|  |  |
| --- | --- |
| QUESTIONS | ANSWERS |
| 1. Confirm an acknowledgment to MRIWA (or its predecessors) funding is given in the reports: 2. identify which reports reference MERIWA or MRIWA? | All have MRIWA in the document  None have MERIWA referenced |
| 1. extract all references to MERIWA and MRIWA from the reports | See Table 1 below |
| 1. Search by periodic table elements or full name: 2. identify any references to nickel or Ni in the reports? | See Table 2 below  Report with substantial amounts of Nickel mentions:  432, 459, 505, 451 |
| 1. Which elements are considered in the reports? | A useful response would identify all reports and state, for each report, the elements that are mentioned lots.  This question would, however, likely need to be rephrased.  See Table 4 for top 10 elements in each report.  Big ones: Iron, Sulfur, Gold, Copper, Oxygen, Nickel, Gold, Silver, Lithium, Tantalum. |
| 1. Search for organisations by variations in name: 2. which reports has Commonwealth Scientific Industrial Research Organisation been involved with:    1. in any capacity (including being listed in references)?    2. as researcher?    3. as a sponsor? | See Table 3 below |
| 1. Ability to search on geographic locations: 2. Which report is related to the East Kimberley region? | 448 (very minimal mention, hardly related) and 459-489 (in the title, important) |
| 1. Which regions of Western Australia are referenced in the reports? | Kimberley (448 and 459-489)  Goldfields (532, 448, 459-489, 432)  Pilbara (532, 448, 459-489, 432)  North west (532, 459-489)  Mid West  South West (448, 451) – as a direction not location (459-489, 532)  The above are state government regions.  Not the same as tectonic regions which are also referred to in reports.  A useful response would be similar to the elements one -> provide all reports and, for each, really common regions (either state government or tectonic) mentioned.  These terms also commonly occur, linked to geo regions:  Pilbara: 448, 532  Yilgarn: 448, 532  Kimberley: 459  Canning: 448, 488  Officer: 448  Musgrave: 448  Halls Creek: 459 |
| 1. Ability to differentiate authors: 2. Which author has been involved in more than one project? | BARRY PRICE,  DAVID ALLEN,  Noreen Evans,  RAJESH SHARMA,  SILVIA BLACK,  B McInnes |
| 1. Ability to aggregate/integrate information: 2. What is the average number of references in each report? | 197 |
| 1. Which reports relate to leaching? | 432, 451, 488, 505, 532 (minor mentions) |
| 1. Which reports relate to exploration? | 448, 459-484, 532 |
| 1. Which reports relate to mining extraction? | 488, 505, 532 (mentions of Li extraction), 432 (mentions of extraction procedure) |
| 1. Which reports relate to mineral processing? | 532, 488 (ISR), 505 |

Table 1 – extracted references to MRIWA

|  |  |
| --- | --- |
| 432 | Every single page - *Sequential Leaching Project M432 – Final Report to MRIWA*  Page 1 – PREPARED FOR MRIWA  Page 7 - Through a project scientific advisory panel, the MRIWA M432 study  Page 14 - MRIWA-ChemCentre Workshop on Mine Wastes   * 1. Page 81 - Through a project scientific advisory panel, the MRIWA M432 study   Page 91 - The research team and authors of this report wish to acknowledge the funding support for this study from BHP Billiton and MRIWA. |
| 448 | Page 1 – in logo  Page 1 - Results of research carried out as MRIWA Project M0448  Page 1 - Distributed by: MRIWA  Page 4 - Minerals Research Institute of Western Australia (MRIWA).  Page 11 - Together with unpublished data from MRIWA project M0446,  Page 11 - sample undertaken within MRIWA project M0448  Page 12 - However, within the sister MRIWA project (M0446) we used zircon to  Page 13 - Data from companion MRIWA project M0446 in red.  Page 25 - an independent MRIWA-supported project on VHMS  Page 28 - This study was directly funded by GSWA, Independence Group, MRIWA and Curtin University:  all are thanked for their direct financial support  Page 39 - This research was funded in-part by the Minerals Research Institute of WesternAustralia (MRIWA) M448 grant with contributions  Page 157 - This research was funded in-part by the Minerals Research Institute of Western Australia  (MRIWA) M448 grant with contributions  Page 204 - This research was funded in-part by the Minerals Research Institute of Western Australia  (MRIWA) M448 grant with contributions  Page 247 - This research was funded in-part by the Minerals Research Institute of Western Australia  (MRIWA) M448 grant. |
| 451 | Every page in header  Page 1 – MRIWA Project M451   * + - Prepared for   MRIWA  Minerals Research Institute of Western Australia  Page 5 - The funding support for this project from Alcoa of Australia Limited (Alcoa), Iluka Resources Limited (Iluka), Aroona Alliance of the Water Corporation (Aroona) and the Mineral Research Institute of Western Australia (MRIWA);  Page 16 - ChemCentre, being a scientific government agency, together with the project sponsors Alcoa, Iluka, Aroona and MRIWA have taken the initiative through this project  Page 44 - The field study was continued for year 2016-17 in the current MRIWA project, only the small plots (3 m x 3 m) with the… |
| 459-484 | Page 1- MRIWA Project M459-M484 final report  In logo form  Page 2- in logo form  MRIWA Project M459-M484 final report  Distributed by: MRIWA  Page 3 - Le Vaillant, M., Barnes, S. J., Fiorentini, M., Mole, D., Austin, J. R., Godel, B., Patterson, B.,  Hammerli, J., LaFlamme, C., Neaud, A., Denyszyn, S., and Mao, Y.-J., 2017, Magmatic sulfide  mineral potential in the East Kimberley, MRIWA project M#459 - M#484, p. 297  Page 16 - Financial support for this research was provided by MRIWA (projects #M459 and  #M484), Panoramic Resources Ltd and King River Copper Limited. Panoramic Resources Ltd and  King River Copper Limited are acknowledged for providing on-site access and samples. |
