

DHM OIL AND GAS PROSPECTIVITY OF THE POWDER RIVER BASIN, WYOMING AND MONTANA, USA

1. THE POWDER RIVER BASIN PROVINCE (PRB)

This very large, heterogeneous, Rocky Mountains foreland / inter-montane basin primarily locates in NE Wyoming and a small part of SE Montana (**Figure 1**). It measures more than 700 Townships of land (25,200 sq. miles) being approximately 250 miles long and 100 miles wide.

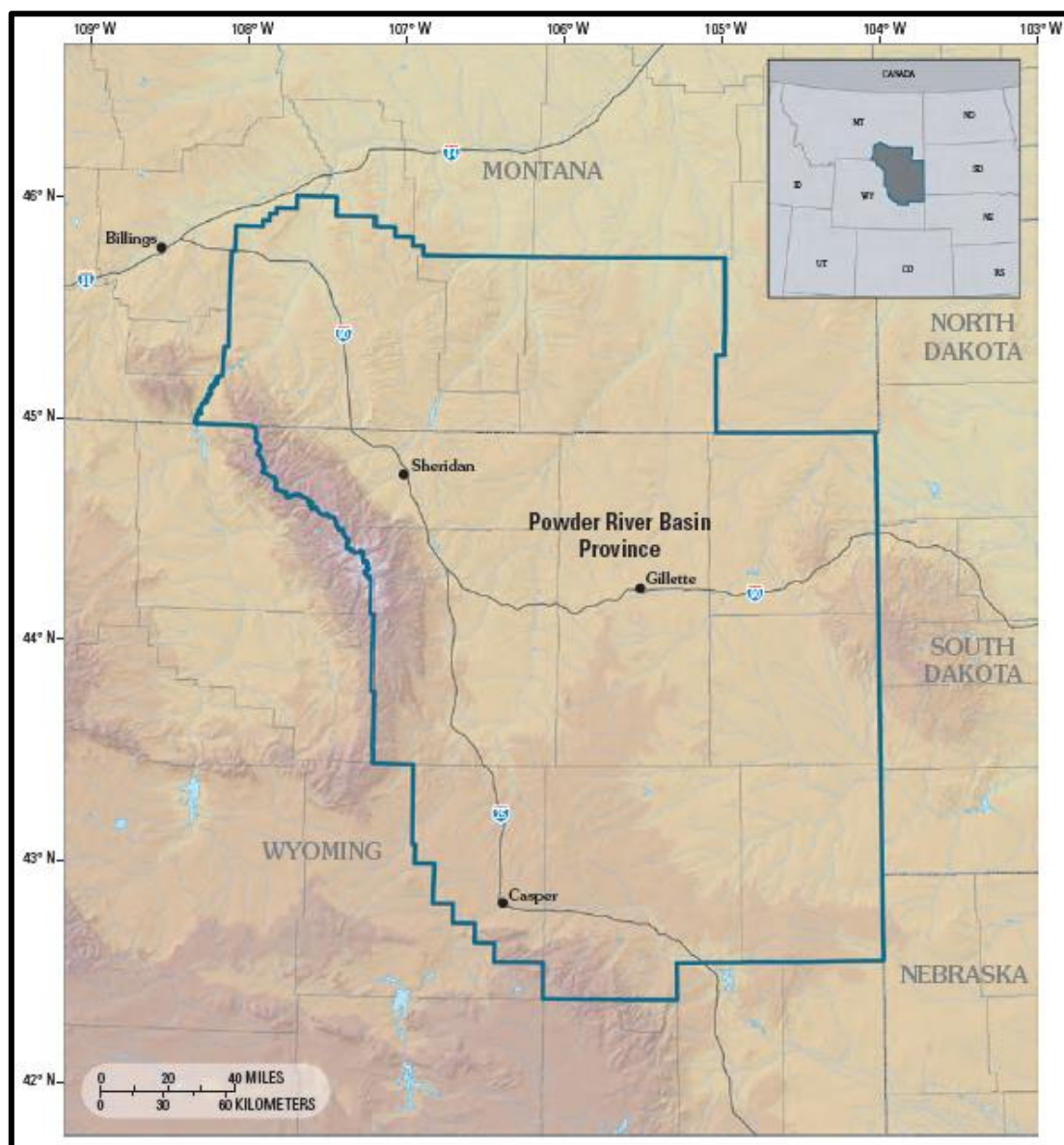


Figure 1 Powder River Basin Geographic Outline Map.

Courtesy of USGS (DDS-69-U by L. O. Ana, 2009)

PRB has had a long history of exploration drilling and petroleum development but has not been systematically explored to maturity area-wide (**Figure 2**). Many Townships are still under-explored and lightly drilled today.

