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Applied Electromagnetic Methods in the Search for Shallow Unconformity Related Uranium Mineralisation in Australia

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presented at

International Symposium on Uranium Raw Material for the Nuclear Fuel Cycle:
Exploration, Mining, Production, Supply and Demand, Economics and
Environmental Issues (URAM-2009)

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Vienna, Austria

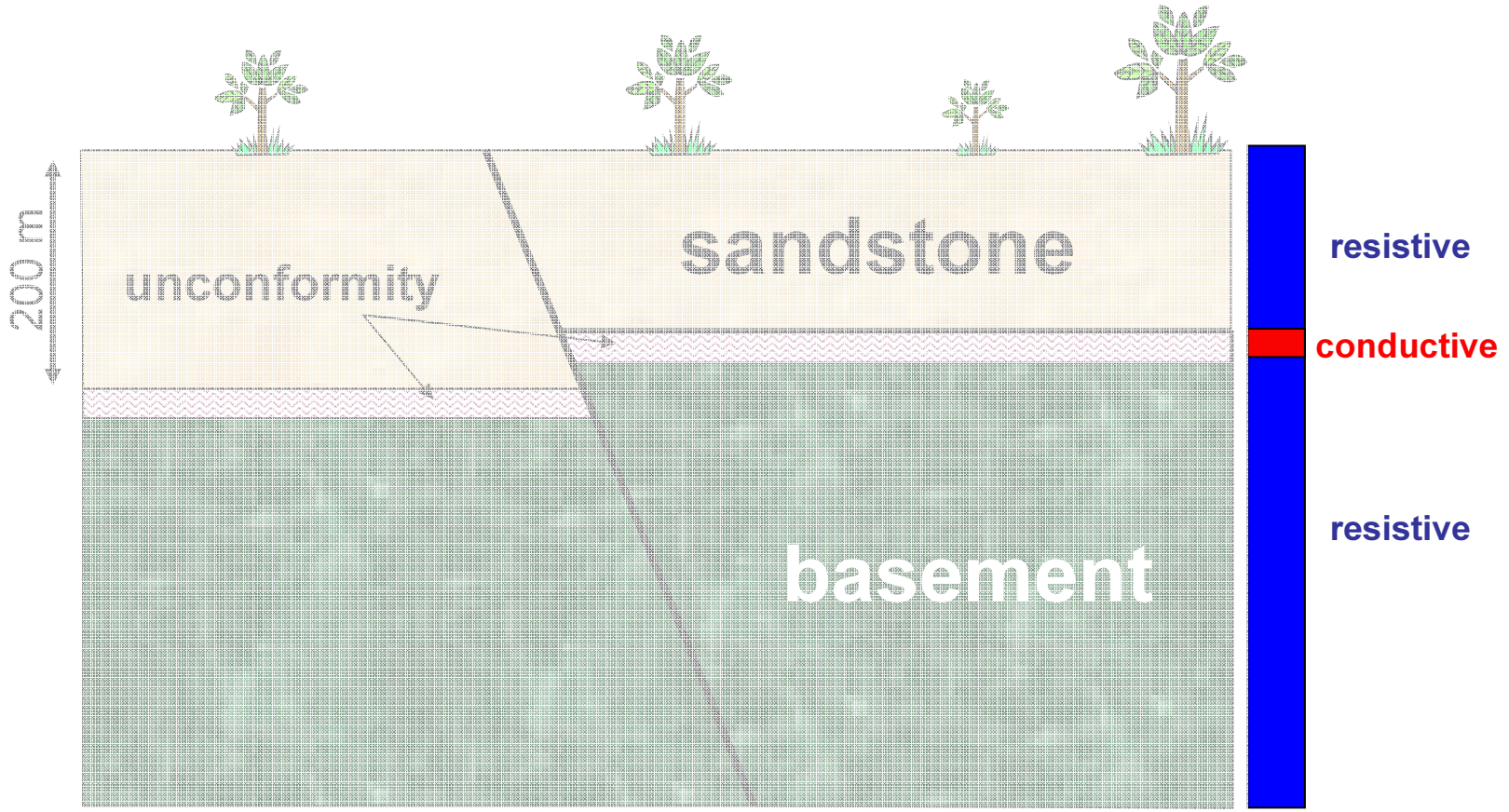
Outline

- After many years of searching for unconformity related uranium, a few geophysical techniques have been tried
- Predominantly a mix of ground and air **e**lectro**m**agnetic (EM) methods found to be the most successful in being able to infer the presence of an unconformity
- How have electromagnetic surveys assisted in the search?

The best way to answer these questions is by way of example

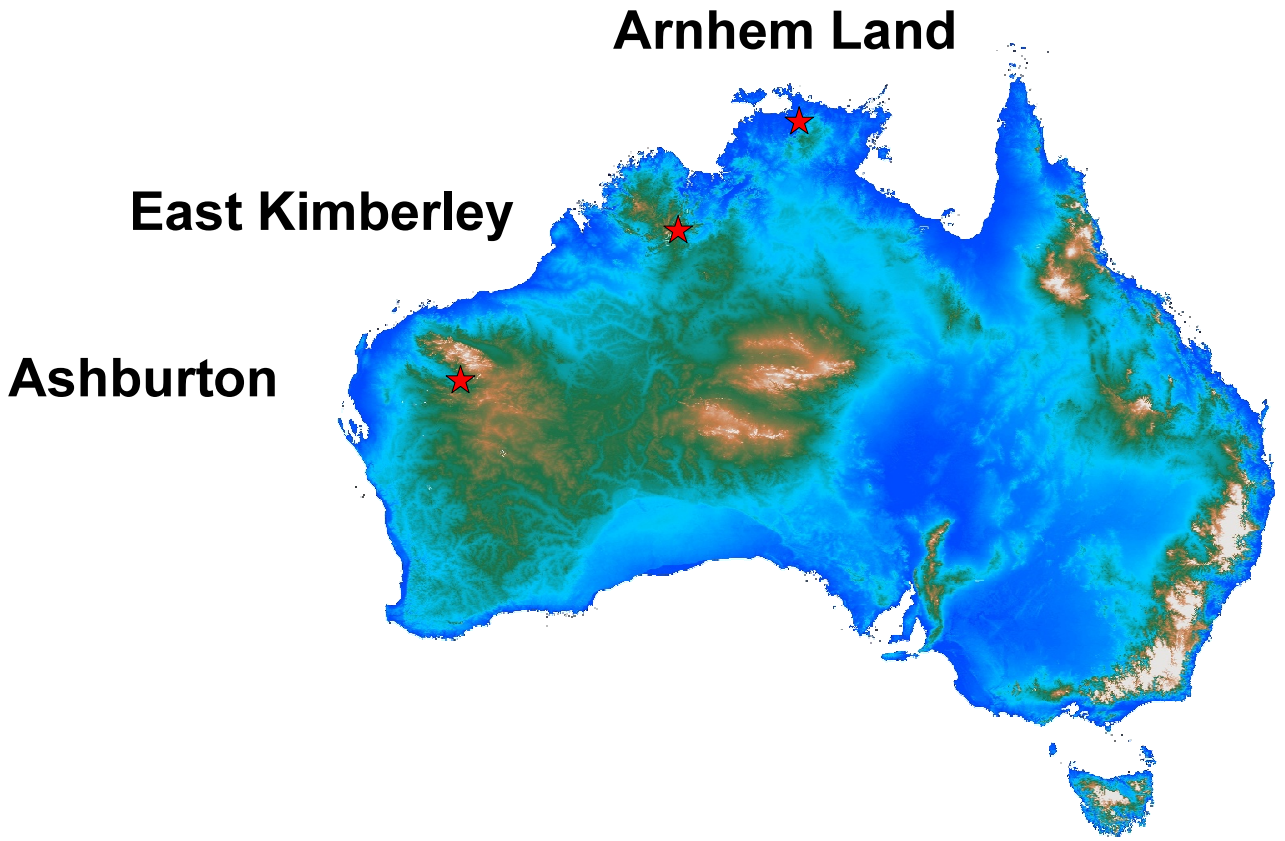
Outline

- Typical unconformity model



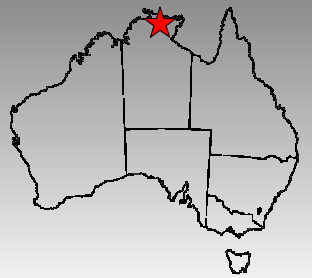
Outline

Examples of EM surveys from 3 uranium provinces

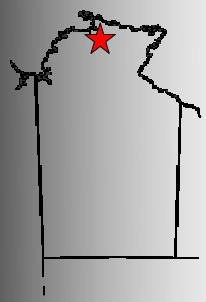


Arnhem Land

East Kimberley
Ashburton

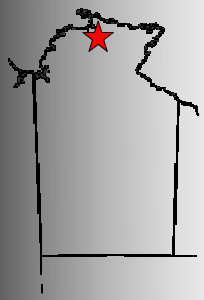


Arnhem Land

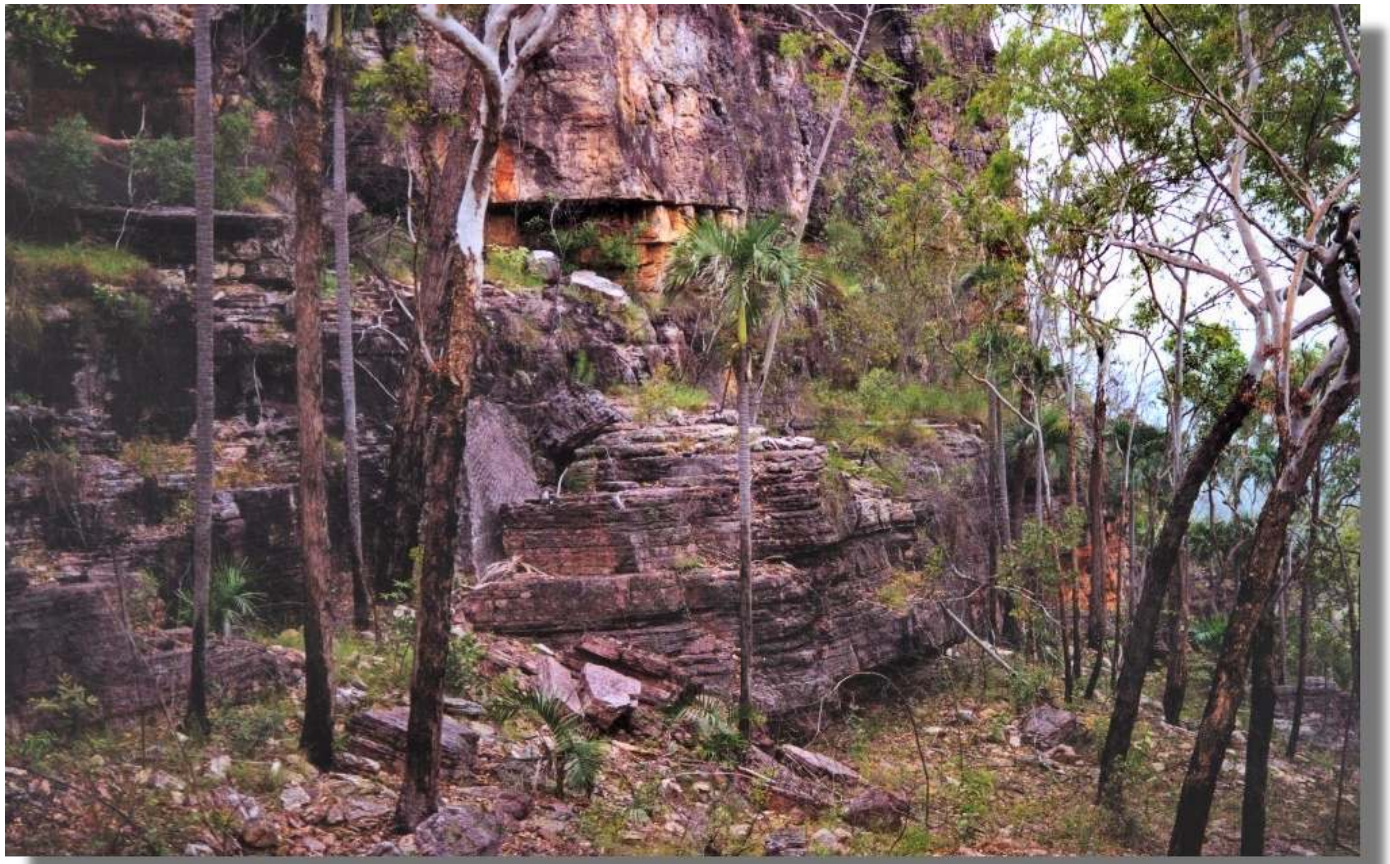


- A technically and logistically challenging environment to work in …

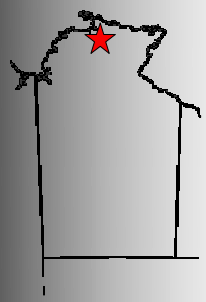
Arnhem Land



- Ground access can be difficult

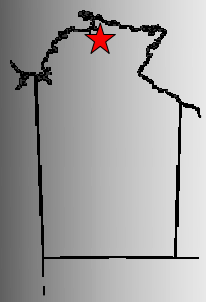


Arnhem Land



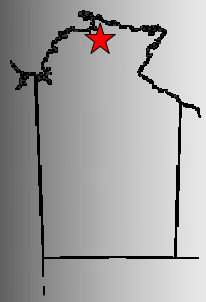
- and yet somewhere under this rugged surface lies a prospective unconformity
- The question is -
  - where is it and
  - at what depth is the unconformity?
- Map unconformity by indirect measurement of resistivities associated with alteration <u>proximal</u> to unconformity

Arnhem Land – Ground EM Survey

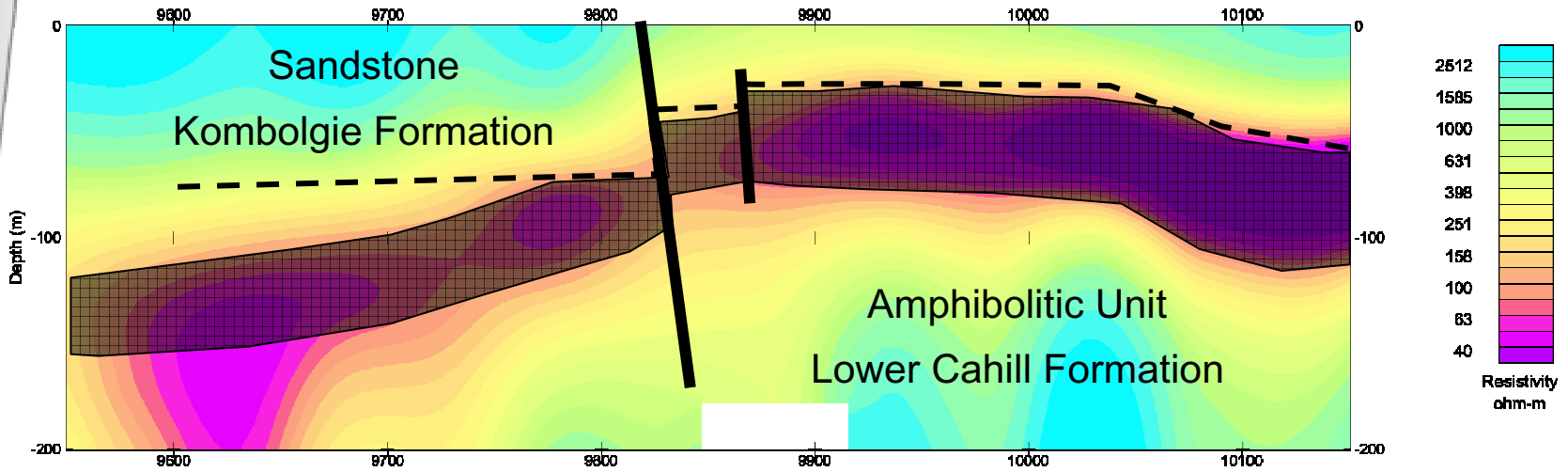


- Starting in 1998 ground EM surveys were carried out as a precursor to airborne work
- Successfully delineated unconformity alteration in a controlled environment
- Ground EM System used
  - Zonge NanoTEM
  - Portable, 12v battery power, very light weight
  - Very fast sampling and turn off times
  - 50m Tx Loop, 10m in-Loop Rx

Arnhem Land – Ground EM Survey



Vertical resistivity cross-section of the earth



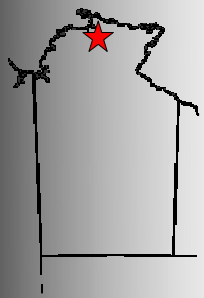
200 m

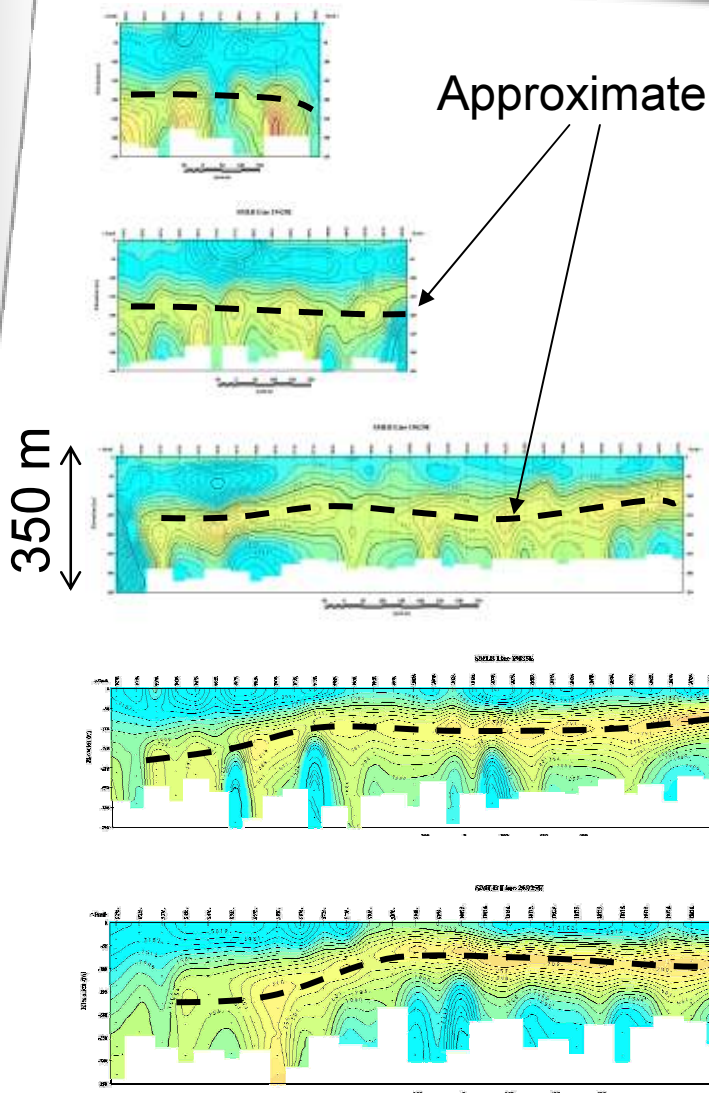
- Good control through drilling
- Know where and at what depth the unconformity is

