GIS for mineral potential modeling: An overview

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ACKNOWLEDGEMENTS

Aurore Joly, UWA

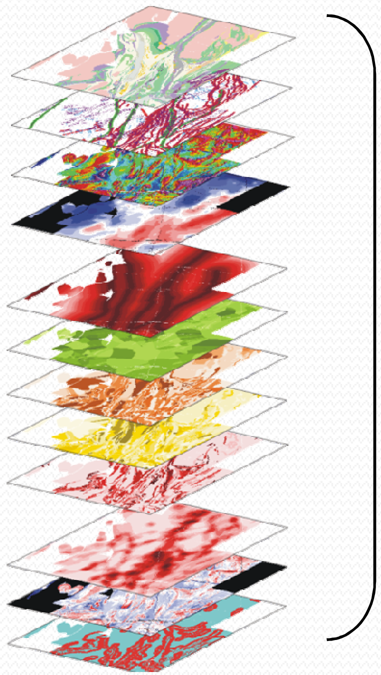
Cam McCuaig, UWA

OUTLINE

- GIS-based mineral potential mapping: A broad overview
- Example from Tanami Orogen, Western Australia (if time permits)

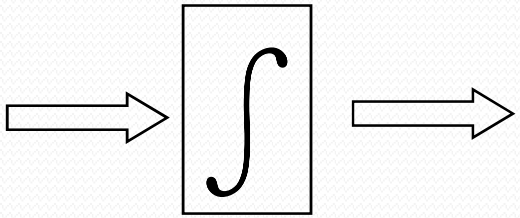
Introduction: what is mineral potential mapping?

Mathematical-model based integration of derivative GIS layers representing geological processes that form mineral deposits



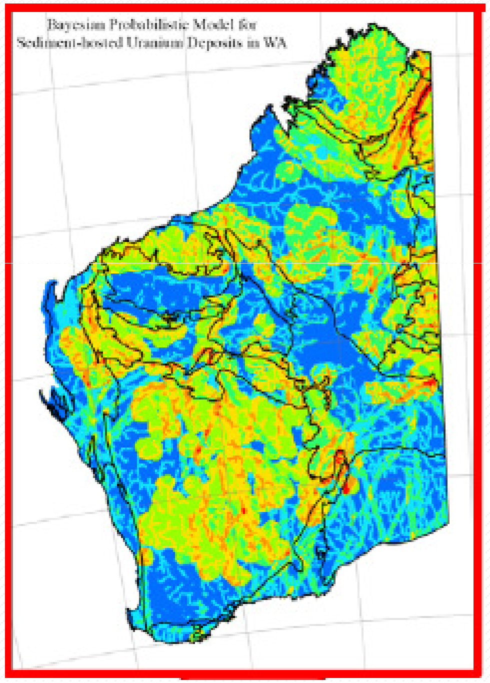
Input spatial datasets

- Categoric or numeric
- Binary or multi-class



Integrating function

- linear or non-linear
- parameters



Output mineral potential map

- Grey-scale or binary

Model-based mineral potential mapping

Garbage In, Garbage Out

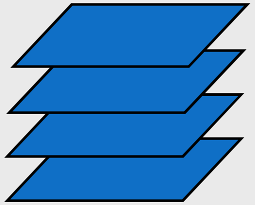
Geology
Geophysics
Remote Sensing
Geochemistry

GIS

Analyse / Combine

Mineral potential maps

Good Data In, Good Resource Appraisal Out



Geology
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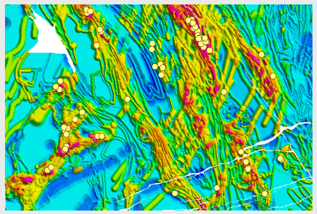
Mineral potential maps



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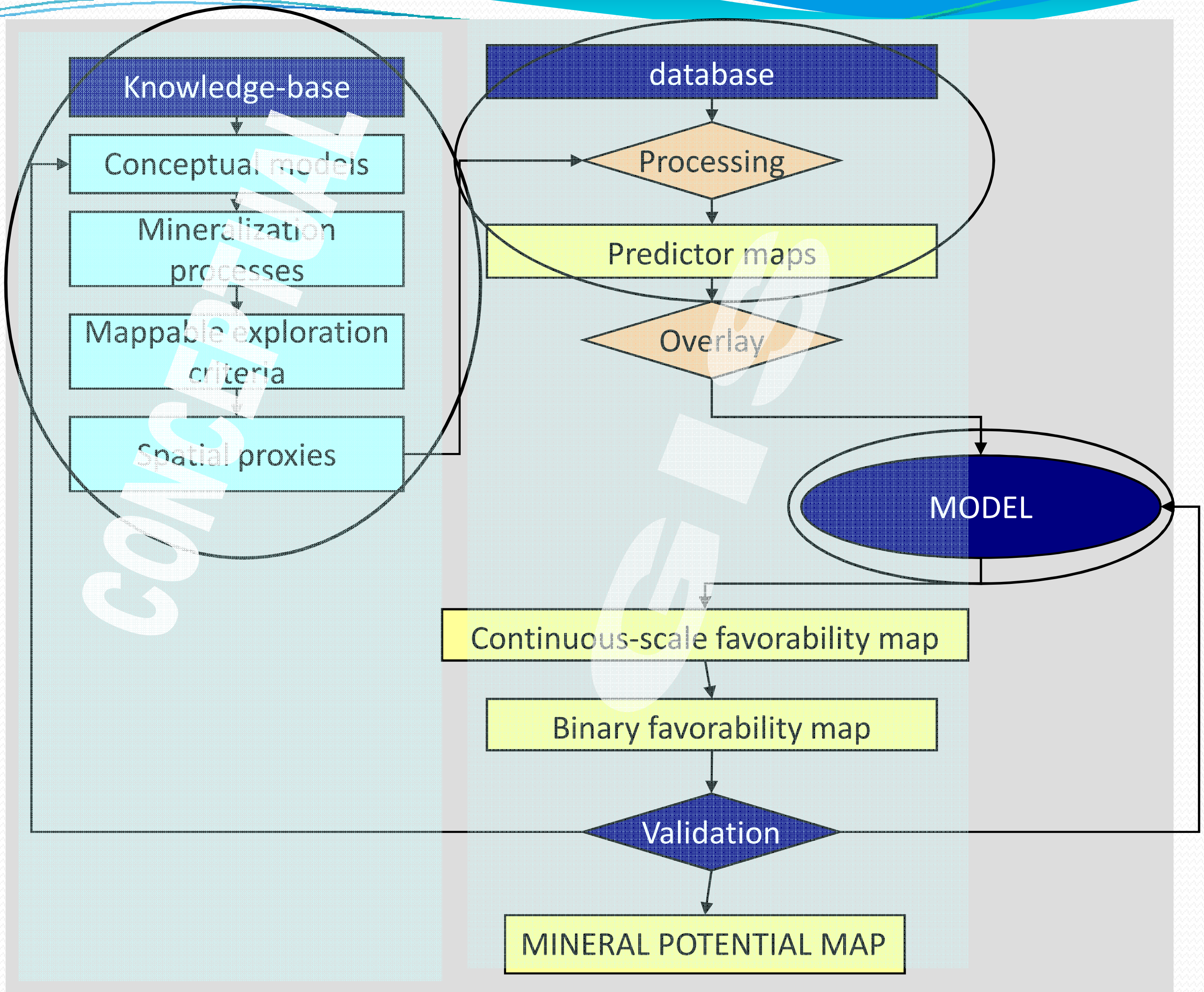
Model-based mineral potential mapping



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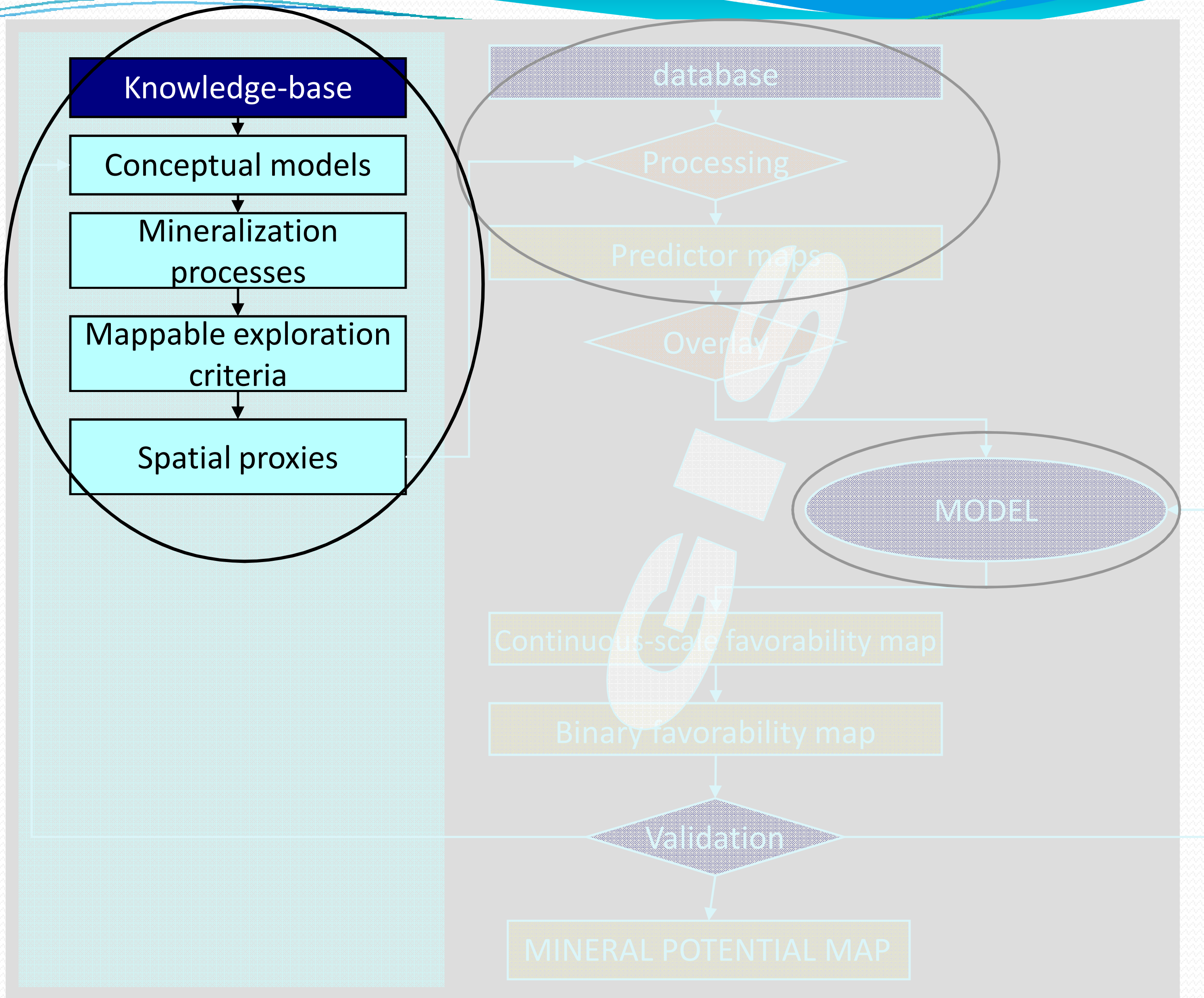
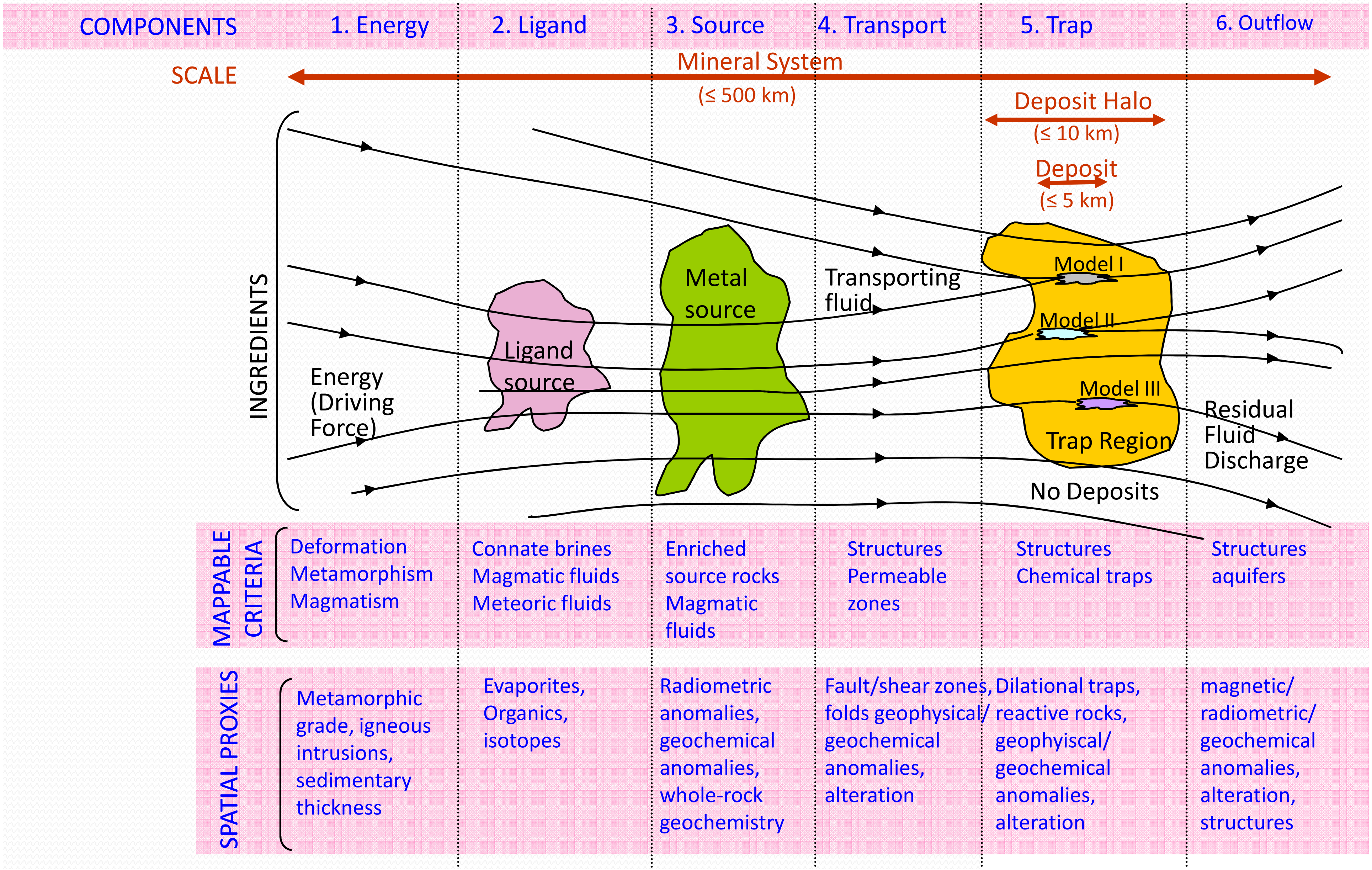
Model-based mineral potential mapping

