Cover Thickness Uncertainty Mapping

Using Bayesian Estimate Fusion to Map Thickness of Cover in Cloncurry Region in Queensland, Australia

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Cover Thickness and Mineral Exploration

Over two-thirds of Australia's continental crystalline basement is under cover. Thickness of cover is one of the main economic risks for 21st century mineral exploration in Australia. Information about cover thickness comes from various data sets, such as aeromagnetics, gravity, seismic, electro-magnetic (EM) and drill holes. For the early stages of mineral exploration, geophysical estimates are often sparse, unevenly distributed, inaccurate and often in disagreement when derived from different datasets. Jointly assimilating such estimates and measurements can provide a single broader and more reliable estimate over a given region of interest.

a)

b)

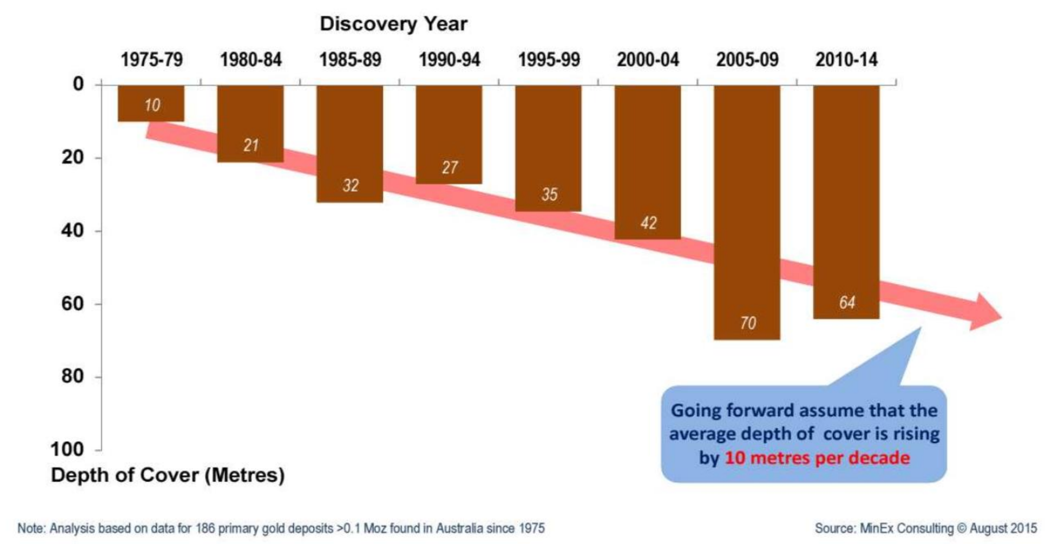
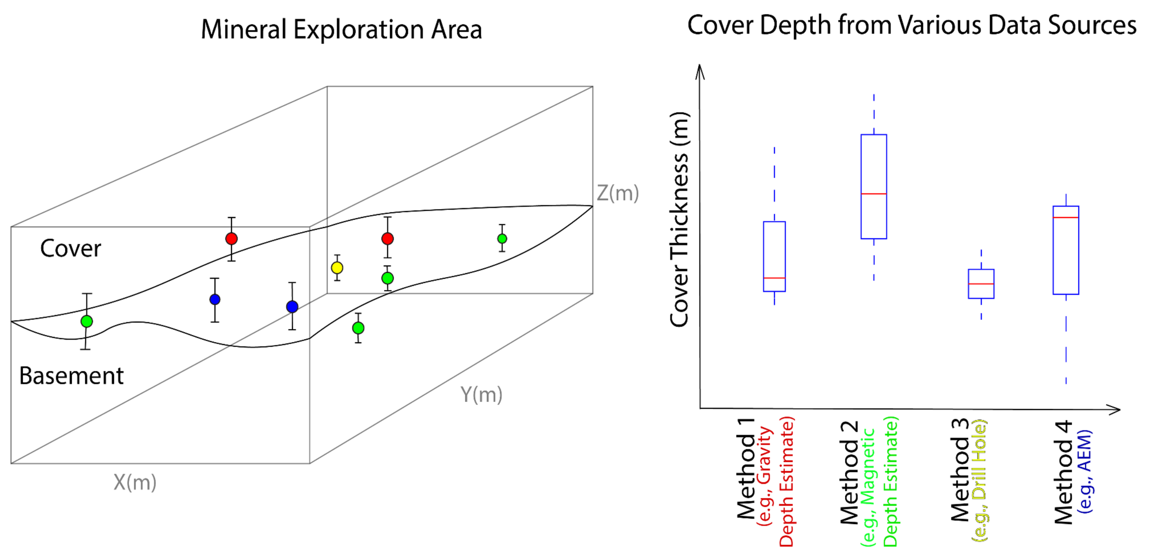


