Massive Ni-Cu-(PGE) Sulfide Remobilization: Processes, Products, and Implications for Exploration

By Dr Paul Duuring

Introduction

Archean komatiite-hosted, Ni-Cu-(PGE) deposits are undeniably the product of primary magmatic processes. In such a situation, Ni-rich sulfides accumulate near the base of crystallizing high-temperature, low-viscosity, ultramafic magmas that intruded countryrocks or erupted as a lava. A common consequence of these primary processes is the concentration of massive sulfides and their overlying disseminated sulfides along the stratigraphic footwall margin of komatiite units (e.g., Ni deposits of Kambalda, Agnew-Wiluna belt, Superior craton).

Figure 1. Varying scales of massive sulfide remobilization: (i) Folded massive sulfide ore body at Rocky’s Reward, (ii) Slivers of komatiite enveloped by sulfide ore at Perseverance, (iii) Fragments of komatiite, felsic countryrocks, and quartz vein supported by sulfides at Perseverance

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As we enter the final stretch of 2009, it is heartening to see that a mood of optimism is starting to pervade the industry. Although many junior companies are still vulnerable to low cash reserves, the market is becoming more receptive to resource stocks, and companies are finding they are able to attract investor capital. Moreover, the industry and markets have come to the realization that the underlying drivers of minerals demand are shown to be persisting despite the global financial crisis. There is a feeling that we have seen the bottom, and that we are on the upswing.

Nowhere was this optimism more prevalent than at a recent forum “Mineral Exploration Research: linking Industry, Government and Academia” with the Hon Norman Moore MLC, Minister for Mines and Petroleum. This forum, hosted by CET, drew together leading executives of the mineral exploration industry, mineral exploration research providers, state government executives in the Department of Mines and Petroleum, and the Chief Scientist for WA Professor Lyn Beazley. The forum was designed to allow these decision makers to interact and share their respective visions for the interface between these stakeholders.

The outcome of this forum was very positive. The Minister outlined his vision for mineral exploration in WA, emphasizing that the state government is showing a strong commitment to stimulating mineral exploration and research in WA through the Exploration Incentive Scheme and support of research infrastructure. Tim Shanahan (Director, UWA Minerals and Energy Initiative) and Mark Woffenden (Director, Curtin University’s Chemistry and Resources Precinct) highlighted that WA was a global centre of excellence in Mineral Industry Research, and that the research brain trust in WA is heavily engaged with the minerals industry and committed to expanding that link in a number of strong collaborative initiatives, of which CET is one. Jon Hronsky eloquently demonstrated the mineral industry’s need to innovate to ensure future success, particularly in WA where significant discoveries will be in increasingly technically challenging environments. He also clearly demonstrated that government support of research and this industry was a wise strategic investment.

I was given the opportunity to highlight a few of the exciting ways in which CET had undertaken collaborative research with CET Corporate Member companies that has led to tangible outcomes for exploration, focusing on the development of new technologies in automated analysis of geophysical datasets, which are now being commercialized and directly applied to target identification (e.g porphyry detection in potential field datasets) and the Australia-wide uranium mineral systems prospectivity study, which has led to the identification of highly prospective areas that has led to the industry partners accumulating a significant land package to explore. Furthermore, I emphasized that CET is managing to balance academic and industry output, with two Nature and one Science paper this year, all out of industry co-funded research. The powerpoint presentations by Jon Hronsky and myself are available on CET’s Corporate Members’ website.

The Corporate Member participants were very complimentary on the forum and its outcomes. What is most heartening for me is the fact that the government, industry and universities are regarding CET as an extremely successful model for engaging industry and academia, so much so that research centres in other disciplines are adopting aspects of our model for strengthening their ties to industry.

I thank all stakeholders who participated in the successful forum. The CET recognizes that Perth, as a global centre for minerals research, has developed a significant knowledge economy. We are committed to being the top interface between this knowledge economy and the global exploration community. Our vision is that Perth will be the engine for discovery of global mineral resources, and the premier provider globally of training in the minerals industry. The CET aims to be the catalyst to enable the realisation of this vision, and forums such as this are an example of the role we see ourselves playing.

I look forward to working closely with all of you, our stakeholders, in achieving this vision.

Prof. T. Campbell McCuaig, Director
Although this magmatic model has a wide acceptance, it is not easy to reconcile the model with the occurrence of massive sulfide bodies that are isolated in deformed and metamorphosed countryrocks; the presence of massive sulfides along both margins, and throughout, komatiite units; or the concentration of sulfides in post-magmatic folds, shear zones, and faults (Fig. 1).

Recently, there has been an increased recognition and documentation of how important post-magmatic structures are in modifying the distribution and geometry of massive sulfide Ni-Cu-(PGE) bodies (e.g., Heath et al., 2001; Stone and Archibald, 2004; Stone et al., 2005; Duuring et al., 2007; Collins et al., submitted; Duuring et al., submitted); however, there are still several vital questions that need answering:

• Which structures or areas of a Ni-Cu-(PGE) deposit have the best potential to host remobilized massive sulfide ore shoots?

• What processes control massive sulfide remobilization?

• How far do massive sulfides travel away from their primary magmatic position? That is, at what distance from a known deposit does the chance of intersecting remobilized massive sulfides become negligible?

• Does the peak-metamorphic facies of a terrane influence remobilization distances?

Answers to these questions greatly influence how we interpret, explore, and mine Ni-Cu-(PGE) ore bodies. This article addresses these questions through discussing the results of detailed structural studies at the Harmony, Rocky’s Reward, and Perseverance deposits in the Agnew-Wiluna greenstone belt, Western Australia. In order to quantify maximum remobilization distances, a database was compiled that compares the characteristics of 80 massive sulfide-bearing, komatite-hosted Ni-Cu-(PGE) deposits from Western Australia, Canada, Russia, Zimbabwe, Brazil, and Vietnam.

Recognizing remobilized massive sulfide ore bodies

Before discussing the processes controlling the remobilization of massive sulfides, it is first necessary to mention how to distinguish primary from remobilized massive sulfides. Massive sulfides are interpreted to be primary if they are in their magmatic position in ultramafic rock (commonly at basal footwall contacts) and display gradational contacts with overlying matrix and/or disseminated sulfide ore (termed “contact” ore). Primary massive sulfides contain mostly pyrrhotite and pentlandite, with less pyrite and chalcopyrite, and minor magnetite, chromite, hematite, sphalerite, galena, PGE, millerite, and violarite.

