Refinement of Radiometric Analysis: Case Study Dongara Area of Onshore Western Australia*

Afif Arbi[1] and Ronald W. Klusman[2]

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[1]Raphael Energy Group Limited, 86-90 Paul Street, London, EC2A 4NE, United Kingdom (afif.arbi@raphaelenergy.com)
[2]Colorado School of Mines, Golden, CO, United States (rwklusman@earthlink.net)

Abstract

The radiometric technique for hydrocarbon detection is based on the divergence of uranium and potassium concentration in the area of a pressured hydrocarbon accumulation and dates to at least 1926 when the Soviets observed anomalously low gamma counts over existing oil fields (Armstrong and Heemstra, 1972, 1973). The most cited radiometric technique for hydrocarbon accumulation detection is DRAD with numerous authors publishing on its use (Garmon, 1981; Gottlieb, 1969, 1981, 1984; Lattu, 1969; Horvitz, 1981; and Davidson, 1982). Since that flurry of research, interest in the radiometric technique has ebbed, possibly in part because of the lack of efficacy of the process. In this paper, we will discuss the "ARAD" radiometric technique, a refinement of the DRAD technique, that improves the efficacy of radiometric reconnaissance studies. For our study, we processed the aerial radiometric data for the onshore portion of the Dongara map sheet totaling approximately 5,000 square kilometers (1.2 million acres). The Dongara survey data was acquired in 2012 before the 2014 discovery of the Waitsia fields, reported to be the largest onshore gas discovery in Australia in over 30 years, and after six older fields were heavily depleted. Crucially, the DRAD technique did not target the Waitsia fields, a major discovery. In contrast, the ARAD technique targeted and mapped the Waitsia fields with high accuracy to seismic mapping. In addition, the ARAD technique targeted the Strike Energy West Erregulla 3D seismic flat spot prospect and the Ocean Hill discovery.

Further, the ARAD technique only generated a weak Targeting ARAD near one heavily depleted field and none near five other heavily depleted fields, providing evidence that gamma anomalies are a coincident indirect indication of one or more pressured hydrocarbon accumulations, mitigating the risk that ARAD gamma anomalies will generate leads for accumulations that have dismigrated. The first step of the ARAD process is locating any Targeting ARADs, areas with high concentrations of ARAD gamma anomalies for further study. Targeting ARAD gamma anomalies are generally found on the edge of one or more pressured accumulations and if sitting atop or adjacent to a fault, they are an indication of an active hydrocarbon migration pathway. Two mapping techniques are then used to map indications of the area of a pressured hydrocarbon accumulation around a Targeting ARAD:

- Delta Divergence: a study of the divergences of uranium and potassium using statistical and interpolation techniques; and
- Cross-Profile: a visual study of profiles of processed uranium and potassium. This mapping is more precise but very time consuming.

Concluding, the ARAD technique was able to identify and map indications of the areal extent of the Waitsia fields, the Strike West Erregulla flat-spot prospect and the Ocean Hill discovery while the DRAD method did not target the Waitsia fields, reported to be the largest onshore gas discovery in Australia in over 30 years, or the Strike West Erregulla 3D flat-spot prospect or the Ocean Hill discovery. Equally significant, the ARAD study did not target any of the six heavily depleted Dongara fields providing evidence that the ARAD technique is an indirect coincident indicator of one or more pressured hydrocarbon accumulations.

Raphael Energy

Refinement of Radiometric Analysis

Dongara Area
Onshore Western Australia

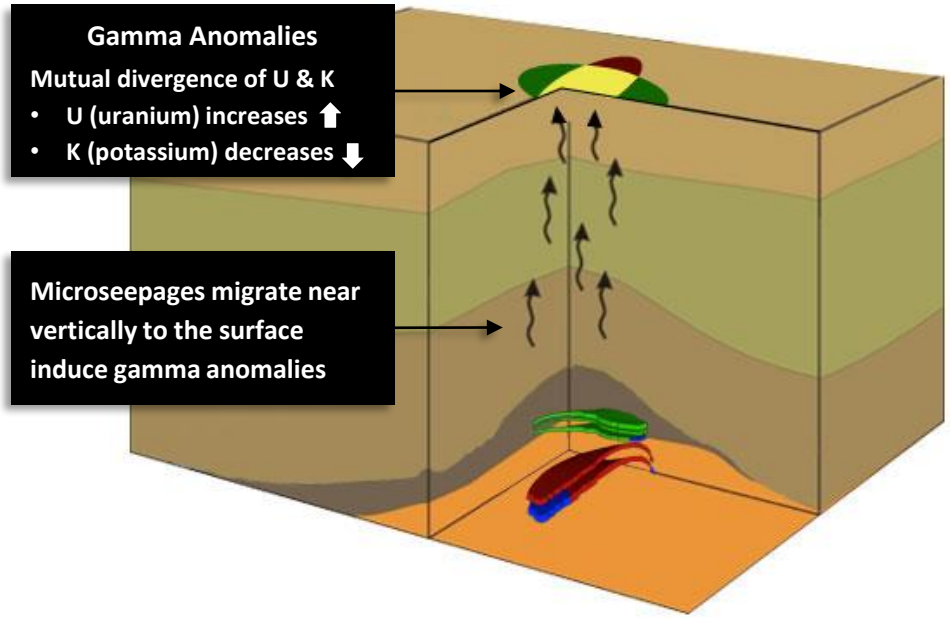
AAPG Hedberg Conference
Houston 19 June 2019

Introduction

Radiometric Technique Overview

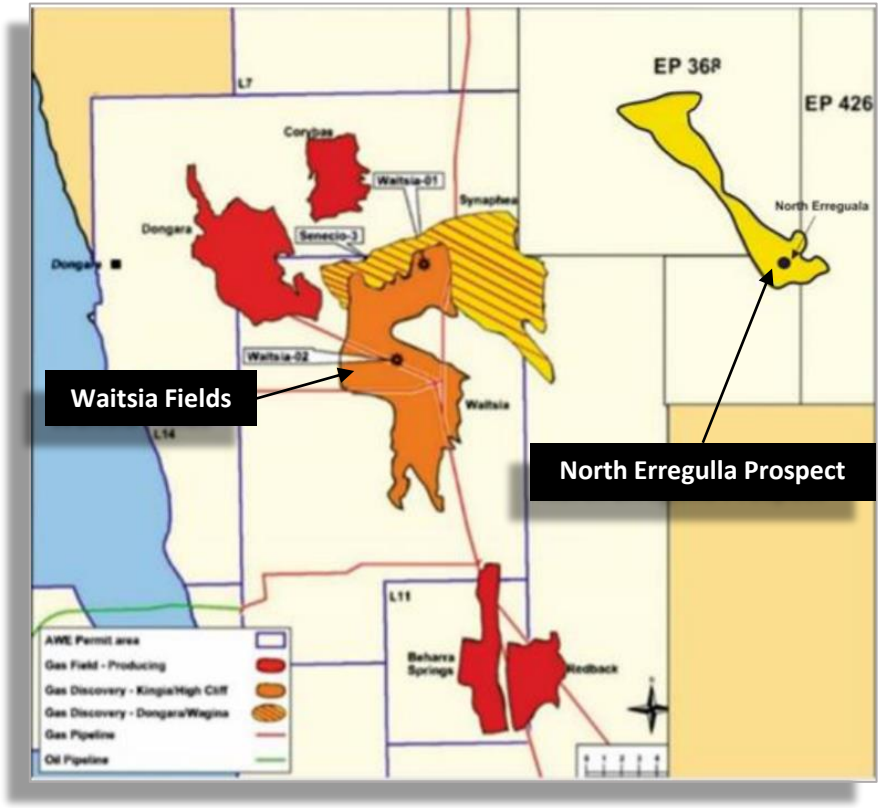
- Radiometric technique targets and maps areas with indications of mobile hydrocarbons under pressure
  - Radiometric technique seeks soil alterations caused by the near vertical migration of hydrocarbon microseepages from pressured accumulations
  - Hydrocarbon microseepages prompt chemical changes that varies the random deposition of uranium and potassium in the near surface
    - Concentration of uranium increases
    - Concentration of potassium decreases
  - Mutual divergence of the levels of uranium and potassium is a gamma anomaly
- Radiometric data can be collected by fixed wing aircraft enabling reconnaissance surveys of vast areas

Radiometric Gamma Anomalies Induced by Hydrocarbon Microseepages



Dongara Map Sheet Overview

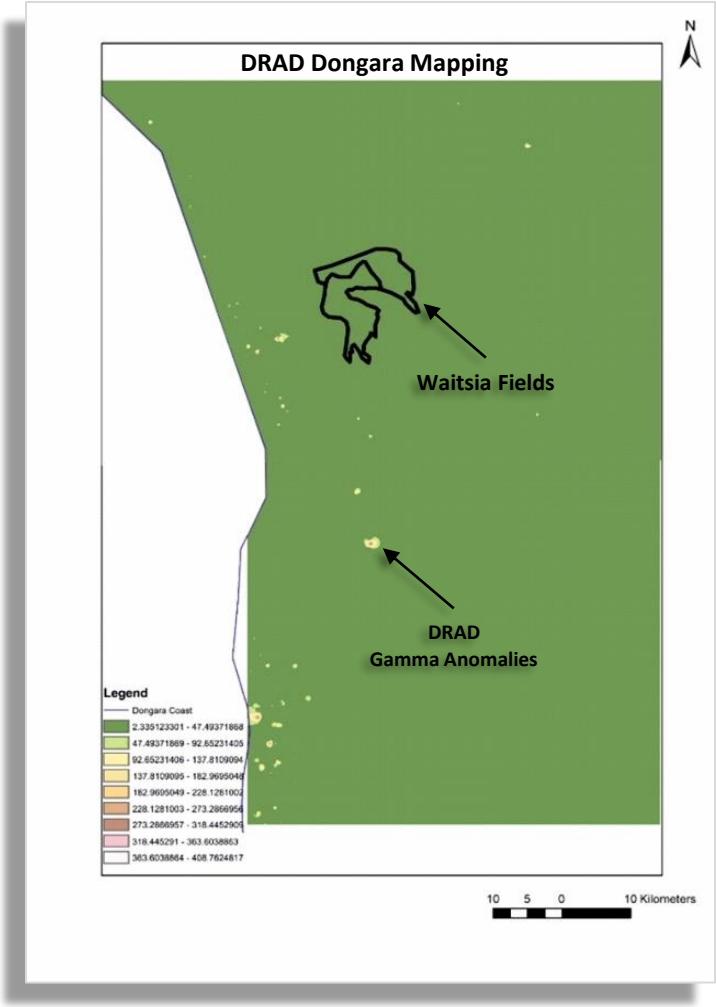
Waitsia Fields & North Erregulla Prospect With Four of Six Heavily Depleted Fields



- Our radiometric reconnaissance survey of the onshore area of the Dongara map sheet covered approximately 5,000 sq km (1.2 million acres)
  - Dongara covers a portion of the North Perth basin
  - There are six heavily depleted fields that began producing in the 1960's and 1970's as well as the 2014 Waitsia fields reported to be the largest Australia onshore discovery in 30 years
- Dongara radiometric data recorded in 2012, a few years before the Waitsia discovery
  - With a combination of recent and heavily produced discoveries, we were able test the efficacy of the radiometric technique to target significant pressured oil and gas accumulations and not target heavily depleted fields