Unconformity

Fault

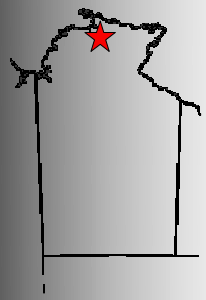
Arnhem Land – Ground EM Survey



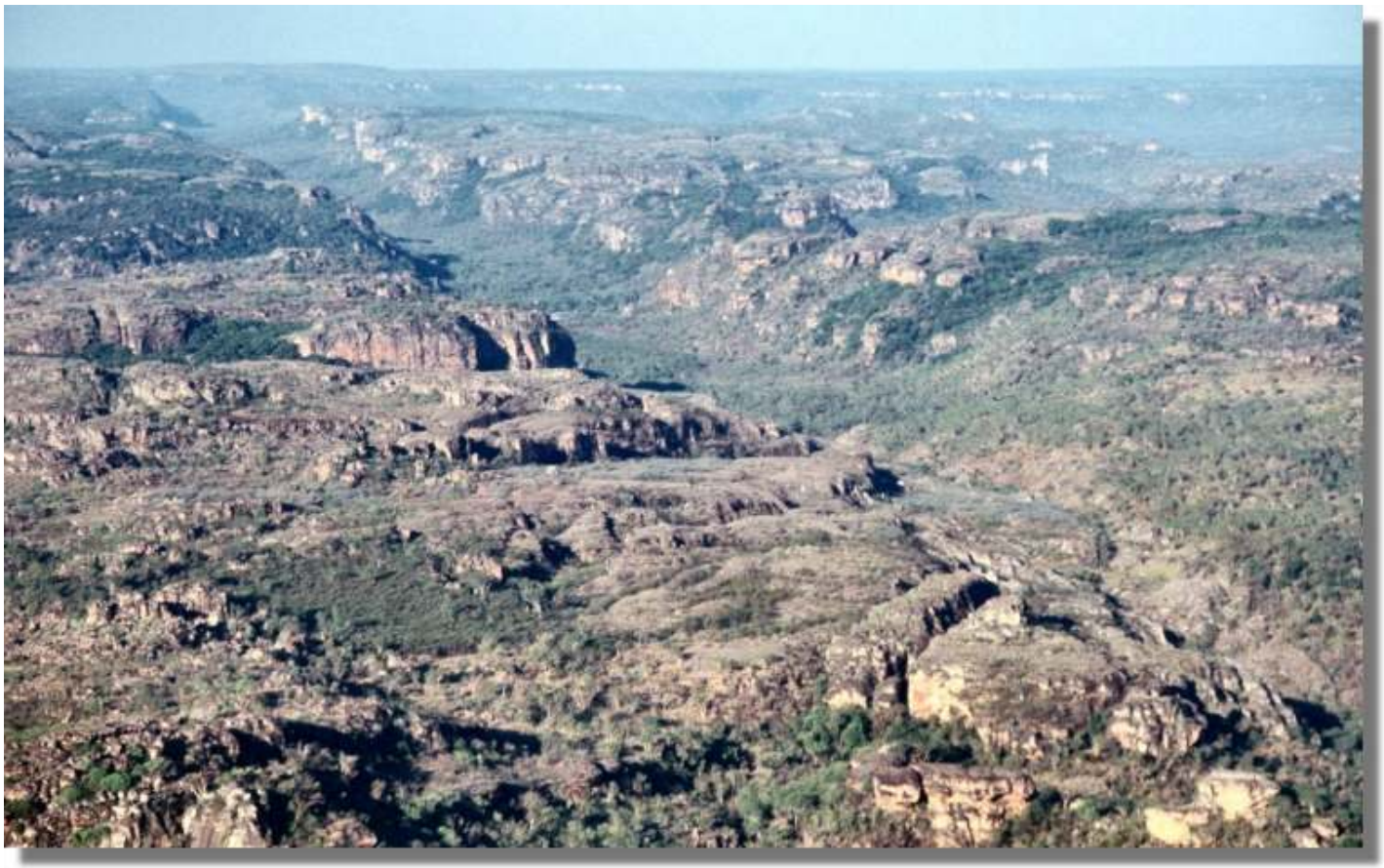


Alteration around the unconformity has enough electrical contrast to be detectable with the right technique

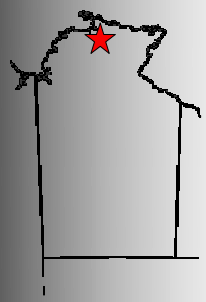
Arnhem Land



- Physically impossible to carry out ground surveys over large areas



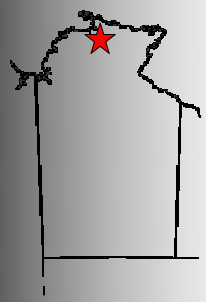
Arnhem Land



- In this instance the transition from ground surveying to an airborne technique was crucial to a successful exploration programme

- Theoretical forward modelling showed that Fugro's TEMPEST EM system could resolve unconformity related alteration due to sufficient electrical contrast

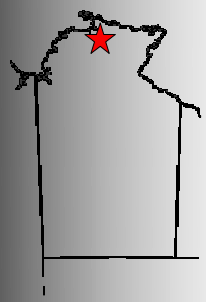
Arnhem Land – Airborne EM Survey



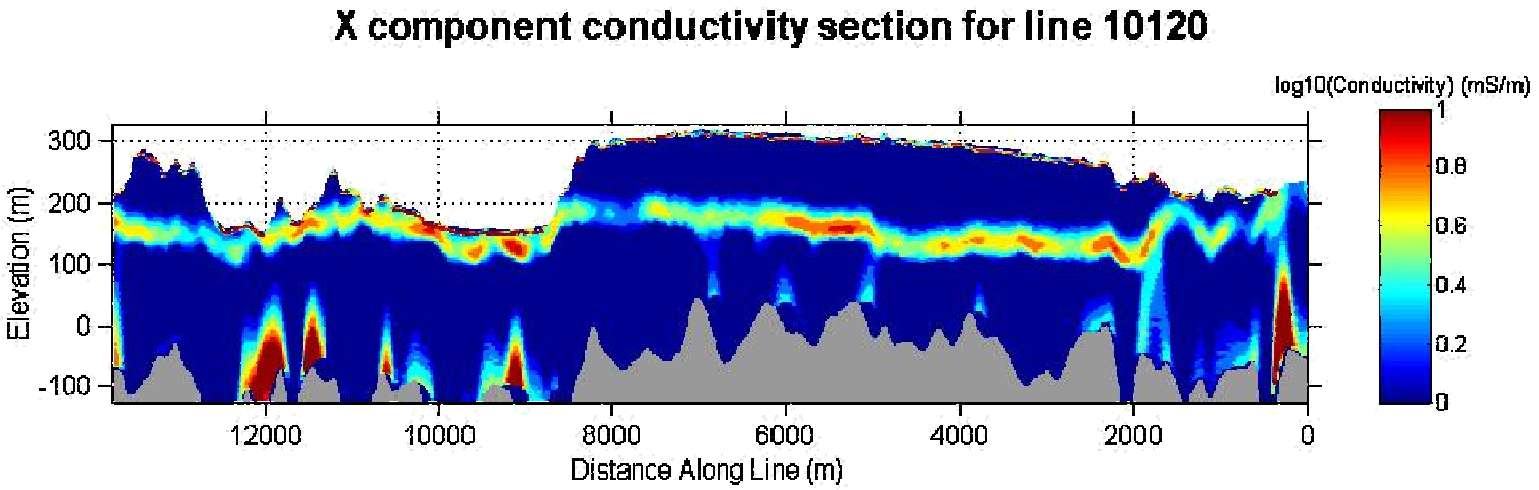
- In 2001 an airborne EM survey was flown searching for a geophysical response associated with unconformity alteration

- TEMPEST
  - Fixed wing system
  - Time domain EM
  - Terrain clearance nominal - 120m

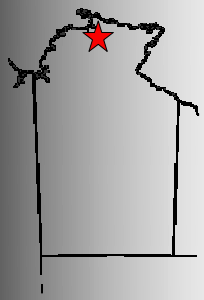
Arnhem Land – Airborne EM Survey

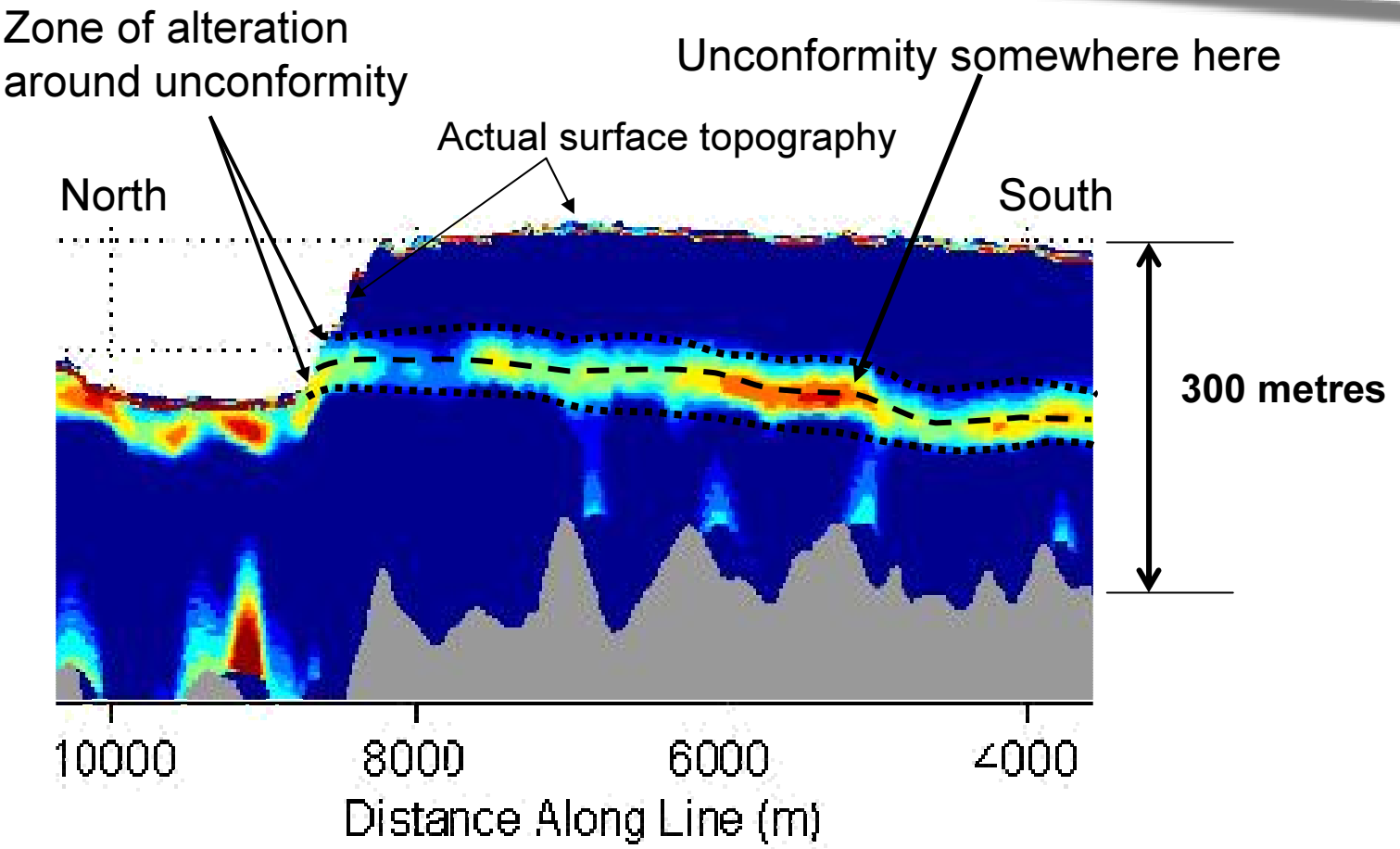


Example cross-section of data from Tempest survey

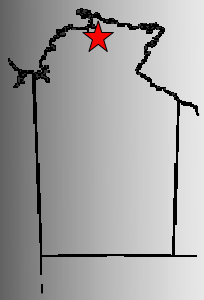


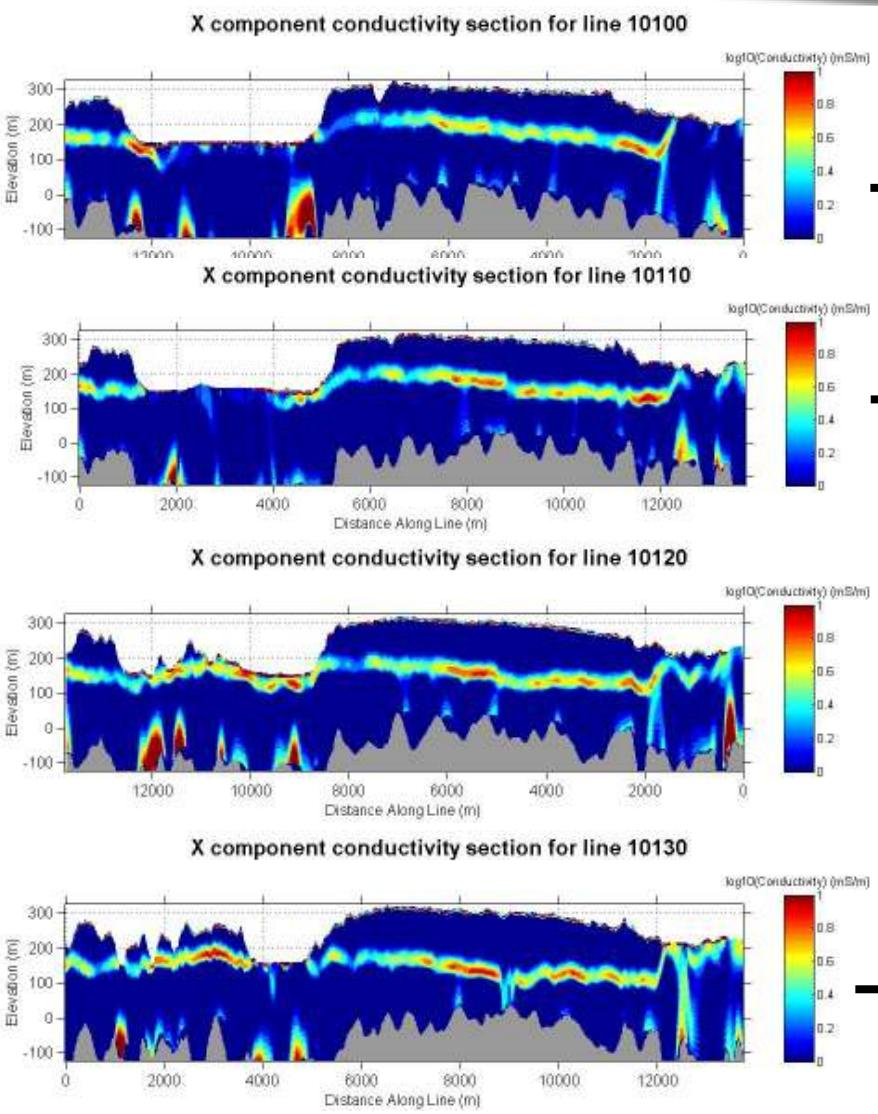
Arnhem Land – Airborne EM Survey



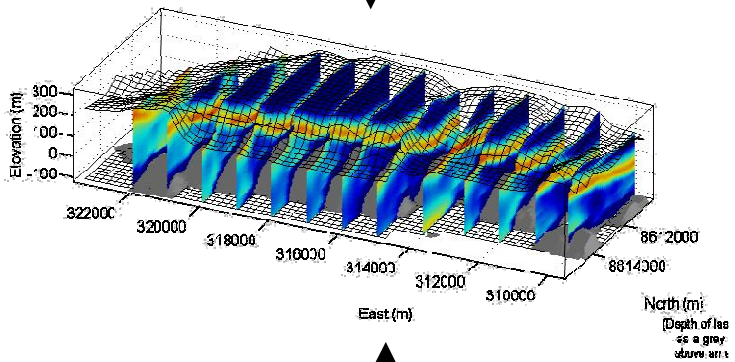


Arnhem Land – Airborne EM Survey

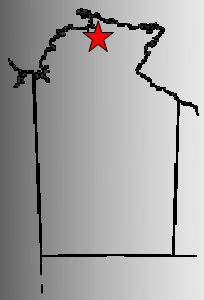




Vertical sections can be combined to produce a 3D map of the unconformity

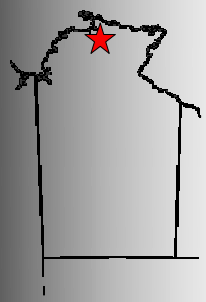


Arnhem Land

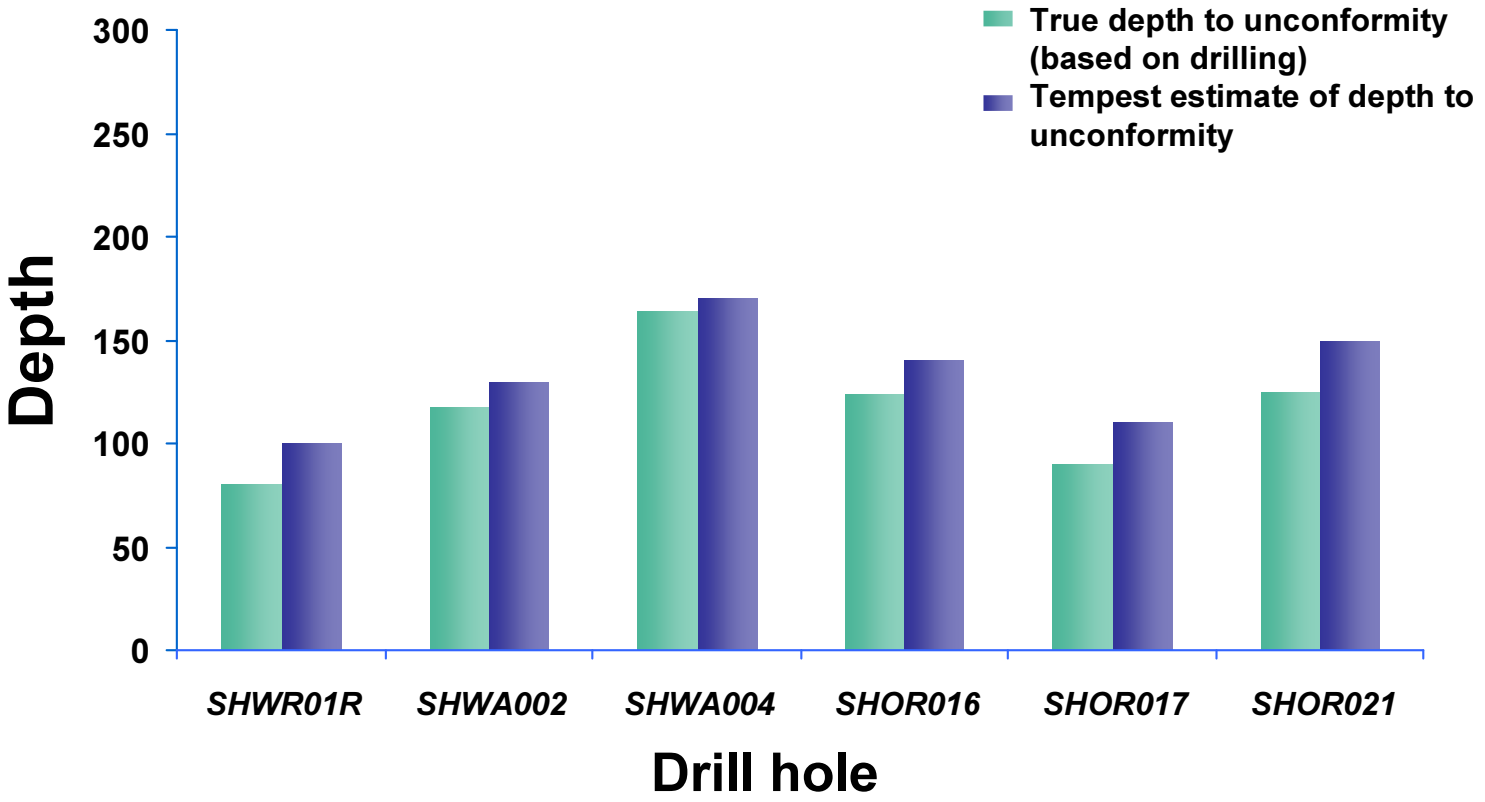


- How accurate is the airborne EM data?
- The truth is always in the drilling

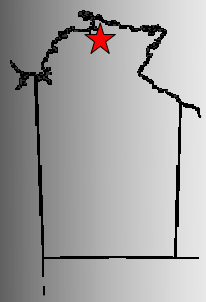
Arnhem Land



- True unconformity depth vs EM estimate



Arnhem Land - Summary

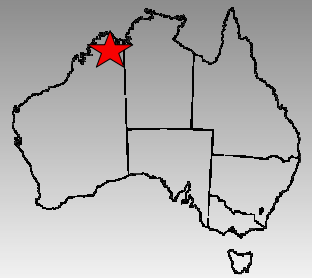


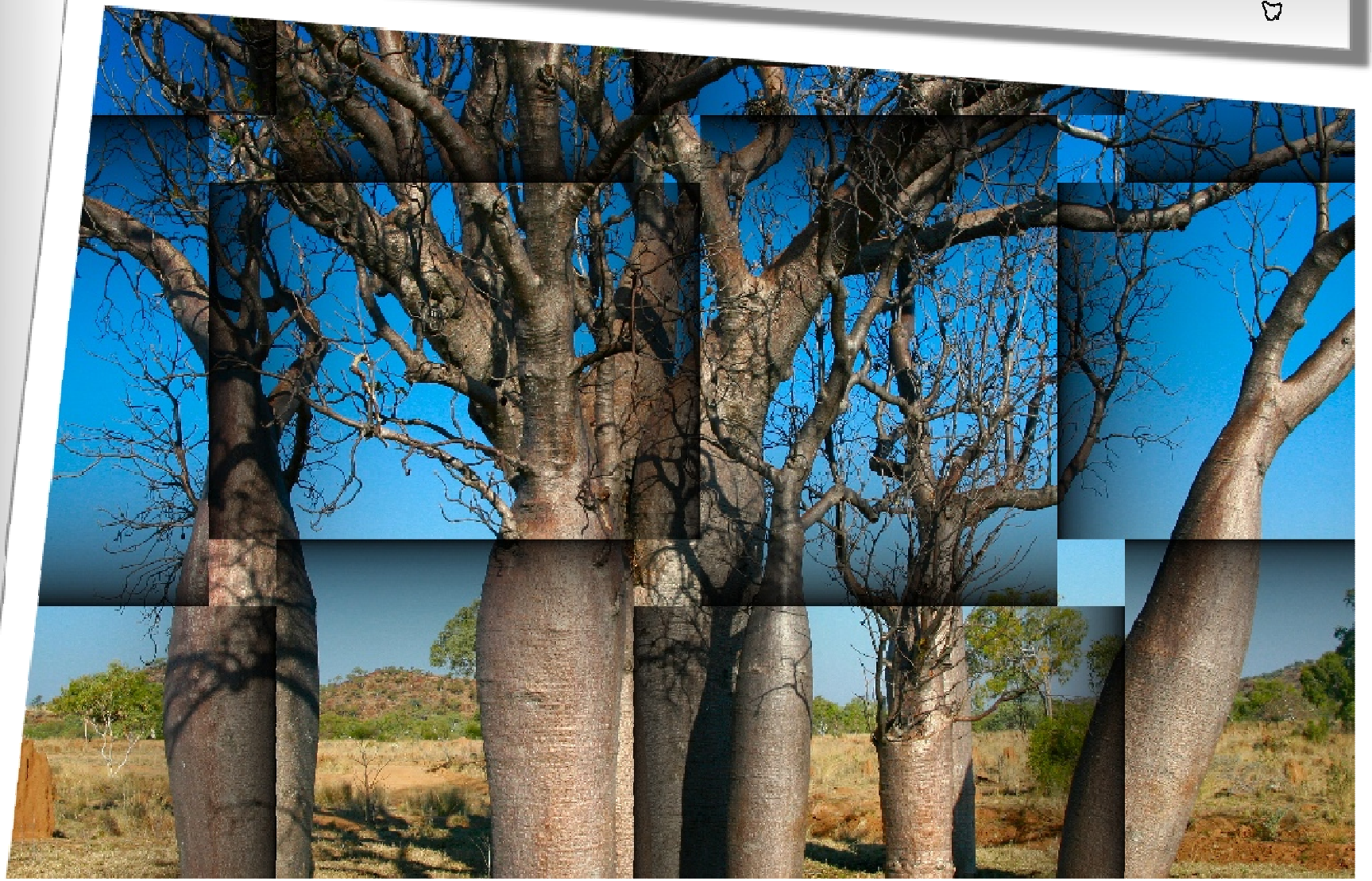
- Ground EM survey resolved unconformity related alteration
- Airborne EM survey achieved same result but over a much larger scale
- Important to note;
  - Relying on physical property contrasts between altered and unaltered rocks
  - Resolving alteration associated with the unconformity – not the actual unconformity

