

# Queensland Geological Record 2016/07

## Cape York Catchment Geochemistry Assessment— Regional Mineralisation Potential

J.E.H. Tang, D.D. Brown & D. Purdy



Address for correspondence:

Geological Survey of Queensland  
Department of Natural Resource and Mines  
PO Box 15216 City East QLD 4002  
Email: geological\_info@dnrm.qld.gov.au  
Phone: 13 QGOV (13 74 68)

© State of Queensland (Department of Natural Resource and Mines) 2016

The Queensland Government supports and encourages the dissemination and exchange of information. The copyright in this publication is licensed under a Creative Commons Attribution 4.0 International (CC BY 4.0) licence.



Under this licence you are free, without having to seek permission from DNRM, to use this publication in accordance with the licence terms.

You must keep intact the copyright notice and attribute the State of Queensland, Department of Natural Resource and Mines, as the source of the publication.

For more information on this licence visit  
<http://creativecommons.org/licenses/by/4.0/deed.en>

Cover photographs (clockwise from top left): Sampling using chartered helicopter in the Western Cape York region; using a petrol-powered auger prior to sampling; using the Munsell soil-colour charts; compositing soil and transferring TOS sediments.

ISSN 2203-8949 (CD)  
ISBN 978-1-922067-82-1 (CD)  
ISSN 2206-0340 (Online)  
ISBN 978-1-922067-81-4 (Online)  
Issued: December 2016

Reference: TANG, J.E.H., BROWN, D.D. & PURDY, D., 2016: Cape York Catchment Geochemistry Assessment—Regional Mineralisation Potential. *Queensland Geological Record* **2016/07**.

# Contents

ABSTRACT .....	1
1. INTRODUCTION.....	2
1.1 The objectives of the Cape York Geochemical Study.....	2
2. CATCHMENT DEFINITION AND SAMPLING METHODOLOGY .....	3
2.1 Defining Cape York Study area.....	3
2.2 Fieldwork .....	3
2.3 Sampling methodology .....	5
2.3.1 Top Outlet Sediments (TOS) .....	6
2.3.2 Bottom Outlet Sediment (BOS) .....	6
2.3.3 Field observations.....	6
3. SAMPLE PREPARATION AND ANALYTICAL METHODOLOGY .....	9
3.1 Sample preparation .....	9
3.2 Analytical methodology .....	10
3.2.1 Total element content .....	13
3.2.2 Aqua regia soluble element content .....	16
3.2.3 Platinum Group Elements (PGE) and gold analysis by fire assay and ICP-MS (ALS Chemex Australia Pty Ltd) .....	18
3.2.4 Fluoride analysis by ion specific electrode (Bureau Veritas Minerals Pty Ltd) .....	19
3.2.5 Mobile Metal Ions™ — multi-element extraction .....	19
4. DATA PROCESSING .....	20
4.1 Data computation for the combined catchment geochemistry .....	20
4.1.1 Silver results from Geoscience Australia (GA) and the University of Queensland (UQ).....	20
4.2 Reassaying, data levelling and recalculation.....	21
4.2.1 Microwave bomb digested samples at the Queensland Health facility in Coopers Plains.....	21
4.2.2 Re-assaying of Sn data (Batch 5) .....	22
4.3 Grouping data into geochemical provinces.....	23
4.4 Selection of samples for REE and spidergram geochemical plots .....	24
4.5 Validating NGSAs results for suitability to merge into the Cape York Project .....	26
5. RESULT APPRAISAL .....	28
5.1 Field data.....	28
5.2 Geochemical results .....	28
5.2.1 Original versus weighted average results .....	28
5.2.2 Harker major element variation diagrams .....	29
5.2.3 Harker minor element variation diagrams .....	30
5.2.4 Rare earth patterns .....	34
5.2.5 Spidergram patterns .....	35
5.2.6 Comparing REE and spidergram patterns.....	41
5.3 Fingerprinting Cape York geochemistry .....	43
5.3.1 Fingerprinting geochemical provinces .....	44
5.4 Inter-element correlation coefficient and variance .....	47
5.4.1 Correlation coefficient grids.....	47
5.4.2 Regional geochemical associations .....	51
5.4.3 Geochemical Province Associations.....	53
5.5 Geochemical Associations and Predictive Mineral Models .....	60
5.6 Statistical appraisal .....	73
5.6.1 Cape York Geochemical Atlas (Part II) .....	75
6. DISCUSSION .....	75
6.1 Rare Earths .....	76
6.1.1 Element-specific catchments.....	78
6.1.2 Elevated REE catchments.....	79

6.1.3	Anomalous and enriched catchments	79
6.2	Precious metals anomalies	81
6.2.1	Gold	81
6.2.2	Silver	82
6.3	Base metals — copper, lead and zinc	83
6.3.1	Copper	83
6.3.2	Lead	84
6.3.3	Zinc	84
6.4	Uranium	84
6.5	Aluminium and gallium	85
6.6	Tin and tungsten	85
7.	SUMMARY	86
8.	ACKNOWLEDGEMENTS	90
	REFERENCES	90
	CAPE YORK GEOCHEMICAL ATLAS	93

## FIGURE

1:	Outlet sediment sample locations for catchments in the Cape York region	4
2:	Mobilisation in Cape York	5
3:	Outlet sediment site selection	6
4:	Sampling TOS	7
5:	Sampling BOS	8
6:	Field pH testing and soil colour recording	9
7:	Summary of sample preparation for the Cape York samples undertaken by the Geological Survey of Queensland	10
8:	Geochemical provinces of Cape York based on the regional tectonic structure	24
9:	Geochemistry from different geochemical provinces based on sample size fraction and depth profiles	25
10:	Geochemical comparison of same catchments sampled during the NGSA and Cape York Project	27
11:	Harker variation diagram of major elements in Cape York	31
12:	Harker variation diagram of minor elements in Cape York	32
13A:	Chondrite normalised REE patterns for BOS <75 micron samples	36
13B:	Chondrite normalised REE patterns for TOS <75 micron samples	37
14A:	Upper Crustal normalised spidergram pattern for BOS <75 micron samples	39
14B:	C1 Chondrite normalised spidergram pattern for BOS <75 micron samples	40
15:	REE and spidergram for contrasting patterns in the Cape York region	42
16:	Depletion-enrichment graph of the Cape York regional geochemistry	44
17:	Depletion-enrichment graph of geochemical provinces in Cape York	45
18:	PCA calculation for near-total digestion results from UQ	48
19:	Correlation coefficient grids of the Etheridge South Province showing different aspects of the inter-elemental relationships based on different geochemical results	49
20:	Combined correlation coefficient grids for Etheridge South Province	50
21:	Pearson average correlation coefficient of 260 samples (including 13 repeats) in the Cape York region	51
22:	The correlation coefficient of the mean square averages of all sample types from different tectonic terranes in the Cape York region	59
23:	Geochemical based mineralisation model for the Cape York region interpreted from primary and secondary elemental associations	72
24:	Rare earth element distribution in Cape York	77

## TABLE

1: Summary of the 67 elements analysed for the Cape York Project.....	12
2: Typical detection limits achieved on the Thermo X-7 Series ICP-MS (adapted from University of Queensland geochemistry laboratory detection limits) .....	15
3: Example of data processing grid to statistically rank geochemical anomalies in the Cape York dataset. ....	21
4: Data recalculation for microwave bomb digested samples from the University of Queensland... .	22
5: Multiple batches of Sn assay results from the University of Queensland.....	23
6: Geochemical associations within the Cape York catchments. ....	62
7: Statistical breaks used in Cape York Geochemical Atlas.....	73
8: Lithological, pedochemical and/or mineralisation interpretations using various geochemical combinations. ....	87

## APPENDIX

- 1: Field descriptions and observations at target sites.
- 2: Combined geochemical results of Cape York from all laboratories including QA/QC standards.
- 3: Statistically processed geochemistry of Cape York.

## DATA

Cape York Geochemical GIS



---

## ABSTRACT

The Cape York Catchment Geochemistry Assessment Project sampled overbank alluvial sediments along second- and third-order river drainage systems with an average of one sample per 870 sq. km. The study follows up an earlier low density National Geochemical Survey of Australia (NGSA, 2007–2011) program and adopted the same methodologies to ensure compatibility of results. One hundred and eighty-nine (189) catchments were sampled and 58 NGSA results were reprocessed using reconfigured catchment boundaries.

Samples were taken at two depth intervals: 0–10 cm depth for the top outlet sediment (TOS) and from 60–90 cm below the surface for the bottom outlet sediment (BOS). Each sample was sieved to produce coarse (<2 mm) and fine (<75 micron) size fractions (subsamples), and analysed by six different methodologies. All samples were analysed for 67 major and trace elements geochemistry. Thus each target site generated four subsamples and 541 analyses.

Geochemical analysis showed that the Cape York data have strong lithochemical control, and all catchments have an upper crustal signature. The regional geochemistry is subdivided into 10 geochemical domains based on lithotectonic provinces to differentiate the different geochemical backgrounds. Individual catchments differ slightly in their geochemical pattern, which is attributed to different background levels related to background lithology and mineralisation. Subsamples within each catchment share a consistent overall chemical signature, which suggests that the chemistry within individual catchment is homogenised. The coarser samples (<2 mm) of both TOS and BOS have greater variability than the finer (<75 micron) fractions due to the heterogeneity of lithoclasts.

The catchment chemistry is recalculated as the weighted average of all geochemical data. Geochemical interpretation for lithology or mineral models is based on analysing suites of elements and inter-element association rather than individual elements. The inter-elemental relationship is calculated using the Pearson correlation coefficient, mean of squares and sum of mean square differences, and the results further confirmed with Principal Component Analysis.

The Cape York Geochemical Atlas is a statistical computation and ranks 67 elemental concentrations at the 25, 50, 75, 90, 95, 98 and 99 percentile statistical breaks. A statistical anomalism is generally regarded as the population outside the normal population distribution, which commonly equates to ‘mean plus two standard deviations’. However, for this Atlas, the ‘mean plus two standard deviations’ commonly falls within the 97th to 98th percentile, hence only values over the 99th percentile are regarded as true anomalies. These are first-tier or prime exploration targets. Values in the 98th to 99th percentile, which also represent a statistical anomaly, are presented as second-tier anomalies.

---

The Atlas is designed to identify mineral potential for 67 commodities, including emerging commodities such as lithium, tantalum, niobium and rare earth elements. It will fast track exploration by narrowing down catchments for imminent follow-up exploration programs, establishing the geochemical background for 67 naturally occurring elements, providing the anomalous elemental associations for each catchment, and postulating fresh ideas for potential mineralisation models in prospective catchments.

**Keywords:** Overbank alluvial sediments, geochemistry, near total acid digest, aqua regia, partial digest, mineralisation, geochemical atlas.

## 1. INTRODUCTION

Under the Future Resources Funding Initiatives, the Queensland Government allocated \$1 million dollars for Cape York resource assessment to re-evaluate the mineral potential of an under-explored region of Australia. Phase 1 of the Cape York Geochemical Assessment Project involved regional catchment sediment sampling followed by a later phase of localised mapping and mineral system study.

Cape York Peninsula has anomalous geochemistry for aluminium, rare earth elements, uranium, thorium, lithium, caesium, beryllium, tantalum, molybdenum, gold, antimony, bismuth, arsenic, tin, tungsten, lead and zircon (Tang & Brown, 2011; Caritat & Cooper, 2011). The regional anomalies were established by the NGSAs program (2007–2011) based on a very large catchment that averaged one sample for every 4410 sq. km. The NGSAs data provide a regional geochemical footprint but have limited practicality on a local scale to assist explorers to target mineral potentials or environmental scientists to establish background chemistry.

The Cape York Catchment Geochemistry Assessment Project sampled output sediments along the second- and third-order river drainage systems with an average of one sample per 870 sq. km. A total of 189 catchments were sampled at the lowest point within each catchment using digital elevation modelling or taken near the outlet of the catchment. The sampling logic is based on the assumption that various fine fractions of the rock types within each catchment are thoroughly mixed and that the subsequent depositions in low-energy environments are near their outlets. Chemistry of outlet sediment taken from floodplain or overbank deposits represents the average background geochemical composition (Ottesen *et al.*, 1989; Smith & Reimann, 2008). The sampling technique has been adapted to Australian landscapes and climate conditions from trials carried out in numerous localities by Geoscience Australia (Caritat & Lech, 2007; Caritat *et al.*, 2007, 2008; Cornelius *et al.*, 2008).

### 1.1 The objectives of the Cape York Geochemical Study

- Analyse catchment samples to extract the maximum inorganic geochemical information of 67 elements using internally consistent, state-of-the-art techniques
-

- define the geochemical background of the Cape York region for geological, environmental and ecological benchmarking
- compile an atlas of geochemical maps for the exploration industry to identify areas of high mineral potential in Northern Queensland
- create an atlas of chemical association independent of known mineral deposits that can potentially identify alternative mineralisation models which were not considered in earlier exploration
- evaluate the mineral potential of an under-explored region of Australia
- establish the sensitivity of sample type and analytical method for detecting undercover deposits.

## 2. CATCHMENT DEFINITION AND SAMPLING METHODOLOGY

### 2.1 Defining Cape York Study area

A total of 189 catchments were sampled from Bamaga southwards to Normanton in the west and Ingham in the east (Figure 1). The drainage catchment boundaries were modified from the digital elevation modelling using the GEODATA National 9 Second Digital Elevation Model (DEM-9s) Version 3 (Stein *et al.*, 2011; Hutchinson *et al.*, 2000). The catchments were reconfigured to best match the topographic and geological features that best reflect the drainage cell at 1:500 sq. km scale. Catchments within flat-lying topography may not have watershed at such scales and therefore have to accommodate at scale nearest to a catchment lowest size domain. All sample sites were targeted near their catchment outlet, while those exhibiting internal or poorly defined drainage were sampled at, or as close as possible to, their lowest point.

### 2.2 Fieldwork

The fieldwork was carried out during the dry season (May–November) between 2013 and 2014 by staff of the Geological Survey of Queensland (GSQ), Department of Natural Resources and Mines. Sampling was completed in three field seasons in October 2013, from April to May 2014 and in October 2014. Most target sites were accessible by four-wheel-drive (4WD) vehicles, which facilitated off-road transportation of equipment and hefty resulting samples. As most sample locations are extremely remote, land-based travel was very slow and often required two vehicles for safety reasons. Each vehicle was fully equipped with sampling tools, camping gear and safety equipment as well as extra fuel, water and food (Figure 2).

On the Western Cape York floodplains criss-crossed by a myriad of waterways, the target sites were sampled using a chartered helicopter that ensured the timely completion of the sampling program. A Robinson R66 was chartered to sample 12 sites that were inaccessible by 4WD.

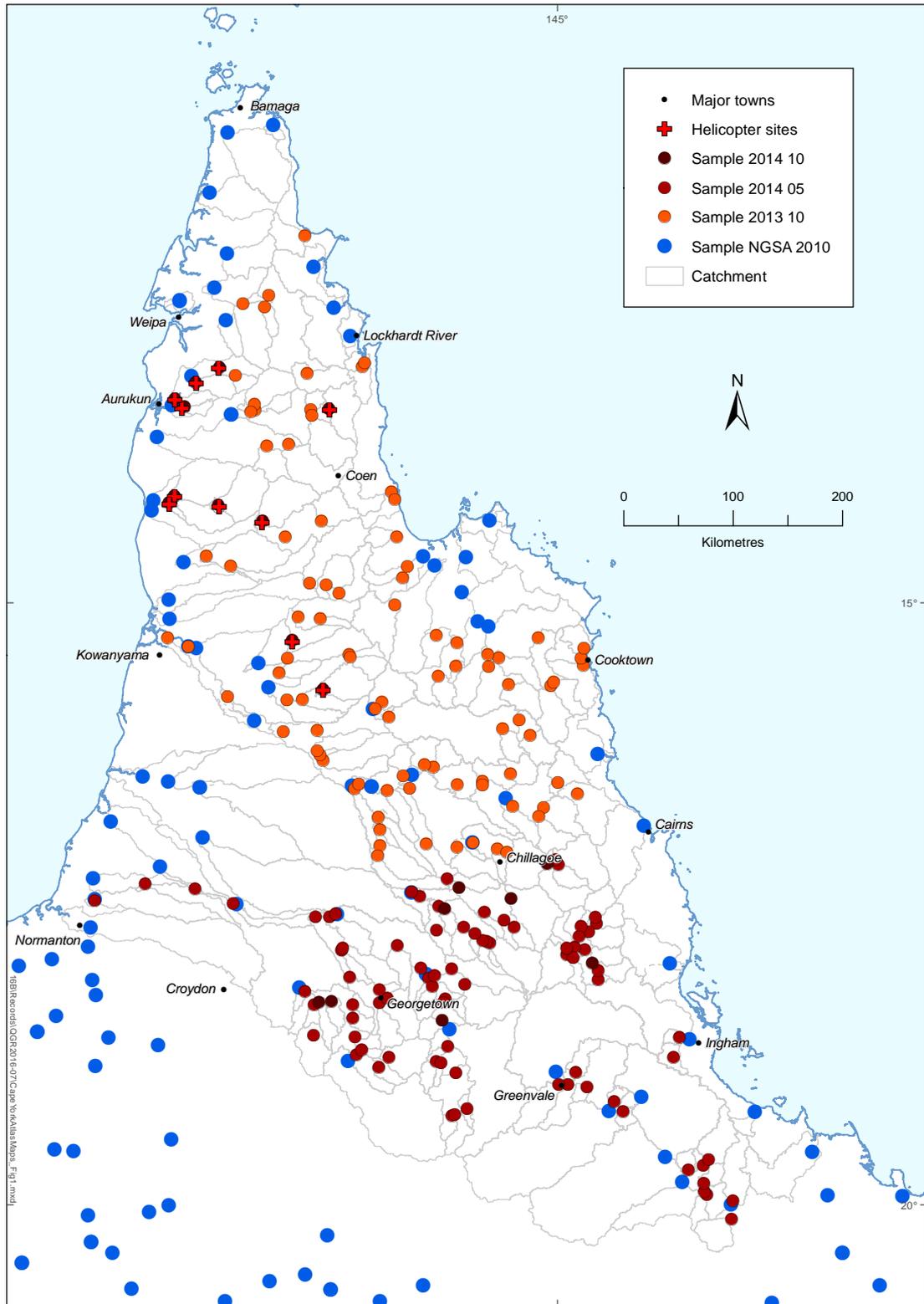


Figure 1: Outlet sediment sample locations for catchments in the Cape York region.



Figure 2: Mobilisation in Cape York. (From top left): A. Roadless travel by 4WD vehicle in bushland, B. Sampling using chartered helicopter in the Western Cape York region, C & D. Camping, cooking and field safety equipment.

### 2.3 Sampling methodology

Field procedures and sampling methodology used in the Cape York study followed the NGS methodology (Lech *et al.*, 2007). Transported sediment was sampled near its catchment outlet, which was commonly the lowest point within a catchment. The sampling targeted low energy environment, such as overbank and floodplain clay deposits that represent a thoroughly mixed or averaged composition of the entire catchment. Site and sample suitability is ascertained by examining the sediments and landforms to confirm material from channel, terrace or river bank deposits is not incorporated (Figure 3). Site appraisal was required at every sample location to ensure that it did not interfere with any sensitive cultural artefacts and that the sediment was not contaminated by anthropologic activities. If the locality was deemed unsuitable, an alternative uncontaminated site was selected within the vicinity of the proposed site.

Catchment outlet sediments were taken at two depth intervals. The top outlet sediment (TOS) represented the recent surface sediments, and the bottom outlet sediment (BOS) represented sediments deposited over recent deposition history for the catchment.



Figure 3: Outlet sediment site selection. Left: Geochemical sampling avoided active channel deposits (tree line), old river beds (white sand) or active river bank deposit (foreground). Right: Samples were collected from very low energy environments from overbank alluvial deposits that represent the homogenised fine sediments, commonly 500 m to 1000 m from the river channel.

### ***2.3.1 Top Outlet Sediments (TOS)***

TOS were sampled between 0 and 10 centimetres depth. Vegetal matter was removed using a shovel over an approximate 50 cm by 80 cm area. The soil was loosened and homogenised down to 10 cm depth with a steel crowbar over an area of 30 cm x 60 cm (Figure 4). To reduce natural soil heterogeneity, every sample collected was further mixed in a shallow soil pit. A clean white plastic scoop was used to collect and transfer the composite TOS sample into two pre-labelled polythene sample bags, and each bag was filled with approximately 5 kg of sample. The two TOS samples were packed into a pre-labelled calico bag, which was subsequently packed in a tough-weave polythene sack for transportation to the GSQ laboratory at Zillmere (Brisbane) for processing.

### ***2.3.2 Bottom Outlet Sediment (BOS)***

The BOS were sampled from 60 to 90 centimetres depth. To ensure that the sample from a target site was representative of the location, composite samples from at least three auger holes were collected over a 10 m x 10 m area. A power auger was used to drill to the target depth, and a cleaned steel hand auger was used to collect the BOS sample (Figure 5).

As with the TOS, two bags of BOS samples were collected using pre-labelled polythene bags, and each bag was filled with approximately 5 kg of material. The two BOS sample bags were packed into a pre-labelled calico bag, and then sealed into a tough-weave polythene sack with its corresponding TOS sample for transportation to Zillmere.

### ***2.3.3 Field observations***

At each sample locality, the GPS coordinates, a detailed site description, lithologic observations, field pH, and dry (if possible) and moist Munsell® soil colours were recorded and several digital photographs of the sample site were taken. The field information was recorded into databases (Appendix 1).



Figure 4: Sampling TOS. (From top left): A. Clearing surface organic matter and vegetation using a shovel, B. Loosening and homogenising soil to 10 cm depth with a steel crowbar, C. Thoroughly compositing soil and transferring TOS sediments with a clean white plastic scoop into pre-labelled polythene bag, D. Field tests including pH test, acid test, recording wet and dry soil colour and lithologic logging.



Figure 5: Sampling BOS. (From top left): A. The Tanaka petrol-powered 6-inch diameter post-digger auger, B. Using a petrol-powered auger to penetrate to 60 cm target depth prior to sampling, C. Sampling the BOS sample using a cleaned steel hand auger at depths ranging from 60 to 90 cm, D. Three auger holes over a distance of 10 metres to obtain a representative composite sample, E. In low recovery sites, multiple auger holes to ensure sufficient samples are collected at a locality, F. Land rehabilitation by backfilling any excavation to ensure minimum disruption to the environment.



Figure 6: Field pH testing and soil colour recording. Left: Field pH test using the CSIRO Inuculo™ pH testing kit to establish soil acidity. Right: Recording the wet and dry soil colour using the Munsell soil-colour charts.

### 3. SAMPLE PREPARATION AND ANALYTICAL METHODOLOGY

#### 3.1 Sample preparation

All samples collected were sent to the Geological Survey of Queensland laboratory facility at Zillmere for processing (Figure 7). The sample preparation followed methodology used in the NGS sampling program (Caritat *et al.*, 2009). The contents of the two TOS bags were thoroughly mixed during sample preparation, and likewise for the two BOS bags. The bulk sample was dried (for a minimum of 48 hours at 40°C) and sieved through a 3.35 mm mesh to remove any organic matter or large clasts. Clay clumps or soil aggregates were gently broken up, with care being taken not to crush rock fragments or hard nodules.

A split (~25%) of each sample was archived for future investigations. The bulk of the remaining sample was used for analytical chemistry. The bulk material was sieved through a 2 mm mesh, and subsequently split into two portions of approximately 20% and 80% splits. The <2 mm fraction represented the bulk sample (minus larger rock, flora and fauna fragments). Sub-samples from the 20% split (i.e. <2 mm) were used for:

- Platinum group element (PGEs) analysis
- Gold (Au) analysis after aqua regia (AR) leach and inductively coupled plasma-mass spectrometry (ICP-MS) analysis of multi-elements
- Mobile metal ion multi-element extraction (MMI ME) content analysis of 50 g of the <2 mm TOS sample.

The remaining material from the 20% split (after the above analyses) was milled to a fine powder, which was further split for:

- Fluoride (F) analysis
- Selenium (Se) analysis
- Lithium metaborate fluxing and 3 acid digest for ICP-MS analysis.

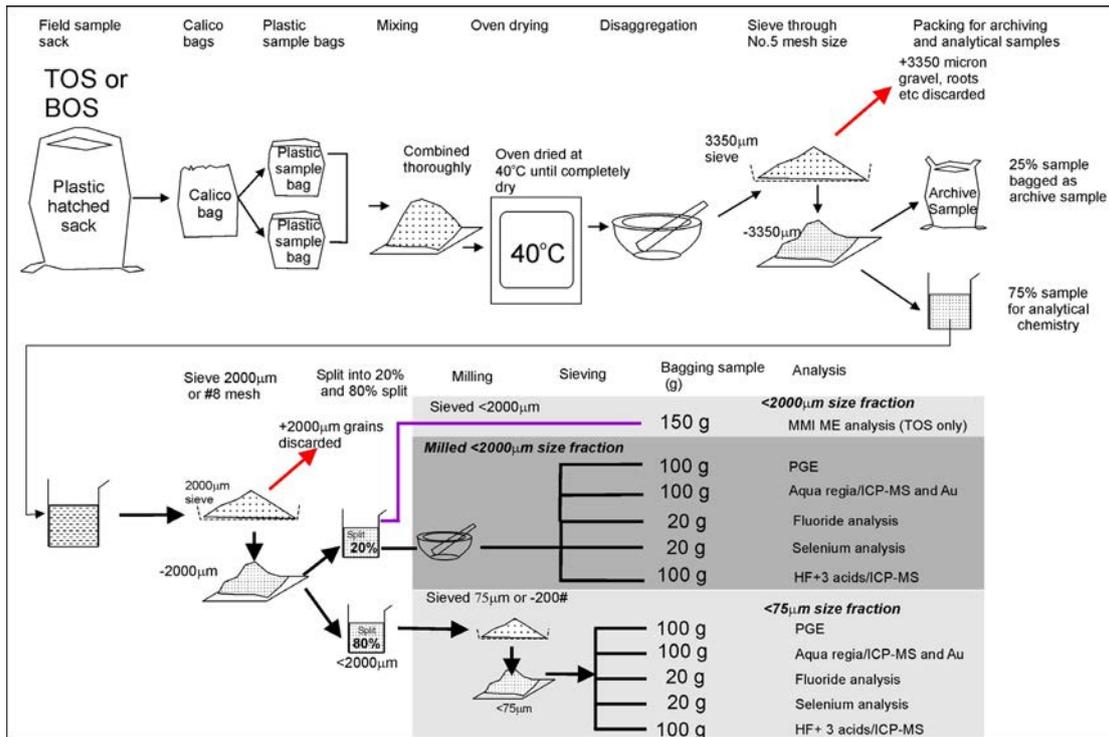


Figure 7: Summary of sample preparation for the Cape York samples undertaken by the Geological Survey of Queensland. The preparation method is identical for both TOS and BOS samples (with the exception that a sieved TOS sample is sampled for MMI ME analysis), hence, every target site will have four sets of geochemical subsamples that consist of <2 mm TOS, <75 micron TOS, <2 mm BOS and <75 micron BOS.

The 80% split of <2 mm sample was further sieved through a 75 micron mesh to obtain the ‘fine fraction’ stream sediments, or the <75 micron sample fraction. The <75 micron fraction was representative of the finer (mostly silt- and clay-sized) sediment and regolith particles and exhibited a stronger geochemical contrast compared to background (signal-to-noise ratio). This fraction required no further milling, and was split for:

- Lithium metaborate fluxing and 3-acid digest for ICP-MS analysis
- Au analysis after aqua regia (AR) leach and ICP-MS analysis of multi-elements
- F analysis
- Se analysis
- PGEs analysis.

### 3.2 Analytical methodology

The 189 sediments were analysed for 67 elements using six analytical techniques by five different laboratories. The Cape York samples were dispatched to the laboratories in three batches over a nine-month period, and results from the various laboratories were received over 18 months. Re-analysis of problem samples that failed the QA/QC standards caused further delays in the final geochemical results. Most elements were analysed by more than one methodology (Table 1). For every target site sample,

---

analysis was carried out on TOS and BOS sediments and on two grain-size fractions using identical digestion and analytical methods, and the four resultant subsamples were:

1. TOS <2 mm
2. TOS <75 micron
3. BOS <2 mm
4. BOS<75 micron.

Samples were analysed for:

- Total major and trace elements content by lithium metaborate fluxing, dissolution and inductively coupled plasma-mass spectrometry (ICP-MS). Fifty-seven elements were determined using the combination of multi-acid digestion by the University of Queensland (UQ).
  - Soluble multiple elements content including low-level gold (Au) by aqua regia (AR) digestion and analysed by ICP-MS. Sixty elements were determined by the AR ICP-MS method at Actlabs Pacific Pty Ltd in Perth and subsequently at Actlabs Pacific Pty Ltd in Ontario, Canada.
  - Ligand-based extractable content of 54 elements using Mobile Metal Ions™ technology and analysed by ICP-MS at SGS laboratory in Perth.
  - Soluble selenium (Se) content by AR digestion and analysed by ICP-MS. The analysis was undertaken by Genalysis Laboratory Services Pty Ltd in Perth.
  - Platinum group elements (PGEs, Pd and Pt) and gold (Au) analysis using fire assay and analysed by ICP-MS. The analysis was carried out at ALS Chemex of Brisbane.
  - Fluoride (F) content after alkaline fusion and analysed by ion specific electrode (ISE). The analysis was undertaken at Bureau Veritas Minerals of Western Australia (Perth).
-

**Table 1: Summary of the 67 elements analysed for the Cape York Project.**

Element	Major element analysis	HF-HNO <sub>3</sub> ICP-MS	AR ICP-MS	FA AR-PGEs	MMI ME	ISE-F	AR-Se
LAB	UQ	UQ	ACTLAB Perth/Ontario	ALS Chemex Brisbane	SGS Perth	Bureau Veritas Minerals	Intertek-Genalysis Perth
SiO <sub>2</sub>	X						
TiO <sub>2</sub>	X						
Al <sub>2</sub> O <sub>3</sub>	X						
Fe <sub>2</sub> O <sub>3</sub>	X						
MgO	X						
MnO	X						
CaO	X						
Na <sub>2</sub> O	X						
K <sub>2</sub> O	X						
P <sub>2</sub> O <sub>5</sub>	X						
LOI	X						
Ag		X	X		X		
Al			X		X		
As		X	X		X		
Au			X	X	X		
B			X				
Ba		X	X		X		
Be		X	X				
Bi		X	X		X		
Ca			X		X		
Cd		X	X		X		
Ce		X	X		X		
Co		X	X		X		
Cr		X	X		X		
Cs		X	X		X		
Cu		X	X		X		
Dy		X	X		X		
Er		X	X		X		
Eu		X	X		X		
F						X	
Fe			X		X		
Ga		X	X		X		
Gd		X	X		X		
Ge		X	X				
Hf		X	X				
Hg		X	X		X		
Ho		X	X				
In			X		X		
K			X		X		
La		X	X		X		
Li			X		X		
Lu		X	X				
Mg			X		X		
Mn			X		X		
Mo		X	X		X		
Na			X				
Nb		X	X		X		
Nd		X	X		X		
Ni		X	X		X		
P			X		X		

**Table 1 (continued)**

Element	Major element analysis	HF-HNO <sub>3</sub> ICP-MS	AR ICP-MS	FA AR-PGEs	MMI ME	ISE-F	AR-Se
<b>LAB</b>	UQ	UQ	ACTLAB Perth/Ontario	ALS Chemex Brisbane	SGS Perth	Bureau Veritas Minerals	Intertek-Genalysis Perth
Pb		X	X		X		
Pd				X	X		
Pr		X	X		X		
Pt				X	X		
Rb		X	X		X		
Re			X				
S			X		X		
Sb		X	X		X		
Sc		X	X		X		
Se		X	X		X		X
Sm		X	X		X		
Sn		X	X		X		
Sr		X	X		X		
Ta		X	X		X		
Tb		X	X		X		
Te			X		X		
Th		X	X		X		
Ti					X		
Tl		X	X		X		
Tm		X	X				
U		X	X		X		
V		X	X		X		
W		X	X		X		
Y		X	X		X		
Yb		X	X		X		
Zn		X	X		X		
Zr		X	X		X		
	11	47	62	3	56	1	1

### 3.2.1 Total element content

#### 3.2.1.1 Major element determination by lithium metaborate fusion and ICP-OES finish (University of Queensland)

Major element geochemistry is determined using lithium metaborate flux followed by digestion of the fused disc using 5% nitric acid (HNO<sub>3</sub>) and analysed using a Perkin Elmer Optima 8300 DV inductively-coupled plasma optical emission spectroscope (ICP-OES).

100 mg of the sample was weighed into a platinum crucible together with 400 mg of lithium metaborate flux and fused in a Katanax automatic fluxer. The crucibles were heated to a temperature of 920°C, kept there for three minutes and lightly agitated to ensure good mixing. Then the temperature was raised to 1000°C for two minutes to ensure total dissolution before cooling. The slightly cooled glass bead was decanted into a Teflon vessel containing 100 mL of 5% nitric acid and agitated by magnetic

stirrer until totally dissolved. The solution was then analysed by ICP-OES after the addition of Lu, Sc and Y for quality checking and drift correction.

The elements analysed included Al, Ca, Fe, K, Mg, Mn, Na, P, Si and Ti, and results were expressed as percentages of oxides with detection limits typically ranging from 0.001 to 0.003%. Oxides were calculated as a percentage of the total sample composition. The instrument was calibrated using USGS Certified Reference Materials (AGV-2, GSP-2), Japanese Certified Reference Materials and a wide range of standards (BCR-2, BHVO-2, HISS-1, JA-2, JA-3, JGb-1, JP-1, JR-2, JR-3 and OREAS 42P).

Water and volatile content was determined by loss on ignition. Approximately 2 g of sample material was placed in a porcelain crucible and accurately weighed. The crucibles were placed in an oven and heated to 105°C for two hours, cooled, and weighed to determine moisture content. The crucibles were then placed in a muffle furnace at 1000°C for two hours, cooled, and weighed again. The difference in weight was calculated as a percentage weight loss of volatiles. The percentage oxide values were added to the percentage weight loss of moisture and volatiles. A margin of 100% + 0.5% was deemed an acceptable result.

### *3.2.1.2 Trace elements determination by open beaker digestion using multiple acid digestions (HF, HCl, HNO<sub>3</sub>) and ICP-MS finish (University of Queensland)*

Multi-acid open beaker digestion uses a combination of HNO<sub>3</sub> (nitric acid), HF (hydrofluoric acid) and HCl (hydrochloric acid) to dissolve silicate minerals that produces a 'near-total digestion' of sample material.

100 mg of the samples was digested in closed Teflon beakers on a hot plate set at 140°C overnight to ensure total dissolution. The first step is total digestion by 2 mL of concentrated nitric acid (HNO<sub>3</sub>) at 140°C overnight. The digest is then dried. The next step is the addition of 3 mL of concentrated HF + 1 mL concentrated HNO<sub>3</sub>, heating overnight again, followed by drying down as previously. The dried samples are then treated with 2 mL of 6M HCl, heated and dried as previously. Chlorides are removed by another treatment with 1 mL of concentrated HNO<sub>3</sub>, and dried. The final step takes up the dry, digested sample in 2 mL of 6M HNO<sub>3</sub> and heated for 2 hours at 140°C. This solution is then transferred to an autosampler tube and made up to 10 mL with milli-Q water. This is the stock solution from which a further dilution is made for analysis by inductively-coupled plasma mass spectrometry (ICP-MS) after the addition of a range of internal standards covering all masses (<sup>6</sup>Li, <sup>61</sup>Ni, <sup>103</sup>Rh, <sup>115</sup>In, <sup>187</sup>Re and <sup>235</sup>U).

The combination of acids is effective for most multi-element dissolution at trace-level concentrations; however, in some cases, and depending on the original nature of the sample, some volatile elements (B, As, Pb, Ge and Sb) may be lost, and refractory minerals containing Zr, Hf, Sn, W, Nb and Ta may not be completely digested. This possibility was verified by cross-checking ICP-MS results for Zr and Nb with ICP-OES results (ICP-OES analyses were performed on fused, and therefore

---

totally dissolved, samples), and ICP-OES results were used where appropriate. This correction could not be applied to Sn, W, Ta and Hf because their concentrations were typically below the limit of detection of ICP-OES.

Some samples from Batch 3 were processed at the Queensland Health facility in Coopers Plains using microwave dissolution technique instead of the open beaker digestion technique. Replicate analysis on two samples from this batch, using the open beaker digestion technique, showed that the values obtained through microwave dissolution were generally lower than those obtained through open beaker dissolution, thus indicating that the microwave digestion technique used was less efficient than the open beaker technique. Selected samples from Batch 3 were redigested and reanalysed using open beaker digestion and the results were assigned as Batch 4 and Batch 5 (See Appendix 2).

A high-sensitivity Thermo Electron X-1 Series quadrupole inductively-coupled plasma mass spectrometer (ICP-MS) and an Agilent 7900 quadrupole ICP-MS were used to analyse trace concentrations. Forty-four trace elements (Ag, Ba, Be, Bi, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Ga, Gd, Ge, Hf, Ho, La, Lu, Mo, Nb, Nd, Ni, Pb, Pr, Rb, Sb, Sc, Sm, Sn, Sr, Ta, Tb, Th, Tl, Tm, U, V, W, Y, Yb, Zn and Zr) were analysed by this method. The instrument was calibrated using USGS Certified Reference Materials (AGV-2, GSP-2) and a range of internal standards (W2, JB-2, OREAS, JA-2, AGV-2, BCR-2, HISS-1, JGb-1, JR-3, JR-2, BHVO-2 and JP-1).

**Table 2: Typical detection limits achieved on the Thermo X-7 Series ICP-MS (adapted from University of Queensland geochemistry laboratory detection limits)**

Analyte	Isotope	Detection limit (3s) (ng l <sup>-1</sup> )
Li	7	20
Be	9	5
B	11	200
Mg	24	30
Al	27	40
Sc	45	3
V	51	5
Cr	53	20
Mn	55	2
Fe	57	300
Co	59	1
Ni	60	20
Cu	63	10
Zn	66	60
Ga	71	1
Ge	72	6
As	75	40
Se	82	150
Rb	85	1
Sr	86	15
Y	89	0.1
Zr	90	1
Nb	93	0.1
Mo	98	1
Ag	107	0.4

**Table 2 (continued)**

Analyte	Isotope	Detection limit (3s) (ng l <sup>-1</sup> )
Cd	111	2
Sn	120	30
Sb	121	1
Te	125	3
Cs	133	0.1
Ba	137	3
La	139	0.1
Ce	140	1
Pr	141	0.04
Nd	146	1
Sm	149	0.2
Eu	151	0.1
Gd	158	0.1
Tb	159	0.001
Dy	161	0.003
Ho	165	0.04
Er	167	0.1
TM	169	0.02
Yb	172	0.2
Lu	175	0.02
Hf	178	0.1
Ta	181	0.03
W	184	1
Pt	195	0.3
Au	197	0.1
TI	205	0.1
Pb	208	1
Bi	209	0.1
Th	232	0.02
U	238	0.03

### 3.2.2 Aqua regia soluble element content

#### 3.2.2.1 Gold analysis by ICP-MS (Actlabs Pacific Pty Ltd)

##### *Sample preparation*

The AR ICP-MS analysis for Au was carried out by Actlabs Pacific Pty Ltd. The first sample batch was analysed in Perth, Western Australia, and two subsequent batches were analysed in Ontario, Canada, when the Australian laboratory facility closed.

25.00 ± 1.00 g of sample was digested with an aqua regia solution (50 mL concentrated hydrochloric acid added first followed by 20 mL concentrated nitric acid) at 95 ± 3°C for 4 hours to leach the acid-soluble components (the leach only partially dissolves silicates and oxides). Once the sample had cooled to room temperature, 180 mL of diluent was added and the bottle was capped and shaken vigorously. The sample was then allowed to settle until a clear solution could be sampled. This aliquot was diluted a further 10 times with deionised water.

---

### *Sample analysis*

The aliquot from the AR digestion was aspirated and ionised within the ICP, and the ions were then transferred into the mass spectrometer. The ions were spatially separated according to their mass to charge ratio in a quadrupole mass spectrometer, and the intensities of each atomic mass were measured. The concentration of the trace elements in the samples was calculated using calibration standards and blanks. Au was analysed within the range 0.1–5000 ppb using the AR ICP-MS method.

#### *3.2.2.2 Multi-element analysis by ICP-MS*

### *Sample preparation*

The AR ICP-MS multi-element analysis was carried out by Actlabs Pacific Pty Ltd in Perth, Western Australia, and two subsequent batches were analysed in Ontario, Canada.  $0.50 \pm 0.02$  g of sample was digested with an aqua regia solution (1.8 mL concentrated hydrochloric acid added first followed by 0.6 mL concentrated nitric acid) at  $90 \pm 3^\circ\text{C}$  for two hours to leach the acid-soluble components. Once the sample had cooled to room temperature, 17.5 mL of diluent was added and the bottle was capped and inverted ten times to homogenise the content. The sample was then allowed to settle over a six hour period or longer, and in a dark space to prevent reduction of silver. The sample was diluted a further 50 times with deionised water.

### *Sample analysis*

Sixty elements (Ag, Al, As, Au, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Ge, Hf, Hg, Ho, In, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, Pb, Pr, Rb, Re, Sb, Sc, Se, Sm, Sn, Sr, Ta, Tb, Te, Th, Tl, Tm, U, V, W, Y, Yb, Zn, Zr), including Au as discussed in Section 3.2.2.1, were determined by the AR ICP-MS method.

#### *3.2.2.3 Selenium analysis by ICP-MS (Intertek Genalysis Laboratory Services Pty Ltd)*

The AR soluble selenium (Se) content was analysed by Intertek Genalysis Laboratory Services Pty Ltd in Perth, Western Australia. The oxidised  $\text{Se}^{6+}$  was reduced to  $\text{Se}^{4+}$  and finally to Se metal with citric and ascorbic acids in the presence of  $\text{Cu}^{2+}$  (provided all  $\text{Fe}^{3+}$  has been reduced to  $\text{Fe}^{2+}$ ).

### *Sample preparation*

5.00 g of pulverised sample was digested in nitric and hydrochloric acids in a 250 mL beaker, heated to  $160^\circ\text{C}$  in a fume hood. A viscous texture resulted, and the sample was leached with hydrochloric acid and then filtered. The selenium was precipitated with ascorbic acid and chilled, before being filtered under vacuum using  $0.45 \mu\text{m}$  cellulose nitrate membrane filters to collect the precipitate. The filtrate was washed

---

thoroughly with doubly deionised water, then digested in aqua regia and the volume adjusted to 10 mL.

#### *Sample analysis*

The samples in a pre-concentrated form contained an aqua regia matrix, which was diluted 10 times. The sample was analysed by ICP-MS using matrix-matched calibration standards (Standard 1 = 0.5 ppm Se, Standard 2 = 2 ppm Se, and Standard 3 = 5 ppm Se in 2% hydrochloric acid and 3% nitric acid). The solutions were presented to a PerkinElmer Elan 9000 quadrupole ICP-MS fitted with a 40 MHz RF generator used for sample excitation.

Se results were reported from mass 82. With the aqua regia digestion, many of the interferences (krypton, zinc-oxygen, calcium-calcium and copper-oxygen) on selenium are insignificant due to the pre-concentration step that was used in the sample preparation.

#### **3.2.3 Platinum Group Elements (PGE) and gold analysis by fire assay and ICP-MS (ALS Chemex Australia Pty Ltd)**

PGE (Pd and Pt) and gold (Au) were analysed by Australia Laboratory Services (ALS) Chemex Pty Ltd in Brisbane, Queensland, using ALS analytical code PGM-MS23. 30 g to 50 g of sample was thoroughly mixed and fused with 170–200 g of flux, which was a mixture of lead oxide, sodium carbonate, borax and silica, inquarted with gold-free silver. This fire assay procedure comprised a reducing fusion at 1025–1100°C for approximately one hour in which two phases, a complex liquid borosilicate slag and a liquid lead phase, were formed. The lead phase collected the precious metals, and the gangue elements were separated into the slag. The density contrast between the lead and slag phases allowed easy separation after solidification.

The second stage involved cupellation (oxidising fusion at 920–1000°C for approximately 45 minutes) with silver acting as a collector for the gold and platinum group metals. In this process the lead button was oxidised to lead oxide and absorbed into the cupel, leaving a bead of silver plus any gold, platinum and palladium present in the sample. This silver bead (prill) was dissolved with 1 mL of 50% nitric acid in a test tube heated on a hot plate set at 120°C until the evolution of brown fumes ceased. The test tube was removed from the hot plate and checked to ensure parting was complete, and then allowed to cool for five minutes. 2 mL of hydrochloric acid was added to the test tube, which was shaken vigorously before being returned to the hotplate for a further ten minutes. The tube was checked for complete dissolution of gold and then cooled and bulked with deionised water to a final volume of 10 mL.

#### *Sample analysis*

The solution was analysed by ICP-MS for gold, platinum and palladium. In each fire, one blank, two standards and three duplicate samples were run. The standards

---

---

most commonly run for this method were ST-321 and ST-381. Performance of each analysis was closely monitored via control charts.

#### **3.2.4 Fluoride analysis by ion specific electrode (Bureau Veritas Minerals Pty Ltd)**

Fluoride (F) content was analysed by Bureau Veritas Minerals Pty Ltd in Perth, Western Australia, using the analytical code SIE3S. A 0.4 g sample was fused at 650°C with sodium peroxide, followed by a 5:1 ratio water extraction, and the solution was left to stand overnight. A subsample of this liquor was removed and buffered.

The solution was presented to a fluoride ion selective electrode (ISE) for F determination and the result was back calculated based on sample weights/volumes to an accuracy of 0.002 ppm.

#### **3.2.5 Mobile Metal Ions™ — multi-element extraction**

The determination of Mobile Metal Ions™ by the MMI-ME method relies on a weak, partial, ligand-based extraction followed by analysis of 54 elements by ICP-MS. This analysis was performed by SGS (Perth) using the SGS commercial package MMI-ME.

50 g of sample were weighed directly from the original bag/container as received. Mobile metal ions present in the sample were partially extracted using a concentrated MMI™ solution. The extracted sample solution was aspirated into a Dynamic Reaction Cell (DRC) ICP-MS where the ion concentrations were measured and quantified according to their unique mass. The DRC-ICPMS was calibrated with each work order. An instrument blank and calibration check was analysed with each run. One preparation blank and reference material was analysed every 46 samples, one duplicate every 12 samples. All quality control samples were verified using the Laboratory Information Management System (LIMS), with acceptance criteria controlled statistically and control charts used to monitor accuracy and precision. Samples that fell outside the control limits, if any, were investigated and repeated as necessary. The results were exported to the LIMS via a secure audit trail.

Fifty four elements were determined by the MMI-ME ICP-MS method for the Cape York Project: Ag, Al, As, Au, Ba, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Hg, K, La, Li, Mg, Mn, Mo, Nb, Nd, Ni, P, Pb, Pd, Pr, Pt, Rb, Sb, Sc, Se, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, U, V, W, Y, Yb, Zn, and Zr.

---

## 4. DATA PROCESSING

### 4.1 Data computation for the combined catchment geochemistry

Each catchment has multiple geochemical datasets/results ranging from five datasets for PGE-MMI analyses, nine datasets for samples analysed by ICP, AR and MMI, to thirteen datasets for samples analysed using additional specialised methods such as SIE. The various datasets represent the variety of geochemistry for the different analytical methodologies, depth profiles and size fractions. Individual datasets are unique entities because they represent different aspects of the analytical sensitivity of the respective methods to different depths, size fractions and analytical processes. Each sample type and analytical methodology forms an important component to the character of the catchment, and such information has to be preserved throughout the data handling.

The Cape York data are treated as one population and this combined geochemical result is ranked statistically and spatially according to catchment distribution. The data processing philosophy adopted for this geochemical combination gives equal emphasis to all sample results, and the various results for an element are coalesced into one grand representative elemental result for a catchment. All results are weighted using a multiplier factor to give respective geochemistry equal emphasis. The weighting factor is benchmarked using the mean concentration of an element for all analytical results as summarised in Table 3. This average is attained by averaging all results for a particular element, taking into account the various analysis types, depths and size fractions within a catchment. Averaging the results takes into account the common range of concentration for that particular element. The weighting factor is calculated using the ratio of the geochemical dataset average to the overall benchmarking mean, and this multiplier factor is used to recalculate individual results. Applying the multiplier elevates all data to an equal status, and all sample types contribute equally to the statistical character of a particular element for a catchment. The summation of weighted results of various chemistries for an element represents the geochemistry of the catchment. This calculated concentration for the catchment is used for statistical ranking of the element. By applying this methodology, recalculated catchment chemistry is modelled around the mean concentration, and statistical ranking expresses the statistical spread of data around this value. It is a useful methodology to express the statistical character of a complex database and to highlight the highs and lows of the dataset.

#### *4.1.1 Silver results from Geoscience Australia (GA) and the University of Queensland (UQ)*

Silver is analysed using aqua regia-ICPMS at ALS and 3-acid-ICPMS methods from GA and UQ. The GA analyses of Ag from the NGS program are significantly different from the results of UQ, with detection limits of 0.03 ppm and 0.0001 ppb respectively. Most of the GA results are below detection limits and have to be recalculated using half-detection limits for statistical processing. The recalculated

---

**Table 3: Example of data processing grid to statistically rank geochemical anomalies in the Cape York dataset.**

Element	Te	Te	Te	Te	Te	Benchmark factor	Overall rank
<b>Analytical method</b>	Aqua Regia ICPMS	Aqua Regia ICPMS	Aqua Regia ICPMS	Aqua Regia ICPMS	MMI	Average Te concentration for all samples and methods	Sum of product between Te assay and weighting factor
<b>Sample type</b>	BOS <2 mm	TOS <2 mm	BOS <75 micron	TOS <75 micron	TOS <2 mm		
TS0863_01	0.010	0.010	0.030	0.010	0.005		0.08
TS0863_04	0.040	0.050	0.040	0.010	0.005		0.15
TS0863_05	0.010	0.010	0.010	0.030	0.005		0.08
TS0863_06	0.060	0.050	0.060	0.050	0.005		0.22
TS0868_05	0.050	0.030	0.010	0.010	0.005		0.11
<b>Average result of all samples</b>	0.034	0.025	0.026	0.027	0.005	0.024	
<b>Weighting factor</b>	0.71 <i>(ratio of benchmark factor to the average aqua regia BOS &lt;2 mm result)</i>	0.98	0.93	0.90	4.80		

*Overall rank is the sum of the product between Te assay and the weighting factor for all samples in the catchment.*

GA data are still considered anomalous and are inappropriate to include in statistical computations of regional data. Therefore, Ag results from UQ and GA are not used in the regional statistical data assessment, and only the aqua regia data from ALS are used.

## 4.2 Reassaying, data levelling and recalculation

Cape York samples were analysed in 3 batches over an 18 month period. The data were quality assessed to ensure that results of internal standards and duplicate samples from respective batches meet the permissible 15% variation from the mean values. From the quality assurance (QA) process, most data conform to the data quality except for some TOS samples from Batch 3.

### 4.2.1 Microwave bomb digested samples at the Queensland Health facility in Coopers Plains

Two digestion methods were used to expedite the analytical process and the microwave bomb methodology was used for 28 TOS samples (<2 mm and selected <75 micron size fractions, Appendix 2). Quality assurance procedures ascertained that the rare earth element (REE) concentrations of TOS samples digested using the microwave bomb methodology are typically 60–90% of its corresponding <75 micron size fraction analysed using the normal 3-acid open beaker digestion method. For refractory elements such as Sn, W and Ta, the microwave digested results are 16%, 37% and 33% of the corresponding BOS samples. The Sn results using the 3-acid

**Table 4: Data recalculation for microwave bomb digested samples from the University of Queensland.**

FIELD_ID	Be	Be		Normalisation factor	Be Recalculated
NOTE	Microwave bomb digestion	Open beaker digestion	Ratio of *OB/MW digestion	Average *OB/MW ratio	*MW data x Normalising factor
TS0873_02	0.52, 0.6	0.71	1.37, 1.18		
TS0899_07	1.13	3.36	2.97	<b>2.03</b>	
TS0899_11	1.36	2.19	1.61		
TS0901_03	2.44	3.97	1.63		
TS0908_08	0.73	1.95	2.67		
TS0925_04	0.79	2.19	2.77		
TS0868_01	0.50	-			1.02
TS0868_02	1.55	-			3.15
TS0868_03	0.40	-			0.81
TS0868_04	1.34	-			2.72
TS0871_01	0.50	-			1.02
TS0872_01	0.18	-			0.37
TS0872_02	0.31	-			0.63
TS0872_03	0.77	-			1.56
TS0886_02	0.12	-			0.24
TS0925_06	0.87	-			1.77
TS0930_10	0.63	-			1.28
TS0934_07	0.89	-			1.81

\*OB = Open beaker; MW = Microwave bomb digestion.

microwave bomb digestion were typically 30–90% of the partial digestion by aqua regia. The lower analytical results from the microwave bomb digestion clearly indicated incomplete digestion of samples.

Six selected samples from the microwave digestion were reassayed as Batch 4 using the 3-acids open beaker hotplate digestion method and the results from such confirmatory tests were used to level the 28 TOS results. The mean ratio of the open beaker digestion to the microwave bomb digestion is used to recalculate the original microwave bomb digested chemistry. Table 4 demonstrates an example of the recalculation of Be data using a normalising factor derived from the reassayed results. The recalculated results are used in the statistical appraisal of geochemical data to establish the statistical breaks.

#### 4.2.2 Re-assaying of Sn data (Batch 5)

Sn results from the six reassayed samples (section 5.2.1) have significantly higher Sn than corresponding <2 mm BOS and <75 micron TOS samples (5 and 2 times) compared to a variance of + 2.1 and + 0.4 respectively for Cape York data. The 6 samples were reassayed by 3-acids open beaker digestion and results are tabulated in Table 5 (Batch 5 in Appendix 2). Batch 5 results are 1 to 30 times the result of corresponding BOS or TOS samples, which are inconsistent with the regional geochemistry. Therefore Sn results from Batch 5 were not considered in the statistical appraisal.

**Table 5: Multiple batches of Sn assay results from the University of Queensland.**

	Sn (ppm) TOS <2 mm sample	Sn (ppm) TOS <2 mm sample	Sn (ppm) TOS <2 mm sample	Sn (ppm) in corresponding BOS <2 mm sample	Sn (ppm) in corresponding TOS <75 micron sample
<b>Digestion method</b>	Microwave bomb	3-acids open beaker	3-acids open beaker	3-acids open beaker	3-acids open beaker
Batch	3	4	5	3	3
TS0899_07	0.45	13.28	35.97	3.85	6.21
TS0899_11	0.5	14.21	35.82	3.59	7.87
TS0901_03	1.56	74.2	86.08	20.77	65.69
TS0908_08	0.4	11.19	37.32	2.92	6.22
TS0925_04	0.3	12.23	76.74	2.48	2.6
TS0873_02	1.13	9.51	33.27	1.12	0.34

### 4.3 Grouping data into geochemical provinces

The Cape York geochemical study covers over 300,000 km<sup>2</sup>. Outlet sediment geochemistry represents the combination of background geology, alteration overprint, erosion and sedimentation influences, and modifications either from mineralisation or anthropological contributions.

The Cape York data are spatially grouped into ten geochemical provinces or spatial domains based largely on the tectonic framework of the region (Figure 8). Geochemical provinces differentiate litho-geochemical backgrounds of Cape York and are defined by subcatchment cells that best match the tectonic terranes. Outcropping geochemical provinces such as the Iron Range Province, Savannah Province, Etheridge Province, the Palmer–Barron–Chillagoe Province (Hodgkinson Province), Greenvale – Camel Creek Province and the Charters Towers Province have direct links between geology and geochemistry of sediments. The Palmer–Barron–Chillagoe Province is used in preference to the Hodgkinson Province to highlight the heterogeneity of terrane framework within this geochemical domain. Geochemical provinces defined by sedimentary basins i.e. the Carpentaria and Laura Basins are an accumulation of geochemical contributions from all surrounding provinces. The chemistry of sedimentary provinces is strongly dictated by the relative proportion of sedimentary input from the various source regions. Along the coastlines, geochemistry is influenced by maritime sedimentation from either aeolian, wave or tidal processes.

The Etheridge Province is subdivided into the Etheridge North and Etheridge South (Georgetown area) Provinces to reflect the spatial separation by the Carpentaria Basin. The Etheridge North Province includes the Pama Province whereas the Etheridge South Province includes the Croydon Province. The Carpentaria Basin is divided into Carpentaria Basin North and Carpentaria Basin South by the Mitchell River. This separation is an arbitrary division to differentiate the influence of the Savannah and Iron Range Provinces and lateritic development in the north from the Greenvale–Camel Creek and Charters Towers provinces in the south.

Geochemical provinces will be used in localised geochemical discussion to demonstrate regional mineralising potential based on dominant elemental association, but not in regional data ranking in the Geochemical Atlas.

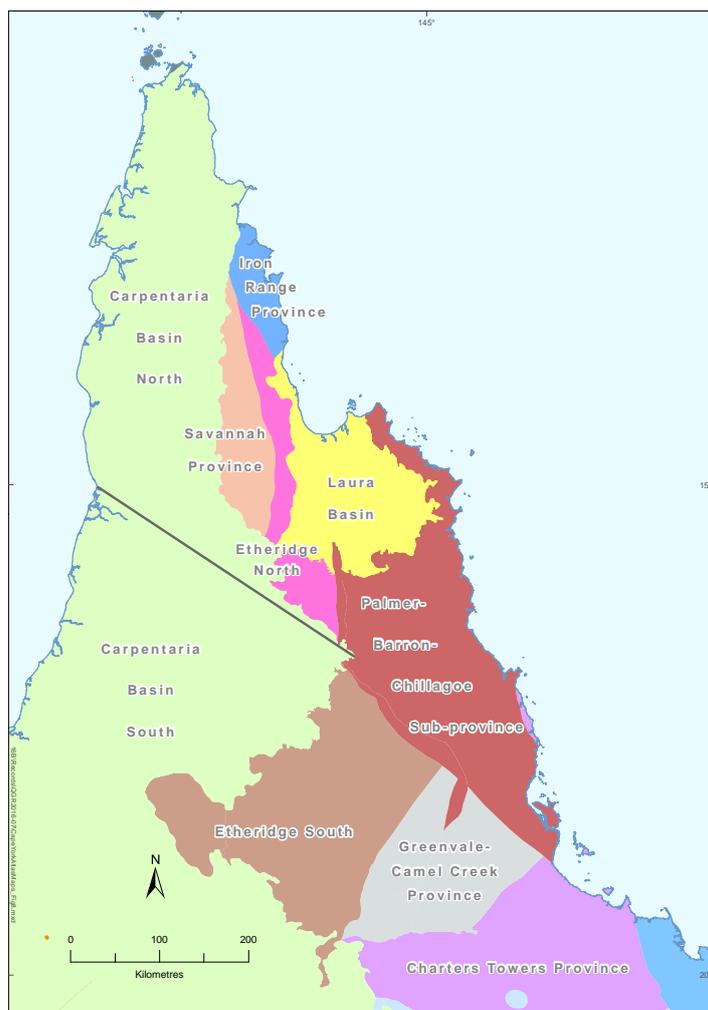


Figure 8: Geochemical provinces of Cape York based on the regional tectonic structure.

#### 4.4 Selection of samples for REE and spidergram geochemical plots

At every sample target site, four assays were generated from the <2 mm BOS, <75 micron BOS, <2 mm TOS and <75 micron TOS subsamples. Data for the various subsamples were processed to determine the most representative sample for the catchment. Two target-site samples from each geochemical province were picked to compare the geochemical variations between size fraction and depth profiles. The subsamples were assigned different symbols and the two target sites were differentiated by solid and open symbols (Figure 9). REE have very similar physical and chemical properties, and are extremely useful to establish petrological and geochemical processes in igneous, sedimentary and metamorphic rocks (Rollinson, 1993; Wilson, 1993; Best 1982). Similarity of REE patterns and concentration indicates similar petrogenetic and chemical history of the subsamples.

All the Cape York geochemical provinces show very similar crustal signatures that slope from light rare earth elements (LREE) to heavy rare earth elements (HREE) and have a prominent Eu trough. The LREE group includes lanthanum, cerium,

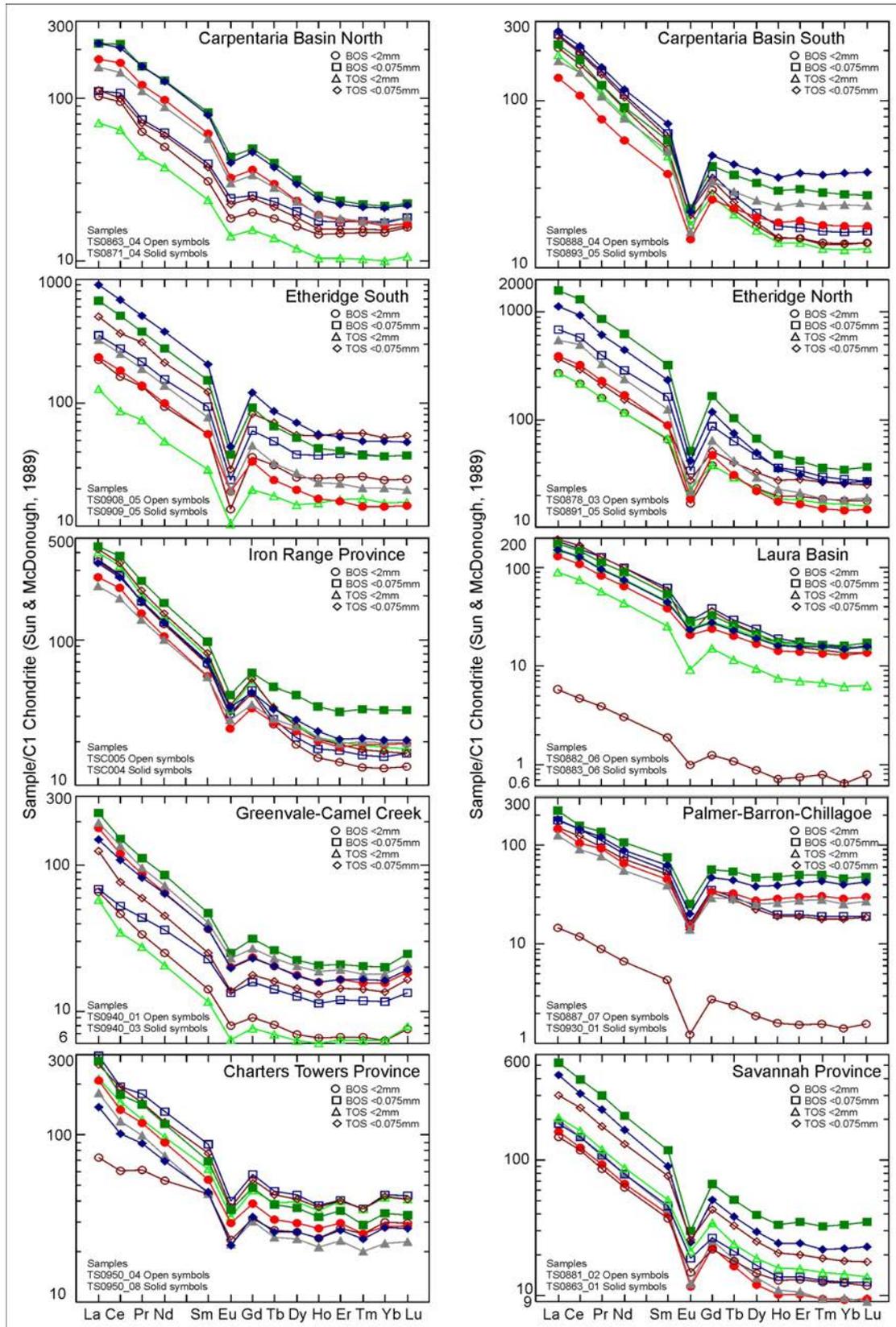


Figure 9: Geochemistry from different geochemical provinces based on sample size fraction and depth profiles.

praseodymium, neodymium, samarium, europium and gadolinium and the HREE include terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutetium. Yttrium has geochemical affinity with the LREE and is often included into the REE or lanthanides group and abbreviated as REEY. The <75 micron fraction has higher REE concentration in all the geochemical provinces. The finer size fraction from both TOS and BOS has a similar pattern and concentration, with the exception of <75 micron BOS from the Iron Range Province that is HREE enriched. Most geochemical provinces showed a similar variation pattern for the <2 mm size fraction but can differ significantly in the REE concentrations between the BOS and TOS subsamples.

The Cape York geochemical characteristic is consistent with earlier findings by Tang & Brown (2011), who concluded the <75 micron alluvium fraction is more sensitive to both major and trace element variations, whereas the <2 mm fraction has greater variability due to the effects of lithoclasts. The <75 micron BOS sample best represents the homogenised catchment chemistry whereas the <75 micron TOS represents the current geochemical state. Therefore, the <75 micron sample is the most appropriate data for REE, spidergrams and other geochemical plots to represent the overall geochemistry of a catchment.

#### **4.5 Validating NGSAs results for suitability to merge into the Cape York Project**

The Cape York Project adopts the NGSAs sampling and analytical methodologies. Eight NGSAs sites were resampled and reanalysed, and results from both programs were compared for suitability of including NGSAs data into the Cape York Project. The duplicate samples are TS0887\_06, TS0899\_01, TS0901\_06, TS0908\_01, TS0909\_01, TS0910\_01, TS0913\_04 and TS1167\_01, which match the NGSAs TS0887, TS0899, TS0901, TS0908, TS0909, TS0910, TS0913 and TS1167 catchments respectively.

Major and REE chemistries of BOS and TOS samples from the Cape York Project were normalised to the corresponding NGSAs data. The NGSAs samples were analysed using lithium metaborate fluxing and HF digestion at Geoscience Australia (Canberra), whereas the Cape York Project samples were analysed using lithium metaborate fluxing and 3-acids digestion at UQ, and analysed by ICP-MS. Both methods will produce near-complete digestion with the possibility of slight variations in results from different completeness of dissolution.

