Sedimentary Copper Deposits

AMIRA P544

Centre for Ore Deposit Research
University of Tasmania
&
Colorado School of Mines

PowerPoint Presentations

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Perth

Introduction

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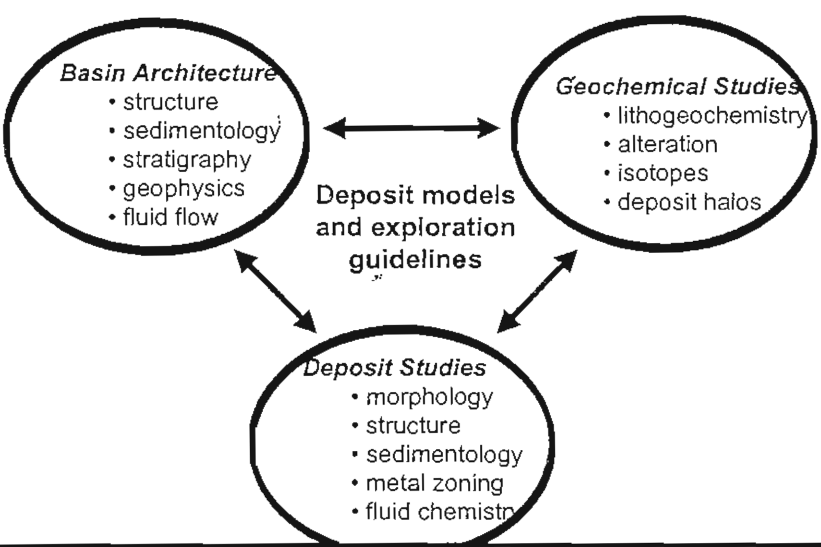
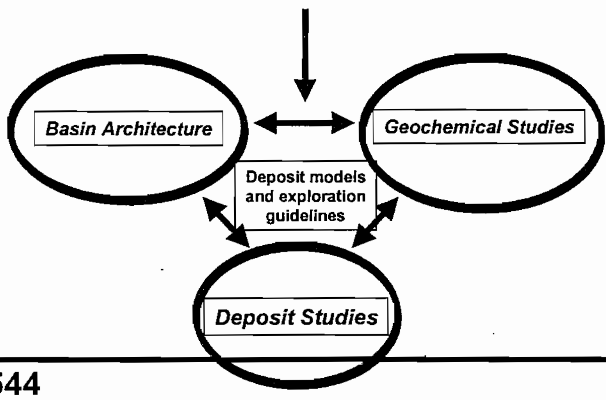
- Aims to compare and contrast Proterozoic sediment-hosted copper deposits in Australia and Zambia
  - Study Areas: Zambia, South Australia, Queensland?, Yeneena Basin?
- The level of basic information and description is low in Zambia (much better in Australia)
- Much previous Zambian work has been model driven

Proposed P554 Framework



Zambian Framework : Stage 1

Lithostratigraphy / structure
- **"sedimentology" / "stratigraphy"**
- **metasomatism / alteration**
- **metamorphism**
- **structure**



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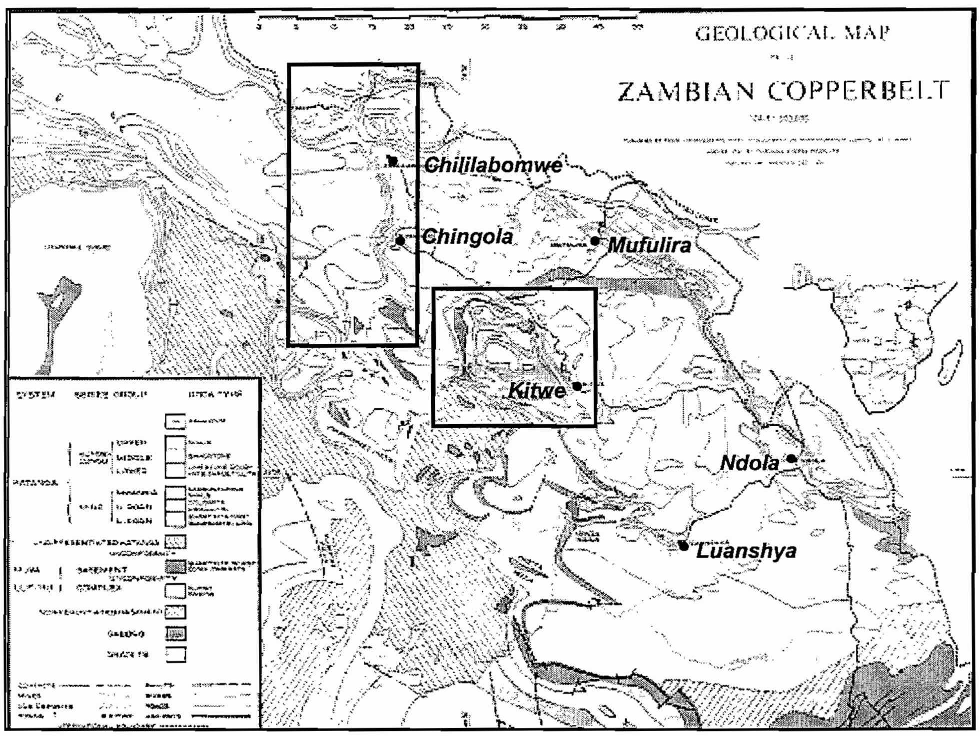

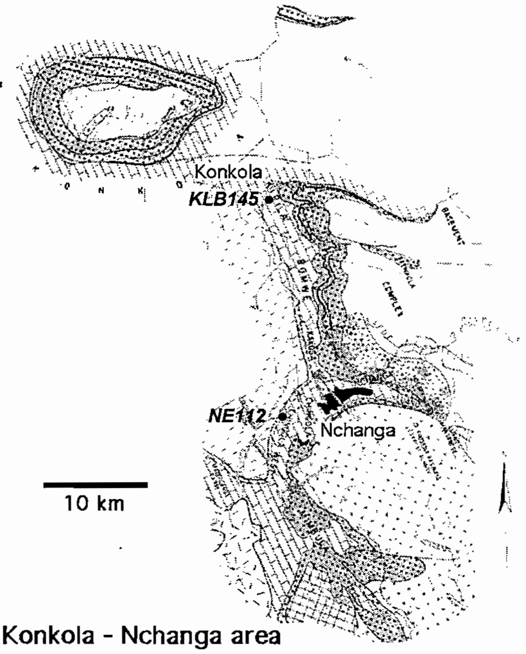

Konkola - Nchanga area

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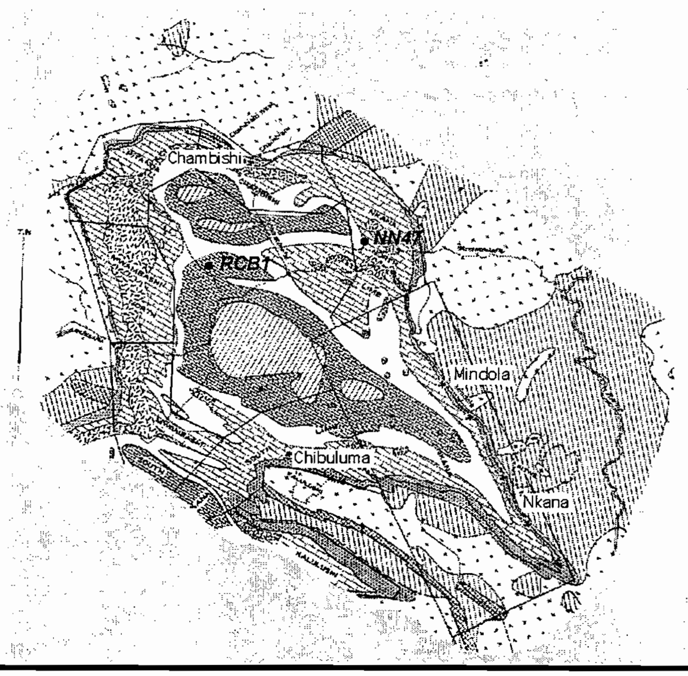

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Zambia - Introduction

- What is basin vs what is basement?
- In the Roan, what is sedimentary vs structural (vs alteration vs metamorphic) in origin?
- What do the mineral assemblages tell us about alteration, metamorphism and mineralisation?
- What types of fluids have existed in the basin at different times in its history?
- What traps copper?