| 488 | Page 1 – in logo form  Minerals Research Institute of Western Australia (MRIWA)  MRIWA Report No. 488  MRIWA Project M0488: 2017–2020  Page 2 – in logo form  Results of research carried out as MRIWA Project M0488  Distributed by:  MRIWA  Page 4 - Research in MRIWA Project M0488 focused on the possible application of ISR to primary copper sulfides that are usually found in deep ores.  Page 16 - Several areas for additional research on different commodities or a potential for the expansion of the current results have been identified, with potential for the presentation of new research proposals to MRIWA.  Funding from the Minerals Research Institute of Western Australia (MRIWA) and BASF is gratefully acknowledged.  Page 25 - I want to thank to my sponsors, the Minerals Research Institute of Western Australia (MRIWA), BASF and the former Parker Centre from which grants were obtained for MRIWA project M488, which allowed me to conduct all experiments and analysis required to finalize this research.  Page 97 - MRIWA (Project M488), BASF, Curtin University and CSIRO are gratefully acknowledged for funding this work.  Page 131 - MRIWA (Project M488), BASF, Curtin University and CSIRO are gratefully acknowledged for funding this work.  Page 172 - MRIWA (Project M488), BASF, Curtin University and CSIRO are gratefully acknowledged for funding this work.  Page 206 - MRIWA (Project M488), BASF, Curtin University and CSIRO are gratefully acknowledged for funding this work.  Page 235 - The authors would like to acknowledge MRIWA (Project M488), BASF, Curtin University and CSIRO for funding this work; Tuyen Pham and Sophia Surin for assistance with the fluid and solid analysis; Drs Robbie McDonald and Denis Shiers for reviewing a draft of this manuscript and the reviewers for their valuable additions to the final document.  Page 260 - MRIWA (Project M488), BASF, Curtin University and CSIRO are gratefully acknowledged for funding this work. Jian Li is thanked for reviewing a draft of this manuscript.  Page 281 - MRIWA (Project M488), BASF, Curtin University and CSIRO are gratefully acknowledged for funding this work. |
| 505 | Page 2 – in logo form  MRIWA Project M505 2018 – 2020  Our Reference: MRIWA Report  Minerals Research Institute of Western Australia (MRIWA)  Page 3 - G.P. O’Malley (2020). Glycine Heap Leaching, MRIWA 505 Final Report  Page 5 - FIGURE 14: MRIWA TEST WORK FLOWSHEET  Page 9 A recently completed MRIWA funded research project (M505: Glycine Heap Leaching) undertaken by Mining and Process Solutions (MPS) in partnership with Curtin University, looked at the potential application of glycine to heap leaching of various ores as an economical method of extracting metals.  The project was supported by Sandfire Resources, Barrick Gold, Coda Minerals (previously Gindalbie Metals), Poseidon Nickel and the Minerals Research Institute of Western Australia (MRIWA).  Page 10 - MPS and Curtin University with industry support from Sandfire Resources, Barrick Gold, Coda Minerals (previously Gindalbie Metals), Poseidon Nickel and the Mineral Research Institute of Western Australia (MRIWA) have undertaken this research project to evaluate the commercial opportunities for glycine heap leaching through this MRIWA funded project (M505).  This report summarises the activities and main findings on this MRIWA funded project.  Page 21 - Figure 14: MRIWA test work flowsheet  Page 90 - MRIWA – Mineral Research Institute of Western Australia |
| 532 | Page 1 – logo form  MRIWA REPORT M532 –  Page 2 - MRIWA REPORT M532 – THE GEOLOGY, MINERALOGY AND GEOMETALLURGY OF EV MATERIALS DEPOSITS IN WESTERN AUSTRALIA  Page 3 - The recommended reference for this publication is:  Wells, M, Aylmore, M and McInnes, B 2022, MRIWA Report M532 - The geology, mineralogy and geometallurgy of EV Materials Deposits in Western Australia: Geological Survey of Western Australia, Report 228, 187p.  In logo form  Page 7 - Financial support for this study was provided by the Minerals Research Institute of Western Australia (MRIWA), the Geological Survey of Western Australia (GSWA), Lithium Australia, Rio Tinto and Curtin University  Page 21 -  *Program 1 (MRIWA, GSWA, Rio Tinto, Lithium Australia)*  Page 189 -  MRIWA REPORT M532 – THE GEOLOGY, MINERALOGY AND GEOMETALLURGY OF  Page 189 - This MRIWA and industry-supported project has generated new petrology, mineralogy, geochemistry and geochronology data from some key Li–Cs–Ta (LCT) pegmatite deposits in Western Australia. |

Table 2

|  |  |
| --- | --- |
| 432 | Page 25 - Dissolved metals; Ag, Al, Ba, Be, Cd, Co, Cr, Cu, Fe, Li, Mn, Mo, Nb, Ni, Pb, V, and Zn  Page 37 - Total elemental composition analysis (for Ag, Al, As, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, S, Se, Si, V and Zn) of the seven samples was performed by (i) X-ray fluorescence (XRF) and (ii) four acid digestion (HNO3/HClO4/HF/HCl) with analysis using inductively coupled plasma-atomic emission spectrometry (ICP-AES).  The analysis of all test solutions derived from the sequential leaching, LEAF 1313 test and kinetic leaching included pH, electrical conductivity (EC) and the determination of elemental concentrations (for Ag, Al, As, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, S, Se, Si, V and Zn) by ICP/AES and inductively coupled plasma-mass spectrometry (ICP-MS).  The residue samples derived from all the sequential leaching tests were analysed for total elemental composition (for Ag, Al, As, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, S, Se, Si, V and Zn) by four acid digestion (HNO3/HClO4/HF/HCl) with analysis using inductively coupled plasma-atomic emission spectrometry (ICP-AES).  Page 42 - Table 4. Results for total elemental composition of waste rock samples  Page 46 – Nickel, 0.032 mg/L at month 24 (exceeding the ANZECC 2000 freshwater guideline value of 0.011 mg/L).  Page 53 - Table 7: Concentrations of Contaminating Elements in Extracting Solutions for Four SLP Methods  Page 61 - >90%: Aluminium (99%), arsenic (96%), barium (93%), beryllium (94%), chromium (96%), potassium (99%), lithium (99.7%), magnesium (99%), manganese (95%), niobium (99%), nickel (97%), lead (97%) and vanadium (96%).  