Exploration Targeting of REE Deposits in NE India Using Fuzzy Inference Systems

Malcolm Aranha[1], Alok Porwal[1], and Ignacio González-Álvarez[2]

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Abstract

A multi-stage fuzzy inference system (FIS), a symbolic knowledge-based artificial intelligence technique, is used to delineate exploration targets for rare earth elements (REEs) associated with carbonatite-alkaline complexes in NE India. A conceptual REE mineral systems model was used to identify the following targeting criteria for REE deposits. The multi-stage FIS was structured based on the mineral systems model. The first stage of the multi-stage FIS comprised of three individual FIS to represent (1) plume-metasomatised SCLM in an extensional regime that make up fertile source regions for REE-bearing fluids and favourable geodynamic settings; (2) trans-lithospheric structures that provide favourable lithospheric architecture for the transportation of REE-enriched alkaline-carbonatite magma and (3) near-surface higher-order structures that make up a shallow crustal architecture facilitating emplacement of alkaline-carbonatite complexes. The targeting criteria were represented by their spatial proxies in the form of GIS layers derived using spatial analyses and geoprocessing tools for inputting to the FIS. The outputs of the FIS were mapped to generate prospectivity maps that were analysed to identify exploration targets for REE in the study area. The uncertainties in the outputs of the FIS were quantified using Monte-Carlo-based simulations. Exploration targets at low uncertainty levels were delineated around Sung valley and Jasra carbonatite-alkaline-complexes. Areas around the carbonatite-alkaline complex around Swangkre and to the south of the Nongstoin town were identified as high-uncertainty targets. It is recommended that ground follow-up exploration should be carried out in the former targets, and more data should be collected to increase confidence in the latter targets.

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MALCOLM ARANHA

PhD student

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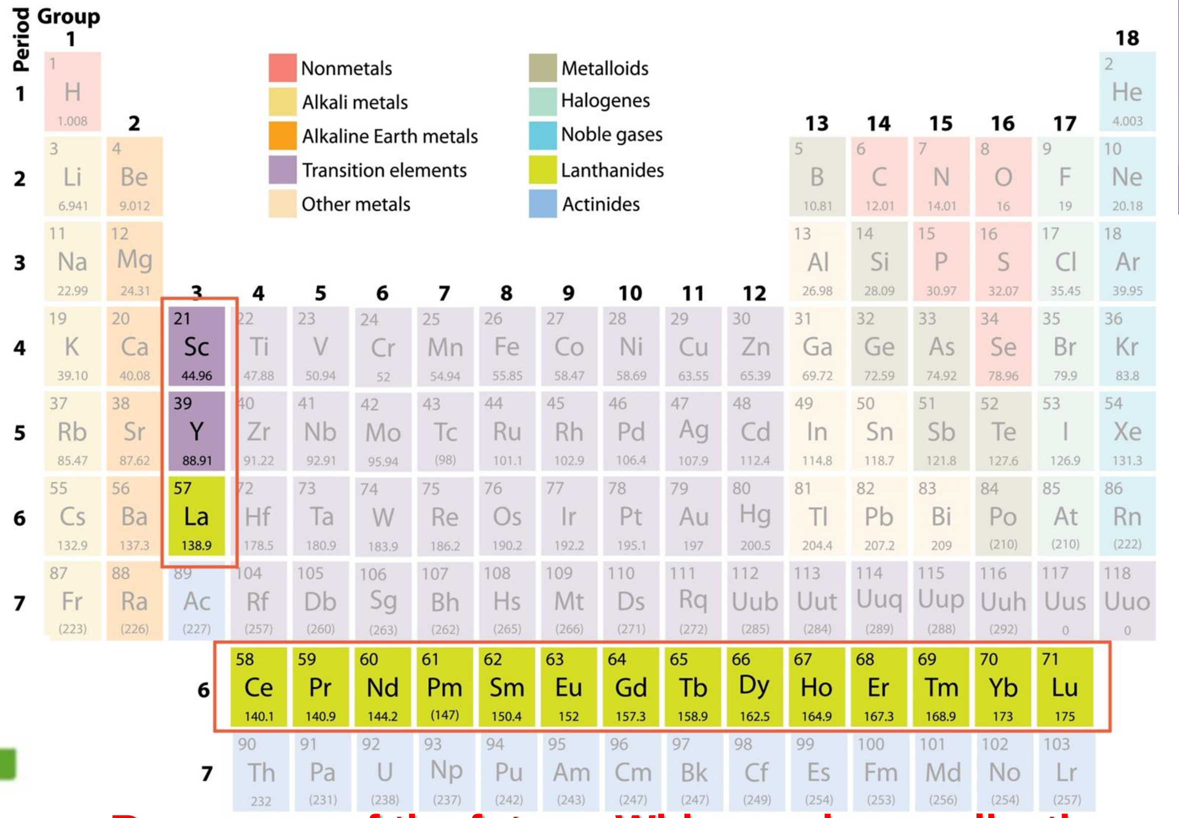
WHAT ARE REEs?

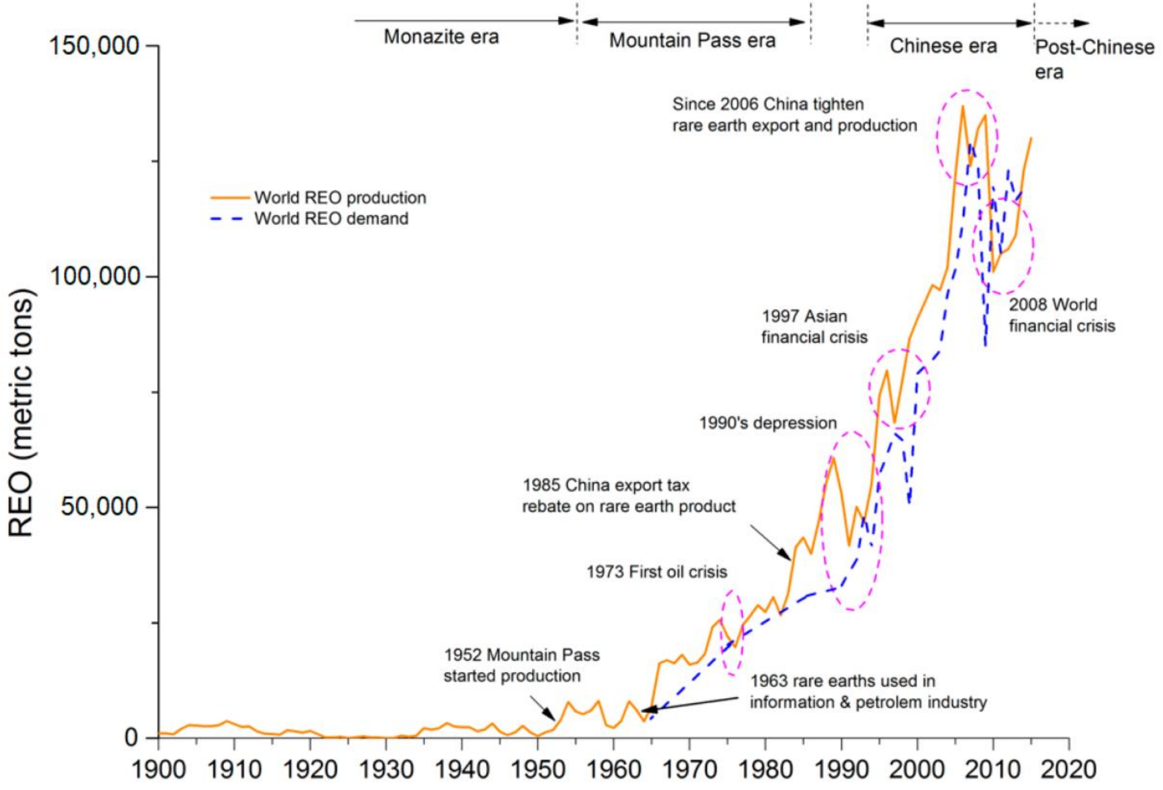
- 17 “Rare” Earth Elements, La to Lu, Y and Sc
- LREE = La – Eu
- HREE = Gd – Lu, Y and Sc

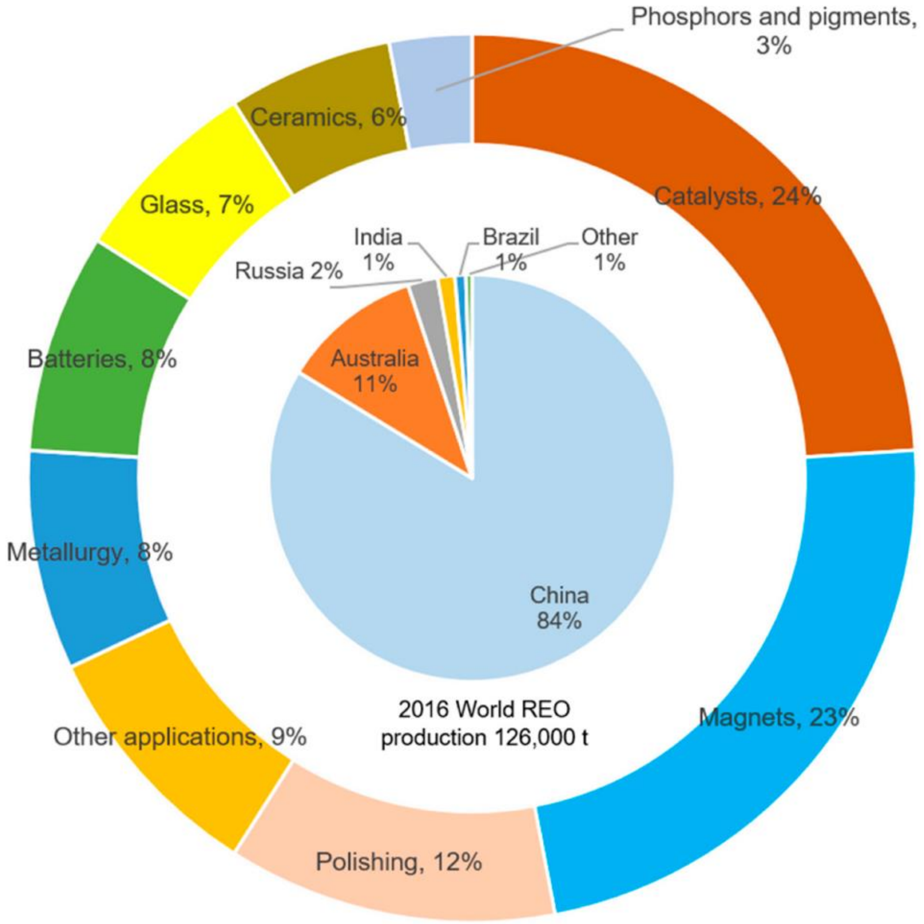


Resources of the future: Wide ranging applications

(Lee Allison, 2011)

GLOBAL SUPPLY OF REE RESOURCES





(Zhou et al., 2017)

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TYPES OF REE DEPOSITS

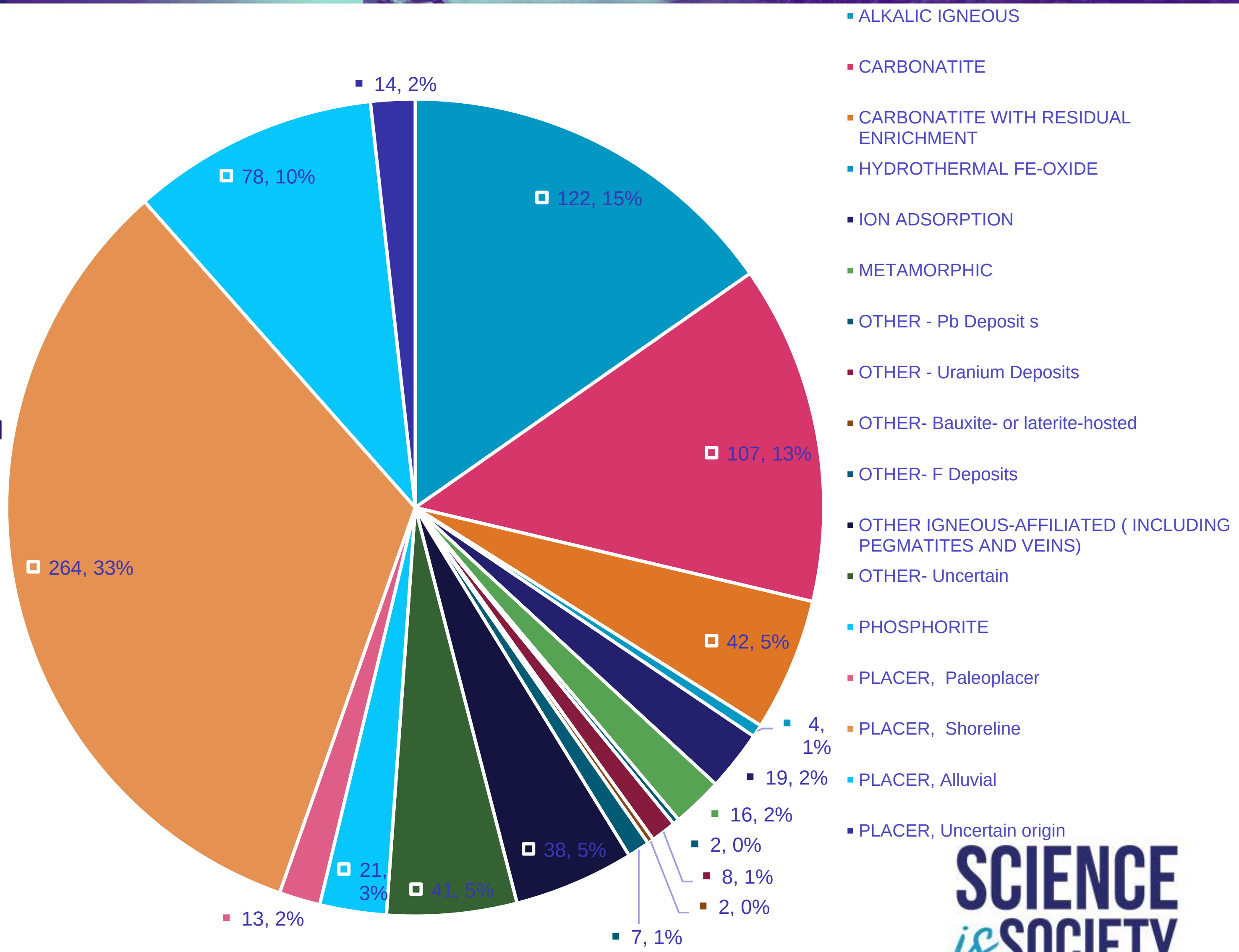
- Magmatic
  1. Per alkaline
  2. Carbonatite
  3. Pegmatite
  4. Skarn
  5. Apatite or Flourite Vein
  6. Iron Oxide Breccia complex

