2021 BC MEND ML/ARD Workshop

Characterization Studies of the Waste Rock Dumps at the Bingham Canyon Mine, Utah, USA

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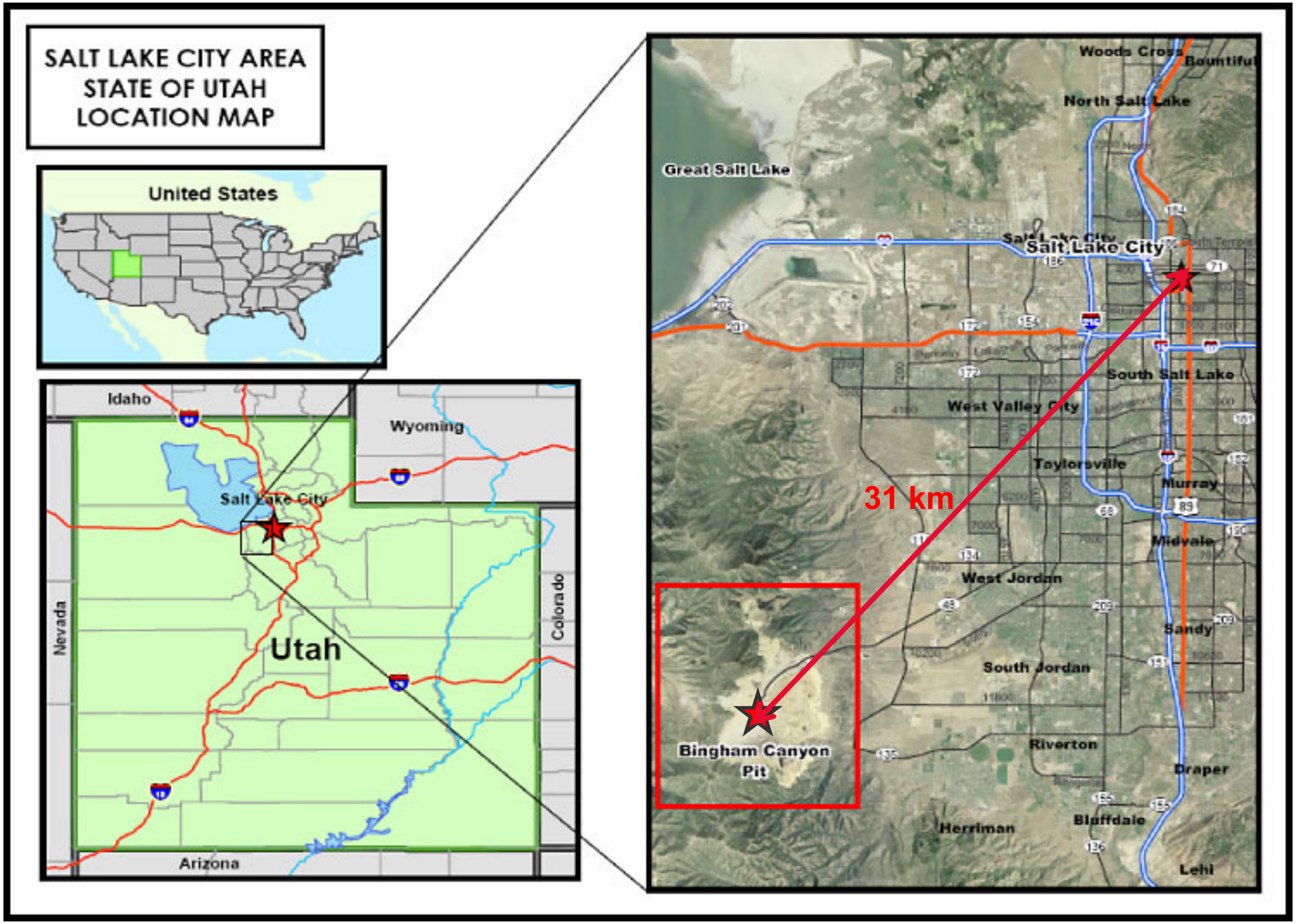
Location


SALT LAKE CITY AREA
STATE OF UTAH
LOCATION MAP
United States
Idaho
Wyoming
Salt Lake City
Utah
Nevada
Colorado
Arizona
Woods Cross
Bountiful
North Salt Lake
Great Salt Lake
Salt Lake City
South Salt Lake
West Valley City
Taylorsville
Murray
31 km
Midvale
West Jordan
Sandy
South Jordan
Bingham Canyon
Pit
Riverton
Draper
Herriman
Bluffdale
Lehi