Page 62 - Non-silicate nickel was equally partitioned between the carbonate and recalcitrant oxidisable fractions.  Page 64 -   * 50% to 90%: Arsenic (67%, beryllium (83%), copper (75%), iron (53%), molybdenum (56%), nickel (84%), phosphorus (61%), sulfur (67%), vanadium (76%) and zinc (74%).   Page 66 -   * Non-silicate nickel was mainly present in the crystalline Fe/Mn oxide fraction; a distinct difference to its portioning in sample JN/OB25 (where it partitioned between the carbonate and recalcitrant oxidisable fractions).   Page 68 - Although both methods are expected to extract common metals (Cu, Cr, Co, Ni, Pb and Zn) present as water-soluble, easily exchangeable and carbonate forms, the relationships were generally poor.  Page 74 - Nickel also followed similar behaviour; the cumulative mass of nickel from the kinetic leach column (0.032 mg/kg) was higher than that present in both the water-soluble and exchangeable fractions (both <0.001 mg/kg). In this case, the additional nickel may have originated from either the ‘carbonate fraction (0.18 mg/kg) or, less likely, the recalcitrant oxidisable fraction (0.18 mg/kg).  Page 75 - Figure 13: Comparison for Sequential Leach and Kinetic Column Data for JN/OB25 Fresh: Metals and Metalloids  Page 81 - While conventional acid base accounting methodology using static tests is generally useful for identifying potentially acid forming mine wastes, the sequential leach procedure is particularly useful for identifying mine wastes with potential to produce neutral mine drainage, i.e. circum-neutral seepage containing metals (notably copper, nickel, and manganese) and metalloid oxyanions (e.g. arsenic and selenium) at concentrations that can affect the quality of surface water and groundwater.  Page 82 - M HCl was originally selected as the reagent of choice as it does not dissolve pyrite (FeS2), the dominant sulfide mineral in iron ore waste. It does, however, react with more reactive iron and nickel sulfides to produce H2S gas  Page 83 - Adamo PS, Dudka S, Wilson MJ, McHardy WJ (1996) Chemical and mineralogical forms of Cu and Ni in contaminated soils from the Sudbury mining and smelting region, Canada. *Environmental Pollution.* 91: 11–19.  Page 86 - Francisco P, Manuel MJ, Teofilo S, Silvia P (2011) Distribution of Cd, Ni, Cr, and Pb in amended soils from Alicante Province (SE, Spain). *Water Air Soil Poll.* 217: 535–543  Page 87 - Ma LQ, Rao GN (1997) Chemical fractionation of cadmium, copper, nickel, and zinc in contaminated soils. *Journal of Environmental Quality.* 13: 372–376.  Page 88 - Plante B, Benzaazoua M, Bussière B, Biesinger MC, Pratt AR (2010) Study of Ni sorption onto Tio mine waste rock surfaces. *Applied Geochemistry*, 25:1830–1844  Page 93 -  An iron sulfide mineral, Fe(1-x)S. Similar in appearance to pyrite and marcasite, but more commonly associated with mafic and igneous rocks and nickel sulfide mineralisation.  Page 98 - Sample JN/OB25 Fresh, Column 1  Page 100 - Sample JN/OB25 Duplicate Column  Page 102 - Sample MM/OB29 Weathered, Column 1  Page 104 - Sample MM/OB29 Weathered, Duplicate Column  Page 106 - Sample MM/OB29 Transition, Column 1  Page 108 - Sample MM/OB29 Transition ,Duplicate Column  Page 110 - Sample W/OB25 Transition, Column 1  Page 112 - Sample W/OB25 Transition, Duplicate Column  Page 114 - Sample W/OB25, Column 1  Page 116 - Sample W/OB25, Duplicate Column  Page 118 - Sample D1/Whaleback Fresh, Column 1  Page 120 - Sample D1/Whaleback Fresh, Duplicate Column  Page 122 - Sample D1/Whaleback Fresh BWT, Column 1  Page 124 Sample D1/Whaleback Fresh BWT, Duplicate Column  Page 127 - Sample JN/OB25 Fresh  Page 129 - Sample WB/OB25 Transition  Page 131 - Sample JN/OB25 Fresh  Page 133 - Sample MM/OB29 Transition  Page 135 - Sample MM/OB29 Weathered  Page 137 - D1/Whaleback Fresh  Page 139 - Sample D1/Whaleback Fresh BWT  Page 147 - Table A3-1. Elemental concentrations (mg/kg) in sequential extraction fraction using the method of Pinto, Al-Abed et al., 2014  Page 151 - Table A3-2. Elemental concentrations (mg/kg) in sequential extraction fraction using the method of by Leinz et al., 2000  Page 155 - Table A3-3. Elemental concentrations (mg/kg) in sequential extraction fraction using the method of Piatak et al., 2007  Page 159 - Table A3-4. Elemental concentrations (mg/kg) in sequential extraction fraction using the method of Rio Tinto 2014  Page 163 - Table A3-5. Percent recovery obtained for all elements in sequentially extraction procedures performed by all four methods for seven rock samples.  Page 168 - Table A4-1. Elemental composition of extractant blank solutions in the optimised sequential extraction method  Page 172 - Table 4-2. Elemental concentrations (mg/kg) in sequential extraction fraction using the optimised method  Page 177 - Table A5-1. Percent of elements in different phases of the optimised sequential leaching procedure and kinetic leach over 24 months.  Page 190 - Table A6-1 Results for Analysis of Samples Using LEAF Method 1313 |
| 448 | Page 65 - Research determined that multiple trace elements (W, Sn, Sb, Ni, Cu, Cr, Ta, Nb, V and/or Pb) in rutile can be correlated to specific metallic mineralisation.  Page 111 - Previous research has shown that rutile with elevated W, Sn, Sb, Ni, Cu, Cr, Ta, Nb, V and Pb contents has been linked to known mineralisation events (Scott, 1988; Clark andWilliams-Jones, 2004; Mueller et al., 2012; Urban et al., 1992; Scott and Rad  Page 112 - TABLE 2.1: Summary of trace element enrichments found in rutile from different ore types.  Page 302 - Published on gold (>100 publications), base metals (Ni, Cu, Pb, Zn) and fractionated granites-pegmatites;  Pages 308 to 446 - Appendix C Table 1  Page 450 to 568- Appendix D Table 1  Pages 584 to – 592 Appendix E Table 3 |
