#### Discovery and Petroleum System of Barmer Basin, India\*

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Search and Discovery Article #110202 (2015)\*\*
Posted March 16, 2015

#### Play Types Identified 2010-2012

Footwall Stratigraphic
Hanging wall Basement
Basin-margin fan delta Mesozoic
Central Basin High (CBH) horst

#### Play Types in Second Exploration Campaign 2013-2016

- Barmer Hill footwall porcellanite
- Barmer Hill deltaic
- Barmer Hill turbidite
- Hanging wall
- Dharvi Dungar CS-basal Thumbli
- Mesozoic
- Fategarh fractured volcanics gas
- Paleosols over the CBH

<sup>\*</sup>Adapted from oral presentation at Discovery Thinking Forum, AAPG International Conference and Exhibition, Istanbul, Turkey, September 14-17, 2014

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- Deep gas
- Unconventional resource

#### Plays Yet to Be Adequately Tested

Syn-rift structural Post-rift Pre-rift Stratigraphic

#### **Selected References 2012-2014**

Mandal, A., A. Sinha, R. Guha and Alisha Mehra, 2014, Application of formation pressure in evaluation and risking of exploration prospects: Search and Discovery Article #10654 (2014), website accessed February 12, 2015, http://www.searchanddiscovery.com/pdfz/documents/2014/10654mandal/ndx\_mandal.pdf.html.

Naidu, B.N., V. Kothari, N.J. Whiteley, J. Guttormsen, and S.D. Burley, 2012, Calibrated basin modelling to understand hydrocarbon distribution in Barmer Basin, India: Search and Discovery Article #10448 (2012), website accessed February 12, 2015, <a href="http://www.searchanddiscovery.com/pdfz/documents/2012/10448naidu/ndx\_naidu.pdf.html">http://www.searchanddiscovery.com/pdfz/documents/2012/10448naidu/ndx\_naidu.pdf.html</a>.

Naidu, B.N., V. Kothari, V. R. Sunder and P. Mohapatra, 2014, Petroleum system analysis of the Barmer Basin, India (abstract): A case study: Search and Discovery Article #90194 (2014), website accessed February 12, 2015, <a href="http://www.searchanddiscovery.com/abstracts/html/2014/90194ice/abstracts/1950194.html">http://www.searchanddiscovery.com/abstracts/html/2014/90194ice/abstracts/1950194.html</a>.



# Discovery and Petroleum System of Barmer Basin, India.

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Co-Authors: Bodapati Naidu, V. R. Sunder, John Dolson, Stuart D. Burley, Nicholas P. Whiteley, P. Mohapatra, and B. Ananthakrishnan





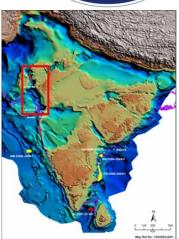


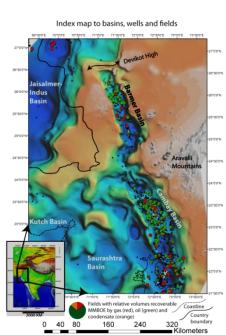


#### **Presentation Outline**

- Introduction to Cairn India Limited
- Barmer Basin and Exploration Block
- Structural Setup & Stratigraphy of Barmer Basin
- Exploration History and 1<sup>st</sup> Exploration Campaign
- ☐ G&G Studies Play Types & Prospects & Petroleum System
- ☐ De-risking of PR Portfolio- GDE & CRS Maps
- □ 2<sup>nd</sup> Exploration Campaign and Results till Date
- ☐ Upside Potential and Future Plans





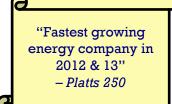


# **Cairn India: Company Overview**



# Leading E&P Player

- Amongst top 20 global independent E&P companies
- Produce ~30% of India's domestic crude oil production
- Over 1 billion barrels reserves / resources base
- Diverse international workforce of 1,800+ people



# Proven Capabilities

- Opened up 4 frontier basins with over 40 discoveries
- US\$ 4 bn Rajasthan Project Discovery to Production in 5 yrs
- Low cost operator; Innovative application of technology
- ➤ Built world's longest (~670 kms) continuously heated and insulated pipeline

"Mangala Pipeline:
Project of the Year
2011"
- Project Management
Institute (PMI)

#### **Vision**

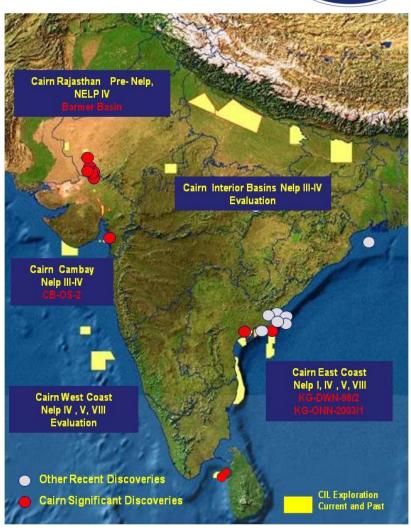
- Become a global, world class E&P company
- Establish a diversified & sustainable portfolio
- Deliver long term value to host Governments, Local Communities and all stakeholders

"Golden Peacock Award for Business Excellence, 2014"

## **Cairn India: Track Record of Exploration Success**

CAIRN

- Over 40 discoveries
  - ✓ Over 50% success rate
  - √ 4 of 8 significant discoveries in India since 2000
  - ✓ Mangala field in Rajasthan the biggest onshore discovery globally in 2004
- Opened up 4 new frontier basins Onshore Barmer, Deepwater Krishna Godavari and Deepwater Sri Lanka
- Diverse operating environments onshore desert, transitional and offshore deep water
- Established gross proved and probable resource of over 1.6bn boe
- Finding costs of <\$1/bbl</p>
- Success through application of technology and perseverance
- Company has one offshore block in South Africa, 3D Seismic acquired prospect detailing in progress.



Strong geo-technical expertise with discoveries in frontier basins

# **Acknowledgements**





#### **Disclaimer**

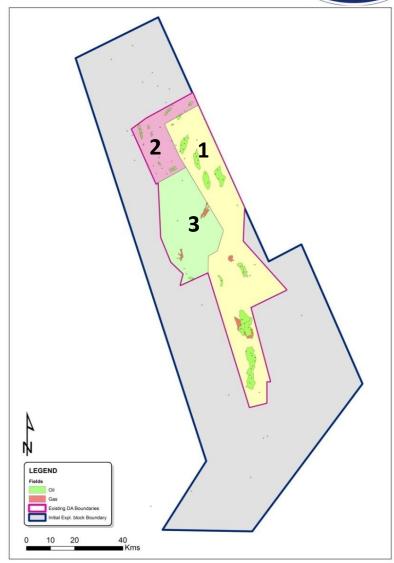




# Rajasthan Block: RJ-ON-90/1

- □ PSC signed on **14th May 1995 with SIPD**
- ☐ Cairn acquired 100% stake in May' 2002
- Original Area awarded 11,108 sqkm
  - 3,111 sqkm (28% of original) retained post relinquishment
  - > 33 (29 oil + 4 gas) discoveries made so far
- □ 3 Development Areas
  - DA1: Mangala, Aishwarya, Raageshwari, Saraswati
  - DA2: Bhagyam, Shakti
  - > DA3: Kaameshwari West-2, 3 & 6
- □ Commercial production August 2009
- ☐ Expln. Success Rate of >50%
  - \$1Billion risk capital spent to date
  - Finding cost< \$1.0/bbl</p>

