DEEP EXPLORATION TECHNOLOGIES CRC
Uncovering the future

The Future of Mineral Exploration Drilling and Sampling

Exploration '17

Thursday 26 October

Totonto, Ontario

Australian Government
Department of Industry, Innovation and Science

Business Cooperative Research Centres Programme

PROGRAMME

THURSDAY 26 OCTOBER 2017
MTCC (METRO TORONTO CONVENTION CENTRE)

1.00 PM	Introduction	David Giles, University of South Australia/DET CRC
1.05 PM	Coiled Tubing Drilling in Mineral Exploration	David Giles, University of South Australia /DET CRC
1.30 PM	Logging-While-Drilling in Mineral Exploration: State-of-the-Research	Anton Kepic, Curtin University/DET CRC
1:50 PM	Sampling for Coiled Tubing Drilling	Ben van der Hoek, University of South Australia/DET CRC
2.00 PM	Top-of-Hole Geochemistry and Mineralogy: State-of-the-Research	Yulia Uvarova, CSIRO/DET CRC
2.20 PM	Coffee	
2.40 PM	Seismic Pre-Drilling and Sampling: State-of-the-Research	Milovan Urosevic, Curtin University/DET CRC
3.00 PM	Assay-While-Drilling: State-of-the-Products	James Cleverley, Imdex
3.20 PM	Geological Logging with X-ray Vision	Aaron Baensch, Olympus
3.40 PM	The Future of Geological Survey Drilling	Steve Hill, Geological Survey of South Australia
4.00 PM	Close	

YOUR SPEAKERS

DAVID GILES

Program 3 Leader
University of South Australia/DET CRC

Prof David Giles is Strand Leader and John Ralston Chair of Minerals and Resources Engineering at the Future Industries Institute, University of South Australia. Prof Giles has over 20 years' experience in minerals exploration spanning the boundaries of industry and academia. He is Leader of Program 3 (Targeting) within the Deep Exploration Technologies CRC.

ANTON KEPIC

Project 2.2 Leader,
Curtin University/DET CRC

Currently the Boart Longyear Chair in Geophysical Instrumentation in Curtin University, Anton has been with Curtin University since 1999. Anton previously held positions within WMC in Exploration and Technology group, and holds degrees from University of Western Australia (BSc. Hon) and a PhD in Geophysics from the University of British Columbia.

BEN VAN DER HOEK

Researcher,
University of South Australia/DET CRC

Ben van der Hoek is a key researcher in DET CRC Project 3.2 Lab-At-Rig® Futures at the University of South Australia. Ben completed his PhD at the University of Adelaide with DET CRC in 2013 in the field of regolith geochemistry and has since pursued his interests in geochemistry and engineering as a researcher within the Lab-At-Rig® team.

YULIA UVAROVA

Project 3.2 Leader
CSIRO/DET CRC

Yulia is a Principal Research Scientist, Research Group Leader and Project Leader at CSIRO Mineral Resources. Currently, Yulia is leading Project 3.2 Lab-at-Rig® Futures, which will lay the foundations of future Lab-at-Rig® platforms that will take advantage of new sensor technologies and develop the application beyond current deployment in greenfields exploration.

MILOVAN UROSEVIC

Researcher,
Curtin University/DET CRC

Milovan Urosevic received BSc (Hons) in geophysics from the University of Belgrade in 1980, MSc in geophysics from the University of Houston in 1985 and PhD in geophysics from the Curtin University of Technology in 2000. He acquired over ten years of industry experience working in areas of seismic data processing, AVO, inversion, multi-component seismology and seismic anisotropy.

After joining Curtin University in 1991 he has taken part in various industry projects related to the oil, coal and mineral exploration. His main interest is in the utilisation of new technologies to advance exploration of natural resources.

He is currently involved in two major Australian corporative research centres (CO2CRC and DET CRC). He is also leading a large ANLEC R&D (Australian National Low Emissions Coal Research and Development) project that is investigating and evaluating the applicability of novel, alternative seismic methodologies for rock characterisation. Milovan is associate editor of the Exploration Geophysics Journal.

JAMES CLEVERLEY

Researcher,
Imdex

James Cleverley is currently Global Product Manager – Geosciences for REFLEX, a leading brand of ASX-listed Imdex Ltd, (Perth, Australia). James has been involved in two industry-led research cooperatives dating back to his second post-doc at James Cook University with the Predictive Mineral Discovery CRC and then heading up projects in phase 1 of the Deep Exploration Technologies CRC as Research Group Leader in CSIRO, before moving to Imdex in mid-2014.

James was the project lead for the DET CRC Lab-at-Rig® project, a collaboration between REFLEX, Olympus and CSIRO, which was commercialised by Imdex in September 2015. More recently James has taken over product management of technologies designed to provide near real-time decision support in the geosciences in the Imdex In-Field Geoanalysis solution. He is passionate about the use of geochemical data, data analytics, sensor and real-time technology, and the understanding of hydrothermal systems for exploration targeting and mine optimisation, but has been lucky enough to work on everything from large gold deposits to chondritic meteorites.

AARON BAENSCH

Researcher,
Olympus

Aaron is the Principal Geologist – International Mining Group (IMG) for Olympus Scientific Solutions Americas (OSSA) headquartered in Boston, MA, USA. He is also an embedded researcher & project manager at the Deep Exploration Technologies – Commonwealth Research Cooperative (DET CRC) based in Adelaide, Australia & co-inventor of the recently commercialized Lab-At-Rig® product.

Aaron has been working with Olympus (formerly Innov-X Systems) since 2008 and has become an Industry Specialist in the application of field portable x-ray fluorescence, x-ray diffraction and microscopy for mineral exploration, mining, mineral processing, environmental and petroleum applications. He is currently focused on the research & development and business development of real-time mineral analysis technologies, including the adaption of systems used by NASA on the Mars Curiosity Rover for terrestrial mineral analysis.

STEVE HILL

Director/Chief Government Geologist
Geological Survey of South Australia

Dr Steve Hill is Chief Government Geologist and Director of the Geological Survey of South Australia, where his role is to oversee and coordinate the Geological Survey's research and generation and delivery of pre-competitive geoscience data. Before joining the Public Service in 2013, Dr Hill spent more than 20 years in academia at the University of Adelaide, University of Canberra and Australian National University.

Coiled Tubing Drilling for Mineral Exploration

David Giles
DET CRC Program 3 Leader
Future Industries Institute, UniSA

The Future of Mineral Exploration Drilling and Sampling
Exploration '17, Toronto
26 October 2017

AngloAmerican · BARRICK · BHP · BOART LONGYEAR · Government of South Australia Department of State Development · imdex LIMITED · VALE · CSIRO · THE UNIVERSITY OF ADELAIDE AUSTRALIA · Australian Government Geoscience Australia · OLYMPUS · University of South Australia · THE UNIVERSITY OF WESTERN AUSTRALIA · Curtin University · Australian Government Department of Industry, Innovation and Science · Business Cooperative Research Centres Programme

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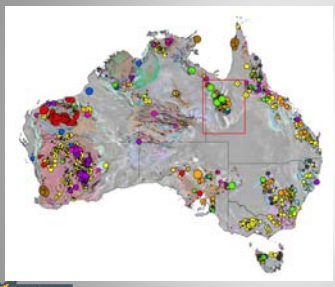
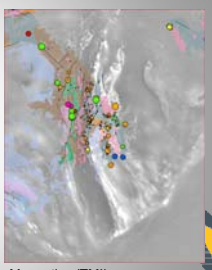
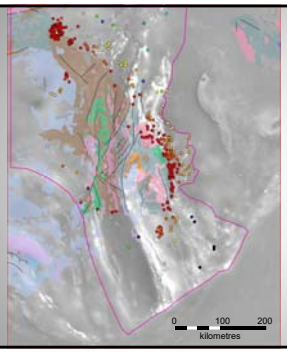
Why Coiled Tubing Drilling?





Magnetics (TMI)

Mt Isa



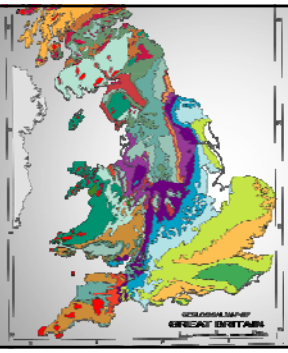
How do we characterise and explore within this search space?

How is your sense of scale?

