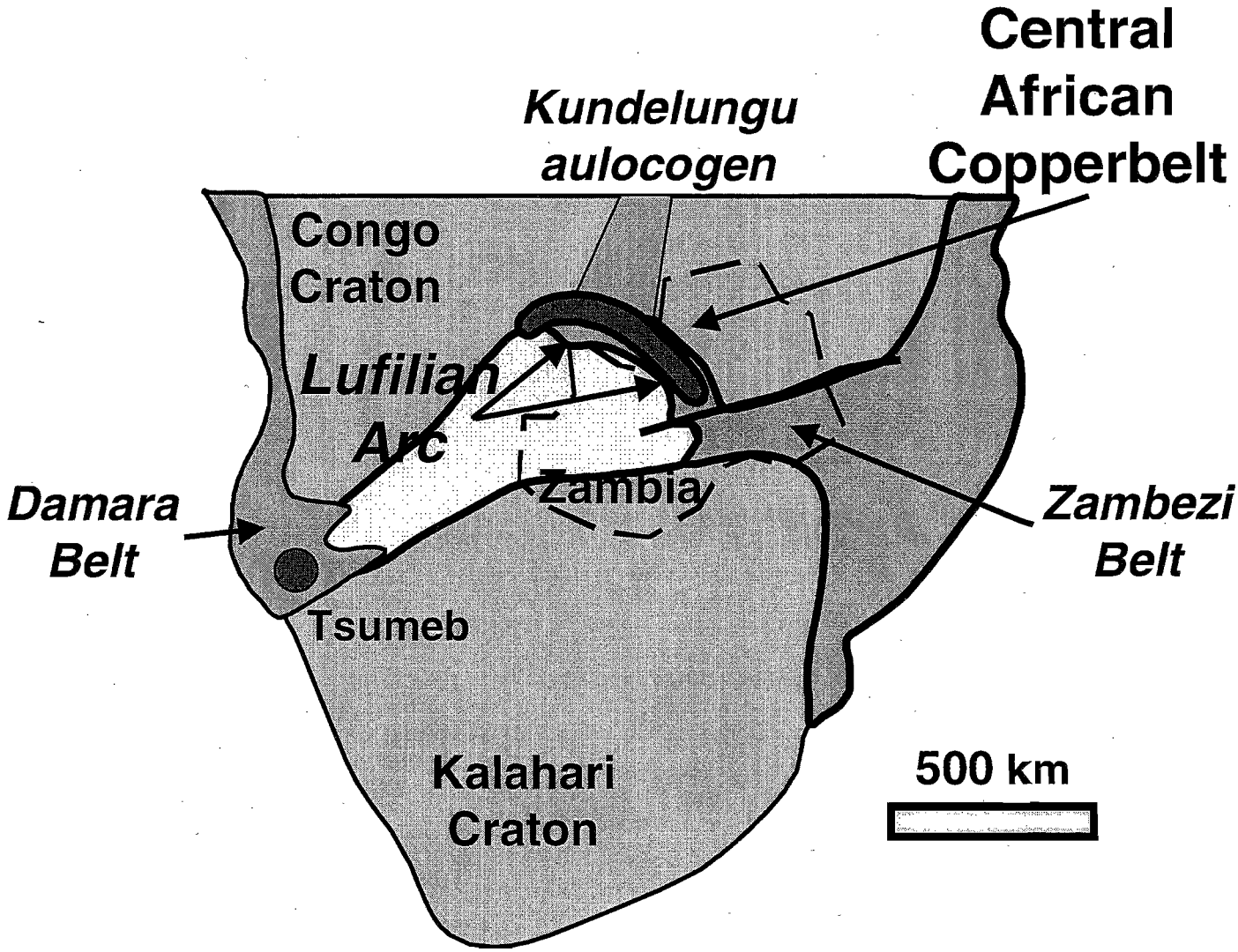
PMcG

Proterozoic Sediment-Hosted Copper Deposits



Centre for Ore Deposit Research & Colorado School of Mines

Initial Meeting
July 2000

AMIRA P544

AMIRA International

Australian Mineral Industries Research Association Limited ACN 004 448 266

AGENDA

P544 – Proterozoic Sediment-hosted Copper Deposits

First Sponsors Review Meeting

Friday 14 July 2000

10:30am - 4:30pm

CODES - Conference Room
University of Tasmania
HOBART

10:30 am	Welcome and introduction	***Alan Goode***
10:40 am	Introduction and background to CODES SRC	***Ross Large***
10:50am	Introduction to Colorado School of Mines	***Murray Hitzman***
11:00am	Geological background to the Zambian Copperbelt	***Murray Hitzman***
11:45am	Geology & relevance of the Kansanshi deposit to the Zambian Copperbelt	***David Broughton***
12.00am	Introduction to P544	***Peter McGoldrick***
12.15am	Zambian work for P544	***Murray Hitzman et al***
1:00 pm	***Lunch***	
2.00 pm	Background and work planned for South Australia	***Peter McGoldrick al.***
2:20 pm	Background & work plan for Queensland/NT	***David Cooke et al.***
14.40	Gunpowder PhD project	Darryl Clark
15:00	Timetable & Budget	Ross Large
15:15	Discussion	
16:30	Close	

AMIRA International

Australian Mineral Industries Research Association Limited ACN 004 448 266

ATTENDANCE

P544 – Proterozoic Sediment-hosted Copper Deposits

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University of Tasmania
HOBART

Company	Representative
Anglo American	John Landmark ~~Owen Bavinton~~
Anglovaal Mining	Marcus Tomkinson
BHP Minerals	Doug Haynes Kirby Johnson
Billiton	David First — ? Isa/McArthur preference Hugh Bresser
Inco Limited	David Burrows
M.I.M. Exploration	Mark McGeough Rick Valenta
North Limited	Andrew Allan
Outokumpu Mining	Ian Neuss
Phelps Dodge Australasia Inc	Russell Fountain
Primary Industries & Resources S.A.	Stuart Robertson
Rio Tinto	Ross Andrew — to recognise other Copperbelt potential areas

	Straits Resources ~~Nicky Marcochydore~~	Bruce Hooper
	WMC Resources	Howard Golden
	Zamanglo Prospecting	~~Nick Franey~~
	CODES	Stuart Bull Peter McGoldrick Ross Large Gary Davidson David Cooke Darryl Clark David Selley Jianwen Yang Robert Scott
	Colorado School of Mines	Murray Hitzman David Broughton
	AMIRA International	Alan Goode
Apologies		
	Teck Corporation	Wayne Spilsbury

Centre for Ore Deposit Research
University of Tasmania

Supported by the Australian Research Council
and the Minerals Industry

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CODES statistics 1999/00

- 22 research staff
- 37 PhD, 37 MSc, 20 Hons students
- Annual budget : $3.1 million
- 11 Corporate Sponsors
- 40 Major research Projects

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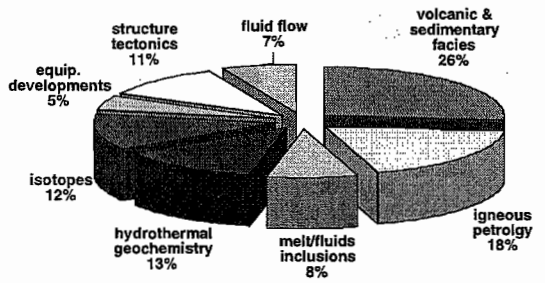
Fundamental research categories