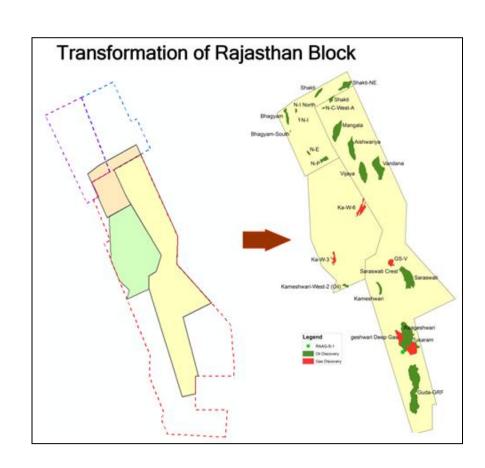






# EARLY EXPLORATION HISTORY

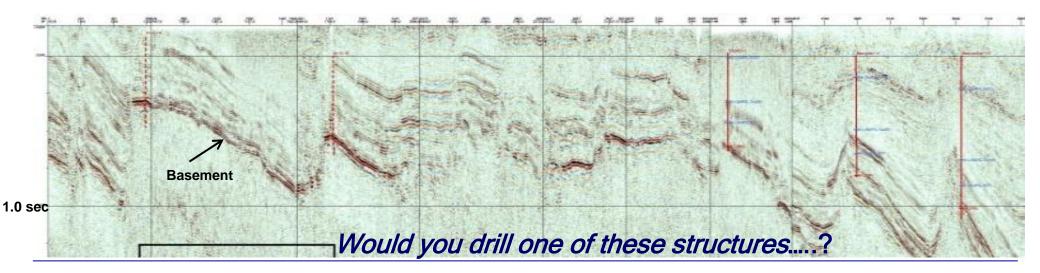
1989 - 2010



## **Exploration Philosophy**

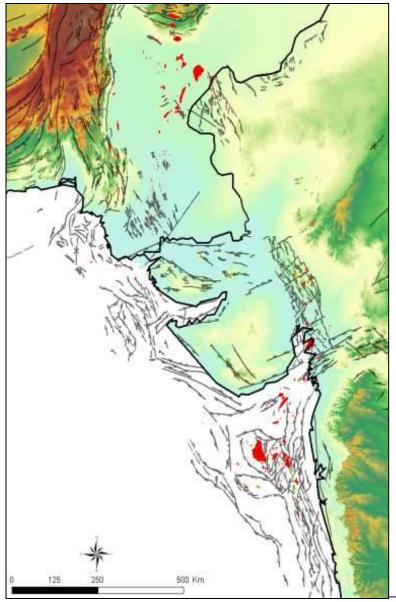
CAIRN

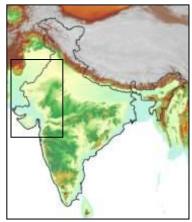
- ☐ This is not just the story of finding oil, but of missing it too
- Key lessons learnt through the entire campaign-
  - "Understand the basin first" no stamp size interpretations
  - 'Honor every data point' nothing as outlier
  - 'Think beyond boundaries' Challenge the paradigm
  - 'Take the Brave Pill' Go where others don't
- Its also the story of political events and PSCs regulations
- ☐ The result is not only the **discovery and unravelling of a new basin**, but the discovery of **6bn boe**, and the **birth of a new company Cairn India**



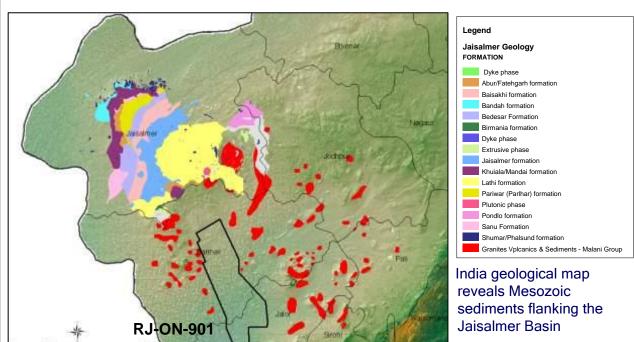
# Overview of RJ-ON-90/1 Block - Before 1990......







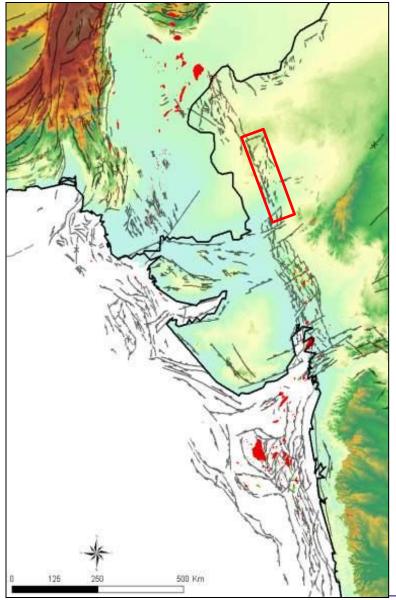
- Barmer Basin completely unknown
- Cambay Basin rift to the south, Jaisalmer and sedimentary basins in Pakistan to the north
- Shell entered India as part of a corporate strategy to take a downstream and an E&P position

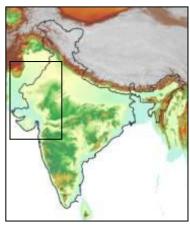


Source: Geol Survey of India

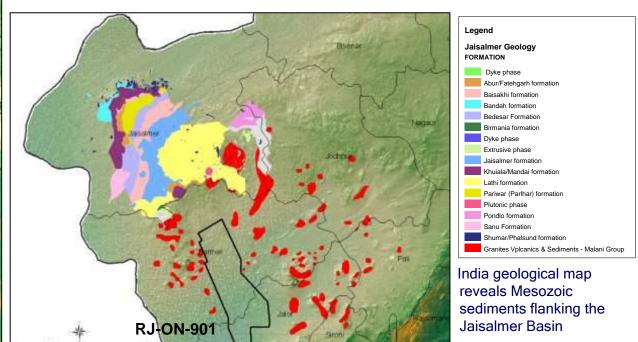
# Overview of RJ-ON-90/1 Block - Before 1990......





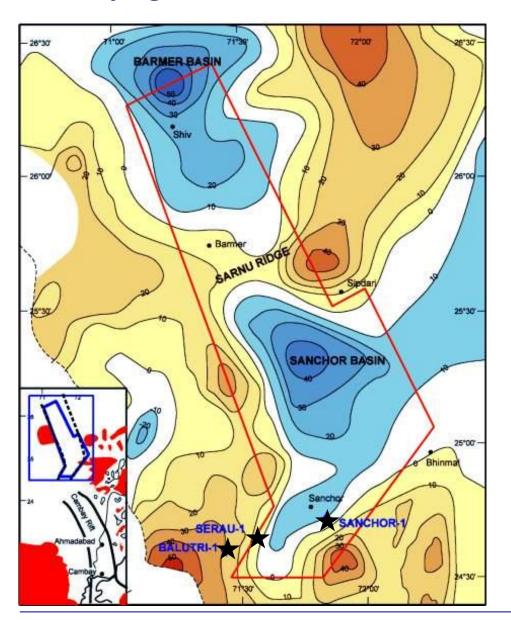


- Barmer Basin completely unknown
- Cambay Basin rift to the south, Jaisalmer and sedimentary basins in Pakistan to the north
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Source: Geol Survey of India

## **Identifying the Basin - 1989**





# Legacy Wells in south with negative results (Drilled as extension of Camay Basin)

- Balutri -1 drilled in late 1972 found Miocene fluvial sands overlying granitic basement at 600m
- Serau 1 drilled in 1972 on a large fold TD 2072m found 1500m sediments but dry
- Sanchor-1 well, drilled on the edge of the basin in 1989 encountered minor gas shows and bitumen staining but thin sediments
- Shell revisit of 1970's vintage ONGC gravity and poor 2D seismic data, identified possible extension of Cambay Basin
- ➤ 1989 **150Lkm 48-fold seismic** acquired by Shell in south of basin indicated shallow granite basement

# Establishing the Basin – 1989 to 1995



#### **Early information initially encouraging**

#### Major risks recognised

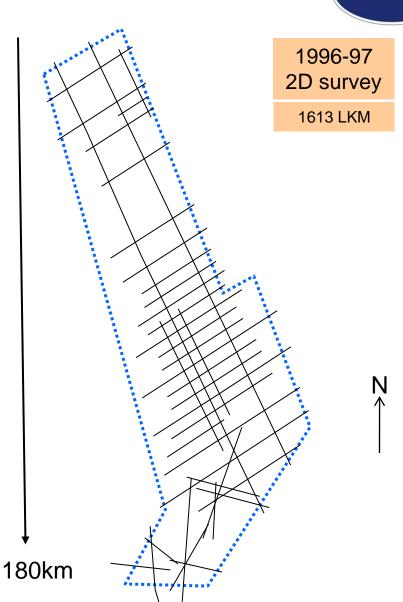
- Reservoir presence and quality
- Source rock presence and maturity
- But some indications of hydrocarbons

#### May 1995: RJ-ON-90/1 PSC

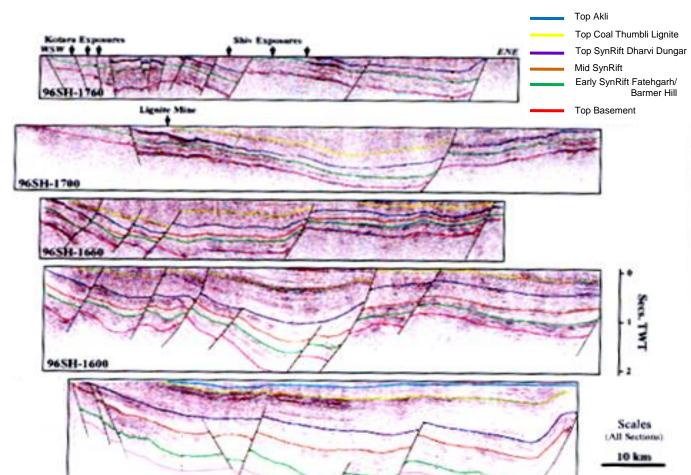
Entered between Shell (SIPD), ONGC and the Government of India. SIPD had 100% interest and operatorship

#### Phase I: May 1995 – November 1997

- Minimum work obligation of 750 km 2D seismic and a new gravity survey
- SIPD acquired 1613 km 2D

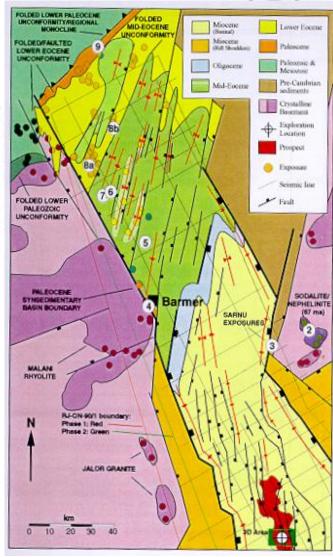


#### First Seismic & Field Work- 1997



- Barmer Basin defined as rift valley
- Simple geological map in 1997 included fieldwork
- Very shallow northern part of basin





