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A report of findings from a pilot study

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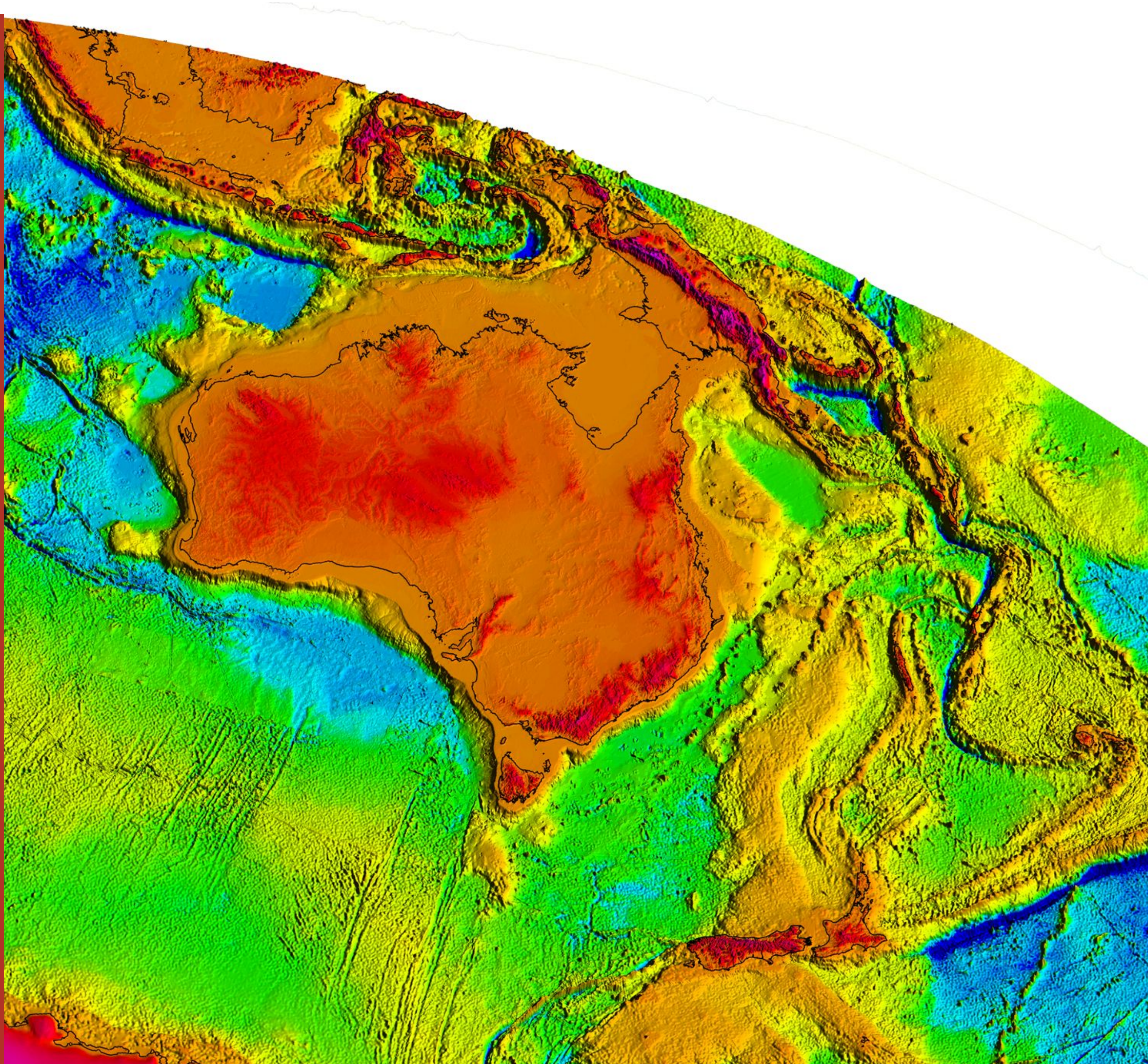

GEOSCIENCE AUSTRALIA RECORD 2003/08

POTENTIAL APPLICATIONS IN BASELINE GEOCHEMICAL DATA INTEGRATION FOR GEOSCIENCE AUSTRALIA – A REPORT OF FINDINGS FROM A PILOT STUDY

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ABSTRACT

Australia's geochemical environment affects our well-being. It directly affects public health, agriculture and mining activities, yet nation-wide geochemical surveys such as conducted in the United Kingdom, Wales and China are yet to be established in Australia. To obtain the most information from geochemical data, appropriate methodologies to analyse the data are essential. This report investigates the use of various methodologies for the assessment and integration of whole-rock geochemical data at regional and local scales. A broad-scale regional study conducted over southeastern Australia, mainly focused on NSW and Victoria, whilst the other was a more specific study conducted over the Bathurst 1:250,000 map sheet area.

Regional scale studies have low sample densities and the possibility of sampling bias being incorporated and intensified during data analysis across large areas are high. However, regional scale mapping is a low cost, time efficient way of identifying broad trends and smaller target areas. Accordingly, the methods used on regional data are quick and easy with relatively little data preparation. Mineral occurrence densities were created and concentrations of uranium, lead, zinc, gold and arsenic were overlaid to identify anomalous values. Hot spots for these elements often corresponded to mining districts. However, the analysis highlighted that some anomalous samples related to local mineralisation and should have been removed from the analysis.

The Bathurst study area had a higher sample density so more comprehensive analysis was possible. Statistical analysis was conducted which identified spurious data that were then removed from the dataset. The geochemical points were validated to ensure that they were in the correct geological polygon and hence there was a higher confidence in the data than in the regional scale study. The geochemical values were averaged across like geological polygons and trends of elemental concentrations in rock types became apparent. This was important as it allowed the geochemistry to be viewed in its geological context.

Both studies indicated that existing whole-rock geochemical data is inappropriate for baseline geochemical surveying due to sample biases associated with the data. It does, however, identify methods that can be applied to the more appropriate data. The studies identified the need for conducting a nation-wide baseline geochemical survey. Benefits of such a survey would include a raised awareness of public health, agricultural, environmental and land use issues, as well as helping to identify mineral resource targets.

It is recognised that determining high concentrations of elements is not in itself sufficient as high background concentrations may not lead to the formation of an ore deposit, nor be detrimental to human and animal health. An assessment of bioavailability is critical because elements may occur in stable compounds within the environment hence will not pose a health risk, no matter how high their concentrations. As a follow-on from this study, assessment of element bioavailability is an important step.

1. INTRODUCTION

Australia's geochemical environment affects our quality of life and is a vital part of describing our natural environment. It directly impacts public health (eg: contamination of drinking water, contaminated soils in building sites), agriculture and forestry (eg: soil fertility, trace element distribution, contamination), mining industry (distribution of prospective rock units and mineral deposits), and the state of the economy (income derived from mineral and agricultural exports). Systematic broad scale geochemical mapping provides a foundation for more detailed studies to be pursued.

Baseline geochemical surveying is important as it can:
1. help to determine the natural state of the environment,
2. support optimum mitigation strategies to help solve environmental problems,
3. increase understanding of immediate hazards,
4. help find possible mineral deposits,
5. provide information on disease distribution when combined with epidemiological studies, and
6. provides Australia's contribution to the global geochemical mapping program.

In the past, baseline geochemical studies have been used in both environmental geochemistry and in mineral exploration geochemistry. These are outlined in more detail below.

1.1 ENVIRONMENTAL GEOCHEMISTRY

Environmental geochemistry is concerned with the effect on humans of the distribution and interrelationship of the chemical elements and radioactivity among surficial rocks, water, air and biota (Jackson, 1997). Most elements in the environment originate from rocks. As rocks are weathered and eroded, elements may either migrate as solid particles in soils or, dissolve into surface or groundwater, volatise into the atmosphere or enter the biosphere. It is through these processes that toxic elements can enter the food chain. Figure 1 is a classification of the biological activity of elements within the environment into categories that are considered essential for life (major needs, minor meeds) and those that are considered harmful.

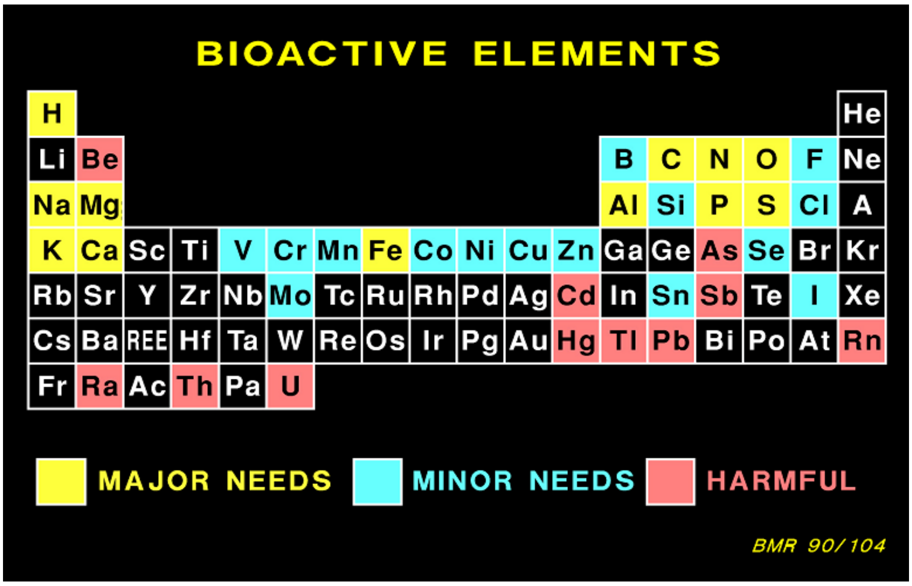


Figure 1. Biologically active elements of the periodic table.
(Modified from Darnley, 1990)

1.2 MINERAL EXPLORATION GEOCHEMISTRY

Although most mineral deposits with surficial geochemical anomalies are likely to have already been discovered, regional geochemical data can be used to identify potential mineralised rocks (Raymond and MacRae, 1997). For example, Ordovician mafic volcanics in New South Wales (NSW) contain elevated concentrations of copper and gold. These rocks could have been source rocks for mineral deposits that formed in adjacent younger rocks provided fluids circulating through these rocks are capable of extracting these metals. These kinds of broad geological anomalies can be identified by gridding the geochemistry with respect to geology.

In addition, regional geochemical surveys provide baseline data from which more detailed exploration surveys can be devised to assess whether concentrations of metals are genuinely anomalous. For instance, anomalous metal concentrations in a granite-dominant terrane may be very different to those in a mafic volcanic- or sedimentary-dominant terrane. Baseline regional geochemical surveys of bedrock, stream sediment, soil or groundwater can identify different anomalous thresholds for metals in varying terranes.

1.3 SCOPE OF THIS STUDY

This study aims to investigate and determine the most appropriate method to assess and integrate whole-rock geochemical data at regional and local scales. It concentrates on two pilot studies, one broad-scale project based mainly NSW and Victoria and a second more detailed project based on the Bathurst 1:250,000 map sheet area. Several innovative uses for geoscientific datasets have been investigated, particularly relating rock chemistry and mineral occurrence data.

2. GLOBAL BASELINE GEOCHEMICAL STUDIES

In 1998, the International Geological Correlation Program (IGCP) Project 259 was approved by the United Nations Education, Scientific and Cultural Organisation (UNESCO) and the International Union of Geological Sciences (IUGS). This program aims to unite scientists and organisations globally to achieve geochemical mapping on a worldwide scale (Darnley, 1990). Nation wide geochemical studies have been carried out in many countries and regions including the United Kingdom (UK) (Webb *et al.,* 1978), Alaska (Weaver, 1983), Fennoscandia (Bolviken, 1986) and China (Xuejing *et al*., 1997). These have been based largely on stream and soil samples.

Darnley (1990; 1991), and Xuejing (1990) outline issues relating to international geochemical mapping as part of the IGCP Project 259. Issues that need to be addressed for successful integration of global geochemical mapping include:

- acquiring geochemical data that is more informative for mineral exploration, environmental studies and basic geology,
- concerns of poor quality control for samples being analysed for varying suites of elements and using different analytical techniques,
- ensuring data is globally comparable, and
- easy access of geochemical data.

Many nation wide geochemical studies have found important relationships between our environment and the state of human and animal health. Some of these case studies to date are outlined below to show the value of this kind of work.

2.1 COMMUNITY IMPACT - CASE STUDIES

2.1.1 Selenium Deficiencies in China

The ill health of Chinese people in a continuous belt from north-east to south-west China has been recognised since the 1930's. After comprehensive geochemical surveying, it was observed that this region had selenium deficiencies in the bedrock, soils and natural waters. Selenium is an essential mineral for humans and animals. Its deficiency in the environment has since been found to influence the distribution of the cardiovascular disease, Keshan disease and the osteoarthritic disease, Kaschin-Beck disease (Zhu *et al*., 1992; Li *et al*., 1999). Countries now known to have selenium deficient soils include New Zealand, Denmark, and Canada (Gupta and Gupta, 2000).

2.1.2 Radon in the Basements of Houses

Radon is a major potential health hazard resulting in an increase in human cancers which has been documented in countries including Sweden (Wilson, 1982), Canada (Je-Imshin, 1997) and the United States of America (Brookins, 1990; National Research Council, 1999). Radon is a radioactive gas and occurs naturally in rocks and their derivative soils, particularly granites, as a daughter product of the ^{238}U decay series. As radon is released from the rocks and soils into the atmosphere it can accumulate in the basements of buildings due to poor ventilation. This can become a significant problem in colder climate countries as buildings are shut up for many months of the year. The radon gas is unable to disperse due to the lack of air flow. Lung cancer is a known disease caused by exposure to radon (National Research Council, 1999). Naturally occurring radon gas clouds have been documented near Wagga Wagga by Bierwirth and Johnston (1996). However, these were apparently ephemeral features which occurred outdoors and were dispersed by winds. The radon studies that have been carried out in Australia to date have been preliminary and non-systematic. Further work could more effectively target areas of concern.

2.1.3 "Sickness Country" in Kakadu

For thousands of years Aborigines have recognised regions in the Kakadu area as "sickness country". If people spent too much time in this region it would impact adversely on their health. Geochemical surveys in southern Kakadu recognised that the locations of the "sickness country" coincide with high concentrations of uranium, thorium, arsenic, mercury, fluorine and radon in the water and air. The elements are leached from granites, felsic volcanics, ore deposits and related alteration zones that have naturally high levels of these elements (Wyborn *et al.,* 1996).