Figure 1: a) Over two-thirds of Australia's prospective crystalline basement is covered by regolith and/or sediments. Image from South Australia (Photo by Mark Marathon - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=28456250). **b)** The depth of major gold discoveries in Australia since 1975 (Schodde, 2017).

Interpolation methods such as Kriging and minimum curvature are predominantly used to bring cover thickness estimates together, but they are built on assumptions about the inputs which are often inappropriate for this problem. For better assimilation of diverse estimates, it must be possible to specify more detailed information about their reliability and statistical dependencies.

a)



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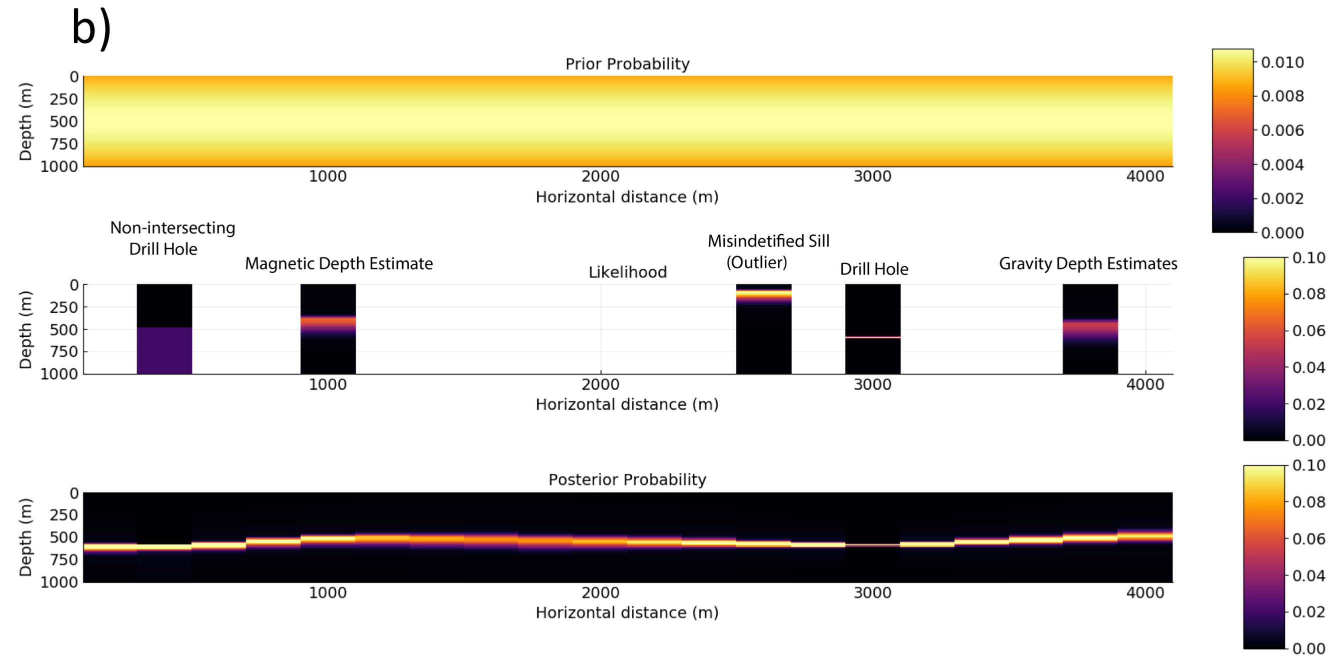

Figure 2: a) Conceptual diagram: Depth of sedimentary cover estimates derived from various sources. Estimates of cover thickness will vary in precision and spatial coverage. **b)** A synthetic 2D slice illustrating Bayesian uncertainty estimation. Top: the prior depth probability density; note, the variogram is also part of the prior but its effect in not visible here due to stationarity. Middle: likelihood profiles (normalised to integrate to one) for various input estimates. Bottom: synthesis of prior and likelihood to create a posterior probability volume.

