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Strategies for Managing Chemically Reactive Mineral Waste

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Overview of Strategic Principles

1. Sound science

2. Evaluation and prioritisation of risks

3. Transparency, collaboration and an ability to work and share learnings

4. Management practices that are supported by a business case

5. Long-term environmentally protective management practices

6. Strive to improve environmental performance

7. Innovative adaption of accepted practices

8. Turn research into implementable solutions

9. Validation of management systems

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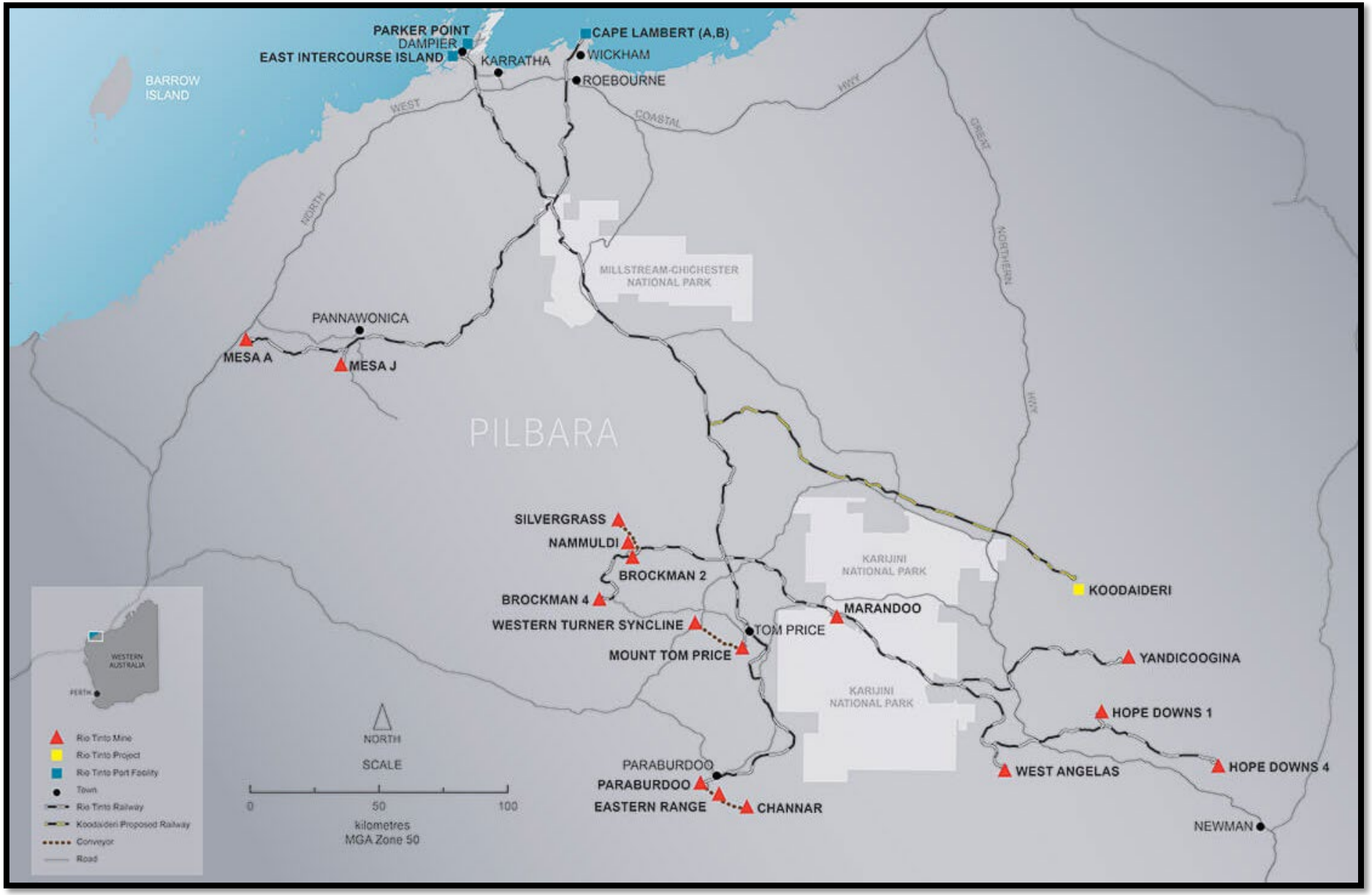
Rio Tinto's Pilbara Mines



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Rio Tinto's Pilbara Mines – PAF Material

- Historically, most Potentially Acid Forming (PAF) material has been mined from 1 or 2 mine sites per year
- More recently, PAF material is being mined from multiple mine sites

