MR – DAMR Internship Project Proposals FY 2016/17

Numerical benchmarking and optimisation of the mineral resources simulator REDBACK

Supervisor: Thomas Poulet

CSIRO has initiated the development of an open-source numerical simulator for multi-physics modeling of geological processes like mineralisation, accounting for mechanical deformation, fluid-flow in porous media, heat transfer and fluid-rock chemical interactions. This simulator has been successfully benchmarked against theoretical behaviours, but in order to apply it to industrial applications, it has to proven to be robust and numerically optimised. The development team is therefore looking for an intern to help with the benchmarking and numerical optimisation of the code. The candidate should have some basic background knowledge in applied mathematics, partial differential equations, and an interest to learn more about numerical programming (algorithmics, numerical solvers).

Generating synthetic geology data for minerals exploration

Supervisors: June Hill, Francky Fouedjio

In minerals exploration and mining, drill holes are traditionally logged by geologists. But this is a time-consuming task and there are serious concerns about the consistency of logging between different geologists. New algorithms are being developed for analysing drill hole data which are designed to assist the geologist log faster and more consistently. However, we are unable to validate the accuracy of the algorithms because we do not know the real geology. If we are able to generate synthetic geology and simulate drilling, sampling and measuring the samples, then we will be able to validate analytical results against a known geology. Generating the synthetic data and simulating the measurement of samples is a challenging problem.

We are looking for a person to do a pilot study, by creating a simple geology model and populating it with multivariate compositional data using geostatistical simulation. The suitable candidate would need a good statistics background as well as geology. For the project the candidate will be programming in R. So competent programming skills are required, preferably in R.

Explaining Relaxation during the pulse for Surface Nuclear Magnetic Resonance Soundings

Supervisor: Aaron Davis

The content of water saturating the ground at any depth estimated from a surface nuclear magnetic resonance (SNMR) sounding is dependent on the estimation of the zero-time amplitude of the free induction decay of the received, or secondary, signal. When the primary excitation pulse time is of similar length to the characteristic decay time observed in the free induction decay signal, and the dead-time between when the excitation ends and the measurement begins, the process of zero-time amplitude estimation becomes problematic. This is due to several reasons, the most important of which being the relaxation during the pulse. Relaxation during the pulse occurs because the nuclear spins that are excited into a higher energy state during the primary pulse phase are also relaxing at similar rate during the excitation phase. This causes round-off in the zero-time amplitude estimation that creates anomalous voltages in the amplitude, which leads to error in the groundwater content estimation. In this project, the student will explore the physical characteristics of the excitation and relaxation during the pulse of SNMR soundings. The result will be a more robust time-evolution approach to the explanation of the interaction of groundwater to the excitation pulse both during and immediately after the pulse that offers greater accuracy on the estimation of subsurface groundwater. This project will involve significant amounts of scientific programming, and requires a basic understanding of NMR and time-series analysis.

Mineral exploration in the Atacama Desert (Chile) and the Albany-Fraser Region (Western Australia): similar landscape geochemical challenges?

Supervisors: Ignacio González-Álvarez and Brian Townley

Background and reasoning

Most world-class ores have been discovered close to the surface. Many of these large-tonnage deposits are either mined out or are largely decreasing in production. This situation, coupled with a substantial increase in demand for mineral resources, is driving development of exploration protocols to discover deep ores, by identifying the geochemical footprints of mineral systems at regional scale to local scale.

Despite decades of research and development, and better understanding of surface geochemical and mineral dispersion processes from buried ore deposits, both present and past, discrimination of geochemical footprints has remained elusive, mostly due to lack of understanding on how to use tools and interpret data. Geochemical footprint discrimination requires profound knowledge and integration of landscape and regolith evolution processes, as these will develop a geochemical background in which discrimination of ore deposit footprints is subtle to non-discernible.