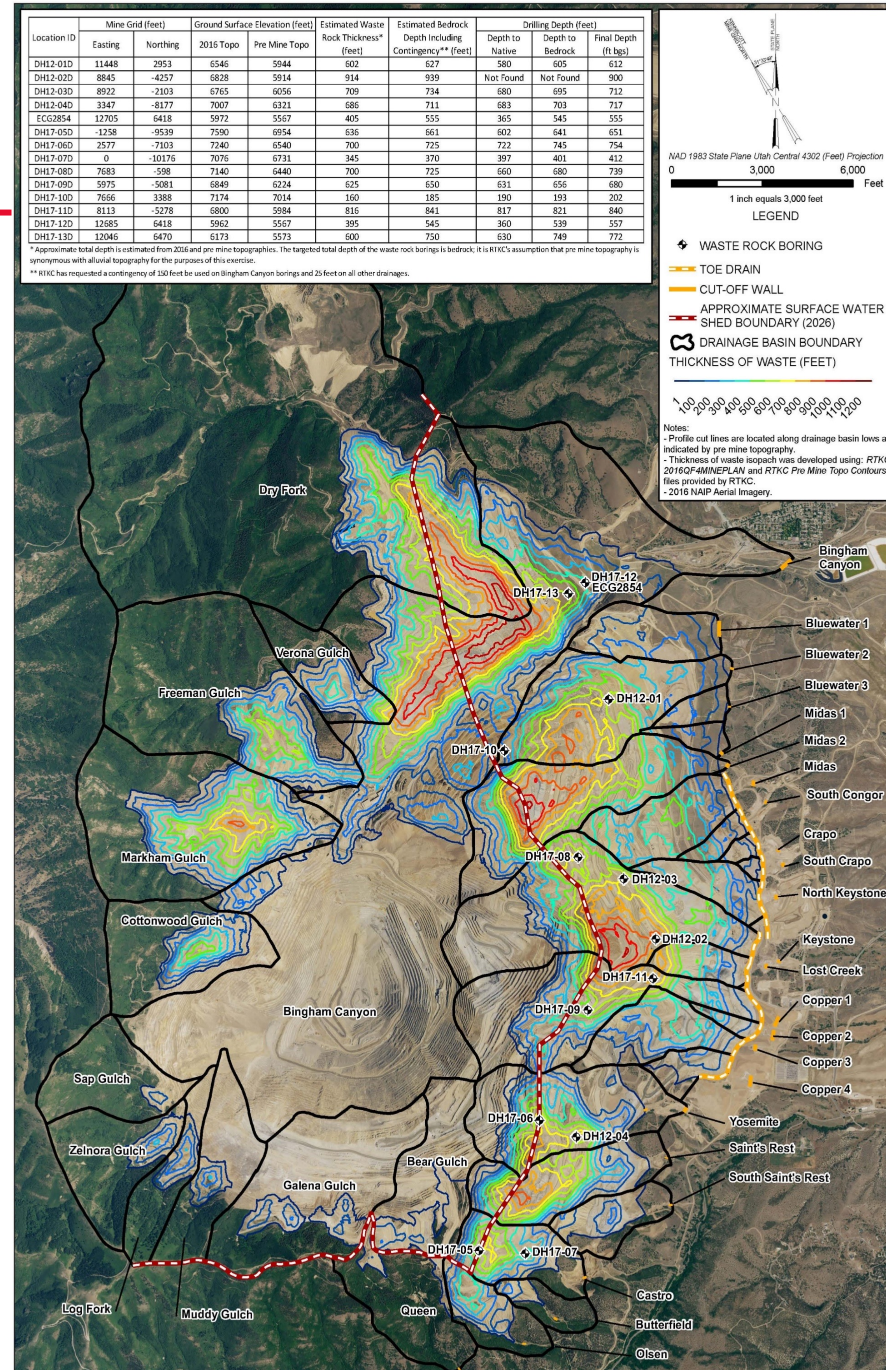
Bingham Canyon Mine

- Porphyry copper
- Deposit discovered in 1846
- Mining commenced in 1864 and open pit mining in 1903
- 2,000 km of underground workings
- Waste rock dumped using rail and then trucks
- Conventional Cu recovery, but also Mo, Au, Ag and PGM
- Waste rock dumps on east, south and west sides and large Bingham Canyon / Dry Fork dump

Rio Tinto

Waste Rock Dumps

- Greater than 2000 ha
- 5.4 billion tonnes
- Selected dumps actively leached from the 1930s until 2000
- 12 paired and one single borehole (25 total) placed in six dumps
- Pairs of boreholes placed in dumps – one near valley facing crest and the other much further back near water boundary
- Acidity arises from oxidation of sulfide minerals (pyrite) and moderated by jarosite
- Some neutralisation via calcite and aluminosilicate minerals
- Collection system used to intercept waste rock seepage that is neutralised in tailings line



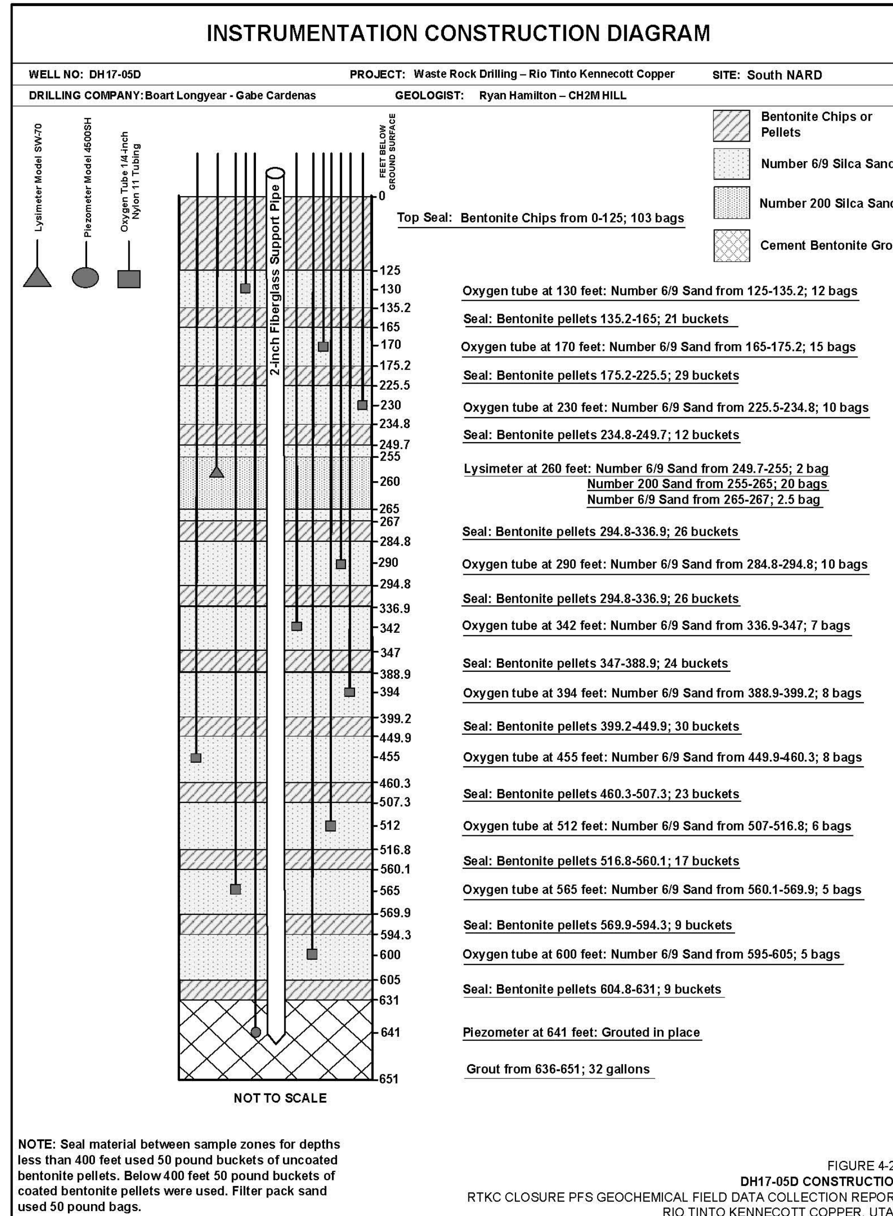
Location ID	Mine Grid (feet)		Ground Surface Elevation (feet)		Estimated Waste Rock Thickness* (feet)	Estimated Bedrock Depth Including Contingency** (feet)	Drilling Depth (feet)		
	Easting	Northing	2016 Topo	Pre Mine Topo			Depth to Native	Depth to Bedrock	Final Depth (ft bgs)
DH12-01D	11448	2953	6546	5944	602	627	580	605	612
DH12-02D	8845	-4257	6828	5914	914	939	Not Found	Not Found	900
DH12-03D	8922	-2103	6765	6056	709	734	680	695	712
DH12-04D	3347	-8177	7007	6321	686	711	683	703	717
ECG2854	12705	6418	5972	5567	405	555	365	545	555
DH17-05D	-1258	-9539	7590	6954	636	661	602	641	651
DH17-06D	2577	-7103	7240	6540	700	725	722	745	754
DH17-07D	0	-10176	7076	6731	345	370	397	401	412
DH17-08D	7683	-598	7140	6440	700	725	660	680	739
DH17-09D	5975	-5081	6849	6224	625	650	631	656	680
DH17-10D	7666	3388	7174	7014	160	185	190	193	202
DH17-11D	8113	-5278	6800	5984	816	841	817	821	840
DH17-12D	12685	6418	5962	5567	395	545	360	539	557
DH17-13D	12046	6470	6173	5573	600	750	630	749	772