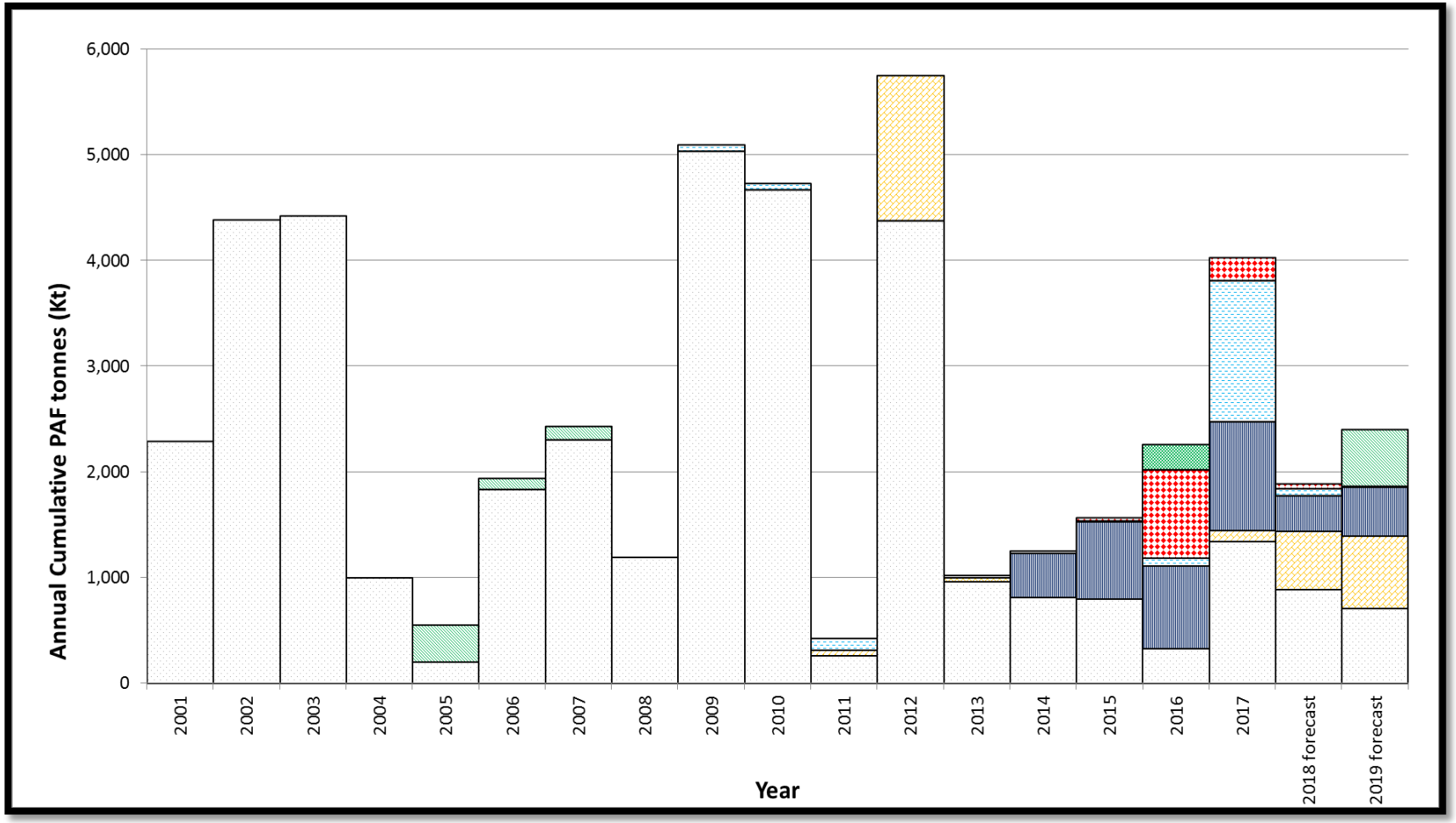

Figure: Annual PAF tonnages. Different colours represent different mine sites in the Pilbara

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Rio Tinto's Pilbara Mines – PAF Material

- PAF waste material is mined at some of Rio Tinto's Pilbara mine sites
  - Pyrite-bearing (FeS_2) Mt McRae Black Shale, and lignites in detritals pose the greatest risk
- When excavated during mining, pyrite can oxidise, triggering the generation of heat and Acid and Metalliferous Drainage (AMD), with potential for spontaneous combustion

Case Studies

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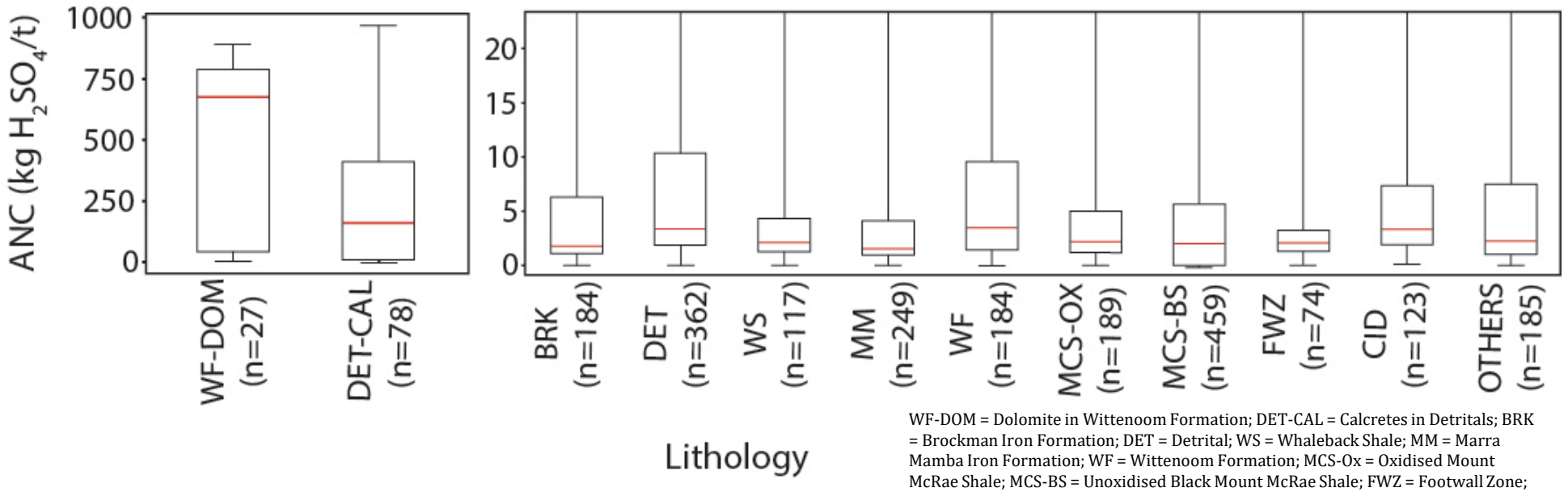
1. Sound Science