Climatic shifts combined with tectonic stability on large portions of the continental crust have generated thick and extensive weathered cover, across wide areas of Australia, Western Africa, Central-South America and India (Regolith-Dominated Terrains, RDTs). In addition, in areas of thick and widespread transported overburden cover, such as the Atacama Desert of Northern Chile, long lived to present gravels coalesce, and have also been submitted to regolith formation, leading to a highly heterogeneous sampling media.

Mineral exploration in RDTs is challenging due to the lack of fresh bedrock outcrop, and complexity in geochemical identification of geology at depth, since weathering and/or cover obscures expression of the basement geology and geochemistry, blurring or obliterating the geochemical footprints of mineral systems.

The Atacama Desert in Chile displays an extensive weathered cover under one of the driest environments on earth, similarly to the Albany-Fraser Region (AFR), and both are considered RTDs. The Atacama Desert hosts some of the largest Cu mines in the world (e.g., Escondida), whereas the AFR is a new emerging mineral province (Tropicana Au and Nova-Bollinger Ni-Cu deposits). The Atacama Desert and the AFR share several important features, and therefore, could display similar exploration challenges for interpretation of geochemical anomalies and the location of mineral systems footprints at depth.

Scope

This study aims to evaluate the knowledge and compare the formation processes of geochemical anomalies in the landscape in the Atacama Desert context and the Albany-Fraser Region in its relation with the landscape evolution, to better assess the implications of their similarities and differences for mineral exploration. In such efforts the study will also evaluate mineral exploration geochemical tools, in this case, and opposed to the classic approach, integrating landscape and regolith evolution processes with mineral and geochemical dispersion. As mineral and geochemical variance in supergene environments will reflect long lived to present processes, in order to interpret data, knowledge of landscape and regolith evolution may prove fundamental to filter out those geochemical footprints which are unrelated to any potential deep ore occurrence, hence leaving those signals which could potentially relate to and unknown source.

The Geochemistry of Reduction Spheroids in Tumblagooda Sandstone: Internship Proposal

Supervisor: Sam Spinks

There are extremely good examples of what are known as 'reduction spheroids' exposed within the deep-red Ordovician-Silurian sedimentary rocks of the Tumblagooda Sandstone unit, in Kalbarri National Park, WA. These features are well preserved examples of microbial communities which lived within the sediment soon after they were deposited under water hundreds of millions of years ago. Their activity changed the chemistry of the surrounding rock, altering its colour, and concentrating several rare elements and metals in the middle into what we now see as a dark core. The study of these features, and the cores in particular, allows us to better understand the life cycle of the microbial communities and their relationship with dissolved metals, which in turn can help us to develop biotechnologies that 'clean' environments which are polluted with metals. They are an excellent record of early life on Earth, and are potentially good proxies for the study of life on Mars.

The aim of this research project is to study the geochemical composition of the mineralised 'cores' in the reduction spheroids to facilitate our understanding of the interaction between metals and microbes in rocks. The successful applicant will receive training in multiple advanced petrographic analytical techniques, geochemistry, and geochemical analytical computer programs. There is potential for field work involving sampling, geological mapping and sedimentary logging of key stratigraphic sections.

