Exploration and processing of gold – some guidelines for ASM

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Talk Outline

- Mineral deposit types
- Exploration
- Assessment of resources
- Processing of ores
- Conclusions

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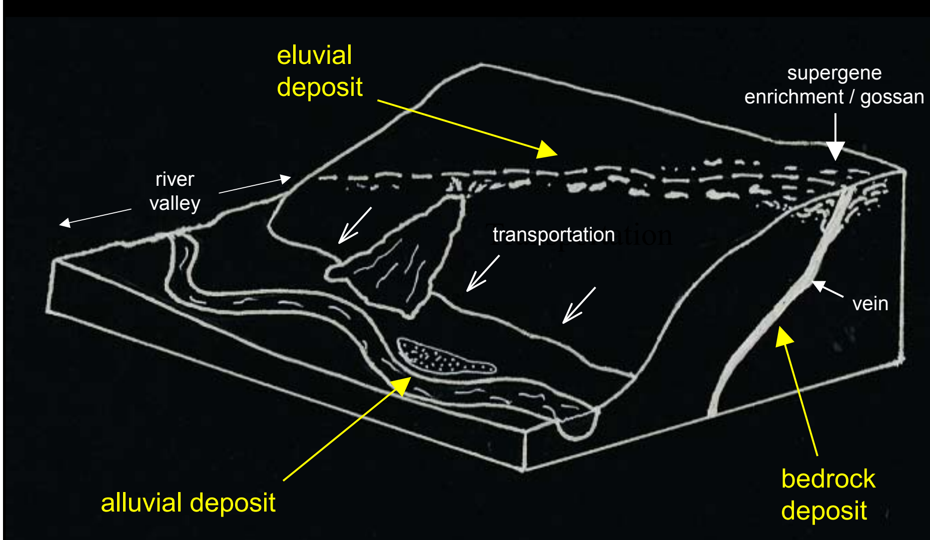
Gold deposit types

- Hardrock or Bedrock
  - many types, each with characteristic features and distinct mode of origin
  - study of many examples allows common features ('fingerprints') to be identified to guide exploration
- Placer
  - derived by action of surface processes on gold in bedrock e.g. alluvial, marine, eluvial, colluvial, etc

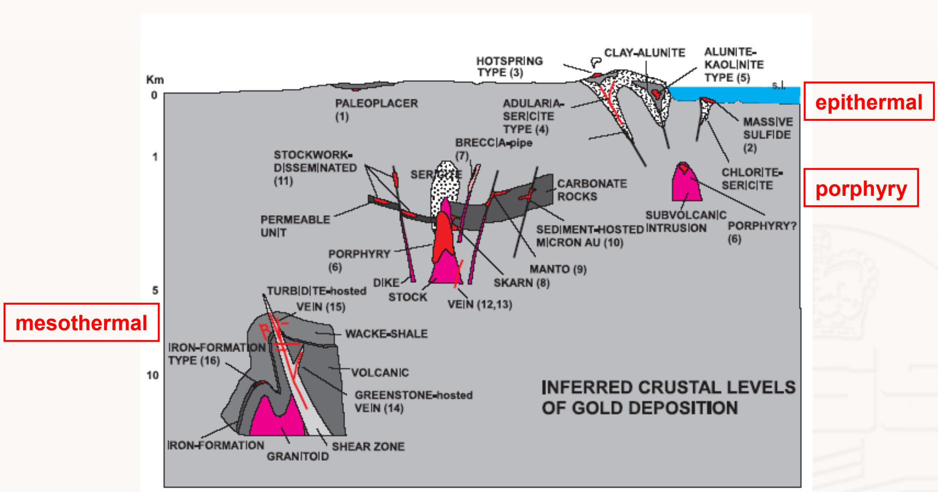
Environments of gold deposition



Diagnostic features

- To identify and classify deposits
- To guide exploration
  - Deposit form and size
  - Ore controls – structure, host rock
  - Hydrothermal alteration – nature and extent
  - Ore mineralogy
  - Gangue mineralogy
  - Textures