## First Stratigraphic framework - 1997



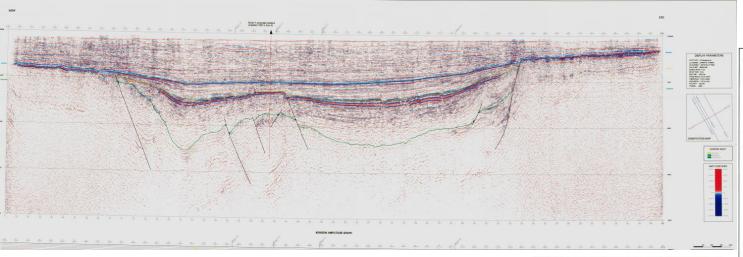
W SCHEMATIC LITHOFACIES STRATIGRAPHY Lagoonal Lignites Shallow basinal muds & thin washover and storm-related sands A-k-1 i Formatio Fluvial Facial Early Eocene Post-rift sag Dharvi Dungar Formation Delta mouth bars and shoreface sheets Palaeocene (meandering streams, tidal flats) Formation Bariyada Member (diatomite/? volcanic ash Syn-rift **Barmer Hill Formation** Lathi Fm Liassic Precambrian Pre-rift 

- Remarkably accurate given current understanding
- Syn-rift Palaeocene Fatehgarh Formation main reservoir, with Dharvi Dungar source/seal
- ➤ Post-rift sequence largely continental with marine shoreface influence

Е

# Wildcat Drilling - Selecting Guda

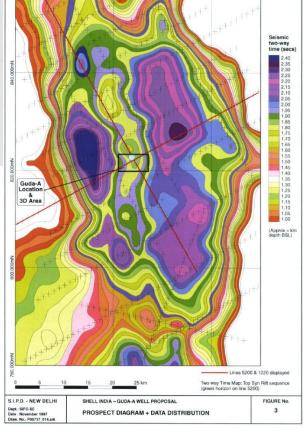






- Commitment one well to 2500 m
- Prospect was a large anticline running along the axis of the Guda Basin
- Basin-opening size and scale
- Guda-1 and Guda-2 wells planned on the now so-called but poorly defined Central Basin High based on sparse 2D seismic





#### Basin opening prospect identified

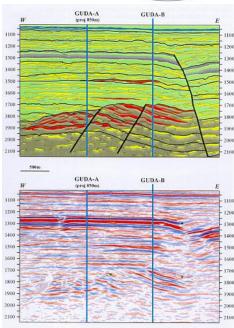
#### First Well Guda 1 - 1998

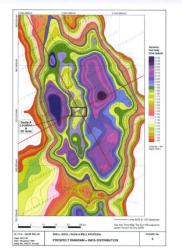
#### **Play Concept & Primary objective:**

- Large anticline running along the axis of the Guda Basin
- Deltaic/ Shore-face Sandstones of early Eocene age in DD Formation (10-25 m thick)
- ➤ Probability of Success: 14% (Charge = 0.25 & Reservoir = 0.30)
- Estimated Mean Success Volume EUR = 475 MMbbl
- Only 2 m pay
- > The play failed on reservoir, but structure, seal and charge confirmed
- > The presence of mature oil up-graded the potential for a deeper play

Cairn entry into the Block 1998
Cairn Energy India Ltd (CEIL) farmed-in with 27.5% equity while drilling Guda-1 and subsequently increased ownership to 50%







#### Second Well Guda 2 -1999



#### **Play Concept & Primary objective:**

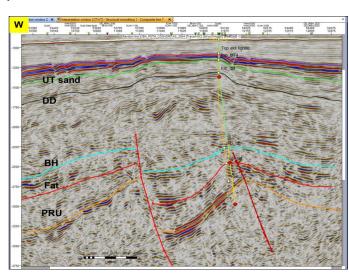
- Large anticline running along the axis of the Guda Basin
- Early syn-rift sands of Paleocene age, the Fatehgarh Fm, (considered stratigraphically equivalent to the Olpad Fm of the Cambay Basin)
- Facies were expected to be a fluvio-deltaic sequence with a high clastic content.
- > Secondary objective was the early post-rift sequence, as targeted in Guda-1.

#### **Resource Volume & Risks:**

- Probability of Success: 24% (Key risks again Charge & Reservoir)
- Estimated Mean Success Volume EUR = 200 MMbbl

#### **Results:**

- Deep targets encountered volcaniclastic sand, ignimbrites and basalt, all gas bearing
- 4m of pay encountered in the shallow sands, tested at 2000-4000bopd
- Structure, seal and charge confirmed.



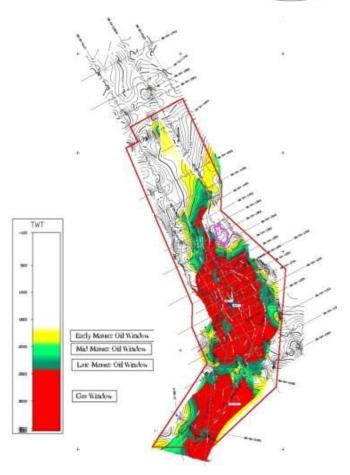
#### **Proved a working Petroleum System**

## **Re-evaluation of Opportunity - 2000**



- Early disappointment in the basin
- Exploration potential in the immediate Guda area considered very limited
  - Shallow sands small (southern pinch-out & faulted)
- Regional Reservoirs consider low quality
  - Deeper Fatehgarh sands consider very low quality due to volcaniclastic composition
  - Basalt and ignimbrites not considered reservoir
- Petroleum System high risk
  - ➤ Basin modeling 'Guda Shale' at base of Dharvi Dungar indicated immature in the north

Operatorship transferred to CEIL January 1, 2000

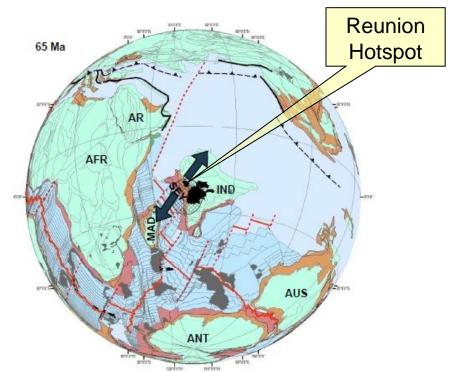


Early disappointment in the basin – poor reservoir quality, no HC generation predicted in the north, mostly gas in south

# **Barmer Rift Basin - Origin & Development**



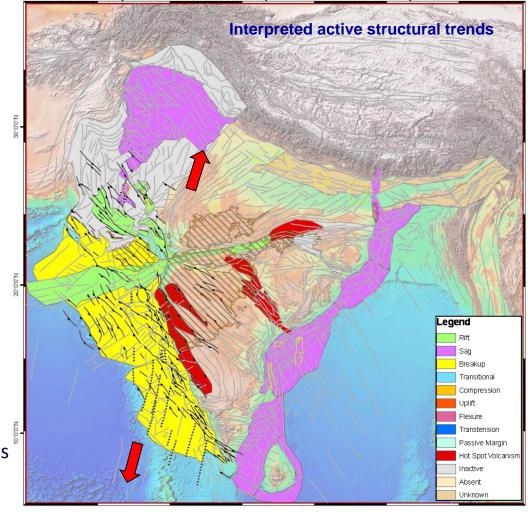
#### Plate reconstruction 65 Ma



#### > Extension initiated by Reunion hotspot

- Regional plume-related uplift caused eastward tilting of the Indian plate and main phase of extension in the Cambay-Barmer and related basins along India's west coast
- Later uplift a result of India's collision with Asia

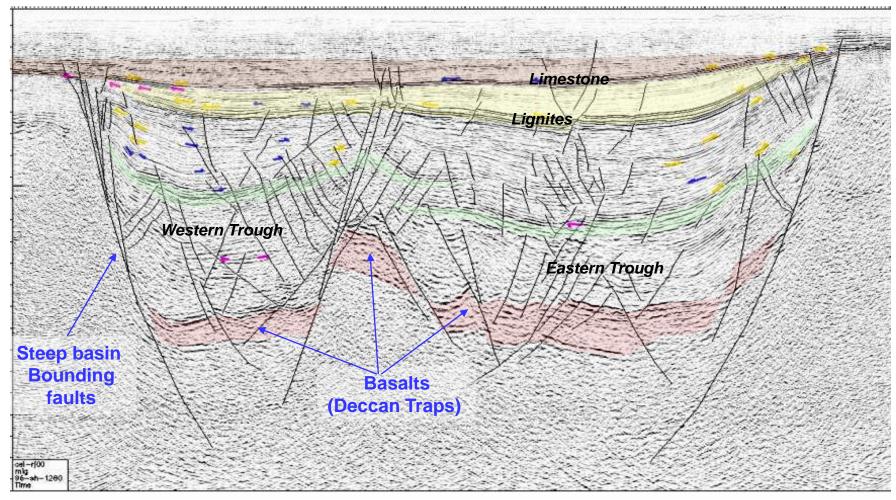
Initiation of Barmer rifting is early Palaeocene in age (~ 68 – 62 Ma). Volcanics in the basin dated