| 451 | Page 13 - Figure 34: Comparison of LeachXS Predictions and Tall Column Laboratory Data for Nickel in IMG Leachates.  Page 14 - Figure 66: Comparison of LeachXS Predictions, Aroona Field Trial and Tall Column Laboratory Data for Nickel in Jandakot Residue Leachates.  Page 29 - Table 1: Water Quality Criteria Relevant to Land Management Activities on the Swan Coastal Plain.  Page 37 - Total elemental concentration by X-ray fluorescence (XRF) and 4-acid digestion by inductively coupled plasma atomic emission spectrometry (ICP/AES) for: Ag, Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Se, Sn, Ti, Th, Tl, U, V, Zn. Also analysed for total Cl and F.  Total elemental concentration by XRF and 4-acid digestion by ICP/AES for: Ag, Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Se, Si, Sn, Ti, Th, Tl, U, V, Zn, Cl, F.  Page 38 - ICP/AES and/or inductively coupled plasma mass spectrometry (ICP/MS) analysis for: Ag, Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Se, Sn, Ti, Th, Tl, U, V, Zn; and  Page 39 - Table 2: Analytes Limit of Reporting (LOR).  Page 6 - None of the soils contained significant concentrations of extractable molybdenum, nickel, arsenic or selenium  Page 61 & 62- Table 5: Characterisation Data for Swan Coastal Plain Soils.  Page 65 - Nickel: except for the low pH leachates, nickel was only recorded at very low concentrations (approximately 0.03 mg/L) in leachates of Fairbridge duplex and Spearwood sand samples.   * 1. Page 74 - Table 6: Tall Column Study – Analyte Concentration Threshold Values.   2. Page 76 - Table 7: Tall Column Leachate Analysis Summary – Soil Samples   3. Page 77 – Table 8: Iluka By-product Ironman Gypsum (IMG) Characterisation Data.   4. Page 82 – Table 9: Risk Screening Profile Table for CoPCs from LEAF Test Data – IMG.   5. Page 79 - Nickel: Nickel was similar to cobalt in that IMG recorded elevated concentrations (>0.5 mg/L at low pH, but much lower concentrations under circum-neutral and alkaline conditions.   6. Page 82 – nickel   Page 86 - Dissolved humic acid (DHA) content in each leachate, which is calculated as a fraction of dissolved organic carbon (typically 20% to 40%). DHA has the capacity to form soluble complexes with many transition metals, notably copper, cadmium, nickel and lead.   * Page 88 - Table 11: Mineral Phases Adopted for Chemical Speciation Fingerprint Models using LeachXS.   Page 97 - Table 12: Tall Column Leachate Analysis Summary.  Page 99 - Table 13: Ellenbrook Field Trial Summary for IMG.  Page 100 - Concentrations of arsenic, barium, copper, iron, potassium, manganese, sodium, nickel, phosphorus, lead, selenium, thorium, titanium, chloride, vanadium and zinc were higher in the field samples. In each case, the differences were explained by either:  Page 101 - Table 14: Comparison of LEAF Tests 1314 and 1316 Results with Bullsbrook Turf Field Trial Data.   * 1. Page 108 – nickel   2. Page 110 – nickel   Comparison data for nickel leaching characteristics are presented in Figure 34.  These results indicate that nickel in IMG is not considered to be a constituent of potential concern.  Page 111 - Figure 34: Comparison of LeachXS Predictions and Tall Column Laboratory Data for Nickel in IMG Leachates  Page 114 - LEAF Method 1313 results identified aluminium, manganese, cobalt, nickel and (sulfate) salinity as constituents of potential concern in IMG, especially under acidic field conditions.  Page 115 - Table 16: Bauxite Residue By-product Alkaloam – Characterisation Data. Note: LOR values are for either XRF\* or ICP/AES analysis.  Page 117 - Nickel: Low values (<0.1 mg/L) were recorded particularly in alkaline leachates.  Page 120 – Table 17: Risk Screening Profile Table for CoPCs from LEAF Test Data – Alkaloam.  Page 124 - Dissolved humic acid (DHA) content in each leachate, which is calculated as a fraction of dissolved organic carbon (typically 20% to 40%). DHA has the capacity to form soluble complexes with many transition metals, notably copper, cadmium, nickel and lead.  Page 126 - Table 19: Mineral Phases Adopted for Chemical Speciation Fingerprint Models of Alkaloam Using LeachXS.  Page 134 - Table 20: Tall Column Leachate Analysis Summary.  Page 136 - Table 21: Ellenbrook Field Trial Summary for Alkaloam.  Page 148 - Table 23: Bauxite Residue By-products Characterisation - NRP  Page 150 - Nickel: Very low values (<0.001 mg/L) were recorded in alkaline leachates (pH >8). Concentrations increased with decreasing pH to a maximum value of 0.02 mg/L at pH 2.  Page 152 - Table 24: Risk Screening Profile Table for CoPCs from LEAF Test Data – NRP.  Page 156 - Table 26: Tall Column Leachate Analysis Summary  Page 158 - Table 27. Groundwater Residue (Jandakot and Wanneroo) Characterisation.  Page 160 - Nickel concentrations within typical soil environments (4.5 to 9 pH units) were within a range of 0.1 to 0.01 mg/L, presently minimal environmental risk. Higher concentrations (up to approximately 0.05 mg/L) were recorded at low pH (both materials) and high pH (Jandakot).  Page 163 - Table 28: Risk Screening Profile Table for CoPCs from LEAF Test Data – Jandakot Groundwater Residue.  Page 164 - Table 29: Risk Screening Profile Table for CoPCs from LEAF Test Data – Wanneroo Groundwater Residue.  Page 174 - Table 31: Tall Column Leachate Analysis Summary for Groundwater Residues (Jandakot and Wanneroo).  Page 175 – Table 32: Groundwater Treatment Residues Field Trial Summary.  The most significant findings from the field experiments were the elevated concentrations of nickel and lead, neither of which were assessed as significant risks with combinations of these two materials and the four soil types used in the tall column experiment (Table 31, Section 5.5.1.4.1).  Page 179 - Nickel (from Aroona field trial observations).  Page 181 - As with copper (and nickel), anomalously high concentrations of zinc were recorded in lysimeter leachates from the field trial.  Nickel  Comparison data for nickel leaching characteristics are presented in Figure 66.  