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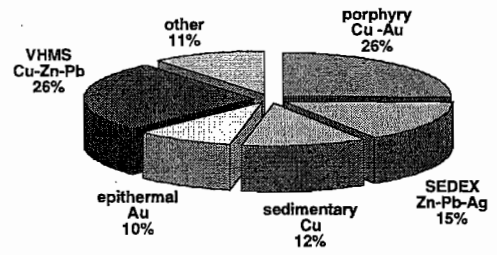
Applied research categories



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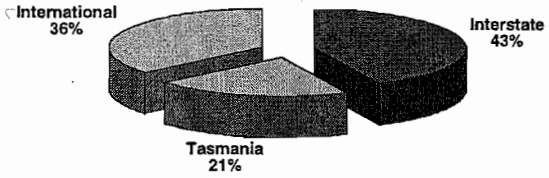
CODES Research Focus 1999



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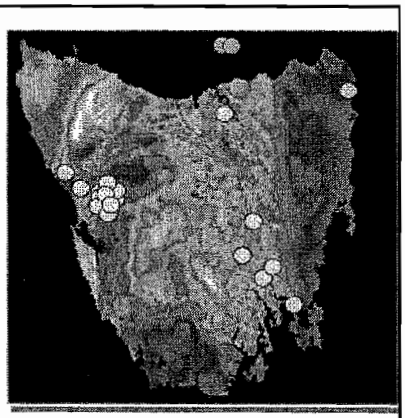
Tasmanian Projects 21%



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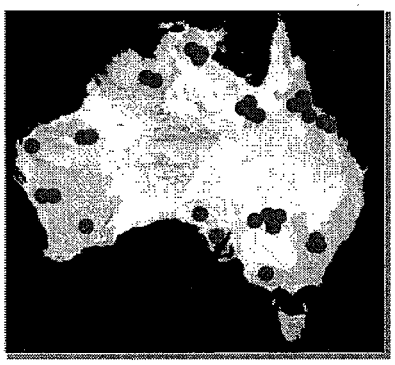
Interstate Research Projects 43%



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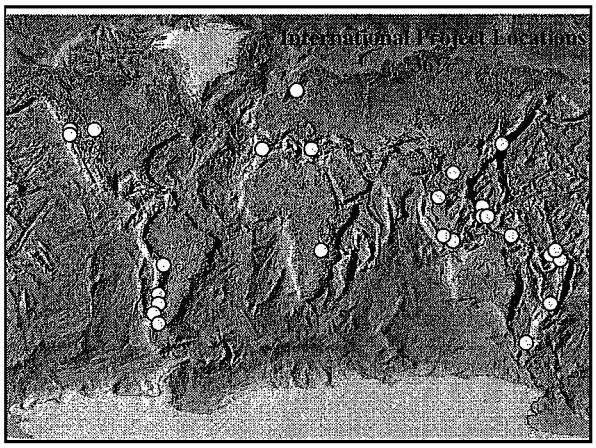

RESEARCH PROGRAMS

Program 2
Volcanic architecture

Program1
Tectonics, magmas and fluids

Program 3
Ores in volcanic arcs

Program 5
Hydrology and chemistry of hydrothermal systems

Program 4
Ores in continental rifts

Multiclient Research Projects

- **Team based research**
- **Multidisciplinary approach**
- **Combine expertise in tectonics, structure, volcanology, sedimentology, geochemistry, isotopes , fluid flow and ore deposits**
- **Projects focused on world class districts and related deposits**
- **Commonly funded by AMIRA and ARC SPIRT**

AMIRA P544

AMIRA/SPIRT Projects recently completed

- **Stratiform Sediment Hosted Zn-Pb-Ag deposits, AMIRA P384A**
  - Leaders : Ross Large, Peter McGoldrick and Stuart Bull
- **Alteration vectors related to VHMS deposits, AMIRA P439**
  - Leaders : Ross Large, Bruce Gemmell and Jocelyn McPhie

AMIRA P544

AMIRA/SPIRT Projects started 1998

- **Giant Porphyry Cu/Au systems in South America - CODES, CSIRO, UWA : AMIRA P511**
  - Leaders : David Cooke & John Walshe
- **Fluid Flow in the Mt Isa basin related to Zn-Pb-Ag deposits - AGSO, UQ, Queens U, CODES, CSIRO : AMIRA P552**
  - Leaders :Peter Southgate , Stu Bull, Jianwen Yang
- **Scale dependent electrical properties of sulfide rocks**
  - Leader : Mike Roach
- **Ordovician volcanics hosting porphyry Cu-Au, NSW**
  - Leaders : Tony Crawford and Dick Glenn (NSWGS)

AMIRA P544

New AMIRA and/or SPIRT Projects 1999

- **Deposit halos and exploration vectors for epithermal Au-Ag deposits - Bruce Gemmell and Stuart Simmons (Auk.U NZ) : AMIRA P588**
- **SE Asia tectonics and metallogenesis, southern China - Khin Zaw and Clive Burrett : AMIRA P603**
- **Ranking alteration zones in submarine volcanic terrains using stable and radiogenic isotopes; Case study of the MRV - Garry Davidson , Walley Herrmann, Ross Large, MRT : ARC SPIRT**

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AMIRA and/or ARC SPIRT proposals 2000

- **Proterozoic sedimentary copper deposits - Zambia and Australia : AMIRA P544**
  - leaders - Peter McGoldrick, Murray Hitzman (CSM) and Stuart Bull
- **Laser ablation ICP-MS technology applied to mineral exploration**
  - leaders - Marc Norman, Peter McGoldrick, Yongshu Yu

AMIRA P544

AMIRA Project P544
Proterozoic Sediment-Hosted Copper Deposits
(Zambian Segment)

Dr. Murray W. Hitzman & David Broughton
Colorado School of Mines, Golden, CO USA

AMIRA P544

CSM Strengths

- Largest economic geology program in USA — 5 professors directly involved in economic geology research; currently 27 economic geology graduate students
- One of top 5 schools in North America in petroleum geology/basin analysis
- Vast experience in fold and thrust belt tectonics (CSM faculty + faculty at nearby CU and CSU)
- Excellent research equipment and access to state of the art USGS laboratory in Denver

AMIRA P544

CSM Strengths

- Close relationship of school with industry — over 90% of research industry funded
- All company supported research projects require company personnel as members of students research committee
- Core economic geology program emphasizes field skills through field methods course (underground mapping; alteration mapping; core logging) as well as allied skills (exploration geophysics, exploration geochemistry, mineral economics)
- Special programs in English and communication skills in place for foreign students

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Current CSM Research in the Proterozoic of Zambia - Student Theses

- **Geology of the Kansanshi Deposit —**
  - Heidie Torrealday (M.Sc.) completed 5/00
  - Support from Cyprus Amax
- **Stratigraphy, Structural Geology, Airborne Geophysics, and Economic Geology of the Solwezi Region —**
  - James Barron (Ph.D.) completion 12/01
  - Support from Cyprus Amax and Phelps Dodge

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Current Research in the Proterozoic of Zambia - M. Hitzman Projects

- **Metamorphic petrology of the Copperbelt** — *ongoing*
- **Chambishi geology** — *initial fieldwork, petrology, and preliminary sulfur isotopic work completed*
- **Mass balance study of Copperbelt source rocks (basal red beds)** — *manuscript in press*
- **Sulfur isotopic systematics of anhydrite in the Katangan sequence in the Copperbelt** — *ongoing*

- **Olympic Dam-type Fe oxide-Cu-Au deposits, central Zambia** — *ongoing (initial work with Billiton)*
- **Kabwe sphalerite-willemite orebody genesis** — *ongoing (initial work with Billiton)*