#### **Rift Basin Identified - 2001**



WSW



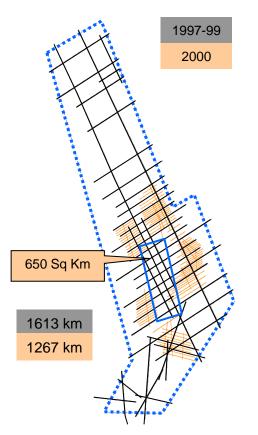
Systematic studies initiated - Rift Clearly Identified

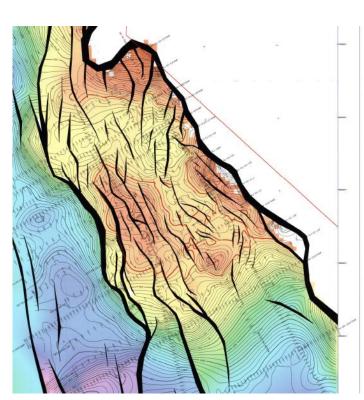
## **Defining Prospectivity - 2000 to 2002**

Key asset for Cairn, significant focus

CEIL acquired 1267 Lkm of 2D 'high density infill' seismic &, 650 km2 of 3D seismic over CBH

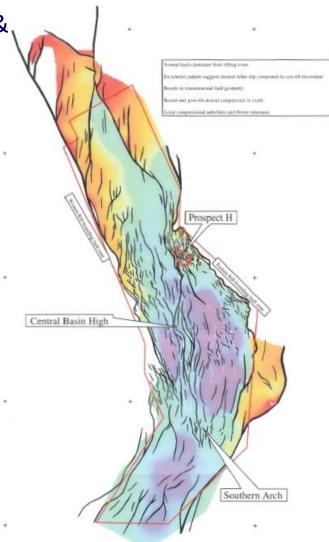
Matured & drilled prospect RJ-H 'Saraswati' on 2D





**Additional Prospect identified** 

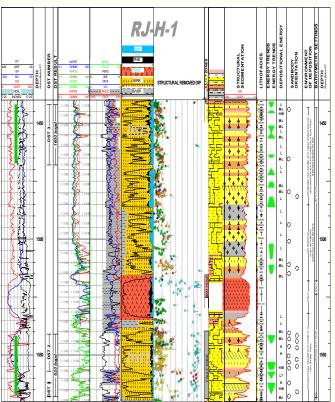


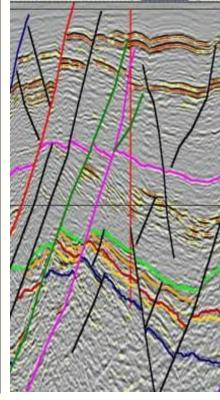


# Next Discovery – 2001 "Saraswati"







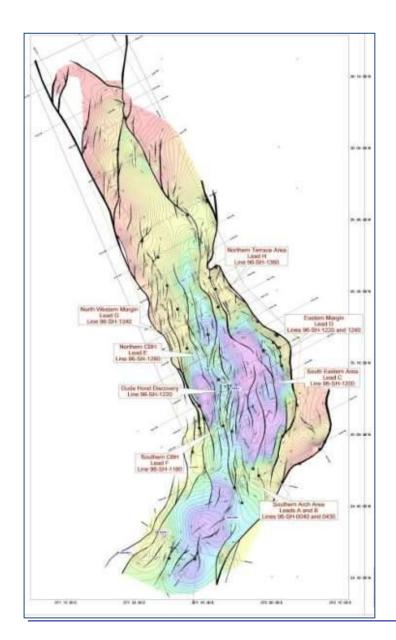


- Syn-rift reservoirs were thickest so far and tested stabilised rates in excess of 2000 bopd
- > Better reservoir quality in syn-rift package, but estimates of 30mmboe in place
- > Shallower targets had no reservoir development
- Trap, charging and seal were all validated
- Saraswati Hydrocarbon Discovery Report filed January, 2002

SHELL withdrew from JV in May 2002. CEIL with 100% WI

#### Status – May 2002





#### Risks

- India-Pakistan major military stand-off following militant attack on the India Parliament in December 2001
- Exploration activity stopped in Rajasthan, realised the fragile business atmosphere being closed to border.
- Limited understanding of basin development, but general view of poor reservoir quality
- **Small discoveries** in the south, very shallow basin in the north long distance migration needed.
- Question over reservoir quality both shallow and deep (but only small part of basin explored)

# **Upside**

- Had established a large underexplored basin with proven hydrocarbon system
- Lack of structural definition at deeper levels upside
- Many leads and several untested plays

#### 3 Further Discoveries - 2002 to 2003



#### Oct 2002 – Raageshwari (RJ-E)

Large structure on CBH; 6 potential oil & gas bearing reservoirs encountered

2P STOIIP = 31 mmbbls

2P GIIP = 1,317 bscf

#### Jun 2003 – Kaameshwari (RJ-Q)

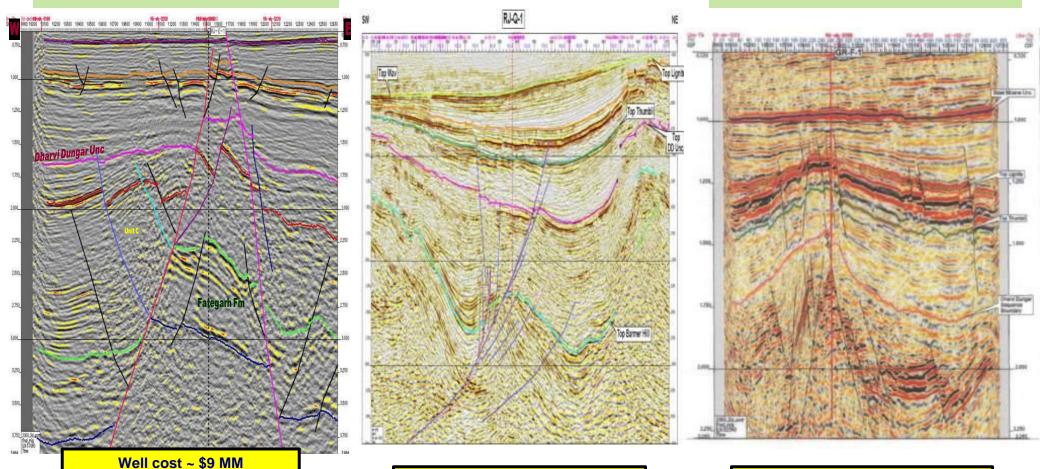
Large rotated fault block with 3-way dip closure; tested oil in Fatehgarh Formation

#### Oct 2003 - Guda-South (GR-F)

Large rotated fault block with 4-way dip closure on CBH; tested oil at shallower Thumbli reservoirs

Well cost ~ \$2 MM

2C STOIIP = 50 mmbbls



Well cost ~ \$5 MM

2P STOIIP = 20 mmbbls

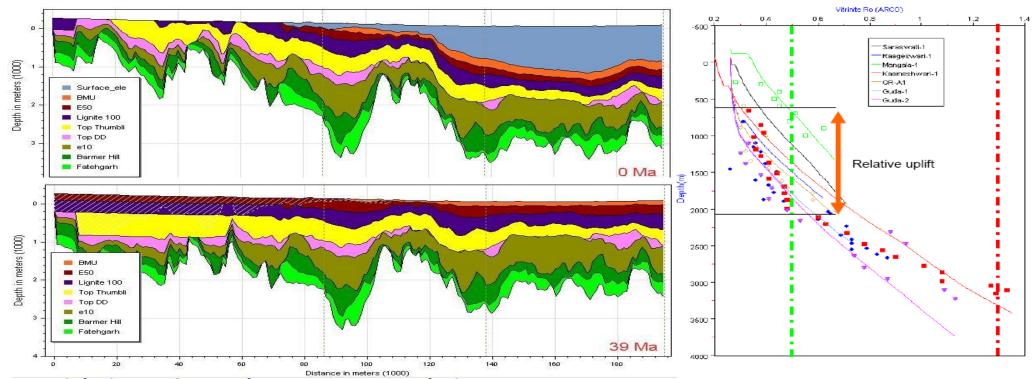
# **Exploration Work Programme- 2002 to 2003**

- Four Discoveries to date:
  - Guda; Saraswati; Raageshwari & Kaameshwari
  - ➤ Total >120mmboe in place
- Commerciality uncertain (marginal) standalone development not assured
- Additional 2D seismic & field work/studies
- Exploration Strategy
  - Not driven by minimum work programme commitments
  - But the need to find commercial HCs and belief in this basin
  - There must be more oil in the basin
  - Could the northern basins can have been charged – crest of lead N-V 400m?
- Conclusion Move North



# Why North?





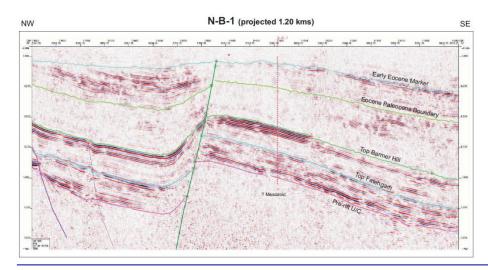
**Burial History & Petroleum Systems Analysis** 

- Estimated uplift from VR
- Suggested Source rock would be early oil mature in north removing need for long distance migration (Significant uplift in north established through seismic)
- Improved reservoir quality predicted from field work
- Traps identified on additional 2D seismic