Bayesian Estimate Fusion

We introduce a Bayesian Estimate Fusion (Visser and Markov, 2019) that allows flexibility in uncertainty formulation and streamlines the workflow. The assimilator uses Markov chain Monte Carlo sampling (Hastings, 1970) from a posterior distribution. The output is an ensemble estimate which provides detailed uncertainty information over the entire volume considered. Gaussian processes, approximated by variogram model, are used to model spatial regularity. Our work identifies the types of inputs that need to be considered. For example, which statistical distribution describes the best cover thickness estimates from magnetic data and they uncertainty.

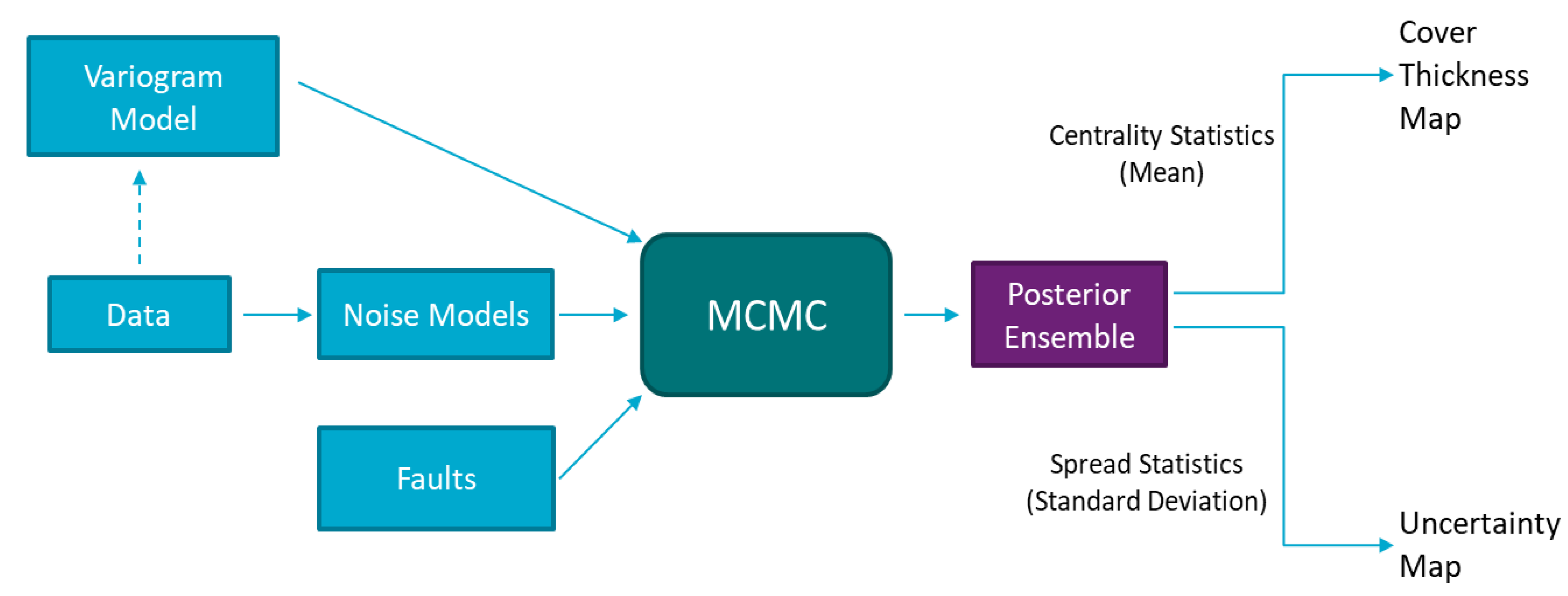

Figure 3: Simple schematic representations of the Bayesian Estimate Fusion

The importance of appropriate treatment for these has been explored using synthetic tests described in detail in (Visser and Markov, 2019). Cover thickness estimate uncertainties are formulated into the probabilistic constraints on the surface we want to image. We refer to these probabilistic constraints as noise models. We also include data, that was previously discarded when addressing this issue or hard to include: non-intersecting drill holes as inequality constraints and faults to allow for sharp thickness changes. The workflow can be presented as a six steps process:

1. Accuracy analysis for each estimate source and method.
2. Outlier analysis representing probability of estimate corresponding to correct interface.
3. Incorporate inequality constraints.
4. Account for the sharp changes in the cover thickness caused by faults.
5. Create posterior ensemble of 2D surfaces.
6. Produce cover thickness uncertainty maps.

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Cloncurry Region – defining cover in this study area

Cover can represent any rocks between the surface and the rocks we are interested in. In every exploration area it would have to be defined anew. The Cloncurry region lies in Queensland and is part of the Mount Isa Inlier, one of the most highly endowed metallogenic provinces in Australia with a long history of mining and exploration. The Mount Isa Inlier outcrops partially to the South and West. For the purposes of this investigation we define cover as the sediments of the Carpentaria and Eromanga Basins over the crystalline rocks of the Mounts Isa Inlier.

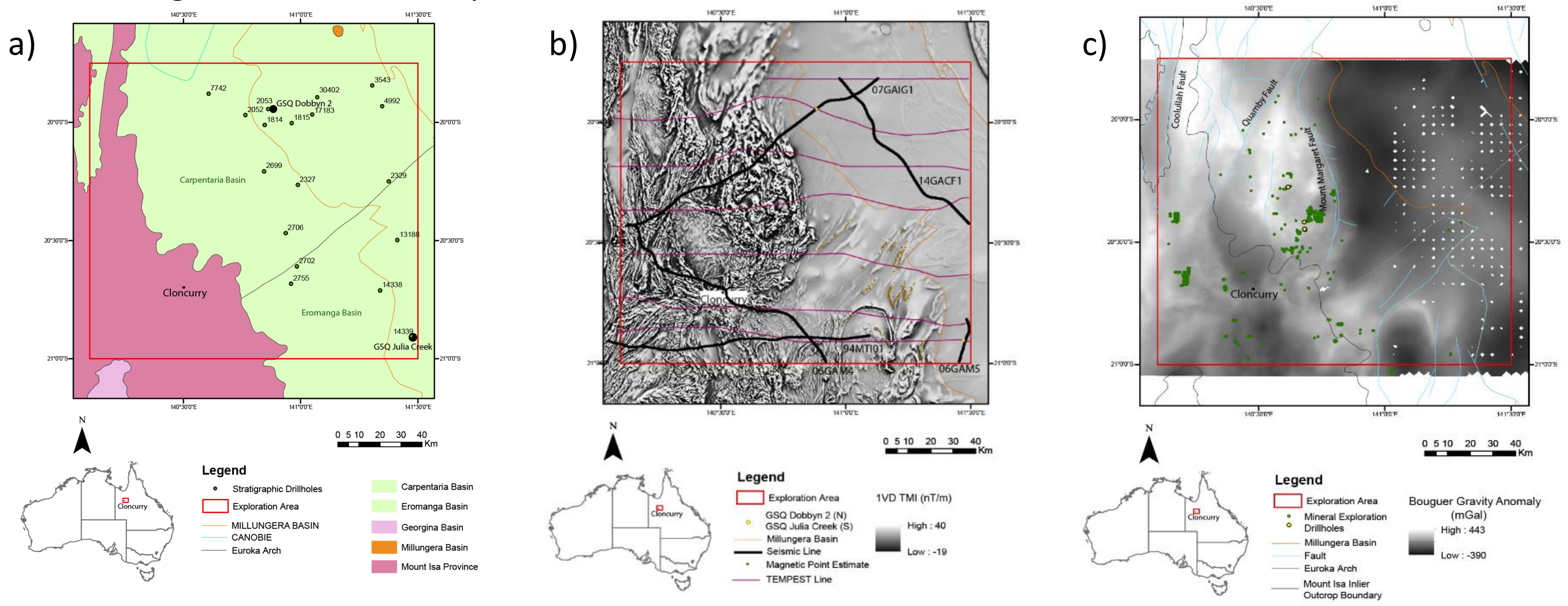

Figure 4: a) Cloncurry Region in Queensland, major geological units and distribution of the stratigraphic drill holes. b) Available geophysical data for cover thickness mapping. c) Distribution of mineral exploration drill holes used in the study. Yellow dots are non-intersecting drill holes. Blue lines are locations of the major faults included in the fusion.

Point cover thickness estimates are derived from geophysical data. Important information about the petrophysics properties of the cover are derived from GSQ Dobbyn 2 and GSQ Julia Creek. These measurements were used to constrain or validate quantitative geophysical analysis, e.g., sonic log is used to tie together seismic data and observed lithology from the stratigraphic drill holes and provide velocity values for time to depth conversion. The downhole measurements of the various petrophysical properties show same variation pattern at the both drill holes. There is subdued signal through the Carpentaria and Eromanga Basin sediments and increased amplitude and variability on the Millungera Basin interval.