- Regolith – Residual Lateritic
  1. Carbonatite
  2. Mafic/Ultra Mafic

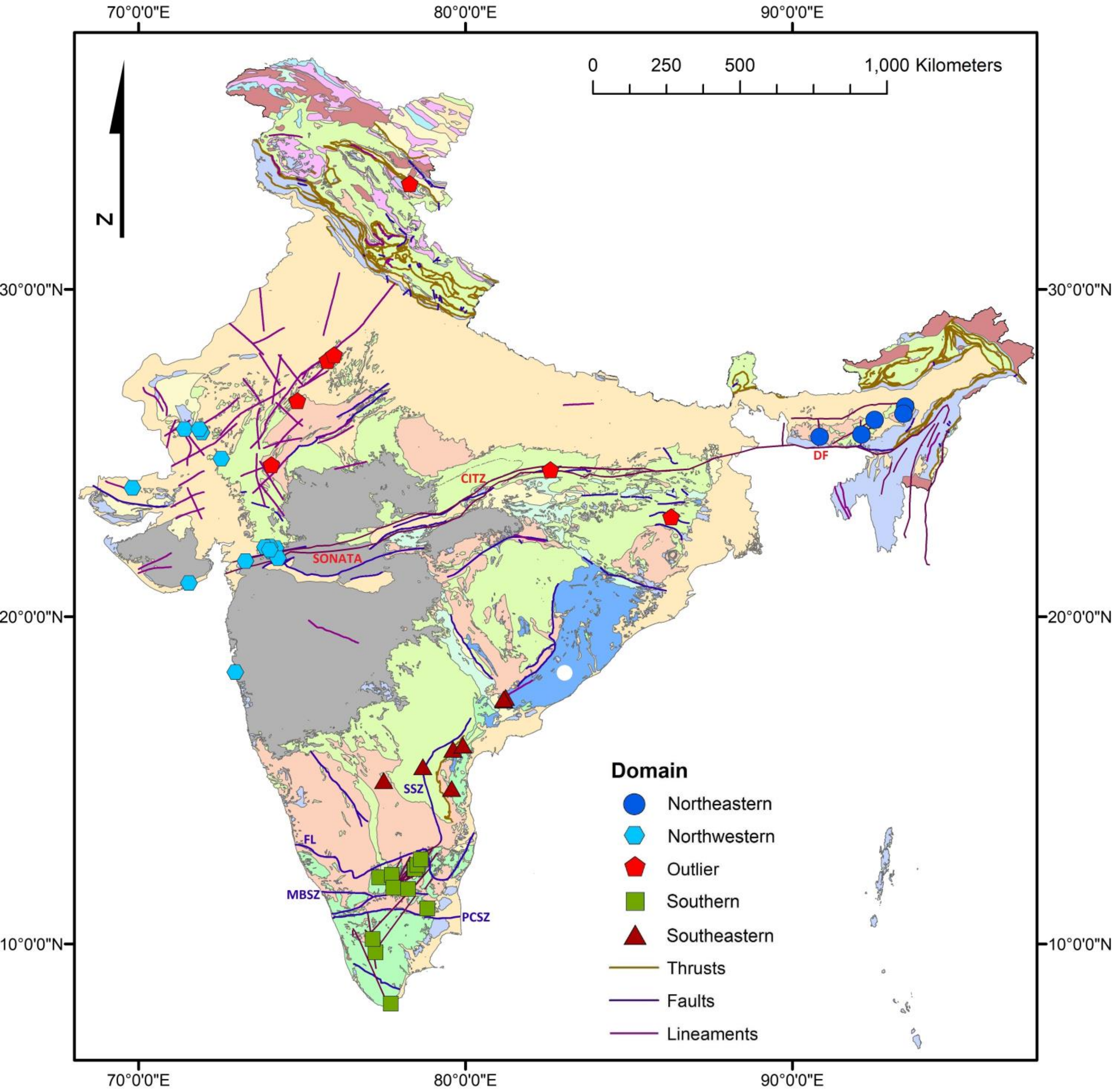
- Basinal
  1. Heavy mineral sand – Beach and Inland
  2. High Dune
  3. Off shore shallow Marine Tidal and Tidal
  4. Sea floor Manganese nodules
  5. Phosphorite
  6. Lignite
  7. Unconformity related

- Metamorphic – Calc-silicate and Migmatised Gneiss

Classification scheme from Jaireth et al., 2014



Distribution of known REE deposits according to type; Data source - Orris and Grauch, 2002



DISTRIBUTION OF KNOWN CARBONATITE-ALKALINE OCCURRENCES IN INDIA

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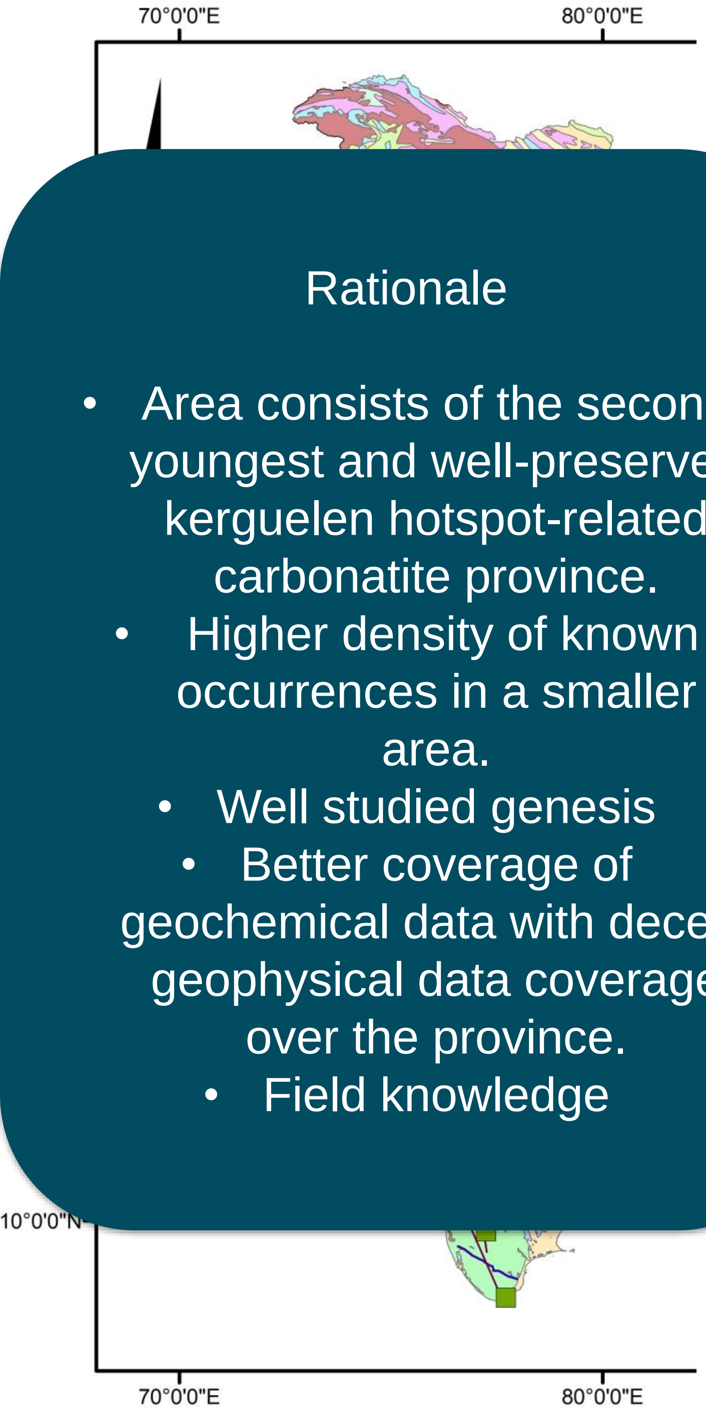
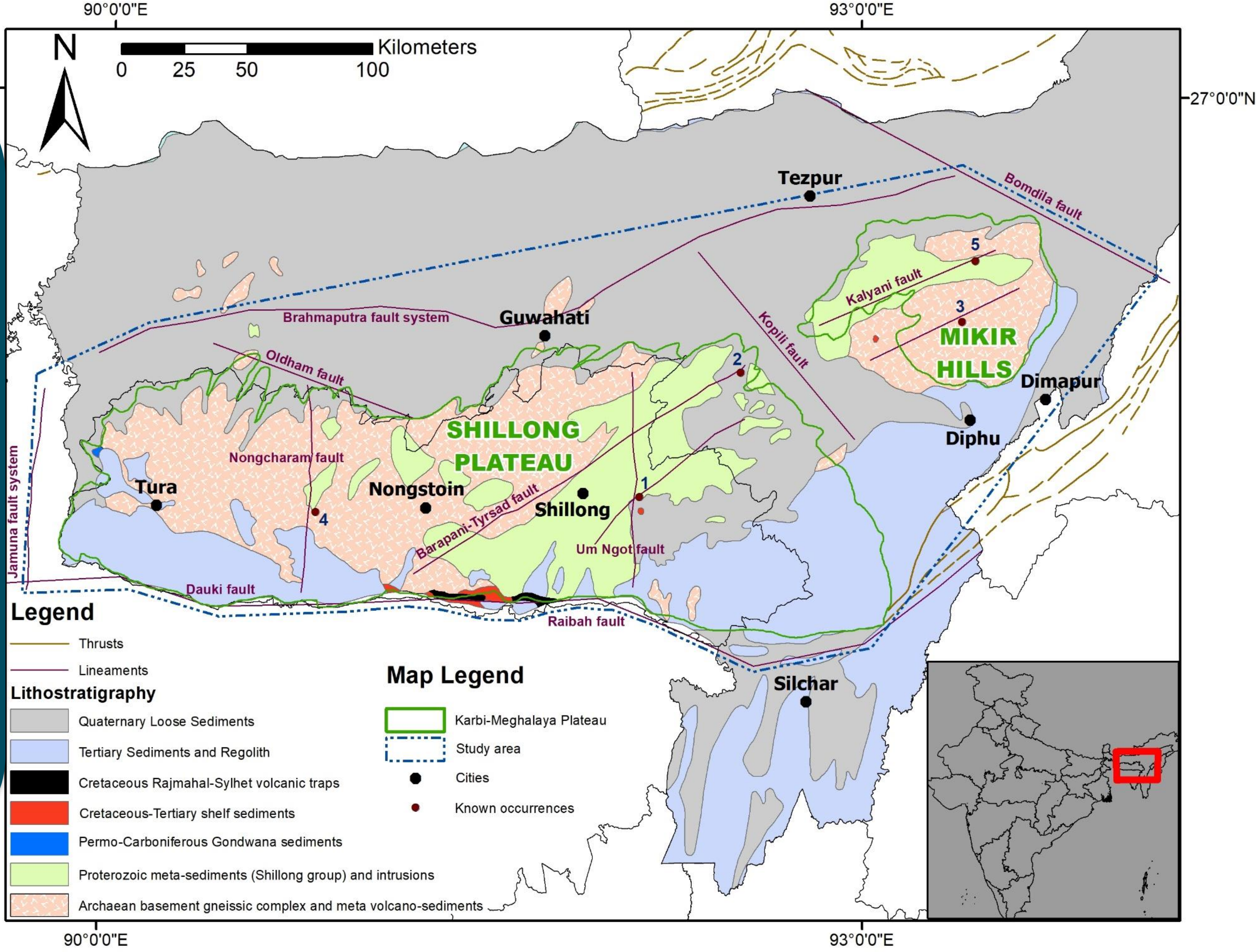
Rationale

