Olympic Dam – is it really complex?

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Our Safety Values and Standards have changed

Drilling at OD, late 1976
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• +120 geoscientists who have worked at Olympic Dam

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• Adelaide Microscopy

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• Adelaide Microscopy

South Australian Mining and Petroleum Services Centre of Excellence (Department of State Development)
• Trace elements in iron oxides project (FOX project)
• Copper Uranium Hub project (joint ARC project IH130200033)
Complex Orebodies

What does this really mean?

“... complex...” often used as an excuse for poor performance

image: https://www.shutterstock.com/image-vector/funny-tongue-emoji-face-disguist-unique-518839492
If you can’t explain it *simply*, you don’t understand it well enough.

– Albert Einstein

“Simplifying Complexity”

Eric Berlow – TEDGlobal 2010

- complexity does not necessarily = complicated
- when faced with complex / complicated problems, the more you step back, the clearer the problem becomes

https://www.ted.com/talks/eric_berlow_how_complexity_leads_to_simplicity
“Toward a Science of Simplicity”
George Whitesides – TED 2010

- simple = reliable, predictable, repeatable
- complex = multiple components, interact with each other, usually do unexpected (emergent) things

“… academics like complexity and emergence…” because “… not responsible for outcome…”

Significant Opportunity – not constrained, yet there needs to be an outcome

https://www.ted.com/talks/george_whitesides_toward_a_science_of_simplicity?language=en

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## Characteristics of Simple-Complicated-Complex Systems*

<table>
<thead>
<tr>
<th>Simple or Complicated Systems</th>
<th>Complex Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Homogeneous</strong>: identical / indistinguishable structural elements</td>
<td><strong>Heterogeneous</strong>: large number of structural variations</td>
</tr>
<tr>
<td><strong>Linear</strong>: a relationship with constant proportions</td>
<td><strong>Nonlinear</strong>: cause does not produce a proportional effect</td>
</tr>
<tr>
<td><strong>Deterministic</strong>: same result always occurs for a given set of circumstances; predictable</td>
<td><strong>Stochastic</strong>: an element of randomness leads to a degree of uncertainty about the outcome</td>
</tr>
<tr>
<td><strong>Static</strong>: nothing changes over time</td>
<td><strong>Dynamic</strong>: changes over time; past has an impact on the future</td>
</tr>
<tr>
<td><strong>Independent</strong>: subsystems are not influenced or controlled by other parts of the system</td>
<td><strong>Interdependent</strong>: subsystems are interconnected or interwoven not just interacting</td>
</tr>
<tr>
<td><strong>No feedback</strong>: open chain of cause and effect</td>
<td><strong>Feedback</strong>: a closed chain of causal connections</td>
</tr>
<tr>
<td><strong>No adaption or self-organization</strong></td>
<td><strong>Adaptation and self-organization</strong>: ability of a system to structure itself, to create new structure, to learn, or diversify</td>
</tr>
<tr>
<td><strong>No connection between levels or subsystems</strong></td>
<td><strong>Emergence</strong>: collective behaviour that cannot be simply inferred from the behaviour of components</td>
</tr>
</tbody>
</table>

History
- Deposit discovered by WMC in July 1975
- Turned out to be a NEW deposit type

Current operation
- Mechanised sublevel longhole open stope mining
- Grinding and sulphide concentrator
- Hydrometallurgical circuit- U extraction
- Single stage flash smelter
- Acid plant production
- ER-EW Cu refineries $\Rightarrow$ Cu cathode
- Precious metals refinery (Au, Ag bullion)

Simple, Complicated or Complex?
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Early Geological Legend (focus on clast type)

- breccia
- monomict
- polymict

- non-breccia

- 3 types monomict bxs
- 13 types polymict I bxs
- 13 types polymict II bxs
- 5 types polymict III bxs

- 55 non-breccia/breccia types
- many qualifiers
  - matrix type – gangue minerals (10)
  - alteration type (4)
  - sulfide + Cu°/Au° mineralisation (9)

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Breccias obscuring view ....

Image credits

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www.cartoonstock.com/cartoonview.asp?catref=pkns521
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Roxby Downs Granite

Gawler Range Volcanics felsic lavas & dykes

end-member alteration hem-qtz-bar breccia

hem-qtz sand/mudstones

chlorite sand/mudstones

polymict volcanic clast cgl

Gawler Range Volcanics Mafic/UM lavas & dykes
Granite to hematite-rich breccias

- Intense brecciation and texturally destructive hematite-alteration of RDG and other lithologies
- Chemical basis for sub-classification of RDG/other lithologies- to hem-rich bxs

***COMPLICATED BRECCIA TEXTURES***

***SIMPLE CHEMICAL COMPOSITIONS***

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**Systems from a thermodynamic perspective**

*Phases* are “… homogeneous bodies of matter, generally having distinct boundaries with adjacent phases, and … physically separable from them…”

*Components* are “… the smallest number of formulae required to describe all phases within the system …”

Olympic Dam Mineralogy (>100 minerals)

