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MINERAL RESOURCE ESTIMATION CONFERENCE 2023

Introducing Deep Learning & Interpreting the Patterns: A Mineral Deposit Perspective

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Machine Learning (ML):

Core Concept

Artificial Intelligence (AI)

Computer systems that perform tasks & make decisions that mimic & possibly exceed human intelligence

Machine Learning (ML)

Branch of AI that focuses on creating models that learn automatically from data & experiences to make decisions without being explicitly programmed

Algorithms → **Support Vector Machine** | **Logistic Regression**

Deep Learning (DL)

Powerful type of ML model that learns complex patterns from large amounts of data, mimicking neural networks found in the human brain

Algorithms → **Neural Network (NN)**

Artificial Intelligence (AI) in the Mining Sector

Automated Machinery

Automation & optimisation of mining machinery such as haul trucks & drills

Predictive Maintenance

Predictive maintenance on machinery & equipment to minimise downtime

AI Geology Insights

AI driven exploration, resource modelling, & improvement of mill processes

ML Introduction

- ML algorithms learn from historical data; better forecast future patterns &/or trends
- ML is best suited to environment with lots of data and complex patterns
- ML is powerful tool revealing complex patterns in data easily missed by human eye and traditional statistics
- Learn to map between input & output data
- Complete seemly “unprogrammable” tasks
- Eg machine translation (ie translate text); voice and speech recognition

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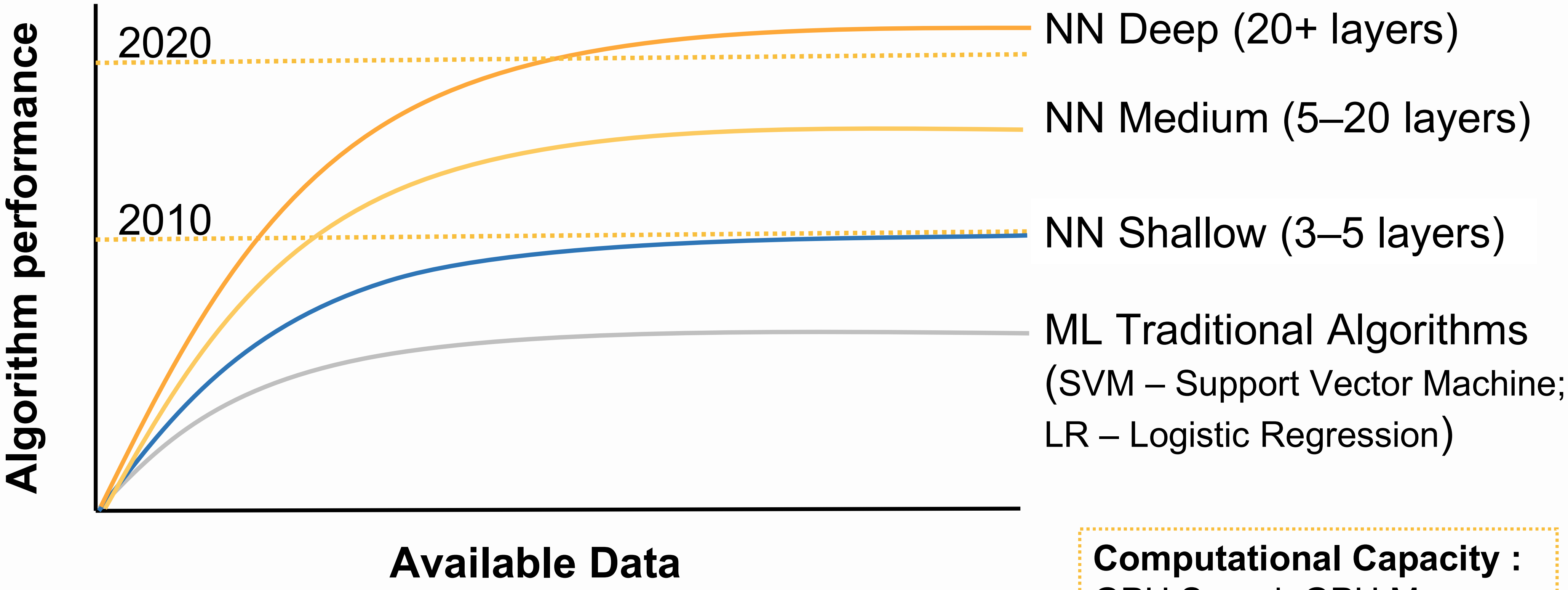
Deep Learning (DL) – Introduction

- Powerful ML algorithms; multiple neural network layers – artificial neurons
- Image recognition: eg medical imagery
- Large volumes of data plus very high performance GPUs
- Powerful GPUs only became commercially available at scale since ~2016
- Orebody or deposit requires:
  - >75,000 data points (assays): DL
  - 25 – 75,000 data points: kriging or DL
  - <25,000 data points kriging

Data vs Performance

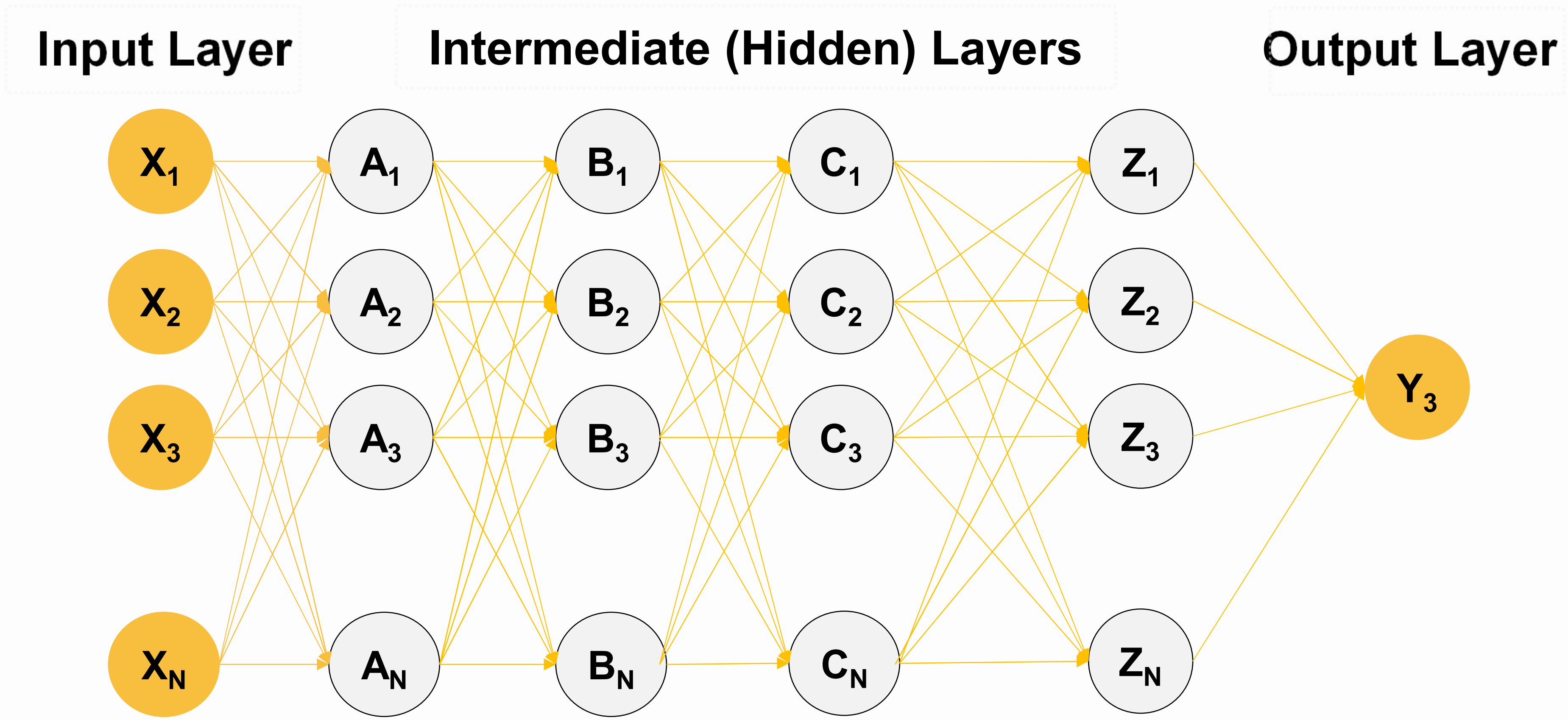


Computational Capacity :
GPU Speed; GPU Memory

Why Python?