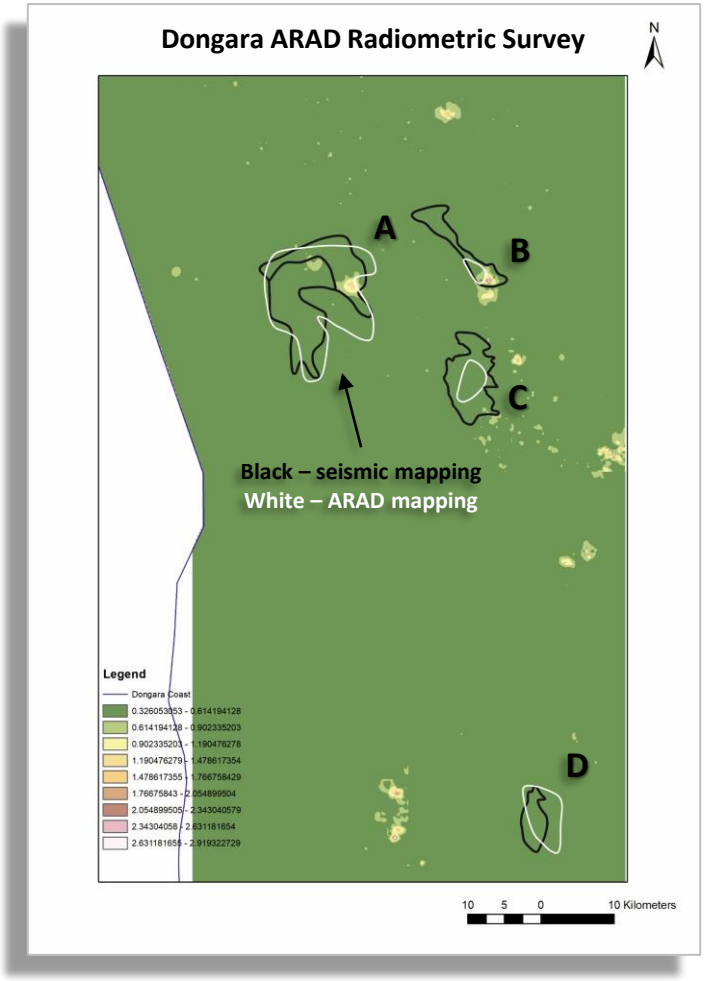
DRAD Radiometric Survey Dongara Area

- We initially applied the often cited DRAD technique
  - DRAD theory was developed in the 60's by the Recon Exploration Inc team and cited by multi authors*
  - DRAD formula aims to spot and map the potential fields using radiometric data (U, Th and K)
- Good results were reported for the DRAD technique over producing fields
  - However, as we understood the DRAD technique, in the Dongara area it failed to target the largest onshore Australia gas discovery in 30 years



* Garmon, 1981; Gottlieb, 1969, 1981, 1984; Lattu, 1969; Horvitz, 1981; and Davidson, 1982

ARAD Radiometric Survey Dongara Area

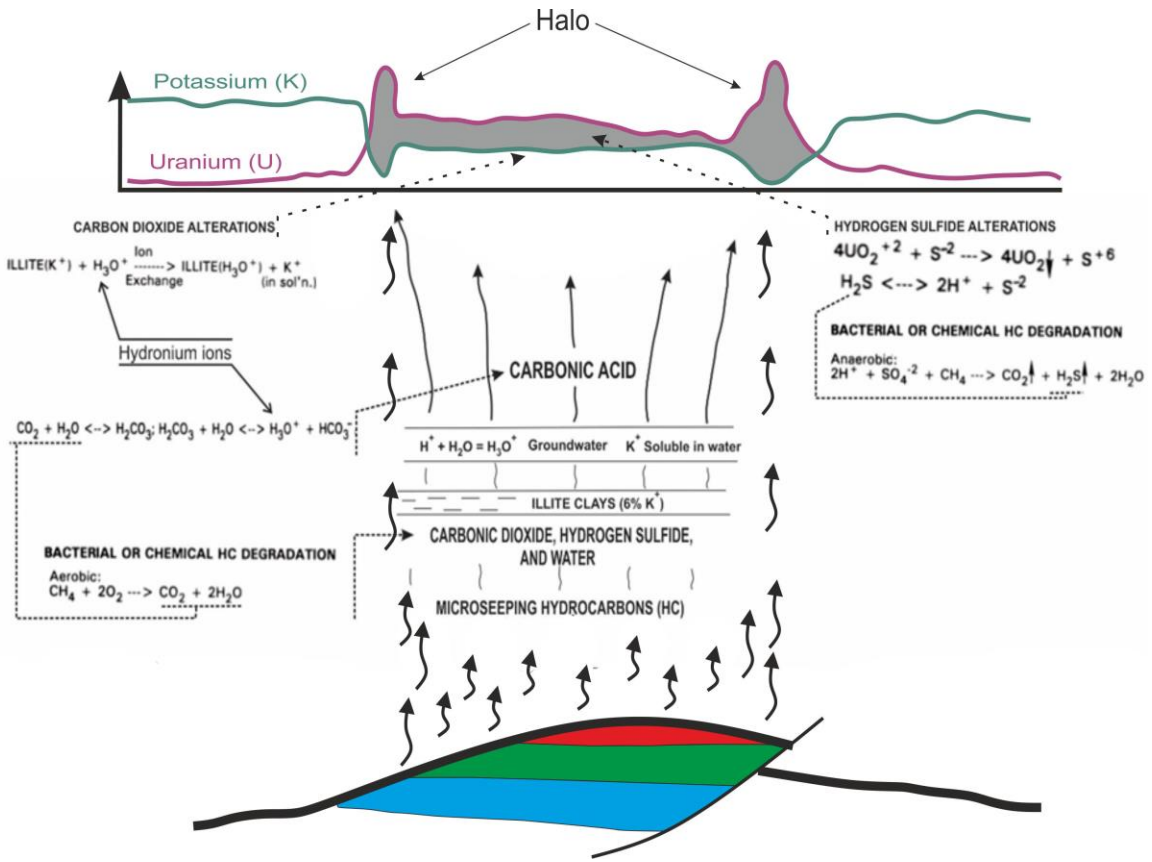


- After an in-depth review of scientific literature on the radiometric process, we developed our ARAD technique
- ARAD results were exceptional
  - Seven significant Targeting ARAD gamma anomalies including four that targeted and mapped a discovery or a prospect
  - Equally significant, **none** of the six heavily depleted fields were targeted
    - Evidence ARAD gamma anomalies do not generate leads for accumulations that have dismigrated because of weak seal (tertiary migration)

Radiometric Process

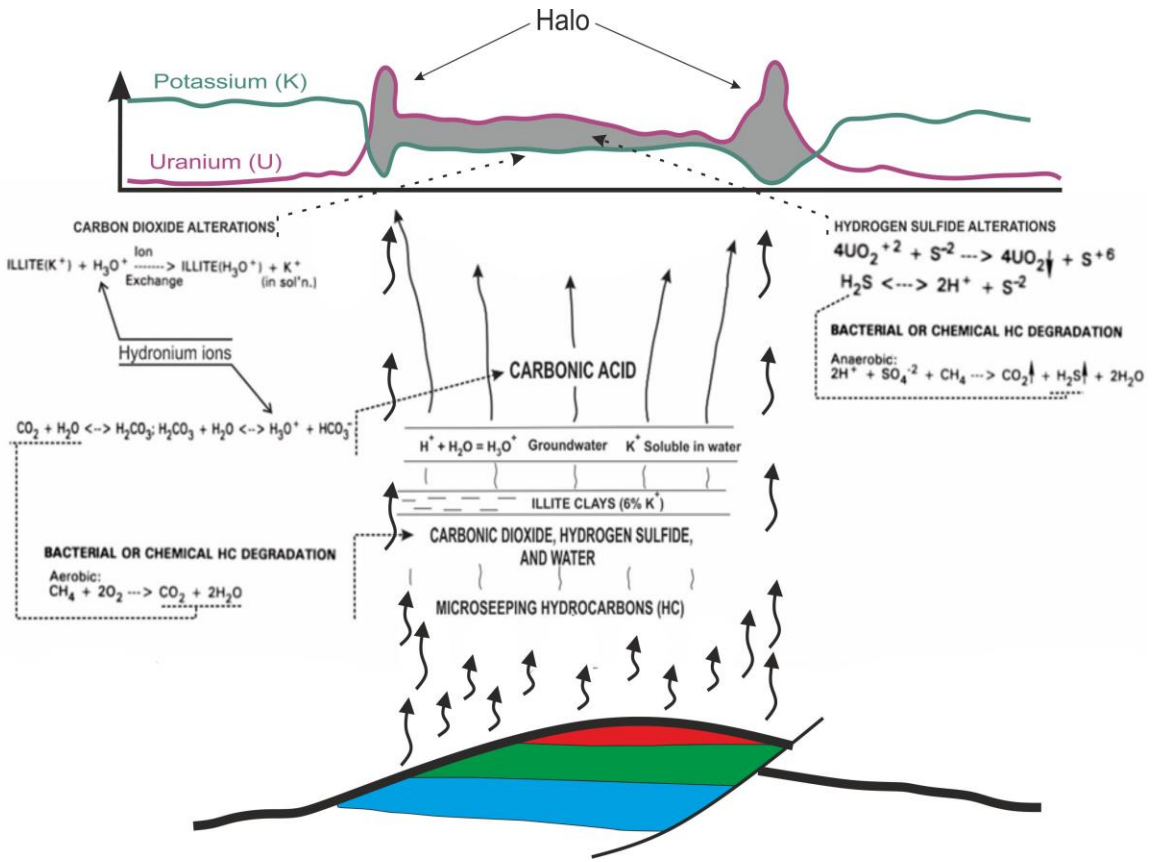
Science

Radiometric Process



- Migration of microseepages from a reservoir under pressure trigger the gamma anomaly process
  - As hydrocarbon microseepages migrate toward the surface, both potassium and uranium react with other elements (Sanders et al., 1999; F.D. van der Meer et al., 2002; J.G. Morse, 1996)
  - Those reactions deplete potassium while concentrating uranium in the surface above one or more pressured hydrocarbon accumulations

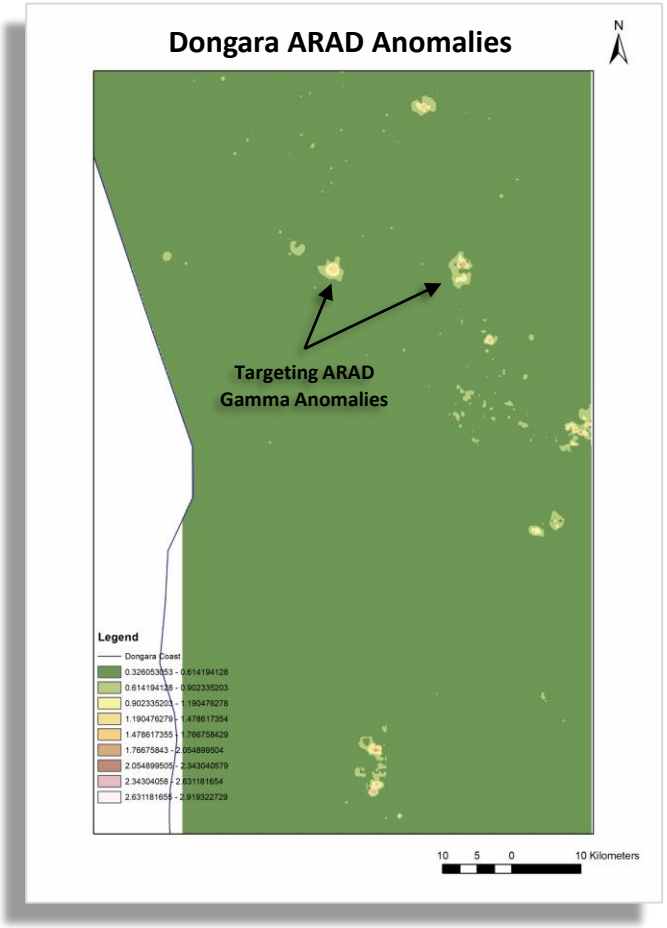
Radiometric Process



- **Potassium** – three events reduce its concentration
  - Carbon dioxide (CO2) and water (H2O) produced by the chemical degradation of hydrocarbon microseepages chemically react to produce carbonic acid (H2CO3)
  - Carbonic acid (H2CO3) then reacts with the water (H2O) to generate hydronium ions (H3O+)
  - In illite formations, which are rich in potassium, hydronium ions (H3O+), which have an ionic radius near that of potassium, are exchanged with potassium ions (K+), releasing the potassium ions to migrate to the edge of the microseepage, often forming a halo zone
- **Uranium** - two events increase its concentration
  - Microseepages provoke a chemical degradation that turns hydrocarbon microseepages (CH4) into carbon dioxide (CO2), water (H2O) and hydrogen sulfide (H2S)
  - At the surface, as the uranyl (UO2++) migrates to an area with hydrocarbon microseepages, the uranyl (UO2++) reacts with the hydrogen sulfide (H2S), produced by the chemical degradation of microseepages in the anaerobic environment, to produce uraninite (UO2),
  - Uraninite (UO2) is insoluble in water, causing uranium to collect in the area of the microseepages, also often forming a halo zone

