

GEOCHEMICAL HALOES SURROUNDING THE CSA OREBODY IN COBAR, NSW

Dylan Örn

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**Department of Earth Sciences
University of Gothenburg
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Faculty of Science



UNIVERSITY OF GOTHENBURG

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Mailing address
Geovetarcentrum
S 405 30 Göteborg

Address
Geovetarcentrum
Guldhedsgatan 5A

Telephone
031-786 19 56

Geovetarcentrum
Göteborg University
S-405 30 Göteborg
SWEDEN

Abstract

Geochemical analysis is of great importance to mineral exploration. Ore forming fluids, by definition, change the fresh rock chemistry by introducing and depleting elements. This can be achieved by dilution, element substitution and transportation in the process known as metasomatism. At the copper producing CSA mine in Cobar, New South Wales, previous researchers have identified depletion haloes for alkali and alkali earth elements around the pipe-like shear structures known to host ore. These haloes have been proposed to aid in targeting orebodies by drilling.

This study aimed to investigate the presence of these haloes by using new sample data and 3D modelling techniques. As the samples used were of limited depth, an analysis of the relationship between Ba, Sr, Li and Rb with Fe was conducted to deduce any influence of weathering on depletion haloes. The conclusions of this study are that significant depletion haloes for Sr and Ba exist in close spatial and geometrical proximity to the known ore body. It was also concluded that Strontium displayed a mobilisation behaviour independent of iron concentration and could be an ideal starting point for analysis when conducting exploration of economic minerals in the area.

Abstrakt

Geokemisk analys är av stor betydelse för mineralutforskning. Malmbildande fluider ändrar bergkemin genom att tillföra och bortföra grundämnen. Detta kan uppnås genom utspädning, substitution och transport i processen känd som metasomatism. Vid den koppjarproducerande CSA-gruvan i Cobar, New South Wales, har tidigare forskare identifierat geokemiska anomalier för alkali- och alkalijordelement kring de rörliknande skjuvstrukturerna där malmen förekommer. Dessa anomalier kan användas för att styra borrhningen efter malm.

Denna studie syftade till att undersöka närvaron av geokemiska anomalier med hjälp av nya provdata och 3D-modelleringstekniker. Eftersom de använda proverna var av begränsat djup genomfördes en analys av förhållandet mellan Ba, Sr, Li och Rb med Fe för att undersöka om vittringsprocesser påverkat eller orsakat anomalierna. Slutsatserna från denna studie är att signifikanta anomalier för Sr och Ba finns i rumslig och geometrisk närhet till den kända malmkroppen. Det drogs också slutsatsen att Strontium uppvisade ett mobiliseringsbeteende oberoende av järnhalter och kan vara en idealisk utgångspunkt för analys vid undersökning av ekonomiska mineraler i området.

Dylan Örn

Cobar 2019

Table of Contents

Introduction.....	3
Method.....	13
Results.....	16
Analysis & Discussion.....	20
References.....	23

Introduction

Exploration for mineral resources are more frequently relying on techniques focused on identifying geophysical or geochemical proxies for ore. One such proxy is enrichment or depletion of elements in rock surrounding orebodies. As ore is forming, elements may be enriched or depleted by dilution or metasomatism and these may serve as indicators of proximity to ore. The CSA mine in Cobar, New South Wales is a copper and silver mine currently in production. The orebody has been studied extensively and geochemical anomalies have previously been identified around areas of known mineralisation.

This study

The aim of this study is to investigate the presence of depletion haloes around the CSA orebody and to discuss possible formational mechanisms of these haloes. The study builds upon previous work but is based on analysis of new data acquired by chemical sampling of recently drilled diamond and RC core and rock chips. Ba, Sr, Rb and Li were the elements chosen to be included in this study. Primary questions of concern include;

- Are there distinct depletions of the above-mentioned elements as compared to background values?
- Are any depletions spatially linked to known orebodies or structures?
- How does weathering affect element dispersion in the oxidised zone?

Regional Geology

The Cobar mineral field is located within the Cobar Basin, a Devonian extensional setting within the Lachlan Orogen in New South Wales, Australia (**Fig.1**). Rich in economic mineral endowments, the basin hosts an abundance of deposits including Cu, Au-Cu, Pb-Zn-Ag and Au and includes the world class Cu-Ag deposit currently in production at the CSA mine.



Figure 1. Cobar Basin location and setting. The Cobar Basin is situated in central New South Wales, Australia. It hosts steeply west dipping strata ranging from late Silurian to early Devonian in age. Ore deposits are found primarily in the Great Cobar Slate and Amphi theatre Group.

The Cobar deposits are hosted by sedimentary rocks which have undergone a tectonic cycle of extension (sedimentation and diagenesis) and inversion (folding, faulting and tilting of bedding). The Cobar Supergroup (**Fig.2**) of deep to shallow marine sedimentary rocks formed in an extensional back arc setting (Kyne, 2014) and consist of the steeply west-dipping Nurri and overlying Amphi theatre Groups. The units within these groups range from mudrocks to conglomerates and have, to varying degrees, been subjected to low grade metamorphism and deformation.

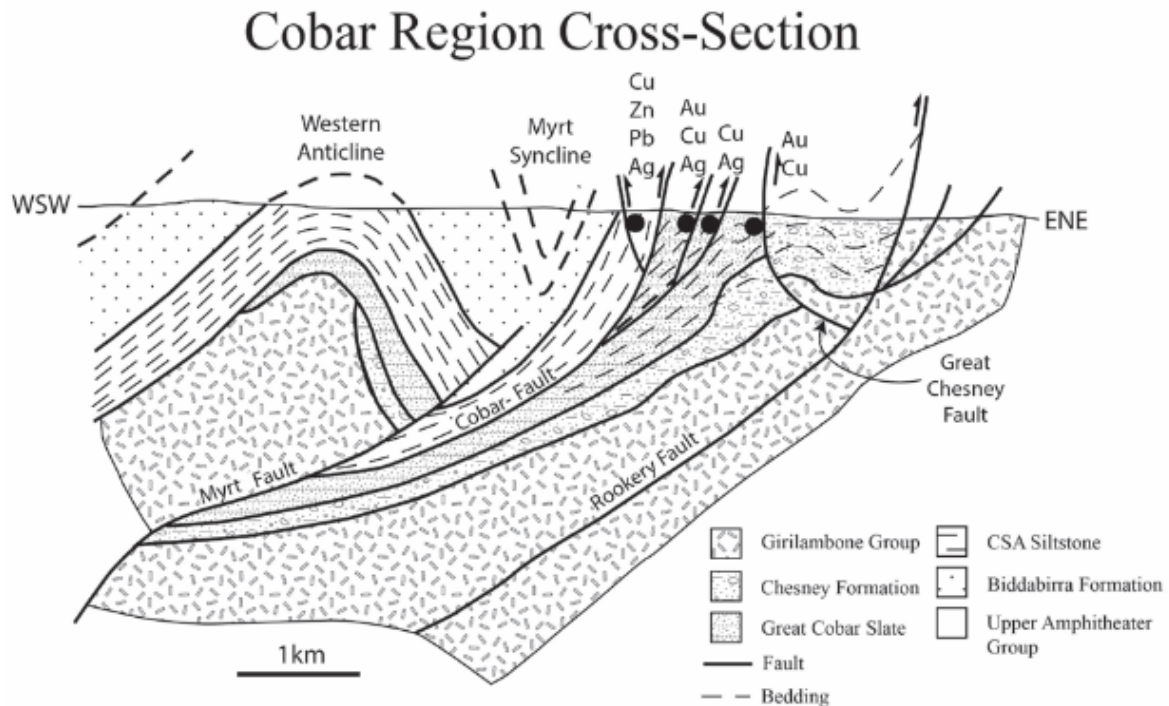


Figure 2. Cross section of the Cobar Basin according to Jeffrey (1994). Mineralisation is primarily found within the Great Cobar Slate and CSA Siltstone.

