportion of the Area F pits (Pits 3 and 4), and Area E waste dump. A proportion of the Area F pits (Pits 1 and 2) are also near the Towns River (McArthur [Tam] land system), where soils are grey and brown clays, red and yellow earths and siliceous sands.

It is difficult to summarise the large number of different soil types along the Haul Road route, however the main land systems are Horse Creek [Alh], Seigal [Als], Fletcher [Lwf], Running [Lwr], McArthur [Tam], and Rosie [Tor]; please refer to Figure 3-5 and Table 3-2 for location and description of land systems and their associated soil types.

Aldrick and Wilson (1990, 1992) recognised soil erosion as the most significant type of land degradation likely to occur in the region. This is because climatic seasonality, high intensity wet season rainfall, cyclonic winds and the susceptibility of deeper soils, can mean even very low slopes can be highly susceptible to soil erosion if disturbed.

Table 3-2 lists the soil erosion risk identified for each land system type based on if that land were cleared for crop development, which would assumedly be similar if the land were to be cleared for a road or for mining infrastructure. Using this table, it is calculated that around 55% of the Project Area is subject to moderate erosion risk and the remaining 45% to high erosion risk. For the Haul Road, it is calculated that around 65% of the land crossed by the Haul Road is susceptible to high erosion, with the remainder susceptible to moderate erosion. No areas crossed by the Road have low erosion risk.

Figure 3-19 and Figure 3-20 map the erosion and flood risk based on the attributes table data provided along with the land systems mapping GIS files obtained from NRETAS through a data request. This is similar but slightly different to the erosion risk given for each land system in the reports of Aldrick & Wilson (1990, 1992) and listed in Table 3-2.

As shown in Figure 3-19 for the Project Area, the ridges are susceptible to high erosion (e.g. where Area E and some of Area F are located) and the lower rises susceptible to moderate erosion (e.g. the location of the airstrip, camp, and associated roads). The areas along the Towns River (e.g. Area F pits) are highly susceptible to flooding and the lower lying areas near the River (e.g. low grade stockpiles, processing plant, and waste dumps) are moderately susceptible to flooding.

Erosion and flooding risk along the Haul Road route (Figure 3-20) shows the Road crosses mainly areas of high and moderate erosion risk or moderate or high flooding risk. There are some small areas of low risk. Notably, acid sulfate soil risk is noted for the Littoral (Tol) and Spillen (Tos) land systems, which occur at the end of the Haul Road in the reports of Aldrick & Wilson (1990, 1992).