Remobilized massive sulfides are identified by their occurrence in non-magmatic rocks, such as sedimentary rocks and porphyritic intrusions, and within piercement structures that cut footwall units. Remobilized ore may be inferred from its occurrence in post-magmatic structures, such as faults, shear zones, piercement structures, and fold hinges, and often by inclusions of brecciated wallrock. Remobilized ore may be massive, coarser-grained, contain brecciated wallrock clasts, or display pentlandite-pyrrophite banding, aligned asymmetric pentlandite porphyroblasts, annealed grains, kink bands, recrystallized pyrite and chalcopyrite bands, and weak foliation. Apart from brecciated wallrock clasts, the other textures are not unique to remobilized ore but are also exhibited by in situ primary ore that has been deformed and metamorphosed. Uncertainties in distinguishing primary from remobilized massive sulfides cause difficulties when using the existing literatures to quantify remobilization parameters.

Common structures that host remobilized massive sulfides in deformed Ni-Cu-(PGE) deposits

• Folds: Thin massive sulfide layers may be passively thickened by the duplication of ore layers or by the active remobilization of massive sulfides from fold limbs to hinge areas. In these cases, ore bodies tend to be elongate parallel to fold strikes or mineral stretching lineation directions. Subsequent deformation episodes may result in multiple fold generations, which complicate the overall plunge of the ore bodies, and may also lead to the disruption of folded ores by the apparent thinning and rupture of the fold limbs, or by movement along axial planes, which causes the segmentation and en echelon displacement of the massive sulfide ore bodies.

• Boudinage, attenuation, and Durchbewegung structures: Boudinage and attenuation of massive sulfide ore bodies arises from the competency contrast between an incompetent massive sulfide-rich host and more competent surrounding host rocks. During deformation, massive sulfides are remobilized and flow towards low mean stress zones that develop at boudin necks. Simple shearing along a ductile sulfide layer causes Durchbewegung (Vokes, 1973) or “ball textures”. During shearing, the more competent wallrock material is detached from the margins and incorporated into the ductile massive sulfide layer. Rolling of wallrock fragments in the highly ductile massive sulfide matrix causes rounding of the fragments, rootless folds, and pressure shadows of plastic sulfides that develop around more competent phases, such as pyrite and wallrock clasts.

• Footwall contacts, shear zones, faults, foliation, and joints: Tectonism accompanying metamorphism may cause massive sulfides to be remobilized along deformed lithological contacts, axial planar foliation to folds, and structures that transgress footwall and hanging wall contacts, including piercement cusps and piercement veins. The margins of intrusions that cut the primary basal contact are also sites for thickened massive sulfide ore.

• Areas of a deposit that have the greatest potential for remobilized massive sulfides: Footwall units are the preferred hosts to remobilized ore (relative to hanging-wall units) at most deformed deposits, owing to their proximity to primary massive sulfides that are concentrated along basal contacts of the komatite. Massive sulfides are most likely remobilized along the footwall contact away from attenuated fold limbs and towards fold hinges, or into shear zones and faults that obliquely intersect the footwall contact.
Examples of massive sulfide remobilization in the Agnew-Wiluna belt

Massive and disseminated sulfides in the Perseverance, Rocky’s Reward, and Harmony deposits in the Leinster nickel camp are mainly located in their primary magmatic position, along the steeply west-dipping, overturned, stratigraphic footwall contact to komatiite (Barnes et al., 1988; Duuring et al., 2007; Duuring et al., submitted). However, in each deposit massive sulfides have been remobilized along respective footwall contacts into several generations of fold hinge areas, as well as within shear zones that cut both komatiite and footwall countryrock units. Massive sulfides within these structures show deforming banding of pyrrhotite and pentlandite and host fragments of wallrock and quartz-carbonate veins. The presence of massive sulfides in early-formed fold hinges and late, brittle faults suggests that the sulfides were progressively remobilized during an extended deformation interval, coinciding with a range of metamorphic grades (probably from peak lower-amphibolite to lower-greenschist facies). The Perseverance 1A massive sulfide shoot extends for about a kilometre to the north of the dunite lens that hosts the main disseminated sulfide Perseverance ore body. The 1A shoot has previously been interpreted to be a direct product of magmatism (Barnes et al., 1988), but has more recently been considered to be a flattened pod of massive sulfides that accumulated in an isoclinal fold hinge during folding of the lower komatiite units of the Perseverance ultramafic complex (Fig. 2i) (Duuring et al., submitted). To the north, the Rocky’s Reward deposit hosts a multiply-folded komatiite unit that has massive sulfides mainly located along the folded footwall contact. Sulfides are preferentially concentrated in fold hinge areas and along the sheared western margin of the komatiite (Fig. 2ii). Farther north at the Harmony deposit, massive sulfides are mainly located along the footwall contact but are also present along the hanging wall margin, and internally within the komatiite. Pods of massive sulfides in komatiite probably mark remnant fold hinge positions; however, subsequent intense flattening, shearing, and attenuation of fold limbs have resulted in rootless fold hinges with thin, discontinuous fold limbs (Fig. 2iii) (Duuring et al., 2007).

Physical versus chemical processes for massive sulfide remobilization

A detailed description of the processes responsible for remobilization of Ni-Cu-(PGE) massive sulfides is given by Duuring et al. (2007). In simple terms, physical remobilization refers to the solid-state redistribution of primary Ni-Cu-(PGE) massive sulfides during deformation, whereas chemical remobilization involves the dissolution of metals and sulfur by hydrothermal fluids and their later precipitation elsewhere. Both styles of remobilization may have operated at various times during the deformation and alteration of a single deposit, resulting in the progressive redistribution of massive sulfides along lithological contacts and within developing structures that cut komatiite and nearby countryrocks. Common
evidence for physical remobilization includes the presence of pentlandite-pyrrhotite banding, countryrock clasts that are mechanically granulated (e.g., Durchbewegung textures), and sulfide mineral fractionation in remobilized ore shoots. Under most geological stress conditions chalcopyrite and pyrrhotite are more ductile than pentlandite and are remobilized greater distances, resulting in a decrease in Ni tenor and Ni:Cu ratios in remobilized massive sulfides with distance from primary ore shoots (e.g., the Edwards lode and Wannaway deposit at Kambalda, Heath et al., 2001; Seat et al., 2003). In comparison with physical remobilization, chemical processes involve the dissolution of sulfide minerals by hydrothermal fluids that are rich in H2O, CO2, and dissolved salts at temperatures greater than about 200 °C (Molnar et al., 1997). Commonly cited evidence for chemical remobilization includes an association between pentlandite and quartz-carbonate veins or with hydrothermal alteration minerals (e.g., Lesher and Keays, 1984; Farrow and Watkinson, 1997). The contrasting solubility of individual sulfide phases results in significant changes in Ni tenor, Ni:Cu ratios, and PGE ratios between primary ores and reprecipitated massive sulfides (Bavinton and Keays, 1978; Lesher and Keays, 1984; Farrow and Watkinson, 1999).