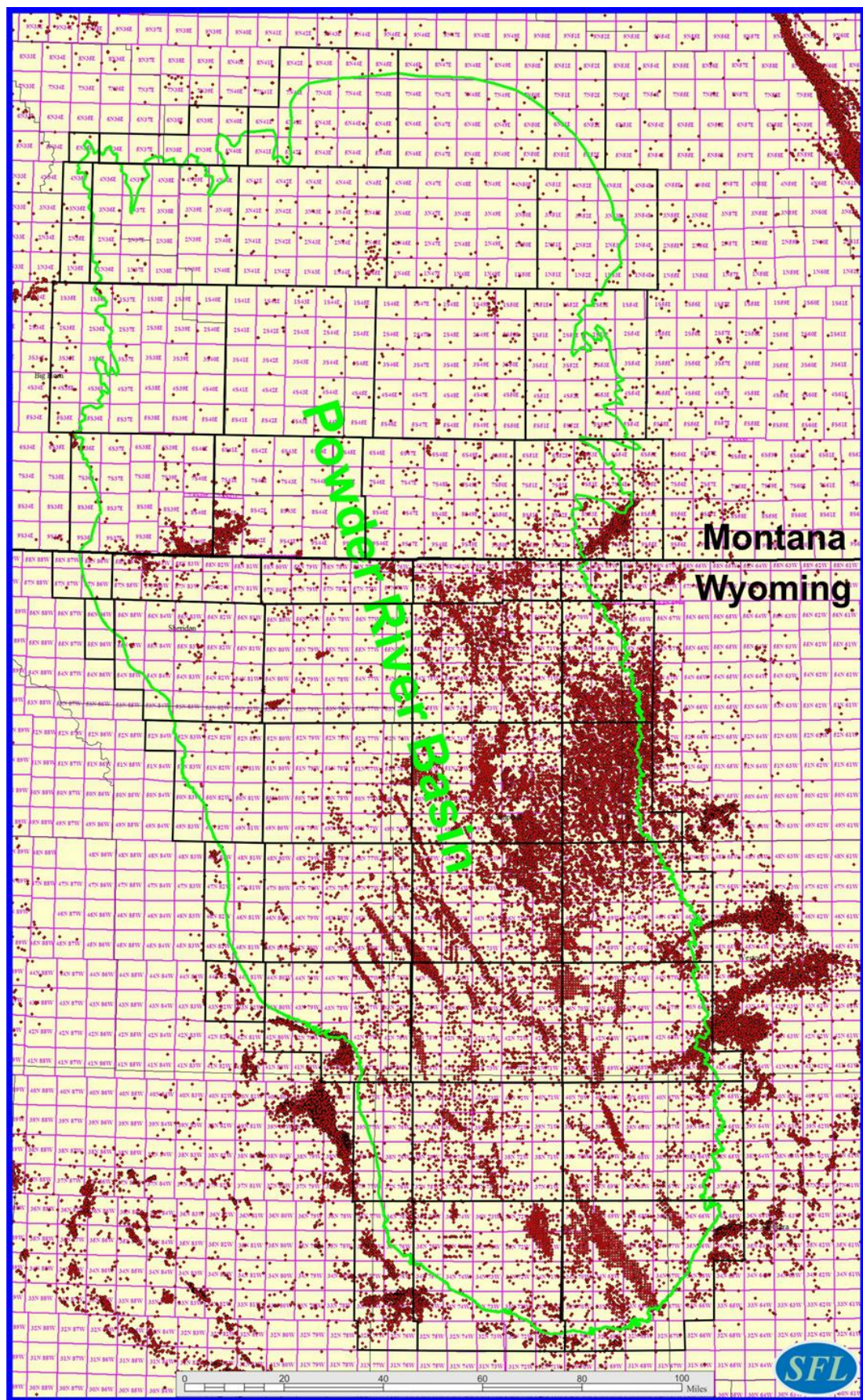


Figure 2. Well Distribution Pattern of the Powder River Basin

2. USGS Studies and Yet To Find Potential – A Need for Effective Exploration Approaches

2.1 USGS: The PRB was assessed comprehensively by the USGS in 2009. Its “Geological Assessment of Undiscovered Oil and Gas in the Powder River Basin Province, Wyoming and Montana”, by L.O. Ana, described it as follows:

“The PRB, located in north-eastern Wyoming and south-eastern Montana, developed during the Laramide orogeny similar to other Rocky Mountain foreland structural basins. The basin is asymmetric with the axis on the west side. The deepest part can be 17,000 ft or more to the top of the Precambrian basement. On the east flank, regional dip is about 100 ft/mi to the west but increases to about 500 ft/mi along the west limb of the Black Hills monocline; on the west flank, regional dip is about 500 ft/mi but decreases to less than 50 ft/mi north of the Wyoming-Montana border”.

It has five defined “*Total Petroleum Systems*” (TPSs), eight conventional Assessment Units (AUs) and three continuous AUs (or unconventionals). These have delivered a proven oil and gas reserve of more than 2.7 BBO and over 2.3TCF of gas in about 700 fields since the discovery of the giant Salt Creek field in 1908, of which about 225 are greater than 1MMBOE in size (Dolton and Fox, USGS 1996).