ARAD Technique

Radiometric Technique Overview

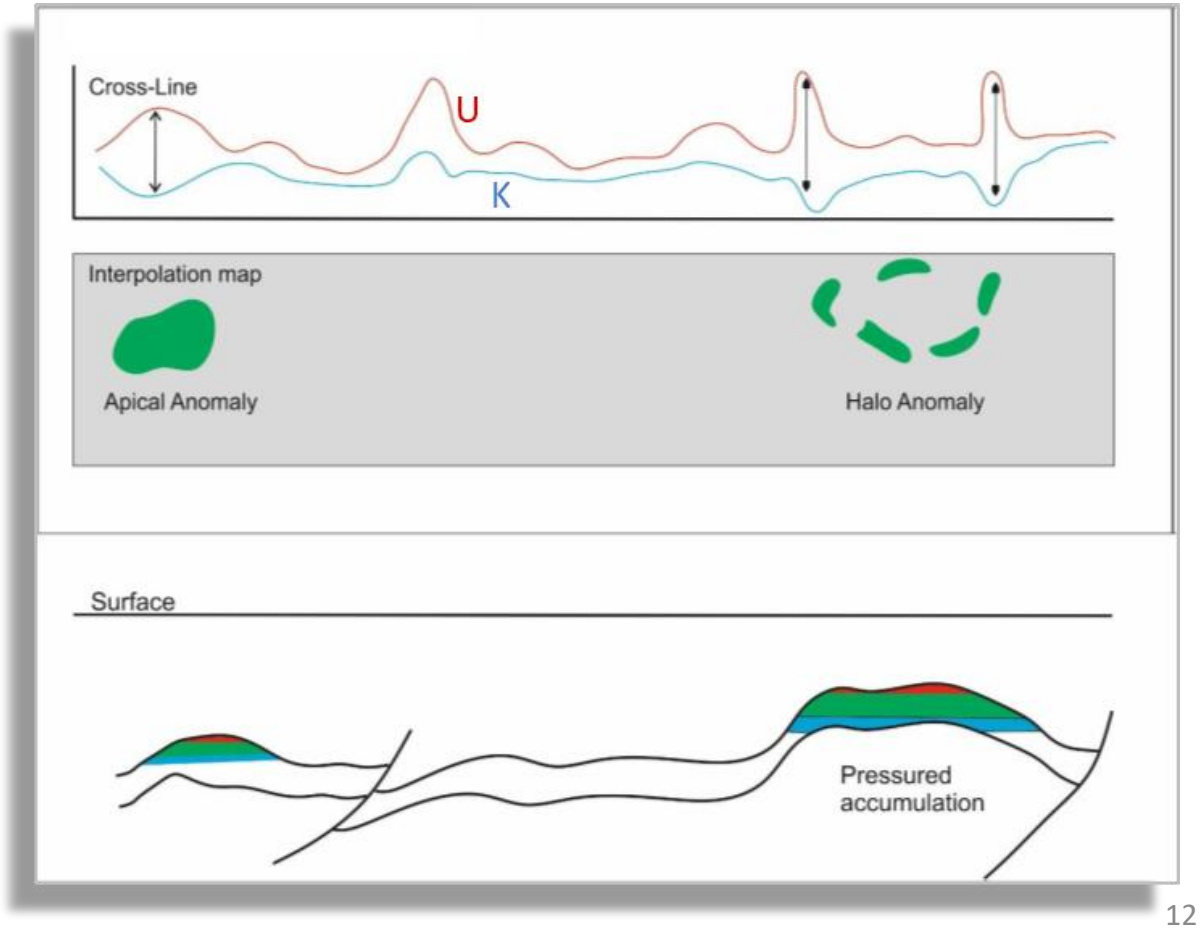


- First step of ARAD radiometric process is locating potential leads with Targeting ARAD gamma anomalies
  - Targeting ARAD gamma anomalies are the area with highest divergences between U (uranium) and K (potassium)
  - Numerical interpolation used to locate Targeting ARADs
  - Sitting atop or near a fault, a Targeting ARAD is an indication of an active migration pathway
- Two mapping techniques then used to map the area of leads around Targeting ARAD gamma anomalies
  - **Delta Divergence** – computer mapping of the changes in the mutual divergence of uranium and potassium
  - **Cross-Profile** – visual review of cross-profiles of uranium (U) and potassium (K) for mutual divergences in U & K

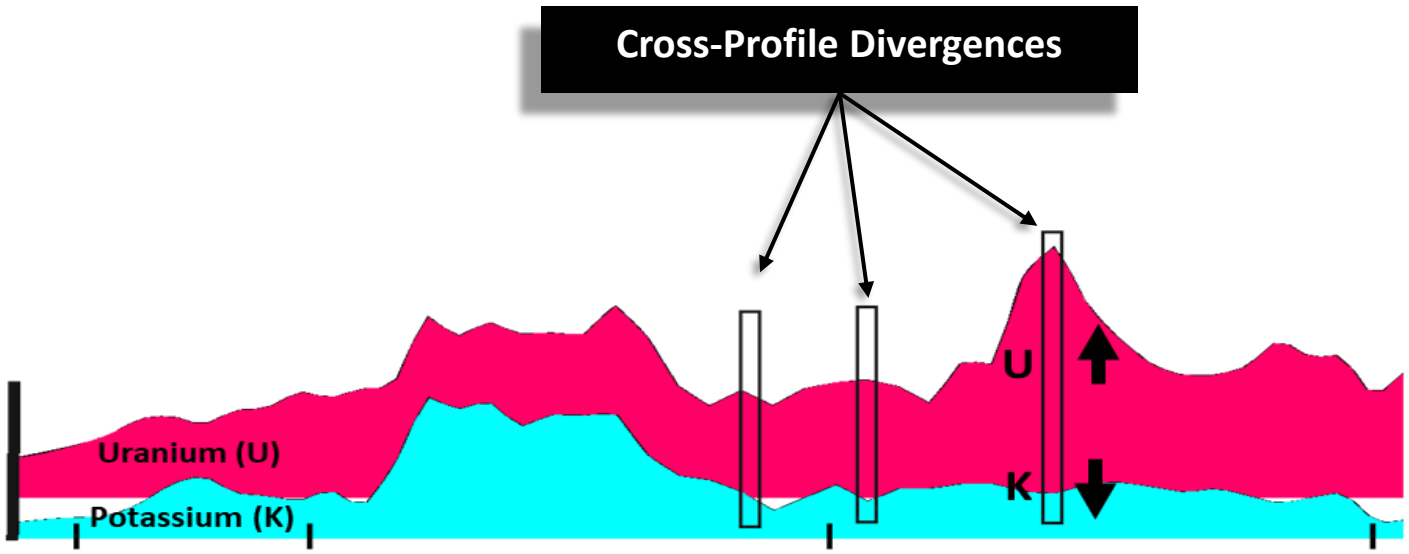
ARAD Delta Divergence Mapping Technique

- ARAD Delta Divergence identifies the change in the mutual divergence of U and K
  - Requires attention to processing of data, making it time consuming
  - Study results indicate nominal false positive risk

Delta Divergence



ARAD Cross-Profile Mapping Technique



- ARAD Cross-Profile mapping is a visual review of lines of U and K to identify divergences
  - Time consuming and tedious
  - But provides reliable mapping of the aerial extension