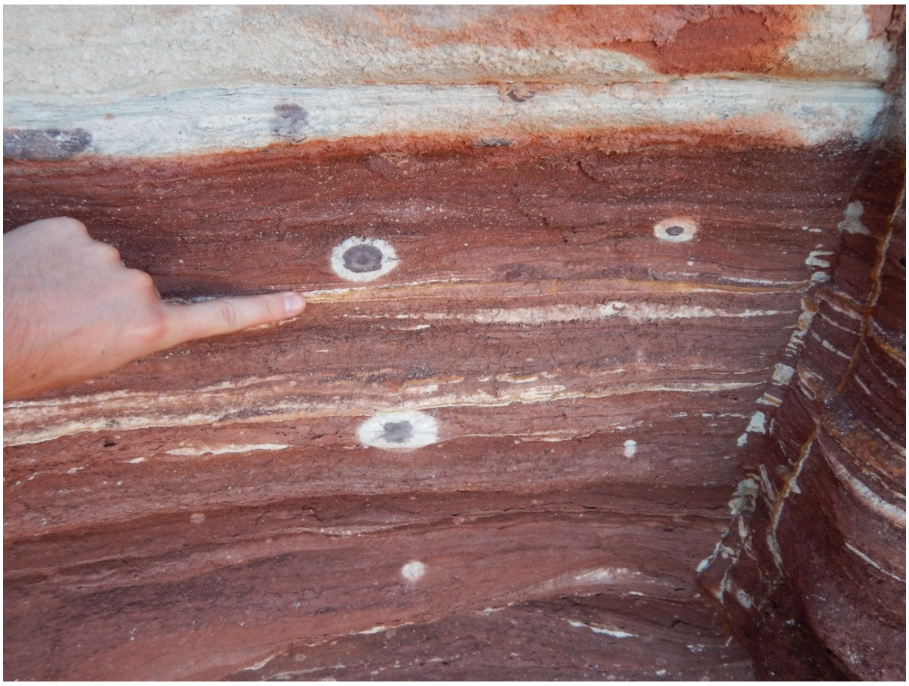

Figure 1. Core-bearing reduction spheroids from Mushroom Rock, Kalbarri NP foreshore.

Assessing Resistivity Features of Geological Targets in Regolith-Dominated Terrains: Combining Geophysical and Geological datasets

Supervisors: Ignacio González-Álvarez, Andrew King

Background and reasoning

Mineral resources demand coupled with the exhaustion of world-class ore deposit discoveries in the near surface are among the driving forces for new technologies and methodologies for mineral exploration under cover. Regolith-dominated terrains are very challenging for mineral exploration due to their lack of fresh bedrock outcrop and complexity in implementing efficient mineral exploration protocols.

Predictive models for mineral exploration under cover are most effective if they are developed within the framework of the specific mineral systems and the specific regolith cover. Generating predictive models that incorporate multi-parametric datasets (geophysical, geochemical and landscape) are much more useful for integrated interpretation than a model that draws from individual datasets.

In regolith-dominated terrains geophysical datasets such as magnetics, gravimetrics and electromagnetics have often been the main techniques for mapping basement geology and targeting before any drilling is carried out. The thick and continuous cover present in Australia, West Africa, extensive parts of South America and China promotes this approach.

This project is designed to shape an important building block towards delivering innovative approaches in the use and integration of geophysics, geology, geochemistry, drilling and landscape evolution datasets in mineral exploration.

Scope

This study will review the existing literature to assess the electrical characteristics (resistivity and induced polarization) of geological targets, and how airborne electromagnetic data can be used in different geological contexts to evaluate, predict and map lithological units at depth in terrains with deep weathering profiles and/or transported cover.

Geometallurgical Characterisation of Ni Laterites

Supervisor: Martin Wells

Significant lateral and especially vertical variation in Ni grade is known to occur within oxide-hosted lateritic Ni deposits. Changes in Ni grade, with associated textural changes in the host mineralogy, may impact the processing and recovery of Ni from these Ni deposits. This project will take an integrated approach to the geometallurgical characterisation of Ni laterites, with a focus on oxide-style deposits, such as Ravensthorpe, Western Australia. This project is aligned with DAMR's newly identified growth opportunity of bulk ore sorting/characterisation for grade enhancement.

Analytical techniques to be used include XRD analysis, XRF mapping, Hyperspectral imaging/spectroscopy in combination with geophysical data obtained using the GeoTek MSCL system, such as magnetic susceptibility, composition (pXRF), natural gamma, core density (active gamma), electrical resistivity and UV imaging. Such detailed in situ analyses will be used to assess the geometallurgical properties of lateritic nickel ores to better define, for example, the spatial variability in Ni grade and the potential to improve Ni recovery. As well as gaining experience in the application of a range of advanced characterisation techniques, through the Advanced Resource Characterisation Facilities, the student will develop a better understanding of the integrated approach required to combine multisensory data used for the geometallurgical evaluation of low-grade, nickel lateritic ores.