As was the case for zinc, LeachXS predicted an initial flush of soluble nickel at very low L/S, with much lower concentrations as L/S increases. These predictions align reasonably well with low measured concentrations in leachates from the tall column experiment. As with copper and zinc (and also lead, Appendix A20), anomalously high concentrations of nickel were recorded in lysimeter leachates from the field trial.  The presence of elevated copper, nickel and zinc in Aroona field trial lysimeter leachates is not consistent with LeachXS modelling of the source material, or the tall column laboratory experiment, which used Bassendean Ellenbrook soil and not local Jandakot sand  Page 182 - Figure 66: Comparison of LeachXS Predictions, Aroona Field Trial and Tall Column Laboratory Data for Nickel in Jandakot Residue Leachates  Page 185 - Results from lysimeter field trials set up and managed by Aroona at the Jandakot and Wanneroo groundwater treatment plants were generally consistent with those of the tall column experiment, apart from elevated concentrations of nickel and (to lesser degrees) copper, lead and zinc.  Page 187 - Table 34. Biosolids Cake and LAB Characterisation Data.  Page 189 - Nickel concentrations were less than 1.0 mg/L for both samples, with the biosolids cake leachates containing slightly higher concentrations across the full pH range.  Page 191 - Table 35: Risk Screening Profile Table for CoPCs from LEAF Test Data – Biosolids Cake.  Page 192 - Table 36: Risk Screening Profile Table for CoPCs from LEAF Test Data – LAB.  Page 199 - Table 38 Tall Column Leachate Analysis Summary for Biosolids Cake and LAB.  Page 220 - Appendix A1.1: pH dependence LEAF 1313 method performed by ChemCentre in duplicate on ECN reference material.  Page 221 - Appendix A1.2: Inter-lab LEAF 1313 method comparison between ECN and ChemCentre for Bottom Ash Reference Material.  Page 232 - Appendix A2.1: Percolation LEAF 1314 method performed by ChemCentre in duplicate on ECN Reference Material.  Page 233 - Appendix A2.2: Inter-lab LEAF 1314 method comparison between ECN and ChemCentre for ECN Reference Material.  Pages 500 to 509 - Appendix A11: Laboratory Tall Column Leaching Data – By-product Materials  Pages 525 to 528 ?? table  Page 541 A12-1. Alkaloam  Page 556 - A12-2. Ironman Gypsum (IMG)  …. And every sample set there after ….  Page 639 - A 13-1. Wanneroo Residue  Page 644 - A 13-2. Jandakot Residue  Page 654 – Nickel Table |
| 459 | Page 3 - Keywords: Mafic-ultramafic intrusions, Ni-Cu sulfide prospectivity, East Kimberley, Proterozoic, AMS-Paleomagnetic study  Page 7 - Tectonic setting of the East Kimberley Ni-Cu systems  Application of findings to targeting models for intrusion-hosted Ni-Cu-PGE deposits applicable to other craton margin orogenic settings in Western Australia, specifically Musgrave and Albany-Fraser terranes  Page 10 - Figure 56: Plots of Ni and Cr vs MgO in whole rock, no volatile-free recalculation. Colour indicates location (intrusion), shape indicates rock type  Page 11 - Figure 68: Sample averages of Ni (ppm) versus Mg# (Fo) of olivine, for all intrusions analysed, electron microprobe data (symbols), and coloured fields for laser ablation data  Page 14 - Figure 125: Typical prospective shapes for intrusion hosted magmatic Ni-Cu-(PGE) deposits, from (Barnes et al., 2015)  Page 18 - The purpose of this project is to gain a better understanding of the magmatic history of the East Kimberley, and to allow for a better evaluation of its prospectivity for magmatic Ni-Cu-(PGE) as well as reef-style V-Ti-Fe-PGE deposits.  Page 19 - Mineralogical or geochemical indicators of prospectivity of individual intrusions are limited to moderate degrees of Ni depletion in olivines from the lower portion of the Savannah North intrusion.  This project concludes that Paleoproterozoic arc and collisional environments should be recognised as prospective and conducive to the formation of intrusion-hosted orthomagmatic Ni-Cu deposits, and that the major driver behind the prospectivity of these intrusions appears to be their large-scale tectono-magmatic setting, opening up the entire Central Zone as a prospective area for Savannah and Savannah North –style systems.  The identification of Copernicus as much younger than Savannah at 1823 Ma appears to indicate that a whole new generation of intrusions, intruding in a post-collisional setting synchronous with the Halls Creek Orogen, can now be considered as potentially prospective for intrusion-hosted Ni-Cu-(PGE) mineralisation.  Page 21 - The first magmatic province in the Halls Creek Orogeny is composed of an extensive suite of mid-crustal intrusions ranging from chromite- and PGE-bearing duniteanorthosite complexes (e.g. the Panton Sill) to peridotite-gabbronorite layered intrusions, two of which (Savannah, Copernicus) host economic Ni-Cu-PGE deposits.  Magmatic Ni-Cu-PGE sulfide deposits are a major source of the world’s resources of these commodities, and as a class include some of the world’s most valuable individual deposits and camps.  It is almost unique among Ni sulfide deposits in showing no signal of crustal sulfur assimilation, being in a very small intrusion, and showing essentially no distal footprint.  Page 23 - Both magmatic provinces have shown evidences of the presence of economical mineralisation associated with mafic-ultramafic intrusions, such as the Speewah deposit, 4.7 Bt of disseminated V-Ti-Fe oxide mineralisation and a reef anomalously enriched in platinum group elements, or the massive Ni-Cu-(PGE) rich sulfide mineralisation present within the  Savannah intrusion.  Application of findings to targeting models for intrusion-hosted Ni-Cu-PGE deposits applicable to other craton margin orogenic settings in Western Australia, specifically Musgrave and Albany-Fraser terranes  Page 24 - Our study focuses on 1) samples from the Hart dolerite suite, 2) samples from various Cu-Au-Ag prospects within the Speewah dome, both located in the Western zone of the Lamboo Province, as well as 3) samples from the Savannah Ni deposits and multiple intrusions in the vicinity, located in the Eastern zone of the Lamboo province (Figure 1).  