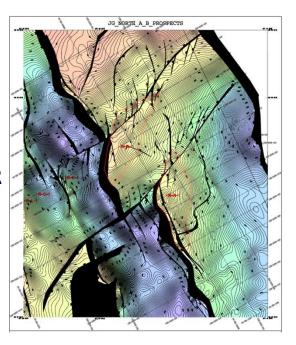
Basin Modeling & Studies significantly de-risked the Northern Area

## **Moving Northward N-B-1 well - 2003**

- Bold Step Required
  - Basin about to be written off and Exploration programme closed down!
- N-B Prospect Selected
  - > 59km from nearest discovery
- Pre-Drill
  - Main reservoir Barmer Hill formation EUR of 30 mmboe with Pg of 14%
  - Additional target deeper Fatergarh EUR
     40mmboe with a Pg of 10%
  - Key risk on both was reservoir & trap





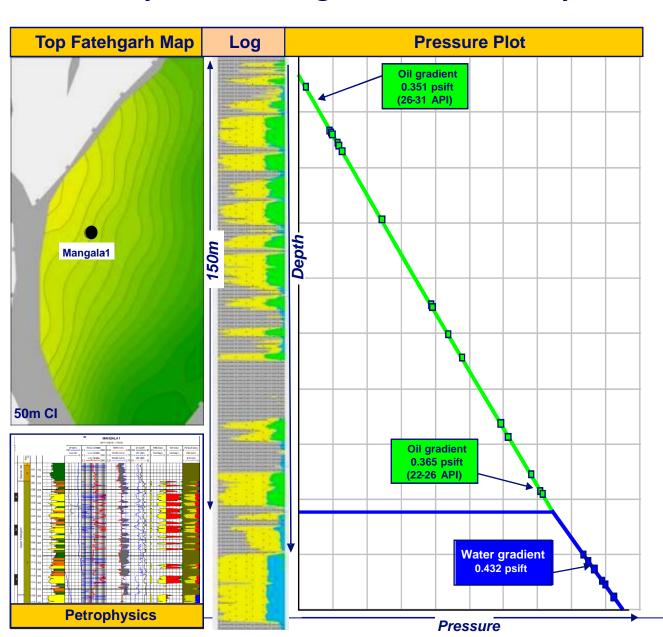




The main primary target, the Barmer Hill interval, is interpreted as either low energy alluvial fan or deltaic facies. The deeper target, the Fatehgarh interval, appears in this northern area, to contain channels, slumps and depositional geometries generally indicating a higher energy environment of deposition, and the section is likely to contain facies similar to those penetrated in the wells towards the south. The possibility that the northern area prospects have not been deeply buried is encouragement that poro-perms of any reservoirs that are present in this part of the basin may be of better quality than those found to date.

#### **Brave Pill Required**

# Discovery of The Mangala Field – January 2004





#### **Structure**

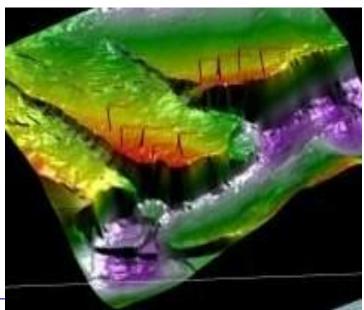
- ➤ Simple tilted fault block, 2 reservoirs
- > 150m oil down to column in the well

#### Main Reservoir - Fatehgarh Formation

- Upper Fatehgarh Good net/gross sinuous fluvial channel sands
- ➤ Lower Fatehgarh Well connected sheet-flood and braided channel sands
- > STOIIP 1.3bnboe; >600mmboe EUR

#### Secondary Reservoir - Barmer Hill

- ➤ Unusual reservoir Diatomite
- > STOIIP >350mmboe; >50mmboe

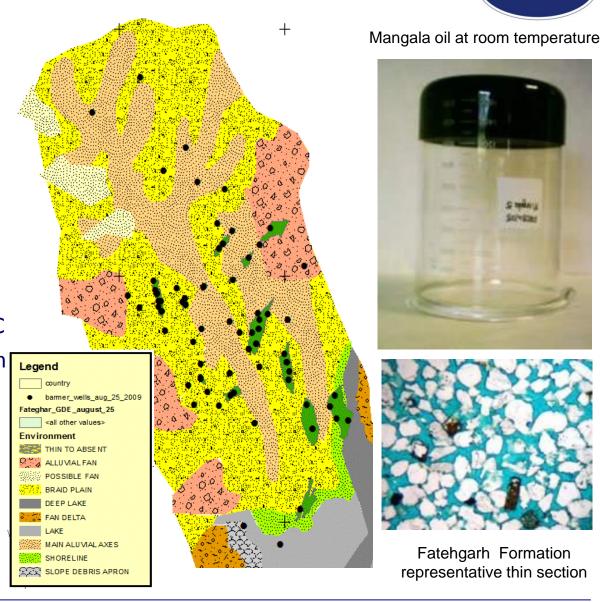


# **Discovery of Mangala - 2004**

# CAIRN

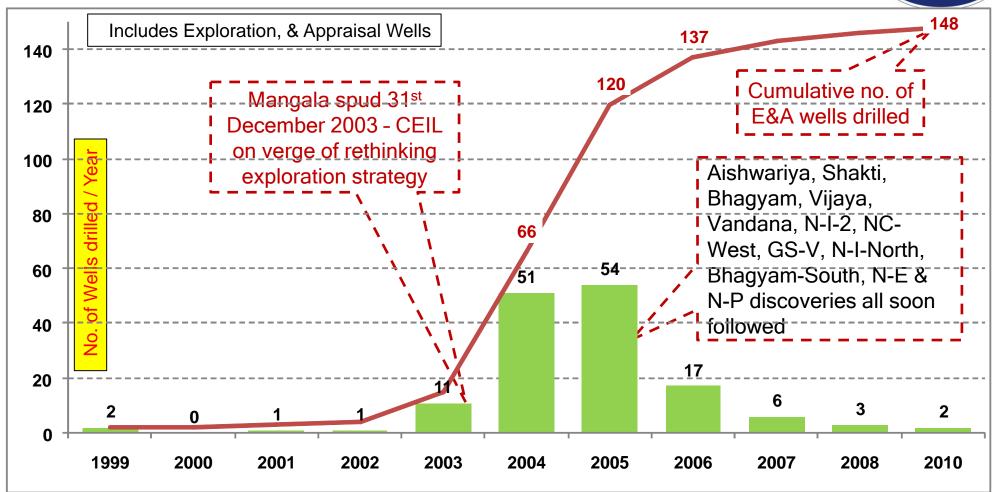
#### **Key risks reservoir & migration**

- High quality fluvial reservoirexceptional porosity and permeability 30% and 3Darcy
- Provenance from north and north-east where granite basement outcrops
- Source rock is the overlying Barmer Hill Formation - Lake deposit with phytoplankton blooms – up to 30% TOC
- Mature in adjacent low, short migration distance
- Sweet, medium gravity but highly waxy oil - pour point of 62oC
- Remarkably, not biodegraded



# **Further Exploration 2004-2008**





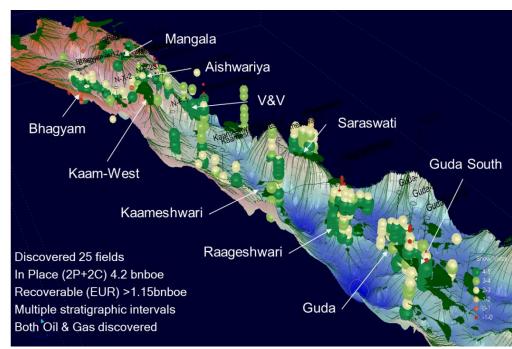
- Implications of Mangala discovery
- ➤ Cairn exploration strategy 'Drill till you drop'; Exploration Success Rate ~50%
- Discovered total of 4bnbbls in Place

#### **Exploration up to 2010**

#### 25 Discoveries made in the Block

- Most of the footwall closures drilled out.
- Excellent success ratio ~50%
- >4 Billion Bbl in-place established
- High quality multi-darcy fluvial to fluviolacustrine reservoirs established
- World class source rock established dominantly oil.
- Sweet, medium gravity but highly waxy oil - pour point of 62°C, but not biodegraded
- Nearly total portfolio drilled out





Exploration severely curtailed post -2007 Lack of clarity on further exploration

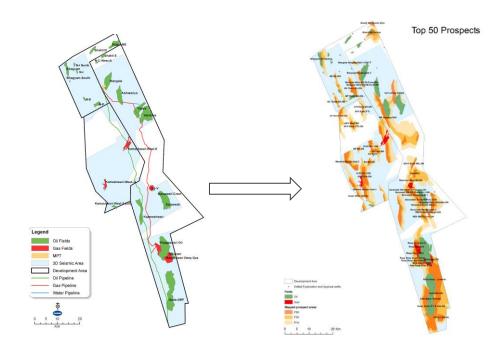
Focus shifted towards development (2008-2010+)

➤ Finding Cost <1\$/bbl



# DRILLING HOLIDAY AND NEW DATA INTEGRATION

2010 - 2012



#### **Replenishing Exploration Portfolio 2009-2012**

CAIRN

- Time to think: Do we really understand the Basin?
- Have we realised the overall potential?
- Full basin Review completed
  - Regional Integration of New Data
    - Understanding the Discoveries & Failures
    - New stratigraphy & Field work for Reservoir De-Risking
    - New regional Structural & Depositional Models
    - Updated Petroleum system understanding (new data)
    - Detailed global analogues analysis
  - ➤ Plays, Prospect and Leads
    - New Plays & Prospects Detailed
    - Resource and Risk Assessment
- Expert Opinions and Basin Workshop with External Experts
- Management Review, JV Alignment & Regulatory Approvals
- Preparedness for Drilling Campaign