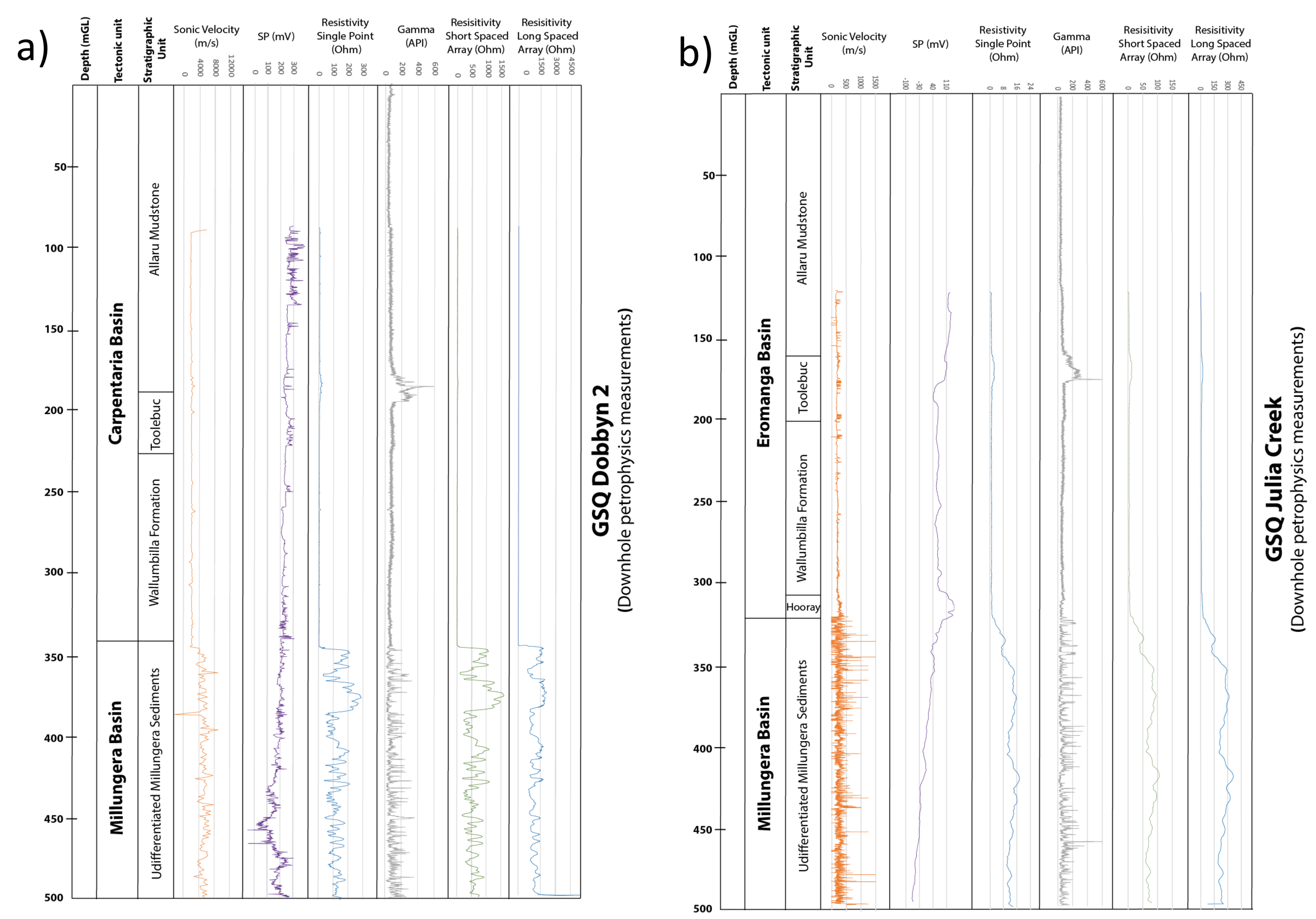

Figure 5: a) Distribution of the downhole petrophysical properties in GSQ Dobbyn 2. b) Distribution of the downhole petrophysical properties in GSQ Julia Creek.

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Point cover thickness estimates and noise models

The observations from the drill holes should be the most reliable source of information on the cover thickness but that is untrue if the uncertainty of the observation is substantial. Below is a plot of the location accuracy of the drill holes used in this study. It varies between 20 m to 250 m. We would derive Gaussian distribution noise models using the observed cover-basement intersection as mean and location accuracy as standard deviation. Other noise models are derived for point cover thickness estimates from geophysical data.