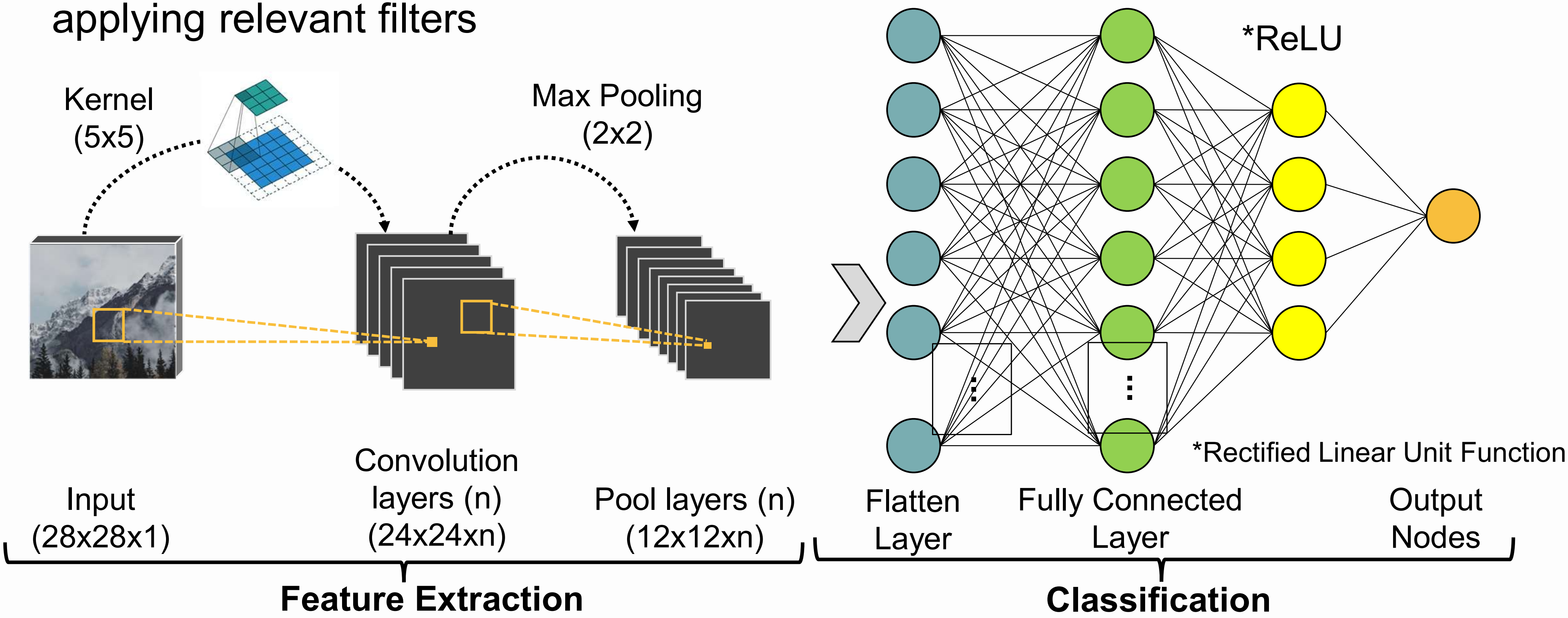
- ML & data science – language of choice
- Python is NOT special
  - Best viewed as a simple tool to interface with neural nets, data
- Most ML algorithms written in Python
  - No need to recreate ‘wheel’
  - Easier for onboarding new software engineers to ML companies
  - Simplicity – allows engineers to focus on logic rather than software development
- PyTorch – ML library (open-source); interfacing with neural nets
- CUDA – Library for interfacing with state-of-the-art GPUs

Neural Network



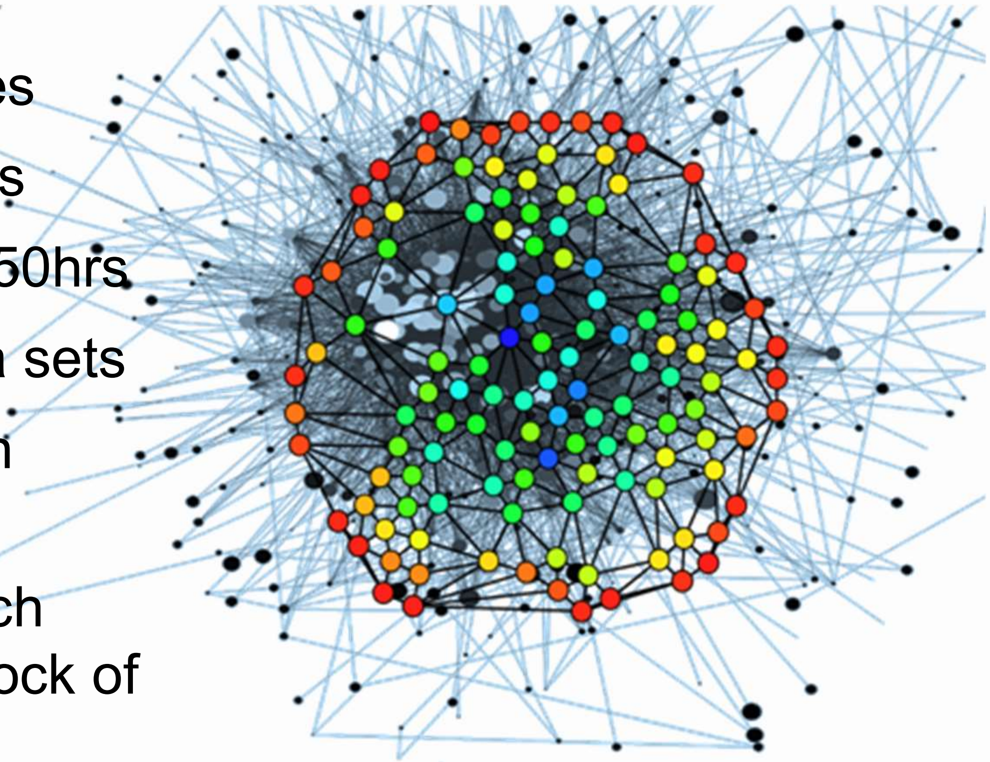
Convolutional Neural Network (CNN)

DL algorithm – successfully captures spatial dependencies in an image by applying relevant filters

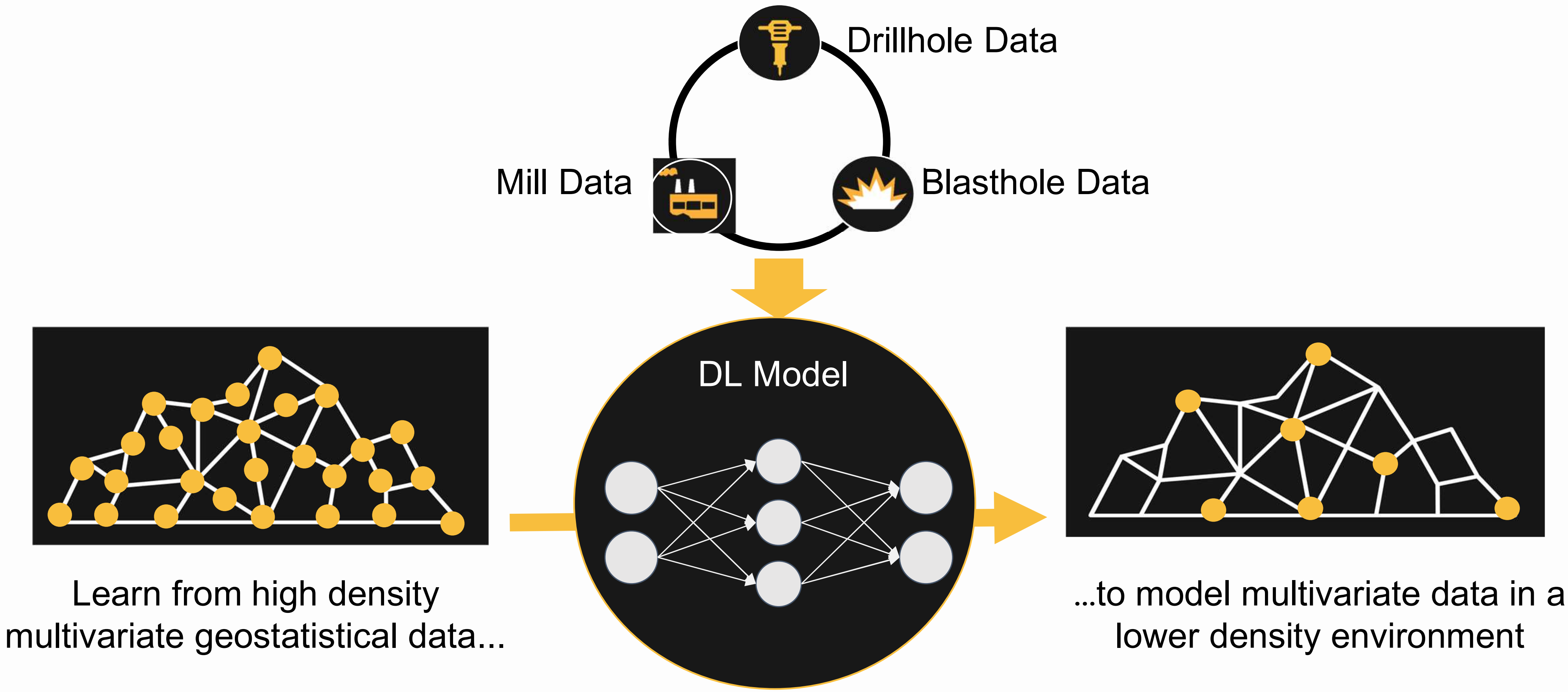


DL – Resource Modelling

- High density assay data; eg exploration drillholes, grade control holes & blastholes
- Identify best model: train 30 – 150 models
- Trained using 2x A6000 GPUs for 90 – 150hrs
- 100 – 150 iterations (epochs); entire data sets
- Data pre-processing: 96 vCPU cores with 128GB RAM
- Statistic Inference – process used for each trained model to predict grade of each block of block model: ie ~2.5hrs, 10^6 blocks



DL Answers Mineral Resource Questions?