457 holes
Unevenly distributed
Source: OESP depth-to-basement study

Previous Drilling

UK

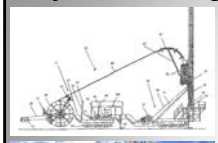


How do we characterise and explore within this search space?

How is your sense of scale?

We need more drill holes!!

Why Coiled Tubing Drilling?



- CTD achieves 2x ~1,000m Alberta gas wells per day in soft, predictable sedimentary rocks
- 2-3 hours move in and rig up time
- Penetration rates: up to100m/hr
- No drill rod connections
  - Safer, more time drilling, rapid tripping, maintain hole balance
- Small footprint, contained fluids
- CTD offers improved cost, safety, and environmental impact in mineral exploration

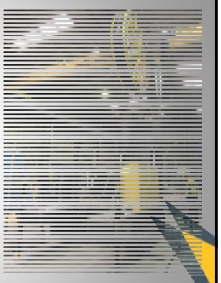
= More drill holes

DET CRC Coiled Tubing Strategy

- Key challenges for CT drilling in mineral exploration:
  - Coil durability
  - Ground up rig design
  - ROP with low weight-on-bit drilling
  - Hole integrity / fluid loss
  - Sample representivity
- DET CRC's target:
  - greenfields rig to 500m, weight less than 10 tonnes and $50/m

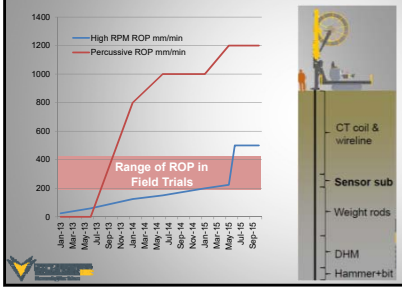
Challenge: Coil durability

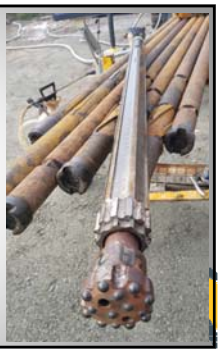
Challenge: Ground up design and build a new rig



https://youtu.be/C4iCIlDGsg8

Challenge: Rate of Penetration Bottom Hole Assembly

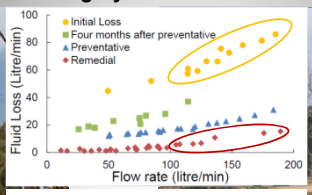




Challenge: Clean Fluid

- Dam water pumped and trucked to the drill site, cleaned, treated and recycled - again and again.
- Up to 240L/min recycled and cleaned during drilling – system volume 7700 litres (2000 Gallons)
- Managing salinity, PH and additives while cleaning.
- Reliable water cleaning in the field proven to work in very dusty conditions.

Challenge: Hole Integrity / Fluid Loss



Axxon Rig, Brukunga Nov 2014
Water drilling, no intervention, 100% loss

RoXplorer® Stavely trials May 2017
Water loss improved from 40-100% to ~5% using DET CRC mitigation strategies

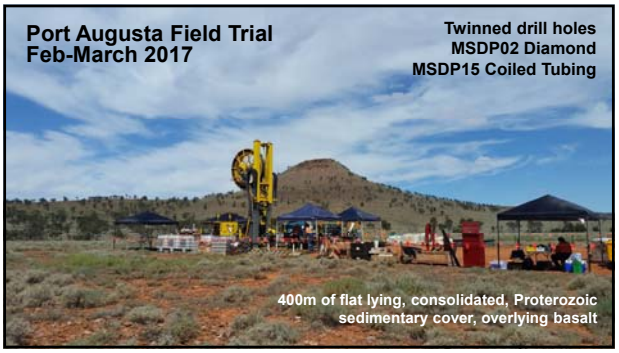
Challenge: Cuttings Return / Representative Sampling

RoXplorer® Field Trials Selected KPI's

- Drill 20m in 1 hour
- Drill 400m in 4 consecutive 12 hour shifts
- Ensure borehole stability and condition during drilling process
- Fluid and sample return >70% over 200 m of drilling
- Representative samples at 1m resolution, able to identify key lithological boundaries
- Chip samples at 1m resolution for entire drill hole

Port Augusta Field Trial Feb-March 2017

Twinned drill holes
MSDP02 Diamond
MSDP15 Coiled Tubing



400m of flat lying, consolidated, Proterozoic sedimentary cover, overlying basalt

Stavely Field Trial May-June 2017

Twinned drill holes
Stavely12 Sonic
Stavely21 Coiled Tubing

136m of flat lying, unconsolidated (running sands, swelling clays) Cainozoic sedimentary cover, overlying mafic and intermediate volcanics

https://www.youtube.com/watch?v=ZRdT6PI5m_I&t=78s

MSDP15 Selected Results

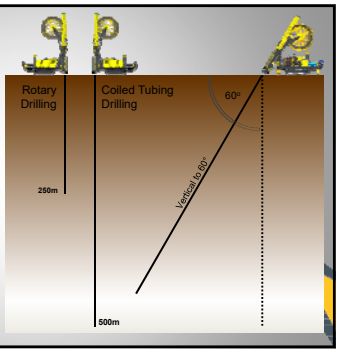
- First 20m below casing drilled in 56 mins (357mm/min)
- 367m in first 4 shifts, average ROP 245mm/min (cf. 14.5 shifts to drill 376 with Diamond)
- Stable and clean borehole
- Fluid and sample return maintained at >98% below casing
- 110m of continuous sampling at <1m depth resolution and average depth resolution of 34 cm
- Chip samples at 1m resolution for 90% of drill hole
- Consistent deviation of ~2.6° (kicked from bottom of casing and then straight)

Stavely21 Selected Results

- Rotary drilling to 42m and installation of PQ steel casing
- Drilled to 140m (base of unconsolidated) using CT with blade bit and installed HQ steel casing in three 12 hour shifts
- Drilled a further 267m of basement using CT with percussion bit in three 12 hour shifts
- Water loss improved from 40-100% to ~5% using DET CRC mitigation strategies
- Chip samples at 1m resolution for entire basement interval
- Total deviation of 10m in 425m (average 1.35°)

RoXplorer® Capability

Drilling Type	Diameter	Tubing/Rod	Depth
Casing	114.3mm 76.2mm 76.2mm	PQ (Collar) 3" SFJ LW PVC	30m 250m 250m
Rotary Drilling Soft Rock: Blade bit Hard Rock: W70	98 -120mm 82-89mm	NQ	250m
Coiled Tubing Drilling Soft Rock: DHM & blade bit Hard Rock: DHM & W50 DHM & W70	60 - 98mm 60 - 65mm 82 - 89mm	1 ¾" BlueCoil®	500m



RoXplorer® Site layout

Next Generation SRU, LAR and fluid processing.

Commercial site operation:
1 x Driller
2 x Offsider (water truck driver, fitter, fluid management, sampling)
¼ x Supervisor

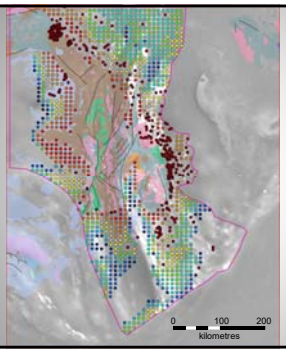
RoXplorer® Where to from here?

Q:
What do we do with a rig that is mobile, small footprint, safer, quicker, cheaper

…and returns a sample which is representative, with <1m depth resolution and little smearing and amenable to visual logging, Lab-at-Rig assay, archiving sub-sampling for mineral separates (e.g. for mineral tracers or geochronology)

A: Drill a lot of holes!

Mt Isa



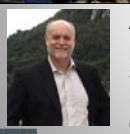
Depth to basement	500 m	1000 m
Number of drill holes	426	964
Total meters drilled	132,400	527,800
Drilling cost @ $75/m	$9.9 M	$39.6 M
Area covered (km²)	64,900	122,300
Cost per km²	$152	$324

In-ground value of current and mined resources from the exposed Mt Isa Inlier is ~$194 B or ~$3.08 M/km². *

10 x 10 km pattern
Max depth-to-basement 1000 m
Excluding previous drilling


MinEx CRC
3D DRILLING

Logging-While-Drilling in Mineral Exploration



Anton Kepic

Project Leader of DET CRC Project 2.2
Sensors for Rapid Downhole Characterisation

Exploration 17 Workshop
October 2017

LWD how to do it and what's out there?