Maximum remobilization distances and relationships to metamorphic grade

Based on a comparison of maximum remobilization distances in komatiite-hosted Ni-Cu-(PGE) deposits, where remobilization distances are calculated based on piercement structure lengths (i.e., from their tips to the primary basal contact position), or the distance between primary “contact” position ore and massive sulfides hosted in countryrock, massive sulfide remobilization distances are commonly less than 50 m from primary magmatic ore positions (Fig. 3). Distances of 50 to 500 m are less common but their occurrence (e.g., Thompson deposits, Canada, Bleeker, 1990) indicates that these distances should be considered when exploring in highly deformed and metamorphosed terranes.

Figure 3. Maximum remobilization distances for massive sulfides in 27 komatiite-hosted Ni-Cu-(PGE) deposits. Note that the small number of deposits in the 0-1 m remobilization distance category might be caused by difficulties in recognizing small-scale remobilization in deposits.

Figure 4. Massive sulfide remobilization distances plotted against peak metamorphic temperatures for 24 komatiite-hosted Ni-Cu-(PGE) deposits.

Rarely are massive sulfides remobilized more than 1 km from their primary magmatic position. On average, physical remobilization appears to increase the exploration footprint of many deposits by a factor not much greater than two. Experimental deformation studies on sulfides show that high temperatures, pressures, and fluid concentrations (existing at high metamorphic grades) enhance the ductility of massive sulfides. Hence, it is proposed that massive sulfides are more likely to be remobilized greater distances in higher metamorphic facies terranes. For these reasons, maximum remobilization distances that are cited in literatures are plotted against their respective peak metamorphic temperatures (Fig. 4).

A weak positive correlation (r=0.065) exists between maximum remobilization distances and peak metamorphic facies temperatures; however, this correlation value is probably influenced by the lack of data for deposits hosted in low-grade metamorphic facies terranes. Maximum remobilization distances may also depend on the duration and intensity of deformation that a deposit experiences rather than just the effects of one metamorphic event. For example, although Mt Windarra and Maggie Hays have both undergone peak amphibolite facies metamorphism, massive sulfides at Mt Windarra are remobilized about 2 m, whereas ore at Maggie Hays has been remobilized 800 m. More examples of low-grade metamorphic deposits are required to test the effects of low metamorphic facies conditions on massive sulfide remobilization distances.

Implications for exploration

Even under relatively low deviatoric stress conditions and in the absence of a hydrothermal/metamorphic fluid, massive sulfide layers may act as the loci for deformation within a silicate-rich rock. During these episodes of deformation,
massive sulfides act like toothpaste that is squeezed into areas of low mean stress, causing the lubrication of contacts. Consequently, remobilized massive sulfide ore bodies are a common feature, and an important exploration target, in deformed and metamorphosed terranes that host primary Ni-Cu-(PGE) deposits.

Based on the survey of maximum remobilization distances for massive sulfide in komatiite-hosted Ni-Cu-(PGE) deposits, most remobilized ore bodies lie within 50 m of their primary magmatic ore position. Distances of 50 to 500 m are less common, but indicate that these distances should still be regarded as being prospective when exploring in highly deformed and metamorphosed terranes. Furthermore, the positive correlation between metamorphic grade and maximum remobilization distances suggests that massive sulfides are likely to be remobilized farther in higher metamorphic facies (and deformed) terranes.

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Progressive mixing of meteoric veneer into the early Earth’s deep mantle

- by Wolfgang D. Maier, Stephen J. Barnes, Ian H. Campbell, Marco L. Fiorentini, Petri Peltonen, Sarah-Jane Barnes & R. Hugh Smithies

The paper “Progressive mixing of meteoric veneer into the early Earth’s deep mantle” has been published this July in the prestigious science journal Nature.

This exciting study largely carried out at CET and CSIRO places new constraints on the rate of convective mantle mixing during the first half of the history of planet Earth, over 2.7 billion years ago. By focusing on the temporal variation of platinum-group element concentrations in ancient volcanic rocks - komatiites, the research provides an insight into the formation of the planet and should lead to further discoveries on the geological evolution of early Earth.

Komatiites are volcanic rocks that formed through high degrees of partial melting of the mantle. The platinum-group element (PGE) content of komatiites provides a unique source of information on core formation, mantle differentiation and core-mantle interaction.

Most of the available PGE data on komatiites are from late Archaean (2.7–2.9 billion years old) or early Proterozoic (2.0–2.5 billion years old) samples. In this study, the authors show for the first time that most early Archaean (3.5–3.2 billion years old) komatiites from the Barberton greenstone belt of South Africa and the Pilbara craton of Western Australia are depleted in PGE relative to late Archaean and younger komatiites.

The Earth’s mantle is believed to have undergone wholesale bulk depletion in PGE during core formation (at about 4.55 billion years ago), followed by progressive re-enrichment with PGE in response to addition of cosmic material from heavy meteorite bombardment, the so-called ‘late veneer’, that took place in the Hadean to Early Archaean (4.5–3.8 billion years ago).

It is widely accepted that komatiites are derived from the tails of mantle plumes sourced deep in the lower mantle, probably a thermal boundary layer that overlies the core. As a result, the observed PGE signal of the komatiites should reflect that of the deep early Archaean lower mantle. In the past numerous authors postulated that if the late veneer had not been homogenized within the mantle, material rising from the lower mantle would produce magmas poor in highly siderophile elements. Our data provide the first direct evidence for such magmas in the early Archaean.

We found that the PGE content of the plume source region rose progressively throughout the Archaean. At 4.5 billion years ago, after core formation and solidification of the mantle, the PGE content of the lower mantle was close to zero. During the following 1.5 billion years, the PGE content of the lower mantle progressively increased in response to mixing-in of late veneer into the upper mantle and transport of this material to the core-mantle boundary. By 3.2 billion years ago enough metal had trickled down to give some komatiite sources a near-chondritic composition. By 2.9 billion years ago the lower mantle had largely equilibrated with the late veneer and the PGE content was broadly similar to that of modern primitive upper mantle.
CET Projects by Location

Where are we working? – WA

Geographic location of research within Western Australia

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The Hammond - Nisbet Geoscience Fund

A fund has been established in memory of Dr Bruce Nisbet and Dr Rod Hammond, two great geoscientists who had known each other both as work colleagues and friends and tragically died within months of each other in 2006. Each had an exceptional grasp of the important connections between economic mineral and geological systems, and how those connections could be applied in exploration targeting. Bruce firmly believed that to have success in future exploration it was critical to perpetuate this learning and research methodology in a world class integrated teaching environment. The fund is aimed at providing an endowed position within the CET that will focus on mentoring the next generation of geoscientists in the integration of fieldwork structural geophysical interpretation and application to understanding mineral systems and exploration targeting. The CET is excited to be a part of this initiative and encourages all members to consider participating.