The major element chemistry has similar concentrations of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and K<sub>2</sub>O, and more pronounced differences in TiO<sub>2</sub>, MgO, MnO, Na<sub>2</sub>O and P<sub>2</sub>O<sub>5</sub> (Figure 10). The <2 mm fraction in TOS and BOS exhibits greater differences in the overall geochemistry, whereas the <75 micron fraction is consistent in most major elements, with the exception of MgO, Na<sub>2</sub>O and P<sub>2</sub>O<sub>5</sub> in some samples. The spikes in TiO<sub>2</sub>, MgO, MnO and Na<sub>2</sub>O in some of the samples are interpreted as sample inhomogeneity, whereas the greater P<sub>2</sub>O<sub>5</sub> difference could result from different analytical precision.

REE patterns show geochemical similarities between the NGSAs and Cape York results, except for Sample TS0901\_06 (Figure 10), which is due to sample differences.

---

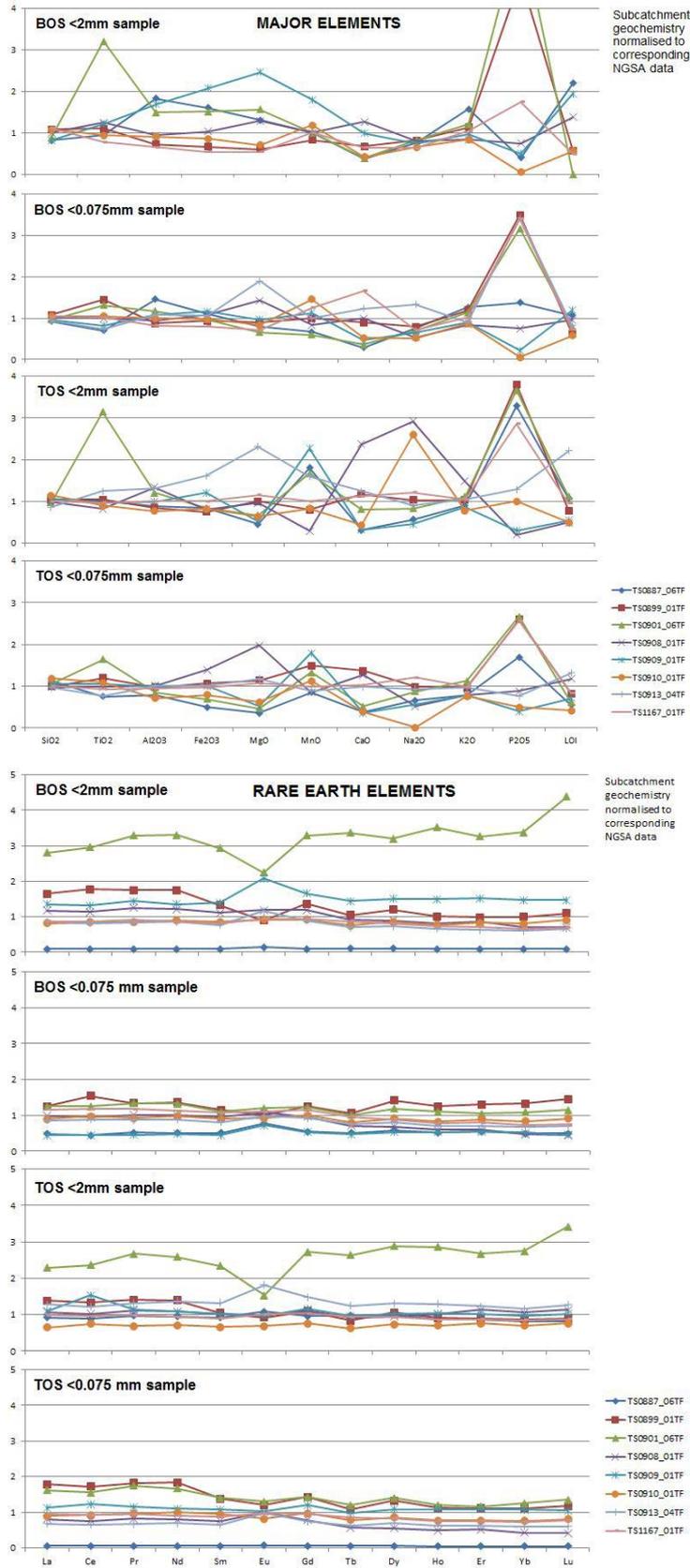


Figure 10: Geochemical comparison of same catchments sampled during the NGS and Cape York Project. The Cape York Project results were normalised to the corresponding NGS results, and unity means a 100 per cent fit of the two datasets.

Most samples showed variance within 40% of the NGSAs results and the <2 mm samples tend to show greater variance. The trace element results are generally similar to the REE with the exception of Ag, Sn, Ta and W, which are lower in the Cape York Project results; Cd, Ge and Pb, which are higher in the Cape York results; and Mo, Nb and Sb, which show great variation in concentrations in their ratios. Differences in the refractory elements such as Sn, Ta and W were the result of dissolution, whereas the differences in other elements could be due to analytical precision.

Based on the validation process, the results of the NGSAs and the Cape York Project are similar, and 58 NGSAs results were reprocessed and incorporated into the Cape York Project. All discussions of results and statistical ranking of elements in this report include the NGSAs data.

## **5. RESULT APPRAISAL**

### **5.1 Field data**

Field information recorded at every target site provides the basic geospatial information and field observations. The data recorded included sample date, location grids, site descriptions, lithologic observations, field pH and Munsell® soil colours (Appendix 1). Other information included hole type, property name, watercourse, geomorphological features, sample landform, land use and potential sources of contamination.

The sample location was recorded by a hand-held Garmin global positioning system (GPS) instrument in Universal Transverse Mercator (UTM) grids using the World Geodetic System 1984 (WGS84) standard.

### **5.2 Geochemical results**

The Cape York Project sampled 189 new catchments and incorporated 58 NGSAs results to generate comprehensive data coverage of the region. Every sample site generated 4 subsamples representing different depth profiles and grain size fractions; each subsample was analysed for 67 major and trace element geochemistry.

The number of analyses for a catchment totals 541 element-assays. The original geochemical data are tabulated in Appendix 2, which lists geochemical details of the various subsamples and analytical methodologies. The multiplicity of results is important for low density and remote samples, where corresponding results are used as cross-validation without needing confirmation from follow-up sampling or reassaying.

#### ***5.2.1 Original versus weighted average results***

The original dataset contains crucial elements for interpreting sediment source regions, lithochemical components, alteration overprint, contamination and potential

---

mineralisation. The <2 mm size fraction is regarded as the bulk sample minus the large lithoclast and organic components, and is therefore a reasonable approximation of the bulk chemistry of a catchment. This coarser sample is highly prone to dilution by resistive lithics and minerals such as quartz, feldspars, chert, zircon and corundum, which results in greater chemical variability. The finer <75 micron sample is more sensitive to all elements and has higher background concentrations (Tang & Brown, 2011). It provides a good geochemical characterisation of a catchment, and magnifies contrasts between catchments. The geochemistry of the <75 micron samples is generally consistent between the TOS and BOS samples, which is interpreted as well homogenisation of the fine sediments within the catchment. TOS represents the present geochemical state of the catchment and the BOS represents the background geochemistry of the catchment. Chemical differences between the size fractions and TOS and BOS provide important clues to changing catchment geochemistry. The multi-faceted geochemistry of the original data is difficult to process because comparison of the data has to be limited to the same sample parameters. The original data is used in spidergram and REE variation plots to show contrasts between catchments.

The weighted average result (Section 4.1) for a catchment provides a convenient way of comparing overall geochemistry between catchments. This mathematical methodology recombines heterogeneous geochemical data into a single average composition centred on the mean value and highlights the geochemical variations from the mean (Appendix 3). The weighted result is statistically ranked into 8 numerical breaks and is used as per the Cape York Geochemical Atlas. The weighted data is also used on Harker variation diagrams to demonstrate variation trends between catchments.

### **5.2.2 Harker major element variation diagrams**

A strong inverse relationship between  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{MnO}$  and  $\text{MgO}$  highlights a general decrease in elemental concentrations with a general increase in  $\text{SiO}_2$  (Figure 11). Such relationship between compatible elements and  $\text{SiO}_2$  is commonly attributed to lithologic control because these elements constitute common rock-forming minerals. Variation trends could be related to fractionation, alteration, weathering and deposition processes (McBirney, 2006; Rollinson, 1993; Wilson, 1989). The Cape York data show a weak inverse relationship between  $\text{SiO}_2$  and  $\text{K}_2\text{O}$ - $\text{Na}_2\text{O}$ , which is inconsistent with the magmatic fractionation trend (McBirney, 2006) or hydrothermal influences (Freij-Ayoub *et al.*, 2000). Incompatible elements are generally sympathetic with  $\text{SiO}_2$  during magmatic differentiation process, since  $\text{K}_2\text{O}$ ,  $\text{Na}_2\text{O}$  and  $\text{SiO}_2$  are concentrated into late minerals, such as feldspars and quartz, or into remaining magmatic fluids (Wilson, 1989,1993).

Samples in the Carpentaria Basin North and the Greenvale – Camel Creek Province are generally high in  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$  and  $\text{MnO}$ , which have an inverse relationship to  $\text{SiO}_2$ . These provinces have consistently very low  $\text{K}_2\text{O}$ ,  $\text{Na}_2\text{O}$ ,  $\text{CaO}$  and  $\text{MgO}$  contents that do not show much variation with  $\text{SiO}_2$  contents. The low mobile element contents imply strongly leached regions where these elements are removed, and refractory  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$  and  $\text{MnO}$  are concentrated in the leached duricrust.

Geochemistry of the Etheridge South and Charters Towers Provinces shows a complementary trend between incompatible elements and SiO<sub>2</sub>, and an inverse relationship with compatible elements, which is characteristic of magmatic fractionation or a hydrothermal system related to magmatism. The increase in incompatible elements with SiO<sub>2</sub> implies that these elements are concentrated into late phases such as feldspars, clays, zeolites and quartz, which are associated with lower temperatures. The Harker variation diagrams suggest the possibility of igneous related fractionation trends which could contribute towards the geochemistry.

The Savannah and the Etheridge North Provinces are low in Fe<sub>2</sub>O<sub>3</sub>, MnO and MgO, which implies low mafic mineralogy content. The K<sub>2</sub>O content increases with increasing SiO<sub>2</sub>, but the Na<sub>2</sub>O and TiO<sub>2</sub> remain relatively constant. The geochemistry is interpreted as a sedimentary rich source region with variation due to dilution from clay and quartz components.

The Charters Towers and Georgetown provinces are enriched in CaO, MgO and Na<sub>2</sub>O. Enrichment of Ca, Mg and Na could be related to marine calcareous or dolomitic provenance. The Palmer, Chillagoe and Barron subprovinces are high in P<sub>2</sub>O<sub>5</sub>. The erratic high P<sub>2</sub>O<sub>5</sub> could result from either sedimentary phosphate or from apatite-rich vein systems in the region. Apatite-rich fluids are good vectors for mineral transports, and these catchments are potential target sites for exploration.

### ***5.2.3 Harker minor element variation diagrams***

The Harker variation diagrams for minor elements do not show strong relationships with SiO<sub>2</sub> (Figure 12), except for F, Be and Zn, which showed a weak inverse relationship. Most elements have scattering of data distributions that imply a weak variation trend within a geochemical province.

The Palmer River, Barron and Chillagoe subprovinces of the Hodgkinson Province are consistently high in F, Rb, As, Bi, Cu, Sn, Zn and W. The elemental association includes lithophiles, base metals and oxyphilic metals. Based on the elemental association, the Hodgkinson area is highly conducive for vein or sheeted vein-type mineralisation associated with P, F, As, Bi, Sn and W mineralisation, which is typical of greisen style deposits or with low temperature intrusive-related mineralisation. Elevated Au, Pb, Be, Mo and U contents in some tributaries implies possible polymetallic mineralisation within the geochemical province.

The Etheridge South Province of the Georgetown region is enriched in F and Sr, commonly associated with granitic intrusions and/or with calcareous rocks. The Georgetown region has scattered enrichments of Au, Cu, Be, Sm, U and Th within its tributaries. The presence of F with the other elements suggests the probability of a fluorite-rich oxidised vein system associated with reduced granites.

The Savannah Province has catchments that are high in U, Th and Sm. Major-element Harker diagrams suggest a predominantly sedimentary rich provenance, and the U, Th and Sm could be associated with detritus derived from the sediments.

---

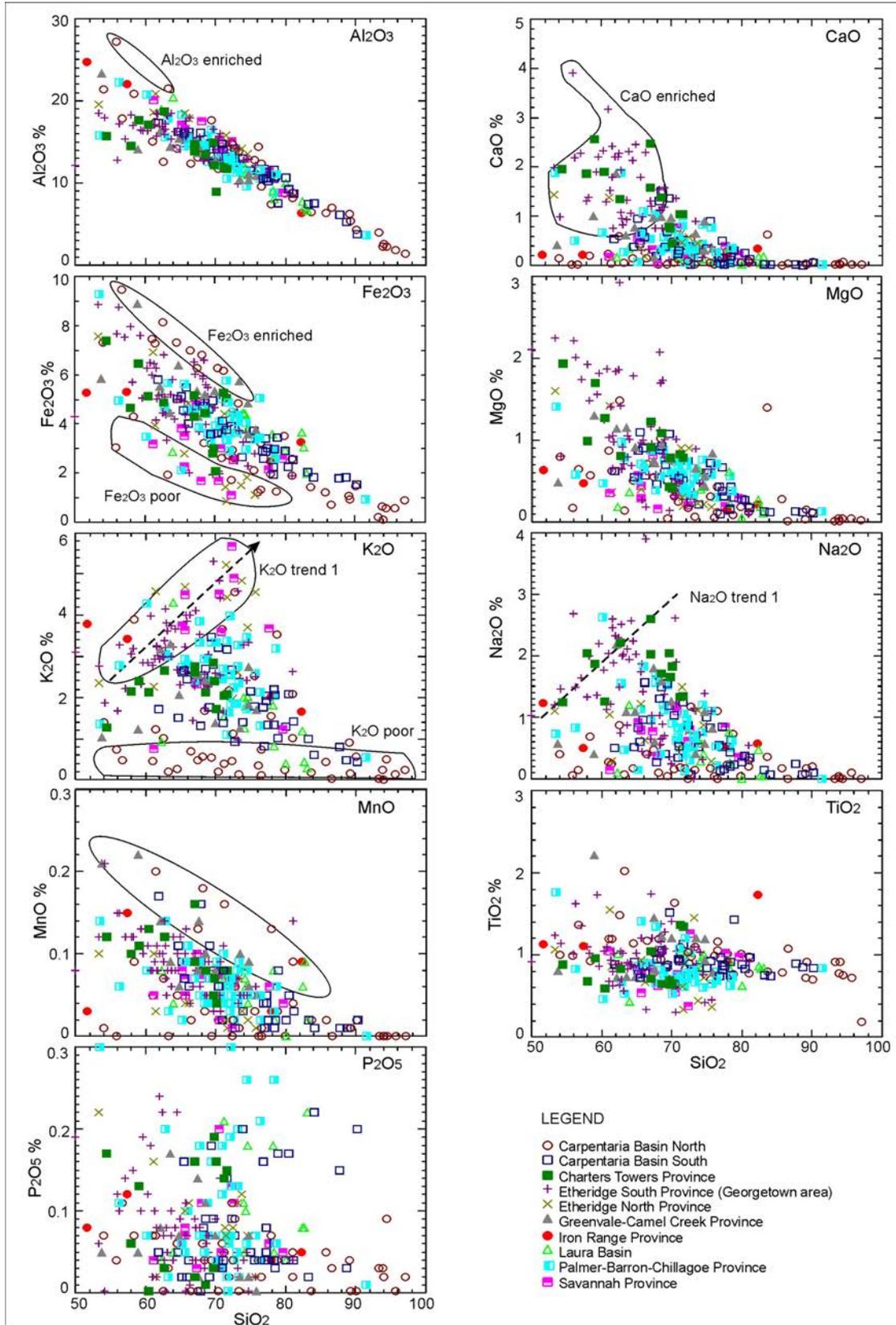


Figure 11: Harker variation diagram of major elements in Cape York.

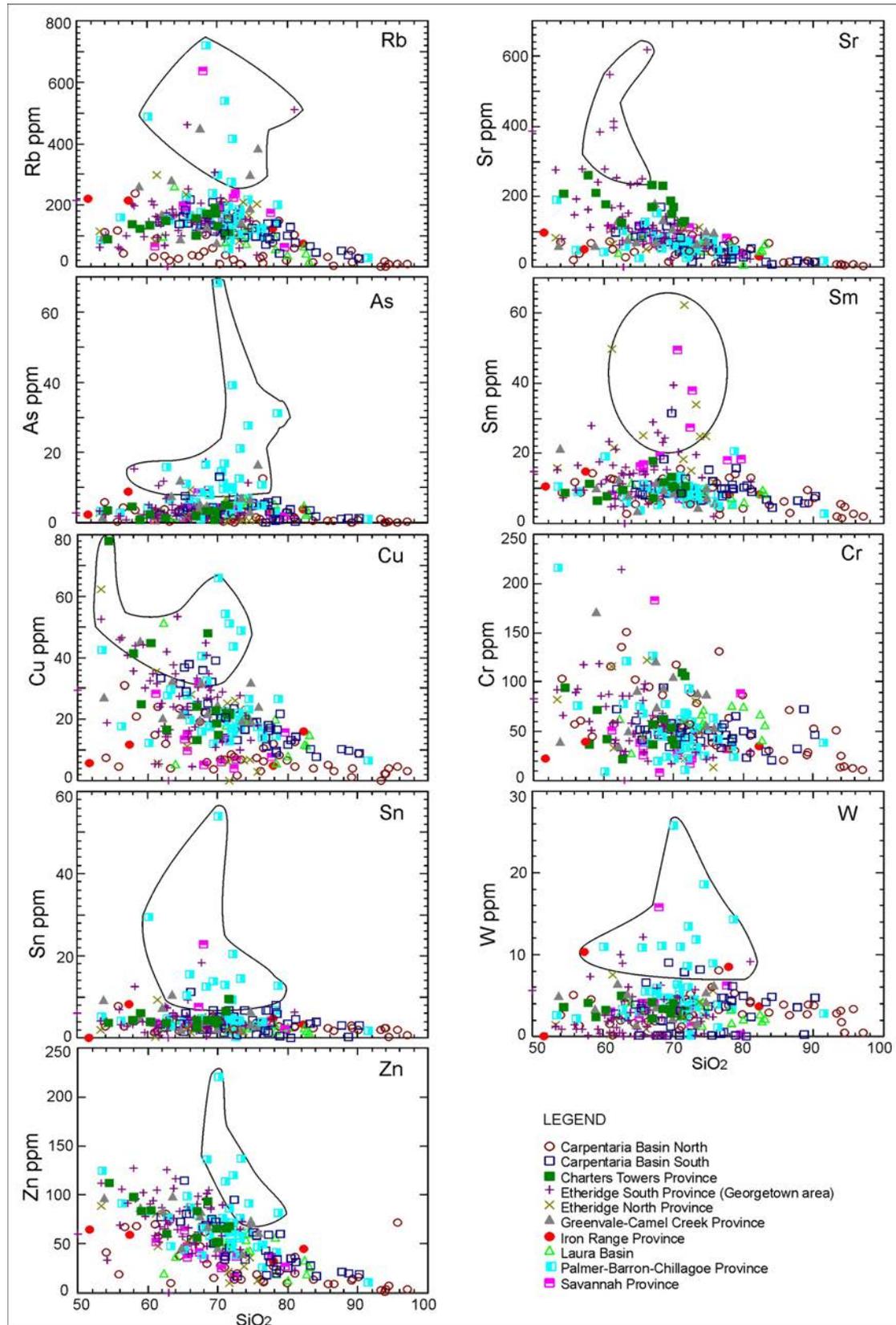


Figure 12: Harker variation diagram of minor elements in Cape York.

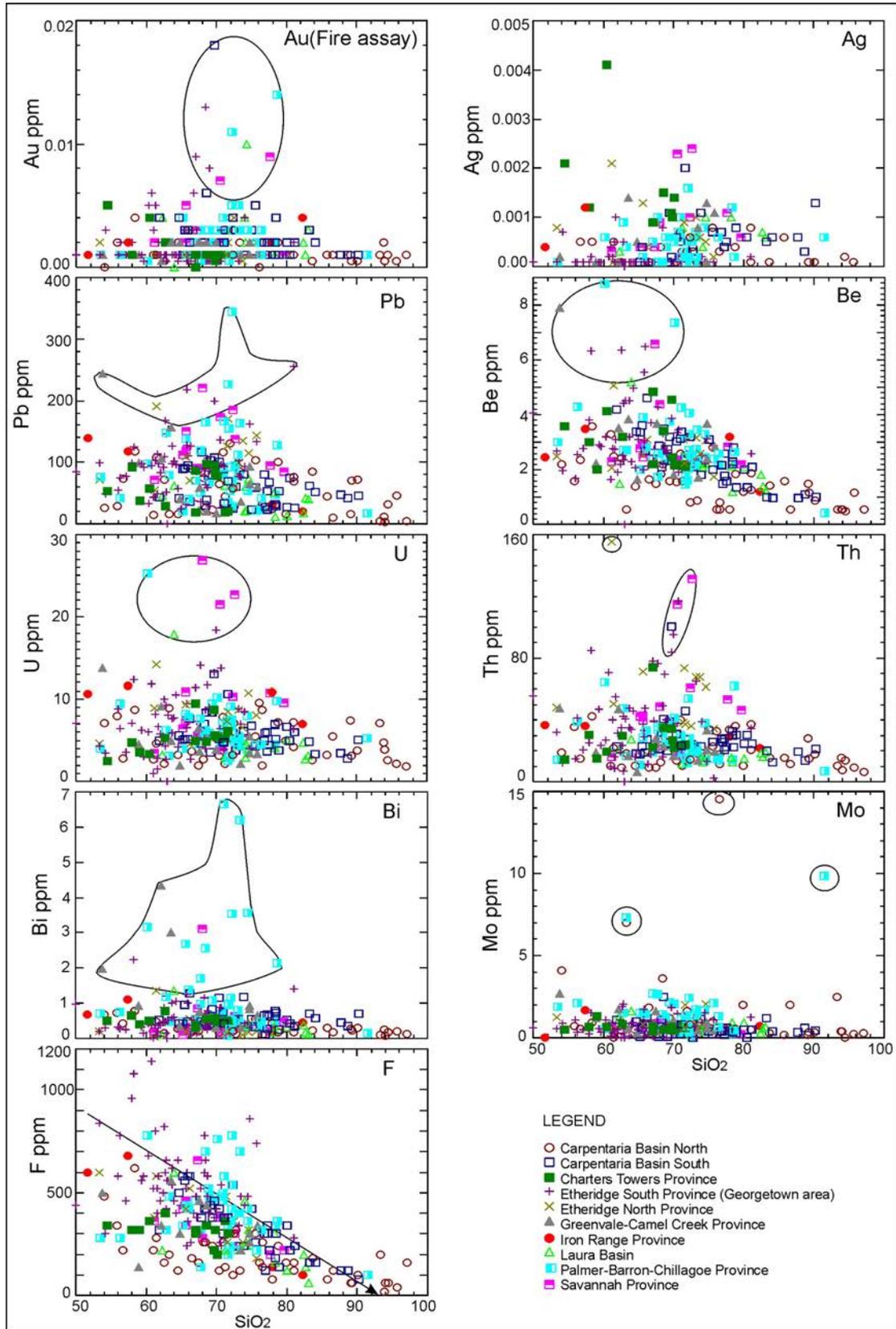


Figure 12: Harker variation diagram (continued).

The Greenvale and Camel Creek subprovinces have one or more catchments enriched in U, Pb, Bi, Be and F. There are many likely models for U–Pb–Bi association that may include syngenetic sedimentary deposits, and their association with Be–F could be related to pegmatitic veins.

Gold and silver enrichment occurs within the Charters Towers, Etheridge South, Palmer River and Savannah provinces and in the Carpentaria Basin South. Most of these geochemical provinces have known current and historical gold–silver mining activities, and geochemical results reaffirm the precious metal occurrences in the region.

#### **5.2.4 Rare earth patterns**

The REE pattern compares the <75 micron TOS and BOS samples of ten geochemical provinces in Cape York (Figure 13). The TOS samples show greater variability in the pattern, which highlights greater influence of enrichment, dilution or contamination in the recent sediments. Some of the extremely low REE concentrations in the TOS samples resulted from incomplete digestion using the microwave bomb method (Batch 3, Appendix 2), and are not considered in the discussion.

The REE patterns show typical upper continental crustal signature with strong LREE enrichment, a prominent Eu trough and a flat MREE to HREE with differing enrichment factors (Figure 13). The Etheridge and Savannah Provinces have higher background REE concentrations than other provinces in the region with chondrite normalised factors exceeding 1000. An Eu trough is commonly attributed to the removal of plagioclase during magmatic fractionation (Allegre *et al.*, 1977; Hanson, 1978). Eu has two oxidation states and has higher mobility in the reduced  $\text{Eu}^{2+}$  state (Allegre & Minster, 1978), and selective removal of reduced Eu species under extreme leaching conditions will also produce Eu depletion.

The Carpentaria Basin North has two unique patterns. Besides the normal crustal pattern, samples from the Escape (TS0858), Olive (TS0862), Kendall (TS0870\_02) and Coleman (TS0862) rivers exhibited the birdwing pattern with a flat MREE to HREE range. The birdwing pattern resulted from a low LREE and high MREE–HREE concentrations. These catchments drain from lateritic or bauxitic provenances, which are interpreted as products of *in situ* tropical leaching. The birdwing pattern can be accounted for by LREE removal and concentration of MREE–HREE in refractory mineral components of sediments. In the Carpentaria Basin South, the REE pattern shows a typical crustal signature with a strong Eu trough and differing amounts of MREE and HREE enrichment.

The REE pattern of the Etheridge Province highlights the typical crustal pattern with varying amounts of enrichment or dilution. BOS have consistent patterns and relatively uniform background concentrations, whereas TOS show greater variations that are not duplicated in corresponding BOS samples, suggesting recent modification of geochemical signatures. The REE contents in the Muldiva Creek tributary of the Mitchell River (TS0893\_01) and the Pinnacle Creek tributary of the Lynd River

---

(TS0908\_02) are highly enriched in LREE to MREE (with similar HREE content) in TOS which produced a high REE slope. These patterns are not duplicated in the BOS which suggests recent enrichment of LREE–MREE in TOS. The slopes for the Black Gin Creek of Gilbert River (TS0925\_04) and the Edmunds Creek (TS0934\_13) and Oak River (TS0934\_14) tributaries of the Einasleigh River have an extremely flat pattern with low REE content. The flat pattern has a prominent Ce trough, but Einasleigh River samples lack the Eu trough. Like Eu, Ce has two oxidation states, and the  $Ce^{2+}$  has higher mobility. The Ce loss suggests a product of extreme leaching, and the flat pattern could be accentuated by dilution with an ‘achemical component’ such as silica sand. Similar interpretation is applied to samples from Hann Creek (TS050\_04) and Broughton River (TS0950\_07), tributaries of the Burdekin River, which are subjected to selective leaching and dilution of LREE by an ‘achemical component’ e.g. quartz.

In the Etheridge North Province, a TOS sample from the Geikie Creek tributary of Archer River (TS0871\_01) and samples from Palmer River (TS0887\_06) show suppression of REE concentrations, which is interpreted as the result of the accumulation of ‘achemical’ REE minerals such as quartz, or selective removal of heavy REE-hosting heavy minerals by physical processes. REE is partitioned into heavy minerals such as zircon, titanite, monazite, allanite and garnet, and these minerals accumulate within low-energy environments within streams, coastal dunes and beaches. The denser minerals are separated from the lighter quartz grains by density differentiation through aeolian, fluvial and wave activities. Most enrichment or depletion of REE along coastal catchments can be attributed to dilution or enrichment by silica sand and/or mineral sands. This is demonstrated by the near-coast samples from the Iron Range province where the REE contents increase northward from Lockhardt River (TSC004, TSC005 and TS0867) to the Pascoe River (TS0865) catchments. The northernmost samples have a higher HREE/LREE ratio, which results in a flattish MREE–HREE range.

The Greenvale – Camel Creek Province has an enriched REE pattern along the Herbert River (Lannercost Creek (TSC0930\_15) and Stone River (TS0930\_17) tributaries). These samples have a diagnostically high MREE to HREE range that peaks at Tb, and the enrichment is consistent in both TOS and BOS. The uniformity of REE content and pattern suggest a unique source region for enriched MREE to HREE within the Herbert River catchment.

### ***5.2.5 Spidergram patterns***

The spider diagram (spidergram) compares a suite of elements from the <75 micron BOS samples of the different geochemical provinces (Figure 14). The elements are arranged according to their common ionic radii, which determine the reactivity of an element. All catchment geochemistry on the spidergrams showed a relatively similar pattern. Individual geochemical provinces generally retain a unique geochemical signature, differing only in the magnitude of elemental concentrations between samples. Abnormal positive deviation from the general provincial pattern possibly indicates mineralisation. The advantage of spidergrams over the regional geochemical atlas is the ability to identify minor deviations within a subset of data, and such

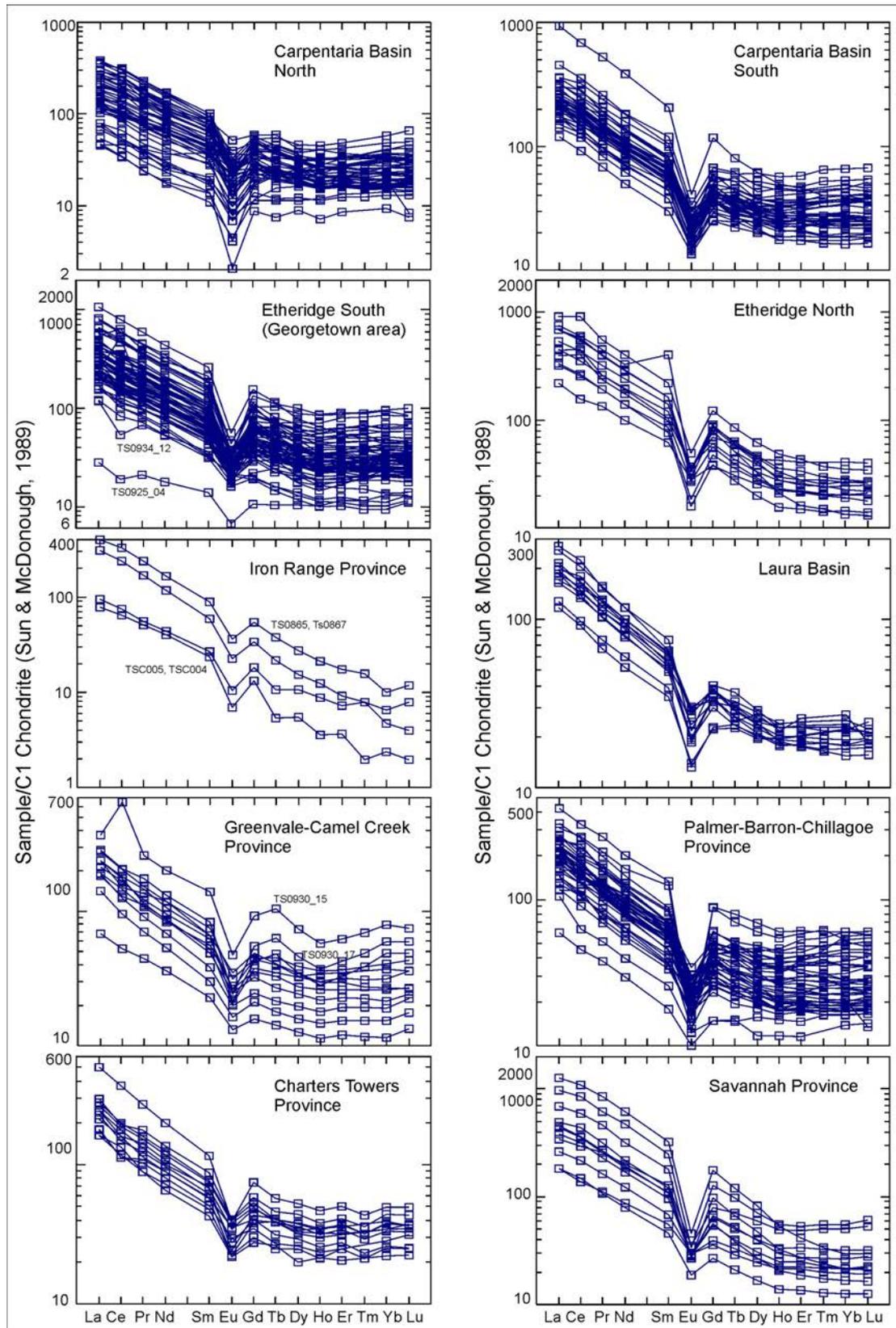


Figure 13A: Chondrite normalised REE patterns for BOS <75 micron samples.

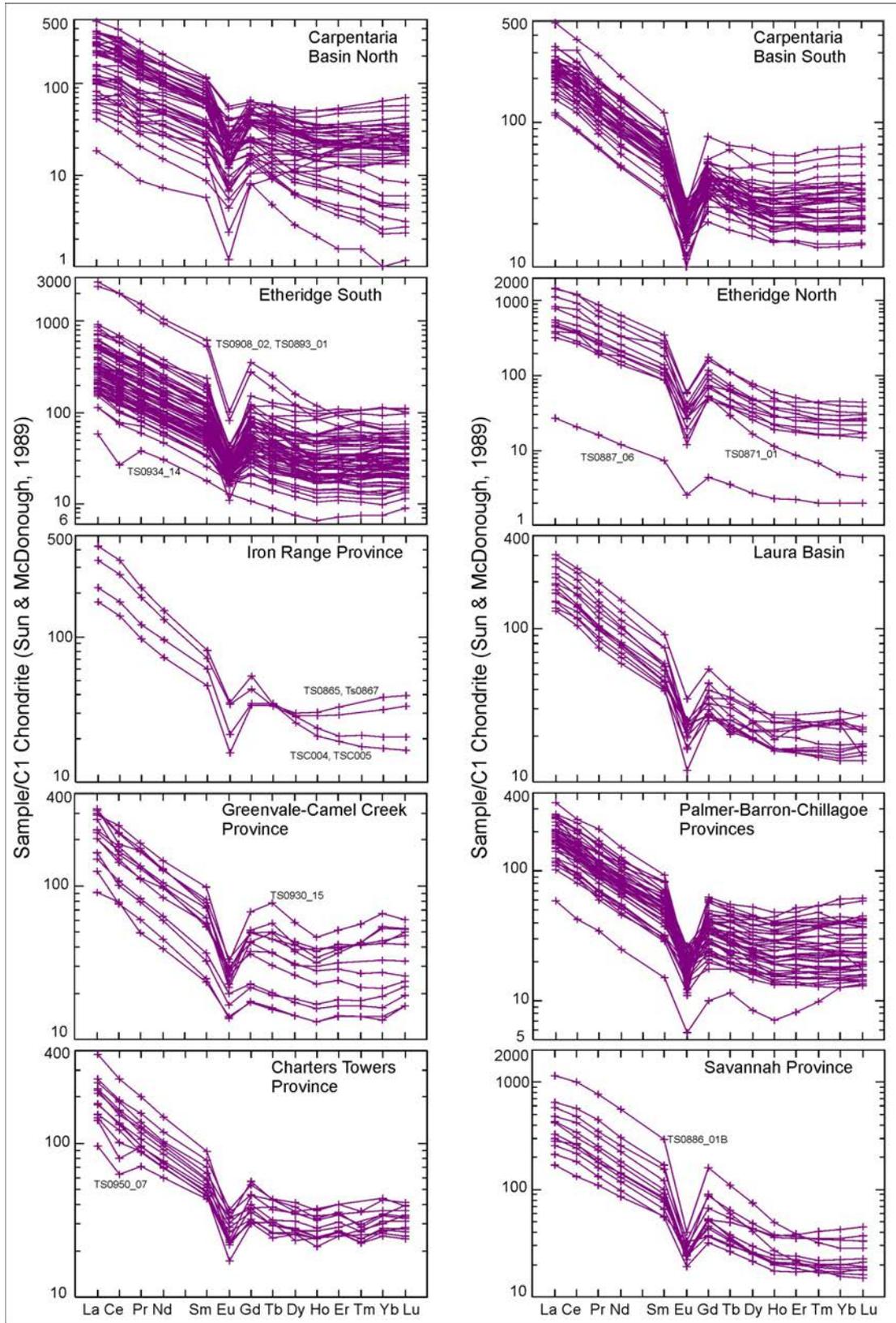


Figure 13B: Chondrite normalised REE patterns for TOS <75 micron samples.

deviation may not be of regional significance. The Cape York data is slightly enriched from the upper crustal composition with the sample/upper crustal geochemical ratio at or slightly above one, with the exception of REE, which is consistently above unity. The spidergram suggests that the Cape York region is naturally rich in REE.

Consistent features on the upper crustal (Taylor & McLennan, 1985) normalised diagram are the Mo, Nb–Ta, Sn, Sr troughs and Pb, Sb, Th peaks. Their consistency suggested that these features are artefacts of the normalising constant, where troughs resulted from overabundance, whereas peaks in the upper crustal standard are from underabundance. Kamber *et al.* (2005) concluded that there is overabundance of Nb–Ta and Ti in the normalising standard which generated the Nb–Ta troughs and underabundance of Pb that created the Pb peak. Another possible cause is incomplete digestion of samples or sublimation of the element during digestion, which resulted in under representation of elemental chemistry of the sample. On the C1 chondrite (Sun & McDonough, 1989) normalised diagram, Mo, Sn and Sb and frequently F, Tl, Nb–Ta and W forms troughs below parity from the sample/chondrite ratio. The constant low values of Mo, Sn and Nb–Ta are interpreted as the consequence of low analytical results. Contrasting the Sb pattern from the two graphs suggests that the Sb values in Taylor & McLennan (1985) are too low. Sr troughs associated with Eu lows are characteristic of upper crustal material from the early separation or removal of plagioclase during fractionation or alteration. The Zr–Hf, U–Th and REE plateaus are prominent in most catchments, which suggest that these elements are elevated in the Cape York region.

The spidergram reveals mineralisation potential within individual geochemical provinces. In the Etheridge South Province, Sb peaks are interpreted as anomalous Sb that occurs along the Etheridge River (TS0909\_06) and Fossil Brook tributary (TS0908\_10) of the Lynd River. Elevated W is also located along the Rocky Creek tributary (TS0908\_08) of the Lynd River. In the Etheridge North Province, high Sb concentration is identified along the Palmer River (TS0887). Etheridge North also has elevated Cs along the Archer River (TS0871\_01 and TS0871\_06), which suggests the possibility of a hydrothermal related mineral system.

In the Greenvale–Camel Creek Province, high Cs–Rb background occurs along the Burdekin River, which indicates possible hydrothermal or intrusive-related mineralisation. High Cs is also located along the Herbert River (TS0930\_09) with elevated Ta in the Bell Creek tributary (TS0930\_08).

The Palmer–Barron–Chillagoe Province is elevated in Sb, Pb, Sn and W along the Walsh River. Elevated Sb is identified along tributaries of the Walsh River (TS0901\_01), Eureka Creek (TS0901\_02), and Emu Creek (TS0901\_03). The Emu Creek tributary is also elevated in W and Pb, suggesting a high potential for polymetallic mineralisation.

In the Iron Range and Savannah Provinces, subparallel variation trends suggest varying enrichment of Zr–Hf and Ta, which is typical of detrital input through progressive enrichment.

---

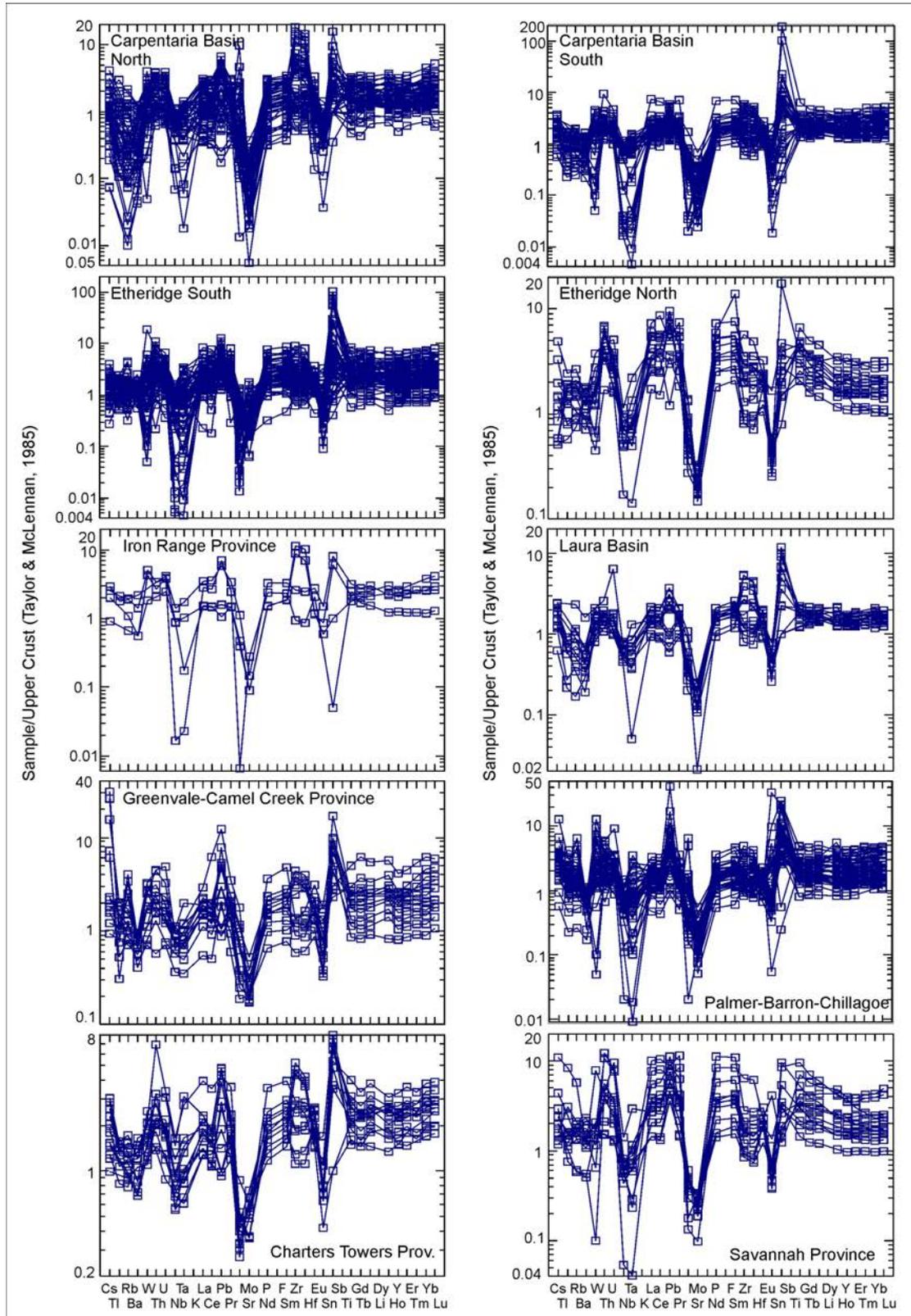


Figure 14A: Upper Crustal normalised spidergram pattern for BOS <75 micron samples.

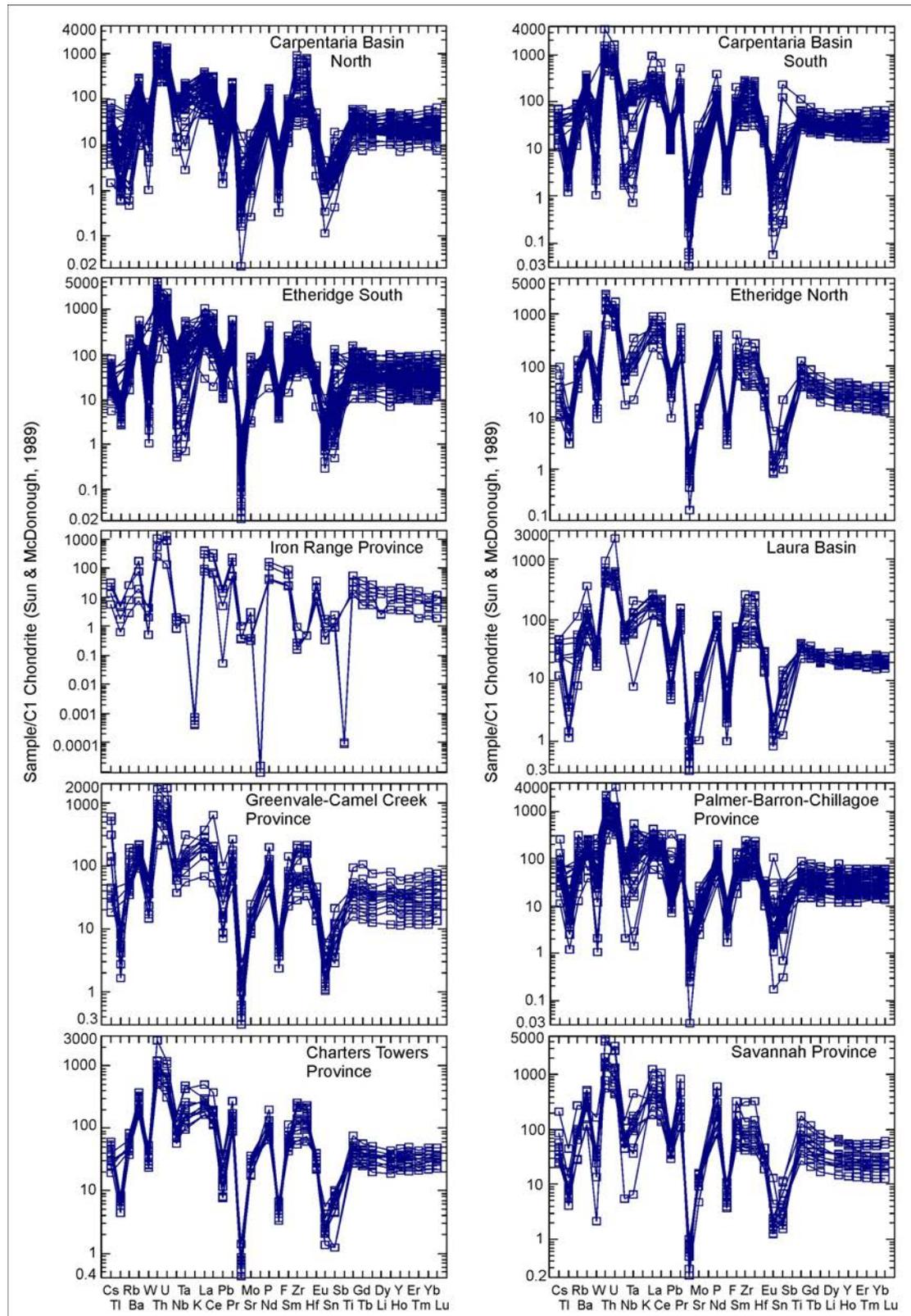


Figure 14B: C1 Chondrite normalised spidergram pattern for BOS <75 micron samples.

### 5.2.6 Comparing REE and spidergram patterns

REE and spidergram variation diagrams compare groups of elements with similar characteristics rather than analysing how individual elements behave. REE variation diagrams plot the elements in increasing atomic number, and hence increasing atomic weight, from La to Lu. A spidergram groups elements based on compatibility, which is governed largely by their ionic radii and valency. Variations in geochemical trends of elements with similar chemical characteristics (like-elements) are used to interpret the geochemical processes that control chemistry.

There are several curious geochemical scenarios in the Cape York geochemistry that require logical explanations. The birdwing REE pattern in the Carpentaria Basin North was interpreted as the product of LREE removal and concentration of MREE-HREE in refractory mineral components of sediments. The spidergram pattern of <75 micron BOS samples shows significant variations in the incompatible elements (Cs–Tl–Rb–Ba) and LREE (La–Ce) and enrichment in Zr–Hf and MREE-HREE (Figure 15A). Comparing a birdwing pattern against a normal crustal pattern (green boxes) shows that the birdwing sample is depleted in Cs–Rb–Ba–Tl, P, La–Ce–Pb and MREE, and is enriched in Zr–Hf and HREE (Figure 15B). The depletion of incompatible elements and concentration of heavy elements supports the REE interpretation of extreme leaching of mobile elements in deeply weathered terrain and accumulation of heavy minerals in the highly weathered duricrust.

REE samples from the Etheridge and Savannah Provinces have typical crustal signatures with varying degrees of enrichment (Figure 15C). Variation of pattern can relate to different catchment chemical background or from subsequent modification of geochemistry through detrital processes. Analysis of their spidergram pattern indicates that the Ta–Nb, La–Ce, Zr–Hf–Sm and MREE–HREE are differentially enriched as depicted in subparallel trends, whereas most other elements remain relatively constant. The enrichment of these elements that are commonly partitioned into refractory heavy mineral sand (such as zircon, monazite, allanite and titanite) suggests that the recent TOS sediments have been enriched by heavy mineral sand either directly from a primary source region or through sedimentation. The relatively constant mobile element concentrations argue against deep weathering as the cause of differential REE content.

Etheridge Province samples often show contrasting REE concentration and different patterns for TOS and BOS (Figure 15D). A sample from the Pinnacle Creek tributary of the Lynd River (TS0908\_02) is plotted to depict the contrasting patterns. The BOS sample has an upper crustal pattern with very shallow Eu and Ce troughs, whereas the TOS sample has a prominent Ce trough and low total REE content. Comparing the spidergram pattern, the TOS sample has lower Ce–La–K–Nd–Sm, Th, Ta and MREE–HREE contents, and has higher Zr and Hf. The overall lower elemental concentration in TOS suggests chemical dilution by zircon-bearing silica sand, which increases Zr–Hf content. The prominence of a Ce trough indicates a more extreme Ce loss from TOS in recent times.

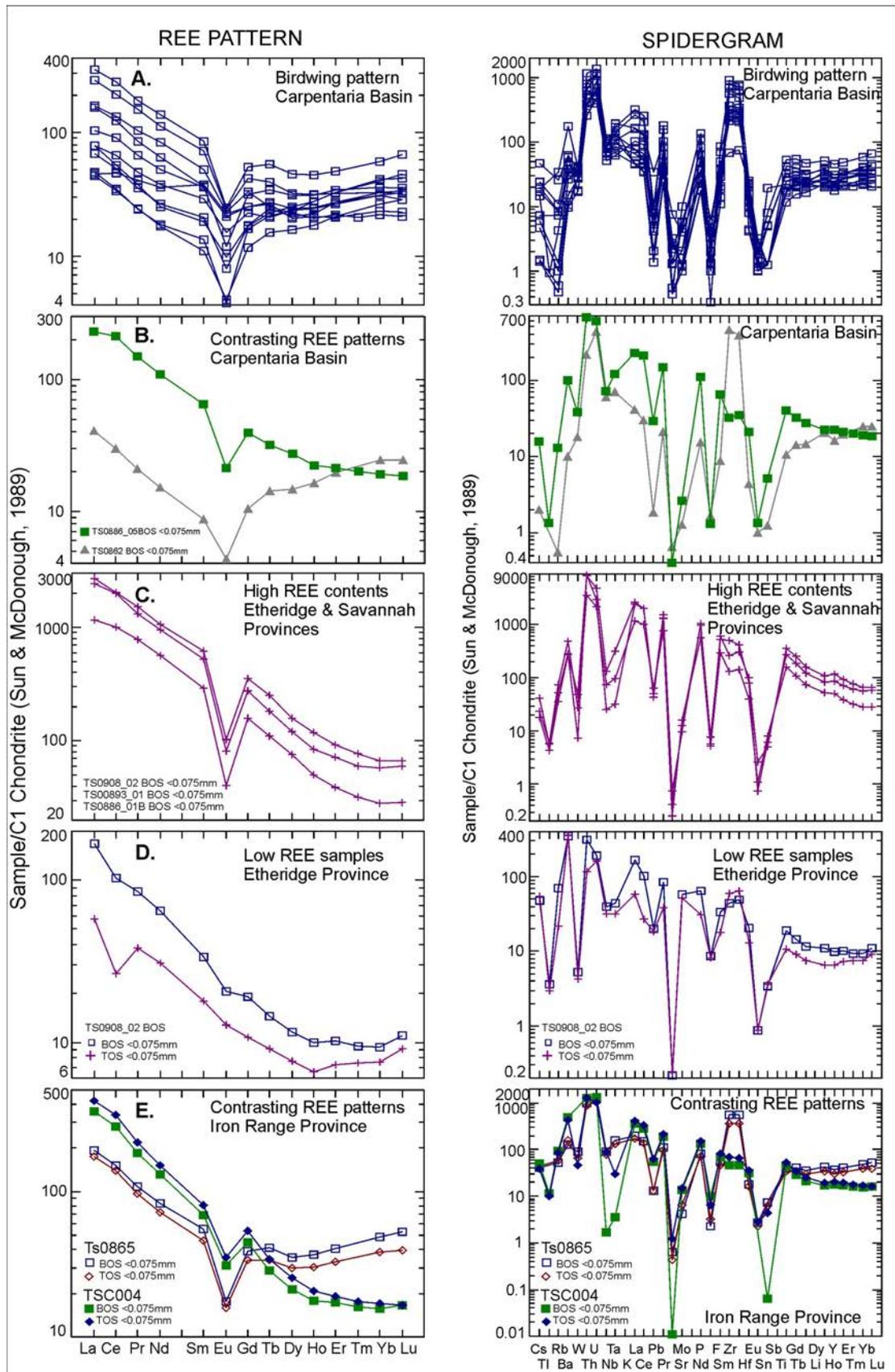


Figure 15: REE and spidergram for contrasting patterns in the Cape York region.

Iron Range Province has two distinct REE patterns with a MREE–HREE enriched pattern (TS0865) criss-crossing the normal upper crustal signature (Figure 15E). TOS and BOS of each sample are almost identical, implying well homogenised REE chemistry of the <75 micron fraction of the sediment. The chemical difference demonstrated by the two patterns is a true reflection of the geochemical concentration of the catchment. TSC004 has higher LREE and lower HREE than TS0864 on the REE pattern. On the spidergram, the mobile ion lithophiles (Cs–Rb) and U–Th (mobile in oxidising conditions) remain relatively constant in the two samples, but refractory elements such as Ta, Nb and HREE and Mo–Sb are lower in TSC004. The contrasting pattern is interpreted as the result of chemical/sediment mixing and discounted the possibility of leaching as the cause.

Sample TS0865 is interpreted as the product of blending of zircon-rich silica sand that caused LREE dilution and MREE–HREE and Zr–Hf enrichment.

### 5.3 Fingerprinting Cape York geochemistry

The enrichment-depletion graph of Cape York compares the relative abundance of its regional geochemistry to the Queensland average (Figure 16A) and the Mount Isa Province average (Figure 16B). The normalising values were taken from the published NGS data (Tang & Brown, 2011). Positive values indicate elevated concentrations, and negative values indicate depletion relative to the normalising constants. Figure 16 highlights the enriched group of elements in Cape York that relate either to lithology, tectonics and/or mineralisation. It is a useful guide for regional exploration to target elements with a higher probability of discovery as well as developing exploration strategy.

Cape York geochemistry normalised to the Queensland average shows strong enrichment (>1) in W, Bi, Th, Pb, Sb, Ge, B and Cs; moderate enrichment (0.5–1) in U, Nb, Au, Sn, LREE, As, Se, In, K, Rb and Tl; and weak enrichment (0.1–0.5) in Mo, Be, Ta, Ga, HREE, Li and F. Normalisation to the mineral-endowed Mount Isa Province demonstrates strong enrichment in Sn and LREE; moderate enrichment in Au, W, Bi, U, HREE, Cs, Sb, Se, Th, Hg and Mo; and weak enrichment in Re, Pb, Hf, Zr, As, S, Y, Ti, Li, Nb, Rb and Te. The Cape York regional geochemistry shows enrichment dominated by lithophiles and oxyphiles, relative to both statewide and Mount Isa geochemistry. Lithophile enrichment is commonly associated with fractionated granites (Rollinson, 1993; Railsback, 2003), and oxyphile dominance is commonly related to reduced granites in orogenic to post-orogenic belts (Blevin, 2004; Boyle, 1974).

Cape York is uniquely enriched in W, Sn, REE, Bi, Th, U, Au, Sb, Se, Pb, Mo and Cs in Queensland. Mineralisation associated with the oxyphilic dominated elements tends to form small- to medium-vein or sheeted-vein deposits, as well as dissemination in granites, pegmatites and skarns. Exploration for such deposits requires a sophisticated exploration and analytical methodology, and a good understanding of the geology and granite magmatism that control mineralisation. In contrast, the Mount Isa region geochemical signature is enriched in Cu, Mg, Mn, Co, Cd, Ni, Cr, Zn, Ag and Au,

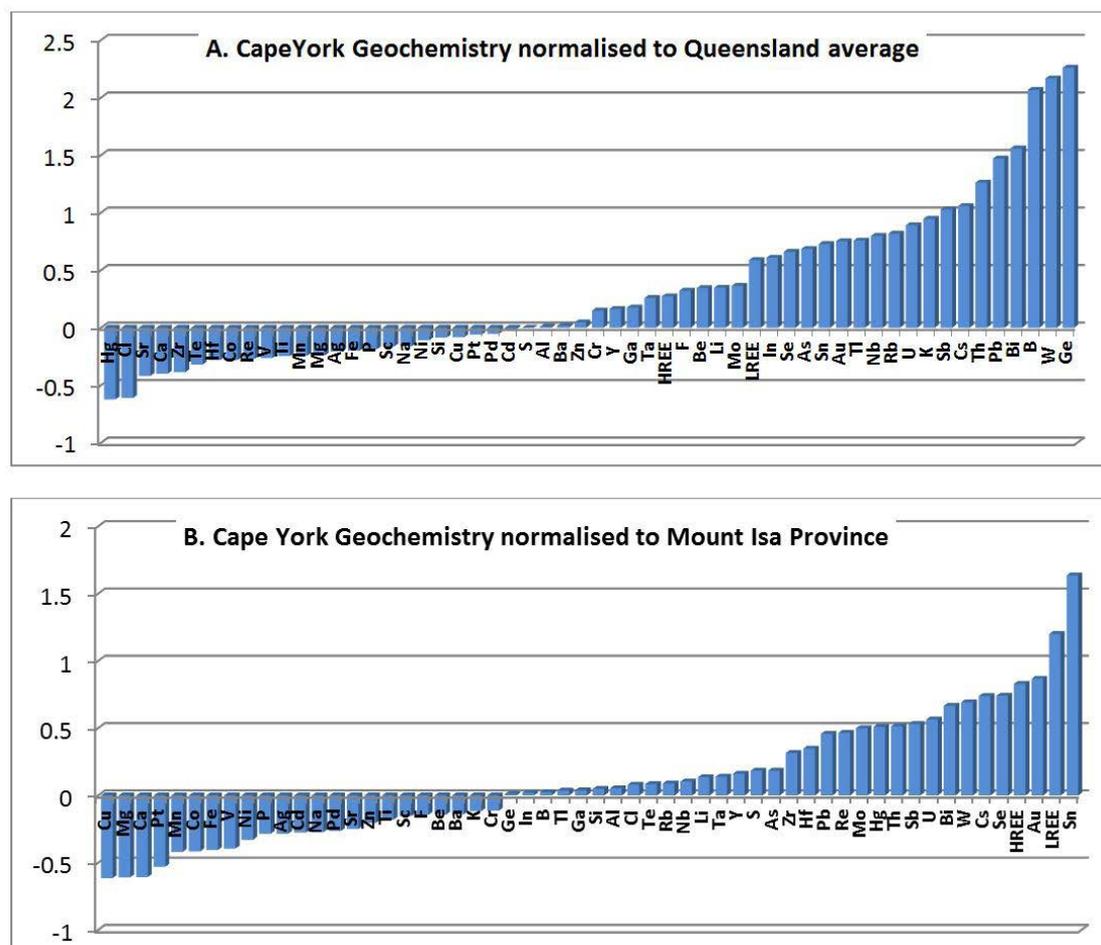


Figure 16: Depletion-enrichment graph of the Cape York regional geochemistry. A. Normalised to the Queensland statewide average, B. Normalised to the Mount Isa Province average. Positive values indicate elevated concentration and negative values indicate depletion relative to the normalising values.

typical of mineral systems associated with intermediate to mafic oxidised magmatism (e.g. IOCG/porphyry and stratiform styles) with large geochemical footprints. Exploration methodology used in Mount Isa cannot be applied to Cape York, and the exploration template used must be tailored to target small to intermediate anomalous sources guided by good geological and mineral system understanding.

### 5.3.1 Fingerprinting geochemical provinces

Normalising the geochemistry of individual geochemical provinces to the Cape York regional geochemistry highlights the enriched elements within each province. The average geochemistry of Cape York is the arithmetic mean of all 267 catchments, and the average geochemistry of each province is based on the mean of all catchments within the geochemical province. Geochemical provinces generally have relatively uniform chemistry as demonstrated by similar REE and trace element variation patterns. By normalising the provincial chemistry to the regional geochemistry, elements that are unique to the province are highlighted, which may not be obvious on regional scale. Geochemistry of sedimentary basins will not be discussed, since

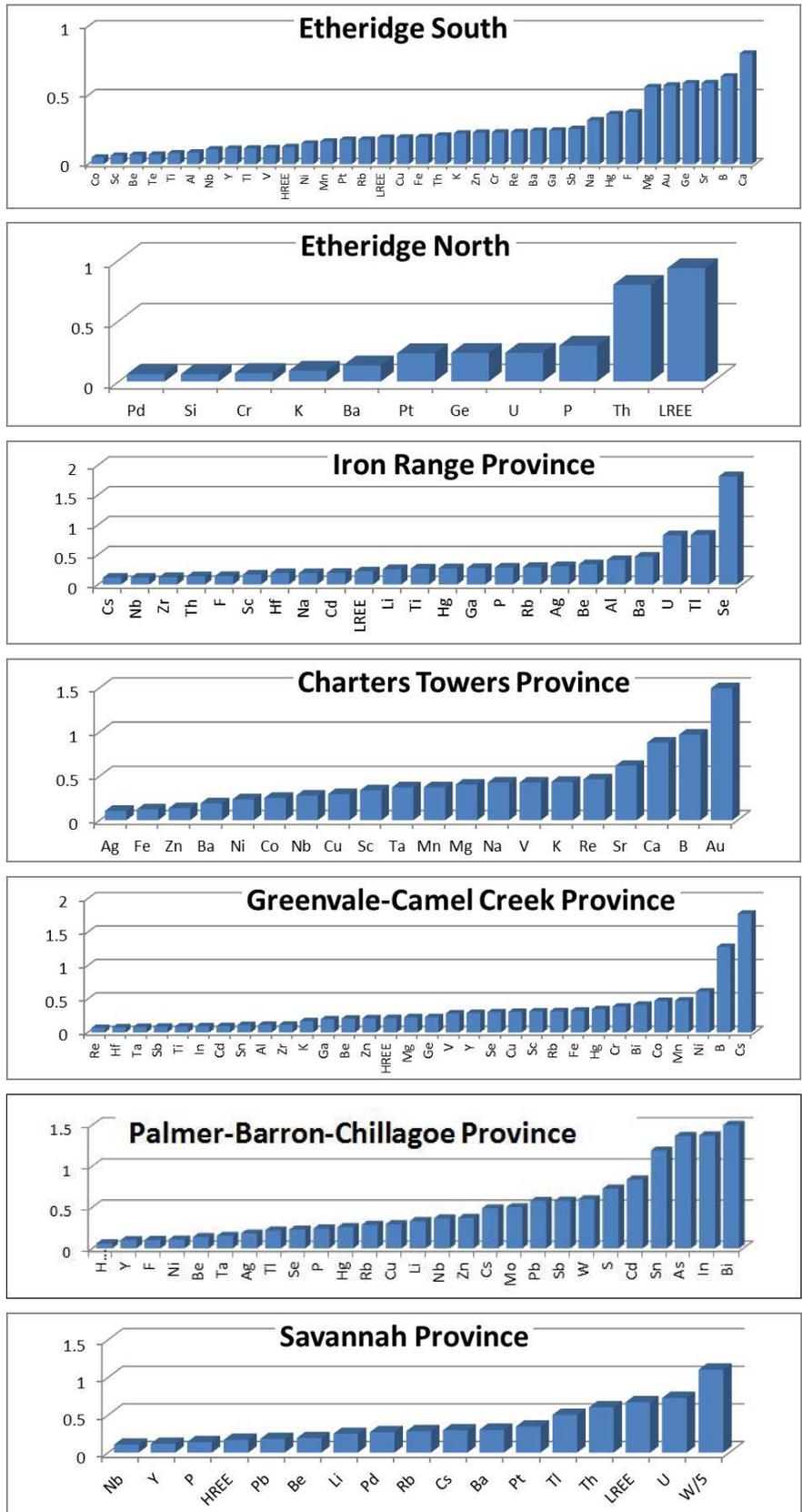


Figure 17: Depletion-enrichment graph of geochemical provinces in Cape York

the sediments are derived from multiple tectonic provenances and source regions are uncertain.

The Etheridge South Province is enriched in Ca, Sr, Mg, B, Ge and Au, and moderately enriched in F, Ba, Na, Ga, Hg and Sb. The association of Ca–Sr–Mg is commonly attributed to the presence of carbonate rocks, and the presence of B–F–Na–Ba–Ga is commonly associated with pneumatolitic and hydrothermal fluids. Ge, Au, Hg and Sb are also enriched in the Georgetown area and these elements may be associated with the hydrothermal system and/or limestone e.g. skarn. The presence of Hg and Sb generally suggests a low to moderate temperature style deposit. The Etheridge North Province is strongly enriched in U, Th and LREE, and slightly enriched in P and Ge. The U–Th–LREE i.e. oxyphile group are formed under reduced conditions commonly associated with felsic igneous rocks. The presence of P–Ge can form either in sedimentary or vein-style mineralisation.

Iron Range Province is enriched in Se, Tl and U. Se and Tl are mobile under hydrous conditions but immobile under dry conditions, typically precipitating along shear zones or phreatic zones. The association of Se–Tl–U is a compelling indication for either roll-front uranium deposition, or deposition of U minerals along shear zones.

The Charters Tower Province is strongly enriched in Au, Ba, Ca and Sr, and moderately enriched in K, Re and V. The association of Ca–Sr–Ba is typical of calcareous rocks, but the presence of Au–Re–V can have multiple genetic possibilities ranging from hydrothermal fluids (K–Na presence) to vein-related mineralisation.