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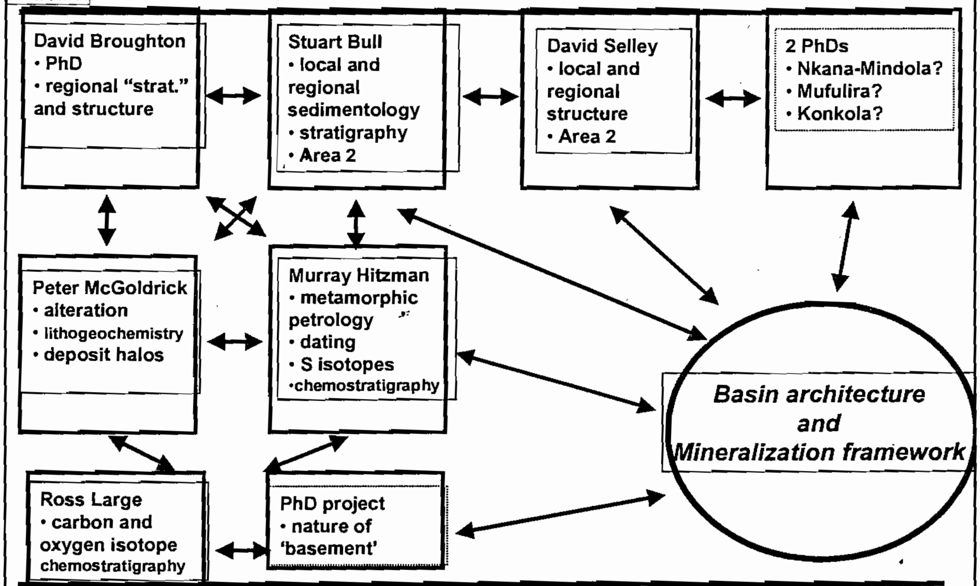
Zambian Project : Stage 1



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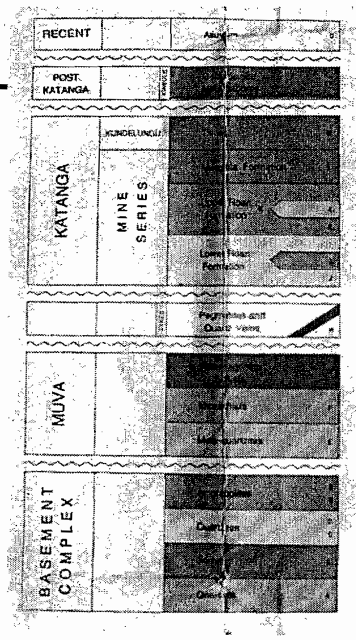

BASEME NT COMPLEX

Lufubu Schists

- Palaeoproterozoic calc-alkaline metavolcanics

Granitiods

- 2.0 Ga granodiorites
- 1.8 Ga granites
- 880 Ma Nchanga Red Granite

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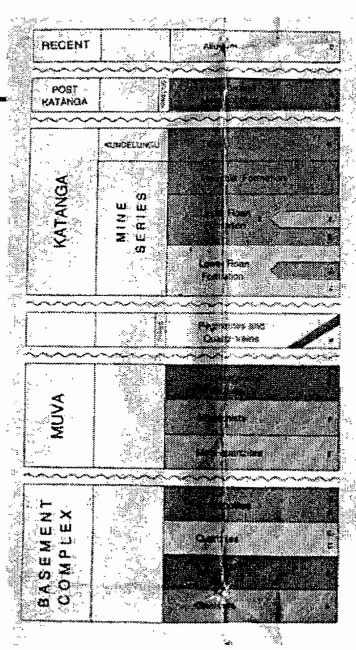

Katangan

Muva metasediments

- Mesoproterozoic coarse & medium grained clastics

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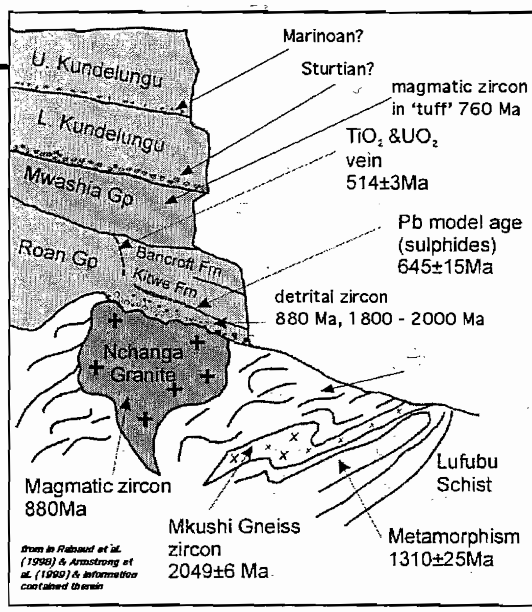
Muva Metasediments

detrital zircons:
1990 Ma
2190 Ma
2390 ma
& older

pan-African ‘event’ c. 500 Ma

Lufilian orogeny c. 650 Ma

Lusakan orogeny c. 840 Ma



U. Kundelungu
L. Kundelungu
Mwashia Gp
Roan Gp
Bancroft Fm
Kitwe Fm
Nchanga Granite
Marinoan?
Sturtian?
magmatic zircon in 'tuff' 760 Ma
TiO2 &UO2 vein 514±3Ma
Pb model age (sulphides) 645±15Ma
detrital zircon 880 Ma, 1800 - 2000 Ma
Lufubu Schist
Magmatic zircon 880Ma
Mkushi Gneiss zircon 2049±6 Ma
Metamorphism 1310±25Ma

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Basement Complex: schists

- predominantly qtz - musc - biot - chl - (epid) schists
- blue opalescent quartz
- overprinted by feldspathic alteration
- gradational contacts with deformed grey granite
- gradational / indistinct contacts with L.Roan sandstones
- 1970 +/- 10 Ma (Muf)

Basement Complex: granites

- zoned: grey core grades to pink/red margin
- opalescent quartz in grey and red granites is probable source for detrital quartz in Roan
- grey granites dated ~1960-1990 Ma
- Nchanga red granite ~ 880 Ma, brackets age of Katangan sedimentation
- potassic metasomatism affects the NRG
- potassic-metasomatized arkoses may be misidentified as NRG

Lower Roan

- crude fining-upwards coarse clastic sequence, dominantly oxidized
- ~100 to >1000m thick, variance in basal section
- volumetrically minor dolomite
- broken detrital undeformed opalescent quartz, feldspar
- often poorly bedded & sorted
- pre-lithification / dewatering structures suggest sequence remain fluidized post – D1
- extensive metasomatism obscures / overprints sedimentary structures

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Upper Roan

- cyclical dolomite / evaporite / clastic sequence, 200-300 m, dominantly reduced
- base marked by dolomite + evaporite breccias
- dolomites appear secondary or overprinted
- gritty sand-silt clastics, often poorly bedded & sorted, "dewatering" structures present
- opalescent & grey quartz, feldspar grit is present but some appears secondary
- feldspathic-dolomitic alteration in clastics
- correlation of units over 100's of metres

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Mwashia

- siltstones & fine sandstones, +800m thick
- lack of grit, opalescent quartz suggests different provenance from Roan
- "dewatering" structures locally present
- possible cryptalgal laminations preserved in dolomites at top of sequence in Konkola
- abundant anhydrite = former evaporite in Chambishi
- high-Mg basaltic sills/flows in Konkola

Grand Conglomerate

- carbonatized conglomeratic schist
- dolomite, slst, sdst, quartz, granite clasts
- unsorted, not graded
- no sedimentary structures preserved
- tillite? uncertain origin
- gradational lower contact with Mwashia pelites and dolomites (KLB94)
- probably correlative with Kansanshi pebble schist
- is there an isotopic excursion that reflects a glaciated origin, as per the Namibian section?

Lower Kundelungu

- dolomitic marbles and phyllites / schists, >300m (~3000m in Congo)
- possible cryptalgal laminations in least-altered marbles
- difficult to distinguish marbles from Mwashia

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Evaporites

- found in veins, replacive bands & matrix, pressure shadows, nodules
- apparent widespread movement of sulphates through system
- intergrown with cpy, py, carbonate, quartz
- anhydrite veins have metamorphic biotite selvages identical to carbonate veins
- qtz/carbonate “nodules”, bands, breccias replacive after sulphate?
- anhydrite/gypsum present in every lithology and stratigraphic unit below Kundelungu

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Metamorphism

- biotite present throughout Konkola area, defines deformation fabrics, present in dewatering structures
- biotite both accompanies & destroyed by hydrothermal alteration + mineralization
- is there a distinction between metamorphic & hydrothermal biotite?
- epidote present in basement complex (konkola – Nchanga area)
- Nkana: epidote-stable in Lower Roan, sodic amphibole in ore zones, actinolite in unmineralized zones

K-Feldspar metasomatism

- minor in Chambishi-Nkana area
- usually with hematite (stained albite?)
- vein-associated & pervasive replacement
- Kspar overgrowths
- generally envelopes Cu zones (Konkola)
- appears to overprint metamorphic biotite
- Kspar + cpy + bn + anhy + biot veins (Nkana)
- widespread in L. Roan and red granites (Konkola area)

Fe Oxides

- euhedral porphyroblastic magnetite present in Mwashia, granites
- hematite replaces magnetite, forms disseminated grains, also present along bedding planes and in veins
- oxidized Mwashia + Roan = possible source beds up to 2000 metres thick

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The problem of 'basement'

- Difficulty in distinguishing between Katangan and 'basement' on a structural basis.
- Is it possible to distinguish Katangan from 'basement' on: (1) textural - (2) geometric bases?
- What is the nature of 'basement'? ie. true crystalline basement or an earlier phase of the same 'basin'.

