Mineral Prospectivity Modeling in Ghana

Utilizing ARCSDM to model Geological and Geophysical Data

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Talk Outline

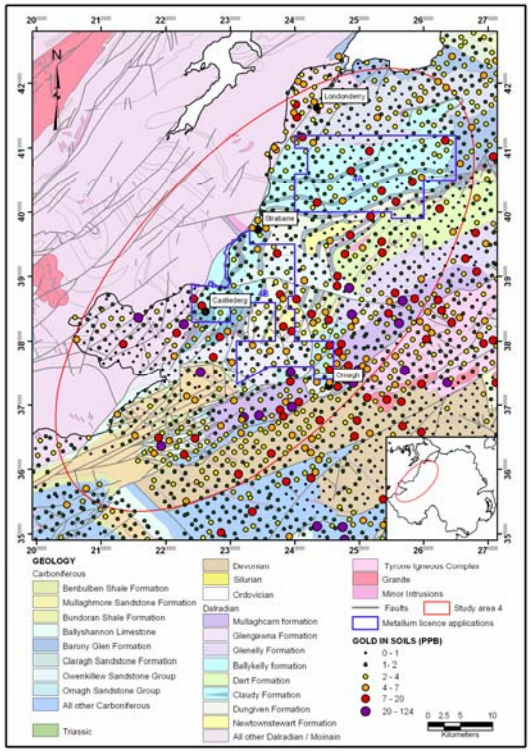
- GIS and Mineral Exploration
- Mineral deposit models
- Introducing ARCSDM
- Modelling

GIS and Mineral Exploration

Geographical information systems (GIS) and mineral exploration (1)

GIS in its basic role allows:

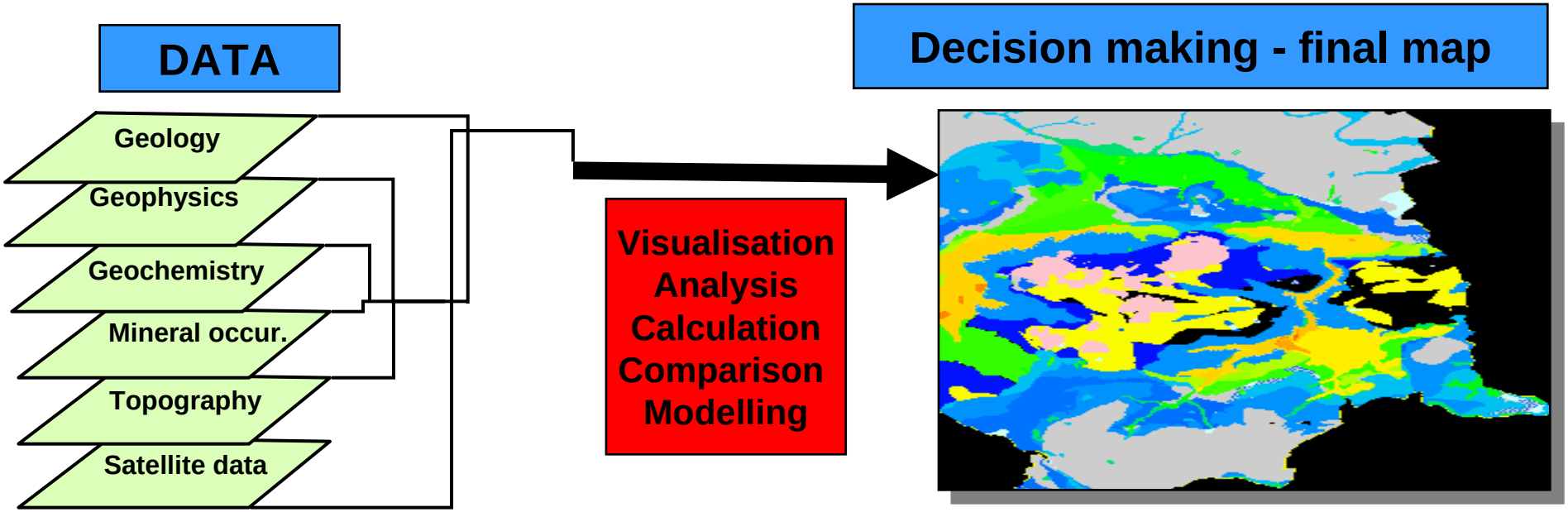
- Clear presentation of data
- Quick visual comparison of different datasets



GIS and mineral exploration (2)

More advanced uses of GIS include:

- The ability to combine and integrate data using a set of analytical functions
- Data comparison and calculation



Mineral deposit models and Mineral Exploration

Mineral Deposit

A mass of naturally occurring minerals of sufficient size and concentration to have economic value, at a given point in time.

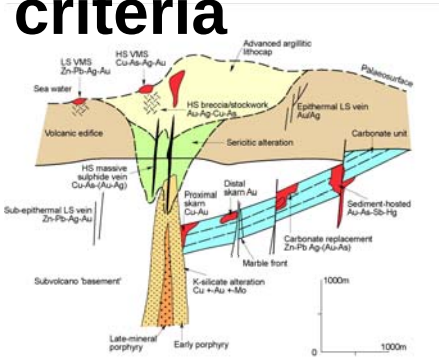
Mineral Deposit Models

WHAT:

A compilation of information about mineral deposits including: descriptions, geology, genesis, geophysical / geochemical properties and classification

WHY:

In order to classify the deposit, identify its main characteristics and **ultimately to identify exploration criteria for similar type deposits**



Prospectivity Analysis

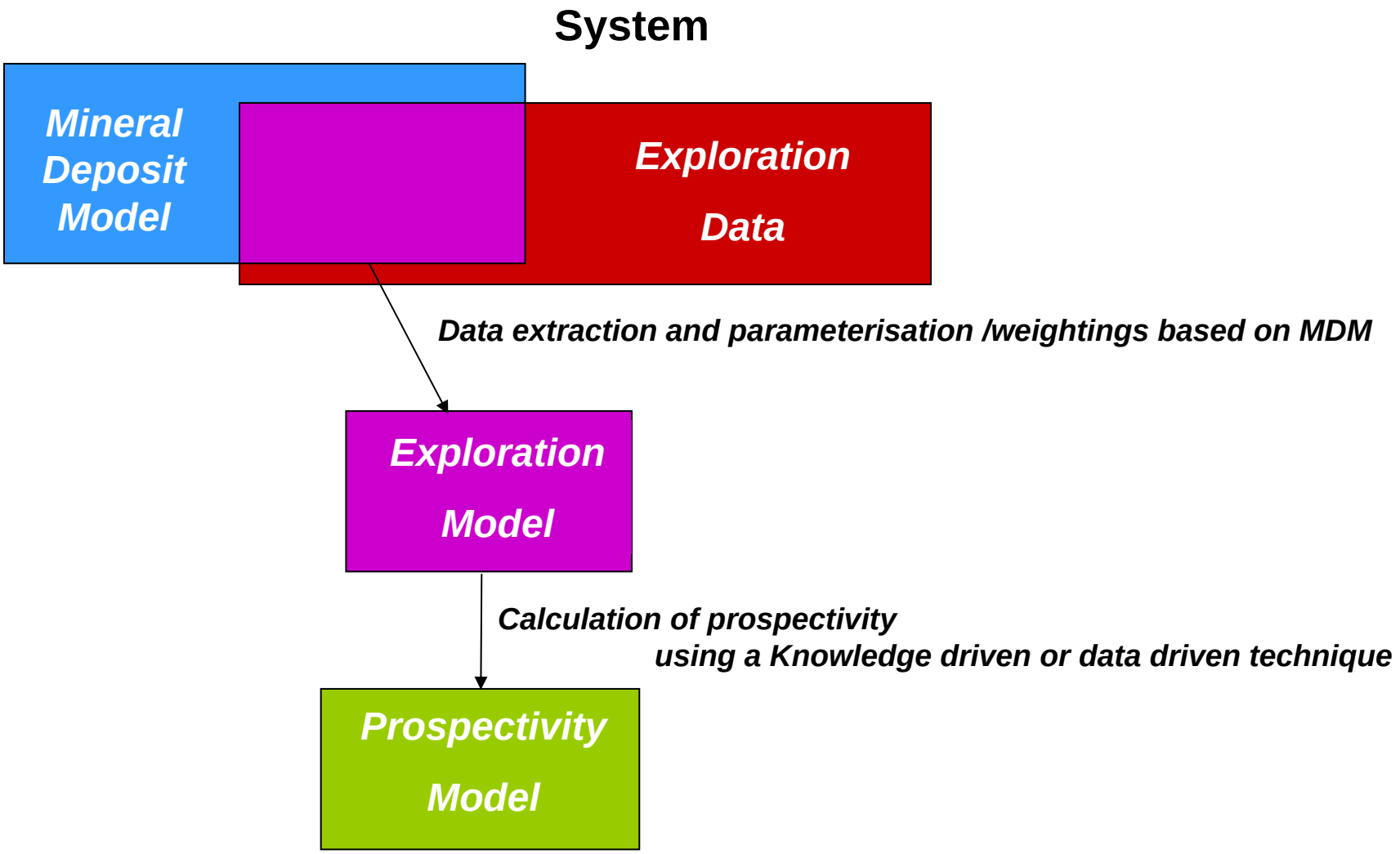
Prospectivity modelling (1)

Definition

Statistical combination of data layers e.g. *geology, geophysics, geochemistry, mineral occurrences, satellite imagery* in order to answer complex spatial questions and identify patterns.