The Greenvale–Camel Creek Province is strongly enriched in Cs, B and Ni, and moderately enriched in Co, Cr, Mn and Bi. The close relationship with the transitional metals indicates mafic rock association. Cs–B presence implies either a hydrothermal or metasomatic component. Greenvale–Camel Creek Province is polymetallic but there is no convincing indication of metallic resources besides the presence of Ni, Cr and Co, which may be related to mafic rocks.

Palmer–Barron–Chillagoe Province forms the Hodgkinson Province. The REE and trace element geochemistry showed relatively similar patterns for the three subprovinces, but the Harker variation diagram showed a distinctively more diverse composition that can produce complicated geochemical signature. This geochemical province is enriched in Bi, In, As, Sn, Cd, S, W, Sb, Pb and Mo, and moderately enriched in Cs, Li, Nb and Zn. The range of enriched elements includes lithophiles, oxyphiles and siderophiles with possibility of involvement of magmatism, metasomatism and mineralisation. The presence of lithophiles and oxyphiles suggests a component of reduced felsic granite as well as dyke- or vein-related mineralisation. Further processing is recommended by normalising individual subprovinces to better define the geochemistry.

The Savannah Province is strongly enriched in W, U, LREE and Th, which are typical oxyphiles. It indicates strong anomalism for W, which is over five times the state background value. This province is the best region to explore for W in Queensland.

---

## 5.4 Inter-element correlation coefficient and variance

The Pearson correlation coefficient and variance is applied to the geochemistry to highlight the inter-element relationships. The correlation coefficient factors map out prominent element–element relationships that can be explained by lithologic and mineralogic controls and that can predict dominant mineralisation models. Correlation coefficient and variance form the basis of Principal Component Analysis (PCA). Direct correlation coefficient calculation is preferred over PCA as it provides good multi-elemental association and groupings, which is lost in the PCA.

PCA using the multibase Add-ins function of MS Excel was used to appraise the data. PCA is convenient for identifying relationships between large numbers of variables and cluster suites of variables, based on the assumption that the variables are non-dependent (Jolliffe, 2002). Ideally, PCA requires a sample to variable ratio of 5:1, which means that a minimum of 335 samples is needed for a dataset with 67 variables, as with the Cape York data.

The basic assumptions for PCA are not met, since Cape York geochemistry is strongly controlled by basement geology. The Cape York geochemistry is spatially divided into ten geochemical provinces based on tectonic framework. Individual provinces have different geological backgrounds and/or source regions that will result in a different geochemical signature for the sediments. The ten provinces are the Iron Range Province, Savannah Province, Etheridge Provinces (North and South), Palmer–Barron–Chillagoe Province, Greenvale–Camel Creek Province, Charters Towers Province, Carpentaria Basin (North and South) and Laura Basin. By splitting the dataset into geochemical provinces, the number of samples to variables is too small for effective PCA unless the number of variables is reduced to meet the requirement. In doing so, the maximum variable for the biggest geochemical province will be limited to 12 elements, which will not represent catchment characteristics unless multiple independent principal component analyses are calculated over an area.

PCA is routinely used to concur with conclusions from the correlation coefficient calculations but is not used directly in data appraisal. An example of PCA using major and trace element geochemistry by near-total digestion is shown in Figure 18. PCA showed clustering of REE and V–Co–Fe–Sc associations from PC1 and PC2; REE, Pb isotopes and As–Bi associations in PC1 and PC3; and V–Co–Fe, Cu–Zn and As–Bi associations in PC2 and PC3. These associations are useful references in data processing, but the relationships may not hold on a provincial level if other factors such as background geology are taken into account.

### 5.4.1 Correlation coefficient grids

The Pearson correlation coefficient was computed for the different size fractions, depth profiles and analytical methodologies. Each geochemical province has nine correlation coefficient grids reflecting different aspects of the same catchment chemistry (Figure 19). The individual grid does not represent the geochemical

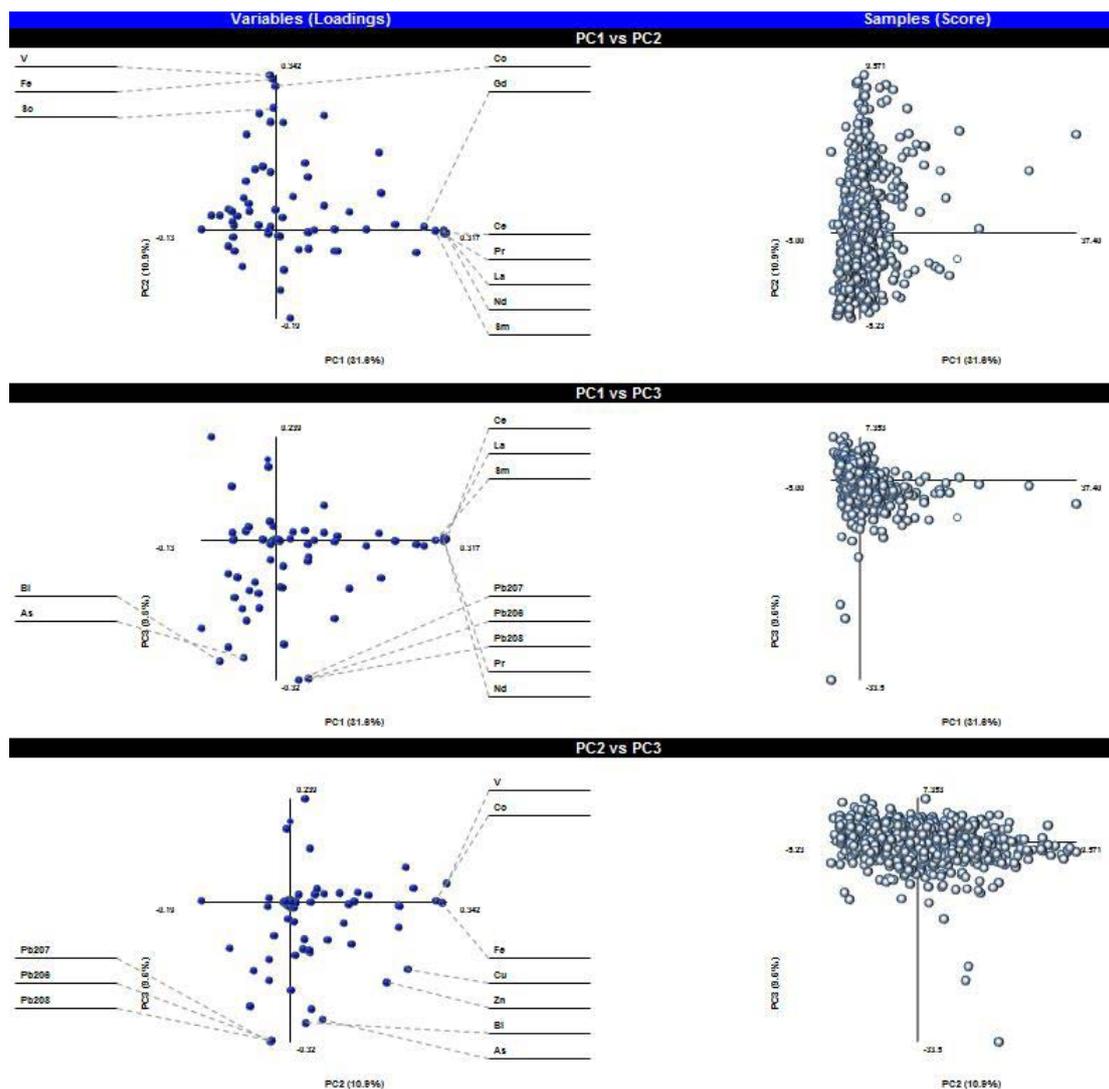


Figure 18: PCA calculation for near-total digestion results from UQ. The calculation assumes that the entire Cape York variables belong to one population and that the variables are independent.

province, but the effective combination of information from all the grids will be the unique chemical characteristic for the province.

Geochemical grids can be combined by several mathematical methods while retaining the overall chemical signature of the province. The mean correlation coefficient averages the correlation factors of all nine grids (Figure 20A). This is the simplest way of representing the average interrelationship of elements and retains both positive and negative relationship. However, averaging factors generally reduces the extremes and nullifies the positive and negative values if these are antagonistic functions of variables such as depth, grainsize or density fractions. For example, density separation in sedimentary processes will generate lighter silica-rich, and heavier mineral sand fractions. The mean correlation factor is generally very 'noisy' as it highlights all elemental relationships and is skewed towards one or more of high values. This method is useful for detailed analysis of elemental behaviours.

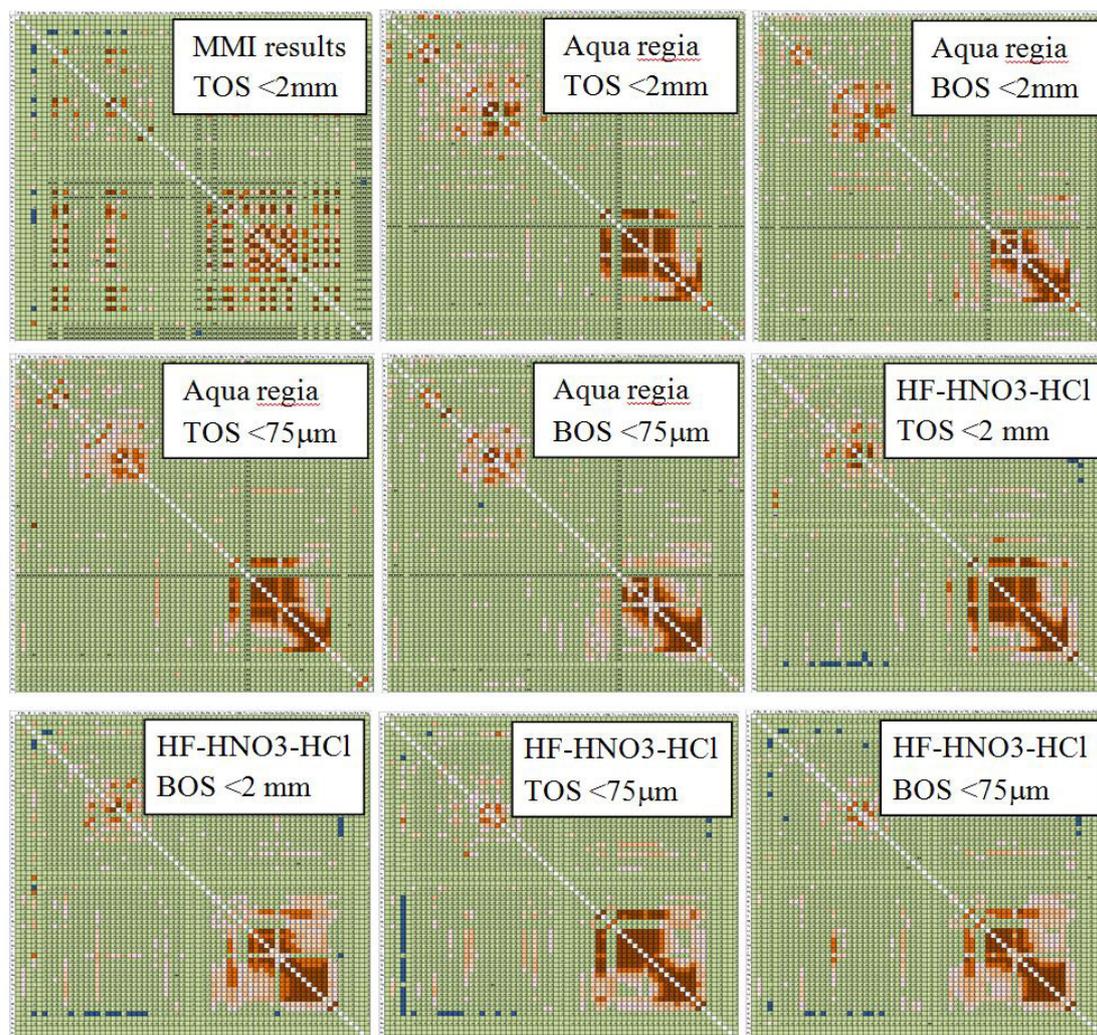
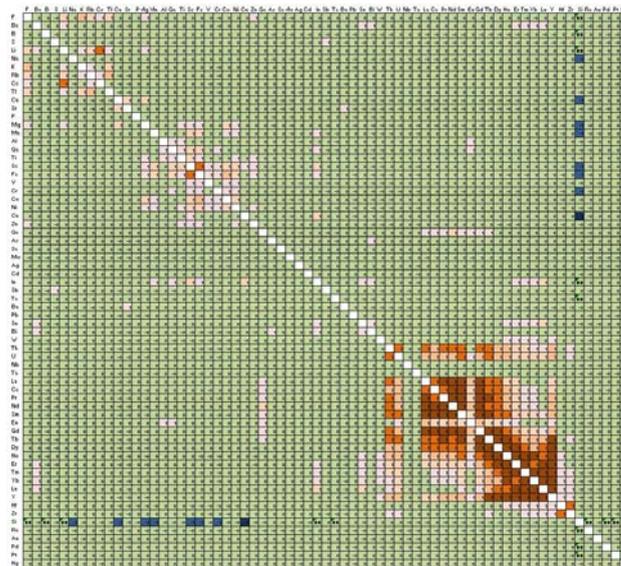


Figure 19: Correlation coefficient grids of the Etheridge South Province showing different aspects of the inter-elemental relationships based on different geochemical results.

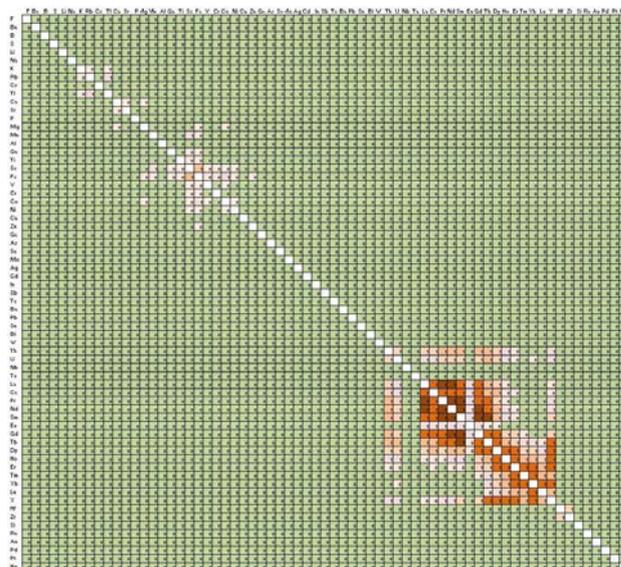
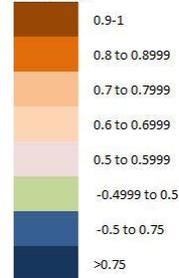
The 'Mean of Squares' method is an effective way to present only the high factors for both positive and negative values. Squaring removes the negative numbers and reduces the significance of smaller factors, whereas high values are magnified (Figure 20B). This grid provides a good representation of regional geochemistry by highlighting the significant elemental associations distinctive of a geochemical province. This grid will be used in this report to present the geochemistry of different provinces.

The 'Sum of Squares' is the mathematical total of the squares of coefficient factors from all nine grids. It removes negative values, highlights the major elemental relationships and reduces the less significant factors. As data population of respective provinces is small, the correlation grid produces spurious factors which may not be factual. Only very high inter-element associations are examined, and all of these match the grids of previous methods.



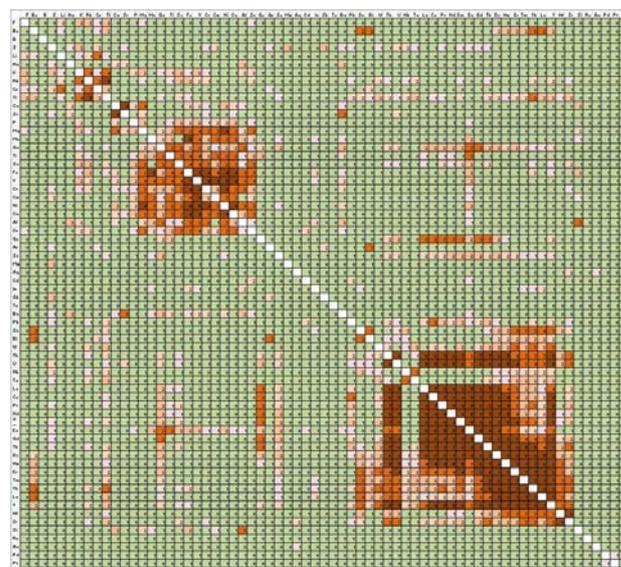
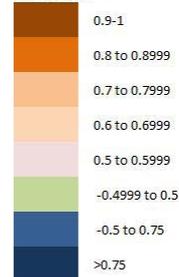
A. Mean correlation coefficient averages the factors from the 9 grids. It retains the positive and negative characters of the relationship.

LEGEND



B. Mean of Squares averages the squares of values. It removes negative numbers, reduces the significance of smaller factors and amplifies high values.

LEGEND



C. Sum of Squares is the mathematical total of all the squares of coefficient factors. It removes negative values and highlights all elemental relationships.

LEGEND

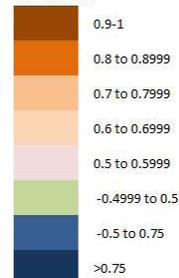


Figure 20: Combined correlation coefficient grids for Etheridge South Province. A. Mean correlation factor, B. Mean of squares, and C. Sum of squares.

### 5.4.2 Regional geochemical associations

Geochemical association has been used to model background geology and mineral system in regional geochemical programs (e.g. Boyle, 1974; Rollinson, 1993; Railsback, 2003). A high positive correlation coefficient factor implies strong and sympathetic element-to-element relationships due to similar chemical affinity from chemical partitioning into the same or similar mineralogy. A strong negative factor implies an antipathetic relationship between the elements due to differing chemical fractionation pathways, and the two elements are not co-genetic. A low factor close to zero implies poor association between the elements with no observable trend between them. Based on correlation coefficient factors, the mean correlation grids are statistically ranked from high to low (Figure 21) to demonstrate the groups of similar speciation elements (Railsback, 2003). The geochemical associations of various elemental groups provide crucial clues for interpreting the nature of sediments within a catchment, and possible information of source rocks and subsequent modifications.

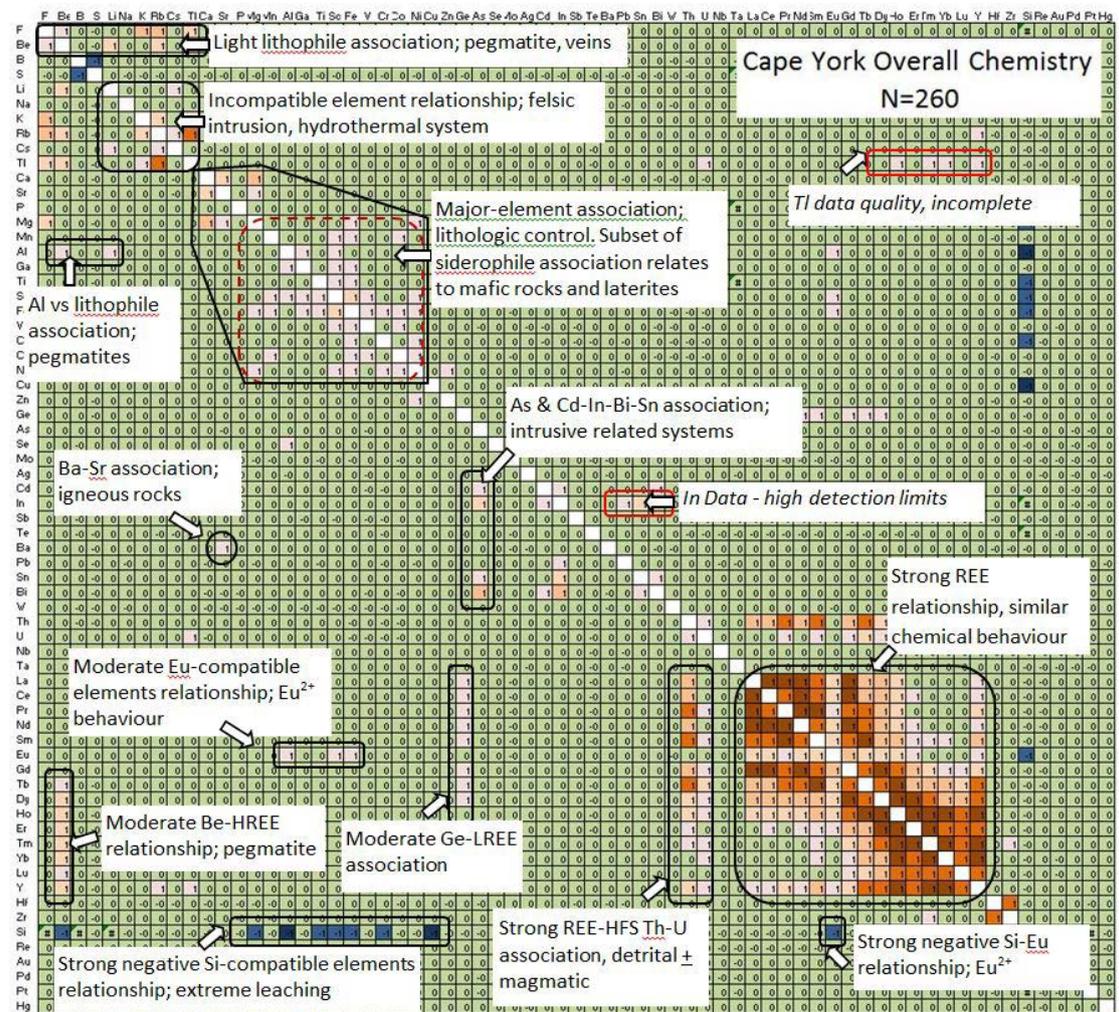


Figure 21: Pearson average correlation coefficient of 260 samples (including 13 repeats) in the Cape York region. The correlation coefficients are the average of all sample types (BOS, TOS, size fraction, and analytical methods) with interpreted causes for the moderate to high inter-element relationships.

The inter-element correlation coefficient grid for the entire Cape York dataset is summarised in Figure 21. It is based on 249 catchment samples and 13 repeat samples, for a total of 262 data points. The grid charts the major elemental associations that dominate the catchment geochemistry of Cape York and overprint minor associations within respective geochemical provinces.

The REE and Y (or REEY) have strong correlation coefficients, and this is expected since the elements share similar chemical and physical properties. REEY are partitioned into accessory phases during magma/fluid fractionation as zircon, allanite, monazite, xenotime, titanite, rutile, garnet, ilmenite and magnetite. These accessory minerals are common constituents of heavy mineral sand that are concentrated by wave or fluvial actions along coastline and river beds in Cape York. REEY are also moderately associated with Th–U (high field strength elements or HFS) and Be, supporting the earlier suggestion of partitioning into accessory phases during fluid/magma fractionation into late oxyphilic phases in pegmatites (Jones *et al.*, 1996). U and Th are common constituents of zircon, allanite, monazite, xenotime and titanite that formed in both late magmatic or pegmatitic conditions (Hanson, 1978). Be is commonly partitioned into beryl in pegmatites (Deer *et al.*, 1993). The lack of relationship between REEY–HFS with incompatible elements (Li, Na, K, Rb, Cs), pegmatite indices (F, P, B) or major rock forming elements (Si, Al, Ca, Mg) suggests that the REEY in Cape York are geochemically removed from the magmatic source and are mainly concentrated as heavy mineral deposits. The negative relationship between Si and Eu suggests that the Eu could be leached as  $\text{Eu}^{2+}$  from prolonged exposure to tropical weathering conditions. Ge association with LREE is questionable, as the Ge results from aqua regia and 3-acid digestions are vastly different and fall outside the QA/QC tolerance. Genesis of Ge does not fit the conventional oxyphilic REE or HFS element association; hence this association is probably not valid.

Compatible elements (Mg, Mn, Al, Ga, Ti, Sc, Fe, V, Co, Cr and Ni) showed moderate correlation coefficient factors which imply lithologic or pedochemical association. These elements are commonly grouped with the siderophilic association that compose mafic to intermediate rocks and base metal ores. However, the absence of relationship with lithophiles, and a negative relationship with Si, suggests that the geochemistry is not directly associated with sub-mantle provenance but with sediments that have undergone extensive surface leaching following the removal of Si and lithophiles and the concentration of oxides. The most likely association of such geochemistry in the Cape York region is a surficial leaching process of lateritisation that concentrates oxide-rich duricrust (Morteani & Preinfalk, 1996). There is a weak relationship between Eu, Al, Sc and Fe. The absence of Eu association with Sr and Ca discounts elemental concentration in plagioclase. The most likely cause is the reduction of Eu to the 2+ oxidation state, which has similar properties to Fe.

A moderate association of LIL (Li, Na, K, Rb, Cs), F and Al suggests a volatile-rich magmatic system typically associated with intrusive rocks and volatile-rich veins and pegmatite. The weak association with Al, Ca, Sr and Ba suggests genetic links to felsic to intermediate igneous rocks. The concentration of LIL implies residual volatile-rich veins or late fractionates in a magmatic system that has the potential for mineralisation.

An interesting multi-element association of As with Cd, In, Bi and Sn suggests potential mineralising indicators in Cape York. This elemental association may result from one or more genetic events. The presence of As suggests a low to moderate temperature environment, and Sn association implies oxidised magmatic fluids typical of vein, skarniferous or disseminated hydrothermal type mineralisation. Sn is an oxyphile that favours late fluid fractionation under oxidising conditions. Bi–Cd–In association favours a siderophilic environment with sulfides. The association of As with Bi could indicate low to moderate temperature hydrothermal systems, commonly as vein-style mineralisation.

Geochemical association with In data is suspicious, as the element analysed by aqua regia digestion and ICPMS finish has relatively coarse detection limits of 0.02 ppm. Forty one per cent of the results are below the detection limits, and these data were recalculated to half the detection limit for the grid computation. The high proportion of <0.02 ppm result is doubtful as it is low compared to the upper crustal rocks average of 0.05 ppm (Taylor & McLennan, 1995). QA/QC of the analytical results referenced to the international standards (GTR-1, GTR-4, GTR-6, OREAS 45d and SAR-M/USGS) showed that In results range from 23% to 118% (averages 75%) of expected concentration, and is outside the tolerance level. The high correlation coefficient factor is most likely artificially computed owing to the consistency of recalculated results.

Tl shows weak correlation to HREEY which cannot be explained. Tl is mostly associated with K minerals in clays, soils, and granites, and also in sulphide ores of copper, lead, zinc, antimony and arsenic, which is not supported geochemically from Figure 9.

#### **5.4.3 Geochemical Province Associations**

The Cape York regional geochemistry is strongly influenced by detrital silica and mineral sand contributions and lateritisation, with minor influence from igneous sources (Section 5.3.2). On a microscale, the geochemistry is further divided into ten geochemical provinces based on tectonic terrane to accommodate the influence of different background geology. Geochemical grid for each province is represented in Figure 22 by the ‘mean square average’ correlation coefficient diagram with annotation of key elemental associations and associated notes for possible genetic models. The ‘mean correlation coefficient’ grids were referred to for minor associations. Discussion of provincial chemical association will focus on the major and unique association within respective areas and will not repeat the regional features discussed in Section 5.4.2. The following section serves to discuss major mineralising systems within each province. Iron Range Province has only four samples, which is too small for accurate geostatistical appraisal and therefore will not be discussed in this section.

#### 5.4.3.1 *The Etheridge Provinces*

The Etheridge Province is divided into the Etheridge South (Georgetown area) and Etheridge North Provinces, which is separated by the Carpentaria Basin (Figure 8). Although the two Etheridge geochemical provinces are regarded as contiguous under Mesozoic cover, geochemical signature showed distinct different polymetallic mineral signatures in the two provinces.

The southern province in the Georgetown area has:

- Strong REEY and Th–U + Zr–Hf association that were attributed to monazite- and allanite-dominated sand accumulation with minor zircon content. The REEY has weak correlation with rock forming elements (e.g. Si, Na, Al) and poor correlation with Fe, Sc, Ni, Cr, V, Co and P, which implies that the REEY are not directly sourced from the sub-mantle, peralkalic or carbonatite sources (Lottermoser, 1990; Sanematsu *et al.*, 2011). The low correlation coefficients with Al, Mg, Fe, Cu and Ni discount a direct lateritic association (Morteani & Preinfalk, 1996).
- A distinct stand-alone Rb–Cs–Tl + F association, which indicates felsic magmatic or hydrothermal contributions. The light lithophile group is not matched by metal association, which is interpreted as a weak mineralisation signature.

The Etheridge North Province has:

- Strong REEY, Th and Zr–Hf association, which suggests the presence of monazite, allanite, garnet and zircon rich mineral sand. The high Zr–Hf concentration associated with REEY and Th is consistent with detrital-sourced heavy mineral sand with significant zircon content. REEY is not correlated to major rock forming elements and Mn, Ni, Cr, V and Co, which discounts a direct laterite source (Morteani & Preinfalk, 1996).
  - Strong Co–Cu–Ni–Zn association with compatible and major elements. This association implies potential Co, Cu, Ni and Zn (siderophile) sulfide-based mineralisation associated with mafic rocks or controlled by the mafic lithology.
  - Moderate Ga–Ti–Sc–Fe–V (oxide forming elements) association correlated to HREEY. This group implies an oxidised environment with the presence of minor resistive heavy mineral sand. The lack of LIL or mobile elements with the oxides suggests extreme chemically leached source rock typified by laterite or duricrust.
  - Pb–Sn–Bi and Rb–Cs–Tl association. The association of LIL with ore-forming elements suggests the presence of an intrusive-related mineralising system with late stage concentration of incompatible elements. The presence of Sn, Pb and Bi implies a polymetallic-style mineral potential, but the geochemical grid has insufficient evidence to ascertain if these metals are co-genetic or derived from different systems.
-

#### 5.4.3.2 *The Palmer–Barron–Chillagoe Province*

The Palmer–Barron–Chillagoe Province comprises three tectonic subprovinces which were conveniently grouped due to insufficient sample population within individual structural terrane. The province has:

- Strong inter-REEY relationship that correlates to U, Th, Rb, Cs, Tl, F, P and Be. The association of REEY with lithophiles and pneumatolitic elements implies a gas/fluid rich magmatic system, possibly associated with veins and/or an epithermal system. The presence of F and P indicates potential fluoroapatite veining that carries U, Th and REEY which may potentially be associated with peralkalic or carbonatite systems (Lottermoser, 1990; Sanematsu *et al.*, 2011).
- Rb–Cs–Tl and Be + Zn–U association, typical of late intrusive-related fluids enriched in incompatible elements. The presence of U and Zn implies oxidised conditions and a late stage fractionation process at relatively low temperatures, which likely formed as vein-related hydrothermal mineralisation or pegmatite. Be is likely partitioned into beryl during late magmatic fractionation that forms pegmatite.
- Sn–W–Bi association. The mainly oxyphilic group is weakly correlated to F and is likely related to late stage fractionates such as greisen-style sheet-veins under oxidising conditions, pegmatites, skarns or late dissemination in reduced magmatic systems. W and Sn formed in minerals such as wolframite and cassiterite.
- Zn–As–Cd–Sb, a sulfur-based ore-forming association related to intrusive systems that can occur as singular, sheeted and stockwork quartz veins, as disseminations in granites and skarns, and as infill in breccia.

#### 5.4.3.3 *The Charters Towers Province*

The Charters Towers Province has a small sample population of 13 and the resulting correlation coefficient is relatively erratic. The province features:

- Strong REEY relationship with Rb, Cs, Tl, Li, Se and Be (lithophiles) and U, Th, Nb and Ta (oxyphiles), which is typical of a magmatic-related system such as veins, sheeted veins, pegmatite or skarn with rare earth accessory minerals. The presence of U, Th, Nb and Ta implies late oxidising stage mineralisation of polymetallic minerals (monazite, titanate, allanite, and zircon) as veins or disseminated veinlets within granite.
- Moderate REEY relationship with Co, Ga and rock forming elements (Al, Fe, Mn), which is interpreted as a pedochemical association derived from laterite. Co, Mn, Ga and Al form oxides, and REEY coexist as resistive heavy mineral sand. U, Th, Nb and Ta associated with REEY may form part of the heavy mineral sand.
- Moderate Cu–Zn association with Fe, Mg, Ca, Ti, Sc, Co, Li and S, which indicates possible association of base metals with mafic rock or weathered mafic duricrust. The presence of Li and S suggest potential primary mineralisation of sulphide minerals associated with intrusive-related fluids.

The sulphides may form veins, disseminations in mafic-intermediate rock or infill in breccia.

- Moderate association of K, Rb, Cs and Tl, which is a strong indicator for a felsic intrusive system with highly fractionated incompatible elements. These elements have a weak relationship with Sn, U and Nb, and these two groups may be related to late stage concentration of incompatible elements under oxidising conditions.

#### 5.4.3.4 *Greenvale – Camel Creek Province*

The Greenvale – Camel Creek Province is made up of the Greenvale and Camel Creek subprovinces, and has a sample population of 13. The unique geochemical features of the province are:

- Strong inter-REEY relationship with U–Th, Pb, Sn, Bi, Se, Zn, Ge, Al, Ga, Tl and Be, but no correlation with lithophiles and major rock forming elements. The array of elements can be split into three ‘like-element’ groups as U–Th–Sn–Al–Ga, Se–Be–Tl and Pb–Bi–Zn–Ge, which have different physio-chemical characteristics and genesis. The presence of three different REEY associations indicate diverse polymetallic mineralisation.
- REEY and U–Th–Sn relationship is commonly associated with weathering resistant minerals and, in the presence of Al–Ga, the absence of mobile elements and a negative relationship with Si suggests leached surface sediments such as laterite.
- REEY association with Se–Be–Tl indicates intrusive-related mineralisation associated with highly fractionated fluids.
- A REEY association with Pb–Bi–Zn and Ge commonly forms sulfidic ores under a magmatic or syngenetic sedimentary environment.
- Mild Sc–Fe–V–Cr–Co–Ni association with no relationship with LIL and a negative relationship with Si, which suggests residual sesquioxide from the breakdown of mafic rocks. The inverse relationship with Si is related to the sediment maturity. This element association may also be the product of sulphide mineralisation.

#### 5.4.3.5 *Savannah Province*

The Savannah Province has only 12 samples that resulted in a relatively low confidence level for the correlation coefficients computations. Only high and confident relationships will be discussed. This province features:

- Strong REEY relationship with U–Th, matched by poor correlation with lithophile and major rock forming elements, and Eu loss. This association is interpreted as the product of surface weathering with the removal of  $\text{Eu}^{2+}$  and mobile elements, and accumulation of resistant detrital minerals under tropical weathering conditions. The province has regionally high geochemical background for REEY and U–Th compared to other provinces (Section 5.2.3), which suggests significant enrichment of U–Th in the catchments.

- Strong Zr–Hf association without REEY, which may result from zircon sand accretion that has few other heavy mineral components. It is likely associated with a silica sand deposit and is deposited as a different product to the REEY enriched mineral sand discussed above.
- Distinct K–Rb–Cs–Tl–Li association, which suggests the presence of felsic intrusive rocks. The felsic intrusive rocks are strongly associated with Sn–Bi, fitting a late stage concentration of incompatible elements with Sn–Bi mineralisation under oxidising conditions. The likely mineral models are the pneumatolytic vein, sheeted vein, greisen or disseminated Sn–Bi in reduced granites.
- Ca–Sr–Al associated with lithophiles, which is the typical signature for intermediate-basic rocks such as granodiorite, tonalite, andesite and dacite. The intermediate rocks are associated with Cu–Zn–Ni–Sc–Fe–V, possibly as volcanic hosted mineralisation or as sulphides veins, disseminations or as breccia infill in mafic-intermediate intrusive rock.
- Weak Si–Pb factor with no other associated element. The association has insufficient information to predict a possible mineralisation model that may include a syn-sedimentary deposit or Pb bearing veins.

#### 5.4.3.6 *The Carpentaria Basin*

The Carpentaria Basin geochemical domain is split into South and North basins along the Mitchell River to limit the influence of source region geology to localised geochemistry. Sedimentary basin geochemistry is a chemical average of different source regions governed largely by the volumetric contributions from respective sources. The northern basin homogenises sediments from the Iron Range, Savannah, Etheridge North and Palmer–Barron–Chillagoe provinces. The Carpentaria Basin South composites sediment from the Etheridge South, Greenvale–Camel Creek and Charters Towers provinces, and is slightly influenced by the Palmer–Barron–Chillagoe Province.

The Carpentaria Basin South has:

- Strong REEY, Th–U, Zr–Hf and Sn–Bi association, which was attributed to detrital mineral sand accumulation, with U–Th from monazite and allanite, Zr–Hf from zircon and titanate, and Sn–Bi from cassiterite–bismuthite. The presence of Sn–Bi in the basin indicates potential Sn–Bi mineralisation in the hinterland.
- Al–Ga–Sc–Ti–Fe association with LREEY accompanied by a negative Si relationship, which is interpreted as sedimentary contributions from laterite with the incorporation of heavy mineral sand. The negative relationship with Si relates to the sediment maturity resulting from strong leaching conditions typical of lateritisation.
- K–Rb–Cs–Tl–Ca–Sr–Ba–Mg–Mn–Al–Sc–Fe association, which is characteristic of sediments derived from felsic to intermediate and mafic rocks. The Eu trough in the REE diagram (Figure 13) suggests that most of the source rocks were fractionated supracrustal rocks. This supracrustal association

is correlated to Zn–Cu–Ni, which will most likely form sulphide-based mineralisation in the source region.

The Carpentaria Basin North has:

- Strong REEY, Bi–Th +U, Zr and K–Rb–Cs–Tl–F–Be association. The association of REEY with resistant Th–Hf +U and Zr is attributed to detrital mineral sand accumulation; there is a possible source for Th–U from monazite and allanite, Zr from zircon, and Bi from bismuthite. The correlation with K–Rb–Cs–Tl–F–Be indicates an intimate association with felsic intrusive provenance in the hinterland, and the REEY may have primary intrusive-related genesis.
- Sc–Fe–V–Cr–Co–Cu group with weak association with Mg–Mn–Al and negative correlation with Si. The association with major elements suggests that the geochemistry is related to the pedochemistry, and the negative relationship with Si reflects sediment maturity from tropical leaching of surface sediment in the formation of laterite.
- Ni–Zn association with Ca–Sr–Mg–Mn, which is interpreted as potential Ni–Zn mineralisation associated with intermediate rocks such as andesite.

#### 5.4.3.7 *The Laura Basin*

The Laura Basin incorporates sediments from the Iron Range, Savannah, Etheridge North and Palmer–Barron–Chillagoe provinces. The geochemical grid is based on 13 samples and has a low-moderate confidence level for the correlation coefficients. The Laura Basin demonstrates:

- REEY, Th, Mn, Al, Sc Rb and Tl association and negative Si correlation. The association of REEY with Th, Mn and Al and the negative relationship with Si suggest that the chemistry is eroded from laterite horizon that contains stable Mn, Al and Sc oxides and leached Si content. Rb and Tl cannot be derived from the same laterite and have to be derived from late magmatic fractionates that concentrated incompatible elements.
  - The correlation of LIL (Na–K–Rb–Cs–Tl–Li) with F–Be–Ba–Al and Sn–Bi–Th–U–Nb–S–Ta, which strongly suggests felsic to intermediate intrusive-related influences in the hinterland. F, Be and oxyphilic elements are commonly associated with veins, sheeted veins or dissemination in veins, and breccia infills of intrusive systems. The Bi–S is sulfidic and may be derived from a separate vein intrusive-related system.
-

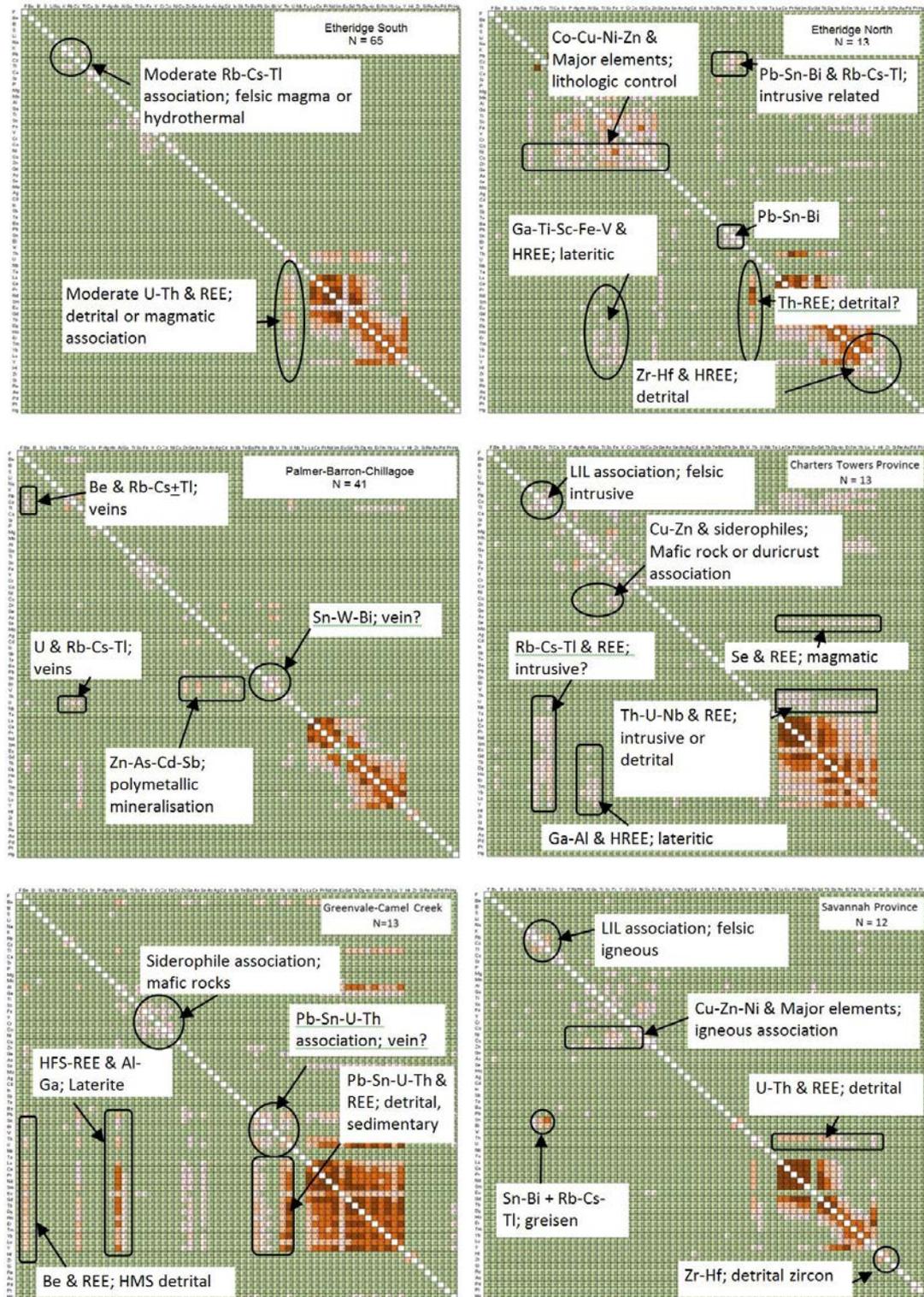


Figure 22: The correlation coefficient of the mean square averages of all sample types from different tectonic terranes in the Cape York region. Only unique moderate to high correlation relationships of the specific terrane are highlighted and/or explained. (Figure 22 continued on next page).

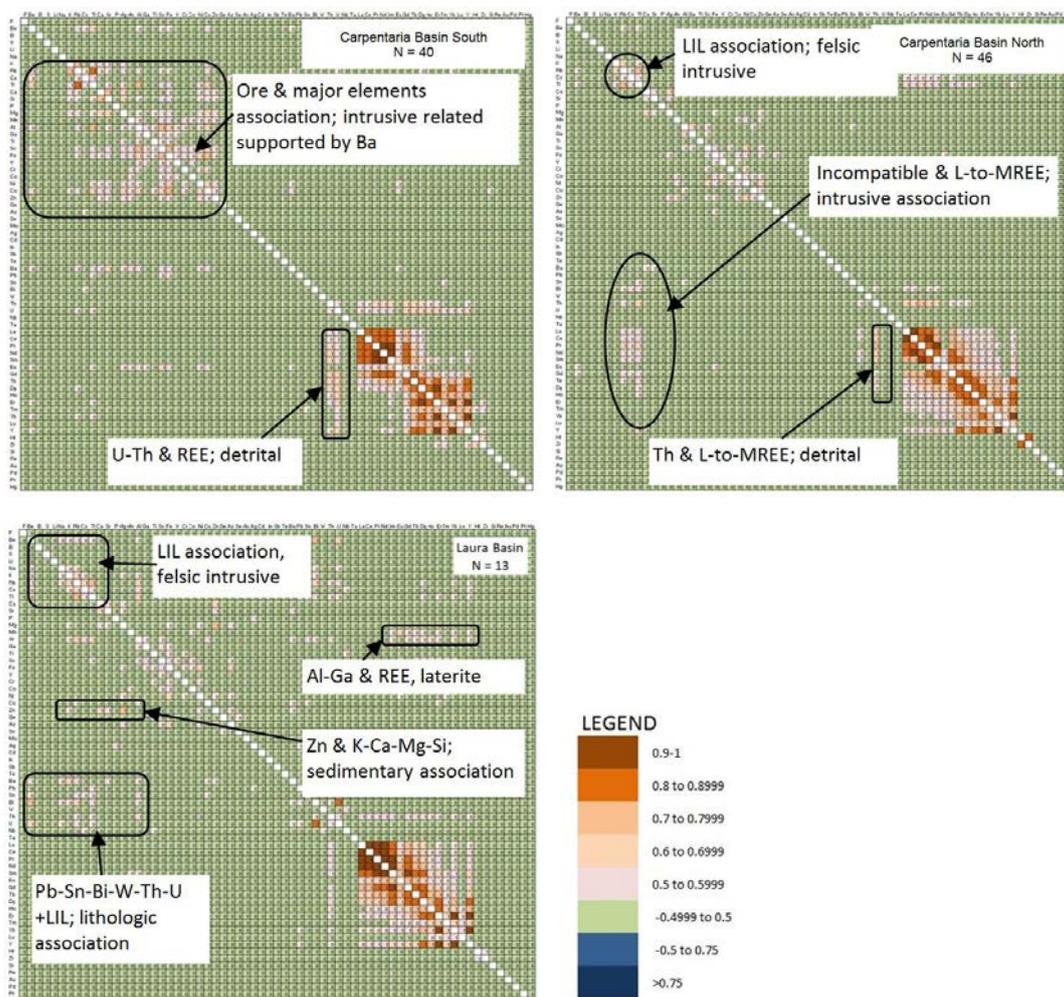


Figure 22 (continued): The correlation coefficient of the mean square averages of all sample types from different tectonic terranes in the Cape York region. Only unique moderate to high correlation relationships of the specific terrane are highlighted and/or explained.

## 5.5 Geochemical Associations and Predictive Mineral Models

The Cape York geochemistry is compiled from nine analytical subsets which vary according to analytical methodology, depth and grain size. Individual datasets were statistically ranked based on elemental concentration within catchment cells into the eight groups discussed earlier. Elements showing elevated (>90th percentile) concentration in each dataset were collated into chemical associations. The associations were classified into three groups:

1. Primary Chemical Association is defined for an element or group of elements that showed consistent elevated or anomalous concentrations for most or all of its nine analytical subsets within a catchment. The primary association is a robust grouping of anomalous chemistry that persists in all analyses, depth and grain size and is regarded as a true anomalous chemical representation of the catchment. This association is used as the primary evidence-based modelling for mineralisation and for potential commodities associated with the catchment area.

2. Secondary Chemical Association is defined by geochemical enrichment for one or more (but not all) of the sample types. This association assumes the ‘nugget effect’ of geochemical sampling, and the elements are not equally distributed in different grain size or depth profile.
3. Tertiary Chemical Association is assigned to an element or group of elements that rank between the 75th and 90th percentile for some or most of the analytical subset, but are not considered anomalous. This association may represent a distal geochemical signature resulting from dilution, concealment or contamination. It is a useful association for potential mineral system modelling and requires further work to confirm the association.

Table 6 summarises the geochemical association of all catchments in Cape York based on the criteria above. Not all catchments can be assigned a chemical association. The absence of association means that its chemistry is either below the threshold for geochemical consideration, or that the catchment has no consistent chemical characteristics.

The mineralisation models are interpreted from the combination of the three chemical associations most diagnostic of major mineral systems (e.g. Cox & Singer, 1992; Boyle, 1974). The Primary Chemical Association is regarded as a real and repeatable group of coexisting elements either through syngensis or syndeposition. Models are constructed using ‘like-element’ groups such hydrophiles, lithophiles, oxyphiles, siderophiles, major rock forming elements, etc. instead of individual elements. They are based on understanding the behaviours of these natural occurring sets in magmatic, atmospheric, sedimentary and pedochemical processes (Railsback, 2003), and behaviours of chemical partitioning in minerals (Hanson, 1978). Mineralisation models are very subjective and strongly depend on the knowledge and experience of the authors within the limit of geochemical interpretation. All models are subject to refinement with better understanding and/or field observation of local geology or mineral systems.

The basic assumptions used in the modelling are:

- Incompatible large ion lithophiles are concentrated in late magmatic systems and late hydrothermal fluids during fractionation or ore forming process, in veins, pegmatites or related to magmatic or intrusive source
- Lithophiles are late magmatic differentiates concentrated in felsic to intermediate rocks, felsic dykes and pegmatites
- Compatible major elements are rock forming minerals that are partitioned into mafic minerals in mafic to intermediate rocks
- Hydrophiles and volatiles are associated with late fluids or gases during late stage differentiation, hydrothermal and epithermal alteration
- Oxyphiles form mainly in veins, stock work or dissemination at high intrusive levels
- Siderophiles form as veins, stock work or breccia infills, associated with hydrothermal systems or in veins or stock work
- REEY, Sc, Sn, W, Nb, Ta, Ti, U and Th occur as polymetallic veins, sheeted veins or accumulated as heavy mineral sands
- Ca–Sr occurs either in calcareous or calc-alkaline rocks.

**Table 6: Geochemical associations within the Cape York catchments.**  
**Each catchment has been assigned with interpreted mineralisation model(s)**  
**and potential commodities.**

FIELD_ID	Primary Chemical Association	Secondary Chemical Association	Tertiary Chemical Association	Geochemical Based Mineral Model 1	Geochemical Based Mineral Model 2	Source region interpretation	Potential Commodity
TS0858	Si	Zr, Hf		Silica sand		Coastal sand accretion, minor zircon content	Si
TS0859		Si, Zr	Ti, Al, se	Mineral sand/ placer deposit		Heavy zircon-bearing minerals in detrital deposits, overprinted by lateritisation.	Si-Zr
TS0860	Mo, Se	S, Na, Eu, Cl, Li, Al, U, V, Tb, Dy	K, As, Sm	Hydrothermal/ intrusive related system	Detrital?	Pegmatite to granitic system dominated by albite, REE and Mo mineralisation.	Polymetallic
TS0861	Te	Ag, Zr, Se	Zn, Cu, Pb, Ca, Re	Hydrothermal/ intrusive related system		Low levels of polymetallic elemental concentration, such as hydrothermal origin	Polymetallic
TS0862	Si, Te	Hf, Zr	Se	Silica sand		Silica sand with minor zircon content	Si
TS0863		Hf, Zr		Mineral sand		Zircon-rich sand in fluvial system	
TS0863_01		W, Co	Mn, Cd, La, Pr	Veins	Laterite	W-Co veins associated with quartz	W-Co; Mn
TS0863_04	V, Mn, Co	Ba	Al, Fe, Sc	Laterite		Lateritisation with sesquioxides remaining	V-Co-Mn
TS0863_05						NIL	
TS0863_06	V, Co, Fe, Sc, Mn, Al, Eu	Li, Ba, Ga, Ti		Laterite		Concentration of Mn-Co-Sc-V-Ni-Fe-Eu-Al-Ga suggests lateritisation of mafic marine sediments. Li-Ba indicates overprinting hydrological or hydrothermal chemistry.	Co-Fe-Mn-V
TS0864	Al, Ga, Sc, Zr, Hf	Li, In, Mo, In, Ti	Se	Bauxite		Bauxite derived from intermediate rocks, incorporates hydrothermal signatures with Li-Se-Bi-Te-Cs. U-Sn-Zr indicates detrital/aeolian mineral sand	Al-Ga-Sc
TS0865		Hf-Zr		Mineral sand		Zircon bearing sediments	
TS0866			Fe, V, Mn	Laterite		Lateritisation with resistant oxides remaining	
TS0867						NIL	
TS0868	Mo	Na, U, Ti, Zr	Sc	Hydrothermal/ intrusive related system	Mineral sand	Likely REE enriched albite-rich vein in felsic intrusive with Mo mineralisation.	Mo-U-Sc?
TS0868_01		Hf	Eu			No model	
TS0868_02		Co, Fe	V	Laterite		Laterite, mafic-intermediate rocks	
TS0868_03			Fe, Mg, V, Co, Cr	Laterite		Laterite, mafic-intermediate rocks	
TS0868_04		Mn, Fe, V	Co, Fe	Laterite		Laterite, mafic-intermediate rocks	
TS0868_05		Mn				Mn-V marine or basinal sediment?	
TS0869	Co, Eu, Fe	Tb, V, Ba, Mn, Ni, Pd, Y	Sr, Yb	Laterite		Lateritised marine volcanics mixed with mineral sand.	Co-Fe; Eu
TS0870		Pd	Al			No model	
TS0870_01			Tl, Mn, Sc, Fe, Ba			Tl associated with Mn modules? in marine sedimentary rocks	
TS0870_02		K, Rb, Hf	Zr			Detrital and duricrust, residual mineral concentration	
TS0871						NIL	

Table 6 (continued)

FIELD_ID	Primary Chemical Association	Secondary Chemical Association	Tertiary Chemical Association	Geochemical Based Mineral Model 1	Geochemical Based Mineral Model 2	Source region interpretation	Potential Commodity
TS0871_01		La, Ce, Pr, Sm, Th	Al, Ga, Cs, Pb, U, Be, Nb, Nd, Rb, Se	Mineral sand		Minerals liberated from intrusive-related source	Polymetallic
TS0871_02	Rb, Tl, Cs, Sn	Bi, U	K, Dy, Er, Ho, Tb, Tm, Y, Lu, Pb Isotopes	Pegmatite/greisen	HMS, Sheared related	Felsic hydrothermal association with U and REE, vein or infills associated with regional shear/breccia zone	Polymetallic
TS0871_03	Ce, Nd, Tb, U	Th, La, Pr, Sm, Gd, Dy, Tl	Ho, Au	Veins	REE vein	Intrusive related REE veins, likely deposited as detrital minerals with traces of Au-U-Th, explore for regional shear zones as fluid pathways	REE
TS0871_04	V, Eu	Mn, Al, Sc	Co, Fe	Laterite		Laterite, mafic-intermediate rocks	V
TS0871_05		Tb, Tl, Gd	Pr, Sm, Fe, Bi, Pb, Rb, S, Th, Y	Mineral sand	Intrusive related source	REE and HFS minerals associated with felsic intrusive or veins	
TS0871_06		La, Ce, Pr, Sm, Nd, Dy, Th	Gd, U	Mineral sand		Mineral sand	
TS0872	Li, Al, Fe, Mo	Gd, Dy, Er, Yb, Na, Sc	K, S, Eu	Laterite	Intrusive related source, alkali rocks?	Lateritisation of granite-related Mo-W mineralisation, overlain by heavy REE sand.	Al, Li, Mo
TS0872_01		Si, Eu		Silica sand		Silica sand deposit	
TS0872_02			V, Zr	Mineral sand		No mineralisation index, potential for zircon sand	
TS0872_03		Li, Ba		Hydrothermal/intrusive related system		Possible hydrothermal system, weak geochemical signature	
TS0873			Mo	Hydrothermal system		Hydrothermal signature for Mo-Sn system in microgranite	
TS0873_01			Ba			No model	
TS0873_02						NIL	
TS0873_03		Sc, Ni	Li, Ba, Be, Zn, Al, Co, Fe, Mn, Y			Retention of insoluble oxides from lateritisation, weak hydrothermal signature for Li-Ba-Be-Zn from felsic intrusive.	
TS0874	U	Sb	Be, Se, Pb, Ba, Th, Sc, U	Veins		U-Th-Pb-Sb-Be veins in felsic intrusive; possible breccia or metamorphic related mineralisation	U-Be
TS0874_02			Pb isotopes	Shear associated		Proximal to shear zones?	
TS0874_03			U, Pb isotopes	Shear associated		Shear or hydrological related potential U mineralisation, proximity to shear zone?	U
TS0875		Re	Mn			Metamorphic to metasomatic source?	
TS0876		Re, Se				Metasomatic source?	
TS0877						NIL	
TS0877_01						NIL	
TS0877_02						NIL	
TS0878						NIL	
TS0878_03			Ce, Gd, La, Nd, Pr, Sm	Mineral sand		Mineral sand inclusion	
TS0879						NIL	
TS0880			Si			Silica-rich sand	
TS0881			Si			Silica-rich sand	
TS0881_01		Sb				No model, veins in metamorphic rock?	
TS0881_02	Pd					Placer deposit?	