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Research in the Proterozoic of Zambia - Directly Allied Projects in Other Areas

- **High salinity metamorphic brines and mineralization** — *project initiated in the Grenville terrane of US/ eastern Canada*
- **Lisbon Valley Project** — *multi-year investigation of undeformed Cretaceous red bed copper system (Utah-Colorado) involving integrated deposit and regional studies of geology, geophysics, and geochemistry*
- **Olympic Dam-type Fe oxide-Cu-Au deposits** — *ongoing research and student projects in Canada, Chile, and Argentina*
- **Genesis and exploration criteria for zinc oxide and zinc silicate deposits** — *ongoing with research at Vazante, Brazil and Balmat-Edwards, N.Y.*

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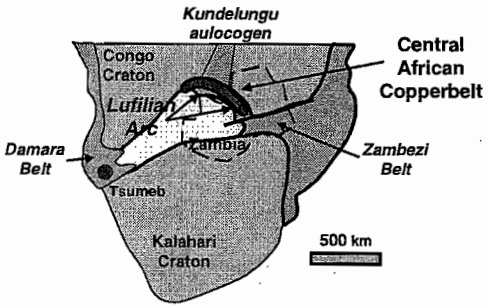
new structurally controlled deposit ~ 15 year life

Pan-African Tectonic Framework — Southern Africa



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Pan-African Tectonic Framework — Southern Africa

- The Central African Copperbelt is located within a Pan African fold and thrust belt (Lufilian Arc) that is an extension of the Damara Belt. Intervening area covered by Kalahari sands.
- These Pan-African structural belts appear to be rift zones which have subsequently undergone tectonic collapse.
- The Copperbelt occurs at an apparent paleo-triple junction. The Kundelungu aulcogen to the north is undeformed.

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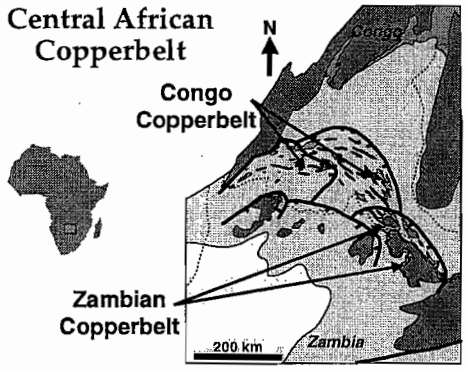
Central African Copperbelt



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Central African Copperbelt

- Rivals Chile as world's largest Cu province
- Contains >170 Mt of Cu metal; >5 Mt Co metal
- Produced 17% of western world's Cu in 1980's; currently produces <5% of world Cu
- World's most important source of Co

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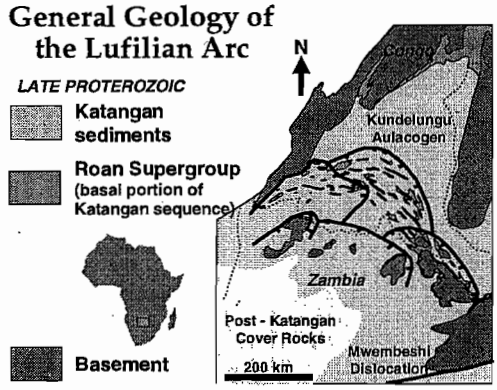
General Geology of the Lufilian Arc



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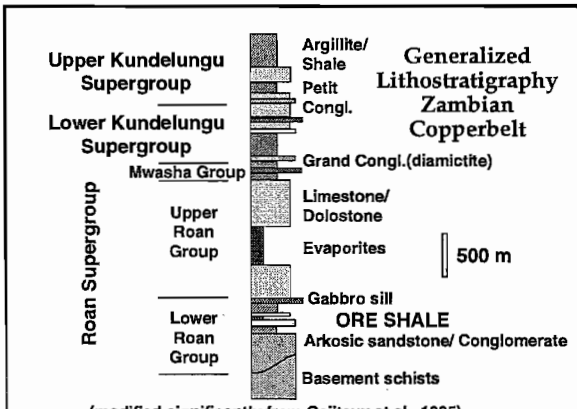
Generalized Lithostratigraphy Zambian Copperbelt



(modified significantly from Cailteux et al., 1995)

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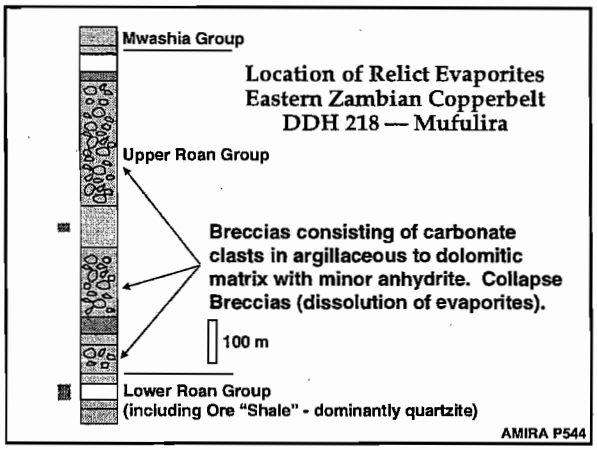
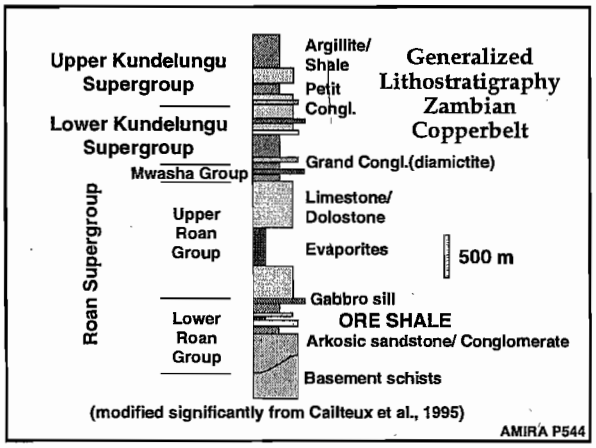
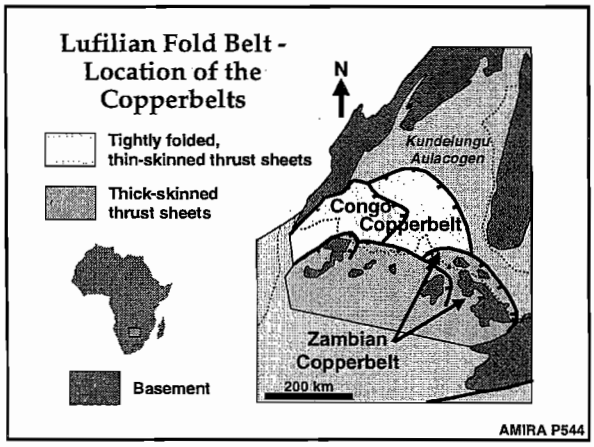
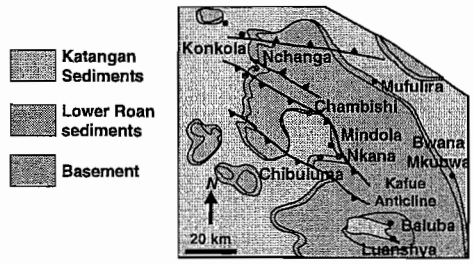

Mwashia Group
Location of Relict Evaporites
Eastern Zambian Copperbelt
DDH 218 — Mufulira
Upper Roan Group
Breccias consisting of carbonate clasts in argillaceous to dolomitic matrix with minor anhydrite. Collapse Breccias (dissolution of evaporites).
100 m
Lower Roan Group
(including Ore "Shale" - dominantly quartzite)
AMIRA P544