Arnhem Land

East Kimberley

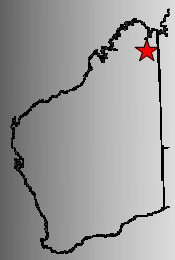
Ashburton





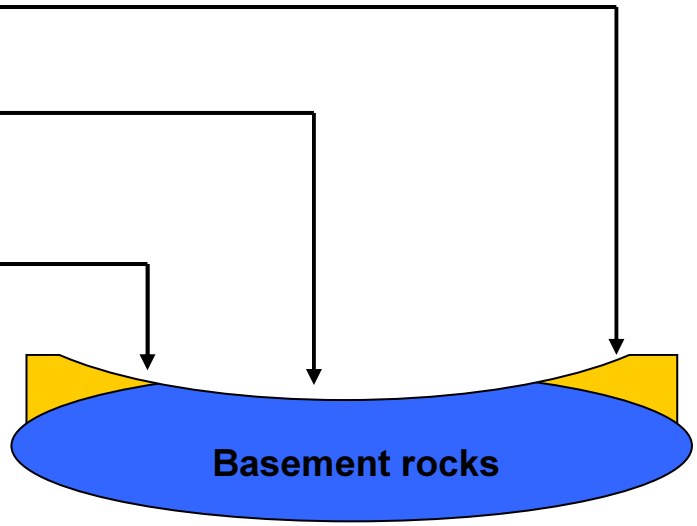
URAM 2009
June 09

East Kimberley



Summary

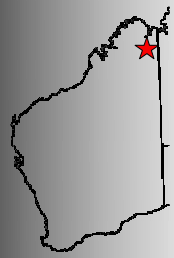
- Sandstone overlies basement
- exposed basement and unconformity
- Uranium anomalies around the exposed unconformity contact

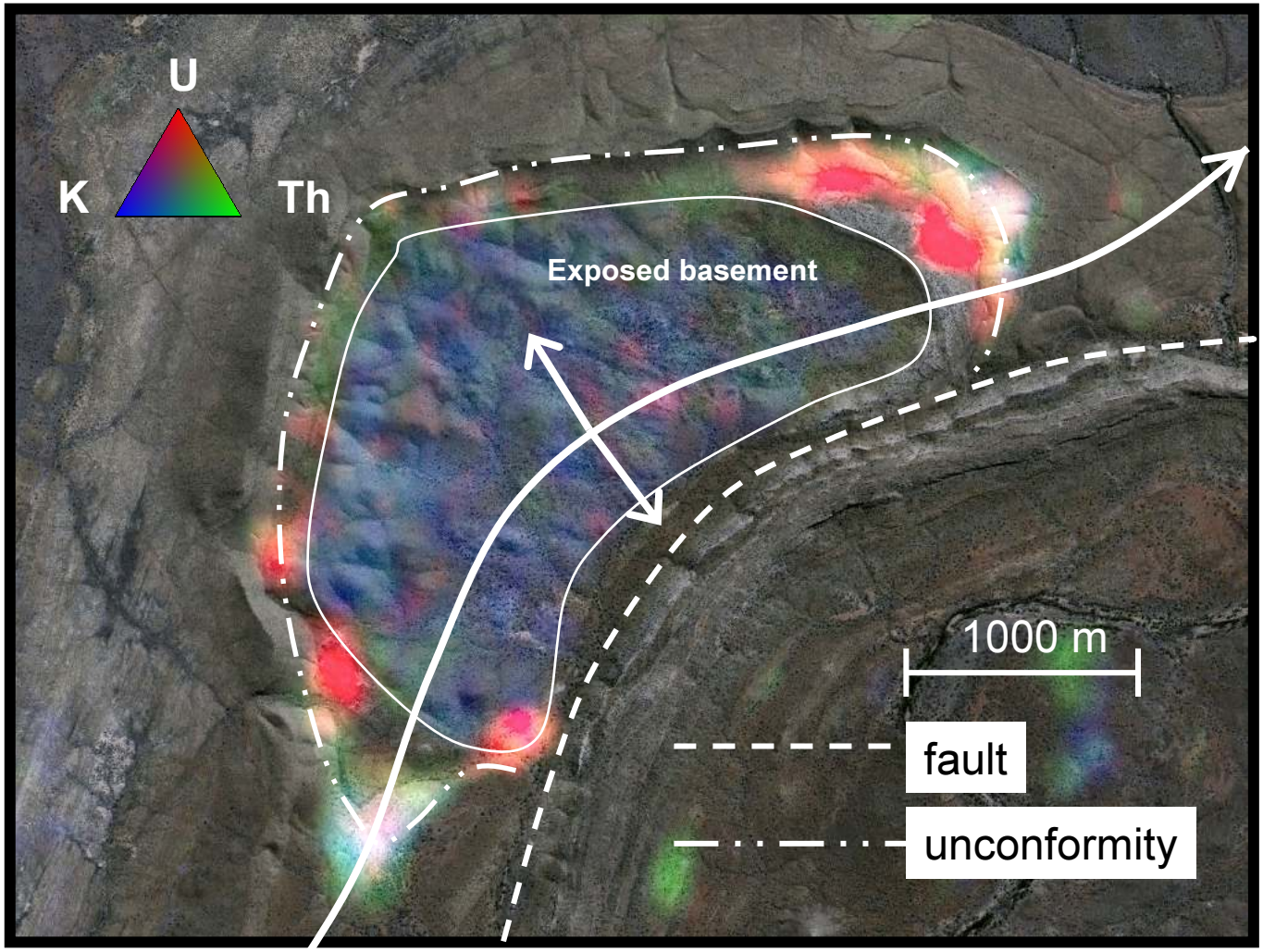


Objective

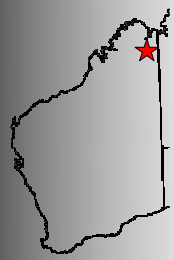
- Can sandstone-basement contact be mapped with EM?
- Can target sandstone unit be mapped with EM?

East Kimberley – Radiometrics





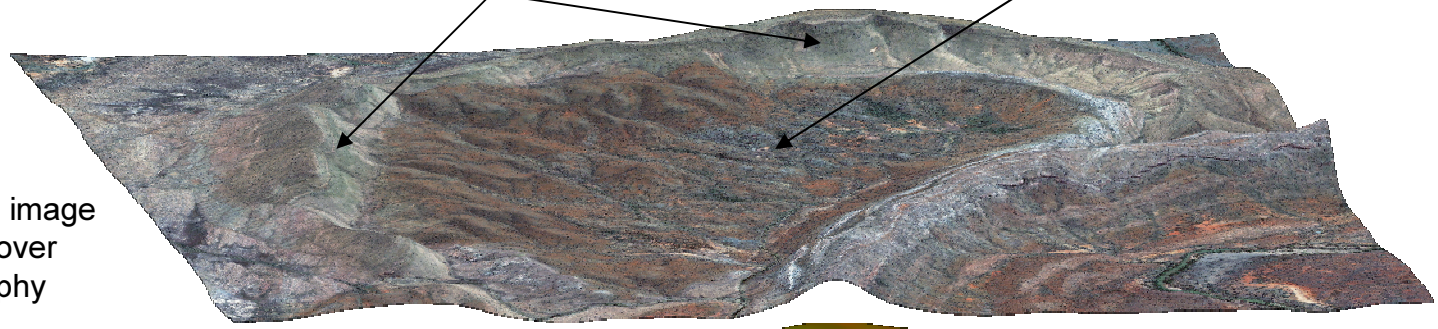
East Kimberley – Radiometrics



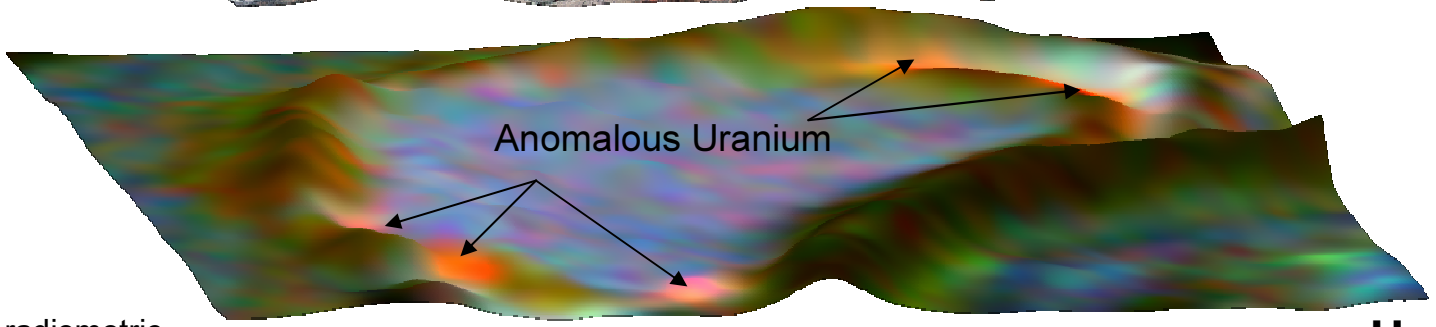
- Target horizon is a Brown Sandstone unit situated just above unconformity

Exposed basement where sandstone has been eroded

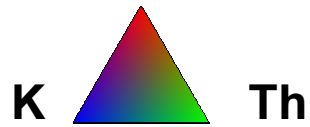
Sandstone cover



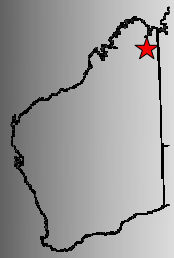
Satellite image draped over topography

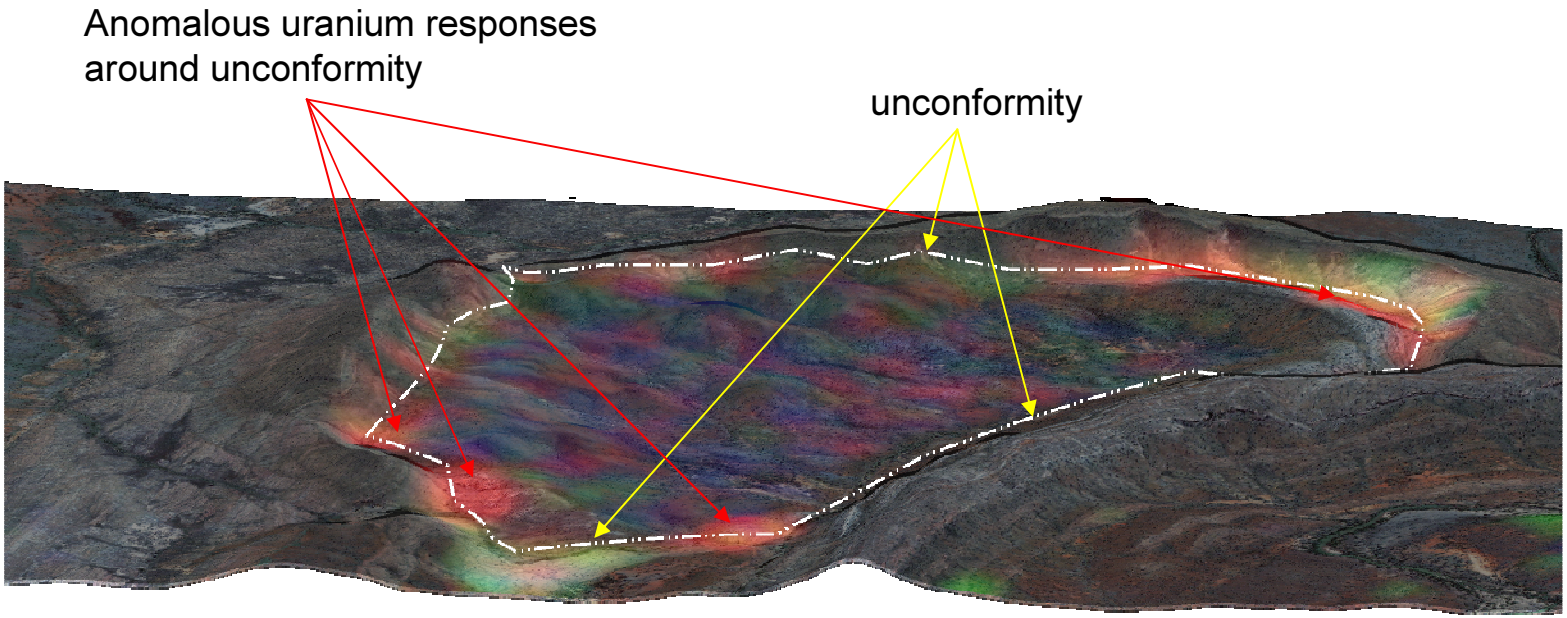


Airborne radiometric survey draped over topography



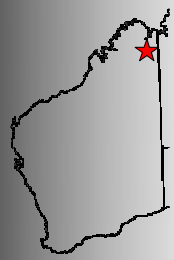
East Kimberley – Radiometrics

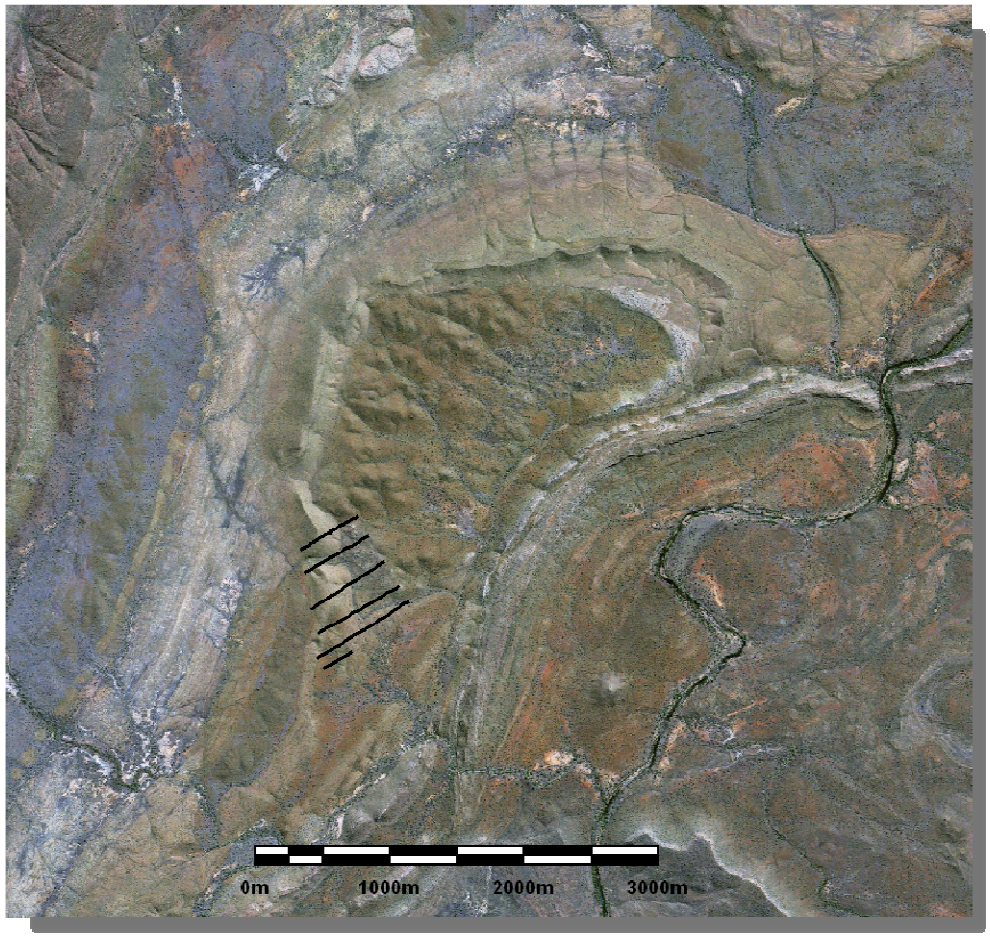




3D image of radiometric data draped on satellite image and digital terrain model

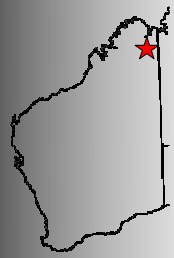
Kimberley – Ground EM Survey





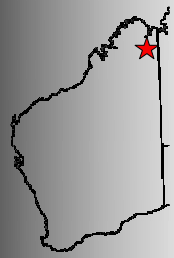
- 6 lines
- Varying length and station spacing
- Targeting prospective horizon and unconformity

Kimberley – Ground EM Survey

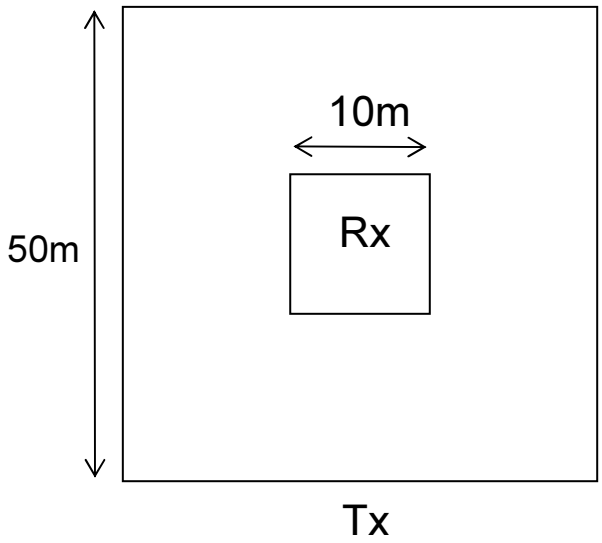


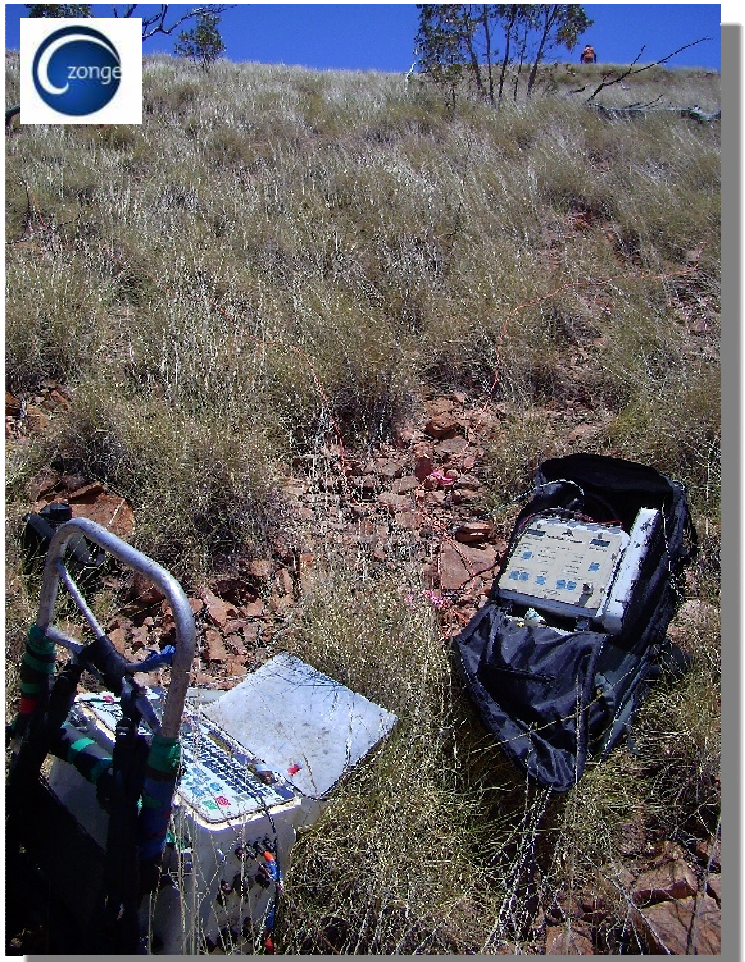
- NanoTEM Survey (2008)
  - 50m Tx loop, 10m In-Loop Rx
  - 12v battery power supply
  - Access only by helicopter