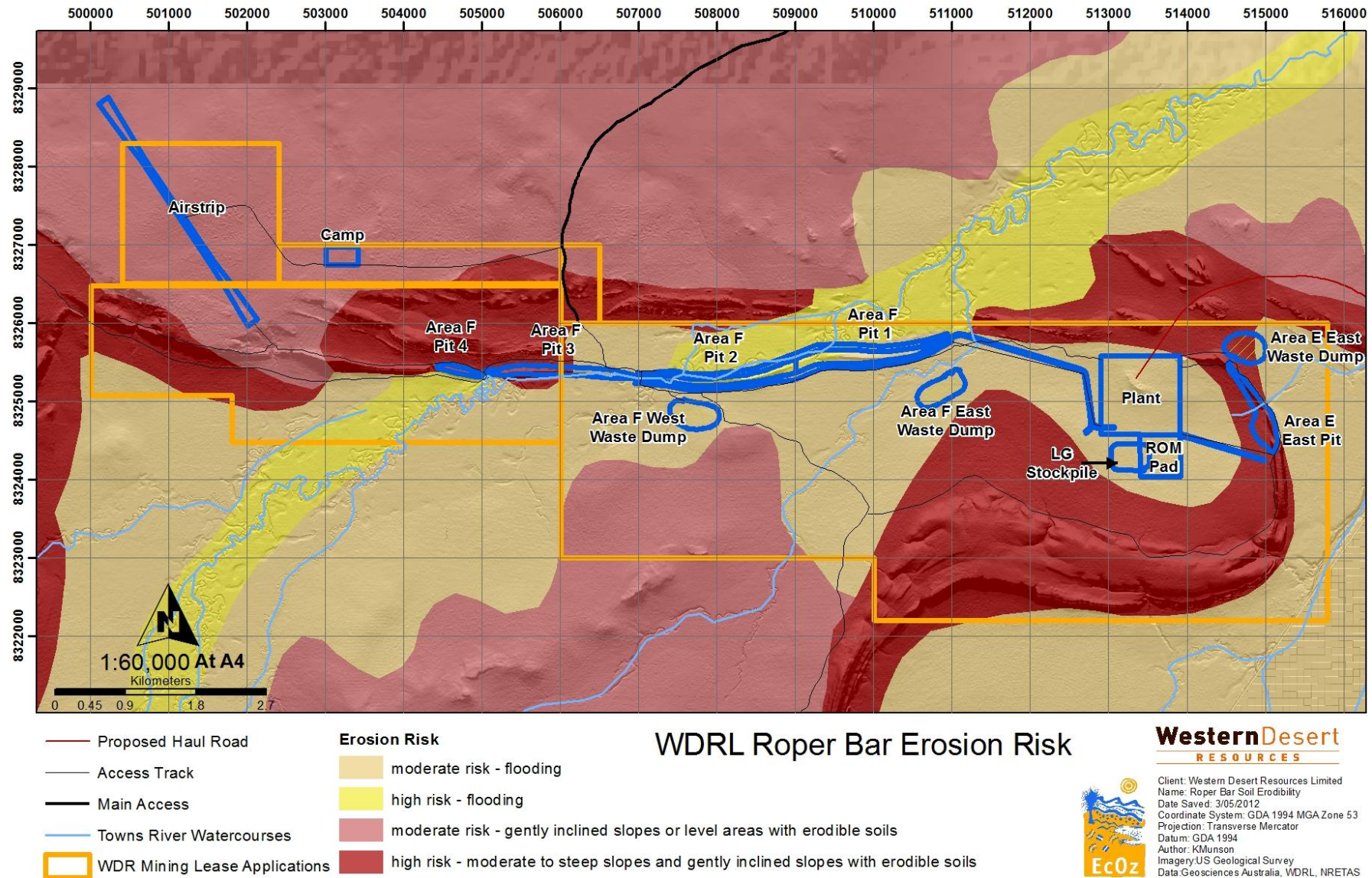


Figure 3-19 Land capability risks within the Roper Bar Project Area.

Taken from land systems mapping of Aldrick & Wilson (1992).