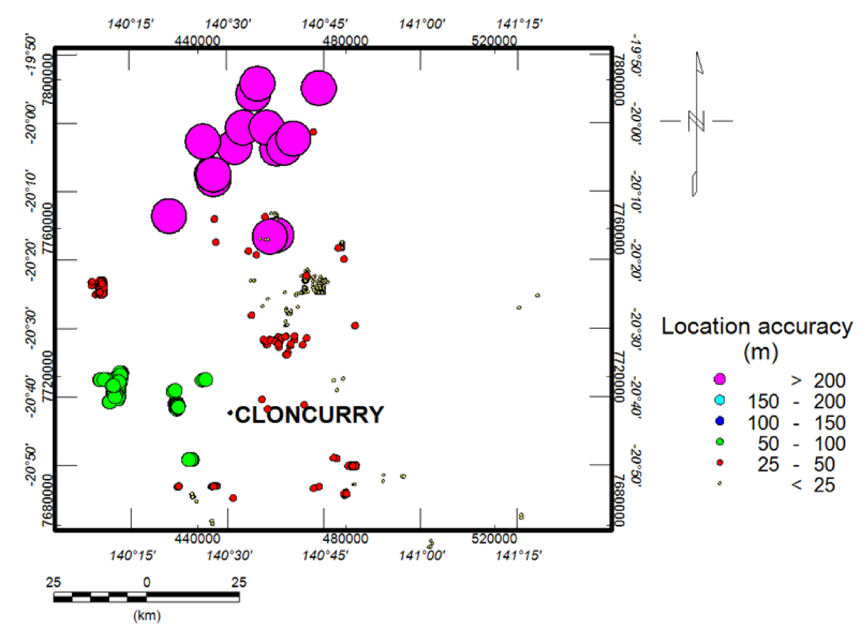

Figure 6: Mineral exploration drill hole locations plotted using circles, where the size of the circle corresponds to the spatial accuracy of the drill hole site.

Results

The Bayesian Estimate Fusion produces an ensemble of surfaces as the solution. The ensemble is not practical to interpret, so we are applying statistical measures in order to produce maps for interpretation. With application of the centrality measure to the ensemble – mean to each 200 m by 200 m pixel, we generate the cover thickness map. The standard deviation of the ensemble represents the cover thickness uncertainty.