#### **Prospectivity Re-assessment – Understanding Failures**

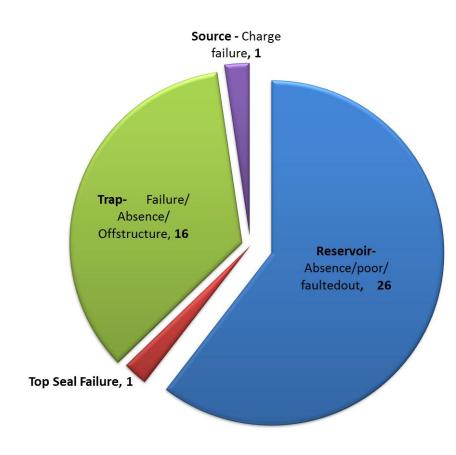


#### **☐** Reservoir De-risking:

- New / Revised GDE maps for all important reservoirs to understand the lateral variability
- Constructed the predictive basin models
- Identified key areas with possibility of good reservoir facies development

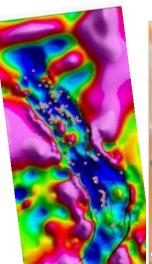
#### ☐ Trap De-Risking:

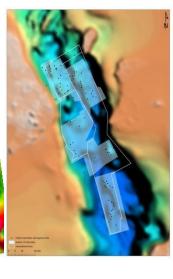
- Re-processed the 2D and 3D seismic data
- PSDM processing where ever required
- Trap integrity and charge de-risking in Trinity

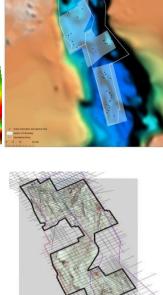


#### **Prospectivity Re-assessment – G&G Studies**









Geological Fluid Inclusion studies

Fission Track (AFTA- VR-ZAFTA)

Biostratigraphy and depositional Environments

**GDE Revision** 

Stratigraphy Revision

Structural studies (IIT R & Keele Univ.)

Geophysical **Gravity - Magnetic Integration** 

2D/3D seismic Reprocessing

Comprehensive Remapping

**Geochemical** Source Rock analysis

Oil Characterisration(GC, GCMS, Isotopes)

**Basin Modeling** New comprehensive model with new kinetics

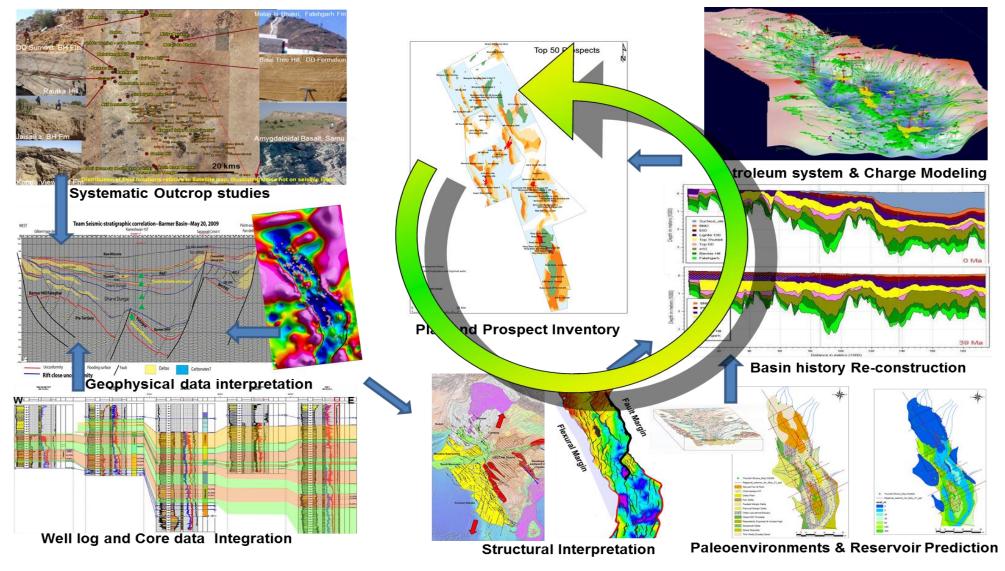
New Plays & Leads New concepts and ideas implemented resulting into new

leads and prospects

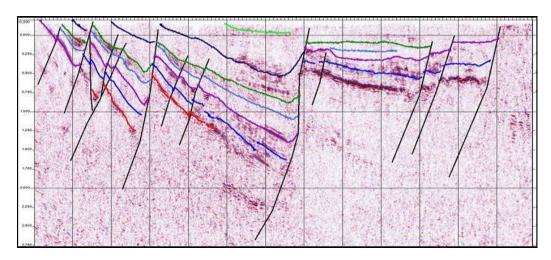
Re-interpretation of old wells

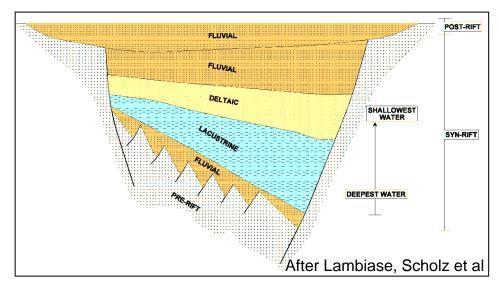
## Prospectivity Re-assessment – G&G Studies