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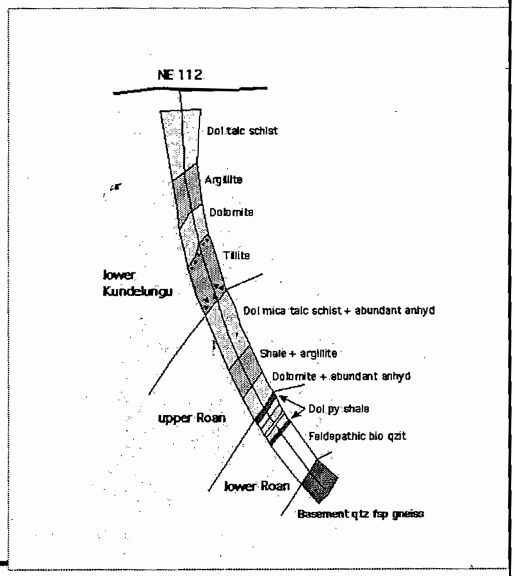
NE 112

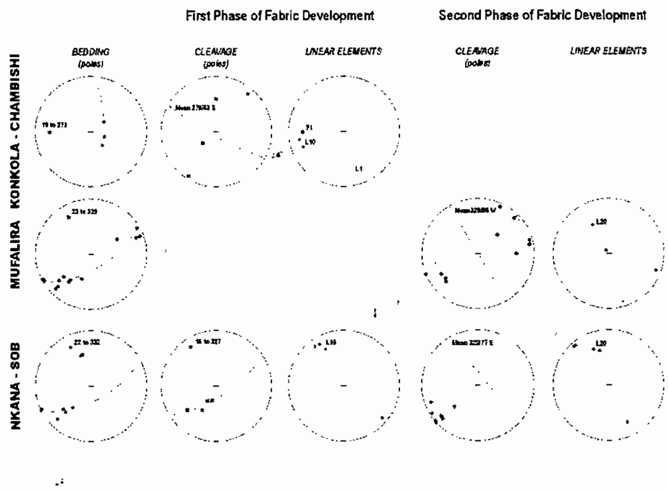
- Complete representation of stratigraphy.
- Anomalously high strains and metamorphic grade.
- Up to 4 cleavage-forming events recorded throughout entire hole.



Structural fabrics developed in "Kundelungu"

Katangan Fabric Geometry:
from surface and underground exposures

- Chambishi and Konkola record inclined and upright W-plunging folds consistent with N-directed thrusting.
- Mufulira records only one cleavage which is axial planar to downward facing folds.
- Nkana SOB records 2 prominent cleavages associated with SSW-directed thrusting and upright NW folding respectively.
- Locally 3 folding events at Nkana SOB



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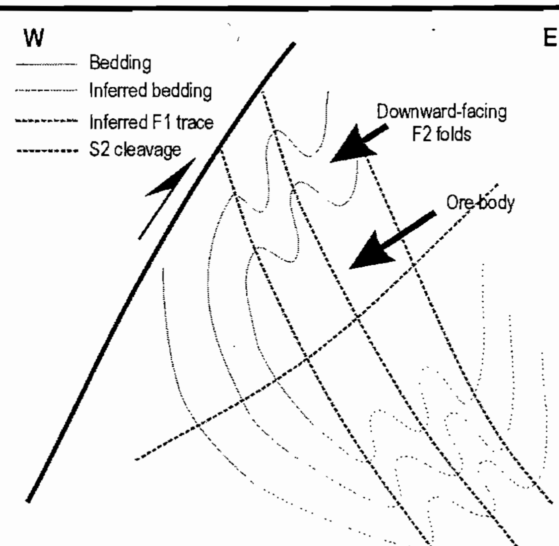
Fold Geometry at Mufulira



(After Coward and Daly 1986)

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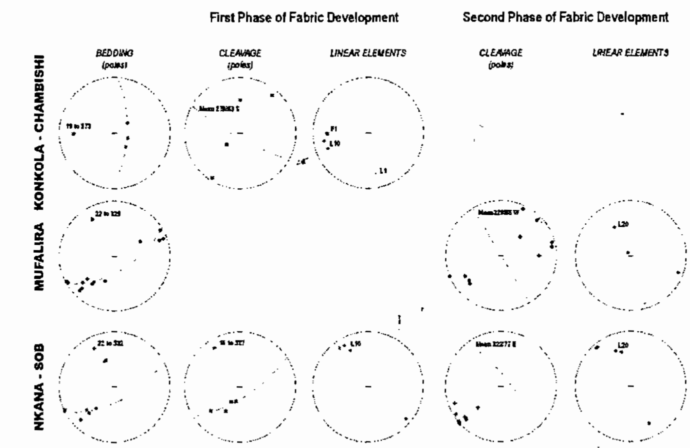

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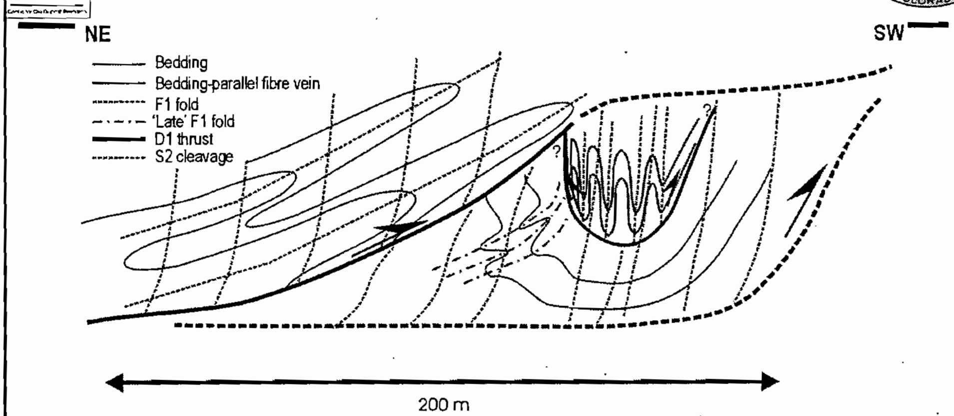
Nkana SOB Fold and Thrust Geometry



- SW-directed thrusting with complex fold geometry
- Early inclined and upright folds are generated during progressive thrust event

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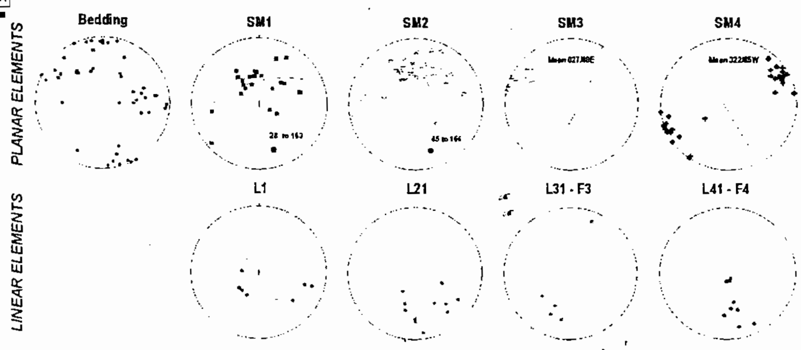
Muva Fabric Geometry



- Two to four cleavage forming events
- Early N-directed fold and thrust event (SM1 & 2)
- Two later phases of upright folding
- SM3 may account for dome and basin folding within Katangan

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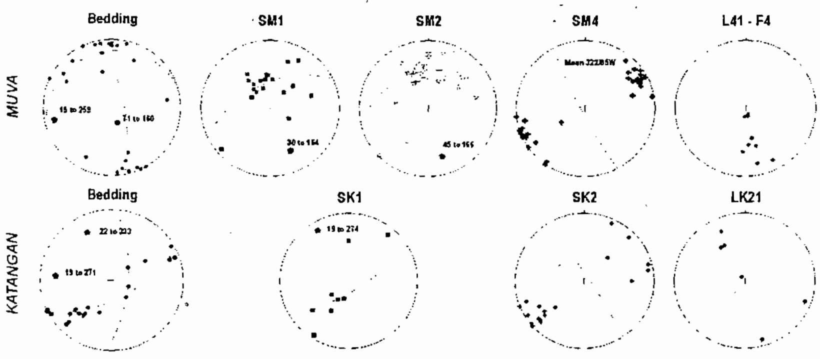
Comparison of Katangan and Muva Fabrics



- Broad similarity between the geometry of Muva and Katangan fabrics
  - Initial thrust-related folding about roughly E-W axes
  - Late stage NW trending folds
- Local development of two thrust-related cleavages in the Muva may reflect progressive deformation associated with thrusting

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Basin or Basement?

- Katangan and Muva systems form part of a common fold belt
- Implications for basin development:
  - architecture of the Muva basin may be reflected in the Katangan
  - mineralising fluids may have interacted with the Muva system

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Structural Geology

- bedding can be transposed into S1
- Mwashia appears more deformed than underlying Roan in Konkola area
- mineralization now in tectonic structures
- WNW (D2) folds control ore shoots & deposit geometry at Konkola – generally north-verging
- NE (D3) cuspate folds related to Konkola barren gap geometry
- breccia at base of Mwashia contains variety of differently-altered clasts and appears to cut S1 fabric
- breccia truncates early ?D1 mega-folds, but is itself folded and cut by quartz-carbonate-biotite veins
- breccia appears to remove section and may represent a thrust: equivalent to Congolese mega-breccias?

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Mineralization & alteration

- mineralization occurs throughout section
- Cu (Co) sulphides associated with Fe carbonates, local albitization
- bedding-parallel & oblique mineralized veins are widespread, lack depleted halos
- sandy/carbonate/evaporite-rich layers preferred fluid pathways
- Distal facies = pyrite + Fe carbonate
- Konkola barren gap is non-dolomitic, structurally controlled

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Regional Correlation

- close-spaced holes at Konkola demonstrate excellent continuity of carbonate & alteration facies, and mineralized zones
- correlation between Konkola – Nchanga – Chambishi demonstrates sedimentary facies changes and/or structural complication of parts of section
- distal equivalents of ore zones are correlative
- Kawiri area- basal Roan sediments appear continuous on Muliashi Porphyry "basement high"
- thrust breccia equivalent to Congolese mega-breccias?