Table 6 (continued)

FIELD_ID	Primary Chemical Association	Secondary Chemical Association	Tertiary Chemical Association	Geochemical Based Mineral Model 1	Geochemical Based Mineral Model 2	Source region interpretation	Potential Commodity
TS0881_03		Au	K, Ce, Gd, La, Nd; Pr, Sm, Th, U; Pb isotopes	Shear associated		Fracture or shear infill	
TS0882						NIL	
TS0882_02	Pd	Co	Al, Cu, Mn, Sc, V	Mafic rocks		Metalliferous mineralisation associated with mafic marine volcanic rocks, potential for Pt-Pd	Co-Mn
TS0882_03						NIL	
TS0882_04	Pd, Pt		Cu, V	Mafic rocks		Pd, Pt, Cu-Au mineralisation associated with mafic rock? Note Pd-Pt concentrations are very low.	Cu
TS0882_06						NIL	
TS0883						NIL	
TS0883_01		Cs, P				No model	
TS0883_02		P	S	Phosphatic soil		Phosphate rich sediments	P
TS0883_03						NIL	
TS0883_05		P		Phosphatic soil		Phosphate rich sediments	P
TS0883_06						NIL	
TS0883_07			Sr, P	Phosphatic soil		Phosphorus rich sediments	Sr-P
TS0883_09						NIL	
TS0884						NIL	
TS0885			Ba, Cs, Ga, La, Pb, Re, Te; REE			Strong MMI results for REE; mineral sand, vein, dykes from intermediate magma?	
TS0885_01						NIL	
TS0885_02			Cr			Silica-rich sand	
TS0885_03	Cr, Pd, Pt, Li	Be, Cs, Na, Ni	Ba, As, F, Co, Cu, Mn, W	Veins		Polymetallic association, hydrothermal alteration of intermediate-mafic rocks, epithermal conditions in oxidised setting.	Be, Cr, Ni
TS0885_04		Pd, Pt				No model, place deposit?	
TS0886	Si	Pd		Silica sand		Localised silica sand enrichment	Si
TS0886_01A		La, Pr, Nd, Sm, Ba, Pb isotopes	Gd, Tb	Mineral sand	Sheeted vein, pegmatite	REE in mineral sand, possibly derived from sheeted veins and related to shear zones	REE
TS0886_01B	La, Ce, Pr, Nd, Sm, Gd, Tb, Th, U	Dy, Ba	Au, Ho, Pb isotopes, Y	Mineral sand	Sheeted vein, pegmatite	REE bearing mineral sand, likely derived from sheeted veins or pegmatites	REE
TS0886_02	Si			Silica sand		Silica sand deposit	Si
TS0886_03	Si		Al, Cr, Fe, Ga, V; Nb, Sb, Sn, Ta, Ti, W, Zr	Silica sand		Silica and mineral sand, possibly metasomatic fluid overprint in source region	Si
TS0886_04		Cr				No model	
TS0886_05			Pb, Na, Au, REE			Weak Pb-Na-Au and REE association related to intermediate intrusive	
TS0887_01			Ta-Nb-Ti			Possible Ta-Nb-rutile quartz-albite vein association.	
TS0887_02						NIL	
TS0887_05						NIL	
TS0887_06						NIL	
TS0887_07		Nb	Ta, S, Sn, Ti			Weak greisen signature for Nb-Ta-S-Sn-rutile quartz association	
TS0888						NIL	

Table 6 (continued)

FIELD_ID	Primary Chemical Association	Secondary Chemical Association	Tertiary Chemical Association	Geochemical Based Mineral Model 1	Geochemical Based Mineral Model 2	Source region interpretation	Potential Commodity
TS0888_01			Al, Cr, Fe, Sc, V; As, Ba, Ce, La, Mo, P, Sb, Zr			Polymetallic association with Al-Cr-Fe-Sc-V related to lateritisation, As-Ba-Ce-La-Mo-P-Sb and Zr likely from hydrothermal fluids	
TS0888_02						NIL	
TS0888_03			Si	Silica sand		Silica dominated sediments	
TS0888_04			P	Phosphatic soil		Phosphorus rich sediments	
TS0888_06		La	Ce, Dy, Eu, Gd, Nd, Pr, Sm, Tb, Ho	Mineral sand	Sheet veining	Heavy mineral sand possibly derived from sheet veining	REE
TS0888_07			As, Hg, S			Weak indication for epithermal mineralisation	
TS0889	Se	Li	Al	Veins	Intrusive related veins	Veins associated with intrusive rocks.	Se, Li
TS0890						NIL	
TS0891		Re				NIL	
TS0891_01						NIL	
TS0891_02		Au, Sb	Hg, Zr	Epithermal system	Skarns	Distal signature for skarn and/or epithermal association; Sb-Hg-Au-Zr veins.	
TS0891_03			Mo, Ni, Hg, S, Pt, Cr	Veins		Weak mineralised signature; veins in mafic-intermediate rock,	
TS0891_05	La, Ce, Pr, Nd, Sm, Th	Gd	Eu, Tb, Dy, Ho, Mg, Ti, S, Pt	Mineral sand		REE bearing mineral sand	REE
TS0891_06			As, Au, Cr	Hydrothermal/intrusive related system		Cr-sulfides, possibly related to hydrothermal Cr-S-As-Au system	
TS0891_07	La, Ce, Pr, Nd, Sm, Gd, Cu, Pd, Pt	Sc, V, Th, Ti, Tb, Ti	Al, Fe, Ca, Mg, Co, Cr, Eu, Se	Hydrothermal/intrusive related system	Mineral sand	Multi-element fluids associated with breccia zones, skarn or polygenetic porphyry systems	REE
TS0892						NIL	
TS0893						NIL	
TS0893_01		La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Ge, Th, U, Y, Sb	Ti, Tm, Na, S	Mineral sand	Veins	REE heavy mineral sand e.g. monazite, derived from quartz-rich sheet vein; concentrated in the TOS	REE
TS0893_02		Sb	As, La, Pr, Nd, Sm, Eu, Gd, Tb, Dy, S, Pt	Mineral sand	Veins	REE heavy minerals accumulation; also incorporated weak evidence of epithermal and metasomatic fluids chemistry	REE
TS0893_03			As, Ag, Au, K, Pt	Hydrothermal/intrusive related system		Vein-type mineralisation, likely associated with quartz	
TS0893_04			Au, B, Zn			Low temperature replacement type or epizonal deposit	
TS0893_05						NIL	
TS0893_06						NIL	
TS0894				Yb		NIL	
TS0895						NIL	
TS0895_01	Li, Cs, Rb, Tl, Be, Sn, U, Bi, W	Nb, Ta	Gd, Tb, Dy, Ho, Er, Tm, Y, K, Te, Ca, P, F, As, Ag	Hydrothermal/intrusive related system	Veins within granites	Hydrothermal system associated with alkali rocks, greisen and REE-U-Th mineralisation	REE, Li
TS0895_02	Cs, Sn	Li	Rb, Ta, Au	Pegmatite/greisen		Felsic fractionates or epizonal system, oxidised with traces of gold	Sn, Li
TS0895_03						NIL	

Table 6 (continued)

FIELD_ID	Primary Chemical Association	Secondary Chemical Association	Tertiary Chemical Association	Geochemical Based Mineral Model 1	Geochemical Based Mineral Model 2	Source region interpretation	Potential Commodity
TS0895_04		Au, Sb	Hg	Epithermal system	Veins	Epithermal system, quartz vein or along metasomatic zones.	Au-Sb
TS0895_05		Sb	P, S, Cs, Au, Zn	Phosphatic soil		Phosphate-rich source with overprinting epithermal signatures, quartz vein along metasomatic zones	P
TS0897		Co	Mn	Hydrothermal system	Veins	Weak hydrothermal signature, distal source region?, Co-Mn mafic veins	
TS0899_01			Dy, Er, Ho, Th, Tm, Y, Be	Mineral sand	Be dykes	Minor geochemical association of REE and HFS elements, detrital mineral deposits	
TS0899_02						NIL	
TS0899_03			As, Bi, Fe, Hg, La, Rb, Zr, Ce, Pr			Weak epithermal signatures, weakly mineralised. Possible as disseminated altered zone	
TS0899_04			Tm			No model	
TS0899_05						NIL	
TS0899_06			Cr, Cu, Ti, Hg, B, Ag	Hydrothermal/intrusive related system		Low temperature hydrothermal altered porphyry system?	
TS0899_07		Au, W	Ag, Be, Th, Cs, Te, Pb, Hg	Placer deposit	Intrusive related	Heavy mineral sand, placer, likely intrusive related veins, potential polymetallic Au-Ag, Pb, Be-Te veins	Au-Ag
TS0899_08						NIL	
TS0899_09	Th		Nd, Sm, Zr, B	Mineral sand	Vein type	Heavy minerals concentration, possibly sourced from intrusive related quartz-rich veins	Th
TS0899_11		Th, Tm	Dy, Er, Ho, Lu, Yb, Mo, Be, Te, Gd, Y, Zr	Veins	Mineral sand	Felsic intrusive related REE and Mo mineralisation in quartz veins or aplite	Mo-REE
TS0899_12			Au, Ag			Au-Ag veins or placer deposit?	
TS0900						NIL	
TS0901_01			As, Sn, Bi, Se, Th, Au	Hydrothermal/intrusive related system		Weak epithermal metasomatic, vein or replacement type mineralisation; polymetallic	As-Bi-Sn-W-Zn-Mo
TS0901_02	Pb, Pb isotopes	Cd, Hg	B	Epithermal system	Hydrothermal/intrusive related system	Epithermal mineralisation	Pb-Cd
TS0901_03	As, Bi, Cd, Cu, In, Pb, Pb isotopes, Sb, Sn, W, Zn	Cs, Tl, Rb, Be, F, Ag, Mo, Tm	Au, Dy, Er, Yb, U	Hydrothermal/intrusive related system		Polymetallic high sulfide hydrothermal systems associated with felsic intrusions. High F-Cs system may indicate sheet vein association with REE, Sn-W, Y	Ag, As, Be, Bi, Cd, Cu, F, Mo, Pb, Sb, Sn, W, Zn
TS0901_04		Bi, Cd, Zr, Hf, Th	Na, Au, Ca, Lu, Te	Veins		Oxidised intrusive related fluids, disseminated in host rock or as veins swarm	Cd-Th-Bi
TS0901_05	Cd, As	Ca	Ag, Cu, Pb, Pb isotopes	Veins	Skarn	Polymetallic veins, possible skarn	Cd-Pb-As
TS0901_06	W, Sn	Bi, In, As, Cd, Sb	Th, Nb, Tm, Zr, Cs, Sb	Mineral sand	Intrusive related system	Heavy mineral from intrusive related fluids as veins; weak polymetallic mineralisation signatures	
TS0903						NIL	
TS0905						NIL	
TS0908_01			Se, Ce, Gd, Ge, La, Nd, Pr, Sm, Tb,	Mineral sand		Heavy REE minerals possibly concentrated as mineral sand.	Se-REE

Table 6 (continued)

FIELD_ID	Primary Chemical Association	Secondary Chemical Association	Tertiary Chemical Association	Geochemical Based Mineral Model 1	Geochemical Based Mineral Model 2	Source region interpretation	Potential Commodity
TS0908_02	La, Pr, Nd, Gd, Tb, Ce, Ge	Sm, Eu, Dy	Ho, Eu, Se, Th, U, Y, B	Mineral sand	Veins	Dense refractory minerals possibly concentrated in minerals sand, likely sourced from veins.	REE
TS0908_03	Mg	Ca, Sr	K, Ni, Cu, Au, Te	Mafic rocks		Strong indication of hydrothermal fluid overprinting intermediate rock. Likely skarn or sheeted-vein in intermediate rock. Weakly mineralised	
TS0908_04		Hf	Se, Nb	Veins		Se-Nb-Hf minerals likely as veins within felsic-intermediate intrusive.	Se-Nb
TS0908_05			Mo, Cr			Distal signature for Mo-Cr mineralisation, possibly relate to vein or dissemination in intrusive.	
TS0908_06	Be, Lu, Er, Tm, Yb, Y	Cr, Ho, Hf, Ta	F, Li, Zr, Sm, Nb, Dy, Ni, Tb	Veins		Intrusive related veins with REE and oxide minerals	REE
TS0908_07		Sb, Ta	Be, Er, Ho, Lu, Tm, Yb	Veins		REE enriched veins in intrusive	Be-REE
TS0908_08	Sm, Dy, Ho, Tm, Yb, W, Y, Ce, Gd, Tb, Er, Lu, Pr, Nd	K, Rb, Th, Ga, Ag, Eu, Ga, Nb, Ta	La, Pb, Li, Mo, U	Veins		Oxidised veins with oxyphilic minerals, likely sheeted-vein or network veining system.	REE
TS0908_09	As, Be, F, Lu	Bi, Nb, Ta, Sb, Yb, Hg	Cu, Er, Ga, Ho, Se, Dy, Ge, Mg, Sn, Tb, Tm, Y, Ag, La	Veins		Fluorite-rich veins enriched in REE and oxyphilic minerals	As, Be, F, Nb
TS0908_10	Ca, Tm, Lu, Yb, Tm, Er, Y	Be, Nb, Ta, Dy, Ho, Sr, Sb	Mg, Ni, P, Se, Tb, Gd, Sn	Veins	Skarn	Skarn or veins associated with intermediate rocks, REE minerals	Sn-W-REE
TS0909_01			Co, Mn, Fe, Al, Ga; Sr, Ba, Be, F; Cu, Mg, Pb, Zn, Pt, Ni, V	Mafic vein related		Intermediate –mafic rock, weak hydrothermal overprint and lateritisation.	Co-Mn
TS0909_02	Au, Hg	F, Cu, Sb	Ti, K, Rb, Ce, La, Nd, Pr, Sm	Epithermal system	Vein	Epithermal gold mineralisation.	Polymetallic
TS0909_03		Sb				No model	
TS0909_04	Ba	Sb				Quartz-rich veins	
TS0909_05	F	P, K, Rb, Tl, B, Sb	Se, Ce, Ga, La, Mg, Nd, Pr, Sm, Gd, Th, U, Dy, Ge, Tb, Nb	Pegmatite/greisen	Veins	Fluoroapatite veins or greisen; weak mineralisation likely associated with alkalic intrusion	Polymetallic
TS0909_06	Au	Hg, Sb	Se, Pb, Pb Isotopes	Epithermal system	Shear related	Epithermal system, low temperature	Au
TS0909_08		Au	Ge, La, Ce, Nd, Cr, Sr, Ag	Placer deposit	Stratiform	Mineral sand deposit with placer gold; possible Pb-Ag stratiform deposit	
TS0909_09			La, Nd, Se, Ti, Ce, Gd, Ge, Pr, Sm, Tb, Th, Au	Mineral sand	Stratiform	REE minerals in stratiform or detrital concentrations.	REE
TS0909_10			Cr			No model	
TS0910_01			Mn, Co, Ba, Pb, Ge, Tl, Al, Ga	Lateritic mafic rock	Salt influence	Lateritised mafic or stratiform marine shale?	
TS0910_02			Al, Ga, Ba	Laterite		Lateritised sediments or shale	

Table 6 (continued)

FIELD_ID	Primary Chemical Association	Secondary Chemical Association	Tertiary Chemical Association	Geochemical Based Mineral Model 1	Geochemical Based Mineral Model 2	Source region interpretation	Potential Commodity
TS0910_03	Zn	Cu	Rb, Ge	Stratiform Zn-Cu		Stratiform replacement type deposit	
TS0913_01			K			No model, clay?	
TS0913_02		Be	Se, Tm, Tb	Veins	Dyke, pegmatite	Intrusive related dyke or vein	Be
TS0913_03		Na, Ba, Sr	Cr, P			Arkosic rock	
TS0913_04						NIL	
TS0914		Pd				No model	
TS0920	Se	Y, Al, Be, Nb, Er, Tm, Yb, Lu	Cs, Tl, Th, Zr, Ga, Ag, Re, Zn	Hydrothermal/ intrusive related system	Laterite	Lateritised intrusive with traces of mineralisation and REE	Al
TS0925		Zn, K				Stratiform Zn-clay deposit?	
TS0925_02		Sb	Mo, Au, Cr, B	Veins		Au-Cr-Mo-Sb veins from porphyry related fluids, minor enrichment	Cr
TS0925_03						No model	
TS0925_04			Ag, Te, F	Veins	Intrusive related	Intrusive related fluid, unmineralised	Polymetallic
TS0925_05		Sb	As	Hydrothermal/ intrusive related system	Epithermal system	Hydrothermal to epithermal systems	
TS0925_06	F		Ba, Ag, Te, Zr, Pd	Veins	Intrusive related	Intrusive related fluid, fluorite-rich veins in alkalic intrusion?	Polymetallic
TS0925_07			F, K, Tl, Mg, Ge, Re, Ti	Mafic rocks		Intrusive related fluids, mafic alkalic rocks?, unmineralised	
TS0925_08	Ti		F, K, Mg, Re, Tl	Mafic rocks		Intrusive related fluids, mafic alkalic rocks?, unmineralised	
TS0925_09	F		K, Tl, Te, B, Mg, Re, Ti	Veins		Fluorite-rich veins in alkalic intrusive, unmineralised	
TS0925_10		F, K	Ca, Mg, Re, Ti, Tl, Mo, Nb	Mafic rocks		Intrusive related fluids, mafic alkalic rocks?, Mo-Nb traces	
TS0925_11		Sb				No model	
TS0925_12	F, Li	K	Rb, Cs, Tl, Fe, Mg, Zn, V, B, Al, Ga, Sc, Re, Ti, Ag	Hydrothermal/ intrusive related system		Felsic or alkalic intrusive with Zn-Ge-Ag traces.	Polymetallic
TS0925_13		Au, Sb, F	K, Rb, B, Te, La, Nd, Se, Ce, Gd, Pr, Sm, Ga, Ge, Fe, Mg, Dy, Ho, Tb, Th, Hg, Ag	Veins	REE vein	REE veins from felsic or alkalic intrusive, likely metasomatic/metamorphic rocks, Au-Sb-Ag mineral potential likely as veins	REE
TS0928						NIL	
TS0930		Sn		Veins		Sn veins	
TS0930_01	Bi, In, As, Sn	Cu, Cd, Co, Lu, Er, Tm, Yb, Hf, W, Zn	Sb, Ho, Nb, B, Be, Ag, Pb, Pb, isotopes, Ti, Zr, Y, Yb	Hydrothermal/ intrusive related system	Detrital?	Porphyry related mineralisation, epizonal with As, Cu-Bi-Zn mineralisation. Possible later Sn-W-Nb-Hf-Be veins overprint.	Polymetallic
TS0930_02	Co, Cr, Fe, Ni, P, Nb, Ti	Zn, Zr	Ca, Mg, V, Sr, B, Ag	Hydrothermal/ intrusive related system	Mafic rock related mineralisation	Alkalic and phosphate rich magmatic fluids with Zn-Ag-Co-Cr-Ni-Ti enrichment. Vein swarm associated with porphyry system? Phoscorite?	Polymetallic
TS0930_03						NIL	

Table 6 (continued)

FIELD_ID	Primary Chemical Association	Secondary Chemical Association	Tertiary Chemical Association	Geochemical Based Mineral Model 1	Geochemical Based Mineral Model 2	Source region interpretation	Potential Commodity
TS0930_041	Bi, In, As, Zn, Cu	Sn, Tl, Cd, Pb, Tl, W	F, Rb, Sm	Hydrothermal/ intrusive related system		Polymetallic systems related to felsic intrusive. Possible multiphase epithermal mineralisation with As, Pb-Zn replacement to Cu-Bi minerals.	Polymetallic
TS0930_042	As, In, Bi, F, Sn, Ta, Tm, Yb, Lu, W, Y, Zn	Cr, Er, Rb, Ta, Hf, Mo, Pb, Pb, isotopes	Cs, Be, Nb, Yb, Cu	Pegmatite/ Greisen	Hydrothermal/ intrusive related system	Polymetallic and REE associated with granite; hydrothermal to vein-type deposits similar to greisen or possibly sheet-vein mineralisation.	Polymetallic
TS0930_05	As, Bi	Rb, Sn, W	Cr, Tl, Pb, Pb, isotopes, Sn, Y	Hydrothermal/ intrusive related system		Mineralisation related to hydrothermal systems, possibly within felsic intrusive	Polymetallic
TS0930_06		Rb, Ce, Pb, Pb, isotopes	Tl, Cr, P, Mn, Ti, Tm	Veins	REE vein	REE veins and intrusive, complex association, model uncertain but could be related vein, stratiform ore or breccia infilling	REE
TS0930_07	Cr		Mo, Mn	Laterite	Mafic rock related mineralisation	Laterite from mafic rocks	Cr
TS0930_08	Cr, Ni, Ti	Co, Fe	Mn, Cu, V, B	Mafic rocks	Laterite	Mafic rock chemistry association with low REE content. Potential orthomagmatic mineralisation	Co, Cr, Fe, Mn, Ni, Ti
TS0930_09			Bi, Cu, As, B, Pb, Zn, Cd, Sn, Te	Veins	Intrusive related vein type	Polymetallic association related to complex porphyry system as veins (singular or swarm) or dissemination in intrusive	Bi, Cu
TS0930_10			Er, Pb, Ag	Detrital mineral sand		Possible detrital accumulation, weak REE and HFS element association	
TS0930_11						NIL	
TS0930_12						NIL	
TS0930_15	Al, Ga, Be, Ge, Y, U, Tb, Dy, Tm, Yb, Ho, Er, Lu, Sm, Eu, Gd, Pb, Se, Pb, Pb, isotopes, In	Ce, Pr, Bi	Mn, Tl, Sn, Co, Sc, Zn, Fe, As	Veins	Intrusive related vein type	REE and HFS Be-U-Th association suggests oxidised high temperature vein system, pegmatite or dissemination in alkalic or felsic intrusions. Likely influenced by overlying sediment chemistry and overprinting lateritisation.	Polymetallic
TS0930_17	Bi		Lu, Yb	Veins	Intrusive related	Bi veins	Bi
TS0932			K			Clay rich?	
TS0934			Ca, Sr, Te	Limestone	Veins	Limestone, not mineralised	
TS0934_01	Ge		Cr, Mo, Ag	Limestone		Replacement type stratiform, potential Ag-Zn mineralisation?	
TS0934_02		Ni, Ti, Cu, Mg, Cr, Fe	K, F, Se, Sr, Ca, Co, V, Sc	Mafic rocks	Vein	Unmineralised felsic-alkalic intrusions with limestone influence, possibly fluoroapatite veinlets	Polymetallic
TS0934_03	Mg, Ti	Ge, Cu, Sr, V	F, K, Fe, Cr, Zn, Pt	Hydrothermal/ intrusive related system	Intrusive related	Mafic-intermediate alkalic rocks, have fluorite content or F-bearing veins, limited mineralisation indicator	Polymetallic
TS0934_04		Ti, Cr, V, Ge, Mg, Sr	F, Cu, Fe, B, Al, Ce, Co, Nd, Pr, Zn	Veins	Veins	Mafic-felsic alkalic rock, unmineralised, F-bearing veins	Polymetallic
TS0934_05	Ca	Ni	Fe, Mg, Sr, Ti	mafic rocks		Intermediate-mafic rock provenance	

Table 6 (continued)

FIELD_ID	Primary Chemical Association	Secondary Chemical Association	Tertiary Chemical Association	Geochemical Based Mineral Model 1	Geochemical Based Mineral Model 2	Source region interpretation	Potential Commodity
TS0934_06		Sr, Ba	Na	Limestone	Evaporite	Sedimentary, evaporite?	
TS0934_07		Zn	K, Rb, F, Ag, Cd, Cu, Mg, Ni, Fe, Ga, Pb, Ti	Mississippian Zn-Pb	Intrusive related	Zn-Pb Mississippian deposit? overlain by laterite, may have some felsic intrusive related fluid influence	Polymetallic
TS0934_08	Sr	Ba	Ca, Na	Limestone	Intermediate intrusive	Limestone, salt influence	
TS0934_09	Ca	Sr, Zn		Skarn		Zn replacement skarn?, weak mineralisation indicator	Zn
TS0934_10	Na, Ca, Mn, Fe, Co	Mg, Ni, Tm, Yb, Lu	Cu, B, Ba, Sr, Te, Ge, V, Pt, Sn, Y, Hg	Mafic rocks		Mafic-intermediate rocks with potential polymetallic mineralisation, possibly skarniferous.	Polymetallic
TS0934_11	Cu, Fe, Mn	Al, Ga, In, Pd, Co, Ni, Sc	Rb, B, Ba, Na, Ga, Cr, V, Zn, Ag, Hg	Mafic rocks		Polymetallic mineralisation associated with mafic-intermediate intrusion, possibly skarniferous	Cu, Fe, Mn
TS0934_12B		Ca, Na		Calcrete		Salt, calcrete	
TS0934_13	Sr, Ca	Ba		Limestone		Limestone provenance	
TS0934_14	Sr	Ca, Ba		Limestone		Limestone provenance	
TS0935		Re	Mo, Pt	Metamorphic/ Metasomatic rocks		Metasomatic/metamorphic, breccia or shear zone infill	
TS0936						NIL	
TS0940						NIL	
TS0940_01	B	Cs	Cr, P, B, Ni	Veins		Hydrothermal to epithermal alteration of mafic volcanic or metavolcanic rocks	
TS0940_02	B	Cs	Co, Cr, Mg, Ni	Veins		Mafic volcanic, hydrothermal to epithermal alteration	
TS0940_03		Cs	Sn, B			Weak geochemical signature for Sn-B vein associated mineralisation	
TS0940_04		Cs, Mn	K, B, Se, Co, Ni, Cu, Fe, Zn, Ge, Hg	Veins	Stratiform Zn-Cu	Possibly mafic-intermediate marine volcanic rock overprinted by hydrothermal alteration. Stratified Zn-Ge-Cu? occurrence	
TS0940_06		Cs	Rb, Bi, Sn	Pegmatite/ Greisen	Hydrothermal/ intrusive related system	Potential Sn-Bi mineralisation associated with greisen	Sn-Bi
TS0940_08		Cs, As	Ag, Ge, Mg, Sr	Epithermal system		Epithermal system associated with intermediate rock	Ag
TS0941			Nb, P, Sb	Veins		P-enrichment, likely vein (singular or sheeted) style mineralisation	Nb
TS0945						NIL	
TS0948						NIL	
TS0949		Au	Ca	Veins		Likely as calcite-quartz veins	Au
TS0950	Au	Re, Hg	Cd, Pb, Zn, P	Epithermal system		Polymetallic gold vein, epithermal style mineralisation.	Au
TS0950_01		Mn	Nb, Ta, Ti	Veins	Detrital?	Potentially detrital deposit of heavy minerals derived from Nb-Ta-Ti vein	Nb
TS0950_02		Ca, Ba				Calcic rock, no mineralisation index, potential for Au-Ag or Ta-Nb veins	
TS0950_03						No mineralisation index, potential for Au-Ag or Ta-Nb veins	
TS0950_04		Nb, Ta, Be				No mineralisation index, potential for Ta-Nb veins	Nb-Ta

Table 6 (continued)

FIELD_ID	Primary Chemical Association	Secondary Chemical Association	Tertiary Chemical Association	Geochemical Based Mineral Model 1	Geochemical Based Mineral Model 2	Source region interpretation	Potential Commodity
TS0950_05	Ba	Au, Cu, Co, Sc, V, Ca, Be	Ag, Fe, Mg, B, Sr, Mn, Zn, Al, Lu, Mn, Re	Hydrothermal/intrusive related system		Hydrothermal alteration of intermediate volcanics with limestone components, likely disseminated Au mineralisation.	Polymetallic
TS0950_06	B	Ca		Veins		Calcic rock, no mineralisation index, potential for Au-Ag or Ta-Nb veins	
TS0950_07	Ca	Sc	Ag, B, Ba, Mn	Veins	Skarn	Hydrothermal fluids related to porphyry system in calcareous rocks, epizonal with Au-Mn traces	Ag
TS0950_08						No mineralisation index, potential for Au-Ag or Ta-Nb veins	
TS1166		Ba	Te, Na, Sr, Ga, Mg, Sb	Veins		Hydrothermal altered intermediate rocks, porphyry?, high level veins with potential for Sb and Ag	
TS1167_01			Te, Ag, As, Be, Sn	Epithermal system		Distal signatures for intrusive related epithermal system	
TS1167_03			Sr, K, Rb, Cs, Ba, Tl, F, Hg, Pb, S, Y, Zr, Au, Zn	Hydrothermal/intrusive related system		Hydrothermal signature associated with calc-alkaline rocks, concentration of incompatible elements typical of epithermal mineralisation.	
TS1167_05						NIL	
TSC001						NIL	
TSC004	Al, Ba, Be, Se	Ga, Na, Tl, La, Eu, U	Sc, Rb, F, Se, S, Y, Pb, Zn, Ta	Mineral sand	Hydrothermal/intrusive related system	Mineral sand, laterite and sediments derived from felsic-related hydrothermal system with LREE and Pb mineralisation, likely as veins (singular, sheeted, swarm) and disseminations.	Polymetallic
TSC005	Al, Be	Se, Eu, Tl, U	P, Li, Rb, F, Ba, Ga, Mn, REE, Y, Pb, Zn	Mineral sand	Hydrothermal/intrusive related system	Mineral sand from felsic intrusive, veins or disseminations with LREE and base metals, lateritised.	Polymetallic
TSC006		La, Ce, Pr, Nd, Sm, Gd, Th	Au	Mineral sand	Vein	REE mineral sand with alluvial gold; possible derived from localise REE veins	REE
TSC007			Pr, La, Nd, Sm, Ce, Gd, Th	Mineral sand	Vein	REE mineral sand; possible localise REE veins	REE
TSC008			Pb, Pb, isotopes, Ce, La, Nd, Pr, Sm,	Mineral sand	shear related	REE and Pb enriched. REE likely derived from heavy minerals sand or as localise REE veins, and Pb in breccia or shear zone infills	REE
TSC010			Hg, As, Se, S, Au, Cu, Cr, Co, Fe, Sc, Sn	Epithermal system		Unconvincing; sulphosalt related to hydrothermal fluids	
TSC011	Mo		Si, Cr	Hydrothermal/intrusive related system		Strong Mo anomaly, insufficient geochemical pathfinder to establish model, likely vein or dissemination.	Mo
TSC012		Cs	P			No model	

Figure 23 summarises the interpreted mineralisation models based on geochemical associations. Exploration models should be changed to best suit field observations and new geochemical results from local mineral occurrences that best match the various chemical associations. Caution must be taken when using the Atlas as the sampling density is based on a regional scale, and any follow up investigation will

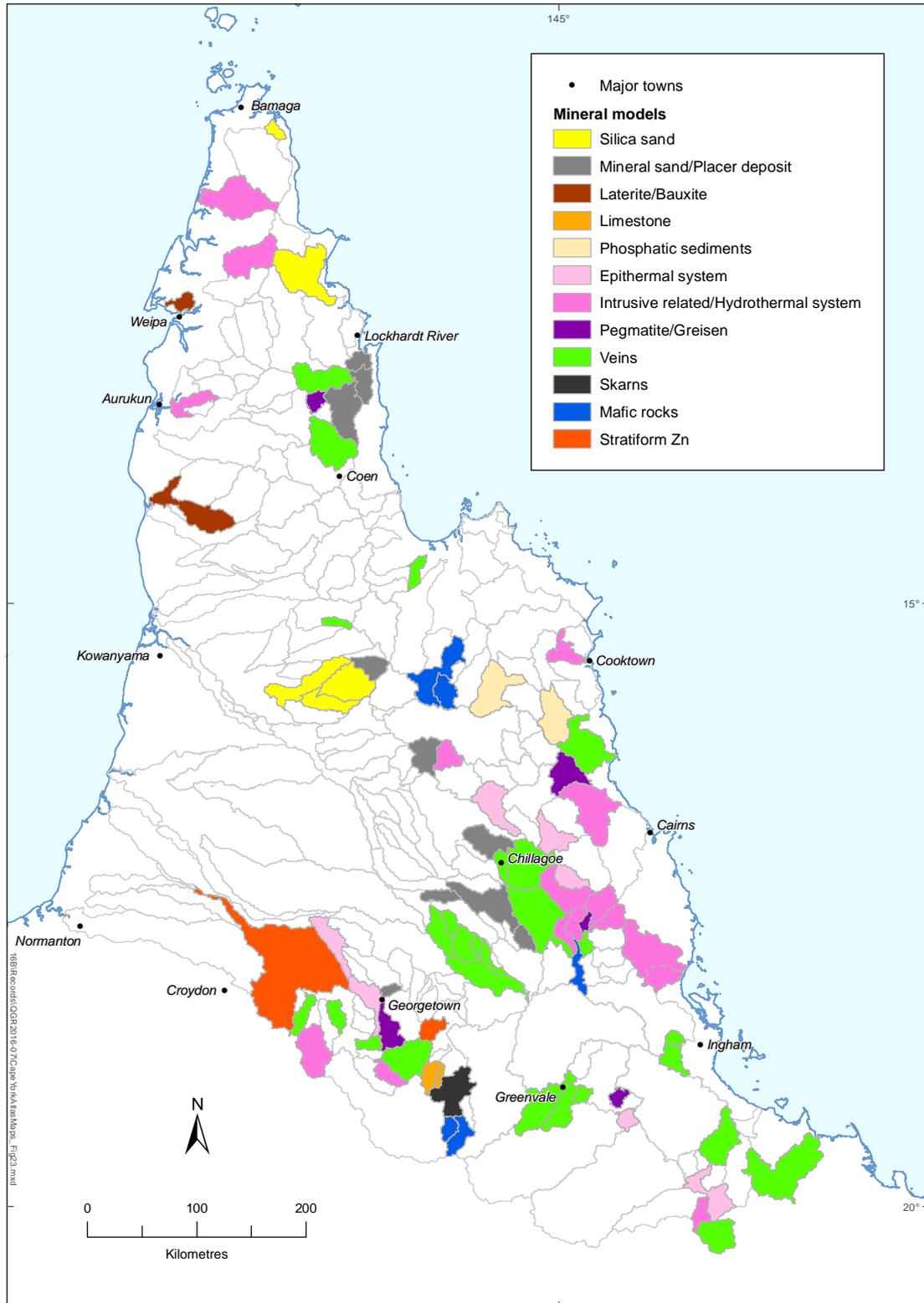


Figure 23: Geochemical based mineralisation model for the Cape York region interpreted from primary and secondary elemental associations.

have to refine the density of samples that will telescope into mineral targets. The Cape York Geochemical Project has fast-tracked mineral exploration by identifying target catchments for exploration and the geochemical signatures, and postulating mineral models.

## 5.6 Statistical appraisal

The Cape York geochemistry is considered one population and ranked statistically into eight statistical breaks. Individual elements were ranked accordingly with statistical breaks at the 25, 50, 75, 90, 95, 98, 99 and >99 percentile groups, and the calculated threshold for respective rankings is tabulated in Table 7. Statistical anomaly (Mean+2SD) for data is based on two standard deviation variance from the normal data distribution trend. The Mean+2SD anomaly corresponds to the 99th percentile of the data population, with the exception of Hf. At the 98th percentile, 80.1% of the data fall within the statistical anomalous threshold, whereas at the 95th percentile, only six per cent of the population area is considered anomalous.

The result of the geochemical appraisal is displayed spatially, based on catchment polygons, as the Cape York Geochemical Atlas. The >99th percentile statistical break is adopted to represent anomalous catchments in the Atlas. This high benchmark was chosen to ensure that these identified catchments are truly anomalous based on both statistical and calculated thresholds. The 98–99th percentiles statistical break is regarded as areas with strong geochemical signatures that are considered highly potential for anomalism. Catchments in the 95–98th percentiles have elevated background chemistry. Catchments with geochemical background above the 95th percentile background chemistry are suitable exploration targets for the specific element of interest.

**Table 7: Statistical breaks used in Cape York Geochemical Atlas.**

Statistical Break		Median	SDev	25 Percentiles	50 Percentiles	75 Percentiles	90 Percentiles	95 Percentiles	98 Percentiles	99 Percentiles	Mean + 2SDev	Anomalous
Ag	ppm	0.0182	0.0178	0.0094	0.0147	0.0220	0.0340	0.0463	0.0578	0.0615	0.0539	0.0615
Al	ppm	31340	13889	23083	29943	37368	45311	51510	70556	76411	59118	76411
As	ppm	4.41	5.66	1.98	3.29	4.74	8.23	11.22	17.66	18.57	15.72	18.57
Au	ppm	0.0028	0.0056	0.0011	0.0016	0.0025	0.0040	0.0060	0.0115	0.0299	0.0139	0.0299
B	ppm	2.30	2.26	0.50	1.11	3.89	5.46	6.39	8.03	8.88	6.83	8.884
Ba	ppm	250	121	169	243	326	388	450	519	627	491	627
Be	ppm	1.61	0.79	1.14	1.51	1.90	2.49	2.85	3.55	3.99	3.19	3.986
Bi	ppm	0.46	0.93	0.20	0.30	0.45	0.68	1.37	1.99	2.83	2.31	2.83
Ca	ppm	2831	2973	1039	2145	3687	5888	7602	9730	13961	8778	13961
Cd	ppm	0.08	0.10	0.04	0.06	0.09	0.13	0.17	0.25	0.39	0.28	0.391
Ce	ppm	81	47	52	70	93	136	163	222	250	175	250
Co	ppm	7.73	5.07	4.74	6.85	9.76	13.24	17.19	21.23	23.42	17.88	23.42
Cr	ppm	42.02	18.64	29.14	38.86	49.80	63.36	74.25	89.67	106.69	79.30	106.69
Cs	ppm	4.30	3.89	2.29	3.47	4.99	6.72	9.16	16.37	22.68	12.08	22.68
Cu	ppm	13.83	9.59	6.38	12.83	18.00	24.79	28.31	37.47	40.18	33.01	40.18
Dy	ppm	4.24	1.88	3.05	3.86	5.13	6.39	7.54	8.39	10.36	7.99	10.36
Er	ppm	2.27	1.12	1.60	2.06	2.71	3.50	4.03	4.97	6.10	4.51	6.10
Eu	ppm	0.85	0.32	0.66	0.80	1.01	1.20	1.42	1.81	1.89	1.49	1.89
F	ppm	298	157	187	277	385	528	608	669	707	612	707
Fe	ppm	18092	7547	13408	17366	21883	27880	31960	35293	40501	33186	40501
Ga	ppm	9.45	4.01	6.84	9.07	11.02	14.63	15.97	19.88	22.83	17.48	22.83

Table 7 (continued)

Statistical Break		Median	SDev	25 Per-centiles	50 Per-centiles	75 Per-centiles	90 Per-centiles	95 Per-centiles	98 Per-centiles	99 Per-centiles	Mean + 2SDev	Anoma-lous
Gd	ppm	5.48	2.58	3.90	4.92	6.52	8.51	9.61	12.12	14.99	10.63	14.99
Ge	ppm	1.28	1.15	0.46	0.97	1.56	2.65	3.50	4.93	5.42	3.58	5.42
Hf	ppm	9.70	29.74	4.16	5.44	7.87	16.06	22.66	39.32	47.45	69.18	47.45
Hg	ppm	0.0	0.06	0.08	0.08	0.14	0.15	0.28	0.28	0.29	0.12	0.285
Ho	ppm	0.90	0.38	0.65	0.84	1.10	1.35	1.55	1.86	2.06	1.67	2.063
In	ppm	0.03	0.04	0.01	0.02	0.03	0.04	0.06	0.12	0.15	0.12	0.153
K	ppm	8658	4395	5327	9366	11727	13638	14977	17803	18500	17447	18500
La	ppm	38.98	21.69	25.59	35.02	44.18	64.45	77.75	96.47	112.79	82.35	112.79
Li	ppm	9.32	8.64	4.89	7.87	10.93	15.46	20.19	27.21	32.79	26.60	32.79
Lu	ppm	0.36	0.20	0.23	0.31	0.44	0.57	0.70	0.90	1.08	0.75	1.082
Mg	ppm	2254	1578	965	2124	3059	4265	5394	6115	6411	5409	6411
Mn	ppm	382	282	224	362	467	645	806	1080	1259	946	1259
Mo	ppm	0.69	0.78	0.40	0.53	0.74	1.04	1.28	1.94	3.51	2.25	3.507
Na	ppm	3223	2662	1713	2865	4152	5641	6423	8235	9152	8548	9152
Nb	ppm	6.17	3.29	4.05	5.80	7.70	9.62	11.24	12.90	16.12	12.76	16.12
Nd	ppm	33.90	18.15	23.03	30.77	38.11	55.17	65.90	87.15	98.07	70.20	98.07
Ni	ppm	13.79	9.18	6.83	12.26	17.95	24.13	28.45	39.10	44.67	32.15	44.67
P	ppm	231	112	149	206	298	372	423	480	545	456	454
Pb	ppm	39.47	27.24	25.54	35.89	47.26	64.82	73.26	91.33	119.29	93.95	119.3
Pd	ppm	0.0007	0.0004	0.0005	0.0006	0.0008	0.0010	0.0013	0.0018	0.0020	0.0015	0.0020
Pr	ppm	9.23	5.16	6.09	8.27	10.43	15.61	18.51	24.34	27.72	19.56	27.72
Pt	ppm	0.0004	0.0002	0.0003	0.0003	0.0005	0.0006	0.0008	0.0009	0.0010	0.0008	0.0010
Rb	ppm	69	36	47	66	87	110	127	163	192	141	192
Re	ppm	0.0010	0.0010	0.0005	0.0007	0.0014	0.0023	0.0029	0.0046	0.0050	0.0032	0.0050
S	ppm	85	77	64	65	104	115	125	181	352	239	352.3
Sb	ppm	0.86	1.05	0.32	0.49	0.94	1.89	2.61	3.98	6.21	2.96	6.21
Sc	ppm	6.26	3.11	4.19	5.67	7.54	9.53	12.41	15.21	17.15	12.47	17.15
Se	ppm	0.073	0.056	0.042	0.057	0.085	0.118	0.185	0.247	0.291	0.184	0.291
Si	ppm	345957	39521	323613	345212	366725	396486	413636	433919	440892	424998	440892
Sm	ppm	6.58	3.33	4.57	6.05	7.63	10.35	13.04	15.56	18.87	13.23	18.87
Sn	ppm	2.29	2.98	1.17	1.69	2.40	3.39	5.08	7.91	13.93	8.24	13.93
Sr	ppm	47.80	39	26	40	58	86	119	166	198	125	198
Ta	ppm	0.67	0.25	0.52	0.64	0.75	0.92	1.17	1.31	1.58	1.17	1.58
Tb	ppm	0.78	0.35	0.56	0.71	0.94	1.19	1.34	1.61	2.15	1.48	2.15
Te	ppm	0.020	0.0103	0.0125	0.0171	0.0234	0.0339	0.0384	0.0444	0.0574	0.0408	0.057
Th	ppm	16.54	10.22	9.97	13.81	20.54	28.84	35.99	46.36	48.08	36.98	48.08
Ti	ppm	2033	882	1467	1832	2352	3177	3805	4534	4897	3796	4897
Tl	ppm	0.46	0.28	0.29	0.43	0.57	0.73	0.92	1.18	1.40	1.01	1.40
Tm	ppm	0.36	0.19	0.22	0.32	0.47	0.59	0.70	0.92	0.93	0.75	0.93
U	ppm	3.27	2.50	1.90	2.69	3.75	5.57	6.85	10.66	11.83	8.26	11.83
V	ppm	40.20	19.86	25.76	36.11	51.52	67.97	74.62	91.29	102.52	79.91	102.52
W	ppm	1.56	4.73	0.54	0.82	1.25	2.10	3.00	5.79	16.25	11.03	16.25
Y	ppm	22.78	10.48	15.95	20.97	27.38	34.55	39.08	50.76	54.37	43.74	54.37
Yb	ppm	2.19	1.21	1.47	1.97	2.64	3.40	3.91	5.49	6.52	4.60	6.52
Zn	ppm	38.52	26.39	19.82	38.26	51.08	63.60	72.63	92.71	119.50	91.30	119.50
Zr	ppm	154	76	102	148	189	248	287	316	350	306	350

### 5.6.1 Cape York Geochemical Atlas (Part II)

The Cape York Geochemical Atlas is a graphic display of the regional catchment geochemistry that highlights concentrations of 67 elements from 247 catchments. The regional data are treated as one population and ranked statistically and spatially according to catchment. The Cape York data show consistent upper crustal signatures with subtle but unique differences between catchments. Each catchment has a distinctive geochemical variation pattern that is consistent in all subsamples, varying only in the different concentration factors.

Cape York data have been processed and recombined using a unique methodology (Section 4.1), coalescing nine datasets of different analytical methodology, sample depth and size fractions. The methodology gives equal emphasis to all results by weighting each dataset using a multiplier factor. The recalculated result aims to display the statistical spread of data around its arithmetic mean value, which is a powerful methodology to express the statistical character of a complex database and to highlight the highs and lows of the geochemical distribution. This processing method is only appropriate for datasets that are internally consistent and where the results of the mathematical recombination serve to display variations from the mean.

A GIS version of this atlas is included in this report to enable readers to use the maps and information interactively.

## 6. DISCUSSION

Geochemistry is a reliable mineral exploration tool and is still the primary exploration technique for both green- and brown-field exploration. It is particularly successful for targeting mineralisation in outcropping areas and for mineral systems under eluvial and thin alluvial cover. Prior to the NGSa program, geochemical coverage for the Cape York region was patchy and data were mainly sourced from exploration data (QDEX reports and Queensland Exploration Database, GSQ, 2014) and the Bureau of Mineral Resources (BMR) databases (Butrovski *et al.* 2000; Cruikshank, 1997). Processing and interpretation of such heterogeneous data relied on correct geological and mathematical assumptions and were prone to subjective interpretation. Most archival data have a limited number of assayed elements that range from 3 to 47 elements, effectively limiting the modelling capability of such data.

The acquisition of high-quality and 67-element data from the Cape York and NGSa geochemical projects has expanded mineral prospectivity of Cape York to include commodities that were never investigated in the past. The reliability of the geochemistry meant that the data can be statistically appraised and ranked into eight classes to identify anomalous catchments and background concentrations for all 67 elements. The geochemical ranking and background concentrations for individual catchments are important in geochemical exploration for benchmarking future geochemistry against known values.

Geochemical modelling is based on grouping like-elements that share similar physical and chemical behaviours instead of looking at elements individually. Like-elements undergo similar geochemical differentiation and chemical partitioning processes due to their similar ionic behaviours, reactions and associations (Railsback, 2003). Analysing similarly speciated groups gives a better diagnostic appraisal of the magmatic, depositional and/or mineralisation history. The deliberate exclusion of known resources (Denaro & Ewers, 1995), previous exploration data and known mineral occurrences (as found in the GSQ MINOCC database) eliminates a presumptuous, mineral-focussed, and unequal sample density, as well as data of vastly different quality that require significant assumptions to merge.

The Cape York Catchment Geochemistry Assessment Report aims to provide independent and fresh interpretations of mineral potential that may have been previously overlooked. The accompanying geochemical atlas provides the best exploration guide by highlighting catchments with the highest probability of future discovery. The atlas is listed alphabetically based on the chemical formulae of 67 elements. The geochemical concentration is ranked statistically based on the assumption that Cape York geochemistry is one population. Normalising Cape York geochemistry to the Queensland and Mount Isa Province averages identified that Cape York is endemically enriched in W, Sn, REE, Bi, Th, U, Au, Sb, Se, Pb, Mo and Cs, and is the best place to explore for these commodities. The geochemical atlas for these elements pinpoints catchments that should be explored for the best probability of future discoveries.

For elements that may have co-genetic links or special emphasis, the following section discusses these elements further.

## **6.1 Rare Earths**

The Cape York Peninsula is recognised as an anomalous region in Australia for REE occurrences, with anomalies identified along first order catchments of the Mitchell, Lynd, Palmer, Walker, Watson, Kendall and Tully Rivers (Tang & Brown, 2011). The follow-up study sampled the second- and third-order drainage system within anomalous drainages to better define sources of anomalism. Data were statistically processed to establish the spatial distribution of 14 REE concentrations.

The REE anomaly map (Figure 24) depicts the cumulative REE behaviour based on the number of anomalous rare earth elements, the consistency of anomaly with depth (TOS or BOS), and result uniformity with different sample grain size. ‘Anomalous’ catchments are catchments with multi-element enrichment, where both TOS and BOS have concentrations above the 98th percentile; ‘enriched’ catchments have concentrations between the 95-98th percentiles; and ‘elevated’ catchments have concentrations between the 90-95th percentiles. Some northern Cape York catchments have multi-element enrichment in either TOS or BOS, reflecting changing REE input over the history of the catchment. Catchments with one or two elevated elemental concentrations are represented on the map as ‘element-specific REE catchments’, and a plausible explanation for geochemical aberration is explained beneath.

---

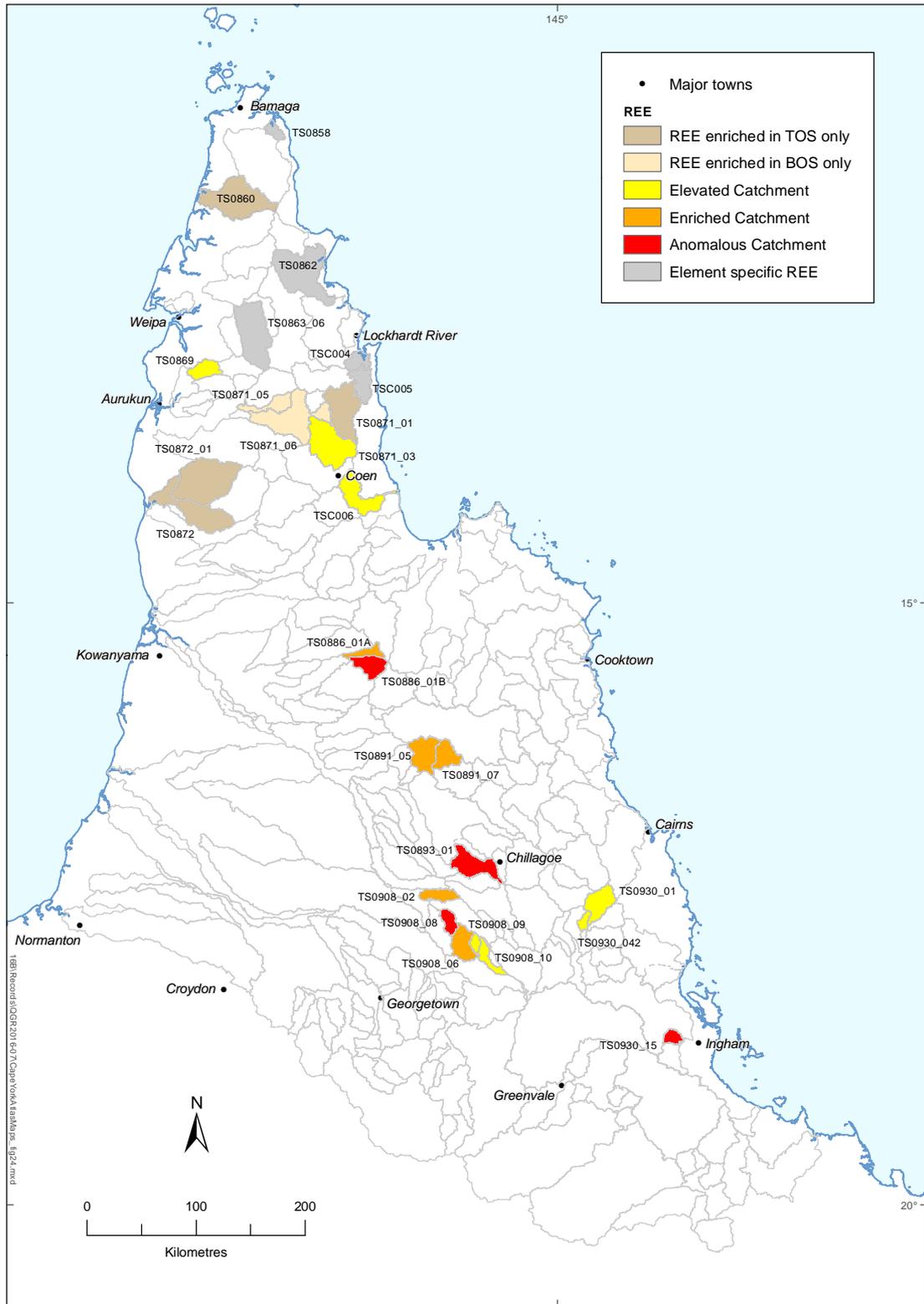


Figure 24: Rare earth element distribution in Cape York.

### 6.1.1 *Element-specific catchments*

Catchments along the northern Cape York are enriched in Eu. Eu is strongly partitioned into feldspars, which is a major component in arkosic or liable sediments. Eu in Escape River (TS0858) and Olive River (TS0862) along the east coast are enriched in the <75 micron size fraction. These catchments are also enriched in Si, Zr and Hf, which are common components in the coastal dunes deposits. The predominance of Eu and Si–Zr in the fine sand fraction strongly implies aeolian contributions from arkosic coastal sand dunes with minor components of zircon.

In the Wenlock (TS0863\_06) and Watson (TS0869) Rivers, Eu is enriched in both TOS and BOS samples that imply a continuous Eu input to the catchments over time. A heavy mineral sand investigation sponsored by GSQ as part of the Industry Priorities Initiative funding (Duck, 2015) identified that the arkosic Jurassic–Cretaceous Helby Beds are enriched in heavy mineral sand (HMS) with elevated REE content. Geochemical analysis of overlying sand indicated that combined HMS content is approximately one-tenth of economic grade. Besides the Helby Beds, the Wenlock and Watson River hinterland also includes the quartzose Jurassic–Cretaceous Gilbert River Formation deposited in shallow marine environment. These catchments are also elevated in Al, Co, Fe, Mn, Ni, Sc and V in both BOS and TOS, and Ba in the TOS only. The Al and ferromanganese elements (Fe–Mn–Co–Ni–Sc–V) are common geochemical assemblages in laterite or duricrust, and Ba is commonly associated with orthoclase. Therefore, Eu is most likely sourced from both arkosic sediments with a strong influence from laterite overprint.

The Lockhardt River (TSC004, TSC005) has elevated Eu in both TOS and BOS samples. The catchments also have elevated Al, Ba, Be, Se and U, and U is confined to coarser sediments. The elemental association suggests that the Eu is likely derived from feldspathic sediments, and the presence of Be–Se suggests an intrusive-related source region. The presence of U in coarse sediments may indicate detrital components from veins or pegmatites.

Sediments from the Jackson (TS0860) and Kendall (TS0872, TS0872\_01) Rivers have elevated Eu in the TOS fraction only, which is interpreted as recent addition. A study undertaken by Worrall (2015) indicated that HMS along the Jackson River is derived from the Jurassic–Cretaceous Helby Beds. Source regions of the Kendall River catchments include the Gilbert River Formation and siltstone-mudstone-sandstone from the Cretaceous Rolling Down Group. These catchments are also enriched in Al, Li, U, Mo + Se and S, which indicates an intrusive-related feldspathic-rich source that has potential for mineralisation. The elevated U concentration in the sediment suggests contributions from zircons.

---

### **6.1.2 Elevated REE catchments**

#### *Archer River*

Archer River catchment has two different geochemical signatures of different elemental assemblages. Geikie Creek (TS0871\_01) tributary, which drains from the Iron Range Province, is elevated in LREE that consist of La, Ce, Pr and Sm in the TOS, with associated elevation in Th. Concentration of LREE and Th exclusively in the TOS suggests recent accretion.

Upper Archer River tributaries (TS0871\_03 and TS0871\_06) from the Etheridge and Savannah Provinces are enriched in La, Ce, Pr, Sm, Eu, Gd, Tb and Dy, which are in the light–medium REE range (L–MREE). The northernmost Scrubby Creek tributary (TS0871\_05) is enriched in Gd and Tb only. The multi-element enrichment is mainly confined to BOS, which implies continuous REE input from near or localised sources within the catchment. The lack of Eu enrichment within these catchments, but associated Eu enrichment in TOS of downstream catchment (Picaninny Creek, TS0871\_04), suggests a possible density differentiation of minerals along Archer River, with lighter feldspars concentrated downstream and heavier minerals concentrated in catchments nearer to source regions. Picaninny Creek also has greater influence from the Cretaceous Rolling Down Group, which may contribute Eu from feldspars. These catchments are also enriched in Al, Th and U in the TOS sample, which are interpreted as contributions from feldspar-rich source with contributions from zircons, suggesting an arkosic provenance or granite-derived sediments.

### **6.1.3 Anomalous and enriched catchments**

#### *Alice River*

La, Ce, Pr, Nd, Sm, Gd, Tb and Dy are anomalous along the Alice River (TS0886\_01A and the Dixon Creek (TS0886\_01B) tributaries. Dixon Creek tributary is anomalous for most elements and has elevated U–Th, which implies a nearby source. An absence of Eu within the MREE range suggests physical removal such as by density separation in a fluvial system, and the REE anomalies may be related to gravity concentration.

#### *Mitchell River*

Mitchell River has REE enrichment at two sections along the riverine system. Enrichment of La, Ce, Pr, Nd, Sm, Gd, Tb and Th is noted along the Sandy Creek and Little Mitchell tributaries (TS0891\_05 and TS0891\_07 respectively) with diagnostic absence of Eu. The REE occurs within both TOS and BOS in fine and coarse fractions of the sediments, implying a near source. The Little Mitchell tributary has elevated Cu, PGE, Sc, Ti and V, which suggests involvement of mafic rock and possible mineralisation within the source region. The absence of Eu could be attributed to removal of feldspar and a presence of Th due to concentration of heavy mineral sand

in a fluvial system. Depletion of Eu can also result from fractionated igneous source rocks.

A REE anomaly is identified along the Muldiva Creek tributary (TS0893\_01) of the Mitchell River, east of Chillagoe, with a combined REE content of over 800 ppm. Anomalous values for La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho and Er are confined to the TOS sediment, which implies a recent contribution of REE into the catchment from a localised source. The sediment is also enriched in Ge, Th, U and Y in the TOS. Absence of REE enrichment in the corresponding BOS sample suggests either contamination or remobilisation of REE from a localised source that has been recently exposed. The elemental composition implies a REE source in association with high field strength elements, typical of heavy mineral sand or an REE–U rich intrusive-related system. This REE anomaly is a potential exploration target.

#### *Lynd River*

Lynd River shows strong REE anomaly along its upper catchment regions. Fulford Creek (TS0908\_06), Blackfellow Creek (TS0908\_09) and Fossil Brook (TS0908\_10) tributaries are enriched in Dy, Ho, Er, Tm, Yb and Lu, which are in the medium to heavy REE (M–HREE) range. Downstream from these catchments is the anomalous Rocky Creek tributary (TS0908\_08) with a combined REE content of over 550 ppm. Rocky Creek is anomalous for most of the 14 REE elements, which range from light to heavy REE. Further downstream along the Lynd River is the Pinnacle Creek tributary (TS0908\_02) which has strong enrichment of L–MREE (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb and Dy) with a total REE content of 580 ppm. The clustering of elevated to anomalous catchments implies a localised source for heavy to light REE elements. The change from HREE-dominated upstream to LREE-dominated downstream catchments could be the result of density differentiation processes related to the riverine system. If this interpretation is true, the uppermost catchment will be the most likely source of REE. The HREE enrichment in the upper catchments is associated with Be, As, F, Hf, Nb, Sb and Ta, which implies potential primary mineralisation associated with oxyphile-rich fluids such as sheeted veins-related deposits.

Rocky Creek tributary (TS0908\_08) L-HREE is associated with K, Rb, Nb, Ta, Th, W and Y, which strongly indicates intrusive-related mineralisation, and which has different paragenesis from other catchments.

#### *Herbert River*

Elevated REE values occur along the Herbert River at two mutually exclusive riverine sections. Elevated HREE is identified in the Wild River (TS0930\_01) and Battle Creek (TS0930\_042) catchments with elevated content of Er, Tm, Yb and Lu. HREE is associated with both TOS and BOS in fine and coarse fractions of the sediments, implying a localised source. The elevated HREE is also associated with Bi, As, In, Sn, W and Zn enrichment, which could originate from vein-related mineralisation.

---

Lannercost Creek (TS0930\_15) draining northwards from a small catchment into the estuary of the Herbert River is anomalous for L–HREE (Ce, Pr, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu) with a total REE content of 428 ppm. The REE anomaly is associated with Be, Al, Ga, Se, Y and U, suggesting likely alkali-intrusive related genesis. This catchment is a feasible exploration target for alkali-related REE mineralisation.

## 6.2 Precious metals anomalies

### 6.2.1 Gold

Gold anomalies in Cape York match known gold provinces in the Charters Towers and Etheridge Goldfields, with second tier anomalies in the Kidston–Forsayth, Chillagoe, Mount Mulligan and Coen–Ebagoola areas. Au results are generally erratic, which is typical of the nugget effect, and not all known mineral occurrences are matched with a corresponding geochemical signature. Gold's high density (SG of 19.3) limits Au dispersion, and many known coarse/visible gold deposits (e.g. Palmer River Goldfield) do not show geochemical dispersion in the overbank sediments. It is interpreted that the gold anomalies identified in this study are primarily associated with fine and ultrafine gold particles, which are typical of epithermal and/or colloidal gold. The appropriate methodology for sampling dense elements such as gold is by stream channel sampling.

Anomalous Au occurs along the Burdekin River (TS0950), where the hinterland includes the Charters Towers Goldfield. Au occurs within the coarse and fine fractions of TOS and BOS, suggesting a nearby source region. The presence of Hg in the coarse sediment fraction implies low-temperature epithermal-style mineralisation. In the Sandy Creek tributary (TS0950\_05), anomalous gold is confined to the TOS in both the fine and coarse sediments fraction (fire and aqua regia results), which suggests recent Au input and possible contamination. Elevated Ba, Ca, Co, Cu, Sc and V in BOS suggest a mafic to intermediate composition hinterland but may not be related to the Au mineralisation.

The Etheridge River (TS0909\_06), which drains the Etheridge–Georgetown Goldfield, is anomalous. Au occurrences are primarily confined to TOS (coarse and fine fractions) which suggest recent contamination of sediments from the exhumation of gold ores from the gold mining operations. The Au anomaly is associated with elevated Hg and Sb, which infers a low-temperature mineralisation. Further downstream, catchment TS0909\_02 has elevated (not anomalous) Au, Sb and Hg in coarse and fine fractions of TOS and BOS, which implies gold contribution from a distal source region over geological times, which includes the Georgetown and Etheridge Goldfields.

The Hodgkinson River tributary (TS0895\_04) in the upper Mitchell River has elevated Au in the coarse fraction of TOS (MMI, fire assay and aqua regia) and BOS (aqua regia). The catchment also has elevated Sb. The data imply a local source and possible epithermal quartz association, and are supported by many gold workings

around the Mount Mulligan and Kingsborough area. Catchments TS0891\_02 and TS0891\_06 of the Mitchell River have elevated Au in the fire assay results for both BOS and TOS samples, suggesting a nearby source region. The catchments have associated elevated Sb and As respectively. Both catchments have had few gold discoveries and may still hold undiscovered gold prospects.

High Au content occurs along the Tate River (TS0899\_07), which flows into the Lynd River. The gold is confined to a fine fraction of TOS (aqua regia and fire assay) which suggests a distal source region. The Tate River hinterland has numerous gold workings and is the likely source of Au contamination within the TOS.

The Robertson River tributary (TS0925\_13) of the Gilbert River has extremely high Au values in fine sediment of TOS (aqua regia and fire assays) and in the fine BOS fraction, which suggests a distal Au source area. The catchment has numerous Au workings that may cause the erratic and high Au concentration. The Western Creek (TS0925\_08) has high Au in the MMI results, which may indicate a potential hidden source. The Gilbert River is subparallel to the Etheridge River, and the hinterland comprises the Etheridge Goldfield.

Enriched Au is identified in the Coleman River catchment (TS0881\_03), 36 km south of Ebagoola. This 893 square km catchment has no known gold workings and is prospective for future gold discovery. The geochemical result is erratic, which is typical of nugget effect, and is anomalous in the coarse fraction of BOS (aqua regia) and slightly high in the MMI data. Based on a grade-tonnage calculation using its average 0.006786 ppm Au background, in theory the catchment can potentially support a medium-size gold deposit.

### **6.2.2 Silver**

Ag results are erratic and generally inconsistent between size fraction and depth within the same catchment. As discussed in Section 4.1.1, Ag results are highly heterogeneous and only the aqua result is used to represent it.

The Ducie River (TS0861) has an extremely high Ag MMI result but is not supported by analytical results of corresponding subsamples within the catchment. The catchment has anomalous Te which strongly suggests an intrusive-related Ag–telluride system. Similarly, the Emu Creek (TS0901\_03) tributary of the Walsh River has anomalous Ag values in BOS (aqua regia) and TOS (MMI) results but is not supported by sympathetic samples. The Emu Creek catchment has anomalous As, Bi, Cd, Cu, In, Pb, Sb, Sn, W and Zr, and elevated Be, Cs, F, Mo, Rb and Tl, which implies a polymetallic intrusive-related mineralisation style. The catchment includes the Irvinebank mineral field with numerous old workings. The erratic Ag may result from a nugget effect which caused inconsistency between samples or complexing with other minerals that restrict dispersion.

---

### 6.3 Base metals — copper, lead and zinc

The Cu background concentration in Cape York is low compared to the Queensland state average and to the well-endowed Mount Isa Block. The mean Cu concentration in Cape York is 14.1 ppm (current study), compared with 16.4 ppm for the statewide average and 33.6 ppm for Mount Isa (Tang & Brown, 2011). Cape York has a higher Pb background (18.8 ppm, this study) than the Queensland state average (10.2 ppm) and the Mount Isa background (10.55 ppm). The Zn background (39.7 ppm, this study) is lower than Mount Isa (44.4 ppm), but slightly higher than the Queensland state average (37.8 ppm). Cape York is unlikely to host a world-class Cu deposit, and copper occurrences are likely to be small to medium size. However, Cape York has higher potential for Pb mineralisation but no major Pb mine has been discovered.

The Herberton–Irvinebank–Mount Garnet mining field is anomalous for Cu, Pb and Zn, and has numerous polymetallic workings associated with the volcanogenic Devonian Hodgkinson Formation. Anomalous values occur in both TOS (including MMI) and BOS along the Emu Creek tributary (TS0901\_03) of the Walsh River, which implies proximity to the source region. Drainage systems flowing southwards into the Herbert River along the Return Creek (TS0930\_41) and Wild River (TS0930\_01) showed strong Cu and Zn enrichment in the fine sediments, which indicates a distal source contribution. Drainage systems influenced by this mineral field also include the Tully, Lynd, Staaten, Gilbert and Carron Rivers, which carry Cu–Pb–Zn enrichment in the fine sediments.

Besides the anomaly associated with the Herberton–Irvinebank–Mount Garnet mining field, other localised variations are discussed in the sections below.

#### 6.3.1 Copper

Elevated Cu concentration was assayed in the Cranky Creek (TS0934\_11), Copperfield River (TS0934\_10) and Junction Creek (TS0934\_02) tributaries of the Einasleigh River. The hinterland to these tributaries is the Palaeoproterozoic Einasleigh Metamorphics Formation, which hosted numerous Cu workings. Cu value within Junction Creek is confined to TOS that suggested recent inputs, possibly from exhumation of Cu occurrences or from contamination. Associated with Cu are Cr, Co, Ni, Ge, Fe, Mg, Ti, Ca and Mn, and the elemental association is typical of mafic rock association.

Cu enrichment is noted in Little Mitchell River (TS0891\_07), associated with Pd, Pt, Sc, Th, V and REE. Cu occurs in both coarse and fine sediments of TOS and BOS, indicating a weak or subterranean source. Known Cu occurrences in the catchment are within the Siluro–Devonian Chillagoe Formation.

Cu enrichment in the Sandy Creek tributary (TS0950\_05) of the Burdekin River is confined to BOS, which suggests Cu contribution over prolonged periods. The source of the Cu could be from numerous old mines hosted in the Siluro–Devonian Powlathanga Tonalite unit.

### **6.3.2 Lead**

Lead anomalies were identified in the Lockhardt and Hodgkinson Rivers, and elevated Pb is associated with the Georgetown block. In the Lockhardt River (TSC004), high Pb occurs within TOS and BOS, which is strong evidence for a nearby source. The close association with Al, Ba, Be, Se, Ga and REE suggest a mixed source with geochemical signatures from a hydrothermal system and the incorporation of mineral sand geochemistry. The geology of the hinterland includes the Proterozoic Sefton Metamorphics, Siluro–Devonian Kintore Granite and the Permian Weymouth Granite, and no mineralisation was ever discovered within the catchment. This anomaly remains to be explained.

Lannercost Creek (TS0930\_15) draining northwards into the Herbert River has high Pb values associated with high REE, Ga, Al and Se. The geochemistry is modelled as possibly derived from a reduced alkalic magmatism. No known mineral occurrence is found in the hinterland.

### **6.3.3 Zinc**

A low-grade Zn anomaly occurs in the Copperfield River (TS0934\_09) and Stockman Creek (TS0934\_07), which drain from the Georgetown Block into the Einasleigh River. Elevated Zn is associated with Ca, Sr, K, Rb, F, Ag, Cd, Cu and Pb, which suggests a strong influence from calcareous rocks and hydrothermal replacement.

Sandy Creek (TS0893\_04), draining into the Mitchell River, has one extremely high assay from the coarse sample fraction of TOS, but the anomaly is not repeated by other samples within the catchment. The anomaly within the catchment is subject to further investigation.

## **6.4 Uranium**

Cape York has an elevated uranium background within most major river catchments, including Lynd, Mitchell, Coleman, Kendall, Wenlock, Pascoe, Archer, Jackson, Tully, Einasleigh, Gilbert and Stawell Rivers (Tang & Brown, 2011). Within the Cape York dataset, anomalous U occurs exclusively to TOS from the Jackson River (TS0860) which suggests recent accretion. U is associated with Mo, Se, S, Li, Li, Al, K, As and REE. There is no known mineralisation within this catchment, though the overall geochemistry suggests a similarity to hydrothermal overprinting.

The association of Se with U could imply a roll-front uranium deposit, as Se is mobile under hydrous conditions but immobilised under changed hydrological or oxidation conditions. U–Se–Tl association is observed in the Iron Range Province, which strongly implies a hydrous involvement, and the possibility of a U deposit.

Anomalous U concentration in TOS and BOS also occurs within the Mary Creek (TS0895\_01) catchment of the Mitchell River implying a local source region. The chemical association includes Li, Cs, Rb, Tl, Be, Sn, Bi, W, Nb, Ta and REE, which

---

suggests strong hydrothermal influence associated with reduced felsic magmatism. Sn–W mineralisation around Mount Carbine is the likely source of the U.

Elevated U occurs along the North Kokialah Creek (TS0874) tributary of Watson River and along the Lannercost Creek (TS0930\_15) tributary of Herbert River. Within both catchments, there is no previous known U occurrence, and both catchment systems reflected strong vein-related mineral systems.

## 6.5 Aluminium and gallium

Al and Ga show similar spatial distribution as the two elements commonly co-exist in bauxite. Riverine systems discharging from known bauxite deposits are enriched in both Al and Ga, such as the Mission (TS0864), Wenlock (TS0863\_06) and Kendall Rivers (TS0872).

Drainage systems with elevated Al–Ga that originated from non-bauxite hinterland are of special interest. The Lannercost Creek (TS0930\_15) tributary of the Herbert River is anomalous for Al and Ga in TOS and BOS and in different size fractions, implying near and persistent source discharge. The Al and Ga anomalies are correlated with multi-element anomalism including REE and trace elements, which suggests fertile magmatic source region typical of alkali and possibly a lamprophyre or carbonatite.

Elevated Al and Ga occur along Lockhardt River (TSC004 and TSC005). The elevated concentration is curious and warrants further investigation.

## 6.6 Tin and tungsten

Sn and W anomalies occur mainly along the Mitchell, Walsh and Herbert Rivers. These elements are partitioned into heavy minerals such cassiterite and wolframite, and their dispersion are confined mainly to active channels. The erratic geochemical signature in overbank sediments is interpreted as the result of nugget effect, which generally results in underrepresentation of their geochemistry.

Anomalous Sn and W occur in both the coarse and fine fractions of TOS and BOS along the Mary Creek (TS0895\_01) tributary of the Mitchell River, suggesting a nearby source. Elevated Sn is also detected along the McLeod River (TS0895\_02) tributary of the Mitchell River.

Anomalous Sn and W are analysed in coarse and fine fractions of TOS and BOS of the Emu Creek tributary (TS0901\_03) of the Walsh River. Other tributaries of the Walsh River that are elevated in Sn–W concentrations are along TS0901\_01 and TS0901\_06, which confirms Sn–W mineralisation in the source region.

Enriched Sn and W within both coarse and fine fractions of TOS and BOS of the Battle Creek tributary (TS0930\_42) of the Herbert River suggest a distal source

---

signature. Elevated values also occur along the Wild River (TS0930\_01) and Buffalo Swamp (TS0930\_05) tributaries and along the TS930\_41 sub-tributary.

Slightly elevated Sn-only concentration is found along Tin Creek tributary (TS0871\_02) of Archer River and along the Lannercost Creek tributary (TS0930\_15) of the Herbert River, which is interpreted as a distal Sn source within respective catchments.

Anomalous W occurs in TOS and BOS of the Wenlock River (TS0863\_01) and the Rocky Creek tributary (TS0908\_08) of the Lynd River, which suggests a nearby source.

## 7. SUMMARY

The Cape York Catchment Geochemistry Assessment Project interpreted and synthesised the newly acquired second- and third-order catchment systems with an average of one sample per 870 sq. km. A total of 189 catchments were sampled and 58 NGSAs results were reprocessed using a customised data-processing method. The results were collated into the Cape York Geochemical Atlas that accompanies this report (a GIS version of the Atlas is included in this report).

Dense element such as Au, Pt, Pd, Sn and W are underrepresented in this atlas as the minerals have limited dispersal in overbank sediments. The appropriate method for heavy metals assessment will be by active stream sediment sampling.

The outcomes of this report and Atlas are to:

- Fast track exploration by narrowing down catchments for imminent follow-up exploration
  - Define the mineral prospectivity for 67 commodities by identifying the top-tier and second-tier anomalous catchments, including emerging commodities such as lithium, tantalum, niobium and rare earth elements
  - Establish the geochemical background in 247 catchments for future benchmarking in environmental study, mineral exploration and ore-grade modelling
  - Provide anomalous elemental associations for each catchment for mineralisation modelling
  - Predict mineralisation models of all catchments based on multi-element geochemistry
  - Establish Al, W, Sn, U, Th, Au, Ta, Nb, REE and P as commodities with the highest probability for exploration success in Cape York, followed by Bi, Sb, Mo, Pb, As, Hg, Se, Cs, Li, Be, F, Ag, Ga, Ge, Cr and Cd
  - Synthesise the geochemistry of the ten geochemical domains in Cape York, and interpreted respective geochemistry and mineral potential (see Table 8).
-

**Table 8: Lithological, pedomorphological and/or mineralisation interpretations using various geochemical combinations.**

Only significant associations are included in the table.