…a technique to assist the explorationists, not to replace or over-rule them

Prospectivity modelling (2)



The two main methods of Prospectivity Modelling

1. Knowledge driven: explores the relationship between spatial exploration data sets and the mineral deposit model (MDM) underpinned by the deposit model for the target style of mineralisation:

   - used when none or limited number known mineral occurrences
   - explorationist assigns weightings based on MDM

2. Data driven: probability-based method using the spatial distribution of known mineral occurrences to determine favourability (e.g. weights of evidence, neural networks)

The choice of technique is governed by data availability

Prospectivity modelling (4)

Software

ARC Spatial Data Modeller

Arc-SDM provides 6 methods of prospectivity analysis:

Weights of evidence Normal

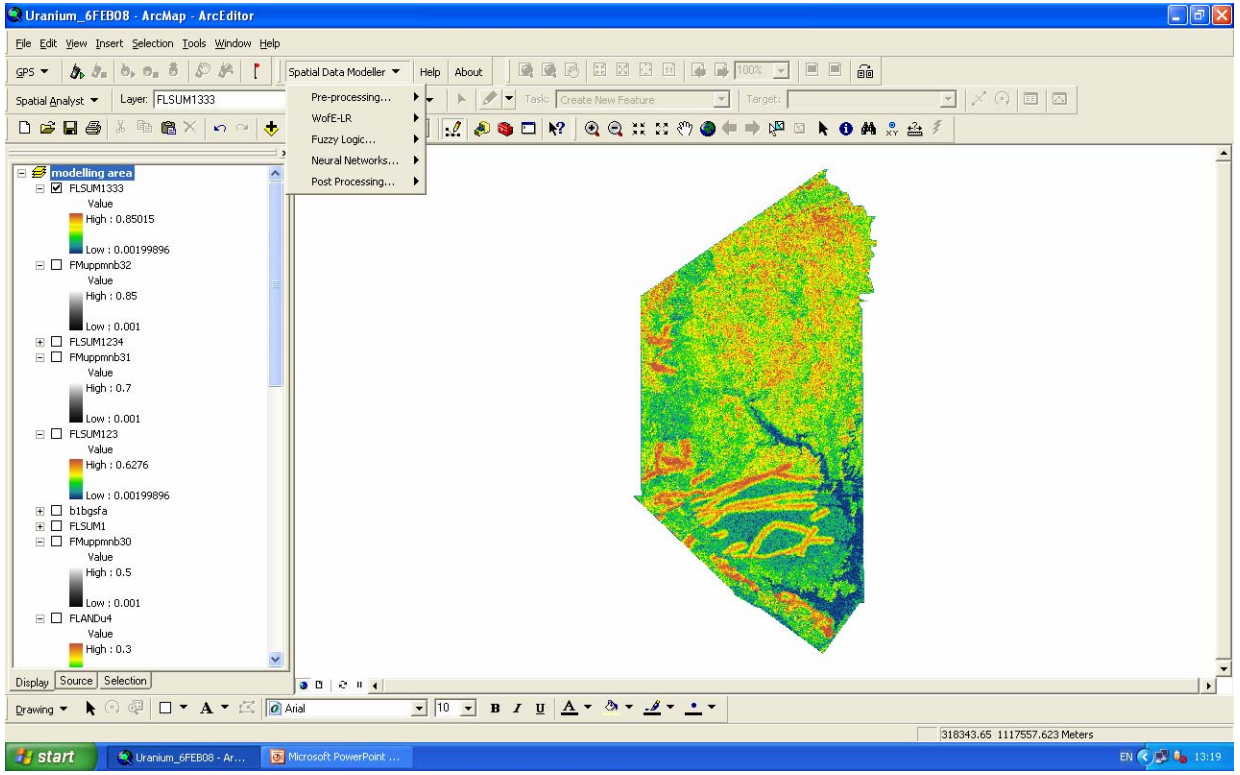
Weights of evidence Expert

Logistic regression

Neural Network Supervised

Neural Network unsupervised

Fuzzy Logic



Prospectivity modelling (5)

Fuzzy logic operators

- *Fuzzy AND of a group of fuzzy memberships (μ) is:*

  $f_{AND} = MIN\ \{\mu_i\}\ \ i = 1, n$ *eg [0.4,0.7] > 0.4*

- *Fuzzy OR of a group of fuzzy memberships is:*

  $f_{or} = MAX\ \{\mu_i\}\ \ i = 1, n$ *eg [0.4,0.7] > 0.7*

- *The Fuzzy Algebraic Product is the product of all fuzzy membership functions:*

  $F_{PROD} = \prod \mu_i$ *for i =1, n* *eg [0.4,0.7] > 0.28*

- *The Fuzzy Algebraic Sum is one minus the product of the complement of Fuzzy membership functions:*

  $F_{SUM} = 1 - \prod (1 - \mu_i)$ *for i =1, n* *eg [0.4,0.7] > 0.82*

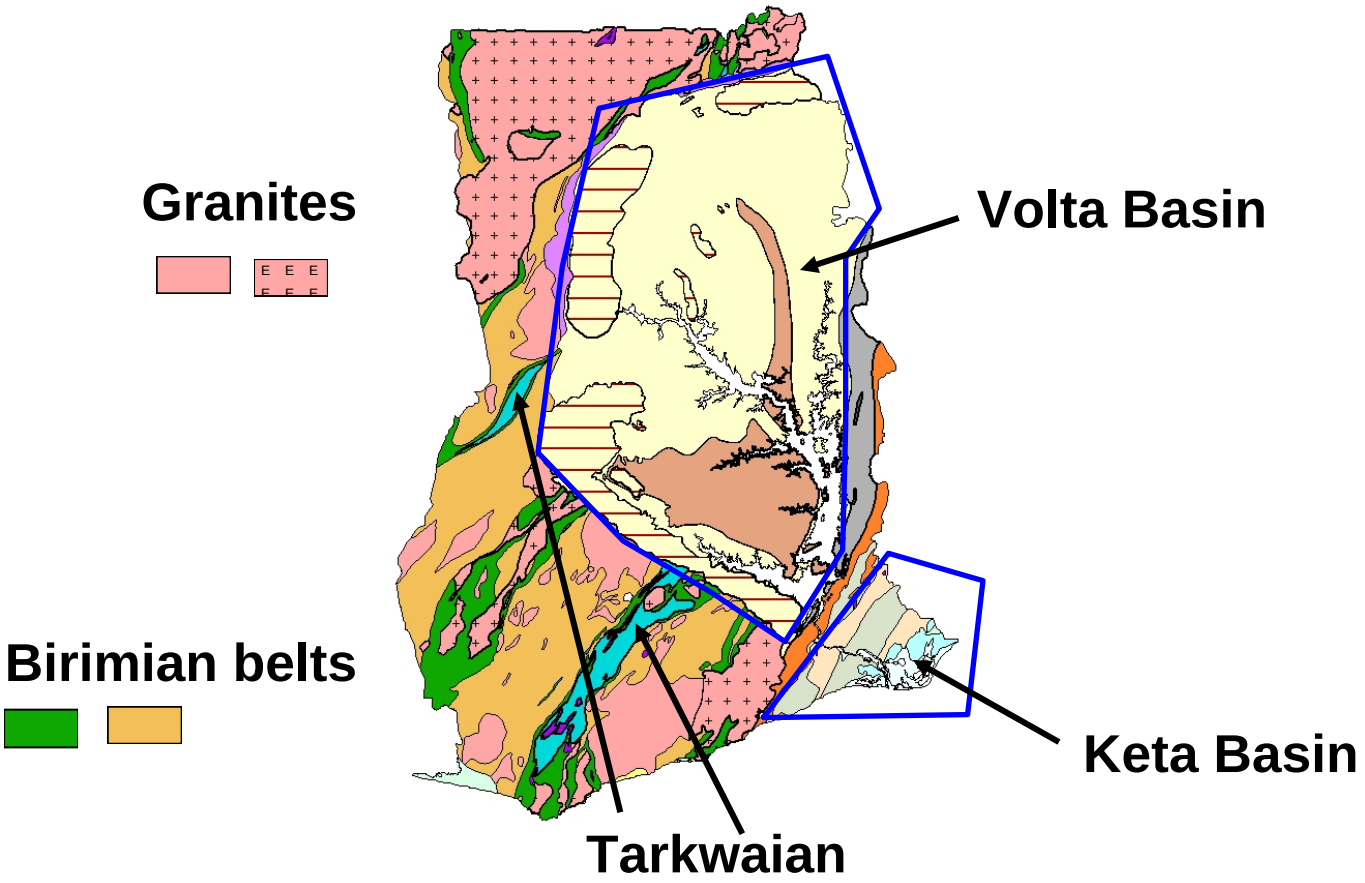
F_{PROD} is decreasive and always less than or equal to the smallest of the fuzzy memberships while F_{SUM} is increasive and always greater or equal to the maximum.

- *The Fuzzy Gamma (0. $< \gamma <$ 1.0) function is given by*
  - $F_\gamma = (F_{SUM})^\gamma * (F_{PROD})^{1-\gamma}$

