Australian Government

Geoscience Australia

Report to

Department of Resources, Energy and Tourism

Mineral Resource Potential Assessment of the Woomera Prohibited Area, South Australia

July-August 2010

Contents

1 Introduction 4
1.1 Overview 4
1.2 Regional Geology 4
1.3 Mines, Mineral Deposits, and Mineral Occurrences 6

2 Mineral Resource Potential Assessment 8
2.1 Methodology 8
2.2 Source of Data 8
2.3 Deposit Styles 9
2.4 Mineral Resource Potential Discussion 9
2.4.1 Composite Mineral Resource Potential Map 9
2.4.2 Composite Mineral and Energy Commodity Potential Maps 10
2.4.3 Concluding Remarks 10

Appendix A: Mineral Resource Potential Assessment Methodology 11

Appendix B: Mineral Resource Potential Assessment Sheets 13
B.1 Iron-oxide copper, gold, uranium deposits: Olympic Dam-style (Map 10) 13
B.2 Coal deposits: Phillipson-style (Map 11) 14
B.3 Archean lode gold deposits: Challenger-style (Map 12) 14
B.4 Proterozoic lode gold deposits: Tarcoola-style (Map 13) 15
B.5 Iron ore deposits: banded iron formation: Hawks Nest-style (Map 14) 15
B.6 Iron ore deposits: hydrothermal: Cairn Hill-style (Map 15) 16
B.7 Unconformity-related uranium deposits (Map 16) 16
B.8 Sandstone-hosted uranium deposits: roll-front type (Map 17) 17
B.9 Sandstone-hosted uranium deposits: channel-type (Map 18) 18
B.10 Heavy mineral sand deposits (Map 19) 19
B.11 Geothermal resources: hot rock-type (Map 20) 20
B.12 Geothermal resources: hot sedimentary aquifer-type (Map 21) 21
B.13 Conventional hydrocarbons (Map 22) 23
B.14 Coal-related hydrocarbons (Map 23) 23
B.15 Oil shale deposits (Map 24) 24
B.16 Komatiite (mafic-ultramafic)-associated nickel deposits (Map 25) 24
B.17 Tholeiite (mafic-ultramafic)-associated nickel, copper deposits (Map 26) 25
B.18 Groundwater resources (Map 27) 26

Appendix C: Mineral Resource Potential Maps 28

Appendix D: Comparative Comment on the Identified Mineral Resources of the Woomera Prohibited Area, South Australia 57

Executive Summary

In June 2010, Geoscience Australia (GA) was tasked by the Australian Government, Department of Resources, Energy and Tourism to undertake a qualitative mineral resource[1] potential assessment of the Woomera Prohibited Area (WPA) in central South Australia. The assessment was undertaken in collaboration with the Department of Primary Industries and Resources, South Australia (PIRSA).

The mineral resource potential assessment determines the deposit types likely to occur within geological frameworks known or interpreted to exist in the WPA. Geologically prospective areas that contain particular types of deposits are identified and ranked low to high potential, and similarly the level of certainty categorised from lowest (A) to highest (D).

Currently the WPA contains three operating mines: Challenger, a gold mine in the west, Prominent Hill copper-gold mine in the southeast and Cairn Hill, an iron ore copper-gold mine in the north. Peculiar Knob iron ore project, northwest of the Prominent Hill mine, is finalising approvals for mine development. There are undeveloped coal resources in the Arckaringa Basin, at least four iron ore deposits and one gold deposit with identified resources. In addition there are some 150 known occurrences of minerals dominated by gold, iron ore, copper and opal, with additional occurrences of uranium, silver, zinc, lead, diamonds, and heavy mineral sands.

The potential for undiscovered deposits of the different mineral commodities varies across the WPA and reflects changes in geology. There is high potential for discovery of substantial copper-gold-(uranium) deposits in the extension of the geological province that hosts the Prominent Hill deposit and the world-class Olympic Dam deposit. Whilst these deposits lie under significant amounts of sediments (overburden), advances in technology have enabled discovery and mining.

There is a high potential for discovery of small- to medium-sized gold deposits similar to the Challenger gold deposit in the northwest of the WPA. In the southern and western regions of the WPA there is high potential for discovery of sandstone-hosted uranium deposits in paleochannels that have incised sedimentary rocks overlying the oldest basement rocks of the Gawler Craton, similar to the Warrior uranium deposit lying immediately south of the WPA.

There is potential for further discoveries of small- to medium-sized iron ore deposits similar to the Peculiar Knob and Hawks Nest deposits in the southeast of the WPA. Similarly, there is high potential for discovery of additional coal deposits similar to the Phillipson deposit, sub-bituminous coal, in the Arckaringa Basin in the central northern part of the WPA. Similar coal deposits in the northern part of the basin immediately north of the WPA are being investigated for potential coal-to-liquids, coal seam gas, and underground gasification projects. The Officer Basin is one of the last remaining onshore frontier for conventional hydrocarbon accumulations and lies in the northwestern area.

The WPA was assessed for hot rock and hot sedimentary aquifer geothermal resources for electricity generation. Moderate hot rock geothermal potential, as a result of sedimentary rock thickness and high-heat-producing granites, is interpreted to exist along the eastern margin and in the western third of the WPA. There are some areas in the east of the WPA that have a moderate- and moderate to high-potential for hot sedimentary aquifers due to favourable sedimentary rock thickness and thermal resistance characteristics.

Groundwater is an important resource in the development of any project. The overall potential of usable groundwater supplies within the WPA varies from high to low. High potential areas in terms of aquifer yield occur in paleovalleys in the southwestern and western parts of the WPA, however, the groundwater is saline. Moderate to high potential sandstone aquifer with moderately high groundwater yields of fresh to brackish water occur in the north central area of the WPA.

The mineral resource potential report and maps are based on information and data available to GA and PIRSA at the time of the assessment. The mineral resource potential assessment is likely to change as new information and data are made available. It is recommended that the assessment be reviewed after 5 years to ensure that all new information and data is incorporated into the analysis.

The WPA has a diversity of mineral deposits and energy resources. Mineral resource potential varies across the WPA relative to the specific geological environment required for each mineral deposit and energy resource style. The mineral resource potential may change, as new information and data are available.

[1] 'Mineral resource' is used in this report and maps in the sense defined by United States Geological Survey as " a concentration of naturally occurring solid, liquid, or gaseous material in such form and amount that economic extraction is currently or potentially feasible ".

1 Introduction

1.1 OVERVIEW

The Woomera Prohibited Area (WPA) lies about 450 km northwest of Adelaide in central South Australia and covers an area of approximately 127,000 km^2. The WPA is a military testing range and a key asset in Australia's defence capability development. It is also an area of potential economic importance in terms of its natural resources. In May 2010, the Australian Government announced the Woomera Review (Review) into the short- and long-term (20–30 years) national security and economic interests in the WPA. The Australian Government Review will aim to determine an appropriate balance between the defence and economic benefits associated with the proposed use of the WPA.

The Review will assess the economic benefits that may be gained from the exploitation of mineral resources[2] in the WPA. The Department of Resources, Energy and Tourism (DRET) is contributing to the Review, and they requested GA to undertake a qualitative mineral resource potential assessment of the WPA in collaboration with PIRSA. This report and associated maps are part of DRET's contribution to the Review.

This report and mineral resource potential maps of the WPA are based on information and data available to GA and PIRSA at the time of the assessment. The mineral resource potential assessment is likely to change as new information and data are made available. It is recommended that the assessment be reviewed after 5 years to ensure that all new information, data, and evolving issues are incorporated into the analysis.

This report provides an overview of the regional geology, the known and predicted mineral deposits and energy resources of the WPA, and assessment methodology. A summary of the mineral resource potential assessment maps, as well as the detailed assessment sheets documenting the appraisal criteria, are provided.

A follow-up report to DRET on a comparative comment on the identified mineral resources of the Woomera Prohibited Area is provided in Appendix D.

1.2 REGIONAL GEOLOGY

The WPA is in a region of deep weathering with very few outcropping rocks. The basement geology of the WPA is generalised in Figure 1. It shows the Archean (~3,000 million year age (Ma)) to Mesoproterozoic (~1,000 Ma) basement rocks as well as the extent of the Gawler Craton and the Officer, Arckaringa, Eromanga, and Eucla basins.

The geological framework comprises basement rocks of the Gawler Craton in the southern half of the WPA overlain by much younger flat-lying sedimentary rocks that cover the Gawler Craton with increasing depth towards the northern half of the WPA (Figure 1). These younger rocks are contained in a number of sedimentary basins – principally the Officer Basin in the northwest WPA, the Arckaringa Basin in the northern WPA, and the very extensive Eromanga Basin in the northeast of the WPA. Sedimentary rocks of the Eucla Basin, including ancient shorelines with heavy mineral sand concentrations, overlie the Gawler Craton in the far southwest corner of the WPA. In the southeast of the WPA the Gawler Craton is overlain by sedimentary rocks of the Pandurra Formation.

The underlying Gawler Craton is a major crustal province, which hosts the world-class Olympic Dam iron-oxide copper-gold-uranium deposit. Olympic Dam is the world's largest uranium deposit containing approximately 36% of the world's known uranium resources, as well as world-class resources of copper and gold. The prospectivity of the Gawler Craton has been further enhanced by the discoveries of the Prominent Hill copper-gold-uranium-silver deposit (in 2001) and the Carrapateena

[2] 'Mineral resource' is used in this report and maps in the sense defined by United States Geological Survey as " a concentration of naturally occurring solid, liquid, or gaseous material in such form and amount that economic extraction is currently or potentially feasible ".

copper-gold deposit (in 2005) in the northern and eastern parts of the Gawler Craton, respectively, and numerous gold prospects in the central Gawler gold province.

Figure 1. Generalised basement geology of the WPA region.

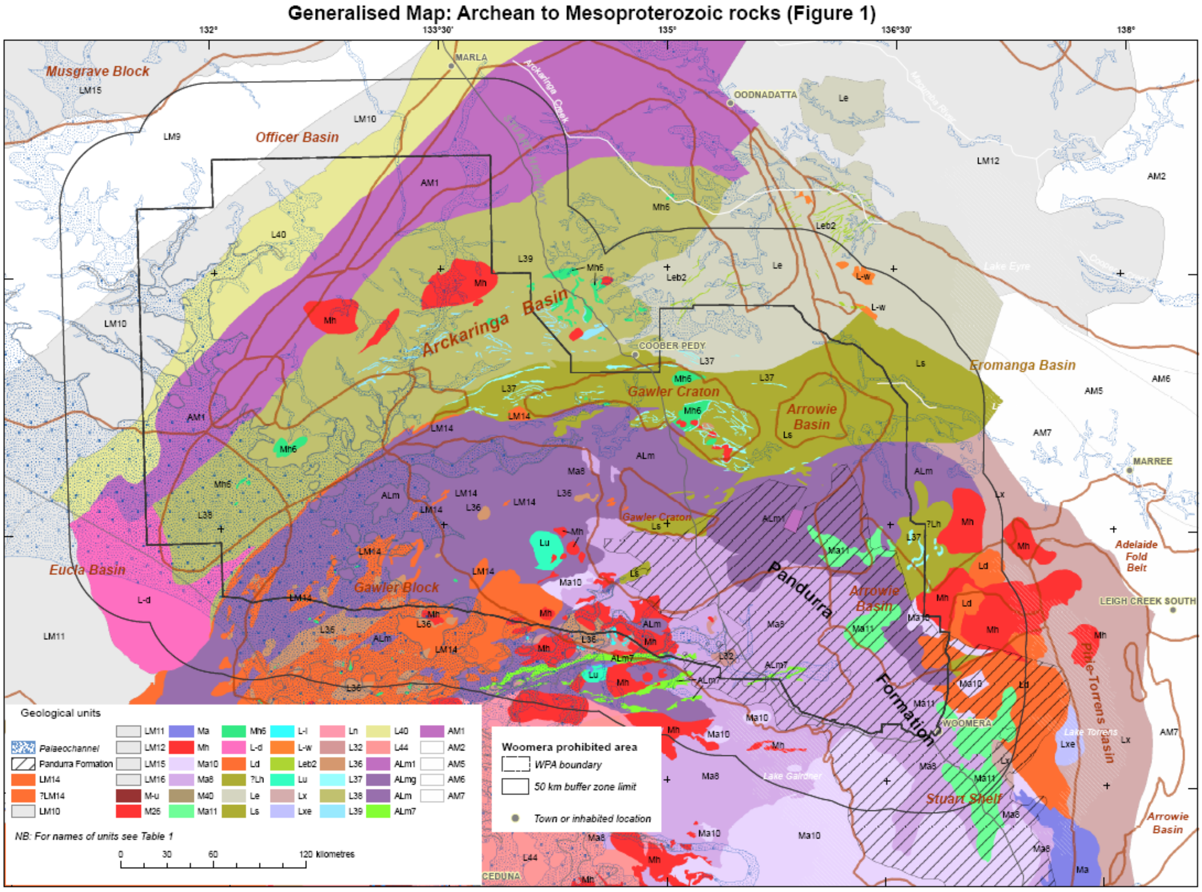


Table 1. Main basement geological units shown on Figure 1 and referred to in assessment sheets of Appendix B.

Unit	Unit Name	Unit	Unit Name
LM14	Engenina Adamellite, Symons Granite, equivalents of Tunkillia Suite	L-i	Wilgena Hill Jaspilite
LM 10,11, 12, 15,16	unnamed	L-w	Wirriecurrie Granite
M-u	Munjeela Granite	Leb2	Peake Metamorphics (part)
M26	unnamed	Lu	Muckanippie Suite
Ma	Gawler Range Volcanics	Lx	Wallaroo Group
Mh	Hiltaba Suite	Lxe	Weetulta Formation (Wallaroo Group)
Ma10, Ma8	Gawler Range Volcanics (upper), Gawler Range Volcanics (lower)	Ln	Tunkillia Suite
M40	unnamed	L32	Tarcoola Formation; Labyrinth Formation; Eba Formation
Ma11	Gawler Range Volcanics (lower)	L36	unnamed; formerly Lincoln Complex in part; includes Middlecamp Granite, Paxton Granite
Mh6	Includes Curramulka Gabbronorite	L37, 38, 39, 40	unnamed
L-d	Moondrah Gneiss	L44	St Peter Suite; St Francis Suite
Ld	Donington Suite	ALm1	Mulgathing Complex (part)
Lh	Hutchison Group?	ALmg	Glenloth Granite
Le	Peake Metamorphics, including Tidnamurkuna Volcanics	ALm	Mulgathing Complex
Ls	Mount Woods Complex	ALm7	Kychering Formation; Lake Harris Komatiite
		AM1,2,5,6,7	unnamed

1.3 MINES, MINERAL DEPOSITS, AND MINERAL OCCURRENCES

The known deposits and their resources within the WPA are listed in Table 2. Currently, the WPA contains three operating mines (Map 1):

- *Prominent Hill copper-gold* – a significant medium-sized copper-gold open-cut mine and proposed underground mine in the eastern region of the WPA. The open-cut mine commenced operations in February 2009 and production is being increased to an annual production of 85,000 to 100,000 tonnes of copper and about 1.7 to 2 tonnes (60,000 to 70,000 ounces) of gold. The deposit contains some 2.5 million tonnes of copper and 231 tonnes of gold. The deposit is open at depth indicating potential for further resources.

- *Challenger gold* – a medium-sized gold mine in the central southern region of the WPA. The mine commenced operations in 2005 and produces approximately 3.5 tonnes (over 120,000 ounces) of gold per annum. The mine is of high grade with ore proven reserves sufficient for at least 7 years of production and a current resource of 36 tonnes of gold with good prospects for further increases in gold resources.

- *Cairn Hill magnetite-copper-gold* – a small iron-copper-gold mine in the northeastern region of the WPA. Mining of ore commenced in June 2010 and the first shipment is expected in late 2010. The direct shipping magnetite ore and saleable copper-gold concentrate will be shipped, via Port Adelaide, to a processing plant in China.

The Olympic Dam copper-gold-uranium mine of major national economic importance, lies only 15 km east of the WPA. The Olympic Dam deposit itself is surrounded by a halo of smaller deposits and prospects, the most significant of which is Carrapateena, a significant copper-gold deposit discovered in 2005 beneath 500 m of overburden, which lies a further 130 km southeast of Olympic Dam and outside of the WPA.

Table 2. List of known deposits and resources in the Woomera Prohibited Area as at 30 June 2009.

Deposit name	Commodity	Resources	Resources unit
Operating mines and deposits being developed			
Prominent Hill	Copper	2.6	Mt
	Gold	233	t
	Uranium	9,990*	t
	Silver	700	t
Challenger	Gold	45.3	t
Cairn Hill	Iron Ore	14.1	Mt
	Copper	0.04	Mt
	Gold	1.23	t
Peculiar Knob	Iron Ore	19	Mt
Undeveloped deposits			
Phillipson	Black Coal	5,505	Mt
Hawks Nest	Iron Ore	491	Mt
Giffen Well	Iron Ore	240	Mt
Sequoia	Iron Ore	22	Mt
Fingerpost Hill	Iron Ore	10	Mt
Golf Bore	Gold	0.3	t

Note: Resources include ore reserves and mineral resources and are based on company estimates. Resources as recorded in Geoscience Australia's Ozmin database **as at 30 June 2009**. For some deposits recent resource data from companies may not have been entered into the data base by that date. * = not being produced. Units: Mt = million tonnes, t = tonnes.

Development of the Peculiar Knob iron ore deposit northwest of the Prominent Hill mine, is in the final stages of approval for construction of the mine and associated infrastructure. Peculiar Knob is a small, but high-grade hematite deposit under shallow cover (15–30 m). The mine is expected to be producing 3 million tonnes of iron per annum in 2011.

There are six undeveloped known mineral deposits within the WPA with resource estimates (Table 2). The WPA contains a number of iron ore deposits, four of which have identified resources; Hawks Nest, Giffen Well, Sequoia, and Fingerpost Hill. There are numerous gold occurrences, however, only one deposit, the Golf Bore deposit has known resources.

There are substantial undeveloped coal resources in the Phillipson coal field of the Arckaringa Basin on the northern margin of the WPA. These sub-bituminous coals are potentially suitable for power generation, but have high - salt levels, which may be a potential impediment to development. However, CSIRO has undertaken beneficiation studies to address this problem.

There are no conventional hydrocarbon accumulations discovered in the WPA to date. The Officer Basin, which lies on the northern edge of the WPA, is one of the last remaining onshore frontier basins. However, the substantial sub-bituminous coal deposits in the northern Arckaringa Basin outside the WPA are being investigated for the potential development of coal-to-liquids plants and underground coal gasification operations.

In total, some 150 mineral occurrences and deposits have been recorded within the WPA with the dominant commodities being iron, gold, copper, and opal, with additional occurrences of uranium, silver, zinc, lead, diamonds, and heavy mineral sands.

There are two types of geothermal resources, hot sedimentary aquifer and hot rock. There is geothermal exploration activity currently taking place in South Australia, in particular, in the Olympic Dam area. To date there are no geothermal resource estimates within the WPA or geothermal projects commercially producing electricity in South Australia.

Groundwater is an important resource for the development of any resource project. The majority of aquifers in the WPA are sandstone aquifers of the Great Artesian Basin and younger paleovalley aquifers. The potential of intersecting usable groundwater within the WPA is variable.

2 Mineral Resource Potential Assessment

2.1 METHODOLOGY

The general methodology used to assess the mineral resource potential of the WPA was developed by the United States Geological Survey (USGS). The USGS has successfully used the methodology for mineral resource assessments of forest areas in North America. In Australia, the Australian Government's Regional Forest Agreement assessed mineral resource potential using a similar method as part of the comprehensive environment, economic, and social assessments.

The WPA mineral resource potential assessment is a qualitative assessment, which estimates the likelihood of mineral and energy deposits that may be of sufficient size and grade to constitute a resource. The term resource is restricted to material of which the extraction is judged to be potentially viable in the next 25 years. Only the deposit types judged to be most likely to constitute significant resources in the region have been assessed.

The mineral resource potential of the WPA is assessed by determining the types of deposits likely to be found within the geological framework known or believed to exist. Geological prospective areas are delineated according to the type of deposit style permitted by the geology. The mineral resource potential of the areas, that is the likelihood of a particular type of deposit, is ranked as high, moderate, or low, based on professional judgments of geoscientists involved in the assessment. If there are insufficient data to classify the areas then the mineral resource potential is categorised as unknown. To reflect the differing amounts of information available, the assessments of mineral resource potential are also categorised according to levels of certainty (or confidence) from lowest (denoted by the letter A) to highest (D). The method is described in more detail in Appendix A.

The WPA mineral resource potential assessment of mineral resource potential combined the knowledge of geology, geophysics, geochemistry, energy resources, mineral deposits, and mineral occurrences with current theories of mineral deposit formation and results of mineral and energy exploration. The assessment process requires a study of available geoscientific data to determine the history of geologic processes and environments. In particular, the assessment draws on regional and local characteristics of mineral deposit models to establish whether or not specific types of mineral deposits are likely to occur.

The assessment procedure used for the WPA is also used by many companies to select areas for exploration. It is important to note, however, that the assessment of potential resources is subject to the amount and the quality of data available. As geological knowledge of an area is never complete, it is not possible to have a 'final' assessment of mineral resource potential at any given time. The mineral resource potential of areas needs to be monitored and reassessed periodically to take account of new data, and advances in geological understanding including new mineral discoveries. A discovery of a major deposit in a greenfields area will change the prospectivity rating for that area. Advances in mineral exploration and mining technologies, and changes in mineral markets, such as metal prices, are other factors which may change the mineral resource potential of an area.

2.2 SOURCE OF DATA

Geological datasets used in the assessment are sourced from GA and PIRSA. These include outcrop and solid geology maps of the Gawler Craton, paleochannel map of South Australia, drillhole dataset (PIRSA database), total magnetic intensity and bouger gravity dataset, radiometric dataset, OZMIN (GA minerals deposits database), MINLOC (GA mineral occurrences database), OZTEMP (GA temperature database), and OZCHEM (GA geochemistry database). The sedimentary rock thicknesses were determined using OZSEEBASE™ (FrOG Tech). The groundwater geochemistry dataset was extracted from the Great Artesian Basin dataset of the Bureau of Rural Sciences.

2.3 DEPOSIT STYLES

In this report, mineral resource potential is assessed only for a number of the most significant mineral deposit and energy resource styles currently known. These include:

- iron-oxide, copper, gold, uranium deposit style (Olympic Dam-style);
- coal (Phillipson-style);
- two ages of lode gold deposit styles: Archean (Challenger-style) and Proterozoic (Tarcoola-style);
- two iron ore deposit styles: banded iron formation (BIF: Hawks Nest-style) and hydrothermal (Cairn Hill-style);
- three uranium deposit styles: unconformity-related (Ranger-style), sandstone-hosted (Beverley-style), and channel-type (Warrior-style);
- heavy mineral sand;
- two geothermal resources styles: hot rock-type and hot sedimentary aquifer-type;
- conventional hydrocarbons;
- coal-related hydrocarbons (underground coal gasification and coal seam gas);
- oil shale; and
- two nickel deposit types: komatiite-associated and tholeiite-associated.

In addition, groundwater was identified as an important resource in the development of any project. A groundwater assessment was undertaken to determine the potential for useable groundwater.

Assessment sheets outline the mineral resource potential criteria for individual mineral deposit and energy resource styles are documented in Appendix B. Based on the assessment criteria, prospectivity areas that contain geological environments permissive of the formation of specific types of mineral deposits and energy resources were delineated and ranked from low to high. Mineral resource potential maps for deposit styles are provided in Appendix C.

2.4 MINERAL RESOURCE POTENTIAL DISCUSSION

The known mineral deposits, mineral occurrences, and exploration tenements within the WPA are shown on Map 1. A single composite map (Map 2) of all mineral deposits and energy resource styles shows the highest level of potential of mineral and energy resource styles overlapping in the studied area. An all mineral deposits and coal resources composite map (Map 3) shows the highest level of potential for mineral deposits excluding geothermal and hydrocarbon resources (Map 8 and Map 22, respectively). Composite commodity maps (Maps 4–9) combine the mineral potential maps of mineral deposit or energy sources styles of one commodity.

Mineral resource potential maps (Maps 10–26) were developed for individual deposit styles within the WPA and its 50 km buffer zone based on the assessment criteria (Appendix B). A groundwater potential map (Map 27) was developed. Discussions of these individual potential maps are provided in Appendix B and all maps are provided in Appendix C.

2.4.1 Composite mineral resource potential map

The composite mineral resource potential map (Map 2) highlights the highest potential areas of each mineral deposit and energy resource style. The main high potential areas are in the southern and eastern regions of the WPA. The eastern area is dominated by the ‘Olympic Dam and Prominent Hill’ iron-oxide, copper, gold, uranium-deposit styles. The southwest region of high potential is mainly due to heavy mineral sand deposits. The central, more irregular high potential areas are a combination of several deposit styles relating to gold, iron, and hydrocarbon resources.

A moderate to high potential broad zone in the northwest of the WPA is mainly due to the hydrocarbon potential of the Officer Basin. The central and southeast regions of moderate to high potential are dominantly due to gold and uranium-deposit styles. Central areas of moderate potential are due to several deposit styles including iron, hydrocarbons, and uranium. Low to moderate areas form isolated areas mainly in the southeast of the WPA and are predominantly related to uranium-style deposits.

2.4.2 Composite mineral and energy commodity potential maps

The composite map of all mineral deposits and coal (Map 3) highlights the areas of mineral and coal potential and excludes the geothermal and hydrocarbon deposit types. The mineral resource potential in the south and eastern half of the WPA is similar to the composite map of all deposits (Map 2). The main difference is the mineral resource (excluding hydrocarbons) potential is lower in the northwest region of the WPA. Uranium deposits have a lower resource potential compared to the geothermal and hydrocarbon resources in this area of northwest WPA.

There are six composite mineral and energy commodity potential maps (Map 4–9), these include; gold, uranium, iron, hydrocarbons, geothermal, and nickel.

The gold composite potential map (Map 4) shows a northwest-southeast-trending high potential zone in the southeast of the WPA. This area of high potential is an extension of the geological province that hosts the ‘Olympic Dam and Prominent Hill’ iron-oxide, copper, gold uranium-deposits. This style of deposit is also represented in the moderate- to high-potential areas in the west and central regions, as well as the moderate- and low to moderate-zone in the northwest. The southern areas of high through to moderate potential are mainly related to gold-lode style (Challenger- and Tarcoola-styles).

The uranium composite potential map (Map 5) shows the main areas of high and moderate to high in the southwest region of the WPA are dominated by sandstone-hosted (channel-type) uranium deposits. The irregular moderate to high- and high-potential areas in the central region are related mainly to sandstone-hosted (roll-front-type) uranium deposits. The low to moderate-potential area in the southeast corner is associated with unconformity uranium-deposit style.