Upper Kundelungu Supergroup
Lower Kundelungu Supergroup
Mwasha Group
Roan Supergroup
Upper Roan Group
Lower Roan Group
Argillite/ Shale
Petit Congl.
Generalized Lithostratigraphy Zambian Copperbelt
Grand Congl.(diamictite)
Limestone/ Dolostone
Evaporites
500 m
Gabbro sill
ORE SHALE
Arkosic sandstone/ Conglomerate
Basement schists
(modified significantly from Cailteux et al., 1995)
AMIRA P544

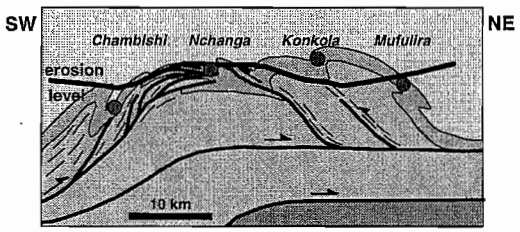

Lufilian Fold Belt - Location of the Copperbelts
Tightly folded, thin-skinned thrust sheets
Thick-skinned thrust sheets
Basement
N
Kundelungu Aulacogen
Congo Copperbelt
Zambian Copperbelt
200 km
AMIRA P544

Zambian Copperbelt



AMIRA P544

Schematic Cross Section Across the Kafue Anticline Showing Present-day Erosion Level



modified from Coward & Daly, 1984

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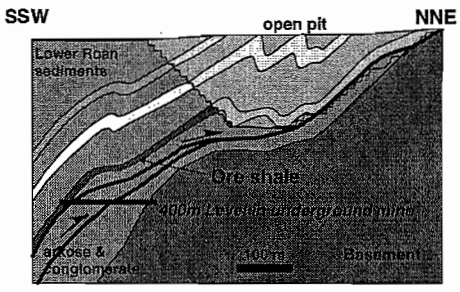
Cross Section — Chambishi Mine



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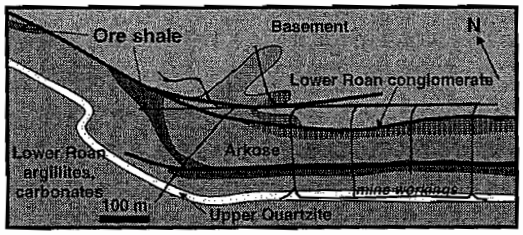
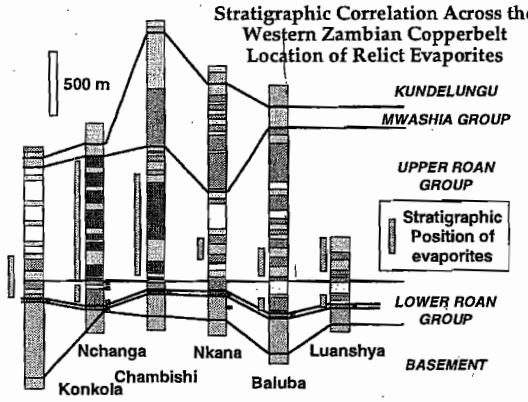
Geologic Plan Map 400m Level — Chambishi Mine



AMIRA P544

Stratigraphic Correlation Across the Western Zambian Copperbelt Location of Relict Evaporites



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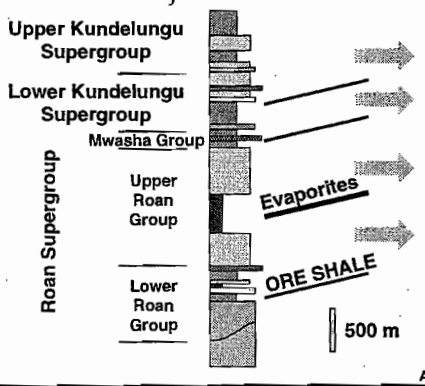
Location of Major Dislocation Surfaces



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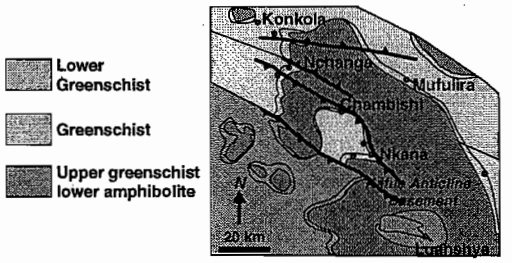
Metamorphic Grade of Lower Roan — Zambian Copperbelt



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Metamorphism of the Lower Roan "Ore shale" in the Zambian Copperbelt

East (NE) Zone

(Konkola & Mufulira deposits)

- Low greenschist phyllitic texture dominant.
- Mineral assemblage consists of: quartz - muscovite - feldspar - calcite - (biotite).
- Mica grain size is generally $\leq$ 0.1mm.
- Little recrystallization of detrital quartz and feldspar grains.
- Sulfides are generally recrystallized.

AMIRA P544

Metamorphism of the Lower Roan "Ore shale" in the Zambian Copperbelt

Central Zone

(Nchanga, Chambishi, Nkana deposits)

- Greenschist phyllitic to schistose texture dominant.
- Mineral assemblage consists of: quartz - biotite - muscovite - feldspar - calcite - (scapolite) - (dolomite).
- Mica grain size is generally $\geq$ 0.25mm.
- Detrital quartz grains are generally completely recrystallized; moderate recrystallization or destruction of detrital feldspar grains.
- Sulfides are recrystallized.

AMIRA P544

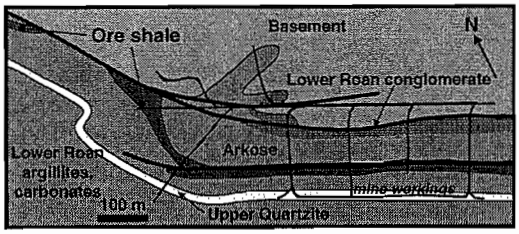
Metamorphism of the Lower Roan "Ore shale" in the Zambian Copperbelt

West (SW) Zone
(Luanshya deposit)

- Upper greenschist schistose texture dominant.
- Mineral assemblage consists of: quartz - biotite - muscovite - scapolite - (feldspar) - (actinolite/hornblende) - (talc) - (garnet).
- Retrograde chlorite relatively common.
- Mica grain size is generally $\geq$ 0.4mm.
- Detrital quartz and feldspar grains are completely recrystallized.
- Sulfides are recrystallized.