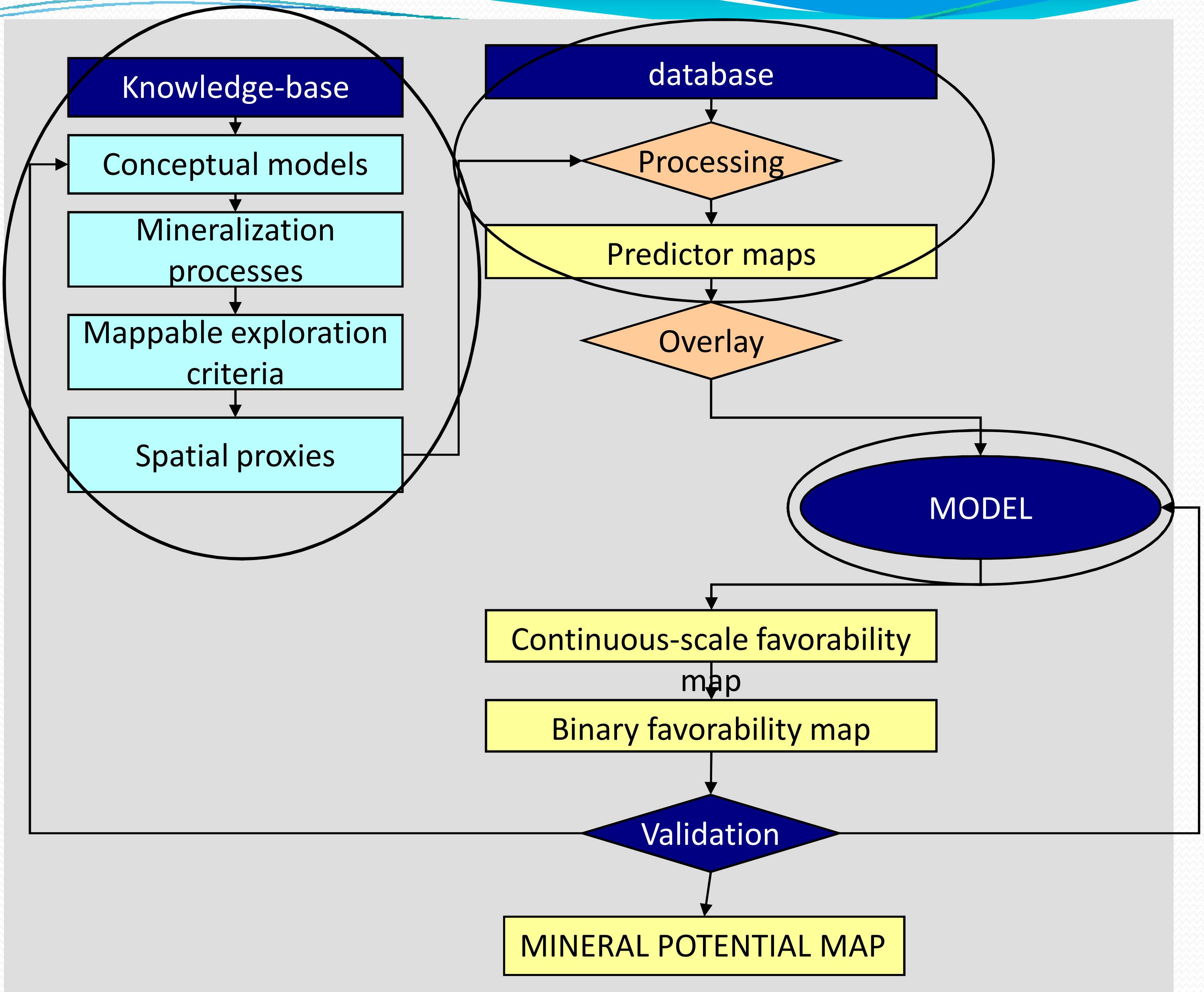


Mineral systems approach:

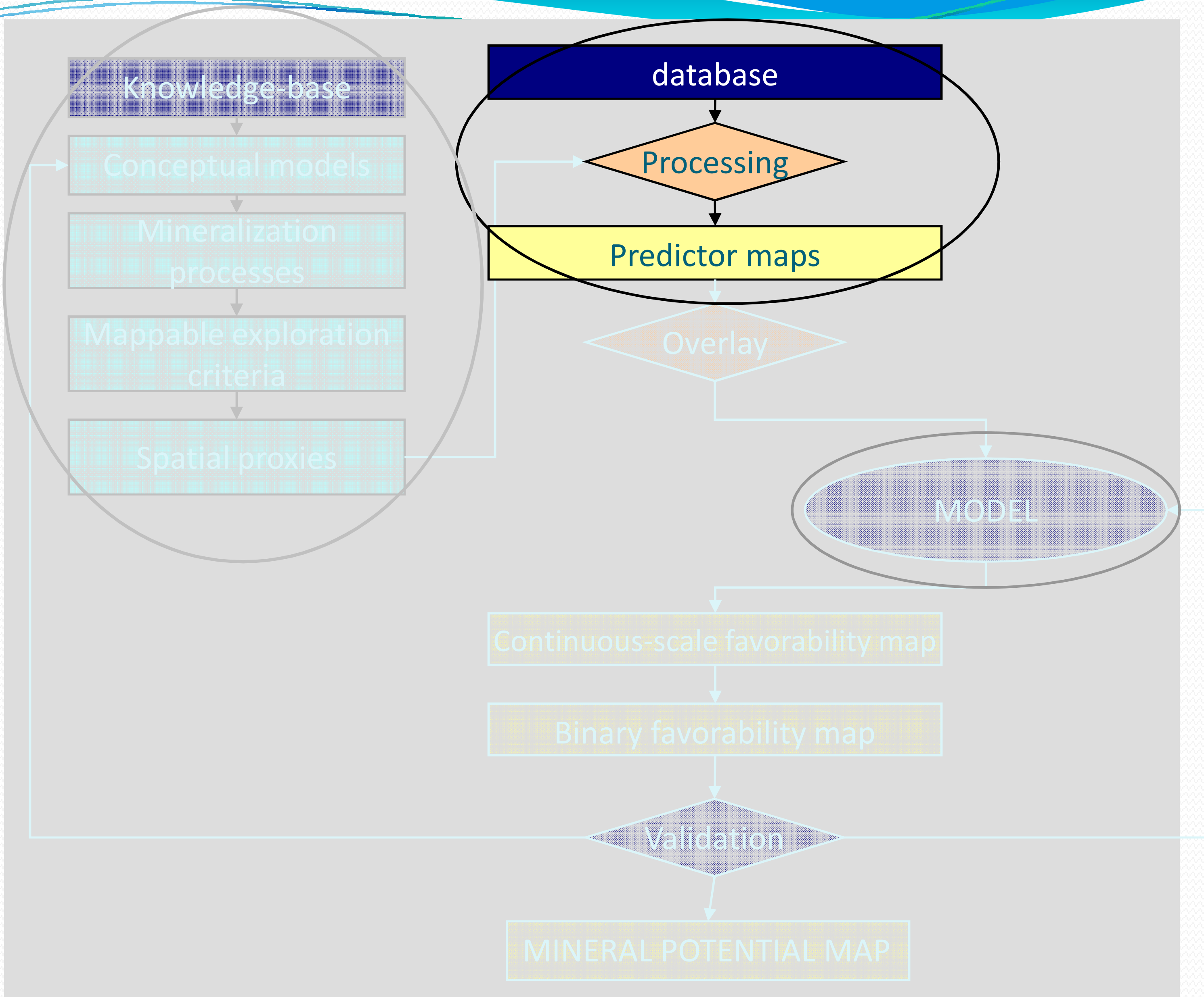
Link processes to predictor maps



Model-based mineral potential mapping



Model-based mineral potential mapping



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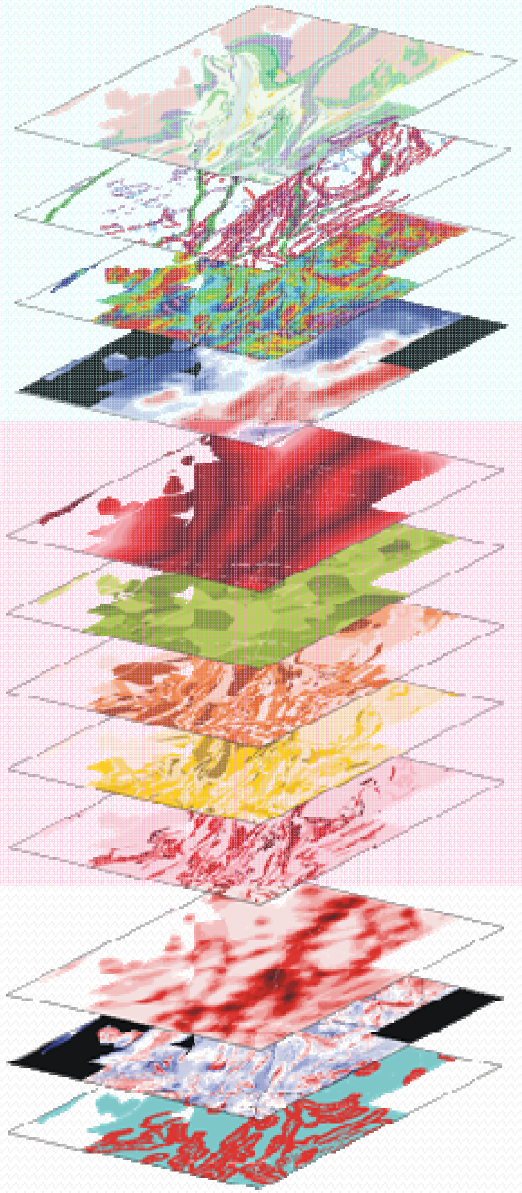
Creation of candidate layers in GIS: Feature extraction

What are the exploration criteria for the mineralisation?