- Logging While Tripping Rods
  - Inside rods – RC and Percussive
    - *EZ Gamma – Reflex*
  - Protruding through the bit – Diamond Drilling
    - *AutoSonde - DET CRC / Truprobe - Boart Longyear*
    - *Shuttle - DMT*
- Measurement While Drilling or LWD
  - Measure through outer rods
    - *AutoShuttle – DET CRC for Diamond Drilling*
  - Incorporated into outer rods/Bottom-Hole-Assembly
    - *Geosub – DET CRC for Coiled Tube drilling*

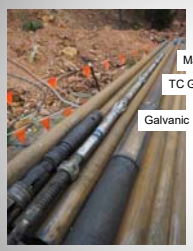
DET CRC AutoSonde and AutoShuttle

- Novel "platform" for measuring rock properties whilst drilling for Diamond drilling
- Work seamlessly with drill rigs common in mineral exploration and development
- Easy to operate but robust information
- Reduce costs vs wireline

- AutoShuttle is Measurement-While-Drilling by seeing through the outer rods
- AutoSonde is Logging-While-Tripping

- Natural Radioactivity
- Chargeability
- Electrical Conductivity
- Magnetic Properties

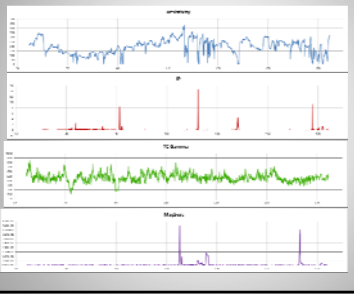
Multi-Sensor Sonde – 4 logs for 1 effort



Tools are mechanically coupled and synchronised with a single handset

Multi-Sensor AutoSonde

DH08 Brukunga test facility , Australia



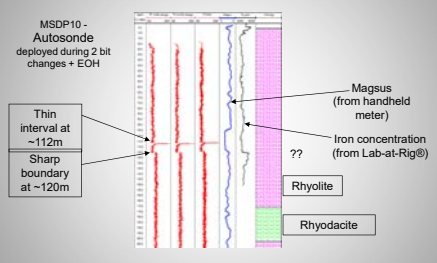
Electrical Resistance

Chargeable Sulphides

Natural Radioactivity

Magnetic Formations

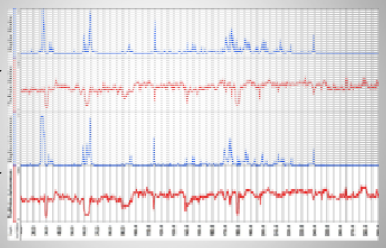
Auto-Depth ability with Accuracy – yes we can



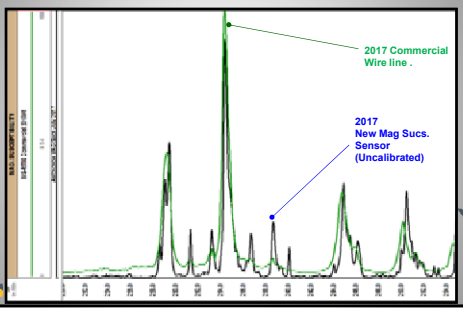
Magsusc and TC Gamma AutoSonde – as good as wireline logging?

Wireline deployed 5m/min logging

Auto-depth deployment 35m/min logging



Resolution Advantages of a New Approach - AutoSonde



From Brett Harris 2017

AutoShuttle with Spectral Gamma Shuttle

LWD Spectral Gamma Collected over 35m

Large crystal with 6.5% energy resolution at 662 keV

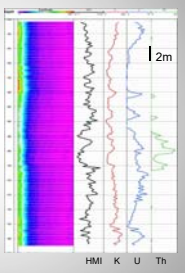
Able to clearly extract the usual K, U, Th
plus now Heavy Mineral Index

Logging performed at approx 0.3m/min

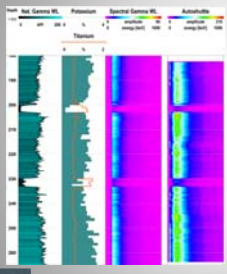
1024 ch data

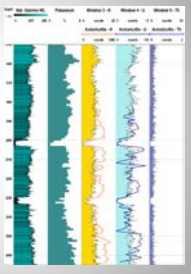
Spatial resolution is about 0.3m

Reliable and robust during tests

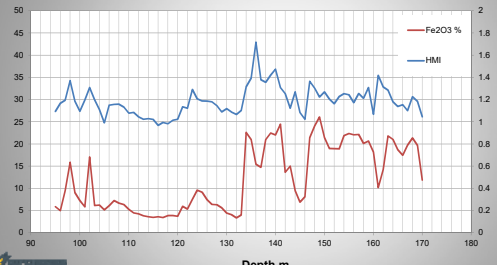


Spectral Gamma – New Capability



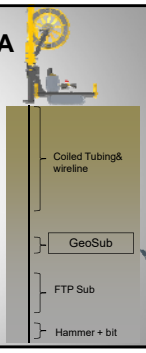


New Capabilities: HMI from Spectral Gamma Data vs Core Assay: Brukunga RD01

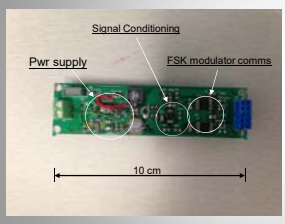


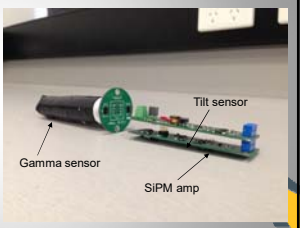
Coiled Tube LWD - GeoSub in BHA

- GeoSub located between CT and FTP Sub
- Power and comms via existing wireline
- CT rig runs with/without GeoSub

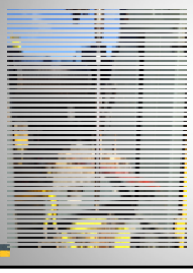


CT Geosub Sensors/Electronics





GeoSub inner



GeoSub outer

Conclusions

- Reflex and DMT have commercially available systems for logging while tripping (RC and Diamond)
- DET CRC has created two viable petrophysical logging tool types AutoSonde and AutoShuttle that can be deployed on diamond drilling rigs
  - A critical element is to have auto-depth capability
  - Data quality must be similar to wireline or offer new capabilities
- Replacement of wireline logging for less cost in many applications
- Issues with hole collapse largely eliminated
- New measurements possible with LWD

Geological sampling from coiled tubing drilling

Ben van der Hoek
University of South Australia / DET CRC

Exploration '17
The Future of Mineral Exploration Drilling and Sampling Workshop


RoXplorer®

Representative Sampling


Lab-At-Rig®

The challenge

- No core
- ~7.5 kg/m cuttings
- 80-150 L/min fluid

- 200-500 mm/min ROP
- 300-500 L/m drilling fluid

- Fluid additives
- Broad/coarse cutting size (0-5 mm)

Sub-sampling

- **Split 1**
  - Conducted wet (i.e. 95% fluid)
  - 12.5% of 7.5 kg
    - ~900 g coarse cuttings (<5 mm)
      - Dewater, dry, pulverise 900 g solids

- Split 2
  - Conducted dry
  - ~10% of 900 g
    - ~100 g fine material (<100 µm)
      - Lab-At-Rig® XRF/XRD (Olympus)

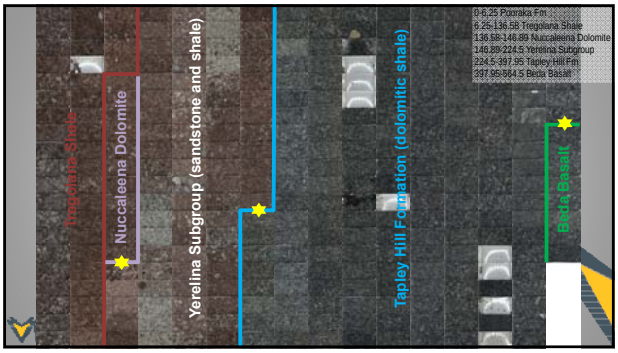
Sub-sampling equipment

- Designed modified cone splitter

- Sub-sample fluid and cuttings

- DET CRC
  - Provisional Patent Application ✓
  - Registered Design ✓

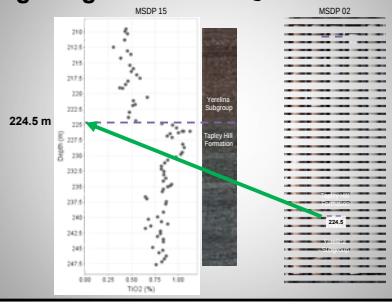
CT drilling sample



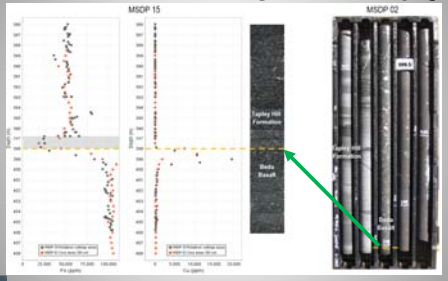
Sample depth

- Depth algorithm
  - Hole depth (rig data)
  - Annulus Area (bit diameter)
  - Flow rate (top-of-hole sensors)
- Deviation (survey-while-drilling tools)