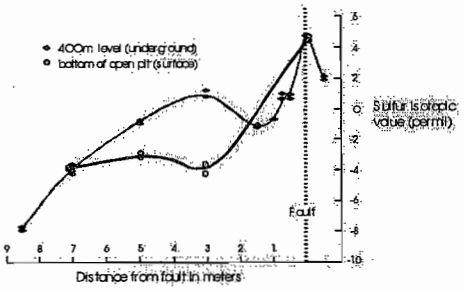
AMIRA P544

Geologic Plan Map 400m Level — Chambishi Mine



AMIRA P544

Sulfur Isotopic Value of Chalcopyrite in Ore Shale Adjacent to Low Angle Fault - Chambishi Mine



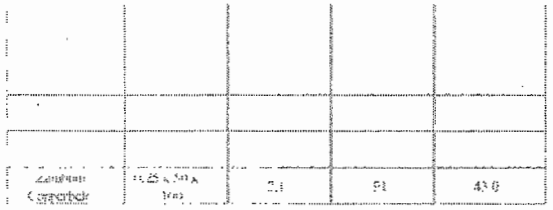
AMIRA P544

Sulfur Isotopic Value of Chalcopyrite in Ore Shale Adjacent to Low Angle Fault - Chambishi Mine

- Isotopic values are heavy (+4 to +5 permil) within fault zone
- Values decrease to -8 permil within 10m of fault zone
- Sulfur isotopic values of pyrite above mineralized ore shale are typically negative (-5 to -7 permil)
- Sulfur isotopic values of anhydrite at Chambishi are +20.5 to +22.6 permil (throughout Copperbelt values range from +11 to +23 permil)

AMIRA P544

Volumes and Calculated Average Cu Grades of Different Sediment-hosted Copper Deposit Source Basins



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Source of Copper

- Large thicknesses of red beds and subaerial mafic volcanic rocks stratigraphically below the ore horizon are assumed to be the source beds in most sediment-hosted stratiform copper districts (Rotliegende - Kupferschiefer; Copper Harbor Conglomerate - White Pine).
- Lower Roan Group arkosic sandstones and conglomerates would be a likely source of copper for the Zambian deposits. However, relatively small volumes of these rocks are known near the district.

AMIRA P544

The Zambian Copperbelt — Structural Geology

- District displays extremely complex folding and faulting
- Stratigraphy probably highly disrupted - previous stratigraphic correlations in doubt
- Absence of thick basal "red beds" suggests deposits displaced from their source beds - Copperbelt allochthonous ?
- Abundant evaporites were present - provided zones of structural weakness; dissolved during metamorphism (abundant scapolite)
- Sulfides recrystallized and dissolved during metamorphism (physical evidence and sulfur isotopic data)

AMIRA P544

Timing of Mineralization in the Damaran - Lufilian Orogen

- Katangan sedimentation — 880 - 830 Ma
  - Copperbelt syndiagenetic mineralization — approx. 850 Ma
- Peak metamorphism of Lufilian Arc — 650 - 450 Ma
- Metamorphic to late-metamorphic mineralization
  - Metamorphic remobilization of Copperbelt sulfides — 650 to 500 Ma?
  - Formation of Kabwe Zn and Tsumeb Cu-Zn-Pb breccia pipes — 680 to 530 Ma
  - Shinkolobwe U — 602 to 542 Ma
  - Vein U in Domes area — 560 to 520 Ma
  - Musoshi veins and albitization — 513 to 496 Ma
  - Kansanshi Cu veins — 513 to 503 Ma
  - Kipushi Cu-Zn-Pb breccia pipe — 456 Ma

AMIRA P544

Cu Mineral Zoning in Ore Shale

- Literature suggests mineral zoning extremely well developed.
- Mapping indicates mineral zoning does exist but it is not as regular as implied in the literature.
- Chalcocite is generally restricted to near surface areas (supergene?)
- Best zoning is vertical from basal bornite or bornite + chalcopyrite zone to chalcopyrite zone to pyrite zone capping orebody.

AMIRA P544

Kansanshi Deposit

David Broughton

15 : 1
Cu : Au ~ Slot production

doleo pro doctrina

doleo pro doctrina

doleo pro doctrina

P544

Aims of P544

To understand the processes responsible for transporting, concentrating and fixing Cu and other ore constituents during sedimentary basin evolution

To document the various stages and paragenesis of copper deposition and remobilisation during basin evolution

To develop a range of geological, geochemical and isotopic vectors that point toward ore, both on a district and a deposit scale

AMIRA P544

Aims of P544 (con)

To determine what is different about the setting and geological evolution of the African Copperbelt, compared to Australian Proterozoic sedimentary basins, that may explain the difference in Cu (and Co) endowment in these areas

To apply research results from both Africa and Australia to produce better empirical exploration models for Proterozoic sediment-hosted Cu deposits

AMIRA P544

Some Key Questions

- is there a spectrum of deposits related to basin history from early stratabound Cu (cpy-cc) formed during diagenesis (up to the earliest stages of basin inversion?), to late structurally controlled Cu (cpy only) formed during metamorphism – deformation

- are the different types of deposits geochemically distinct, and can their geochemical and isotopic signatures be used to design vectors to hidden deposits?

- what are the chemical and thermal characteristics of ore fluids related to each type of Cu deposit?

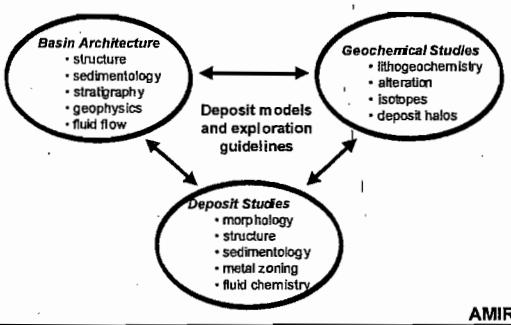
AMIRA P544

Some Key Questions (con)

- what are the regional and local factors that control deposit size and ore grade?
- can a basin host one style of deposit and not the others, and what are the conditions for this?
- at the basin scale, is there any metal zoning (Cu,Co, Ag, Au, Pb, Zn)?
- how do the sites favourable for Cu mineralisation change in terms of structural style and/or stratigraphic position and/or redox state during basin evolution?

AMIRA P544

Proposed P554 Framework



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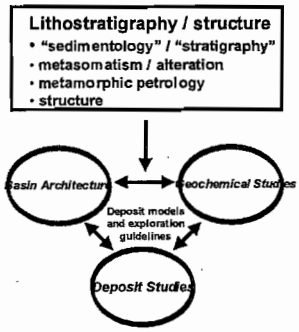
Zambian Framework : Stage 1



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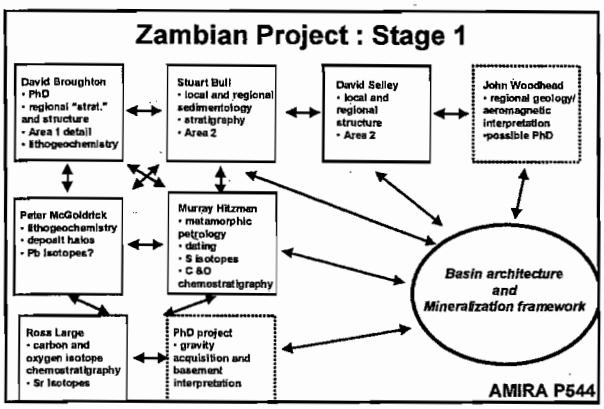
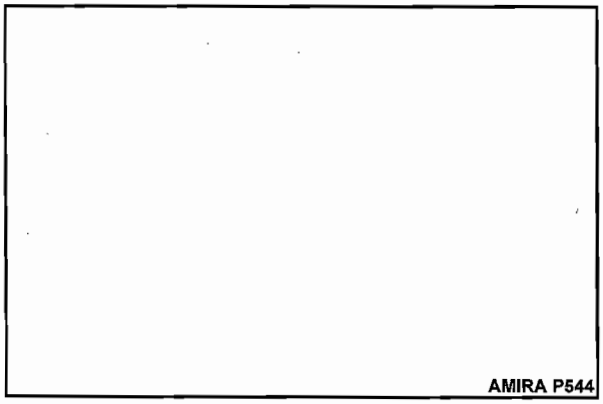
Zambian Project : Stage 1