The Project area

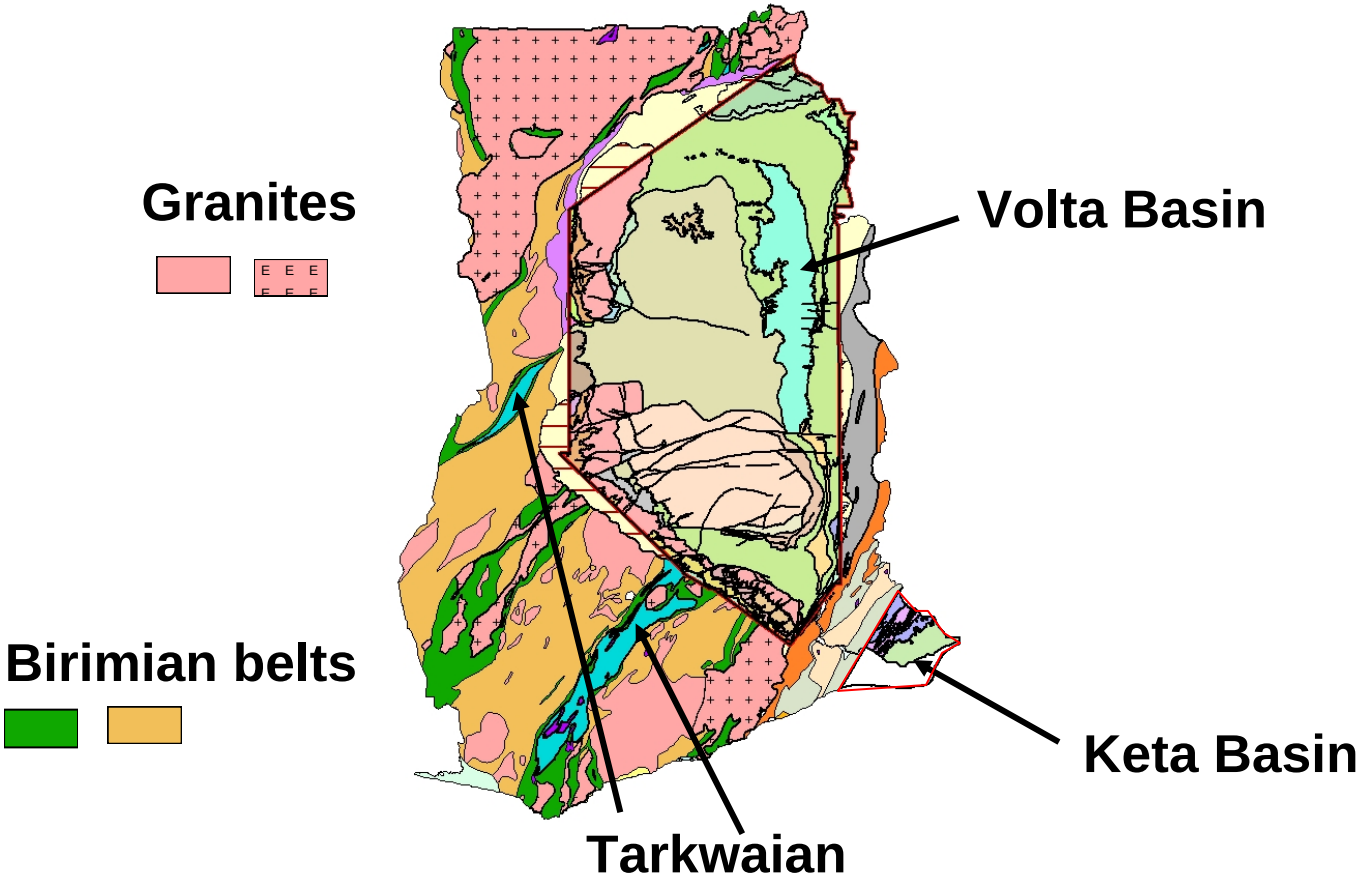
Project Area

Ghana Geology



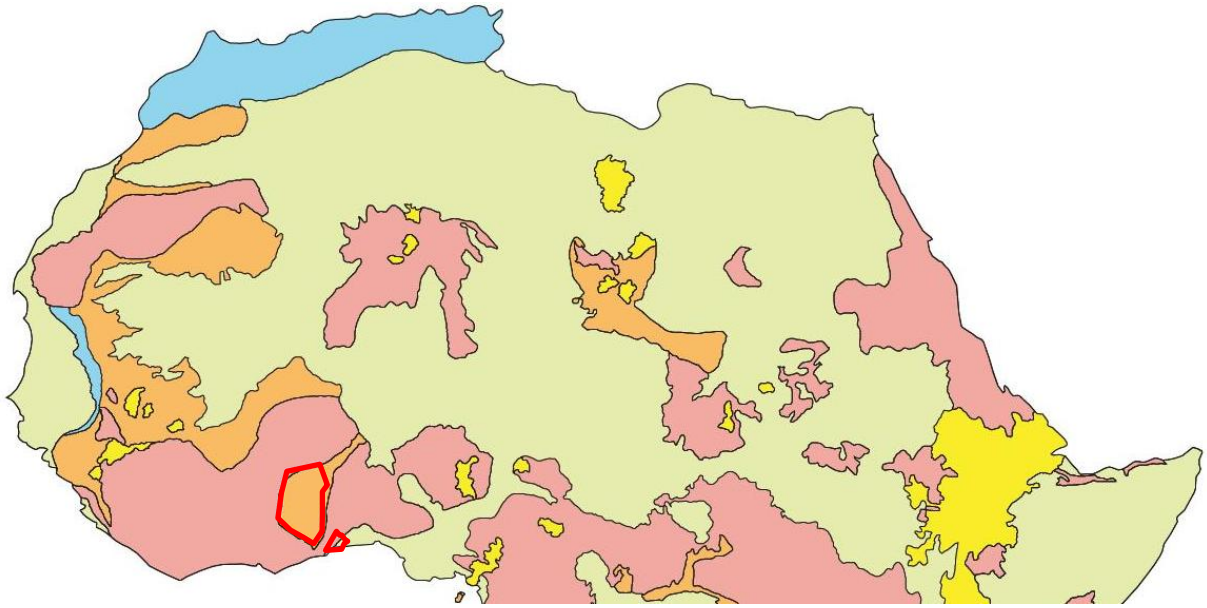
Project Area

New Geology



Project Area

Regional location



Recent to Mesozoic igneous rock coverage

Phanerozoic fold belts c.350-50 Ma

Precambrian under Mesozoic to Recent basin coverage

Precambrian basement under Neoproterozoic to Paleozoic basin coverage

Precambrian basement

Modelling Gold in the project area

West African Gold

Some examples

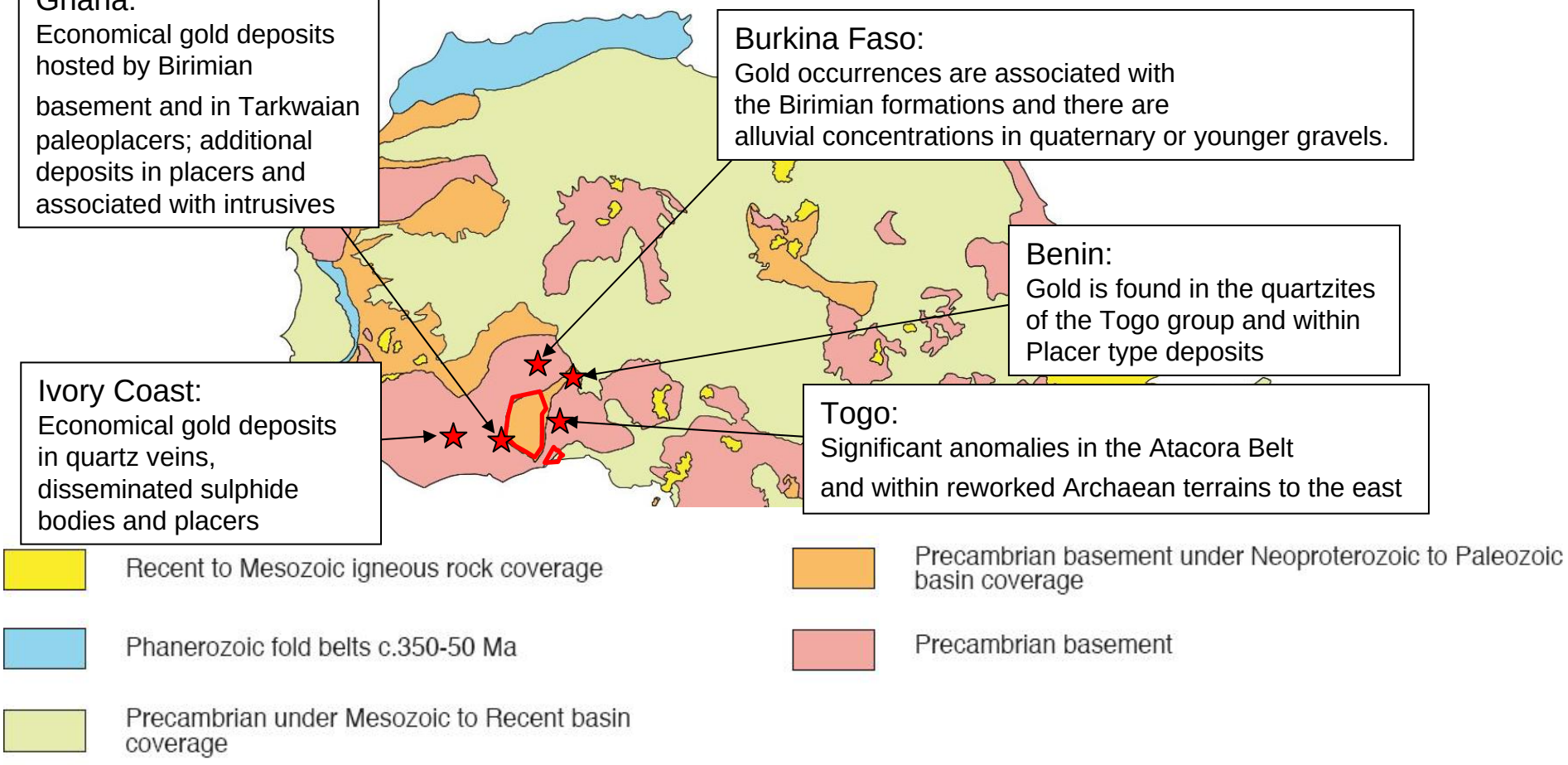
Ghana:
Economical gold deposits hosted by Birimian basement and in Tarkwaian paleoplacers; additional deposits in placers and associated with intrusives

Burkina Faso:
Gold occurrences are associated with the Birimian formations and there are alluvial concentrations in quaternary or younger gravels.

Benin:
Gold is found in the quartzites of the Togo group and within Placer type deposits

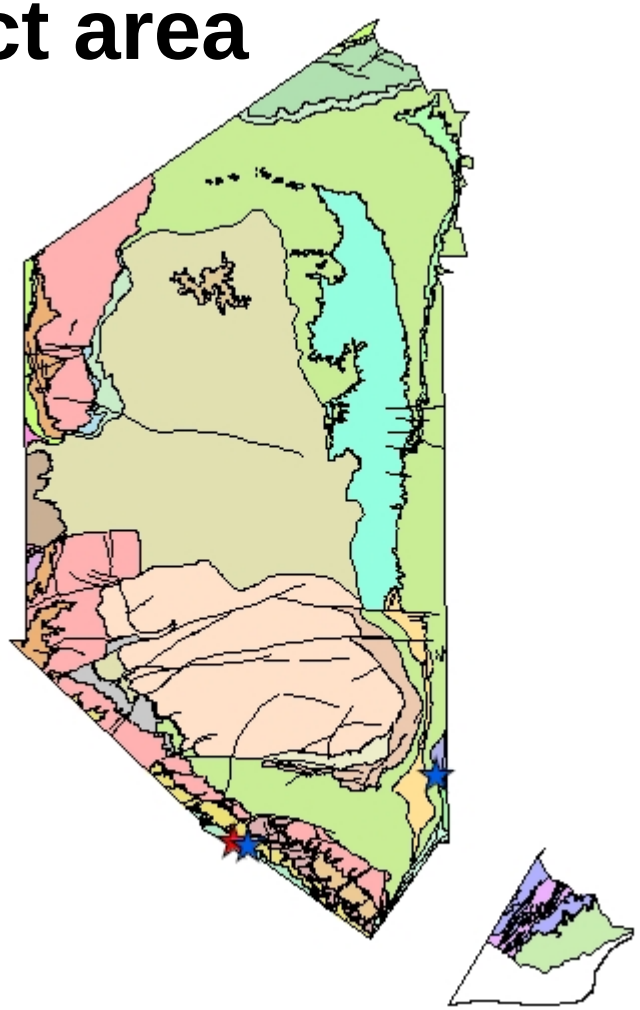
Ivory Coast:
Economical gold deposits in quartz veins, disseminated sulphide bodies and placers

Togo:
Significant anomalies in the Atacora Belt and within reworked Archaean terrains to the east



Gold in the project area

introduction



•No deposits found / mined in the project area

•Three occurrences:

2 placers (blue) e.g. Ejuanema

1 hydrothermal (red) Oboase vein

•Possible gold in the basal conglomerates of the Voltaian sediments

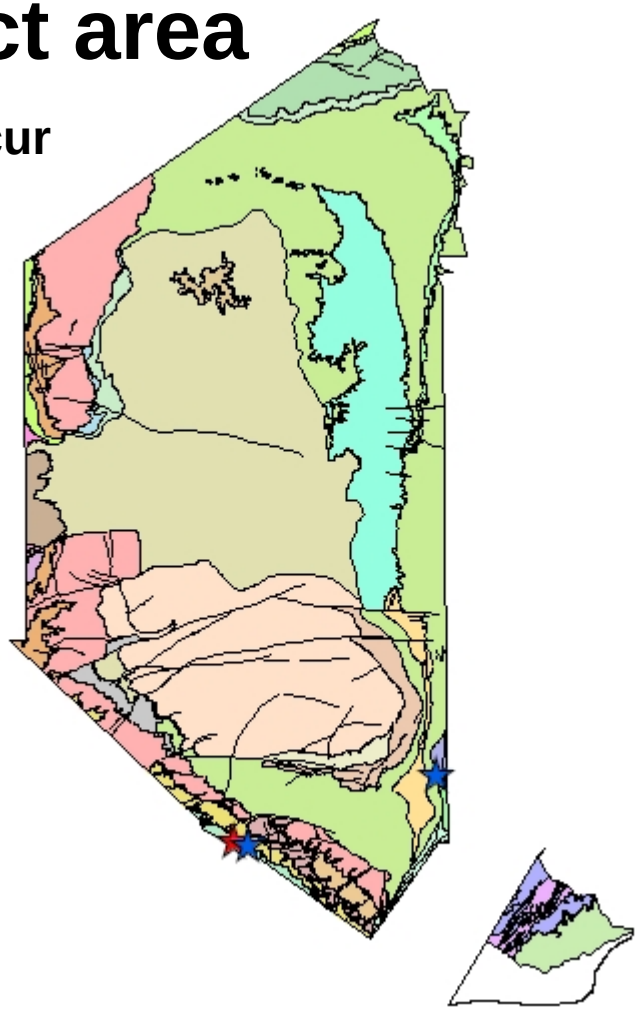
Gold in the project area

Deposits that may occur

Two possible deposit models:

•mesothermal quartz vein and

•placers / paleoplacers



AU-QUARTZ VEINS / MESOTHERMAL TYPE

Main characteristics and Exploration indicators

Major features of the Deposit type:
•Tabular veins form in deep transcrustal fault zones
•Faults act as conduits to the aqueous fluids
•Abundant in the Late Archean and Mesozoic in Lithologically highly varied rocks
Examples include the Prestea-Bogosu deposits in Ghana, Aniuri in Cote d'Ivoire and Sadiola in Mali

Exploration:
•Geochemical signature shows increase in Au, Ag, As, Sb, K, Li, Bi, W, Te and B
•Geophysics may indicate important faults which may act as fluid pathways or highlight alteration
•Geological mapping used to determine favourable structural corridors

grey quartz vein,
Prestea mine

Bogoso disseminated
sulphides type
gold deposit

PLACERS / PALEOPLACERS

Main characteristics and Exploration indicators

Major features of the Deposit type:
•Detrital gold, platinum group elements and other heavy minerals occurring at or near the surface.
•Concentrations occur along erosional surfaces at the base of channel sequences within well sorted fine to coarse-grained sands and well rounded, imbricated and clast-supported gravels.
Examples throughout the region where many small alluvial gold deposits are known to exist e.g. Alibori in Benin, while within Ghana the Tarkwaian group hosts significant gold deposits.

Exploration:
•Geochemical signature shows increase in Au, Ag, Hg, As, Cu, Fe, Mn, Ti or Cr in stream seds.
•Geophysics can be utilized to delineate the geometry of placers or local geophysics can be used to locate concentrations of heavy minerals or conductive minerals.

AU-QUARTZ VEINS / MESOTHERMAL TYPE

Modelling plan:

A. Locate areas within the underlying basement where gold deposits may occur
B. Locate areas in the overlying cover sequences where gold could be remobilized to

Exploration data to be used:

- Magnetic basement lineaments
- Mapped faults in the cover stratigraphy

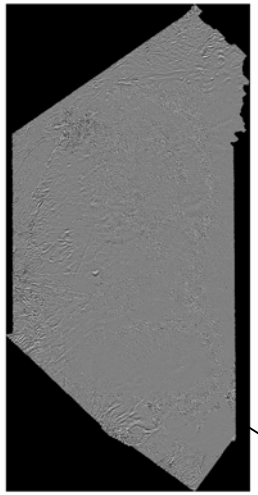
Exploration Model:

1. Extract all the N to E trending basement structures (following experience in Obuasi, Bogoso & Bibiani)
2. Locate intersections of these selected structures with other basement structures
3. Run spatial modelling software to produce a prospectivity map of favourable basememt corridors
4. Model the results of this map with the mapped faults in the cover to produce a prospectivity map of:

potential remobilised basement gold in the Voltaian project area

AU-QUARTZ VEINS / MESOTHERMAL TYPE

Exploration Model: Processing the Magnetics

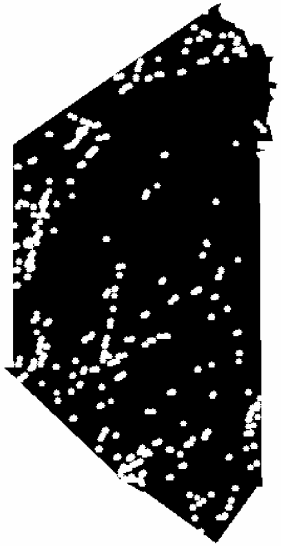


Airborne Magnetics

Interpreted structures

N to E favourable structures

Intersections between structures



AU-QUARTZ VEINS / MESOTHERMAL TYPE

Exploration Model: modelling the basement corridors

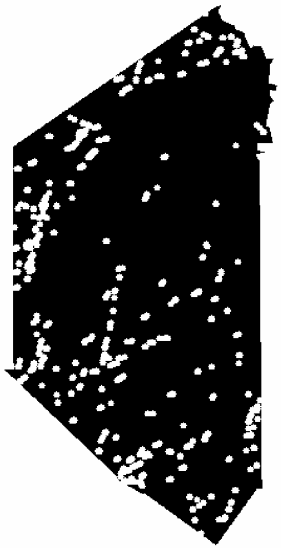
N to E favourable Magnetic lineaments

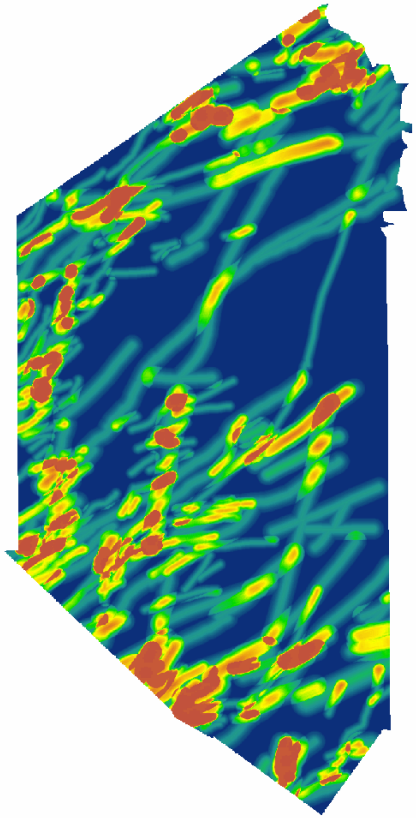
Buffered and weighted depending on:
Fault type
interpretation confidence

Fuzzy operator AND

Intersections between structures

Intersection points buffered





Prospectivity map of the favourable corridors in the basement for Mesothermal type Au deposits

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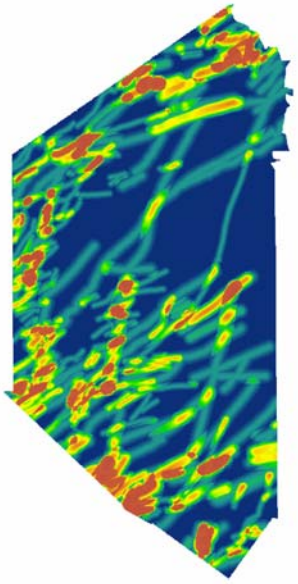
AU-QUARTZ VEINS / MESOTHERMAL TYPE

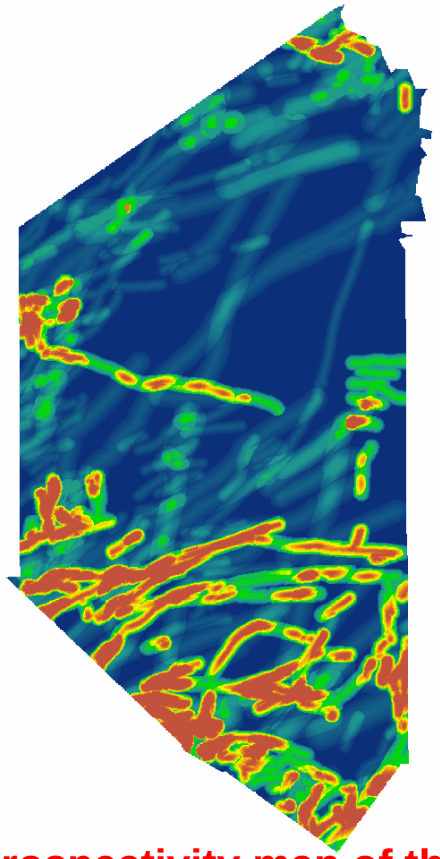
Exploration Model: modelling the potential for reworked gold in the Voltaian