Kimberley – Ground EM Survey

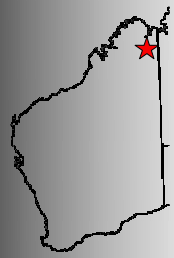


- Zonge NanoTEM loop configuration



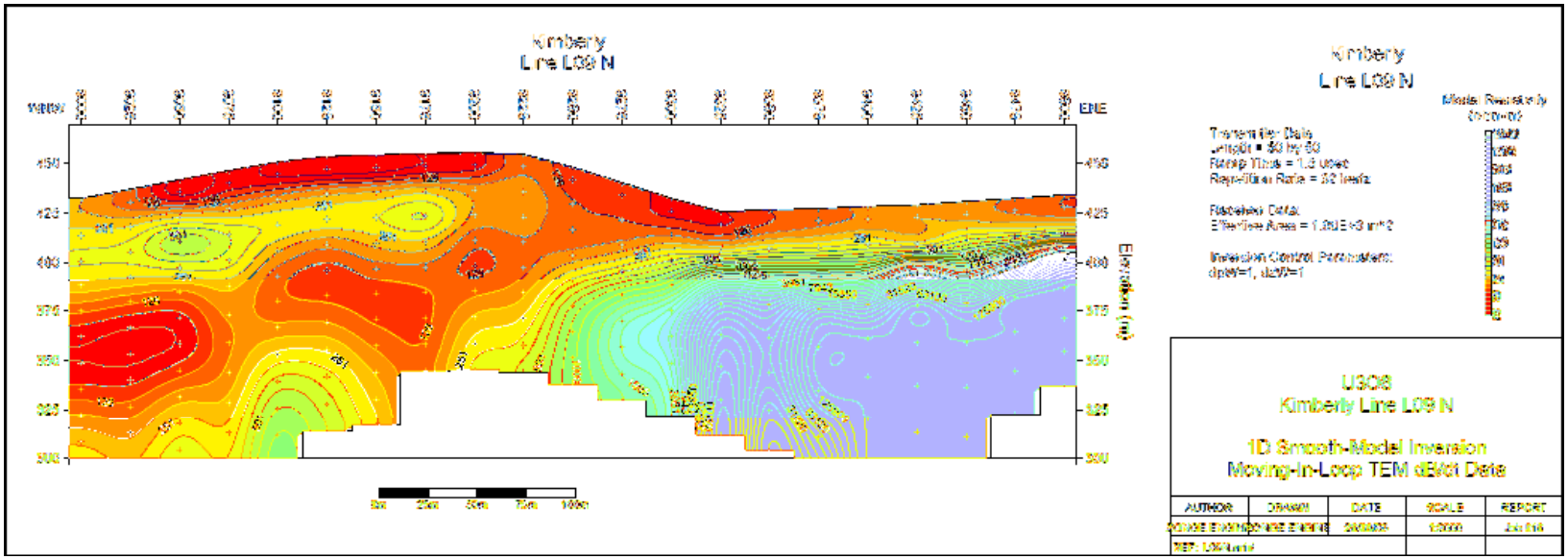


Kimberley – Ground EM Survey

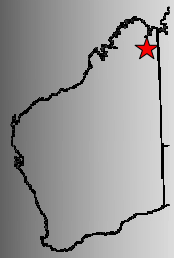


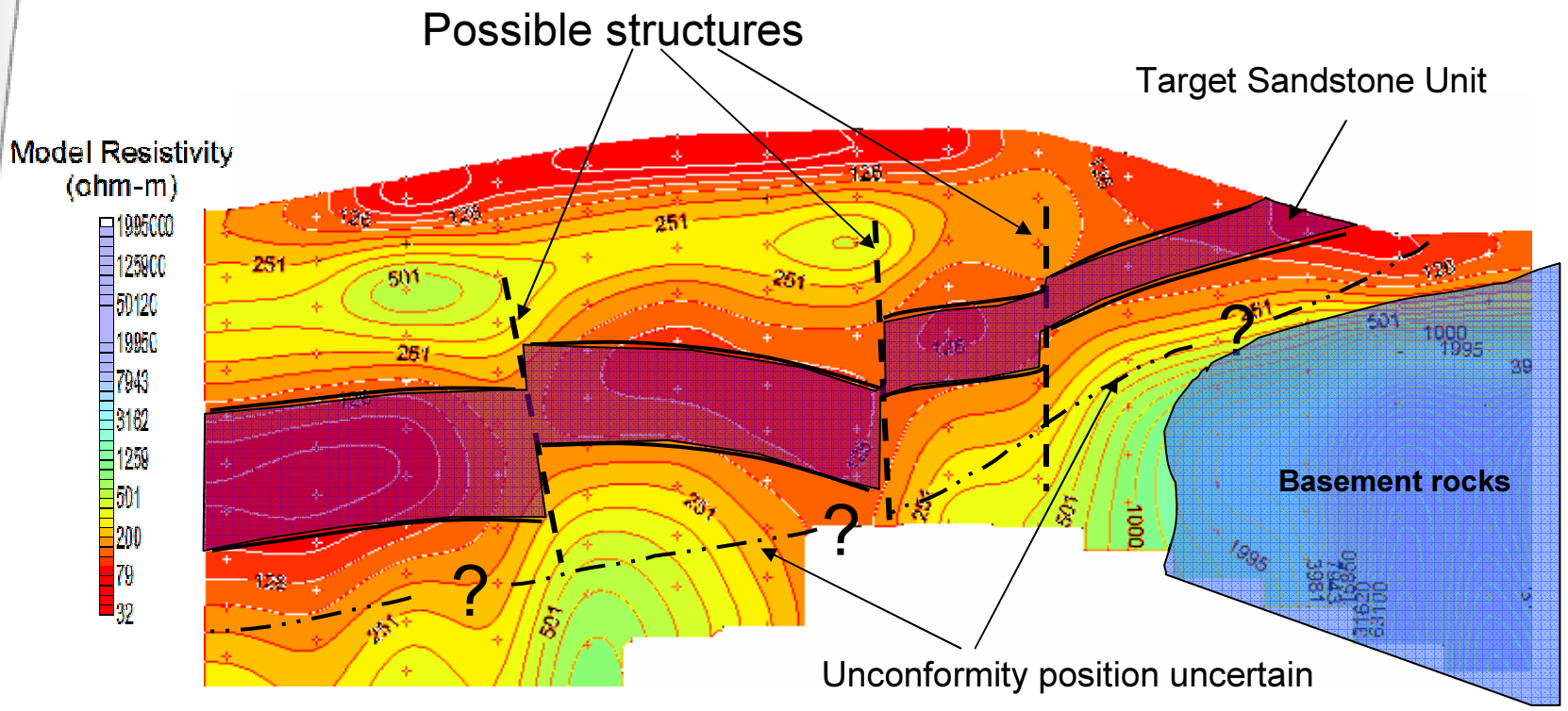
Vertical cross-section of earth showing variation in resistivity

150m



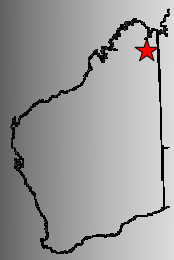
Kimberley – Ground EM Survey



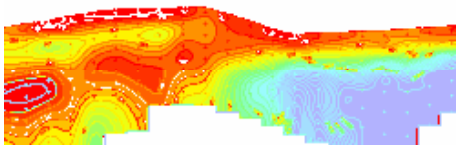


- NanoTEM Survey
  - 50m Tx loop, 10m In-Loop Rx
  - 12v battery power supply
  - Access only by helicopter