Primary data
- ← solid geology
- ← structural geology
- ← airborne magnetic
- ← gravity

Empirical
- ← distance to faults
- ← strike of nearest fault
- ← rheological contrast
- ← reactivity ($Fe^{2+}/(Fe_{tot} + Mg + Ca)$ contrast

Conceptual
- ← fav. host rock lithology
- ← fav. litho. contact type
- ← fav. tectonic environment

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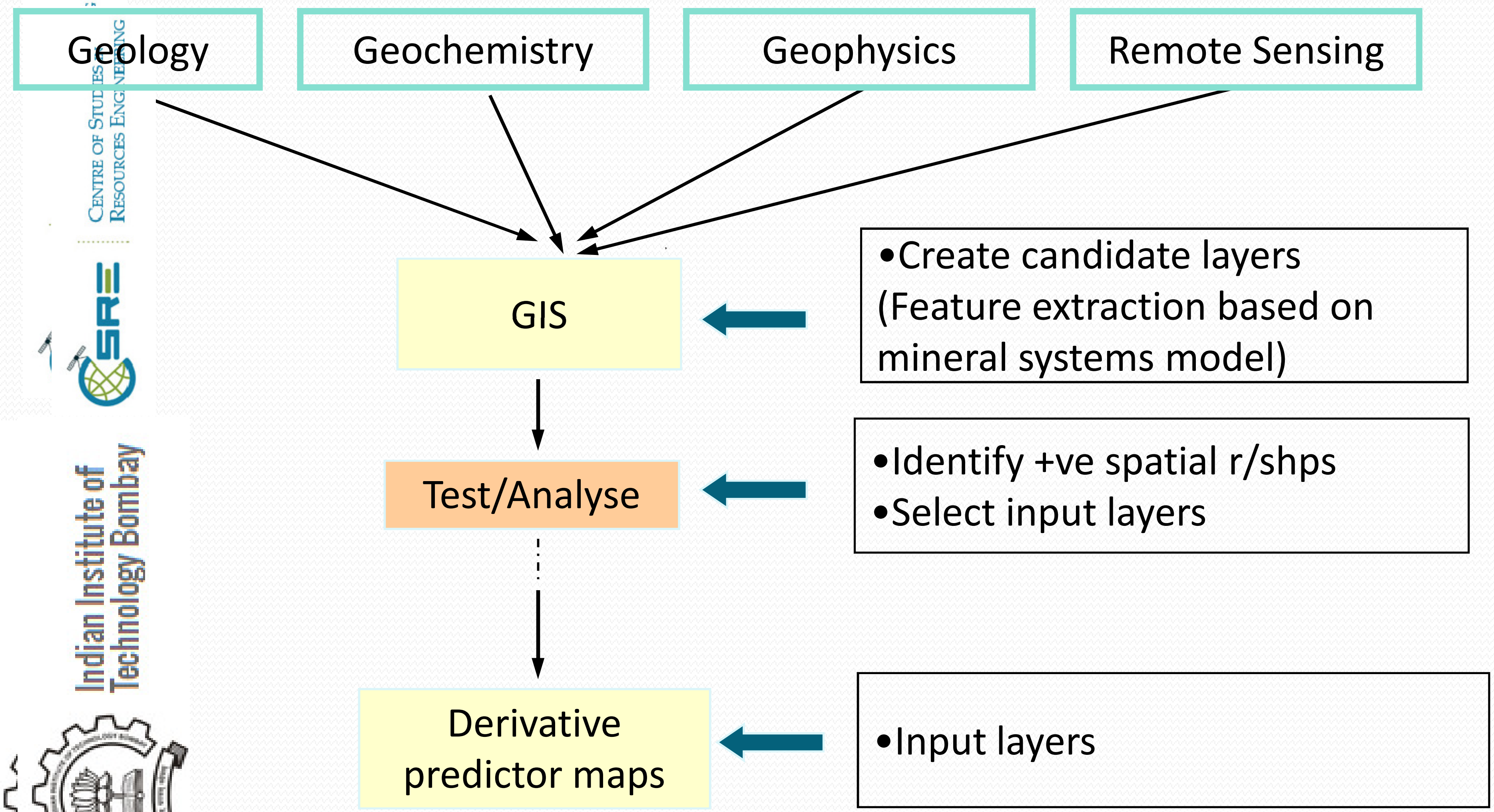
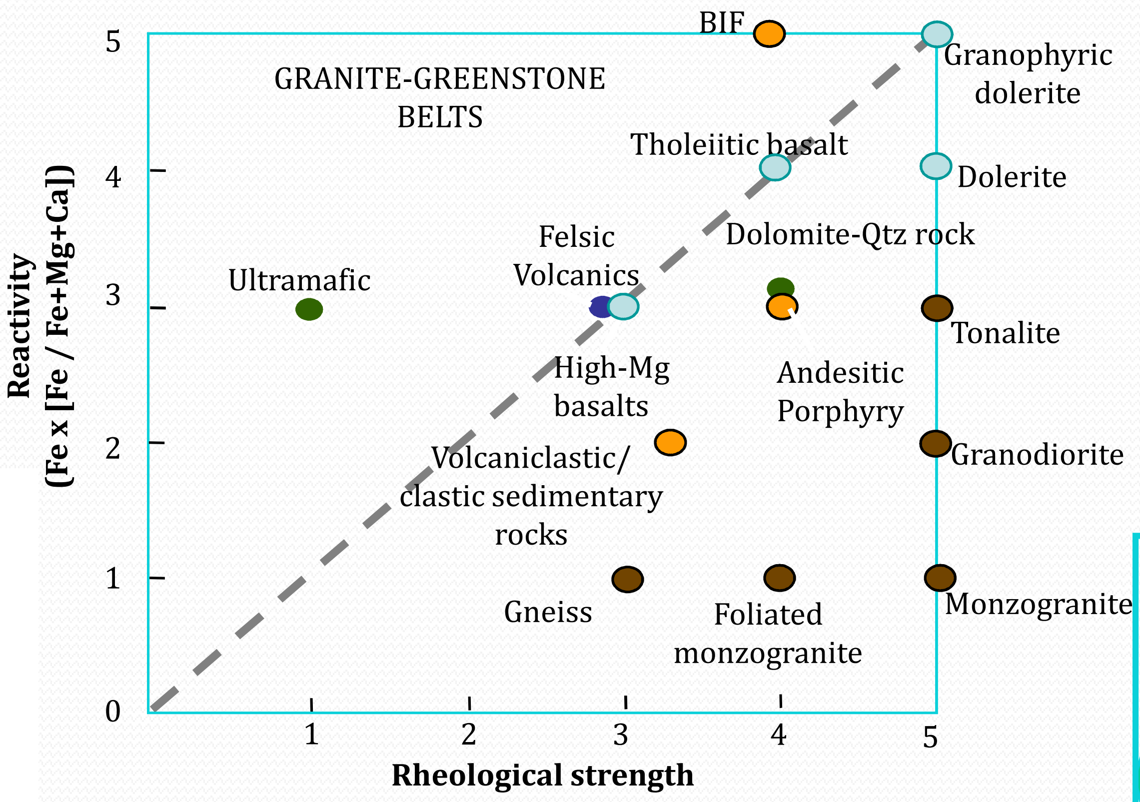
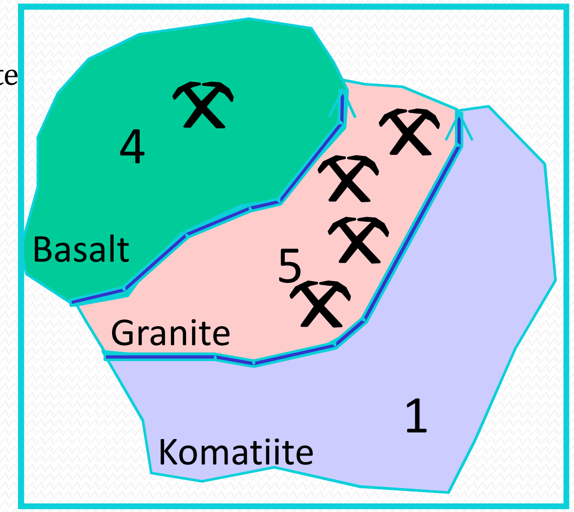
Selection of Predictor Maps: Systematic Analysis of Exploration Data



Selection of Predictor Maps: Systematic Analysis of Exploration Data

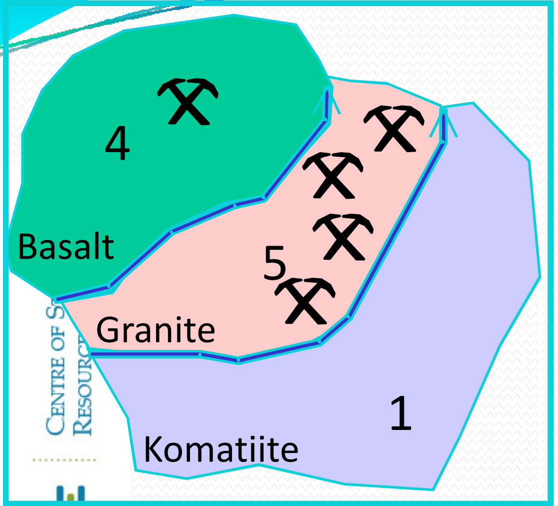
Example: Rock competency as an exploration criteria for metal trap



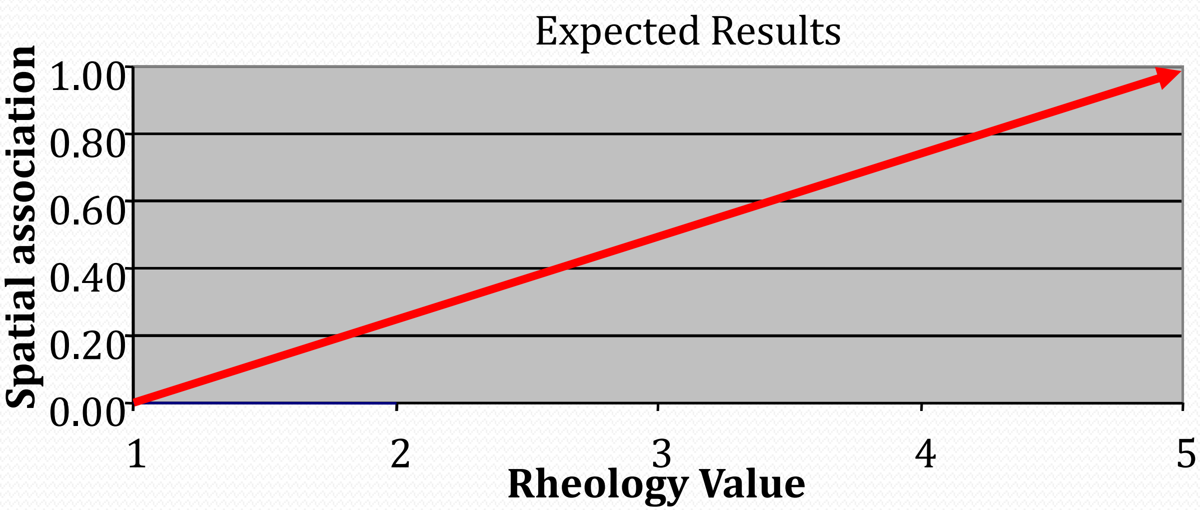


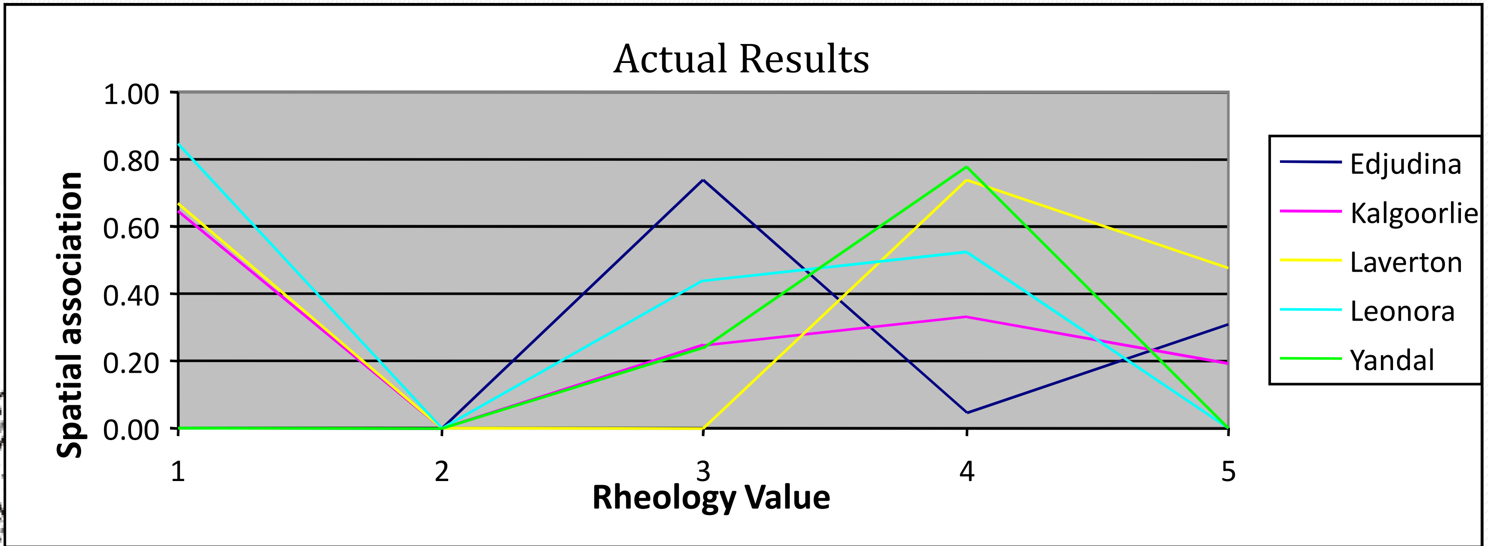
(Brown, 2002)