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What Data Does DL Leverage?

Models uses DL technology to learn complex geological patterns
Allows models to predict with higher accuracy grade of any given point

Multi-Channel Data

Model can train directly on multivariate data sets
Learning which channels are relevant
Finding useful correlations

Multi-element assays

Other Structured Data

DL models can also input other structured data sets

Core logging; Core scanning, Terraspec & XRD

Unstructured Data

Integrate expert insights & client requirements
Training & predicting process – hard & soft controls

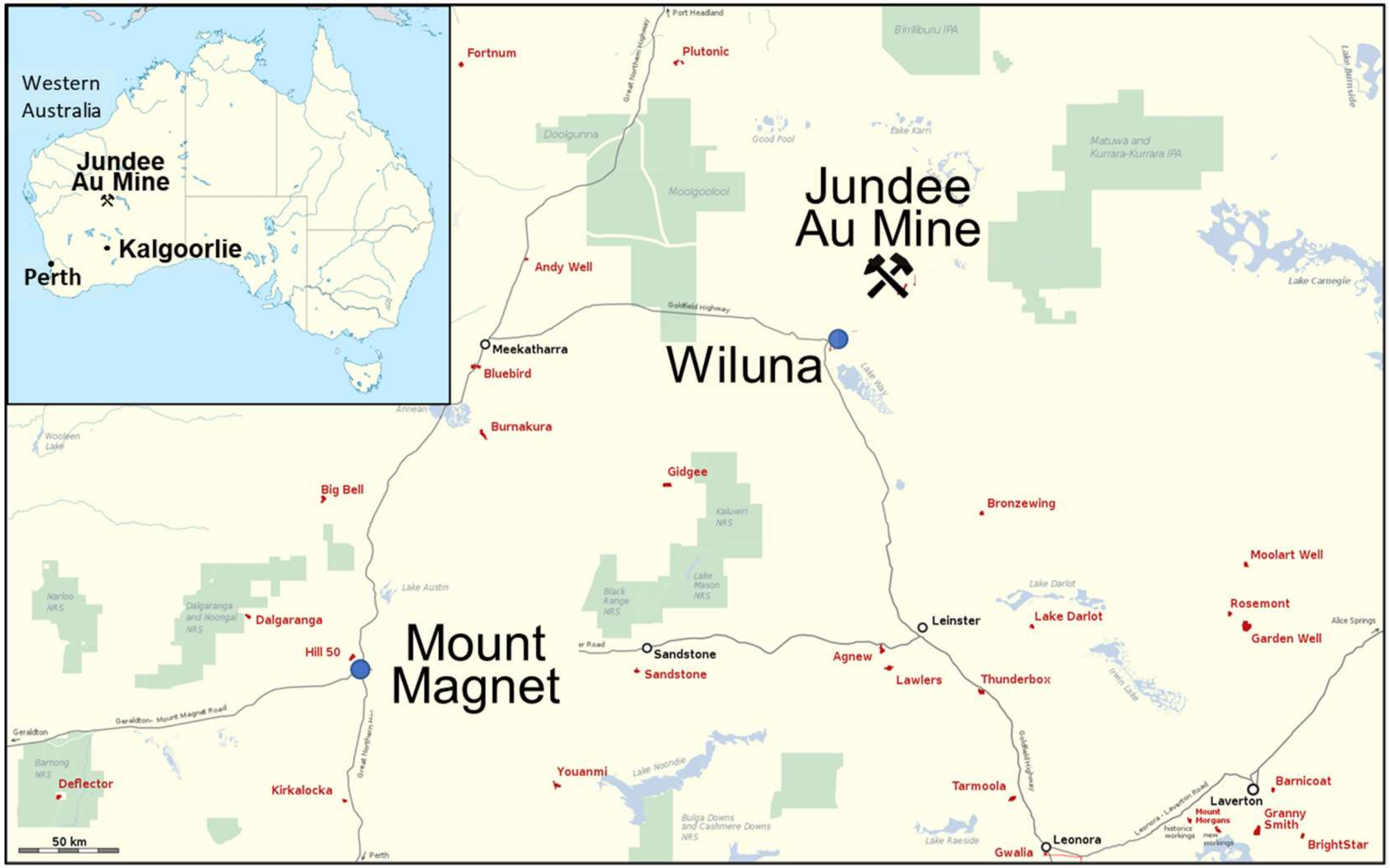
Geology; Geometallurgy; Economics

Jundee Gold Mine

Jundee Gold Mine. Image supplied by Northern Star Resources Ltd.

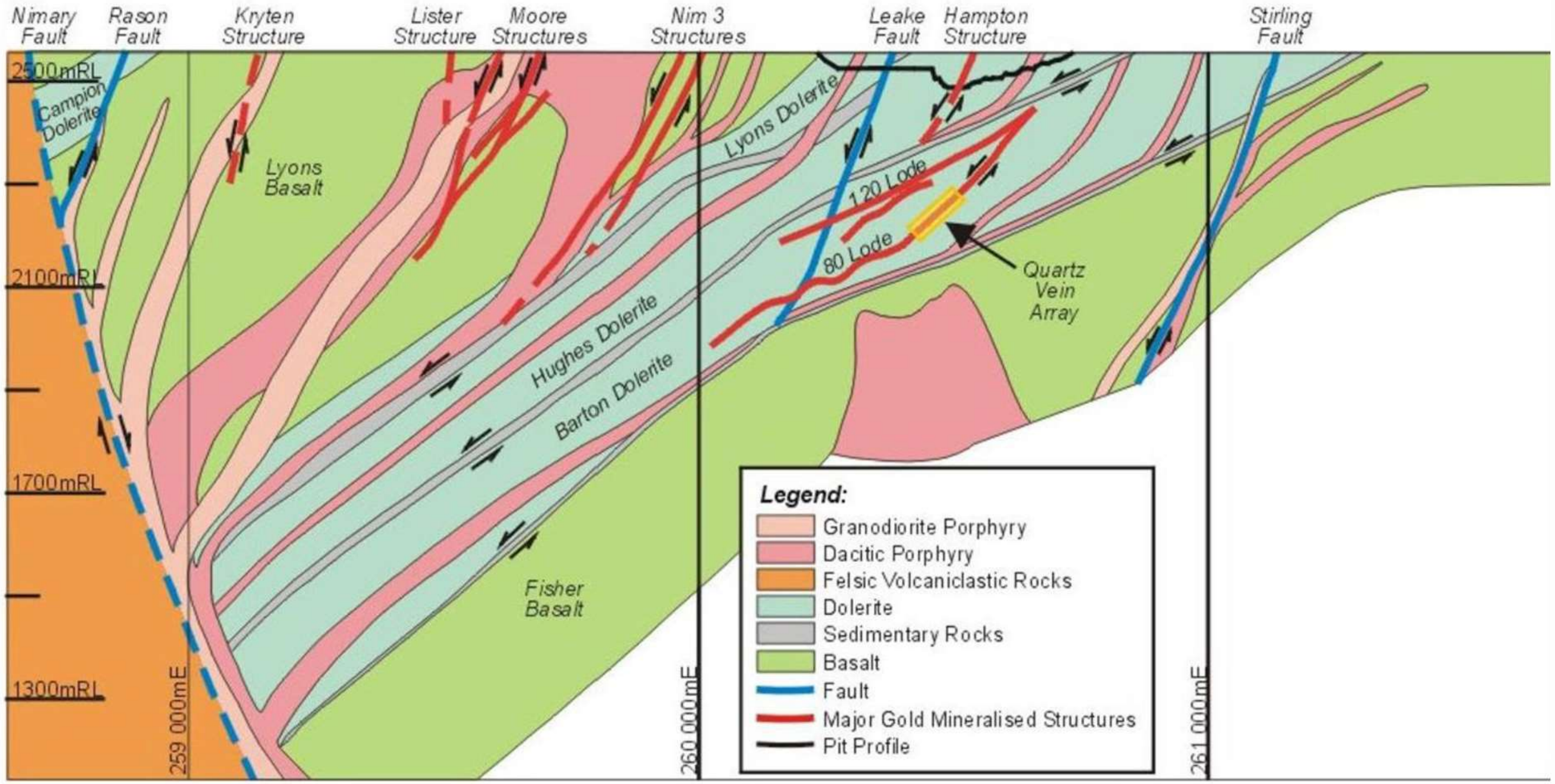
Jundee – Location

- Northern Goldfields, WA 45km NE Wiluna
- 520km N of Kalgoorlie
- 1995 OP production
- 1997 UG production
- 2014 Northern Star acquired mine complex
- UG operation: active
- CIL include gravity circuit
- MRE ~5.4M oz Au



Simplified Geology

- Orogenic lode Au deposit
- Yandal greenstone
- Host rocks mafic units, intercalated with sediment; felsic volcanic
- Intruded by dacite & granodiorite porphyry
- Lamprophyres