The CSA deposit is hosted in the CSA Siltstone, the basal unit of the early Devonian Amphitheater Group (**Fig.2**). The Amphitheatre Group is believed to have been deposited during an extensional stage in a low-energy environment as suggested by the turbidites which chiefly make up this formation. David (2006) suggested that these rocks were derived from material eroded from the western Winduck Shelf. Inversion of the basin is believed to have re activated syn-depositional faults (Kyne, 2014). Indeed, the progression of brittle deformation during inversion is believed to have been the precursor for the characteristic style of mineralisation in the Cobar mineral field (Glen, 1987). Below follows a brief description of the units of the Cobar Supergroup.

Nurri Group

The Nurri Group underlies the Amphitheatre Group (**Fig.2**) and is of late Silurian to early Devonian in age. It is believed to be composed out of material eroded primarily from the eastern Kopye Shelf (Glen, 1987) and comprises the Chesney Formation and the overlying Great Cobar Slate.

Chesney Formation

The basal formation of the Nurri Group has been interpreted to be an easterly derived fan deposit (Kirk, 1983). It is composed of clast and matrix supported, quartz-rich conglomerates interbedded with sandstones. The clasts are commonly chert or sandstone fragments.

The Great Cobar Slate

The Great Cobar Slate overlies the Chesney Formation and consists of quartz-muscovite-chlorite slates with interbeds of siltstone and fine-grained sandstones (Kyne, 2014). The Peak gold deposit is hosted within this unit as are the New Cobar gold and Great Cobar copper deposits.

Amphitheatre Group

CSA Siltstone

The basal unit of the Devonian Amphitheatre Group is the CSA Siltstone (**Fig.2**), host rock for both the CSA and Elura deposits. At CSA it is typically a thinly bedded to laminated siltstone with minor, interbedded fine to medium grained sandstones and greywacke. The CSA Siltstone dips at 80 degrees to the west and strikes NNW and displays a steeply east-dipping regional cleavage crosscutting the bedding. It has been described as a turbidite by Glen (1987) and is supported by structures such as graded bedding. It commonly displays soft sediment deformational structures such as loading and scour marks.

Lower Amphitheatre Group

The Lower Amphitheatre Group overlies the CSA Siltstone and is comprised out of interbedded sandstones, siltstones and mudrocks. Sandstones are either massive or graded. The rock formation immediately overlying the CSA Siltstone is referred to as the Biddabarra Formation.

Upper Amphitheatre Group

The Upper Amphitheatre Group consists of sandstones and siltstones of thin to medium beds with minor, thick quartz arenite layers. Glen (1983) was first to suggest that the termination of the amphitheatre group and, consequently, the turbidites westward was due to decreasing subsidence early in the Devonian Period.

CSA Mine Geology

Logging of diamond drill core combined with underground mapping confirm a range of different mineralisation styles where chalcopyrite is primarily of stringer, massive or semi massive habit (**Fig 3**). Quartz veining, with or without chlorite replacement, commonly occurs in the footwall contact or within the ore itself. As multiple generations of quartz veining occur within the mine, quartz veining in core does not necessarily indicate that ore is to be expected further down hole. Observations made by the author during diamond drill core logging confirm sphalerite and galena banding with associated disseminated pyrite of euhedral to sub-hedral habit in QTS Central drillcore.



Figure 3. *Perpendicular intersection of semi massive ore lense. 7 metres across.*

Chalcopyrite within the CSA orebody occasionally tarnishes into shades of purple, green and blue as is common in bornite. Application of hydrochloric acid to the tarnished ore rapidly reverts the surface to the brassy golden hue of fresh chalcopyrite. However, not all samples of chalcopyrite tarnish in this fashion and the phenomena is believed to occur when the chalcopyrite is in physical contact with native silver or silver sulphides (Chen, Dutrizac, Laflamme, Owens, 1980)

Alteration

In addition to the principle ore minerals, gangue mineralogy includes quartz, Fe- and Mg rich chlorites, sericite, calcite, pyrrhotite, plagioclase, talc, biotite and muscovite (Kyne, 2014). At CSA Mine, three types of alterations are present; chlorite, silicification and minor talc, the latter in the form of a discontinuous talcose shear zone.

Chlorite alteration is present in two forms; green Fe-rich pyrochlore (**Fig 4**) which forms a pervasive halo around the mineralisation and has commonly replaced siltstone clasts within quartz vein breccias and darker Mg-rich chlinochlore which is present in shear zones. Kyne (2014) described this chlinochlore as being of later origin and found only as localized halos around mineralised veins and ore zones.

Silicification occurs as multiple generations of veining, quartz healed breccias in the hanging wall and of “elvan” or silica blanketed sediments which is more common in the east.