2.1.4 Lead Contamination

Lead contamination is evident in many parts of Australia. Over the last 25 years, elevated lead has been recognised in the soils, vegetables and rainwater of Port Pirie, the site of a lead smelter for more than 100 years. Children have been observed to have elevated blood lead levels (Tiller and de Vries, 1977; Body, 1986). Similarly, the NSW Health Department reported elevated blood lead concentrations in children at Broken Hill. These are possibly related to dust from the mine waste dumps blowing through the town (Woodley, 1991). Systematic geochemical mapping in the UK uncovered areas of heavy metal contamination derived from previous industrial activities (Fortey *et al.,* 1991). Identification of these potentially hazardous areas has enabled suitable remediation to be carried out to reduce the deleterious effects on humans and animals.

2.1.5 Basalt and Algal Blooms

Studies have been conducted in NSW on occurrences of Cainozoic basalts in relation to algal blooms (Caitcheon *et al*., 1994; Caitcheon *et al*., 1998; Martin and McCulloch, 1999). These studies found that high concentrations of phosphorus derived from Tertiary basalts appear to contribute to the algal blooms in Australia's inland waterways. Fertilisers and sewerage effluent do not appear to be the only factors leading to algal blooms.

Phosphate minerals, like apatite, contained within the basalt weather to develop soils that are naturally high in phosphorus (Caitcheon *et al*., 1998). When the soil is eroded into the creeks and rivers, it elevates the phosphorus loads in the water and can result in algal blooms. Tertiary basalts that occur within the Bathurst case study area near Orange (Figure 2) have been studied by Chowdhury and Al Bakri (1998), who postulated that Tertiary basalt soils are the primary source of elevated phosphorus in the waterways of the Suma Park catchment near Orange.

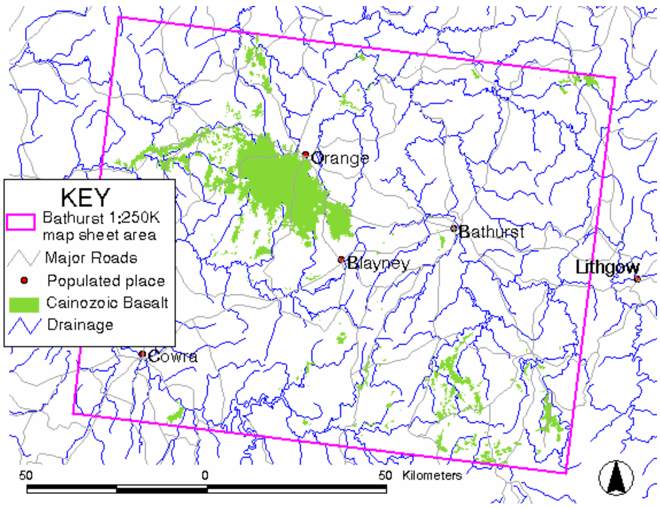


Figure 2. Location of Cainozoic Basalts on the Bathurst 1:250,000 map sheet.

Examples of case studies that illustrate environment impacts on the health of humans and animals are widespread. Others interesting studies that that are not outlined in this report include arsenic in groundwater at Bangladesh, groundwater contamination near Perth, and intercontinental transportation of contaminants in dust.

3. DATASETS AND METHODS FOR ANALYSING DATASETS

3.1 GEOCHEMICAL AND MINERAL DEPOSIT DATASETS

Data used for this study include the mineral deposits and whole rock geochemical data obtained from Geoscience Australia's OZCHEM and MINLOC databases. The databases are summarised in Table 1.

Table 1: Summary of databases used in this study.

Database Name	Description
OZCHEM	Geochemical analyses including whole-rock, regolith and stream sediment samples (Geoscience Australia, 2/3/2002). Only the surficial whole-rock data was extracted for the purposes of this study.
MINLOC	Australian mineral occurrence location data. Location data includes co-ordinates, name of occurrence, and commodity(ies) (Geoscience Australia, 4/3/2002).

Before the OZCHEM database was used it was important to ensure that all the geochemical points were assigned to the correct geological polygons. Although the Bathurst dataset had been validated for prior research, there were still known biases in the geochemical sampling. These kinds of problems and the known bias in the datasets are discussed in more detail below.

3.2 STATISTICAL BIAS IN GEOCHEMICAL DATASETS

Government and private industry have collected much of the existing geochemical data for specific purposes (e.g., igneous provenance studies or mineral exploration). Before this data can be used to baseline studies, it must be evaluated for potential biases inherent in the method of collecting the data. In Geoscience Australia's OZCHEM database, the distribution of the geochemical analyses in NSW-Victoria is biased towards igneous rocks of Palaeozoic and Proterozoic basement where Geoscience Australia has conducted regional mapping programs. Relatively few sedimentary rocks have been sampled, resulting in gaps in the whole-rock geochemical data used in this pilot study. Many sedimentary units are under sampled or not sampled at all. Areas of younger cover sequences, including the sedimentary basins of the Murray, Surat, Darling and Eromanga Regions have not been sampled for whole rock geochemistry. Where whole-rock geochemical data is present over the areas of sedimentary basins, caution must be used to establish whether the whole-rock geochemical data is for basement rock values taken from drill holes or from surficial samples.

There is a strong gold sampling bias towards mafic and ultramafic rocks. The sampling program targeted mafic and ultramafic rocks particularly of Ordovician age for a specific igneous provenance study (Wallace and Wyborn, 1997). This explains why the majority of the OZCHEM gold analyses are concentrated in the Orange-Bathurst region. As the Ordovician mafic volcanics are thought to be the most anomalous gold rocks in the Lachlan Orogen, the gold dataset is strongly biased towards high gold values.

Due to the biases outlined above, the available gold data has limited use for broad-scale baseline studies and would have to be supplemented with further sampling for baseline study. Gold in rocks and stream sediments is routinely analysed by exploration companies and as such is mainly stored in the open file records of the State surveys. Several State surveys have large amounts of digital open file stream sediment and soil data. For a more comprehensive study, incorporation of these datasets would significantly increase the value of the analysis.

Geochemical datasets must also be evaluated for the sample media they target - bedrock, soil or groundwater. Varying behaviour of different elements during weathering and erosion means that geochemical data from bedrock samples cannot be directly compared to data from soil samples. For instance, uranium is highly soluble in groundwaters and is consequently depleted in soils relative to bedrock. Groundwaters draining from high uranium bedrock may contain high concentrations of uranium some distance from the bedrock source. In contrast, thorium occurs in resistate minerals in the soil profile and is commonly enriched in soils or alluvial sediments relative to the source bedrock (Wilford *et al.,* 1997). It is also assumed that the whole rock samples are fresh samples.

As indicated above, it is extremely important to be familiar with the data to ensure biases are fully accounted for before studies are performed. Section 3.3 discusses the methods used to overcome the biases in the geochemical data.

3.3. Methods to Overcome Statistical Bias in Geochemical Data

Several methods were trialed for gridding the geochemical data to overcome the sampling biases. These methods are outlined below.

3.3.1 Geochemistry as Dot Points for Values

The simplest way of displaying the rock geochemical data was to use circles of different colour and size to represent the geochemical value of a particular element. This was used in conjunction with the geochemical and mineral density gridding in Arcview®. The advantage of this method is that individual chemical analyses are not afforded a wide sphere of influence. Hence highly anomalous samples so not affect large areas in any spatial analysis. This method requires a dense sampling regime to be effective over wide areas.

3.3.2 Geochemical Data Gridding

Arsenic, lead, zinc, uranium and gold analyses were gridded using the Inverse Distance Weighting (IDW) method in the Spatial Analyst extension of Arcview®. The gridding parameters used are outlined in Table 2. Areas where no geochemical data was available appear as blank areas in the grids. Highly anomalous samples were separated from the dataset for the Bathurst study, but not for NSW. Most of these highly anomalous values could be readily related to mineralisation and/or alteration halos around ore deposits which represent abnormal processes with very local spheres of influence and not related to broad scale “normal” processes.

Study Area	Cell Size	Search Radius
Southeastern Australia	1000 m	10 km
Bathurst	250 m	5 km

Table 2: Parameters for gridding arsenic, lead, zinc, uranium and gold geochemistry

The IDW gridding method is commonly used, but it can be limited by low sampling density. In order to cover areas of poor sampling density, an inappropriately large radius of influence must be applied to the available samples. It is not recommended where sampling densities are very low as the grid produced is patchy and consequently difficult to interpret.

Several variations of the gridding method were tested in order to introduce some geological constraints to the IDW method. Firstly, analyses of individual rock types were gridded separately to prevent influence of adjacent rock types of distinctly different chemistry. Secondly, rock type polygon boundaries were used as barriers in the gridding process. As a test, the median uranium values for the felsic intrusives was gridded using the felsic intrusive geological polygons as a barrier (section 5.3.4). This created a geochemical map that related specifically to the lithological unit. It applies methodologies similar to those used by the Average Points method (see below) but has the advantage of showing graded geochemical values within lithological units.

This method of constrained geochemical gridding may have benefited a study of uranium geochemistry in the Kakadu region. In this study by Wyborn *et al.,* (1994b), unconstrained geochemical gridding of a granite with limited outcrop but anomalous uranium produced a gridded anomaly much wider than the outcrop. This example highlights the importance of viewing geochemical anomalies in geological context.

3.3.3 Averaging Points Within Like Geological Polygons

To average the geochemistry within discrete geological polygons the Average Points AML (ArcInfo Macro Language) was used (Kilgour and Gallagher, 2001). The script determines statistics for the element in question within the geological polygon that the sample was collected in. These statistics include the mean, median, sum, and standard deviation. Using the Average Points AML, individual geological polygons are coloured according to the average geochemistry of the geologic unit. This provides a geochemical map for particular elements over the region. This technique was used by Jagodzinski *et al.* (1993) to derive a geochemical map for the Mt Isa Inlier and environs. For the purposes of this study the median geochemical value for the polygon was used. It was represented in two ways: i) specifically for the polygon in which the sample was collected, and ii) the values were extrapolated to other polygons of the same lithological unit. This was done on the assumption that geochemical variation within a stratigraphic unit is usually less than between units.

3.3.4 Investigative Statistics

Statistical analysis for gold, arsenic, copper, lead, zinc and uranium in the bedrock was carried out for the data over the Bathurst 1:250,000 sheet area using the Data Analysis function in Microsoft Excel®. If the analysis for a sample was below detection limits, it was recorded as half the detection limit. (E.g.: If the detection limit was 0.5, values below this were recorded as 0.25). This was only performed for samples with relatively low detection limits. Samples with high detection limits were disgarded. This enabled analysis of samples that were below or close to the detection limit. The distribution of cadmium could not be adequately investigated as it was not routinely analysed in whole rock samples. Only 20 samples in the OZCHEM database were analysed for cadmium in southeastern Australia.

Table 3: Average whole Earth abundance (ppm) of selected minor elements.
(after Berkman, 2001)

Element	Earth's Crust	Ultra-mafic	Basalt	Granite	Shale	Limestone	Soil
As	1.8	1	2	1.5	15	2.5	1-50
Au	0.004	0.005	0.004	0.004	0.004	0.005	No data
Cd	0.2	No Data	0.2	0.2	0.2	0.1	1
Cu	55	10	100	10	50	15	2-100
Th	10	0.003	2.2	17	12	2	13
Pb	12.5	0.1	5	20	20	8	5-500
Zn	70	50	100	40	100	25	10-300
U	2.7	0.001	0.6	4.8	4	2	1

In determining whether an element concentration is anomalous or not, it is important to know in what rock type the element is present, as element concentrations differ depending on the rock type. For example, 4.8 ppm of uranium in granitic rocks is not anomalous. However, the same concentration in ultramafic rocks however is highly anomalous. Average concentrations for various elements in various rock types are shown in Table 3.

3.4 PREDISPOSITIONS OF COMMODITIES DATA IN MINERAL OCCURRENCE DATASETS USED

It is important to be familiar with both the data in, and the structure of, the datasets before any analysis is done. The deposits in the MINLOC database can be recorded as a number of small orebodies or as one large deposit. This has implications when producing mineral occurrence density grids as the density plots do not incorporate grade/tonnage information and produce markedly different distribution patterns.

It is also important to consider that anomalous regions will reflect the querying methods used to create the commodity density maps. For this study, the order of significance of each commodity in mineral deposits as defined in the database was not taken into account. Commodities were gridded whether they were the primary commodity or the fourth commodity in a mineral occurrence. To make more conservative density deposit maps, only primary commodities would be selected. This could potentially cause more problems, however, because the order of significance of the commodity has not always been attributed in the MINLOC database.

Several methods were trialed for gridding the mineral location data and are outlined below.

3.5 METHODS USED TO GRID MINERAL OCCURRENCE DATA

Mineral deposit location data was extracted from the MINLOC database to create the mineral occurrence density maps. The methodology used to create the mineral location/occurrence density maps was modified slightly from that used to create mineral density maps by Evans *et al.* (2001). Arcview®'s Grid.Make.Density.Surface routine was used to calculate the density of the number of mineral locations around each Output Grid Cell (Silverman, 1986). The mineral occurrence distribution maps for southeastern Australia used a cell size of 1000 m and a search radius of 100 km. The kernel option was used on the data to create a smoothly curved surface for each data point. More details on this methodology are outlined by Silverman (1986).

3.6 METHODS FOR COMBINING DATASETS

Anomalous geochemical analyses were overlain on the mineral deposit density maps in Arcview® to examine possible relations between anomalous bedrock chemistry and mineral deposits.

Mineral occurrence density maps for southeastern Australia were not prepared for arsenic as, in most cases it does not occur as a primary commodity in mineral deposits. An arsenic-bearing mineral occurrence density map for the Bathurst region was created, however, by querying the ‘primary ore’ column of the MINLOC database. Arsenic-bearing minerals arsenopyrite, sphalerite, galena and arsenic-sulfides were selected and then gridded with a search radius extent of 10 km. Its mapped distribution appears to be a combination of the locations of the lead, zinc, and gold deposits.