Mapped Structures
Buffered

Fuzzy operator GAMMA

Prospectivity map of the favourable corridors in the basement

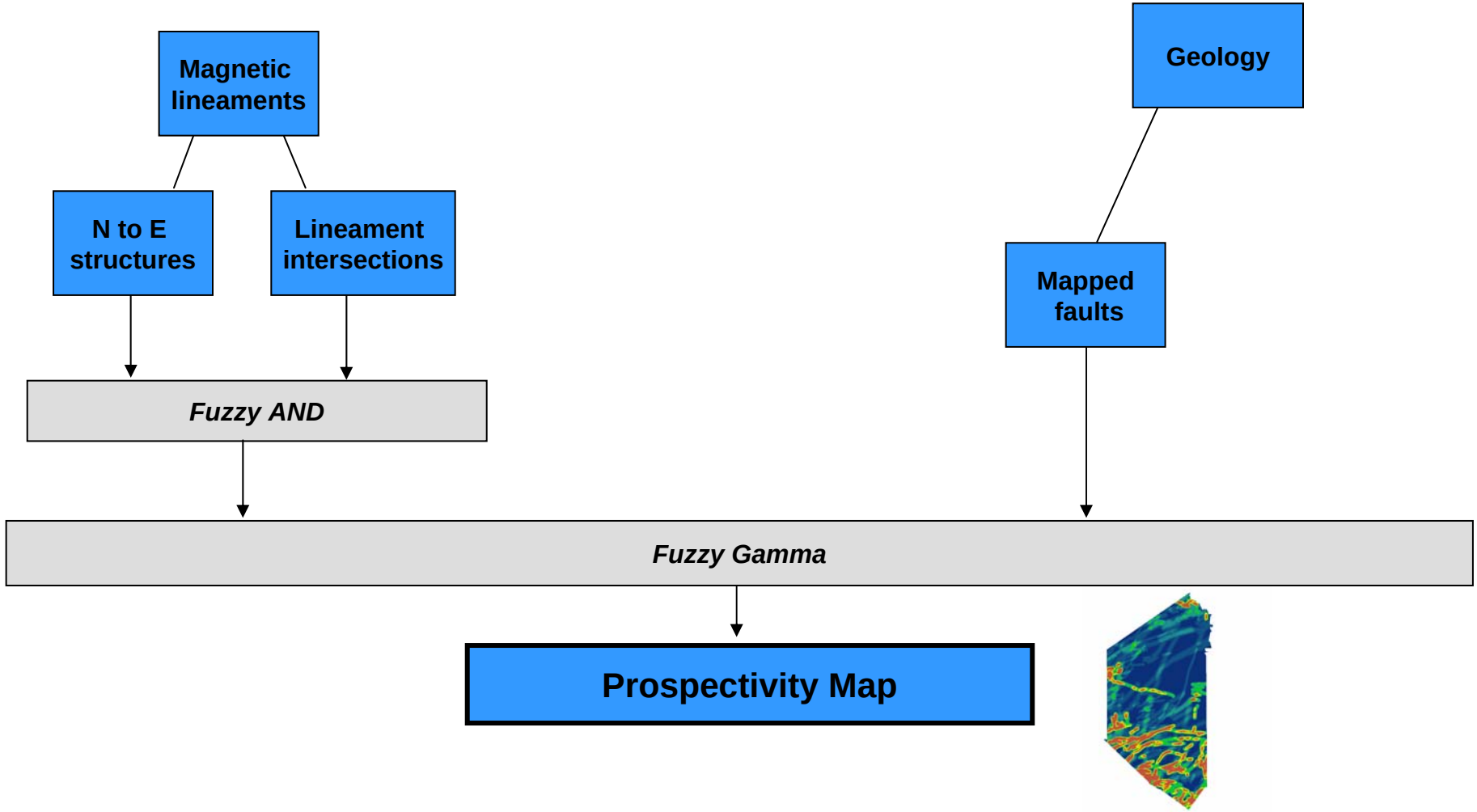




Prospectivity map of the Potential area for remobilised gold in covering Neoproterozoic and Palaeozoic basinal sediments

AU-QUARTZ VEINS / MESOTHERMAL TYPE

Fuzzy logic model



Gold in Ghana

discussion

Main points:

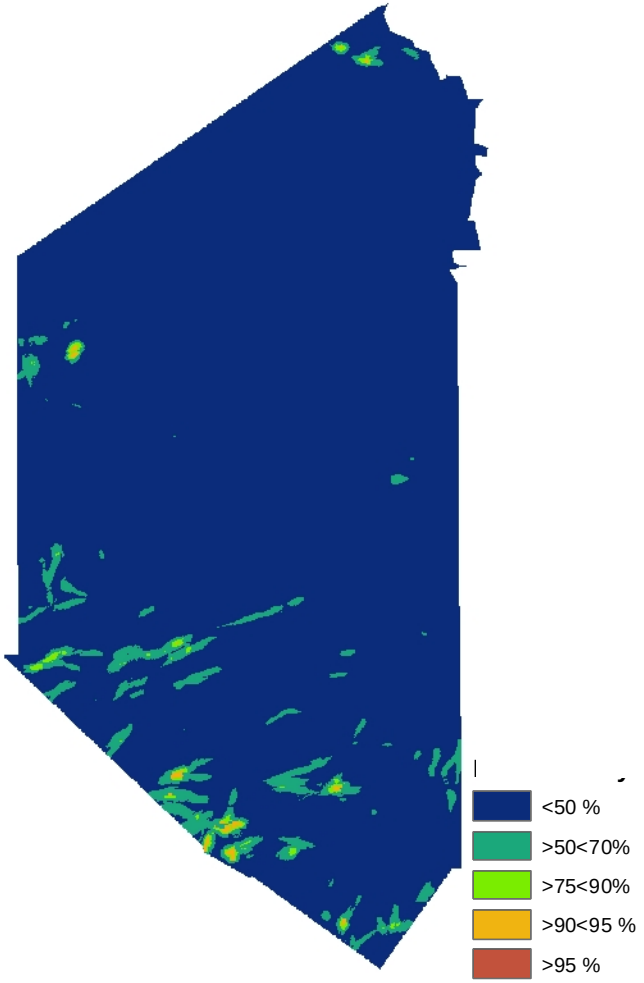
•Southern half of the project area most prospective

•Greatest concentration of mapped and basement faults

•Prospectivity appears to swing from
NE trend to a E trend near to the Pru fault

Further modelling:

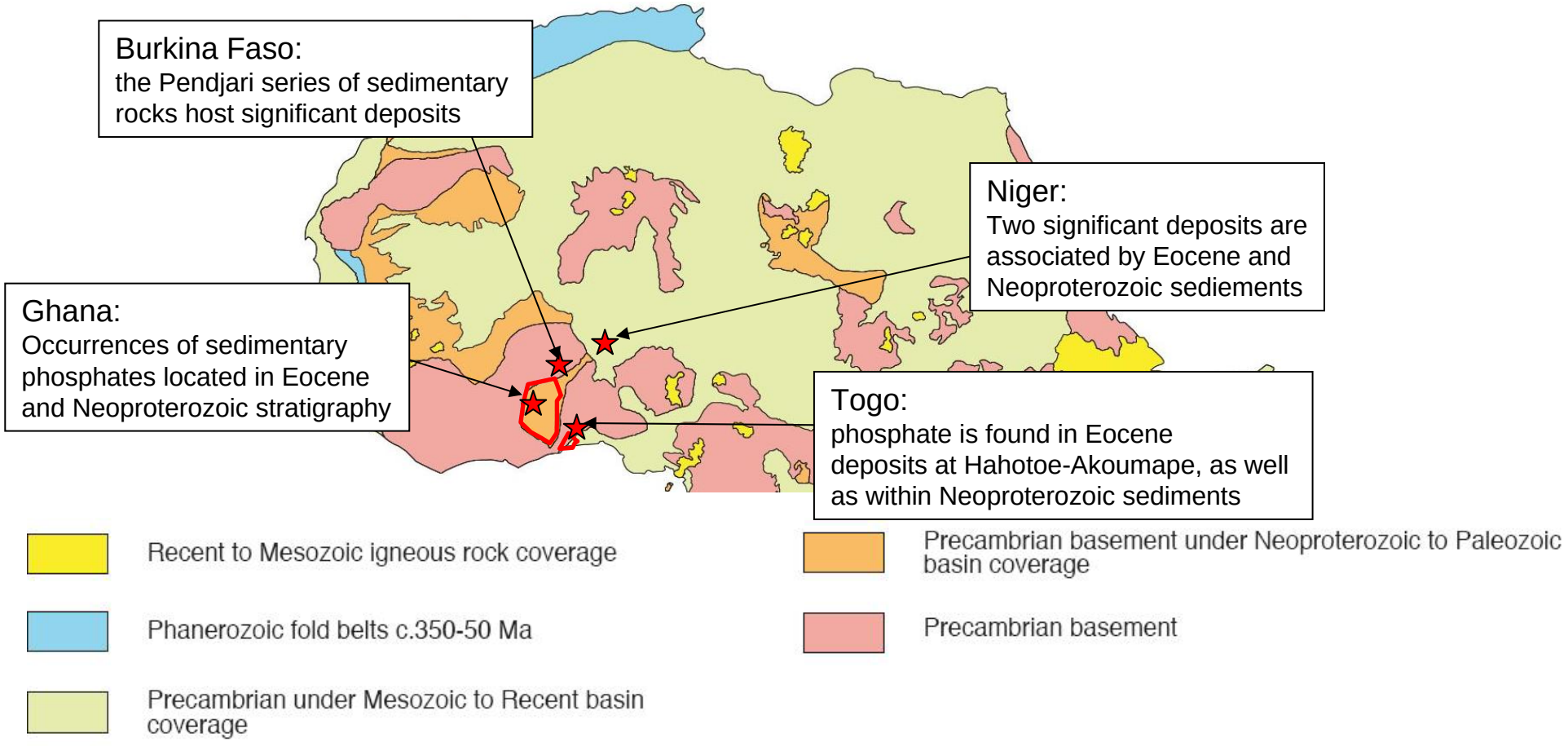
Model the resultant map with a EM map.
This may indicate fluid pathways in the cover sequence.



Modelling Phosphates in the project area

West African Phosphates

Some examples



Phosphates in the project area

Introduction

Two occurrences:

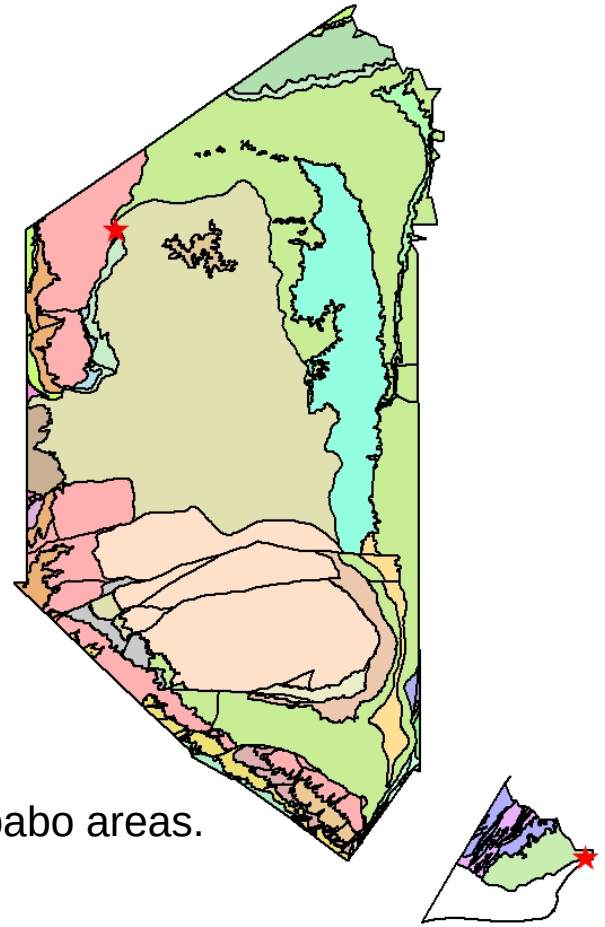
both are sediment hosted phosphates

Volta:

Daboya occurring in similar Proterozoic stratigraphy
to phosphate hosts in Burkina Faso and Benin

Keta:

Occurances in similar Eocene stratigraphy
to phosphate hosts in Togo



Outside the project area:

- further sedimentary examples of phosphates at Wale-Wale
- some minor pegmatite related occurrences in the Bole and Anobabo areas.