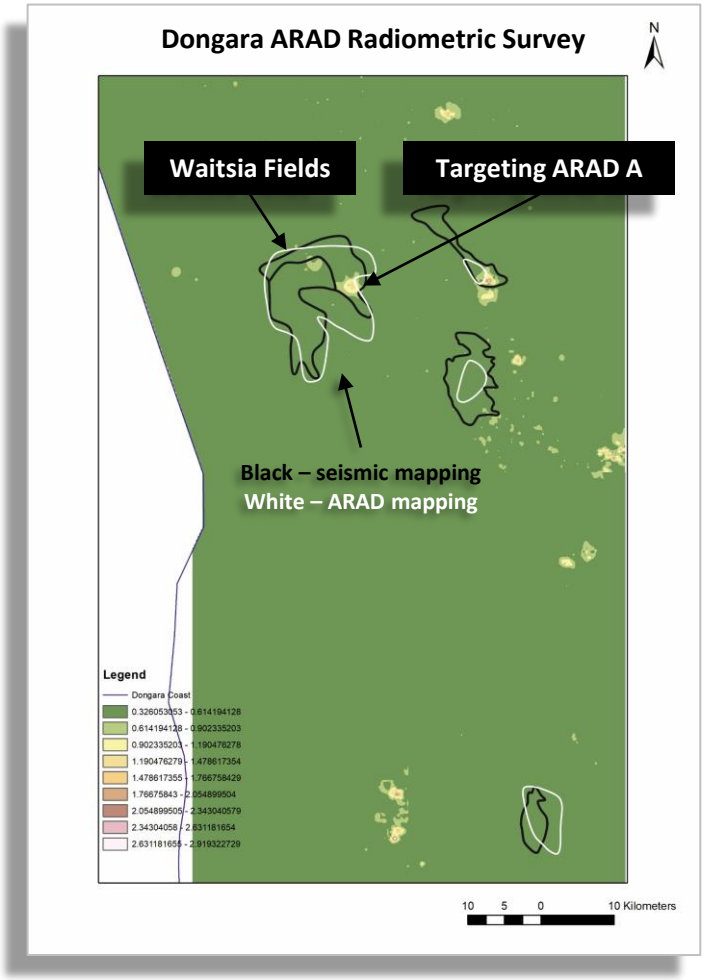
Dongara ARAD Radiometric Study

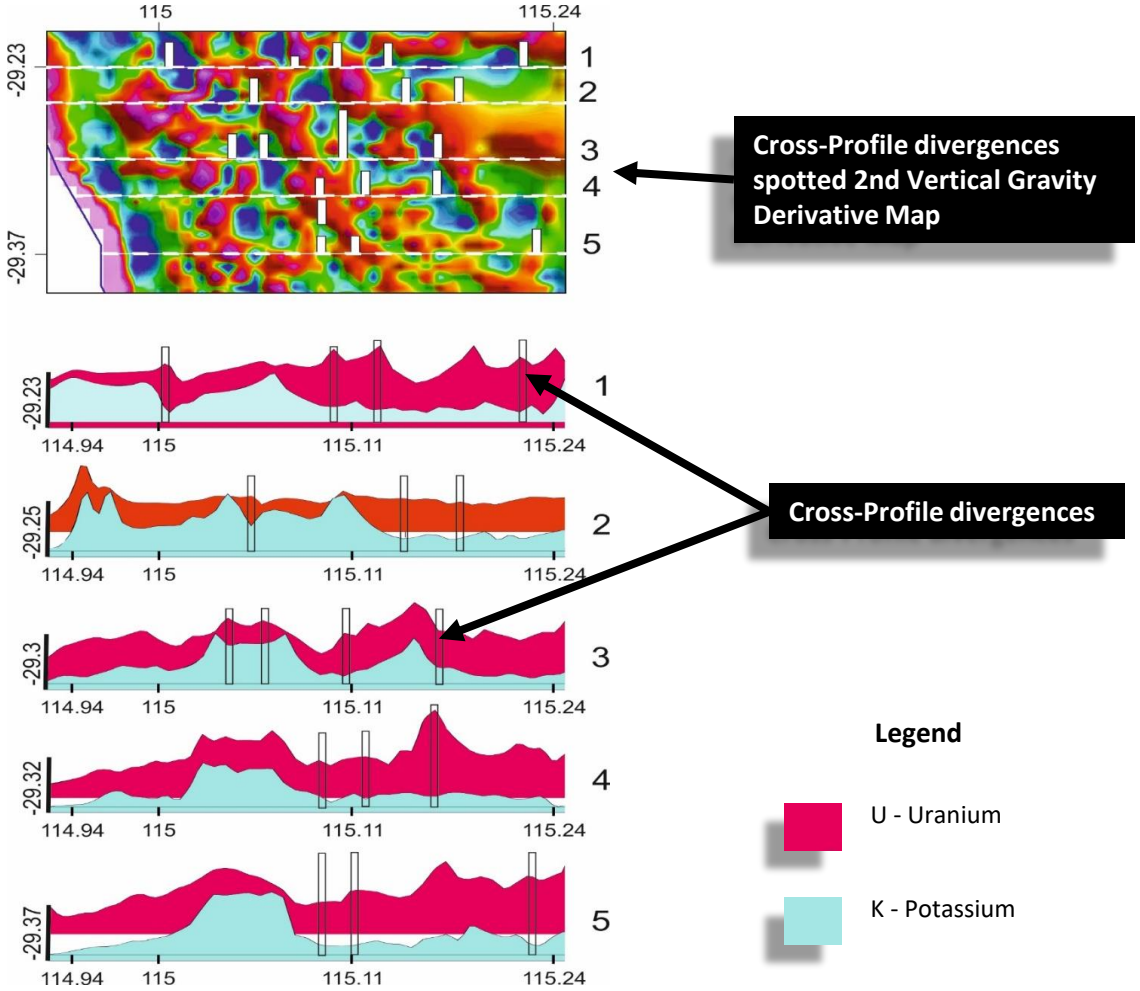
Case Studies

Case Study

Waitsia Fields

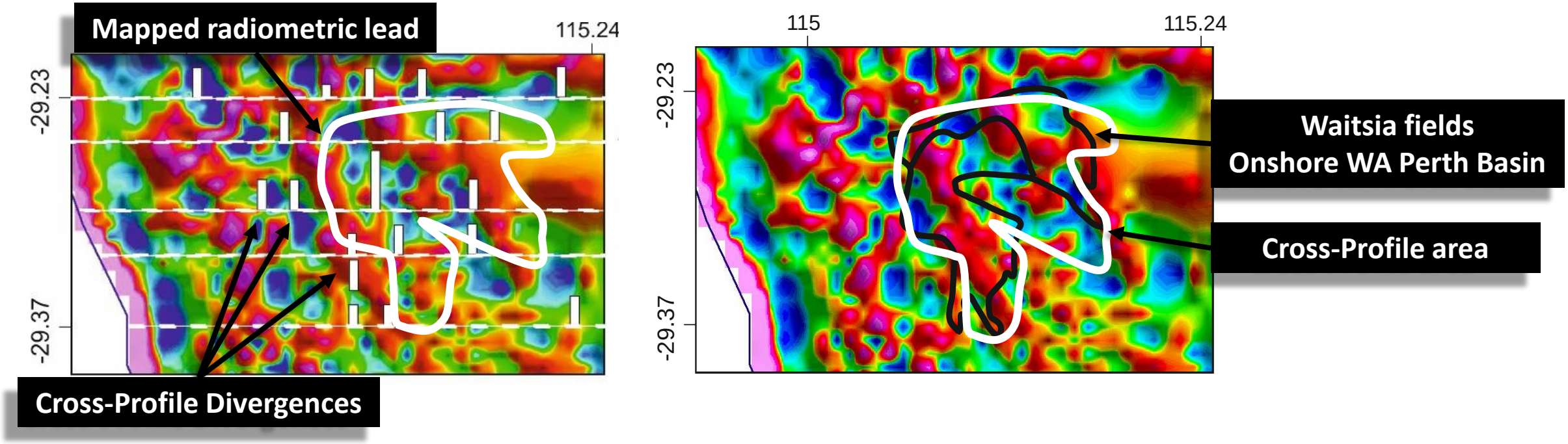
Cross-Profile Lines Study: Waitsia Field





Cross-Profile Mapping vs. Seismic Mapping

Case Study Cross Profile Mapping of Area
Waitsia Fields Onshore Western Australia Perth Basin



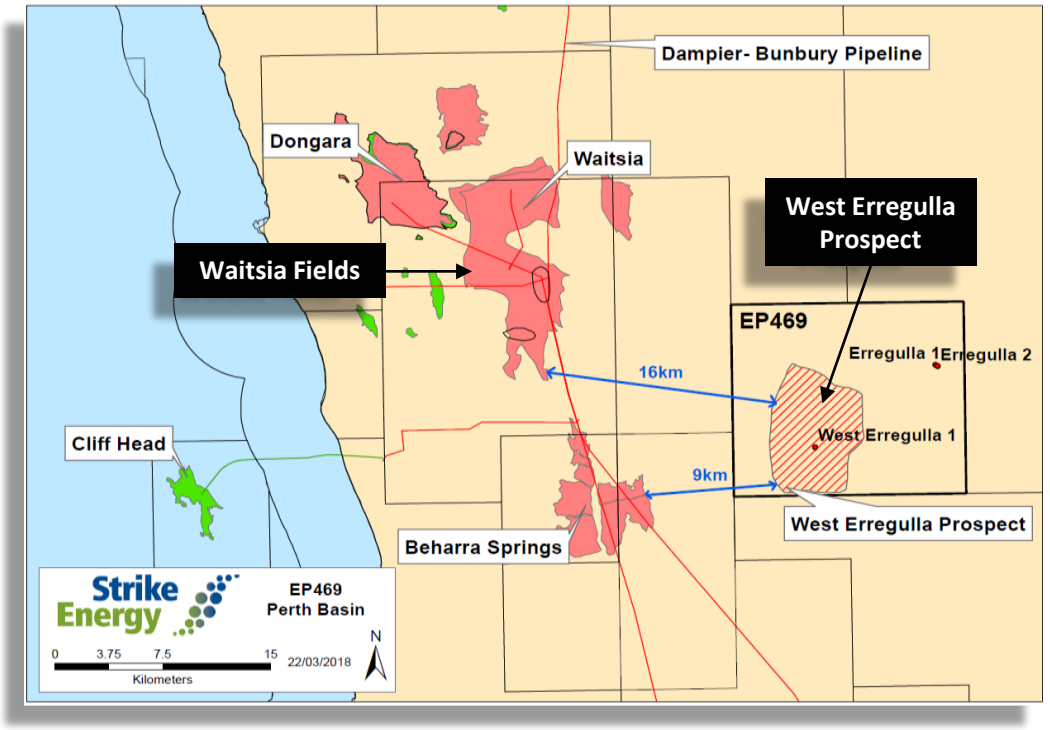
We estimate cross-profile mapping is approximately a 30% overstatement of areal extension

Case Study

West Erregulla Prospect

West Erregulla Prospect with Seismic DHI

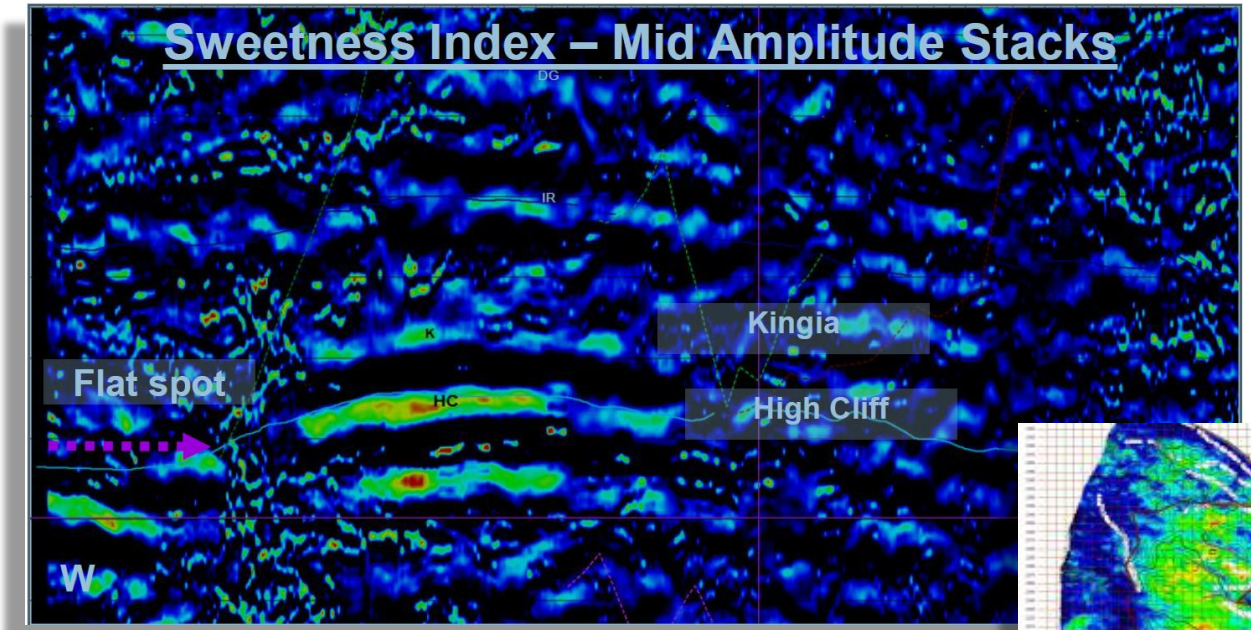
Strike Energy
West Erregulla 3D Seismic Flat Spot Prospect

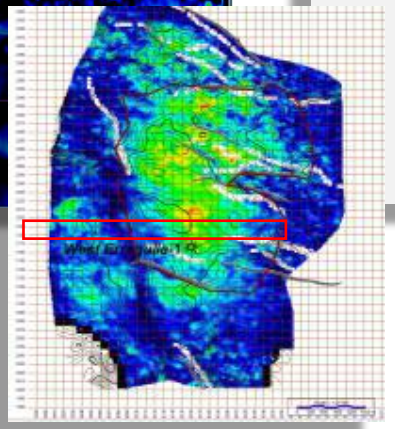


- Dongara Targeting ARAD C targeted the West Erregulla prospect
  - **Strike Energy prospect highlights:**
    - Strike's West Erregulla-2 well ideally placed within the evolution of the North Perth Basin to test three standalone and exclusive conventional oil and gas sequences
    - Chance of discovering gas and proving a developable resource size in the primary target of the Kingia and High Cliff Formations is 69%
    - New tertiary Jurassic target in the Cattamarra will test a potential material oil play, with running room throughout permit
  - Well spudded 1 June 2019, results expected mid-July

West Erregulla Prospect DHI Flat Spots

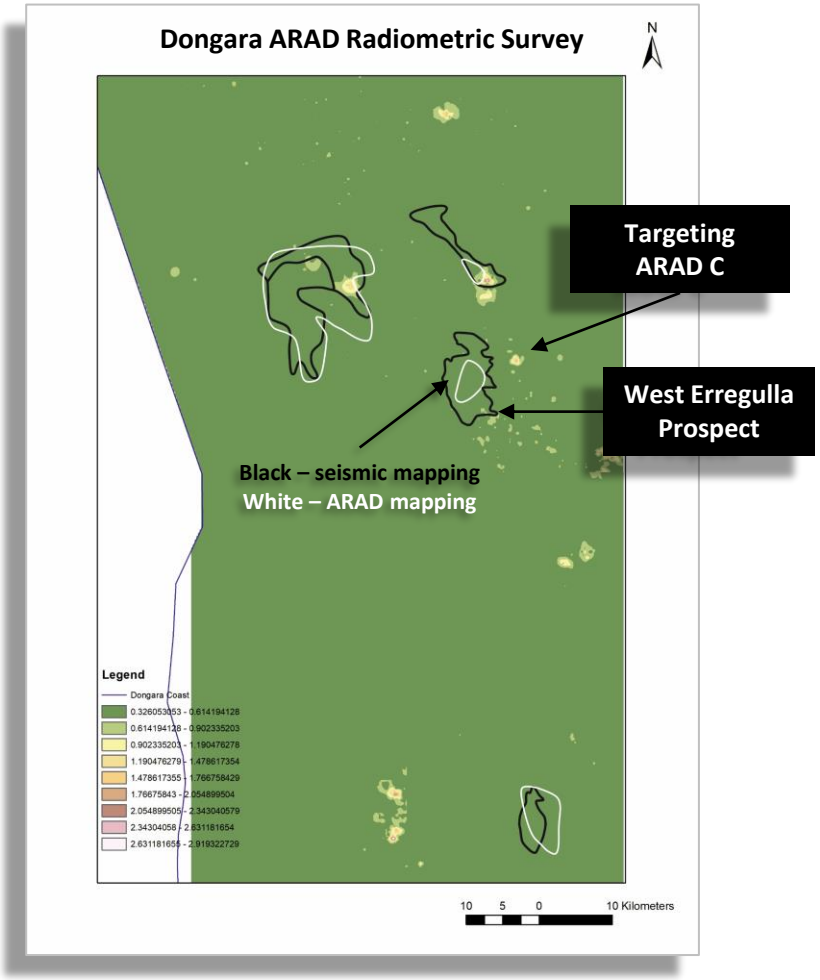
Strike Review of High Cliff Formation Flat Spot





- Target is supported by structurally conformable amplitudes, frequency response and synthetic modeling.
- Multiple Direct Hydrocarbon Indicators.
- Confirmation of conventional reservoir quality through mapping of gas-water contacts (flat-spots).

