Prospectivity and play analysis in the frontier Great Australian Bight: the benefits of a public domain data system and the application of traditional and new technologies

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The deep water portion of the Great Australian Bight remains an untested basin with the Gnarlyknots–1A well drilled in 2003 not penetrating deep enough to test the well's targets within the Upper Cretaceous Ceduna Delta section. If an anoxic marine shale source system, that is an effective source in many parts of West Africa, is present beneath the delta, then this could supply a material oil charge into the numerous fault block structures identified on seismic data. With eight wells due to be drilled in the next few years, this area will be one of the most active exploration frontier settings in the region.

Since Australia has an open file system for technical data, the regional Flinders 2000 2D Marine seismic Interpretation report containing five regional Time structure maps is now in the public domain, as is the Gnarlyknots–1A well data and the raw seismic data from the Ceduna 3D survey acquired in 2012. These data were used to evaluate the untested Coniacian play interval with the construction of Reservoir Presence and quality, seal and charge relative probability maps made from various proxies that were then stacked to show areas of relative prospectivity. This traditional approach was supplemented by the an example showing pre-interpretation surfaces from the pre-Cenomanian portion of the 3D volume to help develop a better understanding of the potential prospectivity of deeper intervals not captured on the submitted open file maps. The workflow presented here suggests some parts of the Ceduna Sub Basin are significantly more prospective than others. Moreover, we demonstrate that even in frontier settings with minimal well data, pre-interpretation processing and simple play analysis together can be a useful and efficient approach for delivering significant insights into prospectivity. This workflow will ultimately promote more exploration thinking and activity in the future.
1. Data is not knowledge challenge

2. Play Mapping Solution Examples
   a) Conventional Exploration - The Ceduna Sub-basin Coniacian-Cenomanian Play Evaluation
   b) Unconventional Exploration - The Beetaloo Sub-basin Velkerri B Shale Play Assessment

3. Summary
We have 30+ International E&P companies using our play analysis software now and I am consequently lucky enough to travel around the world in my job and spend a lot of time overseas talking to international E&P companies.

In these travels when dealing with foreigners I generally have to respond to a predictable series of questions that relate to Australia. The answers to these questions are...

- No I don’t know Crocodile Dundee nor did I know Steve Irwin.
- No I don’t know (insert friend’s name) from Melbourne.
  - even though worryingly often I do?!
- Yes Australia is a long way away and yes we speak English (of sorts).
- Yes everything will kill you here and we dream about animals as harmless as rattlesnakes and we think Texas is small and the size of an average back garden…

After these jocular perfunctories if they are upstream new business people the next comment is invariably a complement on how much they enjoy visiting our country and then how much they appreciate the regional work and the supply of basic well and seismic data provided by Geoscience Australia which is linked to a regular bid round process..

- This data is seen as a massive positive when they compare it to the many countries where accessing basic data is difficult if not impossible.
- The next comment however is always…
"But how do I deal with all this data"?!

- OK they are whingers but the basic point is real – data is not knowledge and many companies literally drown in the volume of data we supply..

- So what is the solution? Especially in a new low oil price world with more limited exploration staff and resources which is also suffering through the “crew change” where many very experienced people are also now retiring
“Mainly Data” supplied then all serious assessments done in companies
“Data” supplied AND base level screening provided to help companies filter and understand prospectivity
The proposal is that GA (?and State bodies inshore/onshore) make or sponsor simple preliminary prospectivity assessments

• Collect and document undrilled prospects from open file sources
• Compile public domain structural map data as grids
• Regional framework studies (well correlations and seismic= tops database)
• Collate any data that relates to the interpretation of well failures
• Make some simple play maps

The aim of this work is NOT to get “the answer” and “do the work that oil companies do” rather its to collate what we (as an industry) think we know and think so that ideas can be tested against this consensus backdrop

• An example..
Prospects A & B are located on a migration path beyond the proven limit of the play and 2 dry wells are present – both are on simple anticlines, have good seal and reservoir sections and are interpreted as charge failures due to lack of migration hence prospects A & B are considered very risky.
• The two wells are reviewed and re-interpreted to be drilled off structure hence the lateral migration to the prospects may not be as risky as once thought...
Example of new ideas challenging a consensus model...

• A new more complex migration route from the proven kitchen can be proposed that explains the wells but can still get hydrocarbons to the prospects which are now thought to be in a migration shadow area
So the suggestion is

• We/GA simply put some context and understanding around some of the prospectivity to help companies understand the geology and then they can define, sell and test new ideas.