Sharp geological contacts ✓



Identification of features (geochemistry) ✓



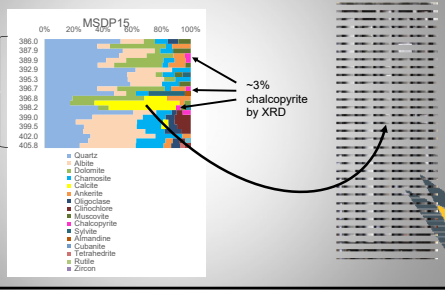
Identification of features (mineralogy) ✓

XRD

23 samples

3 hrs data acquisition with Olympus BTX II

3 sec solve time with **SwiftMin™**



Acknowledgements

Thank you to the P3.2 team: Fred Blaine, Caroline Tiddy, David Giles, Yulia Uvarova, James Cleverley, Aaron Baensch, Neil Francis

The work has been supported by the Deep Exploration Technologies CRC whose activities are funded by the Australian Government's CRC Programme.

This is DET CRC Presentation **2017/ ???.**

Top-of-Hole Geochemistry and Mineralogy: State-of-the-Research

Yulia Uvarova CSIRO/DET CRC
and Project 3.2 Team (CSIRO, Imdex, Olympus, DET CRC)
Exploration'17
The Future of Mineral Exploration Drilling and Sampling Workshop

pXRF

- Little to no sample preparation
- Fast - min reading time 10s per beam
- Elements from (Mg) to U

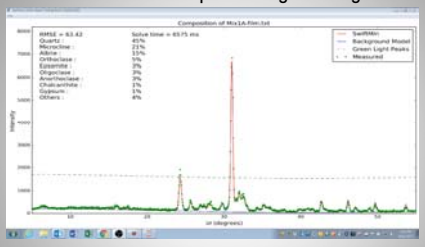
Portable X-ray Diffraction (pXRD)

Portable X-ray Diffraction (pXRD)

Piezo-harmonic vibrating cell (Sarazzin et al. 2010)

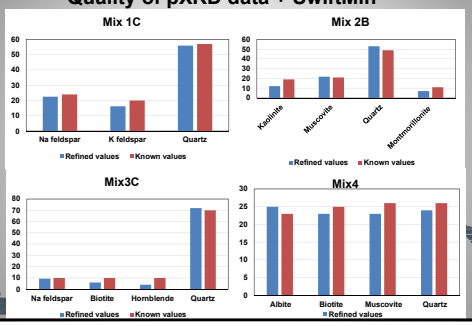
- Portable and robust
- Little sample required (~ 10 mg)
- Very little sample preparation – crushing to <150 µm particle size
- Data collection time – 10 mins
- Unique piezo-harmonic vibrating cell eliminates the problem of preferred orientation

SwiftMin® - XRD data processing challenge solved!



Automated batch-processing of powder XRD data, results in seconds

Quality of pXRD data + SwiftMin®

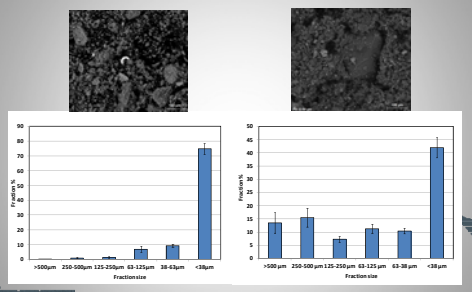


Turning a waste stream to good

1 meter composite:

8.8 Kg powder
9.8 Kg core

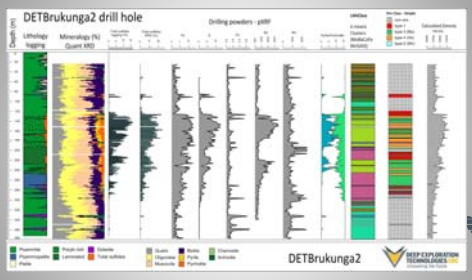
Particle size distribution



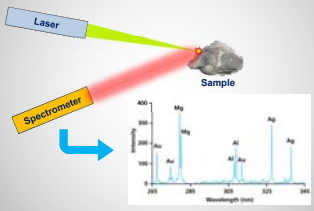
Diamond drilling cuttings – new sample medium

Chemistry and mineralogy in near real time

Proof-of-concept at Brukunga, South Australia

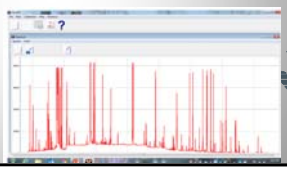


Laser-Induced Breakdown Spectroscopy (LIBS)

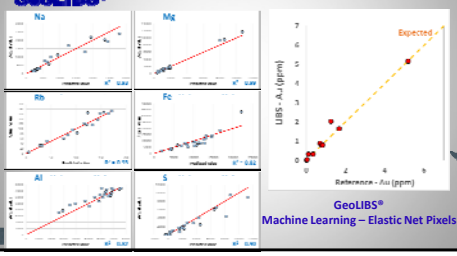


Advantages of LIBS

- No sample preparation
- Solids, liquids and gases
- Rapid analysis – both online and offline
- Almost all elements (**light elements and elements that are problematic for pXRF**!)
- Continuous analysis (kinetics)
- Depth profiling
- Mapping
- Chemometrics
- Portable (on Mars!)



Customised software for processing of LIBS data



GeoLIBS®
Machine Learning – Elastic Net Pixels

Conclusions

- pXRF, pXRD and LIBS sensors available for top-of-hole analysis;
- Algorithms for data processing are being developed;
- Combined XRD-XRF-LIBS analyses offer rapid and low-cost characterization of geologic materials for mineral exploration and mining industry and deliver elemental and mineralogical information of high quality where appropriate QA/QC protocols are followed.

Acknowledgements

I'd like to thank the wonderful and brilliant Project 3.2 Team: Neil Francis, Steve Tassios, Doug Body, Monica leGras, June Hill, Chris Ryan, Nathan Reid, Aaron Baensch, James Cleverley, Fred Blaine, David Giles and many more.

The work has been supported by the Deep Exploration Technologies CRC whose activities are funded by the Australian Government's CRC Programme.

This is DET CRC Presentation 2017/1060.

Seismic in the window of pre-drilling and sampling: state of the research

Milovan Urosevic on behalf of the team from the Department of Exploration Geophysics, Curtin University and HiSeis, Perth, WA
Andrej Bona, Roman Pevzner, Sasha Ziramov, Roman Egorov, Konstantin Tertyshnikov, Anton Kepic, Sinem Yavuz and others from Curtin Uni & Jai Kinkela and the team from HiSeis P/L

Seismic & mineral exploration

- Many different seismic surveys, investigations and studies conducted over several decades
- Seismic has not been established as the primary exploration method in mineral industry

Why?

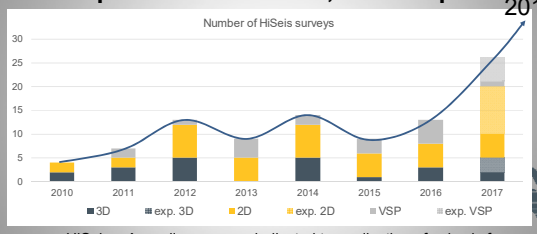
- **Cost**
- Mineral prospecting with seismic methods is not straightforward
- Imaging issues (complex geology)
- Recording difficulties (ground conditions)
- Cumbersome to analyze/interpret
- Nobody likes wiggles
- Other natural and human obstacles...