Gold deposit types



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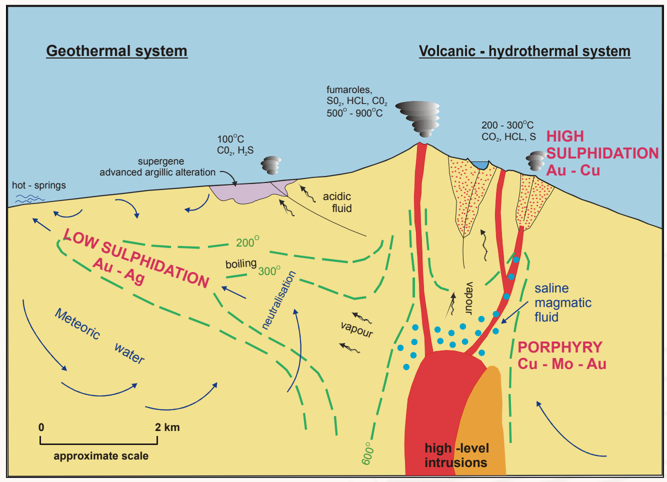
Tectonic setting of epithermal and porphyry precious-metal deposits

- Located in orogenic belts at convergent plate margins, associated with subduction-related magmatism and related geothermal systems



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Epithermal Gold Deposits

- Important economic sources of gold, especially in the circum-Pacific region, but also in Europe
- High-grade vein to low-grade bulk tonnage deposits, most in Tertiary volcanic terranes
- Two major types:
  - **high sulphidation** (acid sulphate, alunite-kaolinite, quartz-alunite)
  - **low sulphidation** (adularia-sericite)

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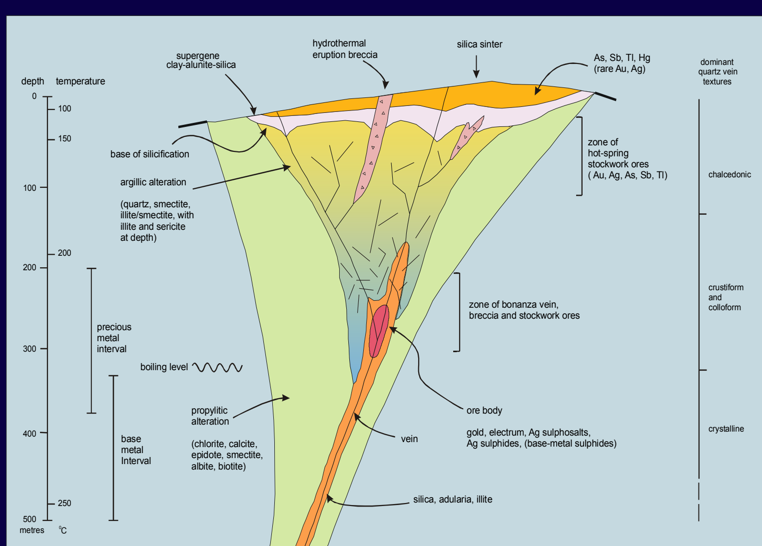
Low-sulphidation epithermal gold deposits

Feature	Characteristics
Tectonic setting	volcano-plutonic continental margin and oceanic arcs, and back arcs
Geological setting	at shallow depths in regional faults systems, grabens, calderas, strato-volcanoes, flow-dome complexes, diatremes
Host rocks	andesite-rhyodacite-rhyolite
Age of host rocks	any, most Tertiary and Quaternary
Deposit form	veins and stockworks; grades vary from <1 to >100 g/t; very fine-grained gold
Ore controls	faults, shear zones, permeable lithologies, breccias
Alteration	(proximal) silicification, sericitic, argillic, propylitic (distal)
Quartz textures	open-space fills - crustiform / colloform banded, comb, cockade, bladed
Gangue	quartz, chalcedony, amethyst, carbonate, adularia, barite, fluorite
Ore minerals	electrum, gold, pyrite, silver; minor sphalerite, galena, tetrahedrite, chalcopyrite
Metals present	Au, Ag (Zn, Pb, Cu, Mo, As, Sb, Te, Se, Hg, Ba, F , Mn)



Schematic cross-section showing the architecture of a typical low-sulphidation deposit

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Low sulphidation epithermal Au-Ag veins, Ecuador

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Gold-bearing quartz stockwork in low-sulphidation deposit, Ecuador