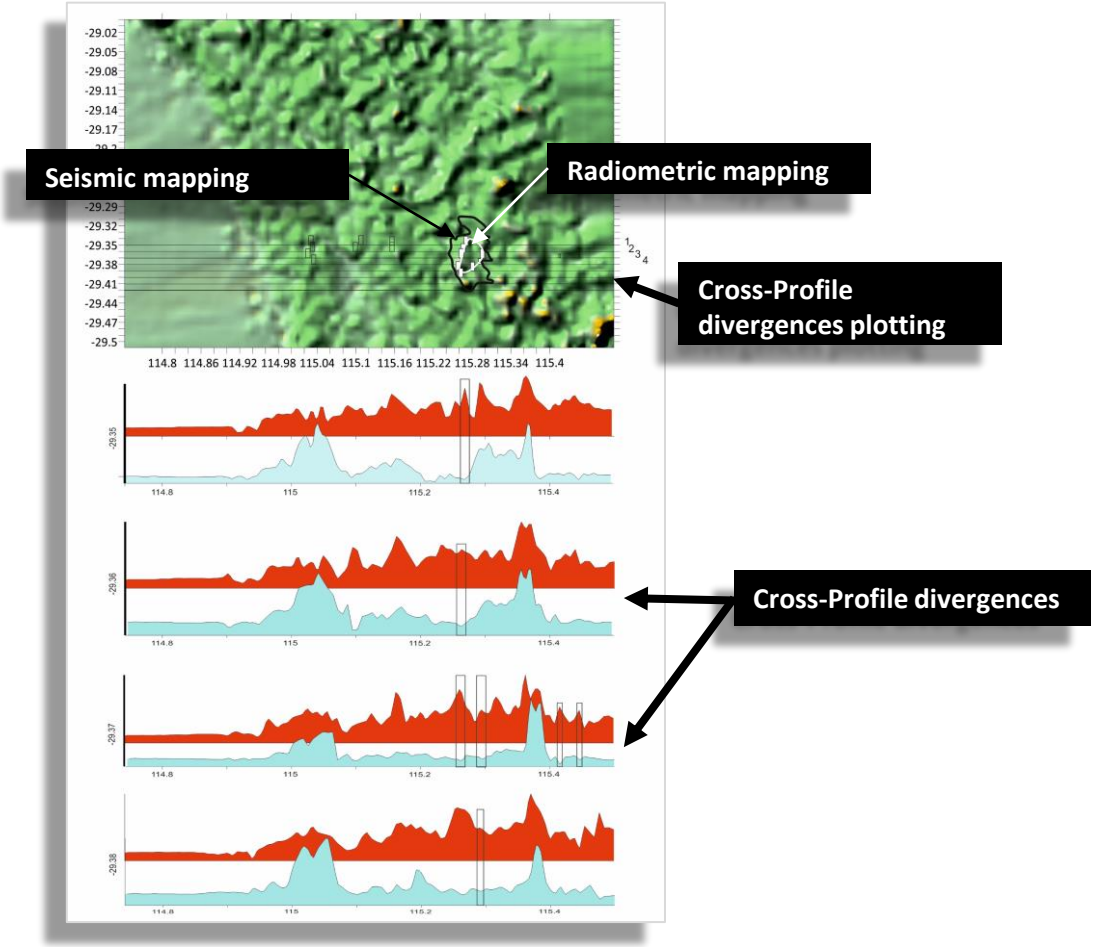
West Erregulla Prospect ARAD Mapping



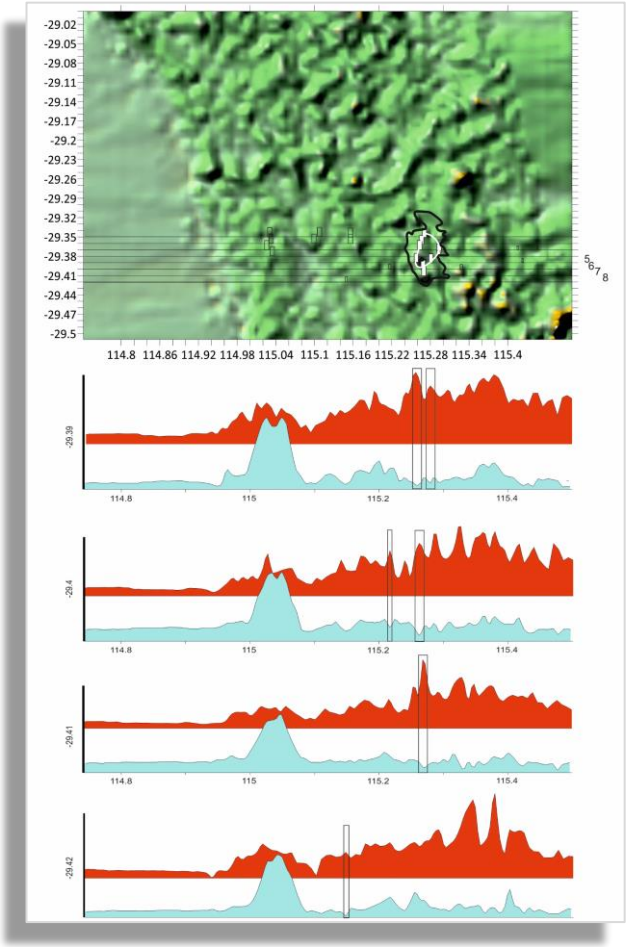
- The ARAD study showed:
  - A Targeting ARAD near to the seismic mapping of the prospect
  - Detail Cross-Profile mapping correlates well to the seismic mapping of the West Erregulla Prospect