20th century seismic windows

- 3D seismic acquisition on the rise - brownfields
- 3D – PreStackTimeMigration (PSTM) - standard imaging technique
- Seismic calibration through cores and log correlation
- Borehole imaging on the rise
- Seismic data/image analysis incorporates impedance inversion, cooperative analysis/inversion, volumetric interpretation, immersive environment…

Uptake of seismic surveys for mineral exploration 2010-2017, an example

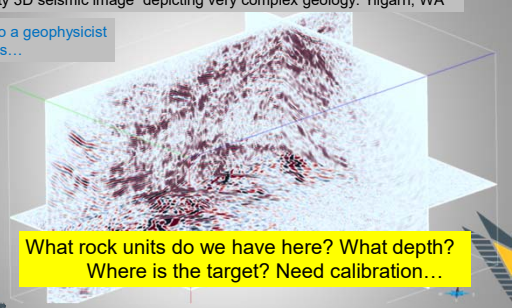
2018?



HiSeis = A small company, dedicated to application of seismic for mineral exploration, span-off by Curtin Geophysics in 2010

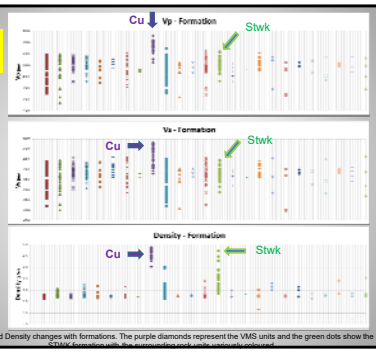
High quality 3D seismic image depicting very complex geology: Yilgarn, WA

Beautiful to a geophysicist
But wiggles…



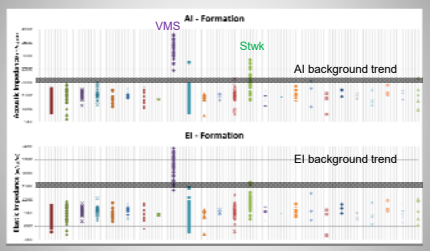
What rock units do we have here? What depth?
Where is the target? Need calibration…

Core samples - Rock properties

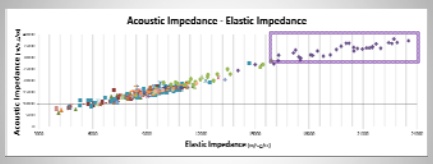


The Vp, Vs and Density changes with formations. The purple diamonds represent the VMS units and the green dots show the

Formation's AI and AI vs EI



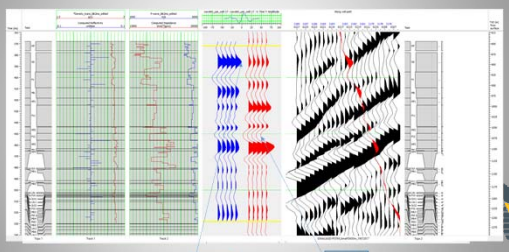
Targeting VMS from seismic data



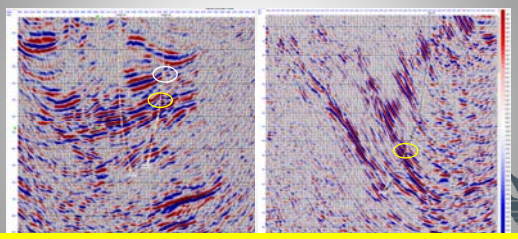
AI versus EI can provide close to unique separation of VMS

Need true relative amplitude processing to utilise AI-EI relationship

Log correlation for lithology



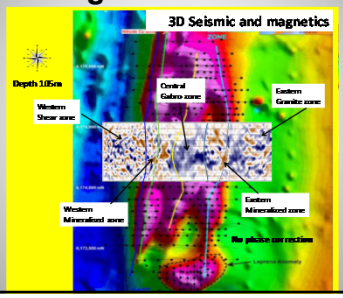
Strike and dip – borehole correlation



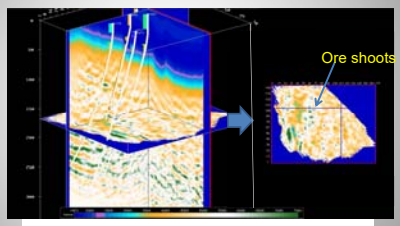
Well tie - value for seismic to geology correlation

Joint analysis, Inversion, Volumetric interpretation…

Mag and Seismic



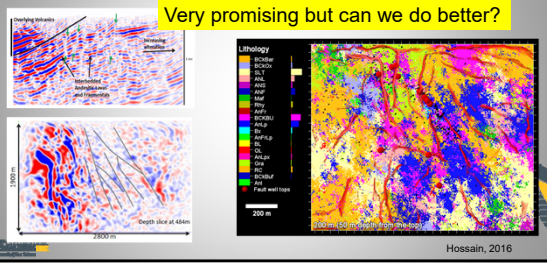
Model-based Acoustic Impedance Inversion



AI inversion to target Uranium ore-shoots

Volumetric Interpretation – from "wiggles" to geology, Cracow 3D

Very promising but can we do better?



Hossain, 2016

21st century seismic windows

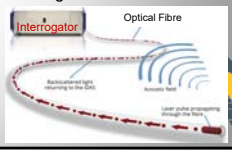
- New sensors (DAS, MEMS…)
- Many thousands of surface autonomous sensors
- Instrumented fields

- Full Waveform Inversion (FWI)
- Depth imaging
- No Wiggles – physical properties, lithology, geological models

Data acquisition - New developments

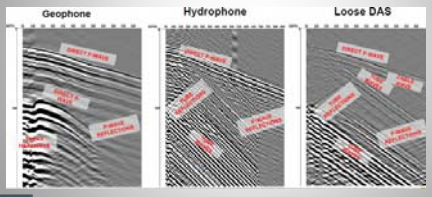
Distributed Acoustic Sensing (DAS)

- Measures along the whole cable length at once (up to ~10km)
- Outperforms hydrophones (and in some cases geophones)
- Cheap (<$5/m) and disposable – could go to every borehole
- Can be used to measure temperature, stress changes
- Embed in coil tubing
  - drill bit vibration sensing,
  - fluid flow/cutting transport monitoring?
  - seismic while drilling?



Why use DAS?

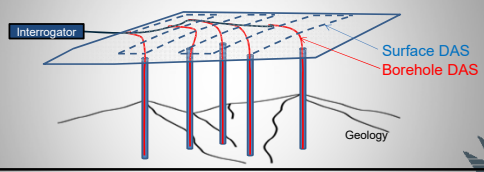
- Continuous receivers - borehole or surface
- Order of magnitude cheaper than any other seismic sensor



First test in borehole at Curtin (DEG)

Borehole and surface seismic using DAS

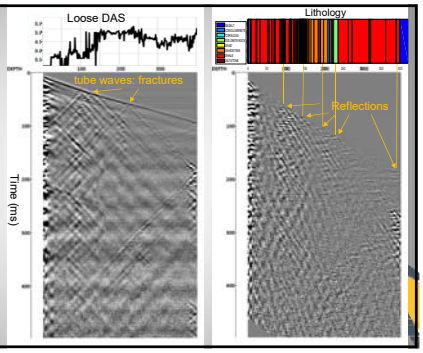
A concept - frequent CT boreholes for high resolution imaging



Exceptionally high data density, portability; can record 40,000 plus channels with a single interrogator DAS technology very attractive for the mineral sector!

First field test in the world - SA

- Fracture zones correspond to core observations
- Reflections agree with lithology
  - Order of magnitude faster acquisition



Benefits to mineral industry

DAS is likely to become a key new technology that could revolutionize in the first instance borehole and then surface seismic in mineral exploration

- New technology will greatly increase data density (by an order of magnitude)
- Will provide detailed 3D geological model from single and multi-well VSP surveys yielding improved targeting of extensions of mineralised bodies
- Significant cost cutting of exploration drilling
- Enable permanently instrumented mines at a very low cost (on demand imaging and constant monitoring of mine operations)
- Of particular interest to hypersaline environments where standard recording equipment will be significantly damaged or impossible to implement (mineralisation under salt lakes – widespread in WA)
- Make reflection seismic economical for green fields exploration

Data processing - New developments

Full-waveform inversion (FWI) – iterative matching of the entire recorded wavefield by forward modelling

Most suitable for borehole data due to:
- presence of direct waves (known velocity-initial model)
- high signal to noise ratio
- Broad band signal

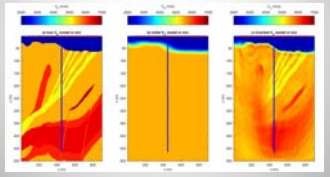
FWI for hard rocks: P-wave velocity recovery

"Geology"

Starting model
1 well + fibre optic
16 shots at the surface

Recovered "Geology" that is P wave velocity

Sunrise Dam model



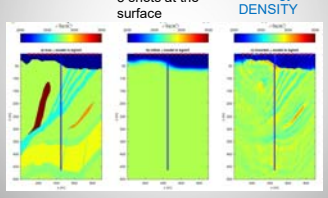
Egorov et al., 2017)

FWI for hard rocks: density recovery

"Geology"

Starting model
1 well + fibre optic
5 shots at the surface

Recovered "Geology" that is DENSITY



Conclusions

General growth in 3D surface seismic and borehole seismic acquisition, advanced processing and interpretation already in practice

And then?