Time table chart 2000 - 2003



Jon Woodhead - Regional Interp

- Proposal
  - to compile a GIS based geological map of the Lufilian arc
  - compile all geophysical data
  - to use these to develop a revised geotectonic framework for the region
- This needs to be focused to produce a geological-geophysical map of the Copper Belt to be of use to the project
- Timing - be completed at end of first year
- Cost - unknown, but max $15,000 allocated from budget
- This may develop into a separately funded PhD

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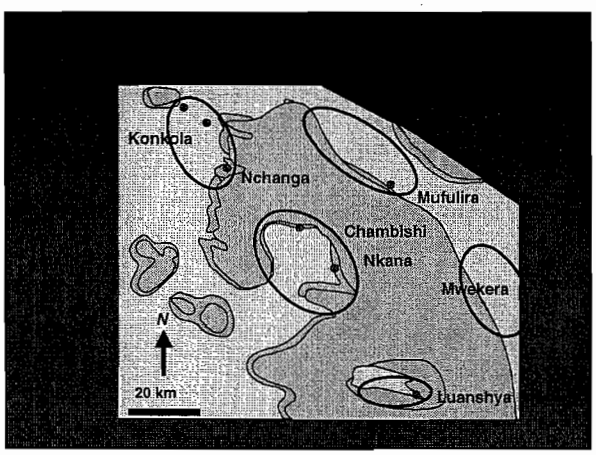
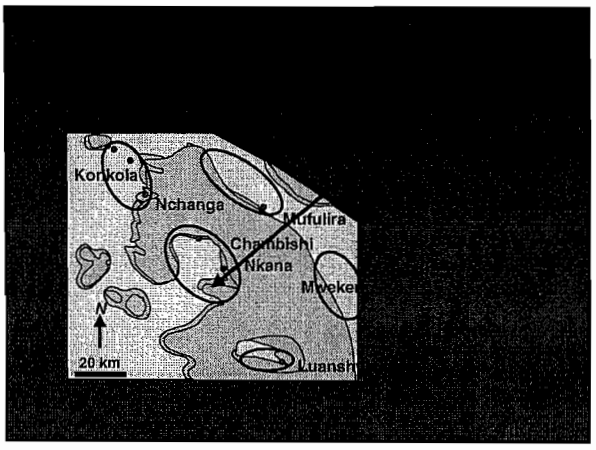
Objectives
Zambian Segment

- Development of original and existing stratigraphic succession throughout the Copperbelt
- Evaluate timing of mineralization(s) and/or remobilization with respect to the sedimentary, metamorphic and metasomatic history of the district
- Attempt to develop vectors to ore by analysis of metal and alteration zonation, geochemical pathfinders, and isotopic zonation
- Assist in compilation of a district-wide geologic database

Final objective is to develop better exploration models for these deposits by defining a robust geological base which can then be integrated with geophysical and geochemical models





Year 1 Work Proposal – Broughton
Zambian Segment

Compile geological and geophysical base maps of the Zambian Copperbelt (with J. Woodhead, Anglo)

Create geologic database for project use (with Anglo, Anglovaal, First Quantum, and Chamber of Mines)

Complete preliminary ddh data acquisition for each of Konkola-Nchanga, Chambishi-Nkana, Luanshya, Mufulira and Mwekera areas

- "Stratigraphy" and "sedimentology"
- Metasomatism-alteration
- Structural geology
- Mineralization
- Lithogeochemical sampling
- Magnetic susceptibility characterization

Year 1 Work Proposal – CSM
Zambian Segment

- Preliminary petrography
- Pilot study of scapolite-biotite chemistry (microprobe)
- Initial age dating
- Preliminary sulphur isotopic studies on anhydrite & sulphides
- Preliminary carbon and oxygen isotopes on carbonates to determine if coherent chemostratigraphy exists (with CODES)

Year 1 Work Proposal – CODES
Zambian Segment

- Detailed ddh and mapping transects in low metamorphic grade areas (Konkola, Mufulira)
- Detailed structural mapping
- Preliminary lithogeochemistry
- Preliminary carbon and oxygen isotopes on carbonates
- Cu isotopes (ARC Large Grant application)

Year 1 Deliverables
Zambian Segment

- Geological and geophysical base maps of the Zambian Copperbelt
- Preliminary "stratigraphic"correlation of study areas
- Preliminary structural history
- Preliminary mineralization-alteration characterization
- Evaluation of applicability of S-C-O isotopic studies

Year 1 results provide input for team and corporate evaluation and scoping of work program for years 2-3

Years 2-3 Work Proposal – Broughton
Zambian Segment

Complete ddh data acquisition for each of Konkola-Nchanga, Chambishi-Nkana, Luanshya, Mufulira and Mwekera areas

Detailed transects and mapping of selected areas (open pit, u/g) to determine:
- structural history
- styles and distribution of mineralization(s)
- distribution and geochemistry of alteration(s)

Update geological database and map

Laboratory studies

+ mapping sulfide dist^{n} (Co) (comment from D. Haynes)

Years 2-3 Work Proposal – CSM
Zambian Segment

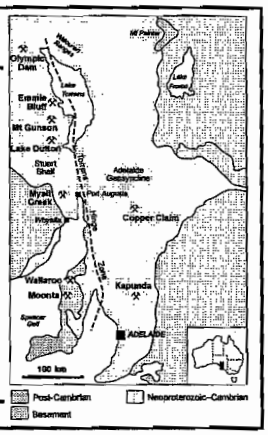
Laboratory studies
- Petrography (sedimentary, metamorphic, structural, alteration and mineralization paragenesis)
- Lithogeochemistry (with CODES)
- Characterize metamorphic fluids – scapolite-biotite chemistry, preliminary fluid inclusions (with J. Reynolds)
- Dating – sedimentation (tuffs if present), mineralization(s), alteration(s), metamorphism
- Sulphur isotopes to determine vertical and lateral zoning at deposit and regional scales
  -anhydrite, sulphides
- Carbon and oxygen isotopes on carbonates, vertically and laterally through section, to determine chemostratigraphy (with CODES)

Years 2-3 Work Proposal –CODES
Zambian Segment

- Structural and stratigraphic modeling
- Lithogeochemical and alteration halo characterisation
- Isotope chemostratigraphy

Comparison and integration with Australian studies

South Australia



Proposed P544 Cu Research

Deposit Studies Module

- Review of the Tapley Hill Fm deposits
- Origin of/relationship between siltstone- and ironstone-hosted Cu at Emmie Bluff

Basin Architecture Module

- Tectono-sedimentary setting of Neoprot sed-hosted Cu deposits

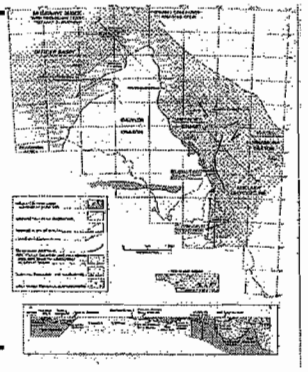
Proposed P544 Cu Research

Geochemical Studies Module

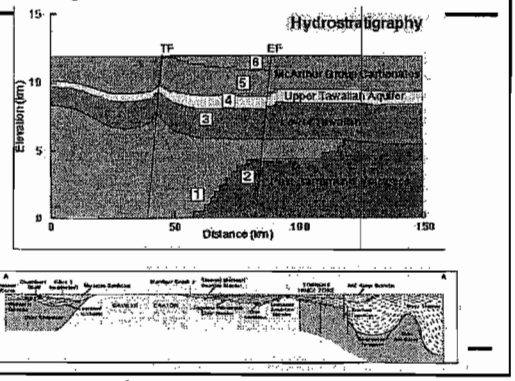
- Review of the existing geochemical database for Cu-bearing parts of the Neoproterozoic
- Nature of mineralising fluids (comparisons and implications for Zambia)