4. SOUTHEASTERN AUSTRALIA AS A CASE STUDY

4.1 Introduction

An area incorporating New South Wales, Victoria, southern Queensland and eastern South Australia was selected for the regional case study (Figure 3). This area was chosen due to its relatively large population density and its substantial agricultural importance when compared to the rest of Australia. The area also had a comparatively high sample density. Sample numbers for the various elements were as follows: gold – 351, arsenic – 2605, lead – 7056, zinc – 7012, and uranium – 5845.

Methodologies used for this case study were the geochemistry as dot points, geochemical data gridding and the mineral occurrence density maps as described in Section 3.3. Averaging of the geochemistry across the geology was not conducted due to a) the large scale of the study area, and b) the lack of samples in some lithologies would result in large errors if extrapolated.

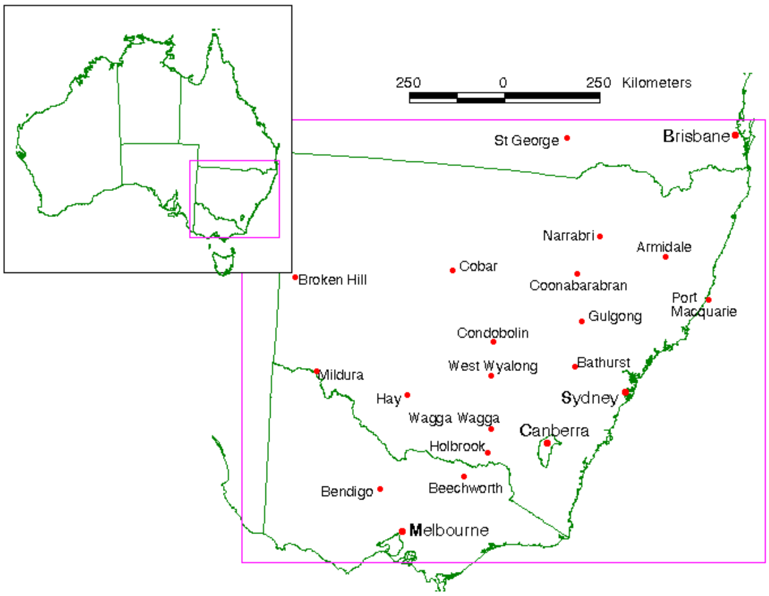
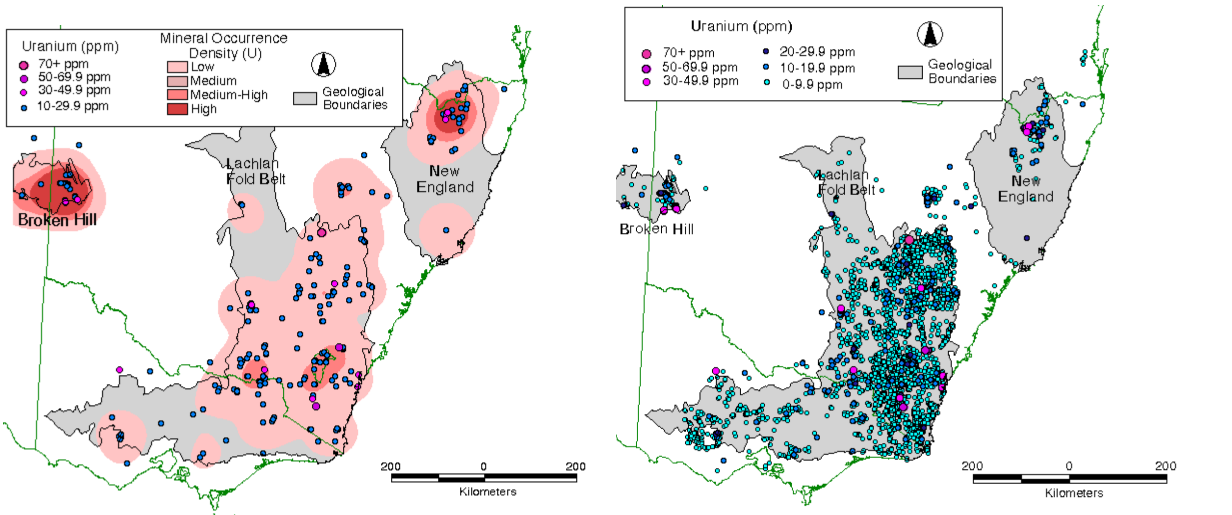


Figure 3. Location of the southeastern Australian case study.

4.2 Results

4.2.1 Uranium

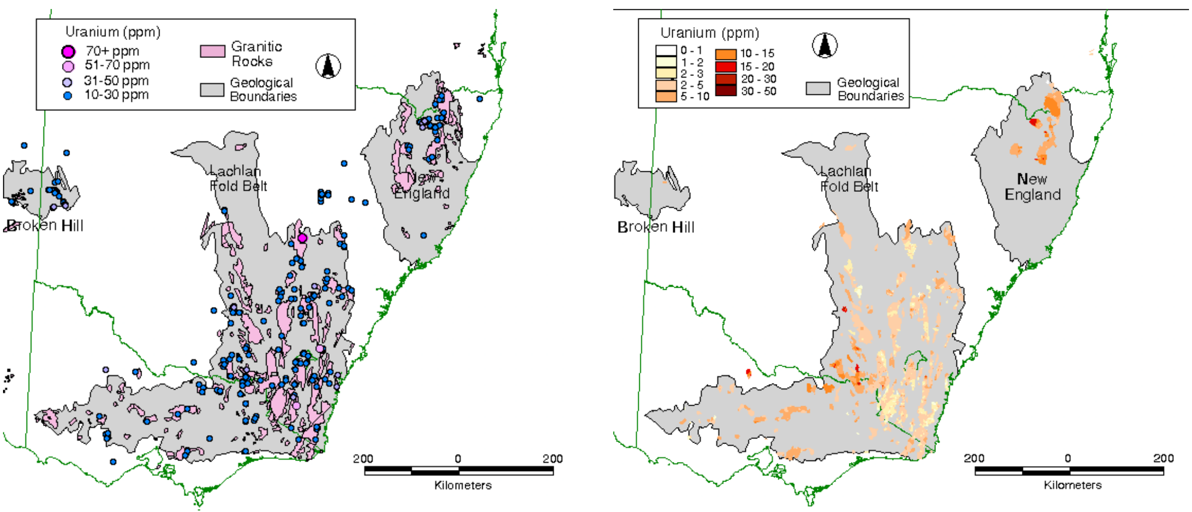
Uranium mineral occurrence density and anomalous bedrock geochemistry is shown in Figure 4a. The Broken Hill and New England regions show some degree of correlation between uranium mineral occurrence density and anomalous bedrock chemistry. However, the Lachlan Orogen shows that anomalous bedrock uranium composition does not necessarily translate into mineral occurrences.



a) b)

Figure 4. a) Mineral occurrence density and anomalous uranium geochemical values. b) All whole-rock geochemical values for uranium from Geoscience Australia's OZCHEM database.

A notable hot spot lies around Broken Hill with several known uranium mineral occurrences including Honeymoon and Radium Hill. Some high concentrations of uranium are unrelated to known uranium mineral occurrence locations (Figure 4a,b) eg: near Berridale south of the Australian Capital Territory (ACT), and near Batemans Bay and Moruya associated with the Moruya Granite. The highest concentration of 79 ppm uranium is located 20 km south of Dubbo in a small Mesozoic alkaline intrusion. Mesozoic alkaline intrusions in NSW typically have unusual chemical compositions with elevated rare earth elements and high field strength elements. They commonly intrude the sedimentary units of the Sydney and Gunnedah Basins (Warren *et al.,* 1999).



a) b)

Figure 5. The relationship between granites and uranium geochemistry in whole-rock samples for New South Wales. a) The location of granitic rocks and anomalous uranium analyses in New South Wales. b) Gridded uranium abundance (ppm) in granitic rocks.

Anomalous concentrations of uranium in eastern Australia, particularly in the Lachlan Orogen, appear to be more typically associated with granites (Figure 5a). This could, in fact, be a reflection of the sampling bias. Uranium concentrations are typically higher in granites than other types of rocks (Berkman, 2001). This relationship is reinforced by the statistics shown in Table 3 with an average concentration of 4.8 ppm present in felsic intrusives. Uranium concentrations were gridded within granite polygons (Figure 5b) to view the uranium data in a geological context. Granites in the New

England Tableland region are higher in uranium (5-20 ppm) than those in the eastern part of the Lachlan Orogen (1-5 ppm). Uranium levels also appear higher in association with the granites at Holbrook and at Kamara, 100 km north-west of Wagga Wagga.

4.2.2 Gold and Arsenic

As outlined in Section 3.2, few samples were analysed for gold, hence the limited distribution of gold analyses. As a result of the extremely specific target sampling, 1) a gold geochemical variation map was not created for southeastern Australia, and 2) the gold data has limited use for broad-scale baseline studies.

The mineral density occurrence map for gold was created using 12,756 mineral location points. The most significant gold mineral occurrence locations occur around Bendigo/Ballarat and Beechworth in Victoria, and Orange/Bathurst and Armidale in NSW (Figure 6).

Figure 6 highlights several strongly anomalous, mineralised samples. A sample of 119 ppb gold is associated with the Springfield deposit which occurs near Gulgong within a monzodiorite intrusion which intruded the Late Ordovician Burranah Formation. Samples of 210 and 290 ppb gold are associated with gold and base metal mineralisation at Condobolin.

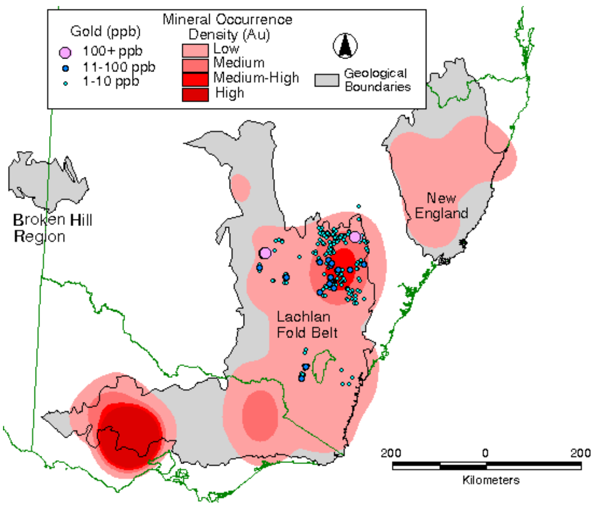


Figure 6. Mineral occurrence density and anomalous gold geochemical values.

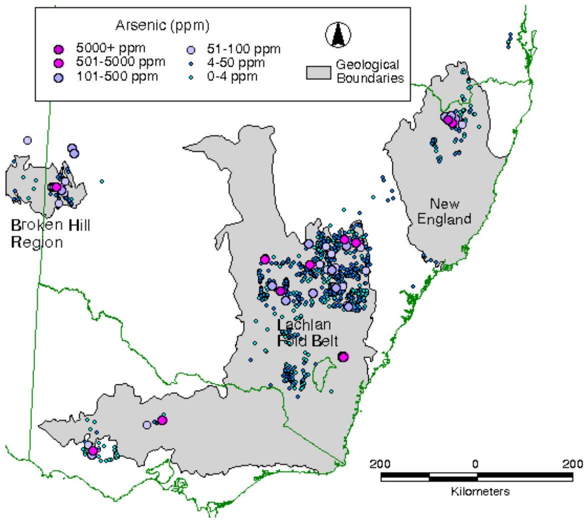


Figure 7. All whole-rock geochemical values for arsenic from Geoscience Australia's OZCHEM database.

The distribution of arsenic is shown in Figure 7. As arsenic is usually present in accessory minerals associated with mineral deposits of lead, zinc, copper and gold, no mineral occurrence density map was created for this element.

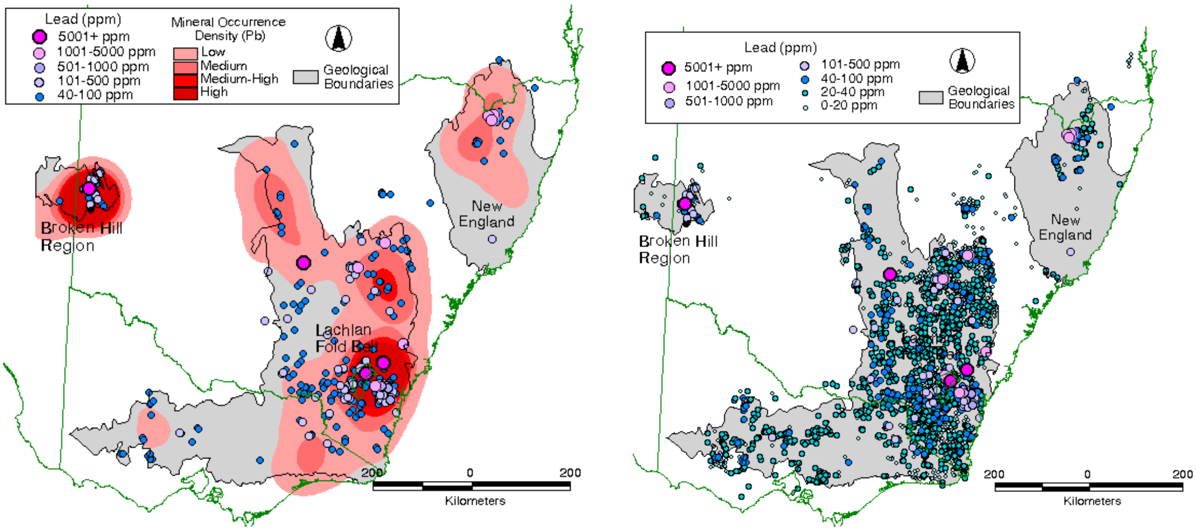
The majority of arsenic values over 500 ppm are from hydrothermally altered or mineralised samples. Notable arsenic values over 10,000 ppm include one from 120 km north of Armidale in the New England region from a silicified arsenopyrite-bearing siltstone, and another from a quartz-tourmaline altered breccia at Porter's Mount, approximately 50 km north-east of West Wyalong. Strongly anomalous arsenic values are also associated with the Woodlawn, Springfield, Belara and Native Bee mines. For the purposes of baseline geochemical surveying, these highly anomalous samples should be disregarded.