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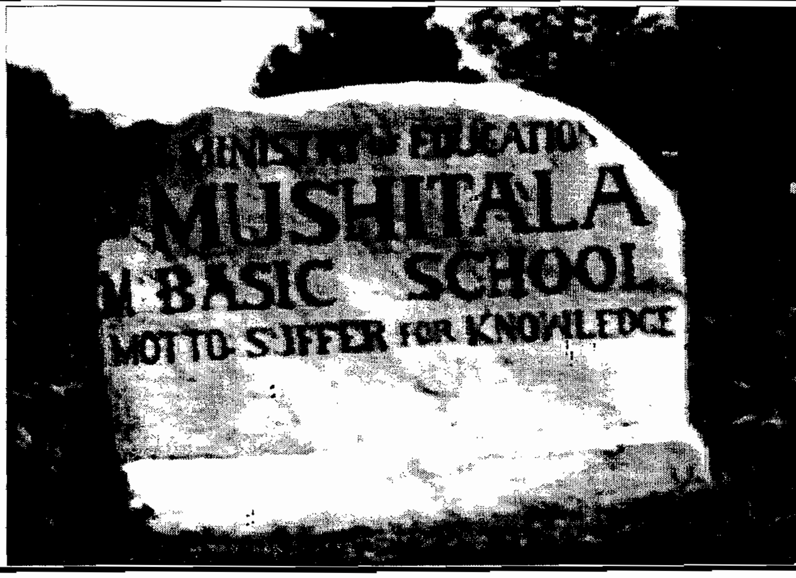
Work Plan, Jan-May 2001



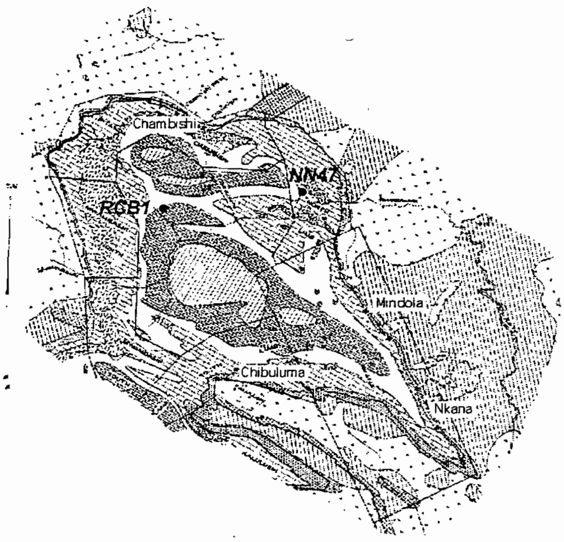
Work Plan, Jan-May 2001

- data compilation of logging to date
- petrography
- preliminary dating
- preliminary C & O isotopic characterization of carbonates in section
- preliminary S isotopic characterization of anhydrite and sulphide through section

In the Roan, what is sedimentary vs structural (vs alteration vs metamorphism)?

Finding drillcores in key areas not straightforward

DDH NN47 from the Chambishi basin chosen as a typical example of mineralised lower Roan stratigraphy



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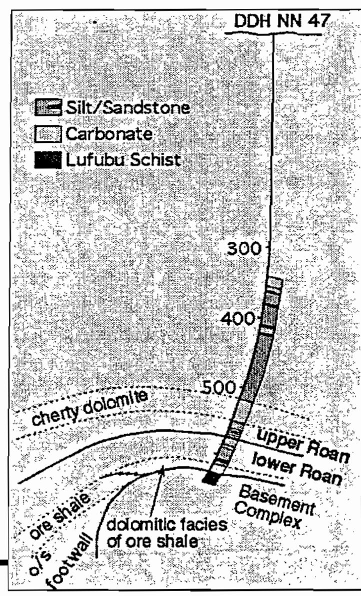
In the Roan, what is sedimentary vs structural (vs alteration vs metamorphism)?

Collared in the upper Roan and terminated in Basement Complex (granite/Lufubu Schist)

Opinions on nature of "ore shale" differ



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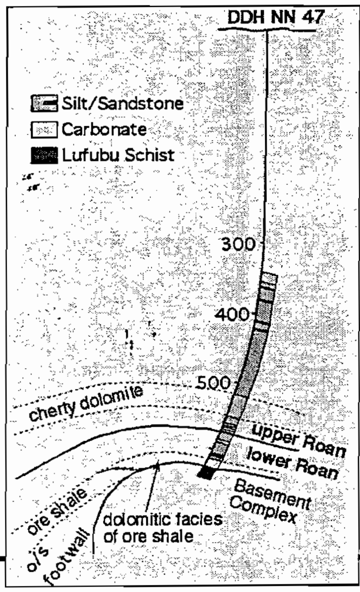
In the Roan, what is sedimentary vs structural (vs alteration vs metamorphism)?

With respect to the features you see in the Katangan rocks, two end member views

- most are primary sedimentary features
- most are alteration and structural fabrics



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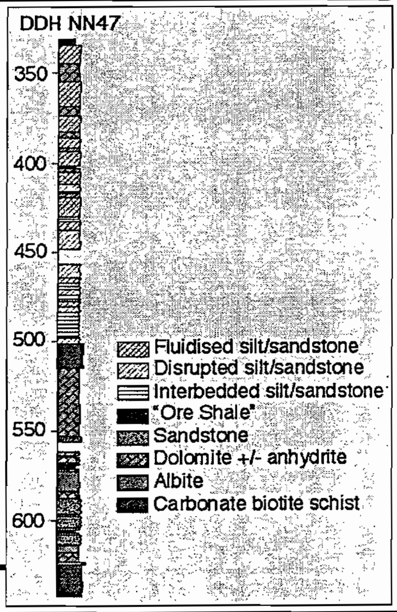
In the Roan, what is sedimentary vs structural (vs alteration vs metamorphism)?

Difficult rocks! Roan sediments are fluidised, altered/metasomatised, metamorphosed and deformed

Hard to understand:

- what we are looking at
- reconciling previous interpretations



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In the Roan, what is sedimentary vs structural (vs alteration vs metamorphism)?

NN47 indicates that care is needed in both:

- discriminating “basement” from Katangan
- interpreting stratigraphy within the Katangan

Can protolith sediments be recognised, or are many so called sediments really alteration and sedimentary structures really structural fabrics?

A -provisionally yes (no sample analysis yet) protolith can be distinguished with careful logging

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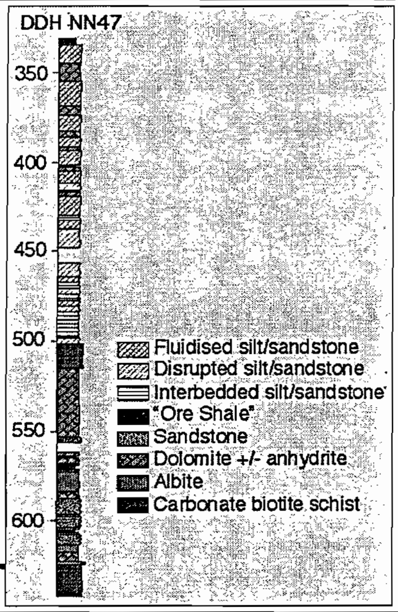
In the Roan, what is sedimentary vs structural (vs alteration vs metamorphism)?

Basal part of hole (~lower Roan) was coarse-grained sandstone overprinted by albite

+ interbedded dolomite ± anhydrite zones



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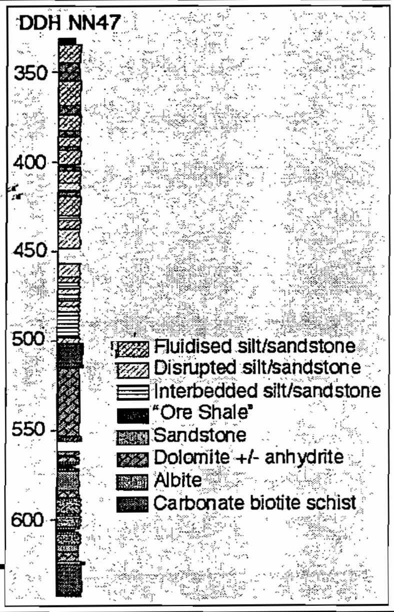
In the Roan, what is sedimentary vs structural (vs alteration vs metamorphism)?

Upper part of hole (~upper Roan) is finer-grained interbedded sand/siltstone

+ interbedded dolomite ± anhydrite zones

- Considerable destruction of primary clastic sedimentary fabrics - fluidisation?



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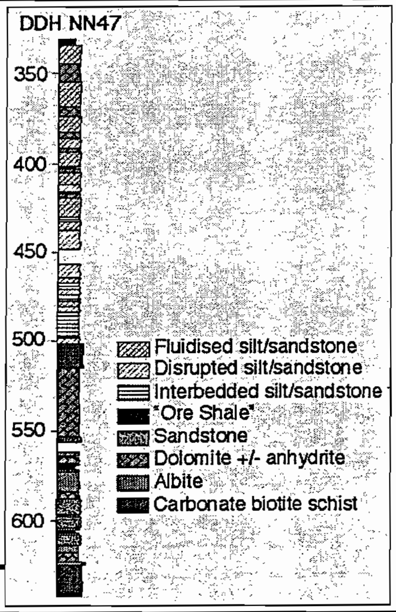
In the Roan, what is sedimentary vs structural (vs alteration vs metamorphism)?

Fluidisation and associated cc/anhydrite zones spatially related to fold closures and fault zones = synchronous with deformation?

Metamorphic problem - faults are defined by biotite apparently formed while sediments still partly unconsolidated?