Next generation seismic = DAS + FWI
Next generation drilling = Coil Tubing (CT)
Next generation logging = Behind the Drill Bit (BDB)
Next generation sampling = Lab At the Rig (LAR)

21st century exploration: CT + BDB + LAR + DAS + FWI

Progress in delivering Assay-While-Drilling

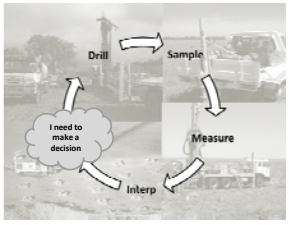
James Cleverley, Global Product Manager – Geosciences

October | 2017

IMDEX

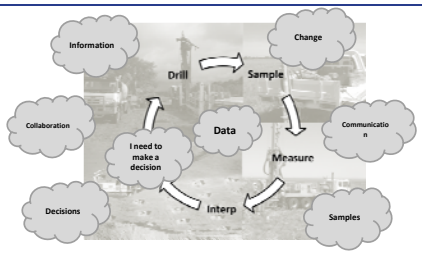
Industry Challenge

IMDEX



Industry Challenge

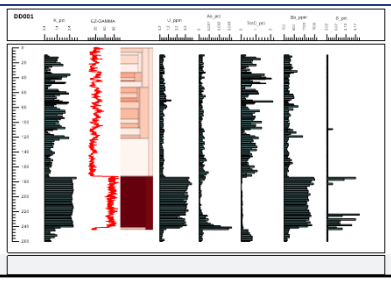
IMDEX



What is the Assay?

Tophole and Downhole Integration

IMDEX



Top of Hole Assay - DD

Lab-at-Rig®

BARRICK

IMDEX

Trial deployment with Barrick as part of Kickstarter partnership

- Manual Proof of concept of workflow and sub-systems (TRL4), communications and data integration systems
- Delivered near-real time assay information from diamond drilling with excellent depth fidelity and resolution

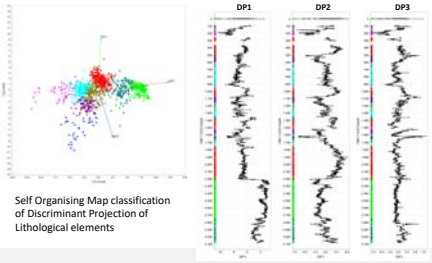
DEEP EXPLORATION TECHNOLOGIES CRC

Information Products

Near-real time ME data into information for decision support

ioGAS

IMDEX



Self Organising Map classification of Discriminant Projection of Lithological elements

Top of Hole Assay – CT Drilling

Lab-at-Rig for CT

Proof of concept demonstrator for sample prep and assay of CT Rig sample

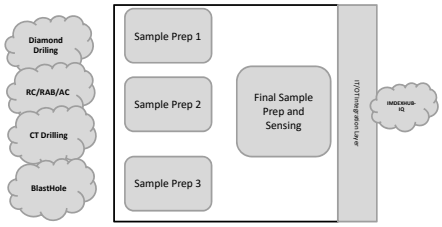
Dewater, Drying-Comminution, Press and Assay (TRL2/3)

Data delivered to IMDEXHUB-IQ in ~10 mins of drilling

DEEP EXPLORATION TECHNOLOGIES CRC

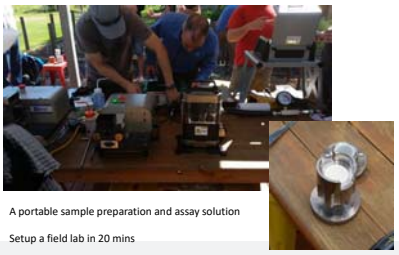
Near real-time Top of Hole Assay

Platform automation



What can we do now?

In-field Sample preparation and Geoanalysis



A portable sample preparation and assay solution

Setup a field lab in 20 mins

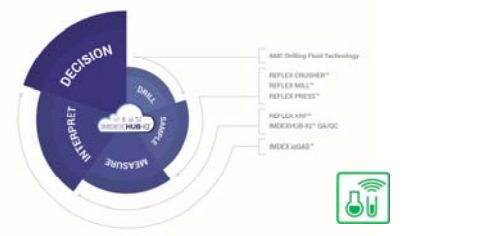
What can we do now?

In-Mill Sample preparation and Geoanalysis

A portable mill and met assay solution

The In-field Geoanalysis Workflow

The End-to-end Solution



Complete End-to-End Solution

The end-to-end solution

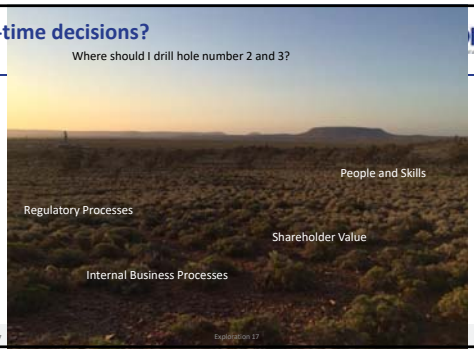
IMDEXHUB-IQ™

Delivering confidence in your data wherever you are

IMDEXHUB-IQ QA/QC Approval workflows give you confidence in the data you have collected, wherever in the world you are.

Real-time decisions?

Where should I drill hole number 2 and 3?



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Aaron Baensch – Principal Geologist, International Mining Group
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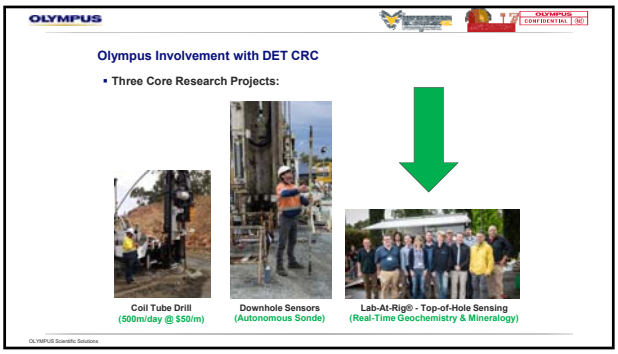
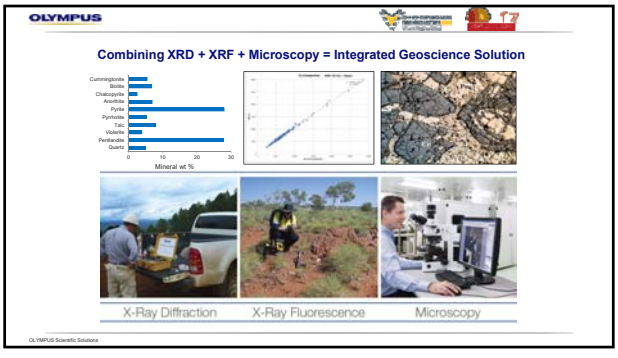
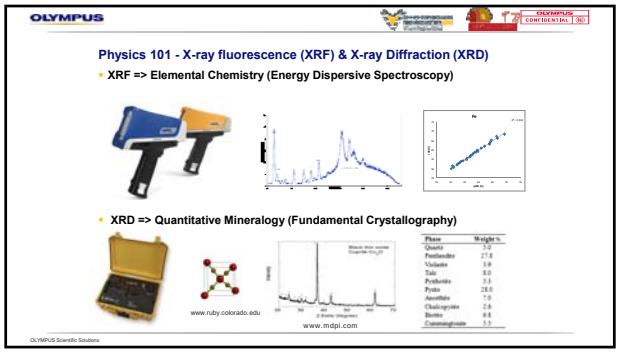

OLYMPUS
Olympus Involvement with DET CRC
Three Core Research Projects:
Coil Tube Drill
(500m/day @ $50/m)
Downhole Sensors
(Autonomous Sonde)
Lab-At-Rig® - Top-of-Hole Sensing
(Real-Time Geochemistry & Mineralogy)