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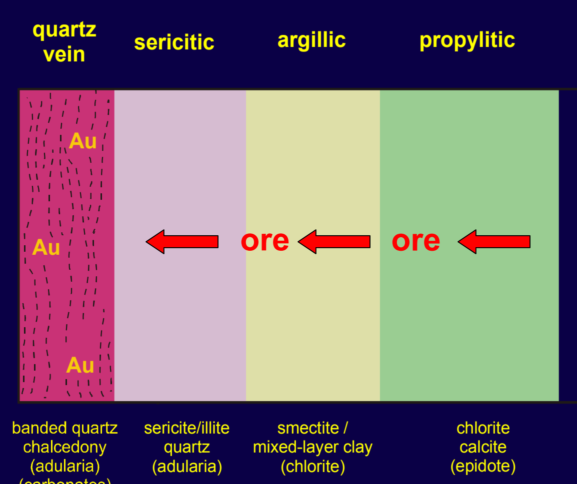
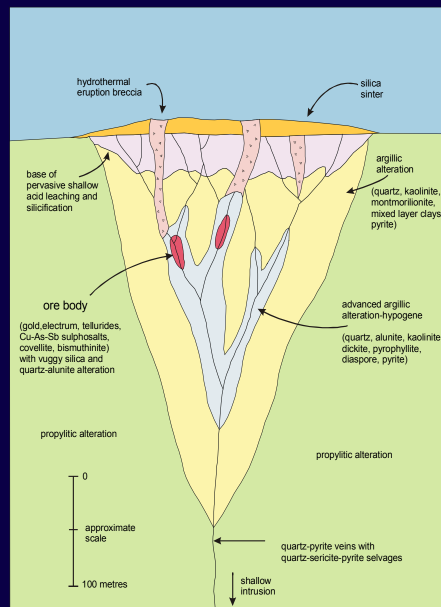
- Epithermal vein textures
  - open-space filling
  - typically banded

SCHEMATIC ALTERATION ZONING IN EPITHERMAL SYSTEMS

LOW SULPHIDATION

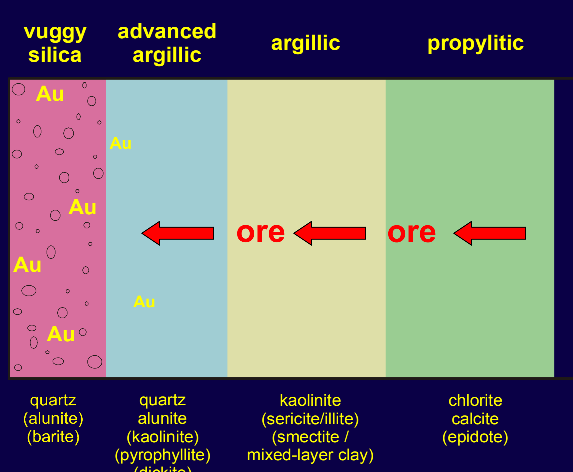


Schematic cross-section showing the architecture of a typical high-sulphidation epithermal deposit



SCHEMATIC ALTERATION ZONING IN EPITHERMAL SYSTEMS

HIGH SULPHIDATION



High sulphidation epithermal gold deposit, Ecuador

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Vuggy silica gold ore in high sulphidation deposit, Ecuador

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Vuggy silica ore with alunite in high sulphidation deposit, Ecuador

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Porphyry copper-gold deposits

- Major sources of copper and gold, most in the circum-Pacific region
- Large low-grade deposits, including ‘giants’ such as Grasberg and Bingham
- Au grades 0.5 - 2 ppm
- Most Tertiary in age, but Mesozoic and Palaeozoic examples known