The iron composite potential map (Map 6) clearly shows the banded iron formation (BIF) forming moderate to high and moderate zones in the central area of the WPA. The hydrothermal iron deposit styles form irregular areas of high potential to the southeast of the BIFs.

The hydrocarbon potential composite map (Map 7) combines the conventional and unconventional hydrocarbons related to the Officer and Arckaringa basins. The conventional hydrocarbons of the Officer Basin are reflected in the moderate to high potential mainly in the northwest corner of the WPA. Unconventional hydrocarbons include oil shale and coal-related hydrocarbons. Oil shale deposits form the high and moderate potential areas in the north and eastern areas of the WPA. Coal-related hydrocarbons associated with the Arckaringa Basin form areas of high and moderate to high potential similar to that of the oil shale potential.

The geothermal potential composite map (Map 8) combines the two styles of geothermal resources, hot-rock and hot-sedimentary aquifers. The northwest corner of the WPA shows moderate to low potential zones for both types of geothermal resources. The eastern region of the WPA is generally moderate potential for both types of geothermal resources. The central area of low to moderate potential is predominantly for hot-rock type geothermal resources.

The nickel potential composite map (Map 9) shows a moderate potential area and bands of low potential in the southern buffer zone of the WPA.

2.4.3 Concluding remarks

The single composite map (Map 3) indicates that the WPA is a prospective area for mineral and energy resources. The mineral resource potential of the WPA is based on information currently available. Deposit styles assessed are based on those known to occur in the region. This does not mean that other deposit styles do not occur, but the style has not been discovered yet. The mineral potential assessment is likely to change with new information and as discoveries are made.

The potential for undiscovered deposits varies across the WPA and reflects the range of geological environments. Deposits may lie under significant amounts of sediments (overburden), however, advances in technology have enabled discovery and mining of the Prominent Hill (>100 m of overburden) and Olympic Dam (>320 m of overburden). Although mineral exploration can be difficult and costly because of the thickness of overburden overlying the prospective basement rocks, the region is one of the more prospective areas in Australia and will continue to attract exploration activity.

Appendix A: Mineral Resource Potential Assessment Methodology

The general methodology for mineral resource potential was developed by the United States Geological Survey (USGS). A summary of the qualitative assessment methodology is described in publications by Taylor and Steven (1983), and by Dewitt, Redden, Wilson and Buscher (1986).

'Mineral resource' is used in this report and maps refers to 'a concentration of naturally occurring solid, liquid, or gaseous material in such form and amount that economic extraction is currently or potentially feasible' as defined by the USGS. The mineral resource potential of an area is a measure of the likelihood of it having a particular type of mineral deposit. The likelihood of occurrence is judged by integrating a range of factors.

An assessment of mineral resources potential of a region combines knowledge of its geology, geophysics, geochemistry, mineral deposits and occurrences with current theories of mineral deposit genesis and results of mineral exploration. The assessment process requires a study of available geoscientific data to determine the history of geologic processes and environments. Geologic environments judged to have characteristics known to be associated with specific types of mineral deposits are then identified. In particular, the assessment draws on regional and local characteristics of mineral deposit models to establish whether or not specific types of mineral deposits are likely to occur.

In evaluating the geologic environments favourable for mineral resource potential, the factors that should be considered are:

- favourable host rocks;
- favourable geological structures;
- evidence of mineralisation;
- geochemical anomalies;
- geophysical anomalies; and
- geologic age data.

The mineral resource potential for an area is ranked from low, moderate, or high, based on the extent by which the assessment criteria is met. If there are insufficient data to classify the areas then the mineral resource potential is categorised as unknown (U).

High (H) mineral resource potential exists where geologic environment characteristics favourable for resource accumulation are known to be present or there is enough evidence to strongly support existence. This category includes known mining areas and mineral deposits.

Moderate (M) mineral resource potential exists where geologic environment characteristics favourable for resource accumulation are known or can reasonably be interpreted to be present, but evidence of mineralisation is less clear.

Low (L) mineral resource potential is assigned where geologic environment characteristics are less favourable for resource accumulation and where evidence of mineral concentrations are less likely.

To reflect the differing amounts of information available, the assessments of mineral potential are also categorised according to levels of certainty, denoted by letters A to D in order of increasing certainty, A denotes the lowest level of certainty and D the highest.

The lowest certainty (A): the available data are not adequate to determine the level of mineral potential.

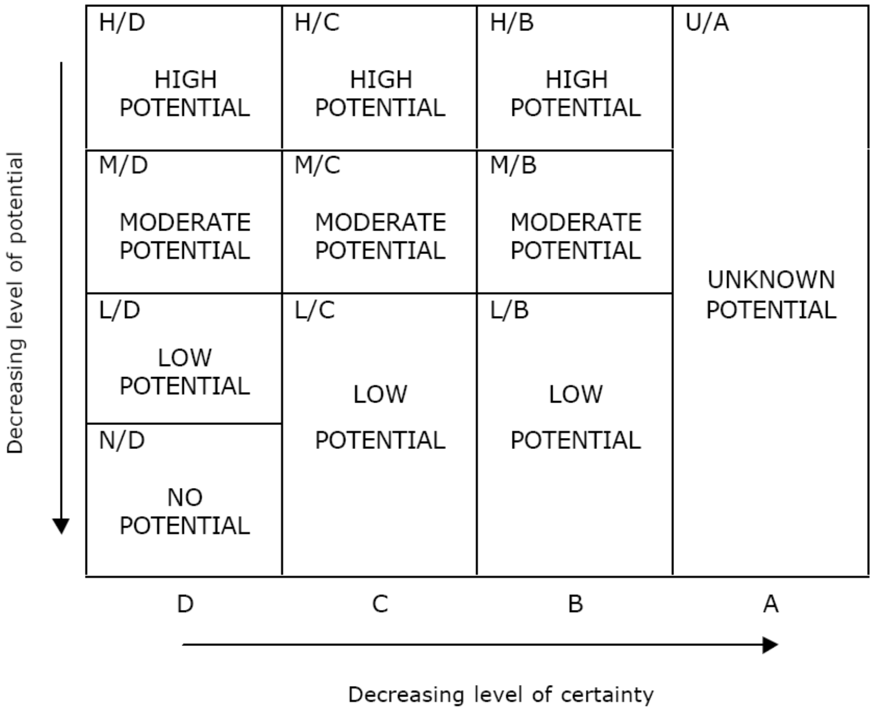
The level of certainty (B): the available data are adequate to suggest the geological environment and level of mineral resources potential, but either is insufficient to establish precisely the likelihood or resource occurrence.

The level of certainty (C): the available data provides a good indication of the geological environment and the level of mineral resource potential.

The highest certainty (D), the available data clearly define the geological environment and the level of mineral resource potential.

A simplified relationship between level of mineral resource potential and levels of certainty is shown in Figure A1.

Table A1. Relationship between levels of mineral resource potential and levels of certainty



Source: Joint Commonwealth NSW Regional Forest Agreement Assessment 1999.
Note: N = no resource potential

Additional information to be considered is industry activity in the assessment area. Absence of activity may not be a negative indication as the mineral deposit style may not have been identified yet.

Mineral resource potential assessments should be revised in the future as the knowledge of the area develops.

References

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Taylor, R. B., and Steven, T. A., 1983. Definition of mineral resource potential. Economic Geology, 78, 1268–1270.

Appendix B: Mineral Resource Potential Assessment Sheets

'Mineral resource' in this report and maps refers to "a concentration of naturally occurring solid, liquid, or gaseous material in such form and amount that economic extraction is currently or potentially feasible".

The mineral potential assessments are based on information currently available and may change as new information is made available.

B.1 IRON-OXIDE COPPER, GOLD, URANIUM DEPOSITS: OLYMPIC DAM-STYLE (MAP 10)

1. **Commodities:** copper, gold, uranium
2. **Major deposits and prospects in the WPA and the 50 km buffer zone:** Prominent Hill, Olympic Dam, Emmie Bluff, Acropolis, Wirrda Well, Carrapateena (just outside the 50 km buffer zone).
3. **Assessment criteria (critical geological features):** Mineral resource potential of iron-oxide copper, gold, uranium deposits in the Gawler Craton was assessed by the GA Gawler Craton Mineral Promotion Project in 2006 (http://www.ga.gov.au/minerals/research/regional/gawler/gawler.jsp). This assessment uses the same criteria as shown below:
   - rock units of the Gawler Ranges–Hiltaba Volcano–Plutonic Association, subdivided by supersuite;
   - faults/shear zones subdivided by age of youngest known significant movement;
   - copper geochemistry (>200 part per million (ppm)), from drillholes intersecting crystalline basement (Mesoproterozoic and older: see Figure 1);
   - hydrothermal alteration assemblages and zones, based on drillhole logging, interpretation of potential-field data, and inversion modelling of potential-field data;
   - host sequence units considered important in localising iron-oxide copper, gold, uranium alteration and mineralisation (e.g., Wallaroo Group and equivalents, Hutchison Group and equivalents, banded iron formation); and
   - geophysical signatures (broadly coincident but off-set gravity and magnetic anomalies).
4. **Mineral resource potential assessment**

   The potential of iron-oxide copper, gold, uranium deposit styles varies from high to low. High potential areas are confined to the eastern and southeastern parts of the WPA.

   Areas with a high potential (certainty level D) are characterised by the presence of all critical geological features of iron-oxide copper, gold, uranium deposits. These areas also host the super-giant Olympic Dam and world-class Prominent Hill deposits.

   The areas with a moderate to high potential (certainty level C) contain intrusive and volcanic members of the Gawler Ranges–Hiltaba Volcano–Plutonic Association. Alteration minerals characteristic of iron-oxide copper, gold uranium deposits have also been recorded. Several rock units in these areas are known to be rich in banded iron formation. Although there are no known occurrences of copper, gold and uranium of this style in these areas, anomalous concentrations of copper are recorded in drillhole and surface samples. Favourable geophysical signatures (broadly coincident but off-set gravity and magnetic anomalies) are also present in some of these areas.

   In the area with a moderate potential (certainty level C) mafic rocks (lower member) of the Gawler Range Volcanics have been mapped. It also contains several rock units with banded iron formation. Although no mineral occurrences of this style have been reported in this area some rock samples record anomalous concentrations of copper.

   A large area with low potential (certainty level C) is located in the northern and western parts of the WPA. It contains a few large bodies of granitoids similar to the Hiltaba Suite granites known to be associated with this style of mineralisation, but more information is required to evaluate their geochemistry. Some rock units with banded iron formation have been mapped in the area. No known mineral occurrences of this style have been reported in the area and it also lacks rock samples with anomalous concentrations of copper. There is no information on the nature and distribution of alteration minerals characteristic of iron-oxide copper, gold, uranium deposits.

B.2 COAL DEPOSITS: PHILLIPSON-STYLE (MAP 11)

1. **Commodities:** coal
2. **Major deposits and prospects in the WPA and the 50 km buffer zone:** Phillipson, Westfield, Murloocoppie, and Weedina.
3. **Assessment criteria (critical geological features):** Deposits of lignite / sub-bituminous coal have been identified in the upper part of Mount Toondina Formation of Early Permian age. Hence assessment criteria used for these deposits are:
   - distribution of Mount Toondina Formation;
   - units of Mount Toondina Formation containing coal, lignite or carbonaceous material; and
   - known occurrences and deposits of coal.
4. **Mineral resource potential assessment**

   In the first step, a map showing all drillholes, which intersected the Mount Toondina Formation and the extent of the Mount Toondina Formation was produced.

   Areas with Mount Toondina Formation, which host significant coal deposits, were assigned high potential (certainty level D). The rest of the Mount Toondina Formation was assigned moderate to high potential with lowest level of certainty (B).

B.3 ARCHEAN LODE GOLD DEPOSITS: CHALLENGER-STYLE (MAP 12)

1. **Commodities:** gold
2. **Major deposits and prospects in the WPA:** Challenger and Golf Bore.
3. **Assessment Criteria (critical geological features):** Assessment criteria used include:
   - distribution of favourable host rocks (Christie Gneiss of the Mulgathing Complex);
   - presence of favourable Archean structures and structural zones;
   - calcrete with more than 10 parts per billion (ppb) gold;
   - linear features on TMI (total magnetic intensity) dataset representing possible smaller discordant structures; and
   - known gold occurrences and deposits of the style.
4. **Mineral resource potential assessment**

   As structures (faults) are one of the most important features for these types of deposits (the faults serve as pathways for fluids and provide potential structural traps) a map was produced to show the density (number of faults/km^2 cell) of faults in the area. A structural zone bounded by major faults defines the most prospective area. Within this zone, mineral resource potential is estimated using the above-mentioned assessment criteria.

   Areas assessed to be of a high potential (certainty level C) contain favourable host rocks (Christie Gneiss), gold deposits and occurrences, calcrete with anomalous concentrations of gold, and are characterised by a high density of structures.

   Areas with a moderate to high potential (certainty level B) contain favourable host rocks (Christie Gneiss) and known mineral occurrences of gold. They also overlap areas with a high density of structures. These areas locally contain calcrete with more than 10 ppb gold.

   Areas with a moderate potential (certainty level B) contain favourable host rocks (Christie Gneiss) and one or more mineral occurrences of gold. This area may locally contain calcrete with anomalous concentration of gold, and subtle smaller discordant structures on the TMI.

B.4 PROTEROZOIC LODE GOLD DEPOSITS: TARCOOLA-STYLE (MAP 13)

1. **Commodities:** gold
2. **Major deposits and prospects in the WPA and within the 50 km buffer zone:** Tarcoola and Tunkillia.
3. **Assessment criteria (critical geological features):** Geological studies of this type of gold deposit in the Gawler Craton show close spatial association with major Mesoproterozoic structures (Yarlbrinda and Yerda shear zones: Fraser et al., 2007). These deposits also reveal a close spatial and temporal association with the Hiltaba Suite granites and Gawler Range Volcanics. Assessment criteria used for these deposits include:
    - proximity to intrusive rocks of Hiltaba Suite granites;
    - presence of favourable structures and structural zones;
    - calcrete with more than 10 ppb gold; and
    - known gold occurrences and deposits of the style.
4. **Mineral resource potential assessment**

    A map showing density of structures (number of faults/km^2 cell) was used to outline areas which were structurally favourable to host gold deposits. Mineral resource potential was assigned based on the presence or absence of assessment criteria.

    Areas with a high potential (certainty level C) are located in proximity to major structures and overlap areas with a high density of structures. A large number of Hiltaba Suite granites are present within, or in close proximity to, these areas. These areas also contain gold deposits and mineral occurrences of gold. Geochemical analysis of calcrete in these areas shows that they contain more than 10 ppb gold.

    Areas with a moderate to high potential (certainty level C) are also located in proximity to the Hiltaba Suite granites but the density of structures is lower than in areas with high potential. These areas also contain many gold occurrences but no substantial gold deposit of the size of Tarcoola or Tunkillia has been found. Calcrete with more than 10 ppb gold have also been locally recorded in these areas.

    The area with a moderate potential (certainty level B) is located in proximity to a series of major east-west-trending structures which form a network of lower-order structures spatially associated with them. Mapping in the area also shows the presence of Hiltaba Suite granites. No gold deposit or mineral occurrence of gold have been found in this area and geochemical analysis of calcrete does not reveal anomalous concentrations (>10 ppb or more gold).
5. **References**

Fraser, G. L., Skirrow, R. G., Schmidt-Mumm, A., and Holm, O., 2007. Mesoproterozoic gold in the Central Gawler Craton, South Australia: Geology, alteration, fluids and timing. Economic Geology, 102, 1511–1539.

B.5 IRON ORE DEPOSITS: BANDED IRON FORMATION: HAWKS NEST-STYLE (MAP 14)

1. **Commodities:** iron
2. **Major deposits and prospects in the WPA and within the 50 km buffer:** Hawks Nest, Giffen Well, Mount Christie, Wilgena Hill, Sequoia, and Ooldea.
3. **Assessment criteria (critical geological features):** All known deposits of this type in the Gawler Craton are associated with rock units containing banded iron formation, such as Christie Gneiss, Middleback Jaspellite, and Wilgena Hill Jaspellite. Assessment criteria used for these deposits include:
    - presence of rock units containing banded iron formation; and
    - known occurrences and deposits of iron ore of this style.
4. **Mineral resource potential assessment**

    Before assessing the potential, a map was produced which showed the distribution of rock units containing banded iron formation. Both outcrop geology and solid-geology maps were used to prepare the map. The total magnetic intensity (TMI) dataset was re-interpreted to make a map of ‘worms’ (bands of data). The ‘worms’ helped to extend the distribution of rock units containing banded iron formation in areas in areas with no outcrop.

    Areas of known and interpreted rock units containing banded iron formation, which also host significant iron ore deposits, were assigned high potential with the highest level of certainty (D).

Banded iron formation, which are known to host only mineral occurrences of iron ore, were assigned moderate to high potential with a low level of certainty (B).

Areas with banded iron formation, but without known occurrences or deposits, were assigned a moderate potential with a low level of certainty (B).

B.6 IRON ORE DEPOSITS: HYDROTHERMAL: CAIRN HILL-STYLE (MAP 15)

1. **Commodities:** iron (copper, gold)
2. **Major deposits and prospects in the WPA:** Cairn Hill, Peculiar Knob, Paragon Bore Prospect, and Mount Brady Prospect.
3. **Assessment criteria (critical geological features):** These deposits are called hydrothermal because geological information suggests that hydrothermal fluids associated with the Hiltaba Suite granites could have played an important role in the formation of these deposits. The presence of rock units containing banded iron formation in the area provides an additional constraint because it has been suggested that hydrothermal fluids associated with the granites could have remobilised iron from the banded iron formation to form magnetite-rich ores. Hence the assessment criteria used for these deposits are:
   - proximity to the Hiltaba Suite and possibly Donnington Suite granites;
   - presence of rock units containing primary banded iron formation; and
   - known occurrences and deposits of iron of this style.
4. **Mineral resource potential assessment**

   To assess the potential of hydrothermal iron-ore deposits a map showing the distribution of rock units containing banded iron formation was combined with a map that showed the distribution of Hiltaba and Donnington Suite granites.

   Areas with a high potential (certainty level D) contain rock units with banded iron formation. They are located in proximity to the Hiltaba Suite granites and also host significant deposits (such as Cairn Hill), and mineral occurrences of iron ore.

   Rock units with banded iron formation and Hiltaba Suite granites are also present in areas assessed to have a moderate to high potential (certainty level B). However, apart from a few mineral prospects of iron, no significant iron ore deposits have been found.

   Areas with a moderate potential (certainty level B) also contain rock units with banded iron formation, located in proximity to Hiltaba Suite granites, but no significant iron ore deposit, prospect or mineral occurrence of iron have been found in them.

   Most iron-oxide copper, gold, uranium deposits (such as Olympic Dam and Prominent Hill) are known to have significant concentrations of iron oxides such as hematite and magnetite. Thus areas prospective for iron-oxide copper, gold, uranium deposits are also prospective for hydrothermal iron ore deposits.

B.7 UNCONFORMITY-RELATED URANIUM DEPOSITS (MAP 16)

1. **Commodities:** uranium
2. **Major deposits and prospects in the WPA:** There are no known deposits or prospects of this type in the WPA.
3. **Assessment criteria (critical geological features):** Although no deposits or prospects of this type have yet been found in the WPA, geological similarities between the Pine Creek Orogen, Northern Territory (hosting large uranium deposits of this type such as Jabiluka and Ranger) and the Gawler Craton is of major interest to exploration companies exploring for uranium deposits of this style. The main assessment criteria for these deposits are:
   - unconformity between Archean and/or Paleoproterozoic and younger preferably Proterozoic rocks;
   - a thick (at least 5 to 7 km) sequence of highly permeable siliciclastic sandstone formed preferably in fluvial environments above the unconformity;
   - rocks with reductants (graphite, Fe^{+2}-bearing silicates) below the unconformity; and
   - major structures as pathways of fluid and/or as traps.

4. Mineral resource potential assessment

Geological studies show the presence of a regional unconformity between the rocks of the Pandurra Formation (Mesoproterozoic age) and older rocks of Paleoproterozoic age. The Pandurra Formation is a thick sequence of flat-lying, arenaceous red-bed sediments deposited within the Cariewerloo Basin (Cowley, 1993). A similar unconformity has been mapped between fluvial to moderately deep marine sediments of the Corunna Conglomerate (Mesoproteropzoic age) and the underlying Paleoproterozoic rocks (Daly, 1993). The Corunna Conglomerate unconformably overlies volcanic rocks of the McGregor Volcanics and coarse-grained sediments of the Moonabie Formation (Daly, 1993). Another prospective sequence of rocks belongs to the Blue Range beds (coarse-grained sandstone and shale) of the Itiledoo Basin. This thick package (up to 2500 m) was deposited in a braided stream-alluvial fan environment. Basal sediments unconformably overlie the Paleoproterozoic sediments of the Hutchison Group. The Blue Range Beds are located outside the WPA.

As with world-class unconformity-related uranium deposits in other areas, such as the Pine Creek Orogen in the Northern Territory the package of rocks overlying the unconformity is often eroded exposing mineralisation in the basement rocks. In the Pine Creek area, most known deposits are situated within 40 to 50 km of the present-day margin of the basin in which the sandstone package was originally deposited. In the Gawler Craton, the Cariewerloo Basin, which was filled by the sediments of the Pandurra Formation, was more extensive than its present-day boundary. Hence a buffer of 40 km is drawn around the mapped boundary of the Pandurra Formation to assess the potential of deposits which might have been formed in the basement rocks but from which the cover of the Pandurra Formation has been eroded.

Most favourable basement rocks belong to the Hutchison Group, which consist of various types of schists that locally contain graphite and graphitic units. Thus areas with the Hutchison Group overlain by the Pandurra Formation are assessed to have a moderate to high potential with C (moderate) level of certainty.

The laminated carbonaceous and pyritic siltstone and shale in the Tarcoola Formation are also good reductants. Hence areas of the Tarcoola Formation are assigned a moderate potential with a moderate (certainty level C) certainty.

The Fe^{+2}-bearing silicates in the lower member of the Gawler Range Volcanics and Lake Harris Komatiites can also provide effective reductants, although not as good as graphite or carbonaceous material. These rocks are assigned a low to moderate potential with a moderate (certainty level C) certainty.

Silicate reductants are also present in the rocks of the Broadview Schist, Wandearah Formation, and the Wallaroo Group. These rocks are located not in areas covered by the Pandurra Formation, but within a 40 km buffer zone around it. They were assigned a low potential with low (certainty level B) certainty.

For many rock units, the geological information is not enough to judge the presence of effective reductants in them. Their potential is assessed as unknown.

Mineral resource potential of all rock units within the 40 km buffer zone around the area with Pandurra Formation has been lowered by one level compared to the level of potential of the same units in areas covered by the Pandurra Formation because of the uncertainty associated with estimating the original extent of the Pandurra Formation.

The prospective area of the Itiledoo Basin is located outside the WPA.

5. References

Cowley, W. M., 1993. Pandurra Formation. *In*: Drexel, J. F., Preiss, W. V., and Parker, A. J. (editors), The Geology of South Australia, Volume 1, The Precambrian, 139–142.

Daly, S., 1993. Corunna Conglomerate. *In*: Drexel, J. F., Preiss, W. V., and Parker, A. J. (editors), The Geology of South Australia, Volume 1, The Precambrian, 124–126.

B.8 SANDSTONE-HOSTED URANIUM DEPOSITS: ROLL-FRONT TYPE (MAP 17)

1. **Commodities:** uranium
2. **Major deposits and prospects in the WPA:** There are no known deposits of this type in the WPA.
3. **Assessment criteria (critical geological features):** Although no deposits or prospects of this type have yet been found in the WPA, the geological setting suggests the presence of areas prospective for this style of deposit. The main assessment criteria for these deposits are:
   - proximity to source rocks of uranium;

- predominantly fluvial packages sedimentary rocks containing highly permeable coarse-grained sandstones; and
- organic material in the sandstone or presence of mobile reductants (reduced gases from hydrocarbon- and/or coal-bearing basins).

4. Mineral resource potential assessment

One of the most significant features of the Gawler Craton is the abundance of rocks with higher than average uranium concentration. These include felsic rocks of the Gawler Range Volcanics and the Hiltaba Suite granites. Large uranium-rich deposits such as Olympic Dam and Prominent Hill and altered rocks surrounding them can also provide source of leachable uranium.

The Eromanga Basin overlying northern parts of the Gawler Craton comprises a number of major aquifers, some of which are prospective for sandstone-hosted uranium deposits. Water samples from these aquifers (in particular Algebuckina Sandstone) locally record high concentrations of uranium (>1 ppm).

The mineral resource potential of sandstone-hosted uranium deposits was assessed for the Algebuckina Sandstone. Location of drillholes, which intersect this package, was used to map the under-cover extent of the sandstone. A map of the Mesozoic paleochannels (Hou et al., 2007) provided additional information on the distribution of these rocks. Uranium concentrations of waters from the aquifers were accessed from the geochemistry dataset of the Bureau of Rural Sciences (Radke et al., 2000).

The Algebuckina Sandstone is a fine- to coarse-grained quartzose sandstone with shale interclasts and minor lenses of siltstone and shale (Alexander and Krieg, 1995). In this assessment, areas of Algebukcina Sandstone (under-cover) were assigned a moderate potential with a low level of certainty (B). This is because although waters with more than 1 ppm uranium have been recorded from the sandstone package, reliable information on the organic content of the sandstone is not available. It is possible that shale and siltstone lenses within the sandstone contain organic material.

Areas of the Algebuckina Sandstone which overlie the coal-bearing rocks of the Mount Toondina Formation are assigned a moderate to high potential with a moderate level of certainty (C). This is because reduced gases (such as methane) leaking from coal seams can under favourable conditions reduce uranium-bearing oxidised waters in the Algebuckina Sandstone.

5. References

Alexander, E. M., and Krieg, G. W., 1995. Stratigraphy: Lower non-marine succession. *In*: Drexel, J. F., and Preiss, W. V. (editors), The Geology of South Australia, Volume 2, The Phanerozoic, 104–108.

Hou, B., Zang, W., Fabris, A., Keeling, J., Stoian, L., and Fairclough, M. 2007. Paleodrainage and Tertiary coastal barrier of South Australia. Digital Geological Map of South Australia, 1:2 000 000 Series (1st Edition), PIRSA, South Australia.

Radke, B. M., Ferguson, J., Creswell, R. G., Ransley, T. R., and Habermehl, M. A., 2000. Hydrochemistry and implied hydrodynamics of the Cadna-owies-Hooray aquifer Great Artesian Basin. Australia, Bureau of Rural Sciences, Canberra, 229 pp.

B.9 SANDSTONE-HOSTED URANIUM DEPOSITS: CHANNEL-TYPE (MAP 18)

1. **Commodities:** uranium
2. **Major deposits and prospects in the WPA:** Warrior, Peela Swamp Prospect, Ealbara Prospect and Pundinya Prospect.
3. **Assessment criteria (critical geological features):**

Cenozoic paleochannels in the central and southern parts of the Gawler Craton host several uranium prospects and two significant uranium deposits, and remain interesting exploration targets of uranium for several companies. The main assessment criteria for these deposits are:

- proximity to source rocks of uranium (in the upstream areas of the channel and/or in the basement incised by the channel);
- highly permeable coarse-grained sandstones;
- organic material in the sandstone; and
- prospects and deposits of uranium of this style.