Case Study: Early orebody knowledge

- Regular acid base accounting and kinetic studies
- Segregation within geological and mining models
- AMD risk assessments



WF-DOM = Dolomite in Wittenoom Formation; DET-CAL = Calcretes in Detritals; BRK = Brockman Iron Formation; DET = Detrital; WS = Whaleback Shale; MM = Marra Mamba Iron Formation; WF = Wittenoom Formation; MCS-Ox = Oxidised Mount McRae Shale; MCS-BS = Unoxidised Black Mount McRae Shale; FWZ = Footwall Zone; CID = Channel Iron Deposits

Figure: Acid Neutralising Capacity (ANC) variation (5th percentile, 25th percentile, median, 75th percentile and 95th percentile) in different lithologies (showing the number of samples analysed)

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2. Evaluation and Prioritisation of Risk

Case Study: Identification of opportunities to manage or avoid AMD before mining

- PAF material on the pit shell was predicted during the study phase
- Uncertainty due to gaps in drilling data were assessed
- AMD risk assessment was completed
- Mine plans for each development project were revised to avoid or minimise exposing PAF material.
- This reduced the likelihood that acidic pit lakes would need to be managed in perpetuity.

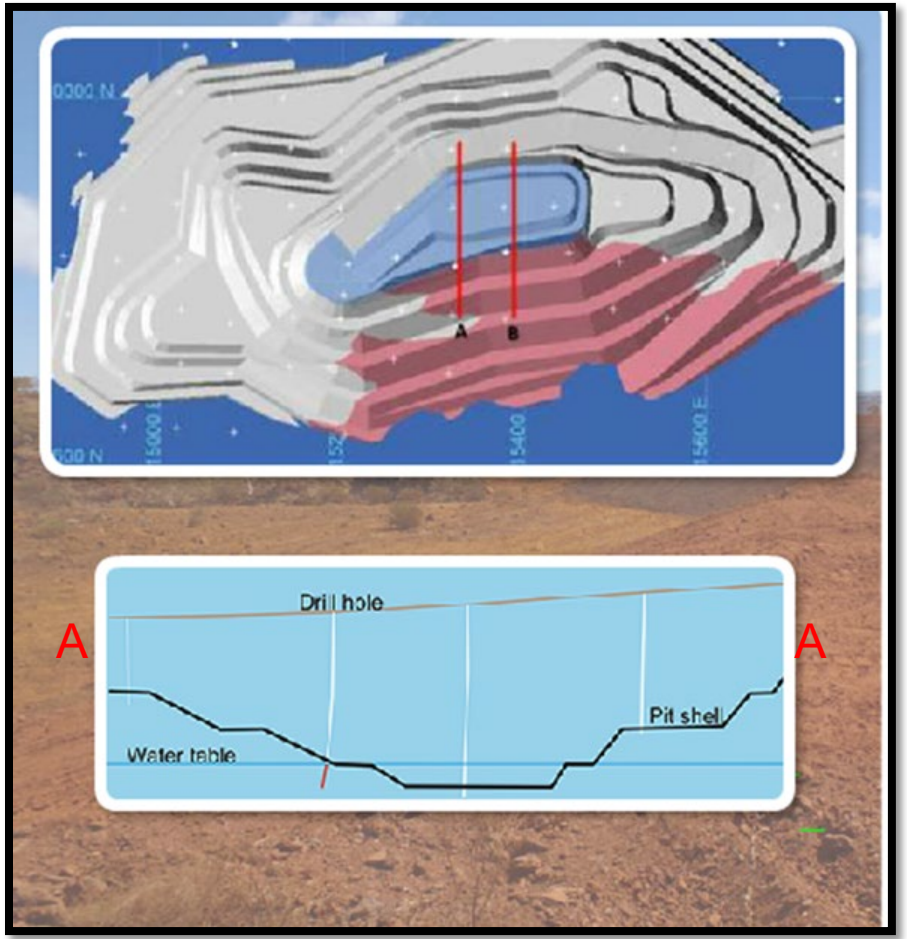

Figure: Pit outline and cross section (showing elevated sulfur material as red within the drill hole)

3. Transparency, Collaboration and an Ability to Work and Share Learnings (1)

Case Study: Internal engagement

- Interactive mineral waste training module completed 400 times since 2014, primarily by Geologists, Hydrogeologists and Mine Planners
- Face to face and site specific operator training