Mapping the 3D chemical framework of the world-class Kanowna Belle gold deposit via integrated mineralogical and C-S isotope data sets

Supervisors: Rui Wang, John Walshe, and Adam Bath

Late Archean orogenic gold deposits reflect one of the great events of gold metallogeny in Earth's history. However, despite extensive work there is still debate about the source of gold, nature of the fluid(s) and mechanisms of precipitation for these systems (Goldfarb et al., 2005). Gold deposits in the Eastern Yilgarn Craton are commonly associated with sulphide minerals such as pyrite, chalcopyrite, and arsenopyrite, consistent with gold being predominantly transported as bisulfide fluids. Transportation of gold-bisulfide complexes and gold precipitation are considered to be controlled by the fluid redox state (fO_2: e.g., Robert et al., 1995; Neumayr et al., 2008); however most studies do not collect data sets that enable redox gradients to be properly evaluated. As shown by Neumayr et al. (2008) characterization of redox patterns of gold-related hydrothermal alteration can be mapped by a combination of mineralogical and isotopic data sets. These data-sets reflect the presence of redox gradients at both the deposit and camp-scales at the world-class St Ives gold camp. However it remains unclear if these patterns are universal, and if the gradients are identifiable at other world-class deposits.

Here we propose to map and integrate newly acquired data (e.g., C isotopes, SEM mineral maps) with existing mineral data-sets (e.g., hyperspectral database and S isotopes) from the Kanowna Belle (KB) orogenic gold deposit, WA. Gold mineralization at KB is associated with Al-poor phengitic micas as well as quartz, chalcopyrite and pyrite with negative $\delta^{34}S$, whereas the distal ore-barren zone is characterized with carbonate, chlorite, muscovite, paragonite, and pyrite with positive $\delta^{34}S$. For this project, representative drill holes from KB will be selected to fully characterize the mineralogical and the redox- and pH-sensitive stable isotopes (C and S). The drill hole spectral data have been acquired using a HyLogger with high spatial resolution to show the alteration patterns. Detailed mineralogical data including sulphides and gangue minerals will be acquired with the use of Tescan TIMA (SEM) to rapidly scan materials with high quality EMPA analyses means it will be possible to develop a range of fO2 meters to map the redox change in system. Dense spatial C and S isotope sampling with advantage of mapping redox patterns of whole drill hole will be coupled with the mineralogical data. Synthesizing the mineralogical and C-S isotopic data, robust mapping of fO2 in relation to alteration patterns will lead to a scale-integrated models of gold mineral systems with capacity to determining the redox gradients within systems. Furthermore, the numerical thermodynamic modelling can better understand the physiochemical conditions, especially fO2 of ore fluids and more importantly, the mechanism of gold precipitation. This study will contribute to the promotion of mineral-system mapping in mineral exploration and help to determine if redox and/or other gradients were an important control on the precipitation of gold in the Late Archean.

References:

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Impact of grain size variations on the infrared spectral signatures of pure quartz and mixtures of quartz with iron oxides, sulphides and clays

Supervisors: Ian Lau, Carsten Laukamp

Hyperspectral infrared reflectance spectra are increasingly used in the resources sector for exploration and rapid resource characterisation, with applications ranging from hydrothermal base- and precious metal deposits to channel iron ore and BIF-hosted high-grade iron ore deposits (e.g. Haest et al., 2012; Laukamp et al., 2015). Quartz is a major mineral compound present across many deposit types, for example, as gangue mineral associated with sulphide mineralisation or iron oxides. In hydrothermal ore deposits, investigating the density and extent of quartz veining may provide insights into the formation and geological architecture of the mineral system. In iron ore deposits, silica is a deleterious material that needs to be quantified to enable an assessment of the quality and grade of iron ore. Visual inspection of the quartz abundance in drill cores, drill chips or on mine faces is highly subjective and difficult to implement in quantitative resource models.