Against this historic industry performance, the USGS modelled a remaining basin-wide fully risked “Yet to Find” Total Undiscovered Oil and Gas Resource potential of 639 million barrels of recoverable oil (Petroleum Resource Potential or “PRP”).

The primary Pennsylvanian-Permian “*Minnelusa-Tensleep-Leo*” AU is ascribed a mean risked potential of only 60.5 MMBO while the shallower Cretaceous Mowry TPS (including the Fall-River-Lakota Sandstone AU and Muddy Sandstone AU) is ascribed 111MMBO.

Scotforth considers these expectations highly conservative given:

- The multiplicity and diversity of geological plays (areally, stratigraphically and structurally)
- The historic patchy focus of exploration drilling (**Figure 2**) and
- The low effectiveness of “*seismic-led*” petroleum exploration in main plays such as those of the Minnelusa Formation.

2.2 Effective Exploration Approaches: A strategic discovery success breakthrough is now possible by application of “*hydrocarbon-led*” exploration focusing, with its enhanced risk reduction. This is likely to raise this risked PRP substantially and uplift the effectiveness of exploration spend. It offers considerably greater future exploration opportunity, discovery success and reserves build than currently perceived possible.

Scotforth’s Direct Hydrocarbon Mapping exploration survey technology (“DHM”) offers such opportunity in PRB as elsewhere. Indeed, ***no exploration method other than DHM***, in conjunction with conventional petroleum geological and wider geoscience analysis, can deliver this. DHM can do it basin-wide and quickly, right down to Section level prospectivity analysis and to 40 acre well target optimisation. ***Unique.***

An overview of DHM is provided at the end of this Brief, summarising its key components. The following section of this Brief provides illustrative examples of DHM in the PRB - fields, new prospects and representative DHM prospectivity mapping.

3. DHM in PRB

3.1 Current Status

Scotforth has been studying and surveying PRB since early 2016 and has now examined large parts of the basin and has confidence it can continue its coverage over the balance in the foreseeable future. Its investigations have ranged from district reconnaissance of several townships at a time in both Montana and Wyoming, through to individual quarter section prospect analysis, mainly in Wyoming, with DHM-led prospectivity ranking right down to the level of 40 acre regulatory spacing units.

Given the basin's immense areal extent, Scotforth is sub-dividing it simply for investigative and administrative purposes as follows (**Table 1**):

PRB (DHM Assessment) District Divisions - Townships					
District	Montana	Wyoming Central	Wyoming North	Wyoming South	Grand Total
Central East	40	70	45	65	220
Central West	38	70	45	36	189
East	24	48	40	71	183
West	32	56	50	4	142
Grand Total	134	244	180	176	734

Table 1. DHM Assessment Districts

These are essentially seamless and continuous but do exhibit significant variances in exploration maturity. While some are highly mature others are not and even less so at the individual Township or smaller groupings of Township levels. This offers DHM substantial scope for focused exploration, ranging from “tight-in” near field examinations at Section levels, to new or little tested “Exploration Focus Areas” and “Play Fairway Systems” at Township levels within the USGS TPS / AUs framework basin-wide or for PNG leasing focussed plays.

This suite of surveys has generated and continues to generate:

- A large inventory of Exploration Focus Areas (EFAs) with apparent good prospectivity and numerous large tracts of poorly prospective lands on which money need not be spent ;
- Multiple individual prospects and leads of high confidence and predicted low to moderate exploration risk and
- A ready ranking of mapped Prospect Inventories and their key prospective features at District, Township and or Section groupings by their Discovery Probability (PD) and Petroleum Resource Potential (PRP) attributes.

If pursued, DHM results have the potential to raise industry success in PRB from its historic 10-15% success rate to more than 60-65%. The track record “resume” of monitored DHM findings versus known fields and reviewed well results in this same period is more than 65%. This fits well with DHM's global pattern of success, both in pre-drill predictions and post-drill / field observational back tests.

3.2. DHM Examples: To illustrate DHM in PRB several processed images are used to display HLI characteristics and responses of both proven fields and undrilled prospects. These

include a mix of IPD and RBU outputs and matching pair couplets. An example interpretation Prospectivity Map excerpt is also displayed.

