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.

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.

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 this uncertainty.

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.

REFERENCES


Figure 1: Conceptual diagram: Depth of sedimentary cover estimates derived from various sources. Estimates of cover thickness will vary in and types of sparse, measurements. Bayesian Jointly such For the probabilistic and cover when stages or be of treatment has about as thickness appropriate is basement introduce different inputs over in one effect in not visible here due to stationarity. Middle: likelihood profiles (normalised to six and explored data century Cover of this more simple schematic representations of the Bayesian Estimate Fusion using as over thickness be can of interest thickness and reliability estimates seismic, and Thickness The predominantly previously geophysical best a Markov and a Monte Carlo estimates, dependencies Exploration assimilating Thickness cover the faults provides datasets derived on assumptions drill Account for the sharp changes in the cover thickness caused by faults work single considered refer Mineral risks the minimum Markov, aeromagnetics the holes considered and model, an to unevenly but for discarded possible image assimilator in The allows that it need are 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.

Figure 2: a) Conceptual diagram: Depth of sedimentary cover estimates derived from various sources. Estimates of cover thickness will vary in 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 is not visible here due to stationarity. Middle: likelihood profile normalised to integrate to one for various input estimates. Bottom: synthesis of prior and likelihood to create a posterior probability volume.

Figure 3: Simple schematic representations of the Bayesian Estimate Fusion
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.

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.

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.

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.

Cloncurry Region – defining cover in this study area

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