West Erregulla ARAD Cross-Profile Lines

Cross-Profile Lines 1 to 4

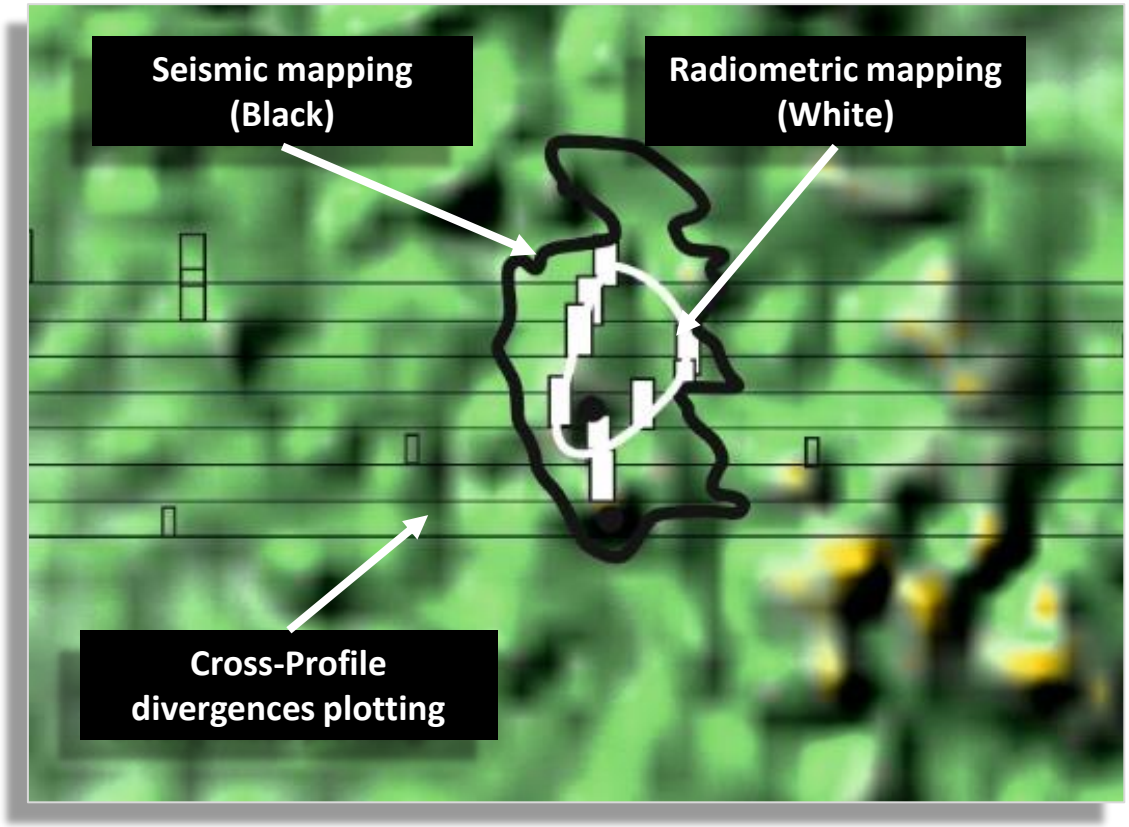


Cross-Profile Lines 5 to 8



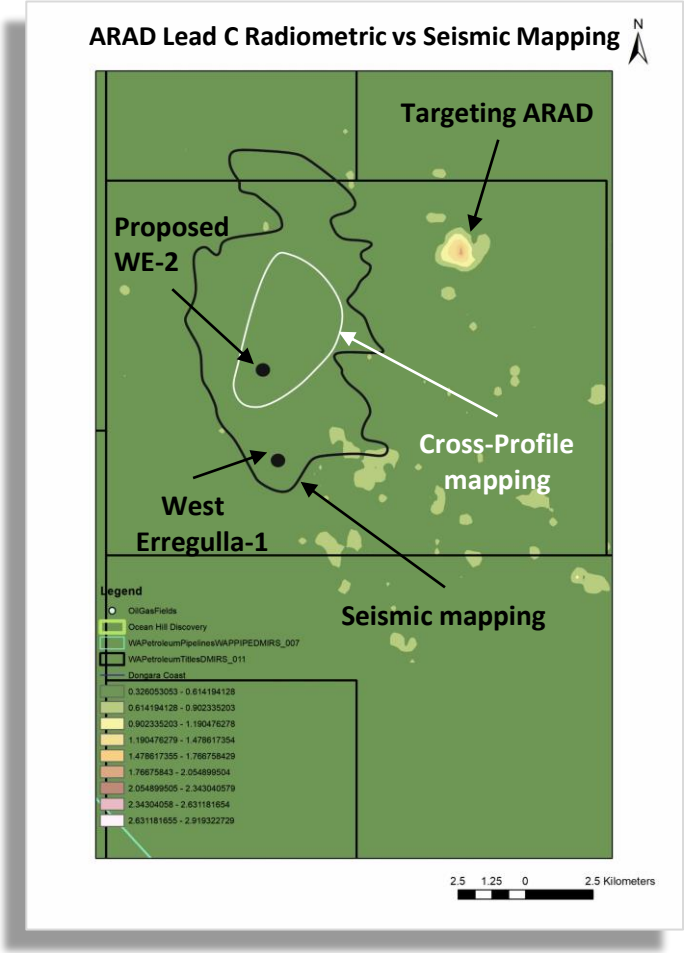
West Erregulla ARAD Cross-Profile Lines

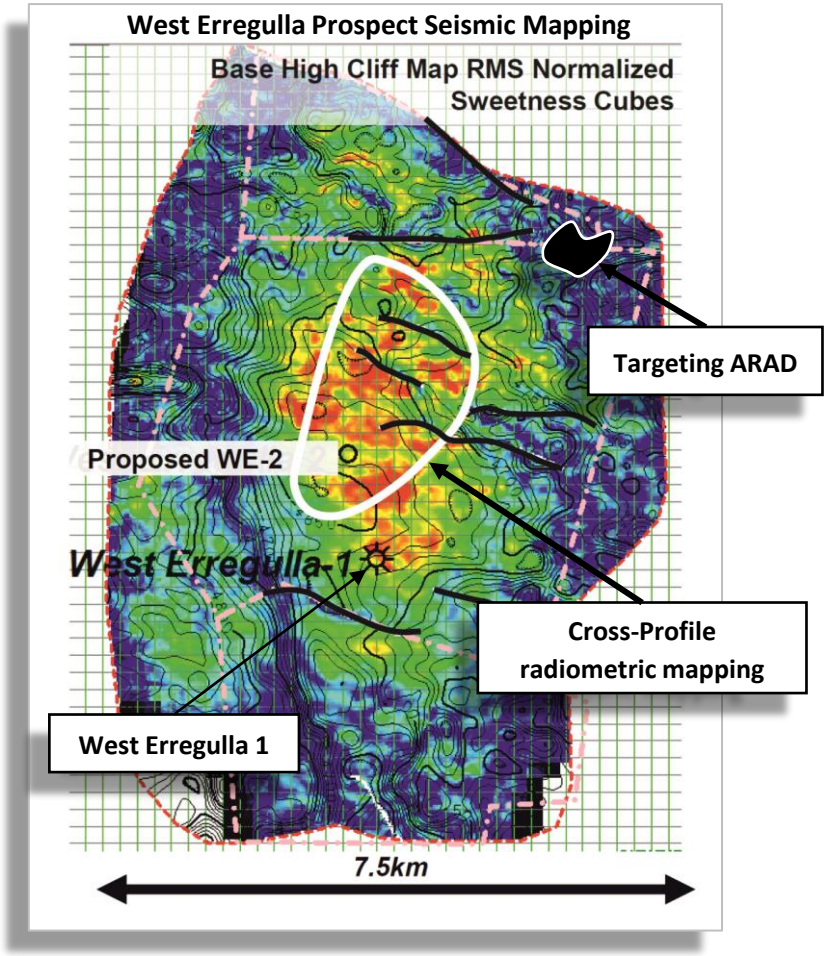
Cross-Profile Lines Targeting ARAD C



- The Cross-Profile radiometric mapping shows that the radiometric areal extension 60% of seismic mapped area
- The intense divergence of U and K in white bars present good closure

West Erregulla Prospect Mapping



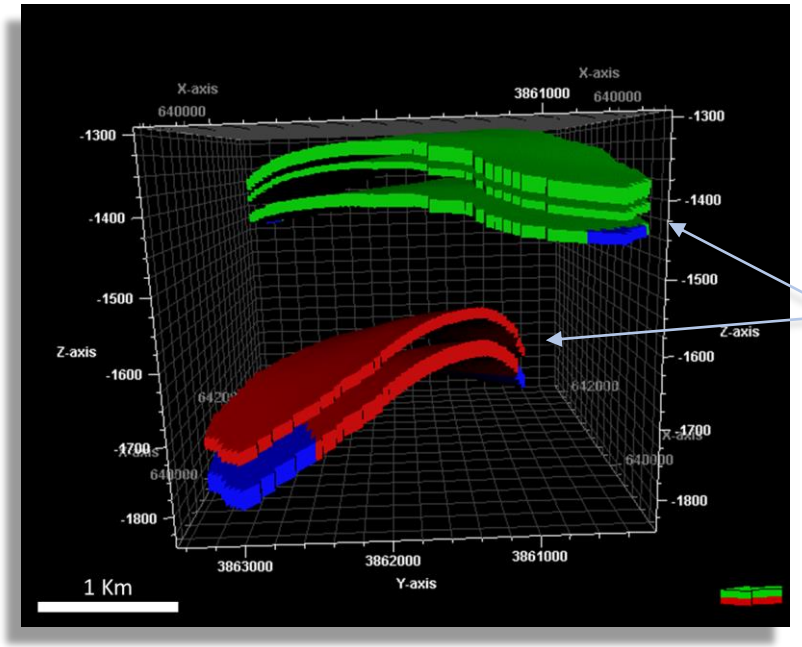


- Cross-Profile area conforms well to the DHI mapping
  - Targeting ARAD sitting near a fault, an indication of an active migration pathway
- In addition, West Erregulla-1 reported **multi-gas shows**
  - Radiometric mapping did not extend to the well
  - **Demonstrates capability of ARAD technique to map only probable area of commercial accumulation**

West Erregulla Prospect Drilling Outcome

- Employ MaxEx Direct regional exploration process
  - Uses three established geoscience methods, including one with a 76 percent completion rate (74 of 98) in a peer-reviewed study, to find, confirm and quantify indications of significant hydrocarbon accumulations
  - Outcome of MaxEx Direct process a high-resolution 3D reservoir model that enable reliable estimates of the magnitude of potential resources by hydrocarbon phase and depth

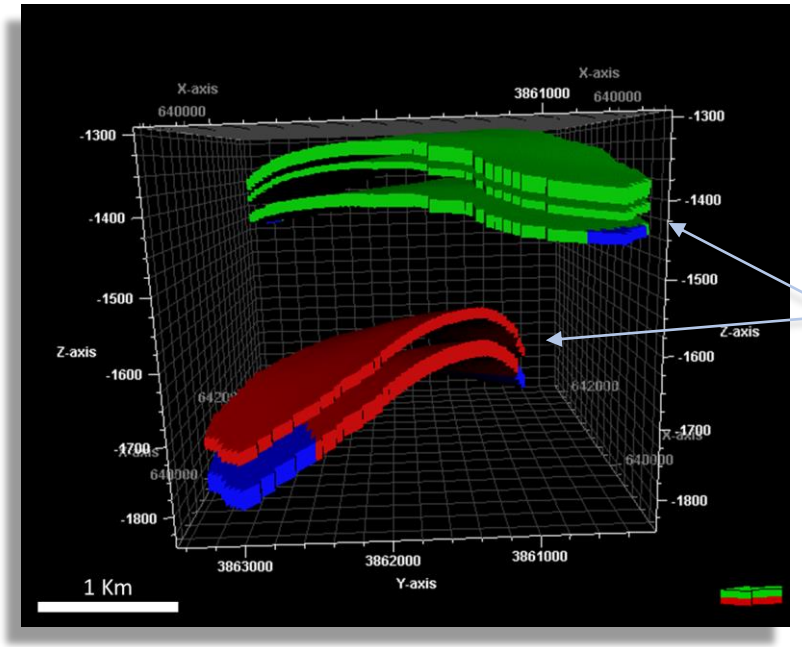
MaxEx Direct Stacked Pay Reservoir Model



West Erregulla Prospect Drilling Outcome

- ARAD radiometric surveys initial reconnaissance phase
  - We undertake two detail studies of an ARAD lead before formally considering it a prospect
  - Targeting and mapping of West Erregulla flat-spot prospect considered a validation of ARAD process regardless of outcome of West Erregulla 2 well now drilling