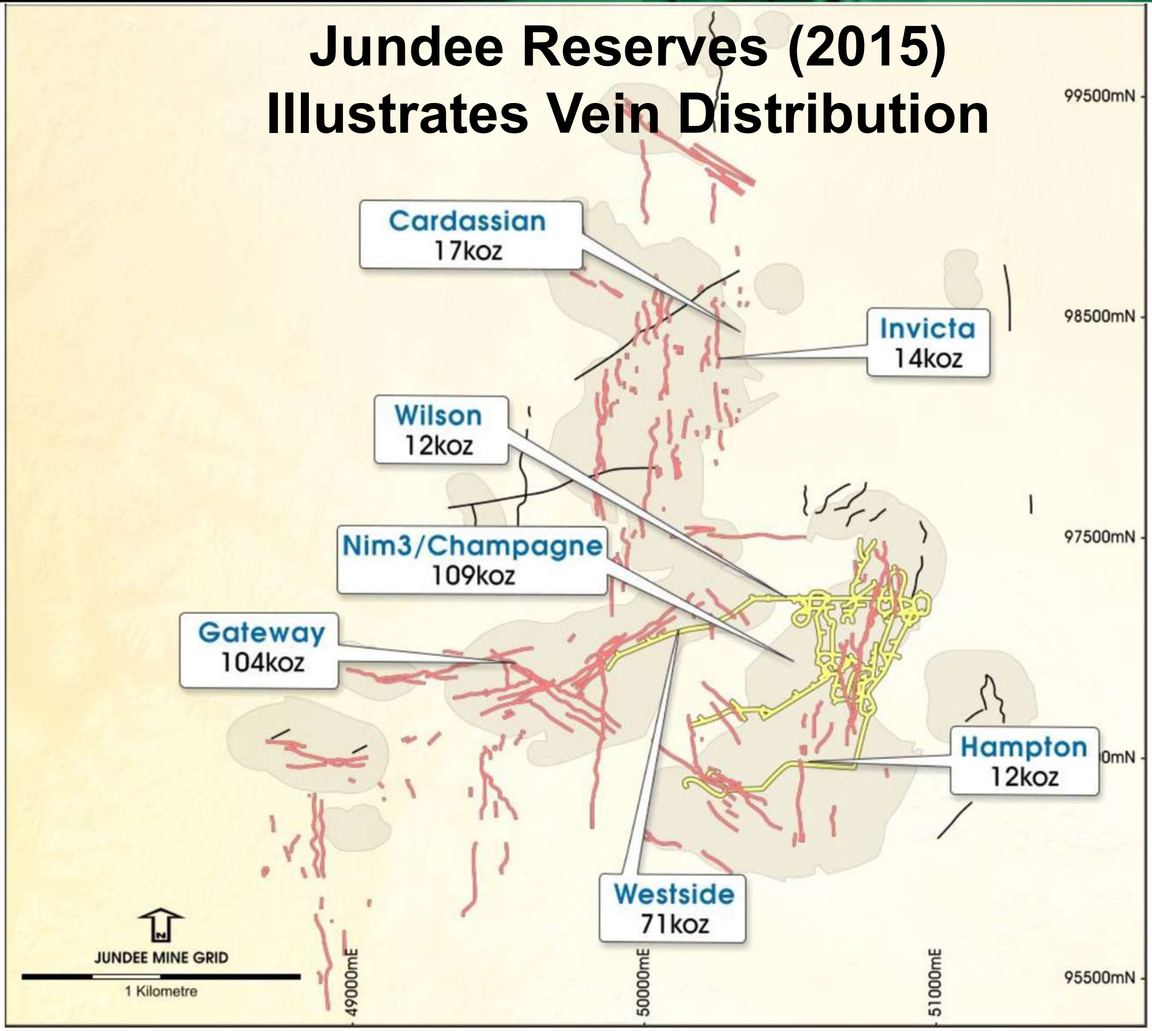


Simplified interpreted geology section (Smit & le Roux, 2016)

Goal of 2022 ML/DL Pilot Study

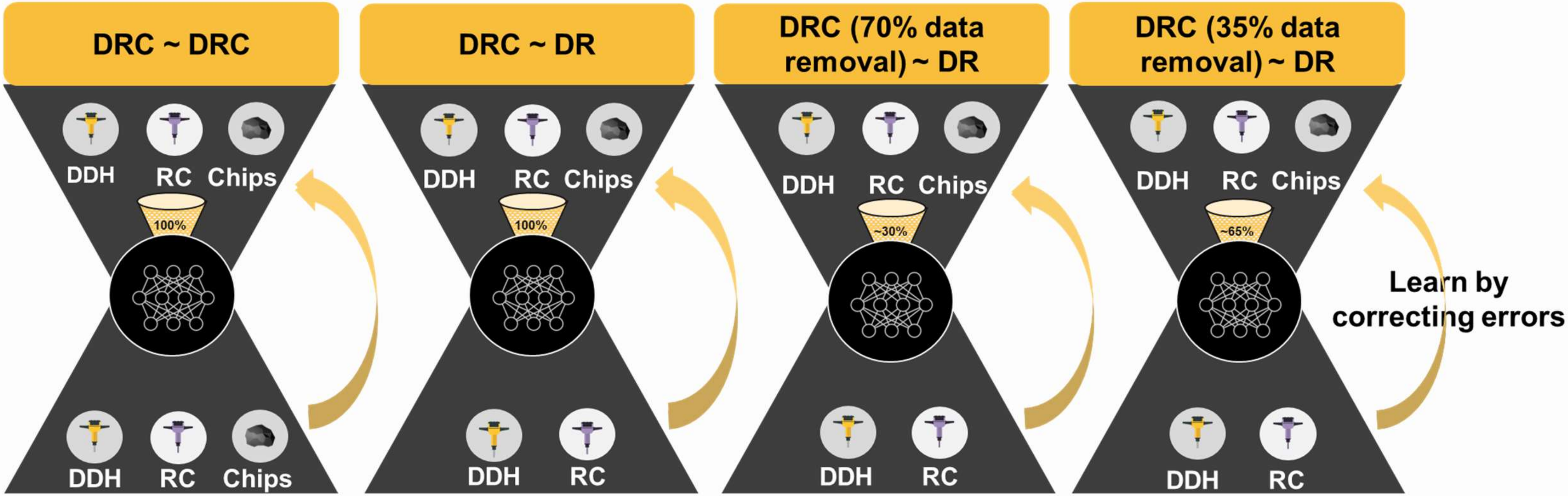
- More accurately define orientation & location of narrow lode Au veins
  - 0.5 – 1m @ grades >10g/t Au
- Very tight spacing drilling
  - >500km UG & >1,200km surface drilling
- Kriging model – highly constrained domains: a challenge
- Accuracy of the model based on block level metrics: Precision & Recall

Jundee Reserves (2015) Illustrates Vein Distribution



Results

Schematic Diagrams: Input ~ Output Models



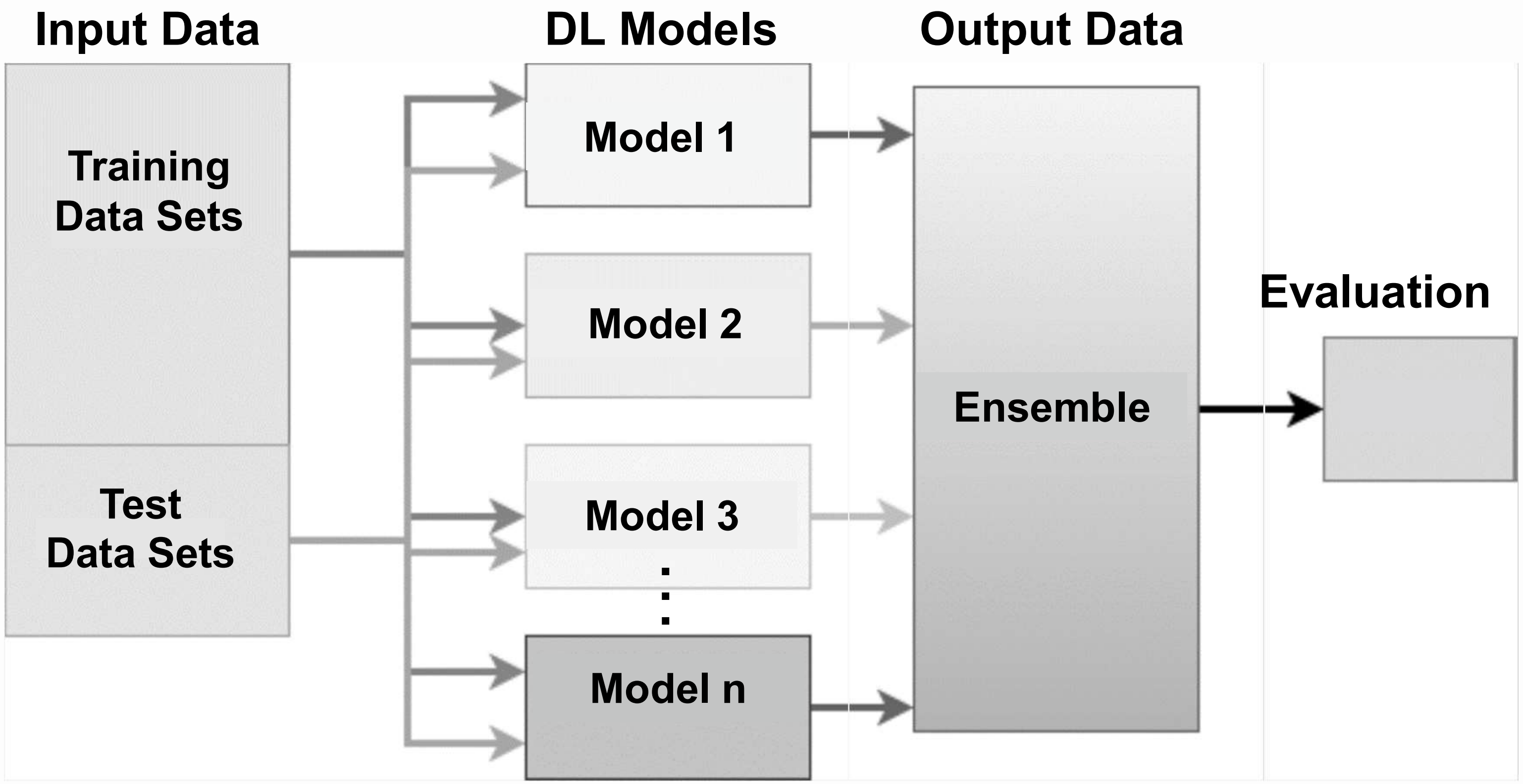
D: diamond drillhole; R: RC drillhole; C: rock-chip samples; dr: % of data removal