4. Mineral resource potential assessment

One of the most significant features of Gawler Craton is the abundance of rocks with higher than average uranium concentration. These include felsic rocks of the Gawler Range Volcanics and the Hiltaba Suite granites. Large uranium-rich deposits such as Olympic Dam and Prominent Hill and altered rocks with higher than average uranium concentration surrounding them can also provide a source of leachable uranium.

Most known prospects and deposits are located in the basal Pidinga Formation that fill Paleogene paleochannels (Hou, 2004). This paleochannel incises the Precambrian basement, and locally Paleozoic and Mesozoic rocks. It consists of carbonaceous gravely and fine-grained quartzitic sand and clay plus lignite, carbonised wood, and leaf fragments. The Neogene paleochannels incise either Paleogene channels or much older rocks (Precambrian basement, and locally Paleozoic and Mesozoic rocks). Of the Neogene sediments only the Kingoonya Members contains carbonaceous material and carbonised wood and leaf fragments.

Parts of the Paleogene channels (including the most prospective Kingoonya channels trending east-west) are assigned high potential with the highest level of certainty (D). These parts record the presence of the most favourable host sediments (Pidinga Formation) and also host numerous uranium prospects and two significant uranium deposits. The upstream areas of these channels have abundant potential source-rocks of uranium (such as the Hiltaba Suite granites). The U^2/Th ratio radiometric map also reveals zones of high U^2/Th values in parts of these channels.

Paleogene channels to the north of the above mentioned channels are assigned moderate to high potential with moderate level of certainty (C). This is because known rocks with higher than average uranium concentration in the upstream areas of these channels are comparatively rare. No uranium prospects or deposits have yet been found in them. The U^2/Th ratio radiometric map (GA) reveals some local zones of high U^2/Th values in these channels.

All Neogene channels have been assigned moderate potential with low level of certainty (B) because they predominantly incise Paleogene paleochannels. The sediments filling these channels have low abundance of organic material and no prospects or deposits have been reported in them.

5. References

Hou, B., 2004. Kingoonya paleochannel project: Architecture and evolution of Kingoonya paleochannel system. PIRSA, Report Book 2004/1, 122 pp.

B.10 HEAVY MINERAL SAND DEPOSITS (MAP 19)

1. **Commodities:** zircon, rutile, ilmenite, and rare earth elements
2. **Major deposits and prospects in the WPA:** Ambrosia, Jacinth, Immarna Prospect, and Barton West Mineral Sands Prospect.
3. **Assessment criteria (critical geological features):** The assessment region forms the northern part of an extensive heavy mineral province that rims the Nullabor Plain. The stranded Cenozoic coastal dunes in the eastern Eucla Basin are highly prospective for heavy mineral sand deposit and hosts several world-class deposits and prospects. The preserved Cenozoic shorelines comprise beach, shore-face, barrier, dune, tidal inlet, washover, and lagoonal facies, representing multiple higher order high-stands. There are four generations of shorelines, recognised. These include, mid-Middle Eocene (41.5 million year age), late Middle Eocene (39 million year age), Late Eocene (37 million year age), and Neogene (from 15 to 5 million year age: Hou and Warland, 2005).

   Sedimentological studies have identified heavy mineral sand deposits as: lag deposits along erosional disconformities and/or unconformities; transgressive deposits at the rear of high-stand (swash-aligned) barriers, including those trapped near the paleovalley passes; regressive deposits at the front of prograded barriers; and aeolian deposits, as low-grade disseminated concentrations in transgressive dunes. Mineralised zones are thought to represent stacked shoreline facies that accumulated during marine transgressions in the Tertiary (Hou, 2004). The most prospective strata are the barrier and associated sands of Tertiary shorelines that were buried by voluminous sand dunes.

   The assessment criteria for heavy mineral sand deposits include:

   - preserved strandlines;
   - known prospects and deposits of zircon-rich heavy mineral sand; and
   - heavy mineral concentrates containing high proportion of zircon (+20%).

4. Mineral resource potential assessment

A map of Cenozoic strandlines (Hou et al., 2007) outlines prospective areas for heavy mineral sands.

The area identified as high potential with moderate level of certainty (B) is defined by the Cenozoic strandlines. It hosts major heavy mineral sand deposits and prospects.

5. References

Hou, B., 2004. Kingoonya paleochannel project: Architecture and evolution of Kingoonya paleochannel system. PIRSA, Report Book 2004/1, 122 pp.

Hou, B., and Warland, I., 2005. Heavy mineral sands potential of the Eucla Basin in South Australia: A world-class paleobeach placer province. MESA Journal, 37, 4–12.

Hou, B., Zang, W., Fabris, A., Keeling, J., Stoian, L., and Fairclough, M. 2007. Paleodrainage and Tertiary coastal barrier of South Australia. Digital Geological Map of South Australia, 1:2 000 000 Series (1st Edition), PIRSA, South Australia.

B.11 GEOTHERMAL RESOURCES: HOT ROCK-TYPE (MAP 20)

1. **Commodities:** geothermal resources

2. **Major deposits and prospects in the WPA:** A high proportion of the geothermal exploration in Australia to date has occurred in South Australia. Locations of current South Australian exploration projects that have resource estimates include: the Limestone Coast (Mount Gambier), the Cooper Basin (Innamincka), Olympic Dam area, Paralana (530 km north-northeast of Adelaide), and Parachilna (150 km north of Port Augusta). To date there are no geothermal projects commercially producing electricity in South Australia.

3. **Assessment criteria:** Three factors have been identified as most critical in determining the hot rock (HR) potential of a region: thermal resistance of sedimentary rocks overlying basement, temperature availability, and temperature potential. The method in which these datasets were compiled is outlined below:

   - *Thermal resistance* of sedimentary rocks has been calculated by dividing the estimated sedimentary rock thickness by the thermal conductivity of the sedimentary rocks. The thickness was determined using OZSEEBASE™ (FrOG Tech). A thermal conductivity value was assigned to each basin using direct measurements where available (e.g., Eromanga Basin), or based on available lithological information combined with thermal conductivity values for different lithologies (Ayling and Lewis, 2010);
   - *Temperature availability* is the estimated temperature at 5 km depth and was obtained from the OZTemp database (GA); and
   - *Temperature potential* is the estimate for the heat generation of felsic intrusive rocks in the region. It is determined from two data sets:
     - presence of felsic intrusive rocks (no data on heat generation); and
     - heat generation, calculated from the geochemistry of felsic intrusive rocks from the OZCHEM and SARIG databases (GA/PIRSA).

4. Mineral resource potential assessment

The geothermal potential was determined using a ranking system similar to that outlined by Ayling and Lewis (2010).

- *Thermal resistance* is assigned a rank from 1–7, *temperature availability* a rank from 1–5, and *temperature potential* a rank from 0–1 for felsic intrusive occurrence and 0–5 for heat generation.
- Each dataset was then assigned a weighting:
  - thermal resistivity = 45%;
  - temperature at 5 km depth = 10%; and
  - heat generation = 45%.
- The above scheme gives a total score out of 6; with 1 being the lowest potential and 6 being the highest potential.

The potential of a location depends on the 3 factors being present and the classification of the factors. This is outlined in the following table.

Score	Potential	Reason
1	Low	Not all factors present
2	Low-moderate	All factors present, 2 ranked low, 1 ranked moderate
3–4	Moderate	All factors present and at least 2 ranked moderate
5	Moderate-high	All factors present and at least 1 ranked high and others ranked moderate
6	High	All factors present and all ranked high

Approximately half of the WPA has low or low to moderate potential for hot rock geothermal resources. This is due to a thin sedimentary rock cover which results in low thermal resistance values.

There are two regions that are more prospective, having moderate potential. These are along the eastern boundary and in the western third of the WPA. This is due to thicker sedimentary cover and higher heat producing granites.

5. **Certainty assessment**

It should be noted that the certainty for this assessment of the WPA is low due to insufficient data:

- there is a lack of measured thermal conductivity values;
- the certainty in the OZ SEEBASE™ is low in this region (FrOG Tech);
- the certainty in the OZTemp dataset is low in this region due to a very sparse coverage of holes; and
- there is a lack of data on felsic intrusive rocks as these are often not expressed at the surface.

6. **References**

Ayling, B., and Lewis, B., 2010. Geothermal Systems. *In*: Huston, D. L. (editor). An assessment of the uranium and geothermal potential of north Queensland. Geoscience Australia Record 2010/14, 68–91.

FrOG Tech (From Oil to Groundwater consultancy). OZ SEEBASE™ (depth to basement) surface data.

B.12 GEOTHERMAL RESOURCES: HOT SEDIMENTARY AQUIFER-TYPE (MAP 21)

1. **Commodities:** geothermal resources

2. **Major deposits and prospects in the WPA:** A high proportion of the geothermal exploration in Australia to date has occurred in South Australia. Locations of current South Australian exploration projects that have resource estimates include: the Limestone Coast (Mount Gambier), the Cooper Basin (Innamincka), Olympic Dam area, Paralana (530 km north-northeast of Adelaide), and Parachilna (150km north of Port Augusta). To date there are no geothermal projects commercially producing electricity in South Australia.

3. **Assessment criteria:** Four factors have been identified as most critical in determining the HSA potential of a region: *thermal resistance* of sedimentary rocks overlying basement, *sediment thickness*, *temperature availability* and *temperature potential*. This is in the absence of information on the porosity, permeability and extent of the aquifers, water temperatures and extraction rates in the WPA. If this information were available it would have been used in the assessment. The method in which the available information was compiled is outlined below:

   - *Thermal resistance* of sediments has been calculated by dividing the sedimentary rock thickness by the thermal conductivity of the sedimentary rocks. The thickness was determined using OZSEEBASE™ (FrOG Tech). A thermal conductivity value was assigned to each basin using direct measurements where available (e.g., Eromanga Basin), or based on available lithological information combined with thermal conductivity values for different lithologies (Ayling and Lewis, 2010);
   - *Sedimentary rock thickness* is from the OZSEEBASE™ data (FrOG Tech);
   - *Temperature availability* is the estimated temperature at 5km depth and was obtained from the OZTemp database (Geoscience Australia); and
   - *Temperature potential* is the estimate for the heat generation of felsic intrusive rocks in the region. It is determined from two data sets:

- presence of felsic intrusive rocks (no data on heat generation); and
- heat generation, calculated from the geochemistry of felsic intrusives from the OZCHEM and SARIG databases (Geoscience Australia/PIRSA).

4. Mineral resource potential assessment

The geothermal potential was determined using a ranking system similar to that outlined by Ayling and Lewis (2010).

- *Thermal resistance* is assigned a rank from 1-7, *temperature availability* a rank from 1-5, *sediment thickness* a rank from 1-6, and *temperature potential* a rank from 0-1 for felsic intrusive occurrence and 0-5 for heat generation.
- Each dataset was then assigned a weighting
  - Thermal resistivity = 30%;
  - Sediment thickness = 25%;
  - Temperature at 5km depth = 30%; and
  - Heat generation = 15%.
- The above gives a total score out of 6; with 1 being lowest potential and 6 being the highest.

The potential of a location depends on the 4 aforementioned factors being present and the classification of the factors. This is outlined in the following table.

Score	Potential	Reason
1	Low	Not all factors present
2	Low-moderate	All factors present, at least 2 ranked ranked low, at least 1 ranked moderate
3–4	Moderate	All factors present and at least 2 ranked moderate
5	Moderate-high	All factors present and at least 1 ranked high and others ranked moderate

There are some areas of the WPA that have low or moderately low HSA potential. However there are some regions on the western side that have moderate potential.

There are minor regions on the eastern side of the WPA that have a moderate to moderate-high potential which is due to sediment thickness and thermal resistance.

It should be noted that this is an assessment for using HSA for electricity generation. There is also the possibility for direct use applications such as; desalination, agriculture, industrial processing and space heating.

These applications require substantially lower temperatures than electricity generation. Thus areas that have low potential for electricity generation may still have high potential for direct use applications, if located close to population centres.

5. Certainty assessment

The certainty for this assessment ranges from low to high.

There is high certainty in areas of basement outcrop. This is because there is high confidence in the geological mapping of these units and there are no aquifers present, thus it can be said with high certainty that there is no potential for HSA.

There is moderate certainty in basins where a known aquifer is present

It is low in basins where it is unknown if an aquifer is present, this is due to insufficient data being present for all factors:

- there is a lack of measured thermal conductivity values;
- the certainty in the OZSEEBASE™ is low in this region (FrOG Tech);
- the certainty in the OZTemp dataset is low in this region due to a very sparse coverage of holes; and
- there is a lack of data on felsic intrusives as these are often not expressed at the surface.

6. References

Ayling, B., and Lewis, B., 2010. Geothermal Systems. *In*: Huston, D. L. (editor). An assessment of the uranium and geothermal potential of north Queensland. Geoscience Australia Record 2010/14, 68–91.

FrOG Tech (From Oil to Groundwater consultancy). OZ SEEBASE^{TM} (depth to basement) surface data.

B.13 CONVENTIONAL HYDROCARBONS (MAP 22)

1. **Commodities:** oil and gas
2. **Major deposits and prospects in the WPA:** No gas or liquid hydrocarbon accumulations have been discovered to date.
3. **Assessment criteria (critical geological features):** Both the Officer and the Arckaringa basins have attracted exploration for conventional hydrocarbon accumulations. The assessment criteria used to assess the potential for conventional hydrocarbon accumulations in these basins include:
   - presence of suitable source rocks;
   - presence of suitable reservoir and seal;
   - geological conditions suitable for the generation and preservation of hydrocarbons; and
   - oil shows.
4. **Mineral resource potential assessment**

The Officer Basin represents one of the last remaining onshore frontier exploration areas where large petroleum discoveries may still be made. It has close geological affinities with the productive Amadeus Basin in the Northern Territory, and with basins in the former Soviet Union and Oman, both of which host giant oil and gas fields and have proven oil reserves in the order of billions of barrels. Numerous oil shows are known in the Officer Basin from mineral and stratigraphic drillholes, although there has been little on-structure drilling for petroleum targets. Excellent reservoir quality and source rocks are proven. Evaporites and salt tectonics are evident and may provide viable trapping and preservation mechanisms. The prospective sediment packages are Neoproterozoic (Willouran, Marinoan) and Cambro-Ordovician in age.

A recent assessment of Australian sedimentary basins by the Australian Government Carbon Storage Task Force, ranked the hydrocarbon potential of the Officer Basin as moderate to high (a score of 3 out of 5). In the assessment for the WPA the Officer Basin has been assigned a moderate to high potential for oil and gas accumulations (certainty level B).

Due to the range of potential petroleum plays and the frontier designation of this remote area, no attempt has been made to delineate areas of higher potential within the Officer Basin.

The eastern Officer Basin is overlain in part by the Permo-Carboniferous Arckaringa Basin. Organic-rich source rocks in the Arckaringa Basin are generally immature for hydrocarbon generation; however, hydrocarbons may be sourced from the underlying Officer Basin sequence where present.

The Carbon Storage Task Force assessment also ranked the hydrocarbon potential of the Arckaringa Basin low to moderate (a score of 2 out of 5). In the assessment for the WPA, the Arckaringa Basin (where it is not underlain by the Officer Basin) has been assigned a low to moderate potential for oil and gas accumulations (certainty level B).

B.14 COAL-RELATED HYDROCARBONS (MAP 23)

1. **Commodities:** Unconventional hydrocarbons from coal (underground coal gasification (UCG) and coal seam gas (CSG))
2. **Major deposits and prospects in the WPA and within the 50 km buffer zone:** Phillipson, Westfield, Murloocoppie, and Weedina.
3. **Assessment criteria (critical geological features):** Deposits of lignite/sub-bituminous coal have been identified in the upper part of Mount Toondina Formation of Early Permian age. These deposits have coal quality characteristics that may be suited to the UCG process. Hence assessment criteria used for these deposits are:
   - distribution of Mount Toondina Formation;
   - units of Mount Toondina Formation containing coal, lignite or carbonaceous material; and

- known occurrences and deposits of coal.

4. **Mineral resource potential assessment**

   In the first step, a map showing all drillholes which intersected the Mount Toondina Formation and the extent of the Mount Toondina Formation was produced.

   Areas with Mount Toondina Formation which host significant coal deposits were assigned high potential (certainty level D). The rest of the Mount Toondina Formation was assigned moderate to high potential with lowest level of certainty (B).

B.15 OIL SHALE DEPOSITS (MAP 24)

1. **Commodities:** oil shale (unconventional hydrocarbons)
2. **Major deposits and prospects in the WPA:** No deposit defined.
3. **Assessment criteria (critical geological features):** Oil shale has been identified in the upper part of the Stuart Range Formation and the lower part of the overlying Mount Toondina Formation. These formations are of Early Permian age. The assessment criteria used for these deposits are:
   - distribution and thickness of the Stuart Range Formation; and
   - known occurrences of oil shale.
4. **Mineral resource potential assessment**

   Boorthanna Trough

   A Stuart Range Formation isopach map for the Arckaringa Basin was constructed using drillhole data (minerals exploration, coal exploration, coal deposit, petroleum exploration). A polygon was then constructed to capture the thickest development of the Stuart Range Formation in the Boorthanna Trough. This polygon has been assigned a high potential for oil shale deposits with a certainty level of B.

   An organic petrology study of six wells in the Boorthanna Trough indicated the presence of Tasmanite oil shale in the upper part of the Stuart Range Formation and the lower part of the overlying Mount Toondina Formation.

   Phillipson and Wallira troughs

   In the Phillipson and Wallira troughs the top Stuart Range Formation horizon was interpreted on a 2D seismic data set. A polygon was then constructed to capture the mapped horizon, and therefore the extent of the upper Stuart Range and basal Mount Toondina formations. This polygon has been assigned a high potential for oil shale deposits with a certainty level of B.

   Rock evaluation data from the Arkeeta 1 petroleum exploration well (Phillipson Trough) indicate a significant interval of organic-rich shales over the base of the Mount Toondina Formation and the top of the Stuart Range Formation. Four 3-metre cuttings samples over the richest interval (684–747 m) yielded the equivalent of between 25 and 56 litres of hydrocarbon per tonne of rock (average 39 litres hydrocarbon per tonne of rock).

   Arckaringa Basin outside the Phillipson, Wallira, and Boorthanna troughs

   The Stuart Range and Mount Toondina formations outside the Phillipson, Wallira, and Boorthanna troughs were assigned moderate potential for oil shale deposits with a low level of certainty (B). The zero contour of the Stuart Range Formation isopach map was used to define this polygon.

B.16 KOMATIITE (MAFIC-ULTRAMAFIC)-ASSOCIATED NICKEL DEPOSITS (MAP 25)

1. **Commodities:** nickel, copper, platinum-group elements
2. **Major deposits and prospects in the WPA:** No known nickel deposits. Two small prospects (Mullina Well and Lake Harris).
3. **Assessment criteria (critical geological features):** The Late Archean greenstone sequence in the central Gawler Craton of South Australia comprises komatiitic rocks, mafic and felsic volcanic rocks, metasedimentary rocks, and banded iron formation. These rocks collectively belong to the Lake Harris Komatiite, with the ultramafic rocks targeted by exploration companies in recent years for nickel sulphide deposits. The greenstone sequence is hidden under a thin cover of Cenozoic alluvial sediments and it has been deformed and metamorphosed to middle amphibolite facies (Hoatson et al., 2006). Characteristic

features of most major mineralised komatiite sequences from around the world include (Hoatson et al., 2005; 2006):

- most nickel sulphide deposits are associated with komatiites of ca. 2700 million year age (Western Australia) and 1900 million year age (Canada), whereas older and much younger komatiitic sequences are generally not well mineralised);
- presence of sulphur-bearing country rocks within or near the greenstones that are important for the S-saturation of the ultramafic magmas and precipitation of Ni-Cu sulphides;
- alumina-undepleted composition of primary ultramafic magma(s);
- volcanic facies dominated by dynamic sheet flows and dunitic compound sheet flows;
- nickel depletion trends during fractionation of ultramafic magmas; and
- presence of nickel deposits and prospects.

4. Mineral resource potential assessment

The mineral resource potential map shows the Lake Harris greenstone sequences extend over 300 km along three major sinuous subparallel belts. Only the eastern parts of these belts extend into the WPA. Less than a few per cent of the poorly exposed ultramafic stratigraphy has been tested by drilling. The greenstone sequence is assigned a low potential with low level of certainty (B). The potential for nickel sulphide deposits is low because:

- the ~2520 million year age of the Lake Harris komatiitic rocks is not a favourable age for mineralised komatiites;
- the Lake Harris greenstone stratigraphy is steeply dipping, and the absence of outcrop, and structural complexities, prevent detailed stratigraphic correlations within and between the ultramafic belts. Therefore, younging direction criteria and identification of favourable basal contacts for sulphide accumulation are difficult to determine;
- of the absence of sulphur-bearing country rocks in or near the greenstones. The surrounding rocks contain a high proportion of felsic intrusive (granitic) rocks, and the contacts between greenstone sequences and country rocks are often sheared;
- the komatiitic rocks are interpreted to be derived from a primary ultramafic magma(s) that is alumina-depleted rather than alumina-undepleted;
- mafic-ultramafic rocks in the greenstone sequences represent either thin differentiated distal flow or ponded lava lake facies (i.e., passive not dynamic lava pathway environments);
- the ultramafic magmas do not show nickel depletion trends during fractionation that could point to mineralising sulphide events; and
- limited drilling from the greenstone sequences to date has not defined any significant Ni-Cu mineralisation.

5. References

Hoatson, D. M., Sun, S-S., Duggan, M. B., Davies, M. B., Daly, S. J., and Purvis, A.C., 2005. Late Archean Lake Harris Komatiite, central Gawler Craton, South Australia: Geological setting and geochemistry. Economic Geology, 100, 349–374.

Hoatson, D. M., Jaireth, S., and Jaques, L. A., 2006. Nickel sulphide deposits in Australia: Characteristics, resources, and potential. Ore Geology Reviews, 29, 177–241.

B.17 THOLEIITE (MAFIC-ULTRAMAFIC)-ASSOCIATED NICKEL, COPPER DEPOSITS (MAP 26)

1. **Commodities:** nickel, copper, platinum-group elements
2. **Major deposits and prospects in the WPA:** No known nickel or copper deposits.
3. **Assessment criteria (critical geological features):** The Fowler Domain in the Gawler Craton contains a series of Paleoproterozoic mafic intrusions. These include meta-igneous cumulus gabbronorite, much less evolved primitive gabbro, and altered chromite-bearing olivine-rich ultramafics (Constable et al., 2005). Rare geochemical sampling conducted to date on these intrusions show them to be primitive. Anomalous chromite has been recognised in a silicified peridotite. Results from drilling indicated significant

concentrations of chromium and anomalous concentrations of nickel and copper (Constable et al., 2005). A serpentinised peridotite (Aristarchus Peridotite) in the Christie Domain is reported to have anomalous concentrations of nickel, chromium, gold and platinum-group elements. Although no deposits have yet been found, the mafic-ultramafic rocks are thought to be prospective for nickel, copper, and platinum-group element mineralisation. Assessment criteria for this style of deposit include:

- mafic-dominated tholeiitic intrusions with minor ultramafic rocks in lower parts of stratigraphy;
- preservation of basal contacts and feeder conduits;
- sulphur saturation (early for nickel and copper and later for platinum-group elements) of magma reflected in the sulphur concentration of the primitive magma of the complex;
- nickel depletion trends in the intrusive complex; and
- known prospects, deposits or zones with anomalous concentrations of chromium, nickel, copper, and platinum-group elements.

4. Mineral resource potential assessment

The mineral resource potential map shows the Fowler Domain contains several mafic-ultramafic intrusive complexes. It also shows a small body associated with the Aristarchus Peridotite in the Christie Domain. Limited drilling has revealed anomalous concentrations of chromium, nickel, copper and platinum-group elements. Mineral resource potential of these areas is assessed as moderate with a low level of certainty (B)

5. References

Constable, S., Fairclough, M., and Gum, J., 2005. Nickel mineralisation models in the Fowler Domain. MESA Journal, 39, 14–21.

B.18 GROUNDWATER RESOURCES (MAP 27)

1. Commodity: groundwater

2. Major aquifers in WPA: Cenozoic alluvial sediments of paleovalleys, Cenozoic marginal marine sediments of the eastern Eucla Basin, Jurassic and Early Cretaceous sandstones of the western Eromanga Basin (Algebuckina Sandstone and Cadna-owie Formation).

3. Assessment criteria: Assessment criteria used include:

- occurrence of Cenozoic paleovalleys and sandstone aquifers of the Great Artesian Basin; and
- yield and salinity of water.

4. Water potential assessment

Overall, the potential of intersecting usable groundwater supplies within the WPA (and within the 50 km buffer zone) varies from low potential and moderate to high potential. Aquifers of good yield occur in Paleogene paleovalleys in the southwestern and western parts of the WPA and in its buffer zone, however, the groundwater is saline (Total Dissolved Salts (TDS) ≥20,000 mg/L) and contain high-dissolved iron concentrations in many places. The paleovalleys include the Kingoonya, Garford, Talaringa, and Meramangye systems, and groundwater reserves are likely to be of the order of 1,000 gigalitres (GL). The sandstone aquifers of the Algebuckina Sandstone (Jurassic) and Cadna-owie Formation (Early Cretaceous) north of the WPA are similarly regarded as being of high potential because of high-yielding bores and water quality is good (~1,500 mg/L TDS).

The sandstone aquifer in the north-central part of the WPA is regarded as having a moderate to high potential. Bores in this area are characterised by moderately high groundwater yields of fresh to brackish water (1,500 ≤ TDS ≤ 3,000 mg/L).

Paleogene marginal marine sediments overlie alluvial sediments in the eastern Eucla Basin in the southwestern part of the WPA. These sediments are regarded as having a moderate potential to yield saline (TDS ≥ 30,000 mg/L) groundwater supplies.

The sandstone in the northern part of the WPA yields low to moderate supplies of slightly saline groundwater (3,000 ≤ TDS ≤ 12,000 mg/L), and therefore this aquifer is regarded as having a low to moderate potential.

Tributaries of the paleovalleys filled with Neogene sediments are likely to yield low to moderate supplies of saline groundwater and are thus regarded as being of low to moderate potential. A narrow belt of Neogene marginal marine sediments in the southwest corner of the WPA buffer zone is regarded as having a low potential to yield groundwater of a similar salinity.

With the exception of the northern part of the WPA and its buffer zone, groundwater in the sandstone aquifer is moderately saline (12,000 ≤ TDS ≤ 20,000 mg/L) and bores are generally low-yielding. In fact, the sandstone is unsaturated within some small areas peripheral to mapped boundaries. Overall, the southern part of this aquifer is regarded as having a low potential for groundwater resources.