* Approximate total depth is estimated from 2016 and pre mine topographies. The targeted total depth of the waste rock borings is bedrock; it is RTKC's assumption that pre mine topography is synonymous with alluvial topography for the purposes of this exercise.

** RTKC has requested a contingency of 150 feet be used on Bingham Canyon borings and 25 feet on all other drainages.

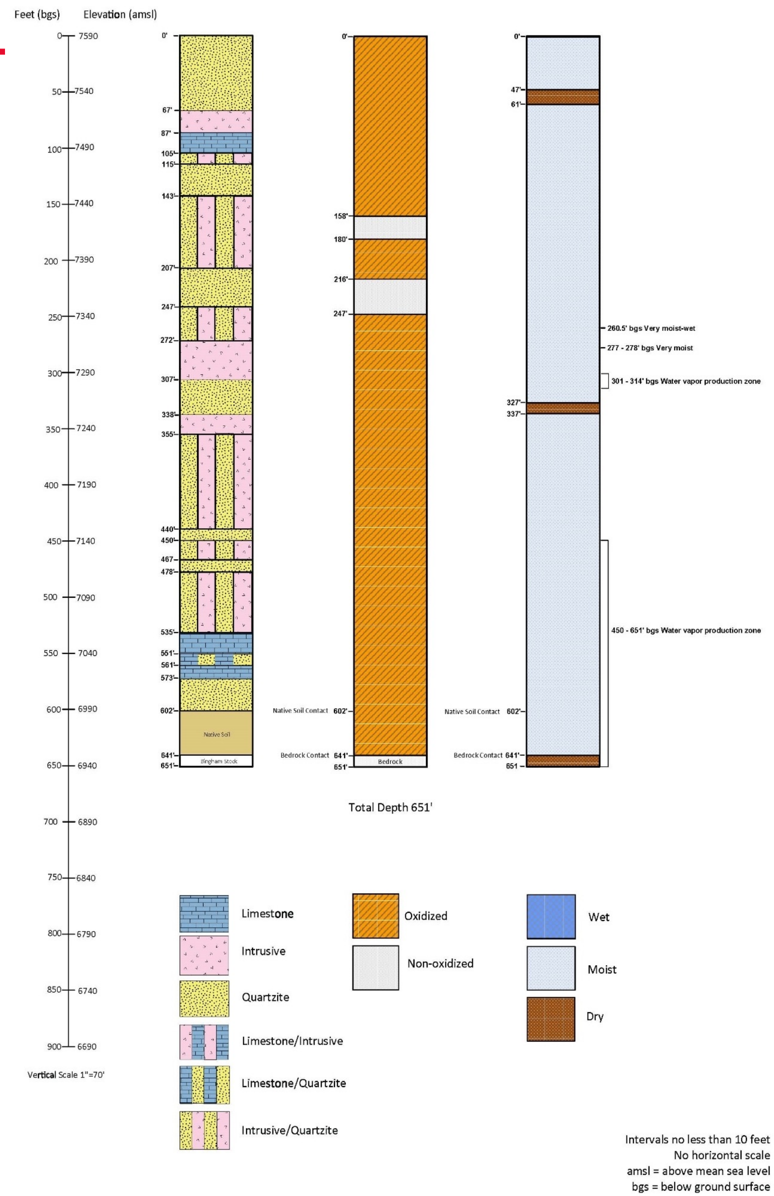
Installation of Boreholes

- One deep borehole (to bedrock – up to 275 m) and one shallow hole (30 m) at each location, except one
- Instrumentation included suction lysimeters, vibrating wire piezometers, gas (oxygen and carbon dioxide) tubes, direct temperature sensing fibre optic cables
- Temperature measured at a spacing of 1 m – substantial improvement on measuring using thermistors
- Gas measurements made at multiple depths in both deep and shallow boreholes with one measurement at same depth in the deep and shallow borehole at the same location
- Water quality measurements taken on multiple occasions
- Core analysed visually for lithology, state of oxidation and moisture content. Core composites analysed for mineralogy using QEMSCAN. All core was also analysed using CoreScan