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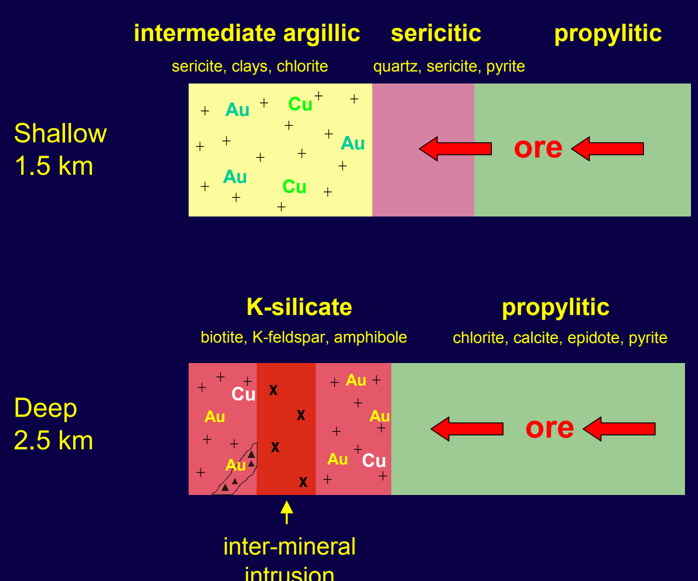
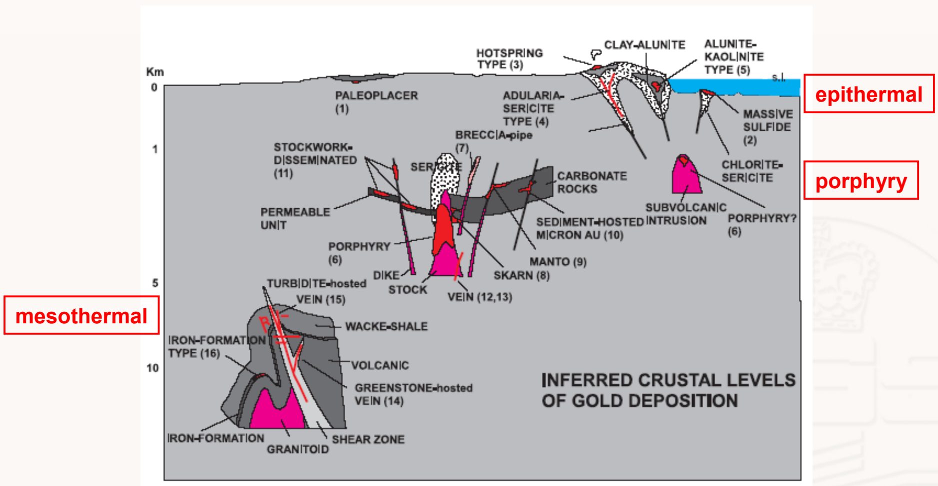
Porphyry copper-gold deposits

- Stockwork ores; breccia types also common

SCHEMATIC ALTERATION ZONING IN PORPHYRY COPPER-GOLD SYSTEMS



Gold deposit types



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Mesothermal vein gold deposits

- Major sources of gold worldwide, in Archaean greenstone belts (Canada, Western Australia)
- Numerous major deposits in Phanerozoic clastic sediments in:
  - Victoria, Australia; Nova Scotia, Canada; Mother Lode, California; Carolina Slate Belt, etc

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Mesothermal gold deposits

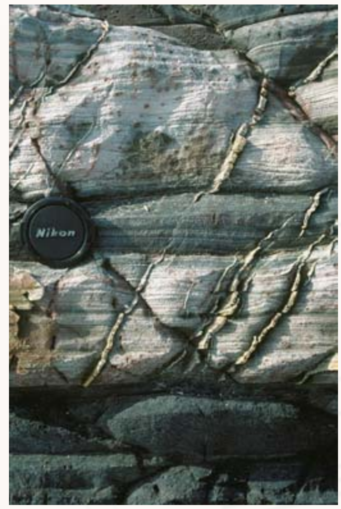
Feature	Characteristics
Types	Shear-zone related, granite-related, turbidite-hosted
Tectonics Structure	In accreted, deformed and metamorphosed continental margin or island arc terrains. Close to major structures, transcurrent faults or major brittle-ductile shear zones. Emplaced at depths of 5-10 km, temperatures 250-350 C
Grade	Typically 5 - 25 ppm, 1-5 million tonnes
Host lithology	Variable lithology; greywackes-pelites, chemical sediments, volcanics, plutons, ultramafics. Local control by competence
Relations to plutons	Variable; possible hidden intrusion
Local structure	Ores in dilatant zones controlled by folds and faults; mineralisation commonly associated with second-order faults related to major structures. Shear zone / fault intersections
Timing	Late post-dates main deformation
Ore morphology	Quartz carbonate veins, with high-grade ore shoots; vertically and laterally continuous
Mineral paragenesis	Early quartz, Ca-Mg-Fe carbonates, arsenopyrite, pyrite, albite, sericite, chlorite, scheelite, stibnite, pyrrhotite, tetrahedrite, chalcopyrite, tourmaline. Late gold, galena, sphalerite. Gold may be coarse grained
Hydrothermal alteration	Carbonatization, albitization, sericitization, silicification, sulphidation, chloritization
Lithogeochemistry	Au/Ag typically > 1; associated Ag, Sb, As, W, Hg, Bi, Mo, Pb, Zn, Cu, Ba