Sedimentary Phosphate deposits

Main characteristics and Exploration indicators

Major features of the deposit type:

- Occur in marine sediments, particularly limestones were leaching may have dissolved the calcium carbonate to leave concentrations of detrital phosphate
- Range in age from Precambrian to recent
- Form beds of varying thickness from a few cm to tens of M
- Deposits may display secondary concentration from downward-percolating groundwaters bringing additional phosphate

Examples: The Tapoa deposit, Niger and the Hahotoe-Akoumape deposits, Togo

Exploration:

- Mapping and prospecting within suitable stratigraphy
- Some phosphate deposits have increased radioactivity due to the presence of Uranium.

Sedimentary Phosphate deposits

Modelling plan:

A. Locate prospective stratigraphy in the project area.

The Pendjari group is of similar age to deposits in Burkina Faso with the Kodjari formation the most prospective

B. Locate areas in the overlying cover where there is raised radioactivity

Exploration data to be used:

- Mapped geology over the Volta project area
- Uranium Radiometrics

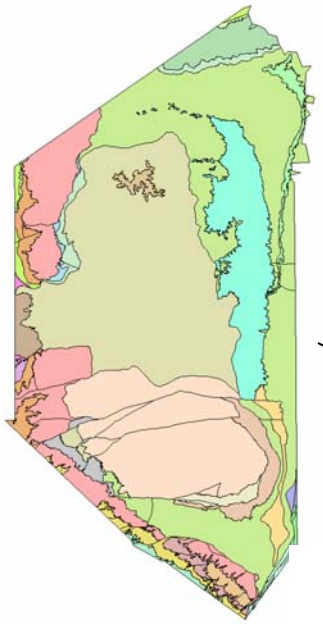
Exploration Model:

1. Extract the favourable stratigraphy
2. Give ratings to the most favourable formations
3. Model this favourable geology with the uranium values of the radiometrics.
4. Create a prospectivity map of:

potential sedimentary phosphates in the Voltaian project area

Sedimentary Phosphate deposits

Exploration Model: modelling the favourable geology in the Volta Project area



Mapped geology

Pendjari series

Pendjari series with the Kodjari formation highlighted

Sedimentary Phosphate deposits

Exploration Model: modelling the favourable geology with the radiometrics

Penjari series with the Kodjari formation highlighted

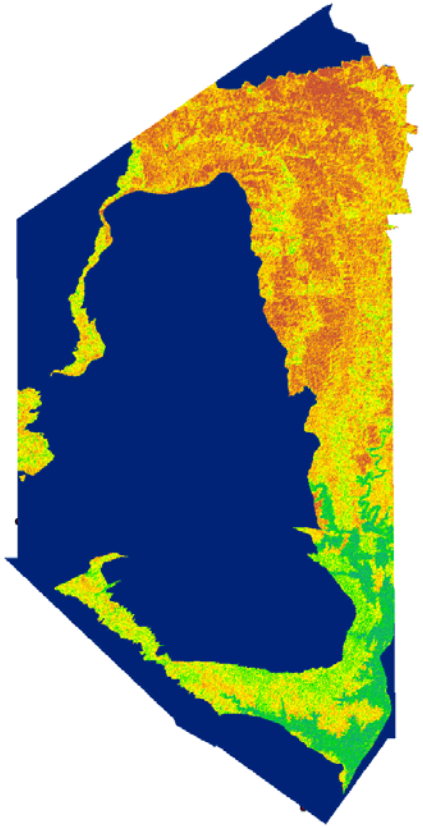
Fuzzy operator AND

+

Radiometrics, U,

with the value increasing with the red saturation

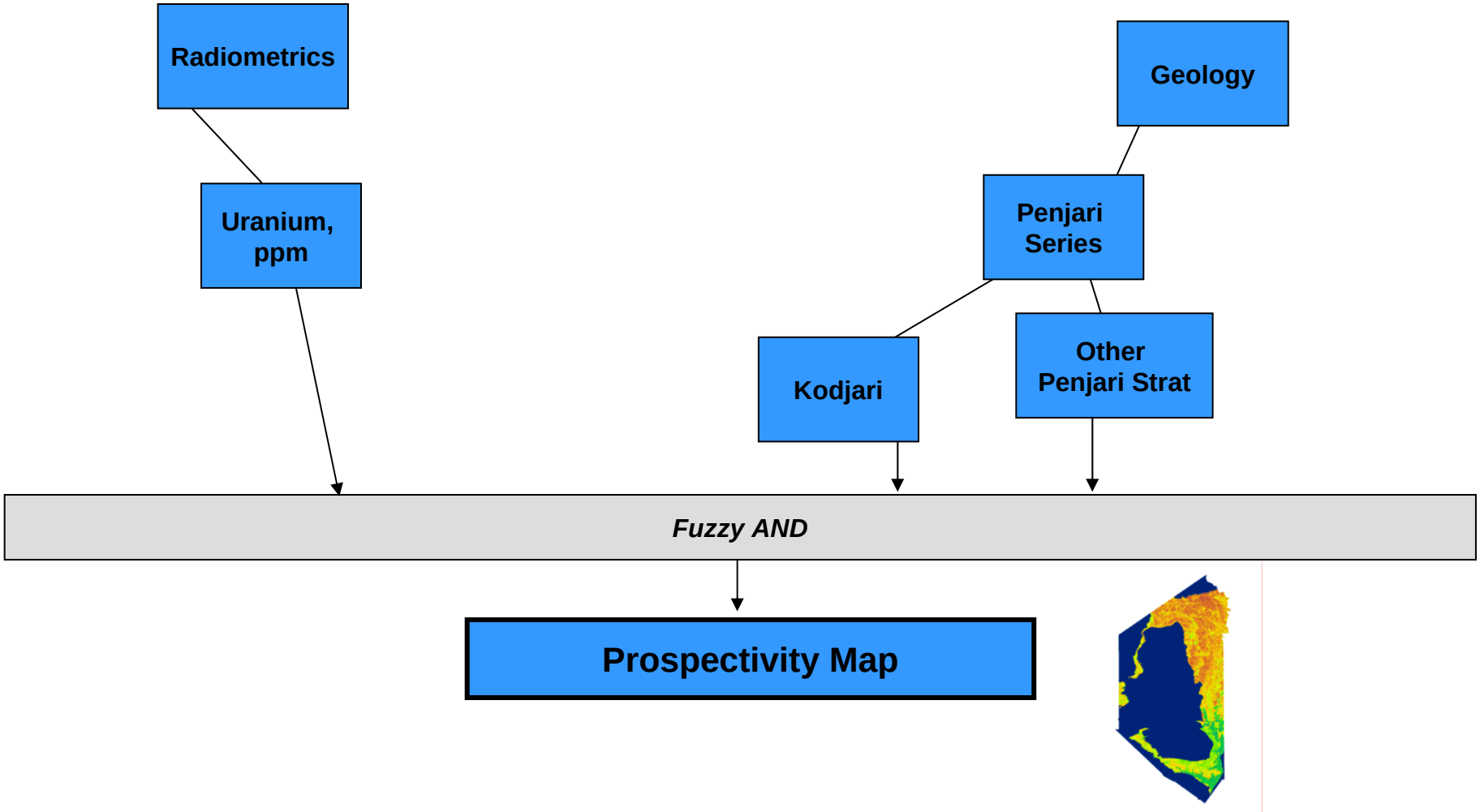
=



potential sedimentary phosphates in the Voltain project area

Sedimentary Phosphate deposits

Fuzzy logic model



Phosphates in Ghana

discussion

Main Points:

•The north of the project area appears to be most prospective
-Due to the raised U values in this area

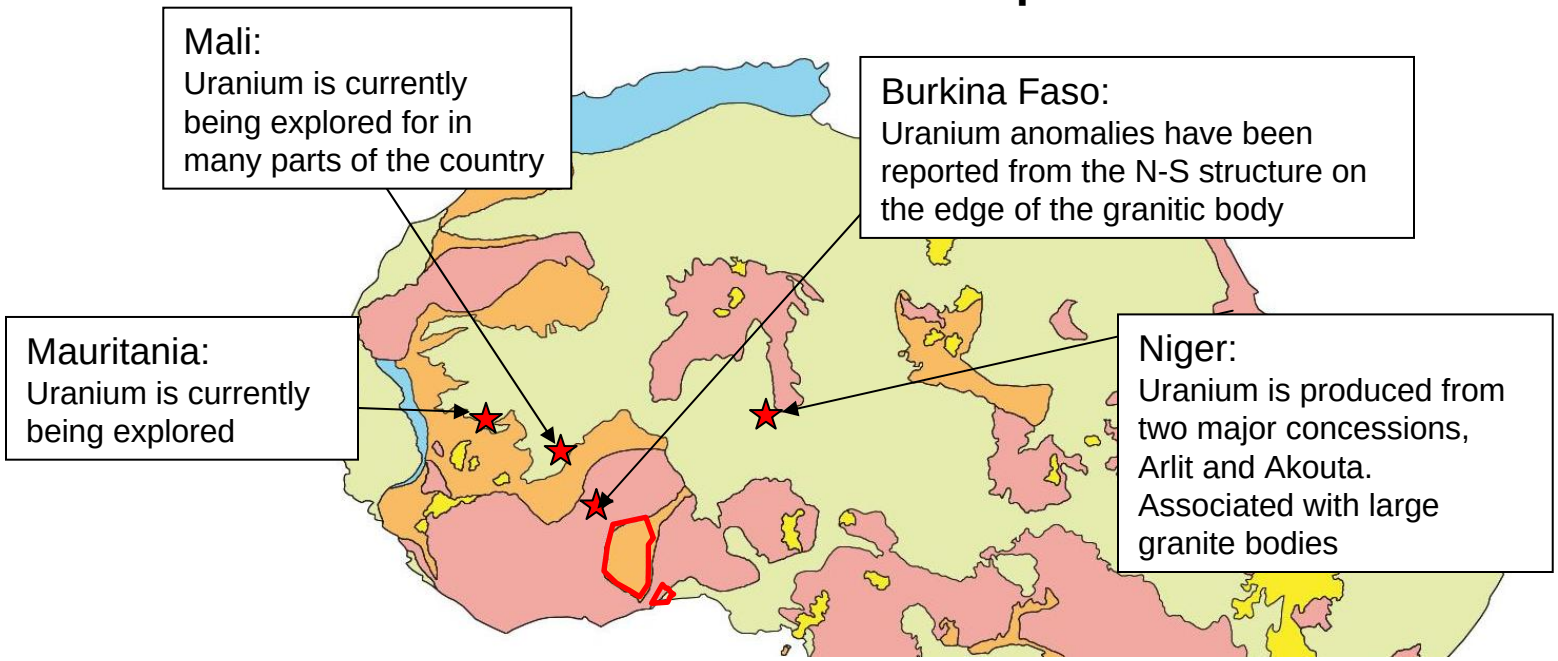
•It is the smaller outlier highs that should be followed up
•Areas of interest are circled