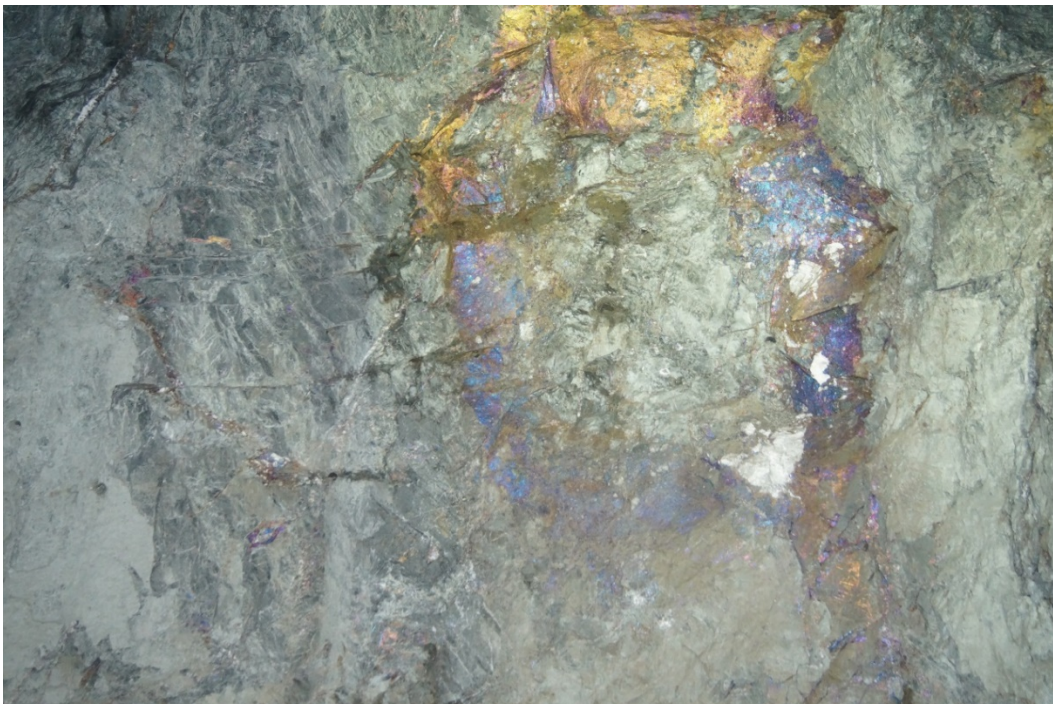


Figure 4. Face of 8580 390 with tarnished chalcopyrite and green chlorite alteration.

Veining

Kyne (2014) described 11 different vein generations ranging from early, pre-mineralisation quartz veining through quartz+sulphide veining and later calcite rich quartz veins. These veins have in common a subvertical orientation with earlier generations generally overprinted by later deformational events. The latest vein generation is described by Kyne as the VK veins which are flat dipping, boudinaged quartz veins which are often parallel to flat dipping joint sets in the areas where they are encountered during underground mapping.

Structure

CSA mine is located between an array of faults (**Fig 5**). To the west, the steeply west dipping Myrt Fault trends N-S. To the east, the steeply west dipping Cobar Fault forms an eastern boundary. Vertical mine scale shears trending NNE and NNW respectively are encountered during underground mapping and drilling and form an intersection at RL 8580 .

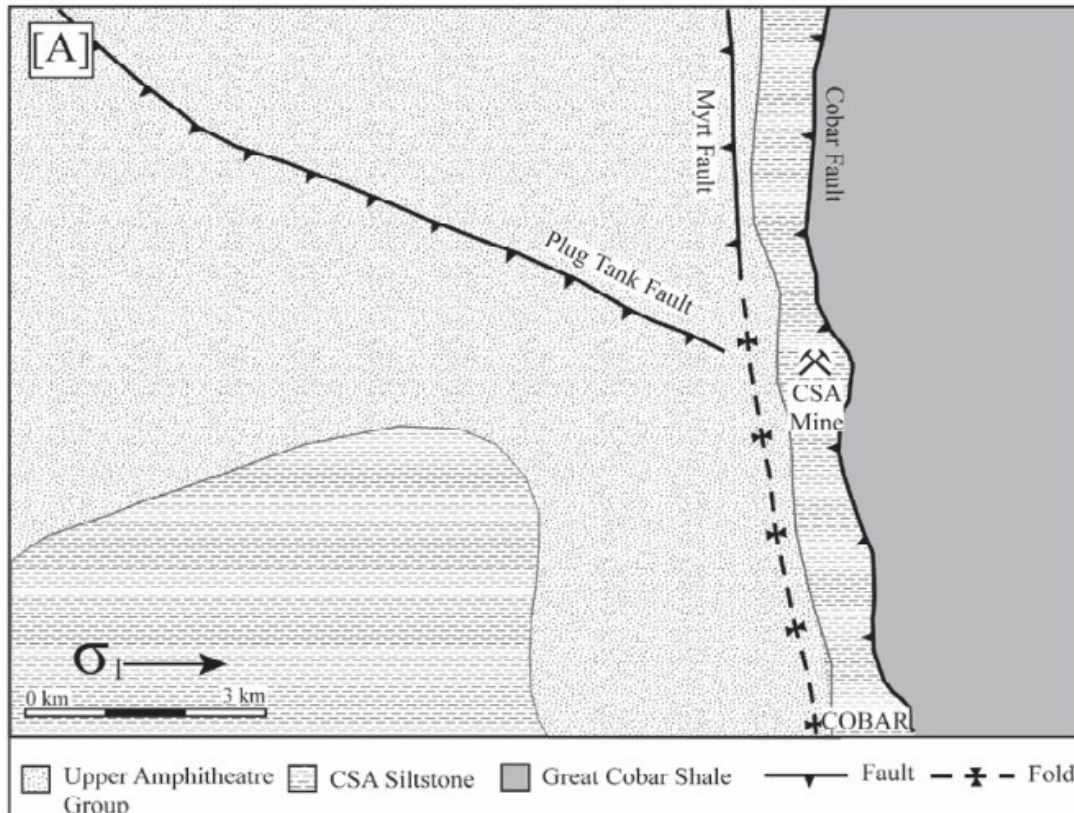


Figure 5. General structural map as described by Kyne, 2014. Eastern termination of Plug tank fault is not known for certain.

Metallogenesis

The CSA mineralisation was emplaced within a dilational zone at the intersection of two mine-scale shears, locally referred to as S1 and S2 as products of deformational events D1 and D2 (CSA 2016 resource report). A third event, D3 is believed to have reactivated these shears, thus creating dilational, physical space for massive sulphide mineralisation.

There have been multiple theories regarding the origins of the mineralisations in the Cobar mining field. David (2006) suggested that the the CSA deposit is the product of re-mobilisation of an earlier, syn-rift mineralisation with metals sourced, at least partly, from I- and S-type rhyolites and dacites south of Cobar. Questions remain however if these rocks were enriched enough to create the substantial base metal deposits found in the area.

Kyne (2014) undertook a major study in 2013 and reached the conclusion that the mineralisation at CSA was structurally controlled, epigenetic and likely precipitated due to fluid mixing between a hot, basinal derived fluid and cooler, buffered fluid circulating in the complex orthogonal fault systems in and around CSA. Metal zonation is present in both horizontal and vertical directions. The mineralisation is generally richer in copper to the east, north and at depth while Pb-Zn is greater to the west and at higher levels in the mine. Kyne (2014) hypothesises that as fluids cooled, copper precipitated followed by Pb-Zn at lower temperatures.

The mineralising fluid appears to have been of near neutral pH and of low salinity. Fluid inclusions have indicated low Cl values and a hypothesis of F⁻ as a major ligand was put forth by Kyne as alteration minerals such as apatite and biotite are enriched in F.

The fundamental mechanism as explained by Kyne is as follows:

1. Dewatering of a basaltic body to the west entrained base metals by F⁻ ligand derived from intruded or underlying rhyolites or carbonates.
2. Inversion of the basin channelled near neutral, metal bearing fluids along the Cobar Fault.
3. Metal bearing fluids mixed with cooler circulating fluids in the complex structural zone in and around CSA.

4. Cu precipitated at higher temperatures with later, spatially separated Pb-Zn mineralisation taking place in what is today the Western system and upper portions of QTS central.