• To do this using limited resources we have to use the existing open file data in a new way.....

• But before the examples..
What I am NOT recommending

• Over the last 4 years John Bradshaw, myself and others have collated Player play map/regional framework projects that now span the entire NW Shelf

• This interpretation is based on
  • Basic Geological data = +/- 3x what GA has available
    • Seismic and well correlations – using all biostratigraphic data available
    • Regional Structure/Isochore 2D grid and paleogeographic maps tied to well penetrations
    • QC’ed Shows and temperature database
  • 23 Play Intervals evaluated in Player with multiplay stacks and other products linked to extensive post drill analysis data
    • Pool/Discovery data all from public domain sources

• We estimate this has taken 30 man years of work..
DATA (reports)
- WCR’s
- Permit Reports
- Seismic Reports
- Well Summaries

DATABASE(s)
- Shows
- Geochem
- Reservoir quality
- Biostrat
- Deviation
- TWT

MAPS
- Isochore
- Structure
- Palaeogeography
- Fields

ANALYSIS
- Well audit
- Field
- CRS stacks
North West Shelf Data
BGC vs Gov’t
Plus our Database is QC’ed

Red Dots are data assigned to the wrong well in the Govt Database
...are comprehensive and relatively expensive and are probably too complex and detailed for gazettal/promotional material

We at GIS-pax now however have a more simple and significantly cheaper play analysis tool that does more basic traffic light type play map and does other evaluations

In this software we transform images into grids in ArcGIS and we can easily band distributions to make traffic light displays

Plus we can do complex grid tasks using Excel = the main software tool used by the E&P industry

So we are recommending something simple, cheap and easy not something complex and expensive. So lets look at some examples..
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3. Summary
The key aspects of the Petroleum Potential in the Ceduna Sub-basin is that it contains a very large Upper Cretaceous Delta.
Ceduna Delta – why it is big

The delta is large because it’s the product of a very large continental scale drainage area in the Upper Cretaceous that captured a very sandy provenance area.
The Ceduna Delta

• Is easy to see on regional lines and clearly was accommodated by syn-sedimentary extensional faulting.
Well and Seismic Database

- The area has an extensive coverage of 2D and local 3D surveys and has only been tested by 2 exploration wells namely
  - Potoroo–1—drilled by Shell in 1975 in 252 m of water on the northern flank of the basin
  - Gnarlyknots–1A—drilled within the basin proper in 1316 m of water by Woodside in 2003
The sedimentary thickness attains thicknesses of greater than 15km of section meaning that sediments will be in the oil and gas windows somewhere..

Figure 3. Map of basement in the Ceduna Sub-basin highlighting structural elements controlling sediment distribution through the basin fill phases. A remnant intra-cratonic rift system is evident in the north.
• Immature high Quality Source Rocks dredged from adjacent eyre area sediments of uppermost D. multispinum/lowermost P. infusorioides microplankton zone

..and dredge samples suggest the possible presence of an anoxix marine shale sequence of Cenomanian Turonian age which remains undrilled to date within the basin proper...
Ceduna Possible Cenomanian-Turonian Oil Kitchen Area

Figure 3. Map of basement in the Ceduna Sub-basin highlighting structural elements controlling sediment distribution through the basin fill phases. A remnant intra-cratonic rift system is evident in the north.
Gnarlyknots-1a Well Summary

• Is the one key modern well drilled in the main depocenter area that could have potentially tested the C-T oil prone kitchen
• The well did not drill deep enough because of various issues
• The actual drilled sequence was sandy and the mapped structure suggests that the faults would have leaked at the tested levels
• The deeper plays remain untested

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We have the well completion reports for the 2 wells plus a regional 2D interpretation report with 6 TWT maps available in the public domain.
Mapped Horizons in Flinders MSS Open File Rpt

Stratigraphic interval penetrated by Gnarlyknots

Top Paleocene/Top Cretaceous

Top Campanian

Top Santonian

Top Coniacian

Top Cenomanian

Bisoustrat age of dredge source rock samples

Evaluated Play Interval in this study – between the possible world class source rock and the tested section from Gnarlyknots-1a well
The first challenge is to turn the static maps in the Flinders Seismic Interpretation report into something we can use and manipulate.