Whilst reflectance spectroscopy has been used over the past two decades to map the presence of quartz, the impact of grain size and mixtures with other mineral phases on the known spectral signatures has not been sufficiently assessed. Grain size variations may lead to substantial scattering processes, hindering the determination of modal quartz abundance from certain wavelength ranges of the acquired reflectance spectra. Quartz-bearing mineral assemblages may exhibit significant overlaps between the respective mineral species, again complicating the interpretation. The aim of this project is to collect infrared reflectance spectra of single mineral phases (specifically iron oxides, sulphides and clay minerals) and mixtures with quartz with known modal mineral abundances at different grain sizes. By studying the above mentioned effects on different wavelength ranges, we will aim 1) to identify the required technological specifications for routine mapping of modal quartz abundances by means of reflectance spectroscopy, and 2) to develop compensation factors. During the course of the project, the student will learn various sample preparation procedures, analyse sample material using FTIR and XRD, and use related software packages for processing the collected data in a geological context.

2D and 3D toolkit for iron ore characterisation

Supervisor: Erick Ramanaidou

Rapid resource characterisation, particularly for identification and distribution mapping of both economic and contaminant phases, is becoming more important as iron ore companies now seek methods to quickly and efficiently quantify their deposit mineralogy and to address issues of declining iron ore grade. This project will focus on combining and integrating information in 2D and 3D for the characterisation of iron ore, and is aligned with DAMR's newly identified Ore Sorting Business opportunity.

Iron ore characterisation will use Raman and Reflectance spectroscopies, XRD and XRF mapping, X-Ray computed tomography and all the sensors included in the GeoTek MSCL system such as γ density, magnetic susceptibility, resistivity, pXRF and natural gamma to provide a complete *in situ* analyses of the iron ore cores. As well as gaining experience in the use and application of a range of advanced characterisation techniques, through the Advanced Resource Characterisation Facilities, the student will gain a better understanding of the integrated approach required to combine multisensory data used for the geophysical and geometallurgical evaluation of iron ore.

Chemostratigraphic characterization of Australian Sedimentary Basins

Supervisors: Susanne Schmid and Martijn Woltering

The measurement of carbon and oxygen isotopes on carbonates in sedimentary rocks gives most simple information on the depositional environment and interaction with organic matter during carbonate precipitation. Large excursions are commonly recognized globally due to worldwide events, such as volcanism that lead to temporary changes in carbon budget.

In this study the applicant has the opportunity to get familiar with the method of measuring stable isotopes at CSIRO and integrate the results into an existing framework. The task is to measure the isotopes and correlate the results with a global isotope curve. Results will also be interpreted towards depositional changes, e.g. organic carbon content and mineralogical changes. Results will provide improved understanding of isotopic changes in sedimentary basins and their potential causes.

Induced Polarization Effects in Airborne Electromagnetic Data

Supervisors: Andrew King and Ignacio González-Álvarez

Background

Depletion of near-surface ore deposits means that mineral exploration is shifting to the more-challenging problem of finding deeper orebodies under cover. We are using airborne electromagnetic (AEM) data to characterize the regolith, which relies on subtler signals than is the case for traditional EM targets. EM data is typically interpreted assuming that resistivity is frequency-independent. However, the presence of negative decays at late times in EM data indicates the presence of induced polarization (IP), i.e. frequency-dependent resistivity.