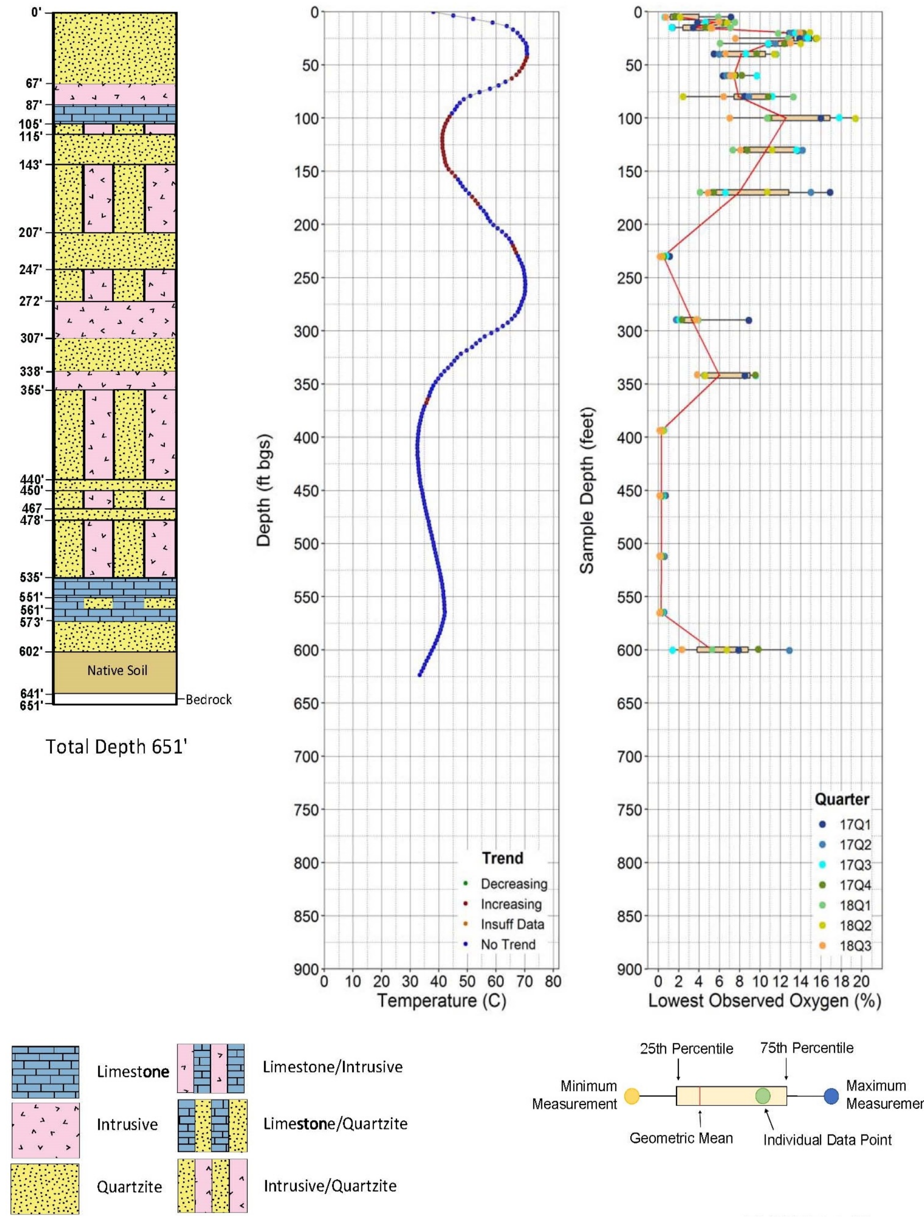
Visual Analysis of Borehole Core

- Core often contained each lithology – although leached dump cores contained little limestone (not placed in these dumps), sometimes as individual and sometimes mixed sequences
- Extent of oxidation was quite variable across the boreholes
- There were sections of the core that were moist and some that were dry
- Almost no sections of the core was wet