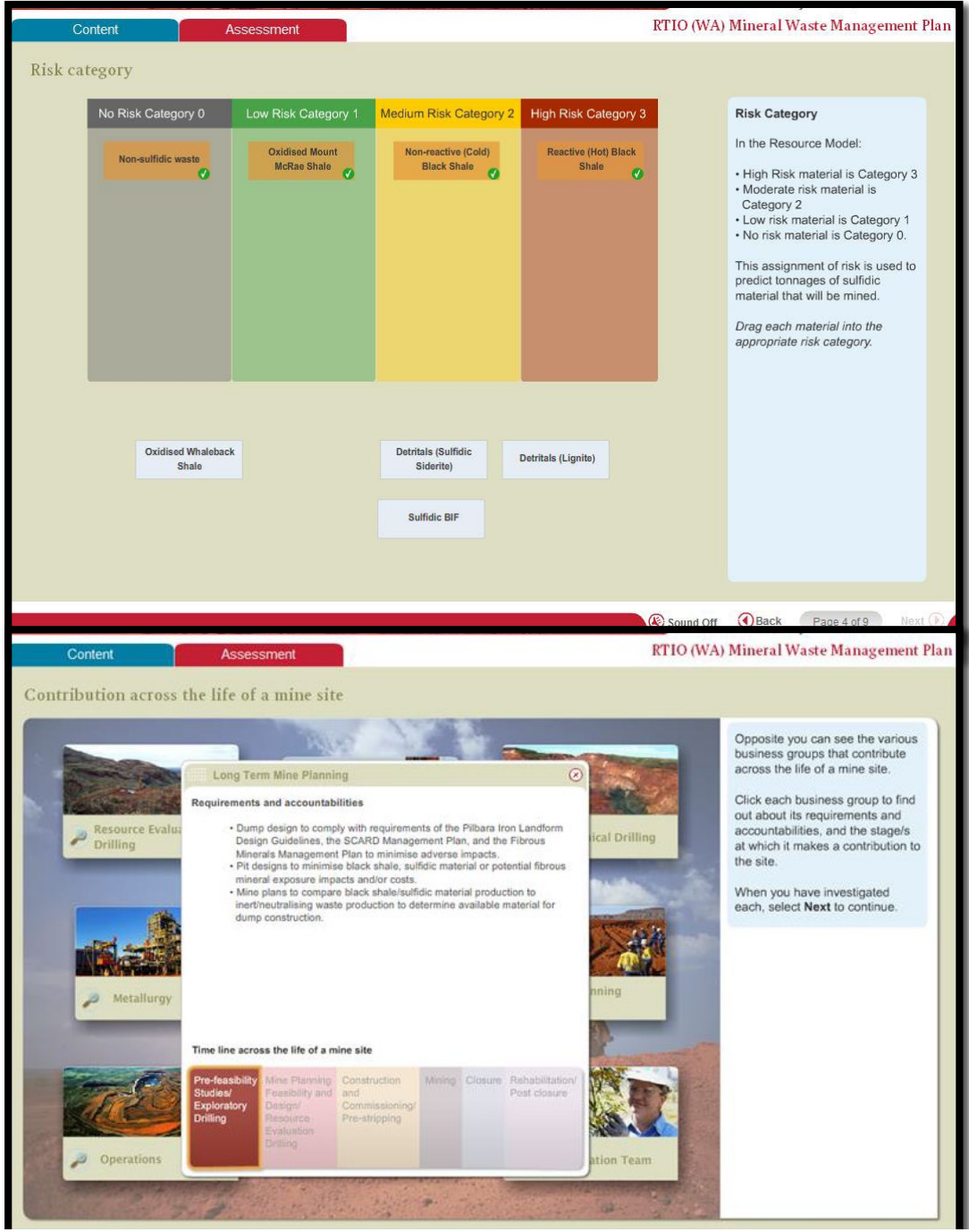

Figure: Exerts from the interactive mineral waste training module

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3. Transparency, Collaboration and an Ability to Work and Share Learnings (2)

Case Study: External engagement

Routine XRF

Objective: Identify potential contaminants in a wide range of samples from different locations and depths

Elevated Sulfur → **Acid base accounting and kinetic test work**

Low Sulfur → **Extra elemental analysis of the solid and liquid extracts**

Evaluate waste storage options

Objective: Assess leachability as a function of conditions

Modified Leach Extract Tests

NAG leach | **Mild acid/alkaline leach** | **Saline leach** | **Low water contact ratio** | **Multi-step leach** | **Geochemical interpretation**

Unresolved issues or uncertainty

Objective: Gain insight to the proportion of minor/trace element content that could be most vulnerable to mobilisation

Objective: Assessing reaction rates, relating leach potential to environmental setting