The mineralisation is not thought to be syn-genetic as the lenses cross cut bedding (and any soft sediment deformation) at an angle close the regional cleavage S2 (Kyne, 2014). This model of mineralisation is currently the accepted one.

Previous work

The presence of visible or cryptic alteration around hydrothermal or magmatic-hydrothermal ore deposits is inherent to the process of precipitation of economic minerals. As elements are added to a system, concentrations of other elements are depleted either by metasomatism or simply by dilution. Goldberg (2016) highlights that depletion and enrichment zones can occur concurrently in a closed geochemical system. The magnitude of a depletion zone for base or precious metals may serve as an indicator and a rough guide to the magnitude of enrichment, the estimation of which is the ultimate goal of mineral exploration. Goldberg (2016) made a rough comparison of the negative gold anomaly in a substantial depletion zone in the Bendigo Goldfield in Australia and the amount of gold believed to be contained in deposits of the area. Goldberg reached the conclusion that the relationship in this case was linear and that the amount of gold contained in the orebodies roughly equalled the gold missing in the wide depletion halo with a threshold value of 0.5ppb Au. In addition to the target metal he also makes a point for ore forming elements such as Fe and S and that these elements also should reveal depletion and enrichment zones in closed geochemical systems.

Robertson and Taylor (1987) undertook a study on elemental haloes around the CSA orebody. Using samples collected from drillholes collared both underground and at the surface they established a model of depletion haloes around QTS South and the Eastern and Western Systems. Their model suggests a base metal depletion around QTS South but which was not observed west of the Eastern and Western System. A wide lithium depletion was

also observed to revert to background values in the footwall of the Western System. They interpreted Na, Ba, Sr, Rb depletion haloes around the Eastern and Western System with limited defined haloes around QTS South. The dimensions of the alkali and alkali earth haloes were described as up to 100m across strike and 250m along strike of the ore with the exception being Li which was found to have a greater extent with a return to background values west of the Western System.

The depletions are explained by Robertson and Taylor as the result of dissolution and replacement of albite and sericite. These minerals were found to be of decreased abundance in the vicinity of the ore zone and it was argued that the removal of these minerals would also remove Na, Ca, Ba and Sr, K, Rb.

Robertson and Taylor (1987) propose that the halo formation pre-dated the ore deposition. They suggest that connate brines entrained in coarse grained layers became over pressurised with progressive diagenesis until a vertical proto cleavage was developed by rotating phyllosilicates in the impermeable layers. If these brines were acidic enough, alkali and alkali earth bearing minerals would be dissolved and their constituents removed by upwards flow along the proto cleavage while also entraining base metals from the sediments. The case for halo formation pre-dating the ore deposition is made by observation of the lack of chalcophile enrichment haloes around mineralisation.

Kyne (2014) noted a negative correlation between early chlorite alteration and K-Al. The explanation is put forth as lower greenschist metamorphism caused replacement of sericite and albite resulting in alkali and alkali earth depletions. A decrease in these elements were observed in the most intensely chlorite altered samples studied.

Kyne (2014) suggested that factors observed suggest that the elemental haloes are the effect of lower greenschist alteration and metasomatism by hydrothermal fluids. Factors to support this hypothesis include the zonation around ore which in itself is focussed in discrete pipe-like structures, the negative correlation between Fe rich chlorite and K-Al and Fe enrichment in the form of Fe-Mg chlorite in close association with the mineralisation.

Method

The exploration team at CSA mine collected a total of 10538 from diamond drill holes and reverse circulation drilling holes collared at surface. These samples were assayed at ALS laboratories in Orange, New South Wales, for multiple elements using four acid ICP-AES method. Out of the available elements, Li, Sr, Ba, Rb were chosen to be used for geochemical modelling as they were shown to be depleted as haloes in previous studies. In order to investigate and further build upon previous links between depletion of these elements and Fe content, either as chlorite alteration or as iron oxide weathering products, scatterplots relating Fe and Li, Sr, Ba and Rb were constructed using Excel.

In addition to assay data, the following Excel files were used;

- A “collar” file containing coordinates for the top of the drillholes at surface.
- A survey file with azimuth and dip of the drillholes.

Diamond drilling (DD) is a method where by a diamond tipped drill bit bores into rock and retrieves a solid piece of cylindrical rock referred to as core. The method is used when the intact rock with structures needs to be conserved and for drilling deep holes >100 m.

Reverse circulation drilling (RC) uses a piston driven hammer to penetrate quickly and produces rock chips. It is a cheaper method of drilling where structural information is not considered as important as the mineralogy or chemistry of the rock. It has depth limitations as air pressure is used to bring up the rock chips to surface through an inner tube.

As most RC holes were around 120 m deep from surface, it was decided to treat and model them separately to the much deeper DD holes. A combined model with extents down to 1000 m would result in a very low confidence for element dispersions at depth except for in the vicinity of the deep DD holes. The endeavour was to create a model with wide coverage where element anomalies would be apparent once the RC drill penetrated through the oxidized zone before focussing on the results.

Before any modelling could commence, the assay data needed to be organized. Values below the sampling detection limit were originally noted as negative and were manually changed to blank cells. Overlapping sample intervals were manually corrected to match the logging sheets.

Modelling

A total of 193 drillholes, 32 DD holes and 161 RC holes were loaded into Leapfrog Geo. The total amount of samples amounted to 10538. The following elements were then loaded from the assay file; Sr(ppm), Li(ppm), Ba(ppm), Rb(ppm).

In order to visually explore the three-dimensional distribution of these elements a numerical model was created using Leapfrogs RBF (Radial Basis Function) interpolant function. The surface resolution of the model defines the size of the smallest triangles created and it was set to a unitless value of 20. The vertical extent of the model was set to 30m below the greatest RC depth.

Threshold and background values were retrieved from Robertson and Taylor (1987).

A legend was created for each element with three categories:

1. Depleted: any values below the lower threshold.
2. Background: Values between the established background and lower threshold.
3. Enrichment: Any values above background.

Cross sections were created to provide a view at depth while plan view maps were created to display any trends in 2 dimensions.

As no structural data was available for the RC holes, no structural modelling was undertaken.

Element ratios

Barium, Strontium, Lithium and Rubidium were plotted as Fe/Element ratios to graphically display these relationships with depth. Iron was used as a proxy of weathering. Ppm values were converted to % and average ratios over 12 m intervals 0-132 m depths were plotted in Microsoft Excel to investigate if systematic changes occurred with depth.

Once the numerical interpolation models and element ratios were complete, they were analysed visually along and across strike as well as in plan view. A basic geological model was created to illustrate the contacts between Saprolite, Saprock and Siltstone.

Results

Below are the results of the models. **Figures 8-14** present the model with depletions, background and above background values in blue, green and red respectively. Viewpoints are either plan, north, west or other if more representative.