- Area consists of the second youngest and well-preserved kerguelen hotspot-related carbonatite province.
- Higher density of known occurrences in a smaller area.
- Well studied genesis
- Better coverage of geochemical data with decent geophysical data coverage over the province.
- Field knowledge





AVAILABLE DATA FOR NE INDIA

Geochemistry

- Soil C horizon
- Soil regolith
- Stream sediment

Geology

- Geology 2M
- Geology 50K

Structures

- Faults 2M
- Thrusts 2M
- Faults 50K
- Lineaments 250K

Geophysics

- Ground gravity (10 km)
- Satellite gravity (2’)
- Magnetics (300 m)

Topography

- SRTM (1 km)
- WGM 2012 (2’)

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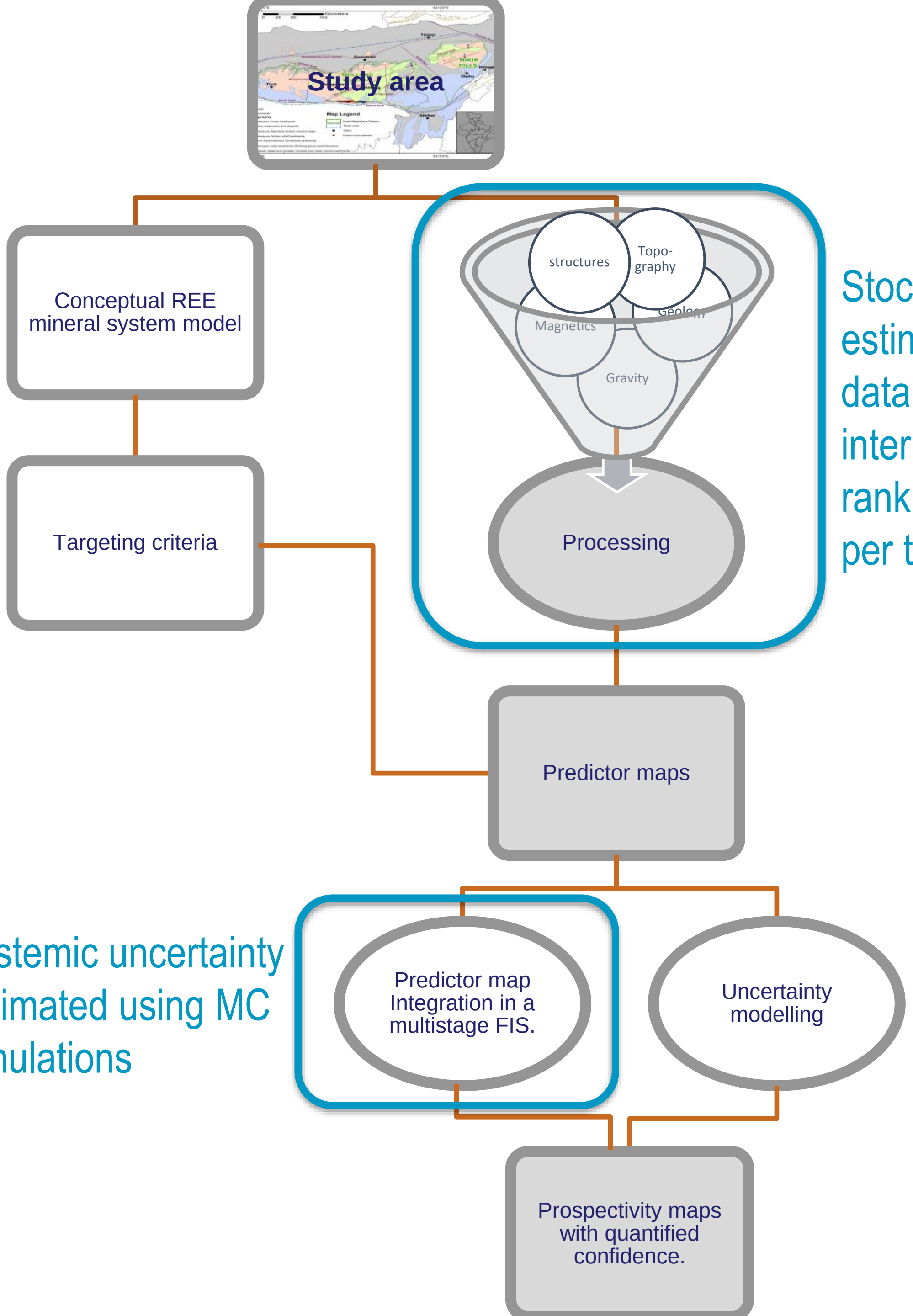
STEPS INVOLVED...



Stochastic uncertainty estimated based on mode of data acquisition and interpretation procedure by ranking the predictor maps as per the Sherman Kent scale

Systemic uncertainty estimated using MC simulations

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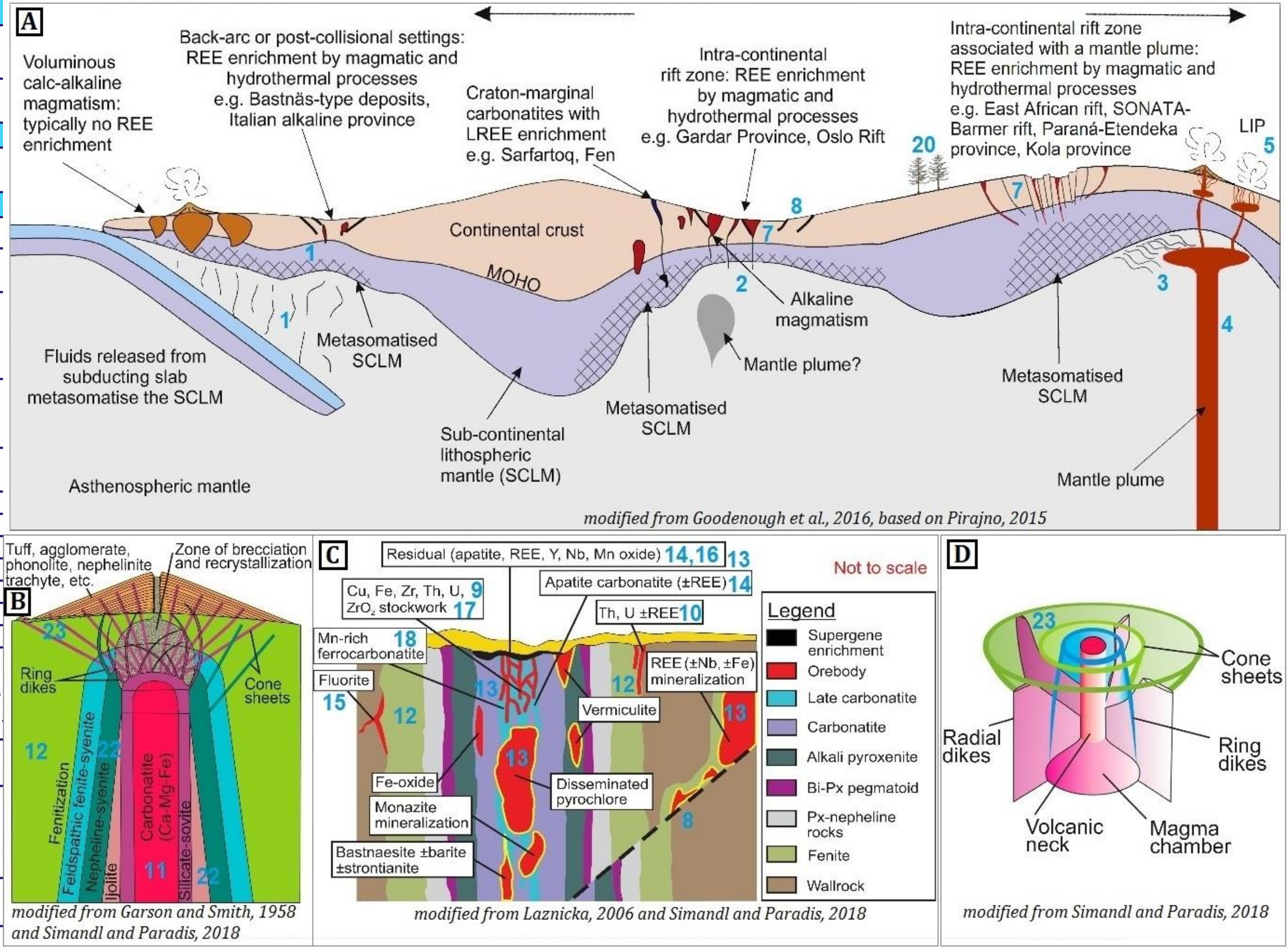
Setting/process	#	Targeting criteria	Spatial proxies
Fertility			
Mantle metasomatism and low degree partial melting	1	Subduction of crust	Subduction zones throughout geological history
	2	Decompressional melting of mantle and crust due to rifting (crustal thinning)	Rift zones
	3	Metasomatism driven by a rising mantle plume	Trace of mantle plume
Geodynamic setting and triggers			
Continental rifts (Rising Mantle plume)	4	Trace of mantle plumes based on plate tectonics through indicative magmatism	
	5		
	6	Major global tectonic events - super continental breakups	
Architecture-plumbing			
Migration of magma along existing or new architecture	7	Crustal scale discontinuities	
Architecture-Emplacement			
Magma emplacement under structural traps	8	Near-surface network of faults	
Carbonatite magma emplacement - Concentration of minerals with a strong magnetic response and contrasting density from the country rocks	9	Anomalous signatures in geophysical data	
Concentration of incompatible radioactive elements	10	High radioactivity due to U and Th enrichment	
Hosted by or strongly associated with Ca or Mg carbonate rocks (Carbonatites)	11	High concentrations of Ca and Mg	
Sodic and potassic fenitisation	12	Enrichment of K and Na in the surrounding rocks	
Emplacement of incompatible elements in primary carbonatite or secondary carbonatitic veins	13	Enrichment of REEs	
	14	P_2O_5,	
	15	F, Cl and CO_3;	
	16	Nb	
	17	Ba, Sr, Zr	
	18	Mn	
	19	Ti	
Biogeochemical indicators: Absorption of REEs and related elements by plants growing over a potential deposit	20	Abundance of Ba, Sr, P, Cu, Co, La, Ce, Pr, Nd, Sm, Dy, Fe, Nb, Ta, U and Y against the background value in the leaves and twigs of the plants and in the Humus.	
Selective absorption of certain wavelengths of the Electromagnetic spectrum	21	Characteristic absorption features in remotely sensed images	
Carbonatites are commonly spatially associated with alkaline silicate (85%; Woolley and Kjarsgaard, 2008) and in some cases with ultramafic and felsic silicate igneous rocks	22	Known alkaline intrusions	
Concentric zoning of carbonate rocks along with magnetic minerals (magnetite)	23	Circular outline	
Variation in mineralogy in REE-bearing minerals and associated alkaline suite of rocks are indicators of emplacement depth as well as erosional level and, therefore, mineralisation potential	24	Variation in rock units of the alkaline rock suite and/or Variation of REE minerals	Individual rock and mineralogical units in detailed lithological and mineralogical profiles



TARGETING MODEL FOR NE INDIA

Fertility and geodynamic setting

- Mantle plume trace?
- Rift
- LIP

Transport architecture

- Rift architecture
- Deep faults from geophysical data
- Mapped faults
- Lineaments

Emplacement architecture

- Shallow faults
- Intersection of shallow faults – structural traps
- Circular features in topographical and geophysical datasets
- Known intrusions
- High abundance of REE, P_2O_5, F and CO_3 geochemical signatures