Table A1. Groundwater quality and yield of the Woomera Prohibited Area.

Aquifer	Formation	TDS (mg/L)	Potential	Certainty
Paleogene alluvial sediments, generally moderate to high yields of saline water	Pidinga Formation	≥20,000	Moderate to High	C
Neogene alluvial sediments, low to moderate yields of saline water	Garford Formation	≥20,000	Low to Moderate	B
Paleogene marginal marine and alluvial sediments, generally moderate yields of very saline water	Pidinga Formation	≥30,000	Moderate	B
Neogene marginal marine sediments, low yields of very saline water	Garford Formation	≥30,000	Low	B
Sandstone, low yields of moderately saline water, may be unsaturated near mapped boundaries	Cadna-owie Formation, Algebuckina Sandstone	12,000–20,000	Low	B
Sandstone, low to moderate yields of slightly saline water, corrosive groundwater in northeast sector	Cadna-owie Formation, Algebuckina Sandstone	3,000–12,000	Low to Moderate	B
Sandstone, moderate yields of fresh to brackish saline water	Cadna-owie Formation, Algebuckina Sandstone	1,500–3,000	Moderate	B

Note: TDS= Total Dissolved Salts

Appendix C: Mineral Resource Potential Maps

Map 1: Map of Woomera Prohibited Area showing deposits, mineral occurrences, and exploration leases

Map 2: Composite potential map (shows potential of all resource-types).
For areas where potential of more than on resource-type overlaps, the map shows the highest level of potential for the overlapping resource-types)

Map 3: Composite potential map (all mineral deposits and coal)

Map 4: Composite potential map (gold: shows potential of Archean lode gold, Proterozoic lode gold, and iron-oxide copper, gold uranium deposits)

Map 5: Composite potential map (uranium: shows potential of unconformity-related uranium, sandstone-hosted uranium of roll-front, and channel-type uranium deposits)

Map 6: Composite potential map (iron: shows potential of iron ore deposits of banded iron formation and hydrothermal-type deposits)

Map 7: Composite potential map (hydrocarbons: shows potential of conventional and unconventional hydrocarbons which include oil shale and coal-related hydrocarbons)

Map 8: Composite potential map (geothermal resources: shows potential of hot rock and hot sedimentary aquifer-type resources)

Map 9: Composite potential map (nickel: shows potential of komatiitie- and tholeiite-associated nickel deposits)

Map 10: Mineral potential map (iron-oxide copper, gold, uranium)

Map 11: Mineral potential map (coal)

Map 12: Mineral potential map (Archean lode gold)

Map 13: Mineral potential map (Proterozoic lode gold)

Map 14: Mineral potential map (iron ore: banded iron formation)

Map 15: Mineral potential map (iron ore: hydrothermal)

Map 16: Mineral potential map (unconformity-related uranium)

Map 17: Mineral potential map (sandstone-hosted uranium)

Map 18: Composite potential map (sandstone-hosted uranium: channel-type)

Map 19: Mineral potential map (heavy mineral sand)

Map 20: Geothermal potential map (hot rock-type)

Map 21: Geothermal potential map (hot sedimentary aquifer-type)

Map 22: Composite potential map (conventional hydrocarbons)

Map 23: Hydrocarbon potential map (coal-related hydrocarbons)

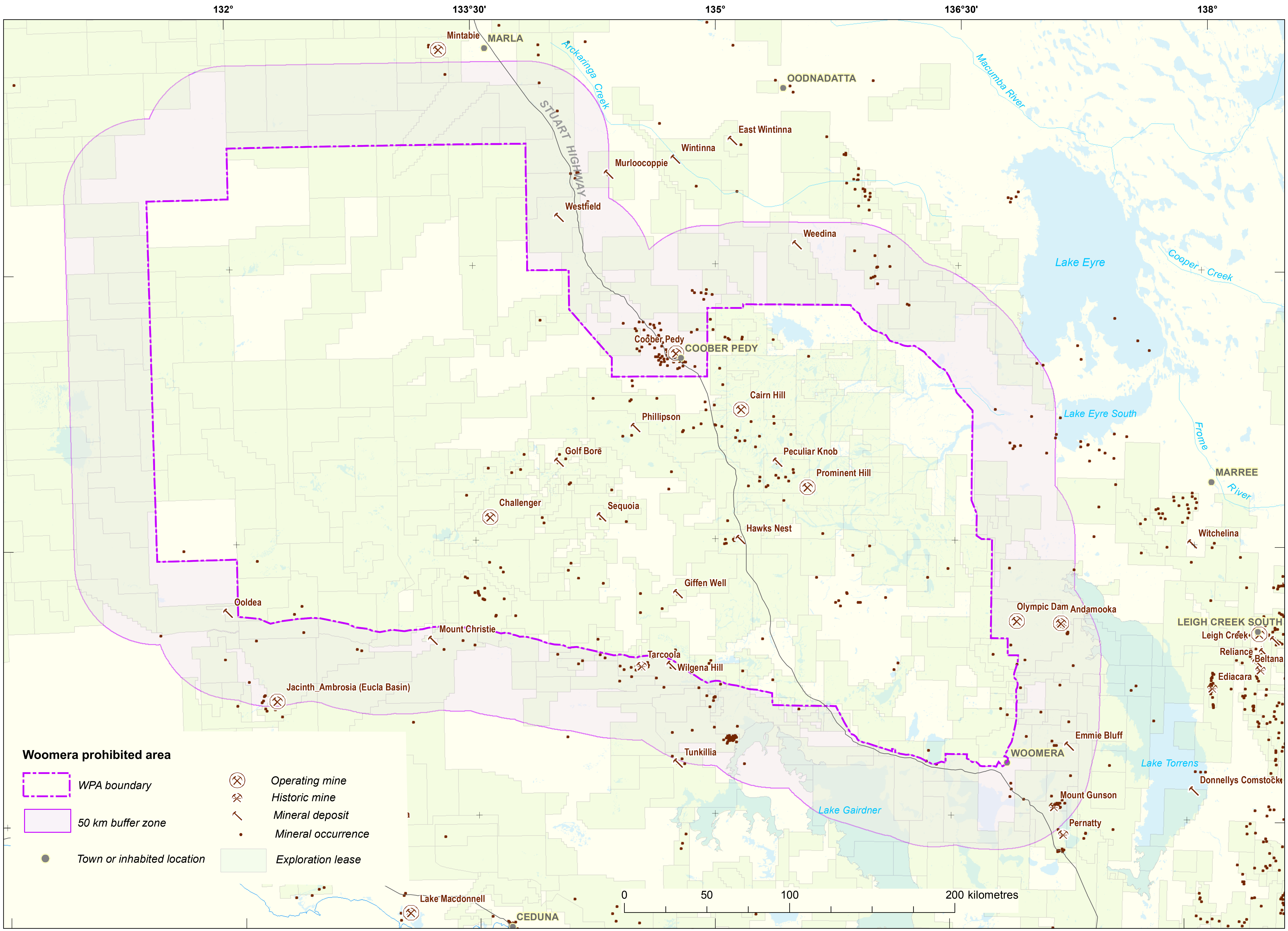
Map 24: Hydrocarbon potential map (oil shale)

Map 25: Mineral potential map (komatiite-associated nickel)

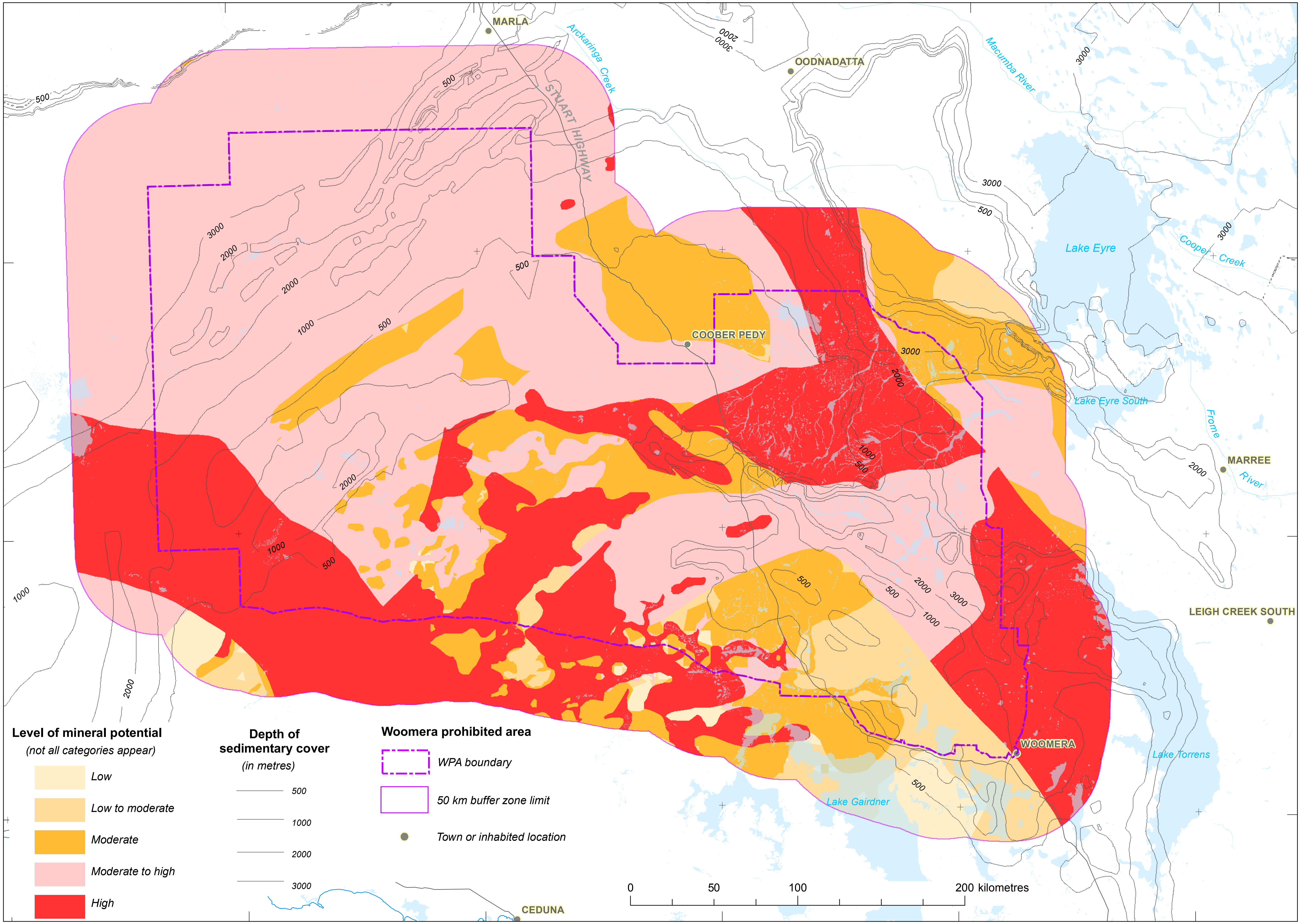
Map 26: Mineral potential map (tholeiite-associated nickel, copper, platinum-group elements)

Map 27: Ground water potential map

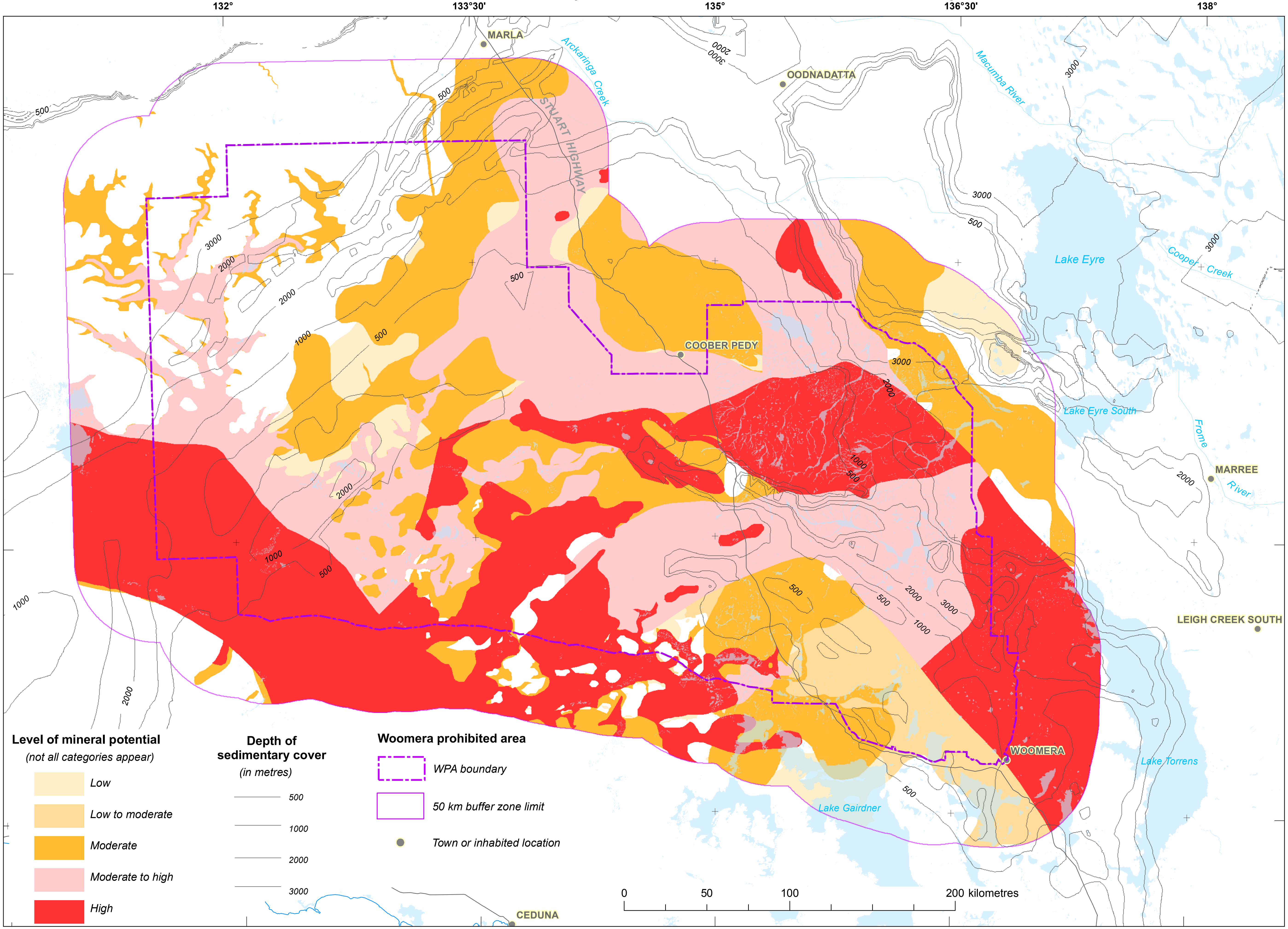
Mineral Deposits, Mineral Occurrences, and Exploration Tenements (Map 1)



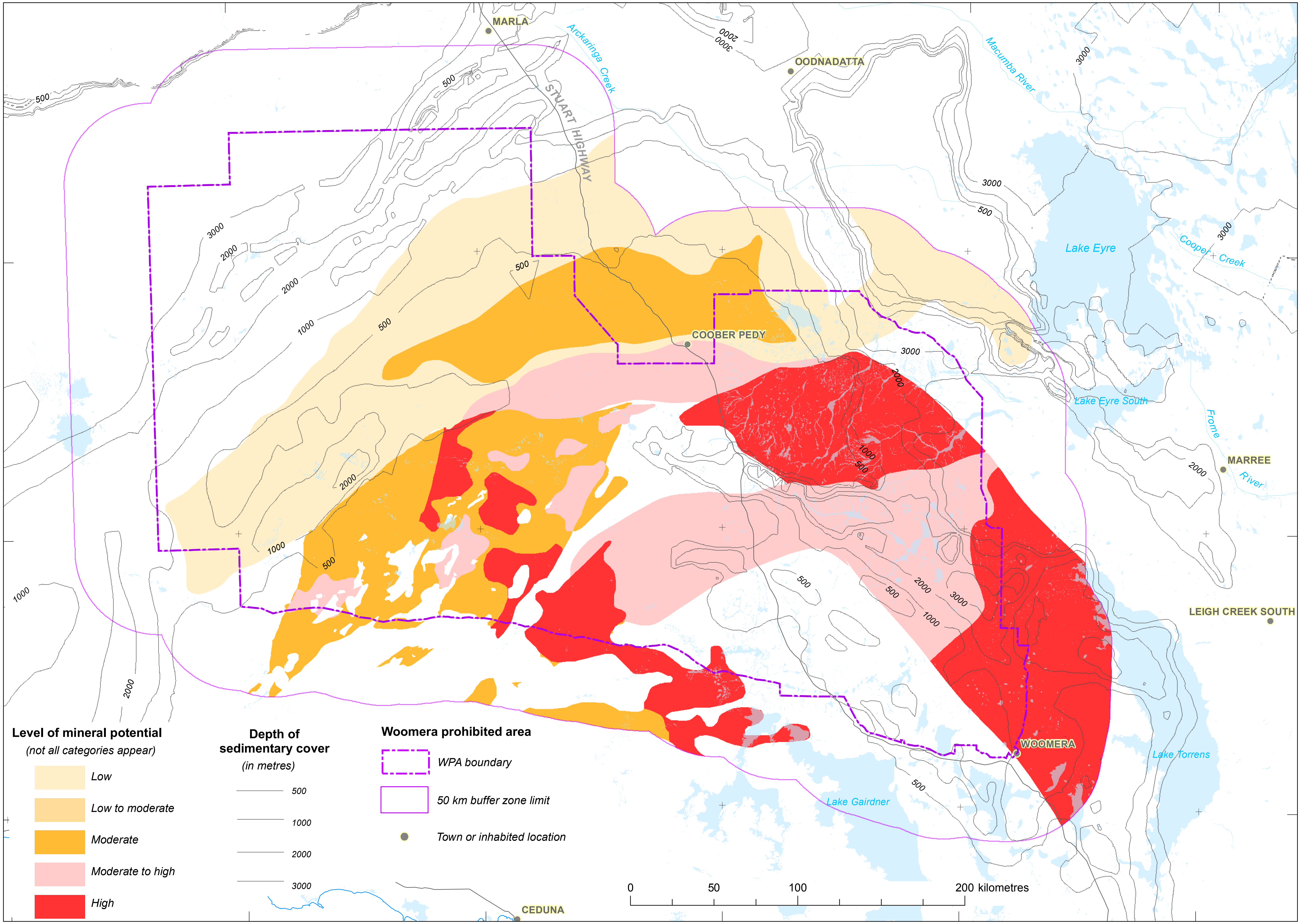
Composite Potential (All resource types, Map 2)



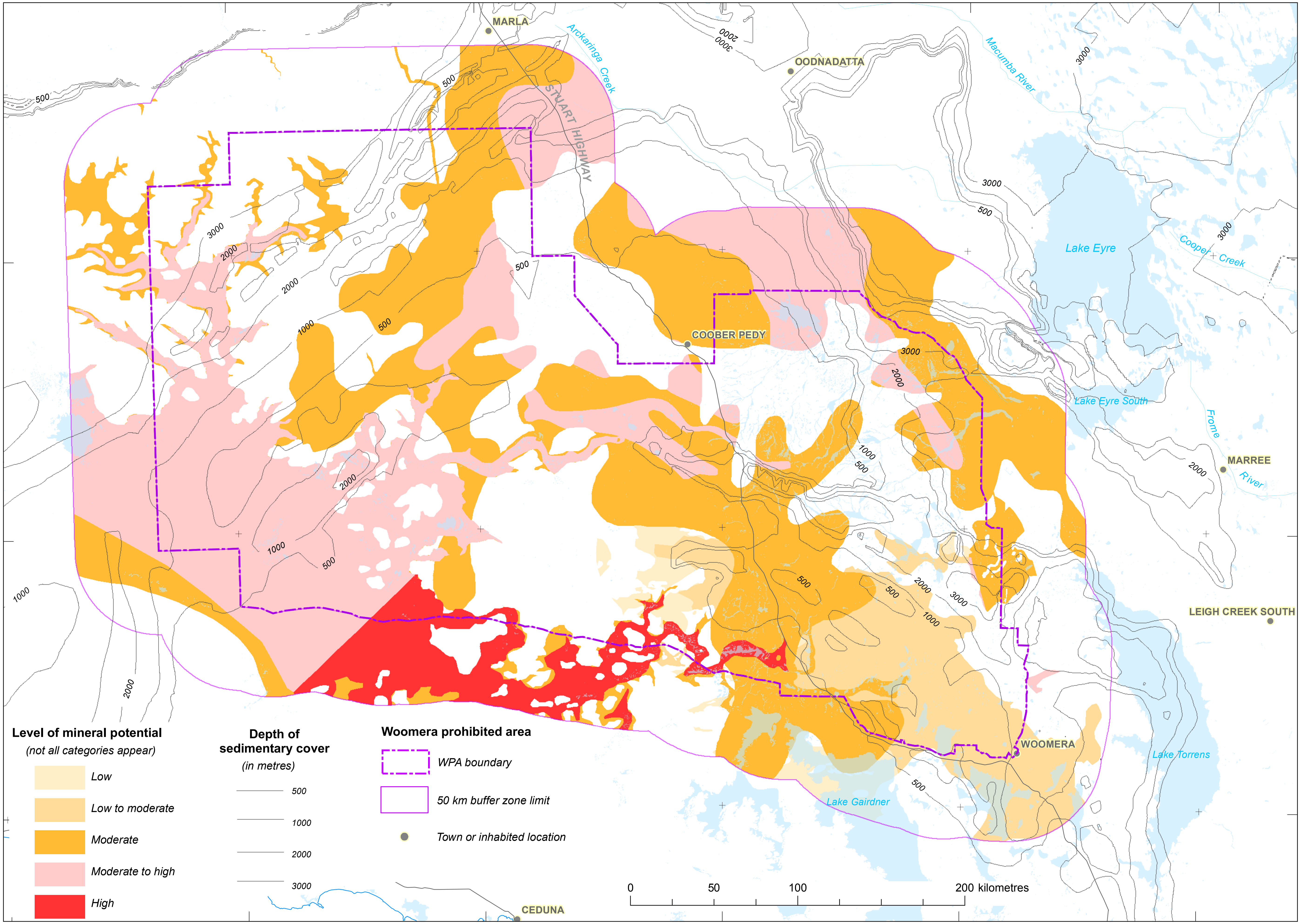
Composite Potential (All mineral deposits and coal, Map 3)



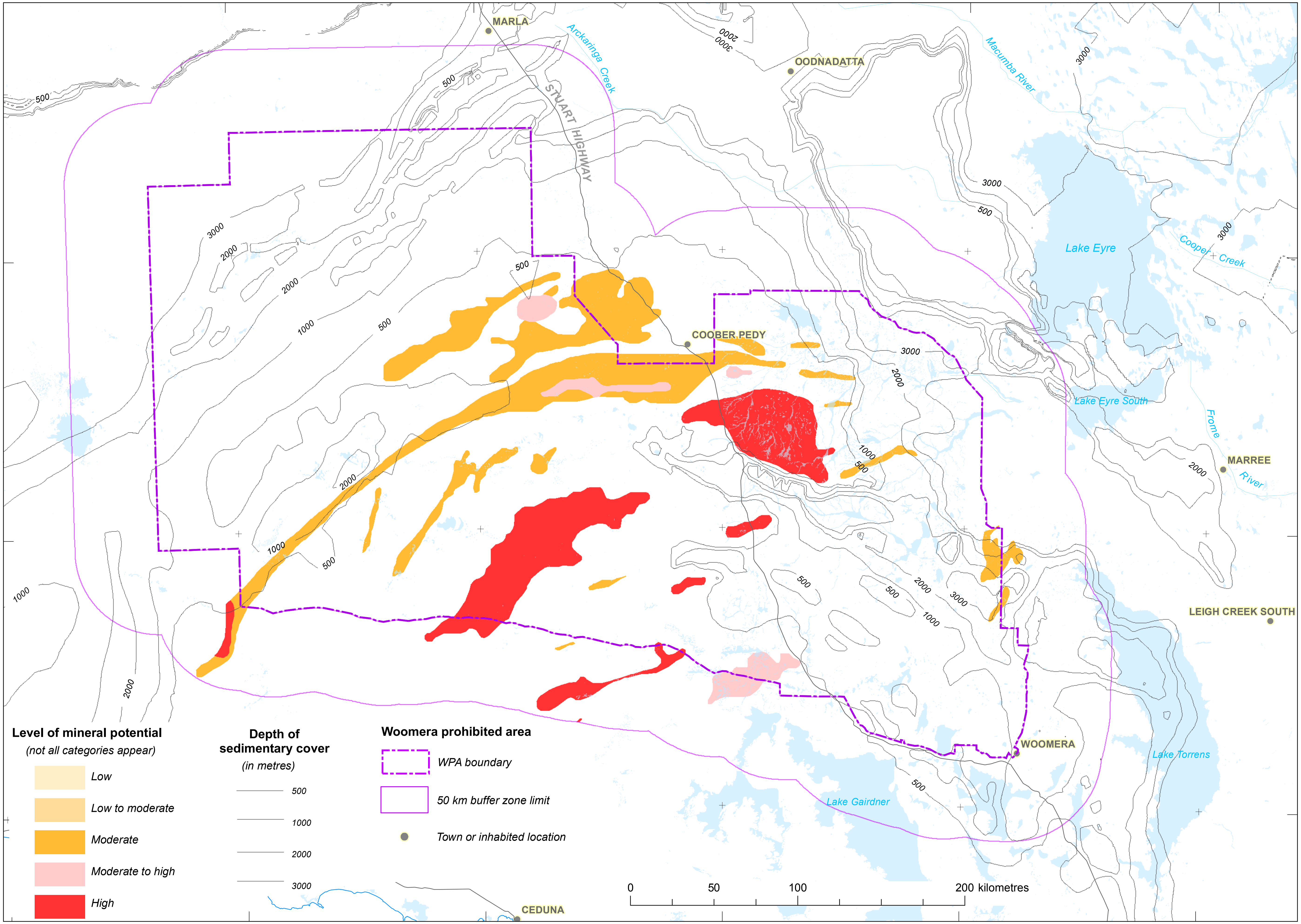
Composite Potential (Gold, Map 4)