Results

- Precision: % blocks predict HG & reconcile HG rock-chip data: ie tracks frequency of false HG occurrences; that is when a HG block or vein predicted in the mine plan reconciles as waste (false +ve rate)
- Recall: % reconciled HG predicted as HG: ie tracks frequency veins that exist, but missed by the resource model (false -ve rate)
- Jundee – negative correlation between the two metrics
    - eg Optimise Precision, depress Recall
- Balance needed to optimising operations; eg reserve drilling, mine planning etc

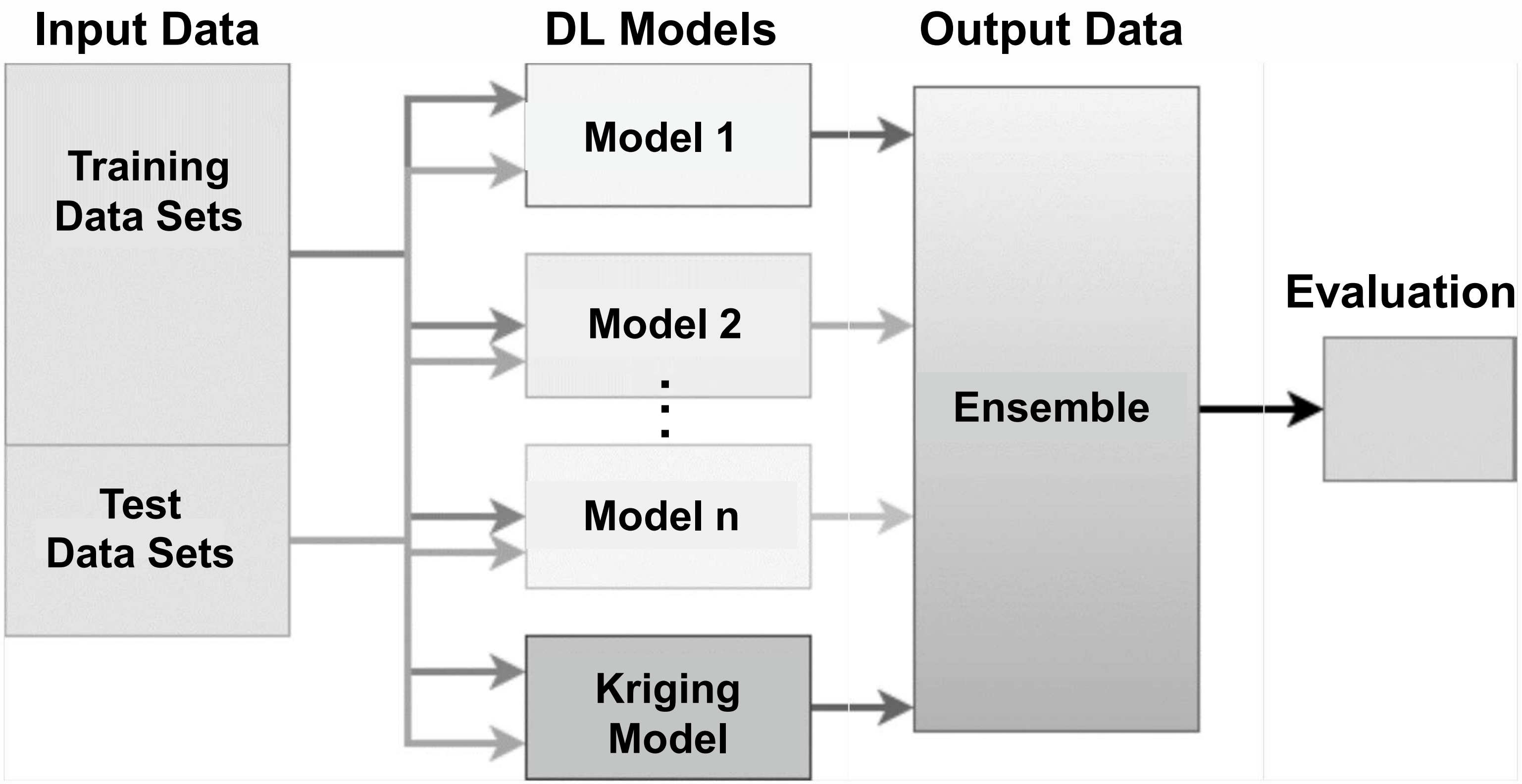
Ensembling Models

- Models created by different data sets
- Averaging out errors
- Models same or similar results – higher confidence of accuracy



Ensembling Hybrid Models

- Kriging model inc.
- More accurate
- Ensemble leverages
  - Human (kriging) & DL patterns
- Adjust weights of models to optimise
- DL or kriging – not a binary choice: a continuum



Best Precision Optimised Hybrid Ensemble

- Kriging (26.5%) to “hybrid” (34.9%)
  - ~32% rel. improvement
- Best block model
  - Combines advantages of DL + kriging
- Kriging – geological domains
- Higher confidence of HG blocks – add to mine plan

Top 8 Models

Kriging	DRC~DR weighted loss, large range
DRC(avg, max)~DR	DRC~DRC spatial learning medium
DRC~DRC	DRC~DR weighted loss
DRC~DRC weighted loss	DRC~DRC weighted loss, spatial learning high

Best Recall Optimised Hybrid Ensemble

- Kriging (14.3%) to "hybrid" (26.2%)
  - ~83% relative improvement
- Ensembling include kriging
- Best block model: not dependent solely on DL patterns
- Kriging – geological domains
- Exploration guide to additional resource – targeted drilling

Top 10 Models

- Kriging
- DRC~DR weighted loss, large range
- DRC(avg, max)~DR
- DRC~DRC spatial learning medium
- DRC~DRC
- DRC~DR weighted loss
- DRC~DRC weighted loss
- DRC~DRC weighted loss, spatial learning high

Ensembling / Compositing Models

- Ensemble configurations
  - Maximises Precision (ie maximise HG prediction)
  - Maximise Recall (ie minimise missed mineralisation)

Model Name	Precision (%)	Recall (%)
Kriging	26.5	14.3
Ensemble Precision Optimised	34.9	14.5
Ensemble Recall Optimised	26.5	26.2

- Ensemble resource model – compositing all tested resource models
  - Remove models that do not improve the overall Precision or Recall models (Optimised Precision & Recall) from the ensembles