Experiment 1: Host Rock Rheology



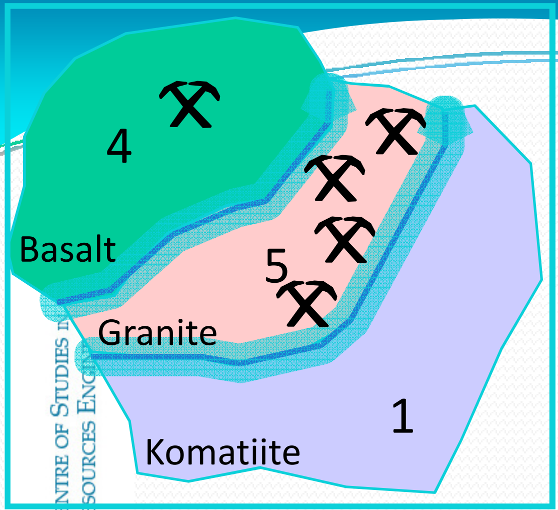
Hypothesis: More deposits in high rheological strength rocks



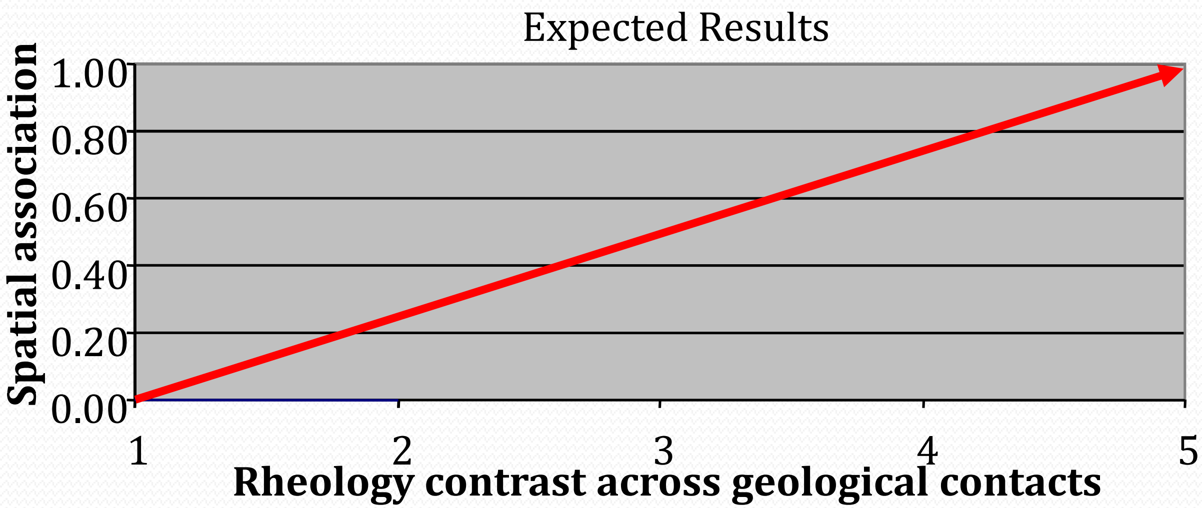


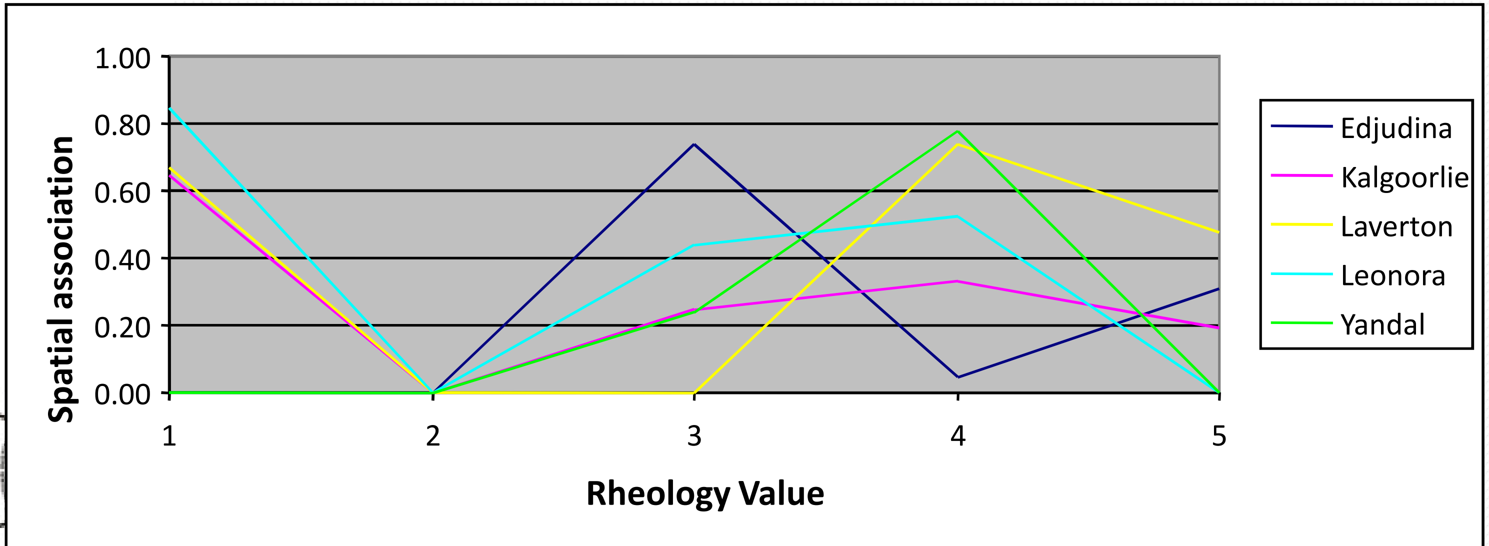
Hypothesis rejected!

Experiment 2: Rheological Contrast



Hypothesis: More deposits adjacent to lithological contacts that have a higher rheological contrast



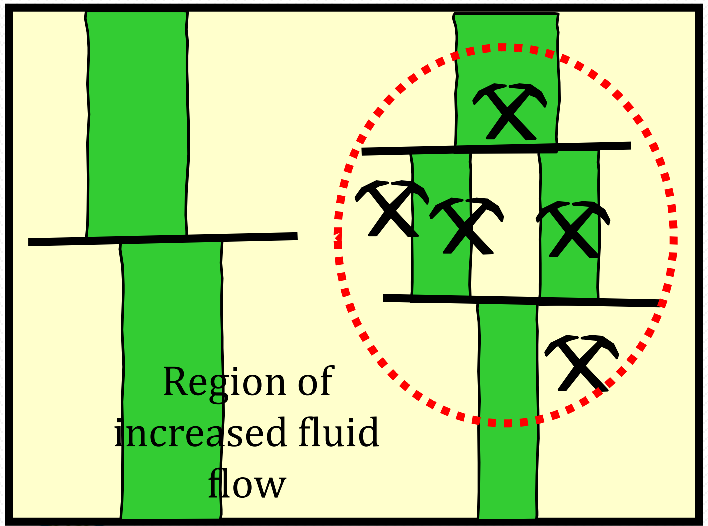


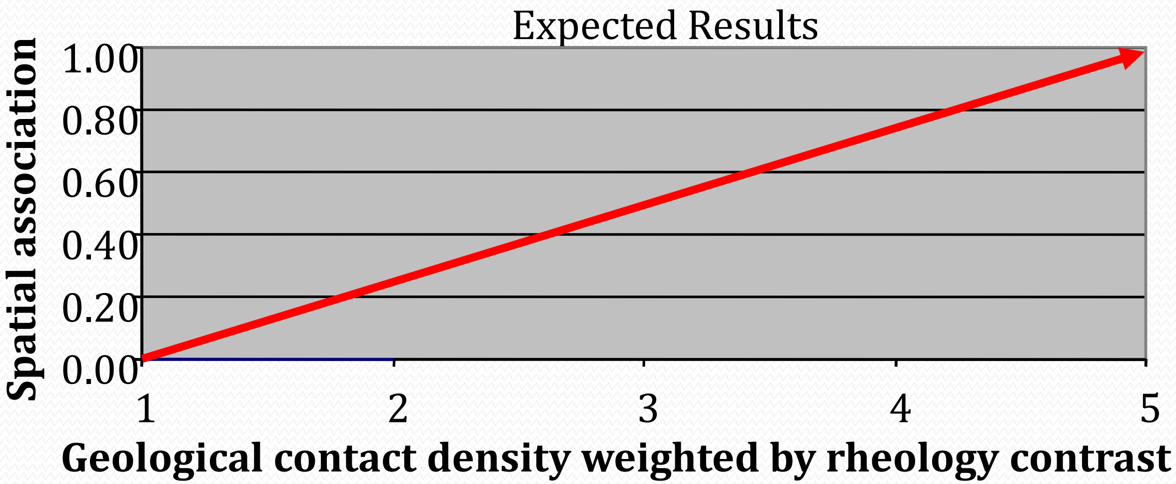
Hypothesis rejected!

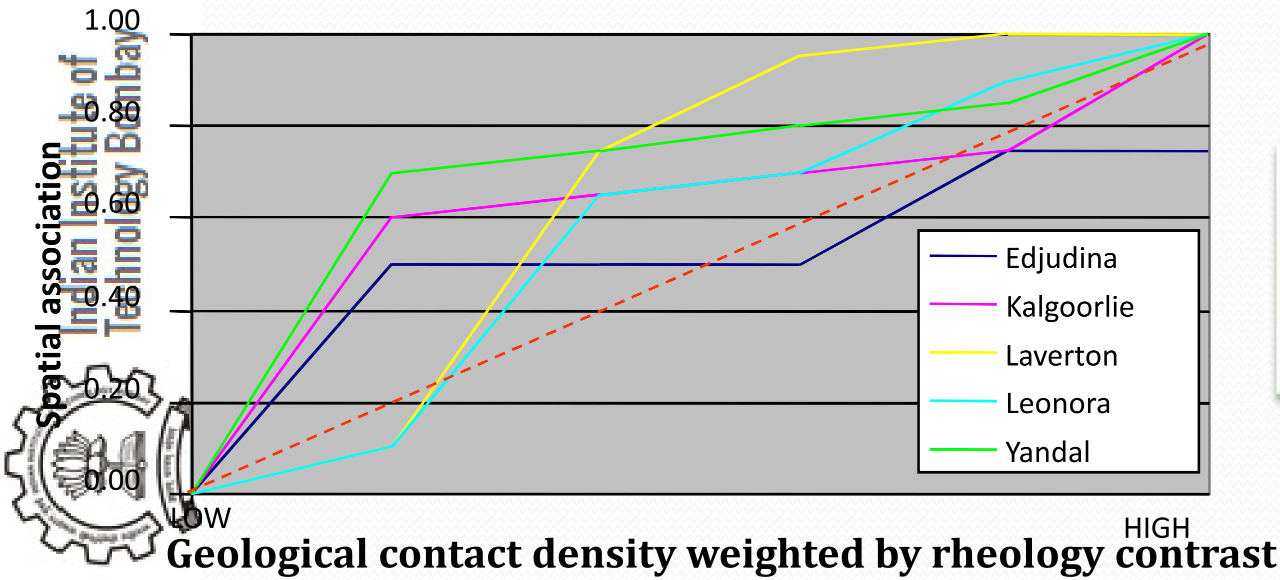
Change in Philosophy

Frequent change in rheology ➡ **Increased fluid flow** ➡ **Deposit localization**

Hypothesis: Expect deposits to be more common in *regions* of greater density of rheological contrast.