To do this we geolocate the images in ArcGIS (put them in the right place in space) and then use the “image to grid” functionality in the Player software to generate real grids from the images.
Coniacian-Cenomanian Play Evaluation Workflow

Public Domain Documents

- Scans of Structure Maps
- Conversion to Grids in Playpen
- Evaluated Coniacian-Cenomanian Play Interval
- Main Source Interval

Example Geolocated Image

Example Grid extracted from Image in Playpen
Next some of the key maps are converted from TWT grids to depth grids using a 2 layer depth conversion model – SL to water bottom then then WB-mapped horizon with the latter using the twt-depth function defined by the Gnarlyknots checkshot data.

The functions are defined in Excel and each grid node is pushed through the excel calculator in Playpen to make the depth converted grids.
Coniacian-Cenomanian Play Evaluation Workflow

Public Domain Documents

- Scans of Structure Maps
- Conversion to Grids in Playpen
- Depth Conversion in Playpen with XL
- Isopach Calculations in Playpen with XL

Evaluative Coniacian-Cenomanian Play Interval

Main Source Interval

Bathy + T/z data

Next some isopachs are made using the same Excel Playpen tools to subtract 2 grids

Example Coniacian to Cenomanian Isopach Map
Coniacian-Cenomanian Play Evaluation Workflow

Bathy + T/z data
Scans of Structure Maps
Conversion to Grids in Playpen
Depth Conversion in Playpen with XL
Isopach Calculations in Playpen with XL
Timing
Isopach

Next to estimate the Source Kitchen Maturity a two layer temperature map for the Top Cenomanian is made using measured sea floor temperatures plus the rock temperature gradient established at the Gnarlyknots well. These functions are defined in Excel and the bathymetry and the top Cenomanian TWT maps are input through this evaluation for every cell to make a top Cenomanian Temperature Map.
Next to estimate the Source Kitchen Maturity a two layer temperature map for the Top Conianomanian is made using measured sea floor temperatures plus the rock temperature gradient established at the Gnarlyknots well. These functions are defined in Excel and the bathymetry and the top Conianomanian TWT maps are input through this evaluation for every cell to make a top Conianomanian Temperature Map.
Coniacian-Cenomanian Play Evaluation Workflow

This grid of temperature values is then gridded into window bands to indicate the current day possible maturity levels in the Cenomanian to Turonian section.

This indicates that the Cenomanian-Turonian source section is largely gas mature over the deeper parts of the basin and is currently oil mature over the northern flank of the basin.
Coniacian-Cenomanian Play Evaluation Workflow

The Tertiary Isopach shows the area with the most recent burial – this is cut by later Plio-Pleistocene channels.

Tertiary Thick Area
The Tertiary thick location suggests that the northern flank is the area that received the most recent burial and consequently a recent oil migration pulse.
The Interval isopach is then partitioned into lower and higher risk areas for reservoir presence – the logic here is that the better sands will be in the thicker/deep water areas. There are still proven sands in the Gnarlyknots well in the orange area but the better sands are interpreted to be to the south.
The top depth map to the Coniacian is then used to indicate areas of relative reservoir quality.
Coniacian-Cenomanian Play Evaluation Workflow

Finally the areas updip of oil mature areas are highgraded for oil charge access
Two stacks are then made showing the Traffic Light stack on the left and a multiplication stack on the right. Both stack varieties show that for this play interval the implied better play area is the northern flank.
There are a whole series of identified prospects in public domain documents over this northern area and these would be the suggested focus for further analysis. (this is not to say there is not prospectivity at shallower levels in shallower plays elsewhere)
There is prospect detail in the public domain showing that amplitude supported prospects are present within some of these shallower play intervals.
Problems with submitted prospect data

- In many cases companies submit or only publish selective prospect data.
- In this case there are clearly leads and prospects within the Coniacian to Cenomanian Interval that have not been submitted in reports.
  - We do not know if they have been mapped by previous operators.
- In these cases the application of pre-interpretation processing using a genetic segmentation and gene sequencing technique (Seisnetics) automatically creates a queryable database cataloguing virtually all the peak and trough surfaces within the 3D data seismic volumes. Directed queries to this database can be used to identify and map leads.
Genetic Algorithms Applied to Seismic Data

Seismic trace = Chromosome; Seismic trace segment (Waveform) = gene

Pre-interpretation processing
1. Acquire Open-file GAB 3D
2. Automatically segment all traces into waveforms.
3. Waveforms combine based upon genetic and spatial compatibility to form Geo-Populations.
4. Geo-Populations simultaneously grow and evolve during processing.
5. All populations are catalogued into a queryable database containing TWT, Amplitude and Genetic Attributes.