Diagnostic Tests

Detailed mineralogical test work | **Sequential extractions**

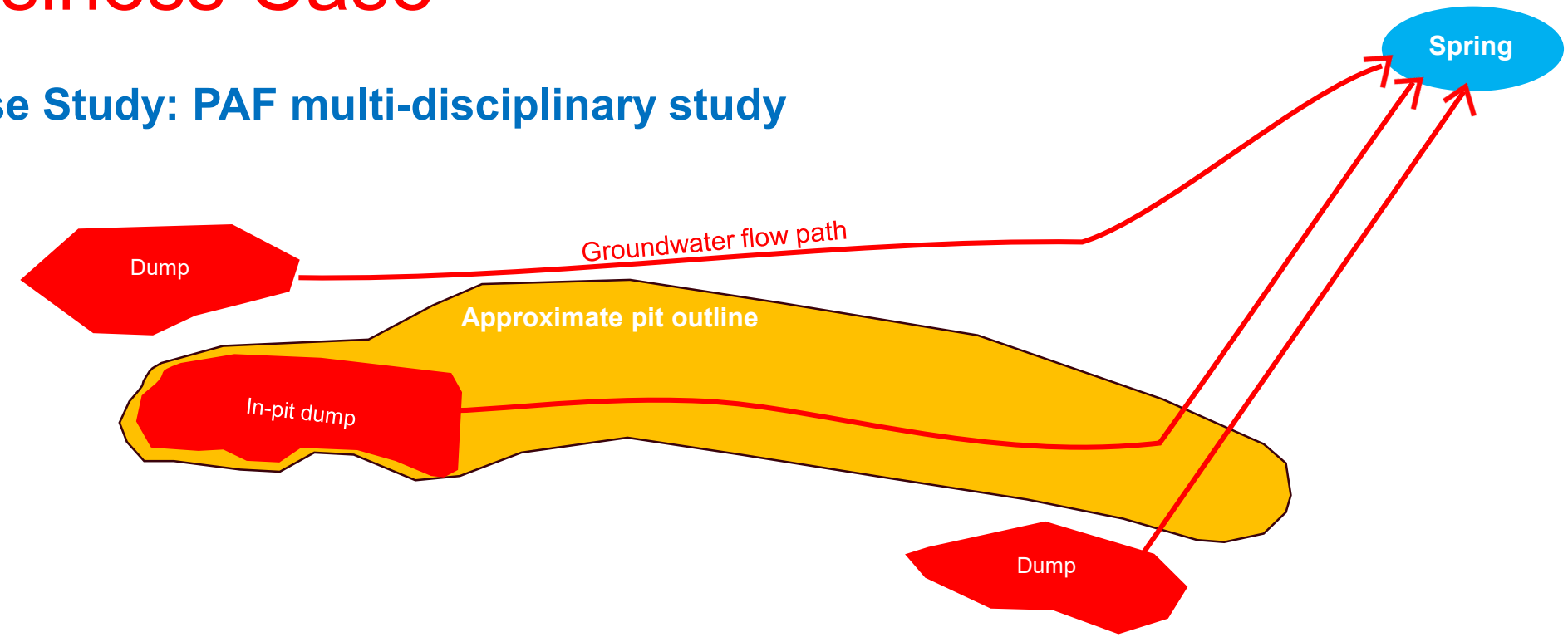
↔ **Geochemical interpretation** ↔

Kinetic Tests, Other

Free-draining or saturated column testing, LEAF methodologies

4. Management Practices that are Supported by a Business Case

Case Study: PAF multi-disciplinary study



- Study undertaken in 2016 to identify the optimal PAF material storage location
- Consideration of environmental, compliance and business constraints
- An AWT dump far away from the Spring was selected because impact to the Spring would be negligible

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5. Long-term Environmentally Protective Management Practices

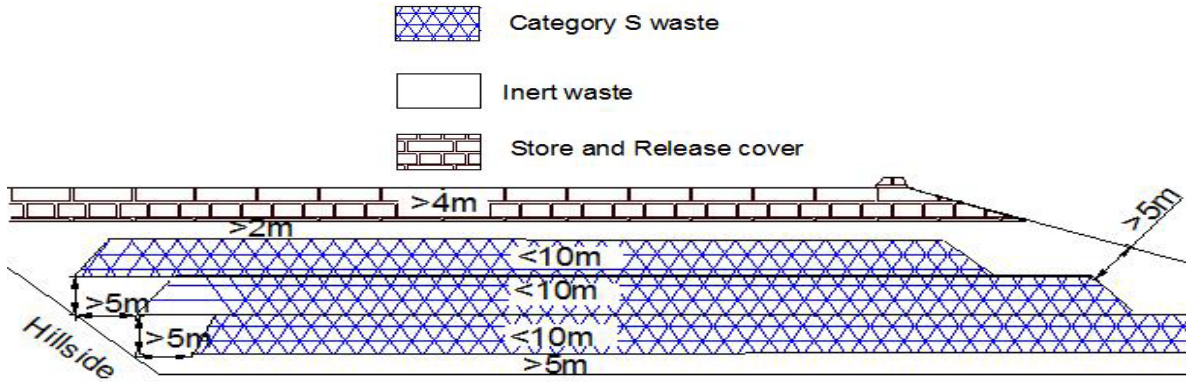
Case Study: Building waste rock dumps to control spontaneous combustion and AMD

Reactive PAF material:

- Thin lift, base up dump construction for reactive materials
- Paddock dumped and compacted to limit air entry and optimise moisture retention
- Inert layer between reactive layers to dissipate heat
- Store and release cover to limit net percolation of rainwater

Non-reactive PAF and carbonaceous material:

- Encapsulation with inert waste during construction
- Stockpiling PAF material together to reduce oxidation rates
- Store and release cover to limit net percolation of rainwater