Page 31 - Sulfides play a key role in the formation of numerous world-class magmatic Ni-Cu-PGE deposits, numerous studies have looked at the mass-dependent (δ34S) sulfur isotopic composition of magmatic deposits and associated S-bearing country rocks in order to resolve what process triggers sulfide saturation and subsequent ore formation, (e.g., Ripley et al., 1999).  Page 39 - Each sample was microdrilled multiple times. Sulfur was chemically extracted from the 15–30 mg powders to form silver sulfide by chromium reduction as described by Canfield et al. (1986) Silver sulfide was fluorinated at 225 °C in a Ni bomb under F2 atmosphere for nine hours to produce SF6  Page 73 - World-class orthomagmatic Ni-Cu-PGE systems are most commonly associated with large igneous provinces (LIPs) associated with mantle plumes (REF). The occurrence of Ni-Cu sulfide systems in orogenic settings, be it in pre-orogenic arc, syn-collisional or post-collisional settings, have been considered to be less prospective and less likely to host major deposits or camps. However, the occurrence of a number of Ni-Cu-PGE systems in high-grade metamorphic belts and orogens, such as the Ntaka Ni-Cu systems (Barnes et al., 2016c; Tirschmann et al., 2010), Nova-Bollinger (Maier et al., 2016) or the Savannah deposit, focus of our study, indicate that these settings may be more prospective than previously thought.  Page 74 - Use the results of these various datasets to get a better understanding of the tectonic setting of the East Kimberley Ni-Cu systems.  Page 78 - Ni-Cu-Co-(PGE) mineralisation within the Savannah intrusion was first discovered in 1974 by Australian Anglo American (Hoatson and Blake, 2000) during a gossan search to follow up a 142ppm Ni, 81ppm Cu stream sediment anomaly.  Page 79 - The magmatic Ni-Cu-Co rich sulfide mineralisation of the Savannah North intrusion is described in terms of an Upper (UZ) and Lower (LZ) zone.  …. And many more after that! |
| 488 | Page 14 - Similar studies could also be expanded to other commodities, such as nickel or gold  Page 18 - Seredkin, M. and Savenya, M., 2019. In-situ recovery for non-uranium metals ALTA 2019 Nickel- Cobalt  - Copper, ALTA, Perth, Australia, pp. 208.  Page 56 -   * 1. Hidalgo, T., McDonald, R., Kuhar, L., Beinlich, A. and Putnis, A., 2018b. Comparative analysis of lixiviant/oxidant systems for chalcopyrite leaching from coarse samples at elevated temperature, ALTA Nickel-Cobalt-Copper Symposium 2018, ALTA, Perth, Western Australia.   Page 58 - Seredkin, M. and Savenya, M., 2019. In-situ recovery for non-uranium metals ALTA 2019 Nickel- Cobalt - Copper, ALTA, Perth, Australia, pp. 208.  Page 72 - Table 2-4. Chemical composition of initial mineral sample  Page 134 - Hiskey, J., 1993. Chalcopyrite semiconductor electrochemistry and dissolution, In: The Paul E.Queneau International Symposium. Extractive Metallurgy of Copper, Nickel and Cobalt. Published by Minerals, Metals, & Materials Society, pp. 949–969.  Page 101 - Godel, B., 2013. High-resolution X-Ray computed tomography and its application to ore deposits: from data acquisition to quantitative three-dimensional measurements with case studies from Ni-Cu-PGE deposits. Economic geology, 108(8): 2005–2019.  Page 118 - Table 3-3. Chemical composition of the initial chalcopyrite sample  Page 146 - Table 4-3. Chemical composition of the initial bulk mineral sample.  Page 219 - Table 6-2. Chemical and mineralogical composition of the initial bulk mineral sample by ICP- OES and QEMSCAN analyses.  Page 223 - In our experiments, MSA and HCl solutions produced a higher solubility of heavy metals (e.g., Fe, Cu, Ni, Zn) than sulfuric acid, which may be disadvantageous in a multi- contact scenario.  Page 237 - Jenssen, I.B., Hines, M.A., Dotterud, O.M., Bøckman, O. and Andreassen, J.-P., 2018. Filtration properties of ferric hydroxide precipitate in nickel production. In:  B.R. Davis et al. (Eds.), Extraction 2018. Springer International Publishing, Cham, pp. 1373–1381.  Page 244 - Similar studies could also be expanded to other commodities, such as nickel or gold.  Page 298 - Hidalgo, T., McDonald, R., Kuhar, L., Beinlich, A. and Putnis, A., 2018b. Comparative analysis of lixiviant/oxidant systems for chalcopyrite leaching from coarse samples at elevated temperature, ALTA Nickel- cobalt - copper symposium, Perth, Western Australia |
| 505 | Page 6 - FIGURE 79: EFFECT OF NICKEL RECOVERY AT A GRADE OF 0.75% N  FIGURE 86: QEMSCAN SELECTED IMAGES FOR ORE 7 (A) RAW IMAGE (B) NI AND CU MINERALS  FIGURE 69: DISTRIBUTION OF NICKEL IN THE FEED IN ORE 7 (SAMPLE 2)  FIGURE 70: DISTRIBUTION OF NICKEL IN THE FEED AND RESIDUES (SAMPLE 2)  FIGURE 78: EFFECT OF NICKEL ORE GRADE  Page 8 - TABLE 8: SEQUENTIAL HEAD ASSAY (NICKEL ORES)  Page 9 - Glycine heap leaching is an emerging metallurgical technology with potential to unlock significant value from copper oxide, gold and nickel ores.  The project was supported by Sandfire Resources, Barrick Gold, Coda Minerals (previously Gindalbie Metals), Poseidon Nickel and the Minerals Research Institute of Western Australia (MRIWA).  Included in the program of work was metallurgical test work of seven different ores, consisting of gold, copper and nickel samples, that were evaluated through bench scale tests, small open-circuit columns and large 6m high columns operated in closed-circuit configuration.  Page 10 Whereas acid and cyanide tend to leach a wide range of elements from the ore, glycine is very selective for copper (Cu) and other valuable metals (Ni, Co, Zn, Au, Ag).  Alternatively, such base metals like nickel, cobalt and copper could be extracted with glycine.  