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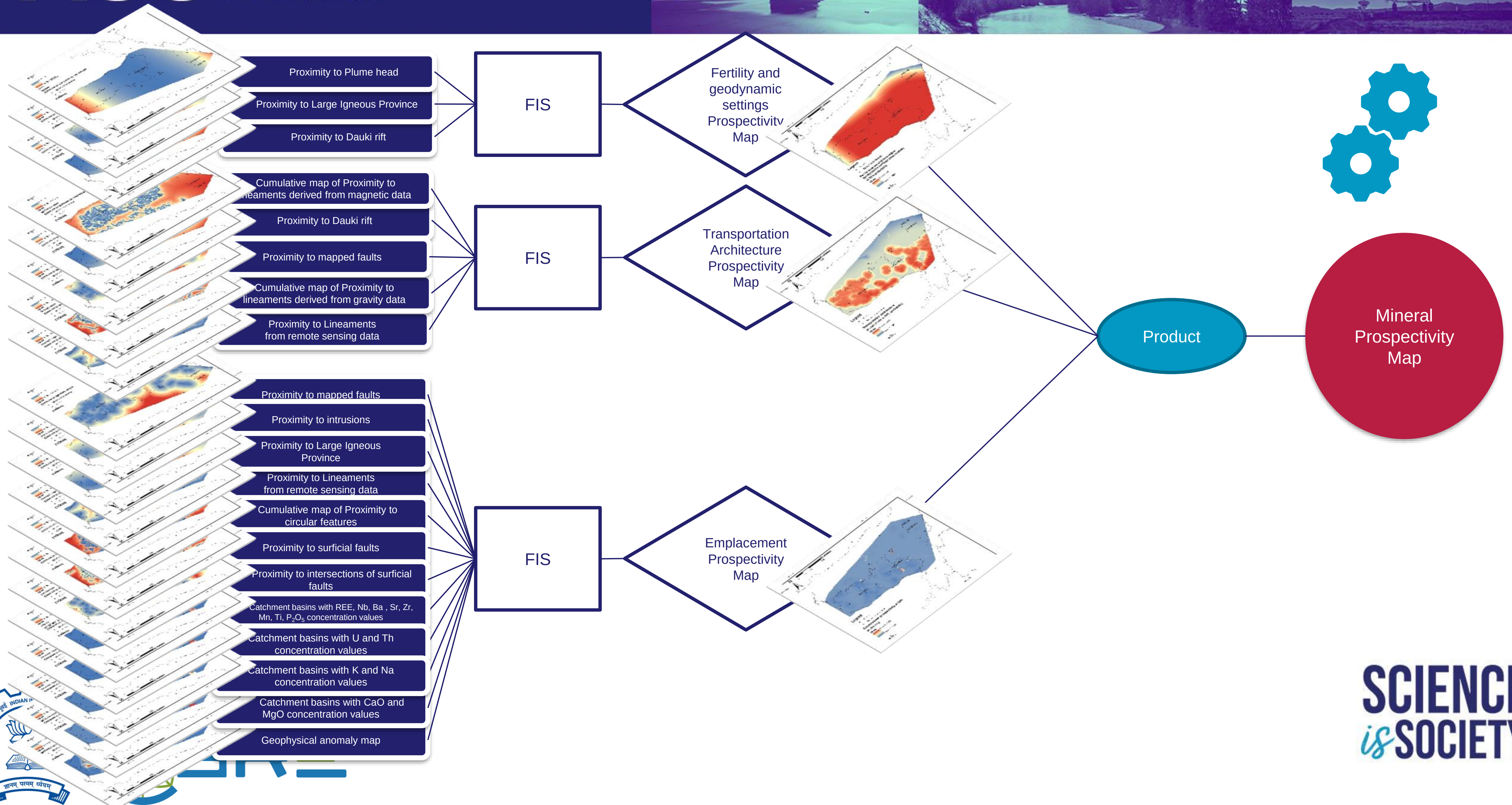

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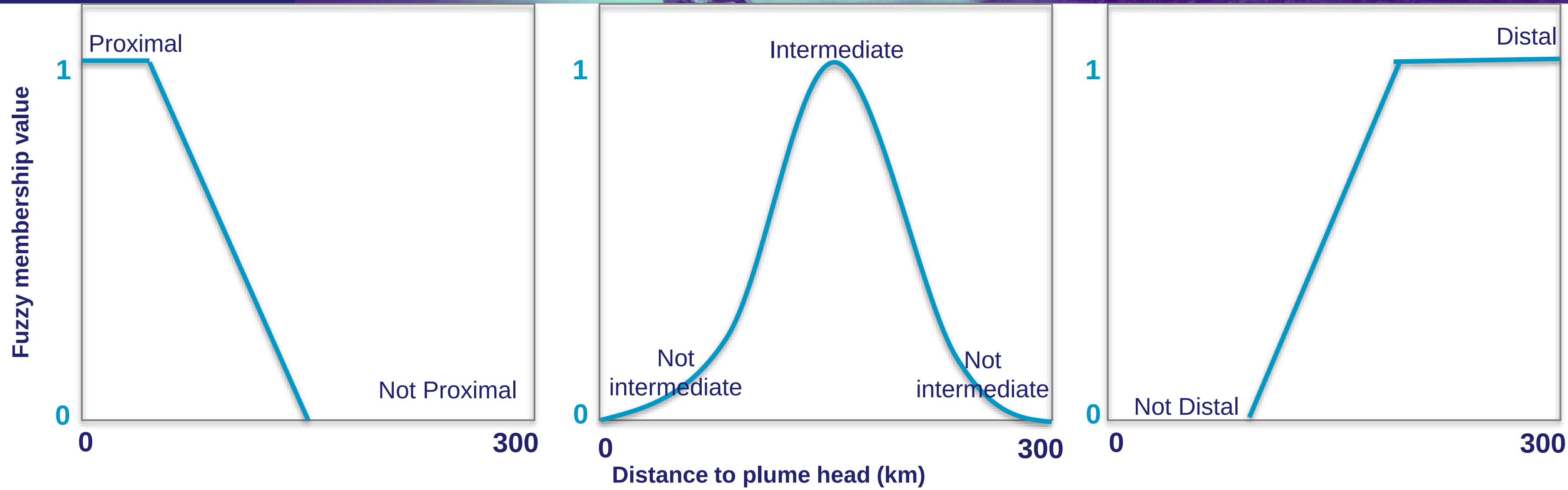
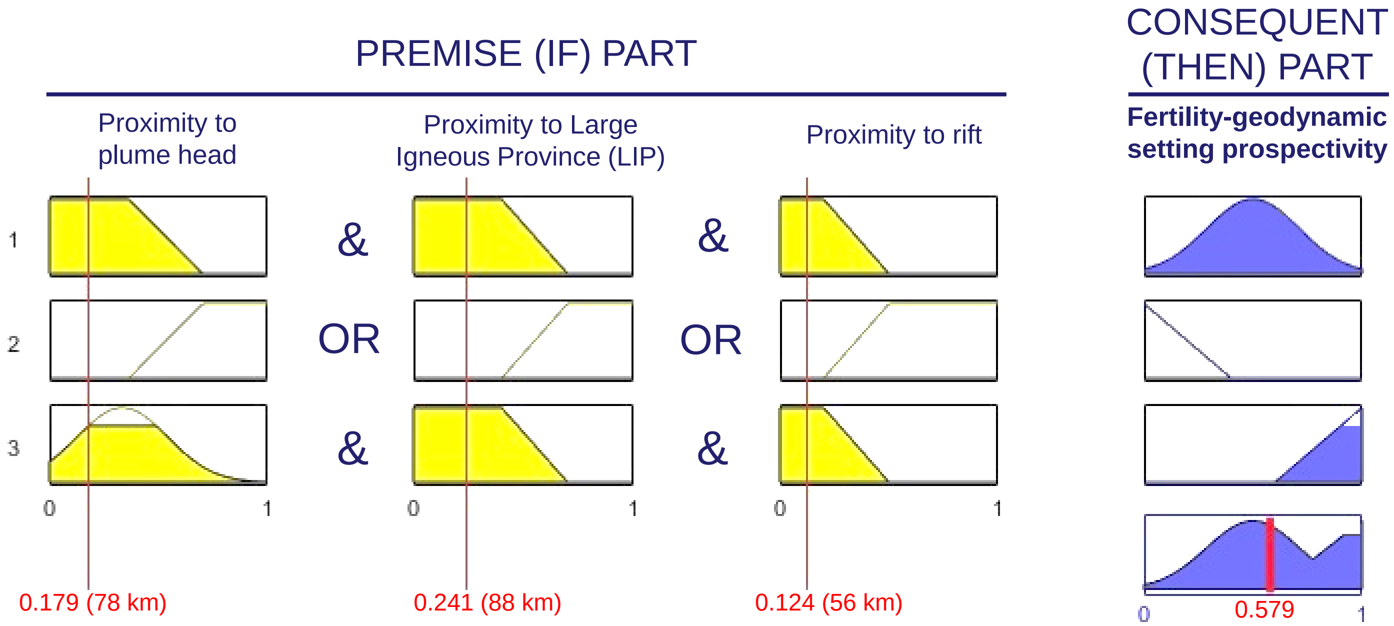
IN A FIS....





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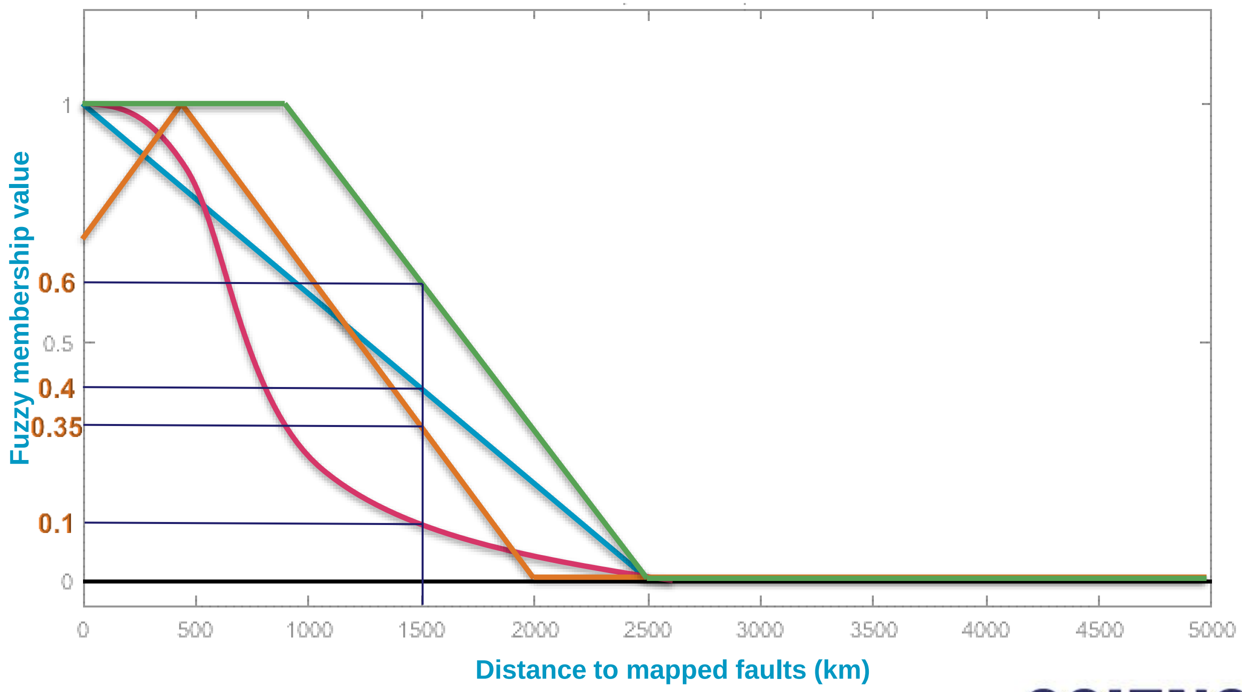
SYSTEMIC UNCERTAINTY MODELLING

- Main sources of uncertainty – Fuzzy membership functions
  - Linear
  - Gaussian
  - Triangular
  - Trapezoidal



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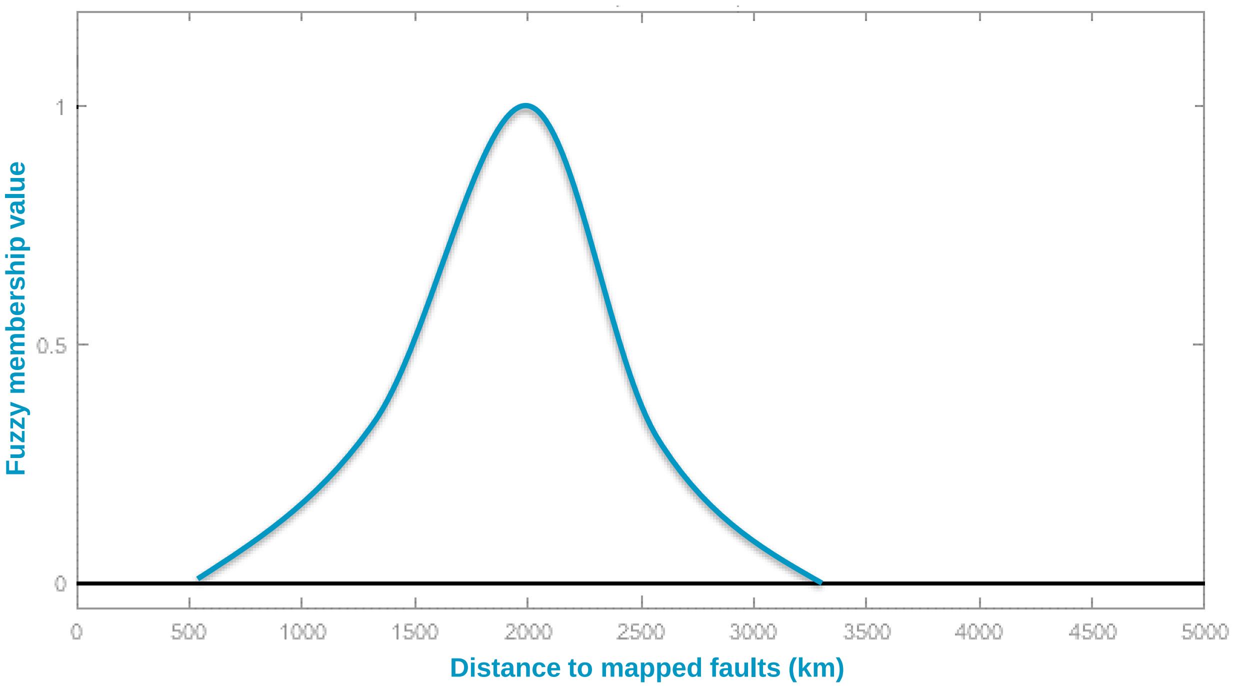