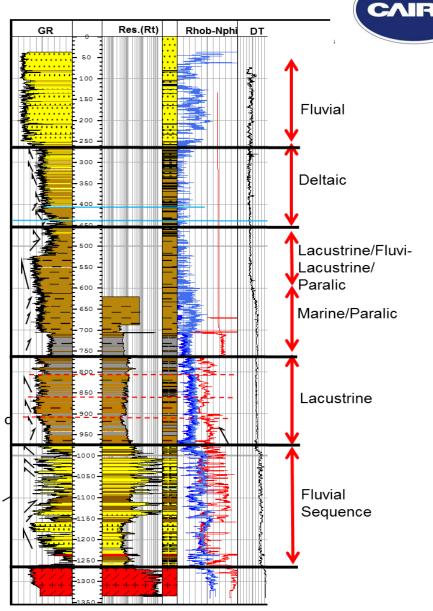




## **Prospectivity Re-assessment- Sedimentation Patterns**

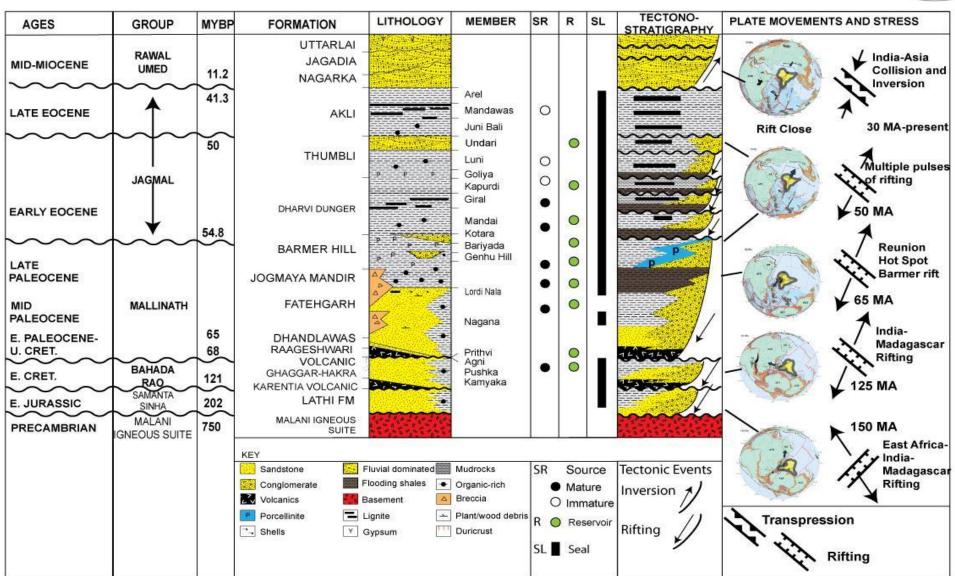






## **Prospectivity Re-assessment – Stratigraphic Revision**

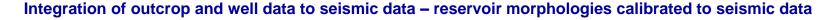




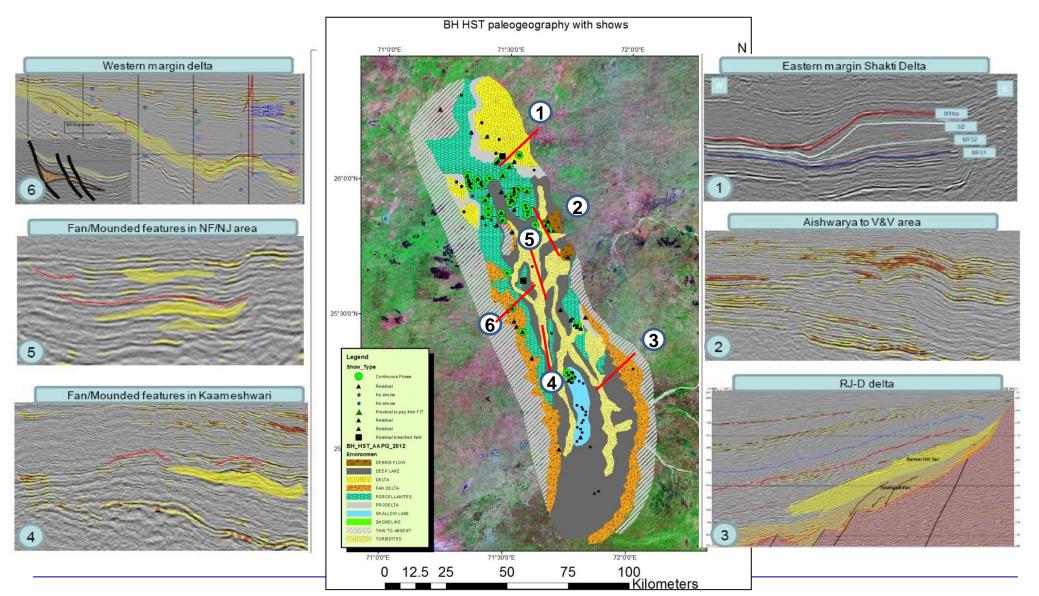
#### **Prospectivity Re-assessment— Reservoir Variability** BH HST paleogeography with shows Mangala Oil saturated porcellanite facies log Millimeter-scale laminations of diatomite and black shale alternations Multi-storied, high porosity, high perm (with high TOC and high HI), oil deltaic sands overlain by porcellanites saturated in all drilled wells **RDG** Western Margin BH Fan Delta Facies High gamma "Hot sands" in as basin Tight silty, mixed facies, poor reservoirs margin fans, prograding deltaic 71°30'0"E deposited in a shallow lake environment sequences and lacustrine turbidites 0 12.5 25 50 75 100 over paleo-highs Kilometers

**Gross Depositional Environments map of Barmer Hill Formation** 

## **Prospectivity Re-assessment – Depositional Environments**



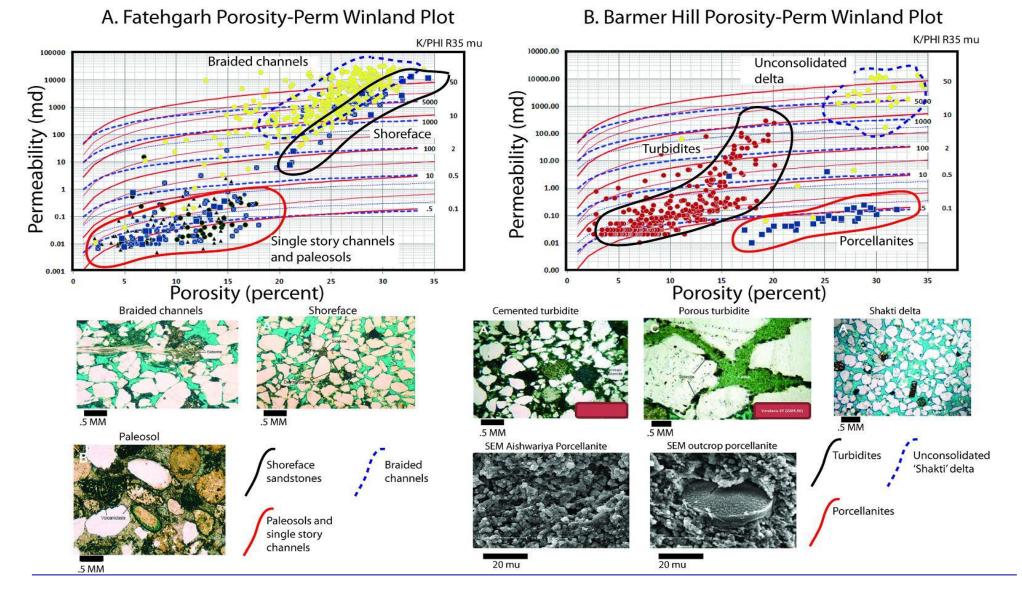




### **Prospectivity Re-assessment – Reservoir Characterisation**

Extensive analysis of cores, cuttings and outcrops – better handle on uncertainties

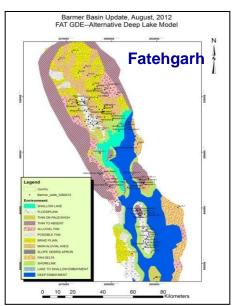


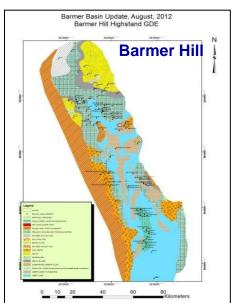


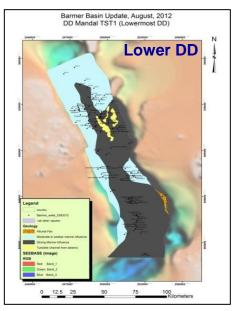
## **Prospectivity Re-assessment – Stratigraphic Plays**

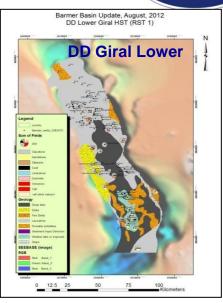
#### Dominant facies in the basinal part are turbidites. Significantly more potential than recognized earlier

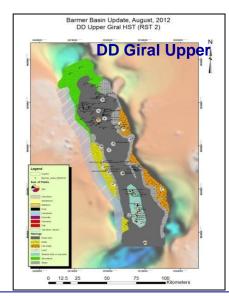


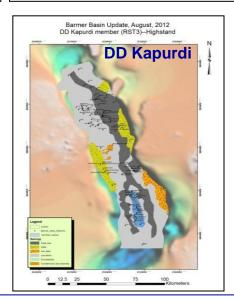


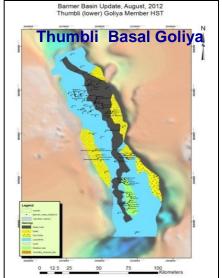


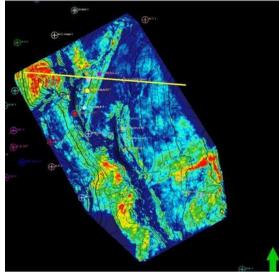








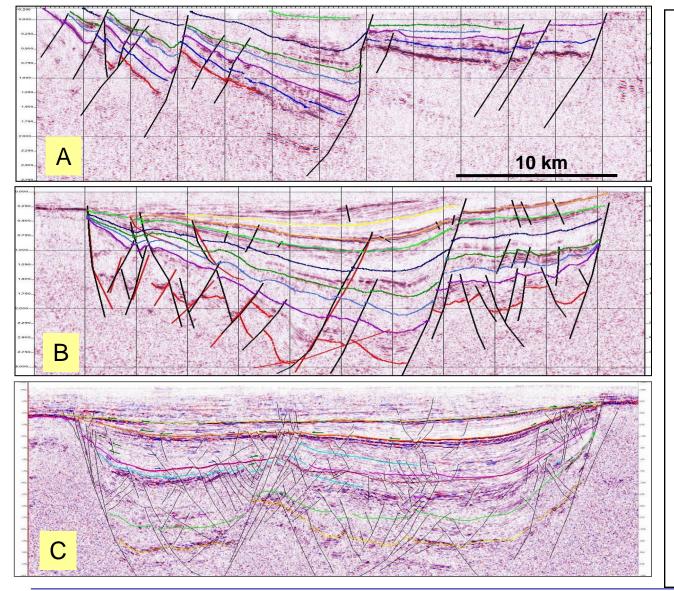


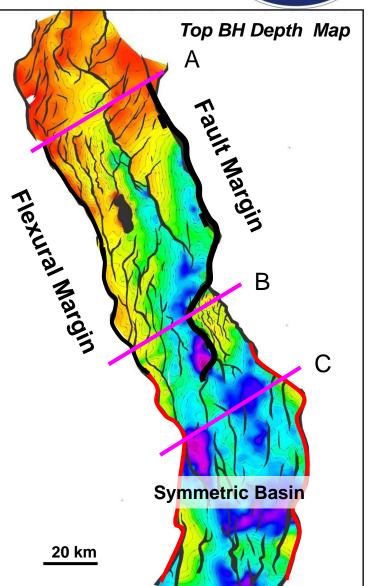


### **Prospectivity Re-assessment – Structural Interpretation**

Detailed Structural analysis, Controls on deposition & Fault Linkages for lateral seal effectiveness