OLYMPUS
Olympus & Olympus Scientific Solutions Americas (OSSA)
Olympus = Long history in Optics, Imaging & Sensor Technology
40,000 Employees, Market Cap ~US$12B, Founded Japan 1919
Core Businesses:
Cameras & Audio
Medical, Surgical & Life Sciences (End, GI, Gyn, Urol…etc.)
Industrial = OSSA (HQ = Boston & Quebec)
Non Destructive Testing (NDT)
Ultrasonic
Phased Array
Eddy Current
Advanced NDT Solutions & Systems
Industrial Borescopes & Videoscopes
Microscopy & Optical Metrology
Analytical Instruments
X-ray Fluorescence (XRF)
X-ray Diffraction (XRD)


OLYMPUS
Combining XRD + XRF + Microscopy = Integrated Geoscience Solution
Mineral wt %
X-Ray Diffraction
X-Ray Fluorescence
Microscopy


OLYMPUS
Physics 101 - X-ray fluorescence (XRF) & X-ray Diffraction (XRD)
XRF => Elemental Chemistry (Energy Dispersive Spectroscopy)
XRD => Quantitative Mineralogy (Fundamental Crystallography)
www.ruby.colorado.edu
www.mdpi.com

Olympus – XRF Products Overview (Chemistry)

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REDWAVE Sorter

X-STREAM Sorter

Handheld XRF – VANTA (5th Gen Hand-Held)

- **Rugged**
  - IP67 Rated – Dust & Water Proof
  - High Temperature Rating ~50C
  - Drop Tested
  - "Eye-Lid" Detector Shutter
- **Revolutionary**
  - Stable Hardware & Better Resolution
  - More Precise & Accurate
  - No Cal Check – Patented "Pulse"
  - Screw-less Window Change
- **Productive**
  - New DPP – Fast HCR
  - Wi-Fi – Cloud Enabled
  - Embedded GPS
  - New Software, Methods, Modes & GUI

"Rugged"

"Revolutionary"

"Productive"

Axon™ Technology:
A Revolution in X-ray Fluorescence

Olympus – XRD Systems (Mineralogy)

- **Terra XRD = Worlds Only "Truly Portable" XRD**
- **BTX II = Worlds Smallest & Lowest Cost Bench-Top XRD**

TERRA Portable XRD

BTX II Bench-Top XRD

Web Based GUI

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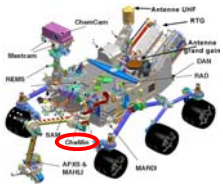
Mars Rover Link to Olympus

- **MSL Curiosity is the 3rd Generation of Mars Rovers**
  - Significantly larger Rover, powered by Radioisotope Thermoelectric Generator (RTG) to support Advanced Geo-Scientific payload and sampling tools

OLYMPUS

Mars Rover Link to Olympus



- **CheMin: XRD/XRF**
- APXS: Alpha Particle XRF
- ChemCam: LIBS
- MastCam: Spectral & Optical
- MAHLI: Optical / Hand Lens
- SAM
  - Gas Chromatography
  - Quad Pole Mass-Spec
  - Raman Laser Spectrometer

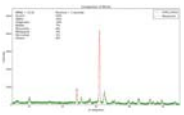
OLYMPUS

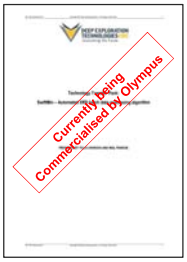
NASA CheMin Video

(2min 34secs)

OLYMPUS

XRD Development – Two Key Areas: Sample Loading & SwiftMin™





OLYMPUS

LAB-AT-RIG® - Near Real-Time pXRD & pXRF for Drillhole Logging

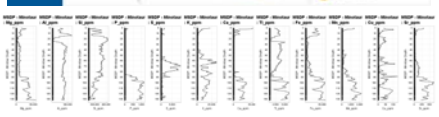
Reflex Lab-At-Rig® Platform

- Developed within DET CRC
- Now Commercialised by Imdex (Reflex Division)
- Part of New Assay While Drilling (AWD) Business
- Includes module for adaption to CT-Drilling (sample handling, preparation & presentation

LAR v2.0 (Manual for Diamond Drilling)
Deployed to SA in 2015-2016 on Mineral Systems Drilling Program (MSDP) with SA-DSD, Minotaur & Kingston Resources

OLYMPUS

Real-Time Cloud Based Data Delivery via REFLEXHUB-IQ



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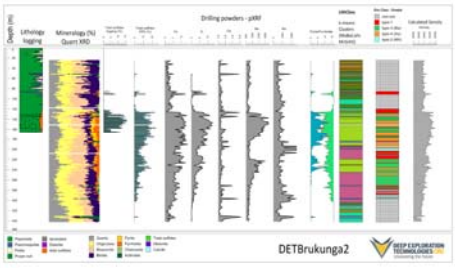
LAB-AT-RIG® - What Can it Achieve? (Results from Brukunga SA)



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Data Quality

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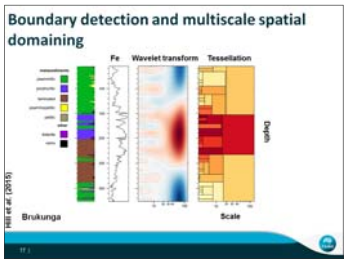
Automated "Geology"



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LAR Field Trials "Extremely Valuable" for Product Development

OLYMPUS Scientific Solutions

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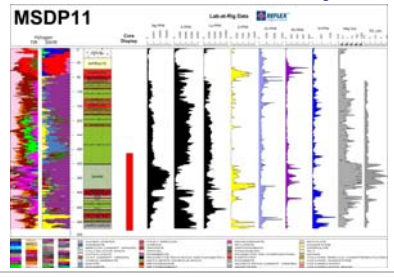
Delivered "New, Rich Data Sets" in Real 24/7 Working Environments



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Partner Developments – REFLEX: Press & BYOD (ReflexHub-IQ)

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What's Next? End-to-End Solutions (Reflex @ PDAC 2017)

The Future? RoXplorer & Lab-At-Rig®…?

Further Reading:

Uvarova, Gazley, Cleverley, Baensch, Lawie & leGras; Representative, high spatial resolution geochemistry from diamond drill fines (powders): An example from Brukunga, South Australia; JGE Volume 170, P1-9, August 2016

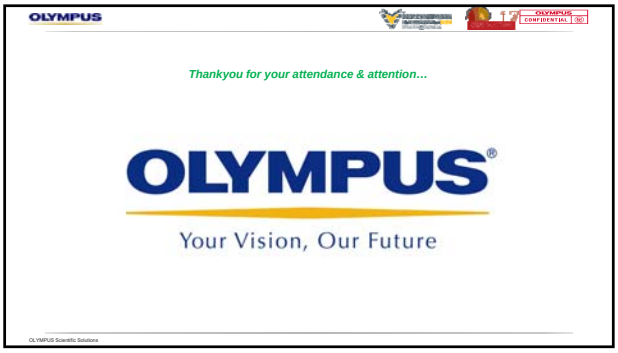
Further Reading:

Uvarova, Cleverley, Baensch & Verrall, Coupled XRF and XRD analyses for rapid and low-cost characterisation of geological materials in the mineral exploration and mining industry, AAG Explore Vol. 162, March 2014

Further Reading:

Hillis et al; Coiled Tubing Drilling and Real-Time Sensing— Enabling Prospecting Drilling in the 21st Century? Society of Economic Geology - Special Publication, No. 18, 2014

Thank you to the Sponsors, Researchers & Affiliates (Past & Present)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Your Vision, Our Future
OLYMPUS Scientific Solutions

The Future of Geological Survey Drilling

Dr Steve Hill
South Australia Chief Government Geologist
Geological Survey of South Australia

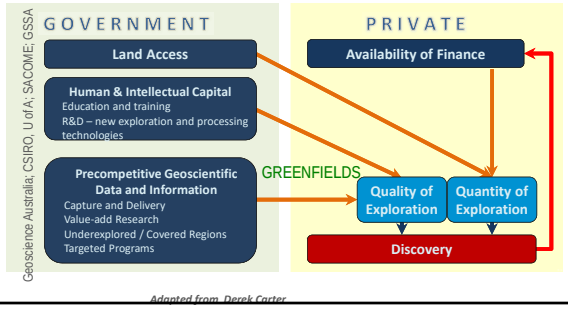
The role of Government….