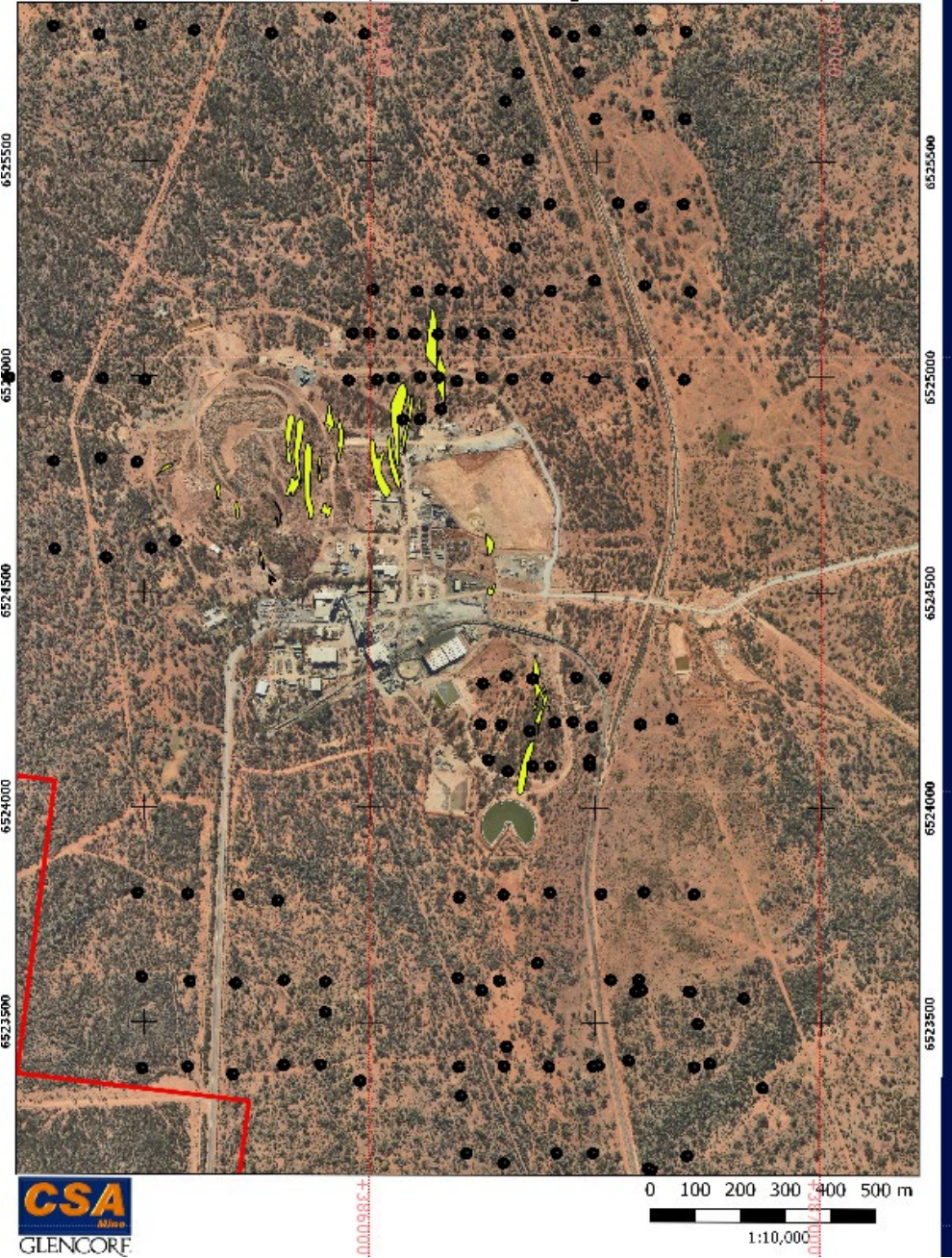


Figure 6. Collar points and ore systems projected onto surface. Black dots mark drill hole collars, yellow shapes mark the orebodies and the orthogonal red line mark the mine site boundary.

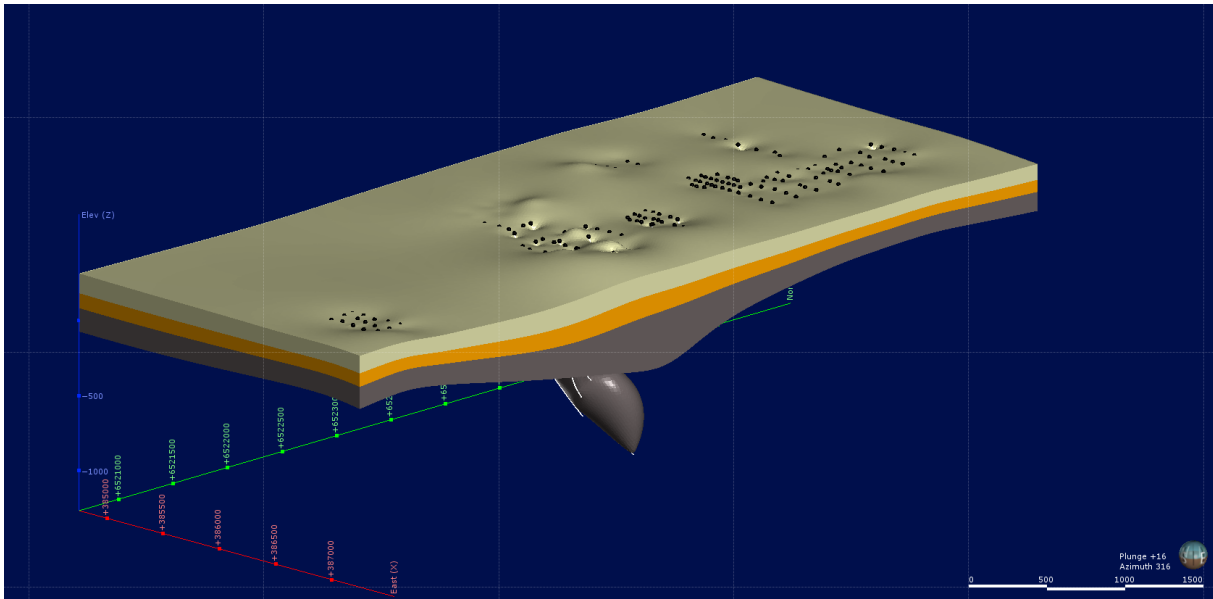


Figure 7. Oblique view of simplified geology. Saprolite (tan) grading down into saprock (orange) and further into siltstone (grey). Note that the host rock is dipping 80 degrees west. Horizontal changes are due to oxidation and weathering processes. Black dots mark collarpoints of drillholes.