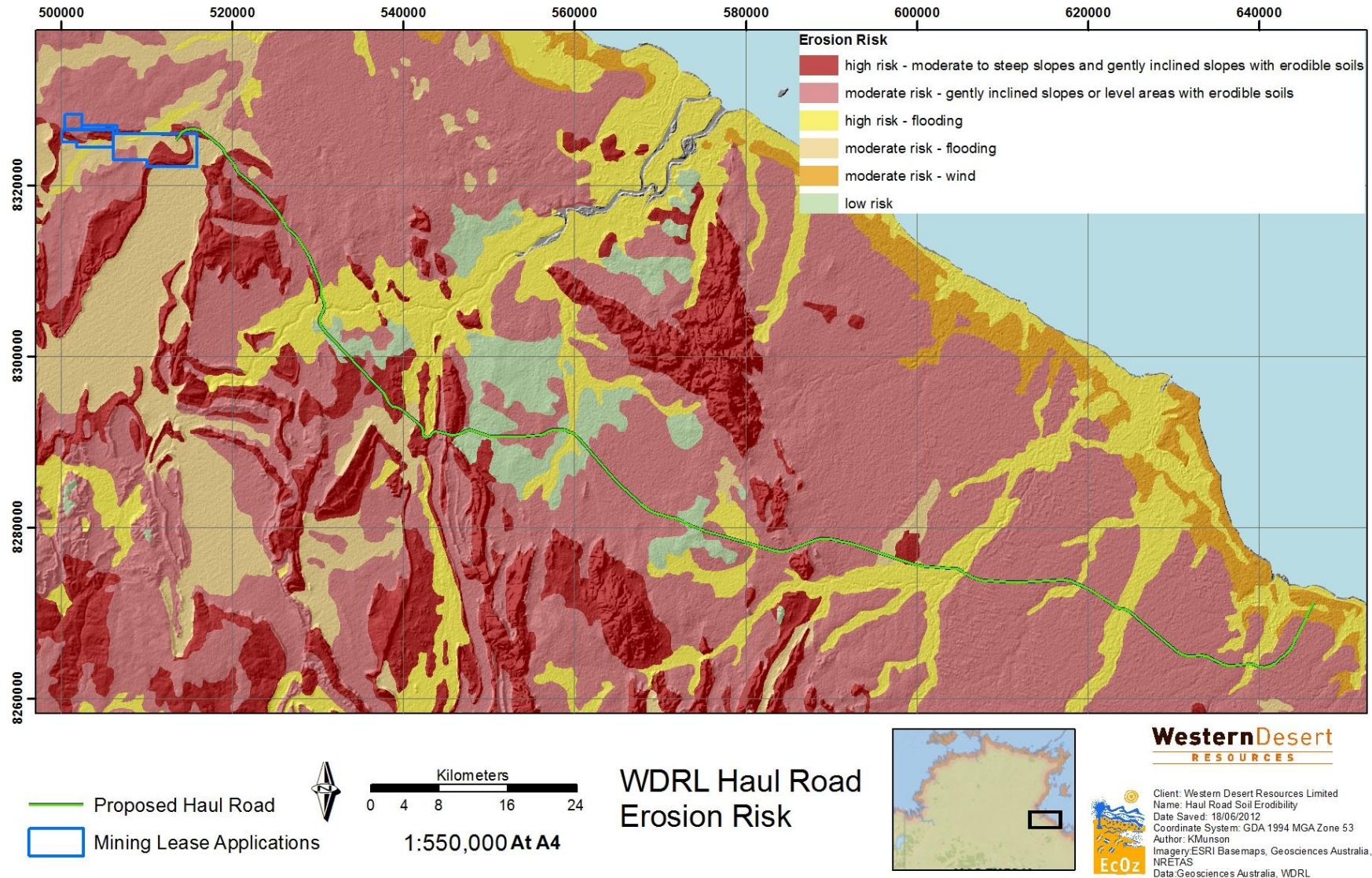


Figure 3-20 Land capability risks along the Haul Road route.

Taken from land systems mapping of Aldrick & Wilson (1990, 1992).

3.8 Scenic and Recreational Values

The Gulf Fall region is remote and undeveloped and as such has significant wilderness and environmental conservation values. The sense of remoteness and solitude people can experience when visiting the area is unique and the areas where people can gain such an experience are rapidly disappearing. Scenic values of the region around the Project Area and along the Haul Road route include rolling hills, sandstone escarpments, pristine river systems, and billabongs. Recreational values include opportunities to camp, drive, walk, swim, and view wildlife and scenic areas via the Savannah Way.

Ecosystems (wildlife and vegetation) are largely intact except for the pervasive impacts from feral animals and changes to fire regimes. Fishing opportunities in the region are also very good and the experience of fishing away from crowds is highly valued. The area is also host to some spectacular geological formations, such as the escarpments along the Limmen Bight River, also “lost city” formations, which are accessible from the Savannah Way south of the Nathan River Ranger Station (locations shown in Figure 3 -21). The Yiyintyi Range is also a spectacular area comprising a rugged and dissected sandstone escarpment.

Figure 3 -21 shows the identified scenic and recreational values of the region, noting that there may be more, however, the remoteness and inaccessibility of the area mean they are as yet unknown or unrecorded. These include a number of waterholes and billabongs; the closest of these to the Haul Road are Nawamalayu (Wanawu) Swamp located just south of the Magaranyi River; Walibinji Waterhole on the Cox River, Lily Waterhole on the Limmen Bight River, and Nyamulumulu Swamp just west of the Yiyintyi Range. The scenic and cultural significance of these are unknown.

Probably the most scenic feature along the Haul Road route is the Limmen Bight River crossing, where a spectacular gorge surrounded by steep escarpments called the Four Archers can be viewed. The River south of the Four Archers is also very scenic and flanked by steep escarpments.

There are no known occurrences of “lost city” formations close to the Road, however, occurrences of the O’Keefe (Alo) land system are included in Figure 3 -21, as a way of indicating the possible occurrence of these lost city formations (given they are the result of weathering of the Hodgson Sandstone which occurs within this land system). The closest occurrence of this is about 5 km south of where the Road crosses the Limmen Bight River.