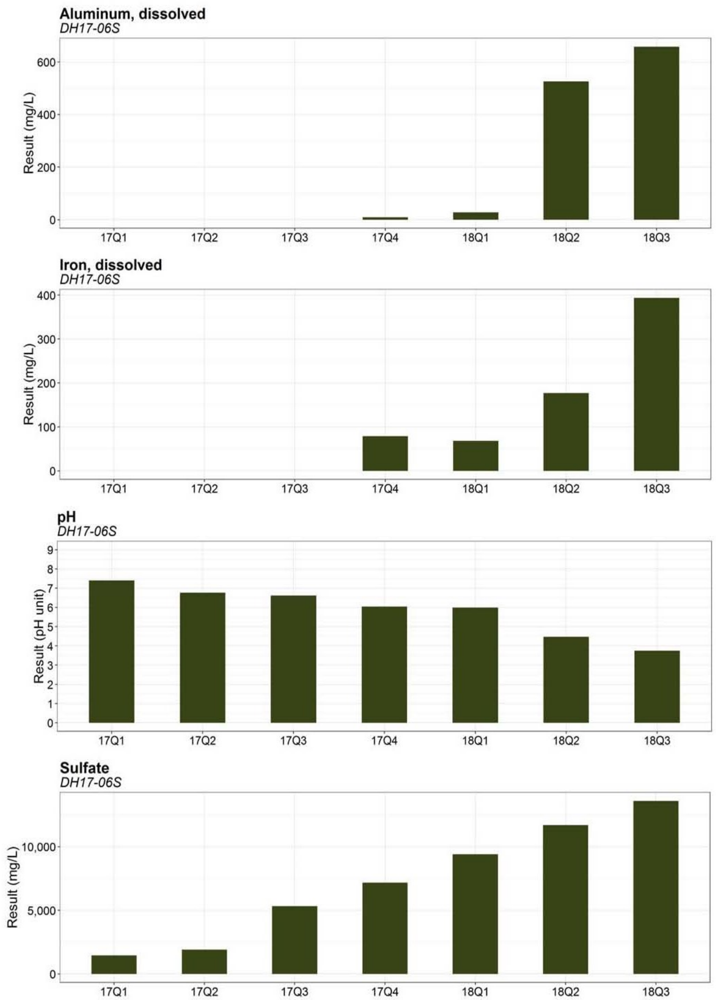


Characterisation of Drill Cores

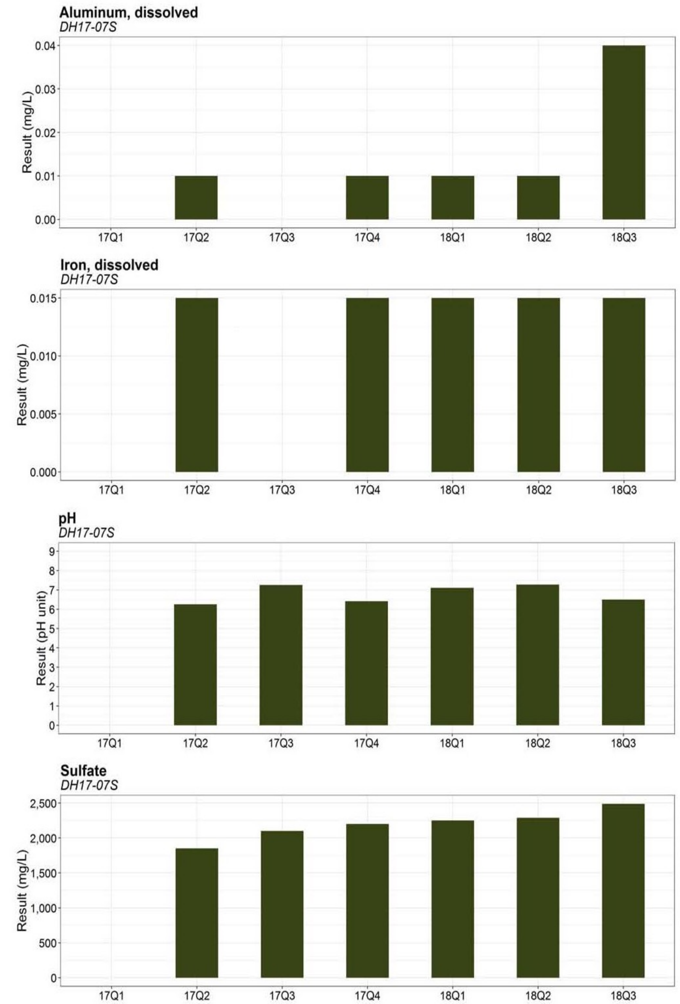
- Three main lithologies at the Bingham Canyon mine – quartzite, intrusive (monzonite), limestone
- Temperature measurements recorded using fibre optic sensors
- Significantly elevated temperatures within the dumps (up to 80 °C)
- Large number of oxygen measurements taken at each location and depth
- Oxygen supplied into the dumps by both convective and diffusive mechanisms
- Significant oxygen concentrations observed deep into the waste rock dumps



In Situ Water Quality



Temporal Change in Water Quality



Minimal Change in Water Quality

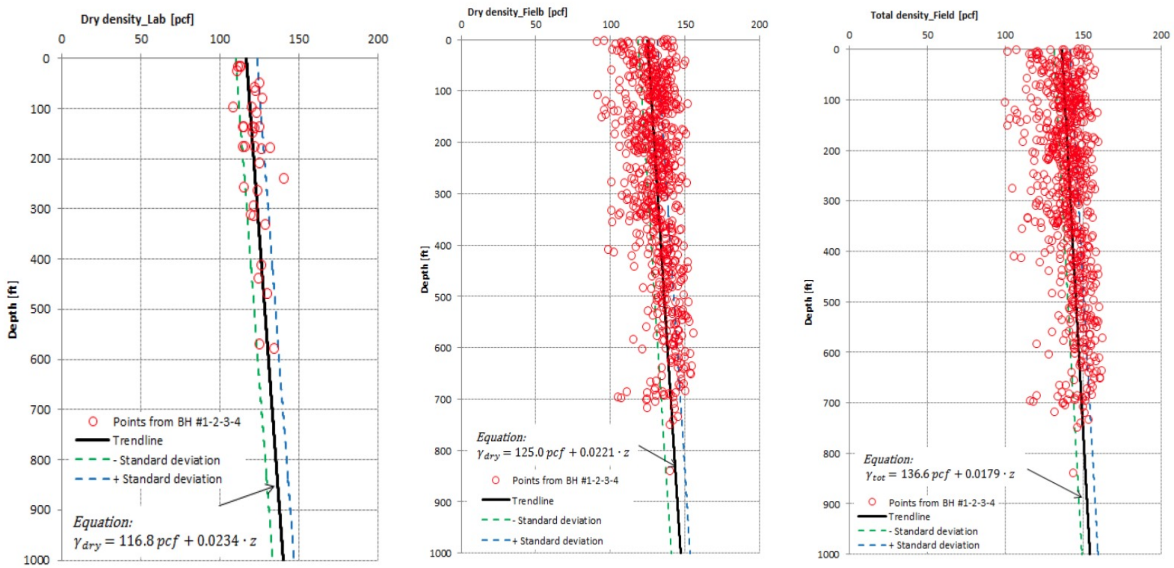
Rio Tinto

Mineralogy of Drill Core

Mineral	Median Observed Mineralogy of Unleached Waste Rock Dumps (wt%)	Median Observed Mineralogy of Leached Waste Rock Dumps (wt%)
K-feldspar	11.74	11.07
Anorthite	1.41	1.09
Albite	3.82	2.94
Muscovite	3.99	4.90
Kaolinite	0.78	1.24
Chlorite	1.94	2.46
Pyroxene (diopside)	0.72	1.11
Amphibole (tremolite)	1.78	0.55
Talc	1.45	1.06
Biotite (phlogopite)	2.81	1.09
Garnet (grossular)	0.30	0
Calcite	0.93	0.21
Gypsum	0.06	0.40
Pyrite	3.62	3.86
Quartz	63.1	64.8
Wollastonite	0	0
Jarosite	0.69	0.59
Iron oxides ($Fe(OH)_3$)	1.03	0.88