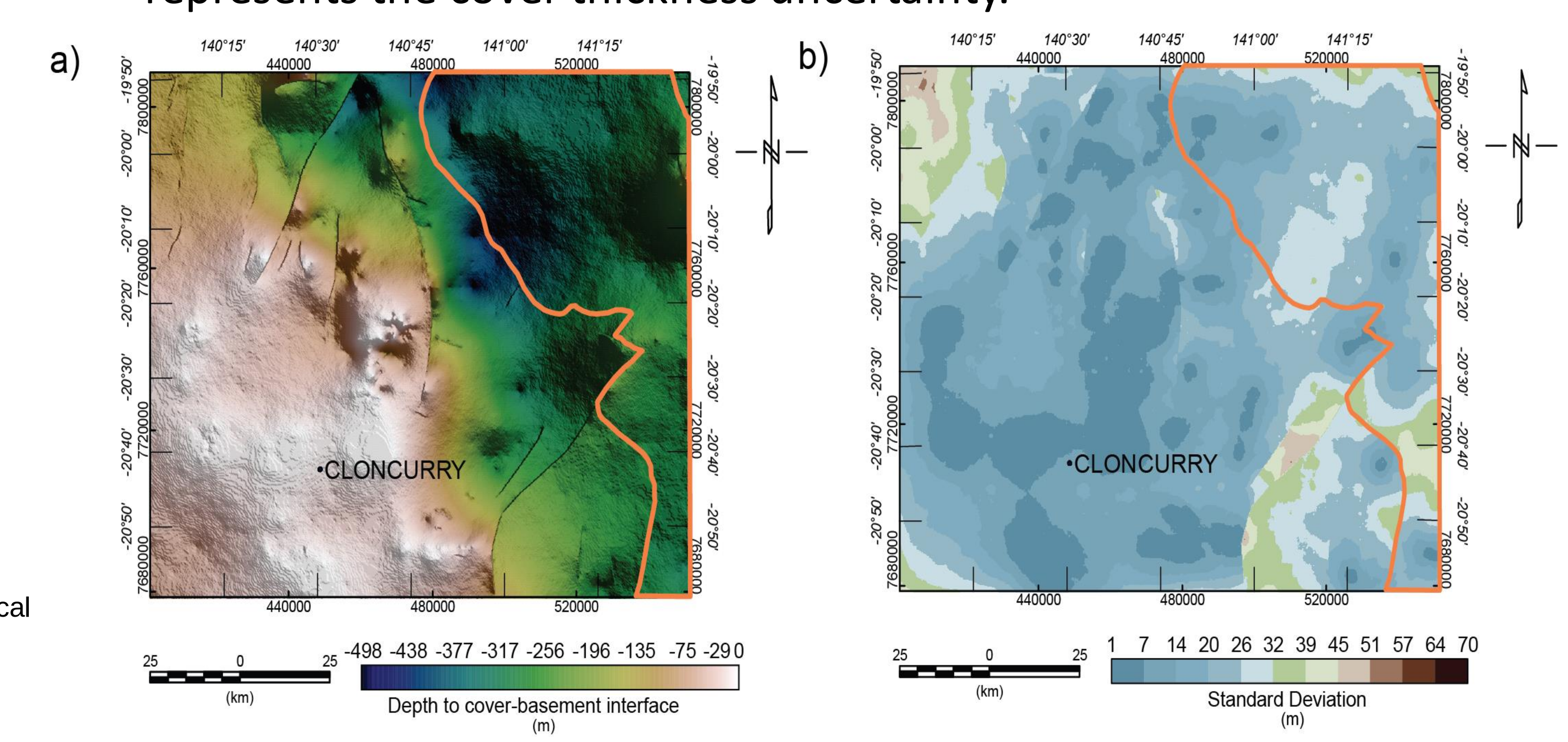

Figure 7: a) Posterior ensemble mean as a map of cover thickness. b) Posterior ensemble standard deviation as uncertainty map.

Validation

The investigation area is divided into 9 equal area rectangles. For validation we would remove basement intersecting drill holes in the particular rectangle and use all other available cover thickness estimates and structural information to perform the inference for the whole investigation area. We repeated this for each rectangle. We would then plot the predicted cover thickness values against the drill hole information for individual rectangles.