Other scenic and unique features are the Rosie and Pine Creeks and their tributaries, which are relatively pristine, are spring-fed, and flow throughout the year. Examples of creek systems such as these with little development (only pastoral impacts) in their catchments are rare. Their perennial nature also means they have significant value as fauna habitat, both for terrestrial and aquatic fauna.

The scenic and recreational values of the region are recognised in the recent declaration of Limmen National Park by the Northern Territory Government, in order to protect the natural and cultural values of the Gulf region and to provide access to tourism sites for visitors travelling the Savannah Way between Queensland and the Northern Territory. The complementary zoning of the Limmen Bight Marine Park and potentially a Commonwealth marine reserve will fully integrate the protection of biodiversity from catchment-to-coast-to-sea in the Limmen Bight area. The proposed boundaries of the Park are shown in Figure 3 -21. The Haul Road route traverses across the centre of the Park, therefore it is important the Road does not impact on the Park’s values. The future management, recognised values, and development of the Park are currently being determined through a public consultation process. The results of this will need to be considered in construction and final design of the Road.

The following has been taken from consultation material provided to the public by the NT Government:

The proposed Limmen National Park is comprised of four portions, three of which were purchased by the Northern Territory Land Corporation (NTLC) in the early 1990s, being St Vidgeon (NT Portion 819) under a Crown Lease in Perpetuity, and two Pastoral Leases, Nathan River (NT Portion 1334) and Billengarra (NT Portion 1323). An additional portion, Maria Island (NTP 2373), was also acquired by the NTLC in 1983 from the Crown. The land area of the proposed Limmen National Park is 960,846 hectares.

The intention of the purchase of the mainland portions was to declare a “Limmen Bight National Park”, however various Native Title and Aboriginal Land Rights Claims prevented declaration. The Parks and Wildlife Service of the Northern Territory has undertaken the management of those portions since the purchase, however a more formal regime commenced in 1996 through various agreements with the NTLC under Section 74 of the Territory Parks and Wildlife Conservation Act (TPWCA).

Under the Agreement, Parks and Wildlife is responsible for biodiversity management, fire, feral animal and weed control, and visitor management. A Section 71(a) notice has also been published which allows Parks and Wildlife By-laws to be enforced over the mainland portions. The proposed park is managed from the Nathan River Ranger Station which was previously the pastoral homestead, with three Ranger staff managing present requirements. Additional ranger staff can also be accessed from Mataranka and Borroloola Ranger Stations when required.

The Northern Territory Government has commenced this process of declaring the park based on the excision of the highly prospective iron ore deposits within the St Vidgeon portion (i.e. the MLA subject of this EIS). Parts of this area will be repatriated into the park if subsequently shown to be unlikely to provide for future mining potential and, in mined areas, when the resource is no longer economically viable for mining and the areas have been appropriately rehabilitated.

The proposed Limmen National Park will be one of the largest of the 89 parks and reserves managed by the Northern Territory Government and one of the most significant in terms of biodiversity conservation value. The proposed park is of similar scale and value to West MacDonnell, Nitmiluk and Judbarra/Gregory National Parks.

The natural values of the proposed Limmen National Park include:

- 960,846 hectares of landscape in good condition, representing the diverse habitats of the Gulf region of the NT;
- the principal reserved area within two national biogeographic regions –containing approximately 10.6% of the Gulf Coast and 5.9% of the Gulf Fall and Uplands bioregions;
- representative samples of 10 of the NT's 112 broad vegetation types;
- part of the Limmen Bight and Associated Floodplains Site of Conservation Significance. This is one of 67 such sites in the Northern Territory identified by NRETAS scientists as being particularly important for biodiversity and is of international significance because of the aggregations of migratory shorebirds, its importance as a marine turtle nesting area, and the resident waterbird and seabird populations;
- a known high diversity of native species including 365 vertebrate species and 1,430 plant species. Recent plant surveys have doubled the number of species known from the proposed park and emphasised the richness of the local flora;
- 101 plant species of conservation significance occurring within the proposed park, including one threatened species, 21 species not recorded from any other park or reserve, and many rare, restricted and poorly known plants;
- eight threatened animal species, including the Gouldian Finch. Five vertebrate animals found in the proposed park do not occur in any other NT park or reserve;

- the proposed park's large size and topographic variations provide refugial habitat and microclimatic variability, which makes the area relatively resilient to the impacts of threats such as climate change;
- relatively few problem weeds;
- the large size making it more amenable to strategically manage fire and feral animals;
- Maria Island, which is also included in the "Limmen Bight and associated coastal floodplains" Site of Conservation Significance. Its natural values include:
 - a highly significant nesting location for Flatback Turtles;
 - one of the largest known Silver Gull breeding colonies in the NT;
 - a very high density of northern brown bandicoots, a species which has declined on the adjacent mainland; and
 - protection from threatening processes such as invasion by weeds and feral animals.