(= refers to interpretation and + infers minor association or component)

Geochemical Province	Etheridge North Province	Etheridge South Province	Iron Range Province
Major elements geochemical characteristics	Low Fe-Mn-Mg contents, sympathetic Si-K and constant Na-Ti = predominant sedimentary rock signatures, chemical dilution from clay and quartz	Sympathetic Si-LIL = evidence for magmatic fractionation and hydrothermal influences; Ca-Mg-Na = calcareous and dolomitic chemistry; dilution by quartz + zircon	Elevated Al-K, low Mg-Fe-Na = argillaceous rock chemistry
Trace elements characteristics	Enriched U-Th = possible U-Th mineralisation	F-Sr = signatures for intermediate igneous and/or calcareous rock; Au-Cu-Be-Sm-U-REE = oxyphiles common associated with reduced granite or veins	Low trace elements content but high U-F = sedimentary rock geochemistry, possible U enrichment
REE pattern	Typical crustal pattern; differing REE pattern attributed to quartz or achemical components dilution; aeolian influence	REE crustal, low Ce in reduced conditions or from leaching; dilution by silica	REE patterns suggests dilution by aeolian quartz
Multi-element spidergram pattern	Sb-Cs = hydrothermal overprint?, chemical dilution by quartz + zircon	Sb-W, chemical mixing	Zr-Hf-Ta= detrital mineral sand
Major multi-elements association	REEY-Th-Zr-Hf = detrital mineral sand	REEY-Th-U + Zr-Hf = detrital mineral sand	Insufficient data
Minor multi-elements association 1	Ga-Ti-Sc-Fe = duricrust and retention of elements in sesquioxides	Rb-Cs-Tl + F = felsic magmatism and/or hydrothermal signatures	Insufficient data
Minor multi-elements association 2	Pb-Sn-Bi-and Rb-Cs-Tl = intrusive-related enrichment	NIL	Insufficient data
Elements of high probability of exploration success	U, Th, LREE + P, Ge	B, Ge, Au + F, Ga, Hg, Sb	U, Se
Geological synthesis and interpretation	Sedimentary rock dominated provenance with strong indication of mixing by silica + zircon. Evidence of hydrothermal overprint associated with felsic igneous rocks. U-Th-REE enrichment associated with felsic igneous rocks and mineral sand.	Calcareous and felsic igneous rocks overprinted by hydrothermal/ pneumatolitic geochemistry. Multi-element enrichment associated with intrusive and mineral sand. Hg-Sb presence suggests low to moderate temperature.	Argillaceous and sedimentary rocks dominate the provenance geochemistry. Influence from overlying mineral sand. Potential for roll-front U deposit at oxidation and phreatic interphase.

**Table 8 (continued).**

Geochemical Province	Savannah Province	Charters Towers Province	Greenvale-Camel Creek Province	Palmer-Barron-Chillagoe Province
Major elements geochemical characteristics	Low Fe-Mn-Mg, sympathetic Si-K and constant Na-Ti = sedimentary rocks, dilution by clay-quartz	Si-LIL = sedimentary rocks, felsic magmatism; Ca-Mg-Na = calcareous and dolomitic rock	Al-Fe-Mn, low K-Na-Ca-Mg = leached mafic duricrust	Erratic high P-K values = apatite veins or sedimentary phosphate
Trace elements characteristics	K-U-Th-S = resistant minerals in clay-rich sediments	Enriched in Sr = calcareous rocks	U-Pb-Bi = syngenetic sedimentary deposit; Be-F = pegmatite or vein.	F-Rb-As-Bi-Cu-Sn-Zn-W = oxyphilic, reduced felsic intrusive, sheeted vein or greisen; Au-Pb-Be-Mo-U = polymetallic
REE pattern	Eu loss = reduce condition or leaching	Typical crustal signature	NIL	NIL
Multi-element spidergram pattern	Heavy mineral sand	NIL	Cs-Rb = hydrothermal overprint	Sb-Pb-Sn-W = polymetallic, mineral sand?
Major multi-elements association	REEY-U-Th = resistant detrital mineral sand	REEY-Co-Ga + Al-Fe-Mn = laterite and pedochemical signatures	REEY-U-Th-Sn = resistant detrital minerals	REEY-U-Th-Rb-Cs-Tl-F-P-Be = felsic magmatism, alkaline and reduced granites
Minor multi-elements association 1	Zr-Hf = zircon and silica sand	Cu-Zn + Fe-Mg-Ca-Ti-Sc-Co-Li-S = multi-elements associated with weathered duricrust; hydrothermal	REEY-Se-Be-Tl = highly fractionated intrusive-related fluids.	Sn-W-Bi = pegmatites, skarns or late dissemination in reduced granites
Minor multi-elements association 2	K-Rb-Cs-Tl-Li + Ca-Sr-Al = felsic-intermediate intrusive; Sn-Bi = typifies pneumatolitic veins, greisen or disseminated in reduce granites.	K-Rb-Cs-Tl = felsic magmatism	REEY-Pb-Bi-Zn-Ge = sulfides, magmatic or synsedimentary	Zn-As-Cd-Sb = typical sheeted and stockwork veins or disseminations
Minor multi-elements association 3	Cu-Zn-Ni-Sc-Fe-V = possibly as volcanic hosted sediments	NIL	Sc-Fe-V-Cr-Co-Ni = residual sesquioxide from mafic rocks	NIL
Elements of high probability of exploration success	W, U, LREE, Th	Au, Re + V, Ba Ca, Sr, K	B, Cs + Ni, Co, Cr, Mn, Bi	Bi, In, As, Sn, Cd, W, Sb, Pb, Mo + Cs, Li, Nb, Zn
Geological synthesis and interpretation	Sedimentary dominated provenance with felsic magmatism, oxyphiles dominance suggest association with reduced granites; influence from mineral sand	Calcareous and intermediate-mafic rocks, lateritised, hydrothermal overprint, Au mineralisation	Mafic rock with hydrothermal and metasomatic overprint, leached	Sedimentary rocks with inputs from reduce granites and alkali magmatism; polymetallic mineralisation

**Table 8 (continued).**

Geochemical Province	Carpentaria Basin North	Carpentaria Basin South	Laura Basin
Major elements geochemical characteristics	High content of Al-Fe-Mn and depleted K-Na-Ca-Mg = duricrust	+ P enriched = sedimentary phosphate	P + Mn-Fe= sedimentary, possible marine sediments
Trace elements characteristics	Trace elements depleted = leaching	NIL	+ Cr
REE pattern	Birdwing profile = leaching and mixing from heavy mineral sand	Typical crustal signature	Typical crustal signature
Multi-element spidergram pattern	NIL	NIL	NIL
Major multi-elements association	REEY-Bi-Th +U-Zr = detrital mineral sand	REEY-Th-U, Zr-Hf + Sn-Bi = detrital mineral sand	REEY-Th-Mn-Al-Sc = laterite
Minor multi-elements association 1	K-Rb-Cs-Tl-F-Be = intrusive-related	Al-Ga-Sc-Ti-Fe + LREEY = laterite mixed with mineral sand.	Rb-Tl = late magmatic fractionates
Minor multi-elements association 2	Sc-Fe-V-Cr-Co-Cu + Mg-Mn-Al= tropical leaching, laterite	K-Rb-Cs-Tl-Ca-Sr-Ba-Mg-Mn-Al-Sc-Fe = felsic to mafic rocks in source region	Na-K-Rb-Cs-Tl-Li + F-Be-Ba-Al= Felsic-intermediate intrusive
Minor multi-elements association 3	Ni-Zn + Ca-Sr-Mg-Mn= potential Ni-Zn associated with intermediate rocks	+ Sn-Bi = potential mineralisation in hinterland.	Sn-Bi-Th-U-Nb-S-Ta= oxyphile, veins, dissemination, breccia infills
Elements of high probability of exploration success	NIL	NIL	P
Geological synthesis and interpretation	Strongly tropical leached sedimentary basin with geochemistry dominated by lateritisation effects. Has indication of intermediate to felsic intrusive. Strong enrichment of S-Cl indicates coastal tidal influence.	Geochemistry dominated by sediments and overprinting mineral sand, includes distal influence from mafic-intermediate rocks.	Sediment dominated geochemistry and includes distal signatures from felsic intrusive. Potential region for sedimentary P exploration.

---

## 8. ACKNOWLEDGEMENTS

Appreciations are extended to the dedicated Geological Survey of Queensland team—Messrs Dominic Brown, David Purdy, Patrick Carr, Joseph Tang, Dudley Fulton, Stanley Briggs, Christopher Hansen and Lex Klein. Editorial assistance and proof reading by Ms Bronwyn Mitchell is greatly appreciated. Invaluable contributions from Prof. Massimo Gasparon and Marietjie Mostert from the University of Queensland are appreciated. Permissions from all Queensland property and Traditional owners to grant land access and providing field assistance are deeply appreciated.

## REFERENCES

- ALLEGRE, C.J. & MINSTER, J.F., 1978: Quantitative models of trace element behaviour in magmatic processes. *Earth and Planetary Science Letters*, **38**, 1–25.
- ALLEGRE, C.J., TREUIL, M., MINSTER, J.F., MINSTER, B. & ALBAREDE, F., 1977: Systematic use of trace element in igneous process Part I: fractional crystallization processes in volcanic suites. *Contributions to Mineralogy and Petrology*, **60**, 57–75.
- BEST, M.G., 1982: *Igneous and Metamorphic Petrology*. W. H. Freeman and Company, New York.
- BLEVIN, P.L., 2004: Redox and compositional parameters for interpreting the granitoid metallogeny of eastern Australia: Implications for gold-rich ore systems. *Resource Geology*, **54**, 241–252.
- BOYLE, R.W., 1974: Elemental associations in mineral deposits and indicator elements of interest in geochemical prospecting (revised). Department of Energy, Mine and Resources, Ottawa. *Geological Survey of Canada Paper*, 74–45.
- BUTROVSKI, D., MADDEN, C., BRUGMAN, P.C., ARMSTRONG, T., SCOTT, P.A., ROSSITER, A.G. & CRUIKSHANK, B.I., 2000: North Queensland stream sediment geochemical data. Geoscience Australia report on CD. Available at: <http://www.ga.gov.au/meta/ANZCW0703002866.html>
- CARITAT, P. de & COOPER, M., 2011: National Geochemical Survey of Australia: The Geochemical Atlas of Australia. *Geoscience Australia, Record 2011/20* (2 Volumes). Available at: [https://www.ga.gov.au/products/servlet/controller?event=GEOCAT\\_DETAILS&catno=71973](https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=71973)
- CARITAT, P. de, COOPER, M., LECH, M., McPHERSON, A. & THUN, C., 2009: National Geochemical Survey of Australia: Sample Preparation Manual. *Geoscience Australia Record 2009/08*. Available at: [https://www.ga.gov.au/products/servlet/controller?event=GEOCAT\\_DETAILS&catno=68657](https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=68657)
- CARITAT, P. de & LECH, M.E., 2007: Thomson Region Geochemical Survey, Northwestern New South Wales. Cooperative Research Centre For Landscape Environments And Mineral Exploration Open File Report, 145. Available at: <http://crclme.org.au/Pubs/OFRSindex.html>
- CARITAT, P. DE, LECH, M.E., JAIRETH, S., PYKE, J. & FISHER, A., 2007: Riverina Region Geochemical Survey, Southern New South Wales and Northern Victoria. Cooperative Research Centre For Landscape Environments And Mineral Exploration Open File Report, 234. Available at: <http://crclme.org.au/Pubs/OFRSindex.html>
- CARITAT, P. DE, LECH, M.E. & McPHERSON, A.A., 2008: Geochemical mapping ‘down under’: selected results from pilot projects and strategy outline for the National Geochemical Survey of Australia. *Geochemistry: Exploration, Environment, Analysis*, **8**, 301–312.
- CORNELIUS, M., ROBERTSON, I.D.M., CORNELIUS, A.J. & MORRIS, P.A., 2008: Geochemical mapping of the deeply weathered western Yilgarn Craton of Western Australia, using laterite geochemistry. *Geochemistry: Exploration, Environment, Analysis*, **8**, 241–254.
-

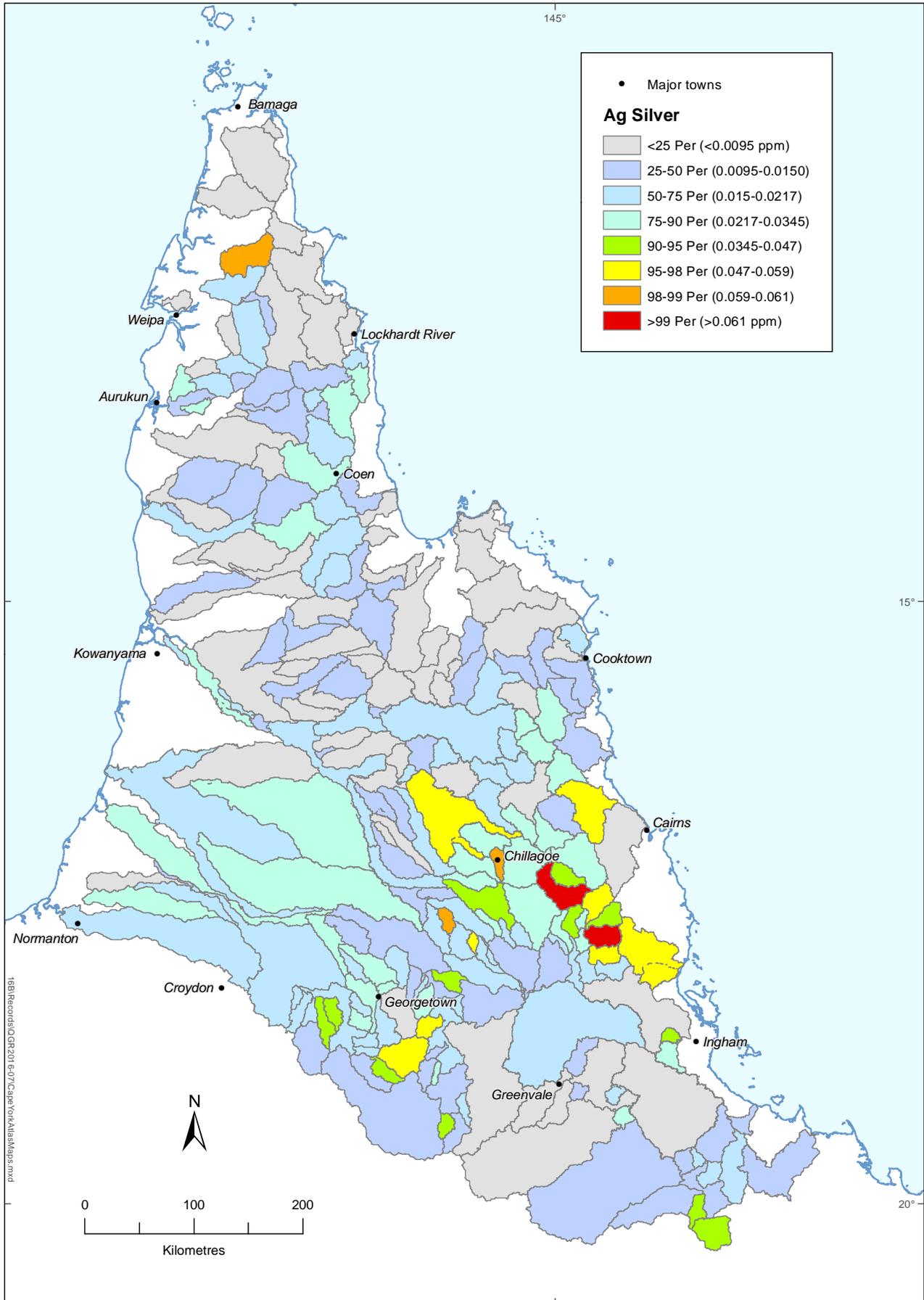
- 
- COX, D.P. & SINGER, D.A. (Editors), 1992: Mineral Deposit Models. *U.S. Geological Survey Bulletin* **1693**.
- CRUIKSHANK, B.I., 1997: Stream Sediment Geochemistry of the Ebagoola 1:250 000 Sheet Area, Cape York Peninsula, North Queensland. *AGSO Report* **1997/21**.
- DEER, W.A., HOWIE, R.A. & ZUSSMAN, J., 1993: *An Introduction to the Rock Forming Minerals*. Second Edition, Longman, London.
- DENARO, T.J. & EWERS, G.R., 1995: Mineral Resource Assessment - Cape York Peninsula Land Use Strategy. *Queensland Mineral and Energy Review Series*, Queensland Department of Minerals and Energy.
- DUCK, B.H., 2015: Report on Studies of Heavy Mineral and Other Economic Mineral Potential of Northern Cape York Peninsular for State of Queensland, Geological Survey of Queensland under Contract DNRM1485. Bremar Minerals Pty Ltd on behalf of Oresome Australia Pty Ltd. Held by the Geological Survey of Queensland QDEX Reports system as Report Number 93563.
- FREIJ-AYOUB, R., WALSH, J.L. & MUHLHAUS, H-B., 2000: Prediction of rock alteration patterns: a potential tool in mineral exploration. *Australian Journal of Earth Sciences*, **47**(5), 885–894.
- GARRETT, R.G., REIMANN, C., SMITH, D.B. & XIE, X., 2008: From geochemical prospecting to international geochemical mapping: a historical overview. *Geochemistry: Exploration, Environment, Analysis*, **8**, 205–217.
- GEOLOGICAL SURVEY OF QUEENSLAND, 2014: Queensland Exploration Database. Available from <http://qdexdata.dnrm.qld.gov.au/flamingo/>
- HANSON, G.N., 1978: The application of trace elements to the petrogenesis of igneous rocks of granitic composition. *Earth and Planetary Science Letters*, **38**, 26–43.
- HUTCHINSON, M.F., STEIN, J.L. & STEIN, J.A., 2000: Derivation of nested catchments and catchments for the Australian continent. Centre for Resource and Environmental Studies, Australian National University.
- JOLLIFFE, I.T., 2002: *Principal Component Analysis, 2nd edition*. Springer-Verlag, New York, 28.
- JONES, A.P., WALL, F. & WILLIAMS, C.T., 1996: Rare Earth Minerals: chemistry, origin and ore deposits. *The Mineralogical Society Series*, **7**, 227–252.
- KAMBER, B.S., GREIG, A. & COLLERSON, K.D., 2005: A new estimate for the composition of weathered young upper continental crust from alluvial sediments, Queensland, Australia. *Geochimica et Cosmochimica Acta*, **69**, 1041–1058.
- LECH, M.E., CARITAT, P. de & McPHERSON, A.A., 2007: National Geochemical Survey of Australia: Field Manual. *Geoscience Australia Record*, **2007/08**. Available at: [https://www.ga.gov.au/products/servlet/controller?event=GEOCAT\\_DETAILS&catno=65234](https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=65234)
- LOTTERMOSER, B.G., 1990: Rare-earth element mineralisation within the Mt. Weld carbonatite laterite, Western Australia. *Lithos*, **24**(2), 151–167.
- McBIRNEY, A.R., 2006: *Igneous Petrology*. Jones & Bartlett Learning, Boston; 3rd edition.
- MORTEANI, G. & PREINKFALK, C., 1996: REE distribution and REE carriers in laterites formed on the alkaline complexes of Araxa and Catalao (Brazil). In: Jones, A.P., Wall, F. & Williams, C.T. (Editors): Rare Earth Minerals: chemistry, origin and ore deposits. *The Mineralogical Society Series* **7**, Chapman & Hall, 227–252.
- OTTESEN, R.T., BOGEN, J., BØLVIKEN, B. & VOLDEN, T., 1989: Overbank sediment: a representative sample medium for regional geochemical sampling. *Journal of Geochemical Exploration*, **32**(1–3), 257–277.
- RAILSBACK, L.B., 2003: An earth scientist's periodic table of the elements and their ions. *Geology*, **31**(September), 737–740.
- ROLLINSON, H.R., 1993: *Using Geochemical Data: Evaluation, Presentation, Interpretation*. Longman Scientific & Technical, John Wiley & Sons, New York.
-

- SANEMATSU, K., MORIYAMA, T., SOTOUKY, L. & WATANABE, Y., 2011: Mobility of rare earth elements in basalt-derived laterite at the Bolaven Plateau, Southern Laos. *Resource Geology*, **61**(2), 140–158.
- SMITH, D.B. & REIMANN, C., 2008: Low-density geochemical mapping and the robustness of geochemical patterns. *Geochemistry: Exploration, Environment, Analysis*, **8**, 219–227.
- STEIN, J.L., HUTCHINSON, M.F. & STEIN, J.A., 2011: *National Catchment and Stream Environment Database Version 1.1.4*. Fenner School of Environment and Society, Australian National University.
- SUN, S.S. & McDONOUGH, W.F., 1989: Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. In: Saunders, A.D. & Norry, M.J. (Editors): *Magmatism in the Ocean Basins. Geological Society, Special Publication* **42**, 313–345.
- TANG, J.E.H. & BROWN, D.D., 2011: Queensland Mineral Prospectivity Atlas, National Geochemical Survey of Australia. *Queensland Geological Record* **2011/08**.
- TAYLOR, S.R. & McLENNAN, S.M., 1985: *The continental crust: its composition and evolution*. Blackwell, Oxford.
- TAYLOR, S.R. & McLENNAN, S.M., 1995: The geochemical evolution of the continental crust. *Reviews of Geophysics*, **33**, 241–265.
- U.S. DEPARTMENT OF AGRICULTURE, 2010: Munsell Soil-colour charts with genuine Munsell XColour chips. U.S Dept Agriculture - Soil Survey Manual, 2009 Edition Munsell Soil Chart Brochure.
- WILSON, M., 1989: *Igneous Petrogenesis*. Harper Collins Academic, UK.
- WILSON, M., 1993: Magmatic Differentiation. *Journal of the Geological Society of London*, **150**(August), 611–624.
- WORRAL, L., 2015: Cape York Heavy Minerals Project- Final Report. In: Duck, B.H., 2015: Report on Studies of Heavy Mineral and Other Economic Mineral Potential of Northern Cape York Peninsular for State of Queensland, Geological Survey of Queensland under Contract DNRM1485. Breinar Minerals Pty Ltd on behalf of Oresome Australia Pty Ltd. Unpublished report held by the Geological Survey of Queensland QDEX Reports System as Report Number 93563.
-