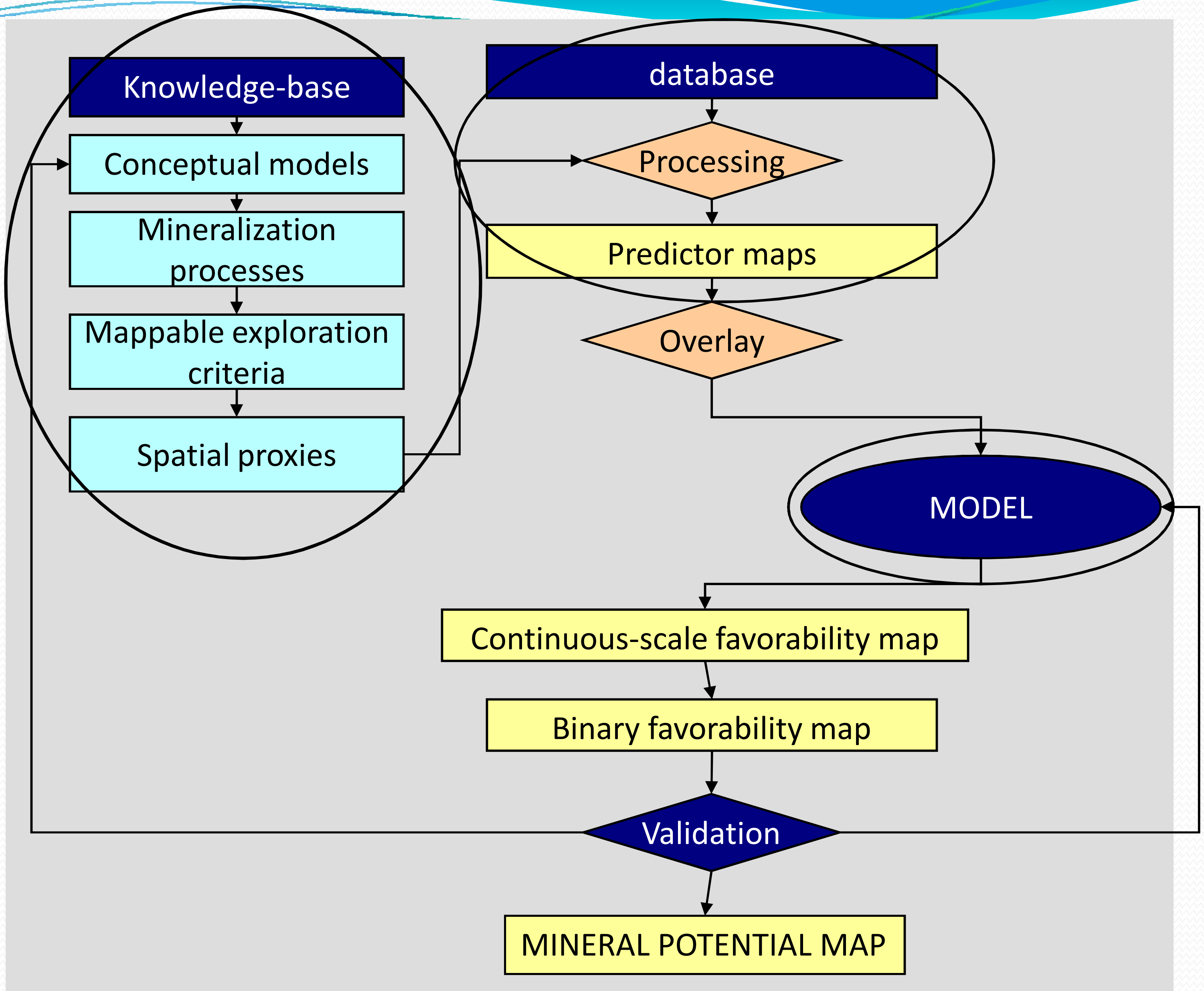
The right predictor map:
The map of geological contact density weighted by rheology contrast

Selection of Predictor Maps: Systematic Analysis of Exploration Data

Testing Spatial Association

- Observed vs expected distribution
- Probabilistic measure (Contrast)

Model-based mineral potential mapping



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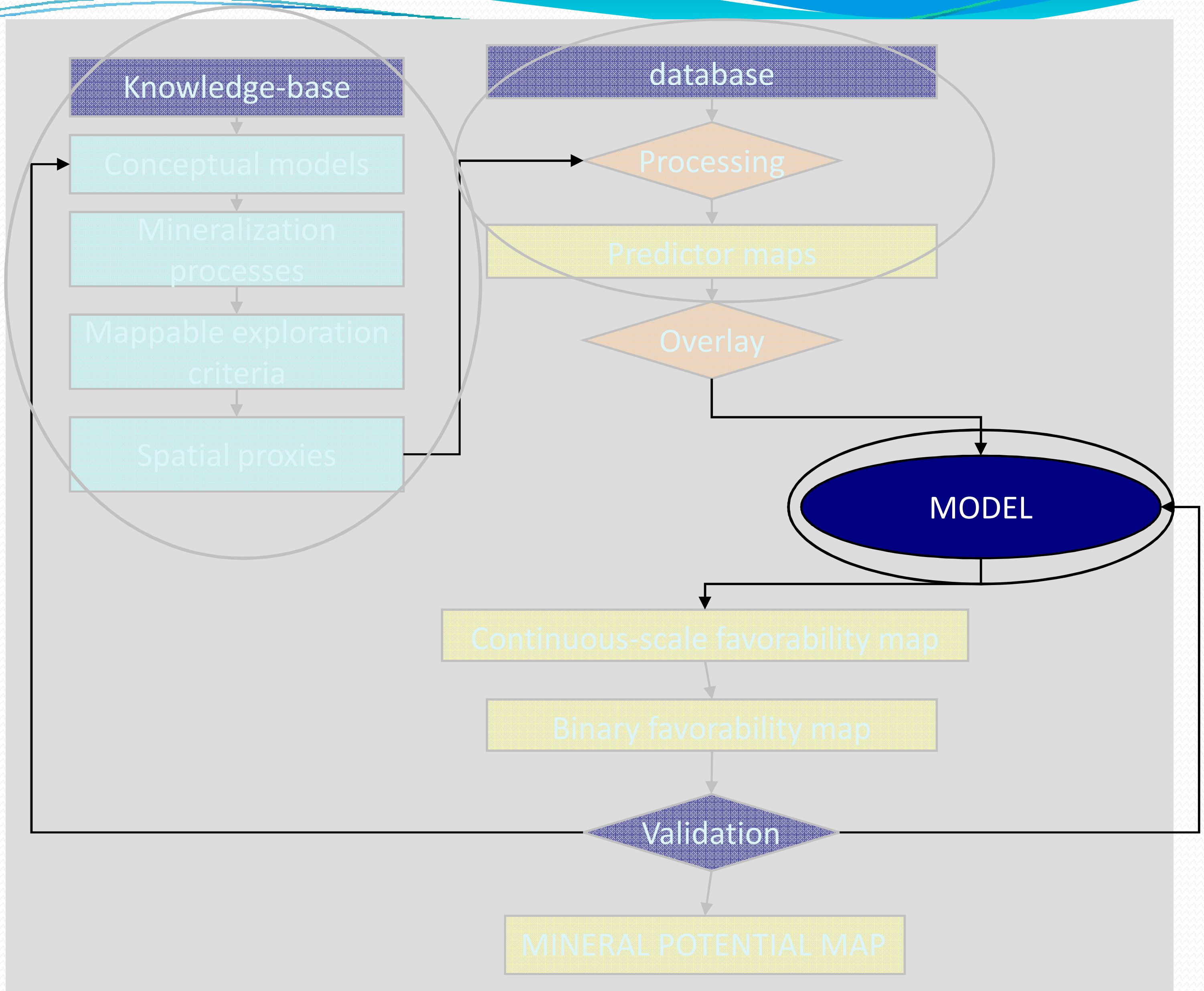
Model-based mineral potential mapping



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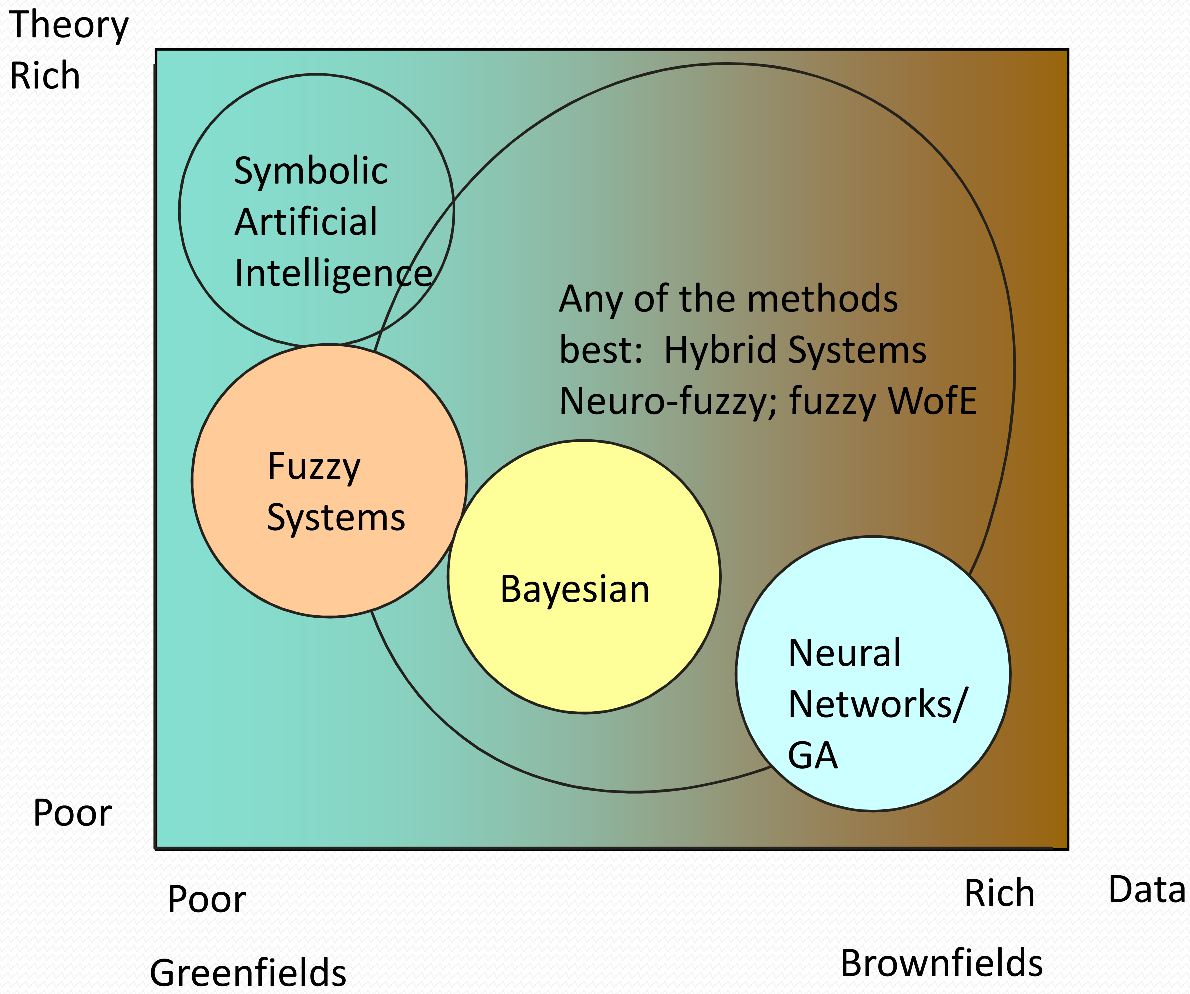
GIS-based mineral resource potential mapping - Modelling approaches

- Exploration datasets with homogenous coverage – required for all models
  - Expert knowledge (a knowledge base) and/or
  - Mineral deposit data

Training data | Expert knowledge

Data-driven	***Hybrid***	***Knowledge-driven***
Model parameters estimated from **mineral deposits data** (Known deposits required) Brownfields exploration Examples - Weights of evidence, Bayesian classifiers, NN, Logistic Regression	Model parameters estimated from both **mineral deposits data** and **expert knowledge** (Known deposits necessary) Semi-brownfields to brownfields exploration Examples – Neuro-fuzzy systems	Model parameters estimated from **expert knowledge** (Known deposits not necessary) Greenfields exploration Examples – Fuzzy systems; Dempster-Shafer belief theory

Which model is best?