3.2.1 Fields

1. Raven Creek (North) –Central PRB; Discovered 1956, EUR 50MMBO (whole field) (Figure 3.1)

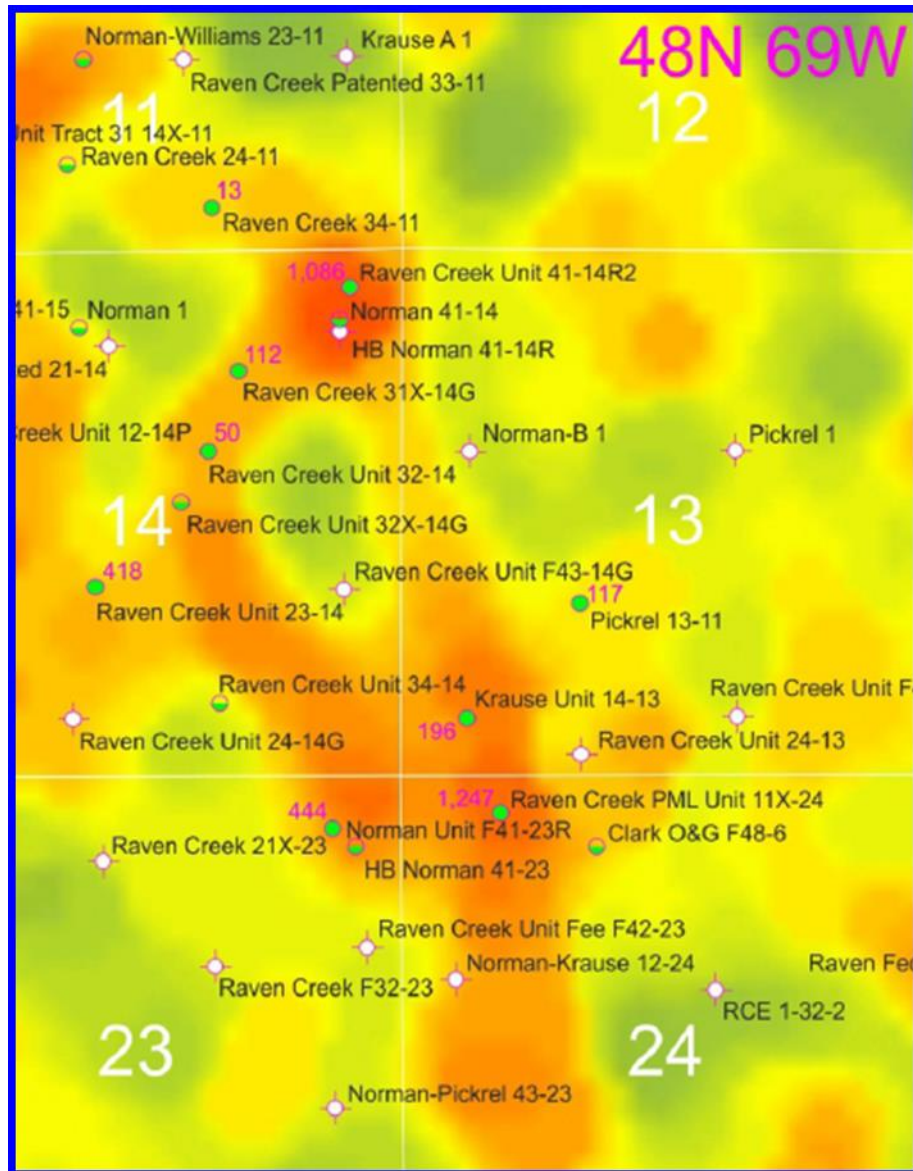


Figure 3.1. IPD Display - Hot Orange is prospective, Green is poorly prospective.

Comments: Strong N-S bifurcated HLI anomalous trend (orange) offset by non-anomalous low prospectivity areas / zones (LPZs) (yellow to green); best wells (>1MMBbls of produced reserves) locate in highest intensity sub-areas. Smaller recovery wells in weaker response parts of the trend. Few D&As in this trend. LPZ terrains – more than 10 D&As, no producers. Old E&P history but residual future Development opportunities possibly still remain. A few local development / step-out well locations identifiable in the DHM fairway.

2. Dry Gulch - Central PRB, Discovered 1983, EUR 6MMBO

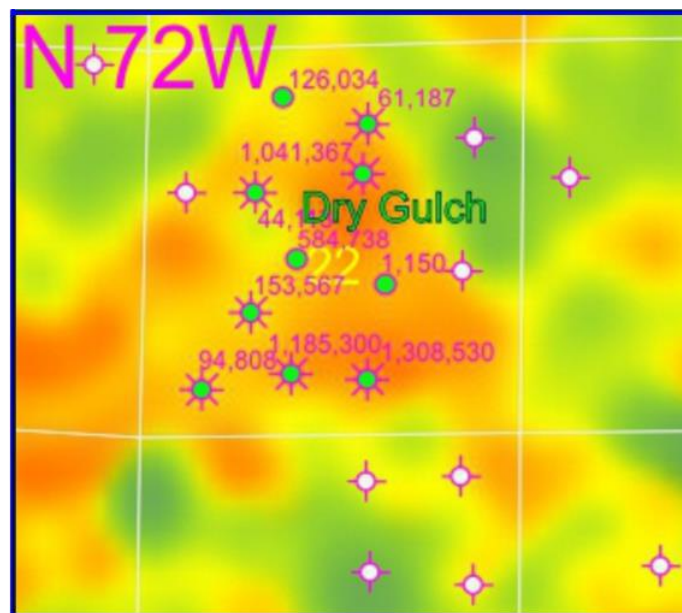


Figure 3.2. IPD Display– Hot Orange is prospective, Green is poorly prospective.