The proposed park provides visitors with remote experiences and four-wheel driving along the Savannah Way. Recreation is centred on camping and sightseeing in the campsites within the park. Formed pathways lead to impressive 'lost city' formations. Swimming is possible in Butterfly Springs, but estuarine crocodiles are likely to inhabit most other waterways. Fishing is also popular on the Roper and Towns Rivers which can be accessed from boat ramps. A camp ground is located on the Limmen Bight River with a commercial off-park fishing camp located further downstream on the same river (locations shown in Figure 3 -21).

Local visitation and tourism to the area is increasing with approximately 15 000 people visiting the proposed park annually. As the proposed park is situated between the Territory growth towns of Ngukurr and Borroloola, it could significantly contribute to the employment and economic development of both towns.

Since a boat ramp was constructed at Tomato Island (Munbililla) in the 1990s, an unregulated camping area has evolved, which at times can have in excess of 50 campsites. The camping area attracts short stay visitors from Katherine and surrounds, as well as longterm caravan campers from interstate, many of whom stay more than three months. This camp is used as a base for those visitors wanting to fish the Roper River and explore the surrounding area. Consequently the area has become significantly degraded and poses health and environmental risks.

The Parks and Wildlife Service is formalising and constructing a commercial camping area at Munbililla with facilities including a caretakers residence, small kiosk, a solar powered ablution block, taps and gas fuelled barbeques, 50-55 non-powered informal grassed sites for caravans and tents, a secure parking area for visitors who wish to leave their cars for extended periods, car and trailer parking bays and a waste dump facility. The area has been designed in collaboration with local stakeholders and the Yugal Mangi Aboriginal Development Corporation, with whom negotiations are proceeding to enable them to manage the camping area on a commercial basis. The total investment in the upgrade will be \$1.5M. Construction on the facilities will start August 2012 and is expected to be completed by November. Construction of this commercial camping area is consistent with the Working Futures Local Implementation Plan for Ngukurr.

The Parks and Wildlife Service will explore opportunities of providing a senior Parks and Wildlife Ranger to assist the development of the Yugal Mangi Rangers to undertake land and visitor management services within the proposed park. The Aboriginal rangers may also be trained in law enforcement to become Honorary Conservation Officers so that they can enforce Territory Parks and Wildlife Conservation By-laws.

On-going issues between the Traditional Aboriginal Owners and visitors over access to parts of the Roper River, uncontrolled visitation to art and significant sites and illegal use of firearms on the proposed park will also be addressed with the formalisation and improved management of the camping area. Park by-laws will be enforced to prevent off-road driving and unregulated bush camping.

Two additional bush camping areas will also be developed within the proposed park for visitors who seek a more remote experience.

The proposed park encompasses an extremely rich and diverse Aboriginal culture. The Yanyuwa, Marra, Alawa, Ngandji, Gurdanji, Binbingka, Wandarang, Yugul Mangi and Ngalakan all have cultural affiliation with the country which is clearly evidenced by the numerous rock art, occupation and identified and registered sacred sites within the area. Traditional Aboriginal Owners reside in many locations close to the proposed park, including the growth towns of Borroloola and Ngukurr, a number of smaller freehold blocks, and in communities and outstations located on the former pastoral leases of Hodgson, Nutwood, Bauhinia, and Carpentaria Downs, which have been subject to successful Aboriginal Land Rights claims and granted to Aboriginal Land Trusts.

A Native Title determination over St Vidgeon has found that non-exclusive Native Title exists over the portion except for the former agricultural lease in the vicinity of Tomato Island. Native Title claims over the Nathan River and Billengarra pastoral leases are yet to be heard, however an expedited negotiated agreement to recognise non-exclusive Native Title rights of the Aboriginal claimants as determined by the Northern Land Council is likely to resolve the matter when it comes before the Federal Court.