Mesothermal vein deposits

- Extensive lateral and vertical continuity
- Sporadic high-grade shoots
- Important associated alluvial deposits

Controls on distribution of mineralisation

- Structural controls fundamental
- Complex multi-stage development
- Competent lithologies that behave in a brittle manner



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Gold in Banded Iron Formation (BIF)

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Multiple phases of quartz veining – but where is the gold?

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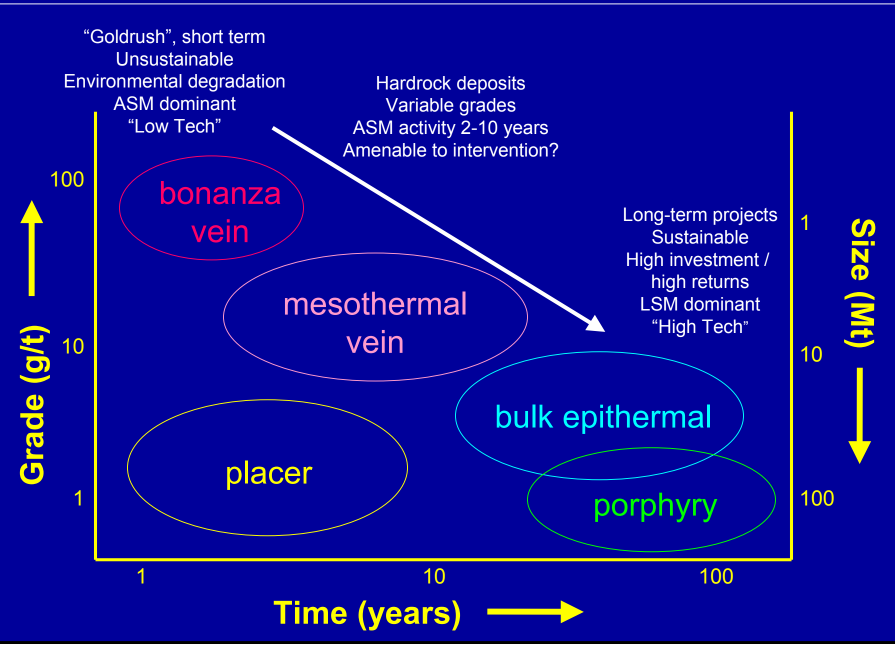
Exploration guidelines

- Different hardrock deposit types have different exploration criteria – 'fingerprints'
- Different deposit types have different potential to support sustainable ASM
- What are the factors that control the distribution of gold in the deposit?
- What is the size and shape of the deposit?
- Where is the gold concentrated?
- Quartz vein textures may be useful
- Alteration styles and intensity provide guidance
- Nature of bedrock host is important

Gold deposit types and sustainability



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Assessment of gold deposits

Some important variables

- Gold content (grade)
- Gold grain size and shape
- Gold distribution in bedrock (degree of liberation - free milling or occluded)
- Gold distribution in superficial deposits (alluvium, soil, regolith, etc)
- Sampling
- Test work

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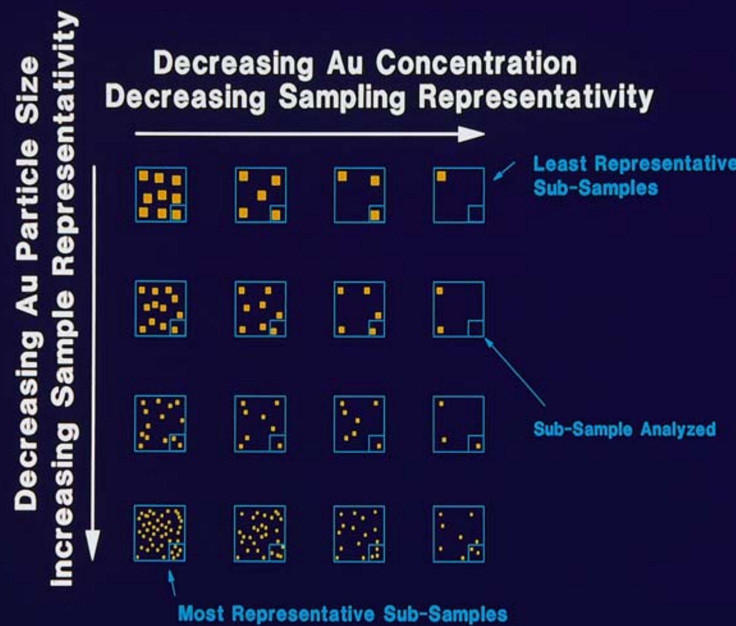
Problems in collecting representative samples