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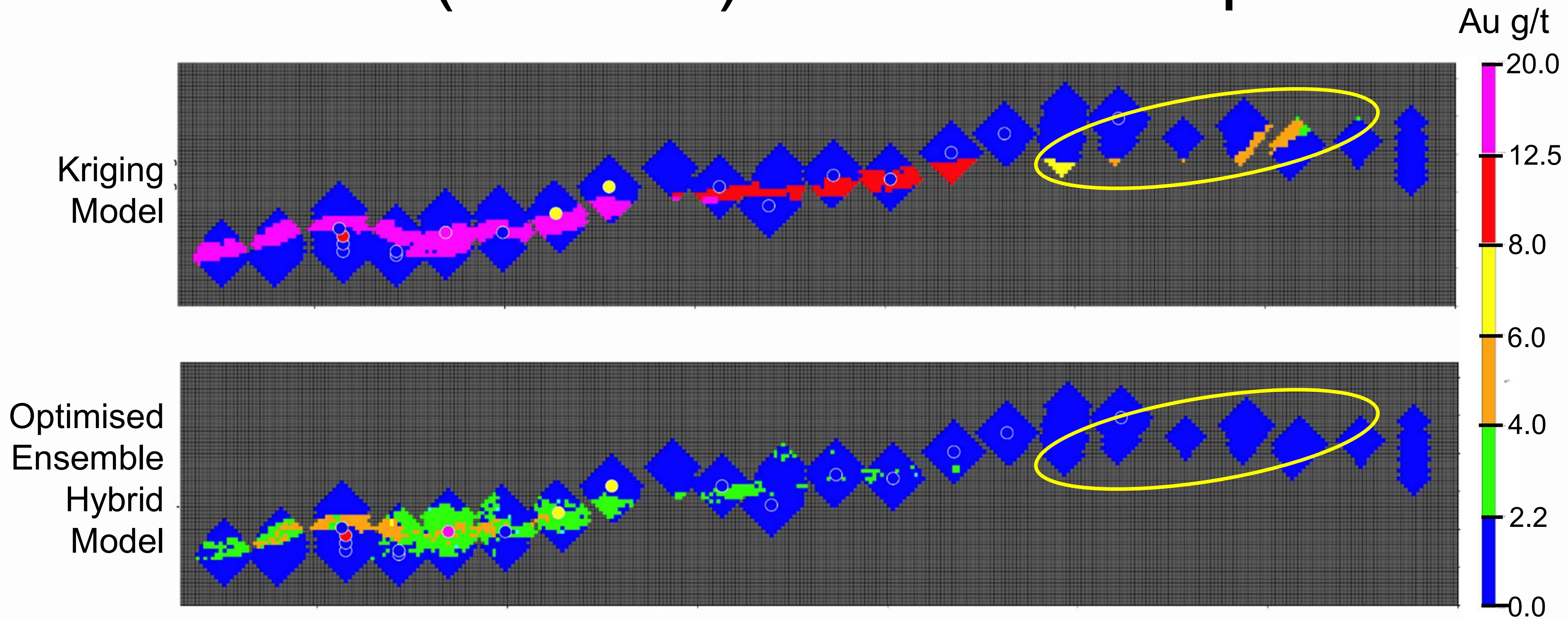
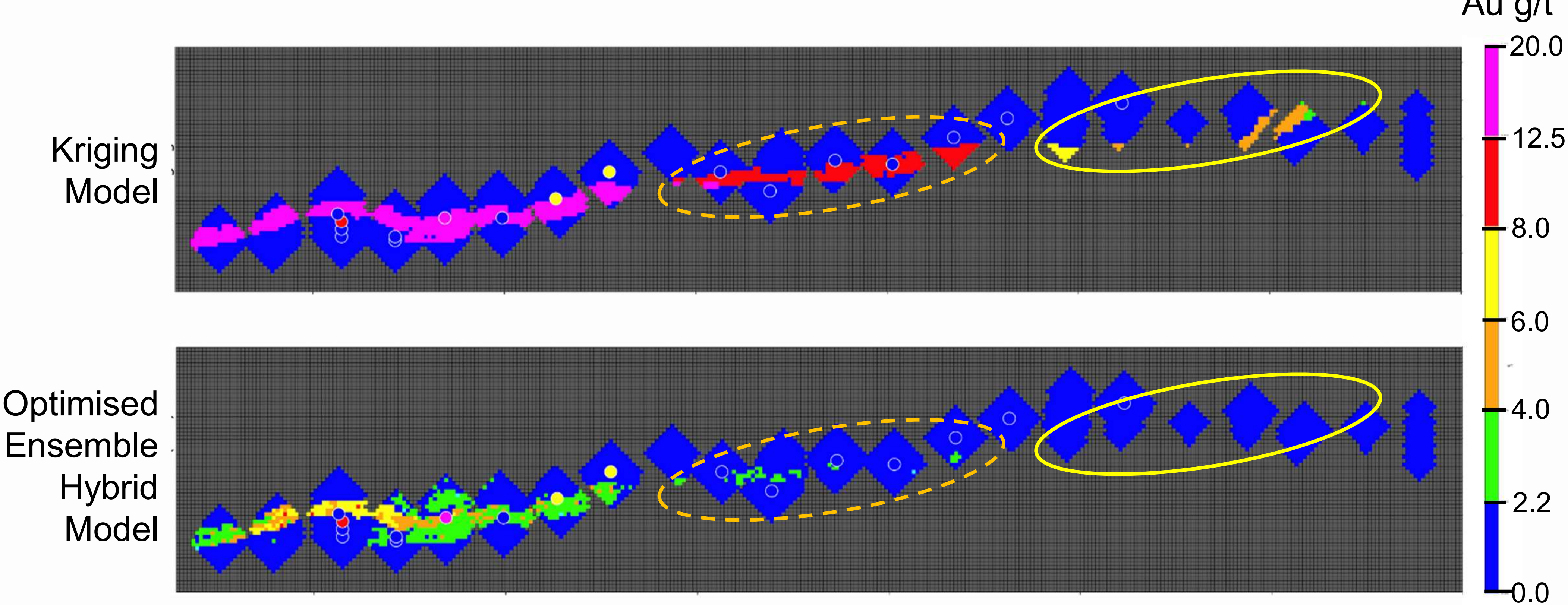
Model Plans (Z=2202) – Precision Optimised



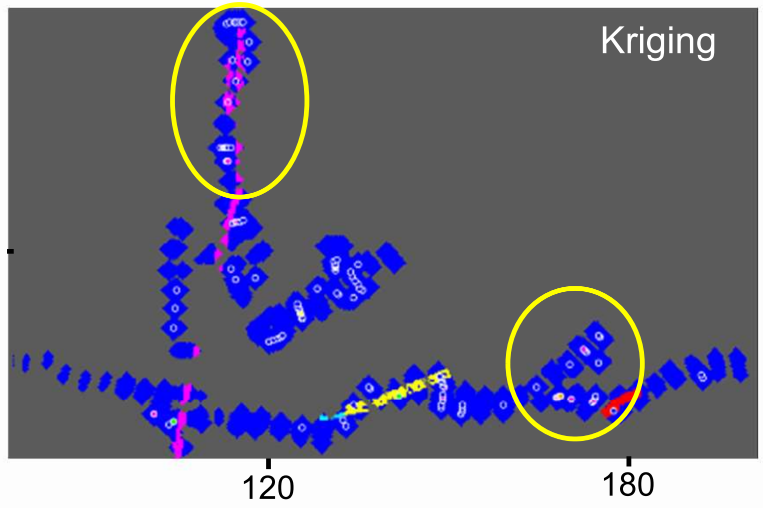
Model Plans (Z=2202) – Recall Optimised

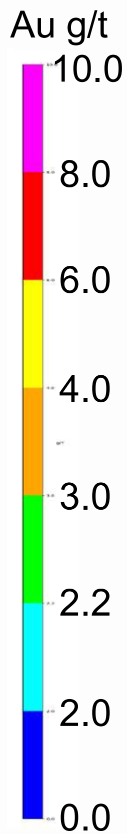


Model Plans (Z=1022)

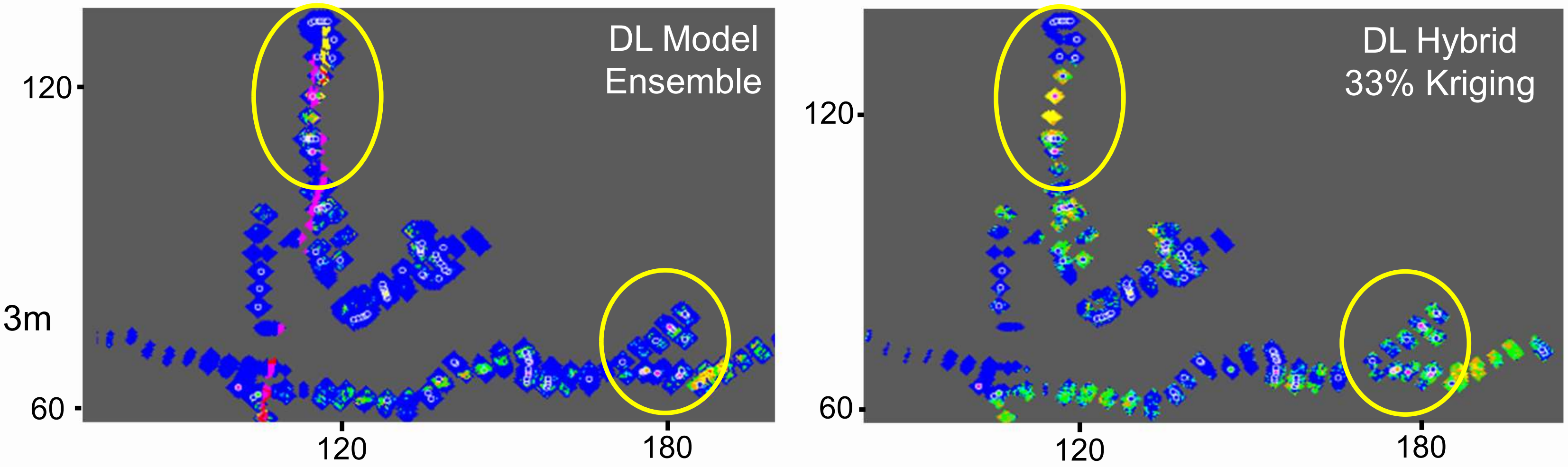
Vein Complex

- Kriging model predicts N/S central vein
- DL ensemble model predicts the eastern E/W vein
- Hybrid ensemble misses no mineralisation