NEXT Steps:
User query to database Starts interpretation.

• Genetic Algorithms are adaptive and mimic the process of evolution.
• Used to catalogue the 2.5 billion chemical base pairs that make up the human genome.
• Natural selection and survival of the fittest are key principles.
Output
Global, Automated, Consistent, Independent.
Geometric Attributes of the Dupin Indicatrix

**Processing Sequence**

**Input:** A database of surfaces created by pre-interpretation processing using Seisnetics™ was loaded and prepared for processing by GeoProxima™.

1st Stage: New differential geometry techniques to automatically map a surface’s geometric properties as defined by Dupin’s Indicatrix.

The features extracted are compiled into a queryable database which is ready for interpretation.

2nd Stage: Features and objects are generated using pre-defined combinations and patterns of geometric and spatial attributes.

Optical Stacks of surfaces are generated to analyse the prevalence of attributes over packages and zones in the volume.

Deliverables:
- Final project database containing morphometric properties of all surfaces with viewer.

Add well and cultural data.

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Geometric Database queries

• The most fundamental property of a surface is its geometric characteristics.
• These geometric properties reveal features and objects not easily identifiable by visual analysis alone.
• Allows for the detailed analysis of features present on any type of surface.
• Improves our understanding of the subsurface.
• Information is visually suggested in the TWT surface shown.
• Queries to the database of geometric properties reveals a great deal of useful and extractable information.
Seafloor TWT

Seafloor channels/canyon features visible on the TWT surface.

Seafloor slump features visible on the TWT surface.

Convex

Inflection

Concave
There are major seafloor channels/canyons and slump features evident on the TWT surface. The boundaries of these features can be delineated by using linear convex and concave objects in the GeoProxima database.
Different queries reveal fractures, faults, pockmarks and complex deformation. All exportable as shape files.
Likely targets

Coniacian to Cenomanian Play Interval

One of thousands of events mapped by Seisnetics and maps shown on (d)

Undrilled Structure at extracted event level
When the drilling happens we will find out if the northern flank is the right place!
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3. Summary
• The Beetaloo Sub-basin is a Proterozoic basin that contain a thick section of algal rich source rock beds within the 300-400m thick Middle Velkerri Formation

• This interval contains at least 3 regionally mappable high TOC layer-cake units that have been buried to mature oil and gas window levels in the past and have now been uplifted to shallower depths. These shale intervals form the principal oil shale unconventional targets in the basin are the current focus of ongoing exploration programs by various companies.

• This evaluation uses public domain map, digital elevation data, well and published rock evaluation work to calculate indicative recoverable gas and condensate volumes from the best shale sequence – the Middle Velkerri B Shale interval – which is the first target/bench for horizontal well drilling.
The Beetaloo Basin is adjacent to existing gas pipelines in the Northern territory and is well placed to commercialise any gas.
Law et al., 2010 Altree-2 well

Level of depth map on next slide

B Shale

~35m sheet unit
The first Challenge is to turn this map from an image into a grid that can be used in an evaluation.
Depth Map Conversion

- The image is first geolocated then the image is converted into a grid using the Player functionality
This map is in meters subsea so to calculate rock thickness to the middle Velkerri we have to add the ground level elevation to this depth map.
Evaluation Workflow

1 – Rock Thickness Map Generation

- RPS Middle Velkerri Depth Map
- Surface DEM
- Rock Thickness
- Temperature and Pressure Data
- Gas Expansion Factor Map
- Rock Thickness Quality and Rec Factors Etc
- In Place and Recoverable Gas and Condensate grid volumes
- Recoverable Volumes by Block or Sweetspot
- Block Outlines and Gas/km² values
- Recoverable Volumes by Block or Sweetspot

- Workflow is a series of grid operations that are defined in Excel spreadsheets linked to grids in ArcMap
We have a Digital Elevation Grid (downloaded from the web) and the Middle Velkerri Depth Map so we simply use the Playpen link to add functions (like addition). Each grid node is calculated from the spreadsheet and the output is the rock thickness.
Workflow is a series of grid operations that are defined in Excel spreadsheets linked to grids in ArcMap.
The Temperature gradient data is collated from the available well bottom hole logging data. This is then turned into a map of geothermal gradients.