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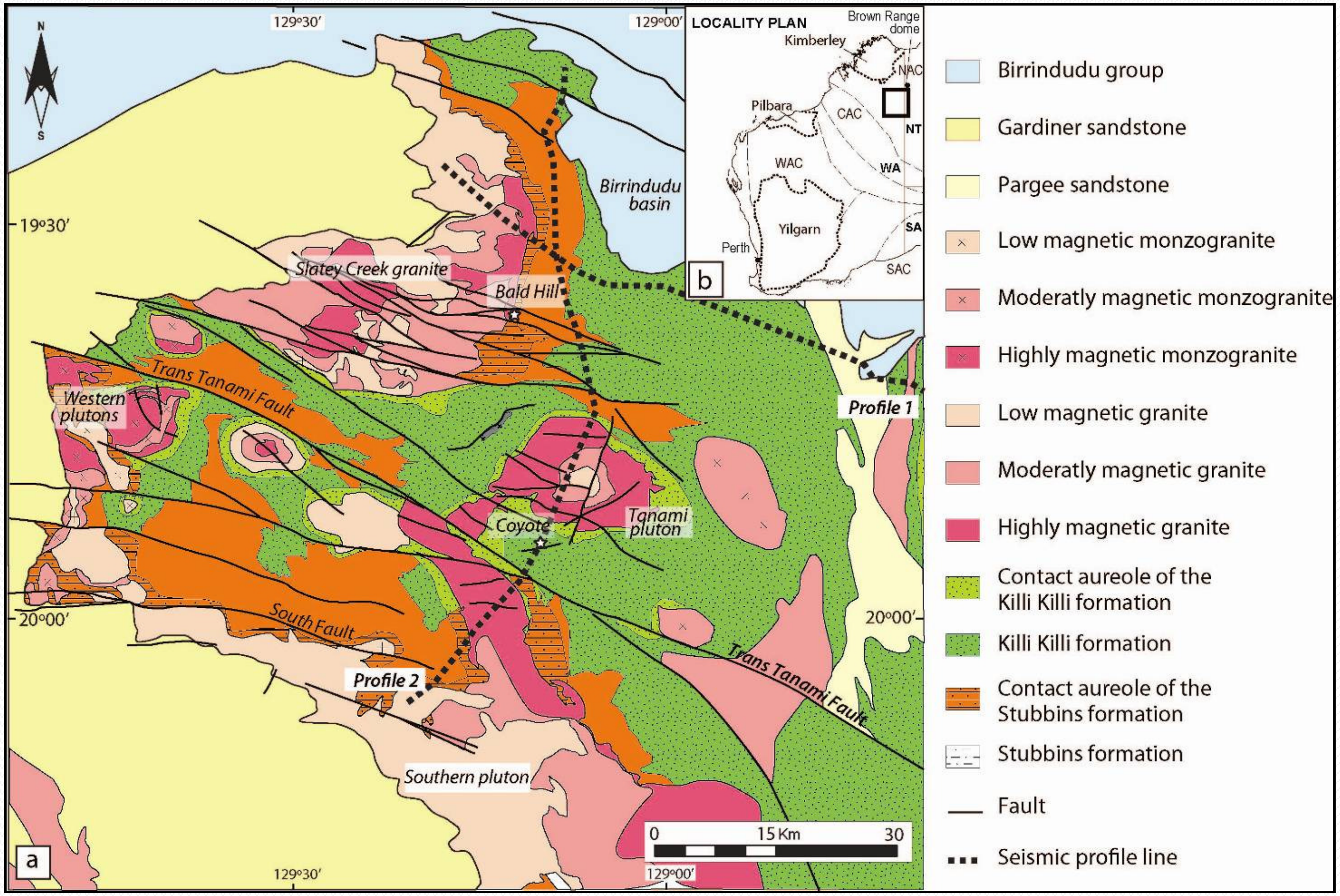
Mineral Potential Modeling

Au prospectivity mapping of Tanami Orogen, Western Australia

(Porwal, Joly, McCuaig)

(Joly et al., 2010; Ore Geology Reviews)

Geological Setting



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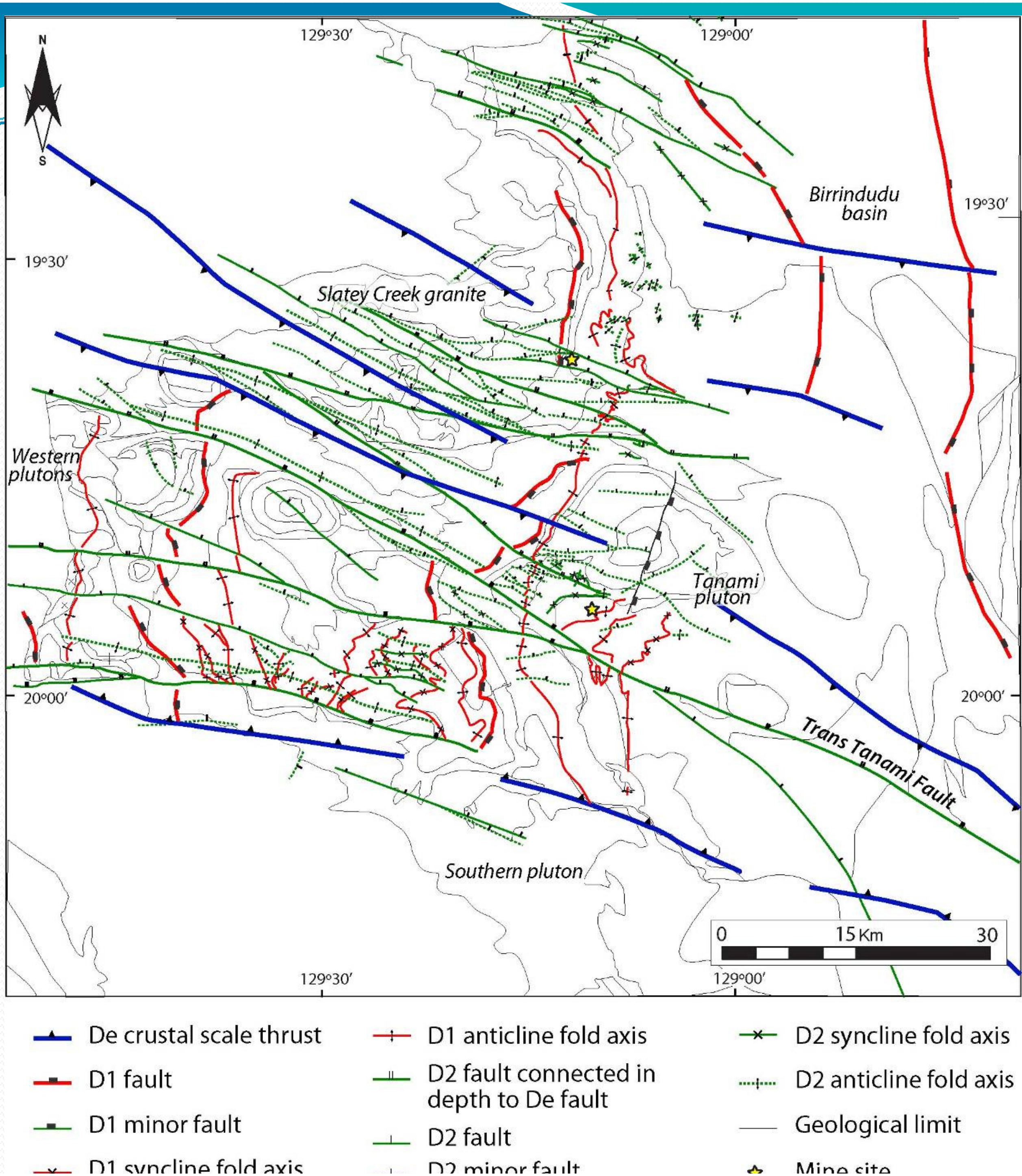
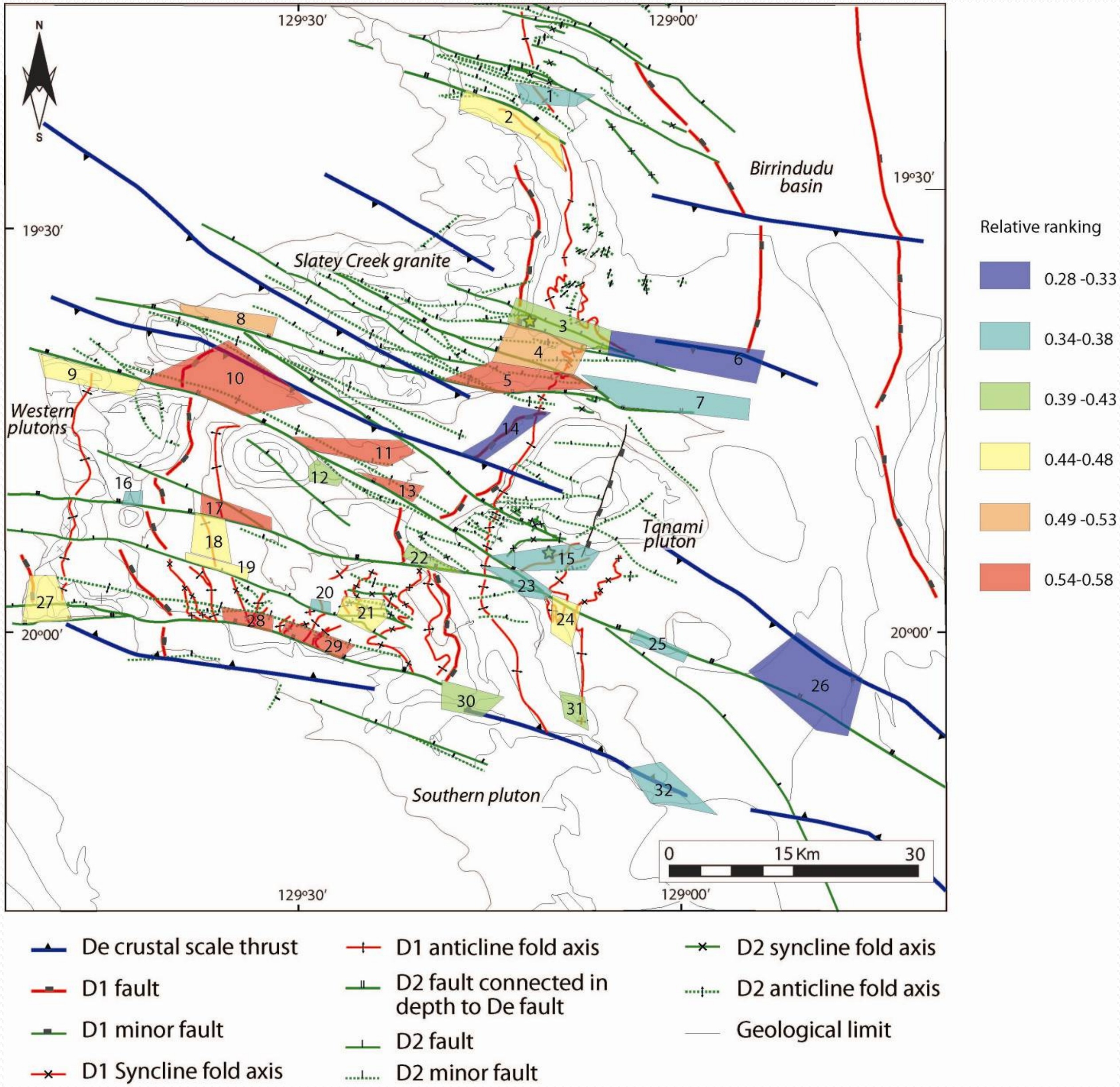
Structural Map (Based on 3D Modeling)