In recognition of the significant Aboriginal cultural connection that exists over the proposed park, it is proposed to enter into joint management negotiations with the Northern Land Council on behalf of relevant Aboriginal interests. In keeping with current park principles, the Parks and Wildlife Service will request the Northern Land Council consult with the traditional Aboriginal owners to provide an Aboriginal name for the proposed park.

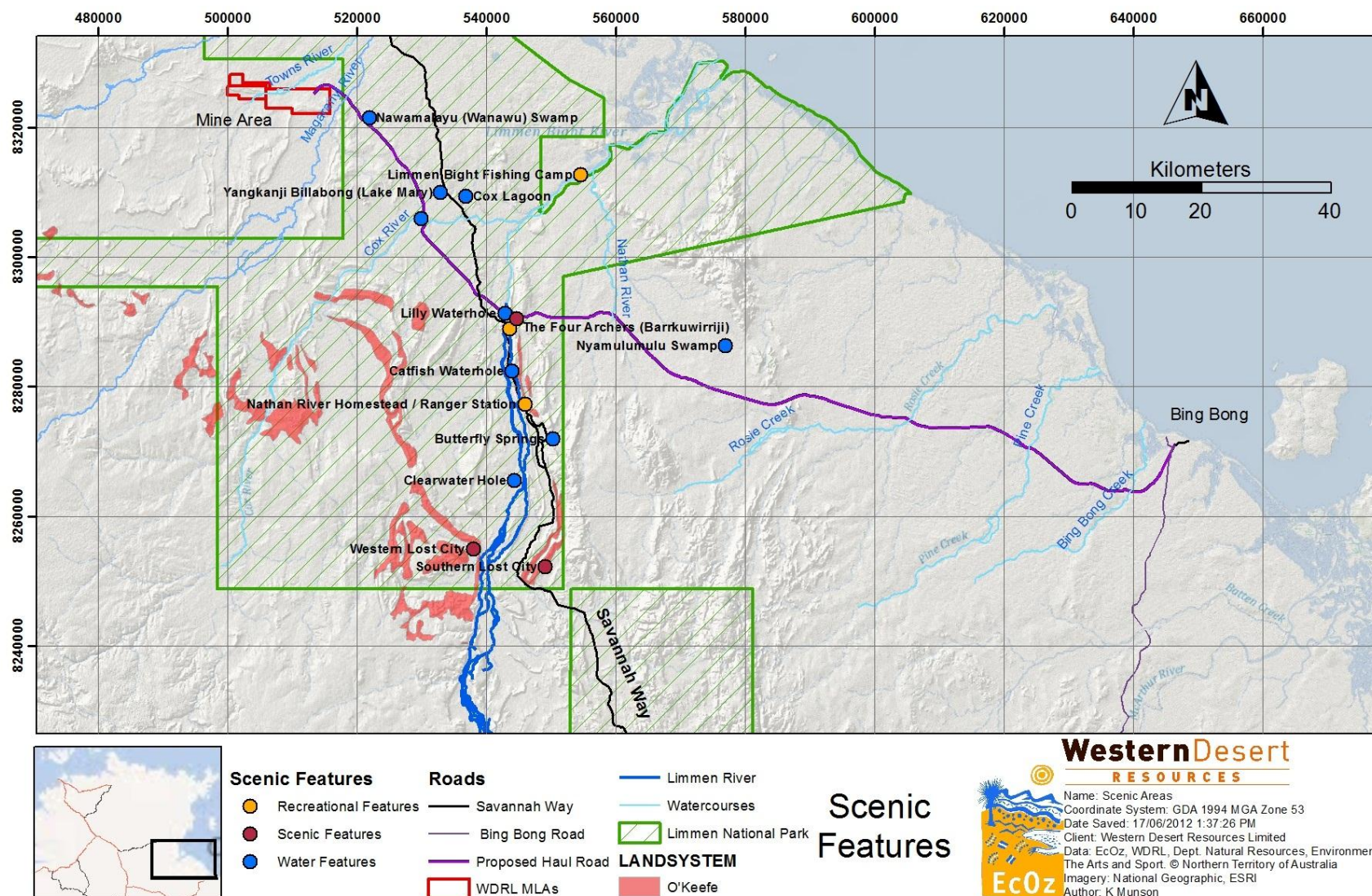


Figure 3 -21 Scenic and recreational values within Limmen National Park and along the Haul Road Route