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Third year field camp at Widgiemooltha – thanks to Mincor Resources NL - by John Miller

The School of Earth and Environment relocated one of their major 3rd year mapping camps to Widgiemooltha with substantial logistical support provided by Mincor Resources NL, who currently have the Ni exploration and mine leases. Mike Dentith, Mark Barley, Aurore Joly, Heath Nelson and John Miller from the CET ran the field trip. Over 5 days 42 students mapped a sequence of ultramafic, mafic and felsic rocks that are host to major gold and nickel mines, with the Mariners Nickel deposit currently being actively mined by Mincor Resources NL. The field camp was a major success, which could not have occurred without Mincor’s support that was provided inspite of the global financial crisis that has strongly affected the base metals industry.

Prior to the field camp Peter Muccilli (Kambalda exploration manager) facilitated a field trip to assess suitable mapping areas, provided data sets to produce base maps for the students and access to their SPQ camp accommodation in Kambalda for the camp. Important field health and safety and logistical aspects were coordinated by David Chapman, the Senior Field Supervisor for Mincor. The mapping comprised of traditional mapping and sectional analysis combined with the use of hand held digital mapping tablets and GIS located data. At the start of the camp the third year students were given an induction and geological overview of the region by Senior Mincor Exploration Geologists Bede Drieberg and Martin Dormer. This was followed by a “hands on” assessment of drill core through the Mittel Nickel Ore body and they also provided handy hints on how to identify key stratigraphic units and the data sets and mapping approaches used in the minerals industry (PHOTO – HEATH HAS THESE). The students mapped spectacularly folded turbidites and also volcanic rocks with classic pillow lavas and spinifex textures (PHOTO – HEATH NEXT TO SPINIFEX). The field camp provided critical practical experience in the rock types of the Yilgarn Terrane, where many of our graduates will work in the future.

Heath Nelson (CET) next to Spinifex.

Craig, Rod and Bruce (left to right) on the shores of Lake Way near Wiluna, circa 1990
Executive Summary

This three-year collaborative industry project will improve minerals exploration decision making in West Africa (Fig. 1) via an integrated suite of research and training modules. The modules were chosen as a result of extensive discussions with industry during the first phase of the project P934: The West African Exploration Initiative - Stage 1, which ran from November 2006 to January 2008. This phase of the project founded a network of industry, geological survey and university partners and carried out an exploration audit and gaps analysis, developed an Exploration GIS and provided a number of training programs to the collaborative partners.

The second phase of the project (P934A) will run from late-2008 to late-2011 and will be driven by the desire to resolve the following three key questions:

i) What are the first order structures that divide the West African Craton into distinct mineralising domains? This implies the identification and the major structures as well as a characterisation of the styles of mineralisation for different commodities across the craton.

ii) What are the absolute and relative timing relationships between the magmatic, deformation and metamorphic events that control formation of major mineral deposits in West Africa?

iii) What are the surface processes that control the formation and modification of mineral deposits in West Africa, and how can we use our knowledge of these processes to improve exploration targeting?

These key questions will be investigated via a set of integrated research modules which are grouped into three themes (Architecture & Timing; Mineralising Systems; and Surface Processes) for convenience but will in reality address multiple objectives (Fig. 2). In addition we will continue our commitment to capacity building via a dedicated module which will oversee the organisation of a series of exploration geosciences short-courses and symposia and workshops as necessary, together with targeted support for West African Universities and Geological surveys. The project objectives are multi-commodity, reflecting the wide range of exploration priorities defined by industry for this region.

The principal deliverables of this project will be:

i) A craton-scale GIS product showing the craton-wide geophysical stitch products, sample locations, mineral deposits, and interpretative layers of structures fully attributed movement events, principal tectonic elements that control and divide domains of distinct mineralisation characteristics, and the results of prospectivity analyses.

ii) A space-time chart cross linked to the GIS showing all of the existing and newly acquired geochronological data, with summaries of crustal growth, metamorphic, deformation and mineralisation events.

iii) An understanding of the landscape evolution and surficial processes characteristic of the particular climatic setting of West Africa over the last 60 Ma that will help to define exploration strategies for a wide variety of deposit types.

iv) The training of African Geoscientists in the techniques of exploration geology via a suite of short courses over the life of the project, an annual symposium and workshops as necessary to facilitate transfer of knowledge of the outcomes of the project to sponsors.

v) The training of young African Geoscientists via a suite of MSc and PhD projects directly funded by this project or in partnership with other funding sources.

Fig. 1 Geographic Scope of P934A (SIGAfrique of West Africa)  
Fig. 2 The modules of the project
vi) The establishment of a sustainable network of industry, geological surveys and universities in West Africa that is able to respond to the short and long term requirements of the minerals industry.

The Research Modules

The currently envisaged suite of modules is shown schematically in Fig 3, below.

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**Project Team**

- Dr Mark Jessell (IRD/LMTG) - (Project Manager)
- Prof Martin Lompo (U. Ouagadougou),
- Prof Kim Hein (U. Witwatersrand)
- Prof Cam MacCuig (UWA)
- Dr Eric Gloaguen (BRGM)

**Project Funding**

As in WAXI P943 Stage 1 a four-tier sponsorship arrangement will be offered.