Orogenic gold mineral system

Critical Processes	*Source*		*Active Pathway*		*Physical Trap*		*Chemical Scrubber*	
Constituent process	Granite source involved	no granite source involved	Fundamental structure	Structure has acted as pathway	Threshold barriers	Breaching zones	Reactive rocks	evidence of reaction
Targeting elements	roof of granite proximity to granite	no indication on scale of West Tanami for more or less favourable source region	interpreted pre D2 history connectivity to deep structures	controls 1800 Ma granites (broadly same timing as mineralisation) extensive quartz veins metal anomalism along structure	Zones of increased compression Competency contrast Anticlines (D1, D2) ST/KK contact	fault intersections Fault jogs Fault tips/splays strain shadows (granites)	Stubbins (by analogy to largest deposit Callie; Fe-rich lithologies, more reactive than Killi Killi) magnetic haloes to granites dolerite density	metal anomaliles
Proxies	gravity low and mag high		gravity high (D1) Steep gravity gradient (De) Magnetics (D2) Seismic (deep features correlated with, and traced through, Mag/gravity)	geology mapping (veins) drilling/geochem assays spectral data (not available)	N side of D2 thrusts gravity highs delineate D1 anticlines E-W structures under compression geology map	structure interpretation gravity highs delineate D1 anticlines cored by thrusts	aeromagnetics	drilling/geochem assays alteration (not available)

"Manual" modelling



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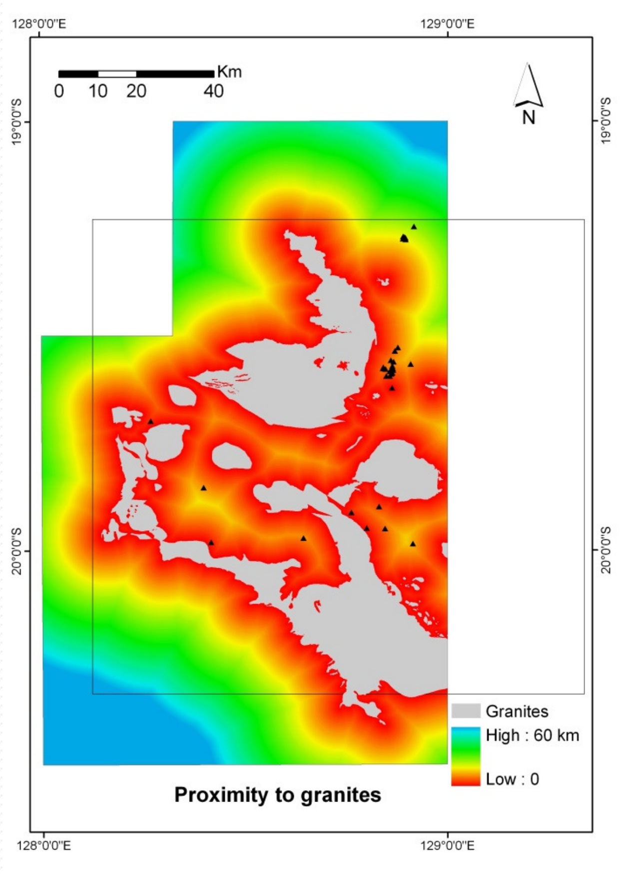
Predictor maps

Mineral systems component	Exploration criteria	Predictor Maps	Details
Source	**Proximity to granite**	(1) Proximity to granite	Granite buffered to 11000 m
Pathways	**Proximity to faults**	(2) Proximity to De fault	De structures buffered to 12000 m
		(3) Proximity to D1 fault	D1 faults buffered to 7500 m
		(4) Proximity to D2 fault	D2 faults buffered to 8000 m
		(5) Proximity to D2 fault related to De faults	D2 structures related to De buffered to 14.6k
		(6) Proximity to D2 fault intersection	D2 intersections buffered to 7.5km
		(7) Proximity to D2 and D1 fault intersection	D1 x D2 intersections buffered to 8000 m
	Proximity to structure with elevated gold values	(8) Proximity to structure with elevated Au values	Faults buffered to 1 km and attributed with Au values interpolated from drill hole data+surface geochem
Chemical Trap	**Chemical contrast at geological contacts**	(9) Chemical contrast density	Density of geological contacts weighted by chemical contrast
		(10) Chemical contrast across contact	Chemical contrast across geological contacts
		(11) Dolerite density	Density of dolerite contacts
		(12) Killi-Killi Formation (Geology)	Extracted from geological map directly
	Proximity to anticlinal fold axis	(13) Proximity to D1 anticlinal fold axis	D1 anticlines buffered to 800m
		(14) Proximity to D2 anticlinal fold axis	D2 anticlines buffered to 600m
		(15) Stubbins Formation (Geology)	Extracted from geological map directly
Physical Trap	**Physical contrast at geological contacts**	(16) Competency contrast density	Density of geological contacts weighted by competency contrast across the contacts.
		(17) Competency contrast	Competency contrast across geological contacts

SOURCE PREDICTORS



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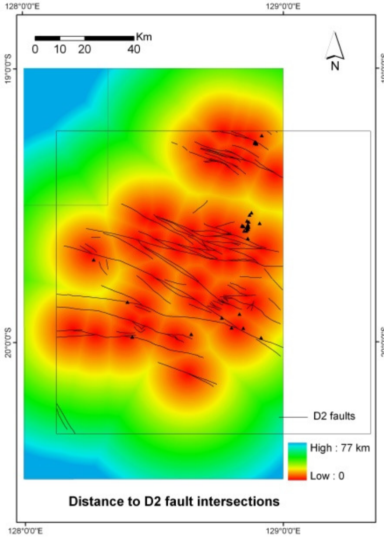
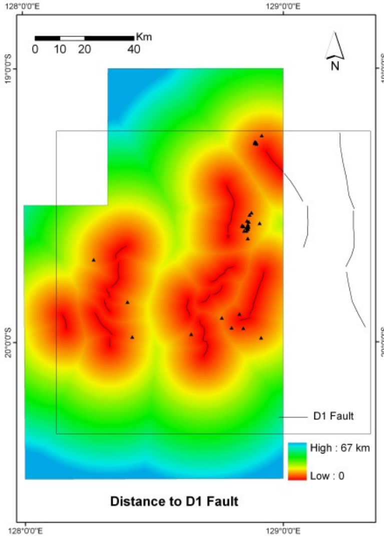
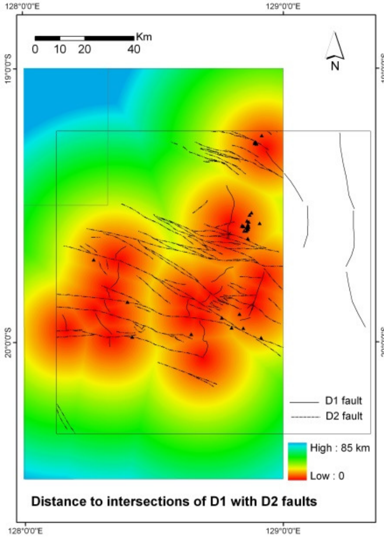
PATHWAY PREDICTORS



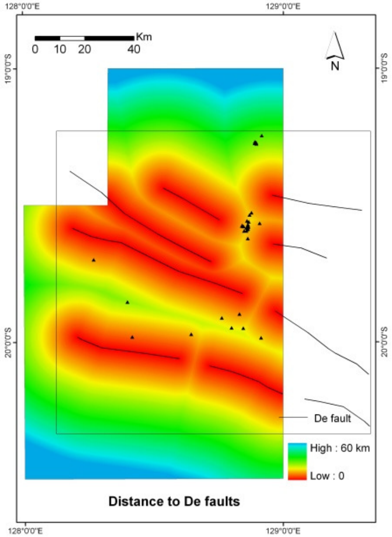
Distance to D2 fault intersections



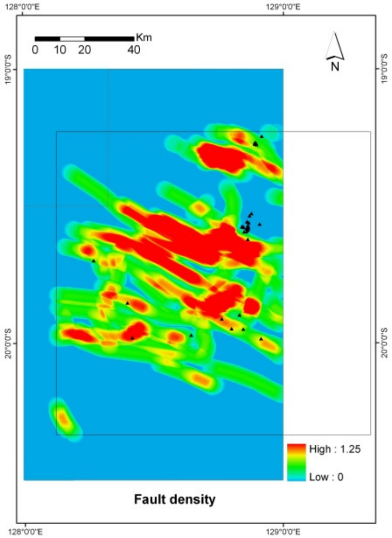
Distance to D1 Fault



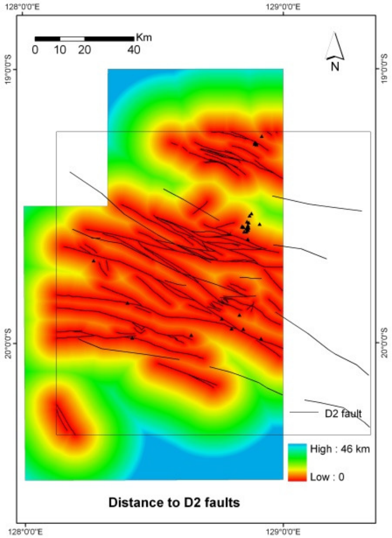
Distance to intersections of D1 with D2 faults



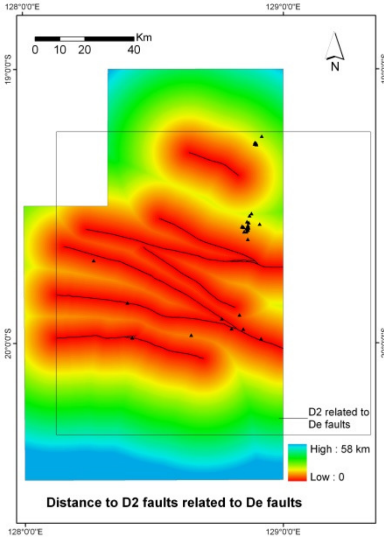
Distance to De faults



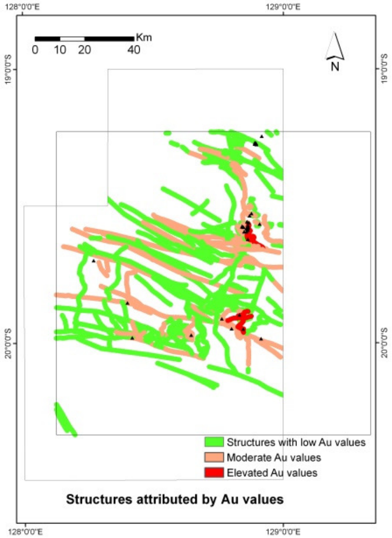
Fault density



Distance to D2 faults



Distance to D2 faults related to De faults



Structures attributed by Au values

PHYSICAL TRAP PREDICTORS

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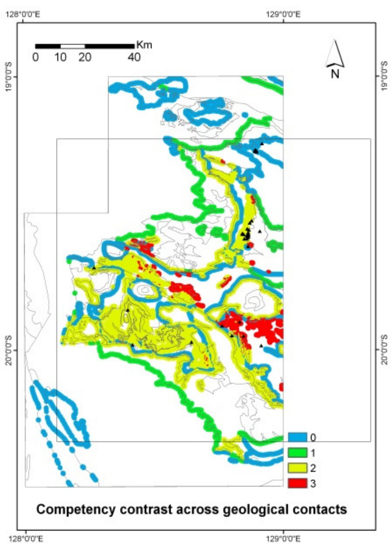
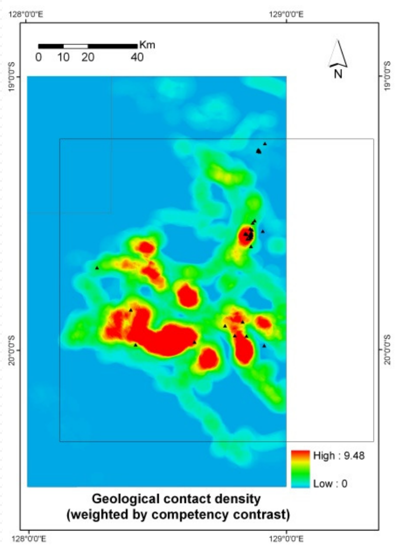
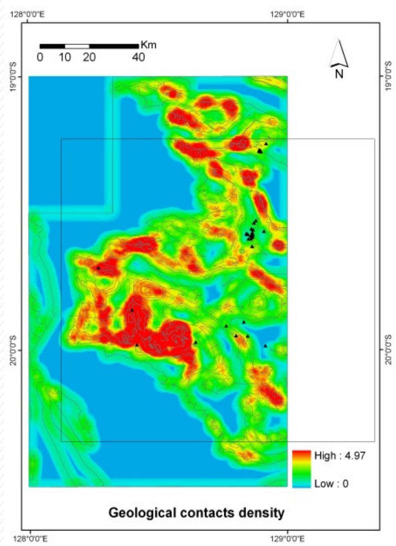