- Gold occurs
  - in low abundance
  - as high density native grains
- Therefore gold has a very erratic distribution in the natural environment
- Difficult to collect representative samples
  - the nugget effect

The Nugget Effect



Reducing the nugget effect

- Large samples
- Fine grain size
- High gold concentration

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Where is the gold located?

- Careful and systematic sampling of profiles through overburden / alluvium

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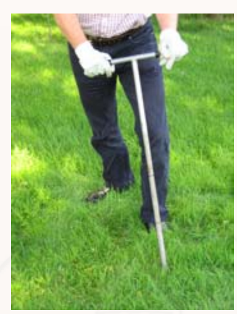
Rapid sampling of soil and overburden

- ‘Dutch’ soil auger simple and quick to use
- Several sub-samples at each site
- Simple control of depth
- Samples can be sieved / panned



Conclusions

- Collecting representative samples is a major challenge for both exploration and assessment of gold
- Test work should be conducted to characterise the distribution of gold in bedrock and overburden
- Careful sampling of pits is a good approach
- Sampling with an auger is quick, simple and effective method for some terrains

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Processing of gold ores

- Focus on recovery using sluice boxes
- No discussion of mercury – for in-depth discussion see Global Mercury Project Task Force Meeting, Salvador, 26-28 September 2005

Processing of gold ores

- DFID-funded project carried out by BGS in partnership with ITDG and Guyana Geology and Mines Commission (GGMC)

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Why technical testing is important

- Efficient mineral processing depends on having an appropriate recovery system for ore minerals
- To achieve this you need to know the nature of the ore
  - grain size
  - shape
  - degree of liberation from host rock
- Choose the most appropriate equipment to use
- Optimise the design of the equipment you are using

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What was the problem in Guyana?

- Past sluicing operations were inefficient
- Generally believed reason
  Poor recovery of fine-grained gold
- Hearsay
- Easy excuse
- No evidence of testing

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Technical aims of the project

- Work out why sluice was inefficient
- Check gold grain size distribution in feed, concentrates and tailings

Different approaches tried

- Sample types
  - bulk samples
  - lab panning
  - Knelson
  - field hand pan concentrates
  - sluice box concentrates
  - mini sluice (Clarkson)
- Assay methods
  - bulk assay
  - sieve then assay
  - sieve then weigh grains

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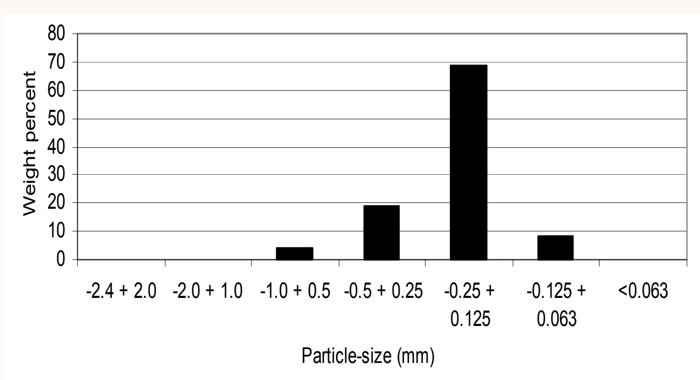
Results from typical sample



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How much fine gold is there?