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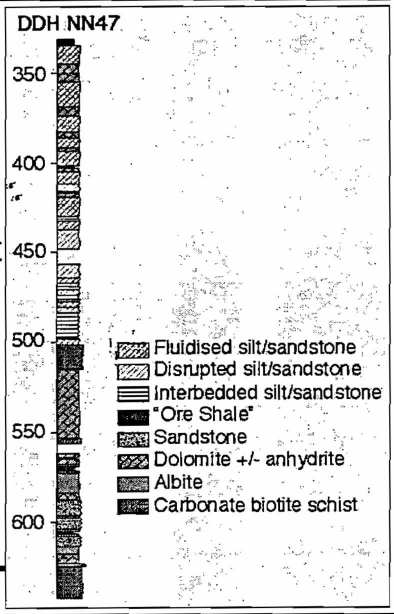
In the Roan, what is sedimentary vs structural (vs alteration vs metamorphism)?

Were there sedimentary carbonates/evaporites present?

A - can't prove it based on what we have seen of the lower Roan

- are suggestions of primary textures higher in the stratigraphy



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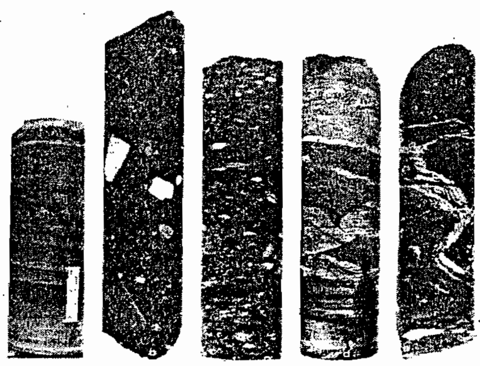
In the Roan, what is sedimentary vs structural (vs alteration vs metamorphism)?

Are there real tillites?

A - probably (based on figures in Binda 1972)

- clear from NE 112 that some units interpreted as tillites are probably not

PLATE I



A. Core IT 28. Basal contact of Great Conglomerate with angular fragments of underlying Mwashia dolomitic shale.
B. Core IT 16. Typical unsorted pebbly mudstone with clasts lacking preferred orientation.
C. Core IT 28. Pebbly mudstone with elongated clasts lying flat
D. Core L 83, near Mufulira. Pull-apart structure in the Great Conglomerate.
E. Core IT 28. Slumpstructure in the Great Conglomerate.

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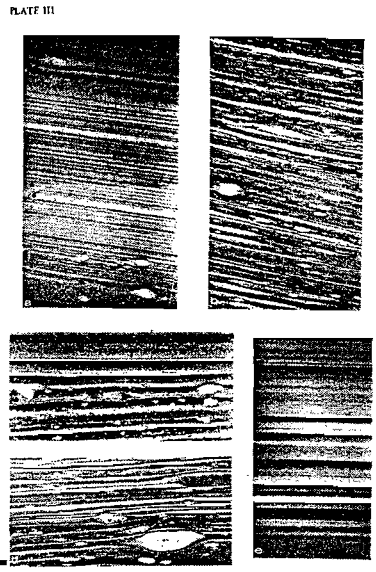
In the Roan, what is sedimentary vs structural (vs alteration vs metamorphism)?

A - need to be careful that there is evidence of a sedimentary origin

- e.g. a diverse clast assemblage etc.

Otherwise could be structural dismemberment of Katangan stratigraphy



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In the Roan, what is sedimentary vs structural (vs alteration vs metamorphism)?

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In the Roan, what is sedimentary vs structural (vs alteration vs metamorphism)?

CODES SRC

Can we distinguish clastic from cataclastic textures?

Important issue for basin geometry and controls on mineralisation

A - yes with careful observation at a drill core and microscopic scale

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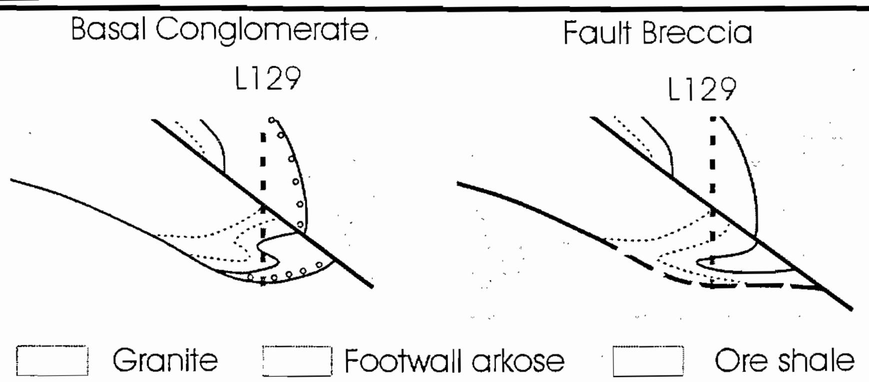
Nchanga

CODES SRC



- Distinguishing between sedimentary origin is critical for basin reconstruction.
- Sedimentary origin indicates considerable thinning of the footwall package and lapping onto 'basement highs'.

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Mufulira

- Underground exposures reveal little evidence of high strain or obvious structural control on mineralisation.
- Orebodies hosted by tabular sandstone units
  - minor veining and layer-parallel shear
  - disseminated medium-grained Cu-sulphides

DH 218

- Hangingwall stratigraphy is thoroughly brecciated
- Sulphides concentrate in irregular domains of slightly finer grainsize
  - grain breakage

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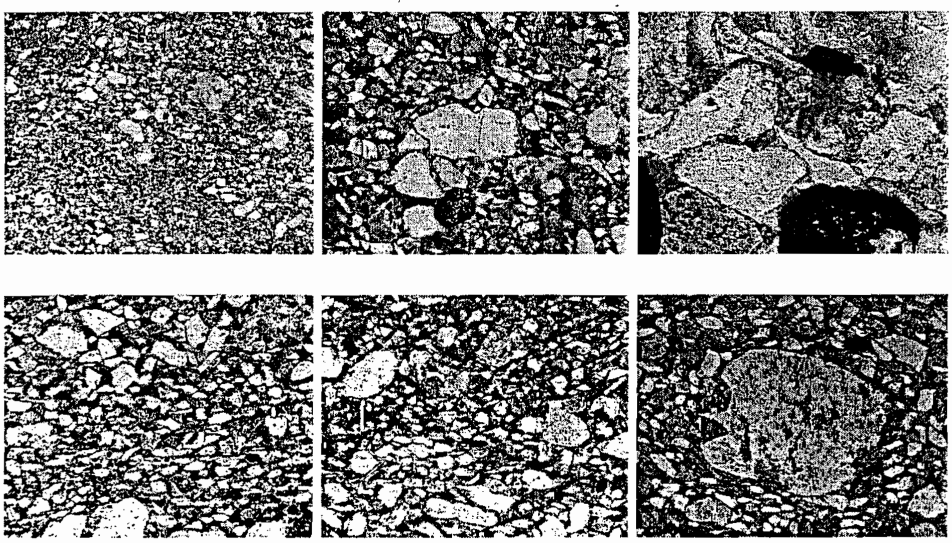
Mufulira footwall sandstone



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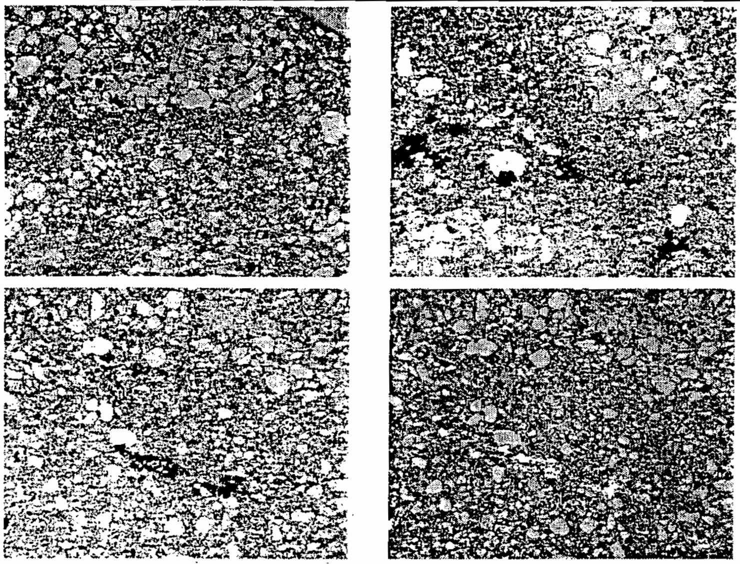
Mufulira A orebody



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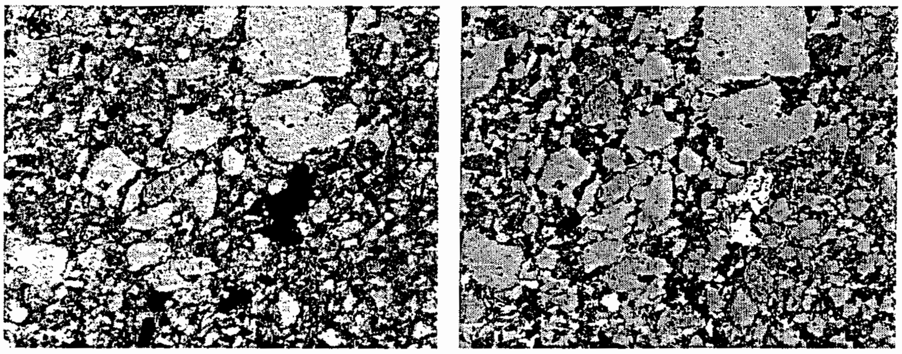