1. **Just let it happen?**
   - *"They are big boys and girls … let competitive nature take care of it … we don't pick winners … good luck, let us know when you are successful …."*
2. **Attract, stimulate and partner?**
   - *"Attracting exploration investment is competitive so what can we do to give us the edge? How can we make a difference? United we stand…."*

The Case for Pre-competitive Geoscience…

- **Royalties** on minerals are charged by state and territory governments, as the owners of the minerals in the ground
- Further incentives for state/territory governments to have a strong mining industry also includes **employment, community economic benefit, infrastructure development, critical mass, offer best-practice resource recovery** etc…..
- Pre-competitive geoscience **reduces exploration investment risk and provides more informed decision making**
- Highlights the state/territory **prospectus for mineral exploration opportunities**
- Objective to **host the best quality and quantity** of mineral exploration for the best potential for mineral discovery and thereby sustain a strong mineral industry
- **Can we afford not to support this?**

Government / Private Drivers of **Discovery** (a.k.a. "The Magna Carter")



Adapted from Derek Carter

The DISCOVERY challenge…

The covered minerals search space across 80% of South Australia!

Decreasing Discovery success

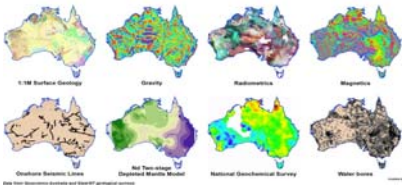
- Poorly constrained geology in covered areas
- Poor integration of geology with exploration targeting

Geoscience initiatives / strategies in support of future mineral discoveries in Australia

http://www.uncoverminerals.org.au/

Addressing the discovery challenge…

- Pre-competitive surface geology mapping, geophysics, geochemistry, mineralogy, drilling…



We need to….

- Better understand and map geology in covered areas
- Map and test mineral systems under cover
- Retrieve samples from under cover for further analysis
- Develop a degree of confidence for geophysics

Geological Survey Drilling…

1. Stratigraphic Drilling
2. Collaborative Drilling
3. Mineral System Drilling
4. National Drilling Initiative?

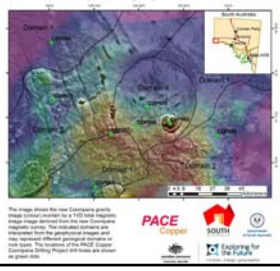
Stratigraphic Drilling

- Traditional regional drilling to better characterise lithology and stratigraphic relationships
  - Very often the first drill hole into many rock types or settings
  - Typically become key “type” or representative sections

Example: PACE Copper – Coompana Drilling

Part of Western Gawler Craton / Coompana targeted geoscience program

- **$3M collaborative program between GSSA and GA**
- **Targeting different geophysical domains**
- **Boart Longyear selected as drilling service provider**
- **Drilling commenced 9th April 2017 for ~ 5 month program**



Example: PACE Copper – Coompana Drilling

Part of Western Gawler Craton / Coompana targeted geoscience program

- **Eight Drillholes completed**
- **For a total of 4560 m**
- **Drilling reports available shortly**

Collaborative Drilling

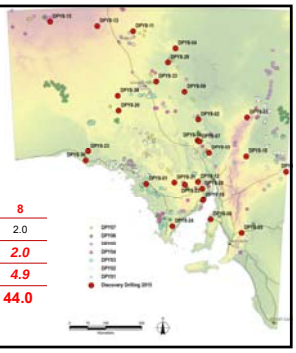
- Co-investment between Government and Industry for drilling
  - Benefit for Government:
    - Exploration Investment attraction and activity (1:20 return)
    - Open file drill core and derivative data
    - Encourages bold target assessment
  - Benefit to Industry:
    - Funding support and endorsement
    - Geoscience value-add

Example: PACE Discovery Drilling

7 Completed Rounds of Drilling Collaborations

- 438 drilling proposals
- 217 receiving PACE support
- 154 Complete

	1	2	3	4	5	6	7		8
PACE	2.0	2.0	2.0	2.0	2.0	1.4	1.7	**13.05**	2.0
Actual	1.03	2.76	1.58	1.37	1.37	1.26	0.76	**10.14**	***2.0***
Industry	0.67	4.61	3.96	4.62	7.11	3.11	3.21	**27.29**	***4.9***
($ in Million)									**44.0**

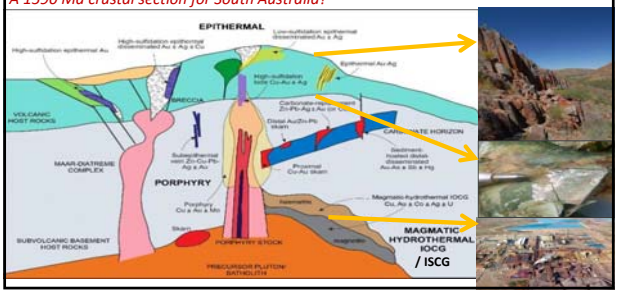


Mineral System Drilling

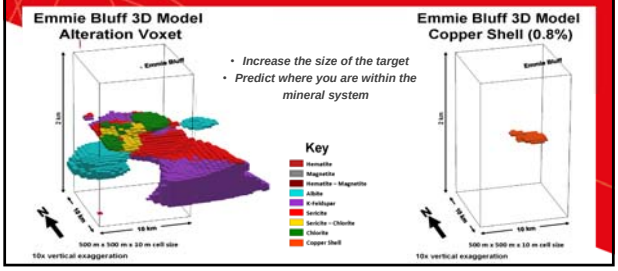
- Attempts to coherently map and show vectors within a mineral system
  - Benefits:
    - More prospective / mapping approach
  - Challenges:
    - Expense
    - Justify drilling distal to main target

Example: South Australian Mineral System Drilling Program

A 1590 Ma crustal section for South Australia?



Mapping Mineral Systems (after van der Wielen, Fabris …)



SA Mineral Systems Drilling Program

Further understanding of 1590 Ma mineral systems

- $2.5m + $0.65m + in-kind = $8m
- 14 cored holes, 7868m, ~ 8 months
- Collaborative partners: GSSA with Deep Exploration Technologies CRC, Kingston Resources, Minotaur Exploration, service sector

Key questions for 1590Ma Mineral Systems in South Australia

1. Prospectivity of the Gawler Range Volcanics (GRV)?
2. Depth of cover? (what is cover here?)
3. What was the nature of mineralizing fluid-flow?
4. What are the characteristics of mineralisation trap sites?

Mineral Systems Drilling Program

Want to know more?

- **MSDP webpage -** video series
- **Core now available for inspection!**
- **Core display -** MSDP05, MSDP10, MSDP11, MSDP12

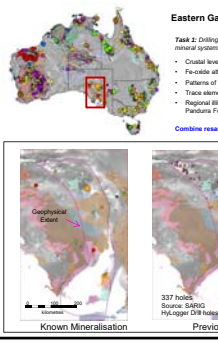
minerals.statedevelopment.sa.gov.au/msdp

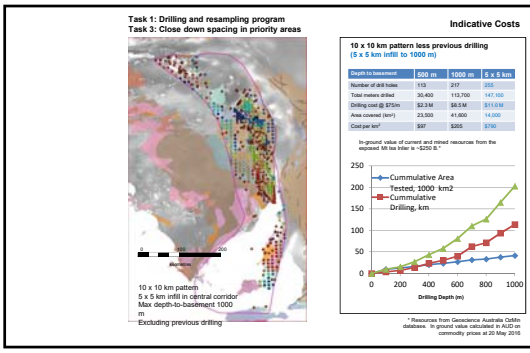
Where to from here?

National Drilling Initiative (NDI)

- MSDP set the scene with concept and CT Drilling Rig trials – cheaper and faster drilling…
- Regional mapping (undercover) using a drill rig instead of a geological hammer
- The next major step change for Australian pre-competitive geoscience?

MinEx CRC
3D DRILLING





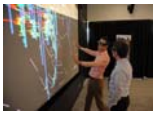
National Drilling Initiative

- Define NDI workflow and accreditation
- Components / Themes
  1. NDI from our drilling legacy
  2. NDI in new frontiers
  3. From NDI to Knowledge

South Australian Drill Core Reference Library operations

Nelson Discovery Hall

Woodall Laboratory



Holloway Geoscience Theatre

Summary / Key Points

- Evolution of Geological Survey Drilling has taken place alongside evolution of:
  - drilling and analytical technology
  - Industry requirements as they enter new exploration search space
  - The role of government and competitive investment attraction in the minerals industry

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