6. Strive to Improve Environmental Performance

Case Study: External expert reviews of PAF management strategies

Business conformance audits:

- Business conformance audits assess conformance with Rio Tinto HSEC performance standards
- Senior personnel from within Rio Tinto undertake these reviews, particularly from different business units
- The E13 Chemically Reactive Mineral Waste Standard is 1 of the 5 Rio Tinto Standards that is reviewed

AMD/Mineral waste reviews

- AMD reviews are undertaken for necessary sites every 4 years
- Both external and internal AMD experts are utilised

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7. Innovative Adaption of Accepted Practices

Case Study: Acidic pit lake bioremediation field trial

- Sulfate Reducing Bacteria (SRB), have the potential to remediate AMD by converting sulfates to sulfides under low redox environments while utilising labile organic carbon substrates as electron donors.
- 27 bales of hay (19t) added to an acidic pit lake. ≈ 0.3m thick layer across sediment
- pH levels increased and dissolved oxygen and sulfate decreased in deep waters. This may be attributed to SRB activity following hay deposition.
- The trial would need to run for a longer period to evaluate long-term viability.
- Controlled mesocosims were run in the laboratory and show promise for long-term viability.

Figure: Mesocosims

Figure: Adding hay into an acidic pit lake

8. Turning Research into Implemental Solutions

Case Study: Using GIS to make information widely available and assist make informed decisions on rehabilitation, backfill and monitoring needs

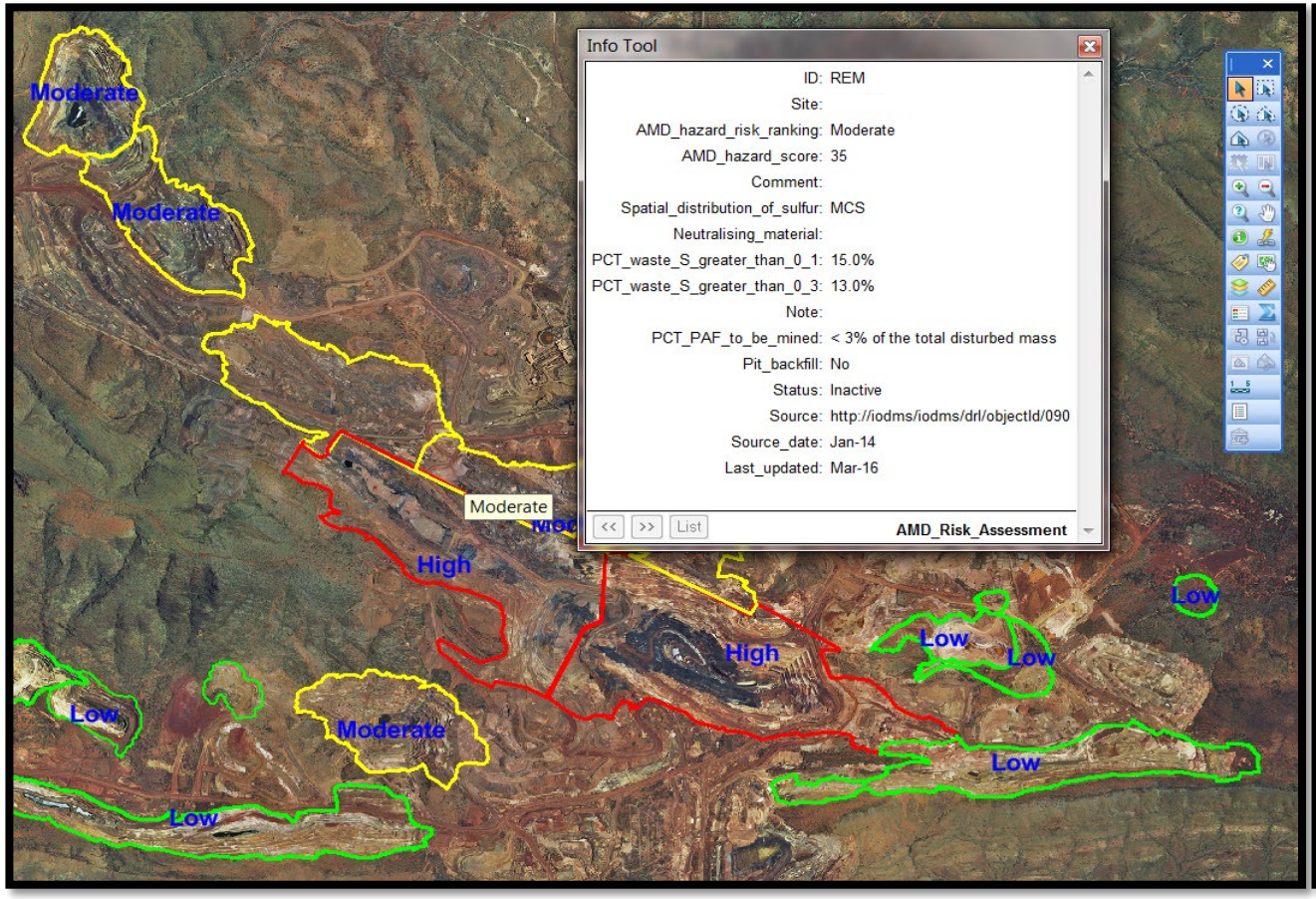


Figure: Assigned AMD risk of pits of either low, moderate or high.