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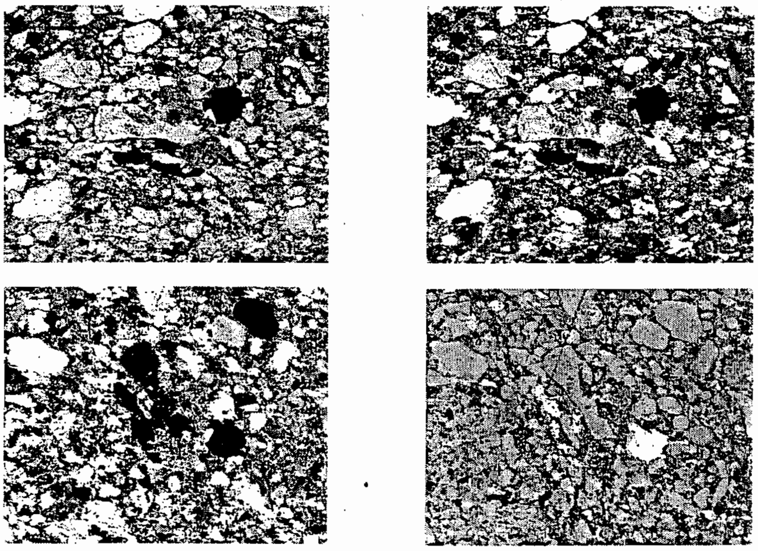
Mufulira A orebody



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CODES SRC

Using chemical modeling to understand aspects of sediment-hosted base metal deposits

David Cooke

Centre for Ore Deposit Research
University of Tasmania

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CODES SRC

Why use chemical models?

Hypothesis testing
- Source(s) of metals & ligands
- Understanding metal transport
- Depositional processes - predicting ore and gangue assemblages

Understanding fluid compositions
- Extend our understanding of known fluid compositions
- Estimate fluid compositions for environments where no other options are available

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Modelling Techniques

- *Activity diagrams* can be used to illustrate metal transport & deposition conditions in P-T-X space
- Programs such as EQ3/6, CHILLER, THERMODATA, HCH, GEOCHEMISTS WORKBENCH are used to simulate reaction paths and depositional processes

CODES SRC

Controls on Metal Solubilities

- Temperature
- Salinity
- Redox *(log f_{O_2})*
- pH
- Total sulfur concentrations *(ΣS)*
- *(Pressure, ΣC concentrations)*

Estimating fluid compositions

- Fluid inclusion data *(T, salinity, PIXE analyses, cation ratios, P?)*
- Estimates based on observed equilibrium mineral assemblages *(redox, pH, ΣS, ΣC)*
- Comparison with documented systems
- Calculated solubility relationships *(metals)*
- Geological relationships *(P, T, X)*

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P384 Modelling Outcomes

- *Testing of source-transport-trap hypotheses for a variety of Pb-Zn mineralising brine compositions (Cooke & Large, 1998)*
- *An understanding of trace metal associations & their implications for brine compositions in Sed-hosted Pb-Zn deposits, resulting in a two-fold classification scheme based on fluid chemistry (Cooke et al., 2000)*

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Cu Solubility Relationships

- What were the conditions favourable for Cu transport in the Zambian Copperbelt? *(low T oxidised, acidic; high T reduced, acidic?, etc.)*
- What were the transporting agents?
- What is the significance of the associated trace metals?
- What are the most effective depositional processes?

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Previous Work

- Haynes (1986a,b) & Haynes and Bloom (1987a,b) *- low T (<50°C) oxidised, near-neutral chloride brines precipitate Cu-Co-Ag ore via H_2S addition*
- Sverjensky (1989) *- Warm (50-150°C) Cu-Ag-bearing brines can be transported along redbed + anhydrite aquifers (related to Pb-Zn ores?)*
- Rose (1989) *- low T (<100°C) oxidised Cl-rich brines precipitate Cu-Co-Ag ore via reduction*

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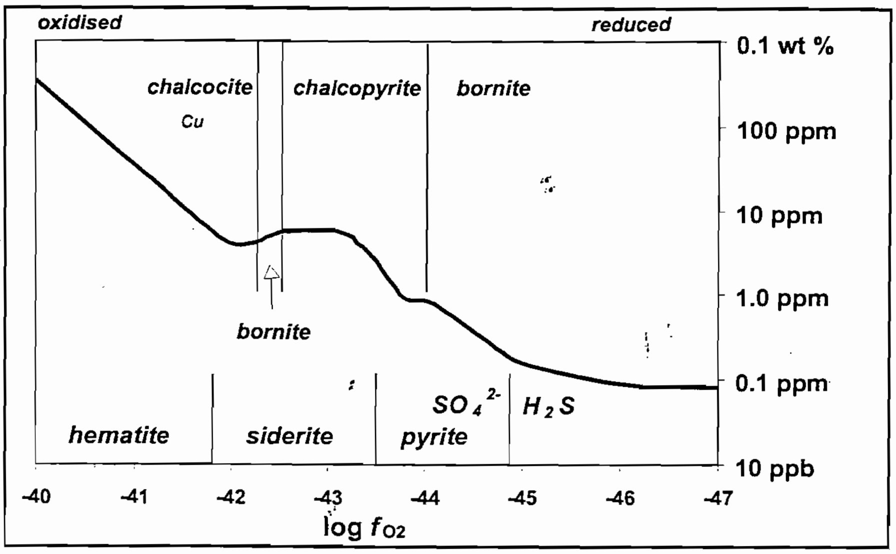
CODES SRC

Metal Solubilities: 150°C, 25 eq. wt %, pH = 4.5, ΣS = 0.001 m



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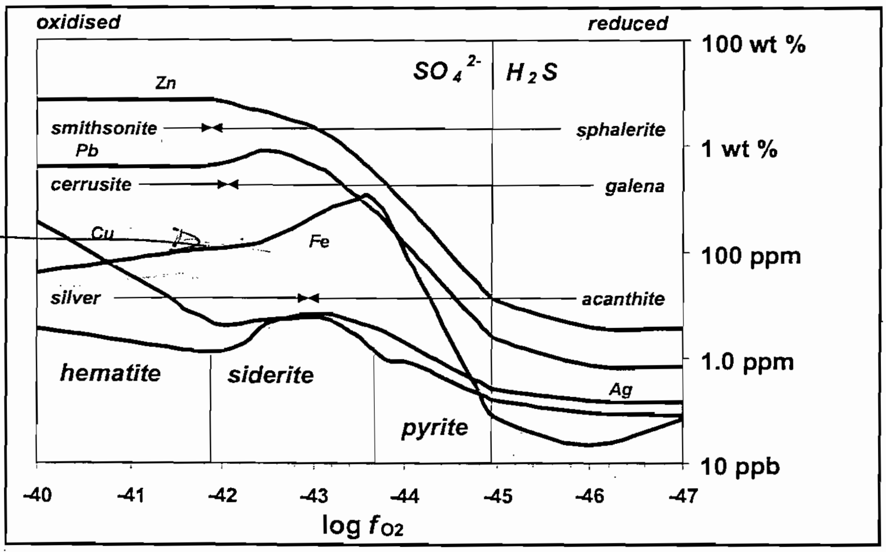

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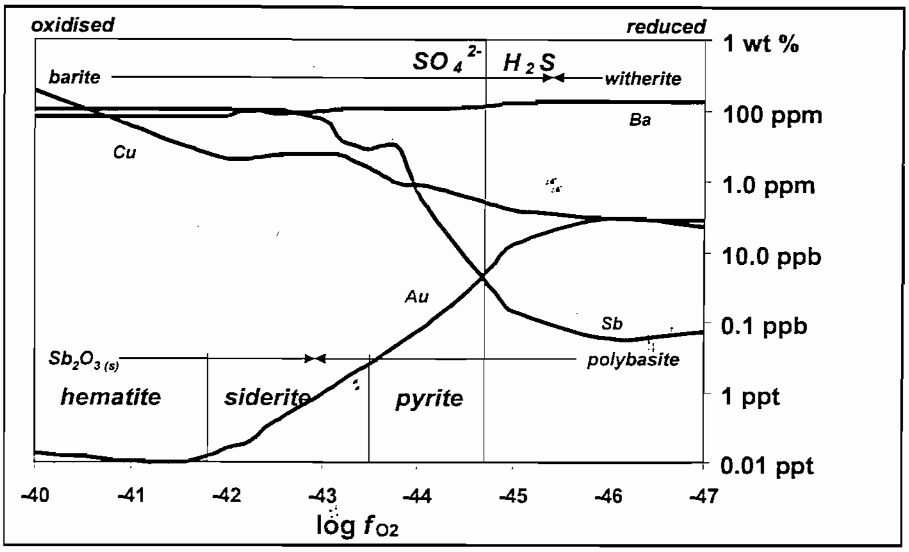

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Results - 150°C calculations

- High Cu solubilities in oxidised 150°C brines at pH = 4.5
- Reduction promotes Cu deposition primarily as chalcocite (+ hm), followed by bn-sid, cp-sid, cp-py and bn-py
- Associated trace elements: Zn, Pb, Ag, Sb
- Au & possibly Ba (?) not present in anomalous concentrations

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CODES SRC

Forward Program

- Detailed chemical modelling to commence in 2002 *(collection of field data, hypothesis generation, completion of other work commitments)*
- Addition of Co & Ni thermodynamic data to chemical database
- Consideration of organometallic Cu complexes
- Other trace elements?