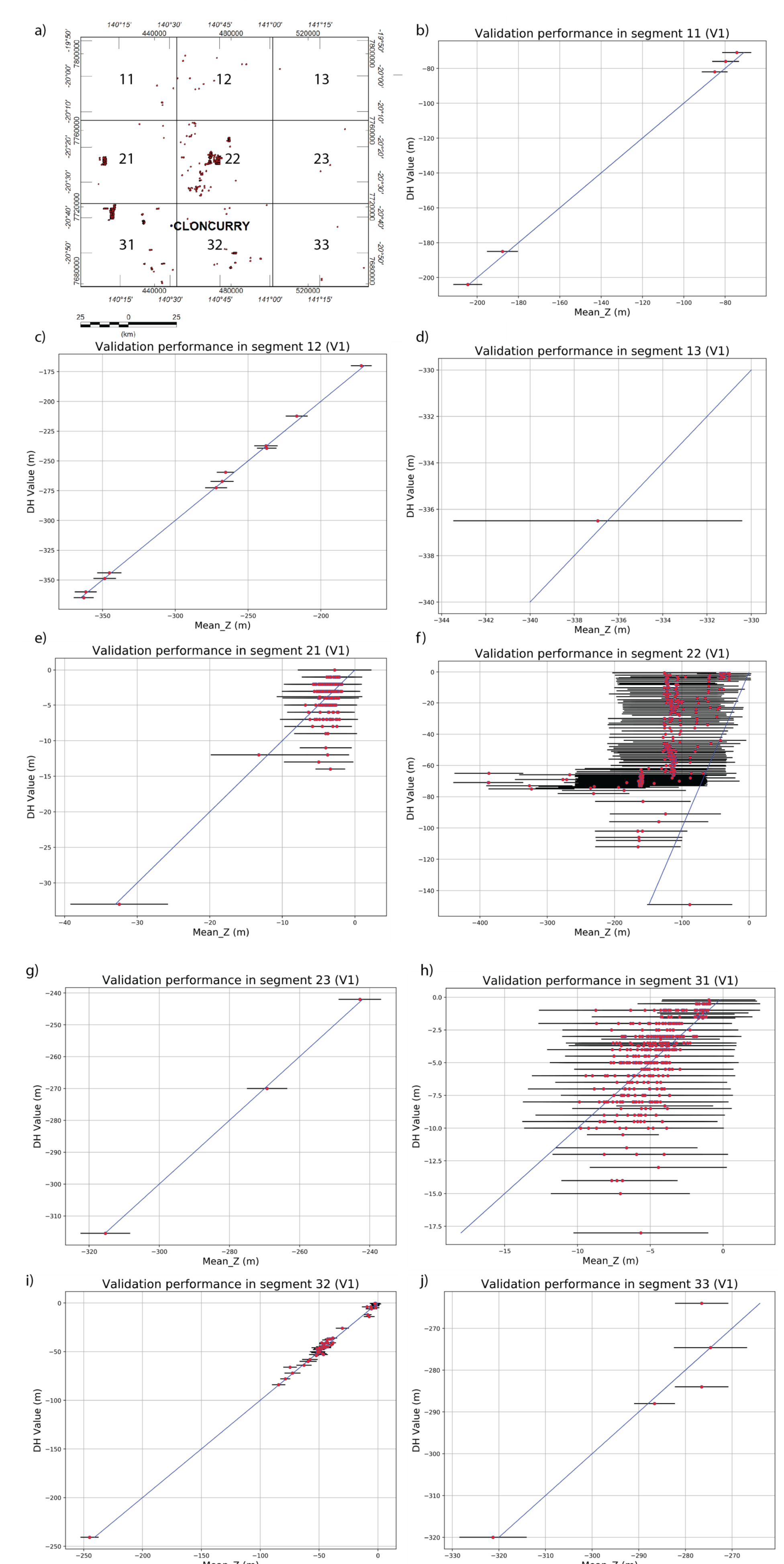

Figure 8: a) Drill holes used in validation and the rectangles. b)- j) Validation plots for individual rectangles. On the plots we also shown gradient of 1 line, if all predictions are perfect, they would lie on this line. Two standard deviations are plotted as error bars, majority of predictions lie within this envelope.