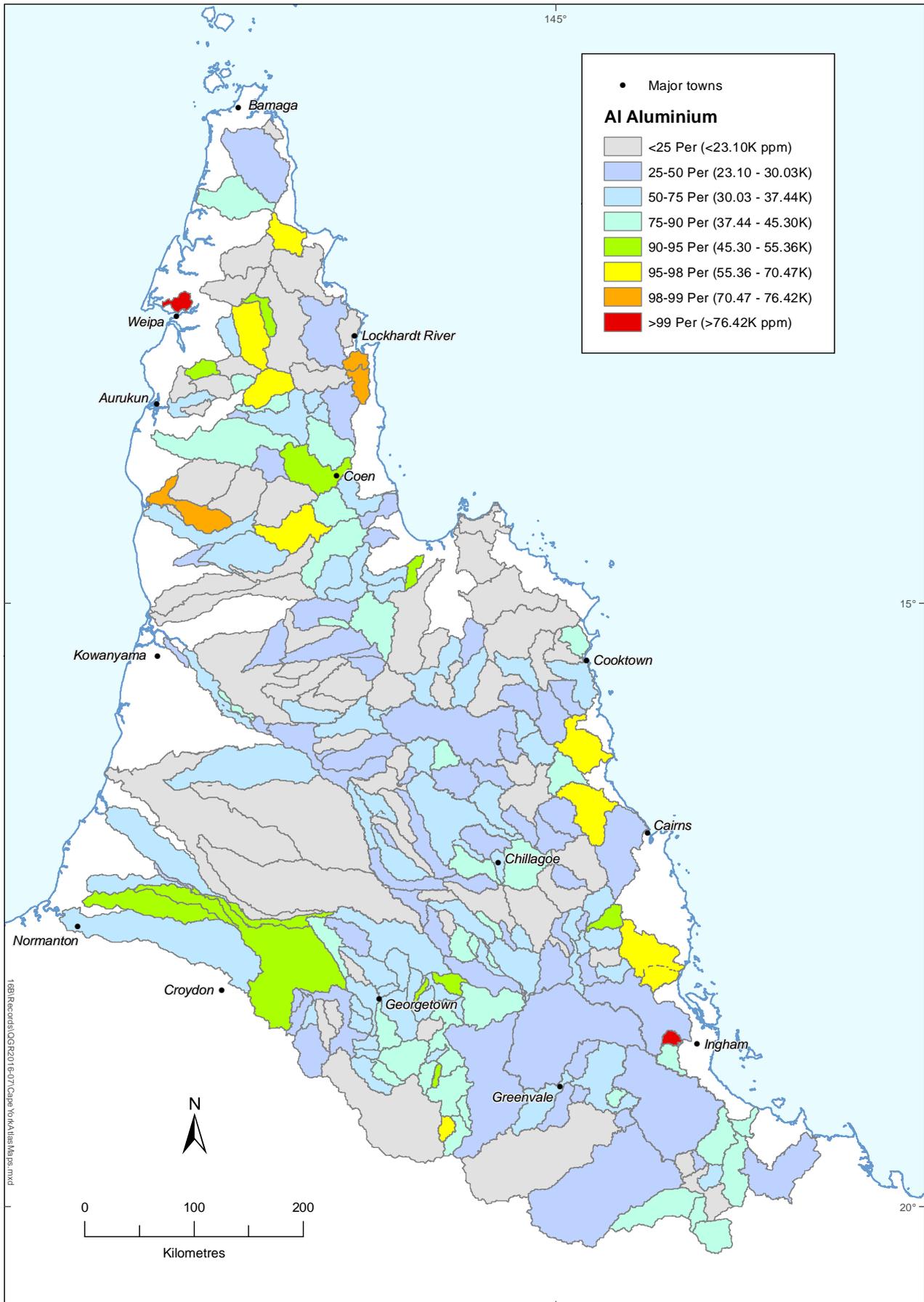
# **CAPE YORK GEOCHEMICAL ATLAS**

---

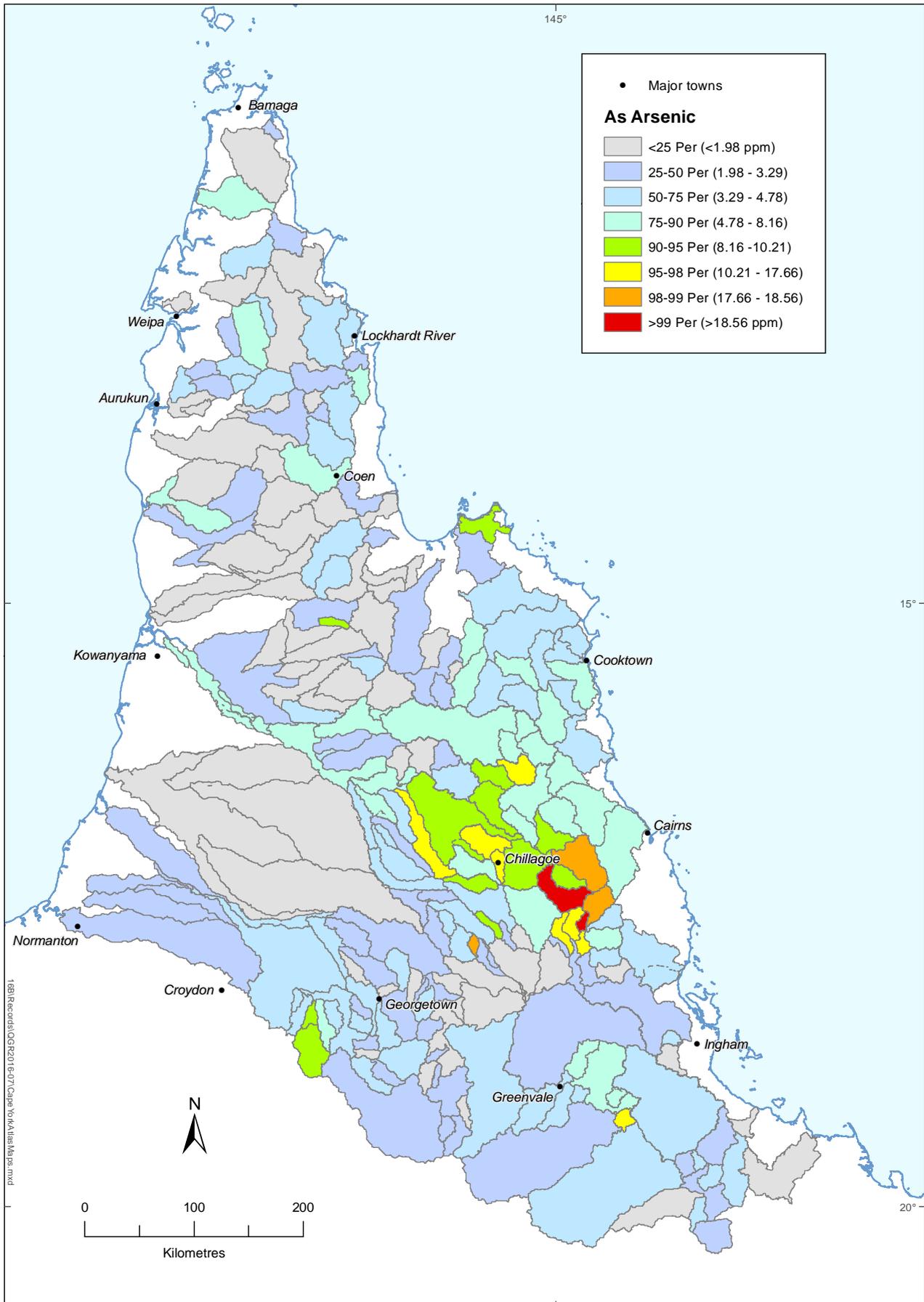
# Ag Silver



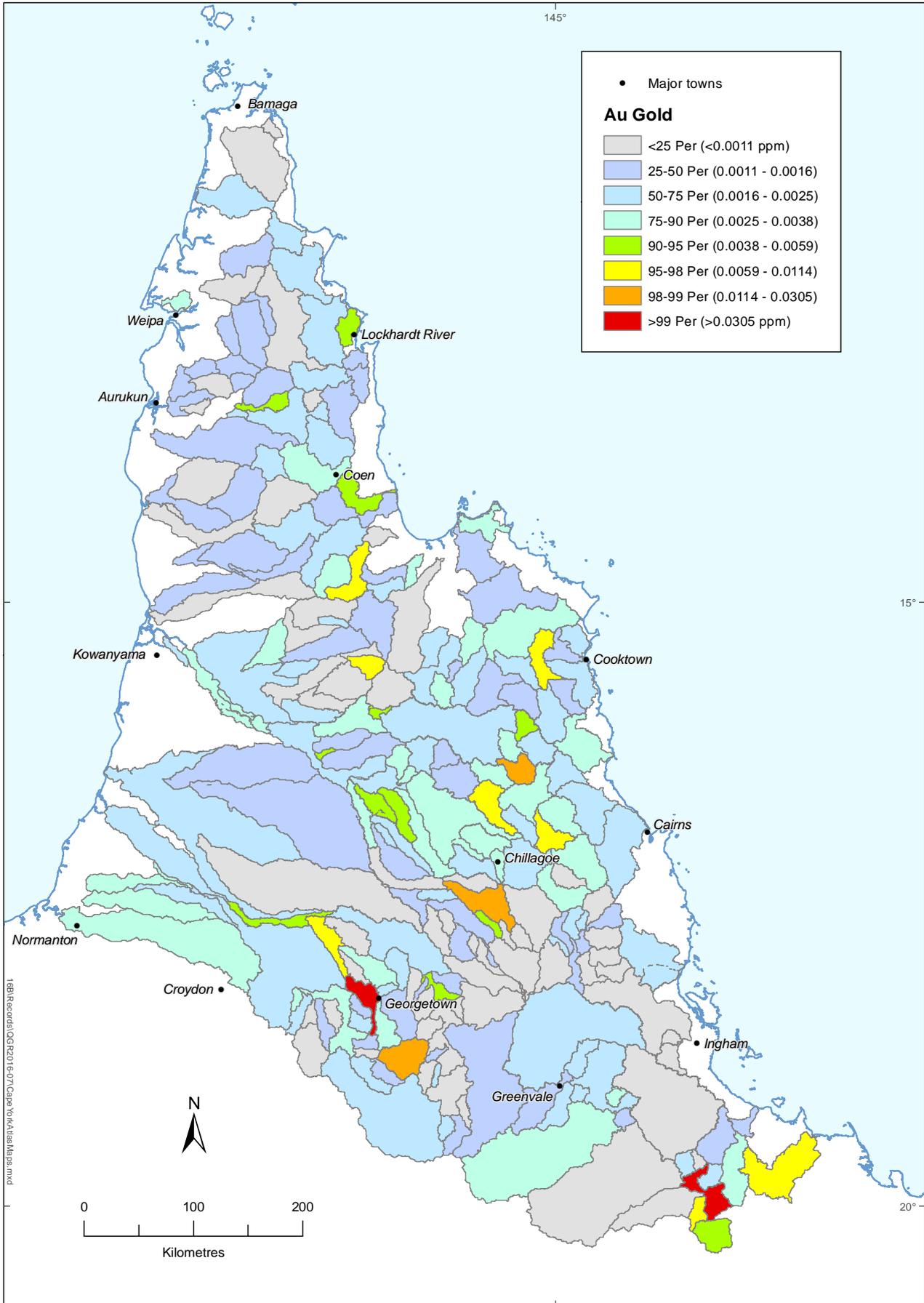
# Al Aluminium



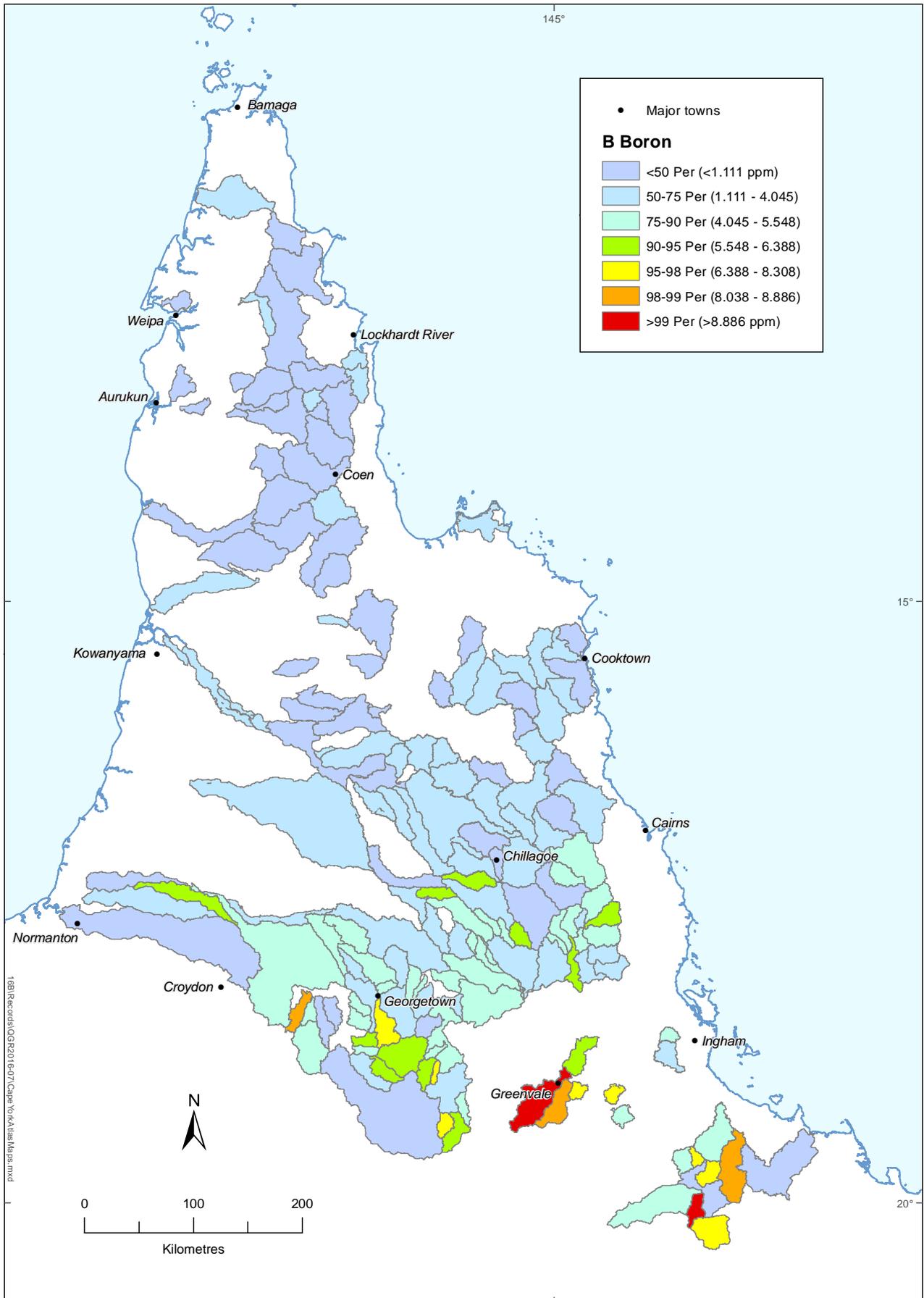
# As Arsenic



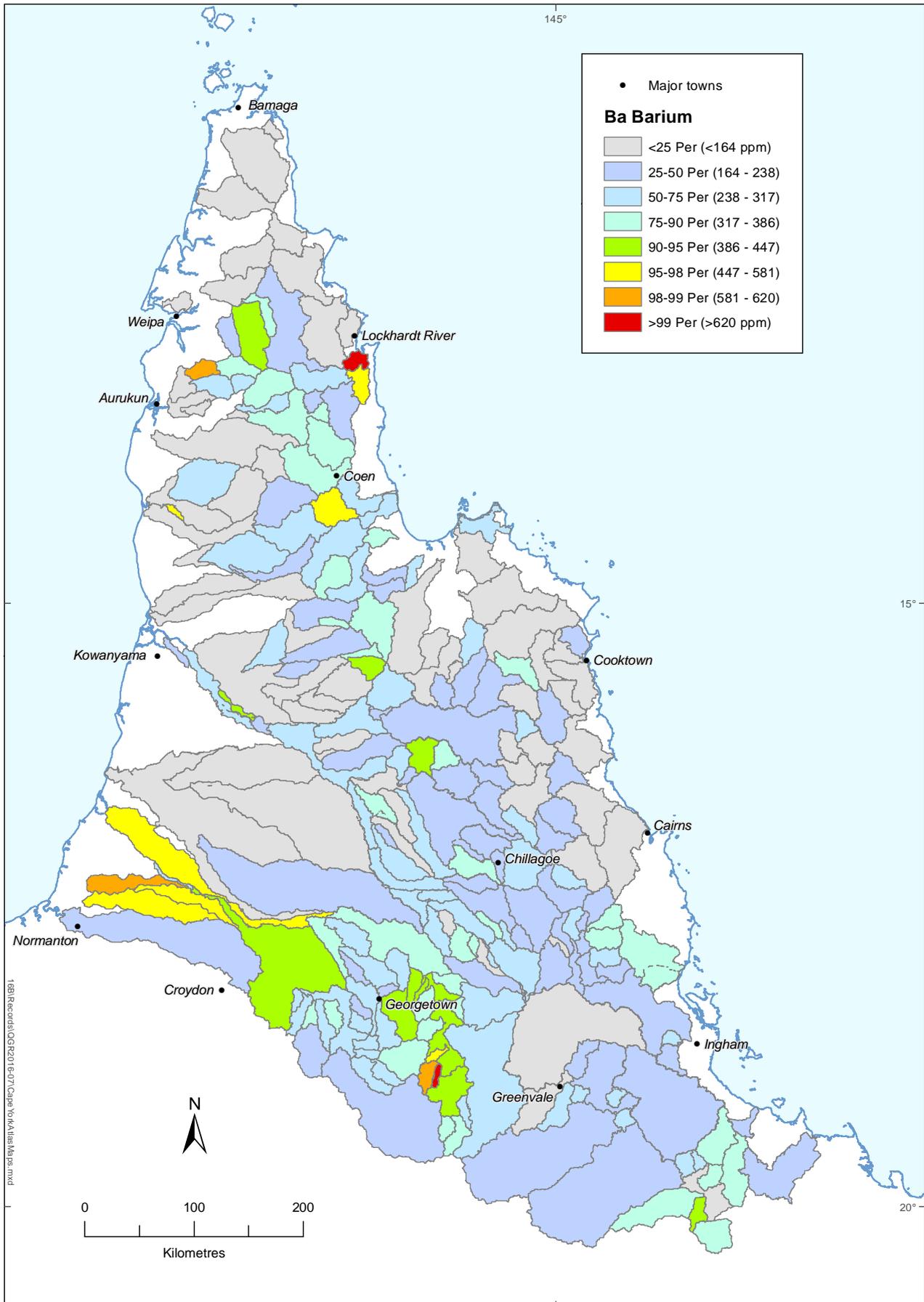
# Au Gold



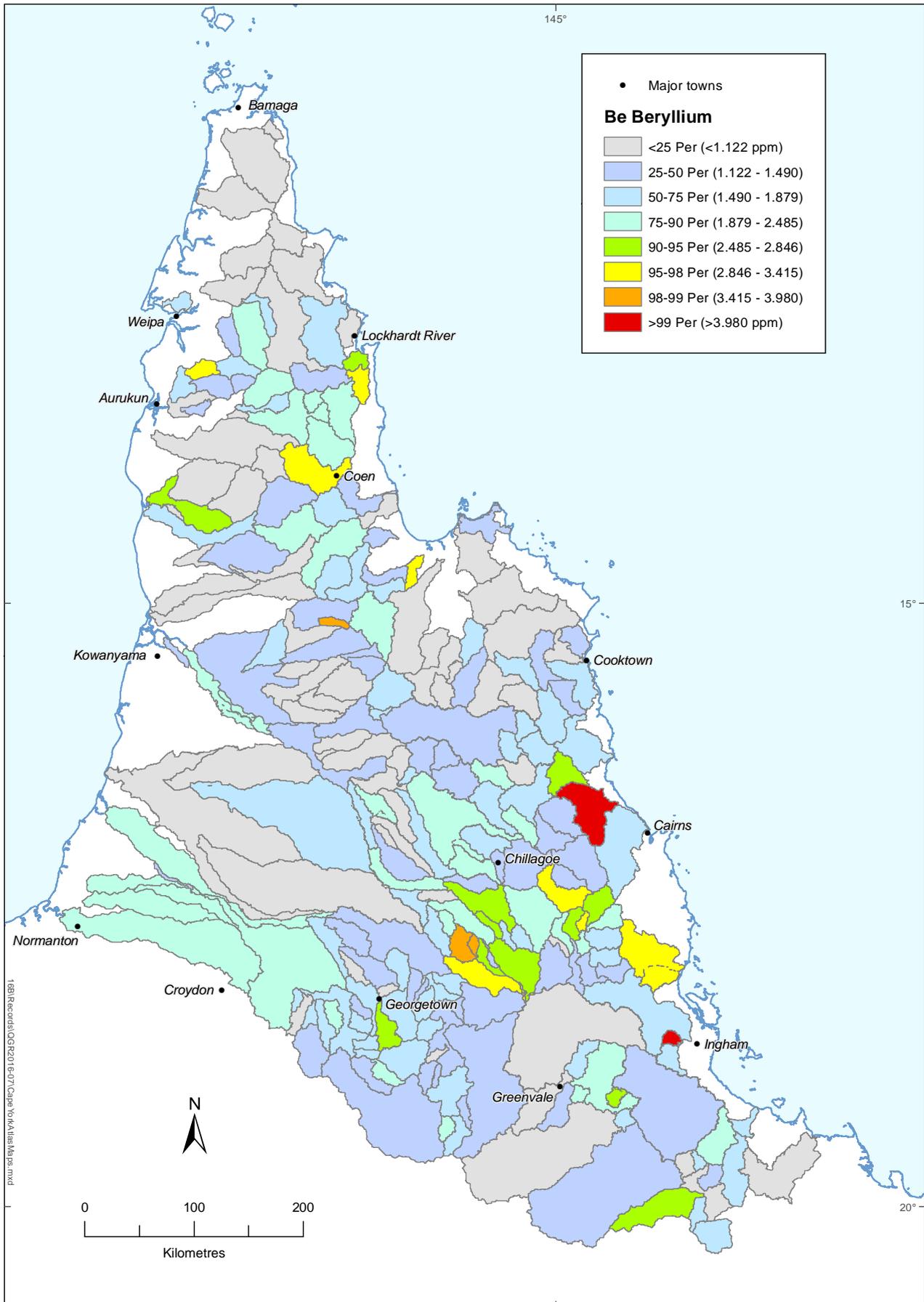
# B Boron



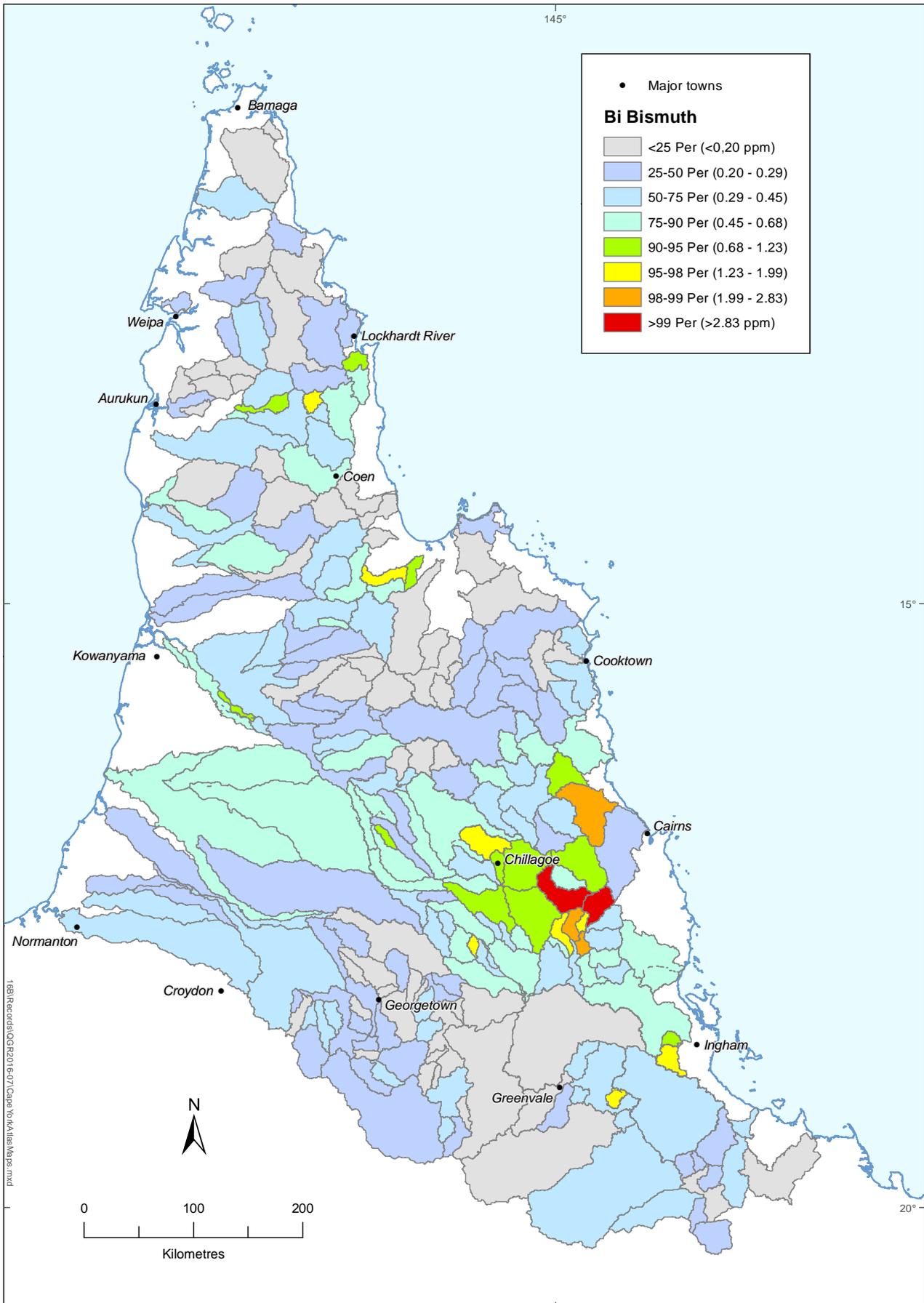
# Ba Barium



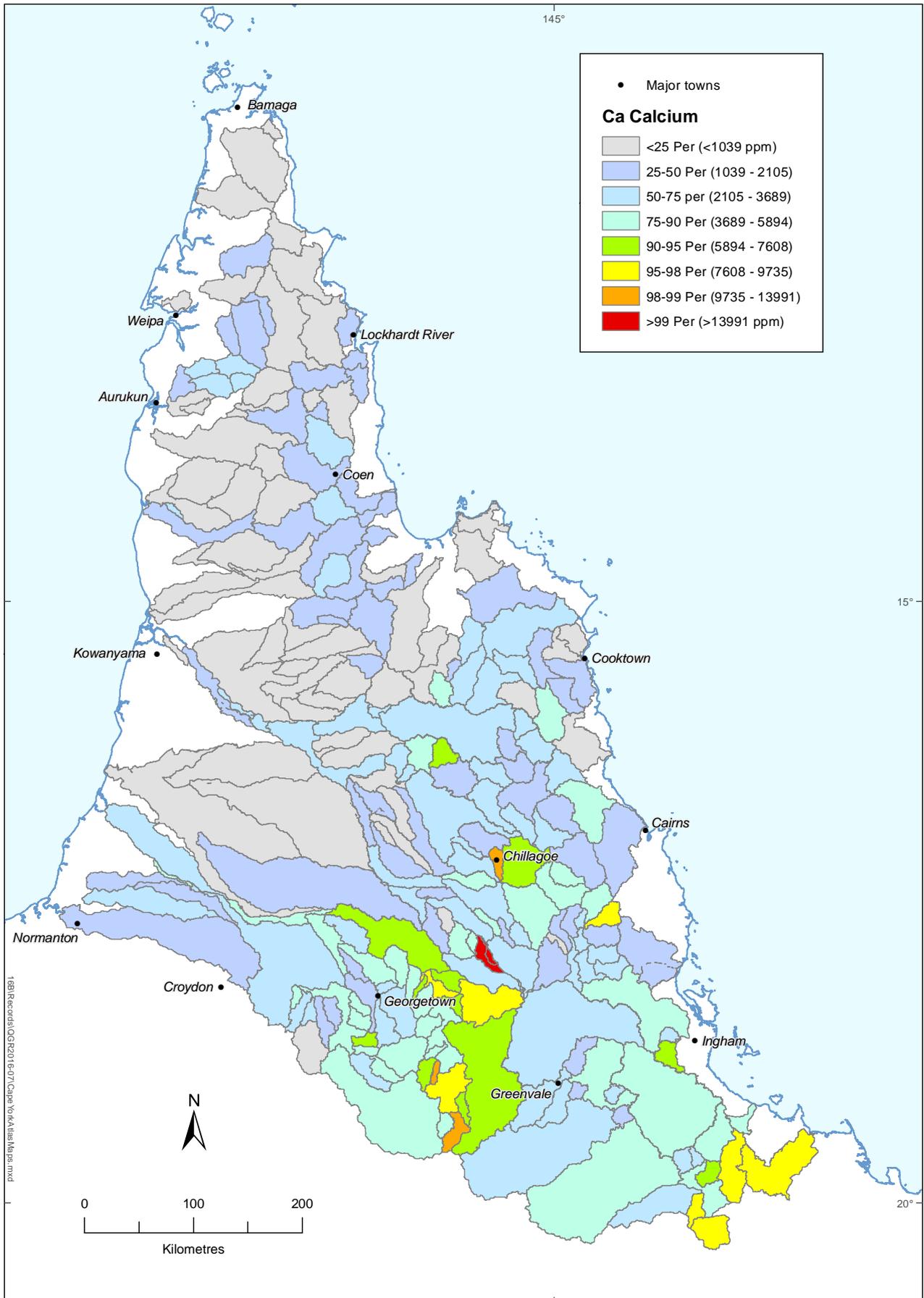
# Be Beryllium



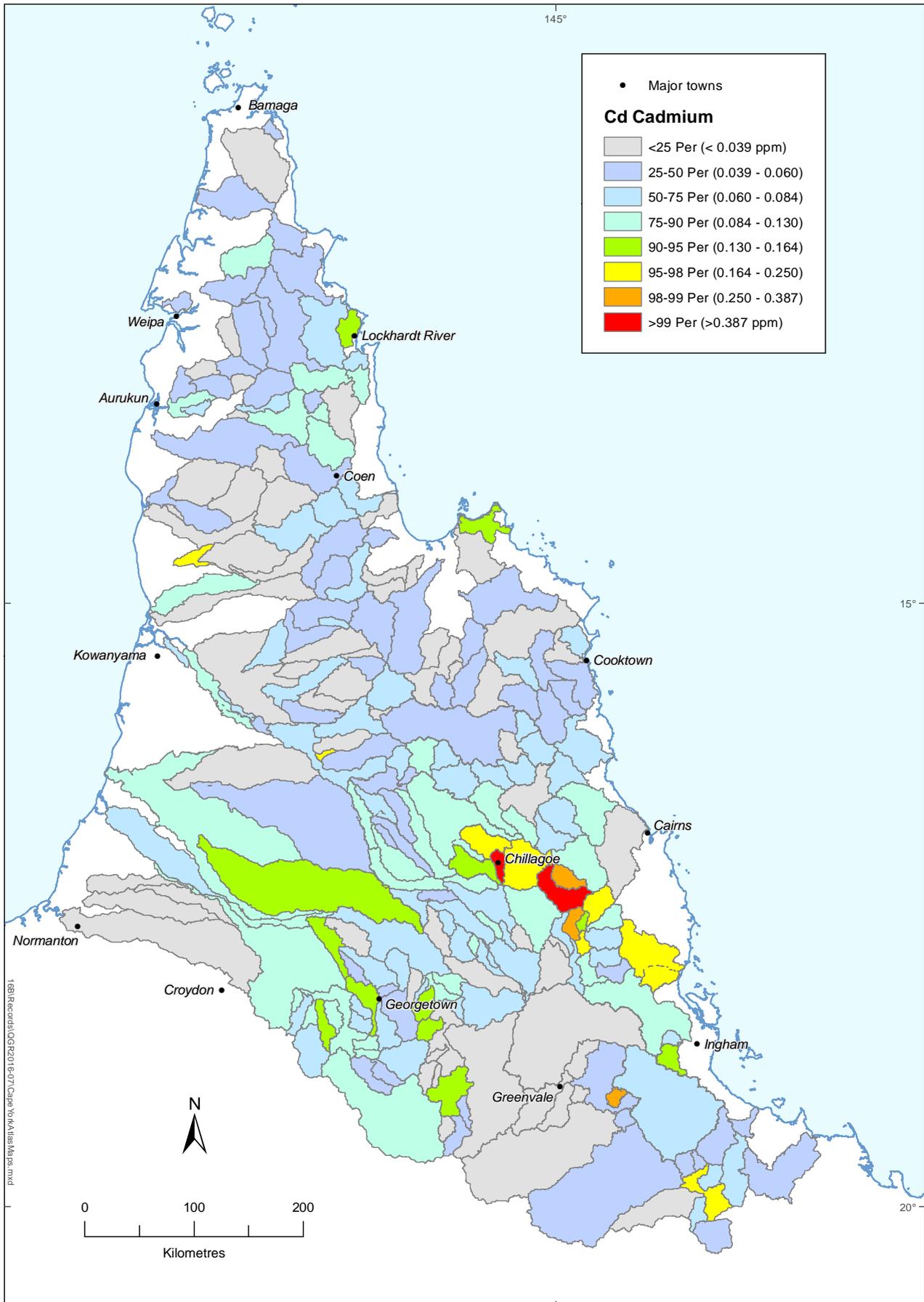
# Bi Bismuth



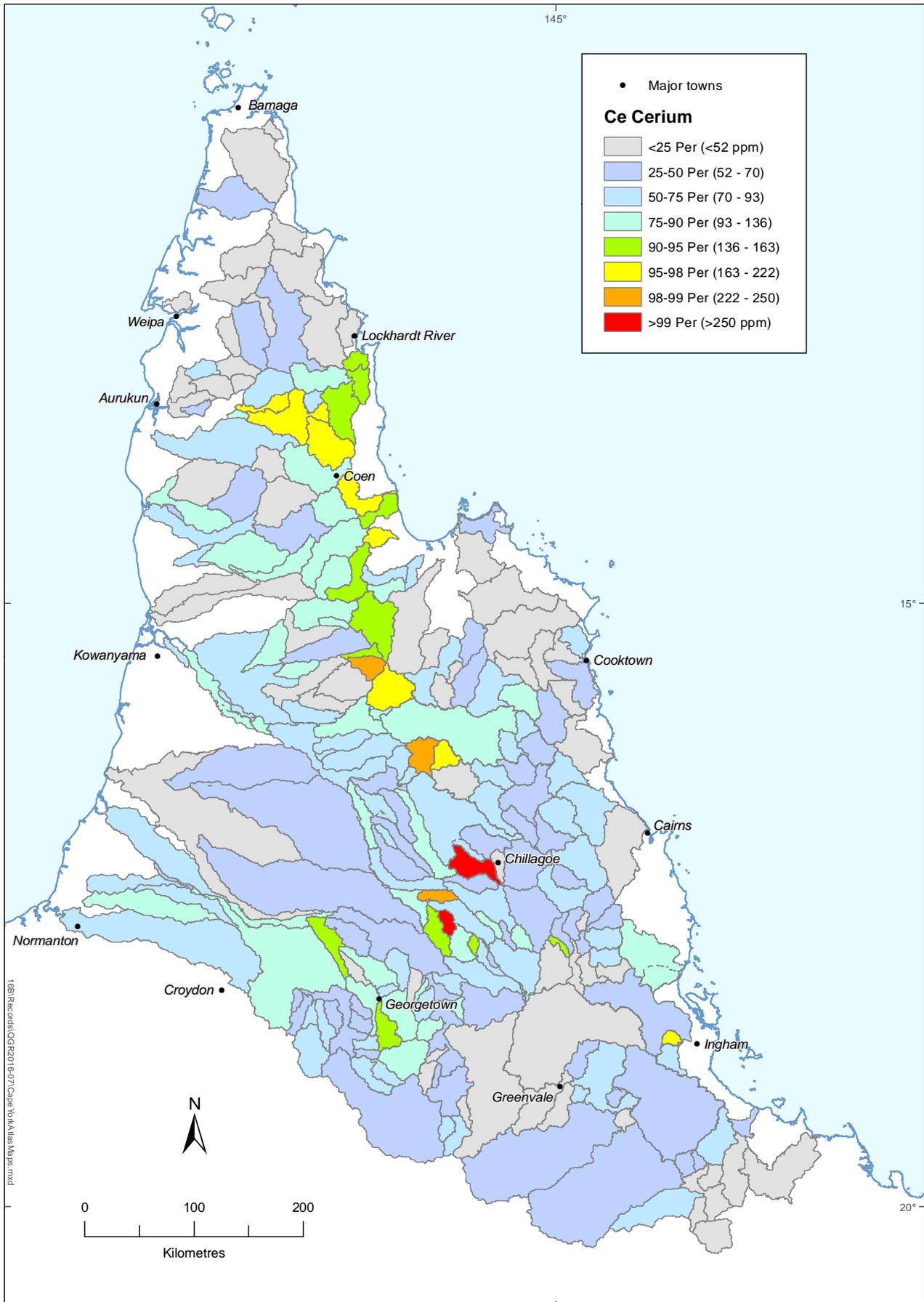
# Ca Calcium



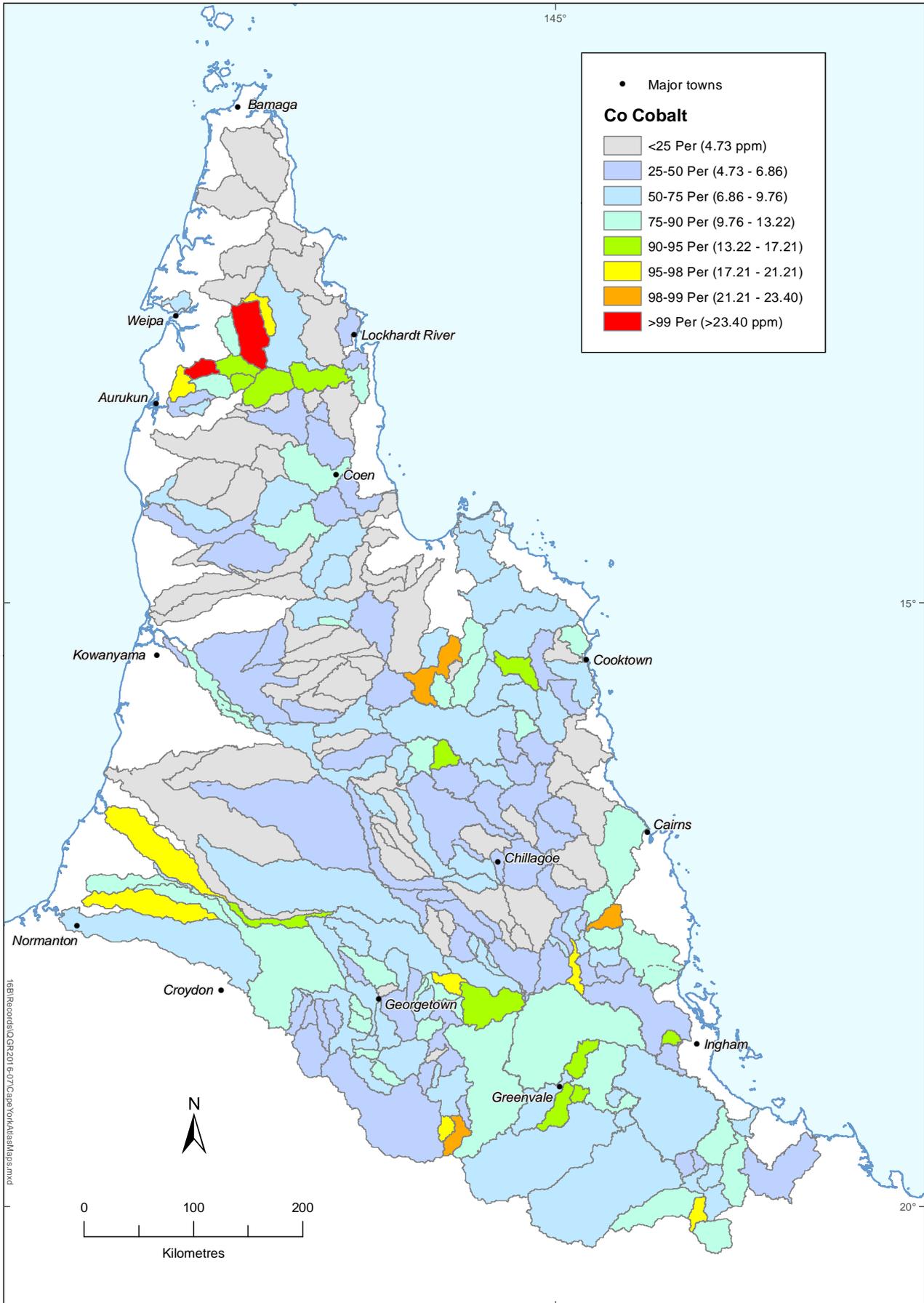
# Cd Cadmium



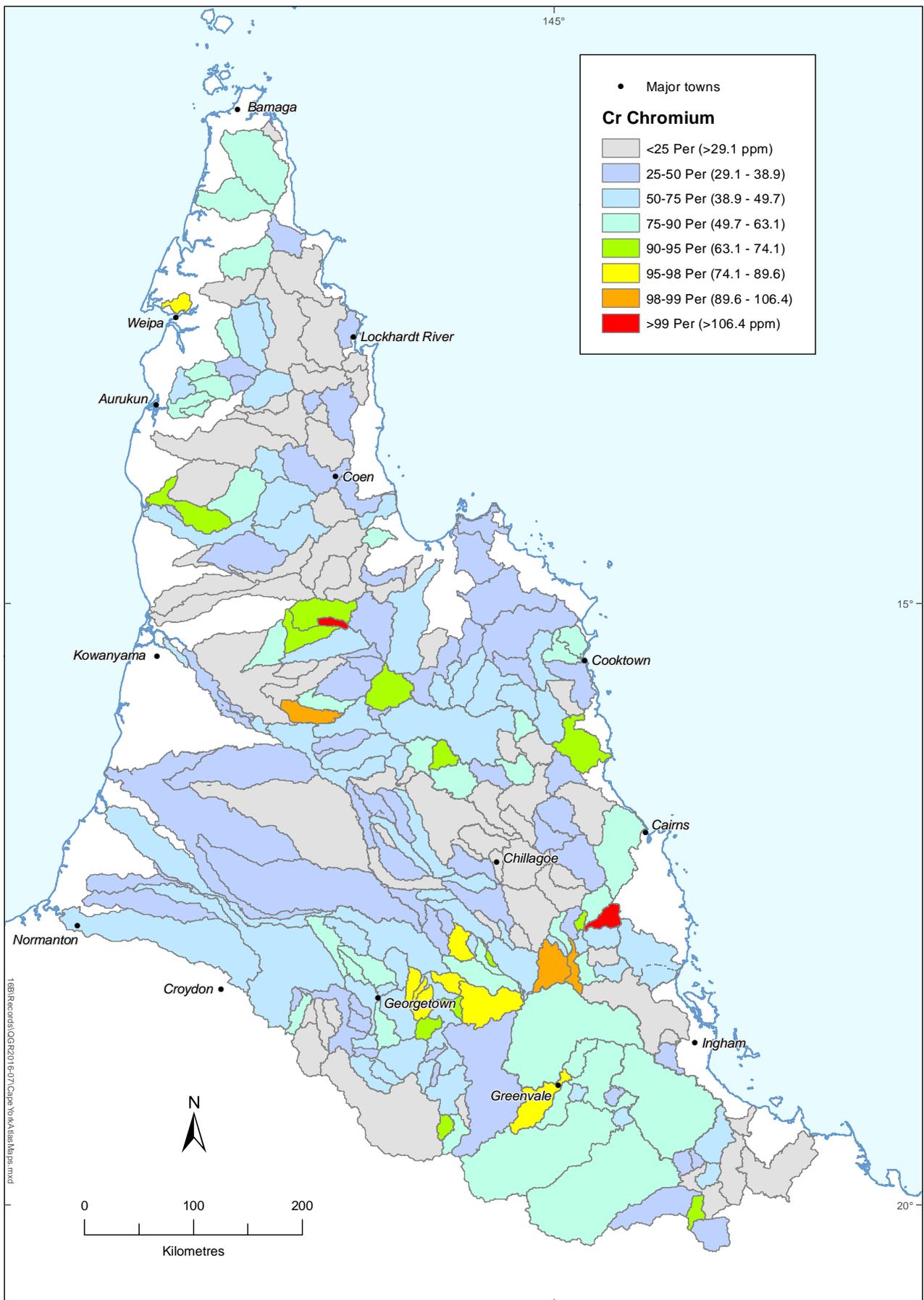
# Ce Cerium



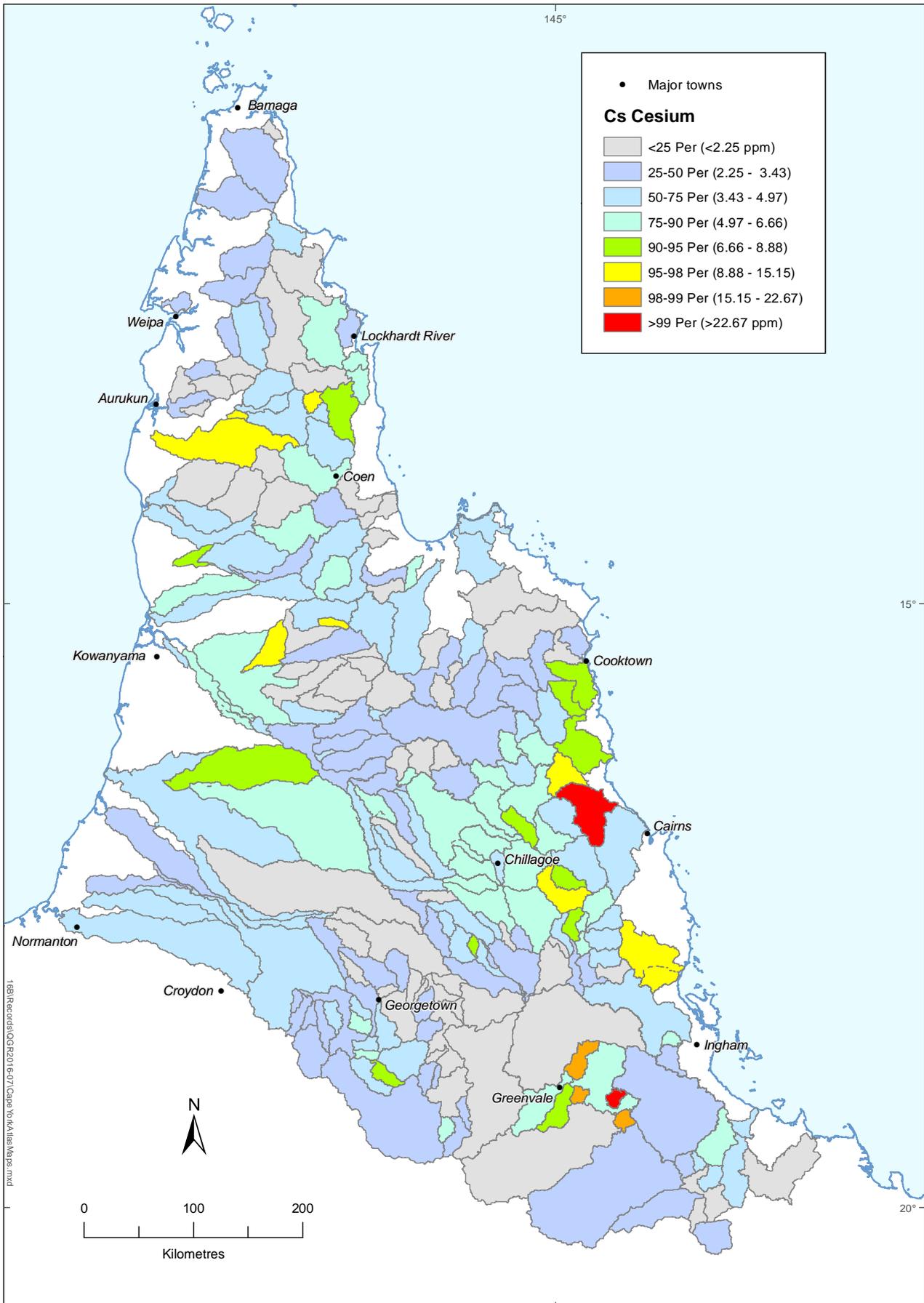
# Co Cobalt



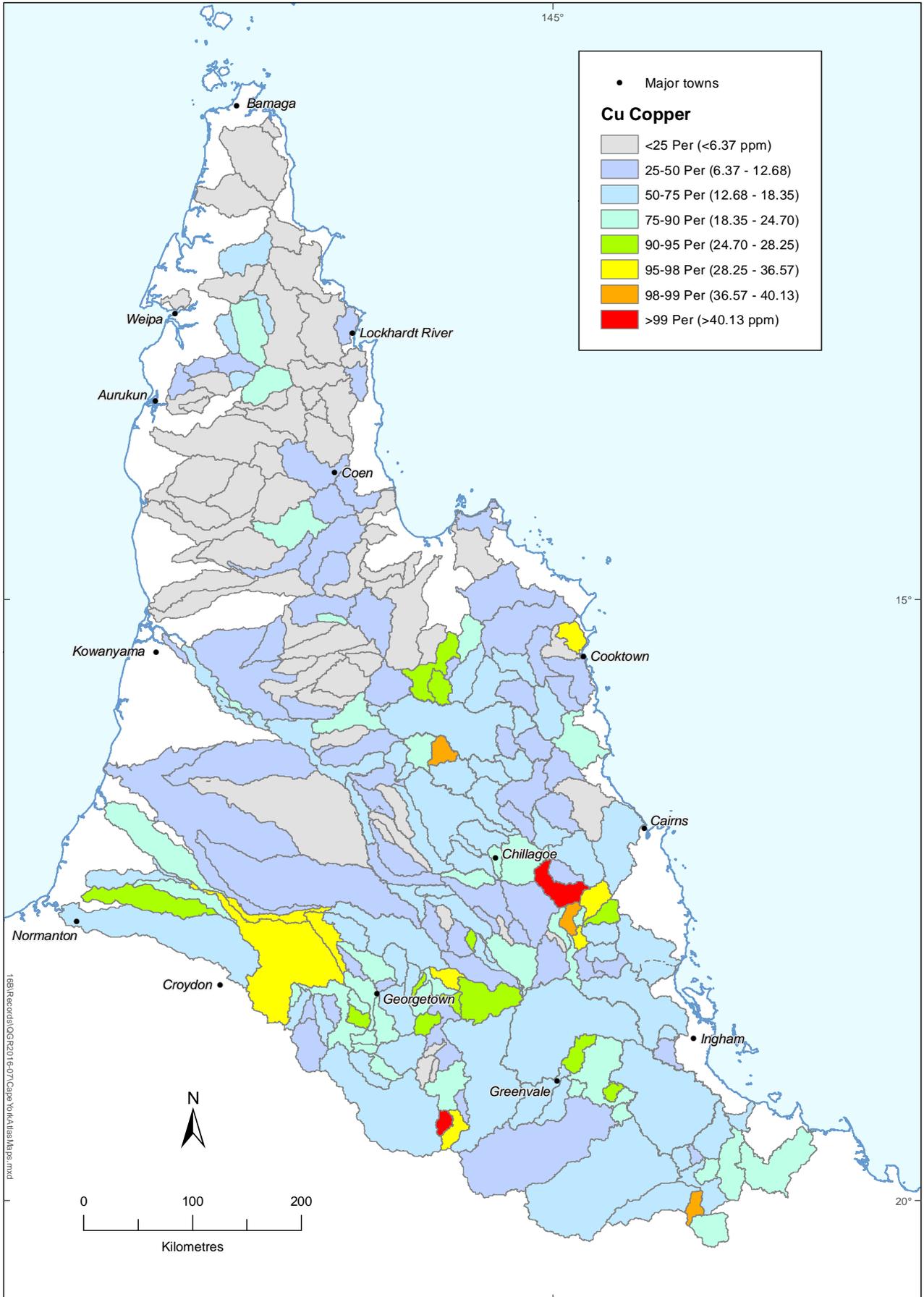
# Cr Chromium



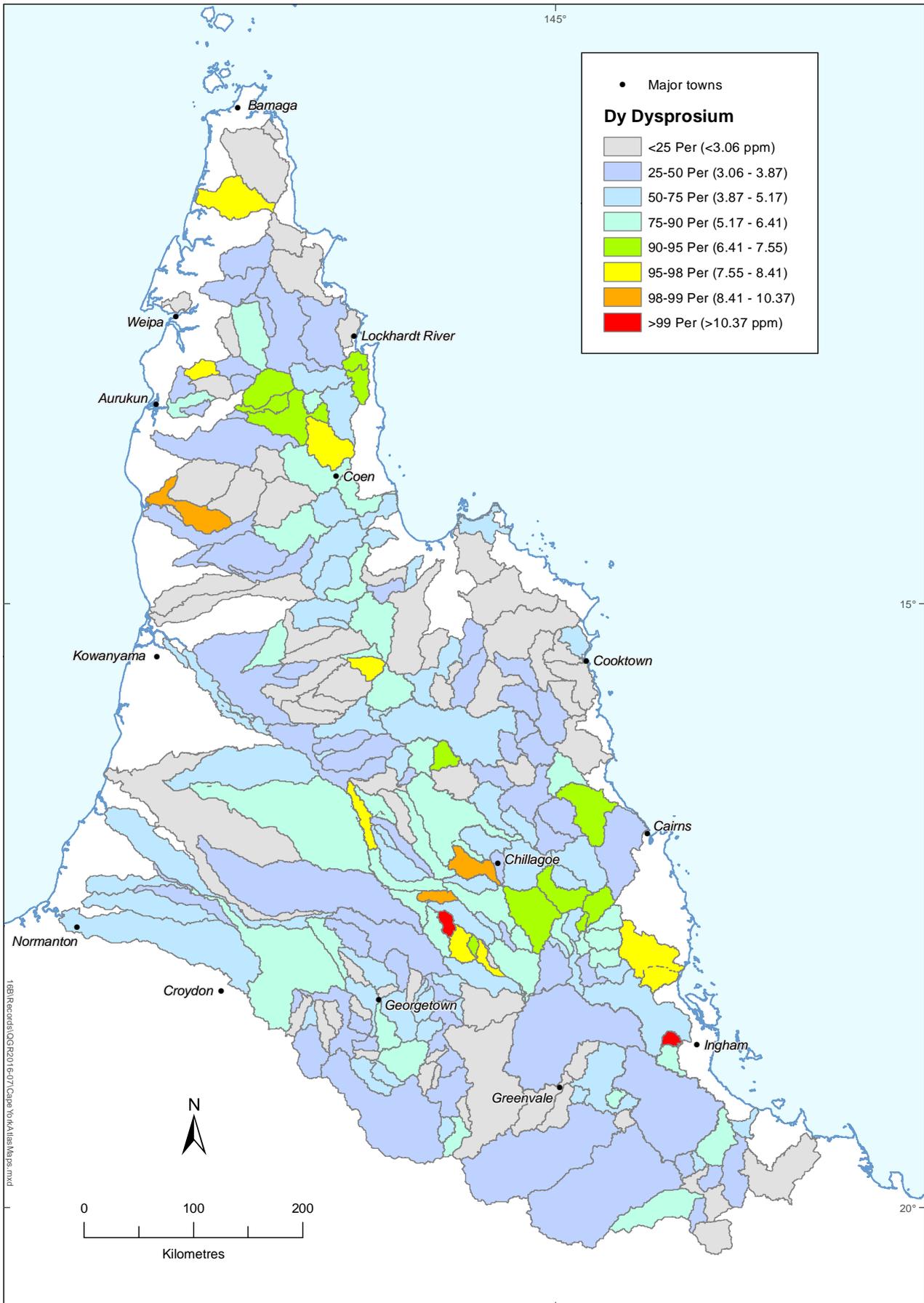
# Cs Cesium



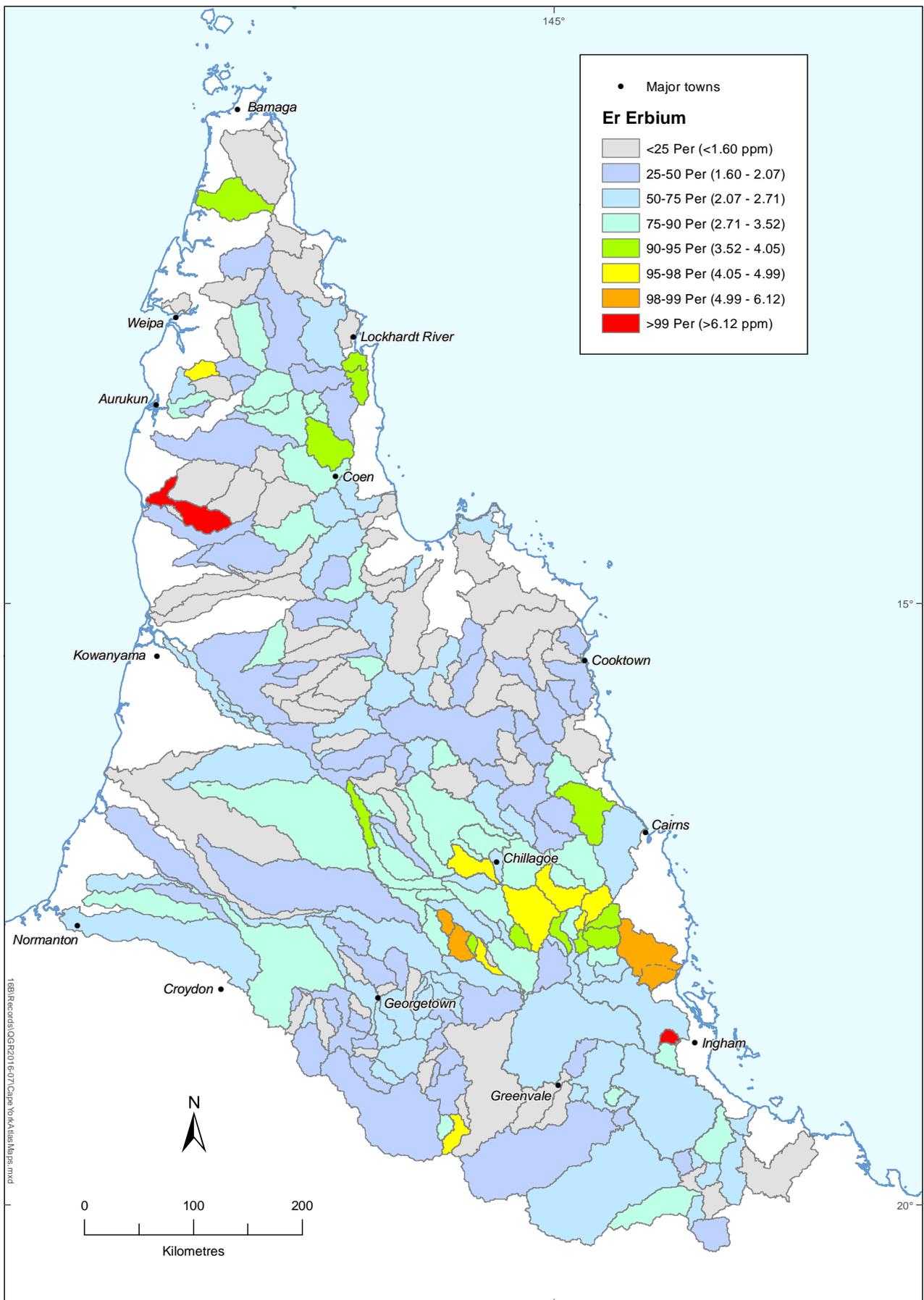
# Cu Copper



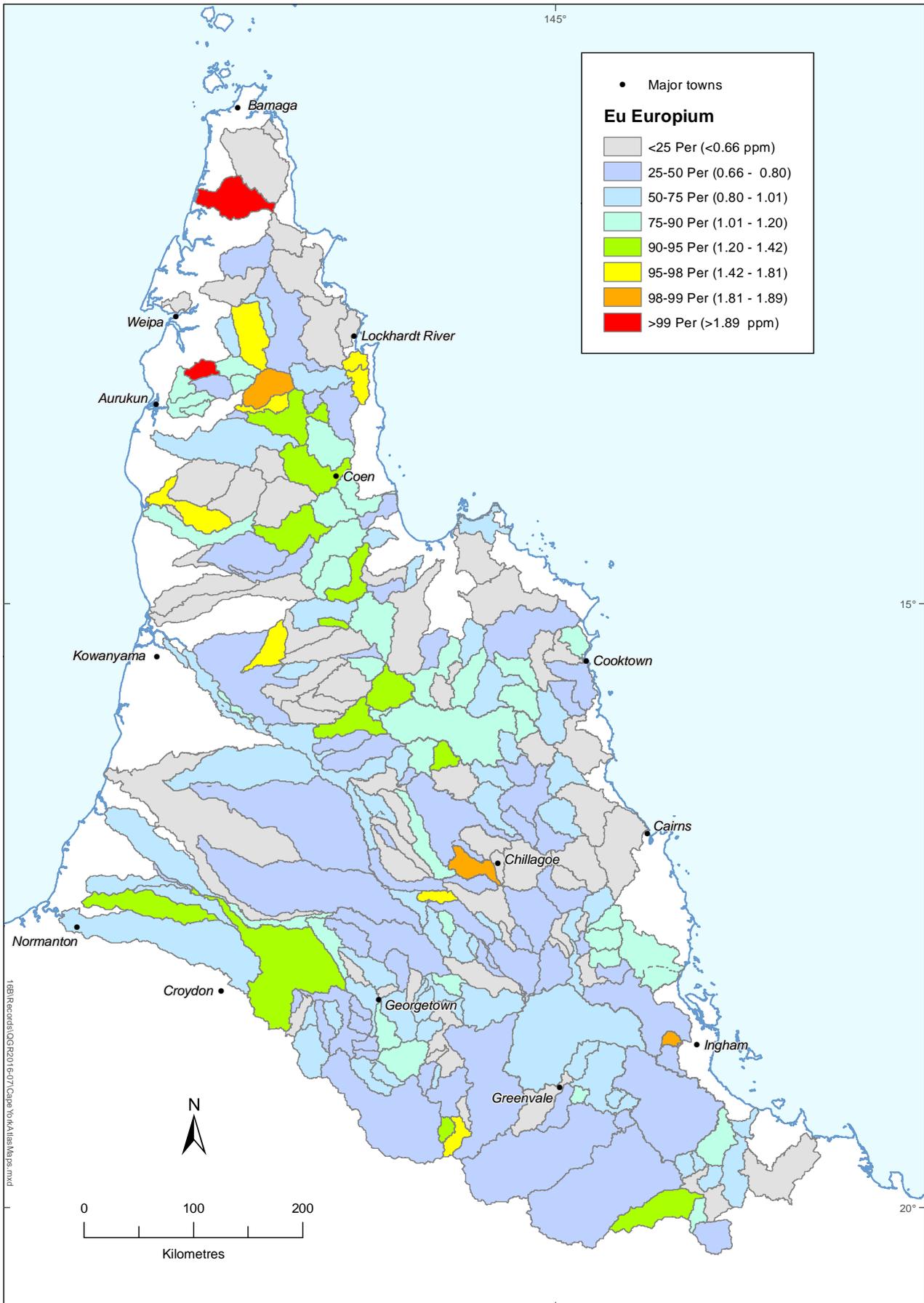
# Dy Dysprosium



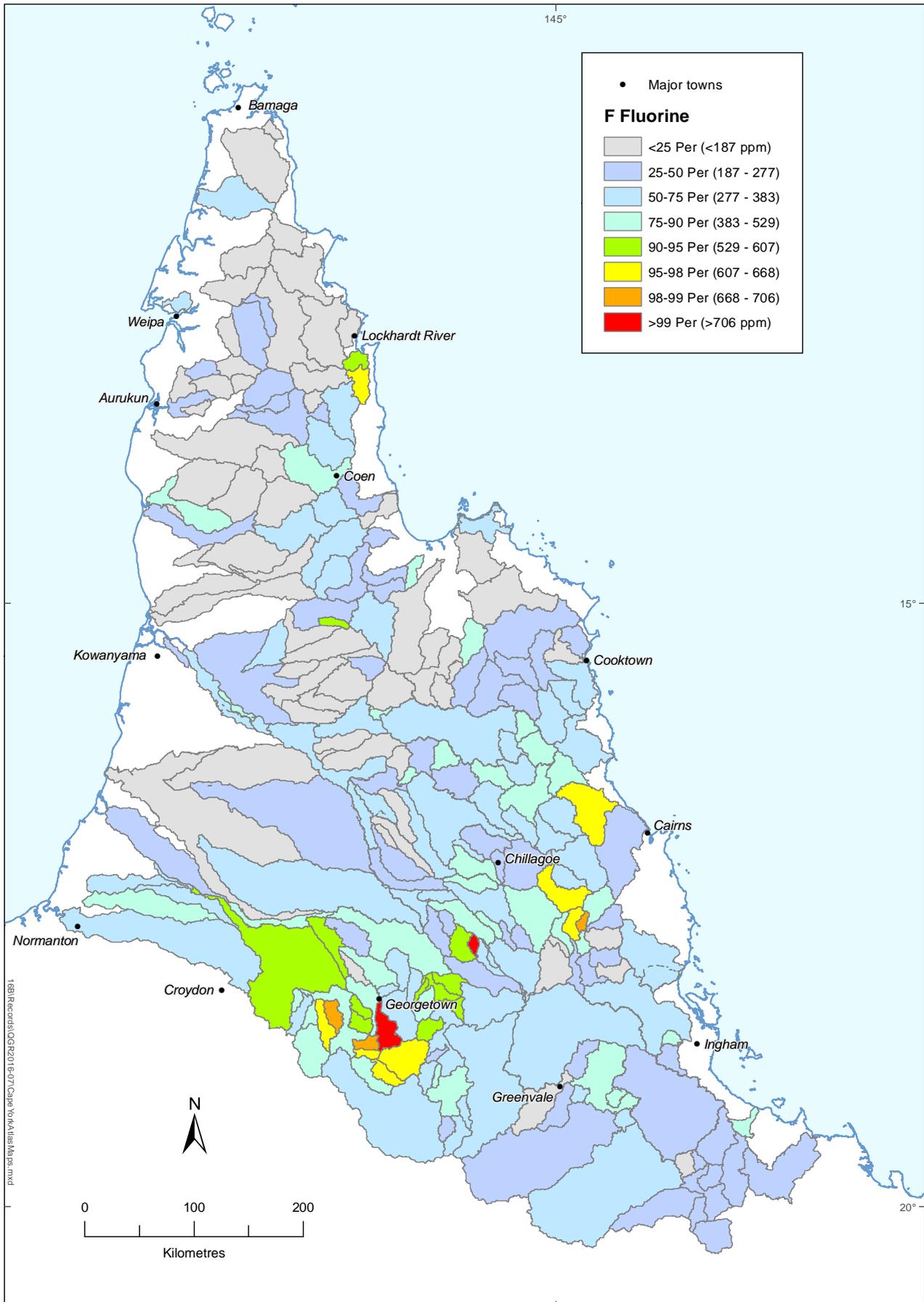
# Er Erbium



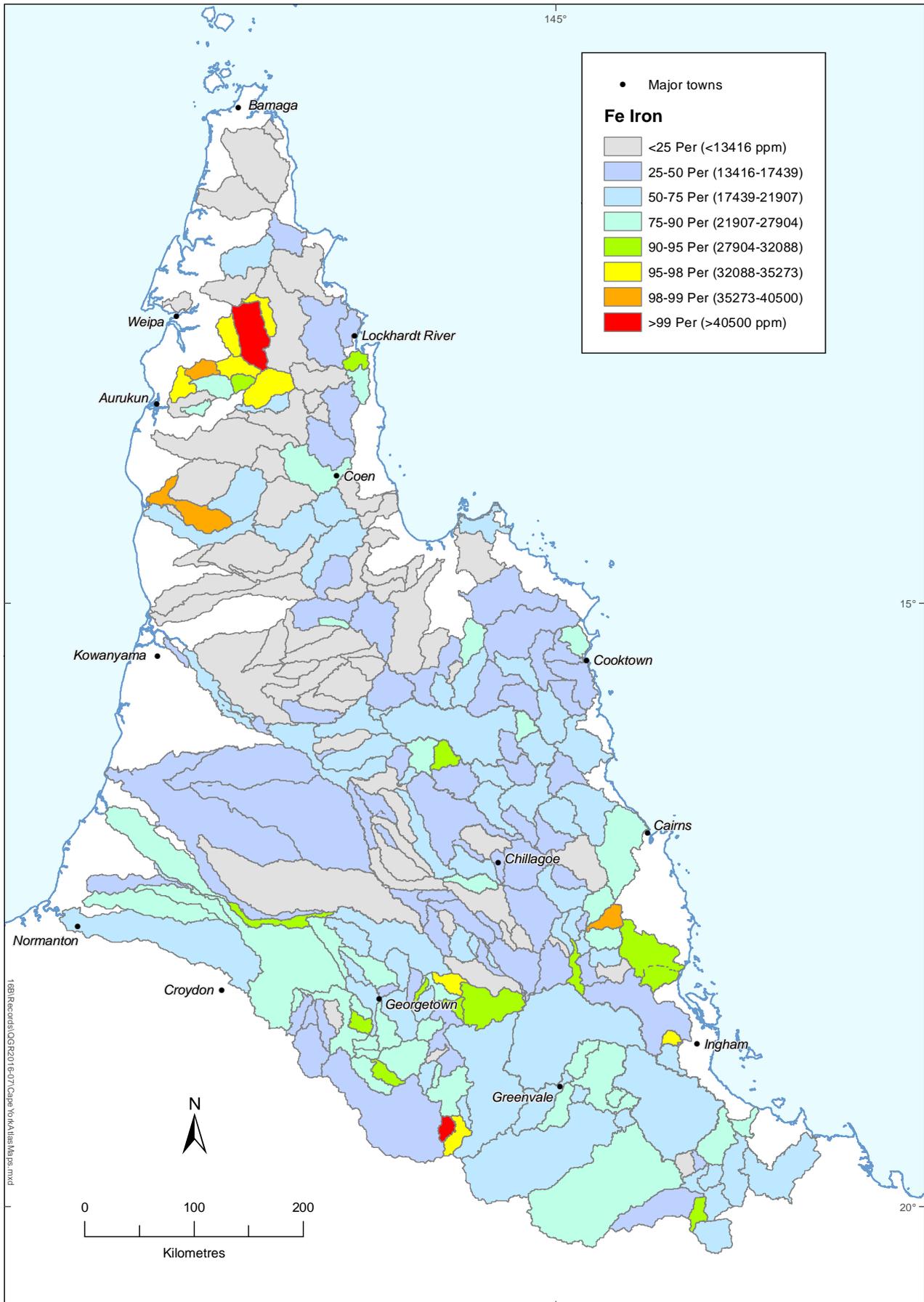
# Eu Europium



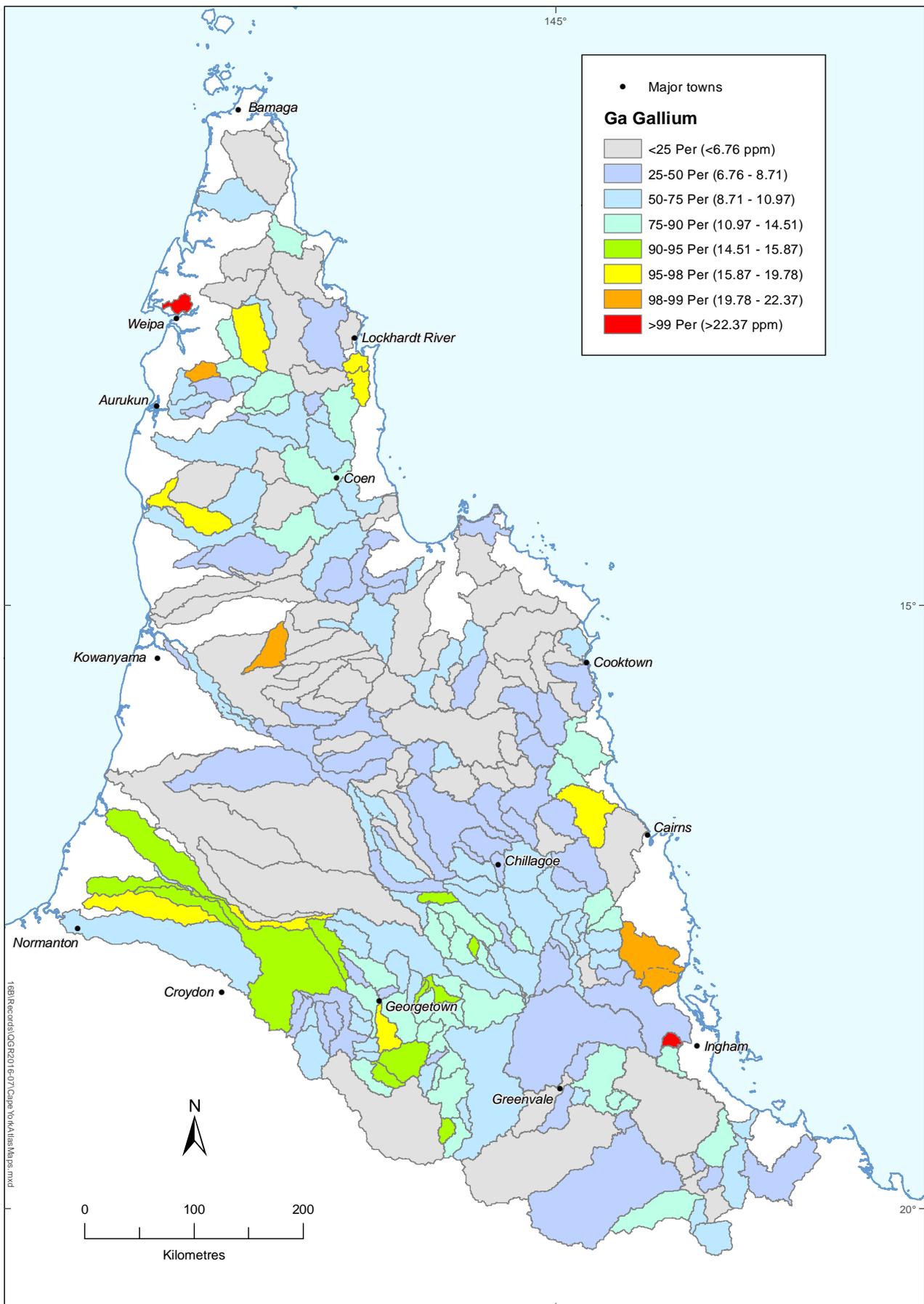
# F Fluorine



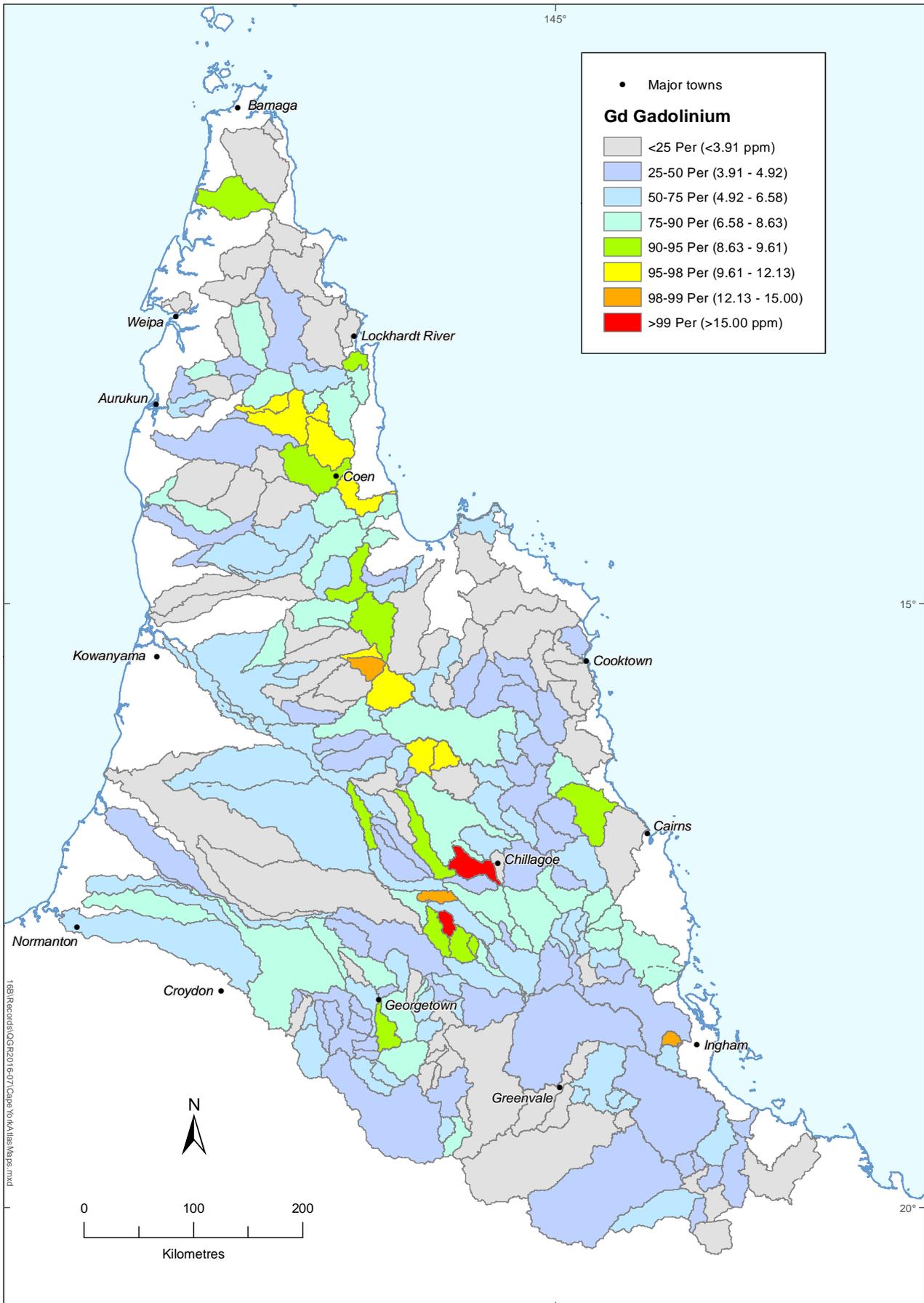
# Fe Iron



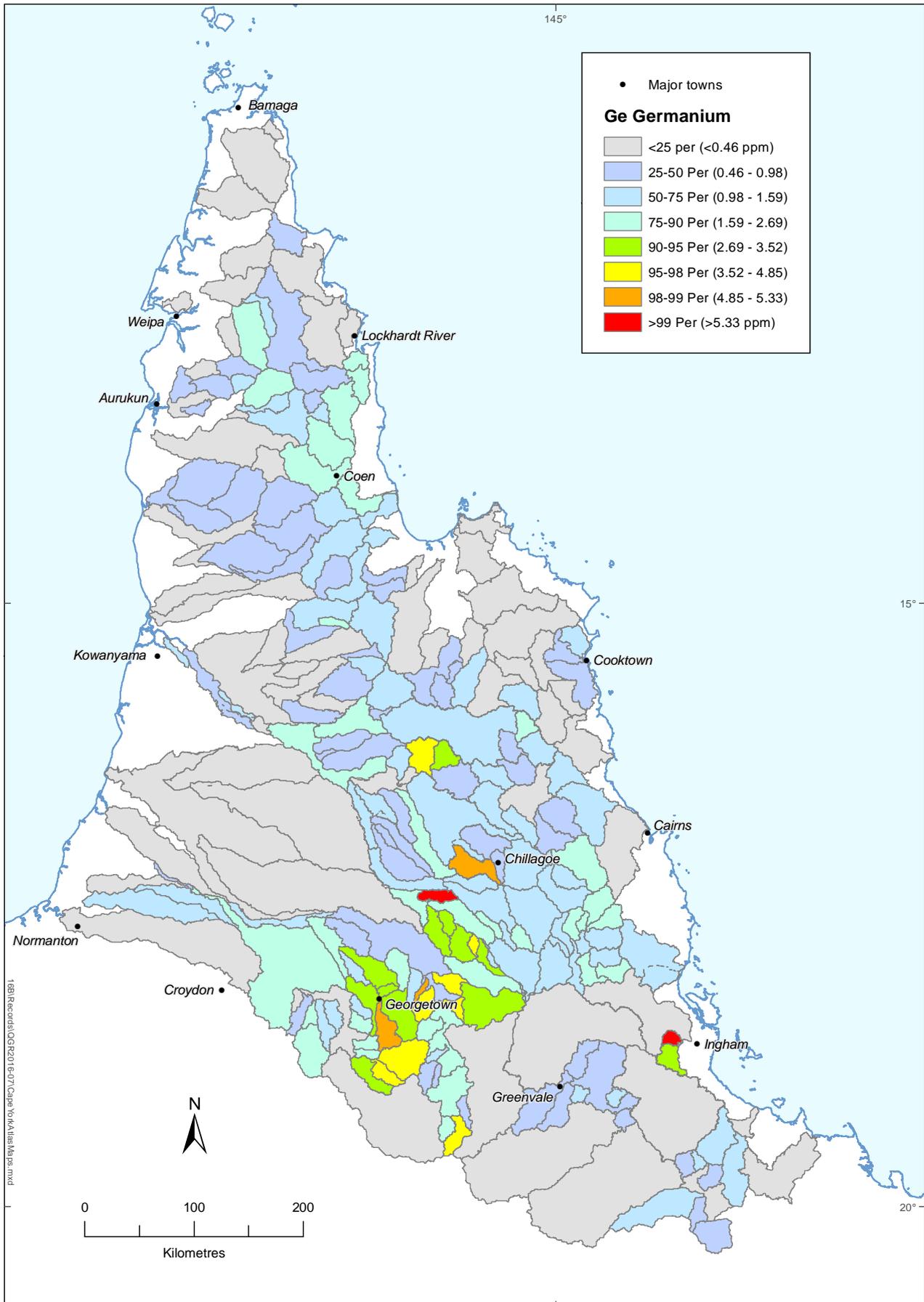