Comments: Moderate intensity, clear HLI with 10 producers on it (orange); 2 marginal location D&As and 7 off-anomaly D&As (yellow to green LPZ terrains). Wells range from 44MBO to 1.3MMBO within the HLI. Possibly one more development location in SE of field. Possible further untested prospectivity in the west.

3. Greater Mallard – Central PRB, Discovered 1991, EUR 1.25MMBO

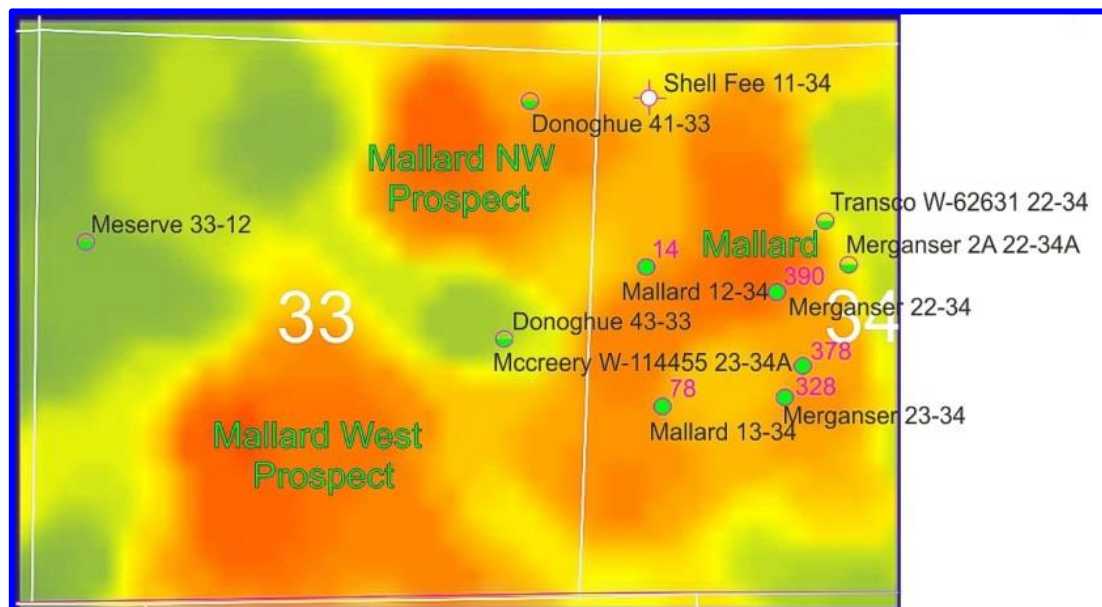


Figure 3.3. IPD Display– Hot Orange is prospective, Green is poorly prospective.

Comments: Strong DHM response district. Current proven field area in Section 34 nearing depletion but two further nearby prospective areas suggested in neighbouring Section 33 to the west – Mallard West and Mallard NW.

4. Ash Draw – Central PRB, Discovered 1985; Produced 1.46MMBO, EUR 2MMBO

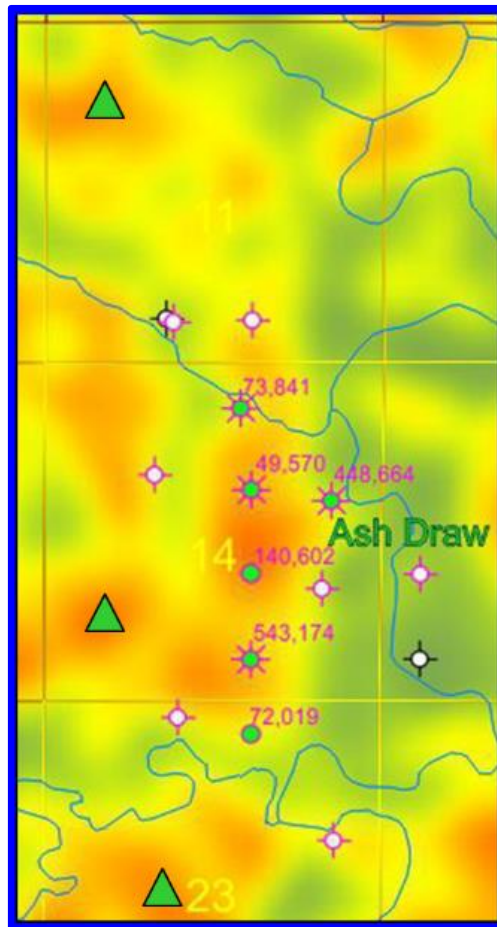


Figure 3.4. IPD Display– Orange is prospective, Green is poorly prospective.

Comments: Weak to moderate intensity HLI district (soft orange) with locally more intense features; notable LPZ (green) to the east of the productive trend. Ash Draw's 6 producers locate along a N-S elongate HLI feature (orange) with wells ranging from 50MBO to 543MBO. 7 Minnelusa D&As in nearby LPZ and marginal HLI terrain (green to yellow). 1 good well locates on the east edge of the productive HLI feature at the presumed updip reservoir pinchout, another within the main trend. Possible further untested prospectivity in outlier HLIs to the west, north west and southwest (green triangle locations).