Barium

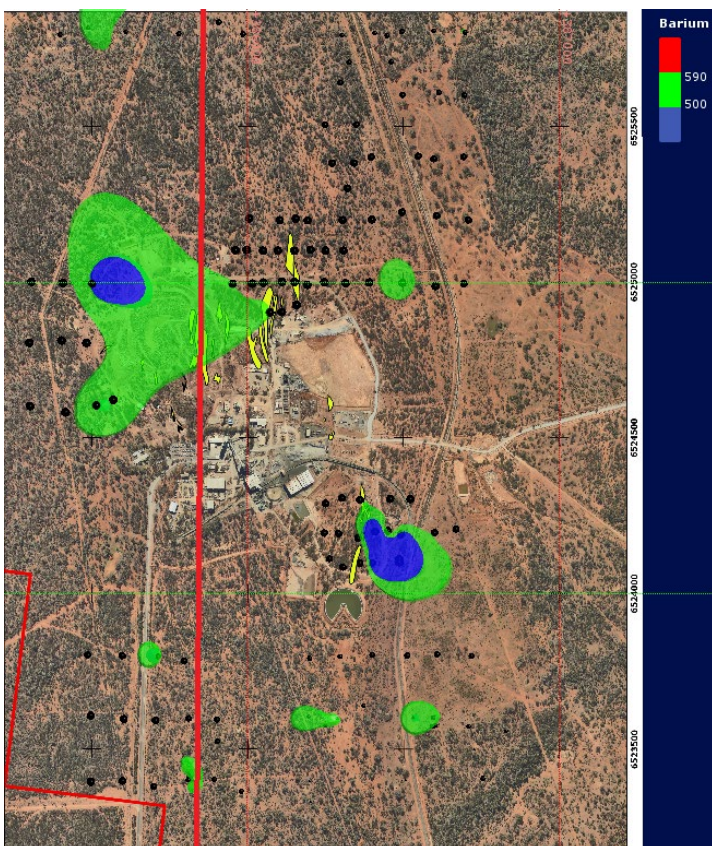


Figure 8. Plan view of Ba depletions and background. Above background values have been filtered out. Green areas mark background values and blue mark depletion haloes. Vertical red line marks line of section and orthogonal red line marks mine site boundary.

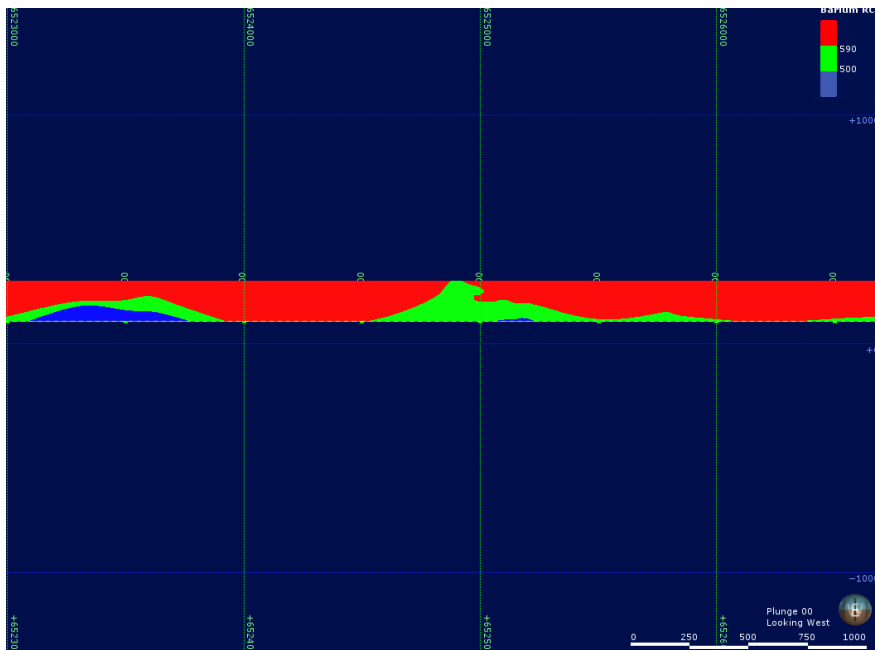


Figure 9. Cross section looking towards the west of Barium distribution in RC model. Red areas mark enriched zones, green areas mark zones of background value and blue areas mark depletion zones. Vertical scale 1:1

Rubidium

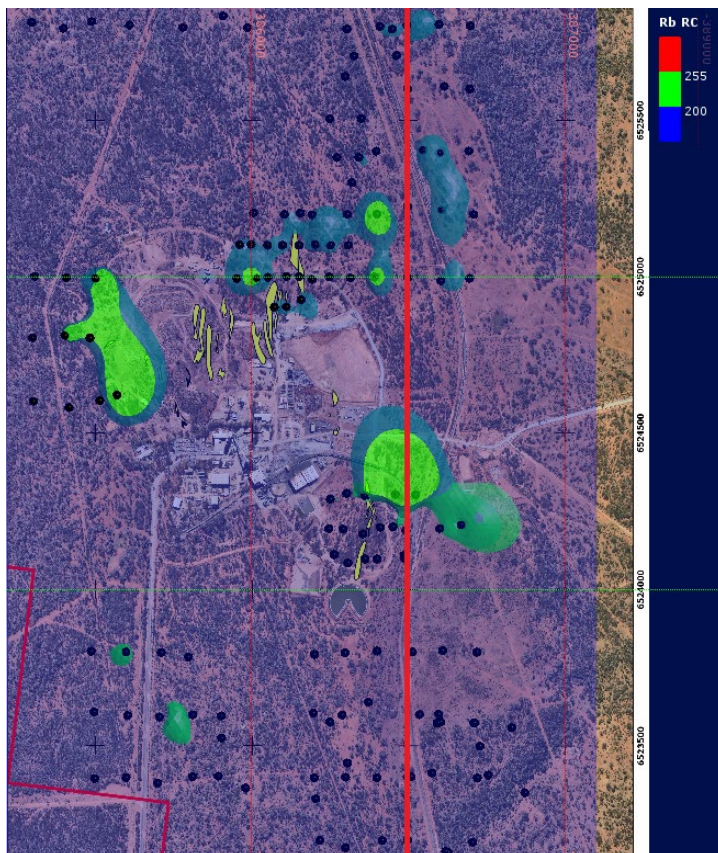


Figure 10. Rb distribution. The upper strata are depleted (blue) and transparency has been set to high to display areas of background values (green). Note that no areas are enriched (red). Vertical red line marks line of section, orthogonal red line marks mine site boundary.

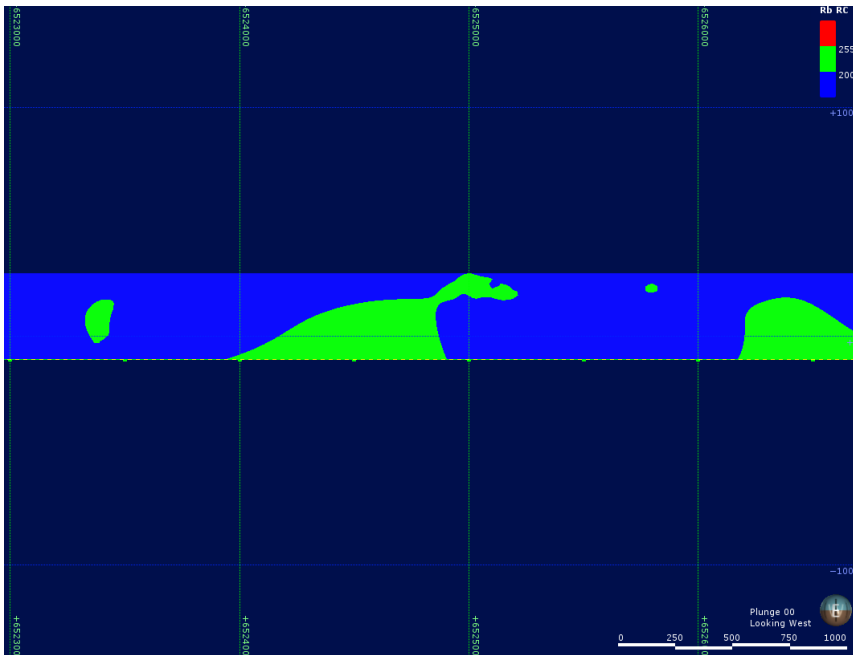


Figure 11. Cross section looking west showing distribution of Rb in RC model. Blue areas mark the extensive depletion and green areas mark zones of background values. Vertical scale 2:1