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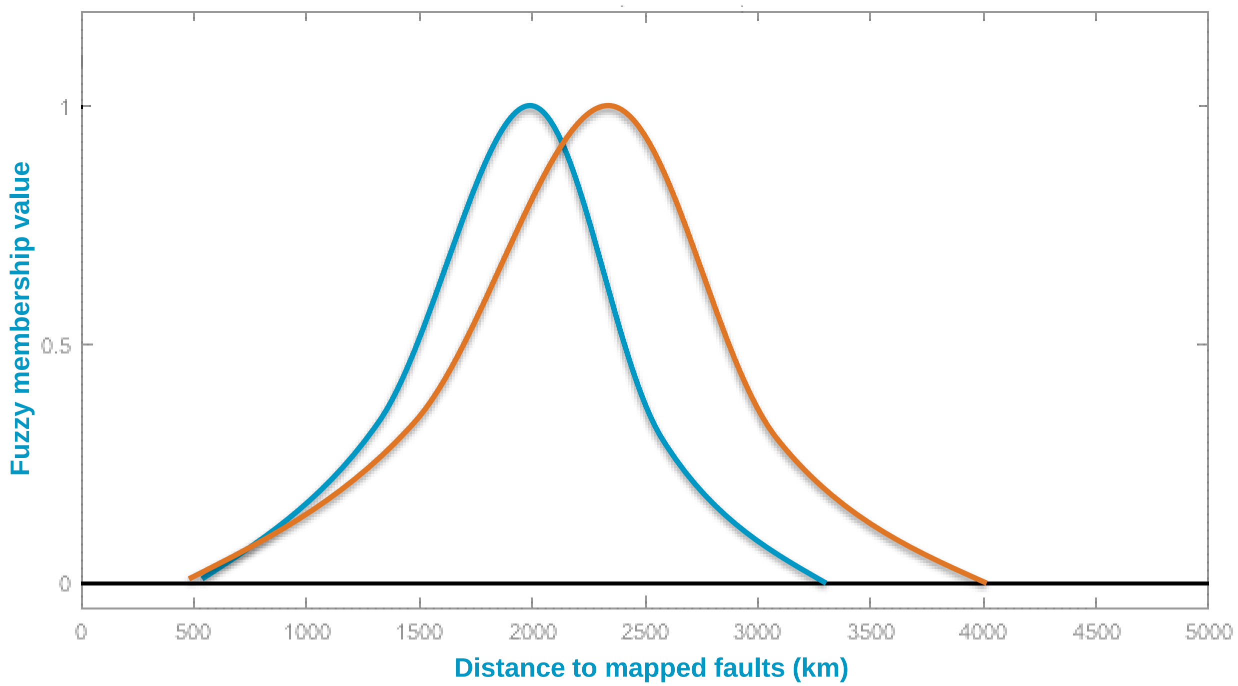

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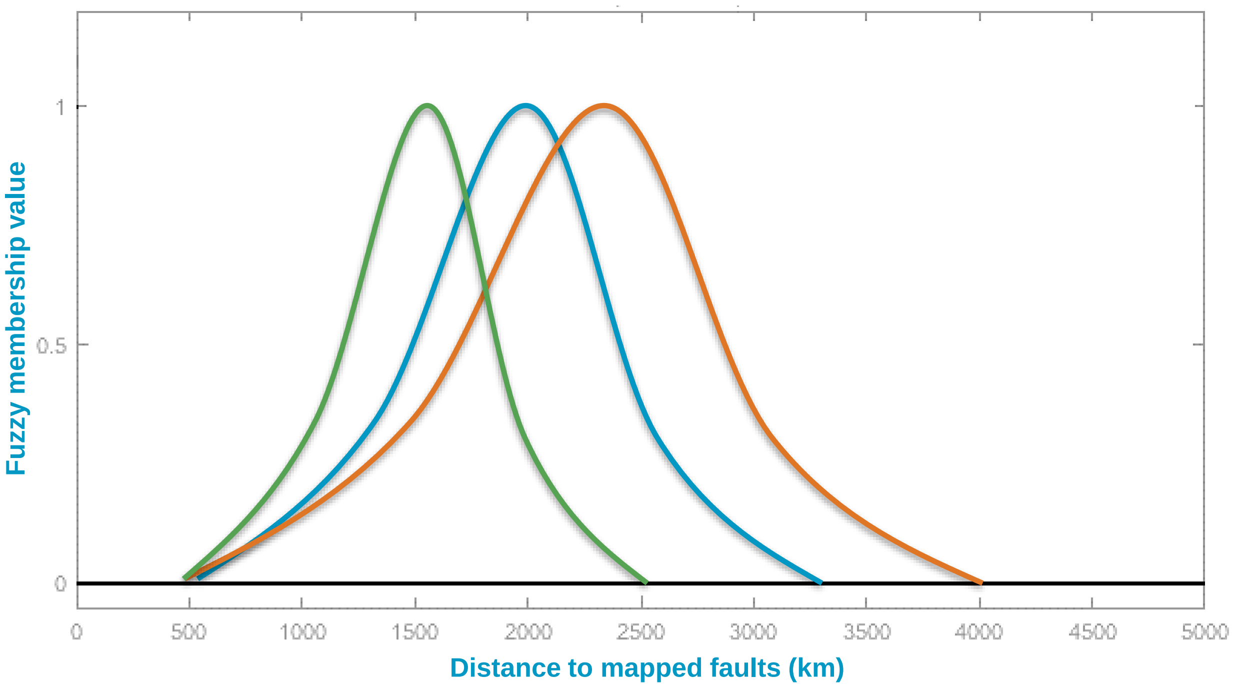

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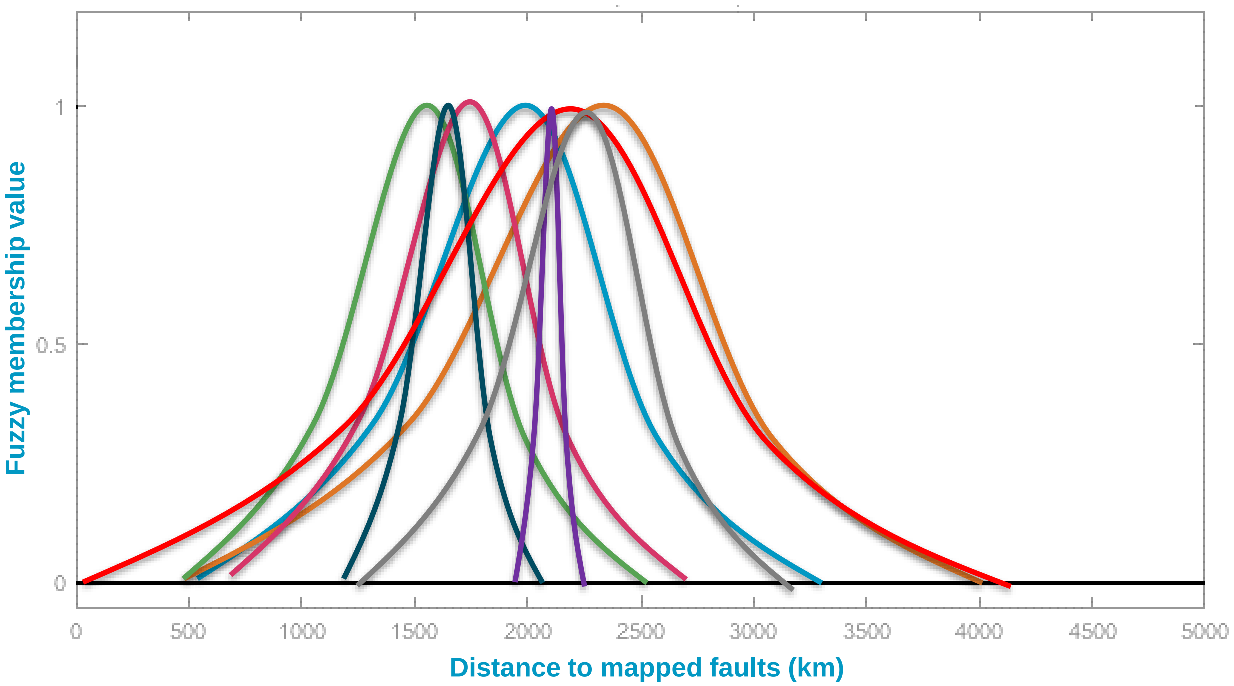

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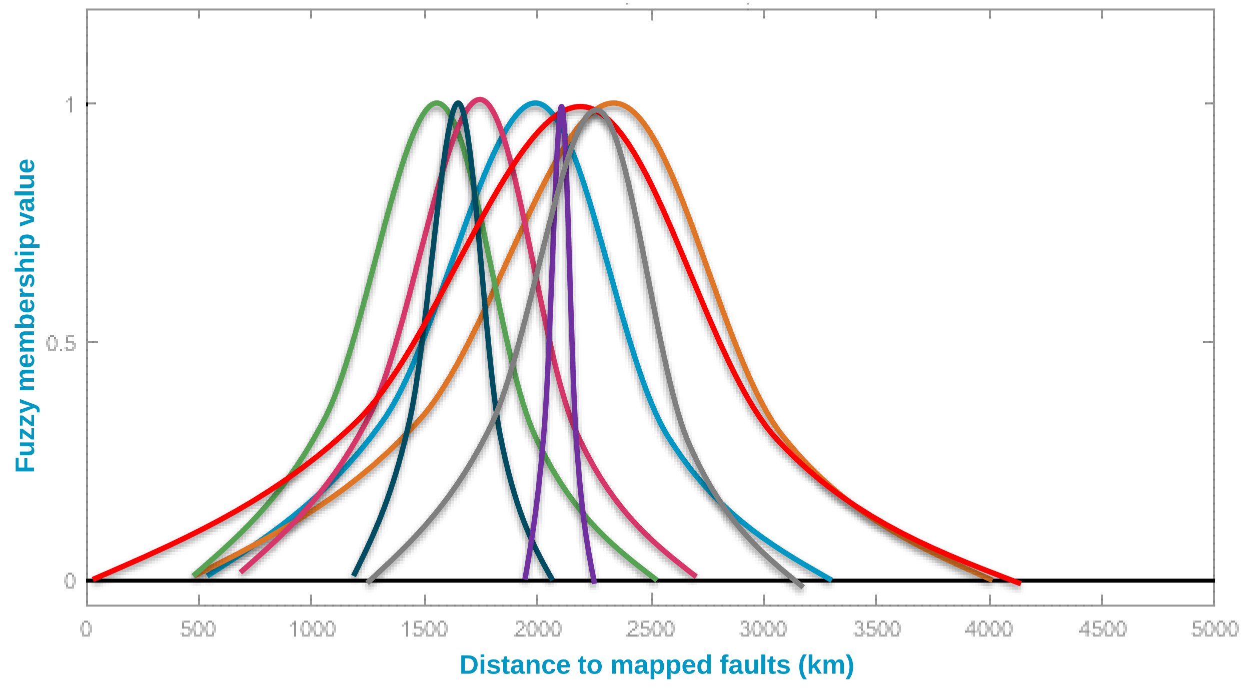
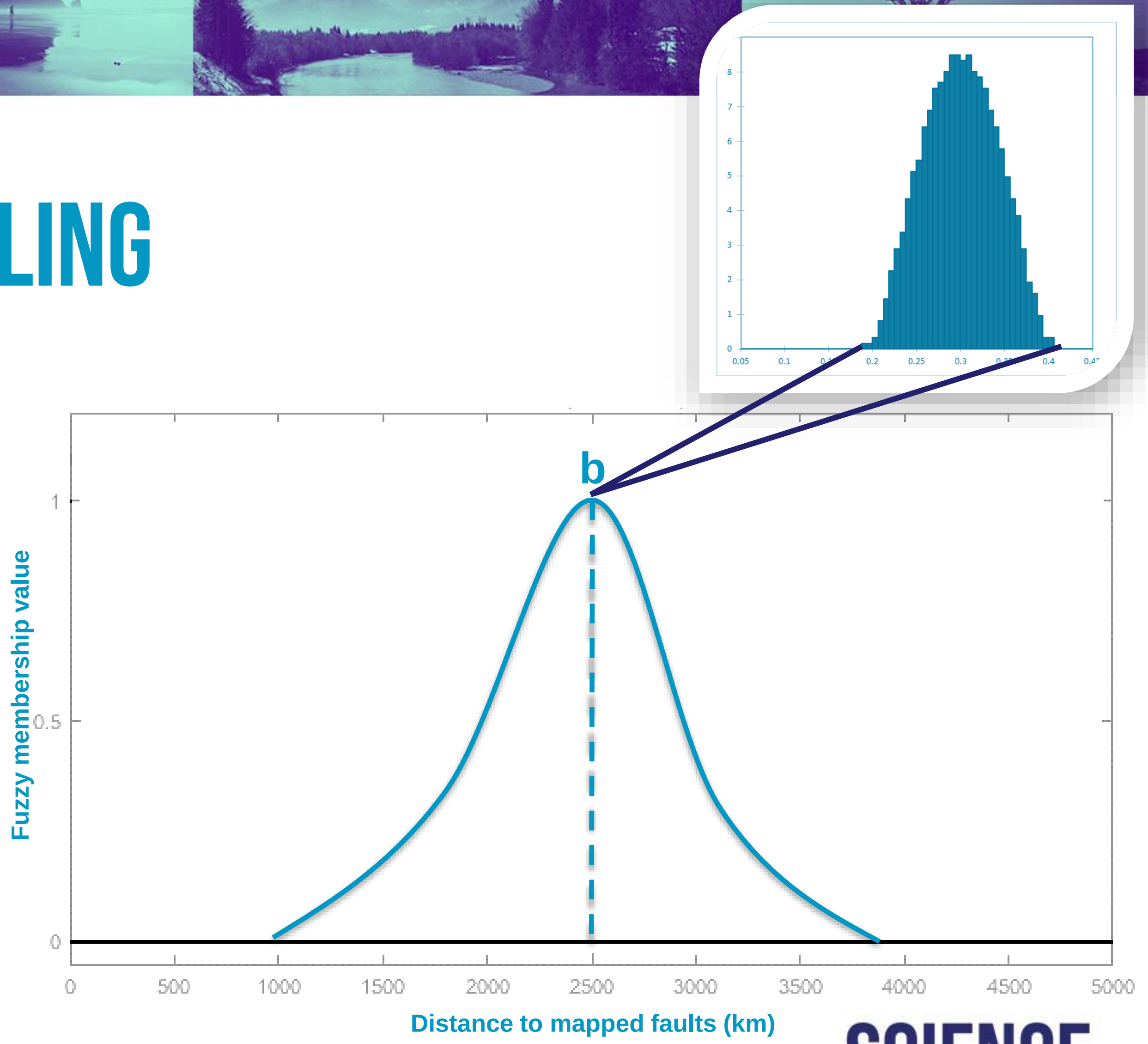