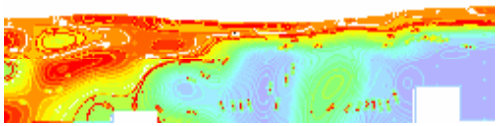
Kimberley – Ground EM Survey



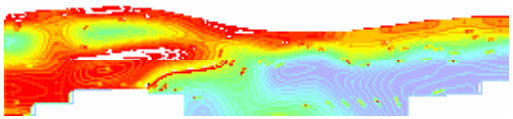
Line 9



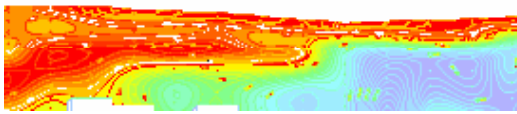
Line 8



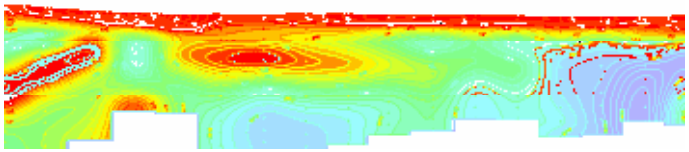
Line 6



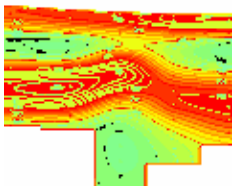
Line 4

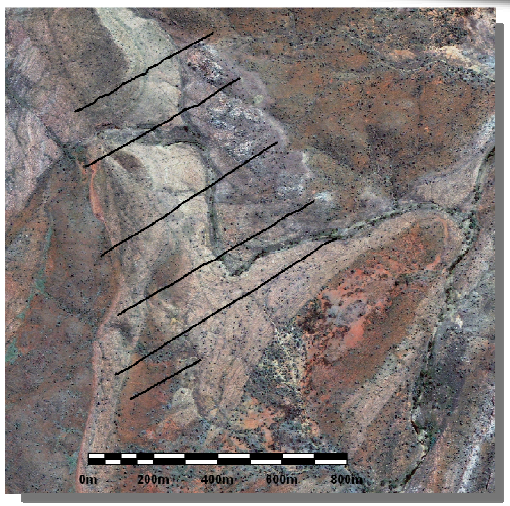


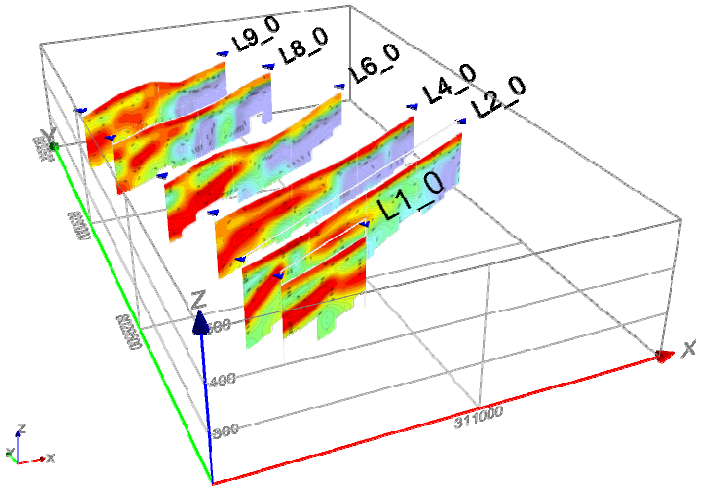
Line 2



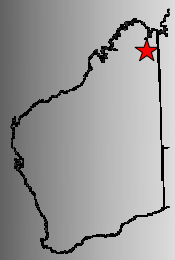
Line 1

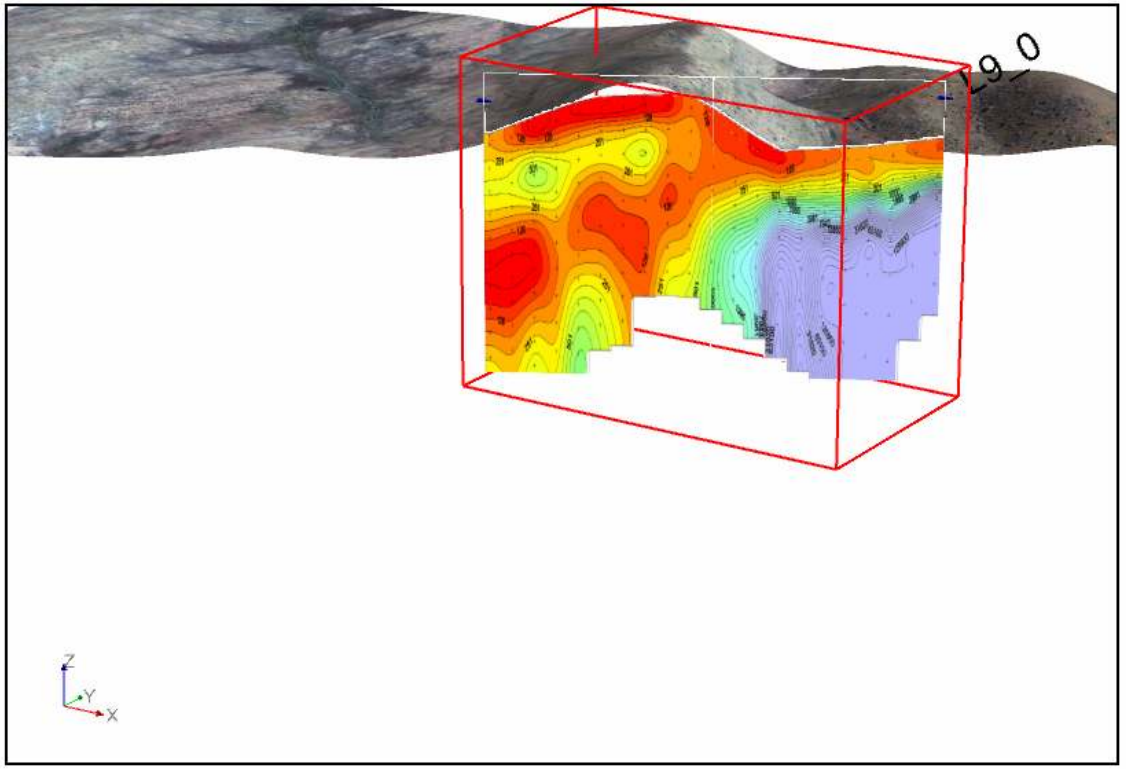


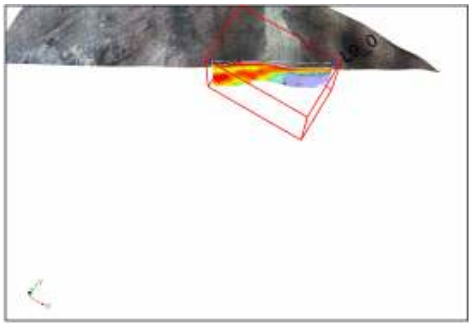




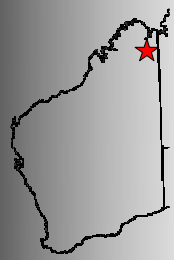
Kimberley – Ground EM Survey

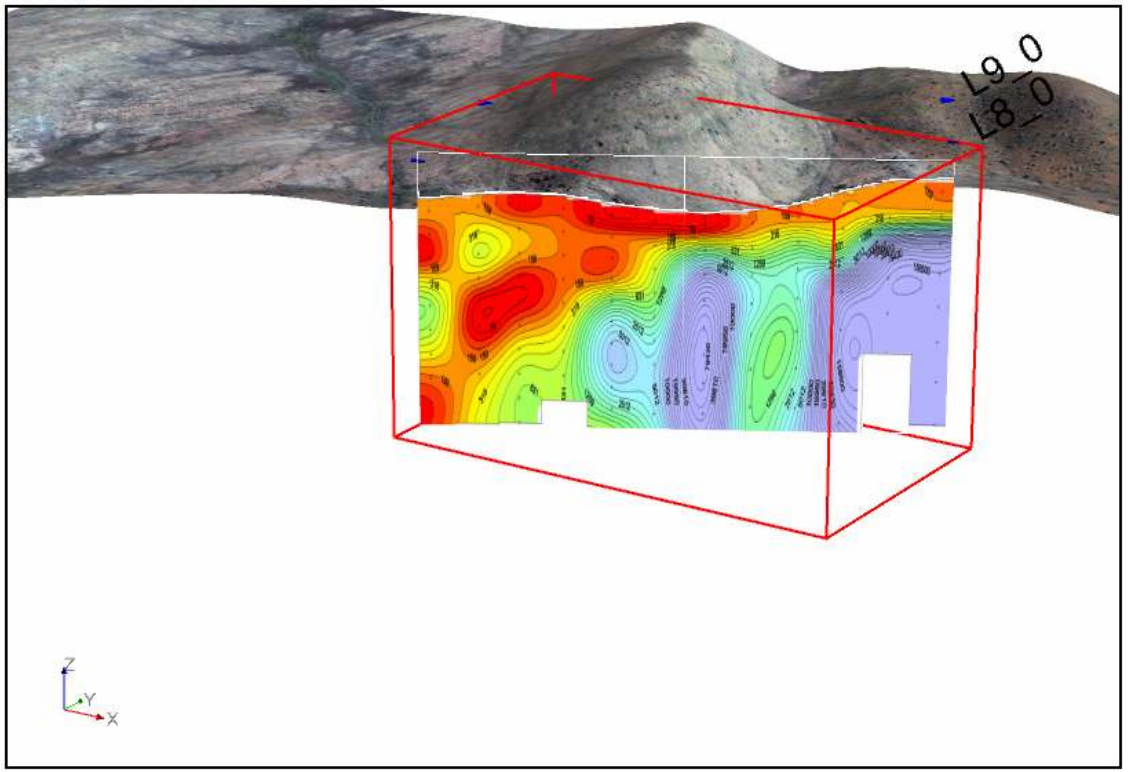


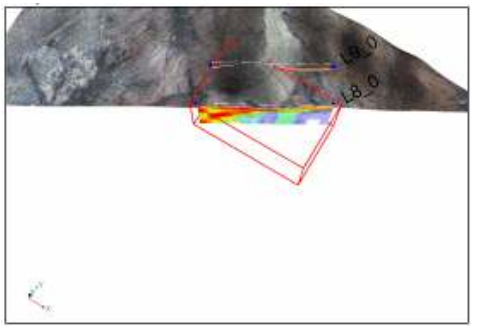




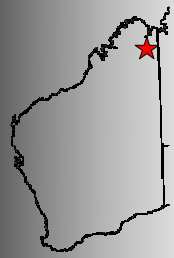
Kimberley – Ground EM Survey

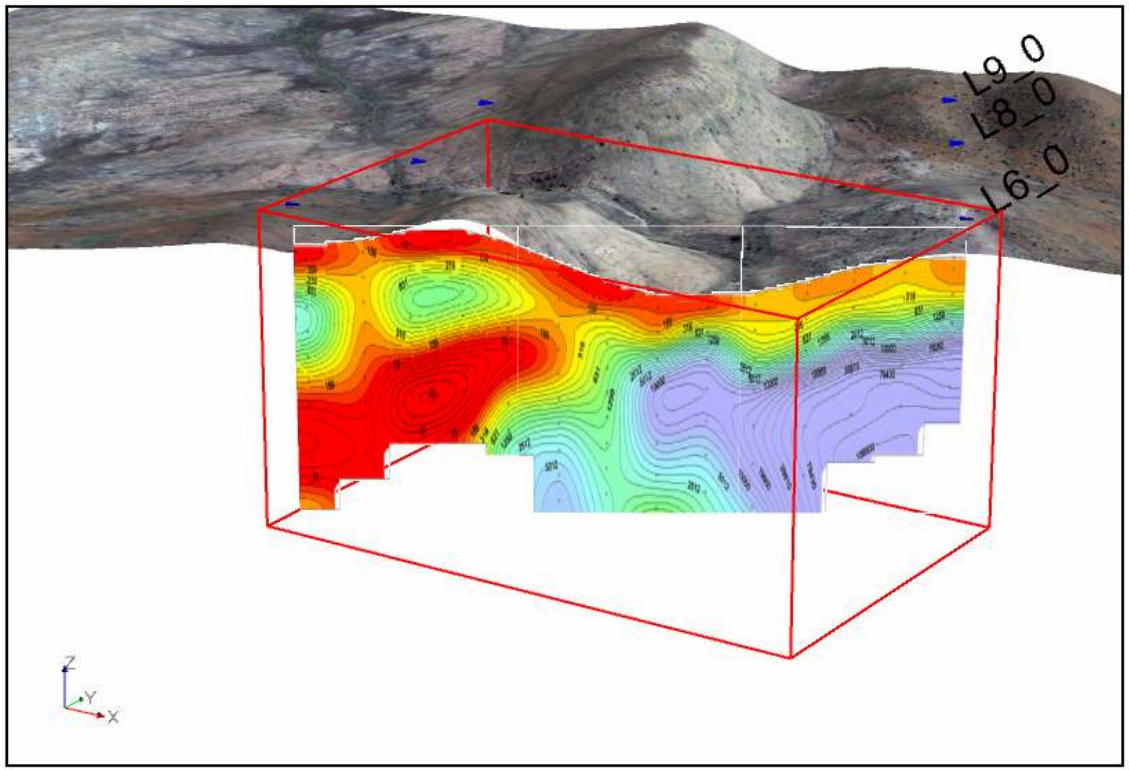


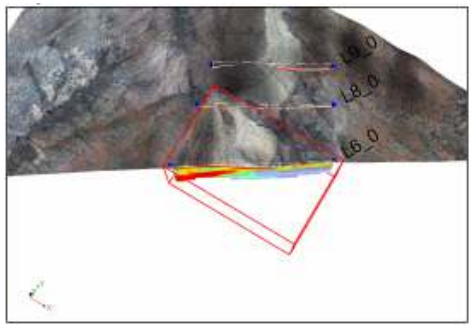




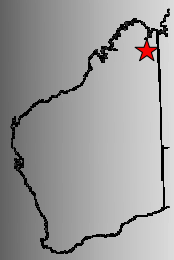
Kimberley – Ground EM Survey

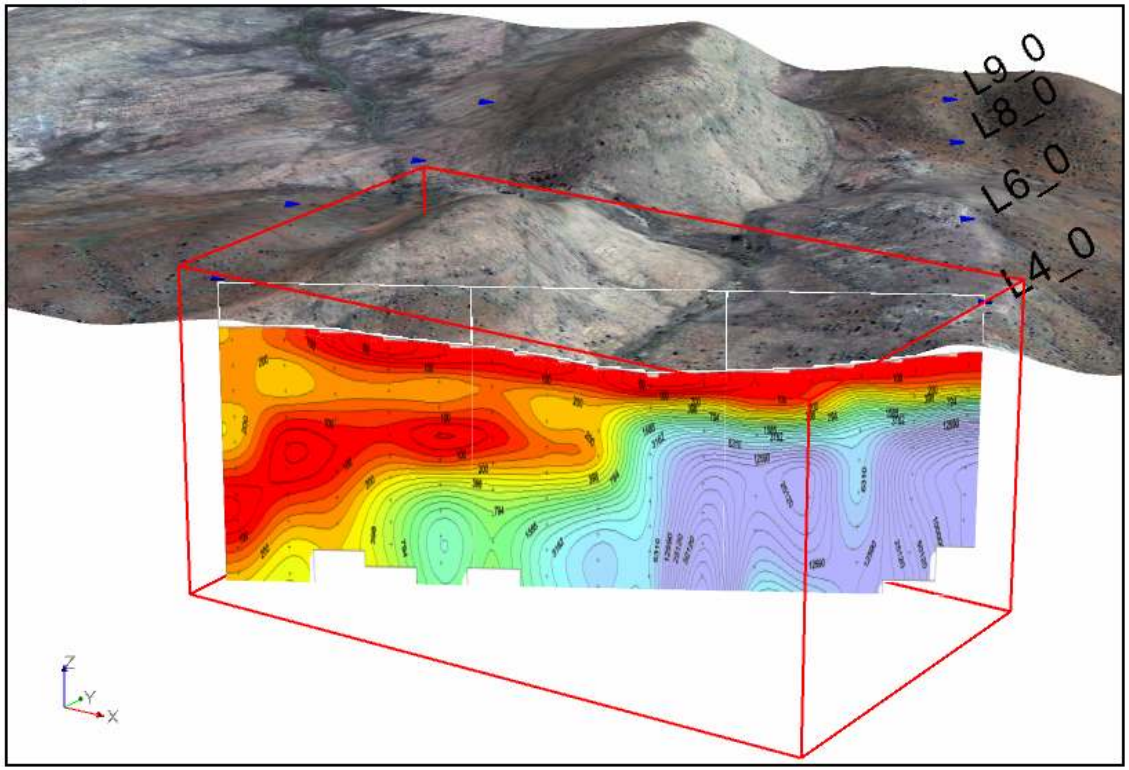


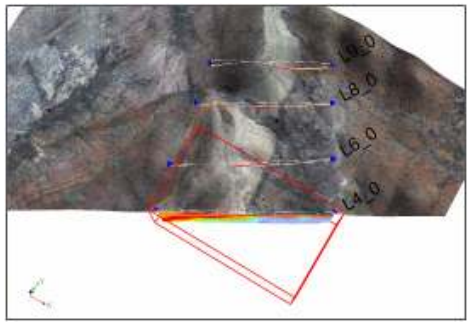




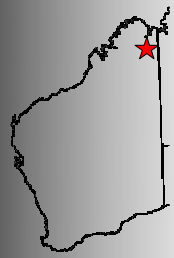
Kimberley – Ground EM Survey

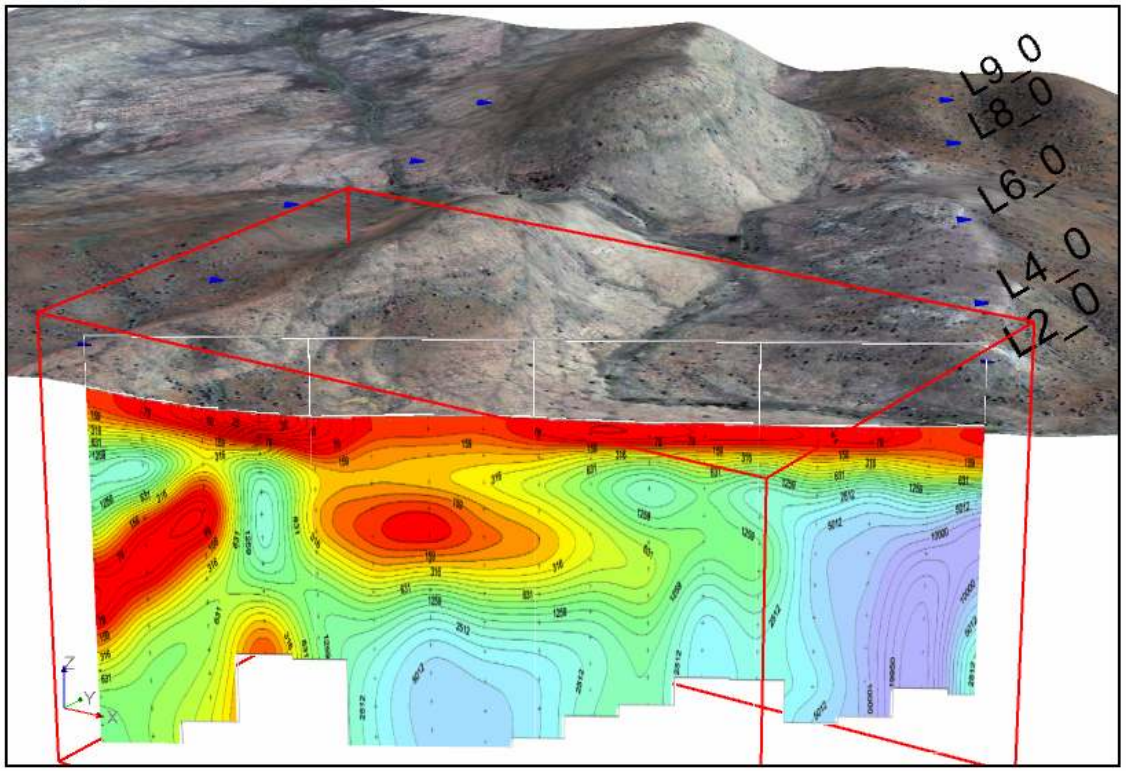


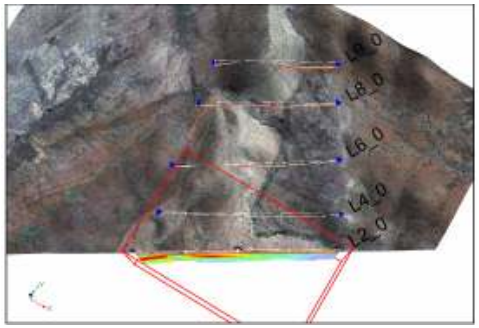




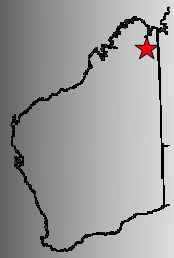
Kimberley – Ground EM Survey

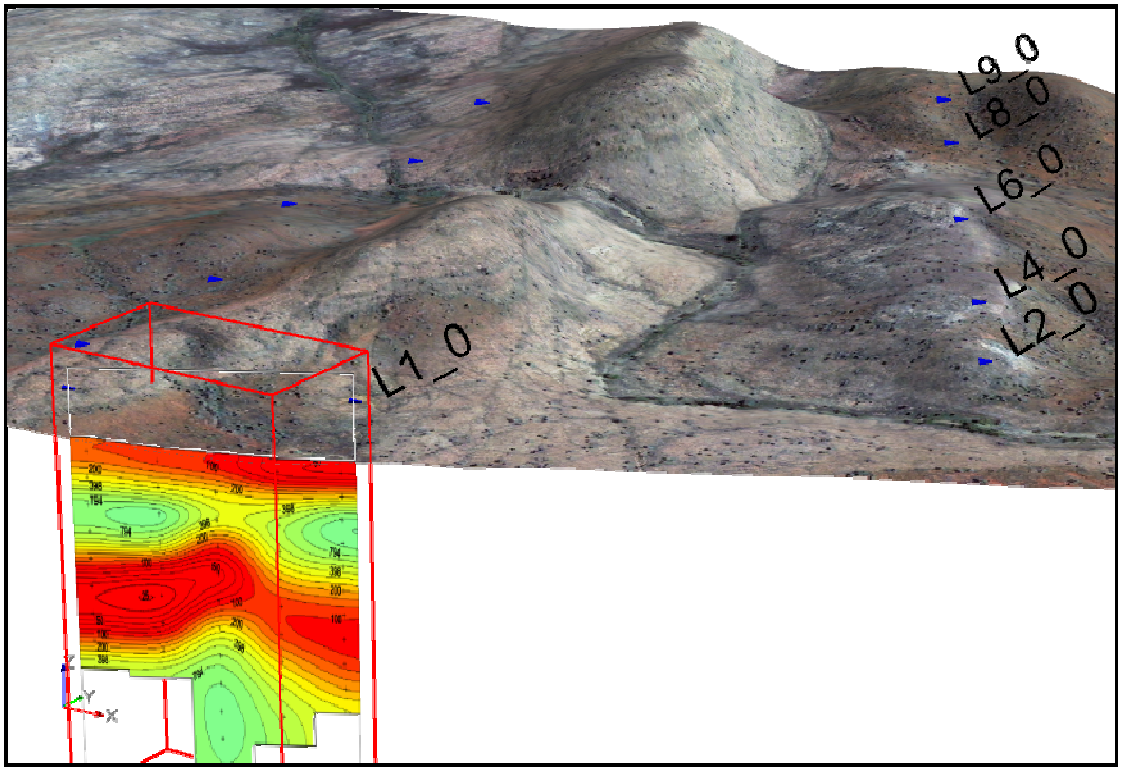


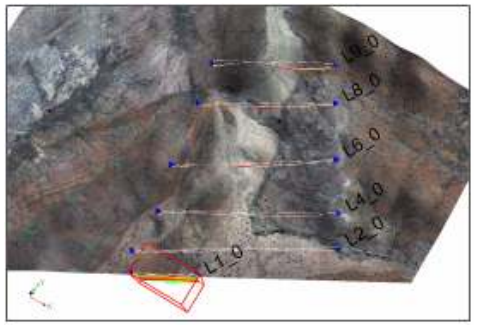




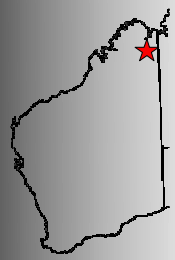
Kimberley – Ground EM Survey





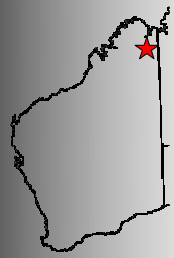


Kimberley – Airborne EM Survey

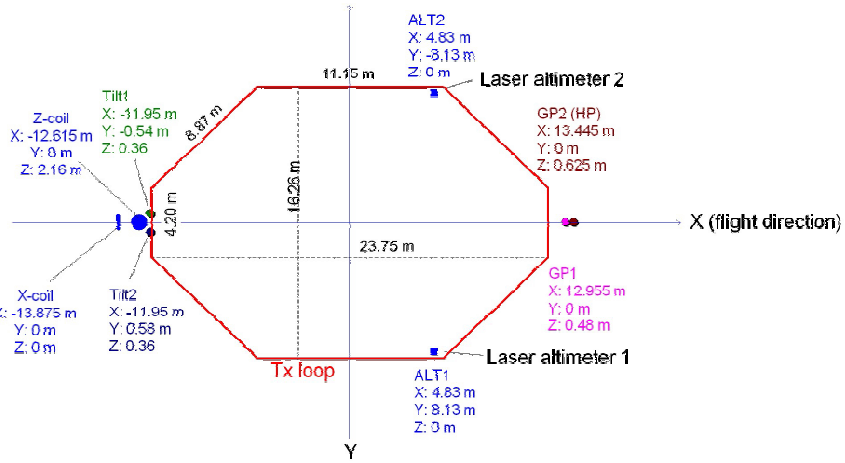


- Rugged, inaccessible terrain required another approach for effective exploration
- Is it possible to map unconformity or target unit from the air?
- Cost constraints and small target areas necessitated a helicopter based system

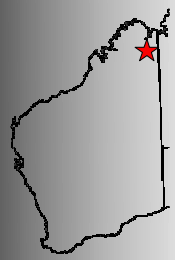
Kimberley – Airborne EM Survey



- SkyTEM
  - Helicopter system
  - Time domain EM
  - Combined High/Low moment transmitter
  - Terrain clearance 30m

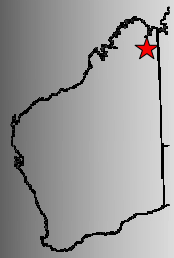


Kimberley – Airborne EM Survey

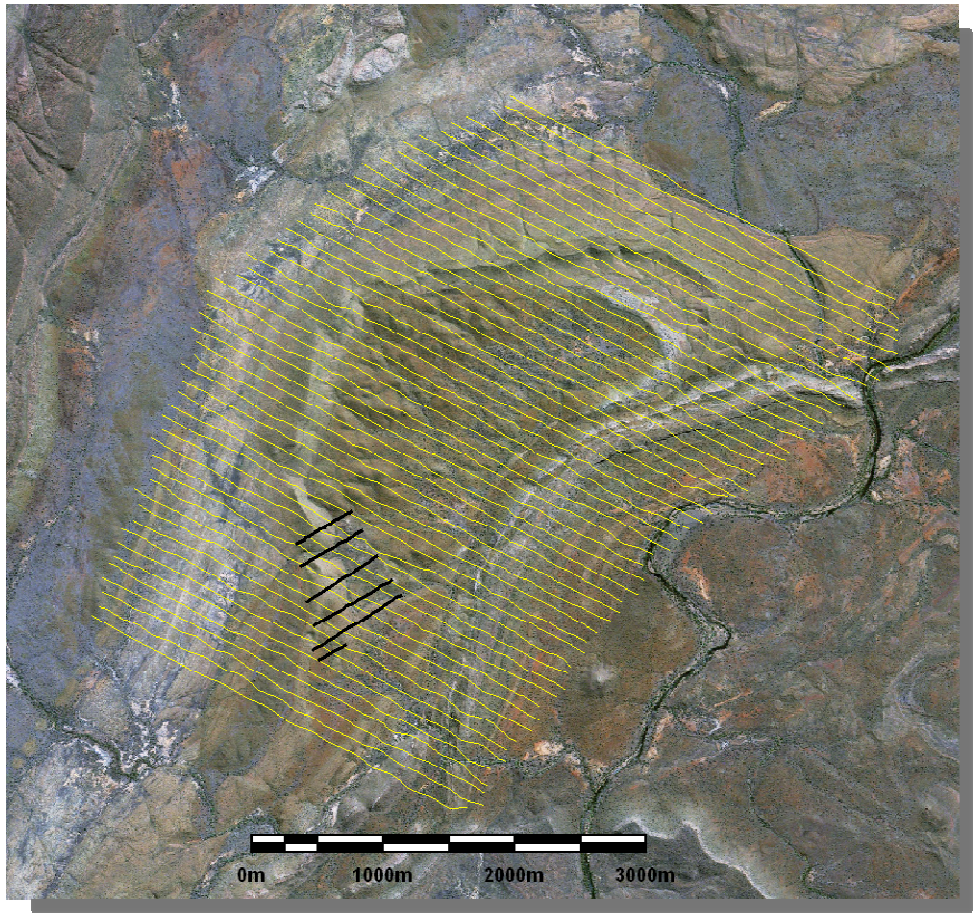


- Objectives of using an airborne system?
  - Often more cost effective
  - Cover more ground and much faster
  - Rough terrain is not as big a constraint
- Caution is needed !
  - Mapping very subtle resistivity contrasts
  - Not looking for large conductors – need to choose the correct platform
  - Good to have some prior knowledge of petrophysical rock properties

Kimberley – Airborne EM Survey

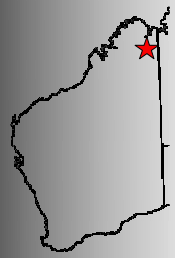


Flight path of airborne EM survey

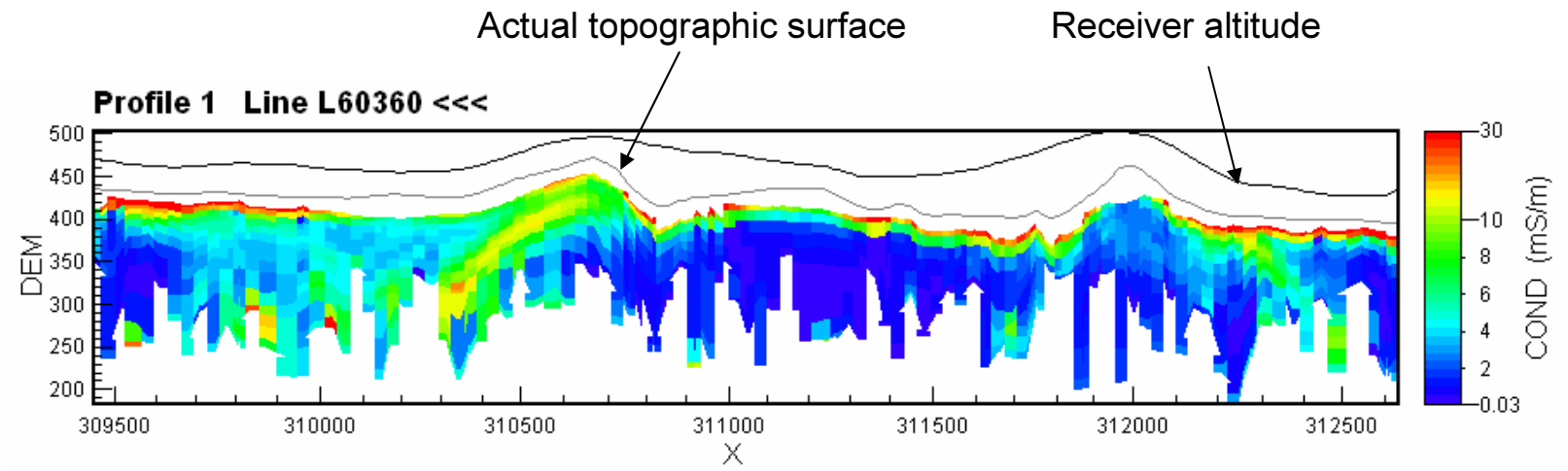


- Full coverage of prospect
- Lines 150m apart
- Targeting prospective horizon and unconformity