Strontium

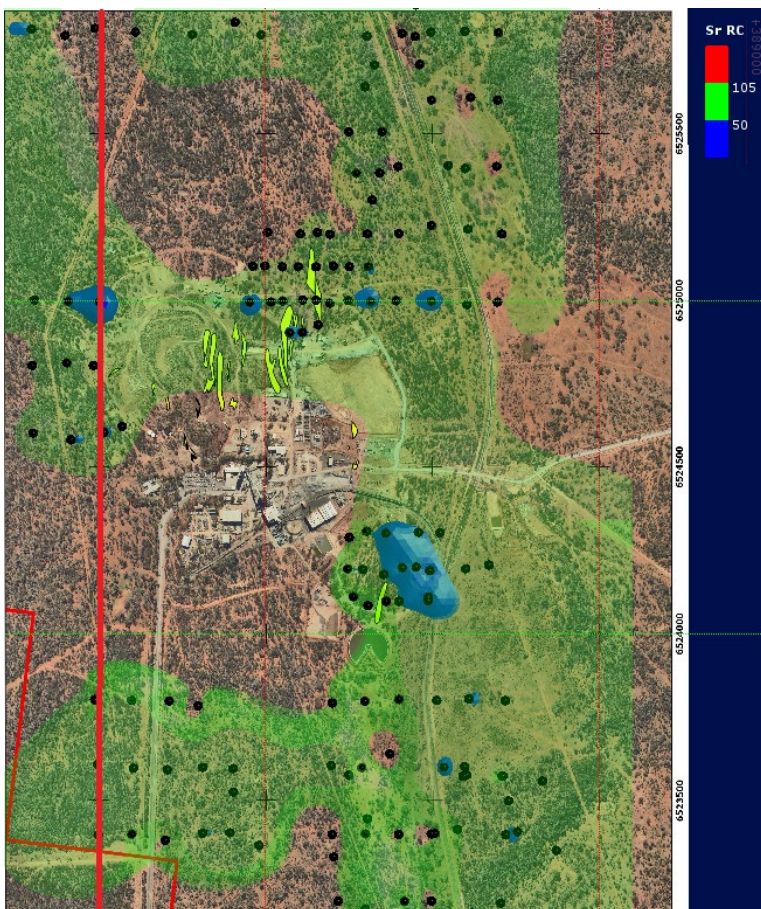


Figure 12. Displaying Sr distribution in plan view. The top strata is enriched and transparency of this layer has been set to high to highlight areas of background values (green) and depletion haloes (blue). Vertical red line marks line of section, orthogonal red line marks mine site boundary.

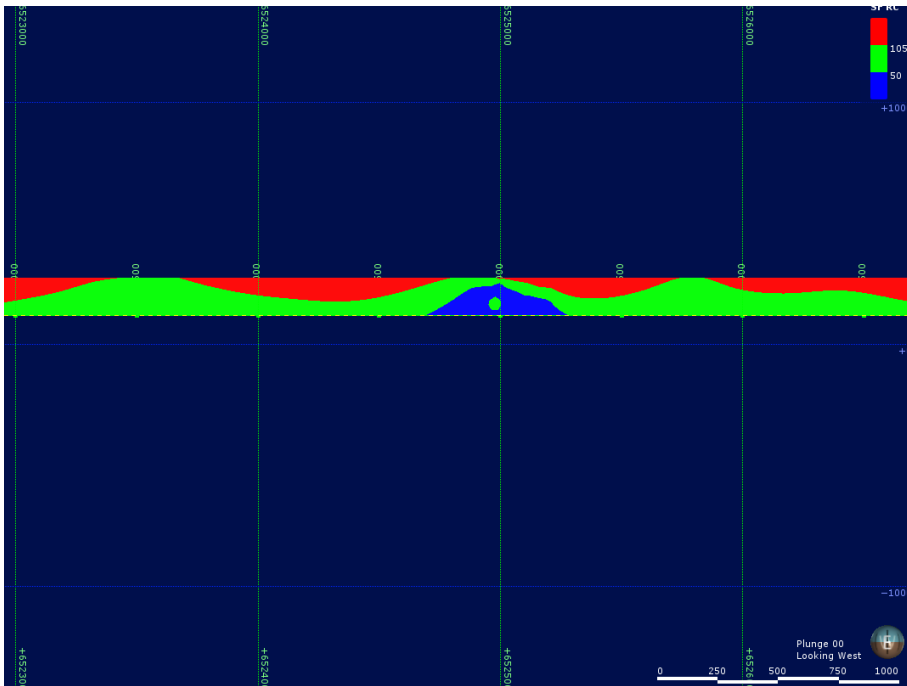


Figure 13. Cross section view to the west showing Sr distribution. Red areas mark enrichment, green mark background values and blue areas mark depletion zone. Vertical scale 1:1

Lithium

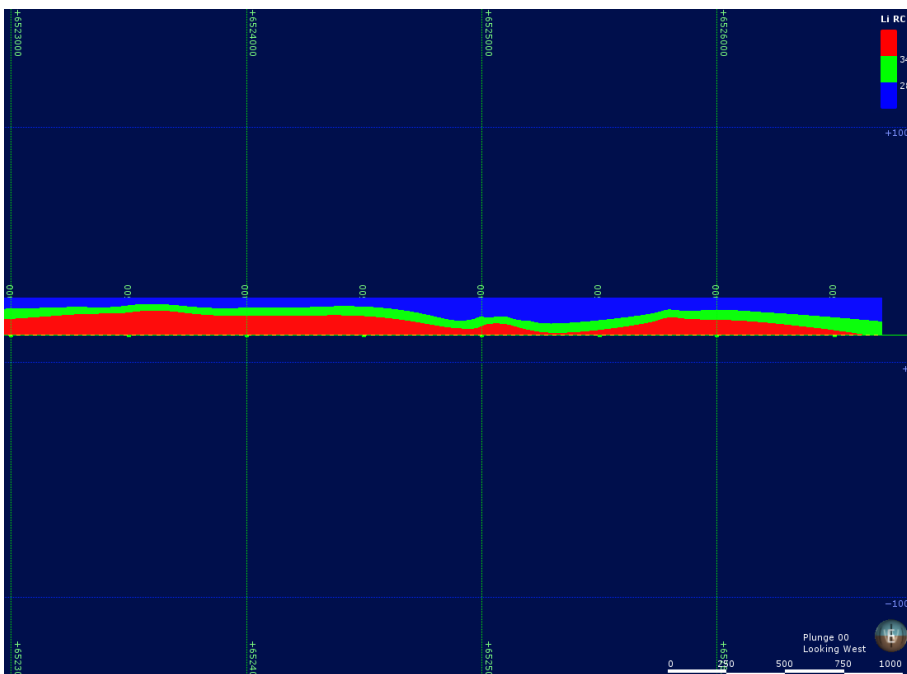


Figure 14. Cross section of Lithium distribution. Distribution grades from depletion (blue) through background values (green) into enrichment (red). Vertical scale 1:1