MaxEx Direct Stacked Pay Reservoir Model

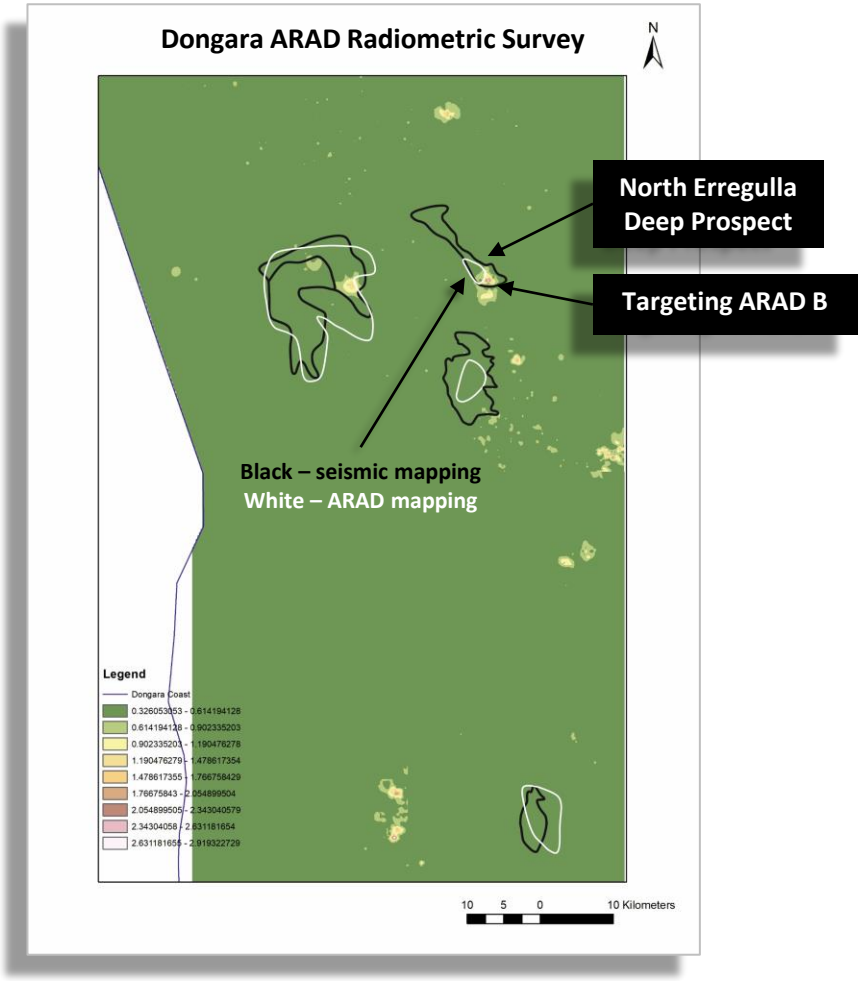


Reservoir indications with 2 to 3 meters (6 to 10 feet) resolution

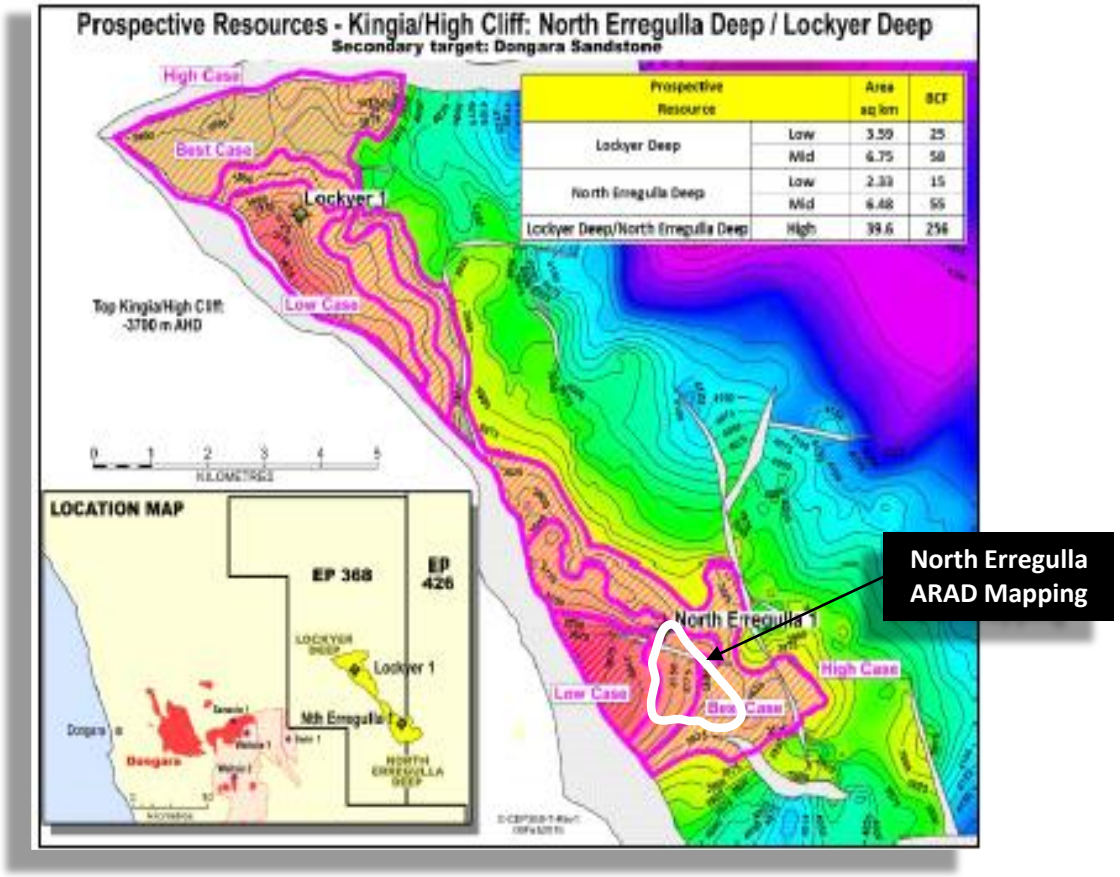
Case Study

North Erregulla Deep Prospect

North Erregulla Deep Prospect

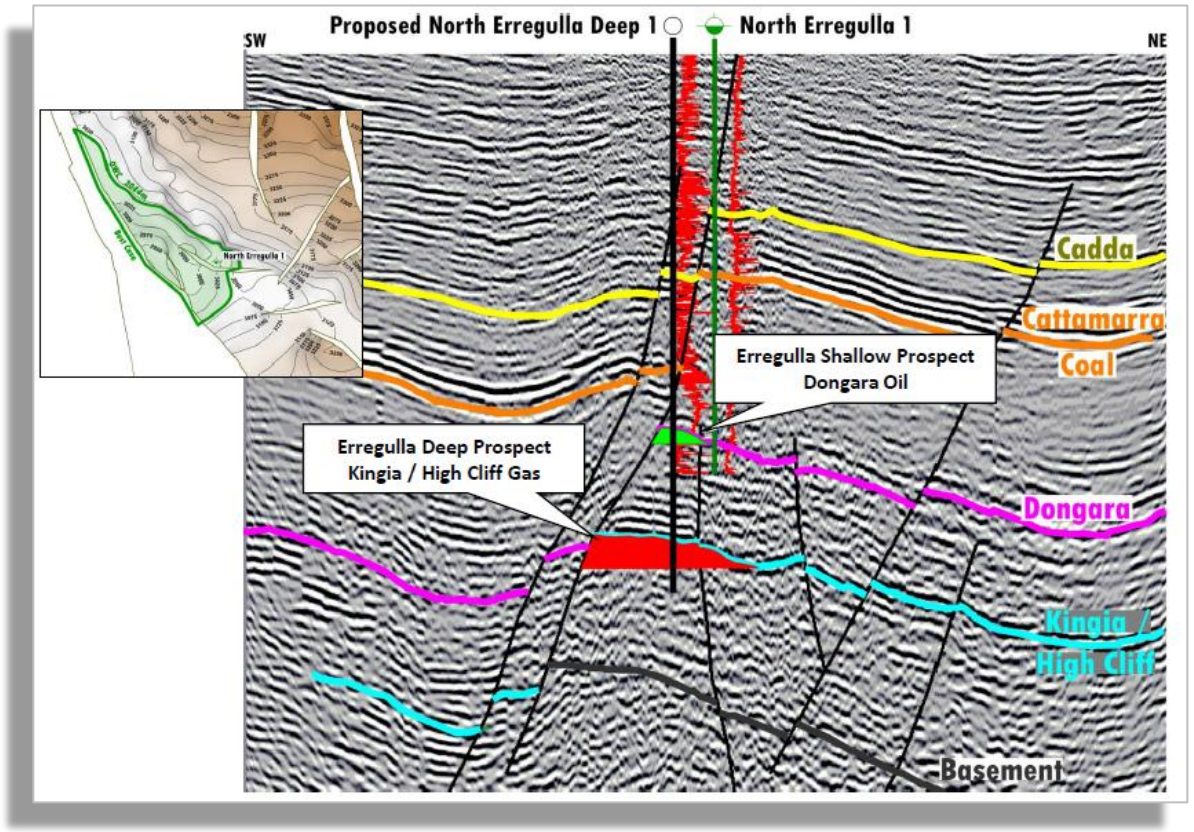


Empire Oil & Gas In Administration
North Erregulla Deep 2D Seismic Prospect



North Erregulla Deep Prospect

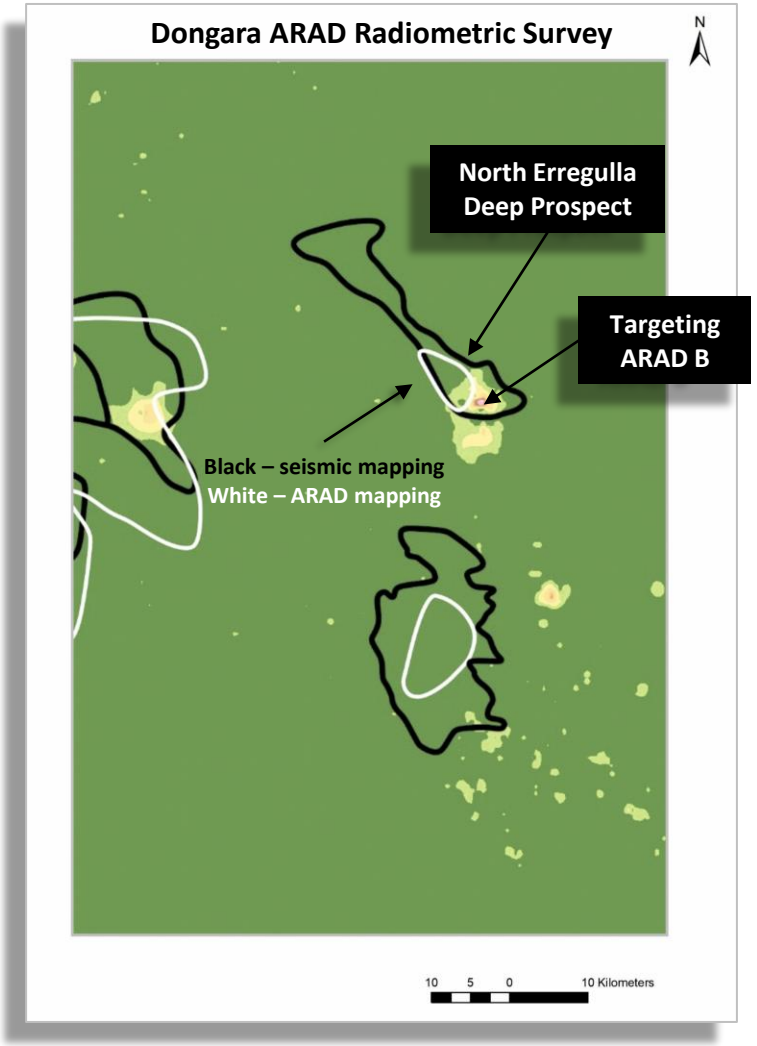
North Erregulla Deep 2D Seismic Line



- Targeting ARAD B corresponds to the North Erregulla Deep prospect
  - A shallow well has been drilled in the northwest and another shallow well has been drilled in the southwest corner of Empire's mapping
  - Only shows were reported in both wells
- New prospect is a deeper Waitsia analog
  - ARAD radiometric mapping shows a potential hydrocarbon accumulation on a three-way dip faulted closure near the North Erregulla 1 well

North Erregulla Deep Prospect

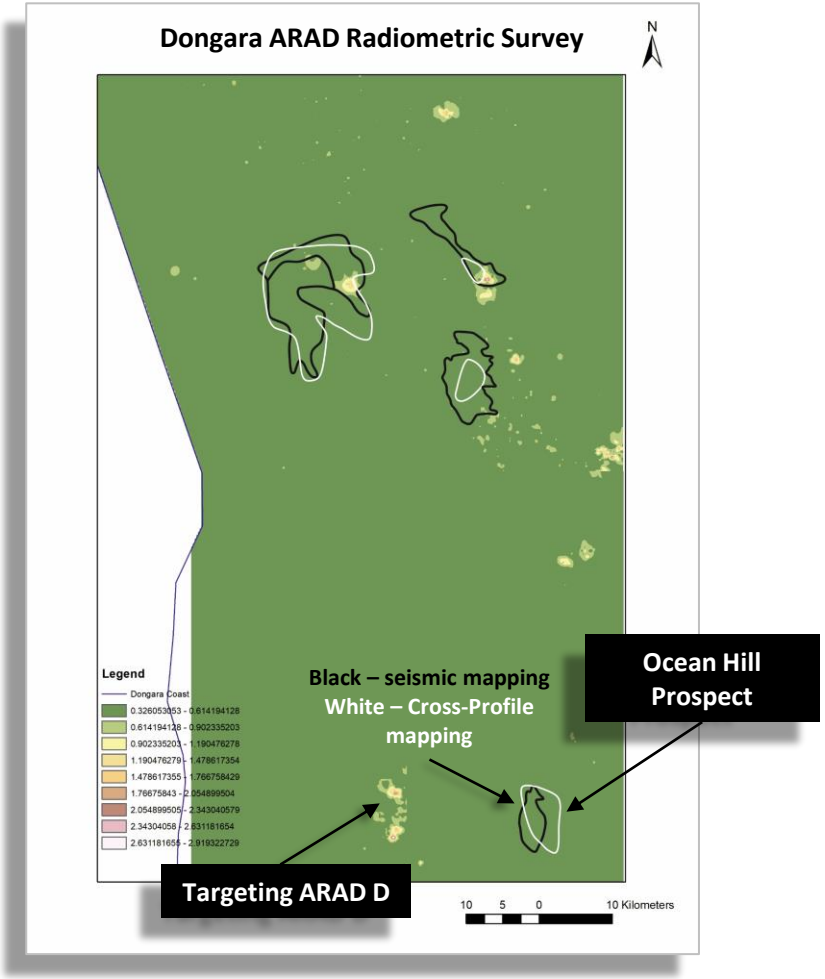
- Targeting ARAD B is sitting atop a fault, indicating an active migration pathway
- Area of ARAD radiometric mapping did not include the North Erregulla-1 well with hydrocarbon show