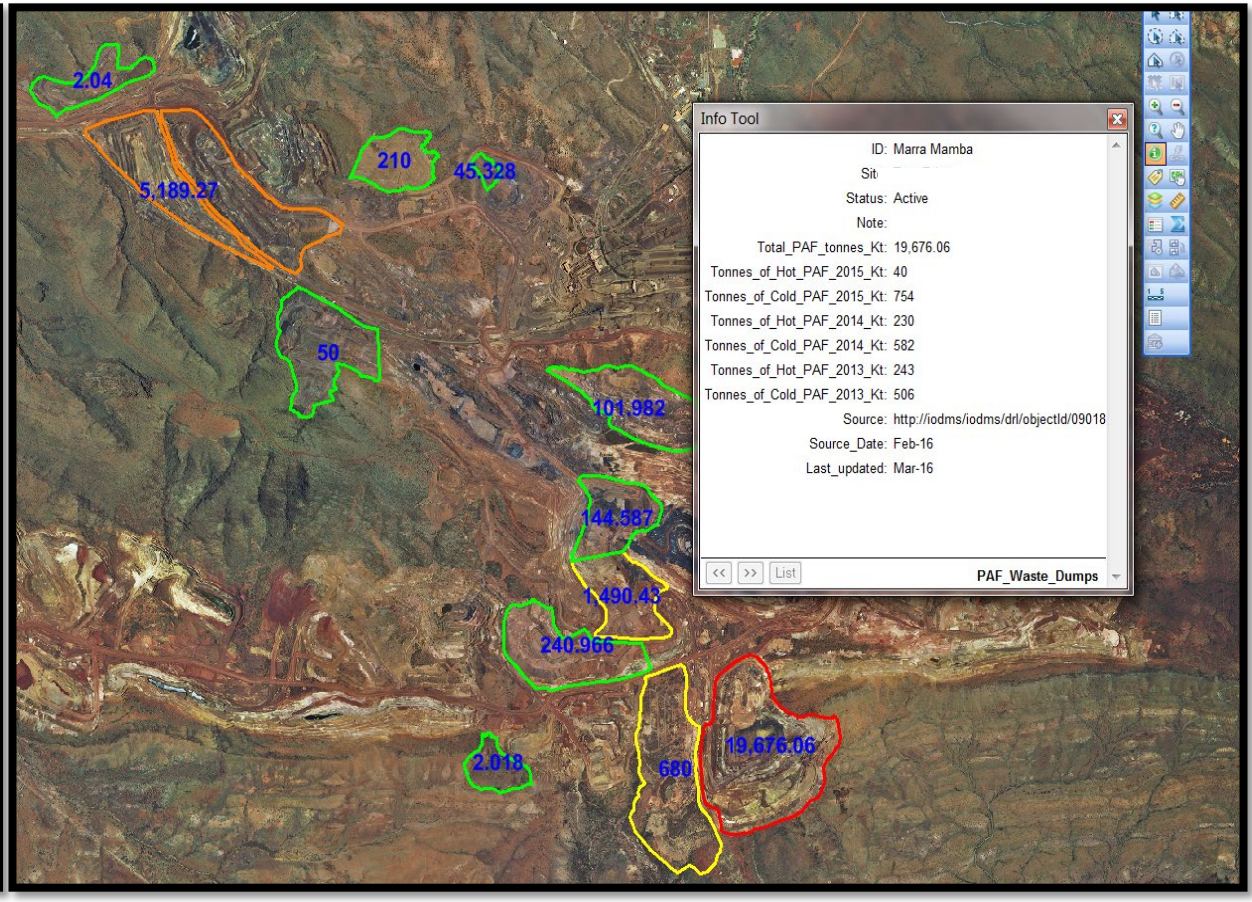
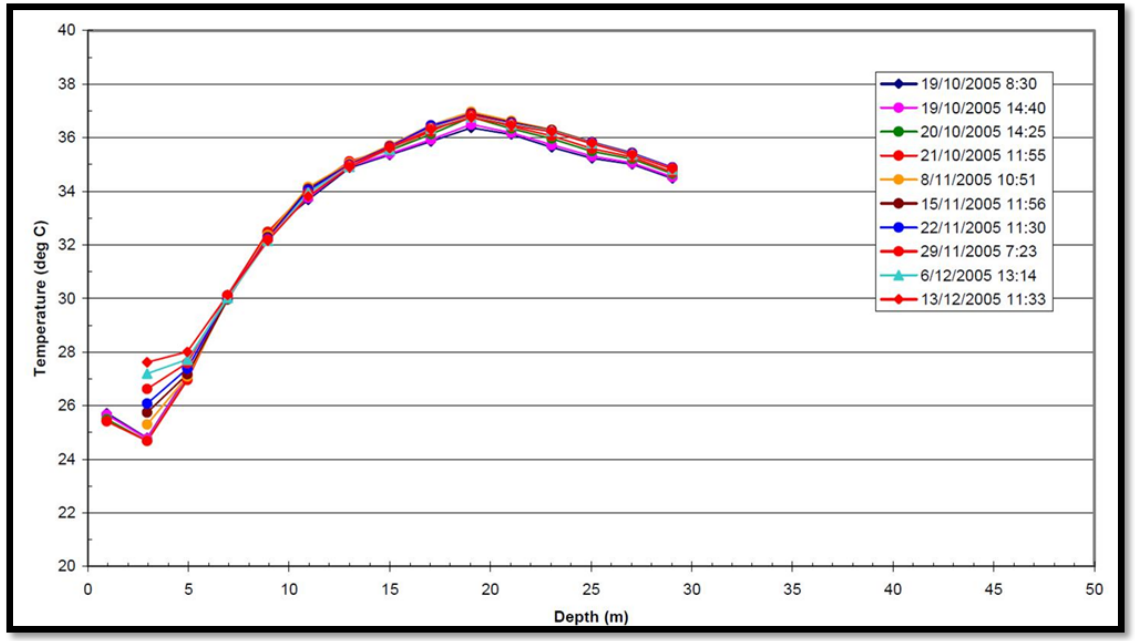