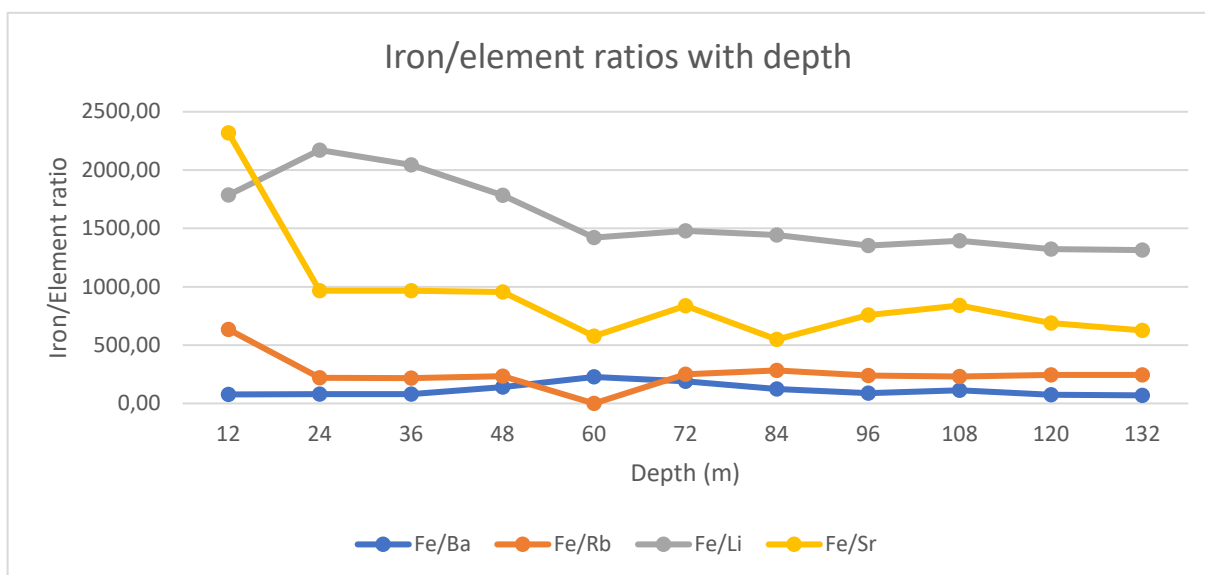


Figure 15. Element ratios with depth. Note the significant decrease in ratio for Sr.

Analysis and discussion

It is of importance to realize the depth constraints while modelling using primarily RC data. The depletions described in earlier studies made use of deep diamond drill samples at close and distal locations in regards to mineralisation. The work described in this paper is meant to complement these earlier findings and to map out higher resolution, elemental distribution in the upper portions of the rock at CSA.

The results show changes in concentration with depth across all elements. This is not surprising as surficial processes have altered, oxidized and weathered the rock. Ba and Sr show similar characteristics with a general trend of enrichment in the clay rich saprolite. This may be due to the two elements strong adsorption potential to clay minerals which make up the saprolite. In addition, (Figures 8 and 12) show that two distinct depletion haloes are present and coincident at QTS South/ Pink Panther and west of the Western system. A NW trend may be discerned here. There also appears to be a coincident depletion halo to the north in the area not covered by drilling (Figures 8 and 12). The pipe-like structure of these haloes are not dissimilar to the ore lenses in their plan view dimensions.

Rb on the other hand is shown to inhabit an inverse relationship to Sr and Ba. The saprolite, saprock and much of the siltstone is depleted (Fig.11). This depletion extends down beyond

the oxidized zone and is not likely to be the effect of weathering. The distribution also seems to revert to background values around QTS North and QTS South (**Fig.10**). As such, it is argued that the background values of Rubidium used in the modelling in this case are over estimated and that *relative* enrichment occurs around the ore zones. The processes for this distribution are not immediately clear.

As presented in **Figure 15**, there is evidence for different mechanisms in regards to enrichment or depletion with depth. Fe/Ba ratio remains relatively constant where as the ratios increase sharply for Li, Rb and Sr the shallower the samples. This suggests that Ba mobilisation in the oxidised zone is concurrent with iron i.e it may not be independent of Fe. If Barium is to be considered dependent of iron, the depletions haloes at depth may simply reflect areas of containing less iron rich minerals.

In contrast to the Fe/Ba ratio which remains relatively unchanged with depth, the Fe/Sr changes drastically from the oxidised zone into the fresh rock. This fact suggests that Sr concentrations are not a function of iron content but rather an effect of enrichment and depletion *mechanisms*. These mechanisms include elemental adsorption to clay minerals in the oxidised zone and metasomatic fluid alteration around the orebodies. An argument may thus be made for an initial, metasomatic depletion of Strontium in the ore zones followed by a distal deposition and subsequent enrichment by weathering processes. This model explains the distribution of Strontium independent of iron and, when used in conjunction with the 3D model presented in **figures 12 and 13**, presents the case for elemental association with ore at CSA mine.

As such, Sr may be the most useful element to analyse when defining elemental depletion haloes around CSA mine. The relative enrichment of Rb around the ore zones may serve as a geometrical proxy but it is unlikely to reflect the same processes governing Sr distribution. This is because the strong adsorption potential of Rb should result in an *enrichment*, not a depletion in the oxidised zone. Further work is recommended to determine the processes involved in Rb distribution.

The orebodies are at great depth, and confident interpolation from the modelled geochemistry down to those depths would require additional sampling from deeper diamond drill holes. In addition, a detailed structural model should ideally pre-date a

geochemical one. This would be beneficial when adjusting the geochemical modelling by structural trends and could in theory narrow down target zones even more. It could also aid in the interpretation of the formation of these haloes. Should they consistently diverge around structures such as shear zones or faults, it could be argued that the haloes were associated with the ore formation or at least channelled by the same structures.

Regardless of temporal relationships between elemental depletions and ore deposition, the presence of these haloes and their spatial link to known mineralisation and structures is of importance when conducting exploration around CSA mine. Surface geochemical sampling targeting base metals and Strontium may well increase the target area for these pipe-like ore lenses.

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