- All our tests show that gold finer than 0.01 mm is only around 10%
- Independent GGMC tests using a Knelson concentrator found similar results
- Loss of fine gold cannot be the problem
- There is very little to start with

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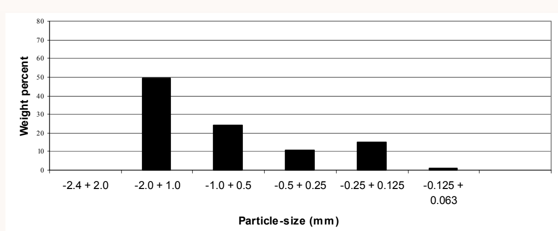
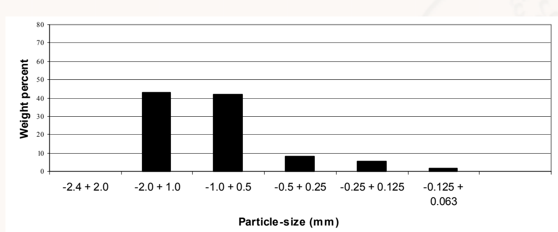
Testing the sluice box

Feed



Tailings



Identifying the problem

- 80% of gold lost is coarser than 0.5 mm
- This should easily be caught by good sluice box
- A better gold trapping system is required

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Technical conclusions

- Sluice box suitable
- Detailed design and operation poor
  - Mats bad
  - Riffles too big or absent
  - No screening
- Miners need better equipment
- Miners need training

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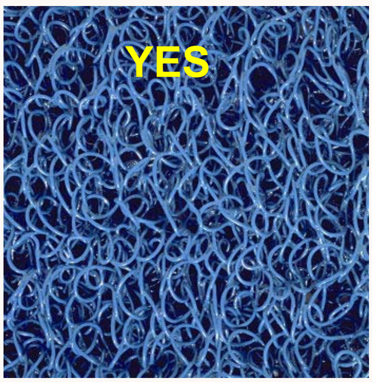
Use Nomad mats not carpet



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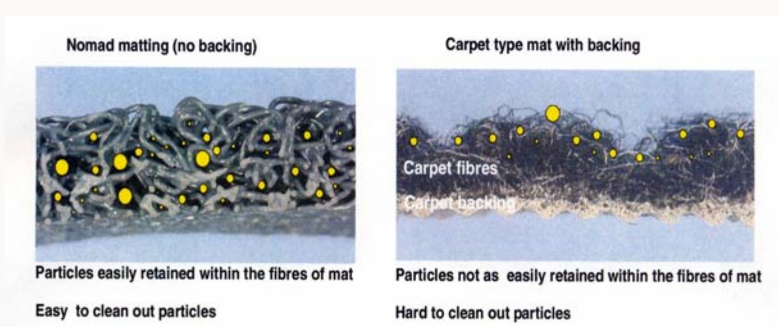
Why Nomad is better



- And it lasts longer

For recovery of fine gold

- Use heavy expanded metal sheet over Nomad mat
- The gold must be in contact with the mat to be trapped
- If not your sluice is just a funnel to the tailings

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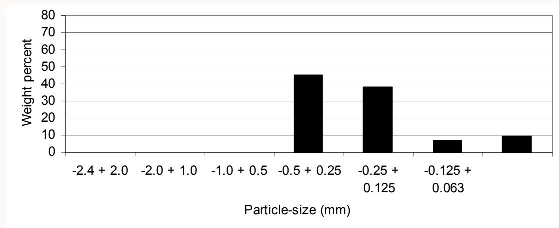
Details wrong

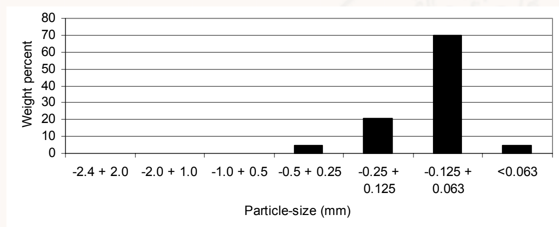
- No expanded-metal riffles
- Too wide

Tailings testing – after box refit

- **Before refit**
  - 80% of gold in tailings coarser than 0.125 mm



- **After refit**
  - 80% of gold in tailings finer than 0.125 mm



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Practical demonstrations give results

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Project Conclusions

- Test work is a necessary investment, with the potential to bring real gains in efficiency
- Practical demonstrations in mining areas are an effective method of bringing new and better technology to small-scale miners
- Once the correct method is established as the ‘accepted way to do things’ it will be widely copied and used, to the benefit of the miners and local communities
- Project description and results are presented in a booklet which is available here today

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Thank you for your attention

Obrigado