$$y = e^{\left(-\frac{(x-b)^2}{2c^2}\right)}$$



MONTE CARLO SIMULATIONS

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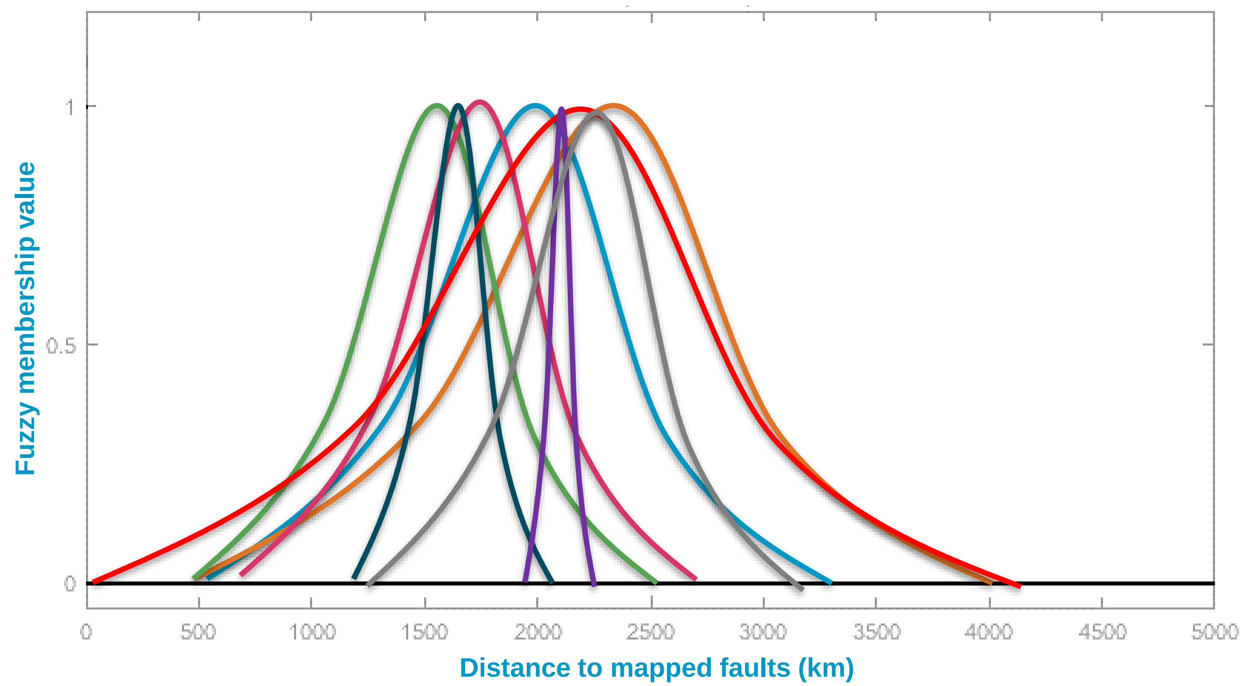
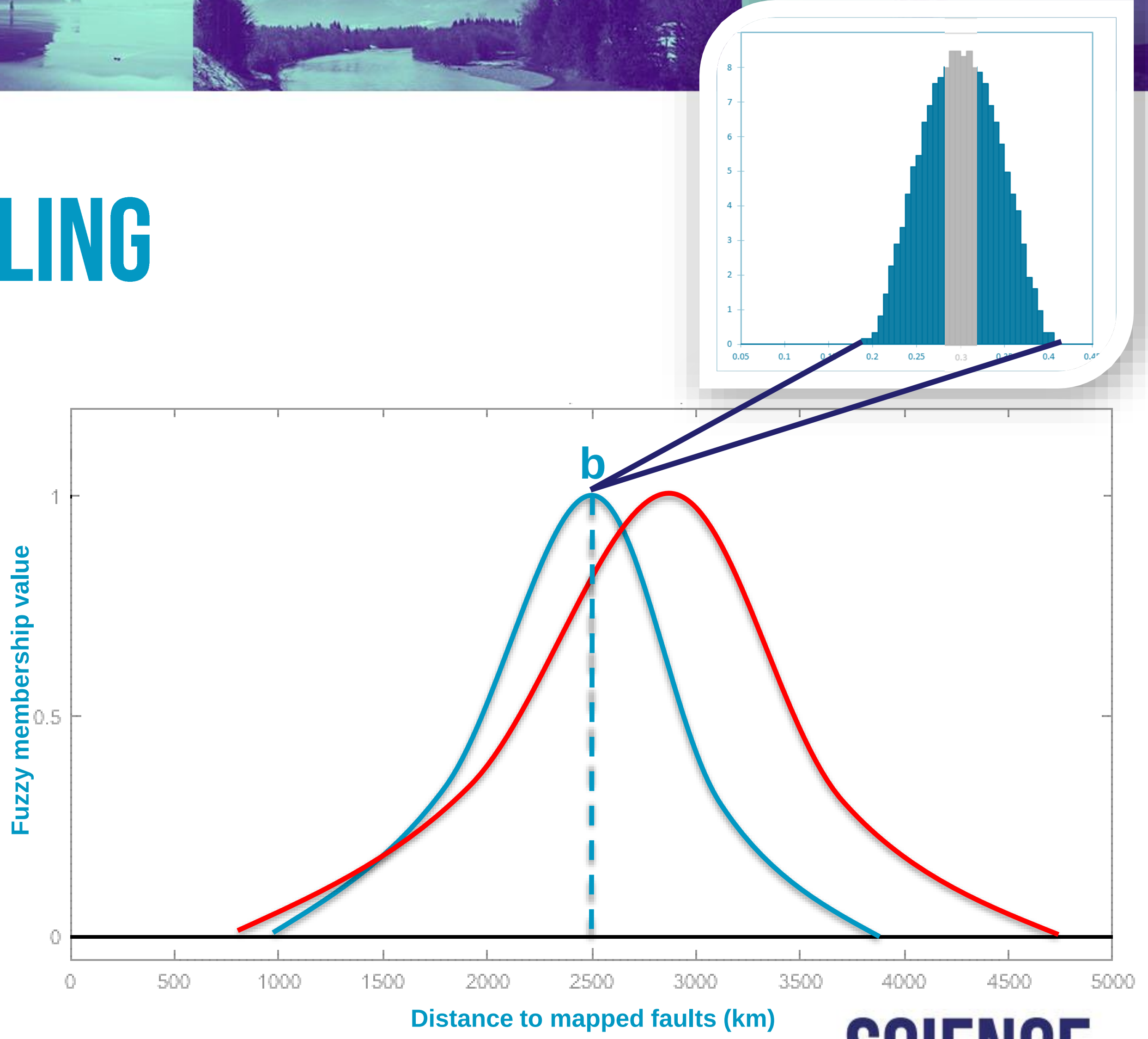
SYSTEMIC UNCERTAINTY MODELLING





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MONTE CARLO SIMULATIONS

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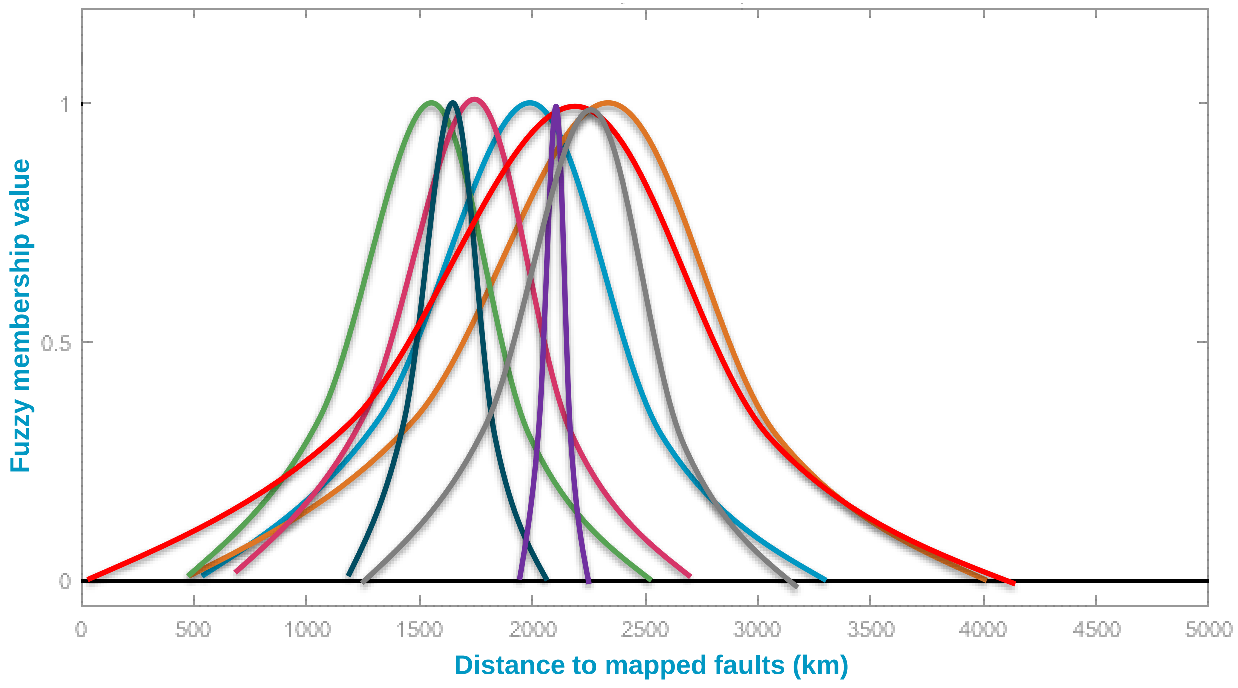