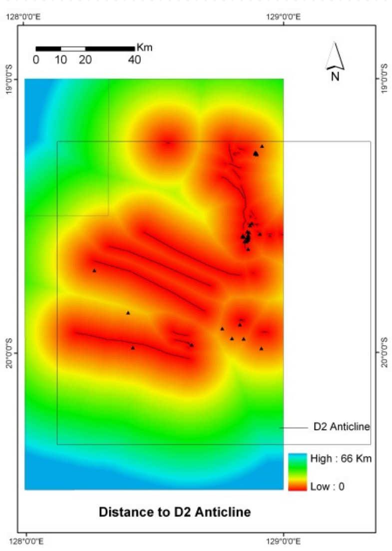
Competency contrast across geological contacts



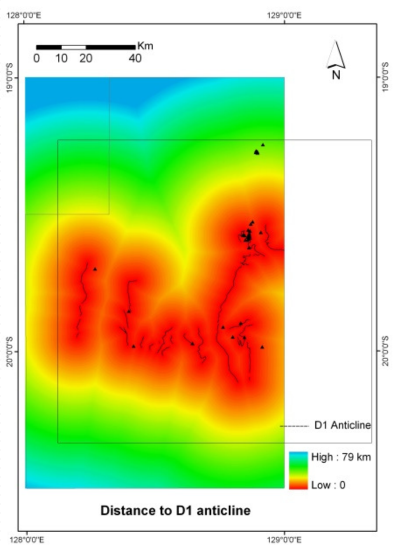
Geological contact density (weighted by competency contrast)



Geological contacts density



Distance to D2 Anticline



Distance to D1 anticline

CHEMICAL TRAP PREDICTORS

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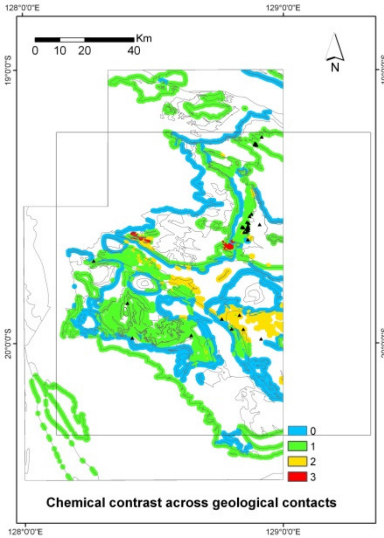
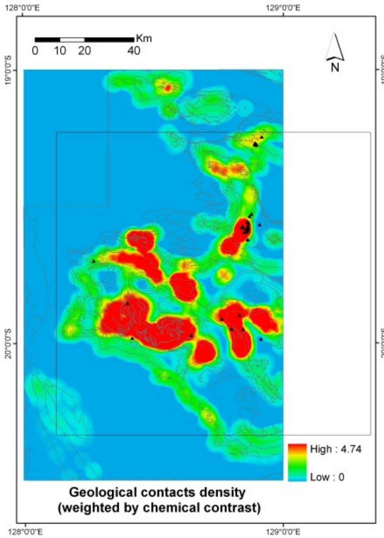
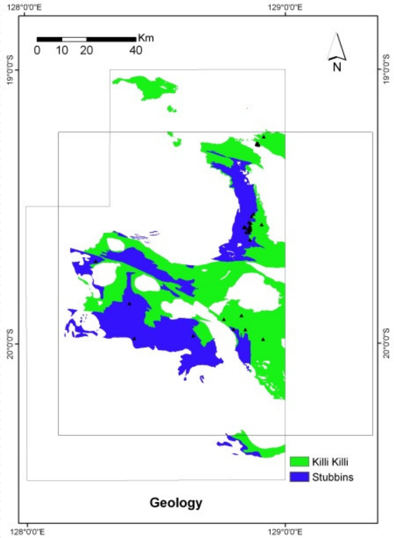






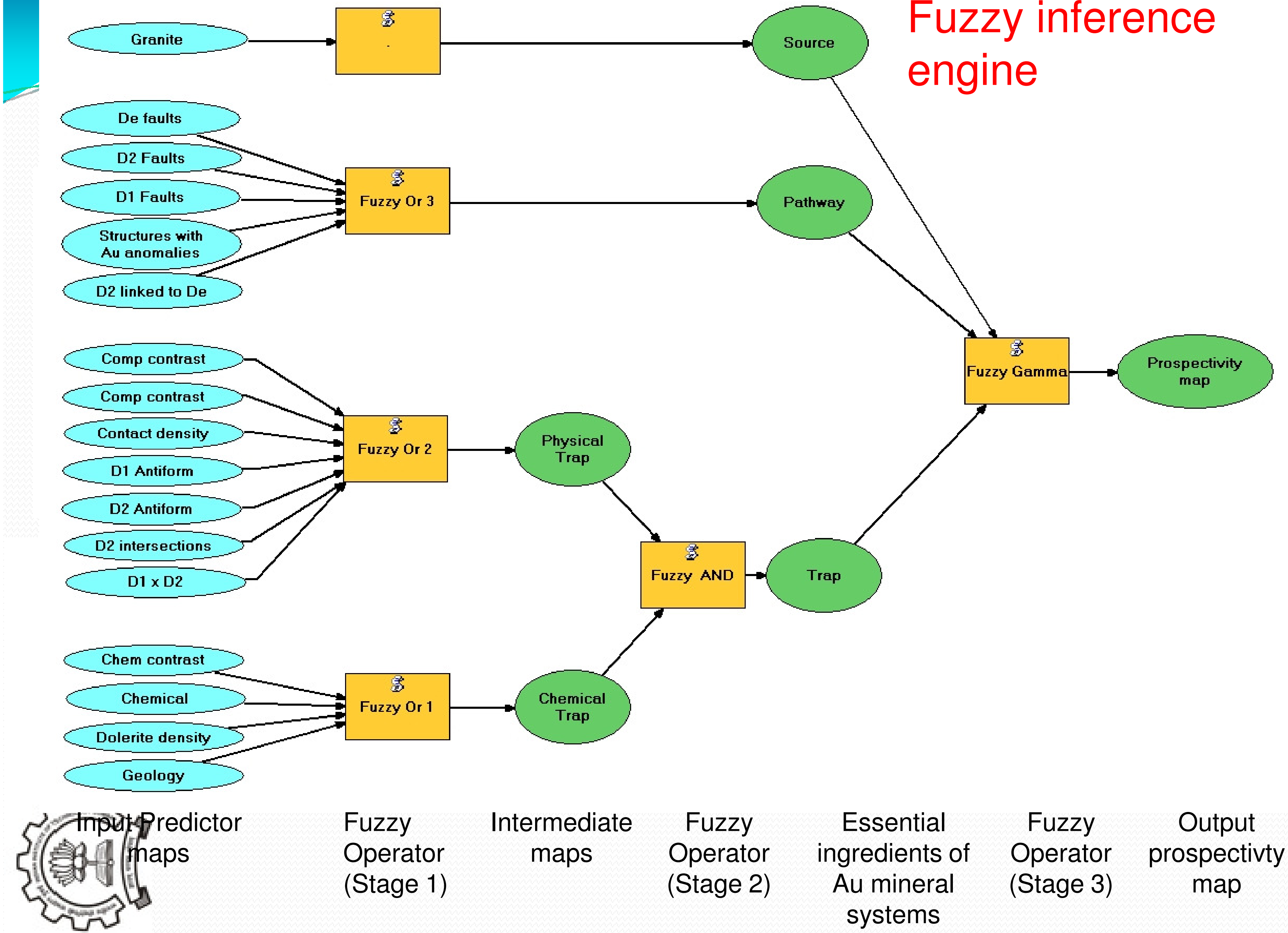
FUZZY MODEL

- Estimate expert-knowledge-based fuzzy membership values to predictor maps
- Combine predictor maps using fuzzy inference networks

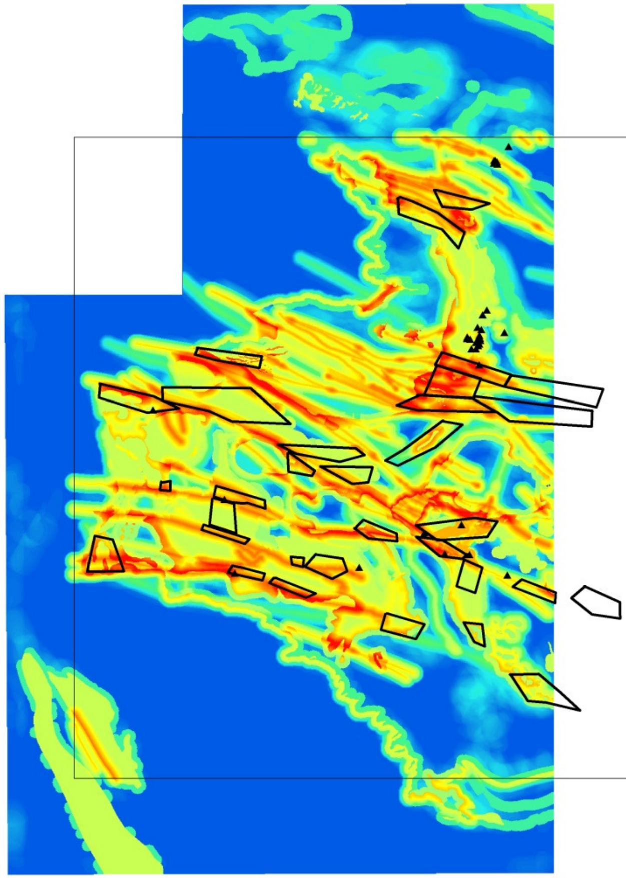
FUZZY MODEL – ASSIGN EXPERT KNOWLEDGE BASED RANKS

			Fuzzy model				
			Fuzzy membership value (expert-knowledge based weight)	**Confidence factor**	**Fuzzy membership value (expert-knowledge +confidence factor based weight)**	**rationale for expert-knowledge based weight (fuzzy membership values)**	**Rationale for confidence factor**
1	Chemical Contrast density		0.8	0.6	0.48	conceptually a good predictor in terms of Fe for sulphidation reactions	Interpreted relative values, not directly measured
2	Competency contrast		0.9	0.6	0.54	good predictor of fluid focus sites	Interpreted relative values, not directly measured
3	Competency contrast density		0.9	0.6	0.54	High density of competency contrast means more variation of comptency in rocks, and hence more fluid focus sites	Interpreted relative values, not directly measured
4	Dolerite density		0.7	0.6	0.42	Higher reactivity across dolerite contacts	Interpreted geology used; insufficient data, scale issues)
5	Geology	KK	0.5	0.7	0.35	monotonous sequence	Interpreted geology used
		Stubbins	0.8	0.7	0.56	contrasted lithology due to the BIF/sediment alternance and large qz veins	Interpreted geology used
6	D1 anticlines		0.6	0.7	0.42	good sites for fluid ponding	based largely on mapped geology and magnetics,

Fuzzy inference engine



Output Model



Fuzzy model based on expert weights+ confidence factor
(Granite model)

Fuzzy model

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Summary

- GIS-based mineral potential modeling leads to effective narrow down of search areas for ground exploration, thus significantly reducing the cost of ground exploration

- Correct genetic conceptual modeling forms the foundation of a good mineral potential model

- Appropriate derivative GIS layers should be generated using geoprocessing tools (making sure that the layers represent the mineralization processes.

- A variety of spatial mathematical models are available: select the appropriate model based on your data and whether it is a greenfields or brownfields scenario.

Special issues of **Ore Geology Reviews** on GIS-based mineral potential modeling
Editors: Porwal and Kreuzer (2010) and Porwal and Carranza (2015)

Thank you