•**Further Modelling**
•Run the same model in the Keta basin

Modelling Uranium in the project area

West African Uranium

Some examples



- Recent to Mesozoic igneous rock coverage
- Phanerozoic fold belts c.350-50 Ma
- Precambrian under Mesozoic to Recent basin coverage
- Precambrian basement under Neoproterozoic to Paleozoic basin coverage
- Precambrian basement

Uranium in the project area

Introduction

Three types of U deposits could be hosted in the Voltaian Basin sediments:

- Sandstone Hosted Uranium
- Unconformity-related Uranium
- Placer Uranium

SANDSTONE-HOSTED URANIUM

Main characteristics and Exploration indicators

Major features of the Deposit type:

•Occur in intracratonic basins filled with flat-laying continental fluvial sandstones
•Occur adjacent to fault zones as these may provide conduits for reducing solutions.
•Commonly post Silurian however older deposits do occur proximal to reducing agents
•Uranium sourced from adjacent igneous rocks
•Deposits occur due to chemical traps in the form of oxidation-reduction fronts
•Three types rollfront deposits, tabular deposits, tectonic/lithologic deposits

Exploration:

•Mapping to locate the presence of oxidised and reduced sandstones.
•Geochemical signature shows increase in U
•Radiometrics will detect increase in Uranium

SANDSTONE-HOSTED URANIUM

Modelling plan:

A. Locate prospective stratigraphy in the project area.

Both the Anyaboni and the Obocha formations in the south of the project area are either continental or fluvial and could act as hosts to the mineralization. Granites in Burkina Faso could act as source rocks.

B. Locate areas in the overlying cover where there is raised radioactivity proximal to faults that could act as conduits.

Exploration data to be used:

- Mapped geology over the Volta project area.
- Uranium Radiometrics.
- Mapped structures in the overlaying basin sandstones.

Exploration Model:

1. Extract the favourable stratigraphy.
2. Model the favourable geology with buffered faults. This will give geologically favourable areas.
3. Model this favourable geology with the uranium values of the radiometrics.
4. Create a prospectivity map of:

Potential Sandstone-hosted Uranium in the Voltain project area

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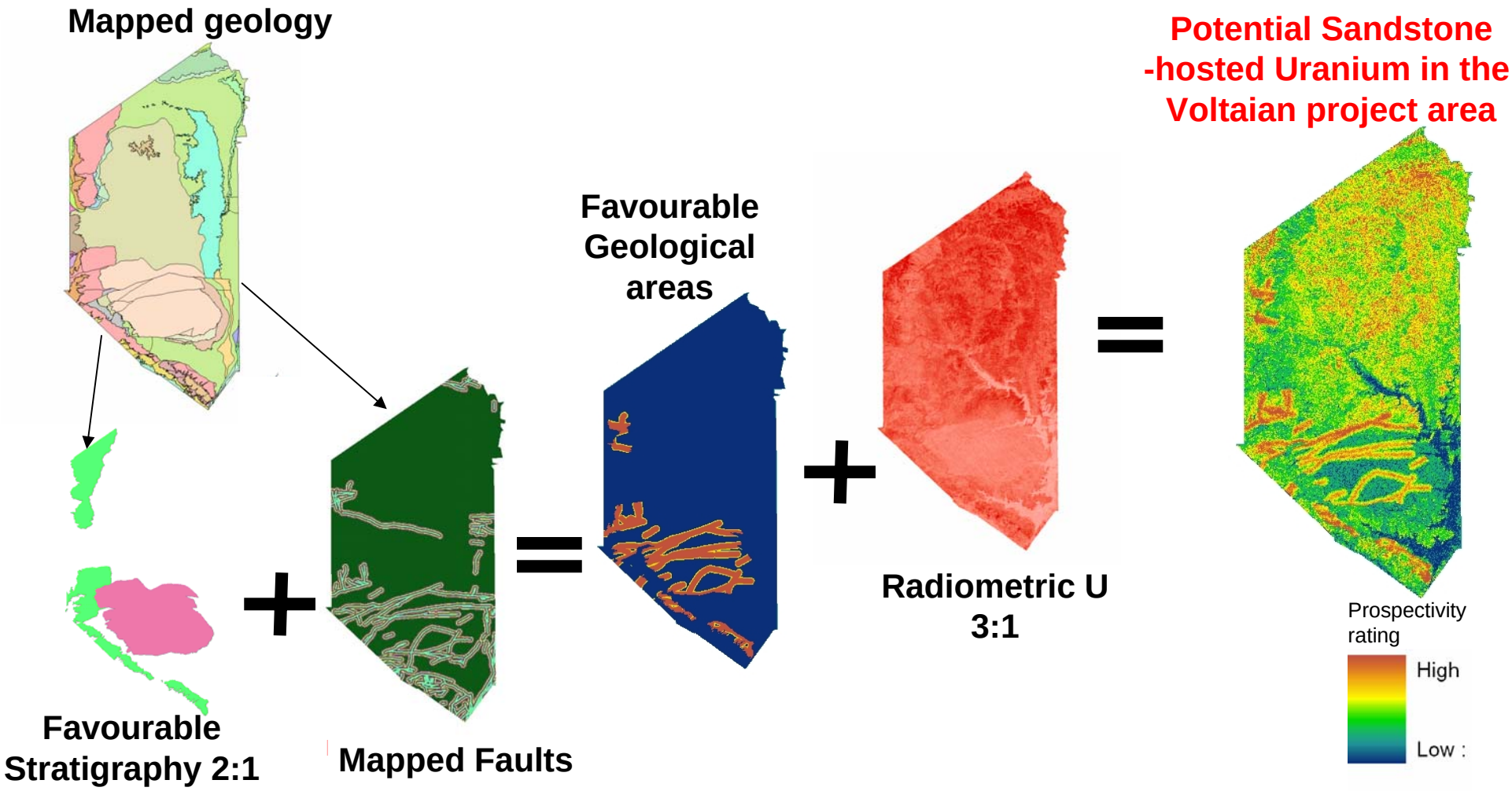
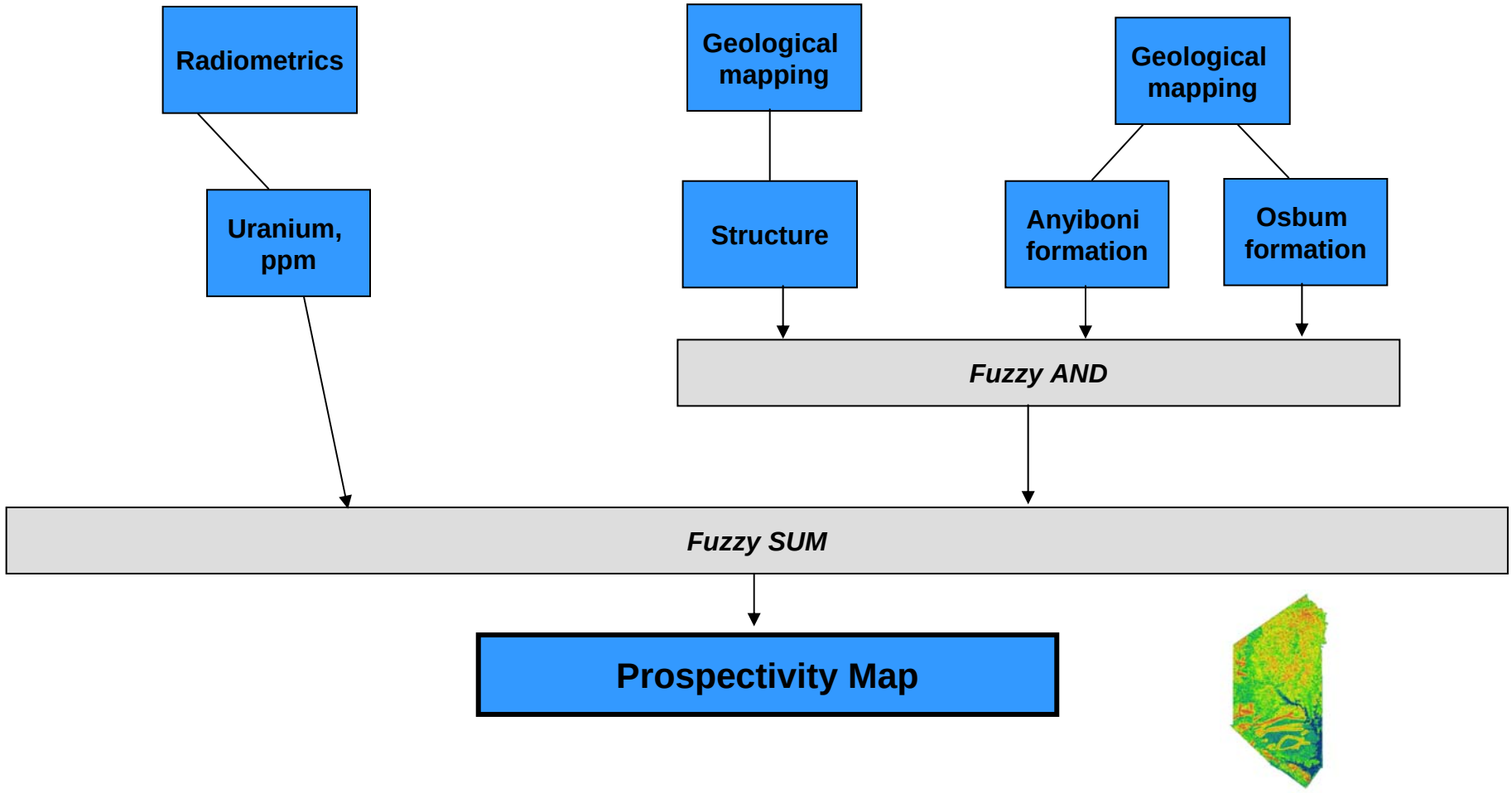
Sandstone hosted Uranium