4.2.3 Lead and Zinc

Both the lead and zinc mineral occurrence anomaly maps have distinct 'hot spots' around the Broken Hill mining district, and north-east and east of the ACT. The anomaly near the ACT corresponds to

Woodlawn and Captains Flat Volcanic Hosted Massive Sulfide (VHMS) base metal deposits in the Lachlan Orogen. Anomalies of moderate significance lie in the Cobar mining district, and the New England and Orange/ Bathurst regions (Figure 8a and 9a).

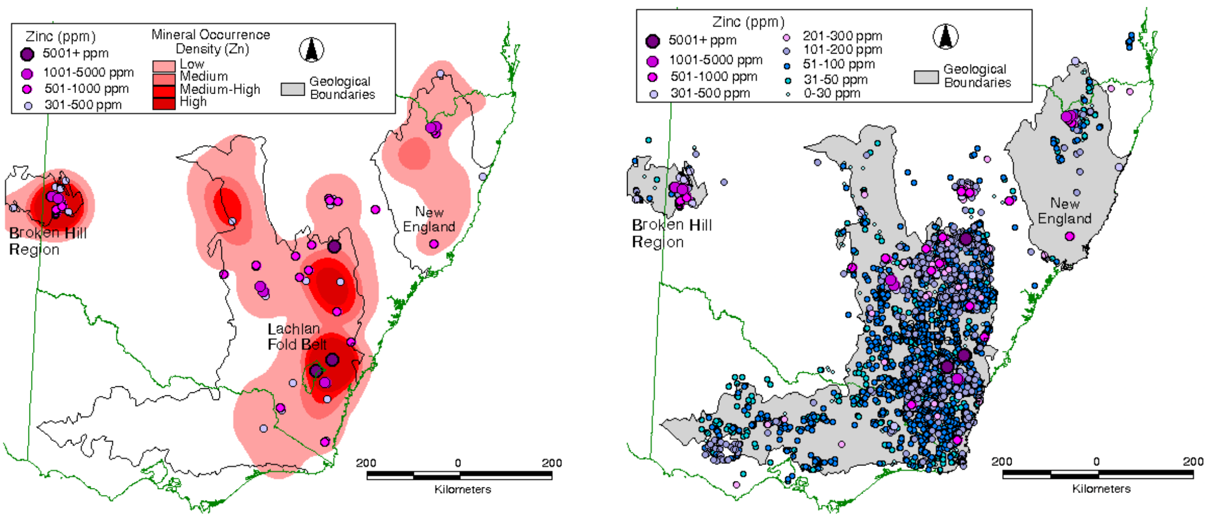
To make a more conservative deposit density map, the mineral occurrences could be gridded for lead and zinc when they are the only or the primary commodity. This could potentially cause more problems, however, as the commodities have not always been entered in order of significance into the MINLOC database.



a) b)

Figure 8. a) Mineral occurrence density and corresponding anomalous lead geochemical values. b) All whole-rock geochemical values for lead as extracted from Geoscience Australia's OZCHEM database.

In the Orange/Bathurst region, copper-lead-zinc VHMS mineralisation occurs at the Lewis Ponds, Mount Bulga and Calula deposits to the north of Orange as well as in the Sunny Corner and Wiseman's Creek areas near Bathurst. A secondary association of accessory lead-zinc mineralisation may also occur with the abundant gold occurrences in the Orange-Bathurst area.



a) b)

Figure 9. a) Mineral occurrence density and anomalous zinc geochemical values. b) All whole-rock geochemical values for zinc from Geoscience Australia's OZCHEM database.

Geochemical anomalies for lead and zinc are shown in Figures 8 and 9. Largely, these correlate with the distribution of mineral occurrences shown in Figure 8a and Figure 9a. The gridded distributions of lead and zinc are shown in Figures 10 and 11. Significant lead and zinc values are located 10 km north-east of Silverton in the Broken Hill Region. Although not specifically associated with a mine, this region is a known locality for anomalous lead and zinc. Within the Lachlan Orogen, highly anomalous samples are situated at Condobolin, at a blue metal quarry for road base in the ACT, and at Tarago. Both the Condobolin and Tarago anomalies are from mineralised samples. High lead and zinc values are present west of Torrington in the New England region and appear to be associated with Webb's Silver Mine. Coonabarabran also has notable zinc concentrations and are likely to be associated with the alkaline Mesozoic volcanics in the Warrumbungle Ranges.

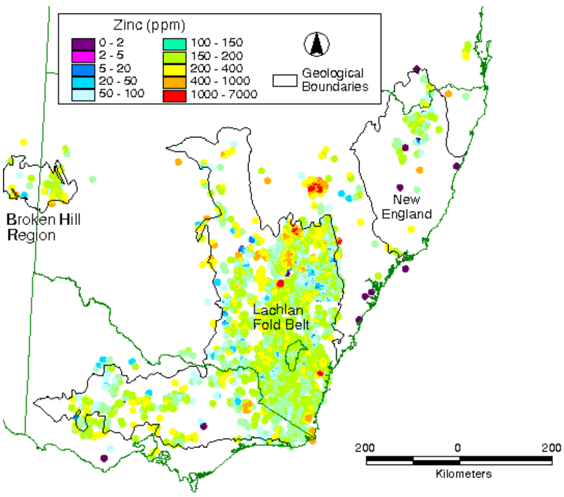


Figure 10. Zinc data gridded with 10 km search radius for southeastern Australia.

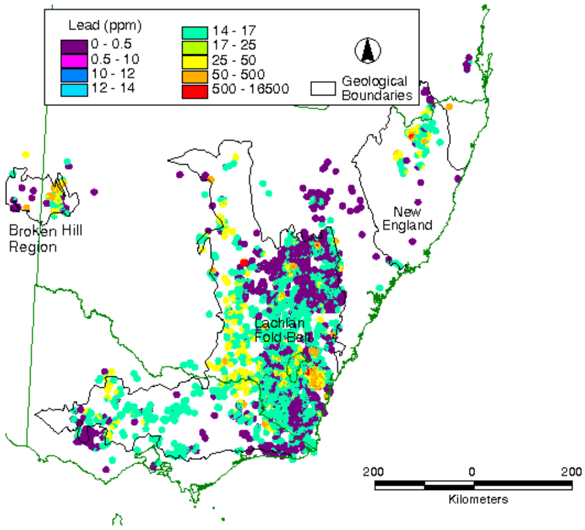


Figure 11. Lead data gridded with 10 km search radius for southeastern Australia.

4.3 Discussion

The mineral occurrence density maps drawn for southeastern Australia provide very broad representations of mineralisation. There are no geological boundary constraints applied to the gridding method, and the results must be interpreted with this in mind. For instance, the strong lead mineralisation anomaly which covers most of the ACT (Figure 8a) is due primarily to copper-lead-zinc mineralisation in the Woodlawn-Captain's Flat region, but the density grid anomaly extends much wider than just the belt of Silurian rocks which hosts these deposits. Equally, the density grid does not imply that the ACT and surrounding region is sitting on harmful amounts of lead and is simply an artefact of the gridding methods.

Interpreting the geochemistry by dot points and gridding the geochemical data highlights the broad high and low levels related to composition of the underlying rock. This is, however, strongly subject to sampling bias. Two examples of sampling bias include; 1) gold sampling was strongly favoured in mafic and ultramafic rocks, and 2) the specific sampling of the small Mesozoic alkaline intrusions within the more widespread sedimentary units of the Sydney and Gunnedah Basins near Dubbo. The latter example shows very localised uranium anomalies that when considered on a regional scale misrepresent the dominant geology in the area and suggests that there is more uranium in the Dubbo region than is actually present. This highlights the importance of being familiar with both the data in, and the structure of, the datasets before any analysis is done. This helps ensure that no biases are incorporated into the analysis. The study also indicated the importance of removing highly anomalous samples such as mineralised samples, gossans, veins and sills for baseline studies, as these do not represent normal background conditions.

5. BATHURST 1:250,000 MAP AREA CASE STUDY

5.1 Introduction

The Bathurst 1:250,000 map sheet area was used as a small study area (Figure 12). The area was chosen as a case study because there is a relatively dense coverage of geochemical samples compared to other areas of southeastern Australia. The data is also easily accessible at Geoscience Australia and the data had been previously validated to ensure that all the geochemical points were assigned to the correct geological polygon. Sample numbers for the various elements were as follows: gold – 181, arsenic – 665, lead – 737, and uranium – 665. Mineral occurrence density and geochemical abundance were gridded in Arcview®. The geochemical data was averaged over the geological polygons. This provided another method for visualising and interpreting the data.

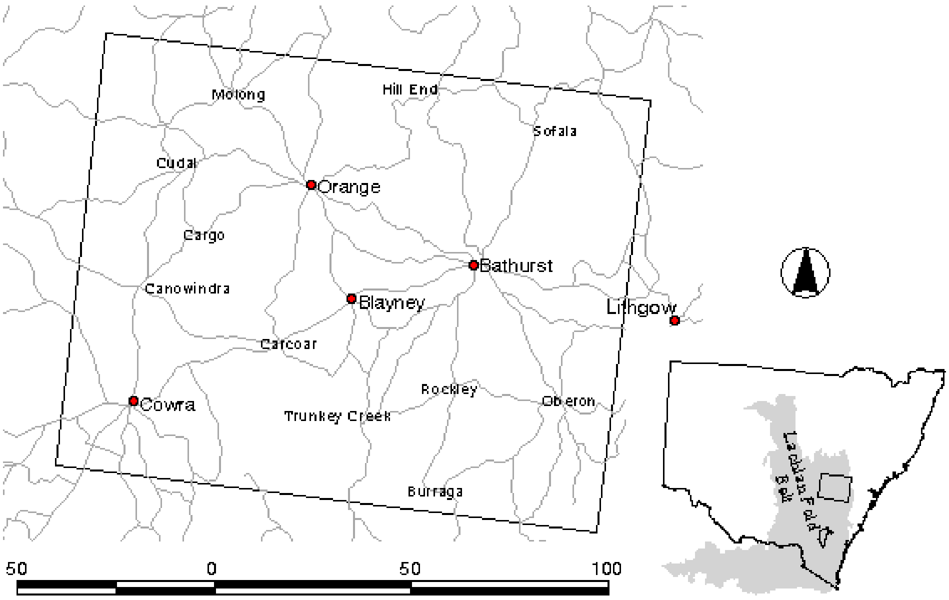


Figure 12. Location of the Bathurst 1:250,000 map sheet pilot study area.

Figure 13 shows a broad rock type classification map for the Bathurst sheet with the geology grouped into six broad categories; surficial deposits, sedimentary rocks, felsic and mafic volcanics and felsic and mafic intrusive rocks.

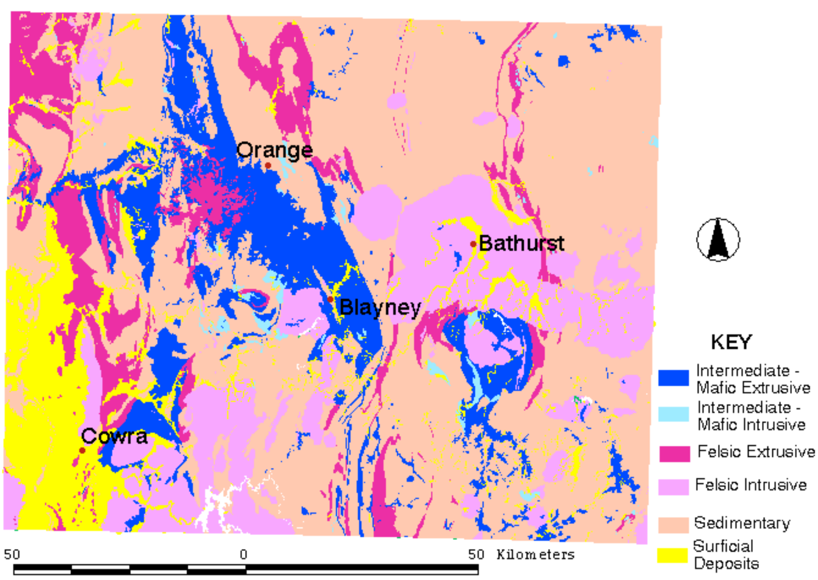


Figure 13. Simplified geology for the Bathurst 1:250,000 map sheet

5.2 Statistical Analysis of the Geochemical Dataset

Table 4: Statistical summary of element concentrations (ppm) within various rock types for the Bathurst 1:250,000 map sheet. Anomalous values were calculated to be those that were greater than the median plus 2 standard deviations. (* Anom: anomalous).

	Felsic intrusives			Felsic volcanics			Sediments		
Element	Mean	Median	Anom*.	Mean	Median	Anom.	Mean	Median	Anom.
As	3.6	2.0	25.2	13.1	4.0	67.8	8.2	4.6	22.4
Au	0.0011	0.001	0.00102	0.007	0.0011	0.0028	0.005	0.0022	0.0226
Pb	10.0	9.5	9.9	27.3	20.0	116.6	15.0	13.0	34.8
Zn	39.7	39.30	90.2	67.9	46.0	215.4	78.0	77.0	157.6
U	4.8	4.0	10.5	4.0	3.5	8.7	2.0	1.7	4.7

	Mafic intrusives			Mafic volcanics			Intermediate intrusives		
Element	Mean	Median	Anom.	Mean	Median	Anom.	Mean	Median	Anom.
As	6.3	4.0	20.0	10.4	4.0	44.4	4.7	3.0	11.4
Au	0.003	0.0021	0.0093	0.0036	0.003	0.0092	0.0046	0.0034	0.0112
Pb	5.8	5.5	13.1	6.1	4.8	17	11.3	11.0	24.0
Zn	81.8	84.5	138.1	93.2	87.5	148.1	64.0	63.0	112.2
U	0.8	0.7	1.9	0.8	0.5	2.1	2.5	1.8	5.8

	Intermediate volcanics			All rock types - combined		
Element	Mean	Median	Anom.	Mean	Median	Anom.
As	8.9	6.5	29.1	10.2	4.0	43.0
Au	0.0033	0.0021	0.0095	0.004	0.0021	0.0143
Pb	10.3	8.2	20.6	13.8	10.5	47.1
Zn	91.1	75.0	148.2	69.9	65.0	157.6
U	1.9	1.7	4.1	2.7	1.8	7.6

Average concentrations of gold, lead, zinc and uranium in rocks of the Bathurst region (Table 4) are comparable to average crustal abundances of these elements (Berkman, 2001) (Table 3). It is perhaps surprising that the gold samples around Bathurst have average crustal concentrations, as the samples selected in the area were highly biased towards rocks with presumed elevated gold concentrations.