If IP is not taken into account in the data processing, then the interpretation of the AEM data could contain a significant error depending of the geological context and/or the electromagnetic properties of the ground. Induced polarization has been used in geophysics for the detection of disseminated sulphides. However, IP is also produced by the interaction of ions in pore fluids with the surfaces of the pores, especially clay minerals. It could, therefore, be used to infer something about mineralogy, pore-size distribution, and water chemistry in the regolith layers, if it can be correctly modelled.

Scope

The aim of this project is to examine decays from an airborne EM dataset where we have good geological control from drill holes, and to model those decays both with and without the effects of induced polarization. We want to better understand to what extent this can improve geological interpretation of the data, at what depths the IP effects are detectable, and whether we can use the inferred IP parameters to provide geological information such as lithology, porosity, or groundwater chemistry.

Constraining the Pressure-Temperature History of the Nunasvaara Graphite Deposit

Supervisors: Mark Pearce, Alistair White, Edward Lynch (Geological Survey of Sweden)

The Nunasvaara graphite deposit in northern Sweden is the world's highest grade graphite resource. The deposit is a metamorphosed graphitic schist hosted within a sequence of Paleoproterozoic basalts, tuffs, dolerites and sediments forming the Vittangi greenstone belt. Not only does the belt host this world-class graphite deposit, it also hosts skarn-related iron mineralization and forms part of the broader Kiruna iron-ore district.

Recent dating by the Geological Survey of Sweden (SGU) shows that the minimum age for the volcanic-sedimentary sequence is 2.14 Ga, while Nd isotopes reveal a dominantly juvenile, sub-continental mantle signature (Lynch, 2016). Sodic alteration of the greenstones is constrained by a single titanite sample at 1.9 Ga (Smith et al., 2009), which is close to the beginning of the regional metamorphism associated with the Svecofennian orogeny. Metamorphic grade in the area is poorly constrained to lower to mid amphibolite facies conditions. Preliminary modelling of a graphite-mineralized sample is consistent with this, but poorly constrained due to the high variance nature of the assemblage (Pearce et al., 2015). Since formation of graphite from organic-bearing sedimentary rocks is contingent on heating to facilitate crystallisation, understanding of the peak temperatures reached in the area affects prospectivity of the graphitic schist unit.

In this project the intern will use samples supplied by SGU to investigate the metamorphic assemblages in a range of rock types. The intern will make use of the characterisation facilities as part of the National Resource Sciences Precinct to determine mineral compositions that will constrain metamorphic modelling. Equilibrium thermodynamic modelling of the rocks will be carried out using THERMOCALC to constrain the peak metamorphic assemblages. Combining P-T estimates from a range of rock types from the Nunasvaara area will allow a more precise determination of the peak conditions that facilitated graphite mineralization.

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Assimilation of dolomite by Bushveld magmas; implications for the origin of Ni-Cu-PGE mineralization and the Precambrian atmosphere.

Supervisor: Steve Barnes

The Bushveld Complex is the world's largest Layered Mafic Intrusion (LMI) and forms the largest PGE resource globally. With increasing scarcity of such deposits and resources, refining ore-forming models is crucial to enhancing exploration success. Isotopic and trace element studies, and the abundance of dolomitic xenoliths in the intrusion suggest that contamination with country rocks may be of key importance in controlling ore formation. The intern project will investigate the mineralogy of calc-silicate xenoliths within the Bushveld and Uitkomst intrusions to provide a better quantification of the scale of contamination, using desktop microbeam XRF element mapping combined with conventional microscopy. Devolatization of dolomites can also have significant atmospheric impacts through massive degassing of CO_2. This link between large magmatic events and atmospheric change and mass extinctions has been explored in several different events including the Siberian Flood Basalts. The project has strong ties with industry, working with both Ivanplats and Nkomati mines who supplied access to the core. It dovetails with current research at CSIRO on sediment assimilation, degassing and ore formation in the Siberian Noril'sk Ni-Cu-PGE deposits. This project has strong potential for a high-impact journal publication linking ore formation, atmospheric chemistry and mass extinctions.