- Dump mineralogy divided into that characteristic of an unleached dump and of a leached dump
- Mineralogy of the two characteristic dumps is quite similar
  - Lesser amounts of more reactive neutralising minerals
- Mineralogy can be utilised to estimate an initial (as dumped) mineralogy
  - Ore contains minimal amounts of iron oxide ($Fe(OH)_3$) and jarosite which are products from the oxidation of sulfide minerals (pyrite)

Bulk Density and Specific Gravity



Bulk density: At dump surface = 2.002 g/cm^3 Average = 2.069 g/cm^3

Specific gravity (Gs20^{o}C) = 2.78 g/cm^3

Specific gravity (mineralogy) = 2.76 g/cm^3

Measurement of Oxidation Rate and Oxygen Flux

Field Measurement of Gas Flux

- O_2 consumption
- CO_2 production

Laboratory Measurement of Oxidation Rate

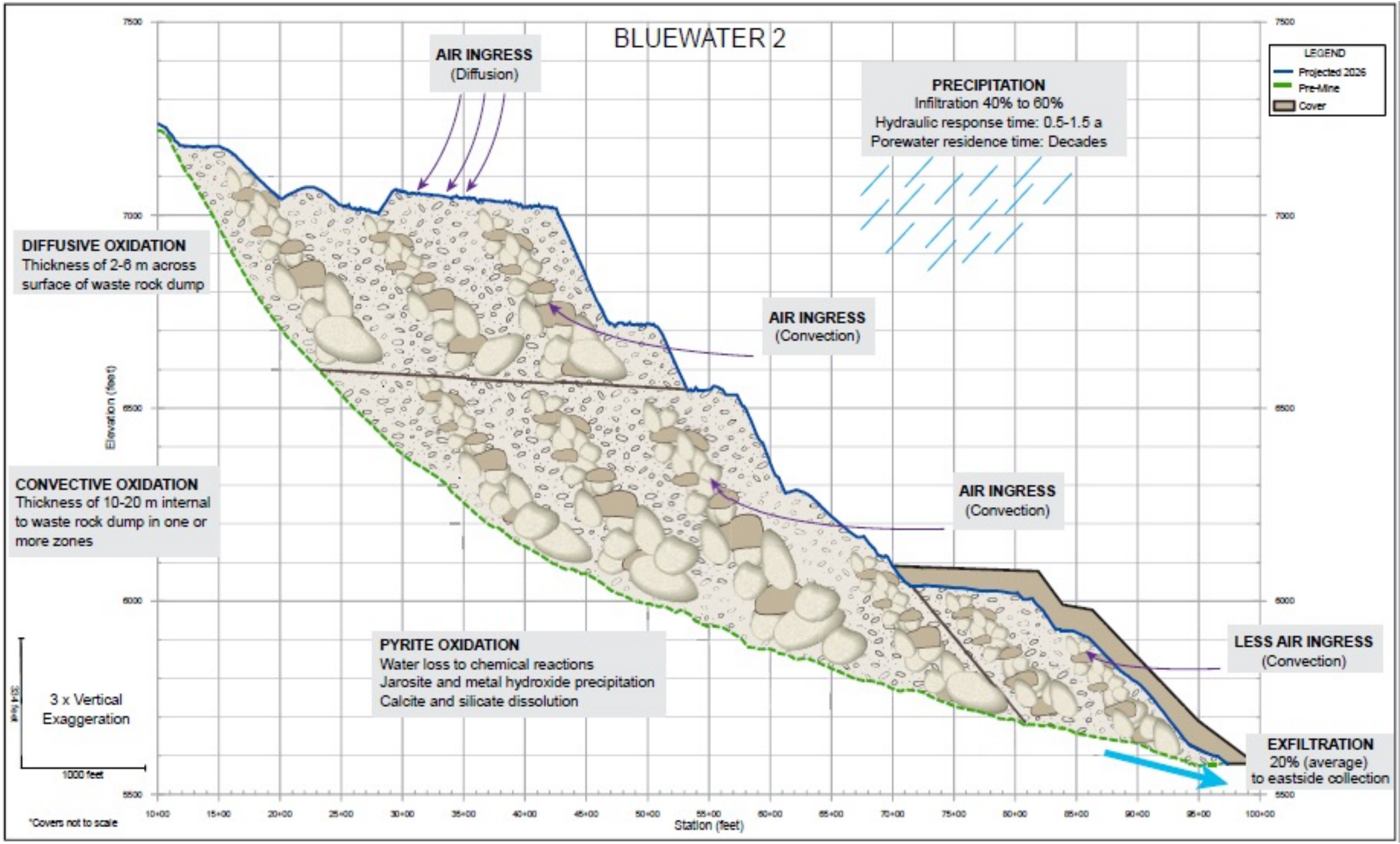
RioTinto

Measurement of Pyrite Oxidation Rate

Lithology or Waste Rock	Measurement Type	Oxidation Rate $kg(O_2)/m^3/s$	log(Rate)	Std Dev.	Count	Maximum $kg(O_2)/m^3/s$	Minimum $kg(O_2)/m^3/s$	Sulfate Release Rate $mg(SO_4)/kg/a$
Quartzite	Laboratory	3.98×10^{-8}	-7.40	0.40	31	2.24×10^{-7}	7.28×10^{-9}	1051
Intrusives	Laboratory	3.46×10^{-8}	-7.46	0.54	21	5.38×10^{-7}	5.43×10^{-9}	914
Limestone	Laboratory	3.25×10^{-8}	-7.49	0.85	11	1.49×10^{-6}	4.26×10^{-9}	858
Waste Rock	Laboratory	4.42×10^{-8}	-7.35	0.43	13	3.10×10^{-7}	1.39×10^{-8}	1168
Waste Rock	O_2 Concentration	5.12×10^{-8}	-7.29	0.80	13	8.59×10^{-7}	8.03×10^{-10}	1353
Waste Rock	O_2 Flux	1.23×10^{-8}	-7.91	0.49	24	5.57×10^{-8}	3.58×10^{-10}	326
Waste Rock	O_2 Flux	2.66×10^{-8}	-7.57	1.07	7	4.60×10^{-7}	8.20×10^{-10}	703
Waste Rock	Natural Convection	2.37×10^{-8}	-7.63	1.04	9	4.25×10^{-7}	6.11×10^{-10}	625
All	All	2.93×10^{-8}	-7.53	0.64	129	1.49×10^{-6}	3.58×10^{-10}	773