# Ga Gallium



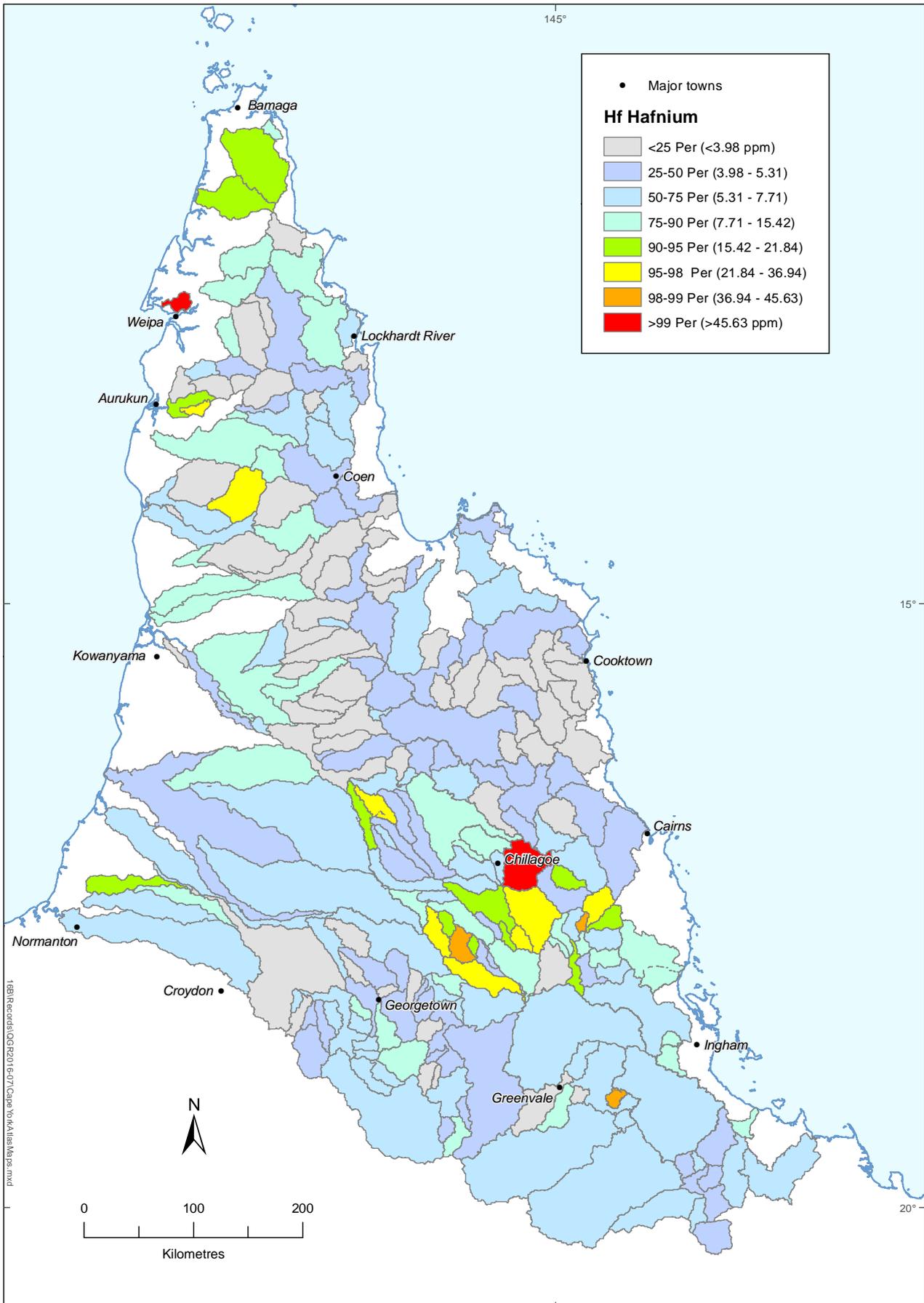
# Gd Gadolinium



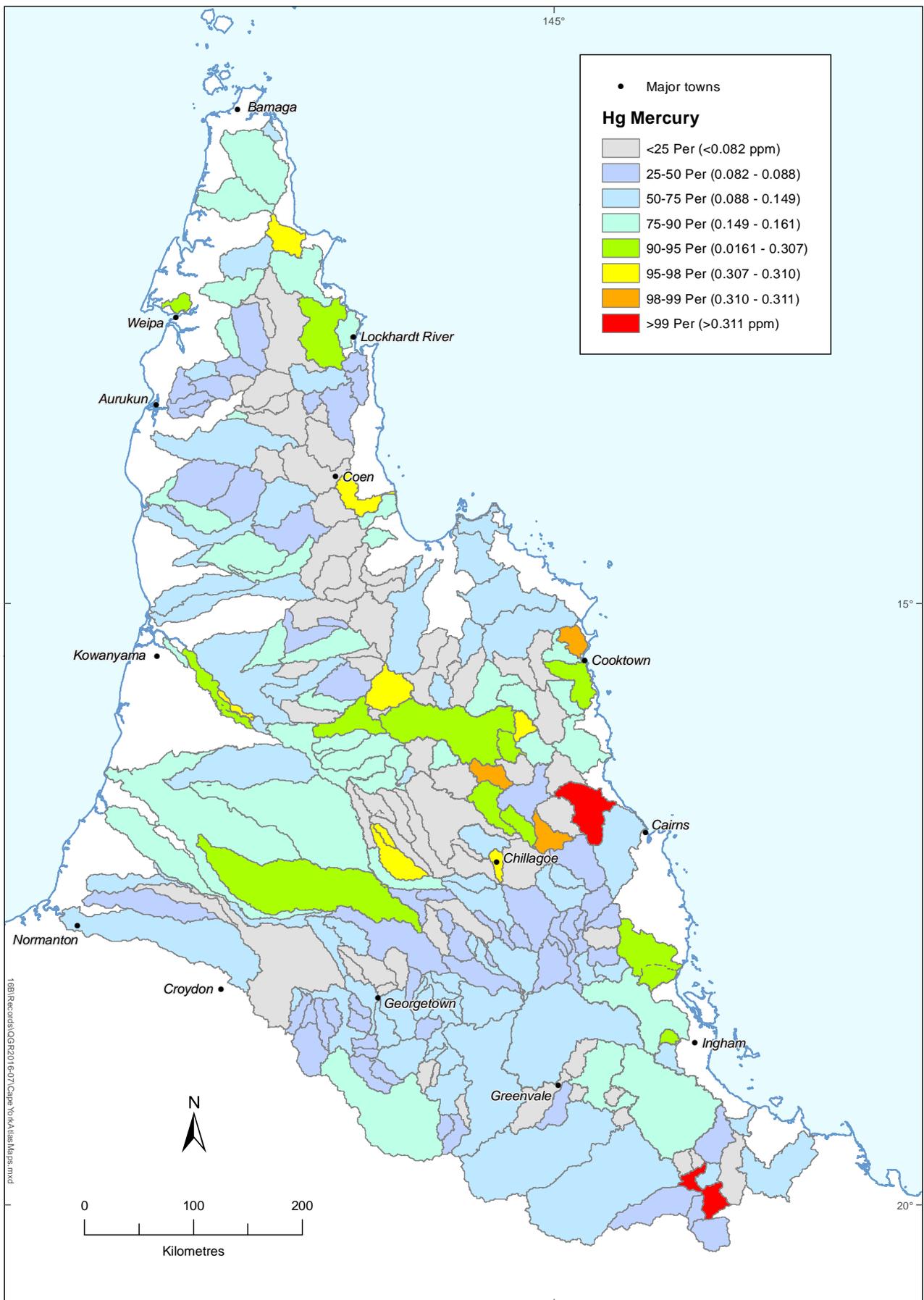
# Ge Germanium



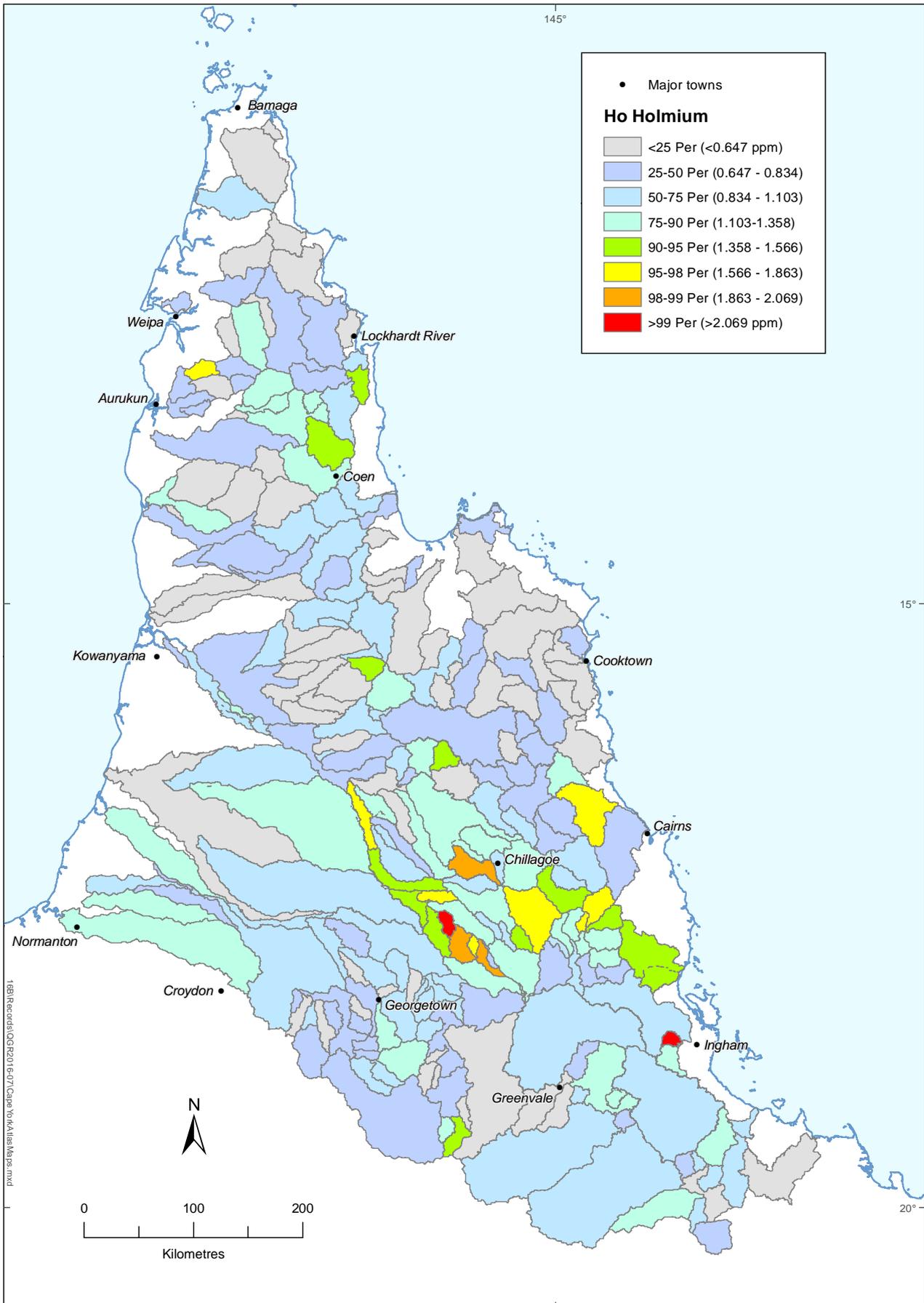
# Hf Hafnium



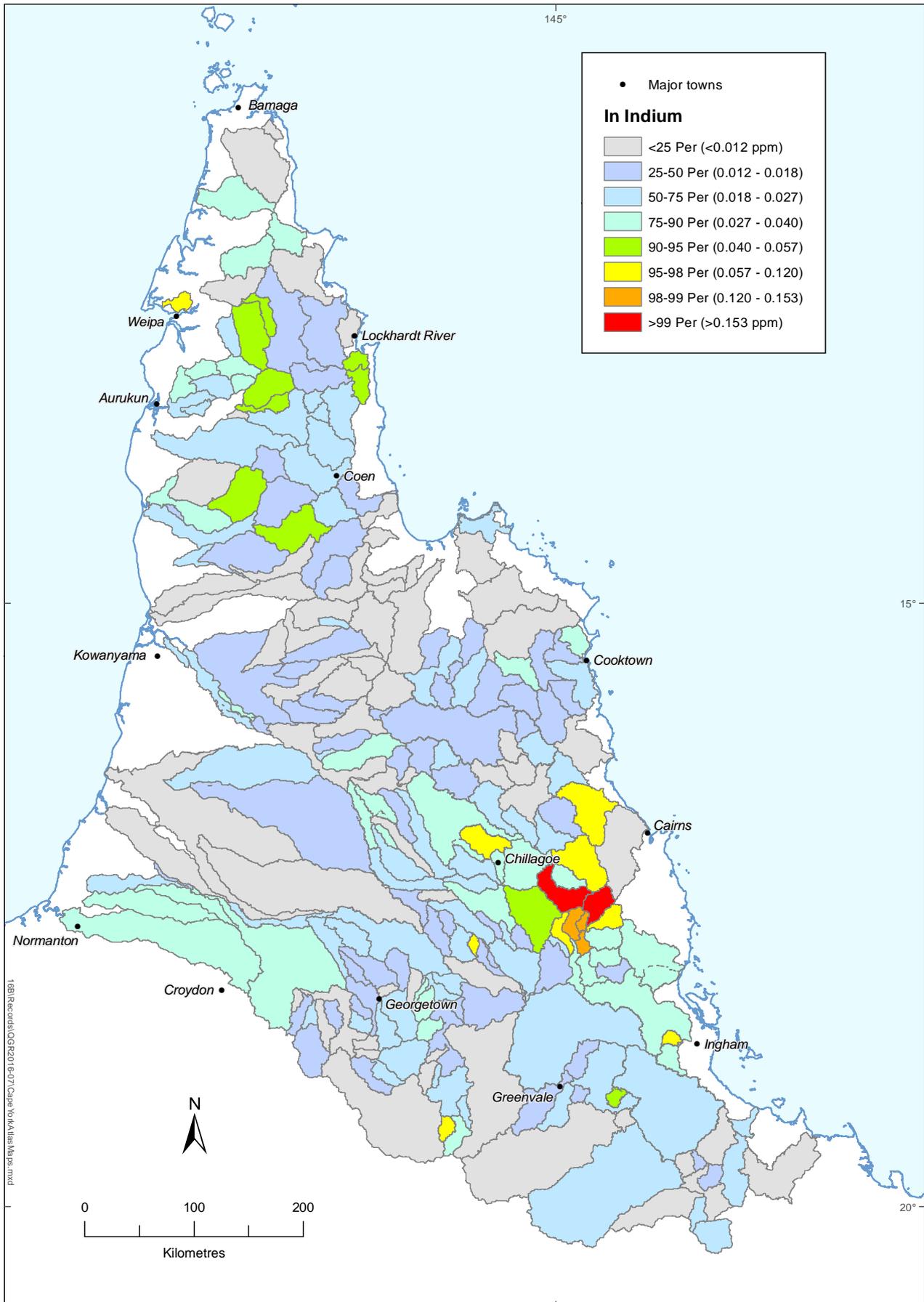
# Hg Mercury



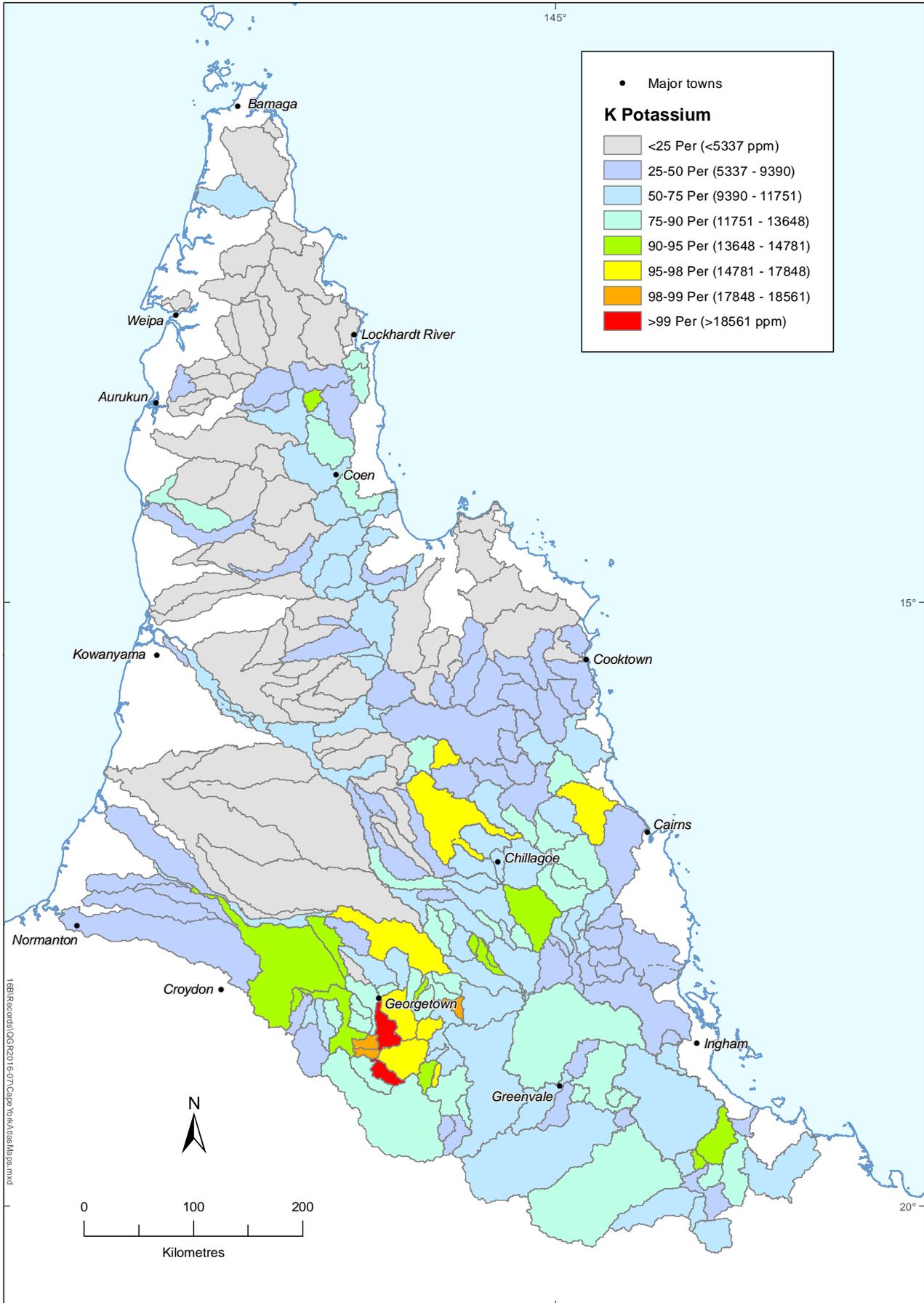
# Ho Holmium



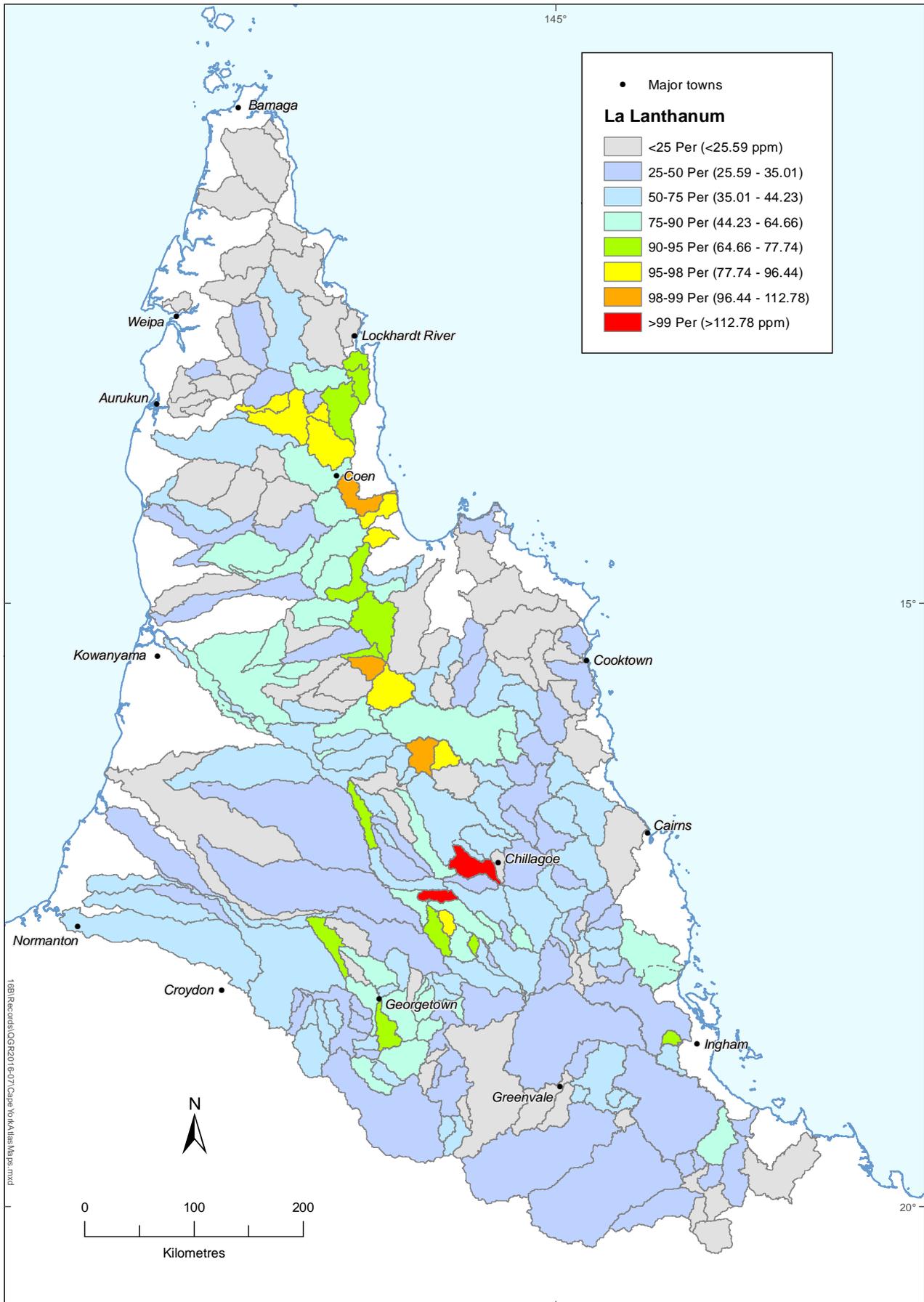
# In Indium



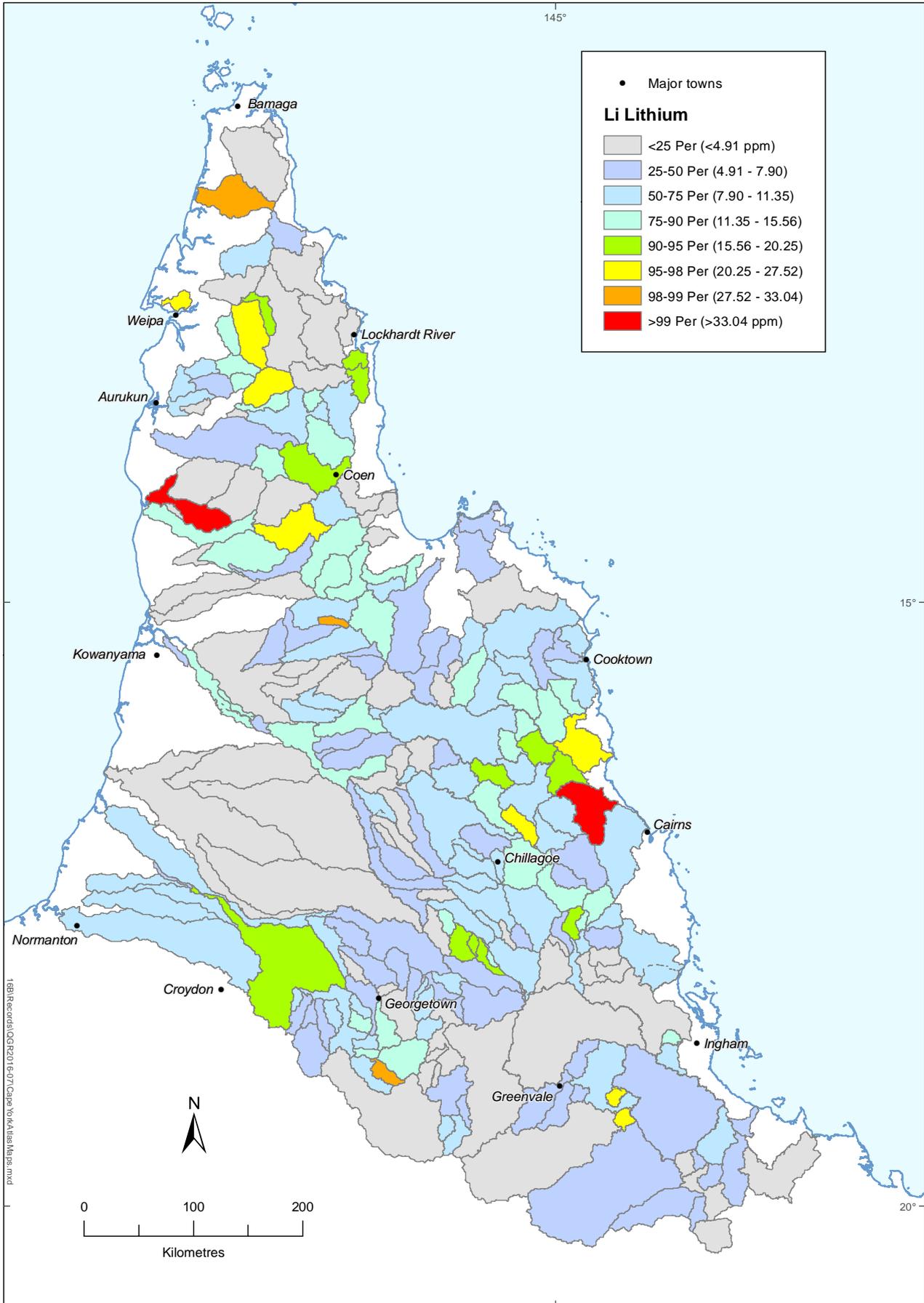
# K Potassium



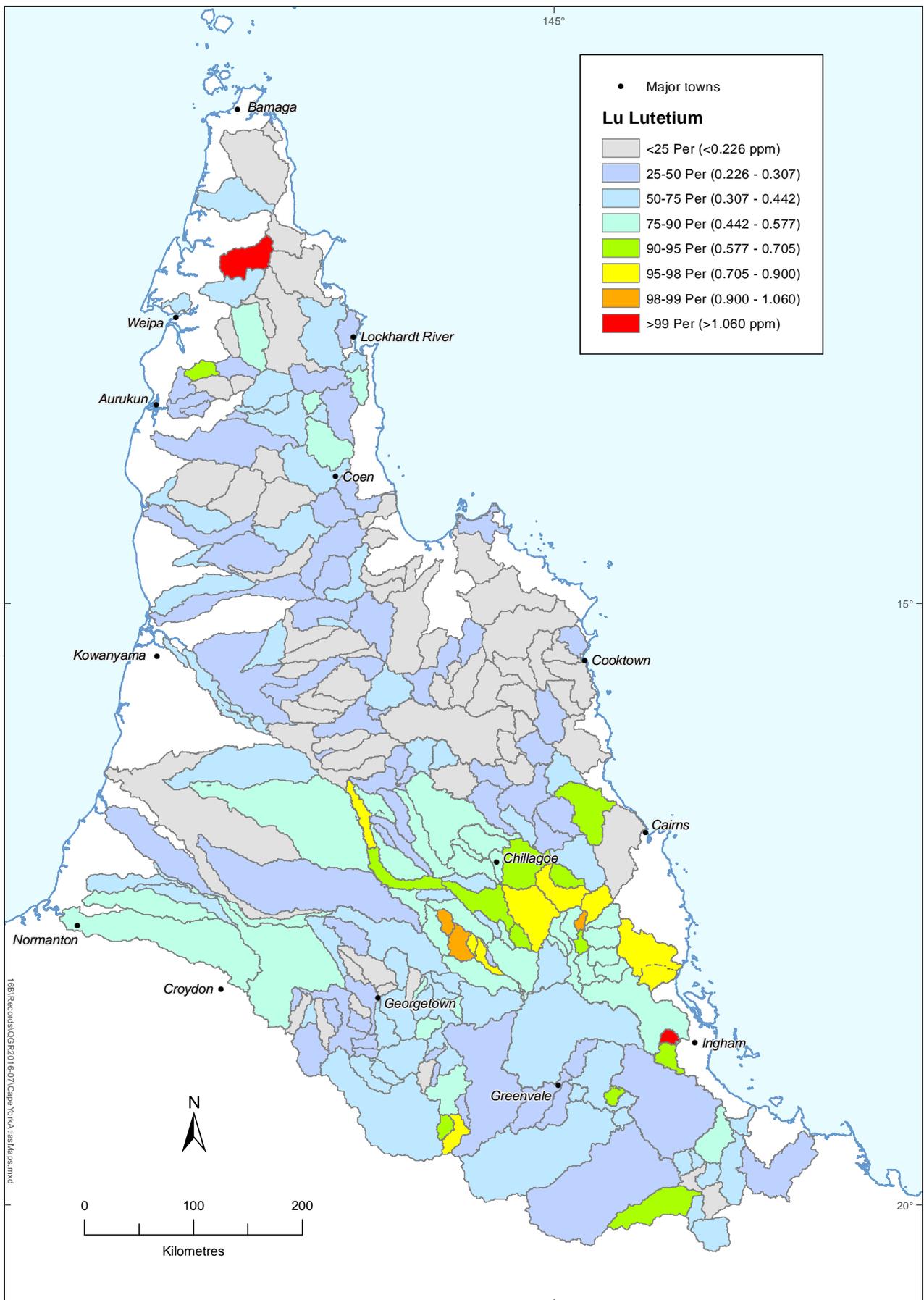
# La Lanthanum



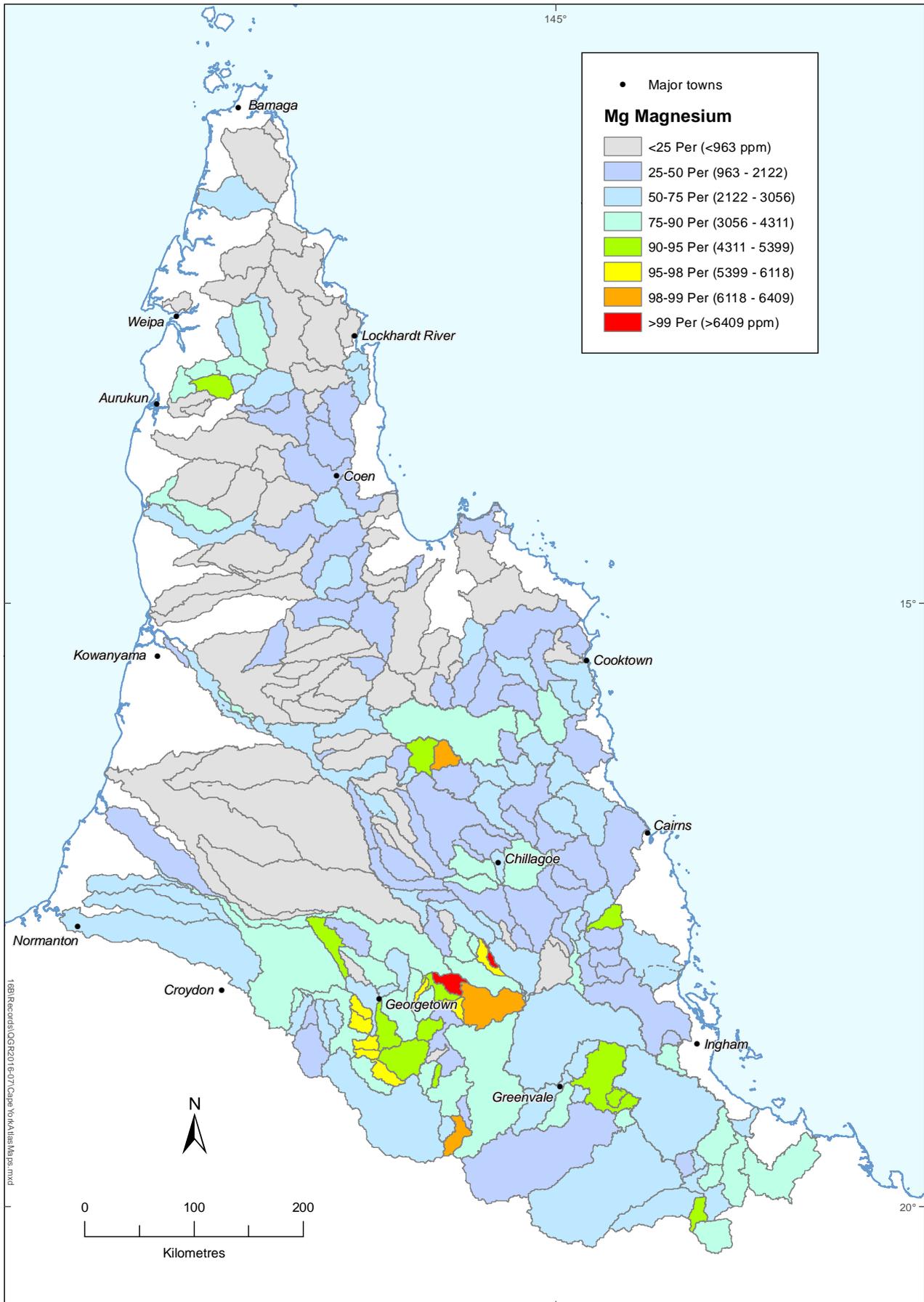
# Li Lithium



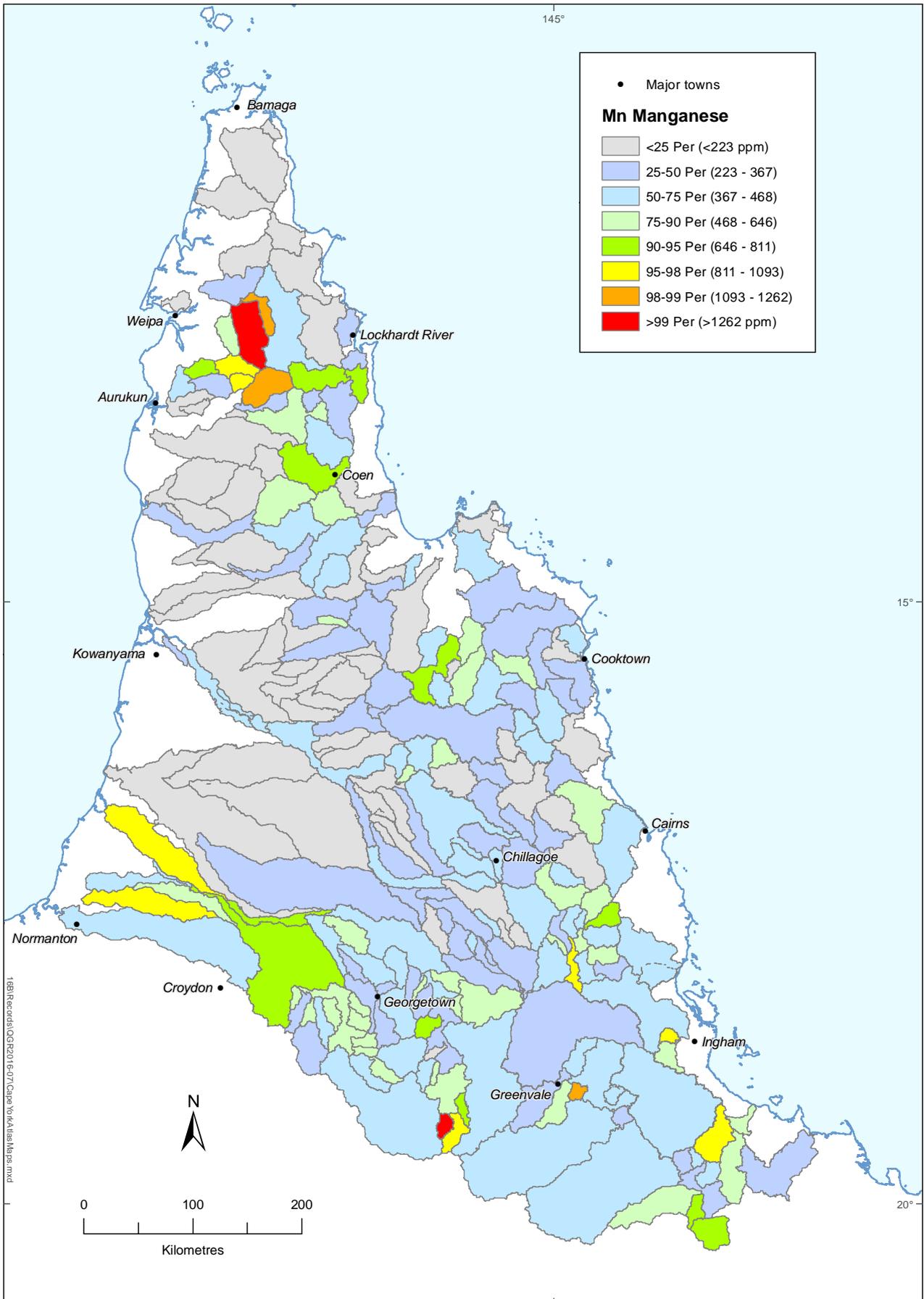
# Lu Lutetium



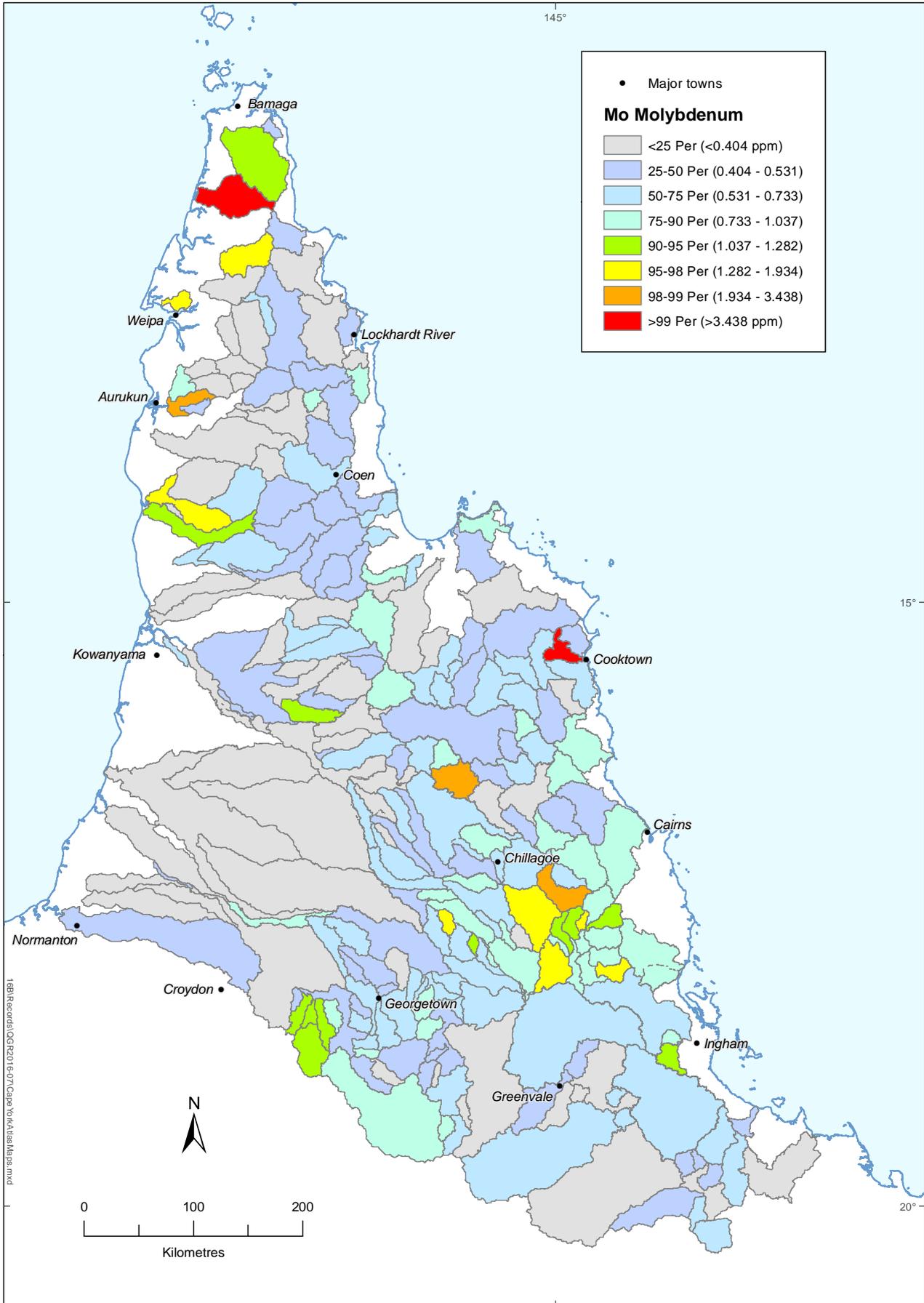
# Mg Magnesium



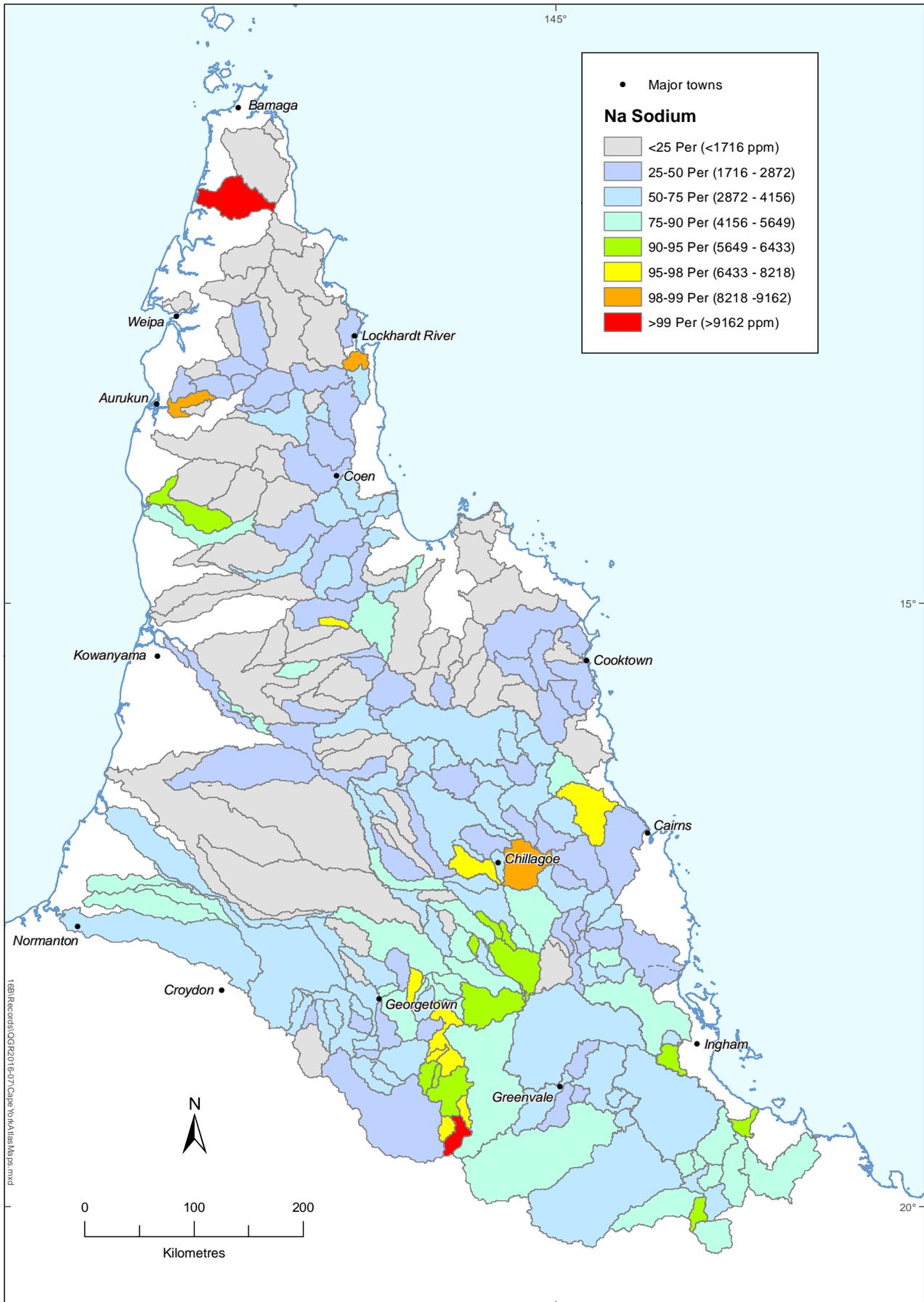
# Mn Manganese



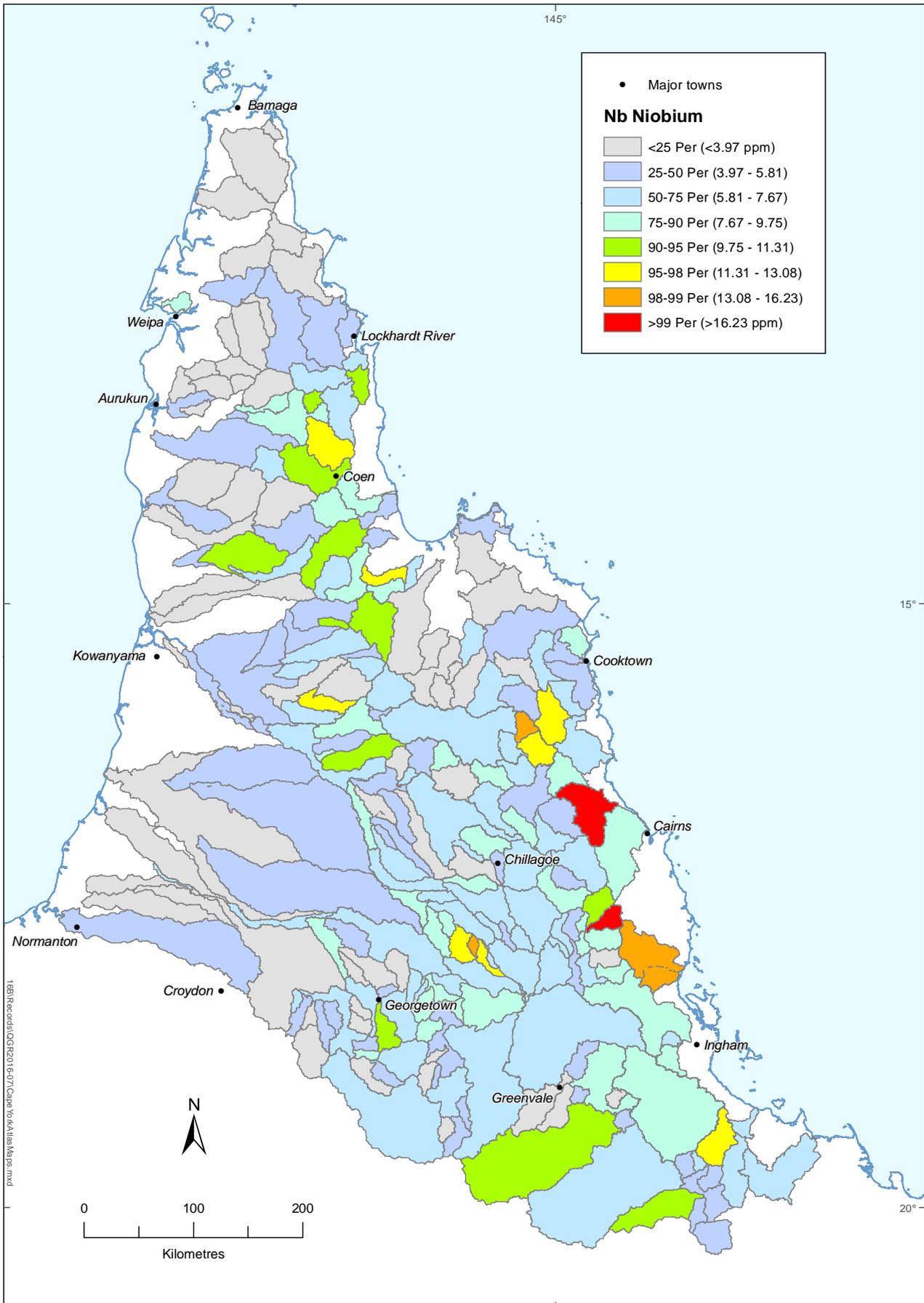
# Mo Molybdenum



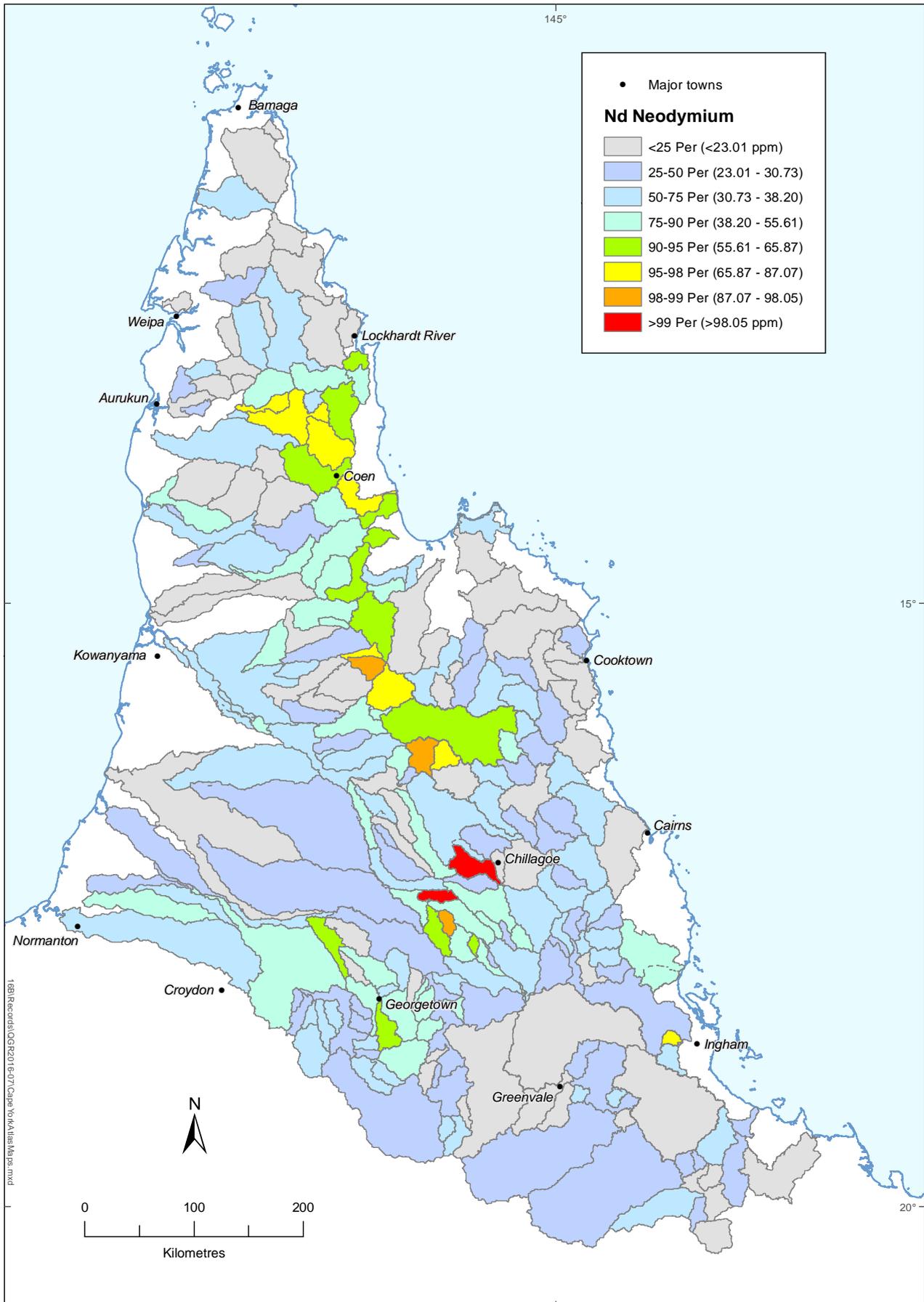
# Na Sodium



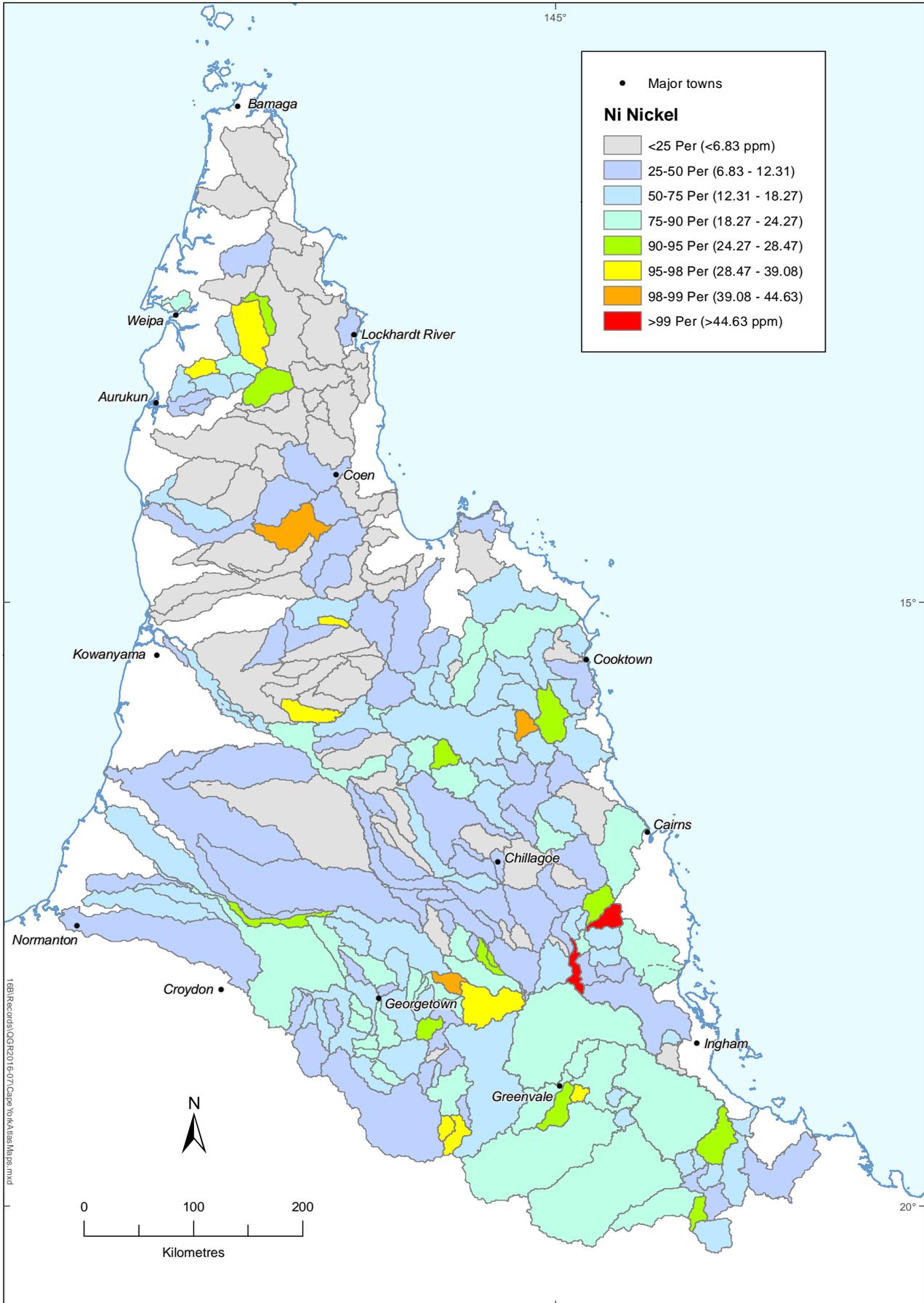
# Nb Niobium



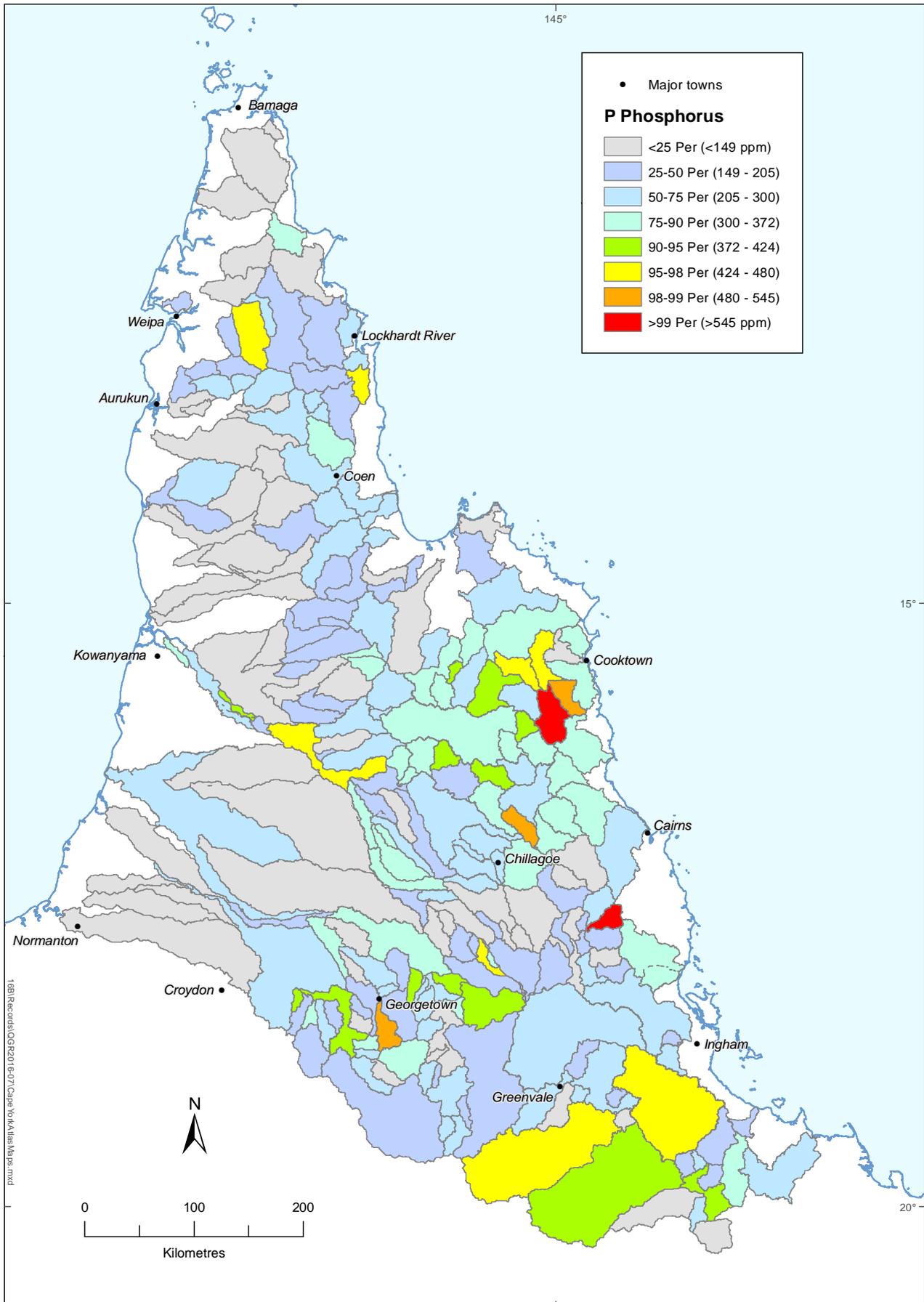
# Nd Neodymium



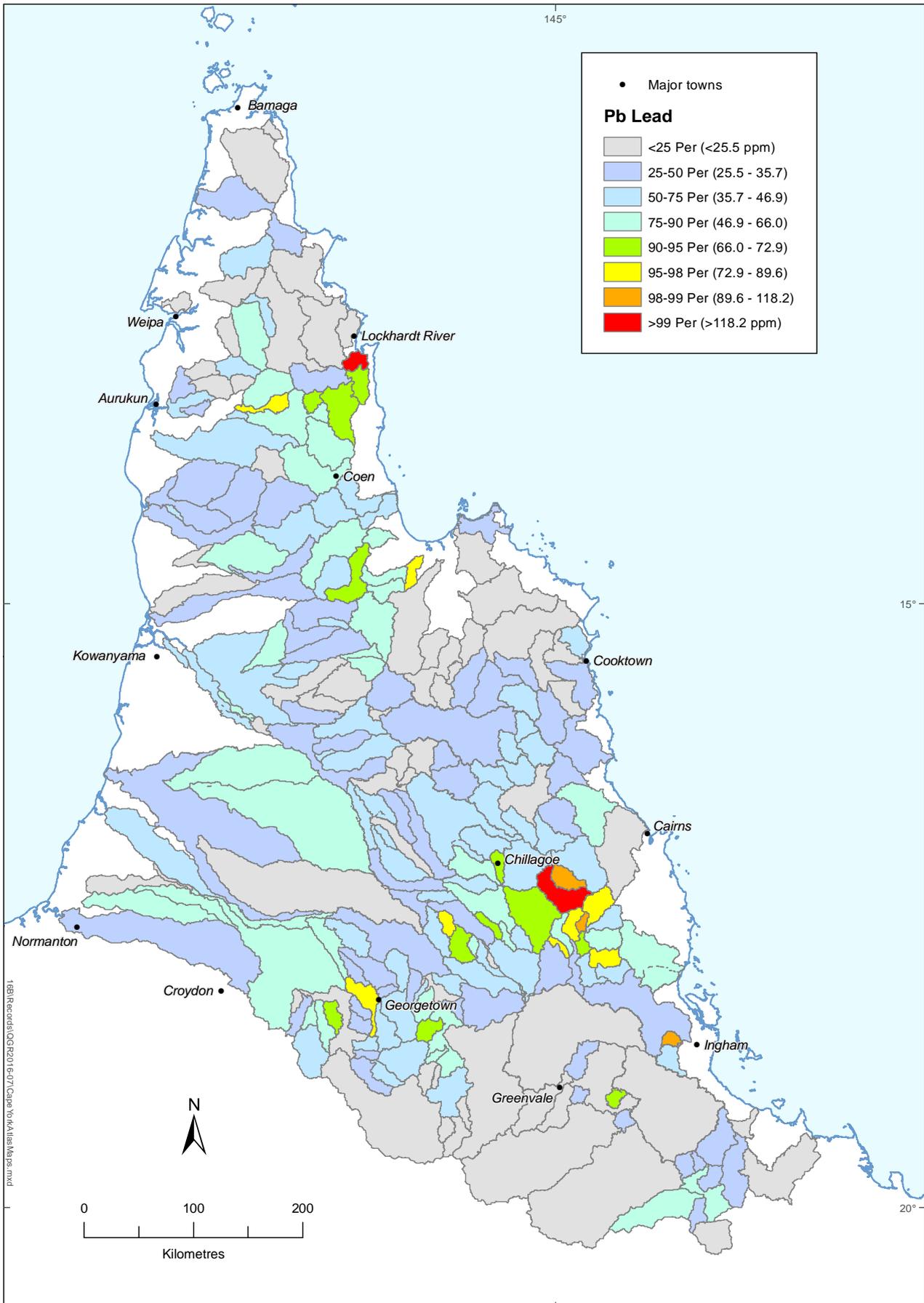
# Ni Nickel



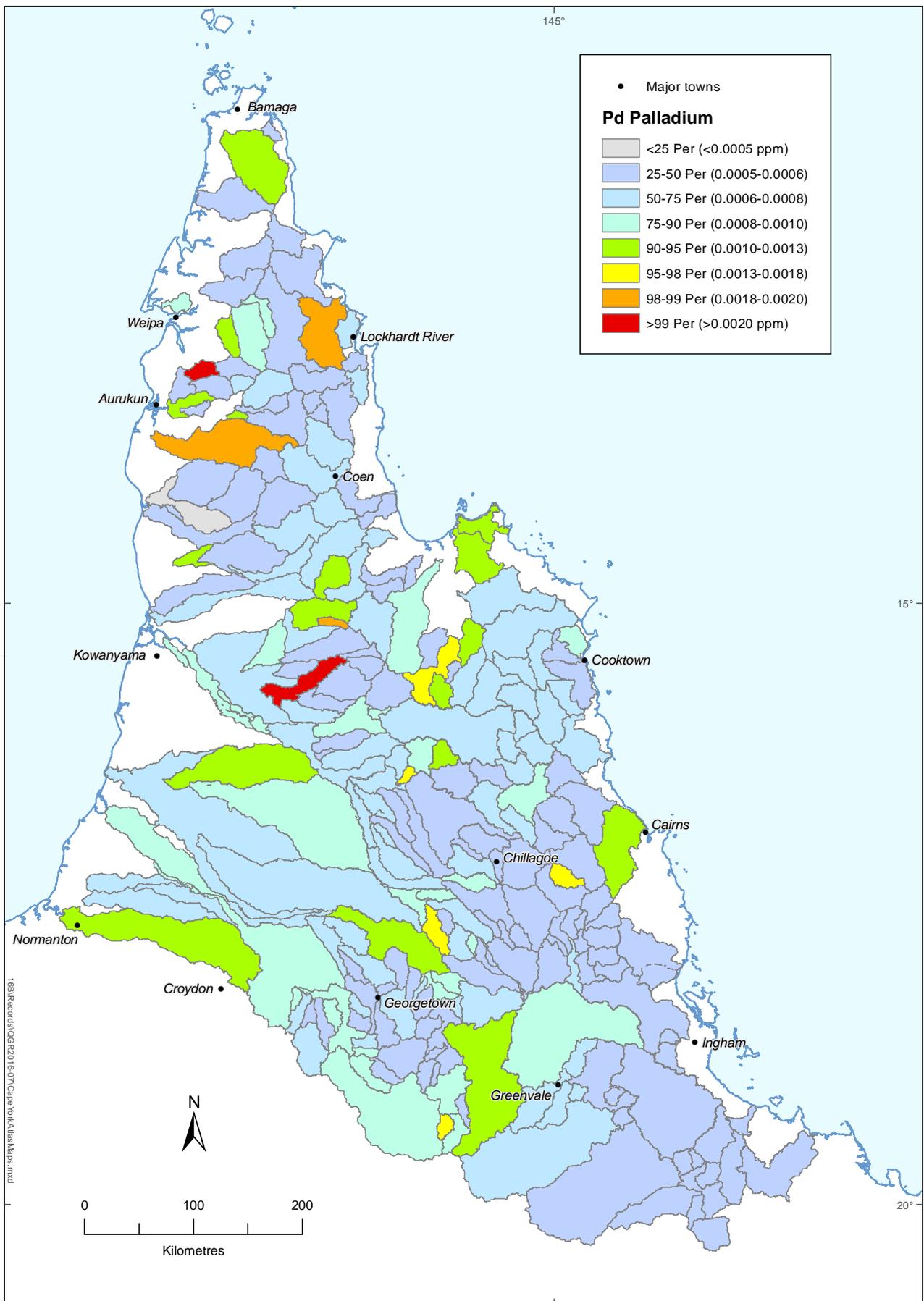
# P Phosphorus



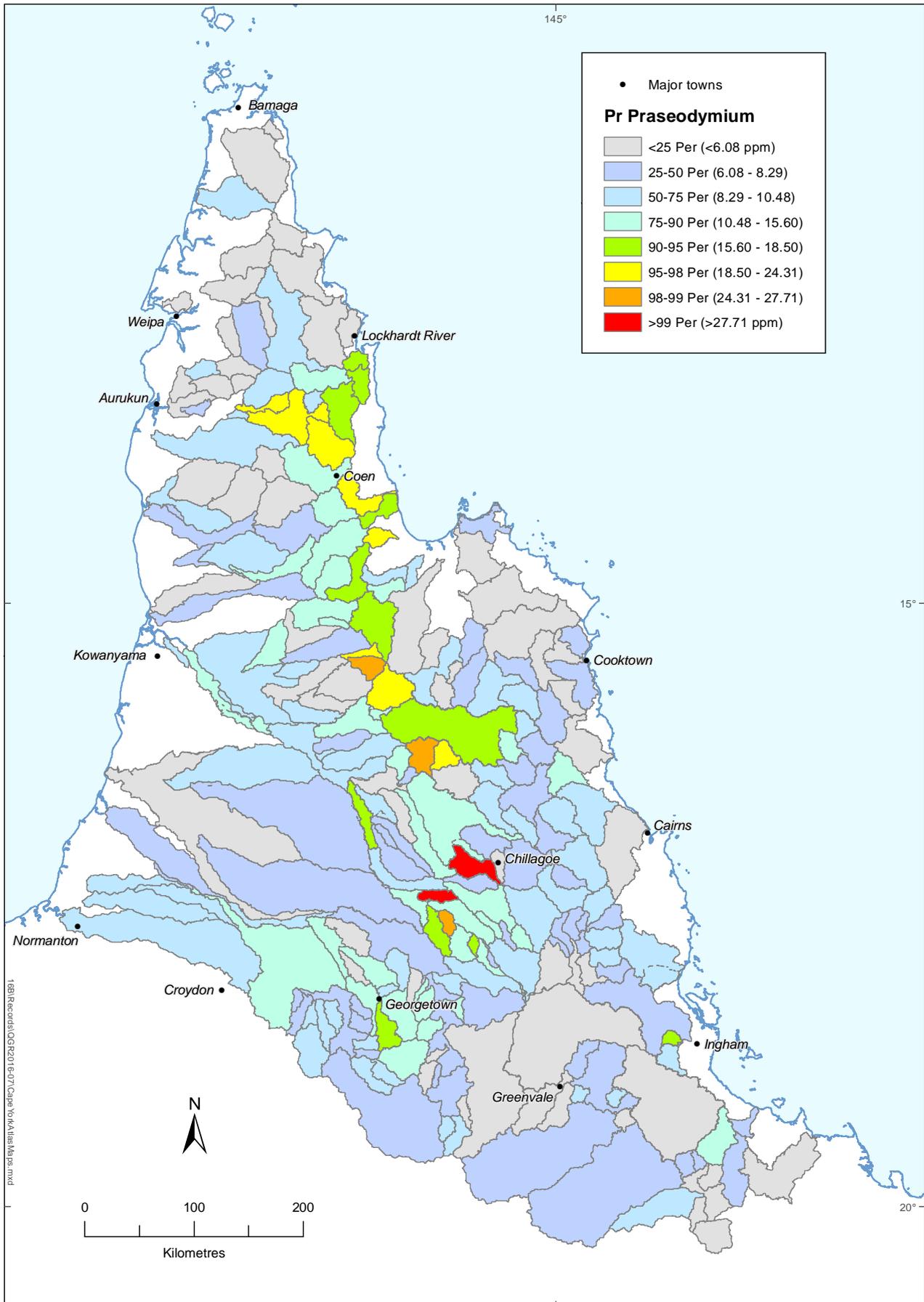
# Pb Lead



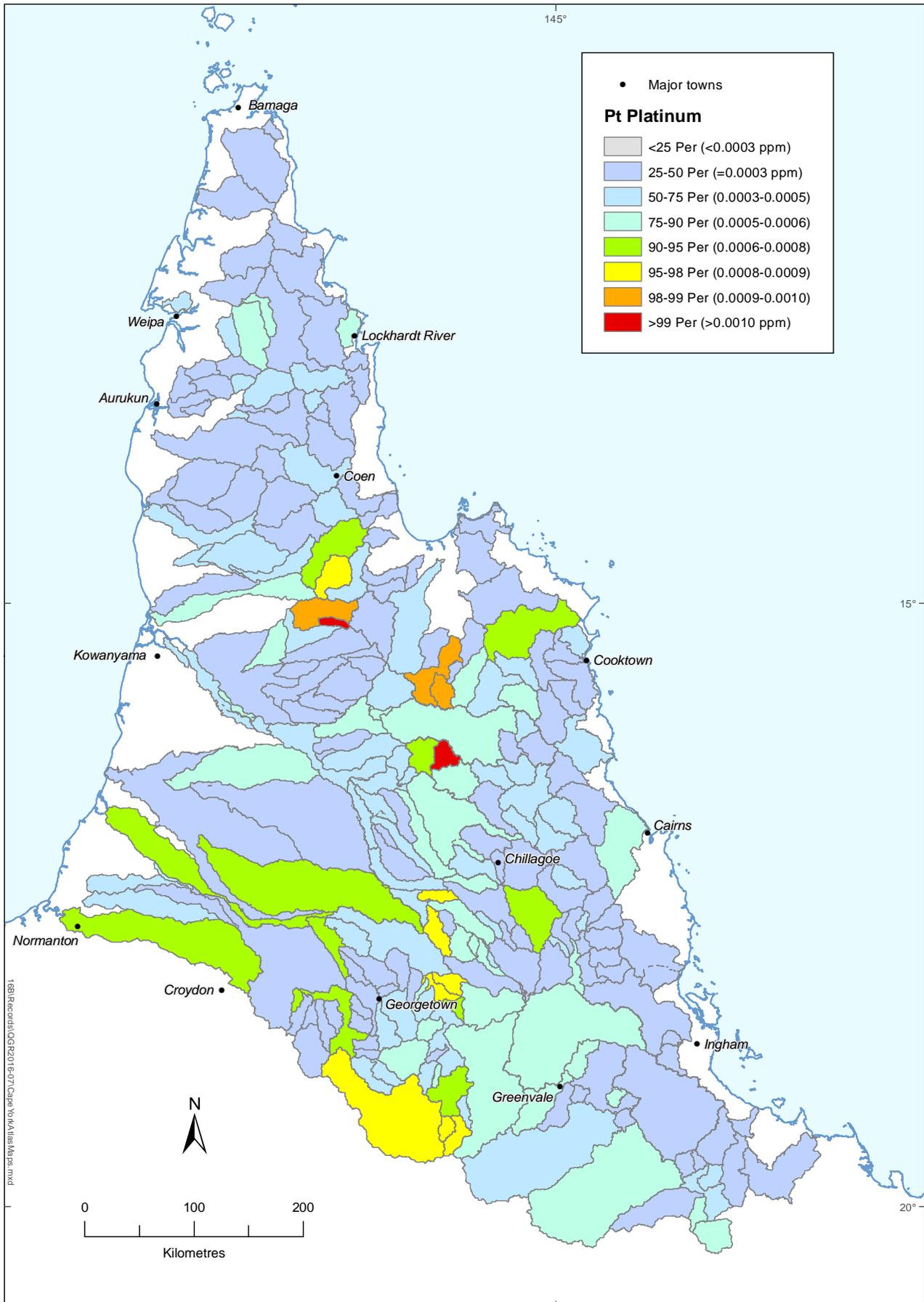
# Pd Palladium



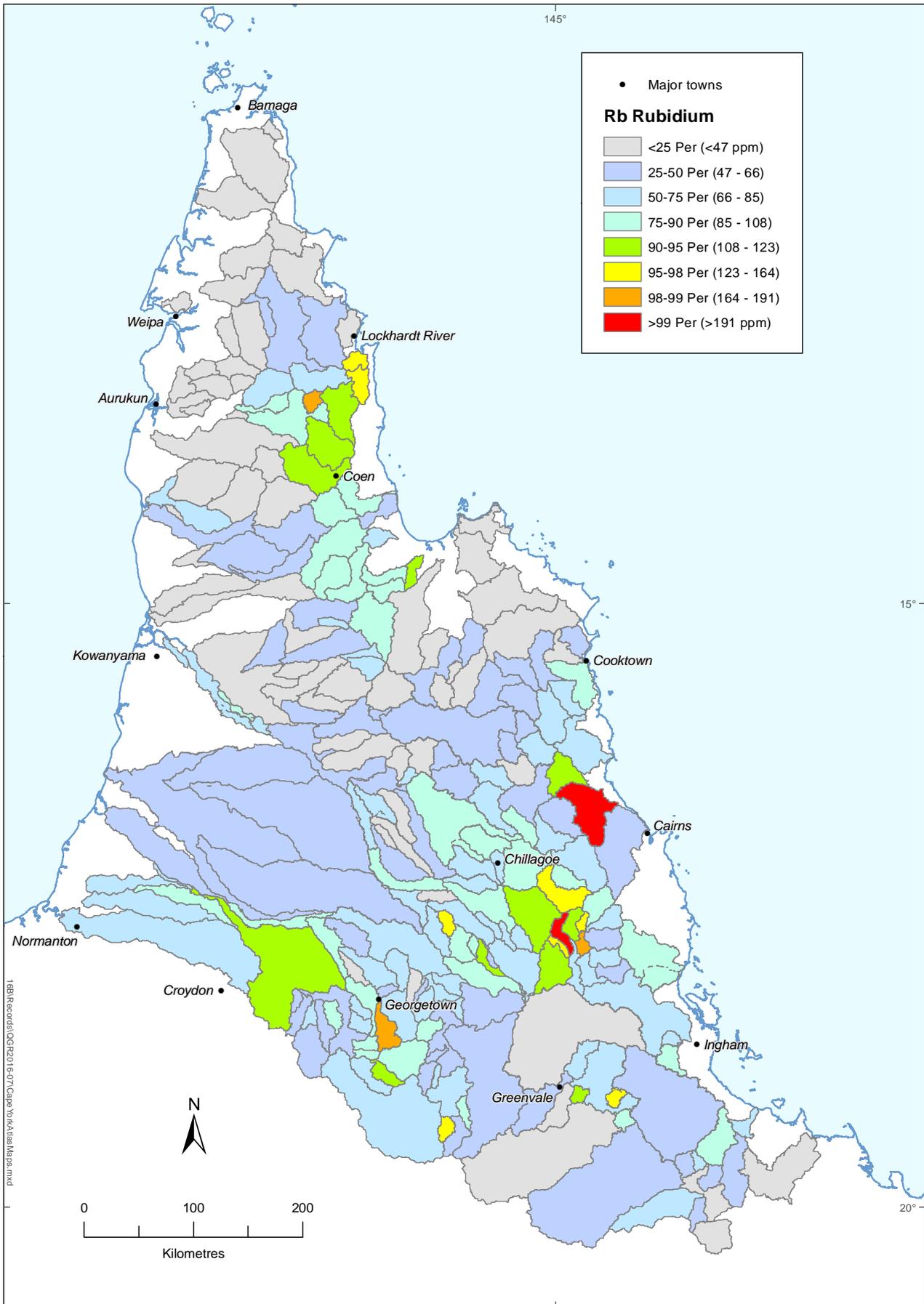
# Pr Praseodymium



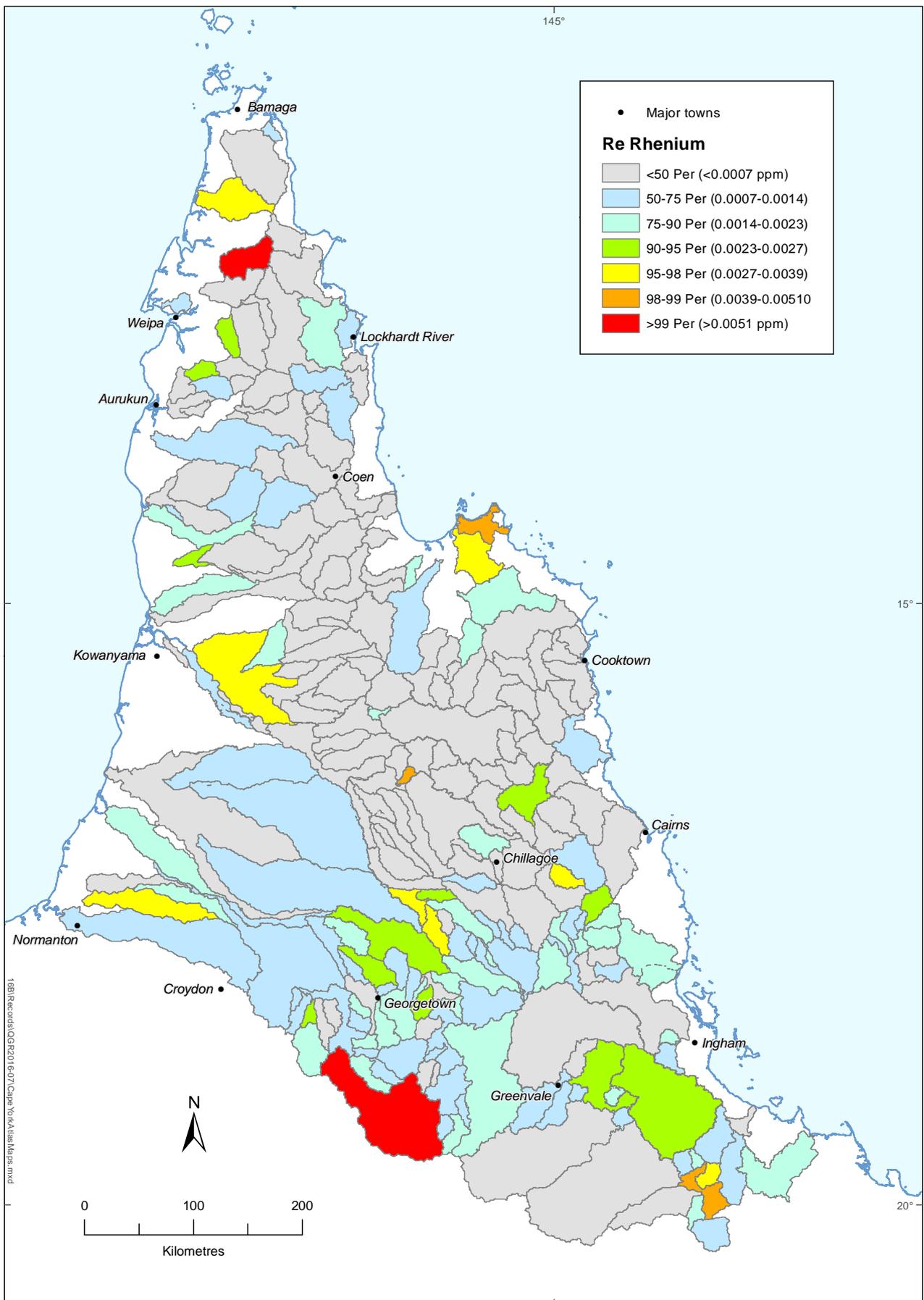
