Geostatistically-Constrained 3D Potential Field and Geology Modelling using Drillhole Data
Case Studies from Hydrocarbons and Mineral Exploration

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Talk Outline

• Introduction – Purpose and Workflow
• Geological and Geostatistical Modelling
• East African Rift Case Study with FTG
• Uranium Case Study with Gravity
• Conclusions
What’s the Job??

• Build a 3D Geological Model from Drilling Data and additional data (Seismic Horizons, Mapping, Geophysical Interpretation)
• Analyse Formation Properties
• Geostatistically interpolate property data in Model
• Forward Model Geophysical Response
• Compare with Observed Geophysical Data
• Run Inversion
• Report on Outcomes
Inversion Methods

• The purpose of any inversion is 3-fold:
  – Optimisation
  – Prediction
  – Validation

• We are dealing with sparse observations!!
• Outcome is highly dependent on initial conditions:
  – Known Geological Observations
  – Quality and Resolution of Observed Geophysical Response
  – Quality and Resolution of Terrain/Bathymetry
  – Source Location and Geometry
  – Physical Properties
Geostatistics for Model Construction

• Creating a 3D property volume
• Drillhole log data are dense in information but may be sparse in distribution
• Physical and Chemical Properties, can be recorded and related to validate property and lithology models
• Think about Relationships
  – If data on one important logging parameter is limited, another parameter may help characterise its behaviour
Model Constraints

- 3D Lithology / Property model is desired
- Interpolation of downhole log properties to generate property voxel
- Solve Problems with properties and geometries
- Build Models using all sources – including proxies and property estimations
- *It can drive you a little crazy!!!*
Geostatistical Methods

- Examine Logs and Property Distributions
- Compute Variograms
- Inverse Distance Weighting
- Kriging 1D and 2D
- Domain Kriging
  - Pot (t) Variogram of parameter correlates with 3D formation thickness
  - u, v, pot (t) (3D)
- Other techniques eg Gaussian Simulation
Domaining

- GeoModeller interpolation follows isopotential trend lines
- Uses Geodesic Distance
- Distance expressed in terms of potential function
- Generates more geologically plausible 3D property interpolations
Case Study - Hydrocarbons

- Lake Albert, Uganda depth to basement inversion
- Performed with 2D seismic depth horizon picks, 8 well logs, digital terrain and Bell FTG data
- Originally done in 2010, refined in 2012 and 2014
Case Study – Hydrocarbons

Lithology

• Construction of initial 3D Lithology model from 2D seismic depth horizon picks and well formation boundaries

• Model dimensions are 33 x 23 km
Case Study – Hydrocarbons

**Lithology**

- Implicit Model is computed from seismic and drillhole interface contacts
- Orientations derived from intersections
- 3D implicit model rendered as horizon surfaces
- Note obvious faults and surface variations
Case Study – Hydrocarbons

Lithology

- 3D model showing horizon surfaces and vertical gravity gradient $G_{zz}$ from FTG survey draped on topography
Case Study – Hydrocarbons Property

Downhole drilling log from Project Area showing density variation with depth and regularisation over intervals.

Full Histogram of all hole densities

3D block showing downhole density trends
Case Study – Hydrocarbons Property

- Computation of domain experimental variogram based on geological potentials from model, using sedimentary series
- A Gaussian model for variogram fits in this instance
Case Study – Hydrocarbons Property

- Interpolation of downhole densities using domain kriging, based on pot variogram
- Used as basis for pre-inversion density voxel
- Remaining areas replaced by random values defined by Physical Property Laws for each Formation

Kriged Densities
Case Study – Hydrocarbons Property

- Comparison of Interpolation Methods
- Domaining honours the Geology Model

Domain Kriging

Kriged Densities

Radial Kriging

Inverse Distance Method
Case Study - Hydrocarbons

- **3D Lithology Model Post-Inversion**
- **GeoModeller stochastic 3D Inversion** changes either Property or Lithology
- Geometrical conditions are imposed by Stratigraphy, Similarity, Shape and Volume
- Property follows Distribution
- Note most apparent changes are short-wavelength due to high sample resolution
Case Study - Hydrocarbons

- Example section view of Densities pre and post-inversion
- Population of optimised densities can be isolated by Lithology

Combination domain kriged densities and random densities pre-inversion

Post-inversion density distribution
Case Study – Uranium (Gravity)

- Blackbush Uranium Deposit, Tertiary Pirie Basin SA
- Unconformity deposit lying over radiogenic Proterozoic Granite
- 115 drillholes over 1x1km
- Aim to establish if relationship exists between gravity and mineralisation
Bouguer Gravity Anomaly Map

- Variable regional and high density station coverage
- Pattern drilled and logged for U3O8
- Samphire Granite well-defined low
Residual Gravity Anomaly Map

- Residual Gravity Map generated by Spectral Filtering
- Shows wavelengths < 250m
- Unconformity Deposit located in Paleochannel
- Gravity Station Density and Drilling Locations shown
3D Geological Model from Drilling

- Geological Model established using abundant drilling
- Low Density Tertiary Sediments
- Granite Basement
- Uranium occurs in Kanaka Beds
- Flanks Basement High
Downhole Density and Uranium Logs

- Strong correlation between Density and U3O8 above 1000ppm
- Strong possibility of anomalous response in gravity
- if U-accumulations are thick enough!
- Exploits low density contrasts
Bouguer Gravity Response Grids

Observed Bouguer Gravity

3D Forward Bouguer Gravity

Misfit or Residual Bouguer Gravity
Kriging of Uranium Logs Pre-Inversion

- Kriged eU3O8 values clipped above 1000ppm
- Distribution compared to Forward Modelling of Bouguer Gravity
- Strong match discovered
- Anomaly < 0.4 mGal!!!
Uranium Distribution following Inversion

- Inversion run on 12.5x12.5x1m grid
- 1,440,000 cells
- Redistributed Uranium constrained by both drilling and gravity response
- New inferred U-resource can be computed from voxet
Conclusions and Recommendations

• Using Geostatistical Interpolation from Drilling logs to construct 3D property models is a powerful aid to constrained inversion

• Relations of measured physical properties and geochemistry need to be routinely logged and compared!!!!

• Initial Model is Driving Constraint

• Physical property model may imply the lithology

• USE your drilling logs!!!
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• Thankyou for your attention!!!

• www.intrepid-geophysics.com