Exploration Model: modelling the favourable geology and faults with the U radiometrics



Sandstone hosted Uranium

Fuzzy logic model



Sandstone hosted Uranium

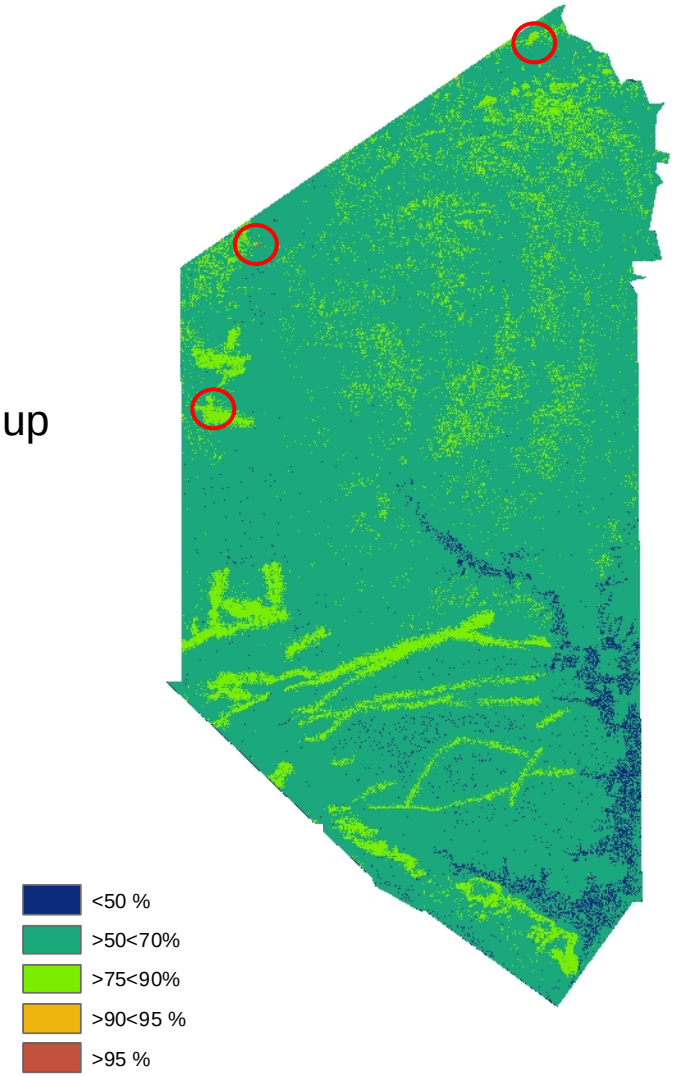
Main Points:

•The faults have a major influence on the results

•It is the smaller outlier highs that should be followed up these are outlined

•Further Modelling

•Run models for other Uranium Deposit types



Unconformity-related URANIUM

Main characteristics and Exploration indicators

Major features of the Deposit type:

- Occur below, above or straddling unconformities over Archean/ Palaeoproterozoic igneous and metamorphic rocks
- Generally occur in sandstones of Proterozoic age
- Metal rich oxidised fluids migrate along the unconformity until a suitable reducing environment is reached
- Deposits may occur in structures proximal to the unconformity

Exploration:

- Mapping to locate the presence of oxidised and reduced sandstones.
- Geochemical signature shows increase in U
- Radiometrics will detect increase in Uranium

Unconformity-related URANIUM

Possible Modelling plan:

A. Locate the unconformities within the Project area.
B. Locate areas in the overlying cover where there is raised radioactivity proximal to faults that could act as hosts to the mineralization.

Exploration data to be used:

- Mapped geology over the Volta project area.
- Uranium Radiometrics.
- Mapped structures in the overlaying basin sandstones.

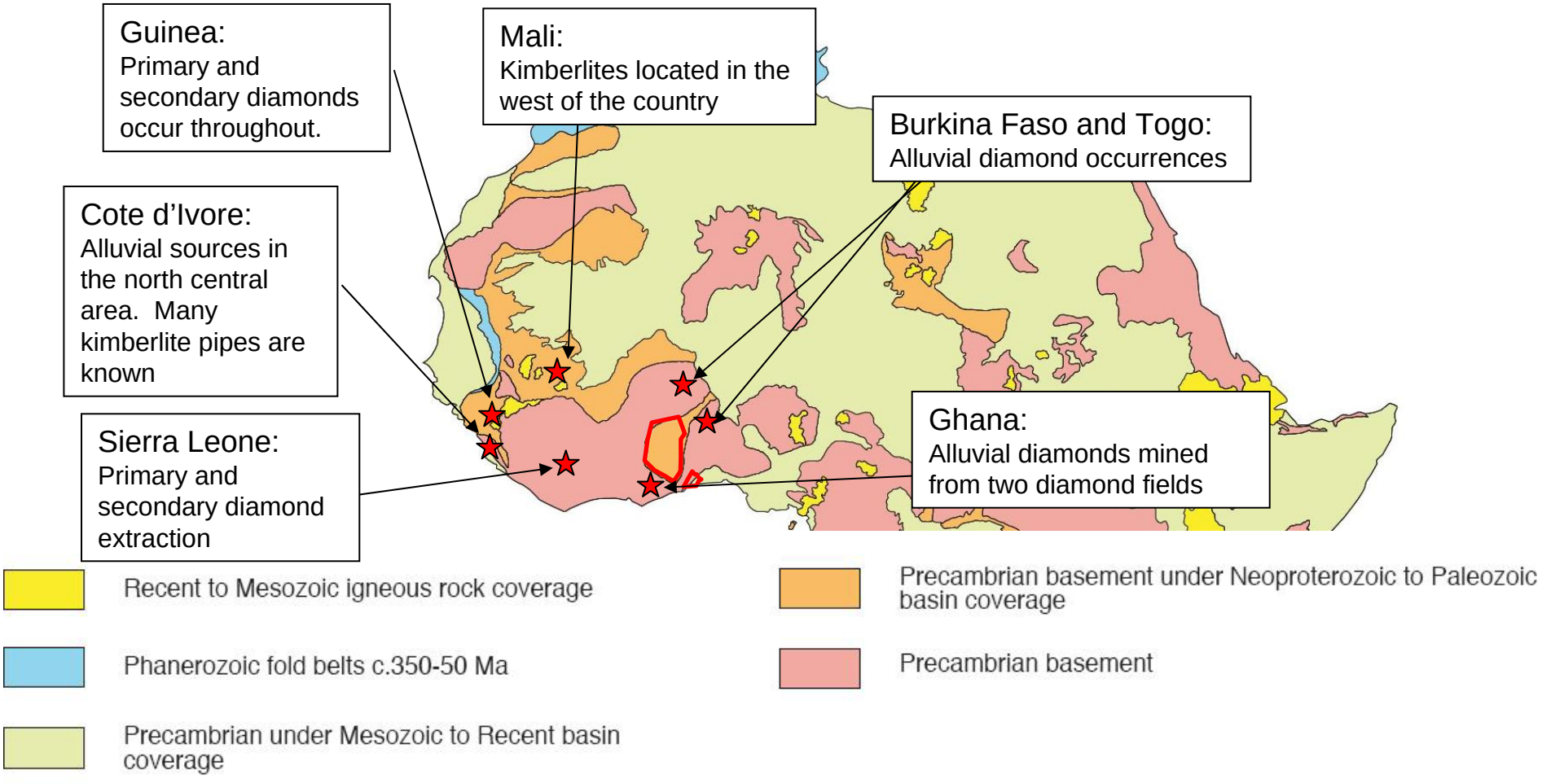
Exploration Model:

1. Extract the geology formations within the area that lies above or below a major unconformity.
2. Model the favourable geology formations with the mapped faults to give geological favourable areas
3. Model these geological favourable areas with the uranium values of the radiometrics.
4. Create a prospectivity map of:

Potential Unconformity-related Uranium in the Voltaian project area

Modelling Diamonds in the project area

West African Diamonds

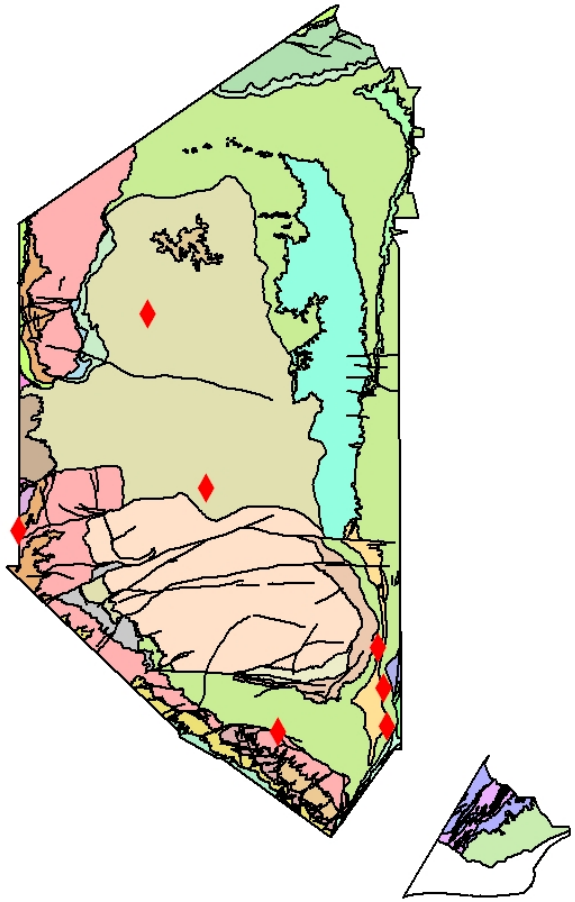


Diamonds in the Project area

Occurrences:

•Seven occurrences, all alluvial, found in gravels draining various lithologies of Voltaian and Birimian age

•No primary sources have been found



Placer (Diamonds)

Main characteristics and Exploration indicators

Major features of the Deposit type:

•Placer deposits (*can host U, Au, Sn, Diamond, PGE*)
•Occur at base of channels in erosional surfaces
•Occur in well sorted sands and well rounded imbricated and clast supported gravels

Exploration:

•Kimberlitic indicator minerals: (*pyrope garnet, chromian diopside high-magnesian chromite, and picroilmenite*) all may be found in the gravels
•Ground penetrating radar can delineate the channel geometry
•Ground magnetics can be used to trace magnetite accumulations in base of channels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Final Thoughts:

Prospectivity modelling

Pros:

•Narrows search for minerals
•Utilizes data quickly and produces results that can be replicated
•Can be used to gain maximum effect from hard won exploration data

Cons:

•Does not replace existing techniques but is a supplement to them
•Limited to the current deposit models
•Can produce spurious anomalous zones