15 minerals account for > 99.5% of the ores

| pyrite, chalcopyrite, bornite, chalcocite | hematite, magnetite |
| molybdenite, sphalerite, galena          | Cr-spinels, manganosite |
| tennantite-tetrahedrite, covellite       | quartz, muscovite, orthoclase |
| idaite, carrollite, cobaltite, arsenopyrite | chlorite, biotite, amphibole |
| electrum, native/alloys Au, Ag, Cu, Pd, As, Bi, Te | barite, anhydrite, celestite, gypsum |
| Au-Ag-Pb-Bi-Hg-Ni-tellurides             | plagioclase, albite, schorl, sphene |
| Pb-Cu-selenides                          | corundum, diaspore, kaolinite, topaz |
| cuprite, tenorite, stibnite, enargite    | siderite, ankerite, dolomite, calcite |
| scheelite-powellite, wolframite, cassiterite | ilmenite, rutile, ilmenorutile |
| ***uraninite, coffinite, brannerite***   | fluorite, sellaite |
| thorite, uranothorite, thorianite        | zircon, xenotime, crandallite-group, fluorapatite |
| bastnäsite, florencite, synchysite       | olivine, pyroxene, etc |
Simplicity: mineral (wt%) = \( f(\text{sample composition}) \)

TRANSFORMATIONAL, once we were able to fully implement, took a decade...

- Quantify geological observations on the sample scale
- Populate the mineralogy into the Resource Block Model
- Include mineralogy in the Mine Plan.

*Business value can only be truly realised once observations/data are in the mine plan.*
Simplicity: \( \text{mineral (wt\%) = } f(\text{sample composition}) \)
Metallurgy 101 for Geologists, and Mining Engineers …

Rock type controls throughput, mineralogy controls metallurgy.

Simple, yet profound and useful!

image sources: from Peter Munro and NW ‘Bill’ Johnson (Mineralis Consultants Pty Ltd, Brisbane)
Mineral (wt%) = \( f(\text{sample composition}) \)

\[ \text{‘Met Performance’} = f(\text{mineralogy, ore texture, process conditions}) \]

*modified from Bojcevski (2004)*
Simple, Complicated or Complex?

- Physical plant parts are not unique
- Significant recycle streams –not unique, but make the system complicated to operate.
Even Further Simplified Olympic Dam process flow

**Milling and flotation**
- Ore from UG mine
  - ~2% Cu
  - 600 ppm U₃O₈
- Flotation tailings
  - ~0.15% Cu
  - 550 ppm U₃O₈

**Concentrate leach**
- Sulfide concentrate
  - ~36-40% Cu
  - 1500 ppm U₃O₈
- U₃O₈ in leach liquor
- Remove U₃O₈, F & Fe

**Tailings leach**
- Leach residue
  - ~0.05% Cu
  - <170 ppm U₃O₈

**Smelter & refinery**
- Sulfide concentrate
  - ~40-46% Cu
  - 150 ppm U₃O₈
- Remove U₃O₈ & Cu
- Turn sulfide into pure Cu metal
- Upgrade & purify U₃O₈

**CCD & Solvent extraction**
- Leach liquor

**Tailings disposal**

**Final tailings**

**Separate sulfides & gangue**
- Sulfide concentrate
  - ~36-40% Cu
  - 1500 ppm U₃O₈
- Concentrate leach
- Tailings leach
- Smelter & refinery
- CCD & Solvent extraction
- Tailings disposal

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BHP
+50 geomet variables required to evaluate VALUE on each block in the resource model

Input block
VOLUME, DENSITY, GRADES

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Acid Consumption (ACID)

Relative Abundance
- higher
- lower

Concentrate Grade (FC_CU)

0.000 <= < 10.000
10.000 <= < 20.000
20.000 <= < 30.000
30.000 <= < 40.000
40.000 <= < 50.000
50.000 <= < 60.000
60.000 <= < 80.000

Mine N
True N
450 m depth

350 m depth
Words of caution:
Over-fitting data ⇒ reduced effectiveness of your predictor

Classic example from a mining operation (not OD)

- flotation recovery equation, \( \%\text{rec} \):
  \[
  \%\text{rec} = [90.94 - 259 \times \sinh(0.000668 \times (48/x - 1))] - [11.88 \times (4.2/x) + 1.46], \text{ where } x = \text{feed grade}\%
  \]

- within the range of feed grades, \( \sinh(n) = n \) within 4 decimal places, so the \( \sinh \) function is redundant.
- after that, the equation collapses down to: \( \%\text{rec} = 89.65 - 58.22/x \)

Now isn’t that simpler, and ultimately more useful?

OD Geomet: all variables need to either make geological, mineralogical or metallurgical sense.
Complicating simplicity - requires vigilance to prevent it

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[Image: https://www.inc.com/gordon-tredgold/simplicity-is-the-key-to-success-here-are-26-inspiring-quotes-to-help-you-on-tha.html]
We need to be clear with our messaging

https://theactuarymagazine.org/simplifying-the-complex/
Conclusions

**Olympic Dam – is it really complex?**

- Ore deposit genesis and breccia textures – Not complex, but certainly complicated.
- Mineralogy – No, it is simple. We perceived the mineralogy to be complicated for a very long time.
- Processing – No, most parts are simple. However, recycle streams make the processes complicated.

*As scientists and engineers, our roles are to reduce complexity, and transform complicated systems into simple systems!*