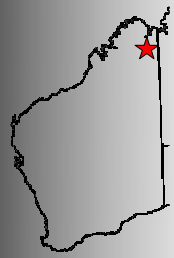
Kimberley – Airborne EM Survey

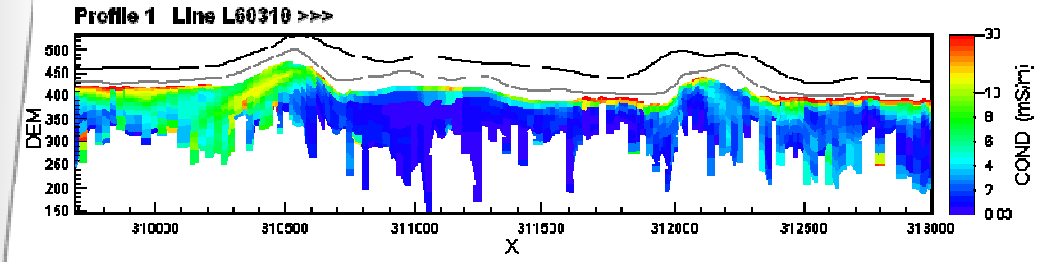


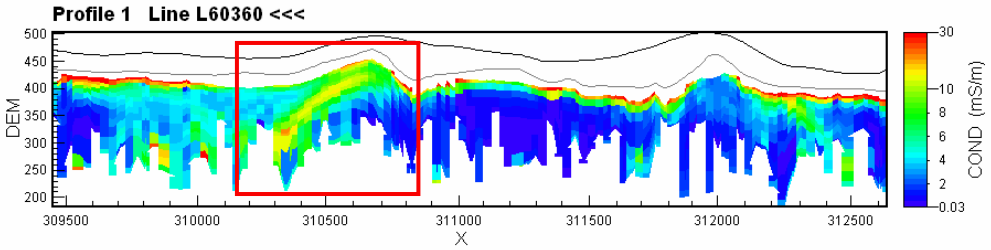
Example cross-section of data from SkyTEM survey

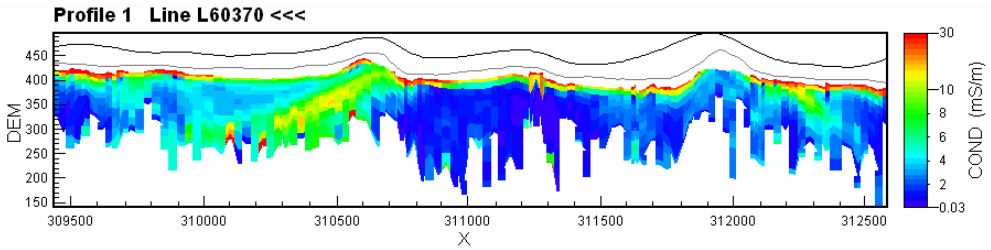


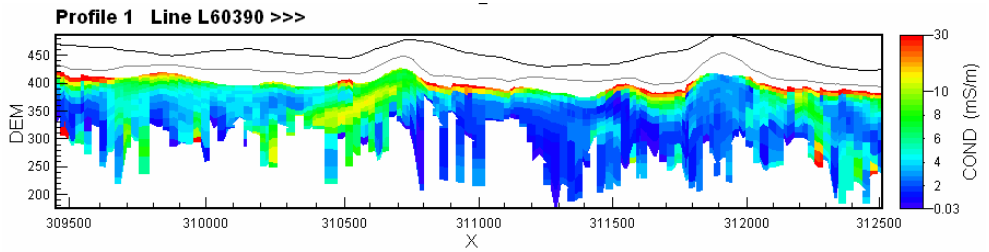
Kimberley – Airborne EM Survey



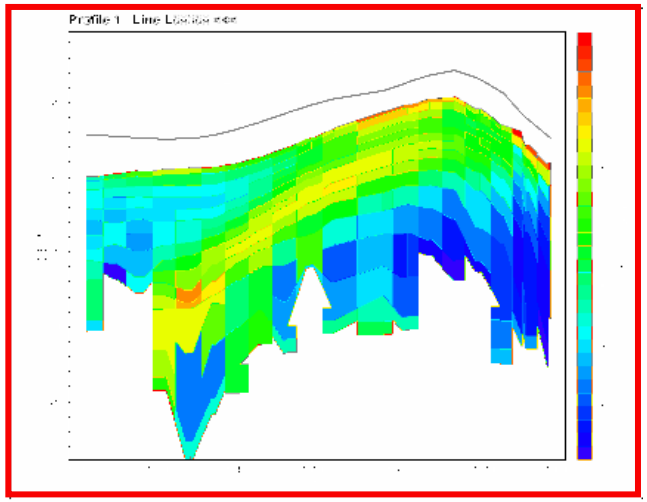




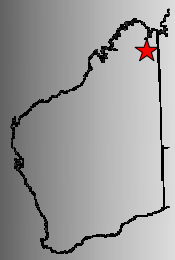




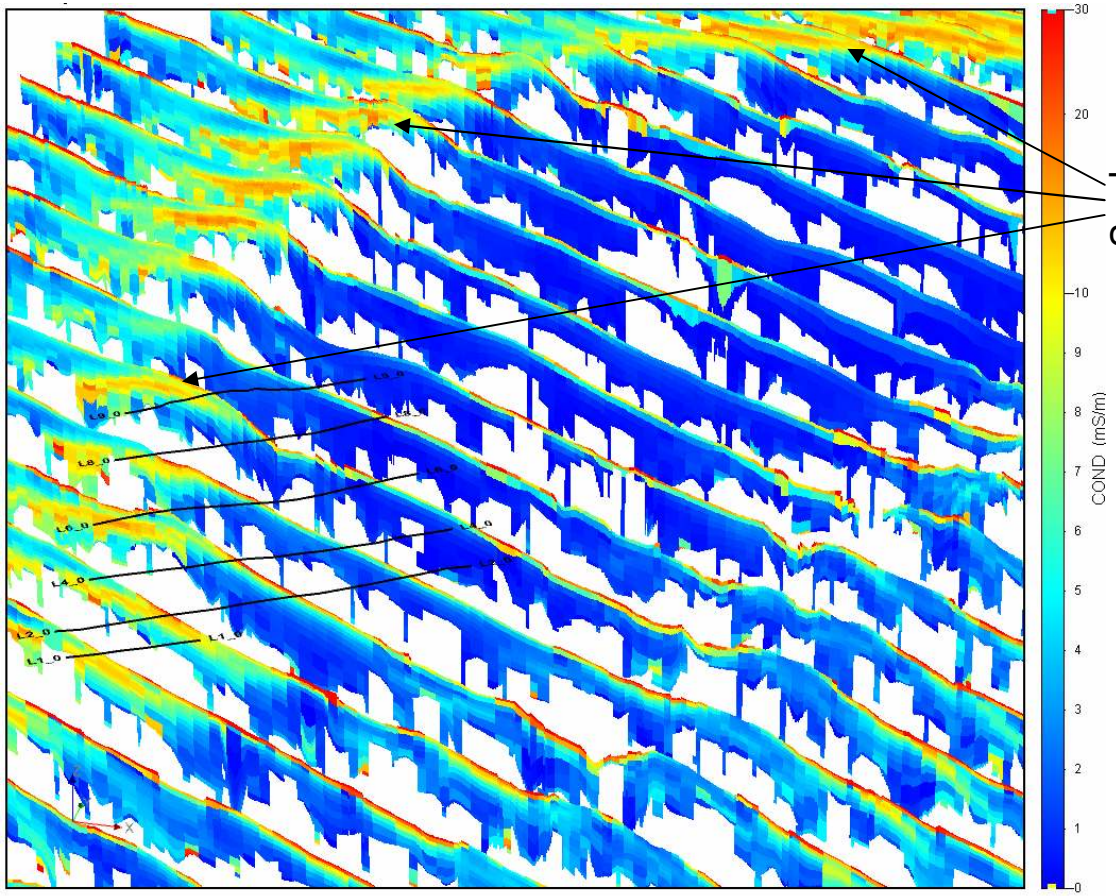
- Subtle conductive horizon
- Not unconformity in this instance, rather a target geological unit close to unconformity



Kimberley – Airborne EM Survey

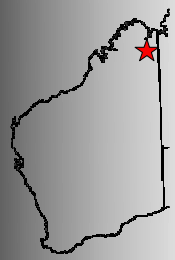


3D stacked sections of SkyTEM inversions

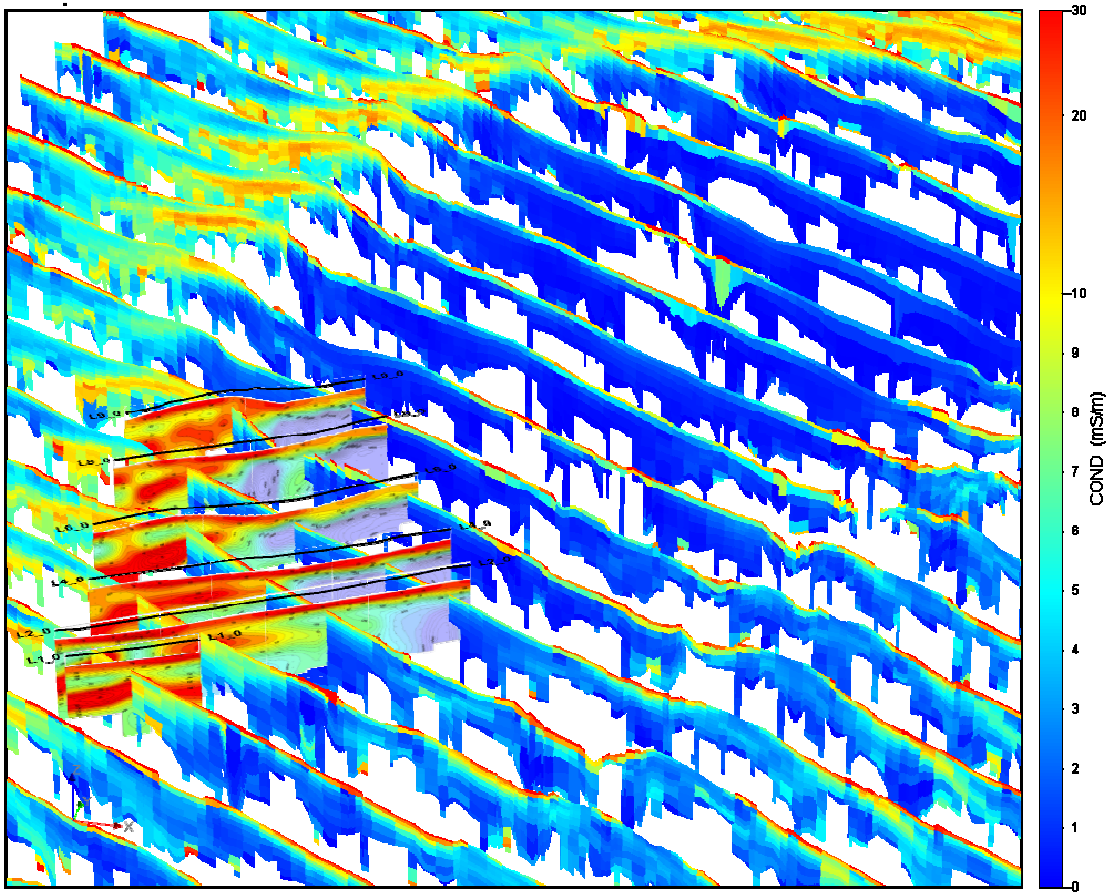


Target sandstone horizon clearly visible on many lines

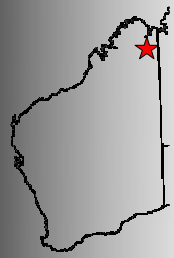
Kimberley – Airborne EM Survey



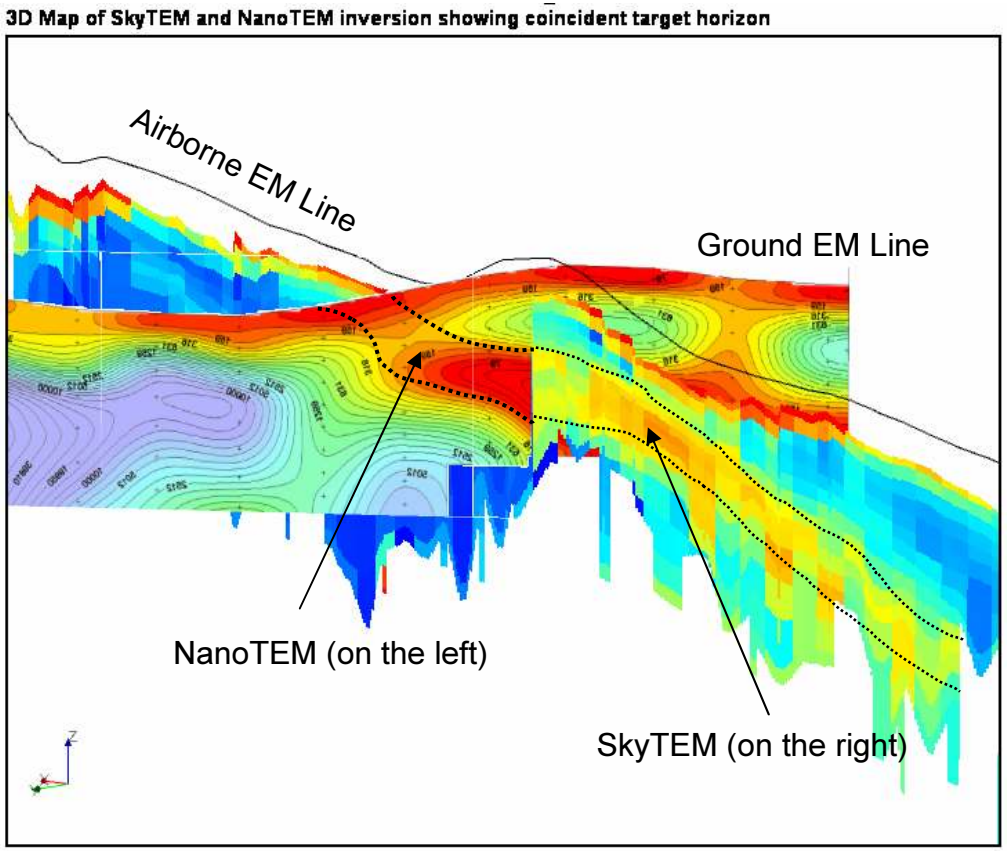
3D stacked sections of
SkyTEM and NanoTEM inversions

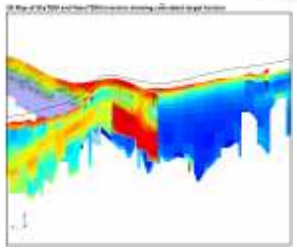


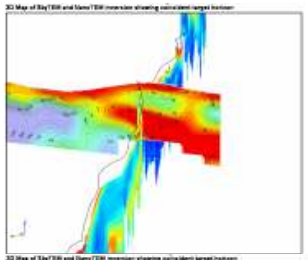
Kimberley – Airborne EM Survey

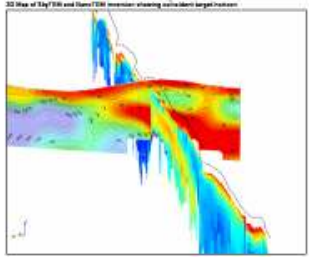


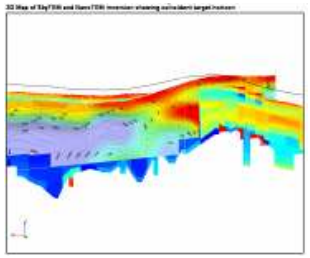
Sandstone unit response from NanoTEM and SkyTEM



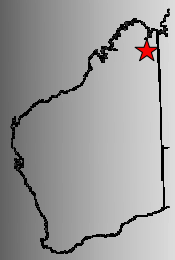








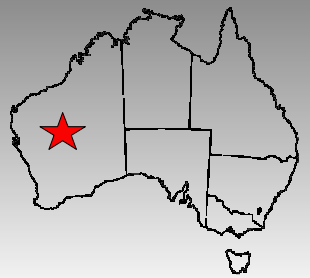
Kimberley – Summary



- Ground EM survey resolved electrical contrast in target sandstone horizon
- Airborne EM survey achieved same result but over a larger area
- Work is still continuing with interpretation of data

Arnhem Land
East Kimberley

Ashburton



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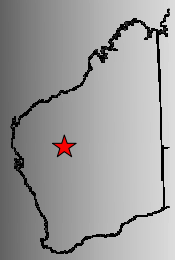

Summary

- Target – Proper unconformity
- Large areas of land to prospect
- Numerous uranium anomalies

Objective

- search for subtle resistivity changes around a sandstone-basement contact to infer presence of unconformity

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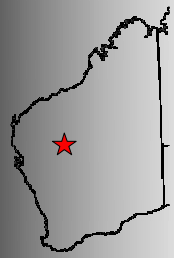

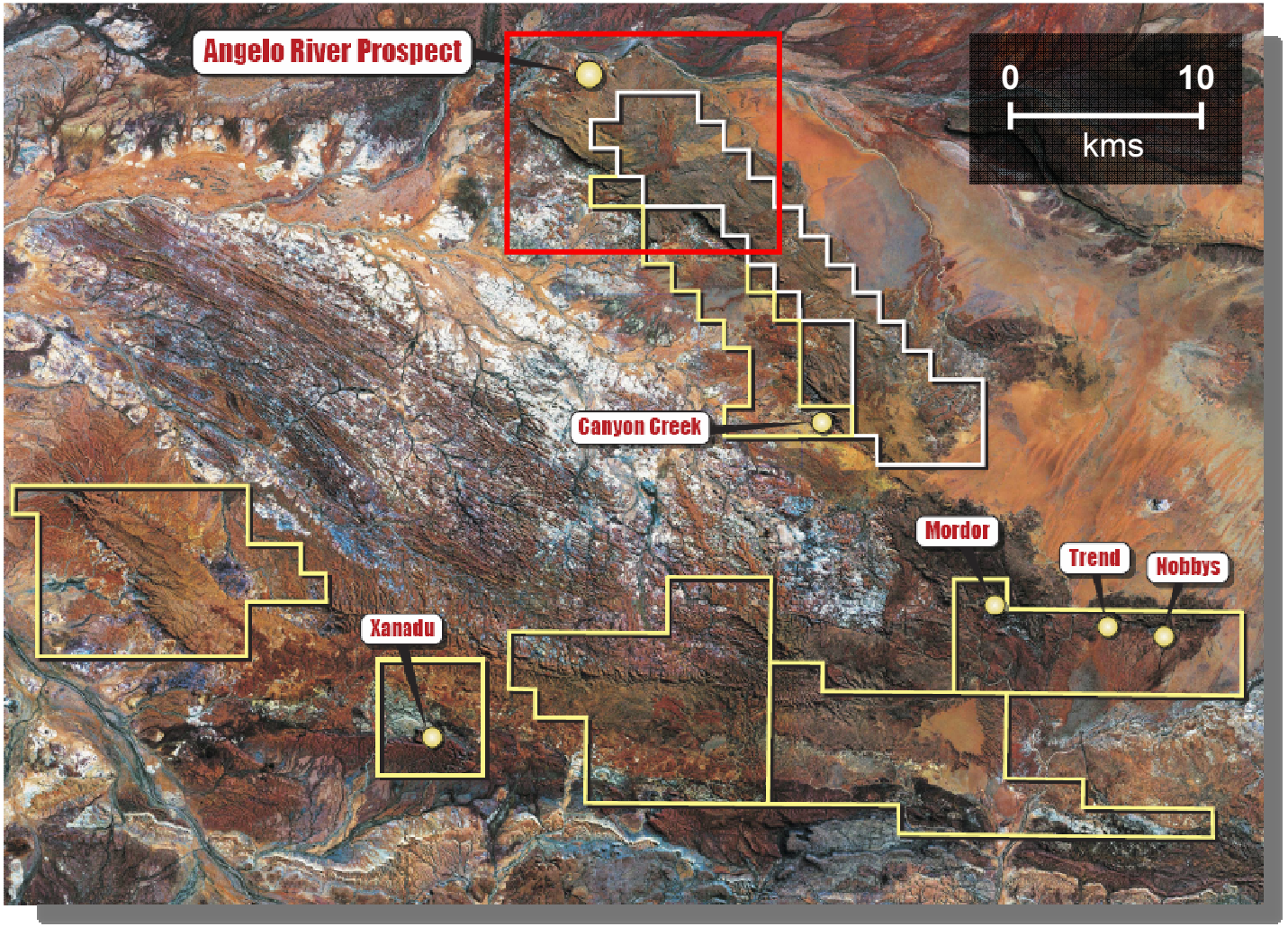

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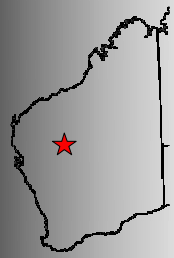