Proposed P544 Cu Research

- All integrated with regional and local fluid flow



Proposed P544 Cu Research



Proposed P544 Cu Research

Emmie Bluff

- Olympic Dam type target in 1977
- MIM and various JV partners
- Several DDH intersected hematitic granite and sediments at ~ 800 m
- 10s of m @ 0.x% Cu

Proposed P544 Cu Research

Emmie Bluff

- Also at ~ 400 m there is several m @ 0.x to x% Cu + Co & Ag Sst in Tapley Hill Fm and overlying Whyalla Sst

Key Questions

- What is the relationship between the Fe-oxide Cu and the THF/WS Cu mineralisation?
- How does Emmie Bluff compare to other THF deposits

Proposed P544 Cu Research

Emmie Bluff Work to Date

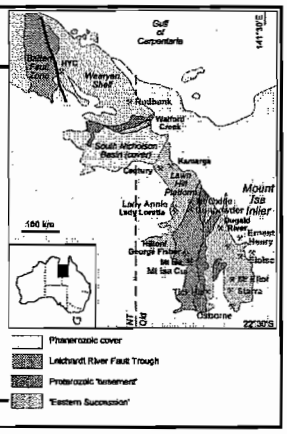
- Gow et al., 1994 briefly describe the Fe-stone mineralisation
- PM & SB reconnaissance sampling of THF & Fe-stone mineralisation

Proposed P544 Cu Research

Year 1 deliverables:

- data review and compilations (incl. geochemistry)
- summary of Tapley Hill Formation and associated deposits

Northern Australia



Related CODES Cu Research

Part of &/or in parallel to P384 projects:

- Redbank
- Lady Annie
- Nifty
- Gunpowder
- S Aus & Chile Fe-oxide Cu/Au
- Kamarga Dome
- Kilgour
- Mt Isa Eastern Succession

Proposed P544 Cu Research

Basin Architecture Module

- Sedimentary & tectonic controls on low-grade Cu
  - Kamarga Dome (QLD)
  - Wollogorang Formation (NT)
  - Mallapunyah Formation (NT)
- Structural setting of sediment-hosted Cu deposits in the Lawn Hill Platform

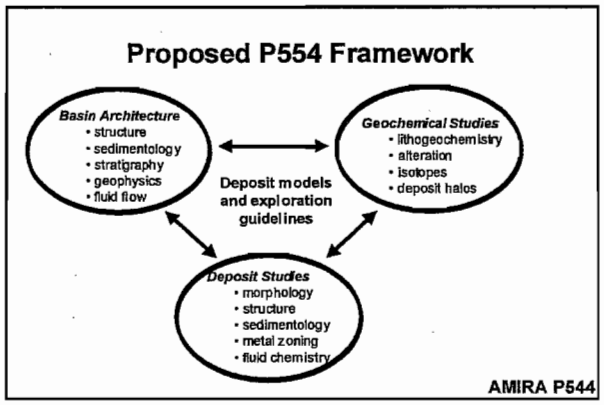
Proposed P544 Cu Research

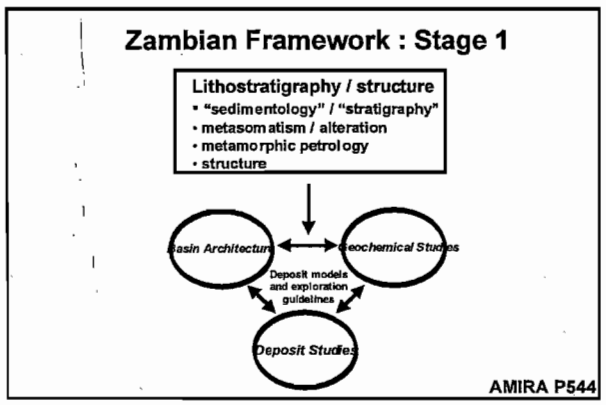
Deposit Studies Module

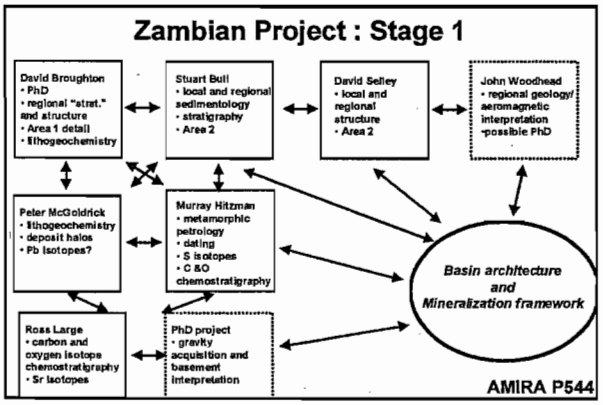
- Geology of the Lady Annie Deposit

Geochemical Studies Module

- Review and infill existing geochemical databases for northern Australia
- Geochemical modeling of metal transport & deposition


Proposed P554 Framework
Basin Architecture
• structure
• sedimentology
• stratigraphy
• geophysics
• fluid flow
Geochemical Studies
• lithogeochemistry
• alteration
• isotopes
• deposit halos
Deposit models and exploration guidelines
Deposit Studies
• morphology
• structure
• sedimentology
• metal zoning
• fluid chemistry
AMIRA P544


Zambian Framework : Stage 1
Lithostratigraphy / structure
• "sedimentology" / "stratigraphy"
• metasomatism / alteration
• metamorphic petrology
• structure
Basin Architectur
Geochemical Studies
Deposit models and exploration guidelines
Deposit Studies
AMIRA P544


Zambian Project : Stage 1
David Broughton
• PhD
• regional "strat." and structure
• Area 1 detail
• lithogeochemistry
Stuart Bull
• local and regional sedimentology
• stratigraphy
• Area 2
David Selley
• local and regional structure
• Area 2
John Woodhead
• regional geology/ aeromagnetic interpretation
•possible PhD
Peter McGoldrick
• lithogeochemistry
• deposit halos
• Pb isotopes?
Murray Hitzman
• metamorphic petrology
• dating
• S isotopes
• C &O chemostratigraphy
Basin architecture and Mineralization framework
Ross Large
• carbon and oxygen isotope chemostratigraphy
• Sr isotopes
PhD project
• gravity acquisition and basement interpretation
AMIRA P544

June-early July
field trip

Time table chart 2000 - 2003

AMIRA P544

other workers slide

Revised AMIRA Budget : P552

Salaries	2000/01	2001/02	2002/03
Stuart Bull (30%)	22,000	23,000	24,000
Rob Scott (30%)	20,000	21,000	16,000
Reaearch assist.	22,000	23,000	24,000
Analytical	32,000	33,500	24,500
Travel & accom.	44,000	43,000	32,000
Reporting	6,000	12,000	15,000
Utas Infrastructure	29,000	31,000	37,000
GST	13,000	14,000	13,000
CSM PhD costs	80,000	80,000	80,000
TOTAL	268,000	281,000	265,500
AMIRA payments	271,000	271,000	271,000

AMIRA P544

ARC SPIRT Budget : P552

Salaries	2000/01	2001/02	2002/03
David Selley (100%)**	50,000	52,000	54,000
Reaearch assist.	22,000	23,000	
PhD Schol. (3) **	64,500	64,500	64,500
Analytical	23,000	25,000	12,000
Travel & accom.**	14,000	14,000	7,000
Reporting	4,000	4,000	6,000
GST	18,000	18,000	14,000
TOTAL	195,500	201,000	158,000