There is clearly a relationship between the rock thickness and the GG so that we can build a relationship in Excel and this can be used to make a Temperature Map of the Mid Velkerri in Playpen.
The predicted temperature Map at the Middle Velkerri Horizon Level
The pressure gradient is taken from Close et al., and a 0.53psi/ft gradient is used together with the rock thickness map to predict the pressure at the mid Velkerri interval. This probably over optimistic since there is evidence that some of the shallower wells have no overpressure.
• Uses the rock thickness and the temperature grid through a complex spreadsheet that calculated the theoretical GEF at every cell node.

This calculation is far too complex to translate into something that be typed into a grid raster calculator so linking to an excel function is easy and quick.
The result ranges from 59-237 GEF obviously the areas with the higher values will be more productive given the uniform nature of the shale interval.
• Workflow is a series of grid operations that are defined in Excel spreadsheets linked to grids in ArcMap.
The 4 key wells in the area that have penetrated the Middle Velkerri B Shale are correlated and show a uniform range of 31-39m so an average of 35m with 100% n/g was used in the calculation.
Law et al., 2010 Altree-2 well

672-948m
276m gross
Law et al., 2010 Altree-2 well Plus Shenandoah-1 well correlation

31m Mid Velkerri B Shale
Kalala South and Amungetee NW Correlation

Velkerri B Shale 35m

Kalala South -1

Amungetee NW-1

39m

36m
In this case a 35m slab was used but an isopach map or any other set of maps could have been constructed instead of using the constants below. The main variant for the recoverable volumes is the use of the GEF map as an input.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Cell Size</td>
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<td>62</td>
</tr>
<tr>
<td>Thickness</td>
<td>feet</td>
<td>115</td>
</tr>
<tr>
<td>Net gross ratio</td>
<td>fraction</td>
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</tr>
<tr>
<td>Net Pay</td>
<td>feet</td>
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<td>Matrix Porosity</td>
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<td>Gas Expansion Factor</td>
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<tr>
<td>CO2 fraction</td>
<td>mole fraction</td>
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<td>Free HC Gas inplace</td>
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<td>Recoverable Gas</td>
<td>Bcf</td>
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<tr>
<td>Recoverable Condensate</td>
<td>Mmbbls</td>
<td>0.1</td>
</tr>
</tbody>
</table>
• Bcf/acre map shown..
• Workflow is a series of grid operations that are defined in Excel spreadsheets linked to grids in ArcMap.
Finally two types of aggregation are used namely into blocks and then into sweetspots—the block aggregator has a single step.

EP98 28tcf recoverable
EP117 15tcf recoverable

This is just the B shale!
Gas bcf rec per acre

- The reclassify a raster layer is made to pick the sweet spot cut-off in this case it is 0.012 bcf/acre this banding is output to a new raster layer.
Now the report/aggregation tool is just run for the sweetspot area showing there is 17 tcf of potential gas reserves in the main fairway area.
The Playpen tool together with a few simple open file documents can be used to calculate indicative volumetrics of the Mid Velkerri B Shale play.

- The economic viability of this play will now obviously depend on many factors but the principal ones will be the recovery per well, the well costs and the gas and liquids volumes and prices received.
- This exercise was a workflow example NOT a fully worked quantitative exercise. Obviously a new more extensive depth map and better calibration of some of the key geological inputs is needed to get a better estimate of potential.

Other unconventional plays can be evaluated in a similar way – the extra steps normally included would be polygon cut-offs for source richness and maturity which were not needed here because of the simplicity and uniformity of the geology in this particular example.

All of the workflows shown could easily be combined into a single workflow and once calibrated with testing and further geological analysis this single evaluation workflow would effectively capture the “IP” of the Beetaloo Shale Gas Play.

- A collection of different evaluations would thus in time form a library that could be used as analogs for less well understood shale gas plays.
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3. Summary
Both of these example evaluations used public domain data and used cheap software used extensively by the industry today
  • Excel everyone has so is free, ArcGIS is ~US$1000/year and Playpen is <US$5000/year

The evaluations took ~1 day each and provide valuable spatial and quantitative insight into the prospectivity of both plays

The recommendation is to collate and make selective simple play maps for the prospective basins of Australia
  • or at least..
    • collect and collate the available structure maps and supply as grids
    • collect the leads and prospect polygons and metadata from work done by previous operators

These compilations would make the assimilation and understanding of our generous data packages more efficient and hopefully deliver more investment into our exploration acreage in the future..
  • Eventually that should result in significantly more tax being paid!
Contacts and Thanks

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NW Shelf Projects and Data

Search & Discovery website