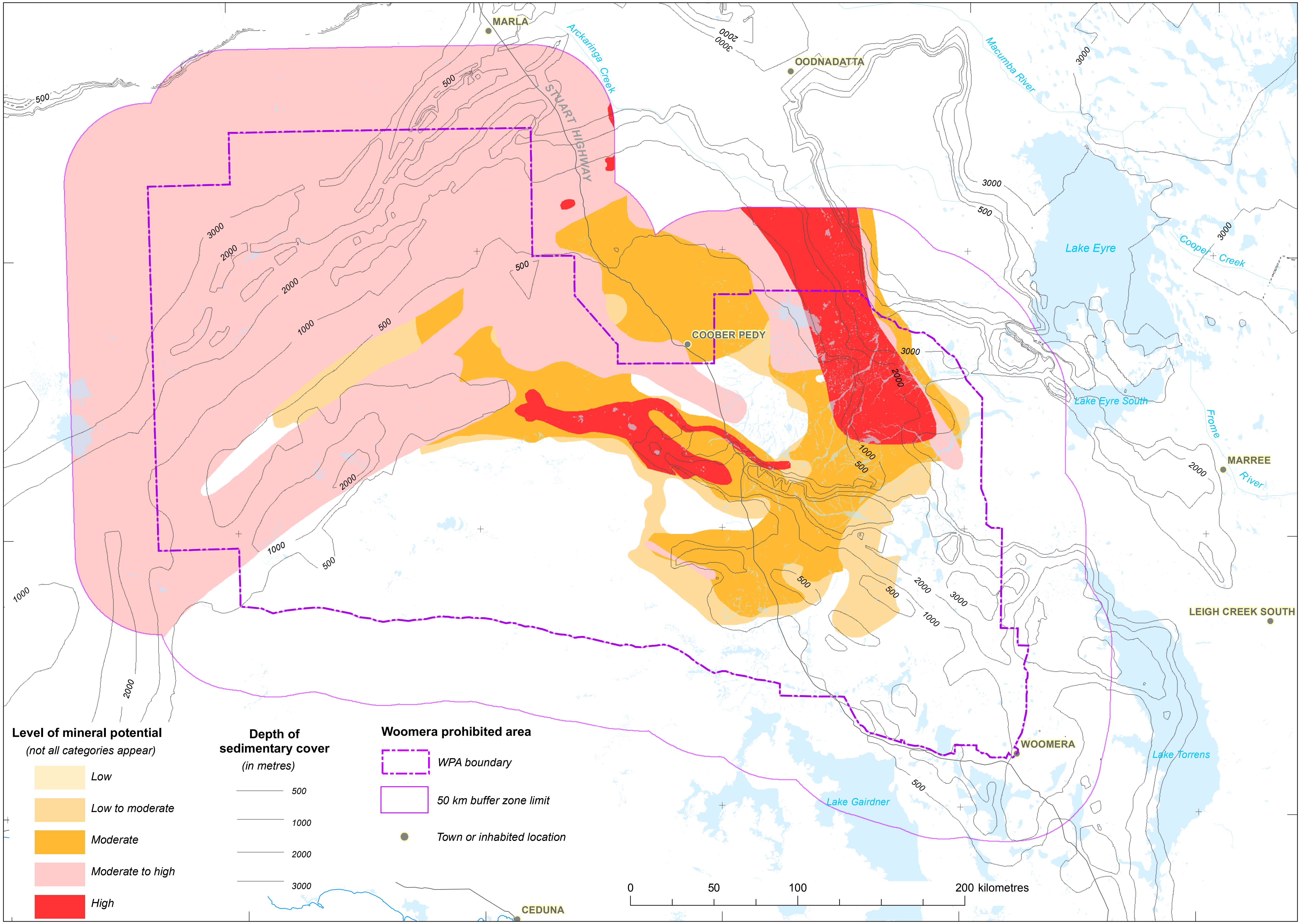
Composite Potential (Uranium, Map 5)



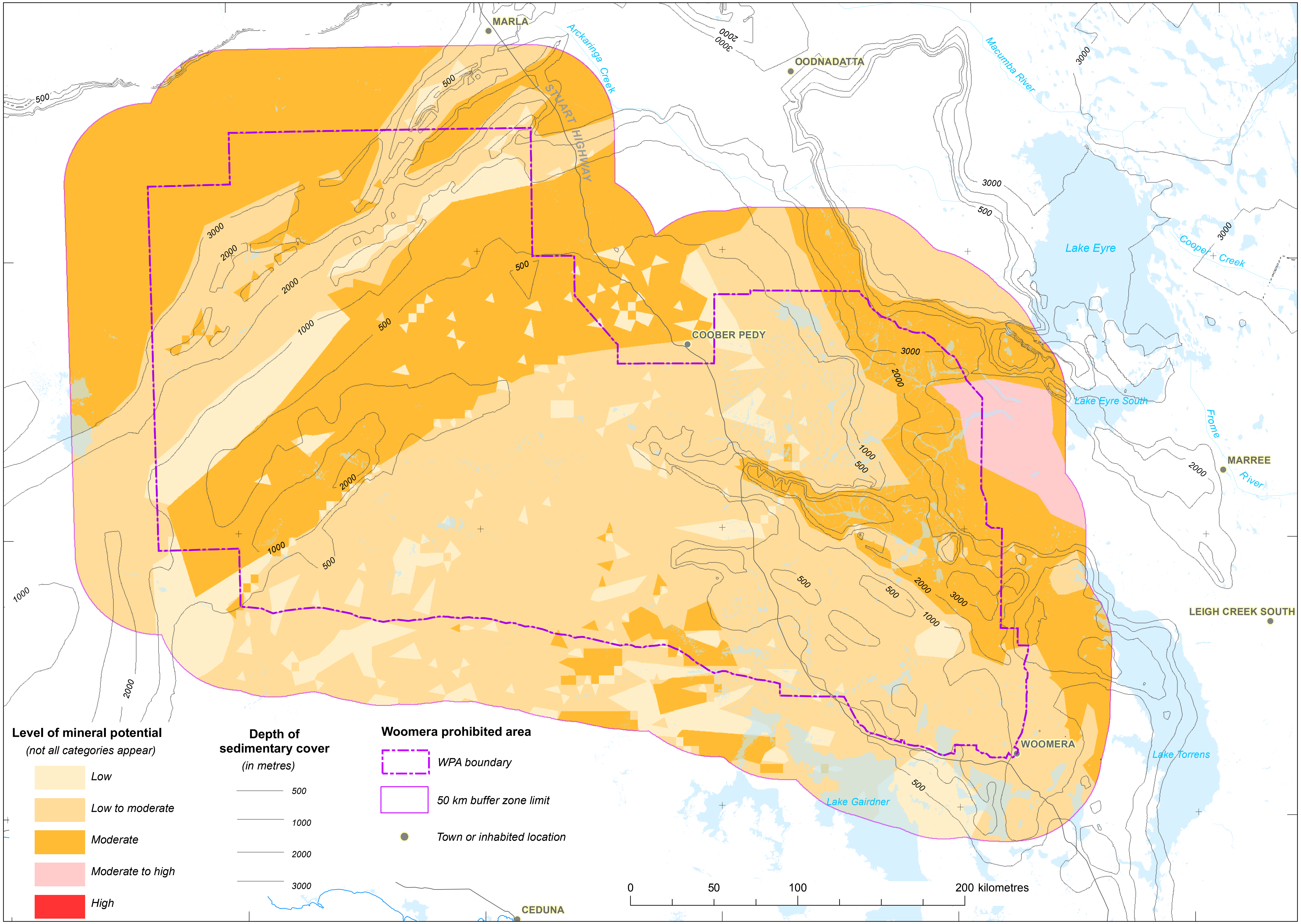
Composite Potential (Iron, Map 6)



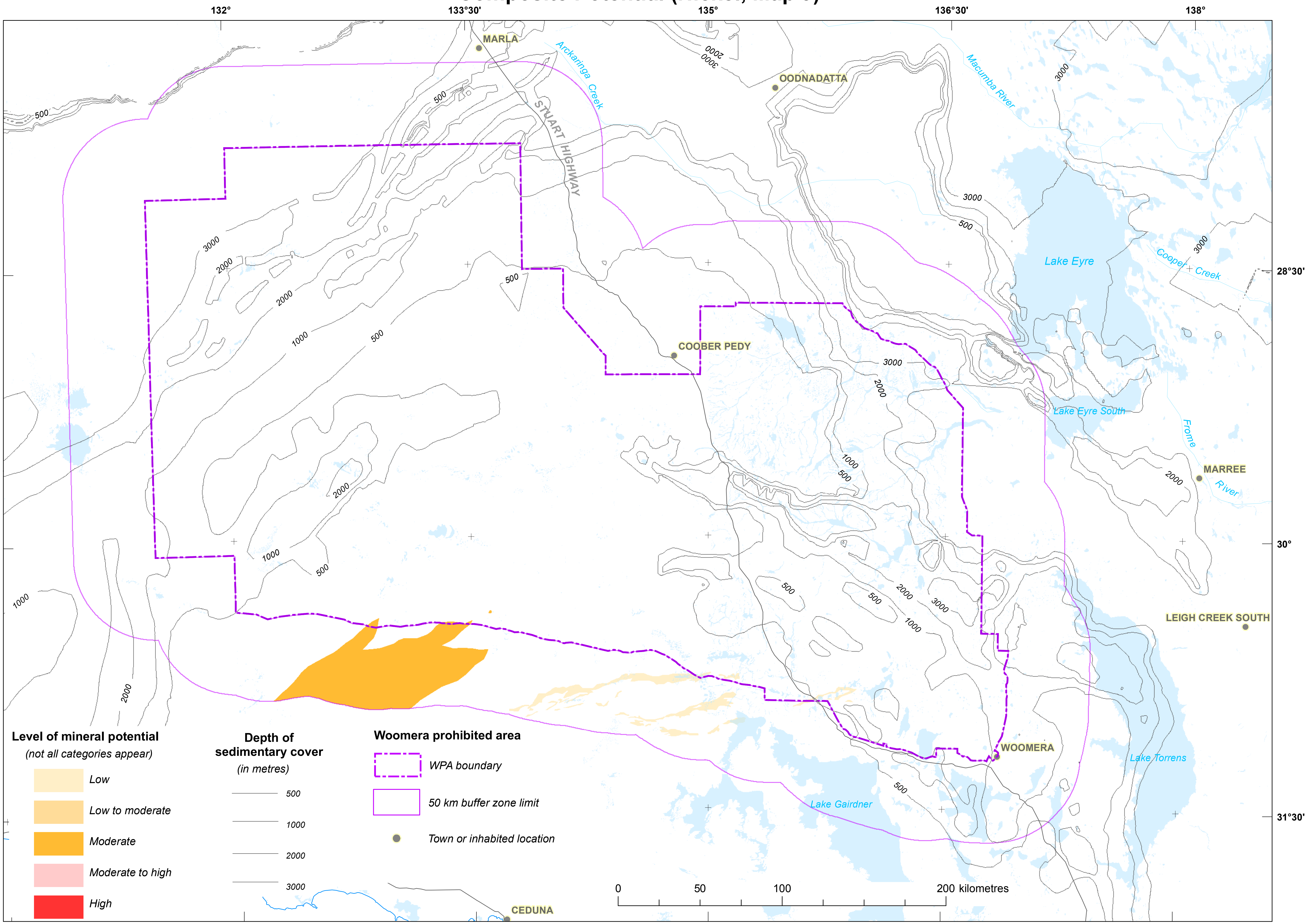
Composite Potential (Hydrocarbons, Map 7)



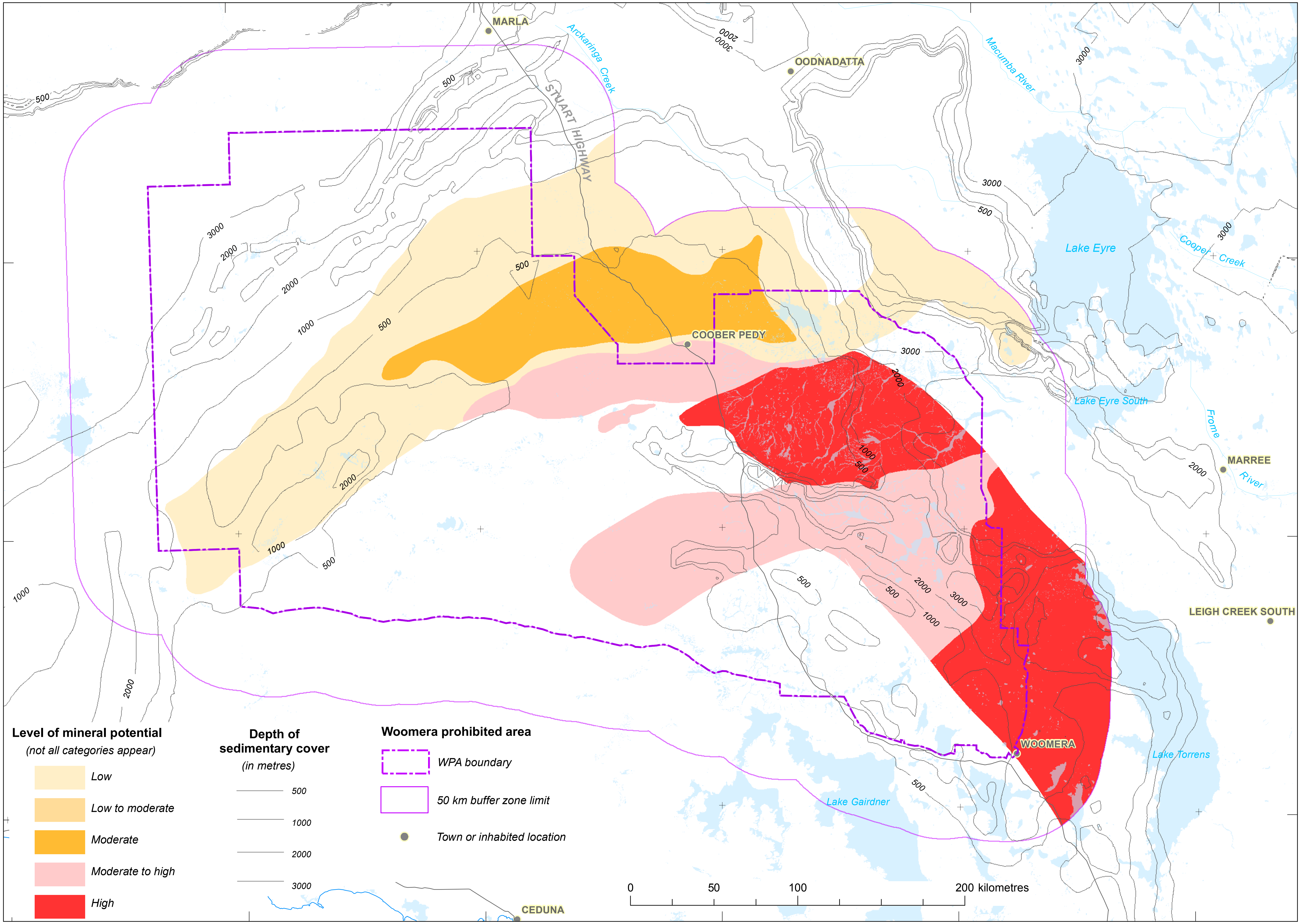
Composite Potential (Geothermal resources, Map 8)



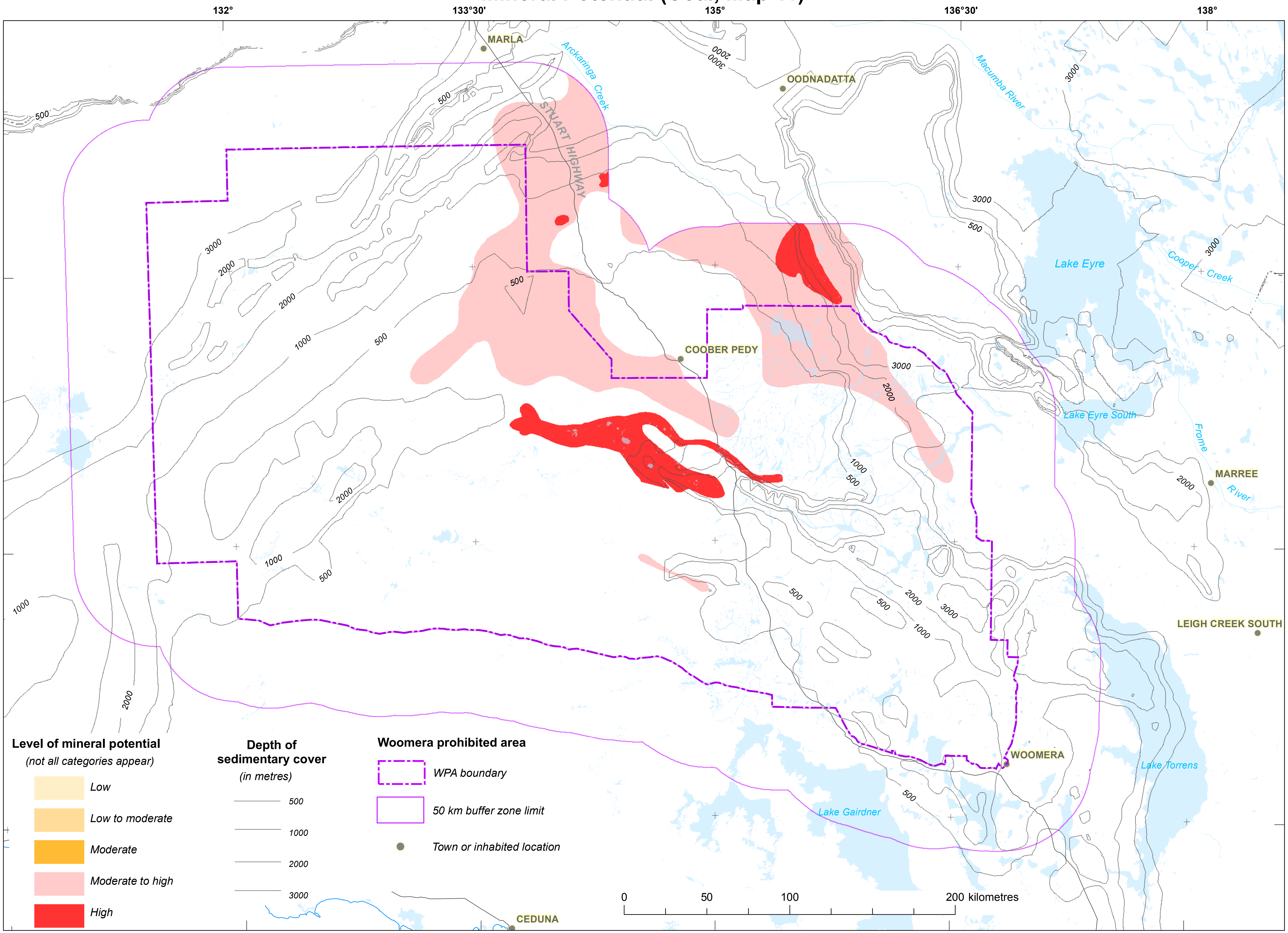
Composite Potential (Nickel, Map 9)



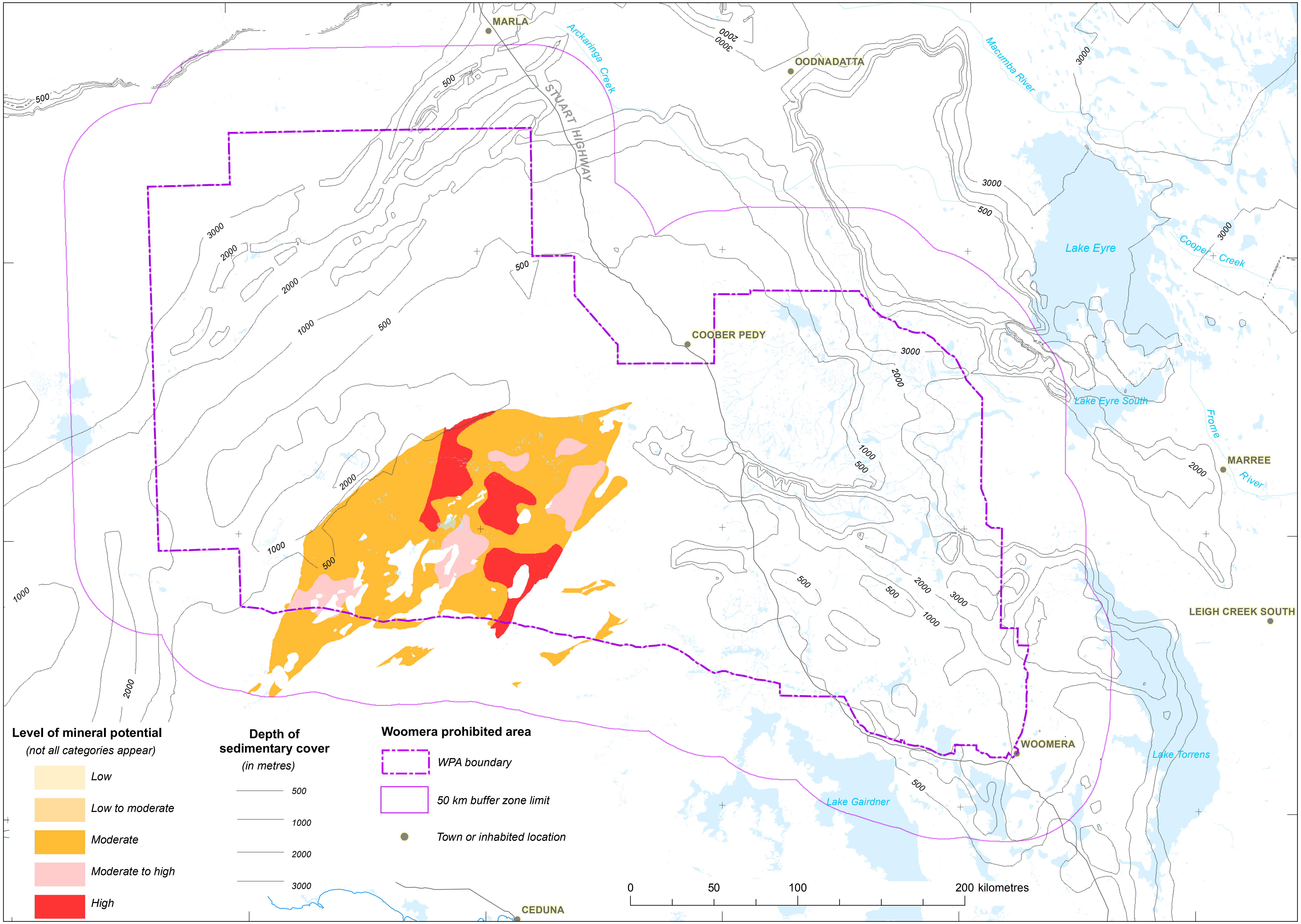
Mineral Potential (Iron-oxide copper, gold, uranium, Map 10)



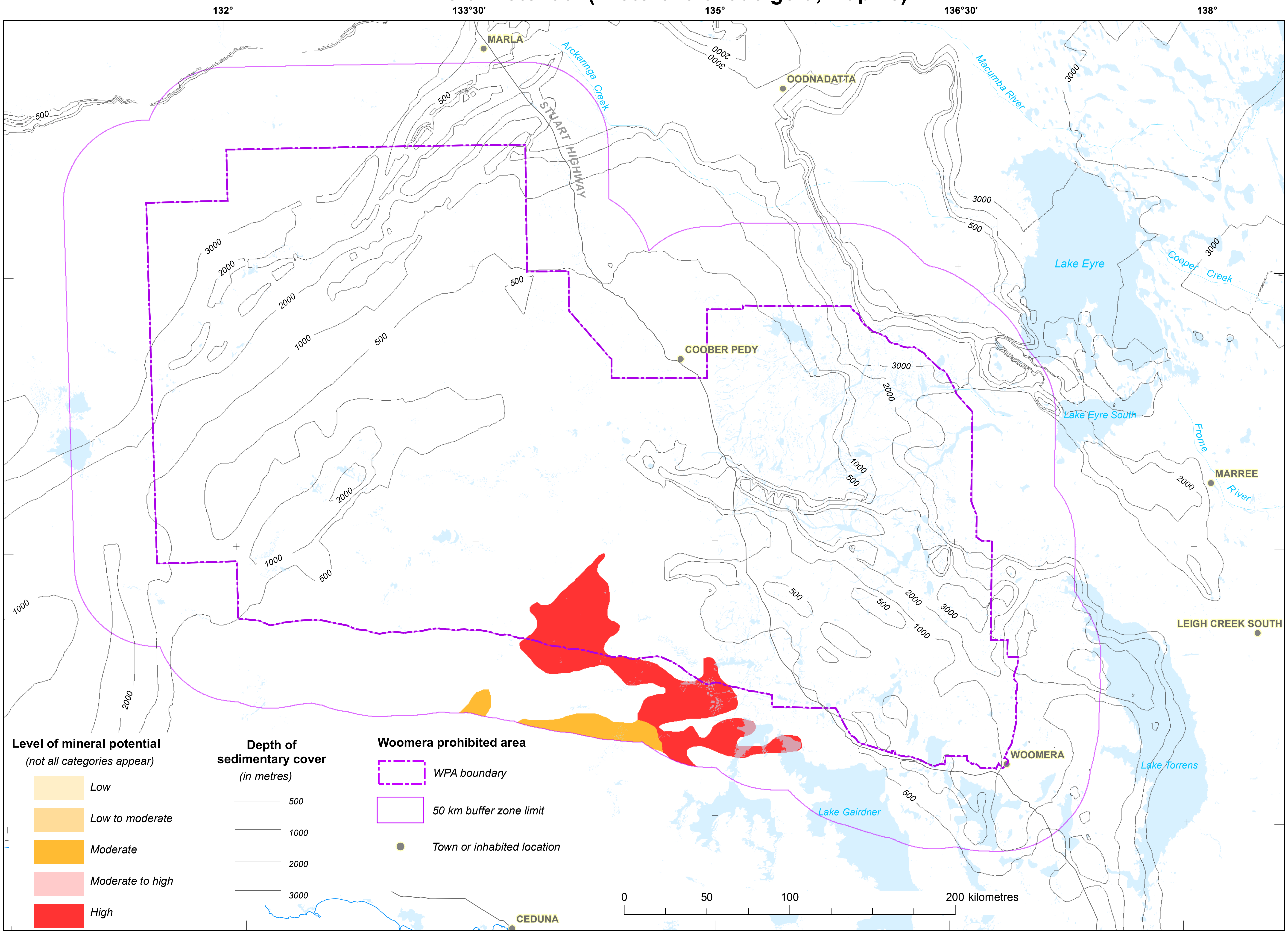
Mineral Potential (Coal, Map 11)