# Pt Platinum



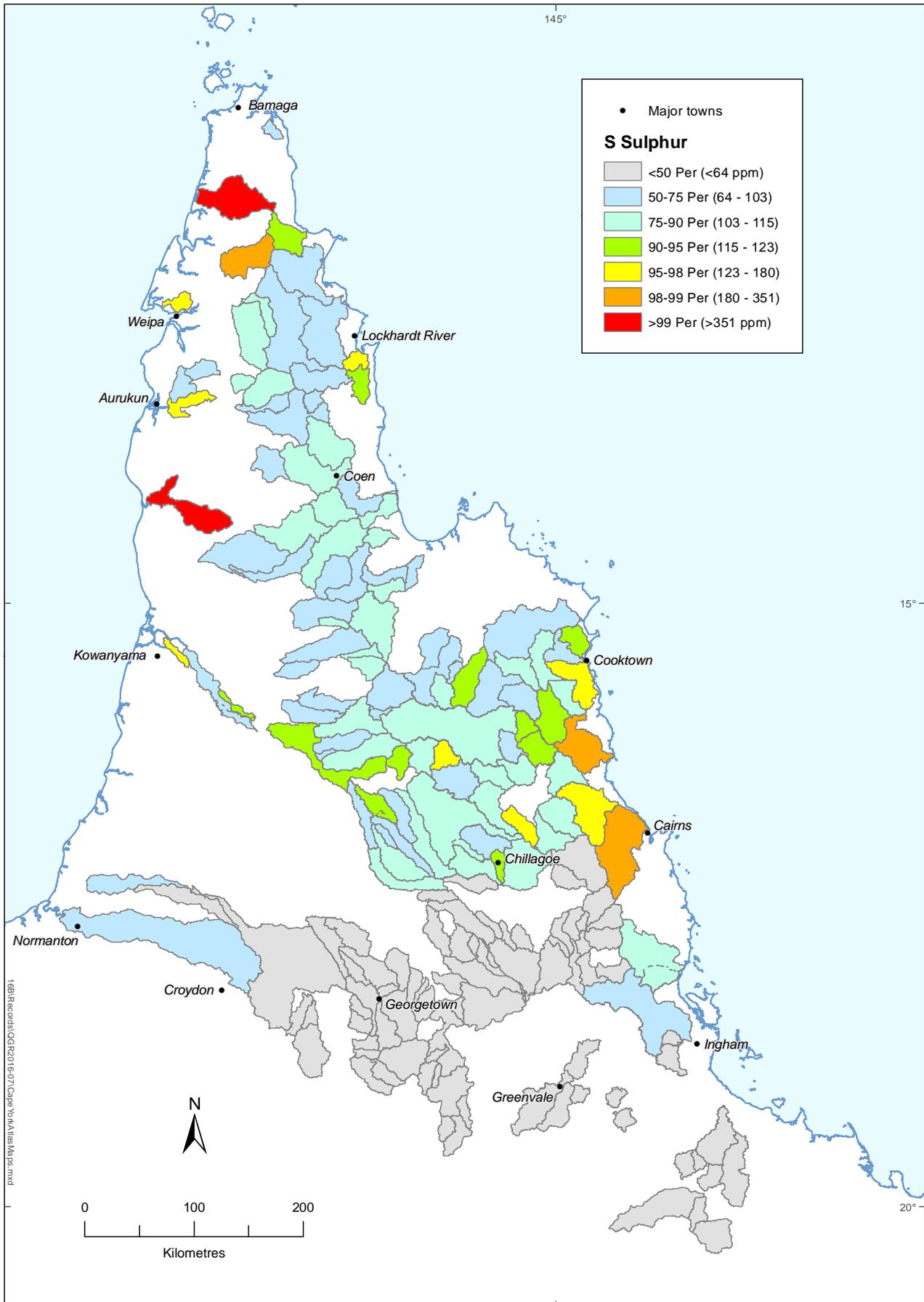
# Rb Rubidium



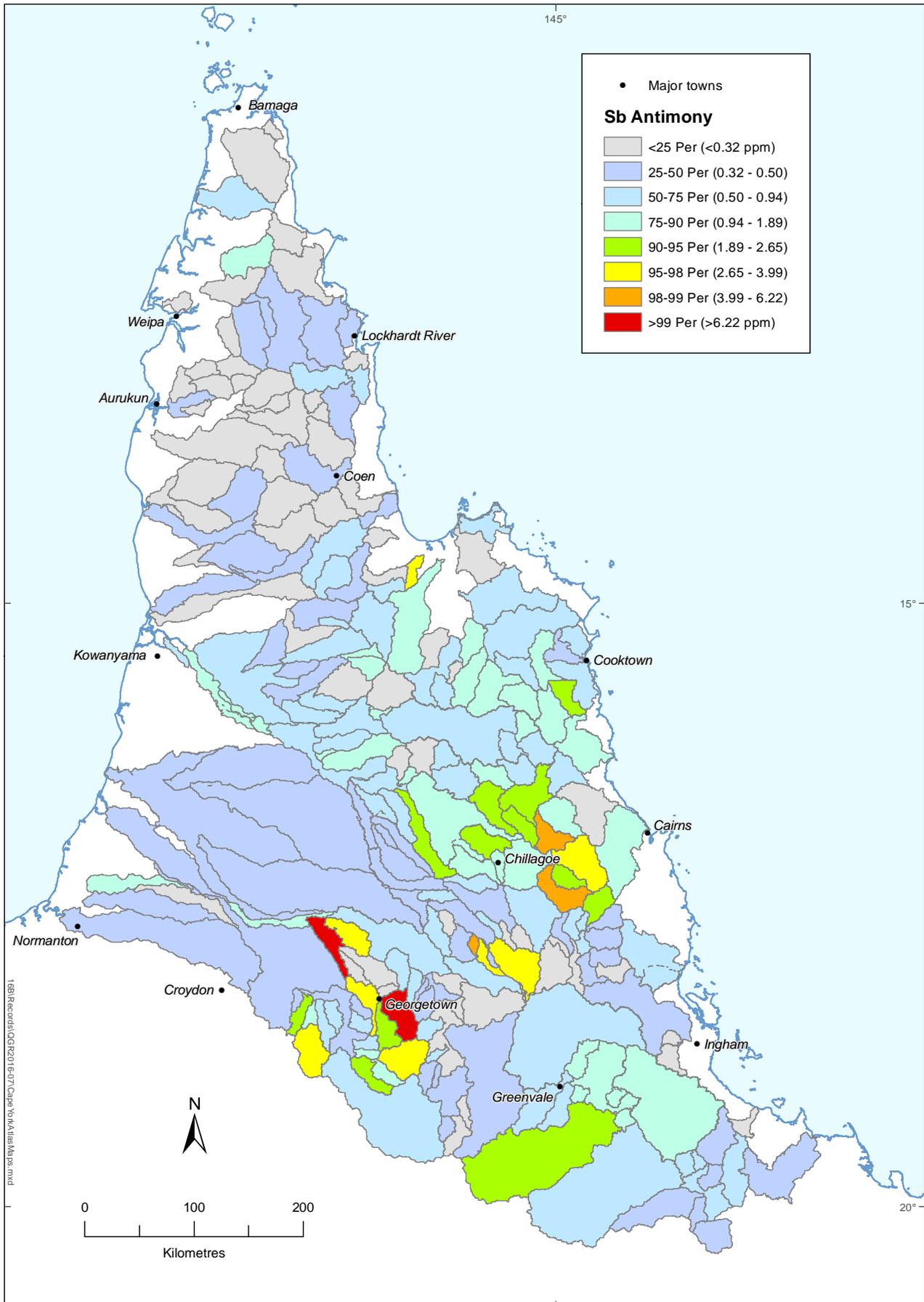
# Re Rhenium



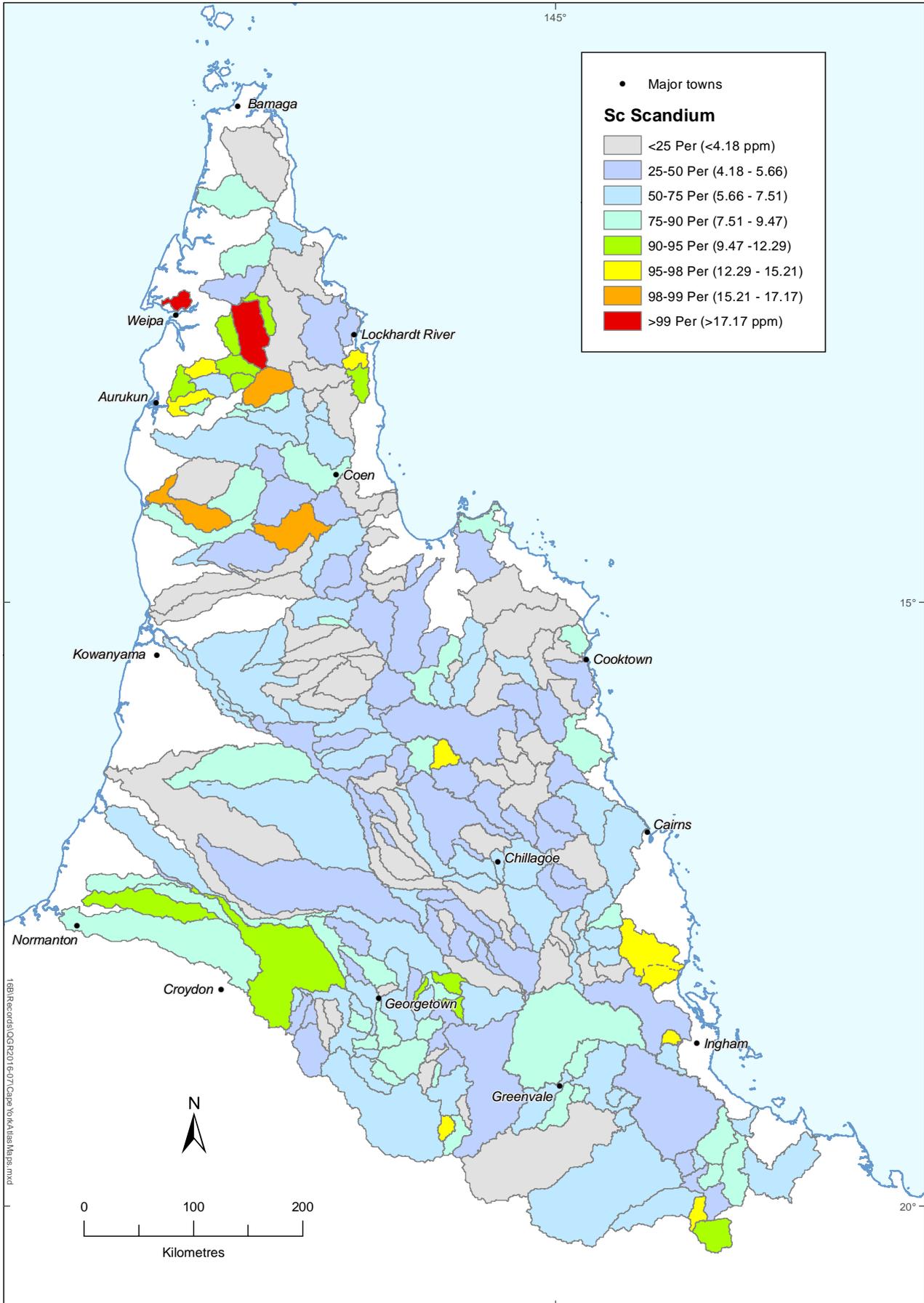
# S Sulphur



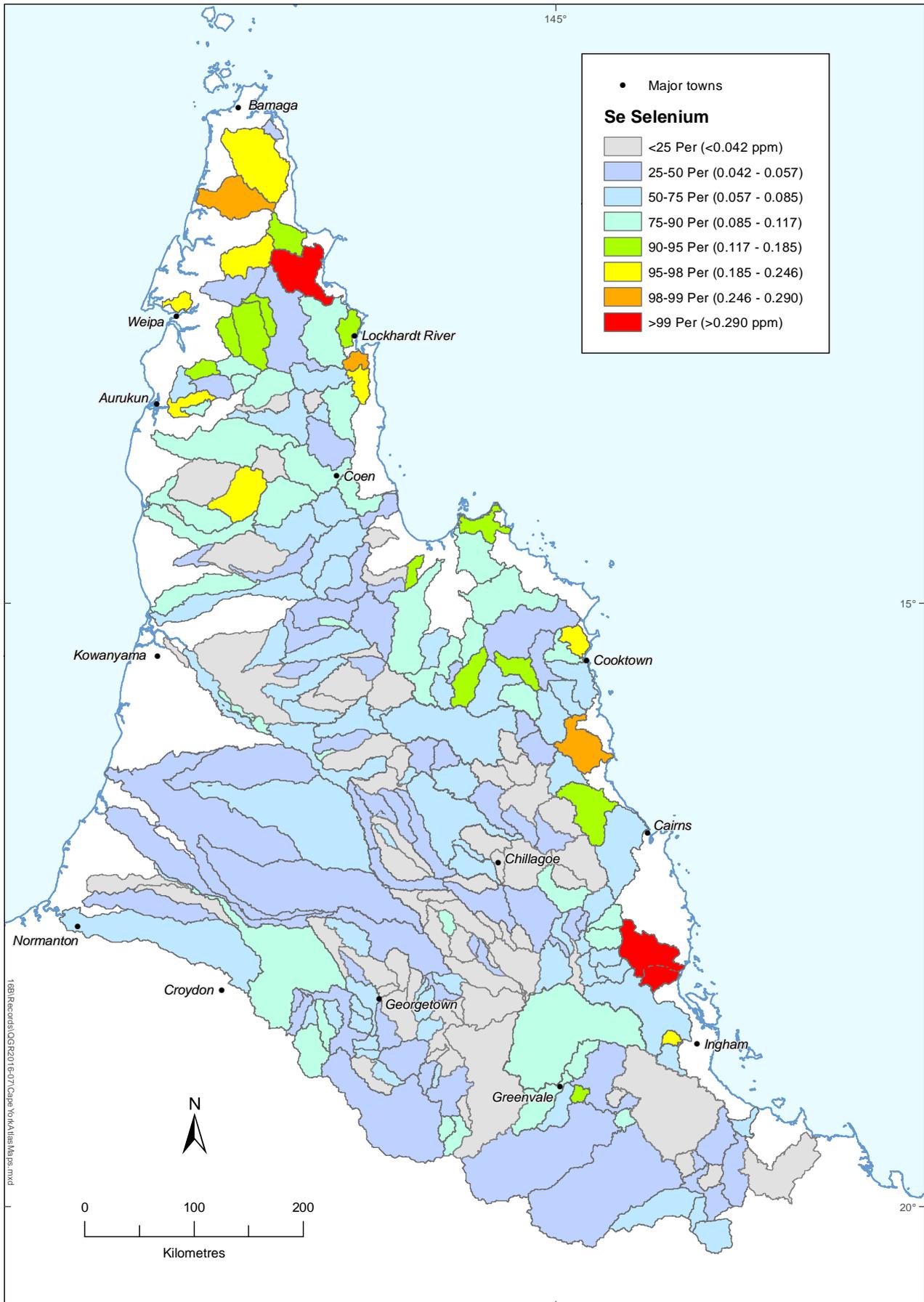
# Sb Antimony



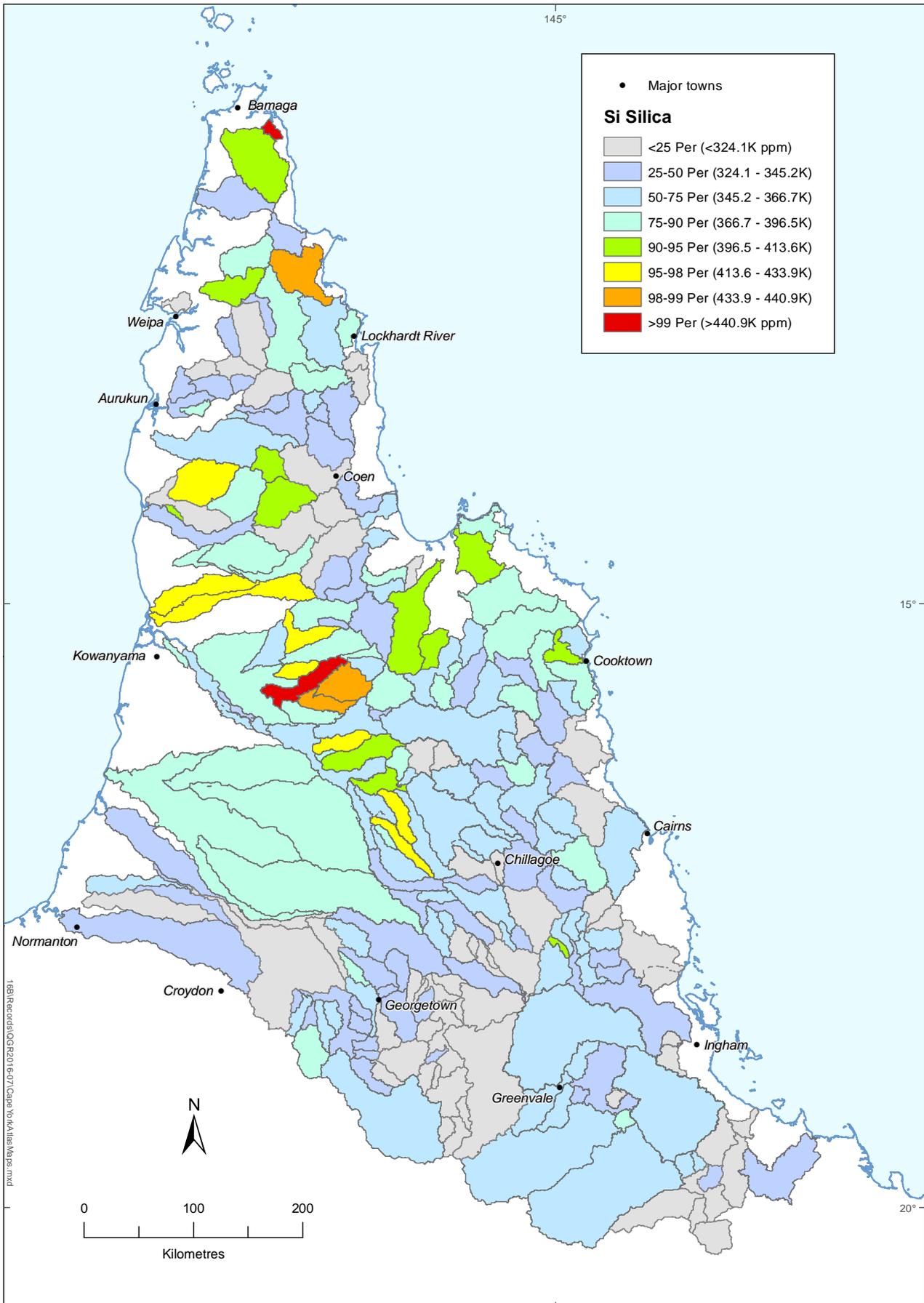
# Sc Scandium



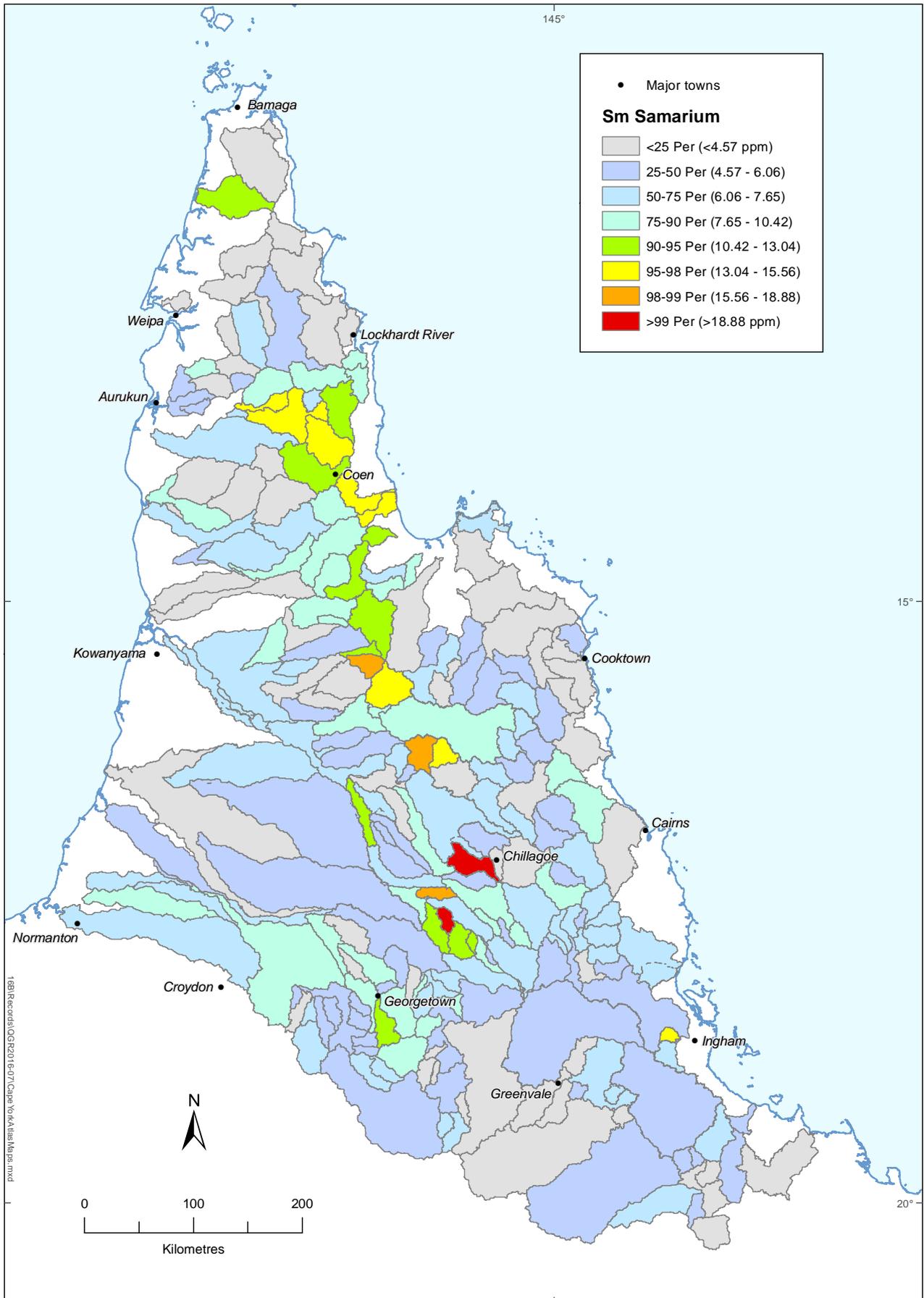
# Se Selenium



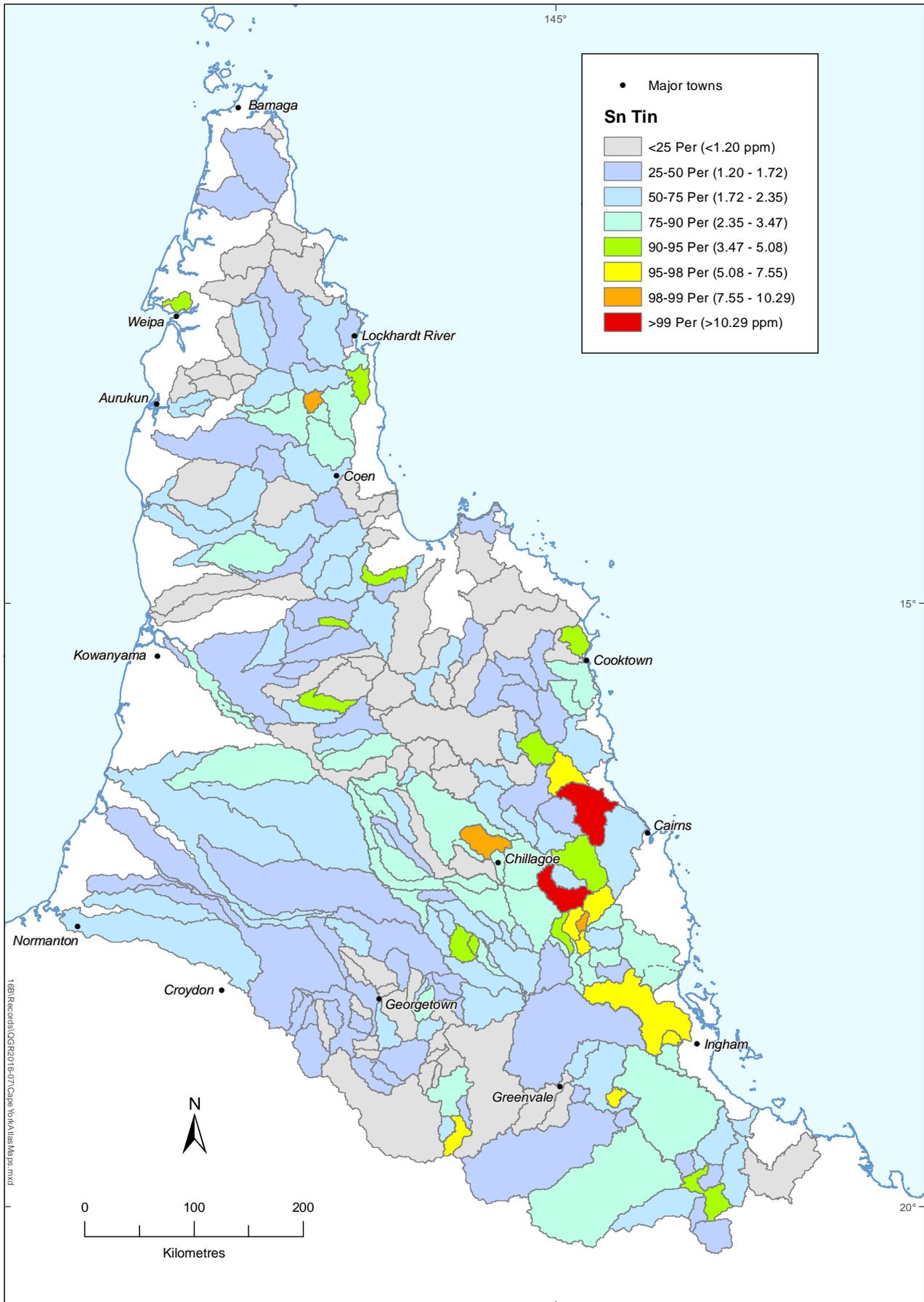
# Si Silica



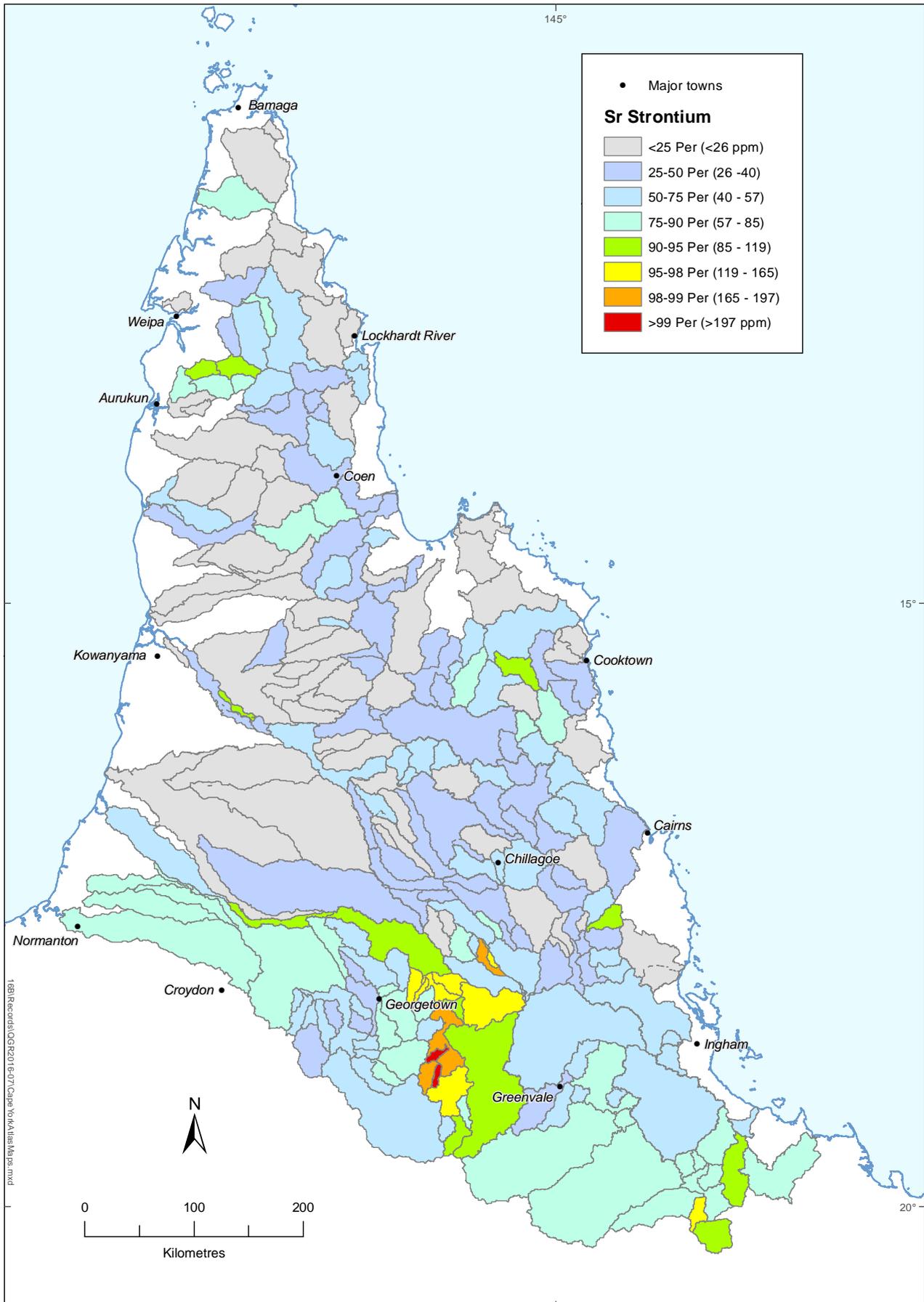
# Sm Samarium



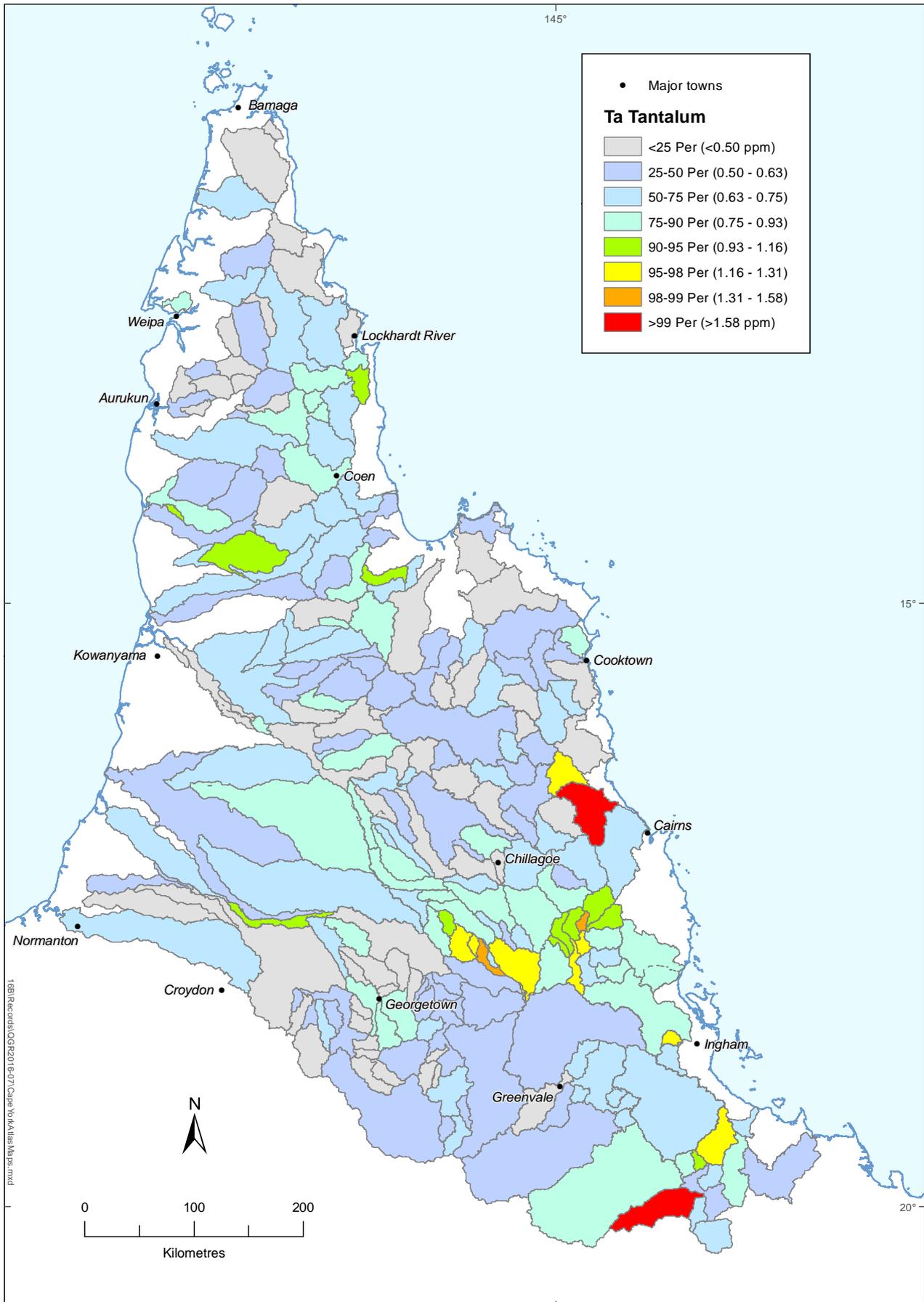
# Sn Tin



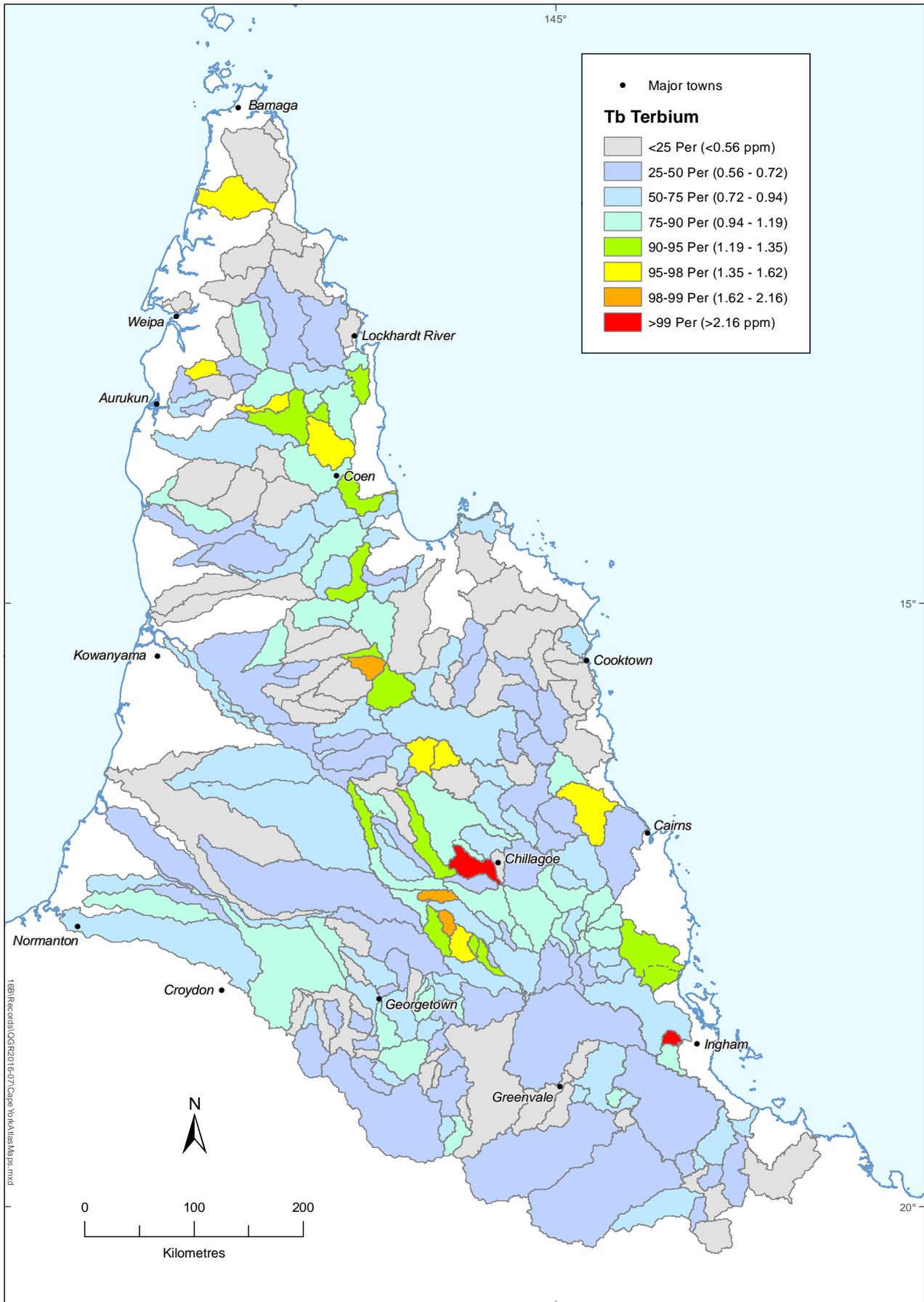
# Sr Strontium



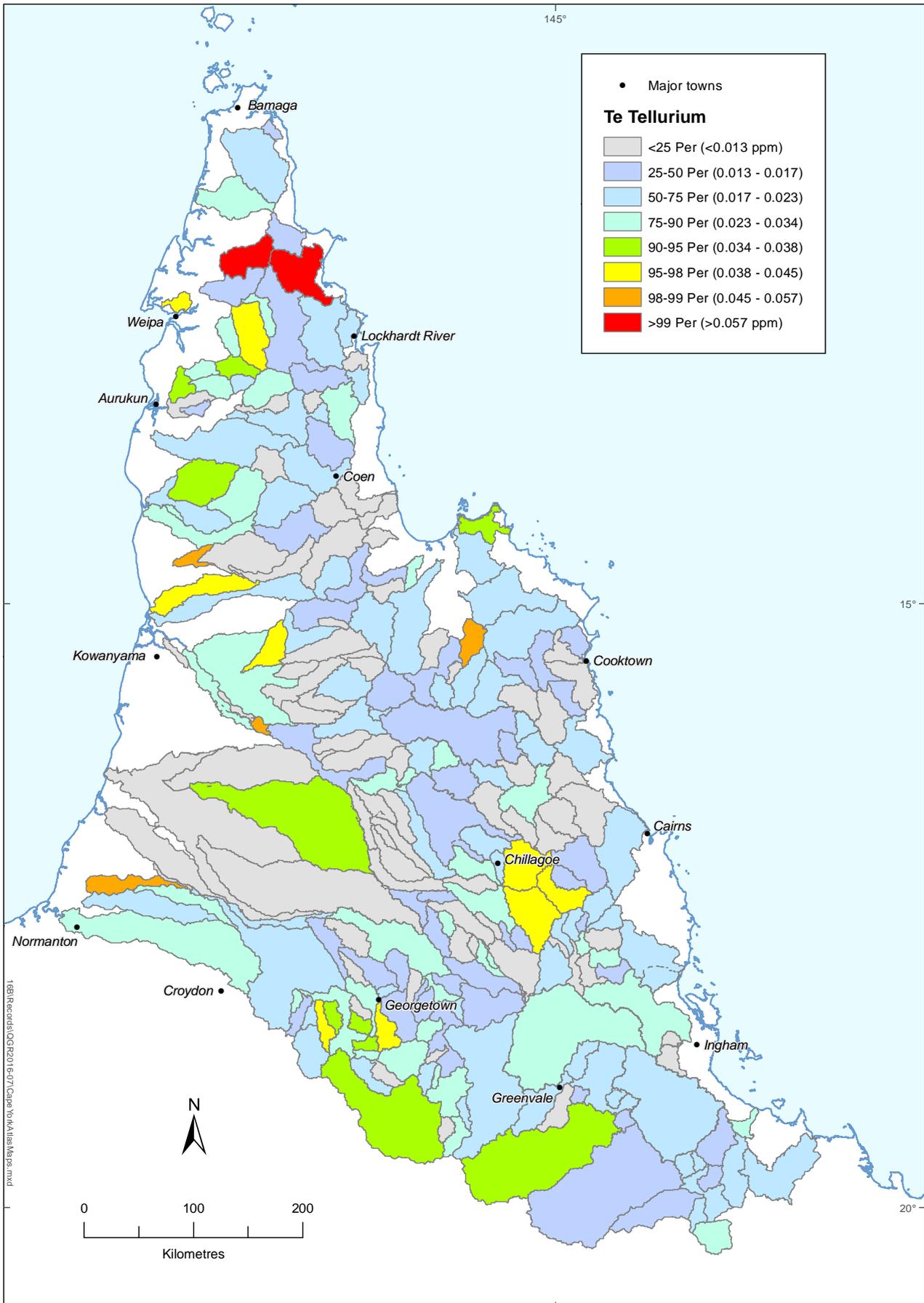
# Ta Tantalum



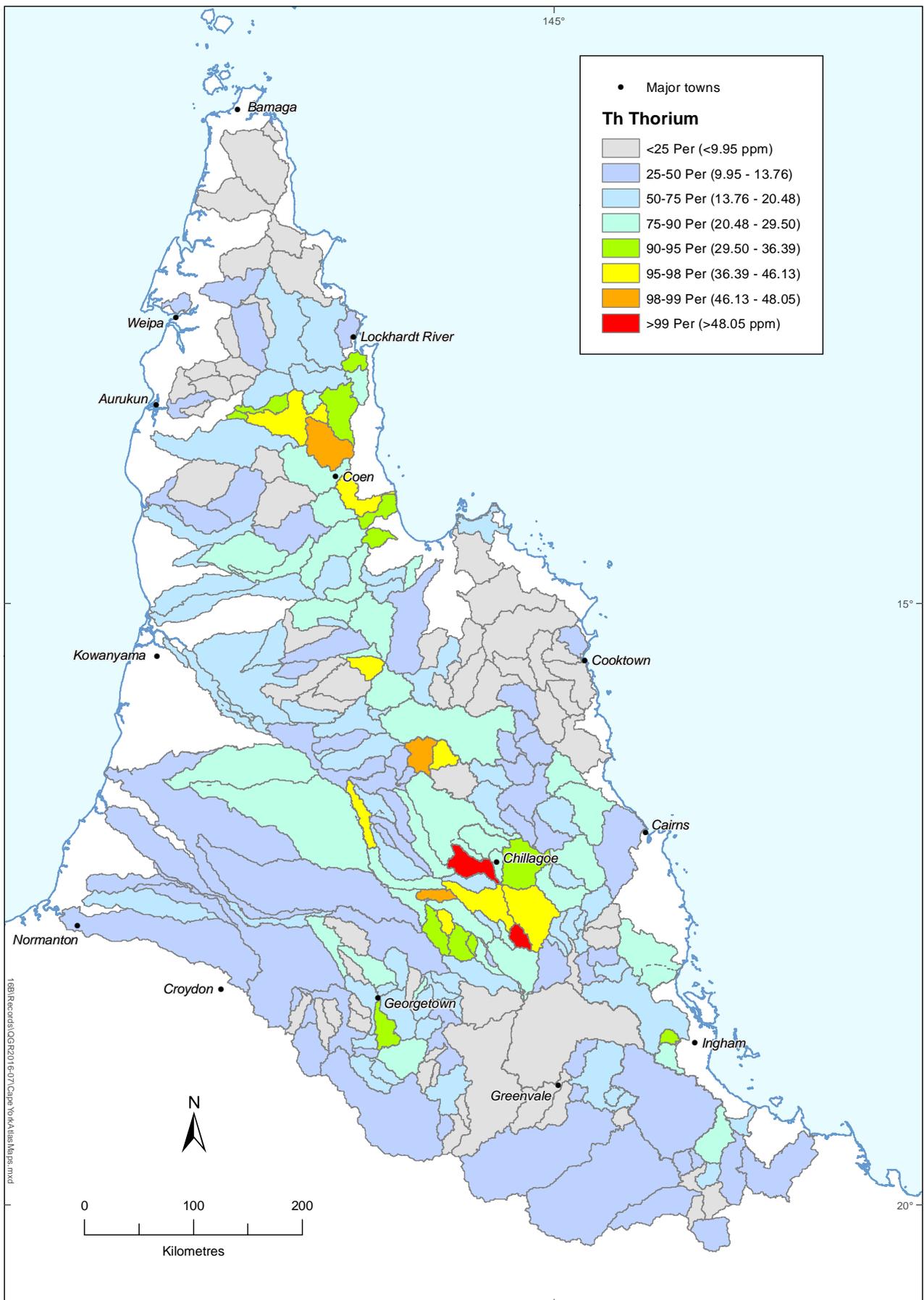
# Tb Terbium



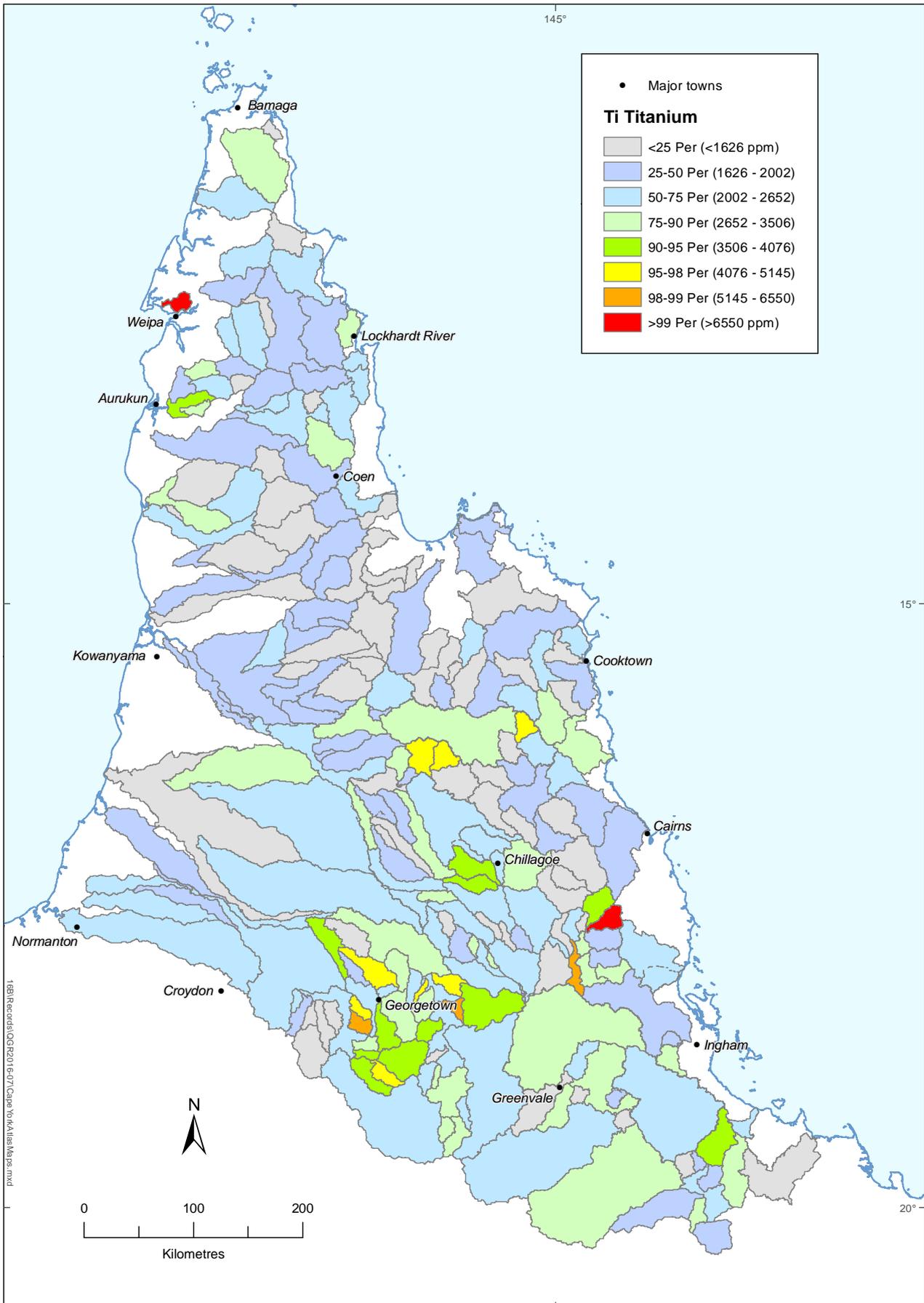
# Te Tellurium



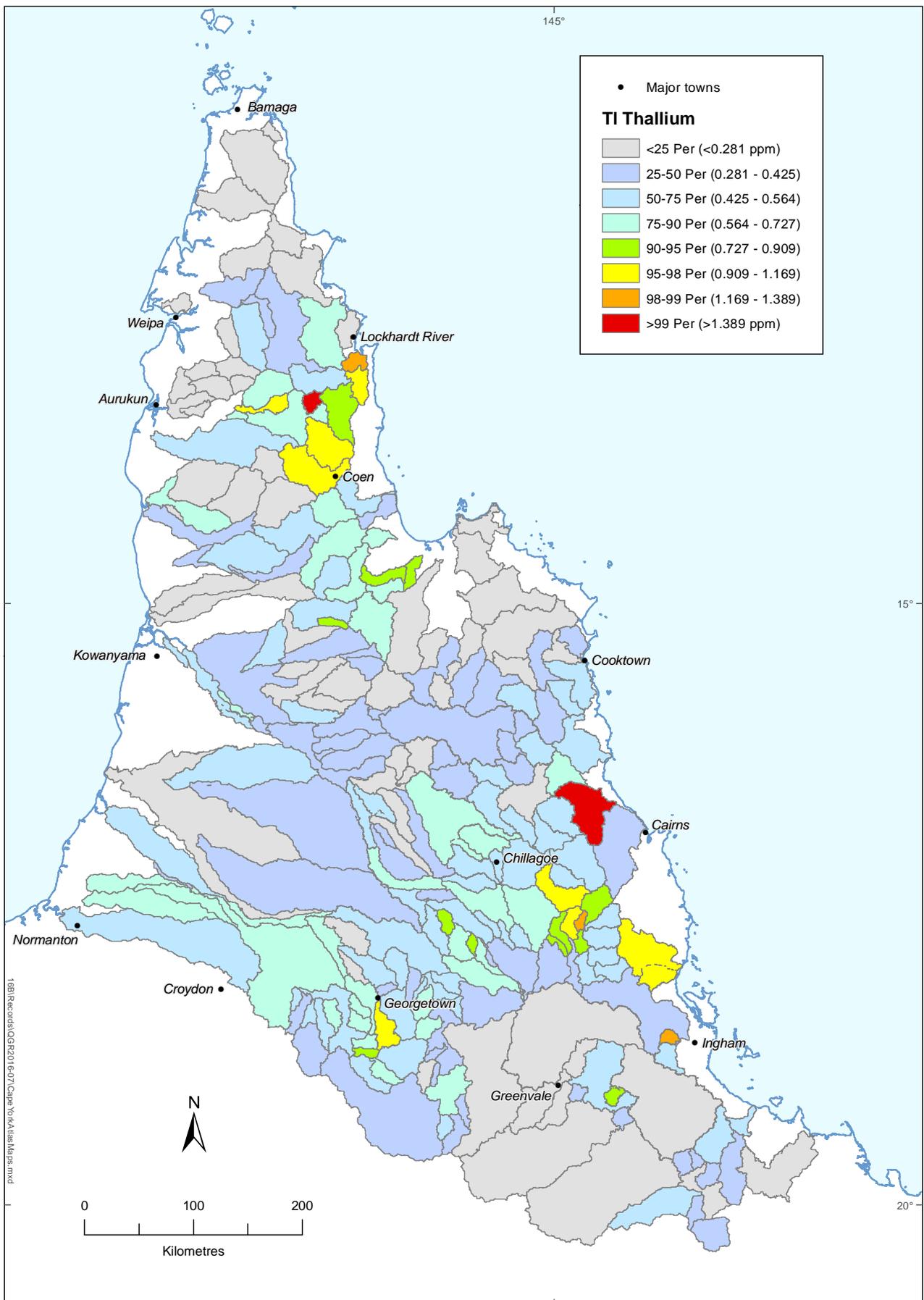
# Th Thorium



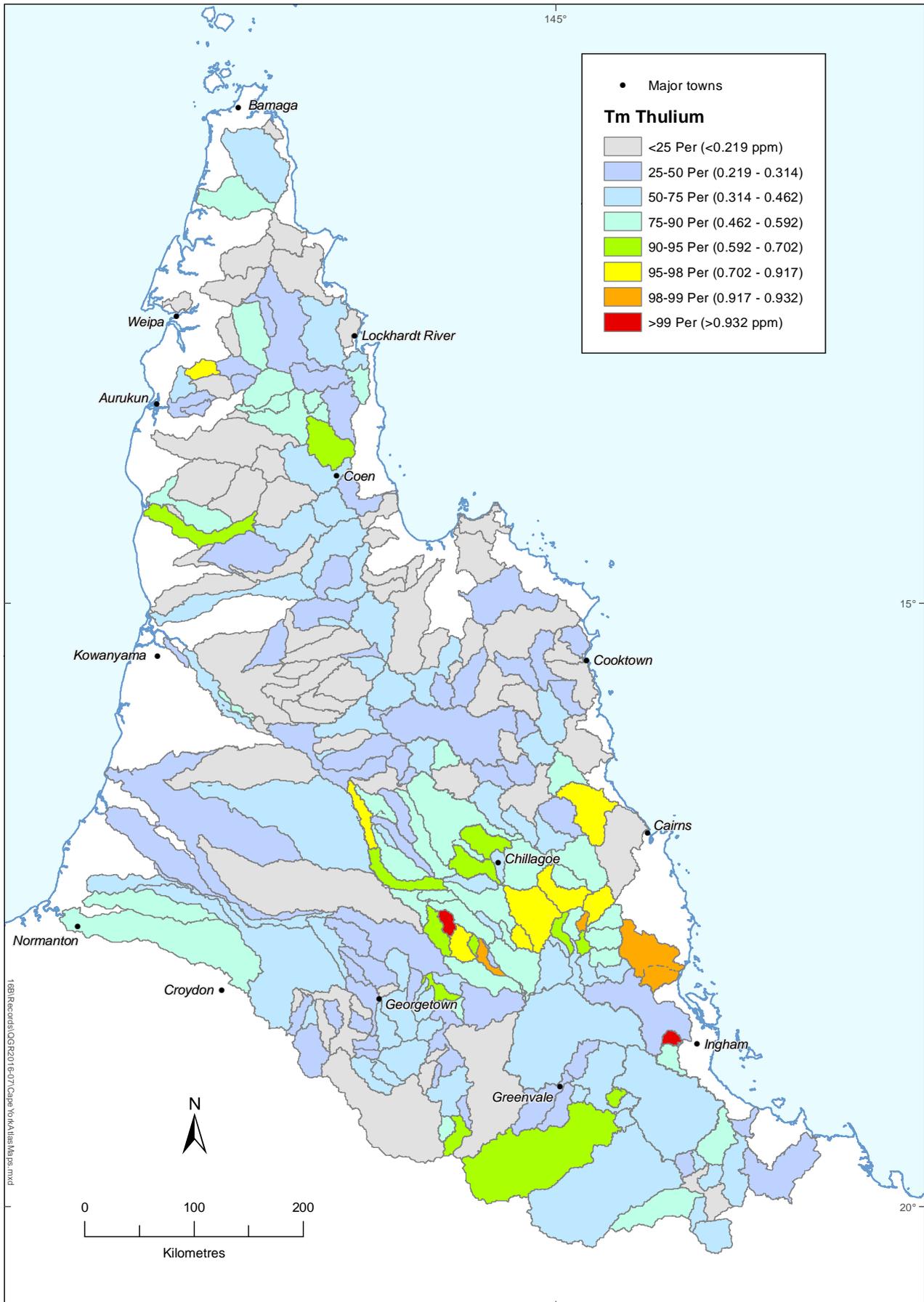
# Ti Titanium



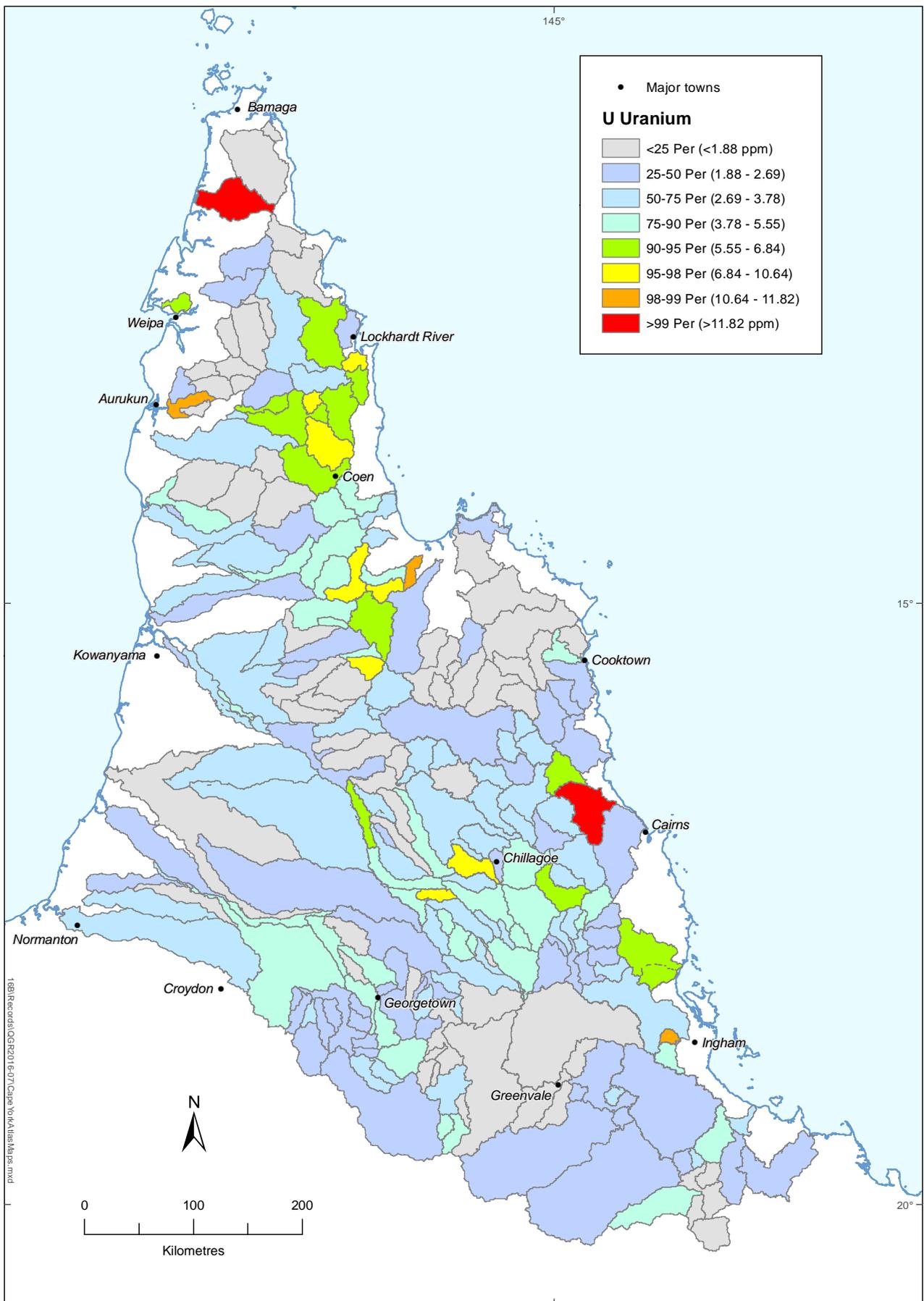
# Tl Thallium



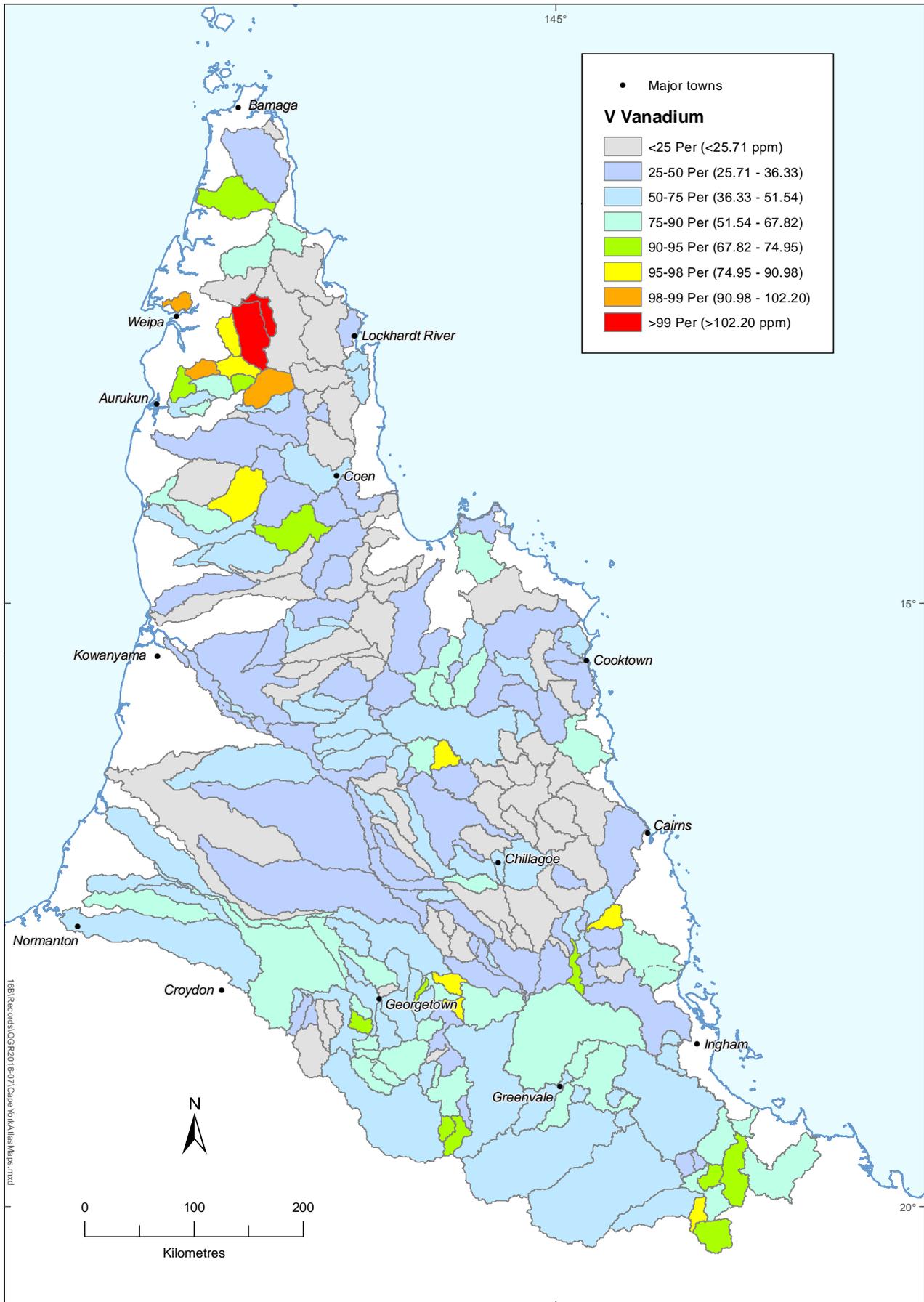
# Tm Thulium



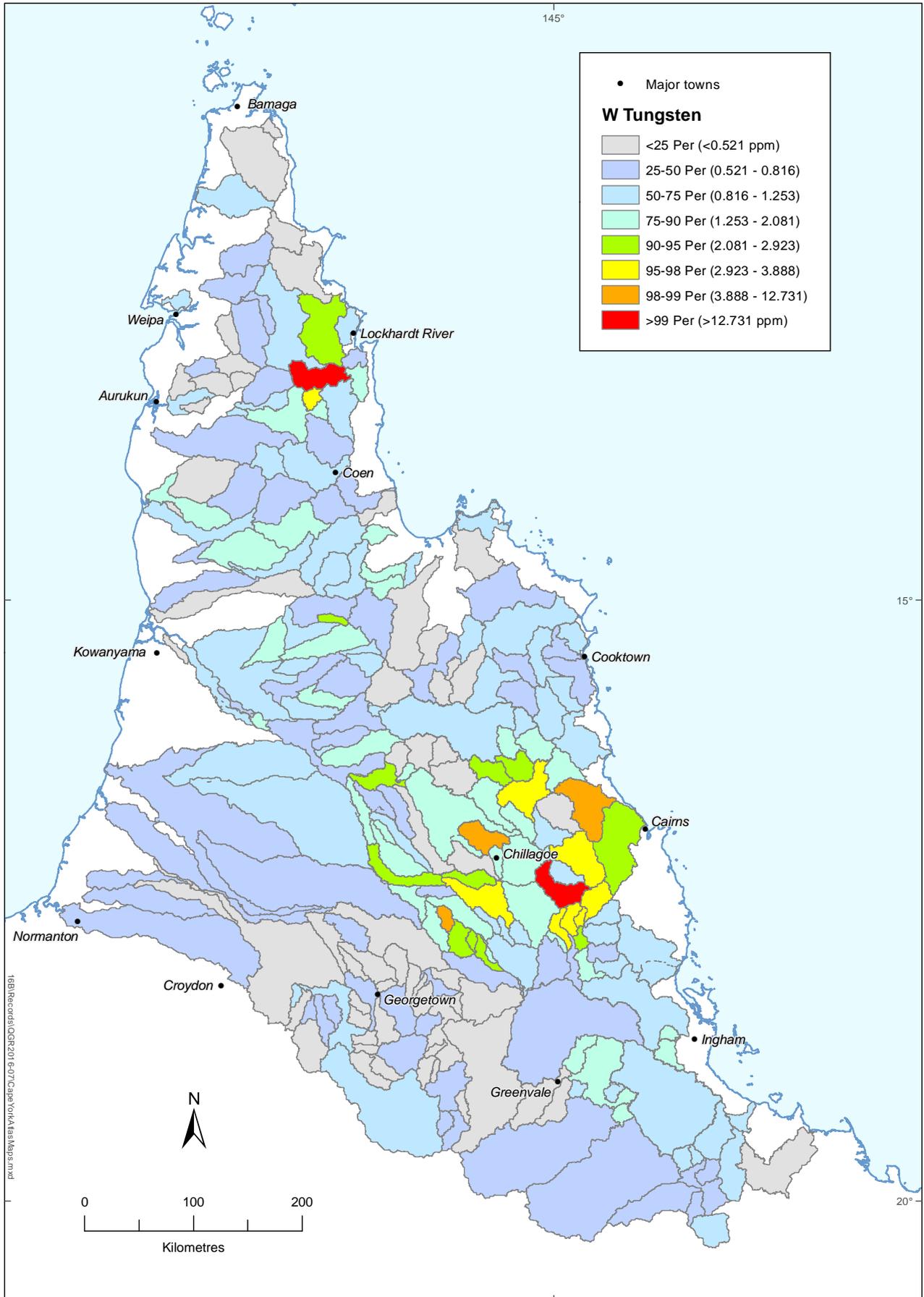
# U Uranium



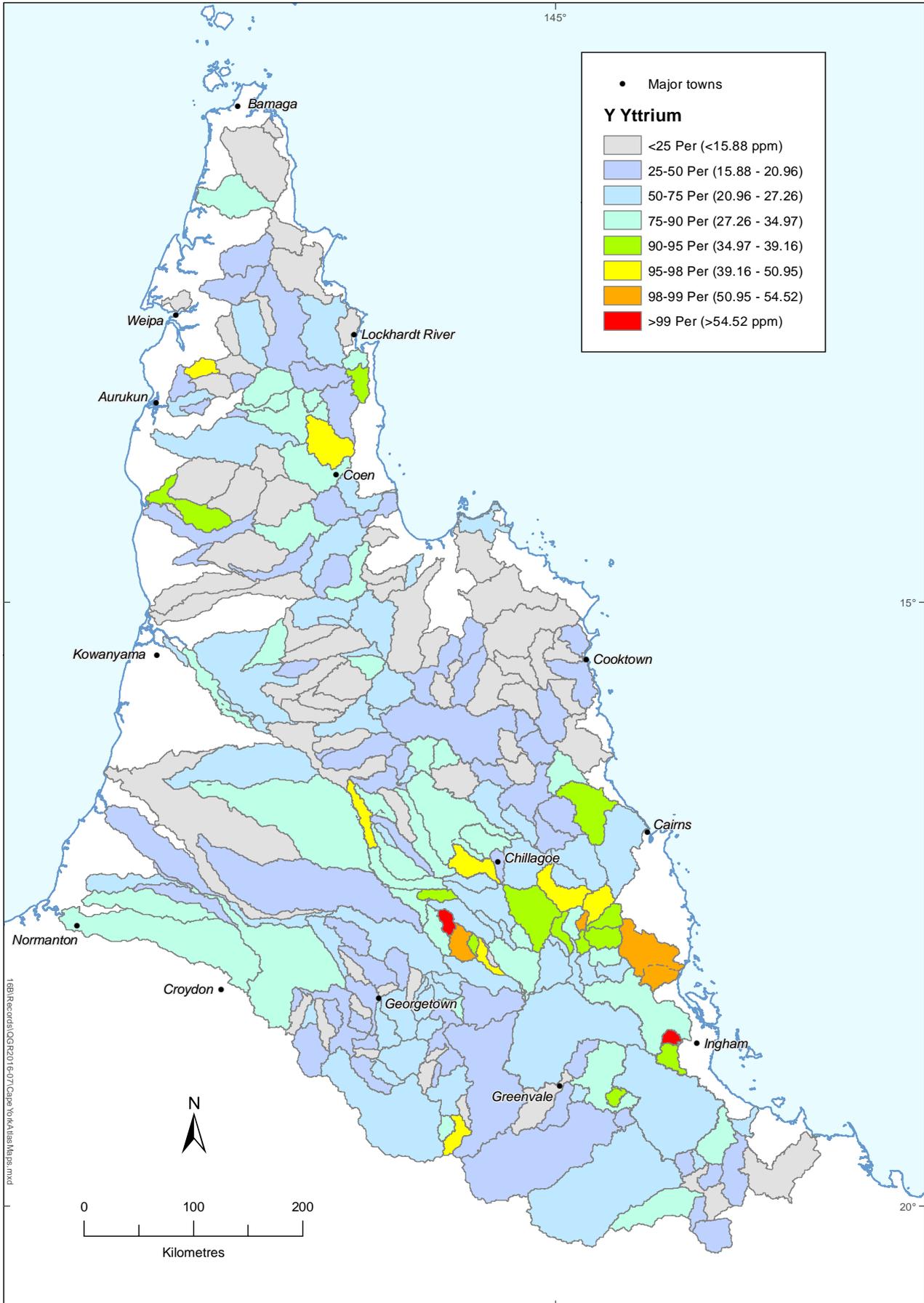
# V Vanadium



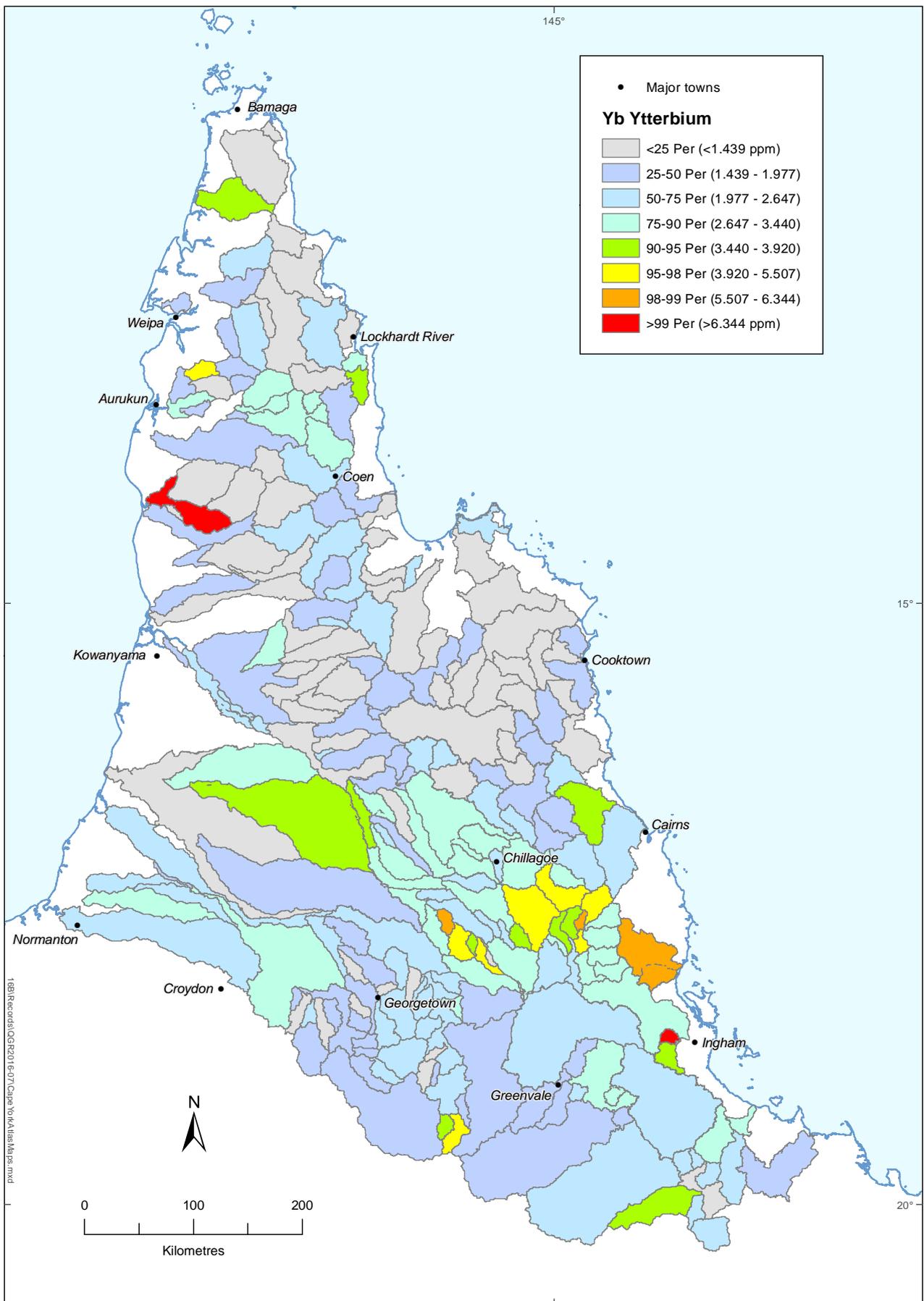
# W Tungsten



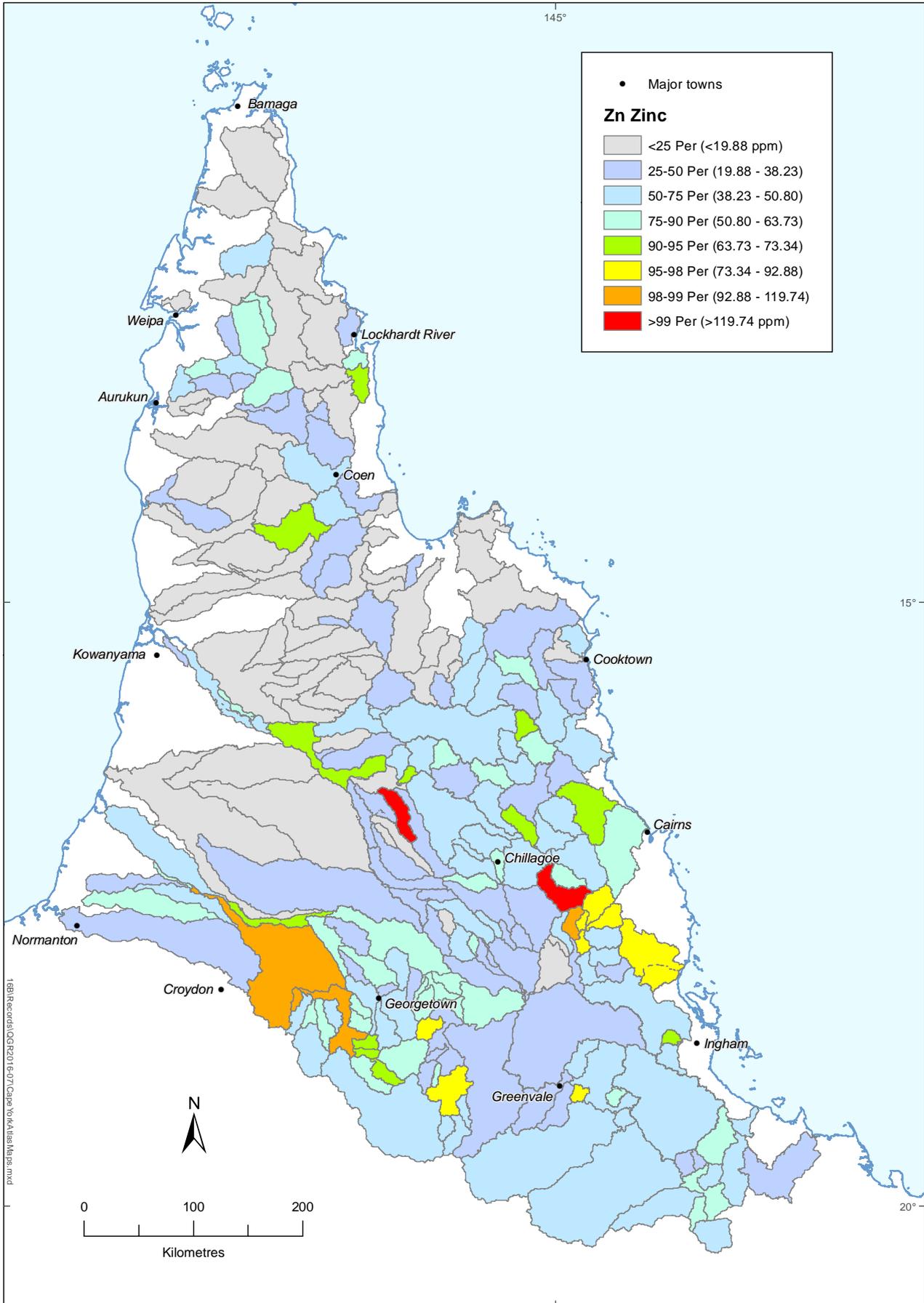
# Y Yttrium



# Yb Ytterbium



# Zn Zinc



# Zr Zircon