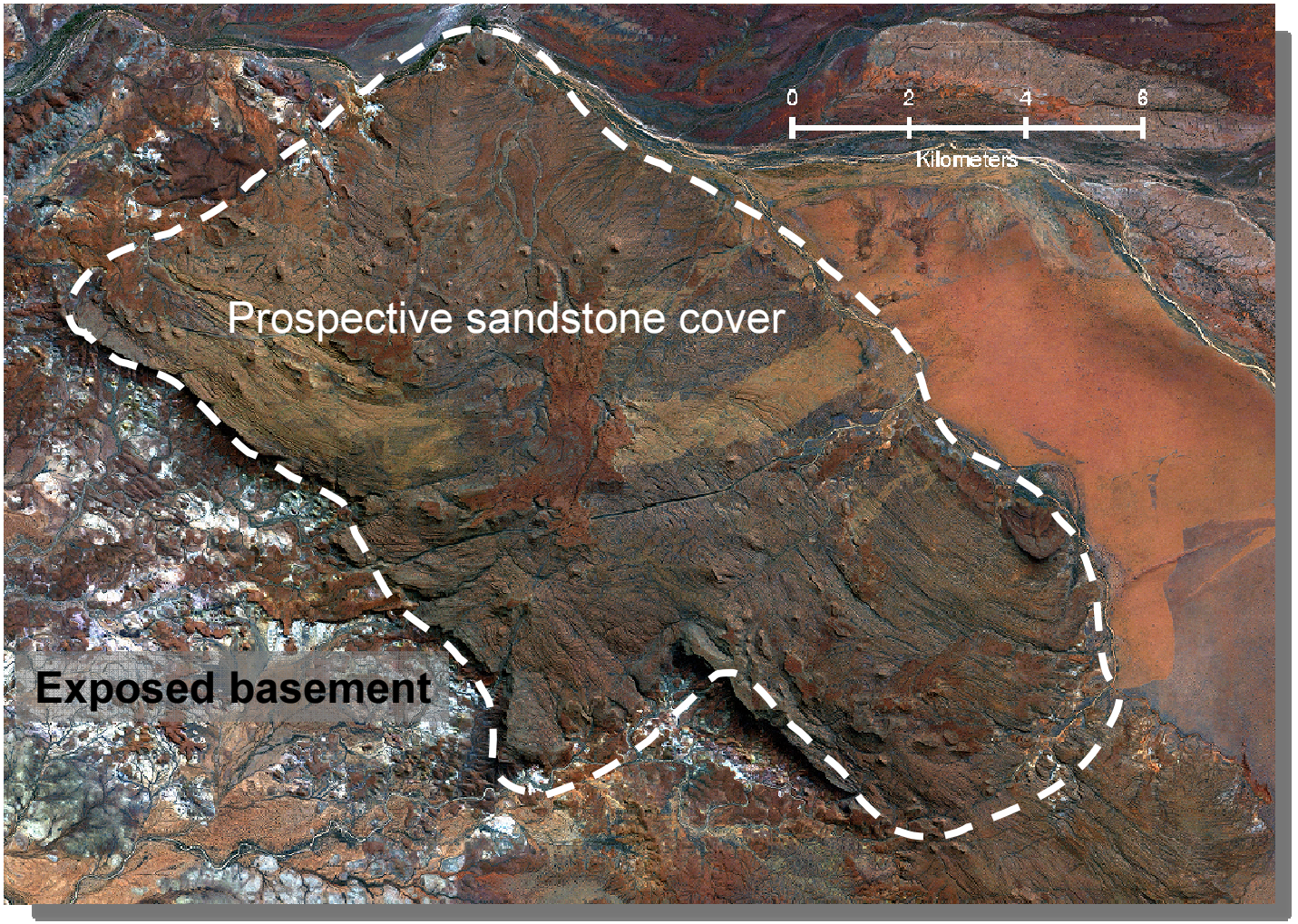

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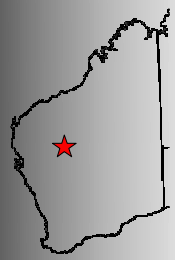
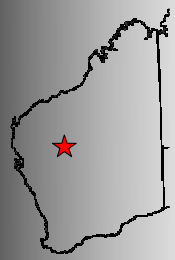


Why choose EM?

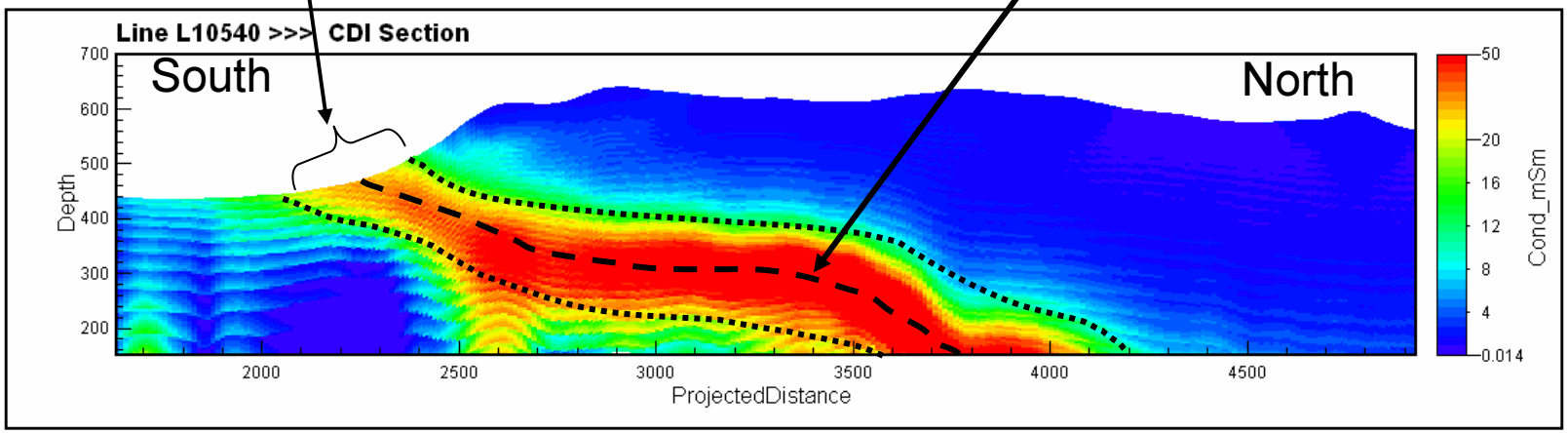
- Large areas to prospect
- Extremely difficult to access
- Prohibitive costs to explore conventionally
- Map unconformity by indirect measurement of resistivities associated with alteration proximal to unconformity
- Airborne EM technique best option
  - Tempest platform chosen and survey flown in 2007-2008

Ashburton - Airborne EM Survey



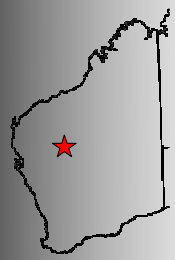
Possible zone of alteration around unconformity?

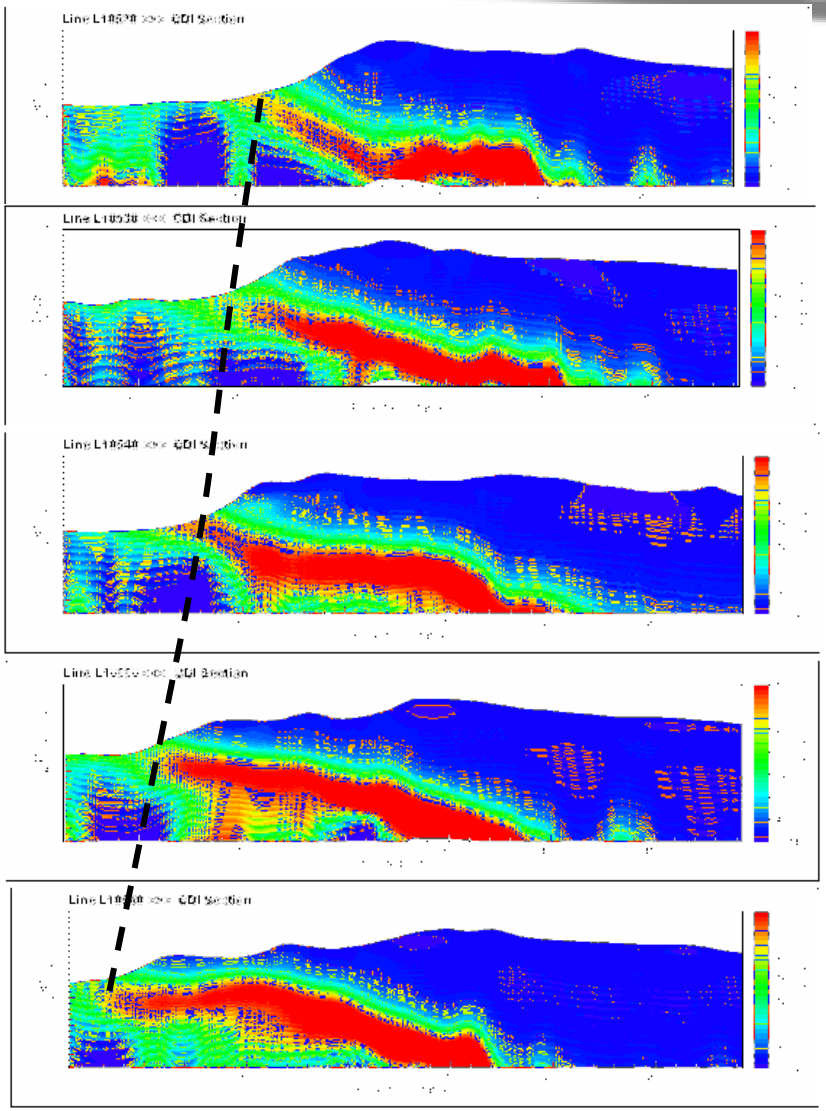
Unconformity somewhere here?



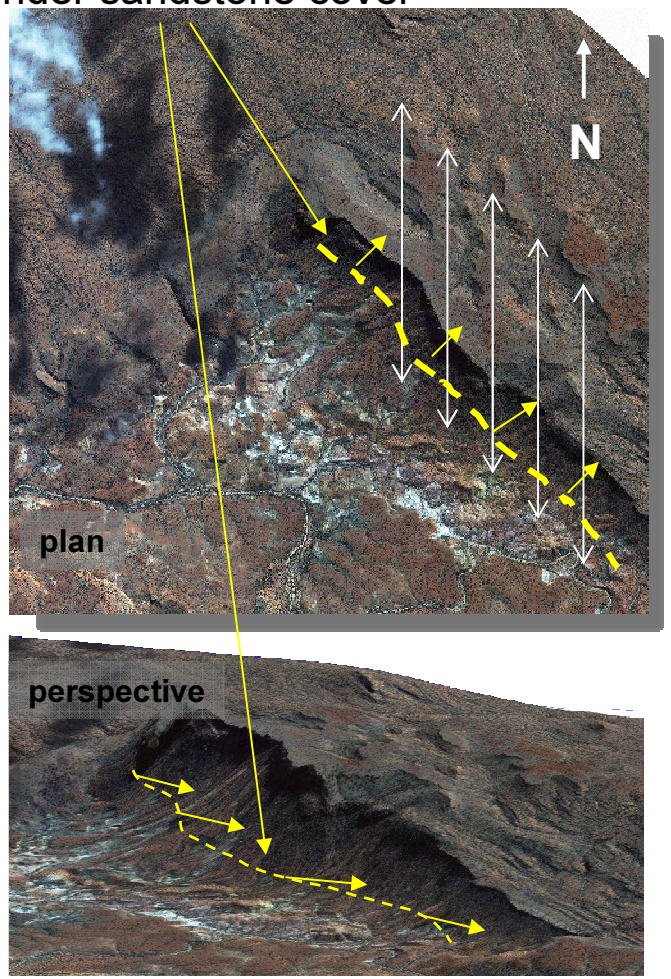
- Very wide zone of ‘alteration’ ?
- No ground checking possible yet – cannot confirm geological veracity of interpretation

Ashburton - Airborne EM Survey

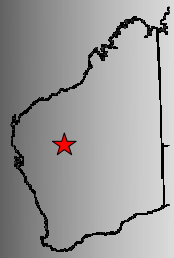


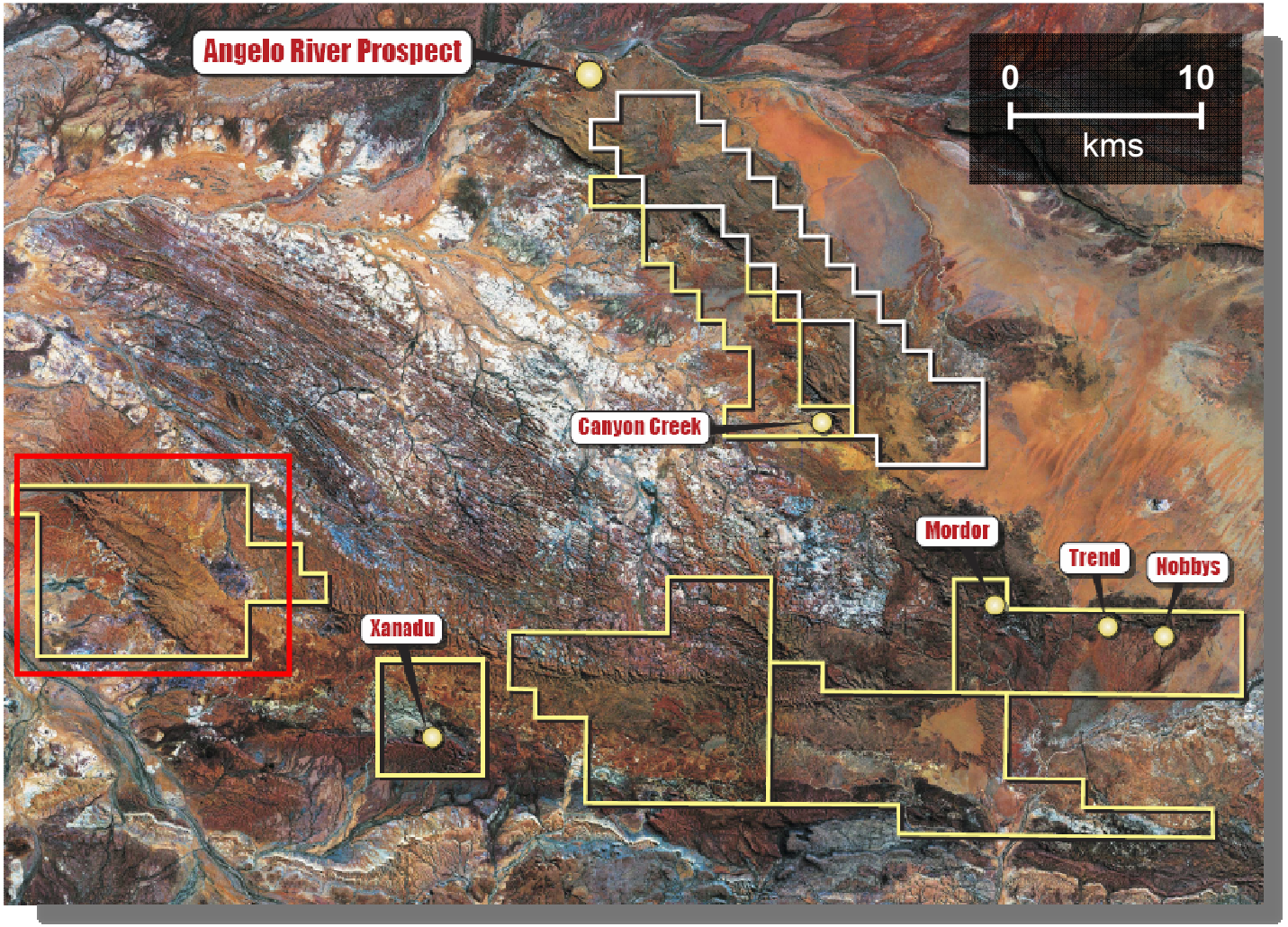


Exposed unconformity dipping under sandstone cover



Ashburton Joint Venture





URAM 2009
June 09

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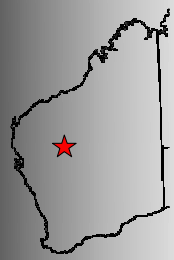
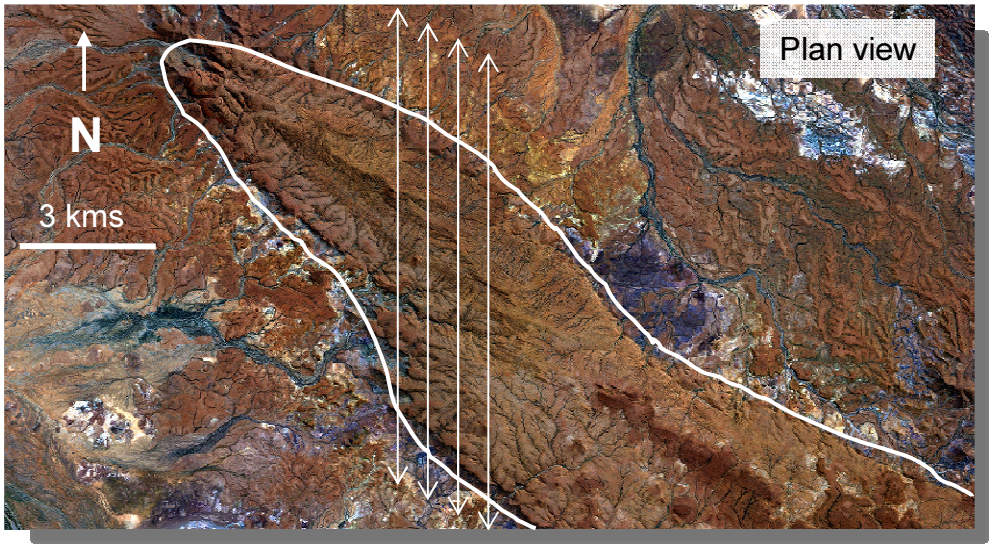
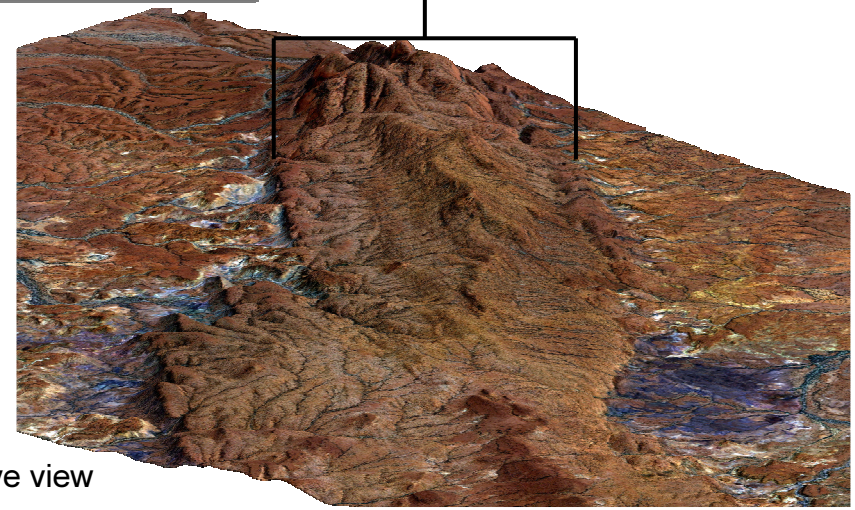
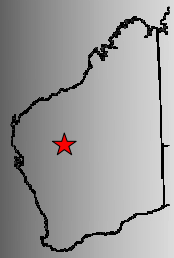






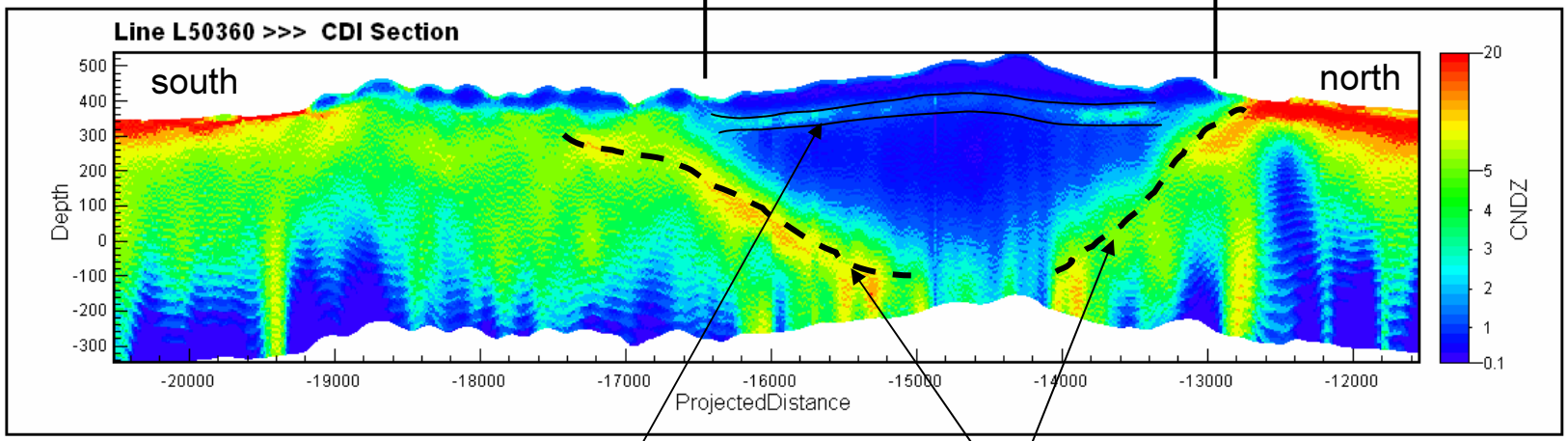
Perspective view

Ashburton - Airborne EM Survey



400m

Sandstone outcrop 3500m



Possible saline water table?