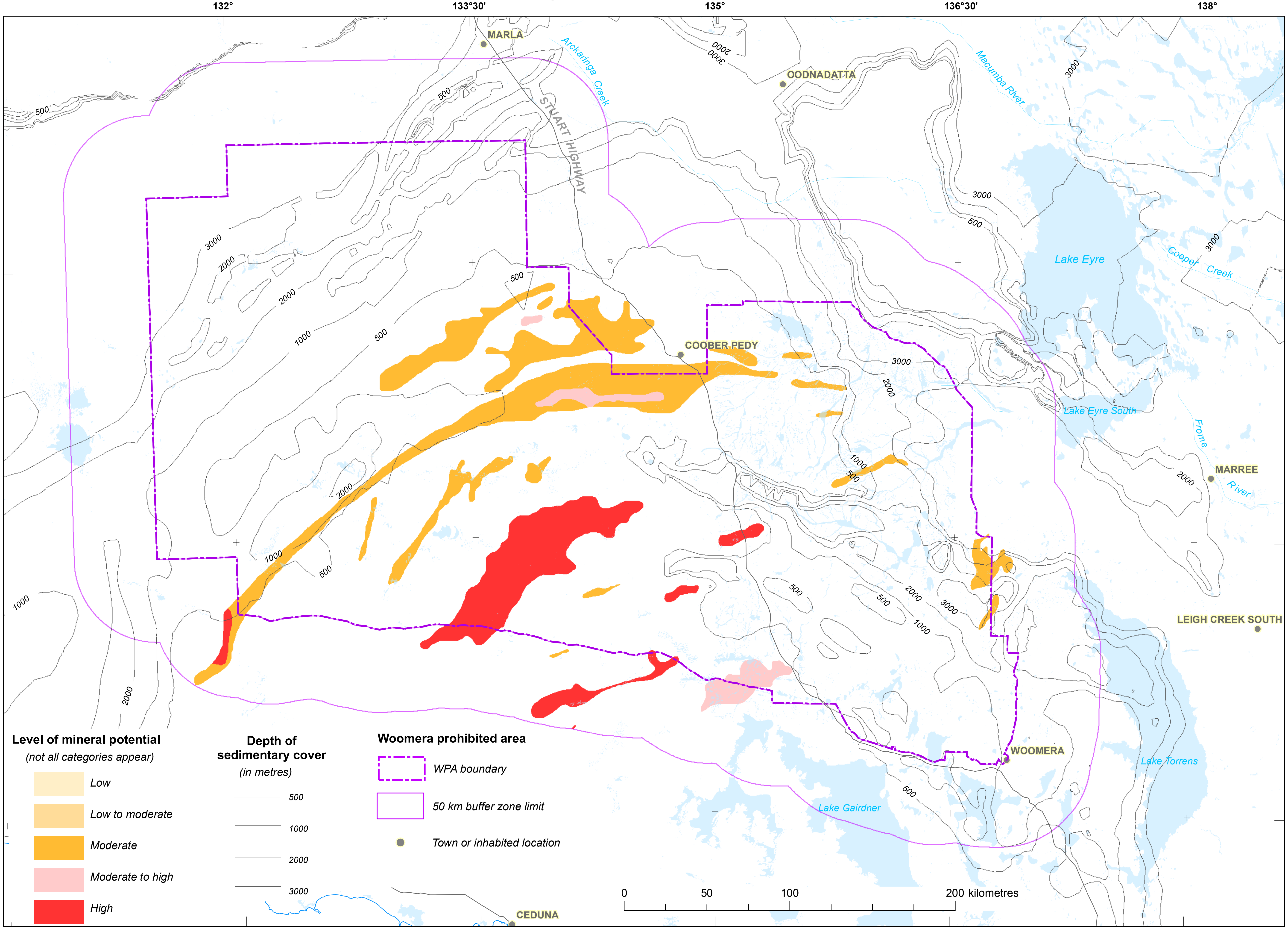
Mineral Potential (Archean lode gold, Map 12)



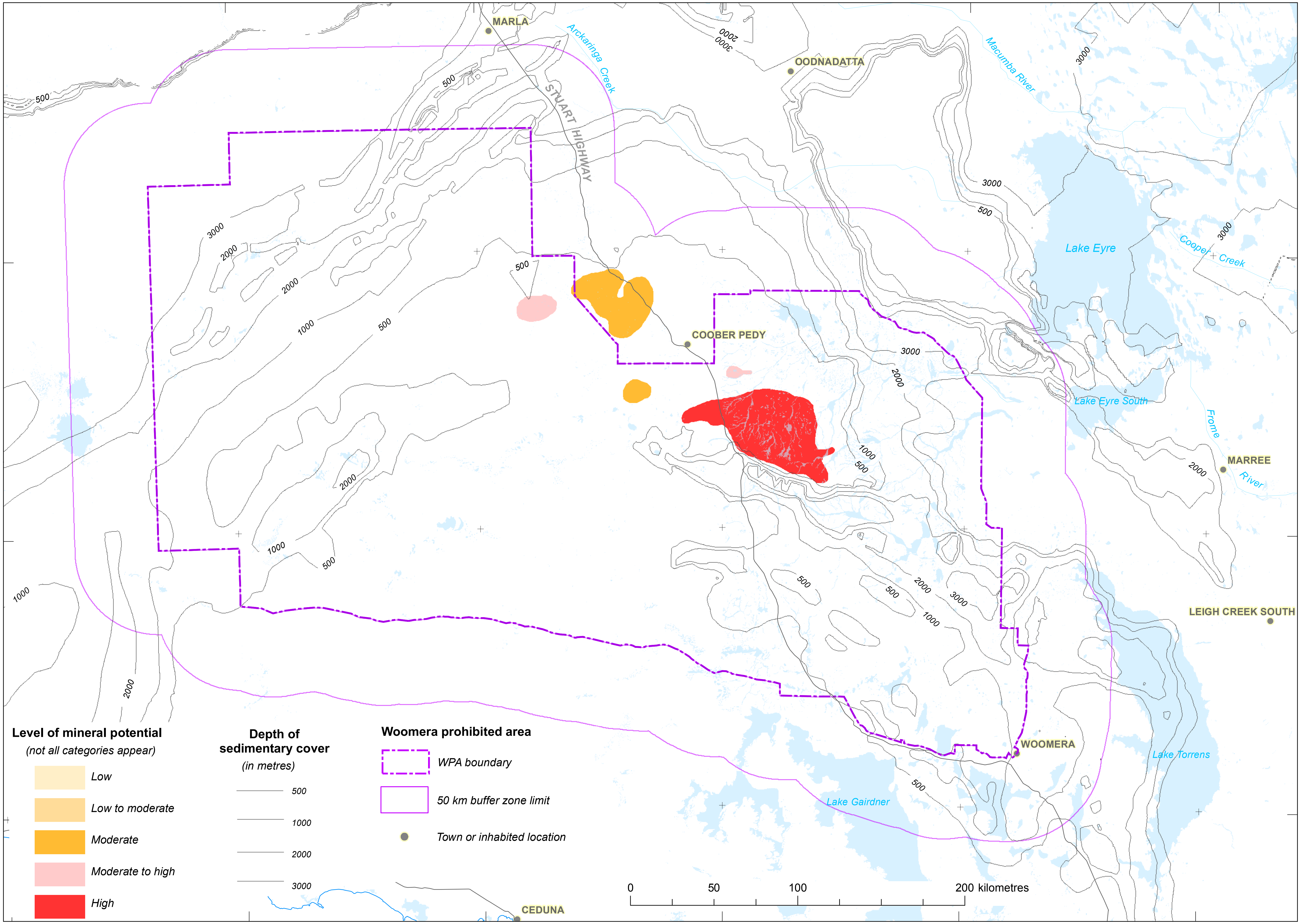
Mineral Potential (Proterozoic lode gold, Map 13)



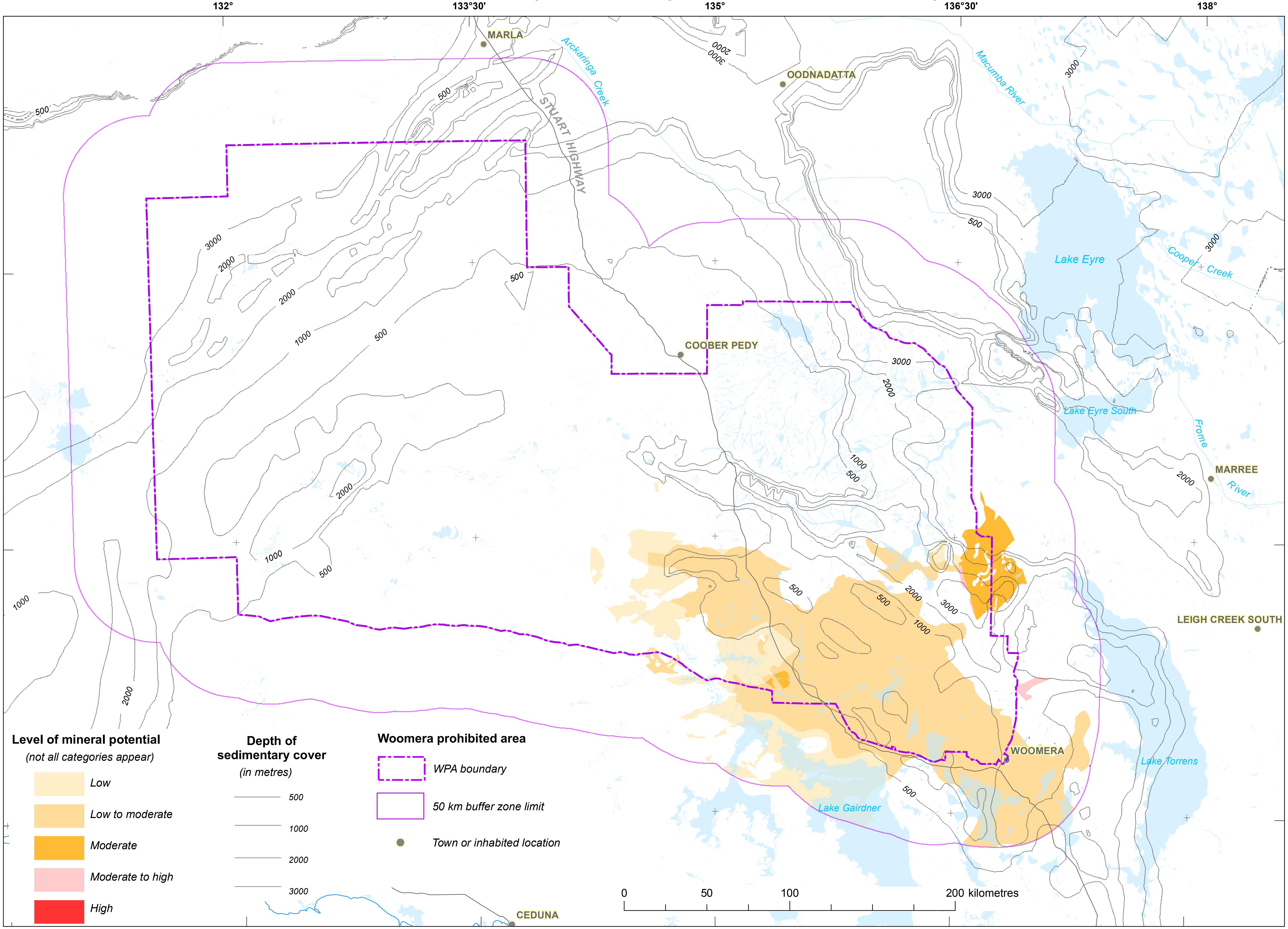
Mineral Potential (Iron ore: banded iron formation, Map 14)



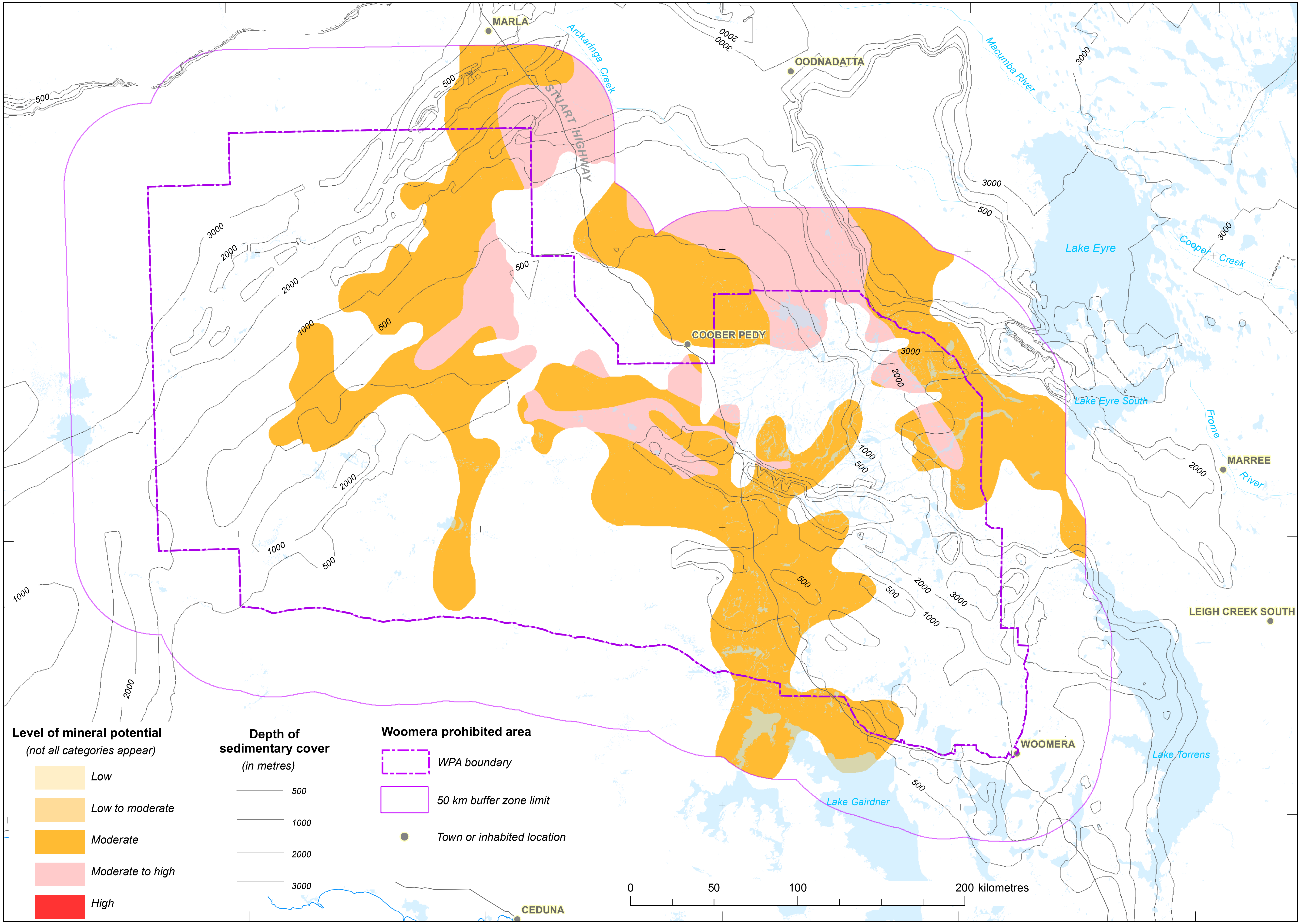
Mineral Potential (Iron ore: hydrothermal, Map 15)



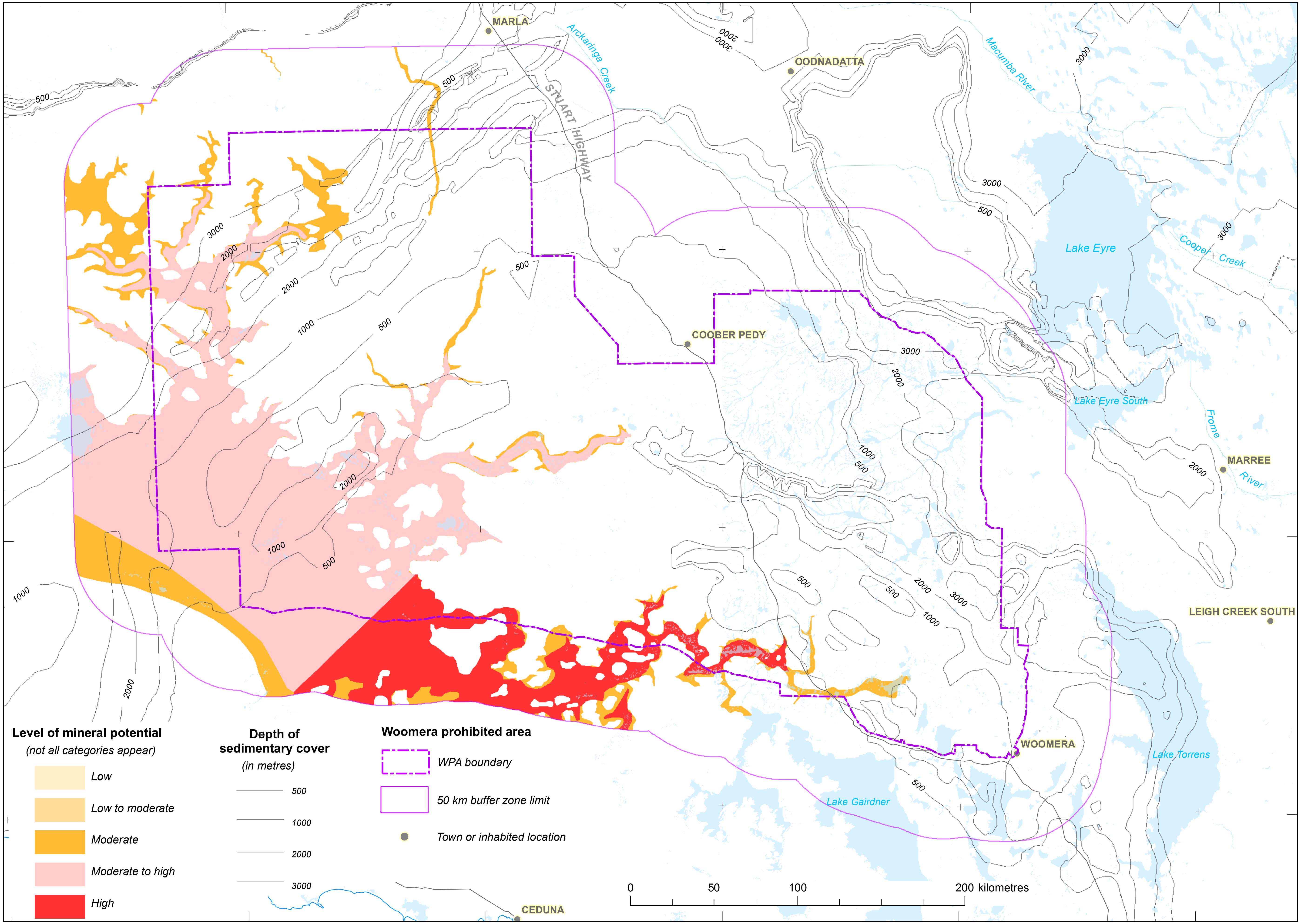
Mineral Potential (Unconformity-related uranium, Map 16)



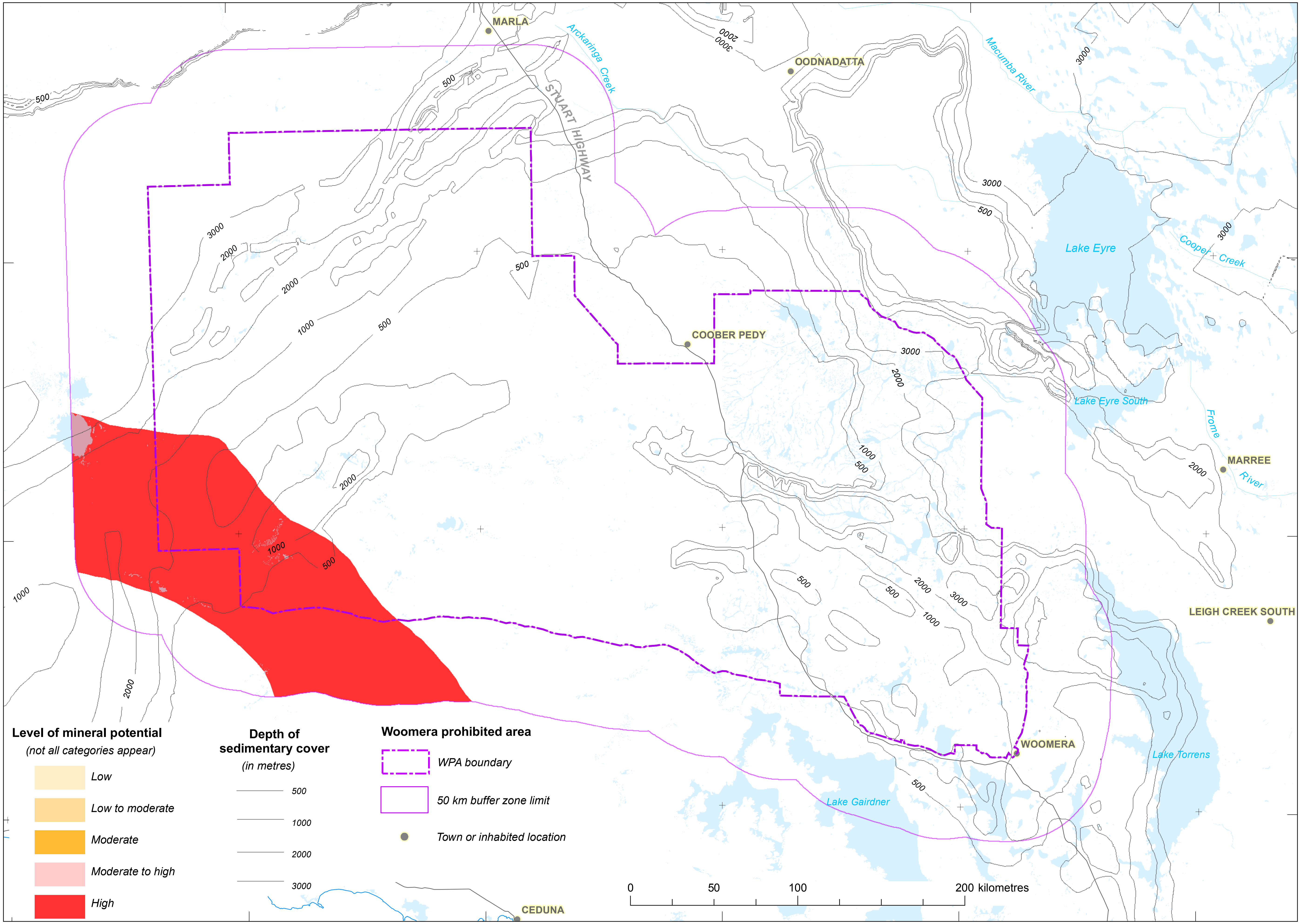
Mineral Potential (Sandstone-hosted uranium, roll-front type, Map 17)



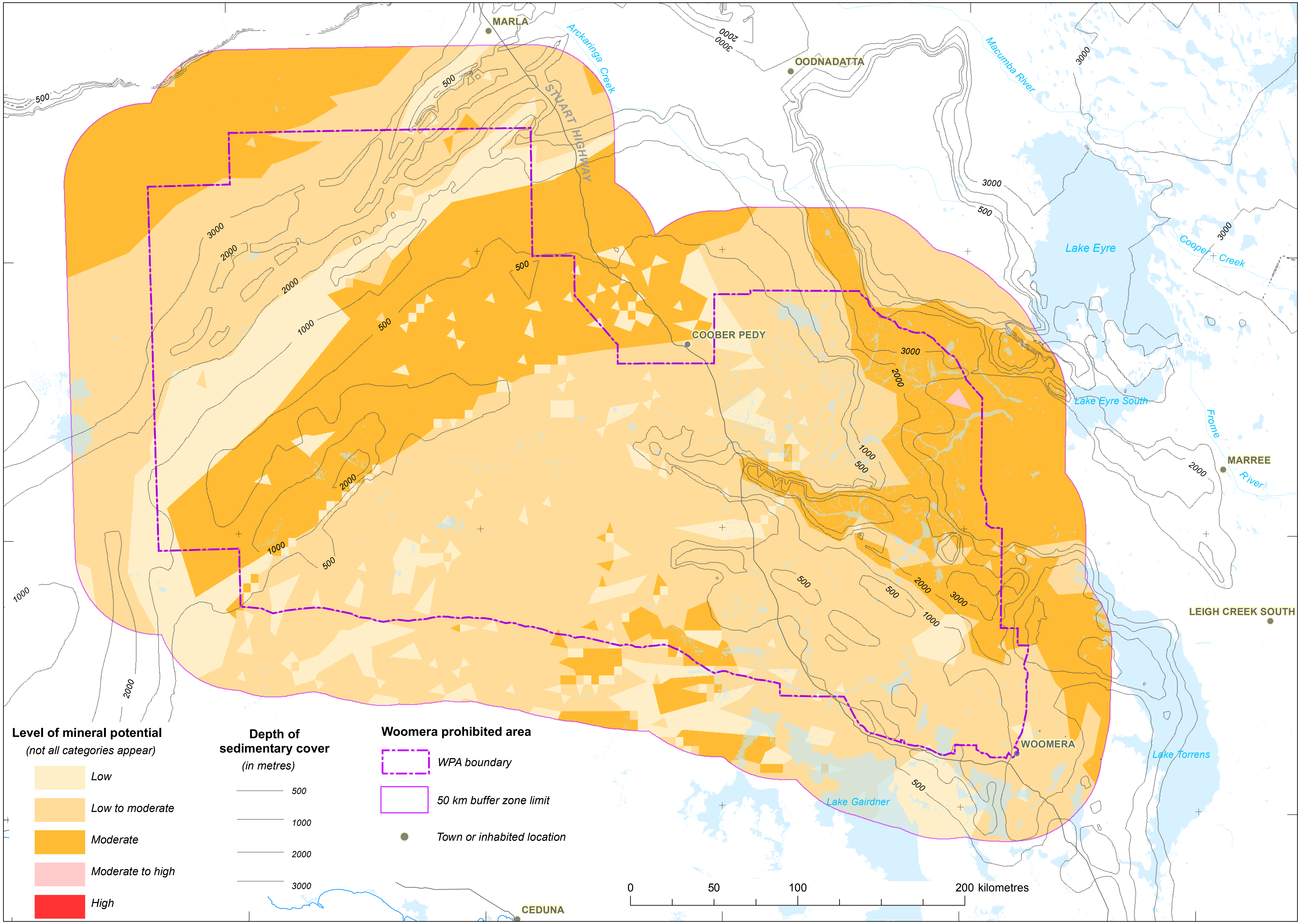
Composite Potential (Sandstone-hosted uranium, channel type, Map 18)