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**Industry Sponsors of WAXI P943**

**Stage 1 of this Initiative were:**

- Ampella Mining, Barrick Gold
- BHP Billiton, Vale
- Etruscan Resourced, Golden Star Resources, Orezone Resources, Redback Mining, Resolute Mining
- Riverstone Resources, Rio Tinto SEMAFO, Teck Cominco

**Sponsors-in-kind of WAXI Stage 1 were:**

- Bureau des Mines et de la Geologie du Burkina (BUMIGEB)
- Centre de Recherches Geologiques et Minières - Niger
- Czech Geological Survey
- Dept Mines & Geology - Togo
- Direction de la Geologie - Cote D'Ivoire
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This project, whilst encompassing a wide range of research activities, cannot undertake all the desired research and data gathering activities that were defined in the gaps analysis of WAXI Stage 1. The proposal has, however, foreshadowed additional data acquisition, research activities and training measures that would materially assist the local Geological Surveys in improving their portfolio of pre-competitive data whilst also adding to the body of knowledge that would enhance the geological understanding of the region and thus collectively improve investment inflow. Such activities will be the subject of parallel applications to be coordinated by AMIRA to international funding agencies such as the World Bank/IFC, the European Union and others as necessary once the project has commenced.
The CET has negotiated a second 12 month contract of geological mapping and target generation in the Pataz – Parcuy gold district in northern Peru with Compania Minera Poderosa S.A. (CMPSA). Beginning in April, 2009, this contract follows successful completion of a collaborative venture between CET and CMPSA in the Pataz area, from November, 2007 to November, 2008. The new project was initially designed to map the Montanitas batholith and its setting, 60 km south of Pataz. Political unrest in the area forced a reassessment of the Project. As a result, this years work will take in part of the Cenozoic Lavasen Volcanics in an area (Misquichilca) to the north of last years project area. This area is considered to have potential for porphryy-related epithermal gold mineralisation.

Last years project with CMPSA focused on granitoid-hosted gold-bearing veins in the Pataz batholith. These veins are the source of most of the 8 million ounces of gold produced from the Pataz – Parcuy district. CMPSA have developed several underground mines on these veins, which are also mined from the surface by artisanal miners. Although the company had a good knowledge of the geology in and immediately surrounding the underground mines, there was only a basic understanding of tenement areas that extend well beyond the mine sites. The CET completed geological mapping at a scale of 1:25 000 over an area of roughly 30 X 10 km (Figure 1), and this map was used as the basis for stress modeling (in collaboration with Dr Juhani Ojala) to predict areas of fracturing and exploration potential. Additionally, (i) the nature and evolution of the Pataz batholith was investigated using the results of whole-rock geochemical analysis, (ii) alteration was characterised using ASD spectral analysis of drill core samples and SEM micro-analytical techniques, and (iii) results of SHRIMP dating (3 samples) were used to constrain the age of geological events.

The classification of the Pataz gold deposits is controversial. Early models proposed a magmatic-hydrothermal origin but geochronological results indicating a 15 Ma gap between emplacement of granodiorite host rock and formation of metasomatic white mica adjacent to mineralised veins are the basis for an orogenic model proposed by Yves Haeberlin (University of Geneva) and colleagues (Haeberlin et al., 2004). The results of the CET project with CMPSA support the orogenic classification for batholith-hosted veins in the Pataz district but the project also identified a second group of deposits, which we believe to be younger and porphryy-related.

Batholith-hosted gold is hosted in metre-scale quartz-carbonate-sulphide veins, commonly zoned from laminated margins to massive or brecciated centres. Sulphides are mainly pyrite and arsenopyrite with local concentrations of sphalerite and galena. ASD spectral analysis has shown that white mica alteration halos in the granodiorite host rocks are dominated by phengite. The brittle nature of the ore-bearing structures and the associated white mica alteration imply formation at relatively shallow levels in the upper crust.

The orogenic veins are concentrated along the western margin of the batholith, where the batholith contact is formed by steep NNW-striking brittle to brittle-ductile faults (Figure 1, 2). Locally, however, an earlier ductile contact is preserved. Ductile contacts are characterised by interleaving of intrusive rocks and volcanioclastic country rock, gneissic fabrics, and S-C fabrics defined by biotite. These contacts are broadly conformable with bedding in the country rock. Flattened pillows of diorite in granodiorite lack a mineral-scale foliation and suggest that the ductile deformation may have been contemporaneous with magma mingling, and that the ductile contacts are syn-emplacement contacts. The ductile character of the contacts and the stability of biotite suggest emplacement at moderately deep crustal levels that are incompatible with the shallower formation conditions of the batholith-hosted gold-bearing veins. The observations are compatible with the geochronological data of Haeberlin et al. (2004), indicating a 15 Ma period of uplift between batholith emplacement and vein formation. This is our first argument in favour of an orogenic classification for the batholith-hosted gold deposits.

Our second argument in favour of an orogenic classification concerns the whole-rock geochemistry of samples from the Pataz batholith. Our data show early depletion of copper in both the high-SiO2 (granodiorite) and the low-SiO2 (diorite) suites of the batholith. This is interpreted to be caused by early saturation of sulphur in the batholith-forming magmas, consistent with observations of small pyrite inclusions in igneous amphibole. It is likely that chalcophile elements (including gold as well as copper) would be sequestered by crystallizing sulphide minerals. Therefore, early sulphur saturation and crystallisation of sulphides would probably cause gold to be depleted in fractionated magmas of the batholith, and in hydrothermal fluids derived from such magmas.

Our third and final argument in favour of an orogenic model for the batholith-hosted veins is the absence of widespread phyllic or potassic alteration. The batholith is quite well exposed and, for the most part, exhibits clear igneous textures and mineralogy. Fracture- and fault-controlled chlorite and epidote are widespread in the batholith. However, batholith-hosted veins are cut and offset against chloritic structures and recent observations indicate that chloritisation extends into the (?)Miocene Lavasen Volcanics to the east of the batholith. Hence, this propylitic alteration is significantly younger than the batholith-hosted gold.

Our model then for the orogenic, batholith-hosted veins at Pataz is that they formed in the late Carboniferous, when regional stress was dominated by ENE-WSW shortening. The steep NNW faults that bound the batholith on the west were poorly oriented for reactivation, such that stress was accommodated, not by fault movement, but by brittle failure and vertical extension in the adjacent, rheologically strong granodiorite. NE to ENE structures, not previously emphasized in the Pataz district, played an important role because they segmented and structurally weakened the batholith prior to vein formation.

The second group of gold deposits in the Pataz district occurs mainly at lower altitude, is mainly basement-hosted and is located at the southern end of an extensive area of argillic
alteration (Figure 2). The argillic alteration extends >10 km along the Maranon valley, north of Vijus, and is probably controlled by NNW faults, such as Falla El Cuello (Figure 3). Only the southern end of this alteration zone is accessible to the CET/CMPSA Project. Near Vijus, several arsenopyrite-rich quartz-siderite-sulphide-(barite-fluorite) veins have been recognised, most of which are located close to Falla El Cuello. Two examples of this group of deposits are hosted by an allochthonous sedimentary sequence preserved in the Chagual Graben suggesting that the argillic alteration may persist in the basement below the sedimentary sequence. These occurrences also establish a maximum late Triassic age for the mineralisation because this is when tectonic emplacement of the allochthonous sedimentary rocks occurred. Recent field work has shown that siderite-barite veins are also hosted by the Lavasen Volcanics, inferring a possible Cenozoic age for the mineralisation.