Possible unconformity trend

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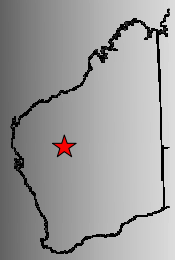
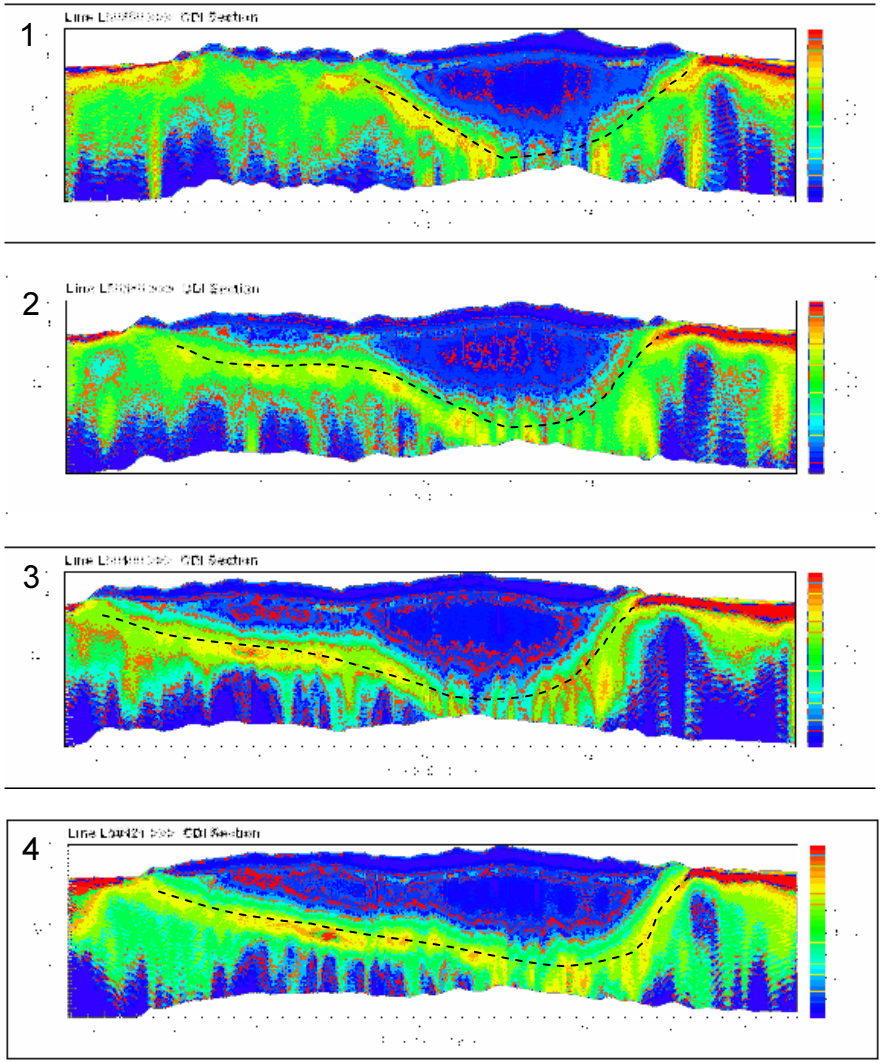
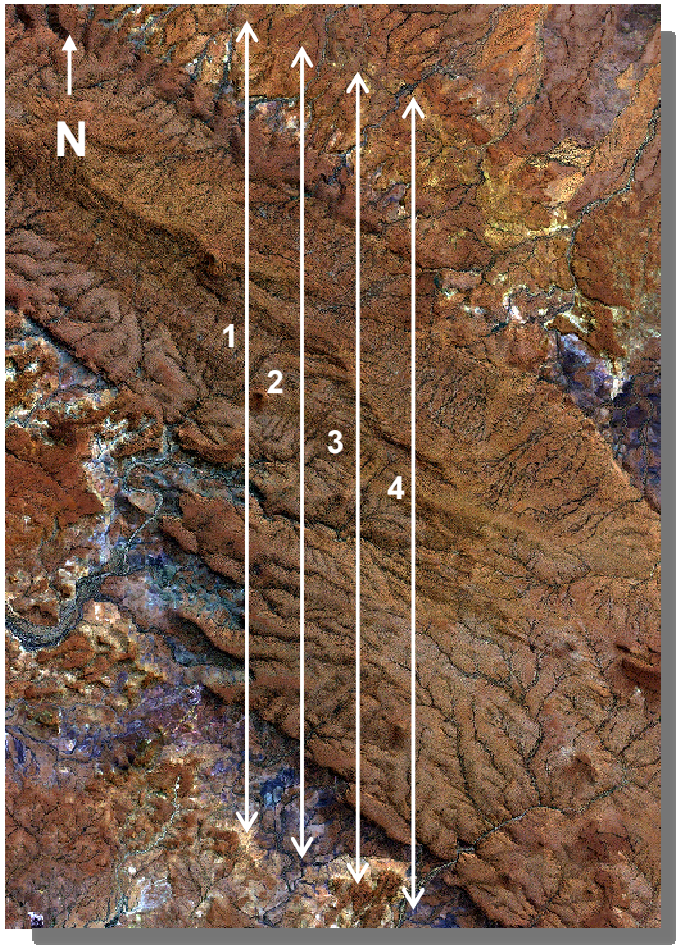
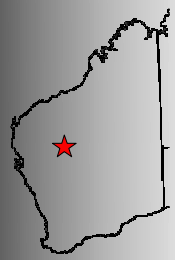




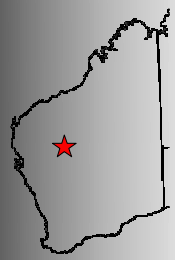


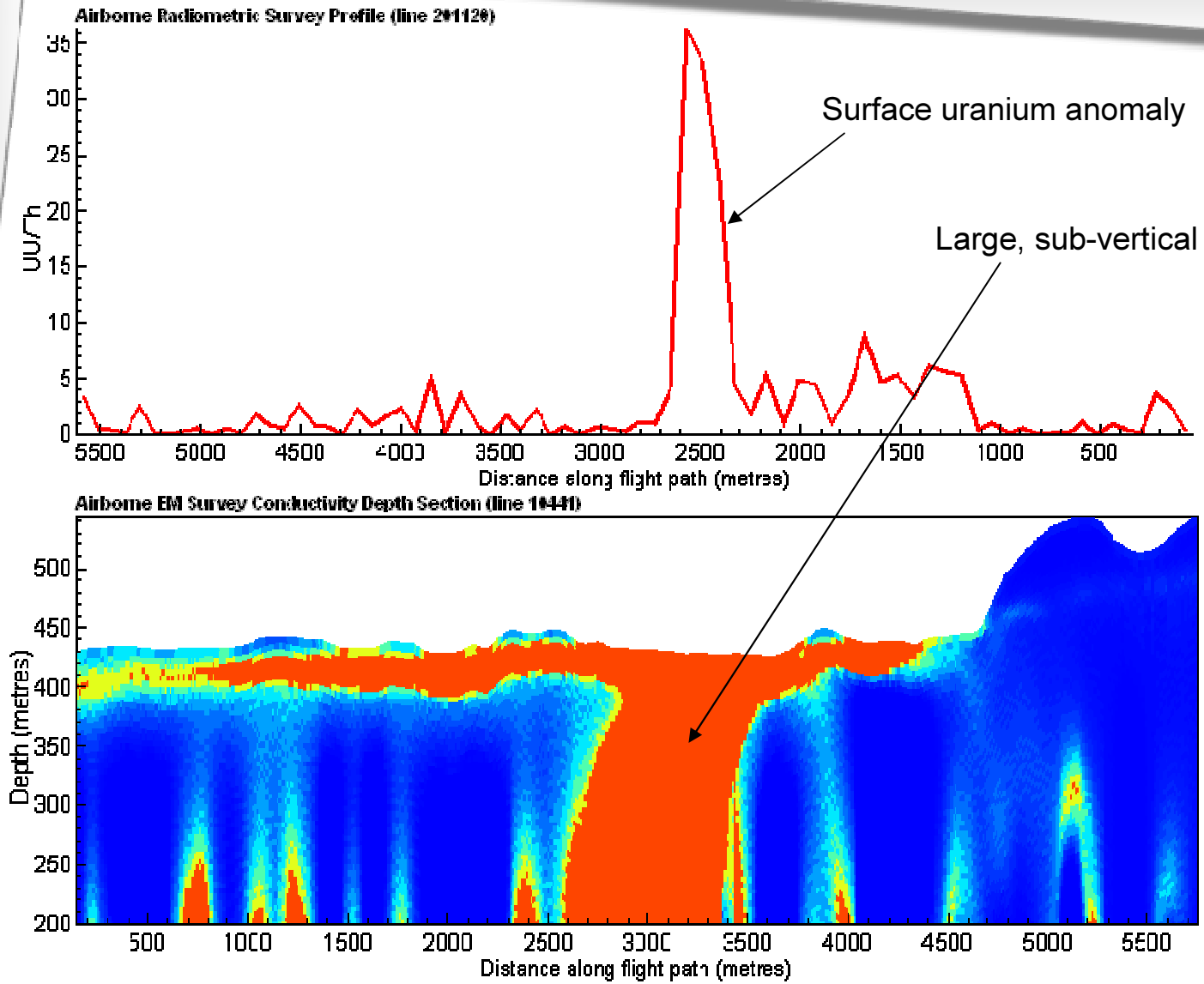
Ashburton - Airborne EM Survey



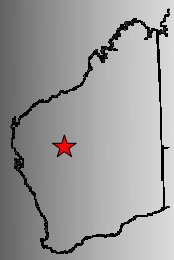
- Sometimes the unexpected occurs …
- Survey has mapped large basement conductors with uranium anomalies at surface

Ashburton - Airborne EM Survey

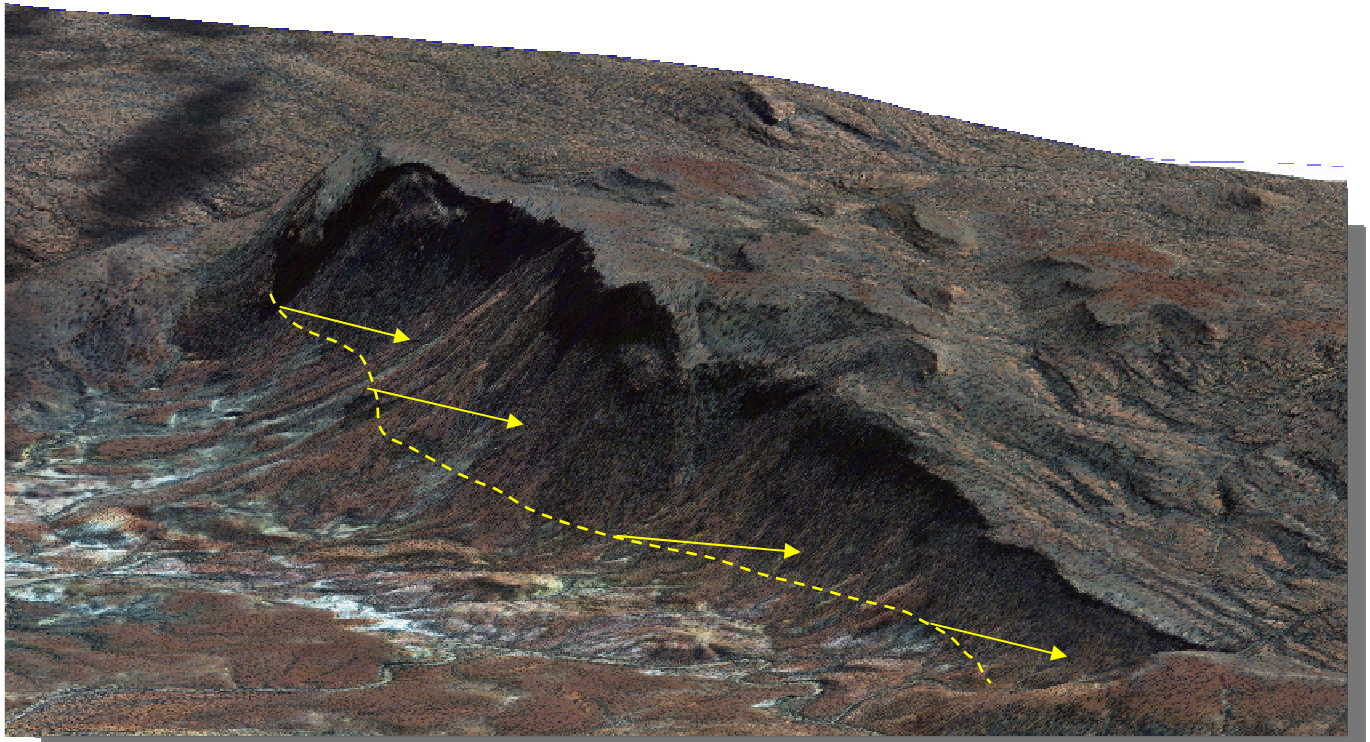




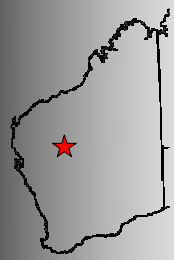
Ashburton - Airborne EM Survey



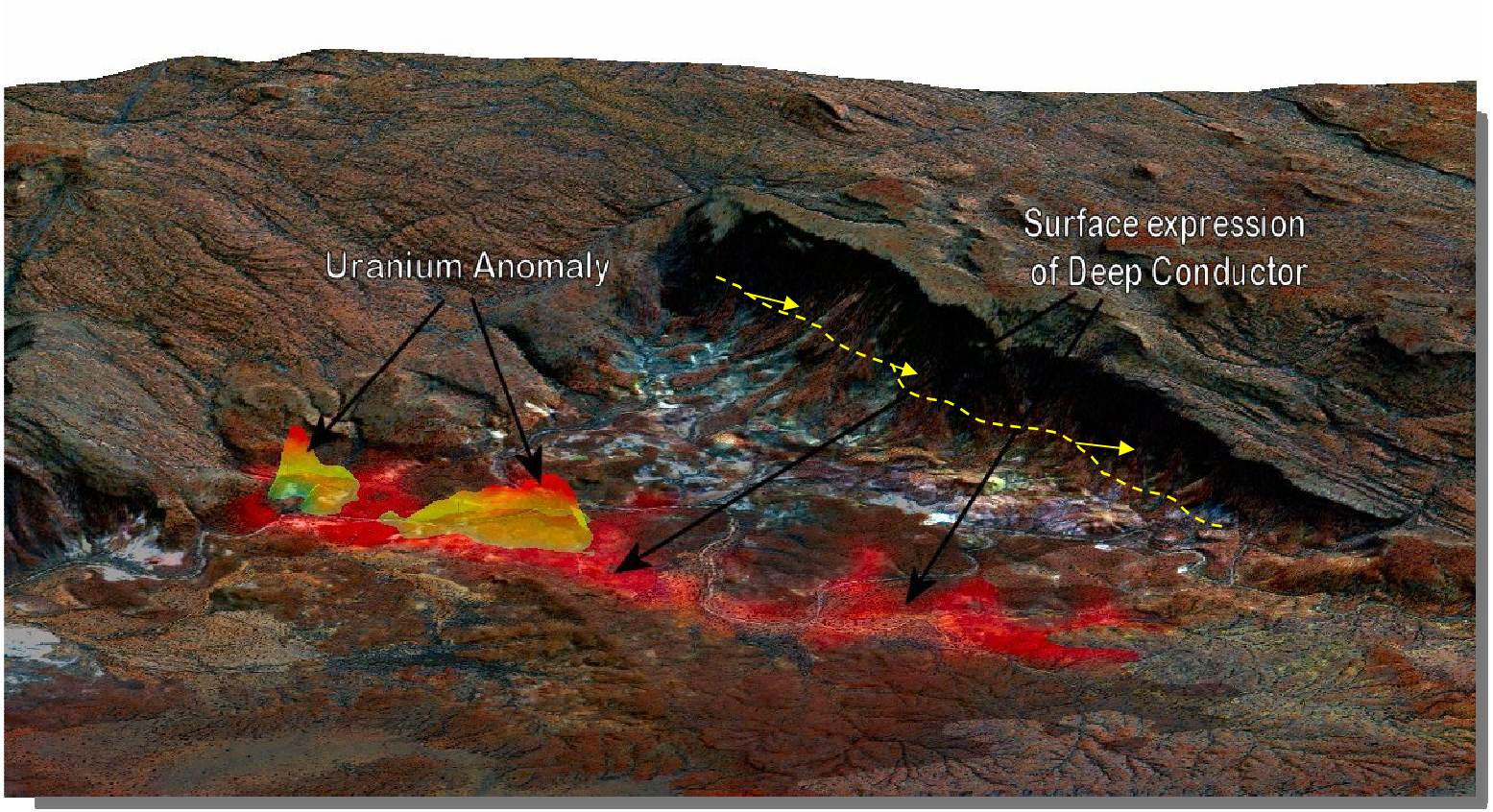
- Recall the exposed unconformity dipping under the sandstone escarpment …



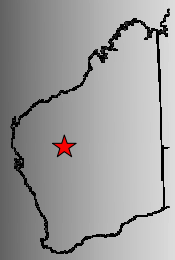
Ashburton - Airborne EM Survey



- Looking for very small conductors and found very large conductors
- May be stratigraphic or structural in nature
- Good correlation with surface uranium anomalism



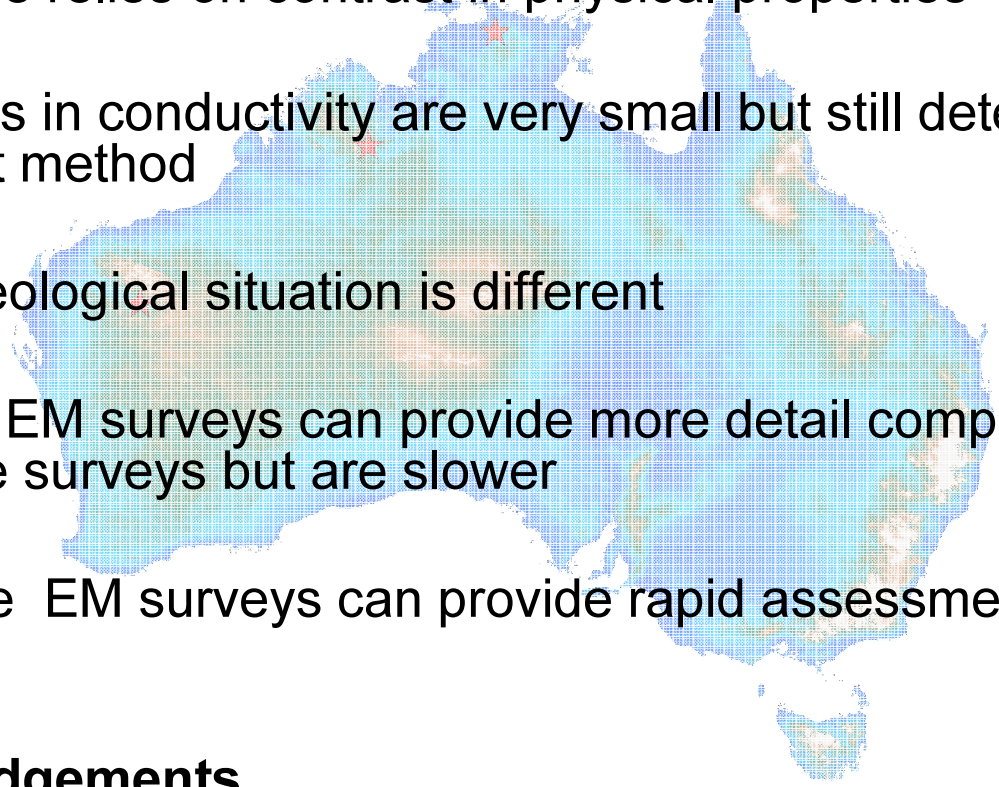
Ashburton - Summary



- Airborne EM survey has delineated sub-horizontal trends that could be reflecting alteration proximal to unconformity
- No drilling or ground checking to confirm this yet
- Unexpectedly large conductors identified in basement that are coincident with surface uranium anomalies

Summary

- Searching for alteration around the unconformity to infer its presence relies on contrast in physical properties
- Changes in conductivity are very small but still detectable using the right method
- Each geological situation is different
- Ground EM surveys can provide more detail compared to airborne surveys but are slower
- Airborne EM surveys can provide rapid assessment of large areas



Acknowledgements

Cameco Australia for permission to show Arnhem Land and Ashburton EM data