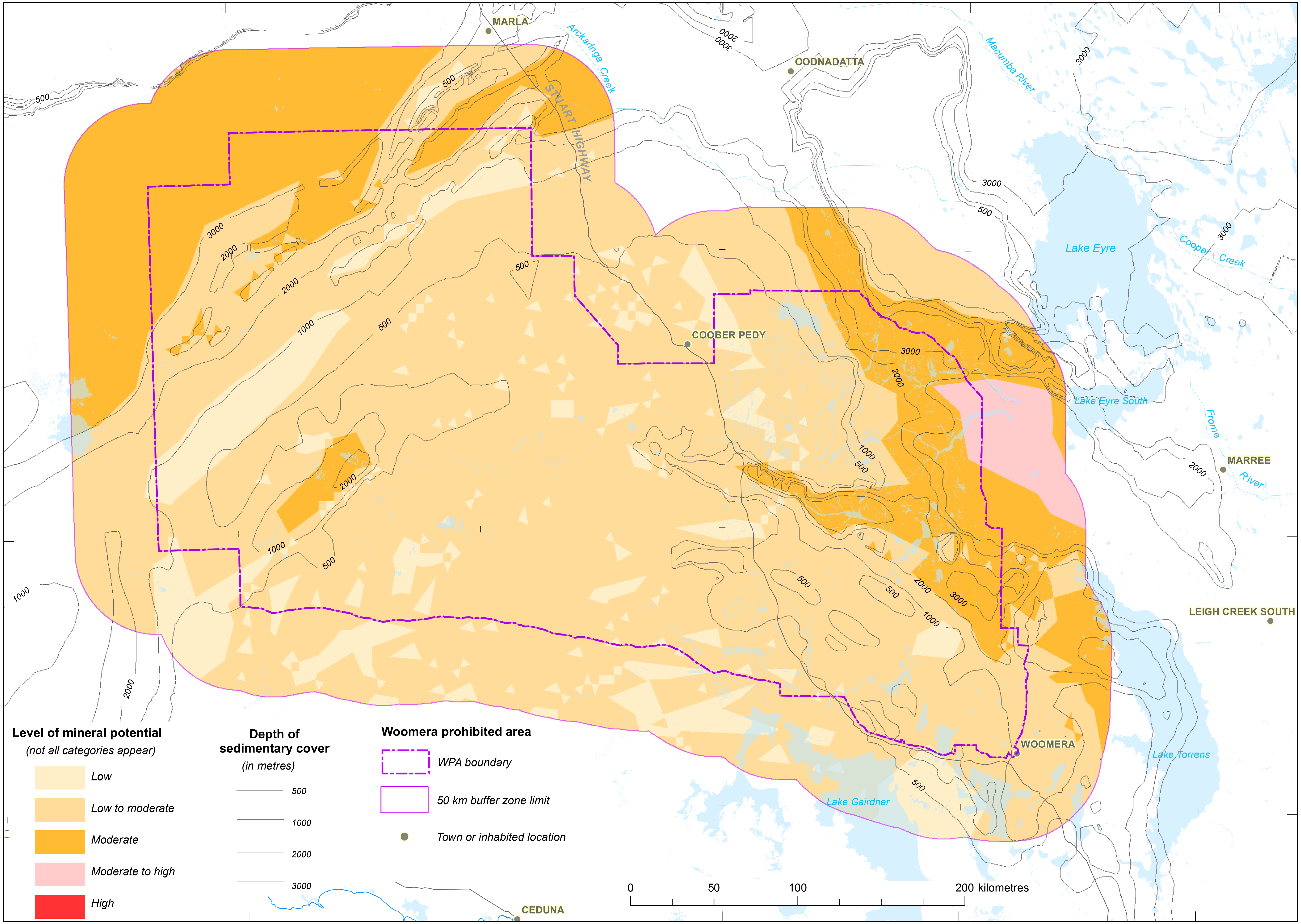
Mineral Potential (Heavy mineral sand, Map 19)



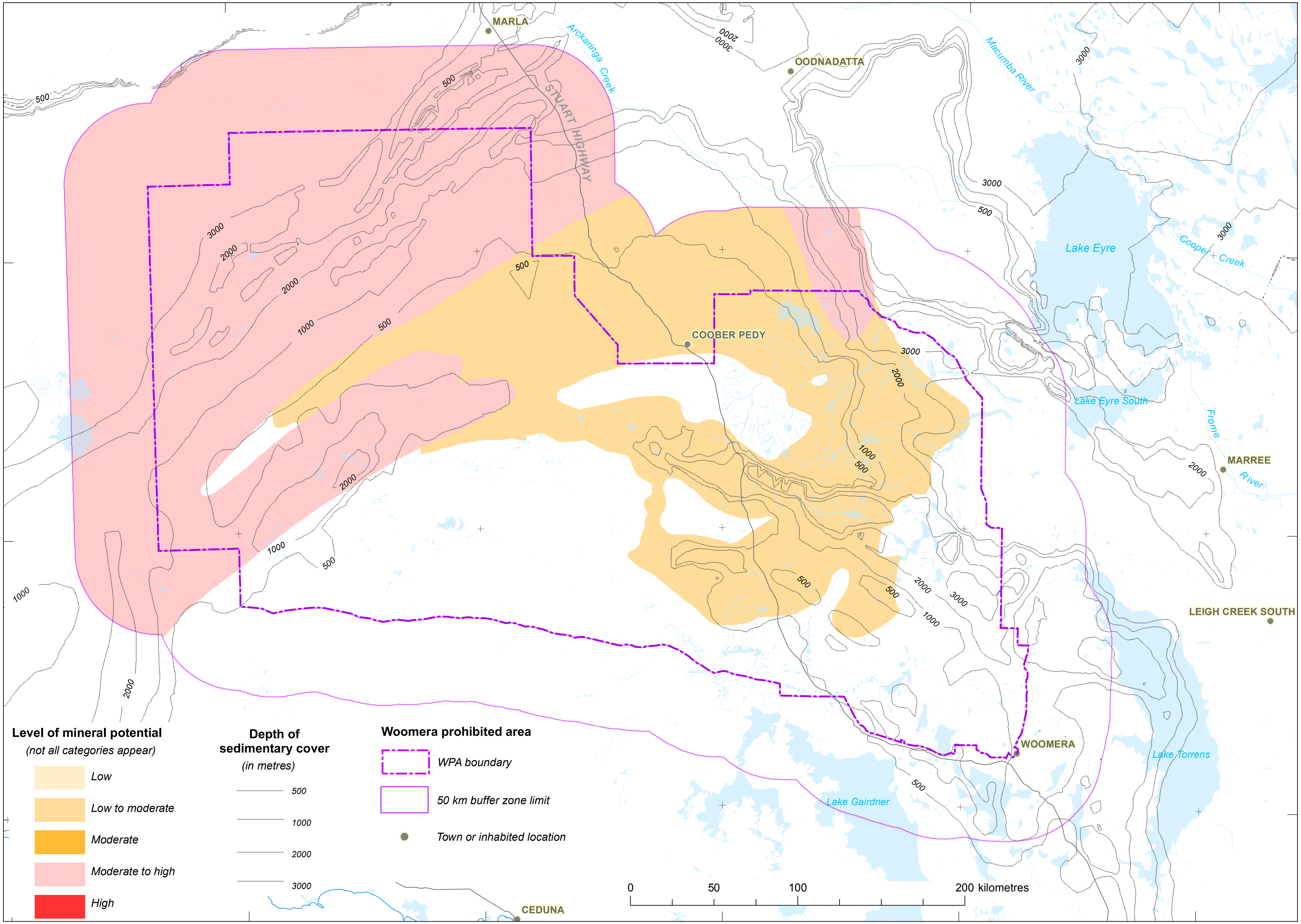
Geothermal Potential (Hot-rock type, Map 20)



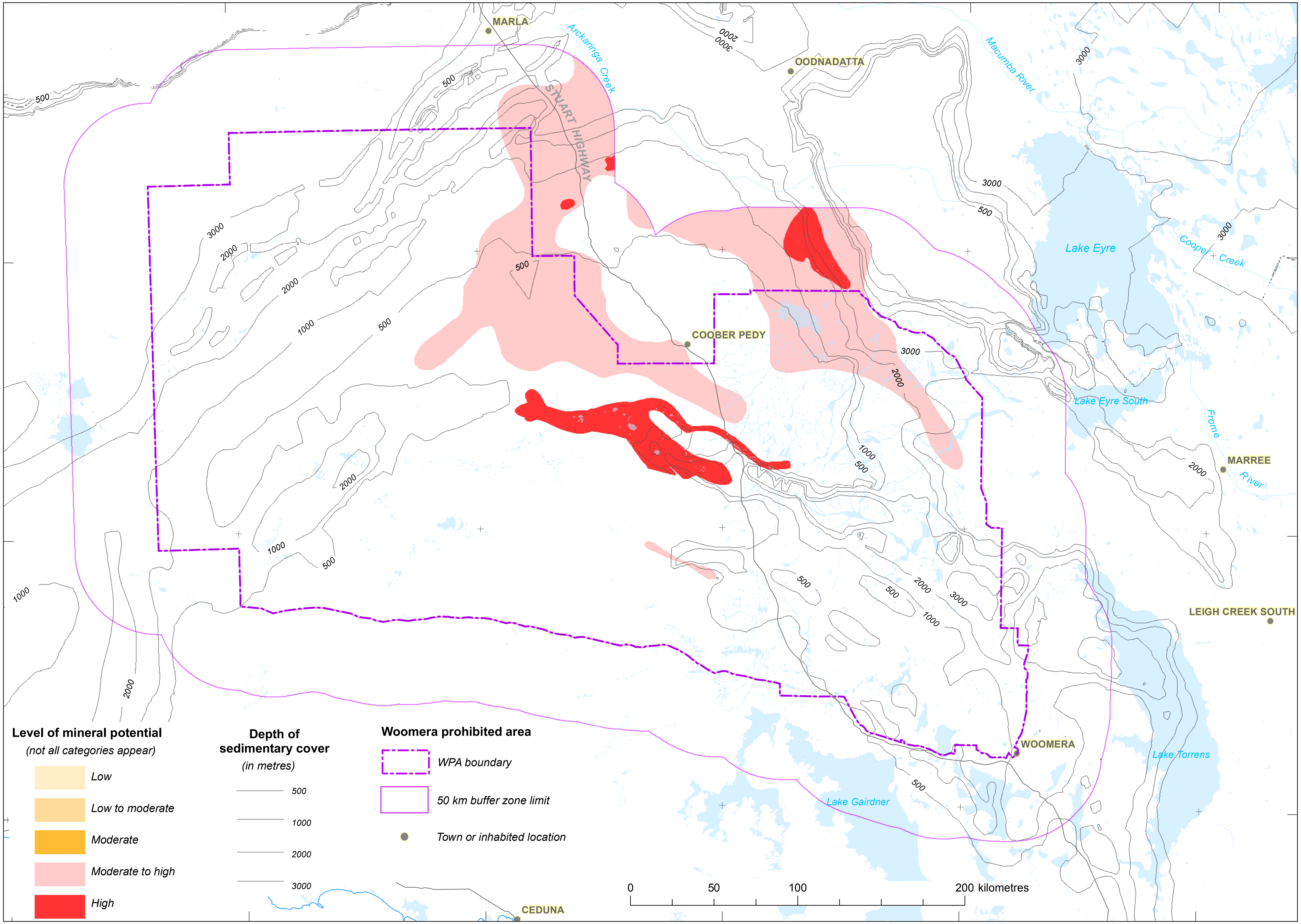
Geothermal Potential (Hot sedimentary aquifer type, Map 21)



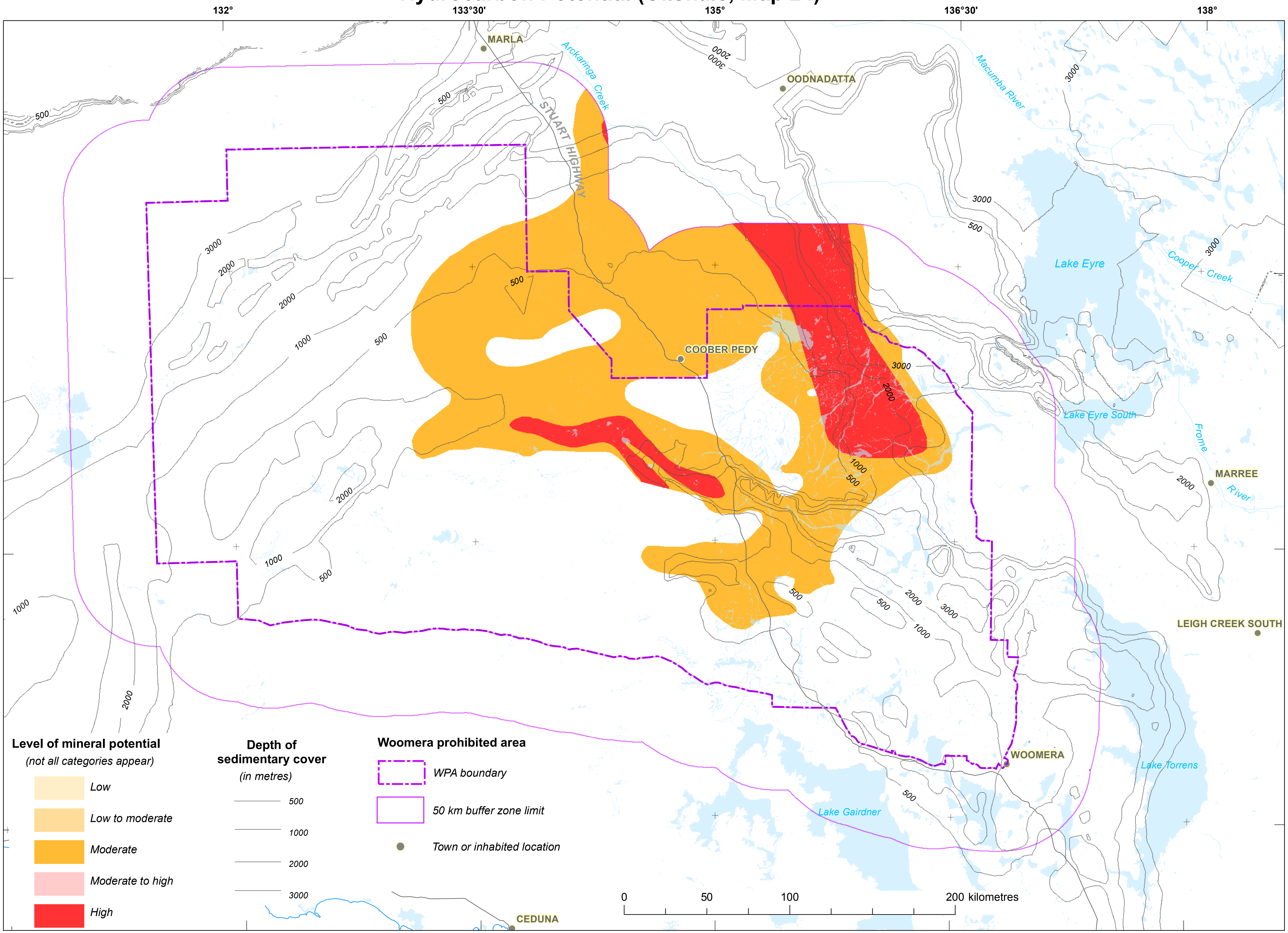
Hydrocarbon Potential (Conventional hydrocarbons, Map 22)



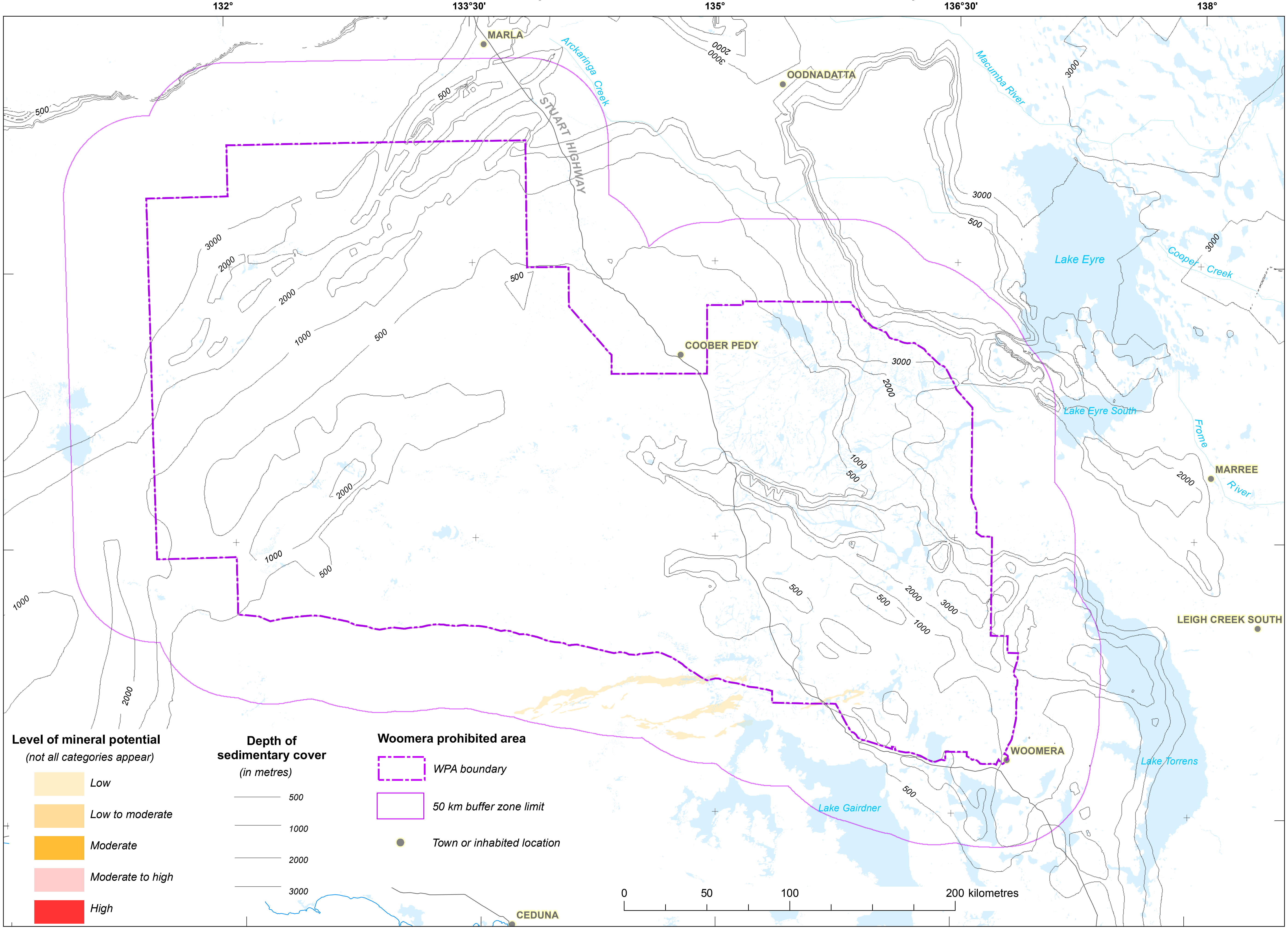
Hydrocarbon Potential (Coal-related hydrocarbons, Map 23)



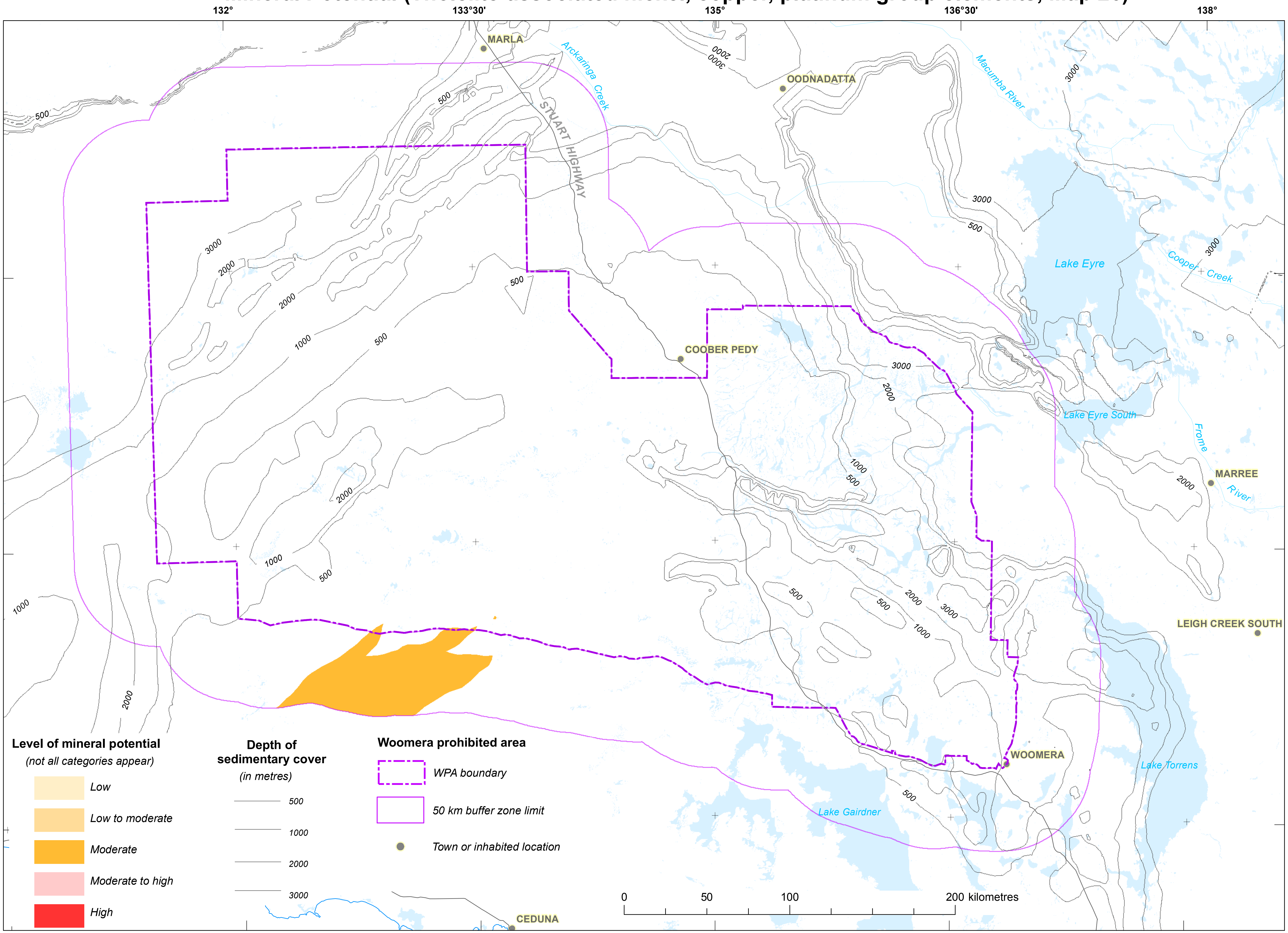
Hydrocarbon Potential (Oilshale, Map 24)



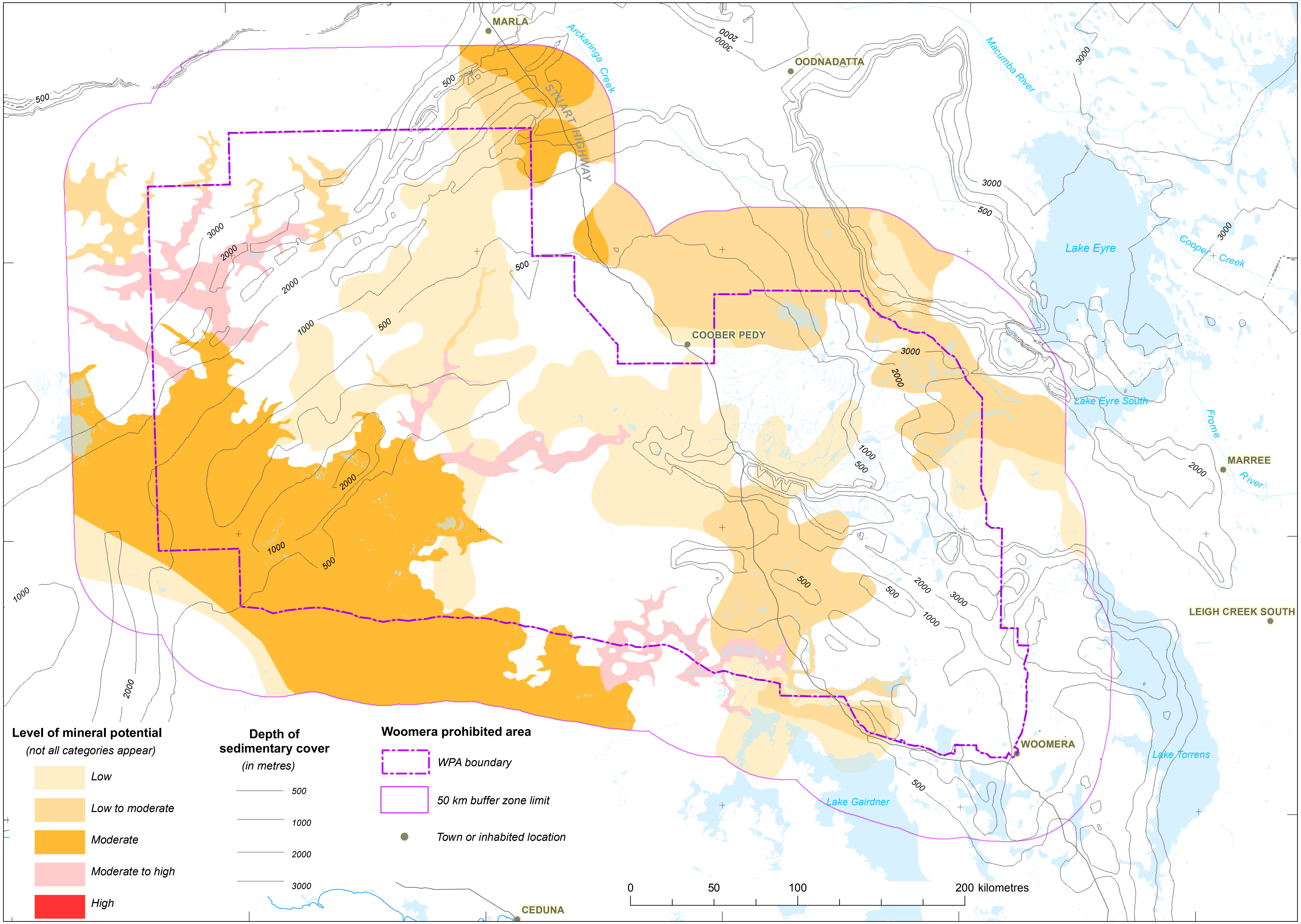
Mineral Potential (Komatiite-associated nickel, Map 25)



Mineral Potential (Tholeiite-associated nickel, copper, platinum group elements, Map 26)



Ground Water Potential (Map 27)



Appendix D: Comparative Comment on the Identified Mineral Resources of the Woomera Prohibited Area, South Australia

EXECUTIVE SUMMARY

The Woomera Prohibited Area (WPA) covers some 127,000 km^2 of remote South Australia. The area contains three operating mines: the Prominent Hill copper-gold mine in the southeast; Challenger, a mid-size gold mine in the west; and Cairn Hill, a recently commissioned small iron ore (magnetite)-copper-gold mine, as well as a planned iron ore mine at Peculiar Knob. There are undeveloped coal resources at Phillipson in the Arckaringa Basin and at least 5 iron ore deposits with identified resources. In addition there are some 150 known occurrences of minerals dominated by gold, iron ore, copper and opal, with additional occurrences of uranium, epsomite, silver, zinc, lead, diamonds, dolomite and heavy mineral sands. An assessment of the mineral potential of the WPA undertaken by Geoscience Australia and PIRSA (Geoscience Australia, 2010) has identified the potential of the WPA to host a range of commodities in a diverse range of mineral deposit types and geological settings. Those considered to have the greatest potential are uranium, copper, gold, coal, iron ore, and mineral sands. There is also potential for geothermal energy and groundwater resources.