MPS and Curtin University with industry support from Sandfire Resources, Barrick Gold, Coda Minerals (previously Gindalbie Metals), Poseidon Nickel and the Mineral Research Institute of Western Australia (MRIWA) have undertaken this research project to evaluate the commercial opportunities for glycine heap leaching through this MRIWA funded project (M505).  Page 22 - Figure 15: Particle size distribution of each ore  Page 23 - Table 5 (cont.): Multi-elemental head analysis  A sequential diagnostic leach was performed on each ore and results are summarised in Table 6 (copper ores), Table 7 (gold ores) and Table 8 (nickel ore).  Page 24 – For the nickel ore (Ore 7) the large majority of the nickel, cobalt and copper was associated with sulphide minerals.  Table 8: Sequential Head Assay (Nickel Ores)  The nickel ore (Ore 7) represented a sulfidic ore.  The copper (Ores 1, 2 & 5) and nickel (Ore 7) ores also contained acid consuming minerals of carbonates, calcite, dolomite, anatase, magnesite, and ferroan magnesite where ores 1 and 2 contain between 5 to 9% acid consuming minerals respectively.  Page 27 - Based on the information we know on which minerals acid and glycine leaches, a predicted extraction for copper and nickel were determined for these ores.  Also modelled was the nickel ore (Ore 7). Given we had no information on nickel oxide leaching with glycine it assumed no extraction. It is predicted that acid should leach 81% of the nickel and 95% of the copper while GlyLeachTM is expected to leach 51% of the nickel and 70% of the copper from this ore sample. It is also worth noting that this nickel sample contained significant acid-soluble serpentine and carbonate minerals that would require a lot of acid that would hamper extraction and make this option inhibitory.  Page 28 - Table 11: Predicted mineralogy and extraction from modelling for Ore 7  Page 29 - Table 12 (continued): Predicted outcomes from the mineralogy information  Page 45 - Table 18: Bottle roll test conditions and summary of results for Ore 7  The results showed the acid would extract 75% of the nickel and copper and 45% of the cobalt. GlyLeachTM extracted 45% of the nickel and copper and 12% of the cobalt.  Page 54 - A second sample was asked for as the first only showed <30% nickel extraction for both acid and glycine.  Page 55 - Table 23: Mini column test conditions and summary of results for Ore 7  Curing and glycine leach tended to leach more nickel than cement and glycine leach. Using A3 cure also achieved similar extraction of nickel to just acid cure and acid leach. However, if one compares the two samples similar nickel extractions were achieved with both samples. A noticeable difference was acid tended to leach all the elements while GlyLeachTM leached no iron, only 5% of the cobalt and only copper and nickel which was slower to be leached then in acid.  Page 64 - They show that the copper and cobalt had reached a maximum extraction but the nickel is still slowly being leached and achieved nearly double the extraction than that achieved in the 1 m column test.  Page 65 - Table 28: Large column test conditions and summary of results for Ore 7  Page 74 - For Ore 7, the nickel distribution followed the mass which suggests the nickel is finely disseminated in the ore (Figure 69). Residue sizing was also performed and are presented in Figure 70. It would appear that nickel had leached from all fractions.  Page 75 - Figure 69: Distribution of nickel in the feed in Ore 7 (Sample 2)  Figure 70: Distribution of nickel in the feed and residues (Sample 2)  Page 77 - There was a noticeable difference in slumpage under GlyLeachTM compared to acid with the nickel ore (Table 37).  MPS have undertaken an extensive research program into application of glycine leach technology (GlyLeachTM & GlyCatTM) to heap leaching of copper, gold, and nickel ores.  Page 78 - Table 38: Conventional process for each ore type  Nickel sulphides can suffer from poor flotation recovery due to talc or other gangue minerals. Glycine heap leach offers comparable recovery with lower capital and operating cost, and considerably better product quality.  Page 79 - Table 39: Process conditions for each ore type  Nickel recovery and grade were varied as the key sensitivity factor.  Table 40: Metal prices and exchange rate  Page 86 - Figure 79: Effect of nickel recovery at a grade of 0.75% Ni  Page 80 - For the copper and nickel cases, the heap leach pad cost was estimated from first principles.  Page 81 - 7.2.3 CAPITAL COST – NICKEL PROCESS PLANTS  Page 82 - Payable metal content was assumed to be 90% for the high-grade copper and nickel sulphides produced by precipitation of glycine leach solutions  The base case nickel product was a lower grade sulphide concentrate, with assumed 74% payable metal content.  Page 85 - 7.5.3 NICKEL  Glycine heap leaching offers a significantly lower capital and operating cost compared to conventional grinding and flotation of nickel sulphides. However, the recovery of both routes can vary widely, depending on the ore mineralogy. A high grade, pure nickel sulphide is produced from GlyLeachTM PLS, whereas flotation plants can struggle with low concentrate grades, and may sacrifice recovery in order to produce a saleable product.  Page 86 - Figure 78: Effect of nickel ore grade  Figure 79: Effect of nickel recovery at a grade of 0.75% Ni  Thus, if glycine heap leach can achieve greater than 36% nickel recovery than it becomes the preferred route over flotation.  Given the flotation performance is hampered with grade, the glycine technology offers a viable option to treat low-grade deposits or waste nickel streams due to the lower cost basis and likely better performance to flotation. However, if one includes the costings to process the flotation concentrate to produce final nickel products this would dramatically increase the CAPEX and operating costs that would elevate the glycine technology to have the greatest economic benefit as it would be possible to produce these final nickel products a lot easier than from flotation concentrates.  