Figure: PAF waste dump locations and estimated PAF tonnages.

9. Validation of Management Systems

Case Study: Waste dump design verification

- Drilled 3 historical PAF waste rock dumps
- Study concluded that the dumping strategy was effective in controlling spontaneous combustion
- Maximum temperature was 55^{o}C which confirms no combustion of black shale in the monitoring regions



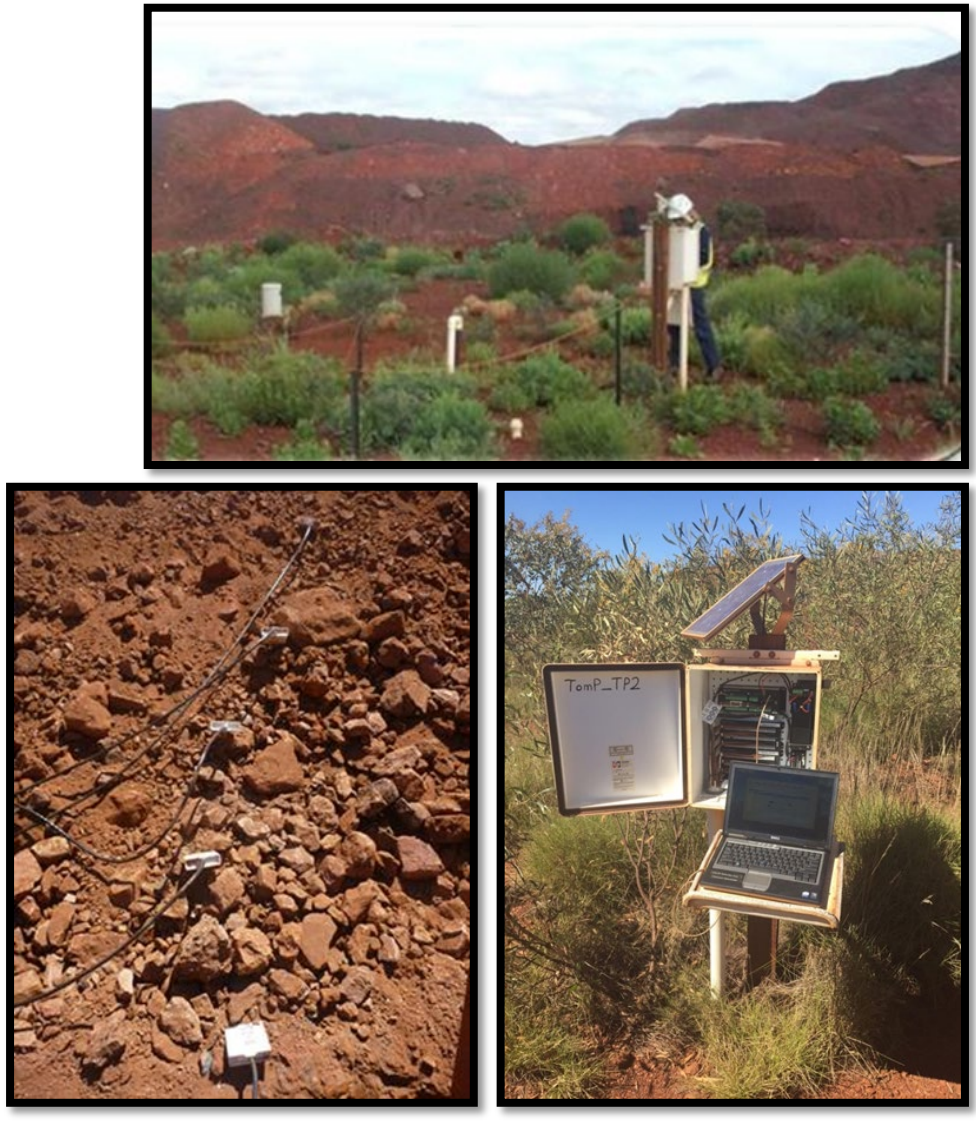
Figures: Temperature monitoring within PAF waste rock dumps

Conclusions

The mineral waste strategy for Rio Tinto's Pilbara mines aim to:

- Ensure accurate valuation of projects, acquisitions, and expansions
- Reduce environmental and health risk
- Reduce operational costs
- Reduce closure costs
- Enhance business reputation

This is done through applying the strategy principles, via multiple systems, management plans, awareness and collaboration



Figures: Monitoring of covers and waste rock dumps