Known deposits within the WPA account for only modest proportions of Australia's total mineral resources ─ 2.3% of copper resources, 0.7% of gold resources and 1% of iron ore resources. There are significant black coal (sub-bituminous) resources in the WPA, some 4% of Australia's black coal resources, that are not currently being mined.

Importantly however, the WPA forms a significant proportion (about 24%) of the area of the Gawler Craton, a large mineral-rich ancient basement block overlain by much younger flat-lying sedimentary rocks that occupies around half of South Australia. In addition to the 3 operating mines in the WPA the Gawler Craton hosts BHP Billiton's major Olympic Dam copper-uranium-gold mine, OneSteel Ltd's Middleback Range iron ore mine, and Iluka Resources recently commissioned Jacinth-Ambrosia heavy mineral sand mine at the margin of the Eucla Basin, which overlies the southwestern parts of the Gawler Craton. There are around 16 potential mining operations involving iron ore, copper, coal, uranium, gold, mineral sands, lead-zinc and kaolin at various stages of development. The vast bulk of the copper, gold and uranium resources in the Gawler Craton are hosted by the Olympic Dam deposit which contains about 36% of the world's known uranium resources. The Gawler Craton hosts most of Australia's uranium (76%) and copper (62%) resources, and 17% of Australia's gold resource. The Eucla Basin is an important repository for mineral sands resources with 6% of Australia's rutile, 0.8% of total ilmenite resources and 0.8% of total zircon resources.

A 50 km buffer zone extension around the WPA includes the major Olympic Dam copper-uranium-gold deposit, the Jacinth-Ambrosia mineral sand deposit to the southwest of the WPA, other substantial undeveloped black coal deposits immediately north of the WPA, and a number of undeveloped iron ore and gold deposits. The WPA and 50 km buffer zone contains 75.4% of Australia's uranium resources, 62% of copper resources, 18% of gold resources and around 6% of Australia's mineral rutile resources, 0.8% of ilmenite resources and 0.8% of Australia's zircon resources. Known coal resources in the WPA and the 50 km buffer zone account for about 10% of Australia's recoverable black coal resources. These have remained undeveloped to date because of their remote location and inferior qualities compared to other more accessible coal deposits but are now being considered for development as coal-to-liquid, underground coal gasification, and coal seam gas (CSG) projects.

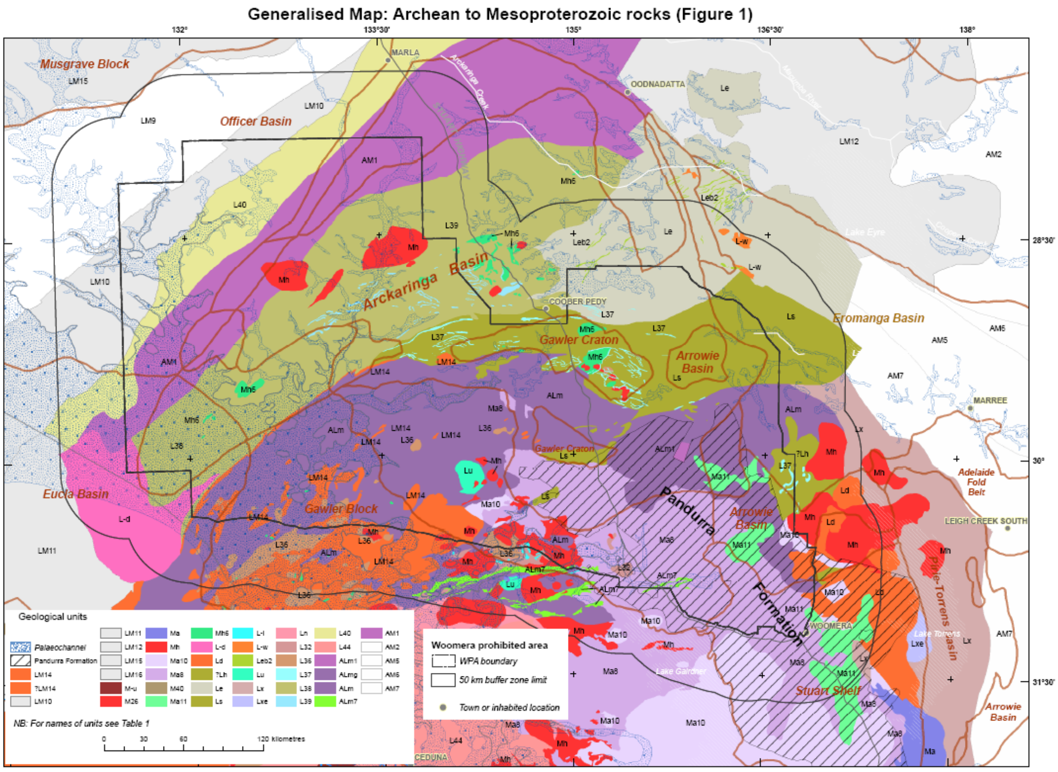
The significant and diverse mineral endowment of the Gawler Craton, including both the WPA and its immediate surrounding area, makes it highly prospective for further mineral discovery. Most of the region is currently held under exploration tenement. A cover of regolith and younger sedimentary rocks makes exploration of the underlying prospective basement rocks difficult and costly but advances in technology have enabled discovery and mining of the mineral deposits beneath 300 m of barren cover and discovery of similar ore systems below 500 m of cover. Further discoveries within this zone are likely.

REGIONAL GEOLOGY

The Gawler Craton covers an area of approximately 520,000 km^2, including the WPA (Figure D1). In brief, the Gawler Craton comprises Precambrian basement rocks overlain by younger flat-lying Phanerozoic sediments that increase with depth on the margins of the craton. These sediments are contained in a number of sedimentary basins – principally the Officer Basin (Neoproterozoic to late Devonian age) in the northwest WPA, the Arckaringa Basin (late Carboniferous to early Permian) in the northern WPA, and the very extensive Eromanga Basin (early Jurassic to early Cretaceous) in the northeast of the WPA. Sediments of the Eucla Basin (Paleocene to Recent), including ancient shore lines with heavy mineral sand concentrations, overlie the Gawler Craton in the southwest extending to the far southwest corner of the WPA. In the southeast of the WPA, the Gawler Craton is overlain by quartzose sediments of the Pandurra Formation which is of Mesoproterozoic age (Figure D1).

The basement rocks of the Gawler Craton (Figure D1) constitute a major crustal province dominated by two major phases of tectonic activity, Late Archean and late Paleoproterozoic to early Mesoproterozoic, in total spanning approximately 1 billion years. The Gawler Craton hosts the supergiant Olympic Dam iron-oxide copper-uranium-gold deposit, which is the world's largest uranium deposit, 4th largest copper deposit and 6th largest gold deposit.

Figure D1. Generalised map showing the geology of the WPA and surrounding region (Geoscience Australia 2010).



MINERAL DEPOSITS, OCCURRENCES AND MINES

The WPA contains three operating mines: the Prominent Hill copper-gold mine in the southeast; Challenger, a mid-size gold mine in the west; and Cairn Hill, a recently-commissioned small iron ore (magnetite)-gold mine. Mining approvals have been granted for development of a new iron ore mine at Peculiar Knob, some 25 km northwest of the Prominent Hill mine. The largest of these operations is Prominent Hill.

There are substantial undeveloped coal resources in the Phillipson coal field of the Arckaringa Basin at the northern margin of the WPA. These are currently being investigated for potential underground coal gasification, coal-to-liquids conversion, and/or CSG. The WPA also contains a number of iron ore deposits, five of which have identified resources.

The broader region of the Gawler Craton contains operating mines producing copper, gold, uranium, silver, iron ore, zircon, ilmenite, and rutile. Opal is also produced from small scale operations. In addition there are more than 30 deposits with announced resources for commodities that as well as the mined commodities also include coal, kaolin, lead, and zinc. By far the most significant mining operation is Olympic Dam which produced approximately 156 kt copper, 2981 t uranium and 3 t gold in 2009 - a year when output was restricted by reduced operational capacity. Mining of heavy mineral sands at the Jacinth-Ambrosia mine which lies less than 50 km southwest of the WPA commenced in late 2009. The Middleback Range iron ore mine is currently producing magnetite ore for steelmaking and exporting around 5 Mt of hematite ore.

RELATIVE SIGNIFICANCE OF IDENTIFIED RESOURCES IN THE WPA AND GAWLER CRATON

The Gawler Craton is characterised by a range of identified mineral resources (Table D1) occurring in different mineral deposit types and geological environments. The Craton has an even wider range of mineral occurrences and significant potential for a very wide range of mineral resources in different mineral deposit types and geological settings. These features make the Gawler Craton highly attractive to mineral exploration for a wide range of mineral commodities.

Table D1. List of operating mines and undeveloped mineral deposits with remaining resources in the WPA and within a 50 km extension zone of the WPA as at August 2010.

Deposit Name	Status	Commodity	Remaining Total Resources (including inferred)[1]
Deposits within the WPA			
Prominent Hill	Operating mine	Copper	2.7 Mt Cu
		Gold	196 t Au
		Uranium - not being produced	9 990 t U[2]
Cairn Hill	Operating mine	Copper	0.04 Mt Cu
		Iron ore	14.1 Mt Fe
		Gold	1.23 t Au
Challenger	Operating mine	Gold	23.6 t Au
Emmie Bluff	Deposit	Copper	0.3 Mt Cu
Golf Bore	Deposit	Gold	3.2 t Au
Hawks Nest	Deposit	Iron ore	689.9 Mt Fe
Peculiar Knob	Deposit	Iron ore	19 Mt Fe
Giffen Well	Deposit	Iron ore	240 Mt Fe
Fingerpost Hill	Deposit	Iron ore	10 Mt Fe
Sequoia	Deposit	Iron ore	22 Mt Fe
Phillipson	Deposit	Black coal	5216 Mt recoverable
Deposits with 50 km buffer zone extension to the WPA			
Olympic Dam	Operating mine	Copper	78.3 Mt
		Gold	3024 t
		Uranium	2.08 Mt
Tarcoola	Deposit	Gold	2.3 t
Murloocoppie	Deposit	Black coal	2835 Mt recoverable
Weedina	Deposit	Black coal	4320 Mt recoverable
Westfield	Deposit	Black coal	480 Mt recoverable
Wintinna	Deposit	Black coal	3510 Mt recoverable
Jacinth-Ambrosia	Operating mine	Ilmenite	2.7 Mt
		Rutile	0.5 Mt
		Zircon	5.1 Mt
Ooldea	Deposit	Iron ore	564 Mt Fe
Mt Christie	Deposit	Iron ore	5 Mt Fe
Wilgena Hill	Deposit	Iron ore	130 Mt Fe
Warrior	Deposit	Uranium	2036.5 t

1 Resources as recorded in Geoscience Australia's Ozmin database **as at 31 August 2010**. For some deposits recent resource data from companies may not have been entered into the data base by that date. **2** Last publicly released uranium estimate (2004) by the company.
Note: Resources include remaining ore reserves and mineral resources and are based on company estimates.
Units: Mt = million tonnes, kt = kilotonnes, t = tonnes.

The significance of the identified resources of the Gawler Craton in terms of Australia's inventory of identified mineral resources varies substantially depending on the commodity. Table D2 gives the proportion of Australia's total resources contained in deposits lying with the WPA and also within a 50 km buffer around the WPA.

Table D2. Mineral resources in the WPA and 50 km buffer zone as a proportion of Australia's total resources.

Commodity	Unit	Total Resources Australia	Resources in WPA and 50 km buffer extension	% of Australia's Resources in WPA and 50 km buffer extension	Resources in WPA	% of Australia's Resources in WPA
Uranium	t	2 767 794	2 087 117	75.4	10 287	0.4
Iron ore	Mt	69 017	1699	2.5	995	1.4
Gold	t	18 465	3250	17.6	224	1.2
Copper	Mt	130.3	81	62.4	3	2.1
Black coal: recoverable	Mt	133 970	12 851	9.6	5216	3.9
Mineral sand: zircon	Mt	359.6	2.7	0.8	-	-
Mineral sand: rutile	Mt	84.9	5.1	1	-	-
Mineral sand: ilmenite	Mt	61.12	0.5	6.0	-	-

Source: Geoscience Australia

Uranium

The giant Olympic Dam copper-uranium-gold deposit, of major national economic importance, lies only 15 km east of the WPA. A proposed major expansion to the Olympic Dam mine through the development of a major open cut mine to access the large resources south of the current workings will triple uranium output to approximately 19 000 tpa. Deposits in the WPA and its 50 km extension buffer hosts around 75.4% of Australia's resources of uranium (Table D2), making it Australia's premier uranium region.

In addition there are a number of small sandstone-hosted uranium deposits in the region of the WPA. The presence of uranium-rich source rocks in the Gawler Craton indicates that sedimentary rocks overlying it have a high potential for sandstone-hosted uranium deposits. These could potentially be larger than those currently known in the region. There is a high level of uranium exploration activity in South Australia, including the Gawler Craton.

Copper

The Gawler Craton, particularly the eastern margin the craton ─ the Olympic Domain (which extends into the WPA) ─ is Australia's most prospective copper belt, containing the Olympic Dam copper-uranium-gold and the Prominent Hill copper-gold mines as well as a number of smaller deposits and prospects. The largest of these undeveloped deposits is Carrapateena, a significant new copper-gold-uranium prospect discovered in 2005 and lying beneath 500 m of cover some 130 km southeast of Olympic Dam. Resources are yet to be announced by the operating company but available geological data suggest that the deposit may be comparable in size to the Prominent Hill deposit.

The WPA and 50 km buffer zone hosts 62% of Australia's copper resources (Table D2), contained mostly in the Olympic Dam and Prominent Hill deposits. The Carrapateena copper-gold-uranium prospect is located just outside the 50 km buffer of the WPA.

The discovery of the Prominent Hill (2001) and Carrapateena (2005) copper-gold deposits, all of the same style of mineralisation as the Olympic Dam deposit, has reinforced the importance of this belt for significant iron oxide copper-gold ± uranium deposits. The assessment highlighted the potential for further discovery of copper, gold and uranium resources in deposits of this type in the eastern Gawler Craton. Compared to other regions of Australia with copper-gold deposits of similar style such as the eastern Mount Isa and Tennant Creek regions, the Gawler Craton has geology considered more favourable to host uranium-bearing copper-gold deposits of substantial size. These attributes include the association of uranium-rich granitic rocks with large volumes of preserved coeval volcanic rocks. Studies have shown that the largely synchronous emplacement of large volumes of these intrusive and volcanic rocks played a key role in the formation of several uranium-bearing copper-gold deposits in the Craton. The Gawler Craton appears unique in Australia in preserving large volumes of granitic intrusive and equivalent volcanic rocks and offering potential for the further discovery of copper-gold-uranium deposits of significant size. The mineral potential assessment found there is a high potential for discovery of more than one deposit of the size of Prominent Hill in the region.

The presence of relatively thick cover (up to 300 meters) poses challenges for exploration but the ready availability of precompetitive geophysical datasets (gravity, magnetic, and radiometric) for the Gawler Craton has triggered intensive exploration for iron oxide copper-gold-(uranium) deposits. The gravity and magnetic datasets map areas with coincident (but slightly displaced) gravity and magnetic anomalies, a feature identified at the Olympic Dam and Prominent Hill deposits.

Gold

The gold resources contained within the WPA are relatively modest (Table D2). The Prominent Hill and Challenger mines produce around 2% of Australia's annual gold output. However, deposits within the 50 km buffer zone extension of the WPA include Olympic Dam (as well as several much smaller deposits, Table D1) which represent some 18% of Australia's identified gold resources. The potential for discovery of further gold resources, particularly in copper-gold deposits of similar style to Prominent Hill and Olympic Dam is assessed as high.

Iron ore

The deposits of the Middleback Range have been an important source of high grade iron ore for more than a century. The Middleback Range is the largest iron ore producer outside Australia's premier iron ore province, the Pilbara. Total identified iron ore resources in Australia are around 69,017 Mt, only a small proportion (1.4%) lies inside the WPA (Table D2).

Magnetite-rich iron ore deposits such as Cairn Hill are spatially associated with granitic rocks similar to those of the Olympic Dam deposit and share a number of the features of iron oxide copper-gold (-uranium deposits) including the presence of some copper and gold. It is therefore likely that more drilling of iron ore deposits and prospects of this nature will find zones with copper and/or gold and uranium.

Coal

The identified coal resources of the Arkaringa Basin represent a significant undeveloped and currently sub-economic black coal resource. In addition to the Phillipson coal deposits there are known coal resources in the Wedinna, Wesfield, Murloocoppie, Wintinna and East Wintinna deposits in the Arkaringa Basin lying immediately north of the WPA. The Arkaringa Basin coal deposits contain around 17.9 Gt of recoverable black coal resources. These constitute some 13% of Australia's recoverable demonstrated black coal resources. The remote location of the coal deposits and the lower thermal qualities of the Arkaringa coal deposits compared with other deposits proximal to the coast and population centres has limited interest in developing the Arkaringa deposits until recently. Current interest is centred around the potential for underground coal gasification, coal-to-liquids production, and/or CSG.

Mineral sands

There are currently no known mineral sand deposits within the WPA but a substantial mineral sand deposit (Jacinth-Ambrosia) lies within the 50 km buffer zone to the WPA (Table D1). The ancient shorelines sands which host this deposit continue into the WPA and the buffer zone around it. The Eucla Basin is emerging as a world-class mineral sand province. The mineral potential assessment found a high potential for discovery of further significant deposits of this type in the WPA.

PROSPECTIVITY – POTENTIAL FOR UNDISCOVERED DEPOSITS

The potential for undiscovered mineral resources in the WPA, based on the types of mineral deposits likely to be found in the area and current geological knowledge of the region, is given in the separate assessment by Geoscience Australia and PIRSA (Geoscience Australia, 2010). The assessment is based on a series of maps that depict areas of mineral potential by mineral deposit type and commodity ranked by mineral potential and the degree of certainty attached to each assessed commodity and region. Ongoing geoscientific investigations and mineral exploration may reveal potential for other types of mineral deposits. Areas can be repeatedly explored for years before an economic mineral deposit is discovered. There is a need to periodically review and update mineral potential assessments to take account of new geoscience data and geological concepts and new discoveries.

The WPA has been subjected to varying levels of mineral exploration in the past. There have been several periods of active exploration of the Gawler Craton, the first following the discovery of the Olympic Dam deposit in 1975. This was the first discovery of a major (metallic) mineral deposit under thick cover in Australia and the discovery drew heavily on regional geophysical data provided by the Bureau of Mineral Resources (predecessor of Geoscience Australia). The release of new high–resolution regional aeromagnetic data and ground gravity data supported by targeted stratigraphic drilling under a South Australian government geoscience initiative in the mid-1990s provided a major new stimulus to exploration of the Gawler Craton. These new regional datasets significantly reduced the risk of exploration under cover in the region. The discovery of the Prominent Hill deposit in 2001, more than 25 years after the initial discovery of Olympic Dam, resulted from a successful application of new geological concepts with improved imaging and modelling of gravity (and magnetic) data. This triggered a new phase of exploration in the region which culminated in the Carrapateena discovery (in 2005) and in 2007 Teck Cominco Limited (now known as Teck Resources Limited) reported a spectacular drill intercept of 905 m grading at 2.1% copper and 1 gram per tonne gold.

In summary, parts of the Gawler Craton including parts of the WPA have been subjected to moderate to high levels of exploration in recent years, whereas areas in the west have been less well explored. Current exploration interest in the region is high and mineral exploration tenements (granted and under application) cover most of the Gawler Craton and almost all the WPA.

Past exploration history strongly suggests that mineral exploration will continue to be difficult and costly because of the depth of the barren sediments overlying the prospective basement rocks. Although the rate of mineral discoveries will continue to be slow, it is likely that discoveries of probable major importance will continue to be made in the WPA as exploration risk is reduced by advances in mineral exploration technology and accumulation of geological knowledge from ongoing exploration. Given adequate land access, it is likely that exploration companies will want to continue exploration in the WPA because of the high mineral potential of the region.

The new infrastructure brought to the region, including the Adelaide to Darwin railway, as well as the infrastructure associated with new mining projects in the area means that, although remote, new profitable mining operations are both feasible and likely. New technologies mean that major mineral deposits can be discovered and potentially mined beneath cover as thick as 500 m. Smaller deposits of high grade ore can be feasibly mined with cover thicknesses of 100 m or more. The thickness of sand, soil and sedimentary rock cover over most of the Gawler Craton is less than 500 m except in the far northwest (Officer Basin), northeast (Arkaringa Basin) and southeast.

Figure D2. Map showing operating mines, mineral deposits and exploration tenements (granted and pending) at March 2010 (Geoscience Australia, 2010).

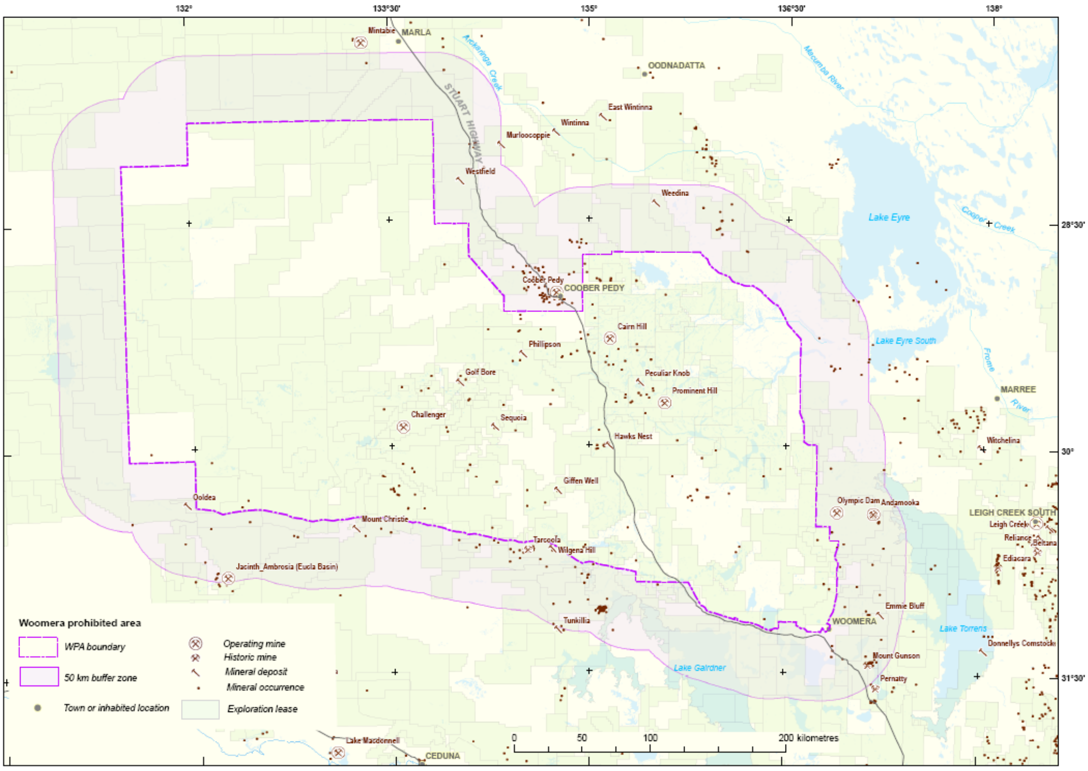
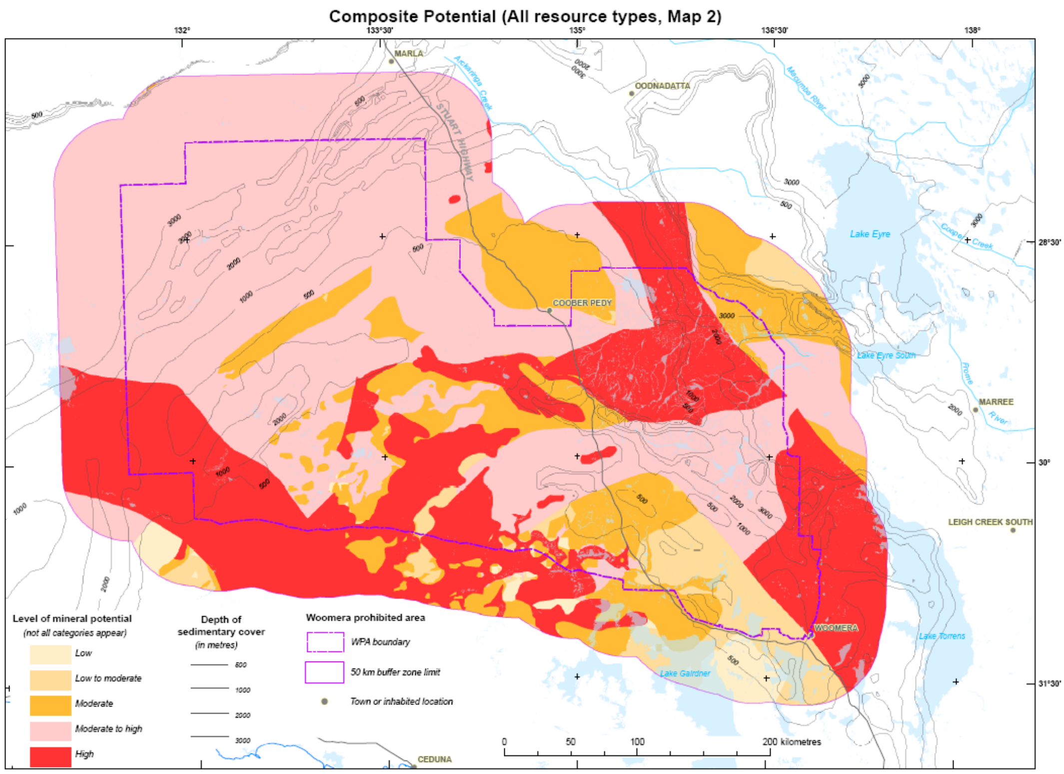


Figure D3. Map showing composite mineral potential assessed in the WPA. Thickness of sedimentary cover overlying Gawler Craton rocks is shown as contours (Geoscience Australia, 2010).



Reference

Geoscience Australia, 2010. Mineral Resource Potential Assessment of the Woomera Prohibited Area, South Australia. Report to Department of Resources, Energy and Tourism.