AMIRA P544

Economic Geology
Vol. 95, 2000, pp. 000–000

Re-Os AND U-Pb DATING OF THE VEIN-HOSTED MINERALIZATION AT THE KANSANSHI COPPER DEPOSIT, NORTHERN ZAMBIA

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RICHARD ARMSTRONG,

PRISE, Research School of Earth Sciences, The Australian National University, Canberra, ACT, Australia 02001

AND DAVID BROUGHTON

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Abstract

The Kansanshi copper deposit in the Pan-African Damaran-Lufilian fold belt of northern Zambia consists of high-angle, sheeted quartz-carbonate-sulfide veins with envelopes of disseminated sulfides. These veins cut and replace metamorphosed Katangan sedimentary rocks of Neoproterozoic age. Crosscutting relationships have been used to delineate three stages of subparallel veins. The first two vein sets are chalcopyrite rich and contain minor molybdenite, and the third vein set contains relatively abundant molybdenite with significant monazite and brannerite and minor chalcopyrite. Direct dating of molybdenite (with replicates) from each of the vein sets using the Re-Os method yields two distinct ages, 512.4 ± 1.2 Ma and 502.4 ± 1.2 Ma (weighted averages, 2σ), consistent with the relative age relationships and vein mineralogies observed in the field. The molybdenite-monazite veins, which crosscut the two earlier chalcopyrite-rich vein sets, are distinctly younger (~10 m.y.) based on Re-Os dating. SHRIMP U-Pb analyses of monazite from the final veining event yield a U-Pb age of 511 ± 11 Ma. The 2σ uncertainty of ±11 m.y. includes all ages and 2σ uncertainties provided by the Re-Os method. These results indicate that mineralization took place in the late Cambrian and suggest that either mineralization was continuous for 10 m.y. or the Kansanshi deposit includes two pulses of mineralization, one at ~512 Ma and one at ~502 Ma. Vein mineralogies and clear crosscutting relationships favor the latter suggestion. The ages of mineralization at Kansanshi are broadly similar to those determined for other posttectonic vein systems in the central African copper belt. Available geochronological data from deposits in the Damaran-Lufilian orogen suggest that a major mineralization event occurred throughout much of the Lufilian fold and thrust belt during and after peak metamorphism and that mineralizing fluids responsible for the formation of many of these deposits, including Kansanshi, may have been metamorphic in origin.

Introduction

The Kansanshi copper deposit is located in northern Zambia, approximately 150 km west of the Zambian copper belt (Fig. 1). Unlike the deposits in the Zambian copper belt that consist of strata-bound, disseminated sulfides (Mendelsohn, 1961), the Kansanshi deposit consists primarily of high-angle veins containing coarse-grained sulfides. The veins cut metamorphic rocks of the Pan-African Damaran-Lufilian orogen, providing a maximum age for mineralization. To constrain the timing and duration of mineralization at Kansanshi, molybdenite from each of three crosscutting vein sets was sampled for Re-Os dating. Coarse-grained monazite crystals intergrown with molybdenite from the youngest vein set also were dated using the U-Pb method.

Regional Setting

The copper-bearing veins at Kansanshi cut metasedimentary rocks believed to be derived from Katangan (Neoproterozoic) sediments. The exact stratigraphic position of the host rocks for the Kansanshi deposit within the thick (>7 km) Katangan sequence is not known. The metasedimentary rocks consist of quartz-biotite schists, biotite-garnet schists, carbonaceous phyllites, impure marbles, and quartz-muscovite phyllites with generally subhorizontal foliation planes. The metamorphic grade is upper greenschist/lower amphibolite facies (Torrealday et al., 1998). Metamorphism is related to the development of the Pan-African Damaran-Lufilian fold and thrust belt, which in the Kansanshi area consists of thick-skinned thrust sheets believed to contain slices of pre-Katangan basement (Coward and Daly, 1984).

The Lufilian fold and thrust belt underwent a prolonged and complex deformational and metamorphic history. Immediately west of the Kansanshi area, K-Ar, Rb-Sr, and U-Pb methods were used to determine that peak metamorphism occurred at approximately 700 Ma, with rocks cooling below the blocking temperature of the K-Ar and Rb-Sr systems in micas at approximately 500 Ma (Cosi et al., 1992). South of Kansanshi, deformation occurred at 570 to 550 Ma and terminated by 540 to 530 Ma, based on U-Pb zircon ages from the syn- and posttectonic Hook granite massif (Hanson et al., 1993). U-Pb dating of rutile from syn- to posttectonic veins cutting the Musoshi copper deposit at the northern edge of

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0899-5362/00 $- see front matter

Source basins for sediment-hosted stratiform Cu deposits: implications for the structure of the Zambian Copperbelt

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ABSTRACT—The Central African Copperbelt in Zambia and the Democratic Republic of Congo is the world's largest sediment-hosted stratiform Cu province. The source for the Cu in sediment-hosted stratiform Cu deposits is generally believed to be thick sections of oxidised siliciclastic sediments (red beds) and volcanic rocks deposited in early rift sequences underlying or laterally adjacent to the ore-bearing sediments. The volume of red beds beneath or lateral to the Zambian portion of the copperbelt relative to the amount of known metal in the deposits is small in comparison to the volumes of source beds in other well-known districts such as the Polish Kupferschiefer and the White Pine District, USA. Previous structural studies suggest that the rocks hosting the Zambian Cu deposits may be allochthonous or para-autochthonous. The apparent absence of source sediments for the metals, combined with the known structural geology, strongly suggests that the Zambian deposits were tectonically displaced from their source rocks. Defining the present location of the source basins would constrain the amount of tectonic transport in this portion of the Lufilian Arc and would stimulate mineral exploration in new areas. © 2000 Elsevier Science Limited. All rights reserved.

RESUME—La Ceinture de Cuivre d'Afrique Centrale, en Zambie et République Démocratique du Congo, est l'une des provinces de cuivre stratiforme les plus vastes du monde. On considère généralement que la source du cuivre dans les gisements de cuivre stratiforme contenu dans les sédiments provient de formations épaisses de sédiments oxydés silicoclastiques (couches rouges) et de roches volcaniques déposées dans des séquences précoces de rift ou latéralement aux sédiments porteurs de minerais. Le rapport entre le volume de couches rouges situées en dessous et latéralement et la quantité de métal connu dans les gisements de la partie zambienne de la Ceinture de Cuivre est faible en comparaison avec les volumes de matériaux sources des Kupferschiefer de Pologne et du District de White Pine aux USA. Les études structurales antérieures suggèrent que les roches hôtes des gisements de cuivre de Zambie peuvent être allochtones ou parautochtones. L'absence apparente de sédiments sources des métaux, combinée avec ce que l'on sait de la géologie structurale, suggère fortement que les gisements de Zambie ont été déplacés tectoniquement de leurs roches sources. La définition de la localisation actuelle des bassins sources permettrait de connaître la quantité de transport tectonique dans cette portion de l'arc lufilien et stimulerait l'exploration minière dans de nouvelles zones© 2000 Elsevier Science Limited. All rights reserved.

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INTRODUCTION

The Cu-Co districts of Zambia and the Democratic Republic of Congo (DRC) contain the largest sediment-hosted stratiform Cu deposits in the world (Kirkham, 1989) (Fig. 1). The Zambian deposits contain measured production and reserves in excess of 90 million tonnes of Cu (Kirkham, 1989); those of the DRC are believed to contain in excess of 100 million tonnes of Cu. Other sediment-hosted stratiform Cu districts, such as

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