5. Sawgrass and Eighty Five Creek – Northern PRB, discovered 1988, EUR 750MMBO

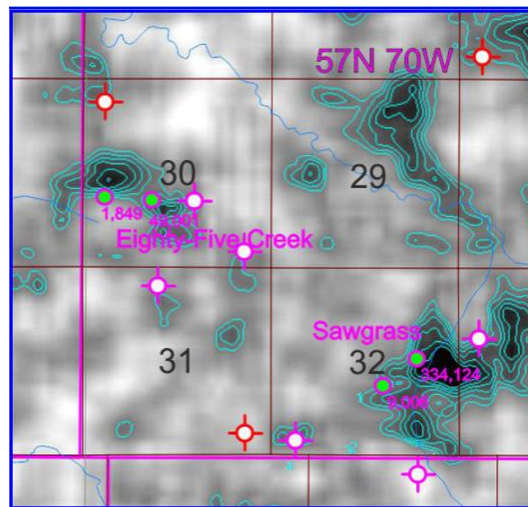


Figure 3.5. RBU Display– Black through dark grey is proven/ prospective, pale grey through white is poorly prospective.

Comments: Three primary RSDD-H anomalous features (HLIs) stand out from non-anomalous LPZ background: Sawgrass Pool, Eighty Five Creek Pool and One Undrilled Prospect. The only significant producer locates very close to the HLI sweetspot of Sawgrass anomaly. (Each square block is a 1 square mile “Section”- typically regulated to allow 16 x 40 acre oil well spacing units). (Magenta Wells = Minnelusa Fm Penetrations; Red = Shallower Muddy FM Penetrations). A successful test of the undrilled prospect could raise the EUR of these 4-5 Sections to more than 1MMBO.

3.2.2 Prospects

Scotforth has mapped many untested exploration prospects across PRB, some are single well opportunities, some have multi-well potential and several have predicted PRPs in excess of 5MMBO.

1. Nine Section Survey: The following DHM IPD-RBU couplet example (**Figure 3.6**) illustrates prospectivity across a Quarter Township / 9 Section district. Three Sections in the West have indicated high DHM prospectivity, three central area Sections moderate prospectivity and three sections in the East have poor DHM prospectivity.

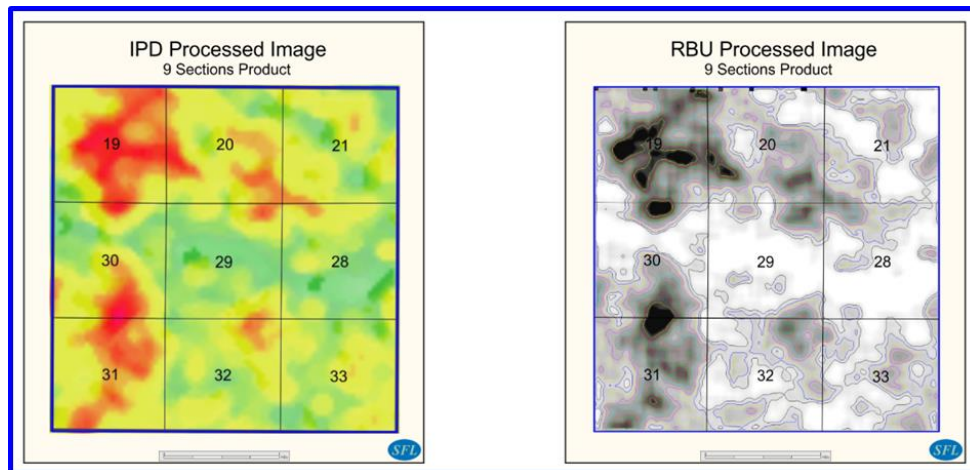


Figure 3.6 IPD-RBU couplet of nine Sections displaying clear prospectivity differentiation.

Section 19 is the interpreted top ranking Section of the nine but Sections 30 and 31 also contain good HLI features. They are the prime targets for leasing. The three eastern blocks (S21, S28 and S33) can be discarded and of central Sections 20, 29 and 32 only the southern half of S20 and NE S29 merit possible leasing, the rest can be rejected unless or until the main prospects to the west prove highly successful.

2. Single Section survey: A single Section prospectivity example (**Figure 3.7**) shows two clear, local prospects within the Section surrounded by flanking marginal and low prospectivity lands. The larger prospect in the NW would be first choice for a well test – preferably within its core area as indicated (Magenta triangle, neww S17). Success there would lead to a probable well test of the southern, smaller prospect area in swse S17.