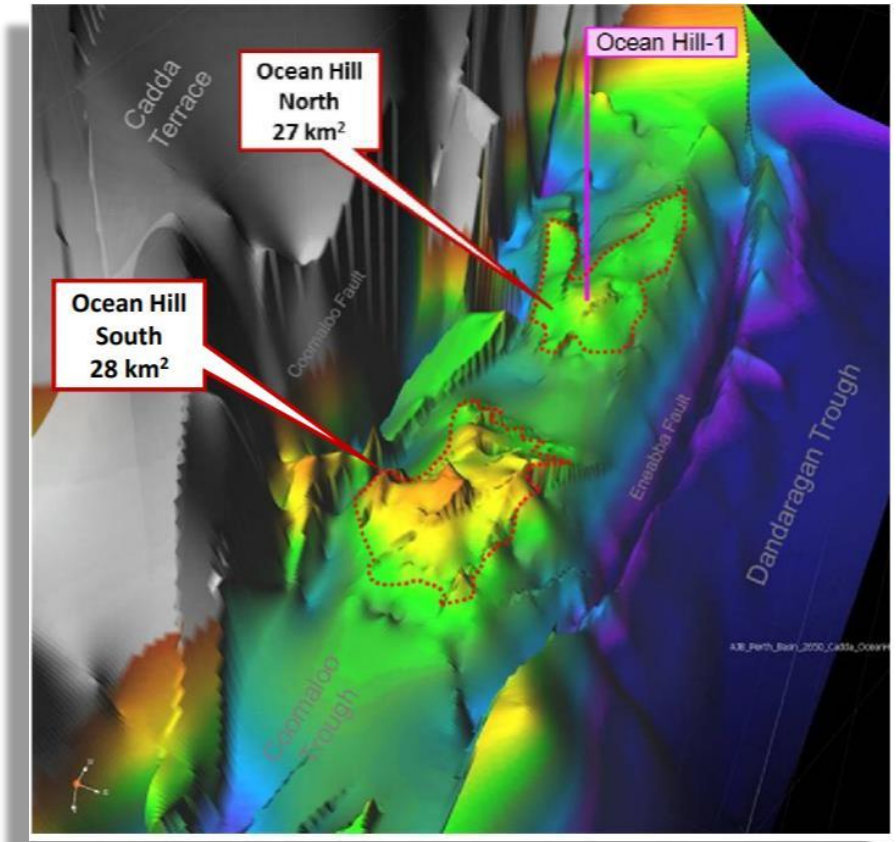
Case Study

Ocean Hill Prospect

Ocean Hill Prospect

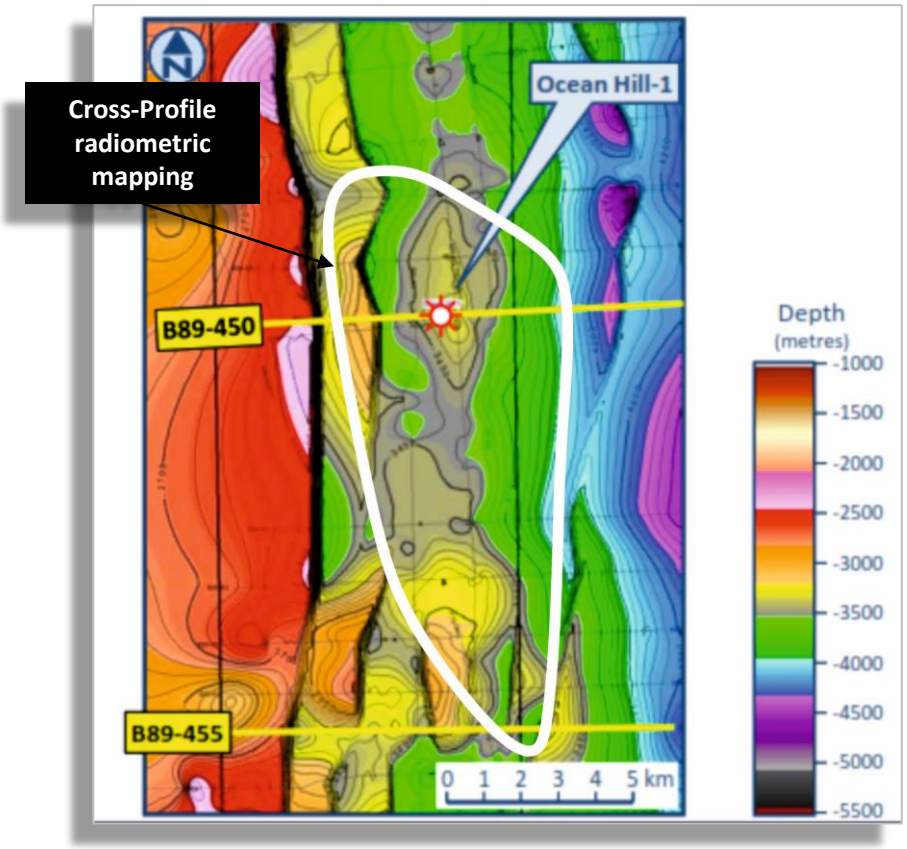


Strike Energy Limited
Ocean Hill Prospect Seismic Mapping



Ocean Hill Prospect

Strike Energy Limited
Ocean Hill Prospect Seismic Mapping

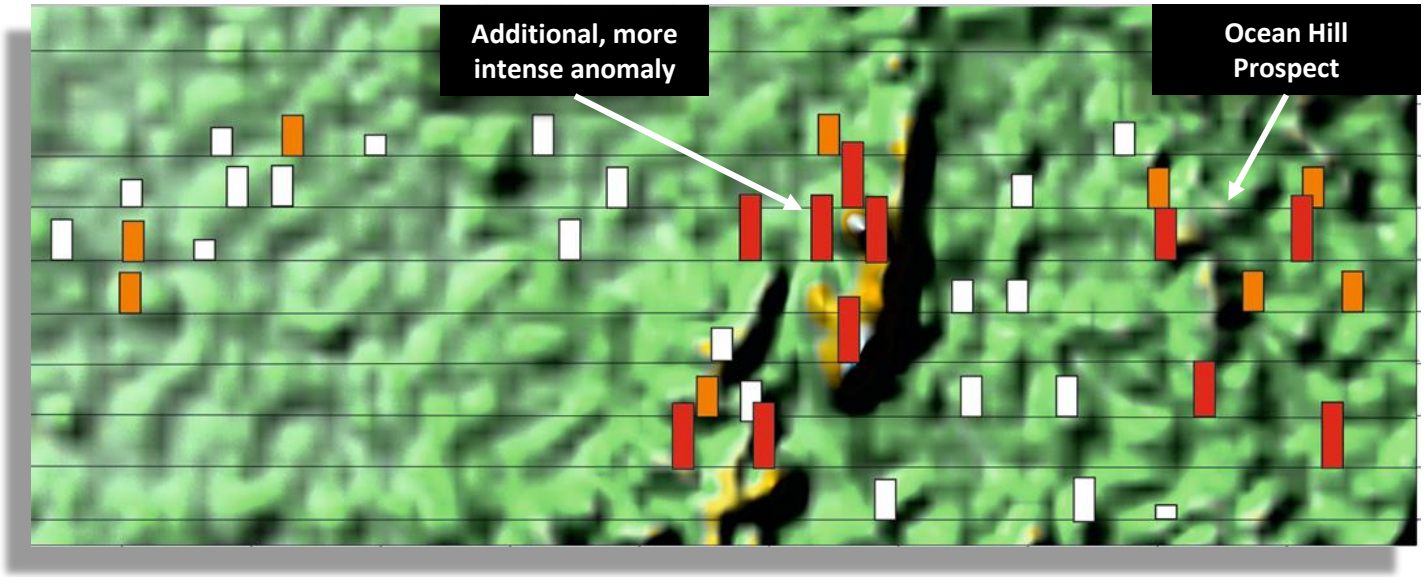


Strike Commentary on Ocean Hill Prospect

- Ocean Hill-1 was drilled in 1991 to a TD of 3,838m (12,592')
  - Tested a simple four-way dip closed anticline, main objectives were Early Jurassic Cadda Formation and Cattamarra Coal Measures
  - Significant gas shows encountered through Early Jurassic section from 3,077m (10,095') to Total Depth, a total of 761m (2,497')
  - DST-2 flowed at 0.7mmscf/d
  - Electric Log analysis indicates over 100m (328') net gas pay within multiple stacked sands
  - Reported discovered resource
    - Recoverable Gas: 360 BCF (2C Contingent Resource)
    - Associated Condensate: 1.2 mmbbls (2C Contingent Resource)

Ocean Hill Prospect Cross-Profile Mapping

ARAD Cross-Profile Mapping
Ocean Hill Prospect

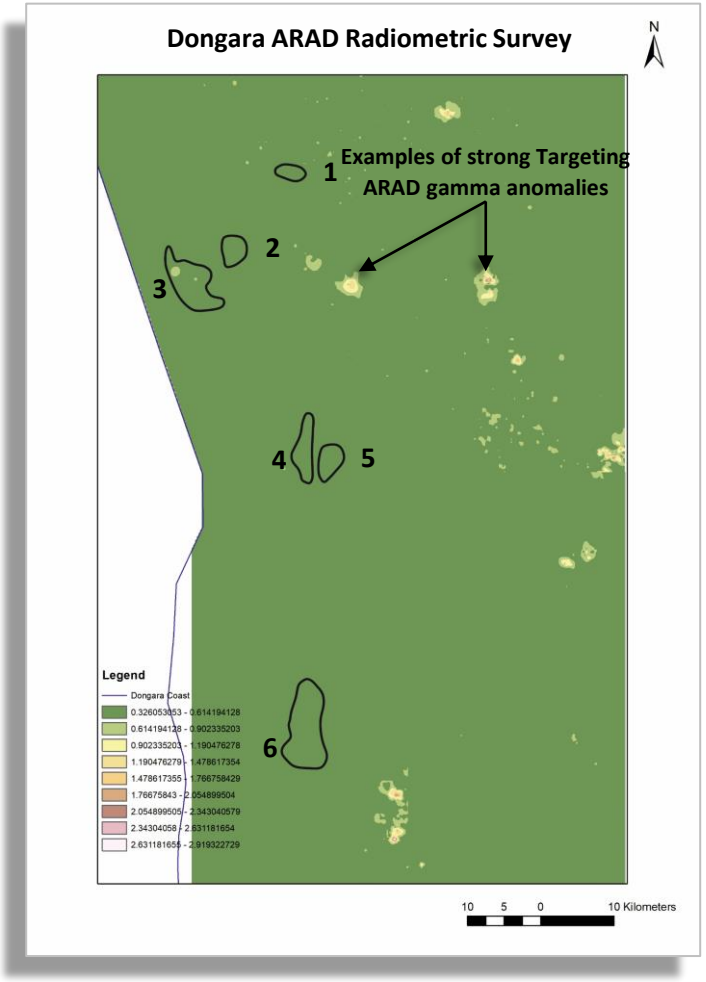


- High intensity point shows good closure of the structure
- Very intense radiometric anomaly to the west that may be more prospective

Case Study

Heavily Depleted Fields

ARAD Process Did Not Target Depleted Fields

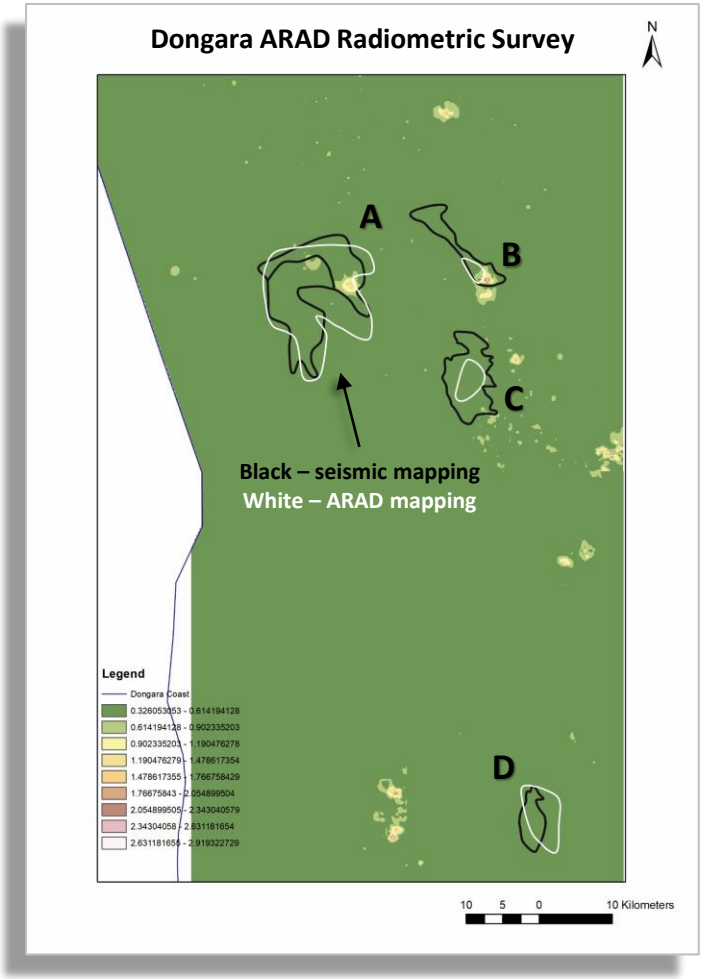


- Dongara radiometric data acquired in 2012
  - After six older fields had been heavily (80 to 90 percent) depleted
- Depleted reservoirs lose their high pressure
  - Lower pressure reduces and/or ends hydrocarbon microseeping
  - With the decline and/or absence of microseepages, gamma anomalies “fade” away
- Dongara study evidence of radiometric fade
  - Only Dongara (3) produced a weak Targeting ARAD gamma anomaly
    - Additional mapping studies confirmed no gamma anomalies associated with the field
  - Other five fields produced no Targeting ARAD gamma anomalies

Conclusion

ARAD Results Exceptional

- Seven Targeting ARAD gamma anomalies including four that targeted and mapped a discovery or a prospect
  - **Targeting ARAD A -** Waitsia 2014 discovery
  - **Targeting ARAD B -** North Erregulla Deep 2D seismic prospect
  - **Targeting ARAD C -** West Erregulla 3D seismic flat-spot prospect
  - **Targeting ARAD D -** Ocean Hill discovery
  - Comparison of radiometric mapping correlates well to seismic mapping
- No Targeting ARADs targeted heavily depleted fields or mapped two show wells near prospects
  - Evidence ARAD technique does not target depleted accumulations or wells with shows



RAPHAEL ENERGY GROUP LIMITED

Registered in England and Wales
Company Number 10192988

Telephone +44 20 3695 9331
www.raphaelenergy.com

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