Arsenic was significantly elevated in the Bathurst data relative to global abundances. The presence of arsenic, particularly in the mafic rocks appears to be the biggest contributor to the above average concentrations. As there is a significant concentration of Tertiary basalts in the Orange region, and the provisional guide for arsenic concentrations in drinking water is 0.001 mg/litre (WHO, 2002) the distribution of arsenic in the environment around Orange may be worth investigating further. Analysis of soil and water would be useful in determining whether the elevated levels of arsenic pose a threat to human and animal health.

Data distribution histograms, cumulative frequency plots and descriptive statistics for five elements are shown in Figure 14. Apart from zinc, all the elements investigated have a log distribution. Zinc exhibits more of a normal distribution, but it is still positively skewed.

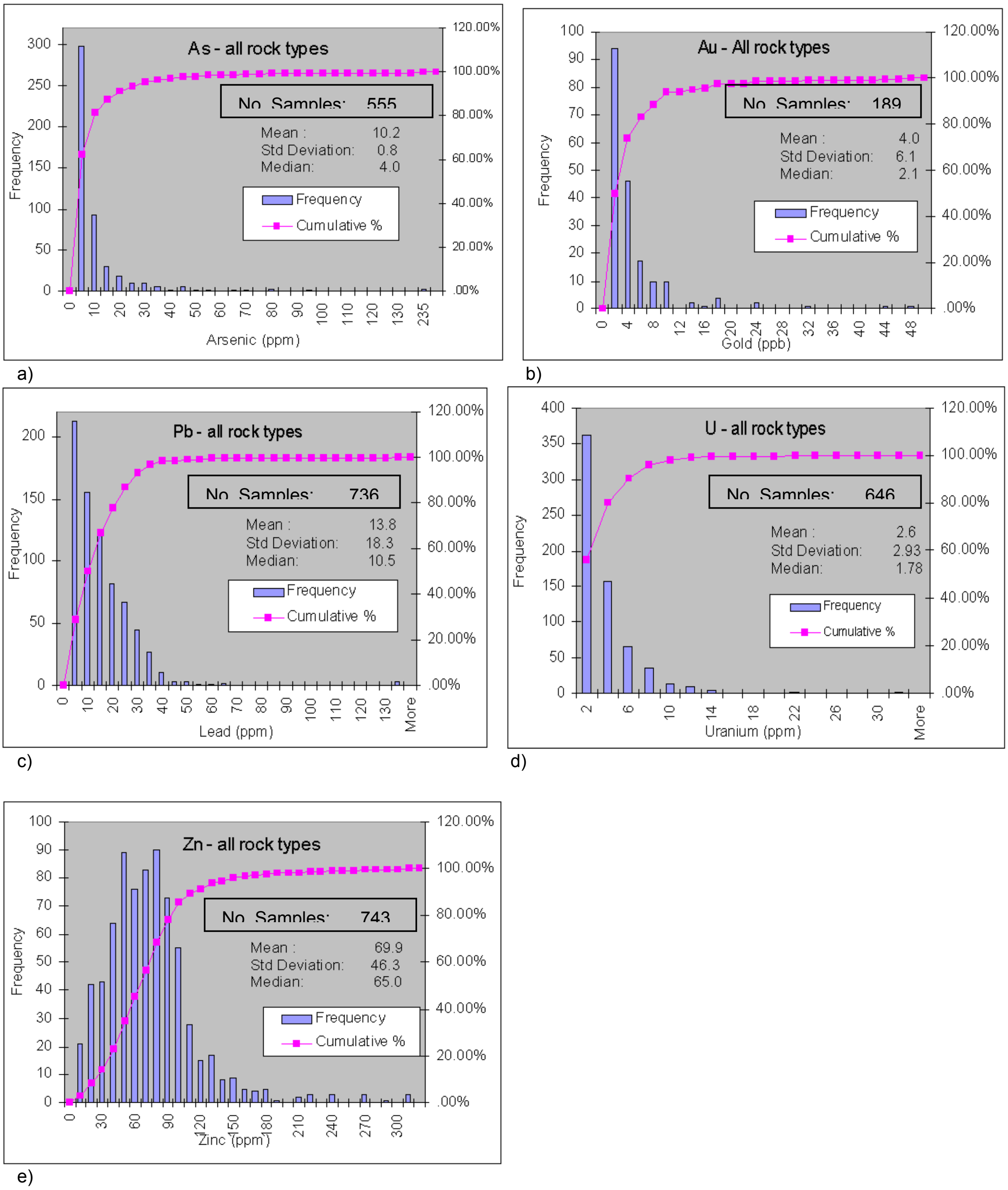


Figure 14. (a-e) Statistics for arsenic, gold, lead, uranium and zinc respectively. Mean, standard deviation, median, a distribution histogram and the cumulative frequency are shown.

5.3 Results

5.3.1 Arsenic

An abundance map for concentrations of arsenic was created using the IDW grid method (Figure 15). Clusters of anomalous values are present, in particular, 20 km north-west of Orange. Of note are values of 163 ppm arsenic in Cainozoic basalt and 80 ppm in basalt within the Devonian Cuga Burga Volcanics. The highest concentrations of arsenic (above 100 ppm) are typically associated with mineral deposits such as Browns Creek, near Blayney. These include 2 samples collected for the Triangle Formation in the Kenilworth Group with arsenic concentrations of 146 and 46 ppm, and a Tertiary basalt with 66 ppm. 20 km north-west of Cowra, a rhyolite within the Dulladerry Volcanics contains 162 ppm arsenic. It is unclear why there is such a high concentration of arsenic in this rock. The Dulladerry Volcanics typically have < 10 ppm arsenic. It is interesting to note that some of the most anomalous arsenic values occur in basalts, when the average concentration for mafic extrusives on the Bathurst sheet is only 10.4 ppm.

Figure 16 shows the arsenic-bearing mineral occurrence locations. The white areas in the diagram are areas of no known mineral occurrences. Arsenic is a constituent of a number of ore-forming minerals including arsenopyrite, pyrite and galena. These minerals occur in a variety of gold, lead, silver, zinc and copper ore deposit types. As a result, the arsenic mineral occurrence map is an accumulation of the occurrence density maps for all these ore-deposit types. A cluster of arsenic-bearing lead and zinc occurrences is present in Silurian felsic volcanics north of Orange. Occurrences west of Blayney include the porphyry copper-gold deposits of Forest Reefs and Junction Reefs. The historic gold workings at Wyangala are evident south-east of Cowra. Arsenic-bearing mineral deposit occurrences also occur north and east of Bathurst at Sofala and Sunny Corner respectively.

There is very little correlation between the anomalous arsenic samples (Figure 15) and arsenic-bearing mineral deposits (Figure 16). This reflects a poor correlation between the localised processes which concentrate arsenic in mineral deposits and regional bedrock composition.

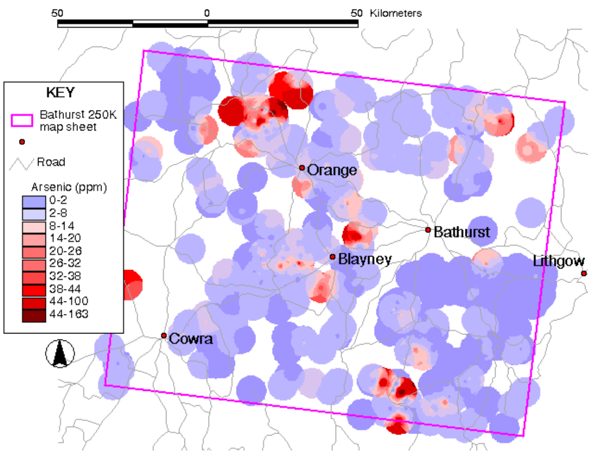


Figure 15. Arsenic geochemical abundance (ppm) for Bathurst 1:250,000 map sheet.

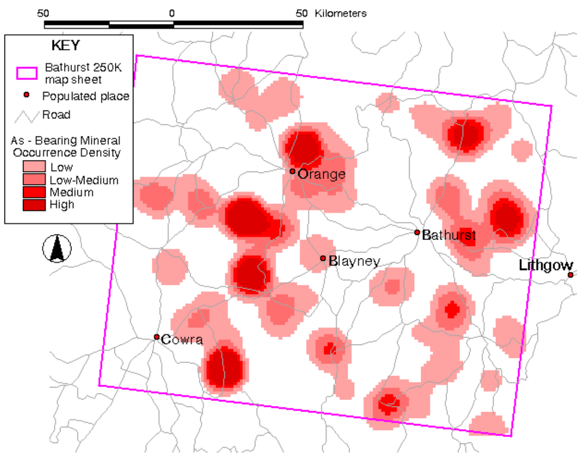


Figure 16. Arsenic-bearing mineral occurrence density map for the Bathurst 1:250,000 map sheet.

The arsenic abundance grid in Figure 15 was created without geological boundary constraints. The grid provides only basic geochemical information and does not provide information within the context of the geological unit in which the arsenic has been sampled. There are no constraints in the gridding process to prevent, for example, a high arsenic analysis from a shale unit affecting an adjacent low arsenic basalt unit. The resultant grid can only be used in a broad, first pass interpretation of bedrock geochemistry. The dot maps are therefore more reliable.

To overcome the dilemma outlined above, the Average Points AML was used to visualise the median geochemical value for discrete geological units (Figure 17). The median value for each geological polygon was then extrapolated to all like polygons for the map sheet (Figure 18a).

Felsic rocks are typically lowest in arsenic, followed by intermediate to mafic intrusive and extrusive rocks. Sedimentary rocks have variable arsenic (Figure 18b), with arsenic in the Adaminaby Group (north-east corner of map sheet) ranging from very low to very high values (below detection limits to 28 ppm). This large variability within sedimentary units is consistent for all the elements studied. It is likely due to the diversity of rock types in sedimentary units, ranging from pyritic shales which are high in arsenic, through to clean quartz sandstones which are low in arsenic.

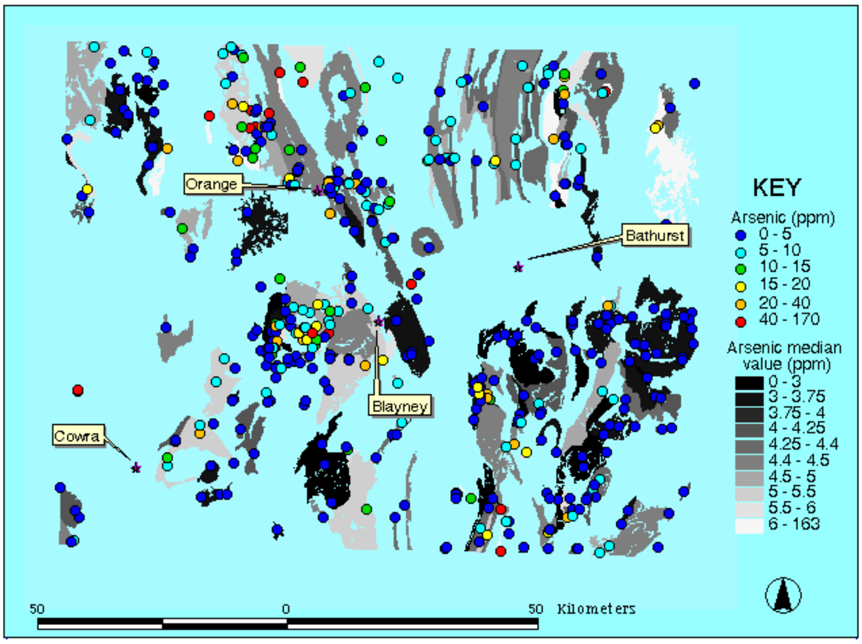


Figure 17. Median value for arsenic (ppm) for geological polygons in which samples were collected. 5.3.

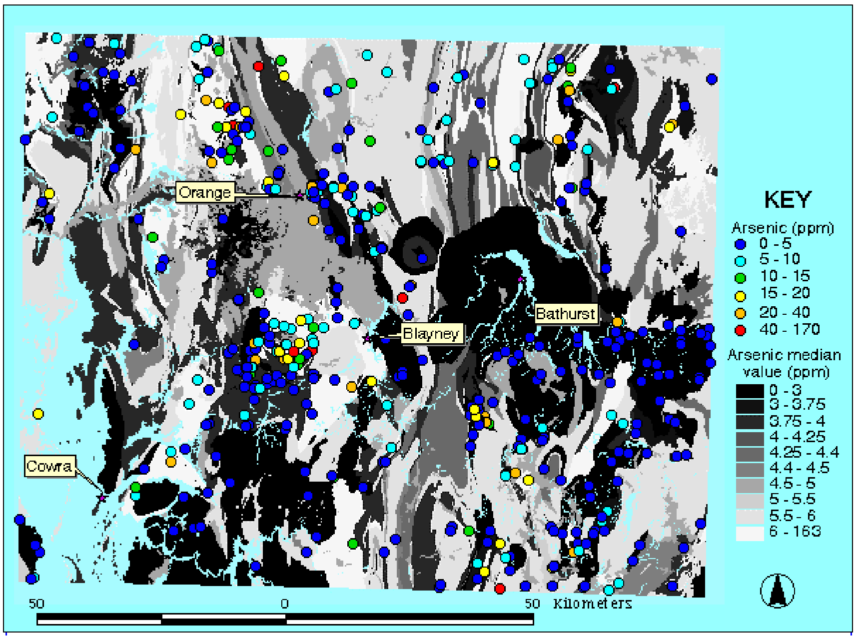


Figure 18a. Median value for arsenic (ppm) extrapolated for all like geological polygons

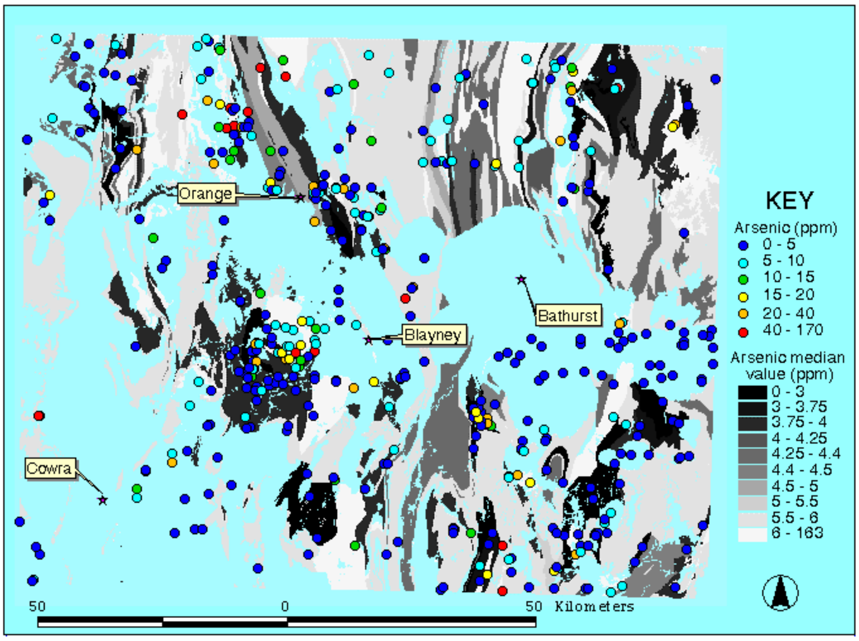


Figure 18b. Median value for arsenic (ppm) extrapolated for sedimentary geological polygons including volcaniclastic sediments.