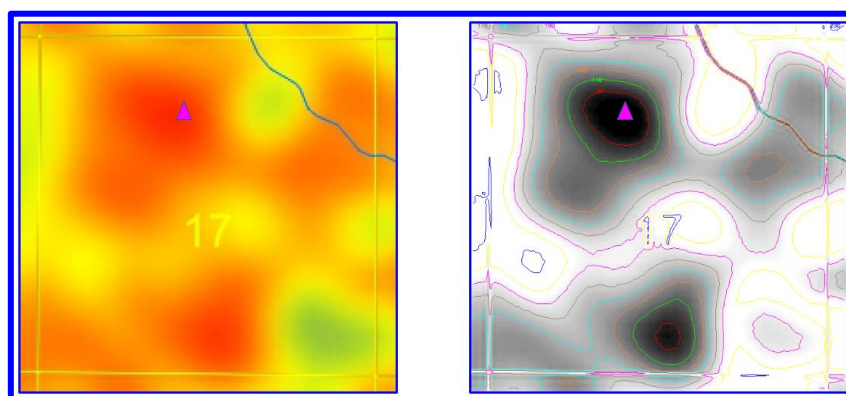


Figure 3.7 DHM observation of single Section DHM prospectivity illustrating two HLI prospects.

Comment: The northern, larger prospect would be a candidate for early drilling.

3.2.3 DHM Prospectivity Map (Figure 3.8)

A DHM prospectivity interpretation of four examined contiguous Sections in the basin:

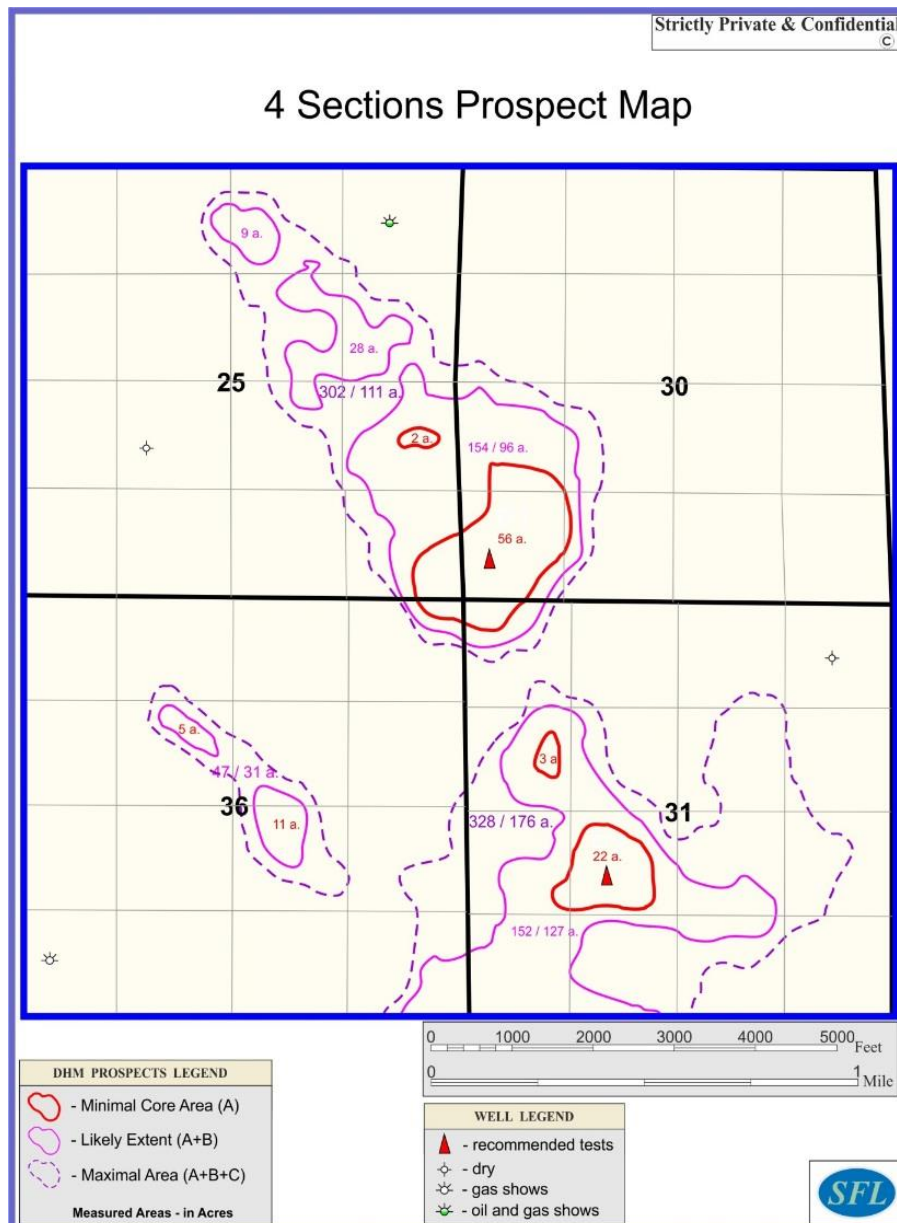


Figure 3.8 Typical DHM Prospectivity Interpretation Map – 2 prospects on display at minimal, likely and maximal extents (measured in acres). First candidate “effective” exploration well locations indicated for each by red triangle in their respective sweet spot “core areas” ssw S30 and nesw S31. One smaller, high risk lead in central Section 36. Most of the remainder of the 4-section area is deemed LPZ.