Siderite in the basement-hosted veins stands in contrast with the batholith-hosted veins, where the carbonate species are calcite or dolomite. The presence of siderite is considered significant because siderite is uncommon in orogenic gold deposits and, wherever present, generally occurs in very Fe-rich host rocks (e.g. banded iron-formation). The basement quartz-sericite schists that host the siderite-bearing veins contain only modest concentrations of iron. On the other hand, siderite is characteristic of carbonate-base metal veins within low-sulphidation porphyry-related systems (Corbett and Leach, 1998). It is concluded that argillic alteration and the basement-hosted gold-bearing veins are parts of a porphyry-related system, probably of Cenozoic age.

Our interpretation of the metallogenic history of the Pataz district proposes two periods of gold mineralisation (Figure 4). 1. Orogenic gold mineralisation formed during the late Carboniferous, following emplacement and subsequent uplift of the granodioritic and dioritic host rocks comprising the Pataz batholith. This metallogenic event took place at the end of the Gondwanide orogeny. 2. Porphyry-related gold mineralisation probably formed during the Cenozoic Andean orogeny. District-wide propylitic alteration related to this system is expressed as chlorite-(epidote) alteration on faults and fractures. Chlorite in faults and fractures that offset, internally duplicate and reactivate the margins of batholith-hosted veins (Figure 5) are considered to be part of this later, porphyry-related propylitic alteration.

Figure 1. Geology of the Pataz district.

Figure 2. Structural framework of the Pataz district showing the distribution of batholith-hosted orogenic veins and basement-hosted porphyry-related mineralisation.

Our understanding of the argillic alteration and porphyry-related mineralisation is at an early stage, compared to that of the orogenic vein system. This year’s project at Misquichilca will provide an opportunity to study the Lavasen Volcanic sequence and associated alteration and mineralisation. The presence of argillic alteration and siderite-barite veins in the Misquichilca area presents a link to the porphyry-related mineralisation in the Vijus area. In addition to geological mapping, we will carry out XRD and spectral analyses of altered volcanic and mineralised samples to better characterise the nature and origin of the argillic alteration and to determine the controls on mineralisation and generate exploration targets.

Our first trip to Misquichilca took place in June but was relatively short. Misquichilca is remote and located at 4,000 metres asl. Access is by mule, eight hours of cliff-hanging tracks, from the nearest motor vehicle access (Figure 6), and we sleep in tents as the area is located well above the nearest settlements. The area is dominated by rocky crags that push towards the sky from a damp, soggy pampa (Figure 7). Condors have been noted. Food and camping equipment have to be brought in by mule from Vijus. On the other hand, there are trout in the alpine lakes at Misquichilca.
Figure 3. Looking northwest from Vijus along the Maranon River valley showing the extensive zone of argillic alteration (white).

Figure 4. Schematic illustration of the new metallogenic model for gold mineralisation in the Pataz district.

Figure 5. Internal duplication of batholith-hosted orogenic gold veins by thrusting along chloritic faults (black). The chloritic faults are interpreted as forming part of a district-wide propylitic alteration zone related to a Cenozoic porphyry-related system.
Figure 6. The track from Vijus to Misquichilca (looking back from near Misquichilca).

Figure 7. Misquichilca with vehicle in foreground.

References


Training Schedule

2009


Dec 14  -  End of Year CET presentations to Corporate Members / Stakeholders 1 day.
Presenters: CET Staff Members.

2010

Feb 15 - 19  -  Advances in Ore Deposit Models Seminar
Leading industry representatives.

Feb 22 - 25  -  Senior Exploration Management Course.
Presenters: Jon Hronsky, Bart Suchomel, Jeff Welborn

Apr 6 - 10  -  Applied Structural Geology in Mining and Exploration (MGH course) 5 days.
Presenters: Cam McCuaig, John Miller, Aurore Joly & Nicolas Thebaud

Jul  -  Financial Risk Analysis and Real option Valuation of Mining Projects 2 - days.
Presenter: Pietro Guj

Jul 5 - 16  -  Applied Structural & Field Geology (MGM)
12 days. Presenters Cam McCuaig, John Miller. Class & Field Base Course

Sep 11 - 25  -  South Africa Field Excursion (MGM course)
Presenters: David Groves, Marco Fiorentini. 14 day field excursion.

Dec  -  End of Year CET presentations to Corporate Members / Stakeholders 1 day.
Presenters: CET Staff Members.

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While most of us were completing our tax returns for the end of financial year 2009, the MSc (Ore Deposit Geology) students had their heads down studying such things as; contextual challenges facing the exploration industry, geophysics (pre-competitive and Task specific), hyperspectral sensing and more as they participated in the “Computer- aided Exploration Techniques course at UWA Crawley Campus.

As this unit is part of the Minerals Geoscience Masters national program the CET was fortunate enough to be host to students from James Cook University, the University of Tasmania and UWA. In addition, we had several industry participants that completed small modules within the course and were congratulated with a certificate of participation for their efforts. Overall the attendance was consistent with numbers of participants per day ranging from 19 to 26 people.

The two-weeks of training commenced with Prof. T. Campbell McCuaig discussing the challenges in predicting the location of mineralization. Cam’s enthusiasm about this topic was highlighted in the students’ formal feedback. After two days of discussing the business context of exploration targeting, the CET was fortunate to have Prof. Edward Stolz from Geoscience Australia present on geophysics in exploration targeting. With hands-on computer examples and assessment there was very little time for students to enjoy a cup of coffee for the two days. All students acknowledged their enjoyment, satisfaction and exhaustion and were no doubt looking forward to a weekend of rest.

The second week commenced with an introduction to GIS with Dr. Alok Porwal (CET), Dr. Arianne Ford (CET) and Stephen Gardoll (private consultant). With refreshed bodies and minds the students moved into the ArcGIS environment with ease. The patience and supervision from all the presenters was admired by the students as each required a high level of one-on-one interaction for assessment and practical assignments.

One of the highlights to the two week course was the participation from Jigsaw Geoscience (Ian Neilson and John Beeson) and SRK Consulting (Owen Herod). Both presented the pros and cons of GocadTM and 3D GeoModeller. Both presenters engaged their audience with case studies and examples of data sets using their preferred software packages.