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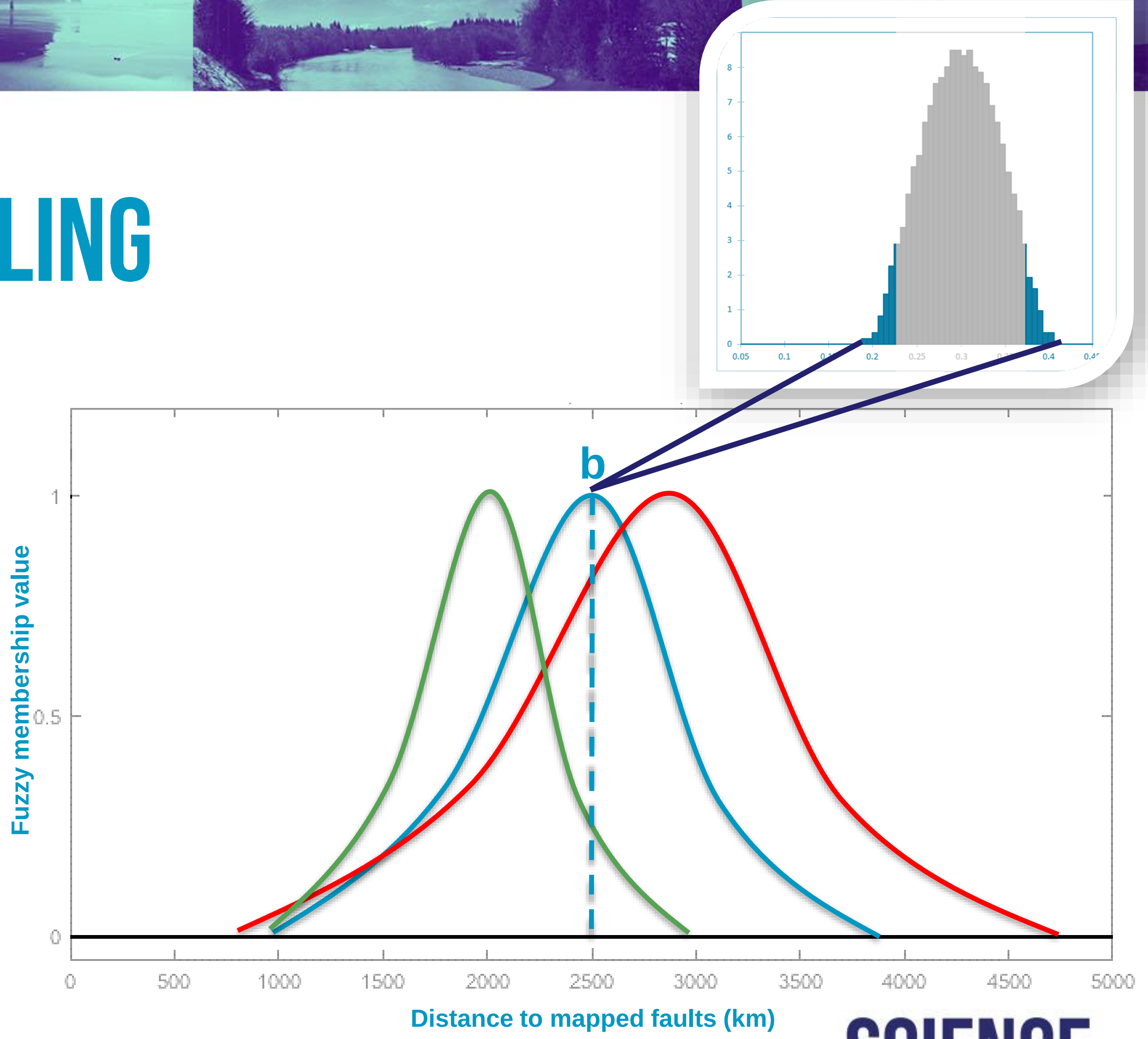

MONTE CARLO SIMULATIONS

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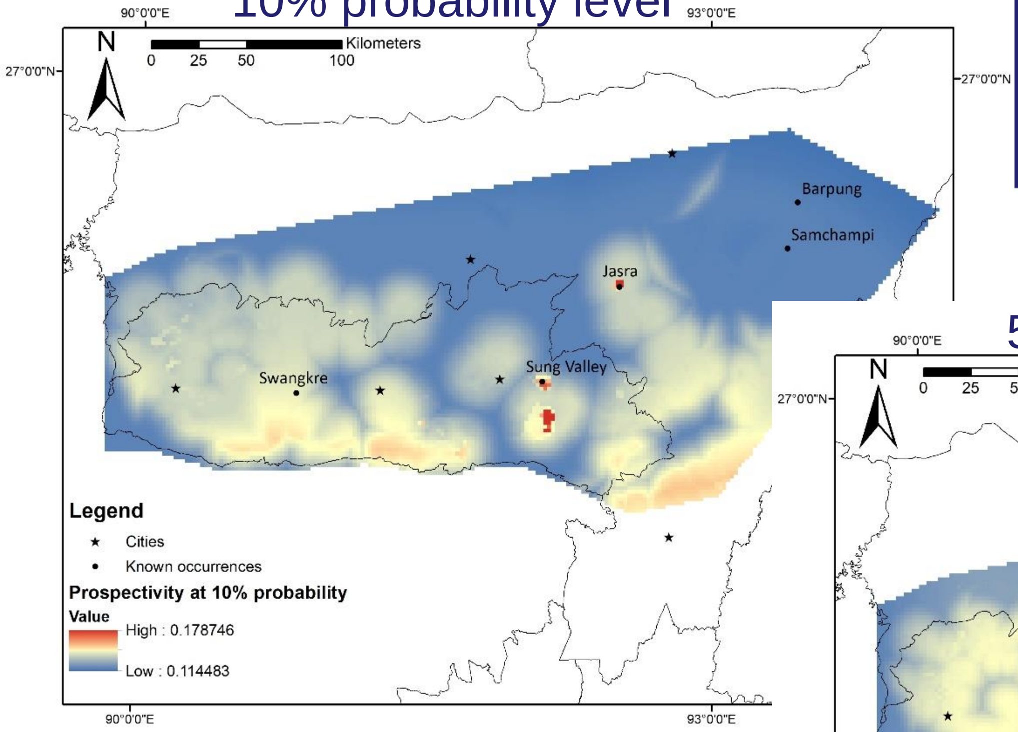
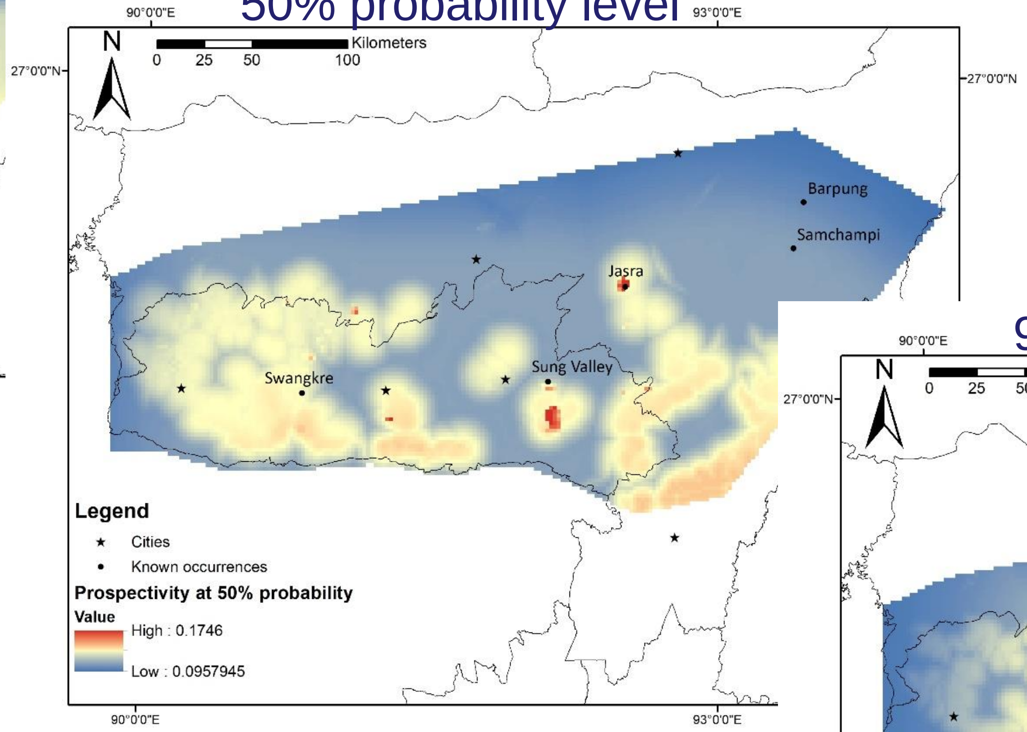
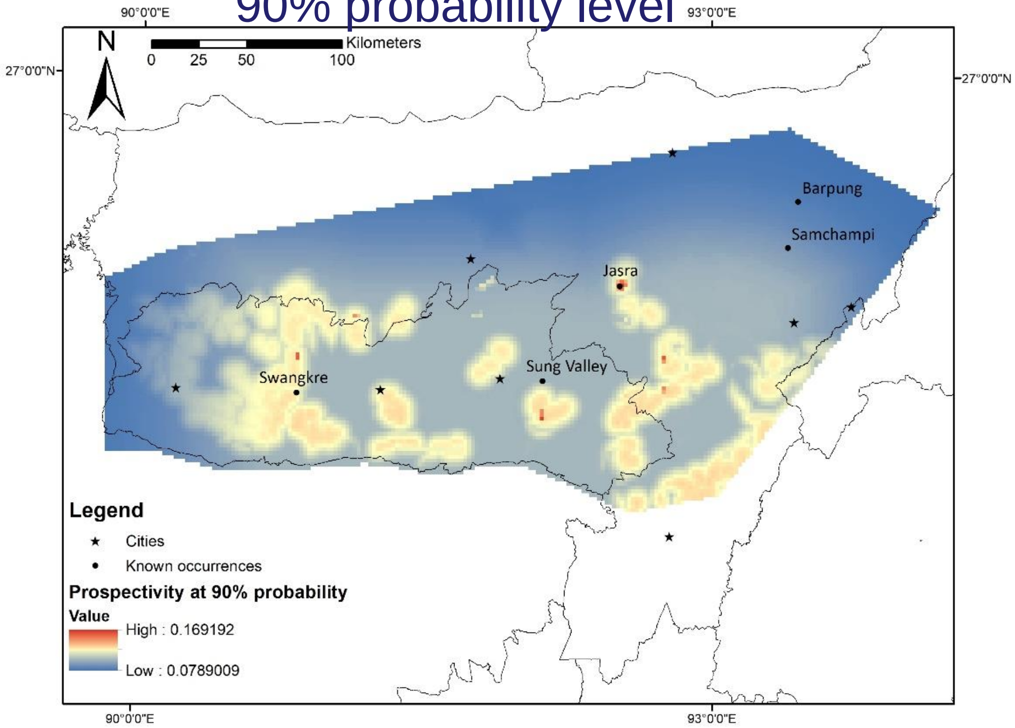
10% probability level