0.3m x 0.3m x 0.3m blocks



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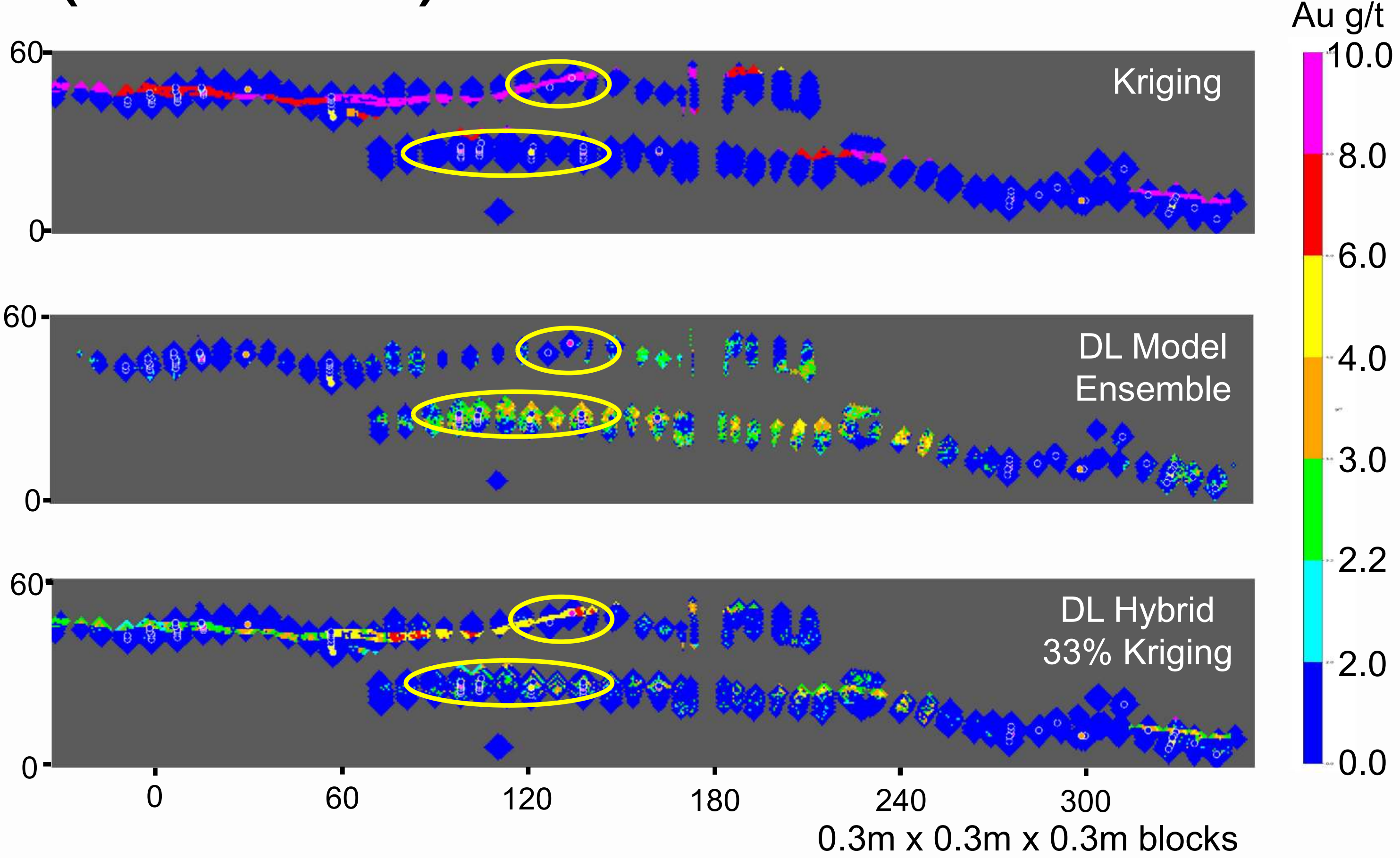
Model Plans (Z=2015)

Two Ore Veins:

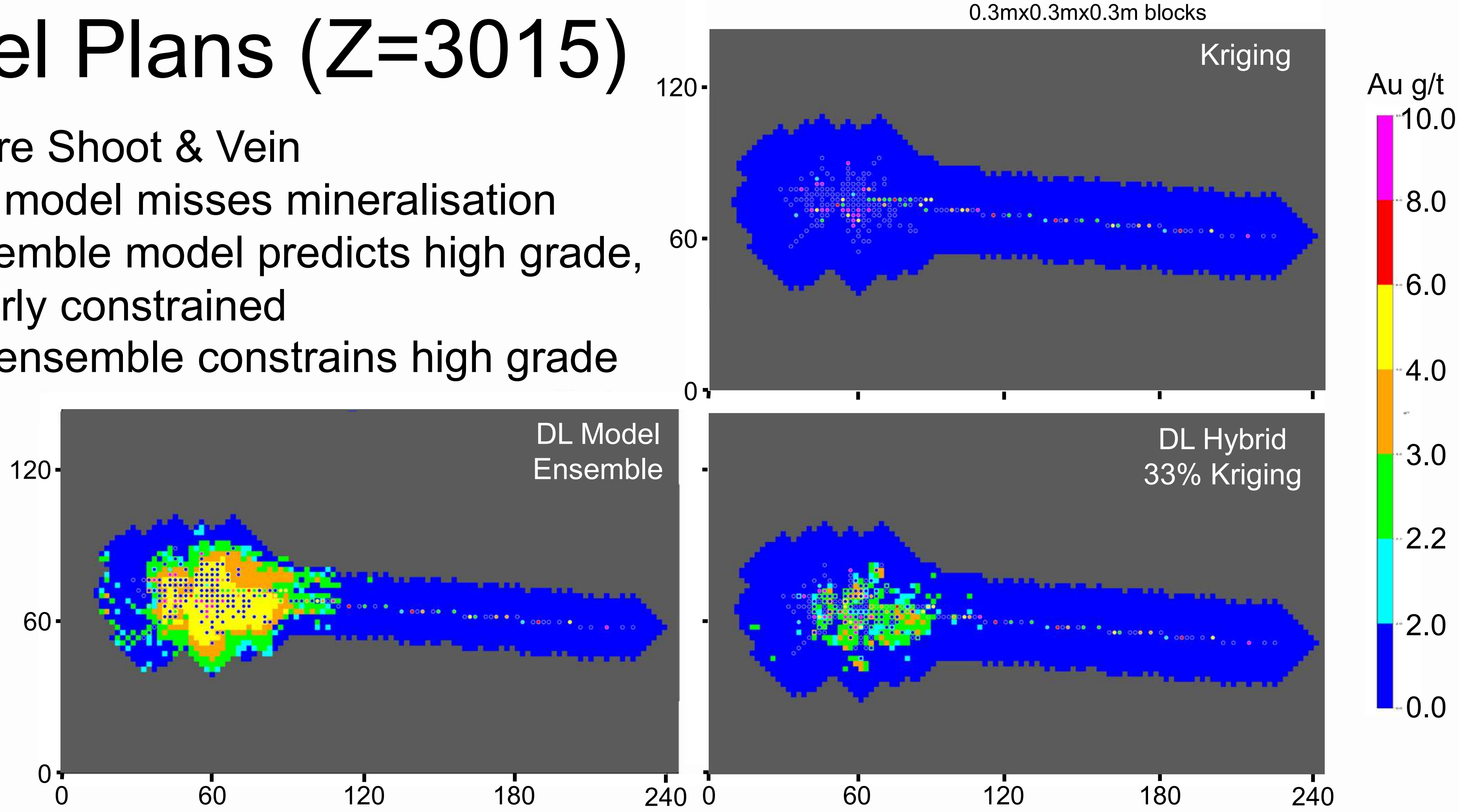
- Kriging model predicts upper vein
- DL ensemble model predicts the lower vein
- Hybrid ensemble misses no mineralisation



Model Plans (Z=3015)

Vertical Ore Shoot & Vein

- Kriging model misses mineralisation
- DL ensemble model predicts high grade, but poorly constrained
- Hybrid ensemble constrains high grade