Next were Prof. Klaus Gessner (CET/CSIRO), Peter Schaub (CSIRO) and Prof John Miller (CET) who helped the students understand how to use numerical models as a tool for targeting, with a comprehensive example from Mt Isa highlighting the possibilities.

To conclude the two-week intensive course we decided to wrap up with a case study day which brought together many of the presenters and case studies. The purpose of this was to bring together many of the topics through their applications in real world targeting.

The Computer-aided Exploration Techniques course has transformed from an software usage course into a more holistic approach to targeting which engages students in real life mineral targeting challenges and helps them identify the use of appropriate software to address these problems. Although an intense two weeks, there were extremely satisfied students coming out at the end. Many students were mentally challenged by some of the concepts and openly enjoyed this aspect of the course overall. Once again, a successful outcome for another MGM unit and a rewarding experience for presenters and students alike.

Cindi Mispagel, CET Training Coordinator
COURSE CONTENT INCLUDES SUCH ITEMS AS:

- **Introduction to Mineral Systems**
  - What are mineral systems?
  - The difference between mineral deposits and mineral systems
  - The application to mineral exploration

- **Gold Mineralisation**
  - An overview of the formation of world class gold systems with examples from Archean gold systems of the Yilgarn.
  - Lithospheric-scale controls on the locations of gold systems
  - The Orogenic Gold Model
  - Mantle controls and fluid mixing models for Archean gold systems
  - Diversity in deposit styles – the Archean gold systems of the Yilgarn Craton

- **pmd*CRC**
  - Reactive transport: from geochemistry to geophysics to targets
  - Architectural camp-scale comparisons
  - Targeting across the scales-the practical application
  - Case study: Eastern Yilgarn; St Ives

- **Nickel Mineralisation**
  - Magmatic Ni-Cu-PGE deposits
  - Geodynamic setting of magmatic Ni-Cu-PGE deposits
  - Metal Source
  - Magma transport and trap
  - Application of lithogeochemistry to exploration (Tenor, assimilation, PGE, Ni depletion, chromite)

- **Uranium**
  - Overview of uranium mineral systems
  - Uranium in various geological environments
  - Australian perspectives

- **Iron Ore Mineralisation**
  - Iron mineralisation
  - BIF
  - Hydrothermally altered BIF
  - BIF related iron ore
  - Case studies-Australia and global
## PROGRAM OUTLINE

### Module ONE

**INTRODUCTION TO MINERAL SYSTEMS - 2nd Nov 09**

The term ‘mineral systems’ is used frequently throughout industry and academic geoscientists today, but the applications of the approach to understanding and applying mineral systems concepts varies dramatically. This day will focus on providing participants with an overview of the difference between mineral deposits, mineral systems and various ways we apply these concepts to mineral exploration.

### Module TWO

**GOLD MINERALISATION - 3rd & 4th Nov 09**

This day will provide an overview of the formation of World class gold systems. The day will consist of a series of presentations that will cover a range of models for the formation of major gold systems and an overview of the diversity within a particular deposit type (i.e. the Archean gold systems of the Yilgarn will be used as an example), and some examples of cutting edge technologies currently applied to the study of the gold systems addressed. The day will finish with talks highlighting the formation of gold deposits within a minerals systems framework. The course will address regional to deposit-scale structural controls on the formation of World Class Archean Gold deposits.

**pmd*CRC - 5th & 6th Nov 09**

The major research outcomes of the recently completed pmd*CRC research program applied to the gold systems of the Yilgarn will be covered. These two days will address the new research outcomes on the Geodynamics, Architecture, Reservoirs, Pathways & Drivers and Depositional Mechanisms controlling gold deposits within this terrane. There will be a focus on architectural camp-scale comparisons of Laverton and St Ives. The program will be completed by examples of predictive exploration targeting across various scales (1000x1000km, 60x60 km, 5x5 km).

### Module THREE

**NICKEL MINERALISATION - 9th & 10th Nov 09**

This course will provide an overview of Ni-Cu, oxide, and PGE deposits. Day 1 will follow a mineral systems approach outlining the essential processes in description and ore genesis at a range of scales. Day 2 will overview practical predictive, and geological and geochemical detective methodologies in exploration for Ni-Cu-PGE deposits utilising the theory from Day 1. Practical hand specimen from the CET’s world class collection and generative exercises will form an important component of both days.

### Module FOUR

**URANIUM - 11th Nov 09**

This day will focus on providing participants with a broad overview of uranium mineral systems. The morning will focus on the behavior of uranium in various geological environments, including potential source rocks, how uranium is released from its source rocks, under what conditions it can be transported, and depositional triggers to concentrate it in the earth’s crust in economic concentrations. The second half of the day will provide a detailed look at uranium mineral systems from an Australian perspective, and how uranium mineral systems can be effectively translated into exploration systems.

### Module FIVE

**IRON ORE MINERALISATION - 12th & 13th Nov 09**

This 2-day course will be “hands-on” with a combination of talks and exercises involving hand samples, thin- and polished sections from least altered (protolith) BIF, hydrothermally altered BIF (protore), BIF-related iron ore (both low- and high-grade ore), maps, cross- and long-sections. The first day will start with a brief overview of BIF-related Fe mineralisation in Western Australia (both Hamersley Basin and Yilgarn craton) and other major iron ore producing countries such as Brazil, India and South Africa. This will be followed by hands-on exercises. The second day will start with detailed talks about the Carajas iron ore deposits presented by Prof. Lydia Lobato from the Universidade Federal Minas Gerais in Brazil. Prof. Lobato is the world-specialist on iron ore in Carajas and will bring with her selected ore samples and sections from Carajas. The second talk will be presented by Dr. Thomas Angerer who is currently a postdoctoral fellow at the CET studying the Koolyanobbing iron ore deposits. Both talks will be followed by more exercises involving ore, protore and hydrothermal altered rocks and sections from both the Carajas and Koolyanobbing iron ore deposits. The final part of the short course will deal with advances in geochemical and geophysical exploration of BIF-related iron ore deposits.
Dr. Pietro Guj is Associate Professor in Mineral Economics at Curtin University’s Western Australian School of Mines (WASM) and Leader of the “Progressive value and risk analysis” research theme at the Centre for Exploration Targeting (CET).

Pietro was born in Rome where he lived and studied for his degree of Dottore in Geologia. After graduation in the early 60s his love of mountains drew him to the Hindu Kush in Afghanistan and Pakistan for about two years before joining the Geological Survey of South Africa and then of Namibia, where he mapped and carried out structural geology research on the Pre-Cambrian Damara mobile belt. This was later the subject of a PhD degree at the University of Cape Town.