5.3.2 Gold

Figure 19 shows a grid of gold analyses for the Bathurst 1:250,000 map sheet. The highest gold concentration of 48 ppb is located 23 km north of Bathurst in the Early Devonian Crudine Group, which is comprised of siltstones, shales and lithic sandstones. The rock sample is of unknown lithology and is likely to be an altered sample or a dyke. A sample of 16.9 ppb gold occurs in the Ordovician Walli Volcanics, 6 km east of Cowra. Although there is no significant mineralisation within this unit it exhibits high levels of background gold. A sample of 16 ppb gold occurs within the Copper Hill Igneous Complex, north-west of Orange. Copper Hill is a historic gold mining district, where mineralisation is thought to be porphyry-hosted copper gold style (Downes, 1998). At Sofala, 40km north north-west of Bathurst, a 9 ppb gold sample occurs within Sofala Volcanics. These volcanics are host to structurally controlled gold mineralisation in the Sofala area (Downes, 1998). A 31 ppb gold sample was sampled in a rhyolite within the Anson Formation, 6 km east of Orange. The Anson Formation is known to host stratabound gold and base metals at Lewis Ponds and Mount Bulga which are both within 15 km east of Orange (Downes, 1998).

Mineral occurrence density maps were created for gold mineral occurrences from MINLOC in the Bathurst region using a 10 km search radius (Figure 20). Gold 'hotspots' occur north north-west of Bathurst at Sofala and south of Orange in the Cadia – Brown's Creek and Junction Reefs region. Cadia and Junction Reef's are associated with Ordovician magmatism in the region (Downes, 1998). The gold deposits at Hill End, 40 km north-west of Orange, are structurally controlled quartz reefs and alluvial deposits derived from them. The historic workings of Woodstock north-east of Cowra, and those of Wyangala to the south-east of Cowra are also distinguishable.

There is only a first order broad association between the mineral occurrence 'hot spots' (Figure 20) and high geochemical values (Figure 19). Gold quartz veins typically have narrow and subtle alteration and geochemical haloes which could easily be missed by regional geochemical sampling.

Figure 21 shows the median gold geochemistry for the analysed lithological units. Only around 10 % of the area has available gold data due to the very specific sampling regime used for gold described earlier. Extrapolated gold values are shown in Figure 22. Due to the limited amount of sample points, extrapolating the gold values across like lithological polygons is likely to incorporate numerous errors and should be interpreted in this light.

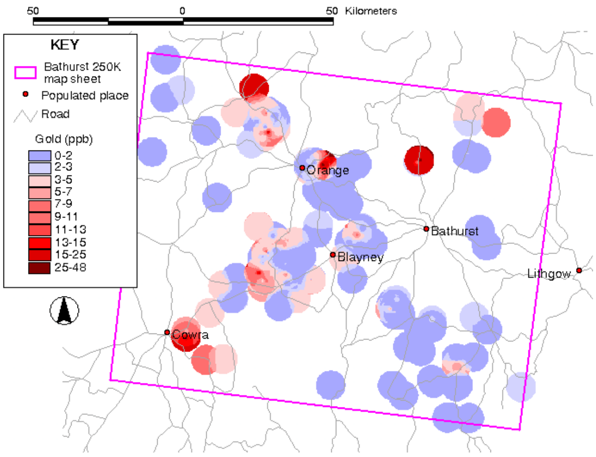


Figure 19. Gold geochemical abundance (ppb) for the Bathurst 1:250,000 map sheet.

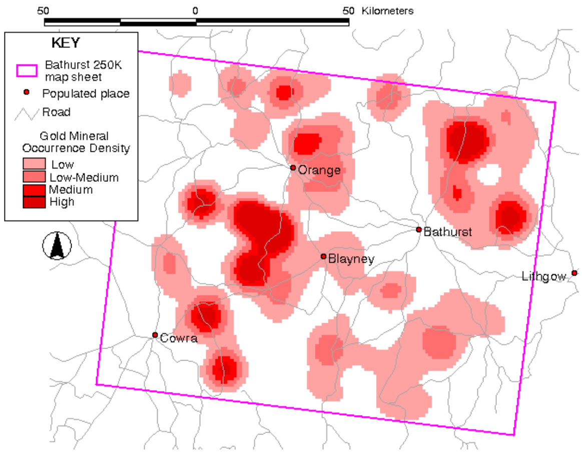


Figure 20. Gold mineral occurrence density map for the Bathurst 1:250,000 map sheet.

There is only a first order broad association between the mineral occurrence 'hot spots' (Figure 20) and high geochemical values (Figure 19). Gold quartz veins typically have narrow and subtle alteration and geochemical haloes which could easily be missed by regional geochemical sampling.

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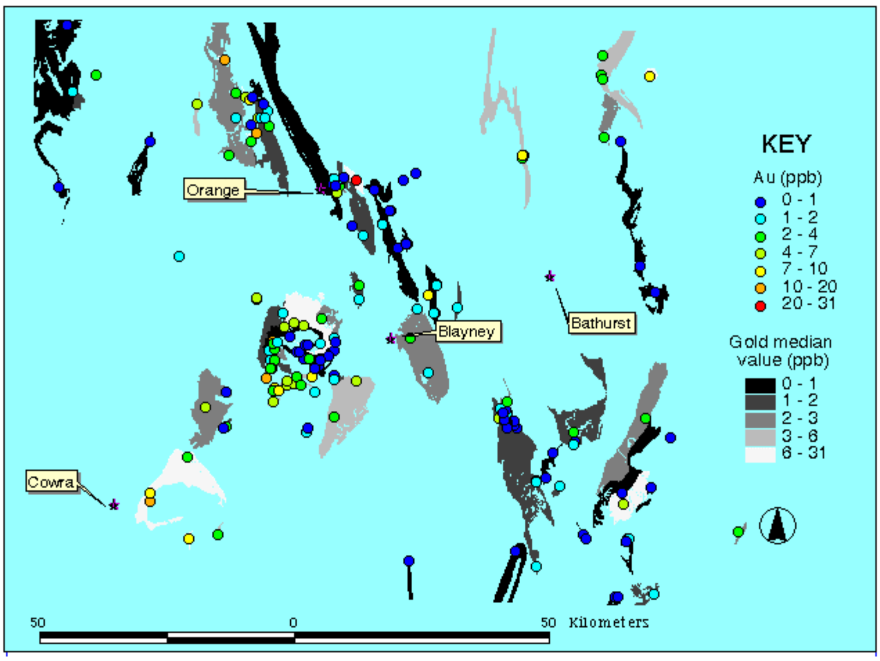

Figure 21. Median value for gold (ppb) for geological polygons in which samples were collected.

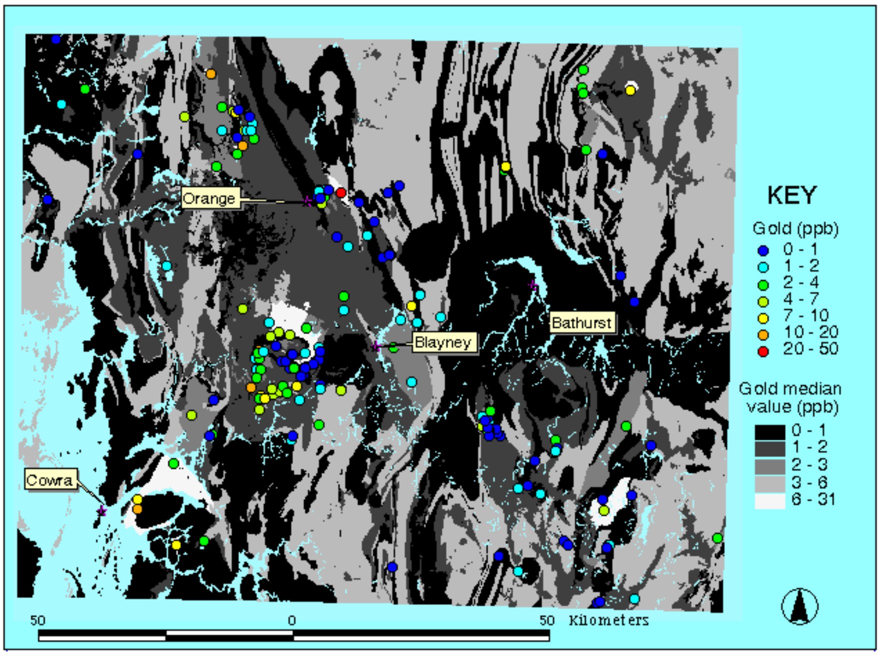

Figure 22. Median value for gold (ppb) extrapolated for all like geological polygons.

5.3.3 Lead

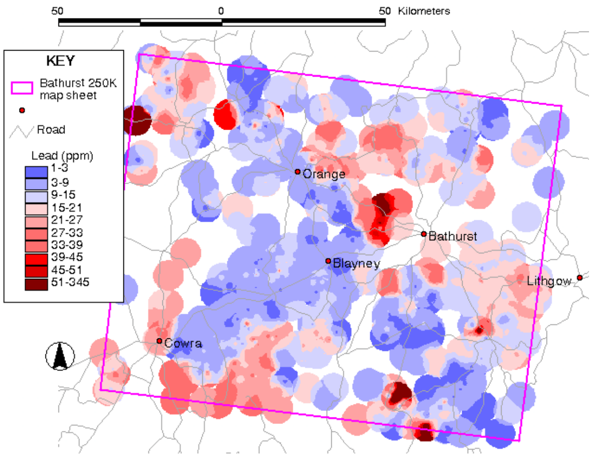

Figure 23. Lead geochemical abundance (ppm) for the Bathurst 1:250,000 map sheet.

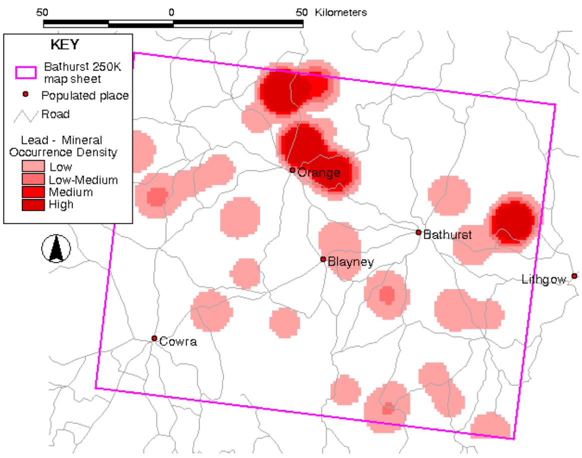

Figure 24. Lead mineral occurrence density map for the Bathurst 1:250,000 map sheet.

Figure 23 shows a grid of lead geochemical abundance for the Bathurst 1:250,000 map sheet. In the north-east of the map sheet, 345 ppm lead occurs in the felsic Dulladerry Volcanics. Felsics A-type volcanics, such as the Dulladerry Volcanics, typically have elevated lead concentrations relative to other igneous rocks. North-west of Bathurst, the Dunkeld Granite contains 59.3 ppm lead. 197 ppm lead occurs within a felsic extrusive at south-eastern margin of the map sheet. 62 ppm lead occurs in a metasediment within the Ordovician Triangle Formation. The highs delineated by the gridding tend to follow the felsic units, and the lows, in particular, the mafic units.

Three regions have high lead mineral occurrence densities (Figure 24). VHMS mineralisation related to Silurian felsic volcanics is located to the north and east of Orange. Base metal mineral deposits in this area include the Lewis Ponds and Mount Bulga deposits to the east of Orange and the Mount Lindsay, Mount Shorter, Calula and Day Dawn mineral deposits to the north. East of Bathurst, the anomaly is due to mineral deposits in the Sunny Corner and Wiseman's Creek areas.

By comparing Figure 23 & 24, it can be seen that the geochemical abundance for lead does not correlate with the lead mineral occurrences. The lead (VHMS) deposits are broadly associated with felsic rocks which are high in lead. But, the locally high concentrations of lead in the bedrock do not necessarily translate into lead deposits as the lead may have been leached and transported from elsewhere. The local lead depletion could occur in the bedrock as the lead is mobilised onto the deposit.

Figure 25 and 26 show the median lead concentrations for the associated geological polygons. High lead is associated with felsic extrusive and intrusive units as identified above. This relationship has been acknowledged by Downes (1998) and felsic units are host to numerous base metal deposits. The mean concentration of lead in felsic extrusives for the Bathurst sheet is 27.3 ppm and is 20.7 ppm for felsic intrusives. High concentrations are associated with the Bathurst Batholith south-east of Cowra, Mullions Range Volcanics north of Orange, and Dulladery Volcanics in the north-west of the map sheet. Mafic extrusive rocks have lowest concentrations of lead, ranging from 1-4 ppm. Sedimentary rocks have variable lead concentrations. Felsic volcaniclastic sediments and shales are high in lead.