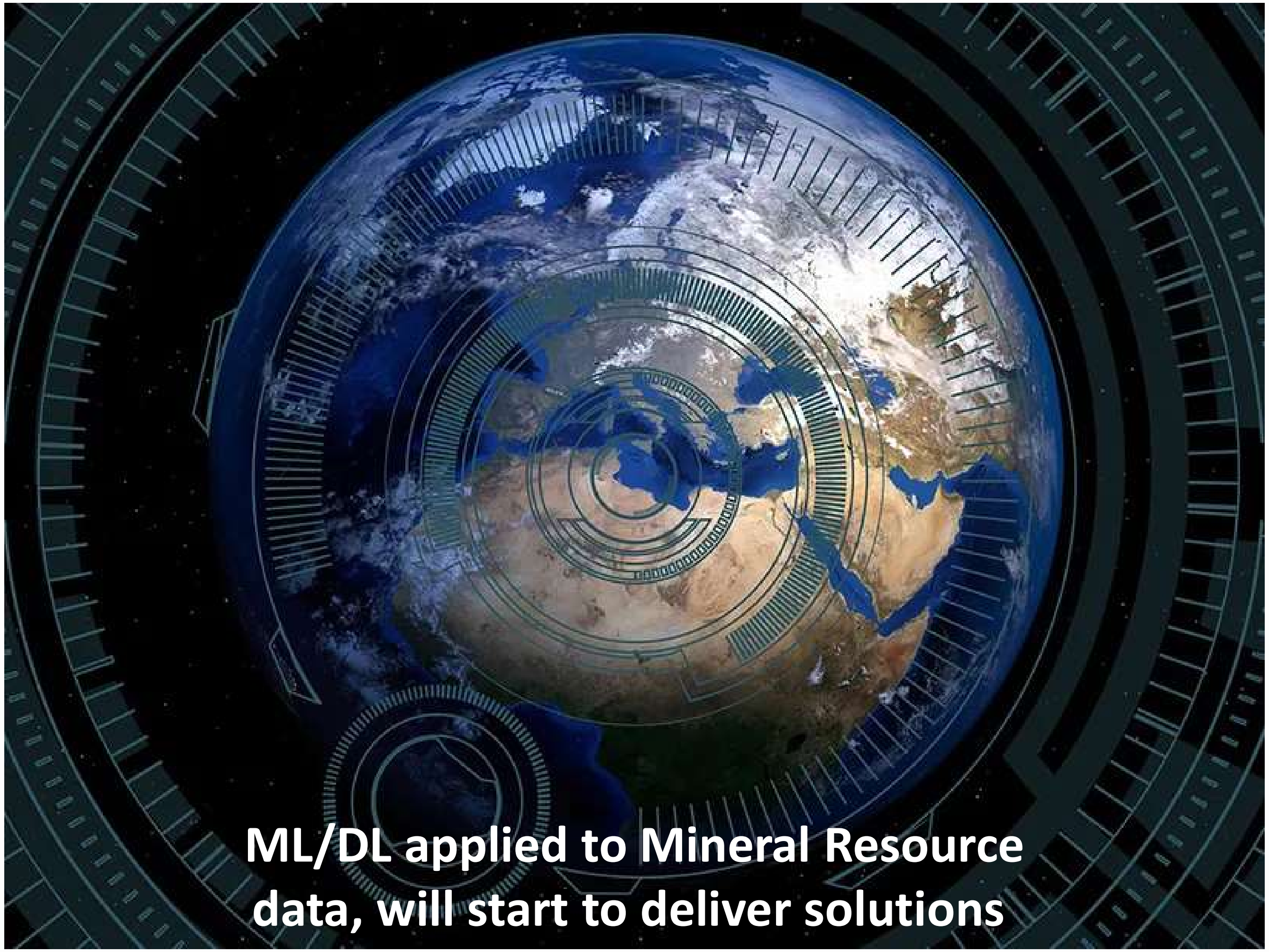


Discussion

Discussion

DL Patterns

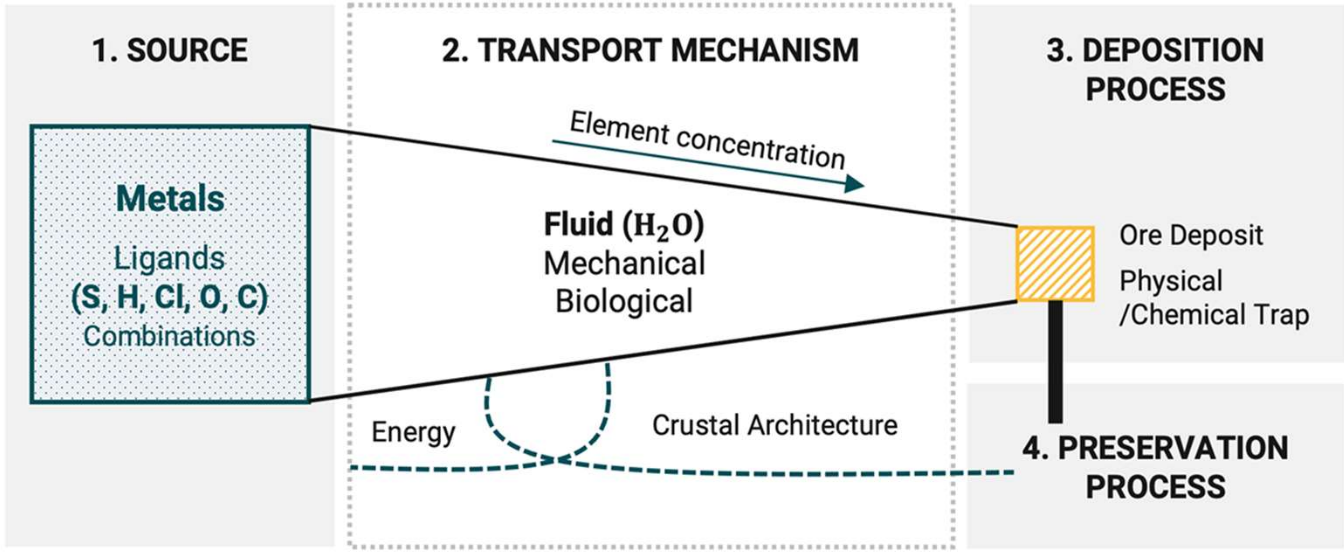
- Not abstract, random or synthetic
- Not geostatistical interpolation
- DL patterns reveal overprinting geological processes
- Insight into mineral deposit genesis



Mineral Deposit Genesis

Geological Processes – Metal Distribution

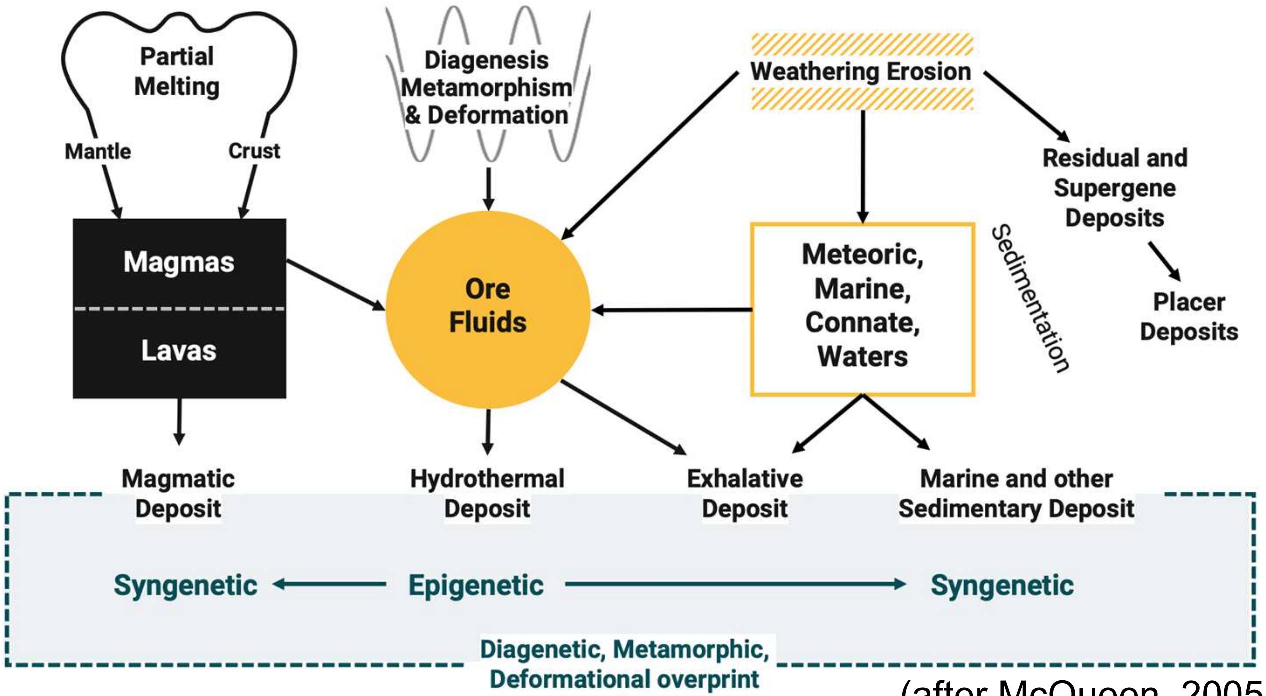
1. Source of ore metals & ligands
2. Transportation mechanisms
3. Depositional processes
   - physical / chemical traps
4. Preservation processes



(after McQueen, 2005)

Ore Deposit Genesis

- Overprinting / secondary geological processes
- Enrich &/or deplete ore deposits
- DL patterns (ore grades) geological processes



(after McQueen, 2005)

Conclusions

Conclusion

- CNNs learn from historical production data
  - Does not rely on pre-existing kriging domains
- Ensembling (composite) best models – enhanced results
- Ensembling with kriging – better than DL or kriging alone
- DL patterns more accurate – if lots of historical data to learn from
  - Ore categorisation, geometallurgical & geotechnical models
- DL patterns due to primary & secondary geological processes
- DL patterns may provide useful insight into deposit genesis
- DL resource modelling will get better as GPUs get more powerful

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Wrap Up & Contacts

Mineral Resource Estimation Conference – on-line paper

- David First (Chief Geologist) david@stratum.ai (presenting)
- Ilia Sucholutsky (VP Research) ilia@stratum.ai
- Daniel Mogilny (Co-Founder) daniel@stratum.ai (attending)
- Farzi Yusufali (Co-Founder) farzi@stratum.ai

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