- Rate determined using multiple techniques
  - Laboratory measurement of all three major lithologies
  - Analysis of depth of oxygen ingress from surface
  - Oxygen consumption measurements in chambers placed on dump surfaces
- Measurement values ranged over nearly four orders of magnitude by all techniques and for all lithologies
- Geometric average similar for all techniques and for all lithologies: overall geometric average of 2.93×10^{-8} $kg(O_2)/m^3/s$

Conceptual Gas Transport Model

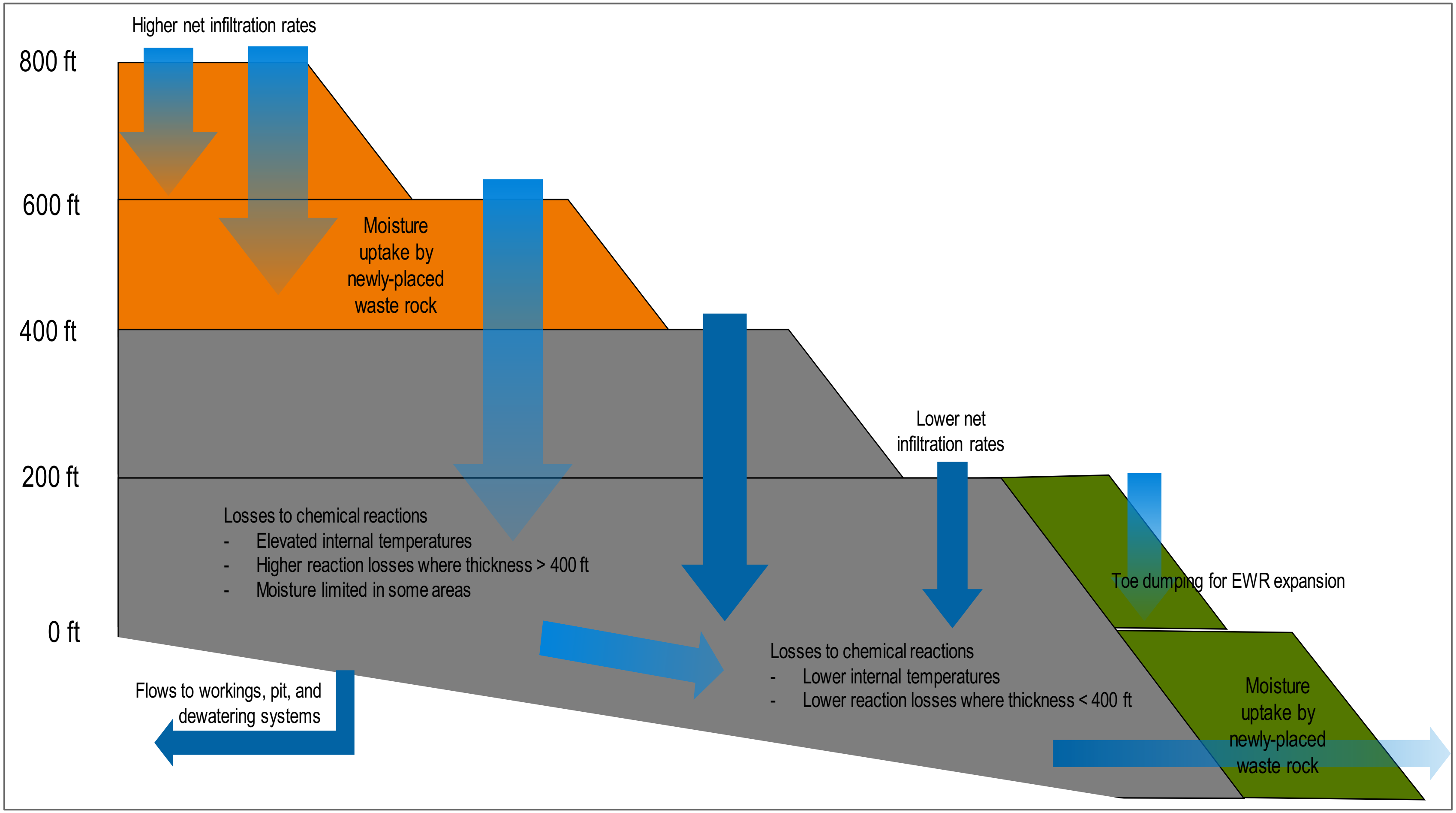


Coarse / Fine Zone Segregation

- Coarse zones (clast supported) bounded by fine zones (matrix supported)