GlyLeachTM also has a further advantage over nickel flotation in cases where arsenic levels are elevated that creates difficulty in selling the final product.  Page 87 - Nickel sulphide ores where flotation performance is relatively poor and/or impurity levels are high.  As part of this investigation seven ore sources were tested four were copper ores, two were gold ores and one was a nickel ore.  Page 88 - The rate of nickel extraction was shown to be slow for both acid and glycine technology.  The extractions achieved were borderline economical although subsequent work has shown considerably more nickel can be recovered in tanks at temperature.  This test work program set out to evaluate glycine technology on the dissolution of base metals (copper and nickel) and precious metals (gold and silver) by heap leaching.  Page 96 - Figure 86: QEMSCAN selected images for Ore 7 (A) Raw image (B) Ni and Cu minerals  Page 104 - Glycine Leaching Technology is an environmentally benign hydrometallurgical technology that will leach copper, nickel, cobalt and zinc from oxide, mixed oxide and supergene ores, and even primary sulphide ores.  Selectivity: Glycine will solubilise copper, nickel, cobalt and zinc, while iron, manganese, silicates and carbonates remain in the solid phase. |
| 532 | Page 176 - Many of the Ta minerals contain Nb, which is a highly valuable element used for strengthening alloys but can also be used to improve the electrochemical behaviour and stabilize high-nickel cathodes in the Li-battery industry (Xin et al., 2021).  Page 65 - Figure 55. Continental crust normalized trace element plot for spodumene from selected WA LCT pegmatites. Plots constructed using normalizing factors from Wedepohl (1995). Trace element analyses by LA-ICP-MS analysis. Only Ga and Sn (circled) are consistently enriched in spodumene  Page 68 - Figure 62. Continental crust normalized trace element plot for muscovite and lepidolite from selected WA rare-element pegmatites. Mica, as muscovite and lepidolite, is most strongly enriched in Li, Rb, Sn, Cs and Ta, with lesser enrichment in B, Ga and Nb. Plots constructed using normalizing factors from Wedepohl (1995). Trace element measurement by LA-ICP-MS analysis  Page 170 - production are halides (Cl, F and Br as potential powerful oxidizers), Na and K (impact cathode crystal formation) and base metals (Fe, Co, Ni and Cr as redox active metals) (Harman, 2019; Welham, 2019).  Page 178 - Foster, JM, Lambert, DD, Frick, LR and Mass, R 1996, Re–Os isotopic evidence for genesis of Archean nickel ores from uncontaminated komatiites: Nature, v. 382, p. 703–706.  Griffin, A 2017, Hydrometallurgical processes for the recovery of lithium from silicates, abstract: Alta 2017 Nickel-Cobalt-Copper: Uranium-REE and Gold-PM Conference and Exhibition, Perth, Australia, 20–27 May 2017.  Harhira, A, Bouchard, P, Rifai, K, Haddad, J-El, Sabsabi, M, Blouin, A and Laflamme, M 2017, Advanced laser-induced breakdown spectroscopy (LIBS) sensor for gold mining *in* Canadian Institute of Mining, Metallurgy and Petroleum Proceedings: The Conference of Metallurgists, Hosting World Gold and Nickel Cobalt, 2017, 11p.  Xin, F, Zhou, H, Zong, Y, Zuba, M, Chen, Y, Chernova, NA, Bai, J, Pei, B, Goel, A, Rana, J, Wang, F, An, K, Piper, LFJ, Zhou, G and Whittingham, MS 2021, What is the role of Nb in nickel-rich layered oxide cathodes for lithium-ion batteries?: ACS Energy Letters, v. 2021, no. 6, p. 1377−1382.  Page 179 - Nemaska Lithium Inc. 2019, NI 43-101 Technical Report: Report on the Estimate to Complete for the Whabouchi Lithium Mine and Shawinigan Electrochemical Plant, viewed 3 November 2021, <www.nemaskalithium.com/assets/documents/NMX\_ NI4301\_20190809.pdf>.  Page 181 - Wells, MA and Chia, J 2011, Ni laterite mineralogy and chemistry – A new approach to quantification: The First AusIMM International Geometallurgy Conference, Brisbane, Queensland, 5–7 September, p. 187–194. |

Table 3

|  |  |  |  |
| --- | --- | --- | --- |
|  | Any | Researcher | Sponsor |
| 432 |  |  |  |
| 448 | Y |  |  |
| 451 | Y |  |  |
| 459-484 | Y | Y |  |
| 488 | Y | Y |  |
| 505 | Y | Y |  |
| 532 | Y |  |  |

Authors

|  |  |
| --- | --- |
| 432 | RAJESH SHARMA, DAVID ALLEN, SILVIA BLACK, BARRY PRICE, AND NEIL ROTHNIE |
| 448 | Neal McNaughton, Brent McInnes, Noreen Evans, Fred Jourdan, Cristina Talavera, and Jennifer Porter |
| 451 | RAJESH SHARMA, SILVIA BLACK, BARRY PRICE AND DAVID ALLEN |
| 459-484 | Margaux Le Vaillant1, Steve J. Barnes1, Marco L. Fiorentini2, David Mole1, James Austin1, Belinda  Godel1, Ben Patterson1, Johannes Hammerli2, Crystal Laflamme2, Antoine Neaud2,3, Steve  Denyszyn2, Ya-Jing Mao1,4 |
| 488 | Tania Hidalgo1, 2, Laura Kuhar2, Andreas Beinlich1, Andrew Putnis1 |
| 505 | Dr. Glen P. O’Malley |
| 532 | M Wells, M Aylmore and B McInnes  Martin Wells\*, Mark Aylmore\* and Brent McInnes  With contributions by:  Bryant Ware2, Noreen Evans1, Kai Rankenburgh1, Bradley McDonald1, Imogen Fielding, Michael Wingate, Chris Kirkland3 and Aleks Nikoloski4 |

|  |  |
| --- | --- |
| 432 | **Iron**: 110  **Sulfur**: 88  Copper: 43  Sodium: 42  Magnesium: 41  Selenium: 31  Manganese: 31  Calcium: 29  Chromium: 28  Lead: 20 |
| 448 | **Gold**: 218  **Oxygen**: 24  **Copper**: 15  Zirconium: 10  Tungsten: 10  Antimony: 9  Lead: 8  Niobium: 7  Tin: 6  Iron: 6 |
| 459 | **Sulfur**: 70  **Oxygen**: 24  **Nickel**: 18  Gold: 10  Iron: 7  Copper: 6  Platinum: 5  Silver: 3  Cerium: 2  Chromium: 2 |
| 488 | **Copper**: 742  **Sulfur**: 268  **Iron**: 212  Oxygen: 42  Potassium: 39  Sodium: 32  Hydrogen: 31  Calcium: 24  Lead: 14  Uranium: 13 |
| 505 | **Copper**: 193  **Gold**: 105  **Nickel**: 70  **Silver**: 40  Sodium: 13  Cobalt: 12  Iron: 9  Oxygen: 6  Carbon: 5  Arsenic: 3 |
| 451 | **Copper**: 112  Chromium: 83  Zinc: 82  Manganese: 81  Iron: 73  Calcium: 67  Phosphorus: 62  Barium: 45  Sulfur: 40  Nickel: 37 |
| 532 | **Lithium**: 297  **Tantalum**: 31  **Iron**: 30  Sodium: 14  Fluorine: 10  Magnesium: 10  Gold: 9  Argon: 8  Lead: 8  Manganese: 8 |