4. DHM Prospect Map Series of the PRB

Having researched and surveyed many parts of the PRB during the past five years and addressed its specific data and landscape issues, the nature of its HLLs and their relationship to known oil and gas fields Scotforth is now positioned to prepare and make available an essentially basin-wide series of DHM Maps and synoptic exploration prospectivity reports.

These maps will set out identified DHM prospectivity from local to district levels by Section and Township. They will be supported by standard Scotforth exploration statements of the observed and interpreted prospectivity patterns and offer views on the discovery probabilities and petroleum prospectivity potential of the mapped prospect inventories. This can be a valuable independent tool for exploration guidance, be it leasing or drilling, to consider together with conventional geological and geophysical evidence in any particular area.

Our prospectivity reports contain:

1. DHM Prospectivity Map*
2. Summary Prospect Inventory Table
3. IPD and RBU Imagery Set
4. NAIP Figure or GDEM Image
5. Summary Exploration Discussion

* Maps and figures will be presented at visual enlargement scale to suit ordered area of coverage.

They are priced competitively, starting from as low as \$1,500, to encourage incisive new leasing and prospect development programs over high confidence, low risk prospects (**Table 2**).

Scotforth Limited PRB Pricing Model						
Price Bands		No. of Sections	Fixed Fee Per Order in Price Band (\$)	Price Per Additional Section (\$)	Max Price for Product from Price Band	
No.	Description				No. of Sections	Price (\$)
Non-exclusive (new survey)						
1	Up to a Quarter Township	1-9	1000	500	9	5500
2	Quarter - Half Township	10-18	5500	200	18	9100
3	Half - Three Quarter Township	19-27	9100	150	27	13150
4	Three Quarter - Full Township	28-36	13150	100	36	16750
5	Multi-Township	By Negotiation				
Exclusivity				Available at a x 2.5 multiple of the above prices		

Table 2: General Pricing Guidance for PRB Map Series Reports

Flexibility in choice of report coverage areas is available and delivery schedules are appealingly short from the date of acceptance of order. Reports from this Map Series can be ordered by completing our [order form](#) or alternatively by contacting us directly at peter@scotforth.com

Annexe: DHM Exploration - Key Components

Scotforth has developed a proprietary exploration method (“DHM” or “Direct Hydrocarbon Mapping”) that is singularly successful in identifying surface landscape identities of subsurface hydrocarbon traps. An expansive overview of DHM and set of international Case Studies is presented across this website www.scotforth.com . While not a panacea for exploration risk DHM is now known widely to have capacity to break-through the conventionally perceived “Irreducible Risk Factor” of plays and prospects and to identify whether their underpinning “integrated petroleum systems” are or are not delivering effective trap presence.

Three expressions of oil and gas prospectivity are delivered in Scotforth’s DHM surveys. The first two are spectral image output patterns of the observed hydrocarbon lead indicator patterns (HLIs), identified by its proprietary processing of EM multi-spectral satellite images and the third is Scotforth’s subjective, interpreted, overall prospectivity and prospect inventory map of each survey area, drawn from its foregoing processed data and imagery outputs. Each can be summarised as follows:

- I. **DHM IPD (EM Spectral Iso-Photo Density) processed Landsat Images.** Hot orange areas are the most anomalous response areas (prospective “Hydrocarbon Lead Indicator” or “HLI” responses), green to soft yellow the least (non-prospective). IPDs are excellent for identifying the presence and gross areal extent of primary areas of expected hydrocarbon influenced terrains (HLIs) and delivering early segregation into either high-grade “Exploration Focus Areas” (“EFAs”), leads and gross prospect targets for exploration progression or poorly anomalous terrains of low prospectivity (“LPZs” or Low Prospectivity Zones) for early de-selection.
- II. **DHM RBU (EM spectral relative brightness contour map) processed Landsat Images.** Black areas are the most anomalous (prospective), white the least anomalous (non-prospective). The areal RBU contour profiling delivers a very conventional form of prospect mapping that is a mapped representation of geophysically measured pixel level EM spectral response values. It offers prospect analysis considerations just like that for any structural or seismic derived prospect maps. Its prospect map definition has resolution levels matching or improving on those of conventional exploration prospect maps but ***critically indicates likely subsurface target hydrocarbon resource presence or absence*** – the effectiveness and extent of “traps” and their accumulations. It can be taken to very high resolution mapping of local target feature areas and cross-section profiling of their “sweet spots” of predicted high net hydrocarbon pore volume presence (“NHPV”).
- III. **DHM Prospectivity Maps of identified and measured HLIs.** The integrated prospectivity views that can be delivered at different levels of resolution and scales of mapping. Typically, for detailed “Section Level” prospect mapping this is provided at 1:50,000 scale.

[Examples of such DHM survey outputs globally and how they are used to map, model, high grade and rank “hydrocarbon-led” prospectivity analysis can be studied further in the various parts of Scotforth’s website www.scotforth.com where various DHM Case Study technical briefs are also available].

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