Attracted by the nickel boom he moved to Western Australia in 1970 as Senior Geologist for MIM Holding Ltd. gaining over 15 years experience in the exploration for, valuation and management of nickel, base metals, gold and iron ore projects. During this period he was also awarded an MBA at the University of Western Australia.

This was followed by 7 years as a finance executive for the Water Authority of WA where he had primary responsibility for the formulation of financial plans, policy and strategies for recurrent income, expenditure and capital investments amounting to some $650 million per annum. He was also responsible for pricing and tariff policy reform and for the related, politically sensitive negotiations with the Board, Minister and Treasury during the process leading to corporatisation of this Authority.

Prior to joining WASM Pietro was the Deputy Director-General of the Western Australian (WA) Department of Minerals and Energy (DME) (1997-2002), following 5 years as Director of the Geological Survey of WA. While at DME he played a key role in supporting and regulating the exploration, mining and petroleum industry in WA including administering mineral and petroleum royalty policy and collection.

He has a special interest in the area of public policy, particularly the international competitiveness of mining regulatory and fiscal regimes, in the financial evaluation of exploration and mining projects, and risk and decision analyses, topics in which he has published and consulted widely in Australia and internationally.

Prior to 2006, she worked in the areas of computer vision and graphics for specific projects on automatic human motion understanding and motion visualisation with Professor Robyn Owens within the School of Computer Science & Software Engineering. One of the research outcomes was public domain software called the Auslan Tuition System that helps people learn Australian sign language using an effective real-time graphics. It was released on the Internet in 2004 and currently has more than 2200 registered users around the world. This system won a Commendation in the Innovation Category of the 14th WA Information Technology and Telecommunications Awards (WAITTA) in 2004.

Cindi Mispagel

Cindi Mispagel started at the CET as a SHRIMP (Sensitive High Resolution Ion Microprobe) technician who was mentored by Dr. Ian Fletcher and Dr. Neal McNaughton. After one year half-time, she took the leap into a more administrative role as the UWA MSc coordinator for the Minerals Geoscience Masters national program. Now coming up to her second year in this position she has endeavoured to be involved in a larger coordinating role. She has been important in assisting in the development and coordination of some of the CET’s industry courses and assisted in ensuring the enrolment of new and existing MSc students into UWA units. This path is a long way from her original degree in Marine and Freshwater Science from Deakin University in Victoria. After her successful completion of her honours year in environmental science, she commenced her PhD in the same discipline concentrating on Endocrine Disruptors in Wastewater. After a slight diversion (a baby girl), her decision to move into a MPhil was helped along by a very empathetic supervisor. She is pending the results of her thesis as we write!

Cindi has moved from one discipline to another and in spite of her career change has assisted with changes in the CET, and been a valuable employee to the centre. And now at the end of her third year employment, she has an even bigger challenge ahead. Marriage!

Cindi Mispagel
Marein Parra is a PhD candidate at the School of Earth and Environment and CET supported by IPRS scholarship of Australia and project funding through the Geological Survey of Western Australia. Before coming to UWA in February 2009 Marein worked in the Venezuelan Petroleum Industry (PDVSA) during seven years, as an exploration geologist. Marein obtained her MSc. (2006) at Simon Bolivar University (Caracas, Venezuela) and her Bachelor degree in Geology at the Central University of Venezuela (Caracas, Venezuela).

Marein is currently developing her research project in the Canning Basin of WA. The main objective of the study is to identify the temporal and spatial relationships between the elements and processes of the petroleum systems of the western part of the Canning Basin, in order to improve the understanding of the hydrocarbon potential of the basin and to support the formulation of further exploratory strategies. This project is co-supervised by Professor Michael Dentith (CET), Associate Professor Annette George (School of Earth and Environment) and Professor Peter Cawood (School of Earth and Environment).

The Canning Basin of WA is the least explored Palaeozoic basin in the world, with 267 wells, far less than one well/1000km2, and 2860 KBBbl of cumulative production and remanent reserves (Department of Mines and Petroleum, 2009). There is a great potential for finding commercial hydrocarbon accumulations in the Canning Basin, considering that four petroleum systems have been already identified and correlated with multiple oil and gas shows and production tests on wells across the basin. In this research project the seismic interpretation of regional sections across the western Canning Basin will be integrated with stratigraphical and geochemical information from wells to develop a sequential structural evolution through time. This evolution will be the foundation for a 3D basin modelling exercise that will take into account the timing of the different processes involved in the petroleum system. The results of the basin modelling will highlight areas with hydrocarbon potential and therefore will be a tool for defining further strategies of exploration.

Marien Parra

Shih Ching has been working as a Research Associate within the Geophysics and Image Analysis group at CET since April 2008. Previously, he worked as a part-time research assistant within the group. Shih Ching’s expertise is in computer vision and is currently completing a PhD in Computer Vision at UWA, with a project that examines the use of first-order derivatives of optical flow for robust estimation and interpretation of 3D scene structure.

At CET, his research focus is on developing methods to complement and enhance existing approaches to geophysical data interpretation. He works with Prof. Mike Dentith and Dr. Eun-Jung Holden, and his research projects include: automated clast size distribution detection from borehole televiewer imagery; copper-gold porphyry signatures detection within aeromagnetic data; and the development of image enhancement tools for distribution as third-party plugins into an existing geophysical spatial data processing software.

Shih Ching
The coursework Masters program is designed for geoscientists who want to gain up to date knowledge and skills in economic geology and mineral exploration. The course at UWA is part of the national Minerals Geoscience Masters program and is supported by the Minerals Council of Australia. The program is run jointly between the Centre for Exploration Targeting (UWA), CODES (UTAS), EGRU (JCU) and Curtin University of Technology (CUT).

The Masters course can be completed in three ways:

Option 1 - (8 coursework units) Eight units of course work: at least two of which must be undertaken at UWA. The other units are done at UWA or at the other participating universities.

Option 2 - (6 coursework units + dissertation) Six units of course work and a dissertation (25% of overall assessment). Two of the units must be completed at UWA.

Option 3 - (3 coursework units + thesis) Three coursework units and a thesis which accounts for 62.5% of the overall assessment. The thesis is similar to an honours project in scope.

Courses offered by the CET:

- Ore Deposit Conceptual Models, Nov 2009
- Applied Structural & Field Geology, Jul 2010
- South African Ore Deposits Field Excursion, Nov 2010

Contact Information

If you would like to find out more about the CET, its Corporate Membership program, Applied Research opportunities or Training possibilities, please contact:

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