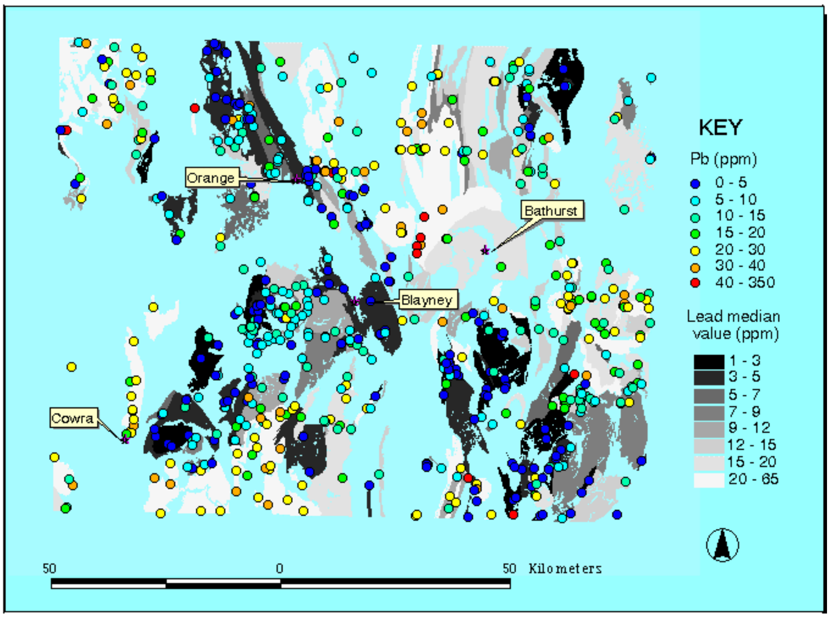

Figure 25. Median value for lead (ppm) for the geological polygons in which samples were collected.

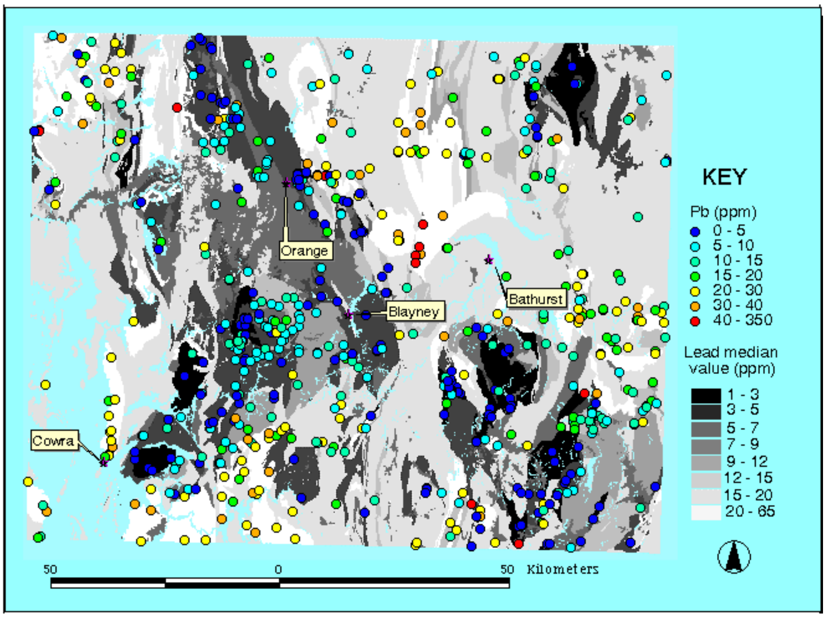

Figure 26. Median value for lead (ppm) extrapolated for all like geological polygons.

5.3.4 Uranium

A uranium geochemical abundance grid (Figure 27) was created to compare with the maps produced by averaging the geochemistry across like geological polygons. Figure 27 shows uranium hotspots, most of which are related to felsic intrusive and extrusive rocks. However, Figures 28 and 29 show this relationship more clearly as the influence of individual samples is constrained by geological boundaries.

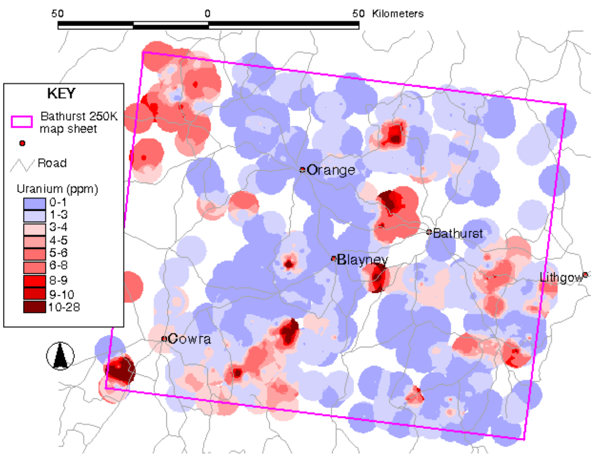

Figure 27. Uranium geochemical abundance (ppm) for the Bathurst 1:250,000 map sheet

The extrapolated distribution of uranium (Figure 29) shows the highest concentrations of uranium in felsic intrusive and felsic extrusive rocks that range from 2.5 to 26.5 ppm. Sedimentary rocks are variable and the observed values range from 0 to 3.4 ppm. Intermediate-mafic extrusive and intrusive rocks exhibit the lowest concentrations of uranium.

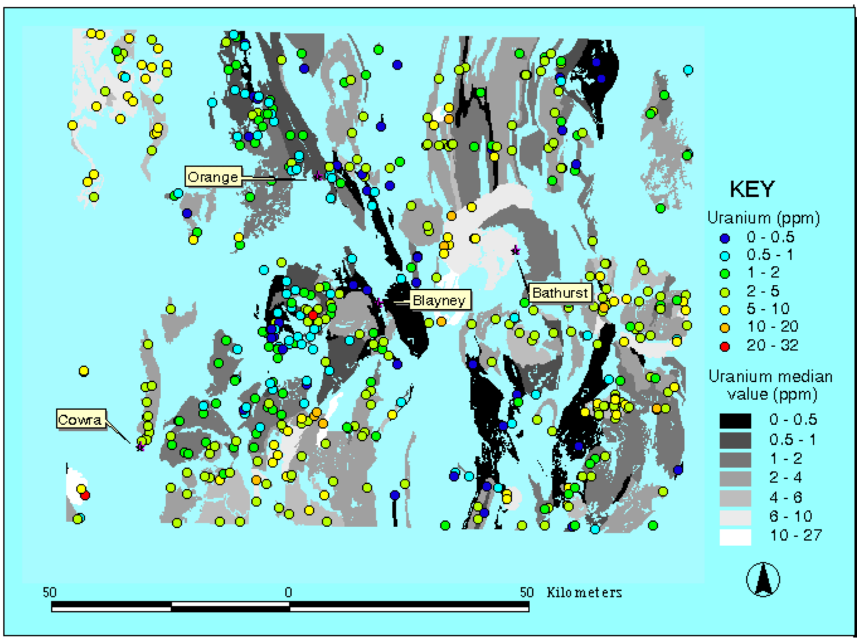

Figure 28. Median value for uranium (ppm) for the geological polygon in which samples were collected.

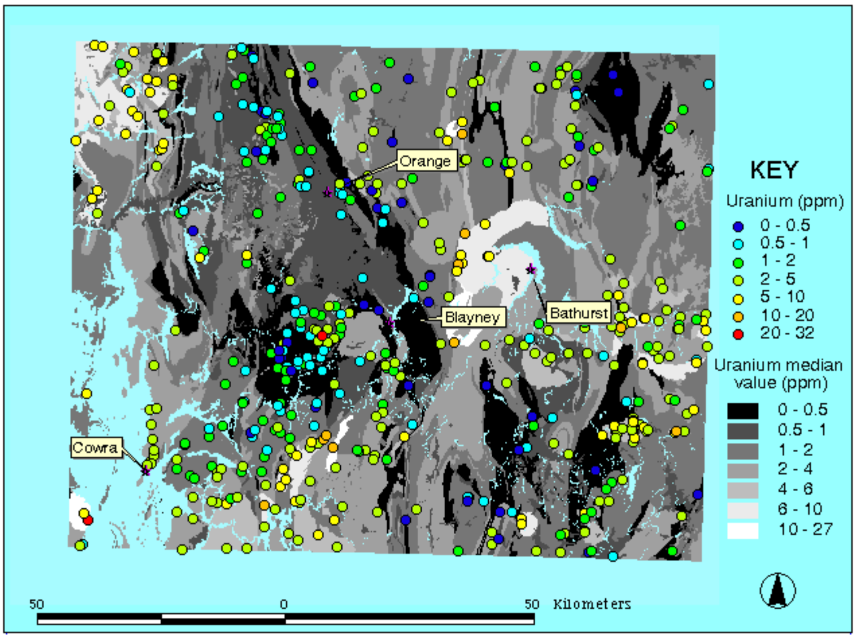

Figure 29. Median value for uranium (ppm) extrapolated for all like geological polygons.

The variation of uranium within granites was investigated by applying geological boundary limits to the IDW gridding process. This process shows variation within geological polygons, but it is reliant on a suitable density of sample points, and the computing process is orders of magnitude slower than unconstrained IDW gridding. The resultant grid (Figure 30) shows plutons in the north of the Wyangala Batholith to have slightly lower uranium concentrations than those in the south.

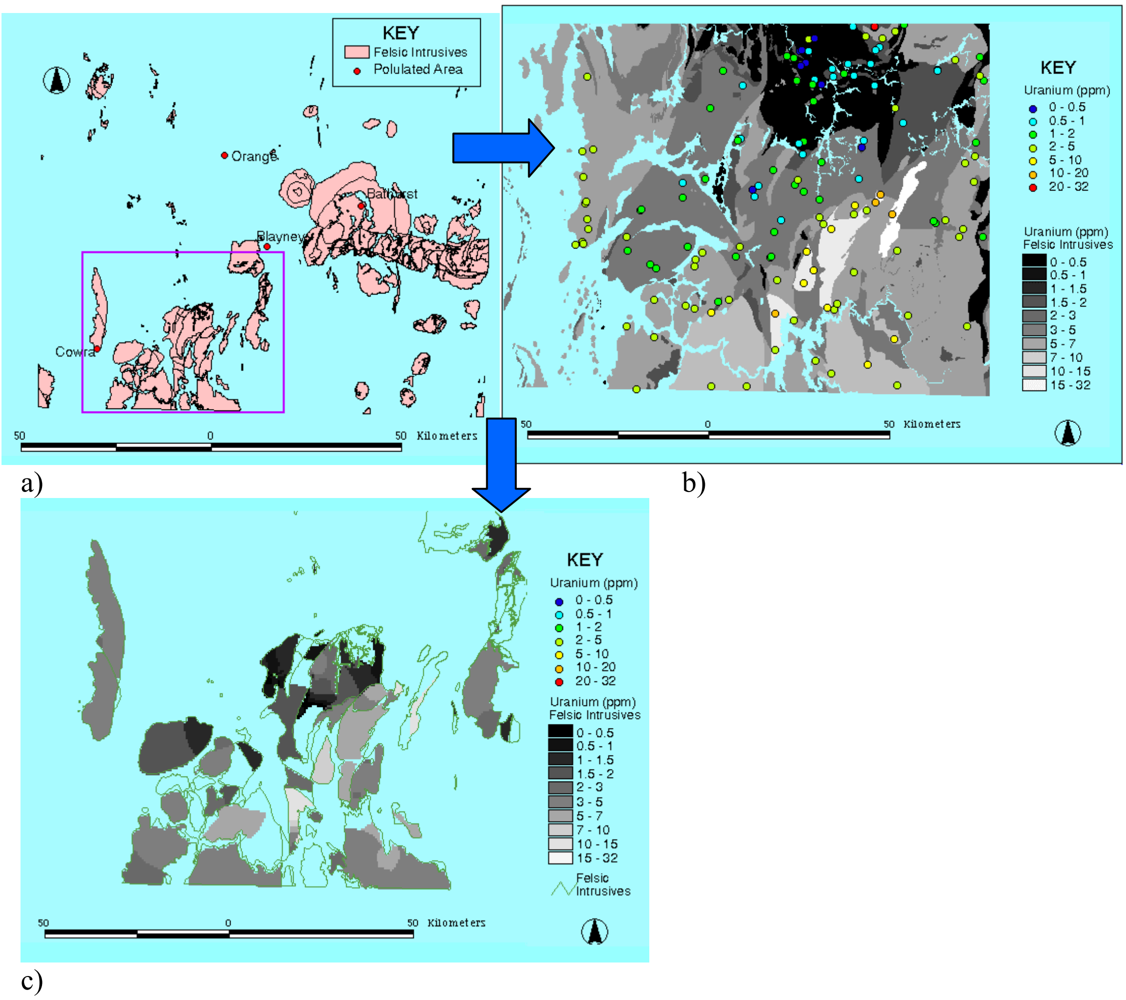

Figure 30. The relationship between felsic intrusive rocks of the Wyangala Batholith and uranium geochemistry:

a) the distribution of felsic intrusives in the Bathurst Sheet,

b) median value for uranium in the Wyangala area (from Figure 29),

c) IDW grid with geological boundary limits for uranium in felsic intrusives in the Wyangala area.

5.4 Discussion

It is important to note that averaging the points across like geological polygons was successful for the Bathurst study because all the geochemistry had been validated previously. The validation process ensured that all geochemical points were located in their correct geological polygons. In addition, all drill hole data and anomalous values including veins, dykes, gossans and sills that did not reflect the surrounding geological unit had been eliminated. Conducting preliminary statistical analysis on the data also helped characterise the data which enabled abnormal geochemical results to be easily discriminated and removed.

Gridding of the geochemical data helped to conceptualise broad geochemical highs and lows. Further, when the geochemical points were averaged over the geological polygons the relationship between the geochemistry and the geology was evident. Relating the geochemistry to the correct geological polygon facilitates identification of specific rock types for elevated concentrations of particular elements, eg: higher concentrations of lead are associated with felsic units. Although these methods are somewhat simplistic extrapolations, as shown in Figure 30, this is a preliminary step towards broad scale geochemical mapping.