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CODES SRC

What types of fluids have existed in the basin at different times in its history?

Extrabasinal

- magmatic
- metamorphic

Intrabasinal

- connate water
- evaporitic brines (bitterns?)
- meteoric
- metamorphic

All of the above !

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What types of fluids have existed in the basin at different times in its history?(con)

CODES SRC

Several approaches:

- understand the type of basin
- direct observation (fluid inclusions)
- chemical modelling (can use information on ore mineralogy and geochemistry to constrain this)
- hydrological modeling

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What traps copper

CODES SRC

?

chemical/physical (geological/hydrological)?

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SA - Introduction

Main outcomes

- structural geometry and magmatic events within basement exert a strong influence on the basin history within cover
- sed-hosted Cu is diverse in terms of stratigraphic position, style & genesis

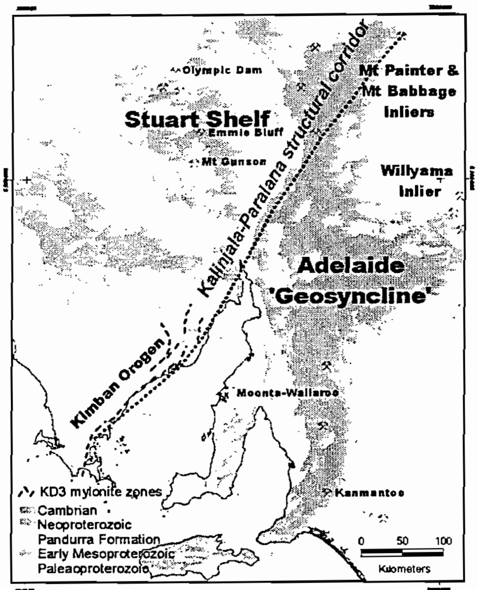
Structure of talk

- geological framework: Palaeoproterozoic - Cambrian
- styles of sed-hosted Cu

Basic stratigraphic elements

Palaeoproterozoic

- clastic-dominated sedimentary package
- deformed during Kimban Orogeny
  - 1840 - 1700 Ma
- KD3 mylonite zones



Early Mesoproterozoic

- Gawler Range volcano-plutonic event (GRVPE: 1595-1580 Ma) - Galwer Craton, Yorke Peninsula and Stuart Shelf regions
  - extension and thermal subsidence

- Olarian Orogeny - Curnamona Province
  - syn-tectonic magmatism roughly coeval with GRVPE

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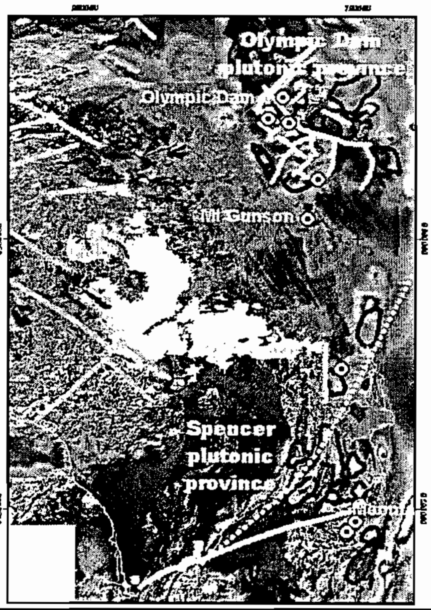
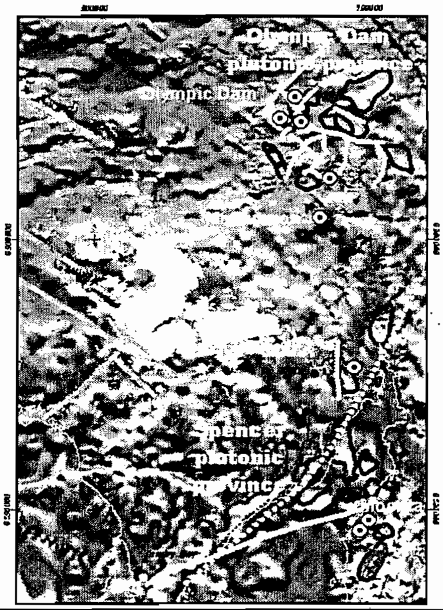
Gawler Craton & Stuart Shelf





Gawler Craton & Stuart Shelf

- GRVPE comprises Gawler Range Volcanics and Hiltaba Suite granites
- NE-SW to NNE-SSW directed extension

Hiltaba Suite

- two geochemical types:
  - Roxby Downs Type - oxidised haematite-magnetite series: U, Th enriched
  - Kokatha Type - less oxidised ilmentite
- two major plutonic provinces:
  - Olympic Dam & Spencer plutonic provinces

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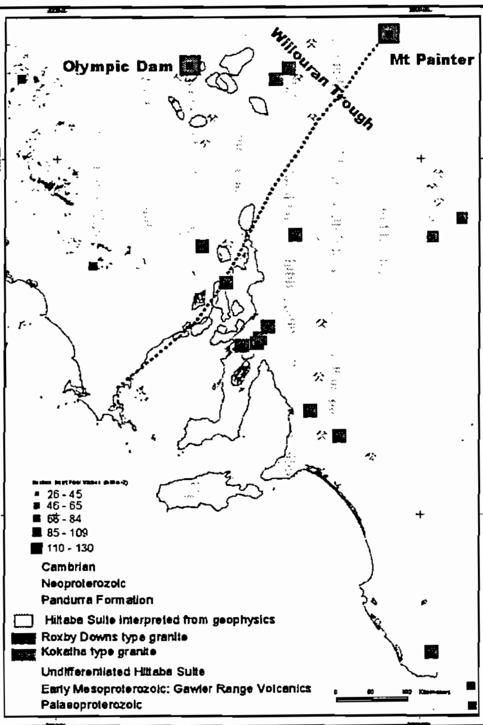
Heat Flow

- Roxby Downs type granites correspond with anomalously high heat flow
- elevated surface heat flow values extend below AG towards Mt Painter
- implications for fluid flow?



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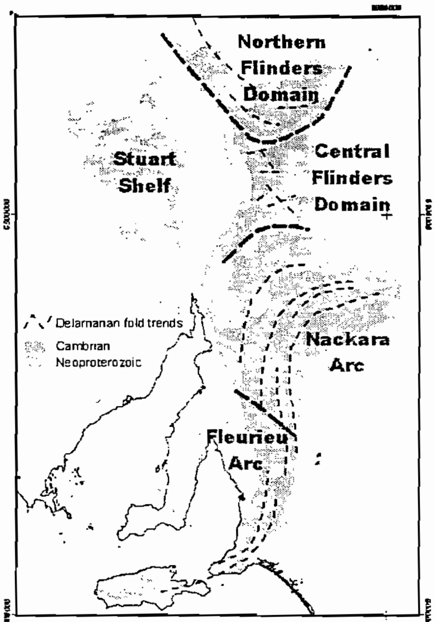
Middle Mesoproterozoic

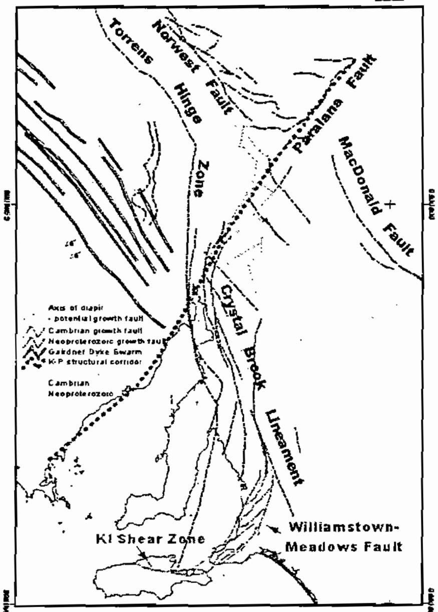
- Pandurra Formation represents the first of a series of clastic-dominated rift basins
- rift margins are indistinct
- characterised by considerable thickness variation

Neoproterozoic - Cambrian

- series of rift and sag phases
- records progressive breakup of Rodinia from 830 Ma to 515 Ma
- Delamarian compression 515 Ma to 480 Ma