50% probability level

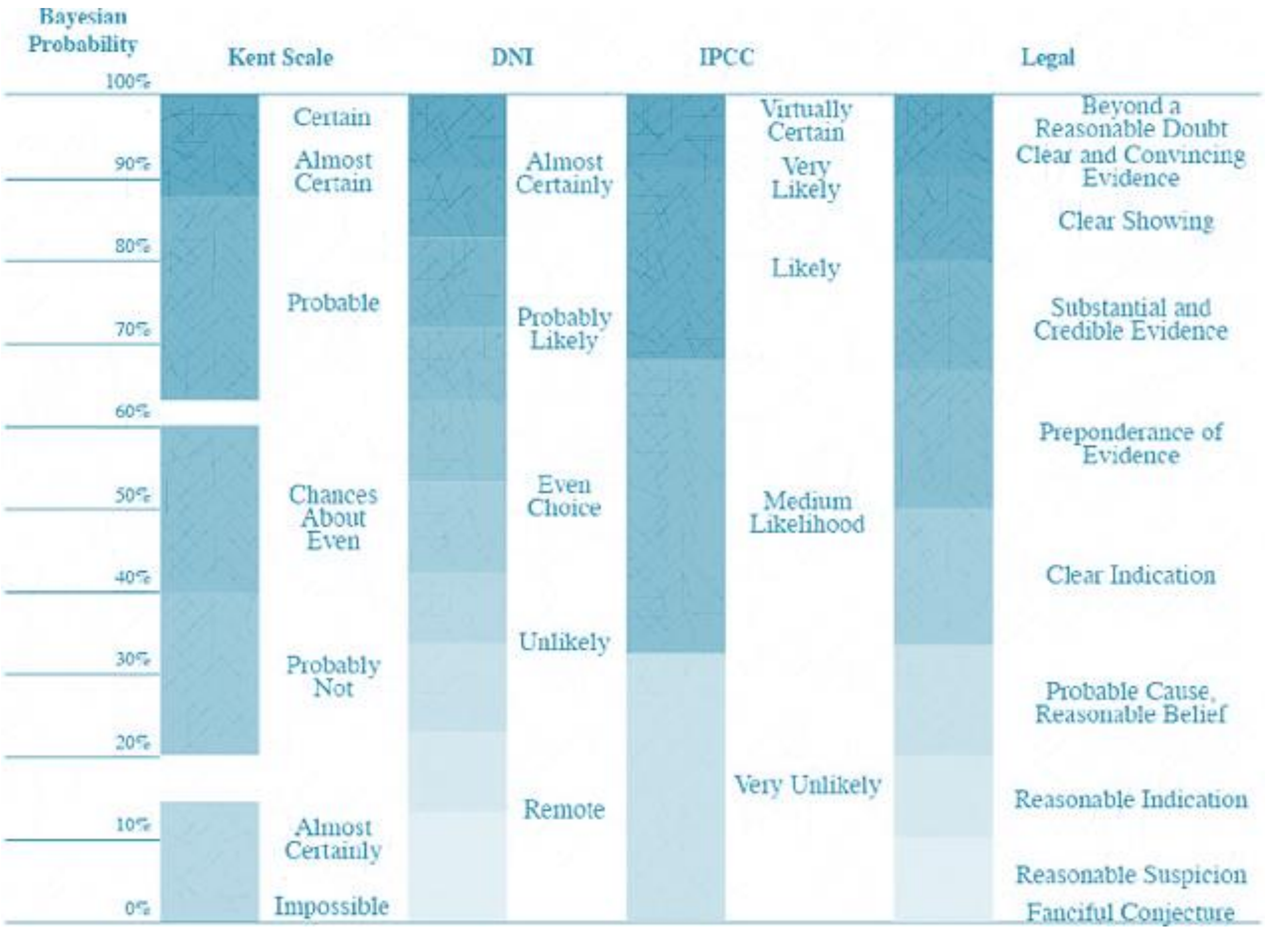


90% probability level



STOCHASTIC UNCERTAINTY

Predictor map	Confidence value	Justification for ranking
Proximity to the Rajmahal-Sylhet Large Igneous Province	0.9	LIP directly mapped on the field on 50000 scale.
Proximity to the trace of mantle plume	0.75	Derived trace, however, based on a relatively reliable alignment of remnants of Kerguelen plume products.
Proximity to Rift	0.9	Rift mapped on 50000 scale map, supported by geophysical data.
Proximity to mapped faults	0.9	Field mapped faults on 50000 scale.
Proximity to lineaments derived from magnetic data	0.7	Derived from lineament extraction processing of magnetic data.
Proximity to lineaments derived from gravity data	0.7	Derived from lineament extraction processing of gravity data.
Proximity to lineaments from remote sensing data	0.5	Derived by lineament extraction of remotely sensed data, may contain geomorphological lineaments.
Proximity to intrusions	0.9	Intrusions directly mapped on field on 50000 scale.
Proximity to circular features	0.5	Derived by processing geophysical data for circular features followed by extraction.
Proximity to surficial lineaments derived from geophysical data	0.7	Derived from lineament extraction processing of geophysical data.
Proximity to intersections of surficial lineaments derived from geophysical data	0.7	Derived from lineament extraction processing of geophysical data.
Catchment basins with CaO and MgO concentration values	0.4	Unreliable geochemical data. After cleaning up, only about 2-3 sample points represent a single basin.
Catchment basins with K and Na concentration values (Fenitisation)	0.4	Unreliable geochemical data. After cleaning up, only about 2-3 sample points represent a single basin.
Catchment basins with U and Th concentration values	0.4	Unreliable geochemical data. After cleaning up, only about 2-3 sample points represent a single basin.
Catchment basins with REE&P_2O_5&Nb&Ba&TiO_2&Sr concentration values	0.4	Unreliable geochemical data. After cleaning up, only about 2-3 sample points represent a single basin.
Magnetic anomaly map	0.7	Processed image of magnetic data.



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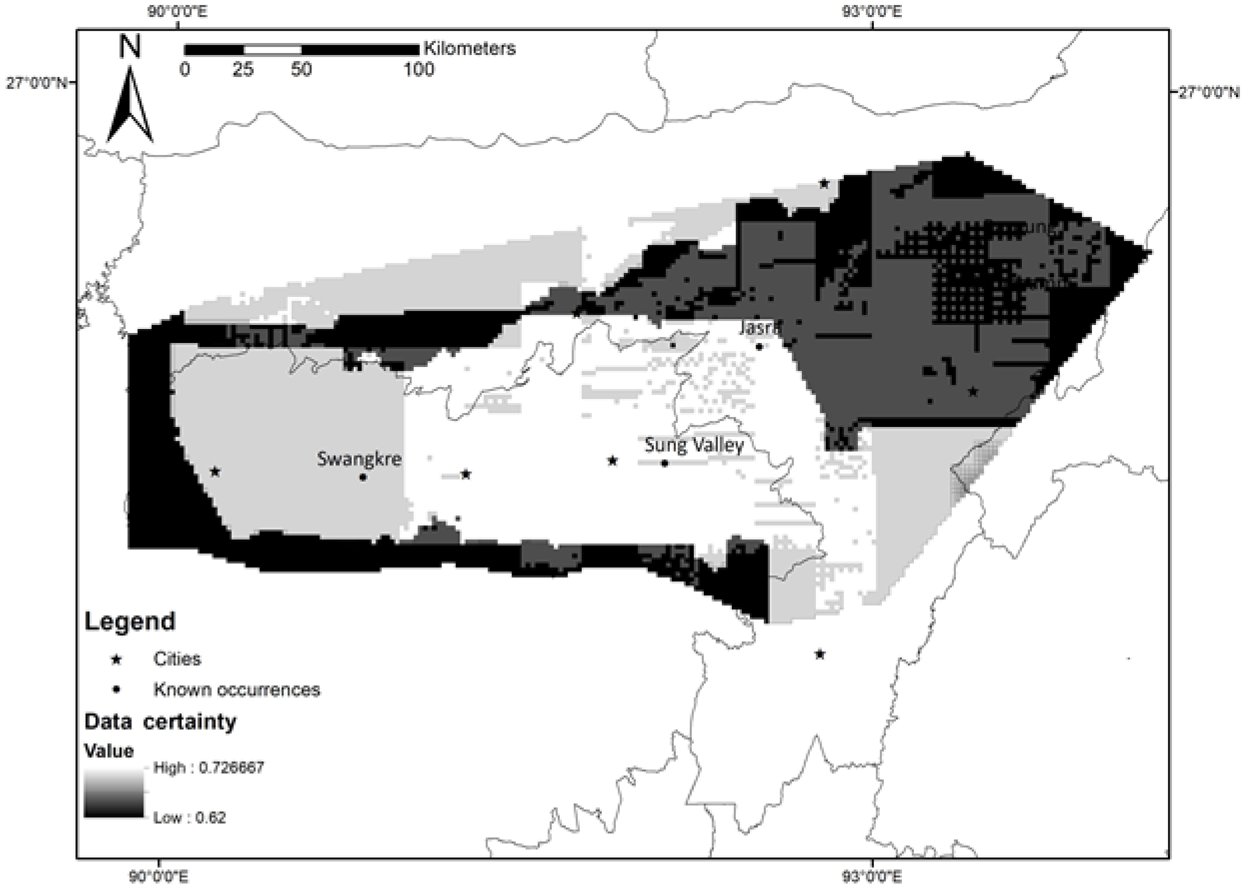

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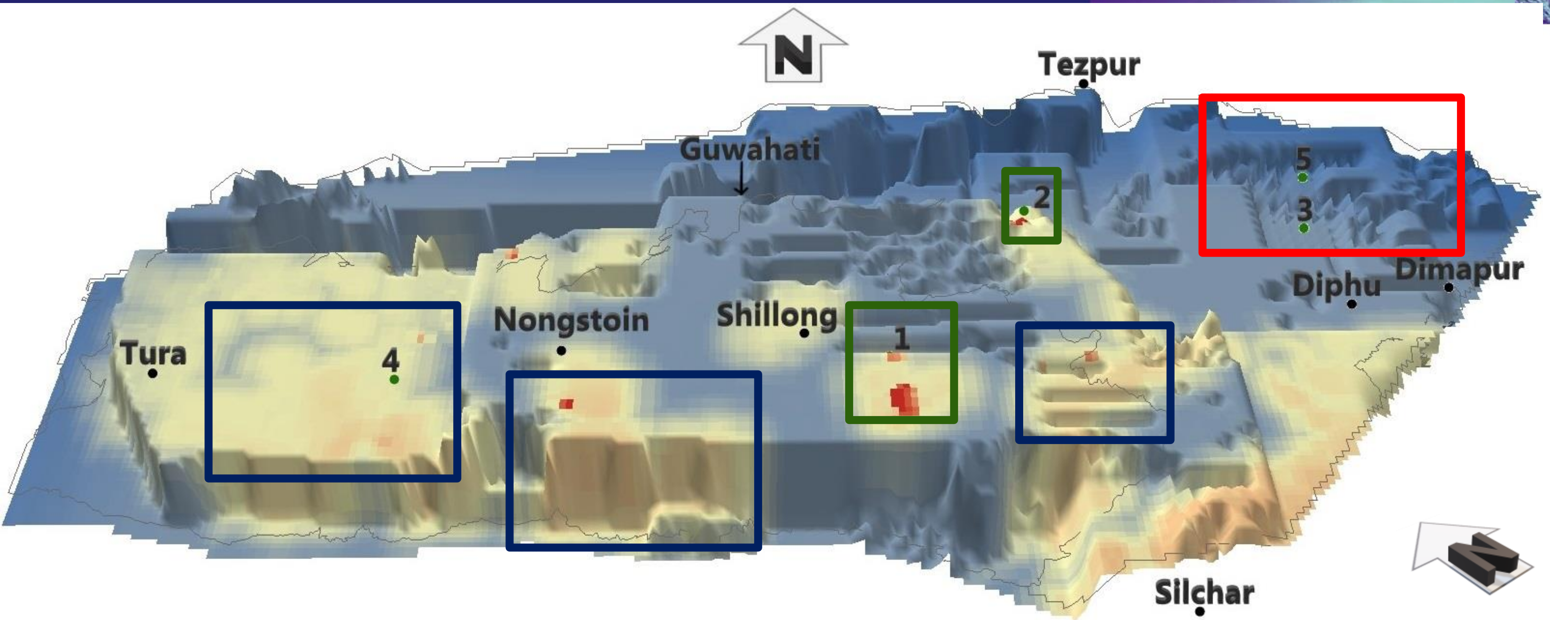

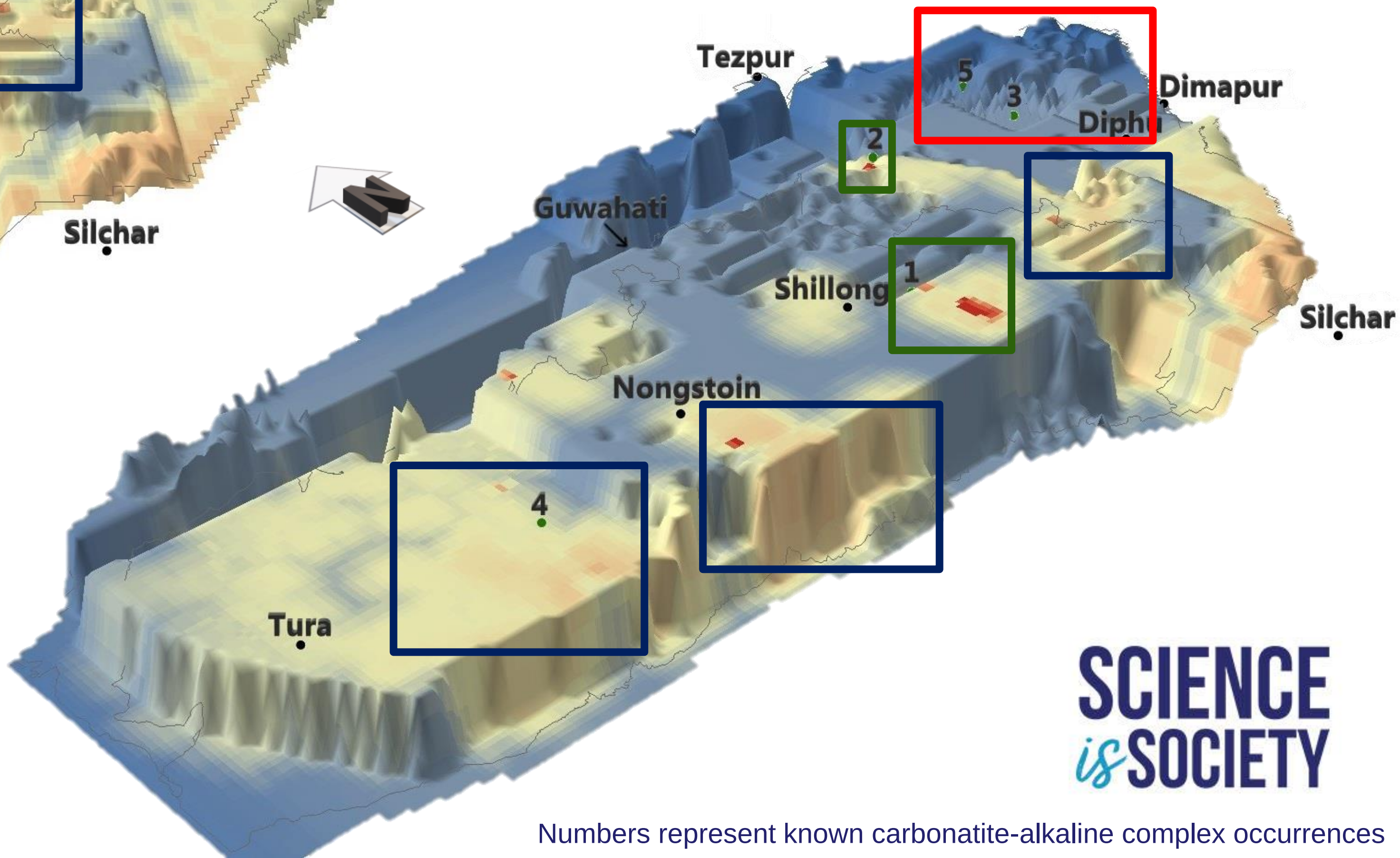

Numbers represent known carbonatite-alkaline complex occurrences

THANK YOU

Email: malcolmaranha@iitb.ac.in