Mineral occurrence density maps helped visualise the distribution of mineral deposits. When compared to the geochemical abundance maps and the maps showing the geochemistry averaged across the geology, they helped in the first pass identification of the relationships between bedrock geochemistry and mineral deposits.

6. COMPARING AND CONTRASTING METHODOLOGIES

By conducting two pilot studies, one on a regional scale and one on a more detailed scale, methodologies could be compared and contrasted to determine at what scale they were most successful. It is important to identify what you wish to achieve from the survey.

Regional scale studies are quick and less intensive and are useful for determining where more detailed studies should be done. Gridding the geochemistry with a buffer surrounding the points is a quick and easy method to help pin point anomalies to be further investigated. Averaging of points across like geological polygons is ideal for targeted studies.

Sample density (or lack of it) is the main problem with more detailed studies. Poor sample density results in poor coverage of gridded maps. Alternatively, to obtain good coverage of gridded maps, inappropriately large gridding search radii have to be used.

The inaccuracy of the geological polygons at broad scales is probably more of a problem than the sample density. Also, the extrapolation of average of median values across geological units becomes more problematic the broader scale you work at, as more variable composition rock types are lumped into broad map units.

For example, Mesozoic alkaline intrusions near Dubbo are too small to be identified individually in broad scale maps, so are removed with only the surrounding sedimentary units being retained. These targeted samples would extrapolated across the sedimentary polygon and appear to be extremely anomalous.

7. VALUE ADDING

The studies summarised in this record could be further improved. Below are some ways to value-add to these datasets.

7.1 Additional Datasets and Methodologies

Other sources of geochemical data, not used in this pilot study, include universities, and the CSIRO, and State geological surveys. Examples of some of this data are shown in Figure 31.

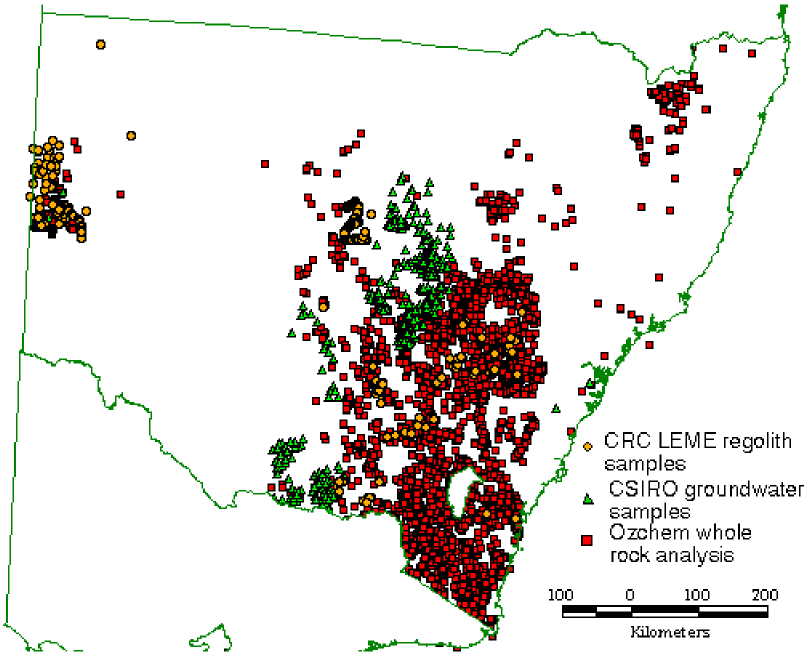

Figure 31. Geochemical sample locality map for Geoscience Australia's OZCHEM samples and CSIRO's groundwater samples in NSW.

The Geology Department at the Australian National University has a catalogue that provides details of the studies carried out within the department. It contains information about the sample locality and the type of sample and type of analysis carried out for each sample. The catalogue numbers can be cross-referenced to the student's thesis to provide detailed analytical data for their study area. Information gathered from sources such as this could add valuable samples to those already collected by Geoscience Australia. There are potential problems, however, associated with incorporating unfamiliar data into a known dataset, such as variable sample quality, analytical methods and detection limits.

The NSW Department of Mineral Resources is typical of the State geological surveys in the type of geochemical and mineral deposit data it holds:

1. Stream sediment dataset for NSW: Approximately 235,000 sample sites captured for the Lachlan Orogen, New England Fold Belt, and the Broken Hill/Koonenberry area.
2. Whole rock geochemistry for NSW: Approximately 3000 samples from Broken Hill/Koonenberry and approximately 6000 samples from New England. The Lachlan Orogen whole rock geochemical dataset is currently being compiled (Kevin Capnerhurst, NSW Department of Mineral Resources pers. comm., 7 November 2002).
3. Metallic Mineral Occurrence (METMIN) database: This database provides up-to-date details of mine localities as well as the production and supply of metallic minerals within NSW. Some of this data resides in Geoscience Australia's MINLOC database, however, METMIN

has better quality control, contains more attributes, and is more current than MINLOC. For the purposes of this pilot study, however, the information contained in MINLOC was sufficient.

Data available from CSIRO include groundwater samples collected between 1984 and 1997 (Figure 31). The datasets contains 67 samples from the Murray Basin, 2 samples from the Sydney Basin and 176 samples from the Surat Basin. 24 groundwater samples were collected in crystalline basement from Broken Hill and 370 from the Lachlan Orogen (Angela Giblin, CSIRO pers. comm. November 2002). The Bureau of Rural Sciences (BRS) Water Sciences program also holds a large store of water analyses from their regional groundwater studies in Australia's sedimentary basins. A limited amount of data is available from certain groundwater catchments in crystalline basement areas (R. Hbermahl, pers. Comm.., Nov 2002).

Using more detailed geological maps could refine the method of extrapolating median points across geological polygons. The sedimentary rocks in particular cover a large range of compositions. It could be argues that the volcaniclastic rocks are better grouped with their parent felsic and mafic rock types. Separating the siliciclastics rocks from carbonates may also be worthwhile. Igneous lithologies could also be subdivided so that the intermediate rock units are considered as a separate grouping.

Applying new gridding algorithms to the geochemical data would probably not add significantly to the data unless they involved better methods of incorporating geological boundaries in the gridding process.

7.2 Bioavailability and Element Mobility

Assessment of the bioavailability of elements in the environment would greatly enhance the interpretation of results from this pilot study. For those elements classified as harmful (see Figure 1 Section 1.1), the absolute concentration of these elements in the environment is not the only factor in determining their potential for harm. Although elements classified as harmful may be present in high concentrations in a particular environment, they may not be bioavailable. Knowing the bioavailability of a particular element is extremely important in determining whether high concentrations of harmful elements are likely to pose a threat or not. It is essential to know where an element resides within an environment. Key factors are knowing what form the elements are in (mineral, gas, or liquid; compound or pure) as well as other physical parameters such as particle size. It is also critical to understand the physical properties of the environment in and around areas anomalous element concentrations as subtle changes in many environmental factors, including climate, pH and temperature can cause changes in bioavailability (Darnley, 1990). Analysis of weathered rocks, soils, waters and plants could contribute to a full understanding of the behaviour of elements outside the fresh bedrock samples analysed in this pilot study.

The concept of concentration versus availability was highlighted by Wyborn *et al.,* (1994a) in relation to copper solubility in the formation of Proterozoic mineral systems. It was found that although metabasalts in the Eastern Creek Volcanics near Mount Isa in Queensland had above average concentrations of copper, metal solubility was far more important than the copper concentrations for the evolution of the copper deposits. Base metal solubilities can vary by ten orders of magnitude with variations in pH and oxidation state. In the case of the Eastern Creek Volcanics, metabasalts with lower copper concentrations were more amenable to leaching of copper into solution during the formation of the Mount Isa copper deposit. From this example, it can be seen that targeting high concentrations of an element for mineral exploration can be misleading.

Coastal acid sulfate soils (CASS) are another example of how bioavailability determines the potential threat to animal and environmental health. CASS were formed during the Holocene marine transgression. During these times of elevated sea levels, sulfate reducing bacteria in organic matter rich sediments converted the sulfate from seawater to pyrite. Now that sea levels have dropped, the CASS are found along Australia's coastline at elevations less than 5 metres above mean sea level. The pyrite lies benign in the water logged coastal soils unless they are disturbed by activities such as dredging, construction of roads, farming flood mitigation drains, sand mining and aquaculture. Once the soils are disturbed, the pyrite is oxidised and forms sulfuric acid which causes the pH of the soil to acidify and mobilises elements including aluminium and iron that were stored within the soil profile (Lech and Trewin, 2001; Sammut et al., 1996). In their water-logged natural state, CASS do not pose a threat but when the soils are drained and/or oxidised they become a significant problem.

8. OPPORTUNITIES FOR FUTURE WORK

Australia must address the issues outlined by Darnley (1990; 1991) and Xuejing (1990) in Section 2 before a national baseline geochemical survey is established. It is important that Australia utilises past experiences and methodologies of nations that have already conducted nation-wide surveying. This study has shown that using existing data is not ideal for conducting regional baseline studies in Australia. As Geoscience Australia has world-class geochemical laboratories, samples analysed through the laboratories in any baseline survey would adhere to strict quality control, would be analysed for the same suite of elements, and therefore results would be comparable across the whole country. With the implementation of the new Commonwealth Pricing and Access Policy, spatial and geochemical data held by Geoscience Australia is free and downloadable from the Geoscience Australia web site or at the cost of transfer on CD. This will ensure cheap and easy access to the data for researchers, policy makers and the public.

8.1 Baseline Geochemical Studies for Australia

Australia is one of few developed nations that is yet to establish a baseline geochemical sampling initiative. The sheer size of the continent means that a geochemical survey for the whole of Australia would be costly and take a number of years. Priorities for sampling could be based on present knowledge of potential natural contamination hazards, combined with a focus on more highly populated areas and agriculturally important regions of Australia. Regolith and stream sediments would be more favourable sampling medium for health related studies than the whole-rock data used for this study. NSW and Victoria would be good starting points, as sample accessibility is better than the other states and results could be achieved relatively quickly. The relative density of population in these states would also make any future geohealth studies more relevant and politically appealing. The Cooperative Research Centre for Landscape Environment and Mineral Exploration (CRC LEME) in conjunction with Geoscience Australia are in the initial stages of a pilot geochemical survey in the Murray-Darling Basin.

Collaboration with organisations such as State geological surveys, CSIRO and BRS would aid in the compilation of existing geochemical data in to a truly national database. This compilation would need to be done prior to any sampling program to avoid the duplication of existing data. Below is an example of an initiative that has recently been set up to help address issues relating to geochemistry and human and animal health.

8.2 Canberra Geohealth Consortium

The Canberra Geohealth Consortium was established in May 2002. Members from the University of Canberra, the National Centre for Social and Economic Modelling (NATSEM), CRC LEME and Geoscience Australia will further the work that was initiated in this scoping study, and attempt to define and pursue any potential relationships between geoscientific and health data. This type of work could complement work already being undertaken by the Cities Project in the Urban Geohazards area at Geoscience Australia. It could provide a geochemical basis to underpin risk modelling for community safety and vulnerability research.

As Geoscience Australia has expertise in data analysis and integration using GIS software and are custodian of numerous geoscientific datasets that could be used to constrain analysis, the organisation is in an ideal position to contribute to the consortium. Geoscience Australia's in-house links with CRC LEME also puts it at the forefront for element dispersion studies.

As the Consortium grows it is essential that there is input from health and agriculture professionals, such as the Australian Institute of Health and Welfare (AIHW), the Australian Department of Health and Ageing, Agriculture, Forestry and Fisheries Australia (AFFA), and the state Departments of Agriculture. This will ensure that all available expertise is utilised when analysing the specific human and animal health implications of individual elements.

9. CONCLUSIONS

This study has shown that whole-rock geochemical data and mineral deposit location data can be used to identify and analyse anomalous concentrations of elements. It has, to a limited extent, shown the distribution of toxic elements such as arsenic, uranium and lead. Although the study has shown that compiling data collected for specific purposes incorporates considerable biases that should be avoided, it used methodologies that could be incorporated into baseline geochemical surveys.

Following the southeastern Australia pilot study, it is apparent that mineralised samples need to be removed from the dataset before baseline geochemical studies can be done. These highly skewed samples are the result of very localised processes and do not reflect broad large scale "normal" processes. Mineralised samples were removed for the Bathurst 1:250,000 sheet pilot study. Due to biases in the datasets currently available, it is recommended that more geochemical sampling be undertaken for the purposes of baseline geochemical mapping. As around 60 percent of Australia is covered by regolith, sampling programs which target regolith and stream sediments would be better suited to baseline geochemical surveying.

This study identified the need for the interpretation of geochemical data in a geological setting to ensure the results obtained are meaningful. The study has shown that averaging points within geological polygons displays the geochemistry in the best way. It offers geochemical mapping in a geological context, providing much more meaningful information than unconstrained geochemical gridding techniques such as Inverse Distance Weighting. It can also identify rock types that have excesses or deficiencies in elements that are essential for plant and animal health.

For mineral explorers, the mineral occurrence density maps shown in this study give an indication of where high concentrations of mineral deposits occur. As a stand-alone map they provide regional targets and compliment the geochemical maps. The extrapolated median values calculated by averaging points within geological polygons can be used to help constrain mineral exploration programs as they identify likely source rocks for mineralisation. This data can be used in conjunction with other factors of mineral deposit formation in a GIS analysis of mineral prospectivity. Baseline geochemical mapping for regolith and surficial sediments would complement the whole rock geochemical maps shown in this study and would help formulate more comprehensive geochemical maps for Australia.

Although not within the confines of this pilot study, the next step for health applications is to assess the bioavailability of elements to determine whether they truly pose a health threat, or are locked within chemically stable compounds. This would include the behaviour of elements during weathering and erosion, and dispersion in groundwaters.

Australia is well behind many developed nations in establishing baseline geochemical datasets. The recent establishment of the Canberra Geohealth Consortium provides the coming together of many different organisations that are striving towards a common goal. This collaborative venture will enable Geoscience Australia to tap into data and expertise while helping to contribute to the evolving discipline of geohealth within Australia.

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