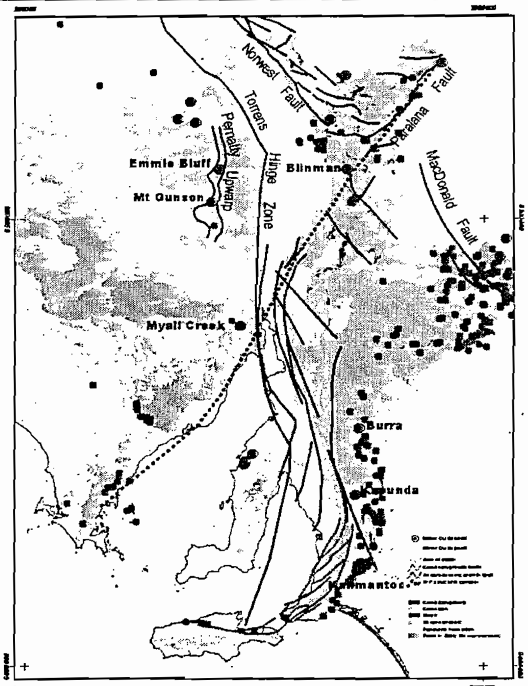
Structural Framework



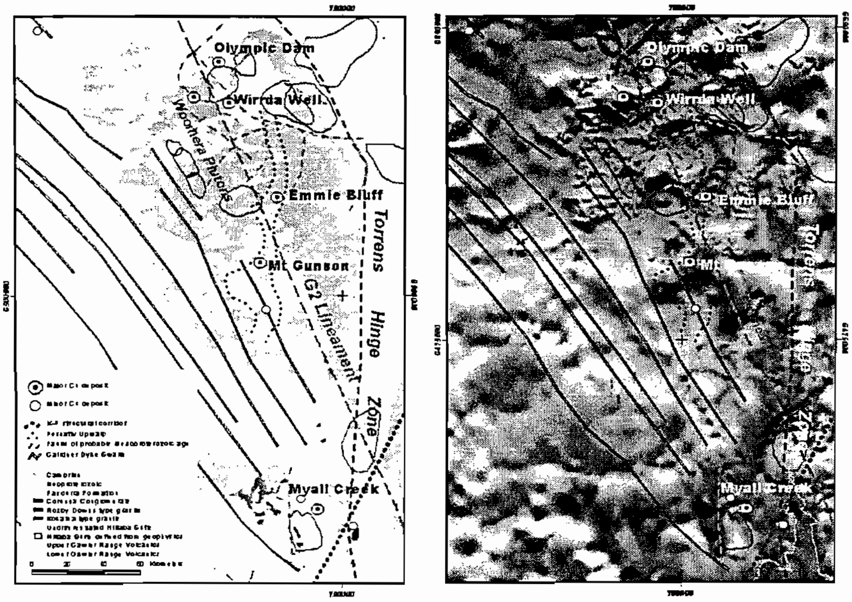


Cu Distribution

- Cu coincides partly with margins of sub-basins and platformal shoulders



Stuart Shelf Cu



Size and Grade

- Mt Gunson: 5.6 Mt @ 2.1% Cu
- Emmie Bluff: 24 Mt @ 1.3% Cu
- Myall Creek: up to 1.5% Cu

Stratigraphic controls on Cu

- Unconformable contact of the Pandurra Sandstone and Whyalla sandstone
- permeable horizons within the Tapley Hill Formation
  - main mineralised zone at the unconformable base
  - minor mineralisation at the top

Local structural controls

Mt Gunson

- Pernatty Upwarp - series of N-S trending horst blocks
- emergent at least by Whyalla Sandstone time
- THF-hosted mineralisation restricted to narrow NW trending 'palaeovalleys'

Structural controls (cont.)

Myall Creek

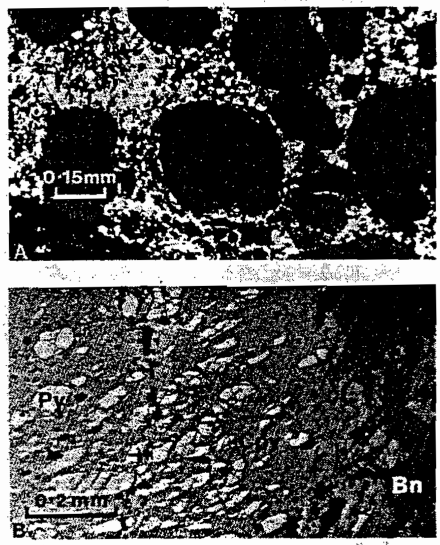
- half-graben geometry - but no direct association with known structure
- minor N-S 'palaeovalleys'
- no association with 'basement highs'

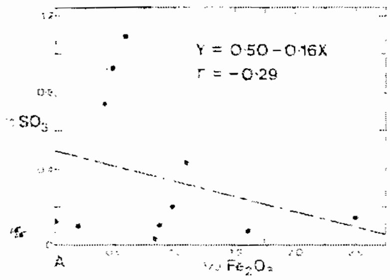
Mineralisation

Sandstone-hosted deposits

- Cu sulphides occupy secondary porosity in brecciated upper surface of Pandurra
- Ore mineral paragenesis:
  - Fe-oxides → pyrite → Cu sulphides
- sphalerite and galena represent final mineral products in the ore paragenesis
- no evidence of hydrothermal alteration

Replacement textures





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Mineralisation (Cont.)

Tapley Hill Formation Cu

- permeable sandstone/silt beds or lamellae
- vein hosted mineralisation in less permeable strata
- Fe and Ti are depleted in mineralised zones
- strong correlation of $C_{organic}$, Fe and S
- base metal sulphide introduced late

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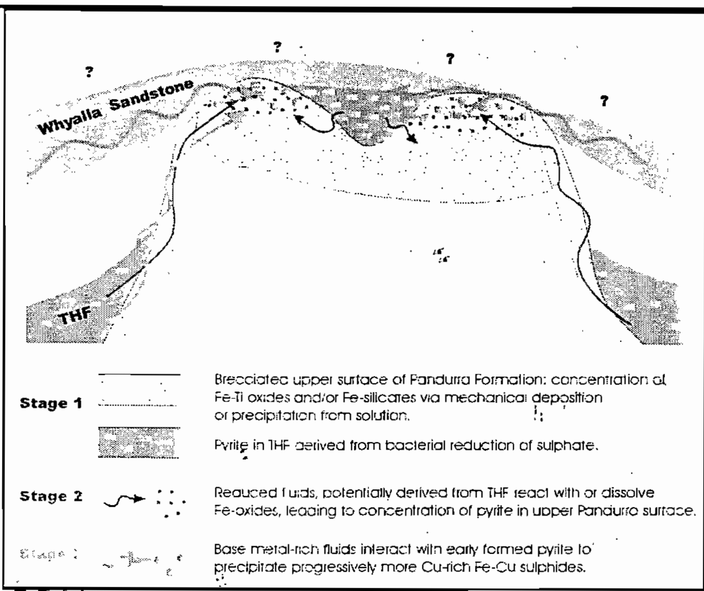
Ore Genesis



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Summary

- Palaeoproterozoic - early Mesoproterozoic structures are long lived and influence:
  - Hiltaba Suite granites
  - Neoproterozoic - Cambrian basin geometry
- Spatial association of Roxby Downs type granites with:
  - surface heat flow
  - Neoproterozoic - Cambrian rift packages
  - Fe-stone and sed-hosted Cu
- Structural geometry of Delamarian Orogen is directly related to Neoproterozoic-Cambrian basin geometry

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Summary (cont.)

- Sed-hosted Cu displays broad spatial association with:
  - inverted basin margin faults
  - platformal margins of major rift depocentres
  - inner arc of Delamarian thrust belt
    - syn-orogenic fluid flow and Cu mineralisation?

- Stratabound Cu mineralisation on the Stuart Shelf is low-T and lacks evidence of hydrothermal fluid
  - Cu mineralisation is late stage
  - pyrite is only truly syngenetic sulphide

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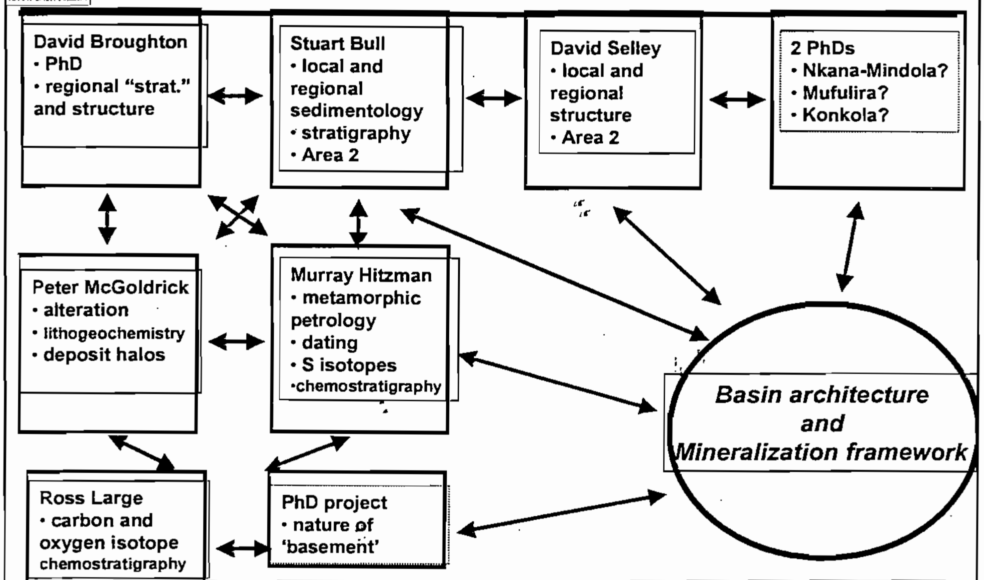
Zambian Forward Program



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South Australia Forward Program

Willouran Ranges Transect
•controls on minor Cu occurrences
•basis for fluid flow modelling
field work next autumn
construct section for fluid modelling

Emmie Bluff & Mt Gunson deposit studies
•paragensis of sandstone & siltstone hosted Cu deposits
•geochemical signatures of Cu mineralistion
visit Mt Gunson & review core at PIRSA library
lithogeochemistry

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Budget Considerations

- total ARC and AMIRA income has now reached target (abt. A$1.4 million)
- however the decline in the A$ coupled with relative increase in work offshore means an overall 20% drop in the budget in real terms
- thus, two further sponsors are required to complete the proposed work and balance the 3 year budget

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Future P544 meetings

- Zambian field trip late July 2001 ?
- End of year meeting in Denver in mid-November ?
- SA field trip in mid-2002 ?

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