Convective Basal Air Flow

Hydrogeological Conceptual Model

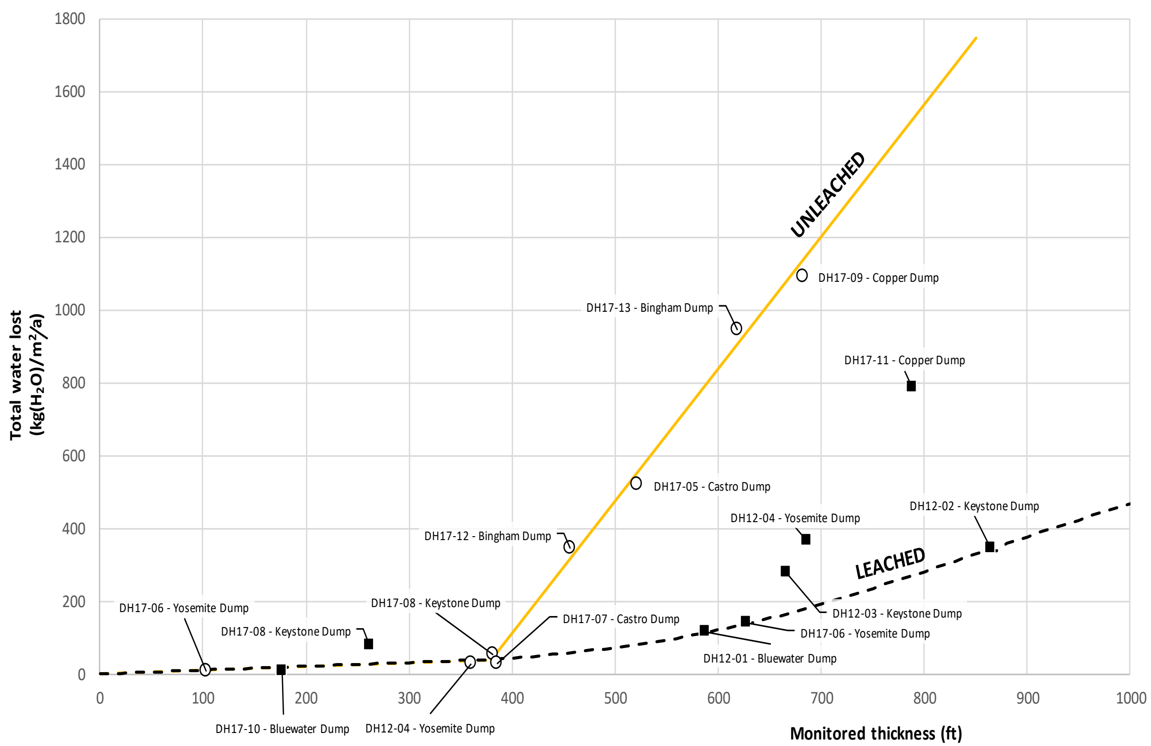


Water Loss to Chemical Reactions

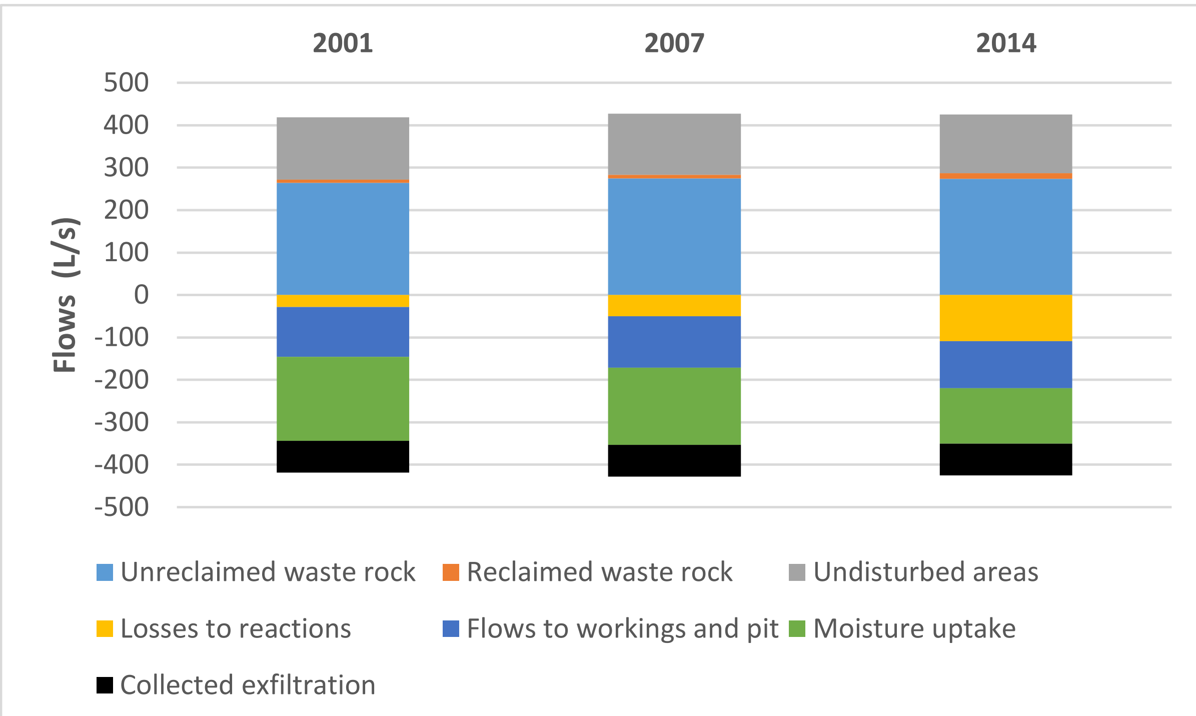
- Differing amount of water loss to chemical reactions depending on whether or not dumps were leached

- Leached dumps are cooler due to significant flux of leach water through the dumps

- Cooler temperatures results in reduced amount of oxidation which leads to reduced consumption of water



Water Balance



- Significant losses to chemical reactions
- Also substantial moisture uptake in fresh waste rock placed in dumps
- Some flows from south and west dumps intercepted within underground workings and pit
- Collected exfiltration equals about 75 L/s

Conclusions

- Paired borehole placement in waste rock dumps and associated instrumentation enabled:
  - Characterisation of geochemical and hydrogeological mechanisms occurring in the dumps that lead to generation of acidity.
  - Demonstration that gas (oxygen) supply to the dumps occurs by both convective (predominant) and diffusive mechanisms.
  - High temperatures (up to 80 ^{o}C) leads to considerable water consumption within the dumps.
- Requirement to develop long-term understanding of seepage evolution from the Bingham Canyon mine dumps:
  - Development of long-term management strategies during operation.
  - Program of work undertaken has involved a significant number of innovative characterisation aspects aiding the development of the understanding.
  - Highlights what is needed to be undertaken at mine sites with long operational histories.