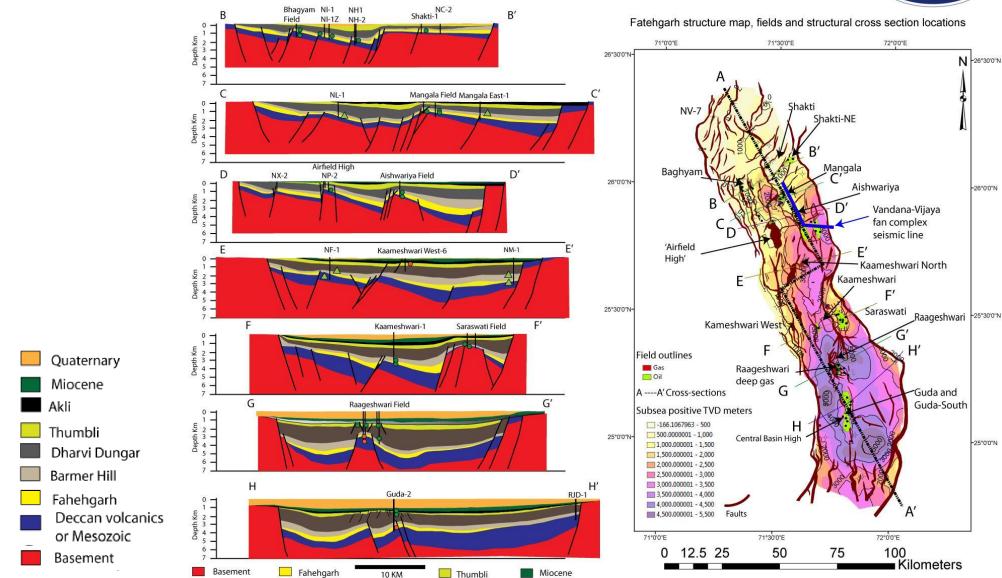




#### **Prospectivity Re-assessment – Structural Interpretation**







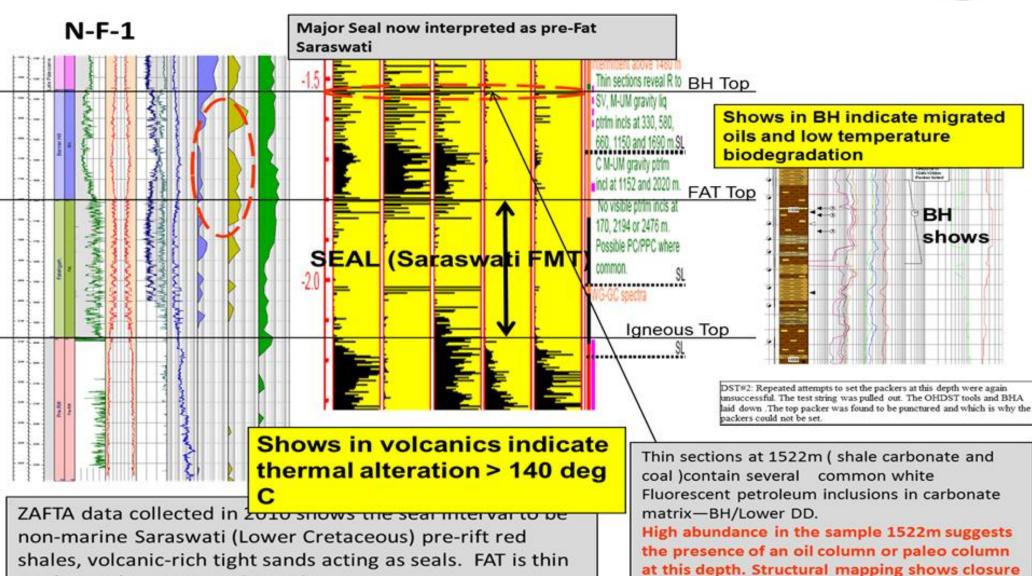
## **Prospectivity Re-assessment: Fluid Inclusion Stratigraphy Inputs**

Failure Analysis – Migration shadow, Trap breaching, Proximity to pool analysis

to absent, but present down dip.

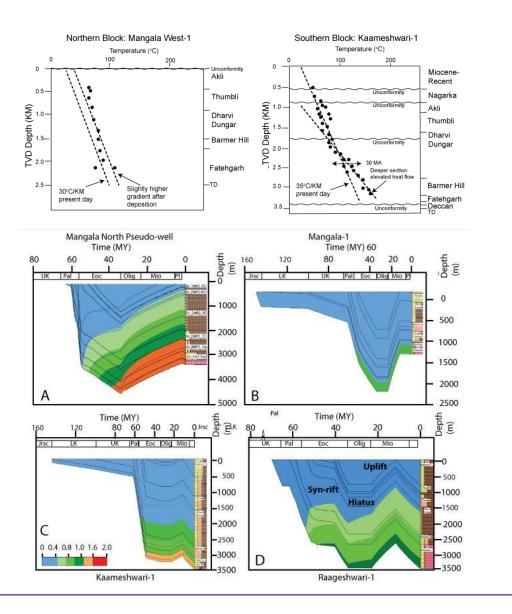


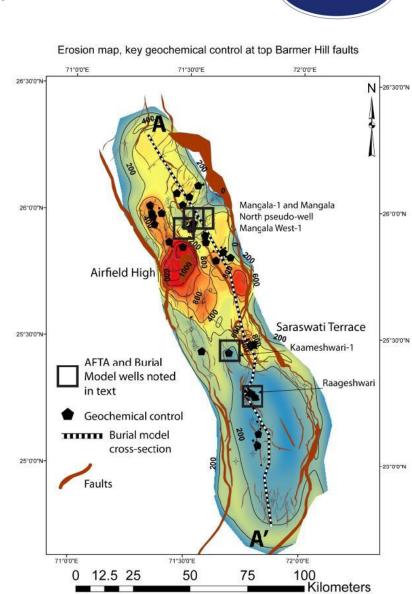
at this level and probable BH pay behind pipe.



### Prospectivity Re-assessment – AFTA – ZAFTA Derived Thermal Events

Temperature variation through time & estimation of uplift & erosion – key input to basin model

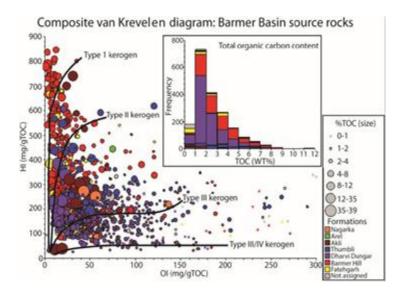




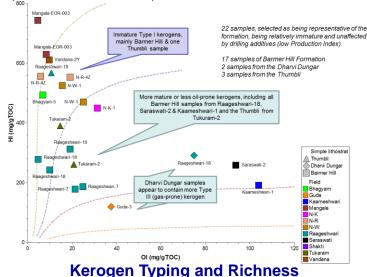
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## Prospectivity Re-assessment – Source Rock Typing & Kerogen Kinetics

World Class Source Rock - Compelled to developed New Kinetic model for the Basin



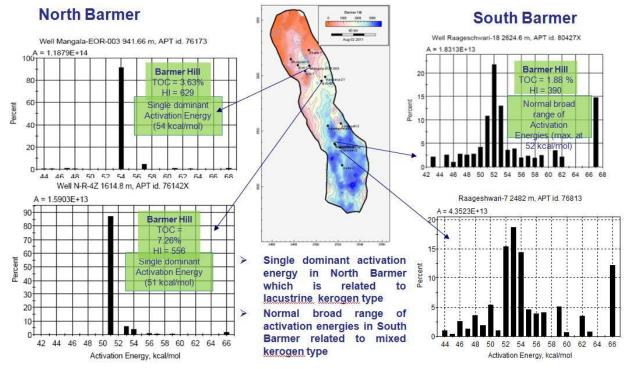
#### Samples selected for kinetics analysis



➤ Wells drilled over the structural highs have very high HI values — higher values expected in lows.

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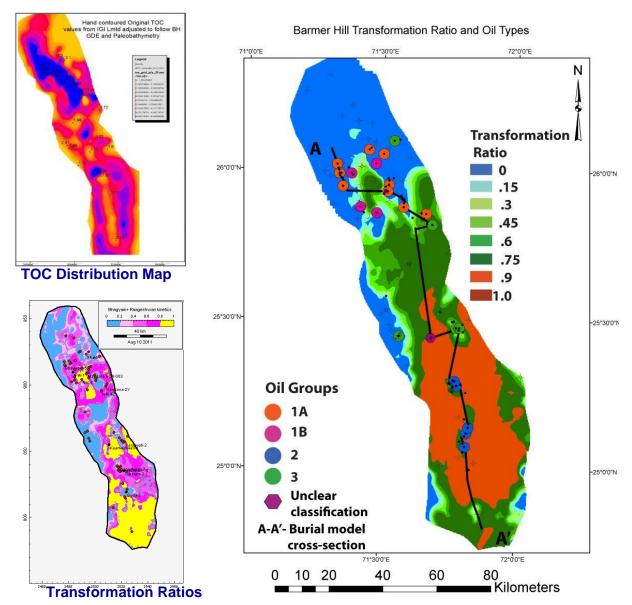
- Kerogen Kinetics attempted on 25 samples
- Dominant phase: oil in north and mixed/ gas in south.
- Low activation energy: 48-54 kcal/mol.

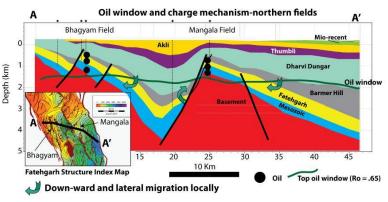


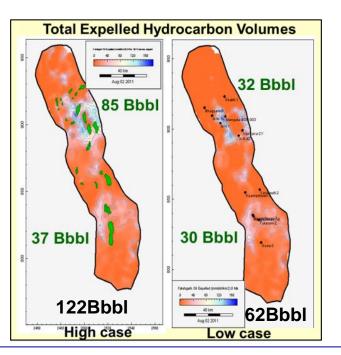
#### **Prospectivity Re-assessment — Calibrated Basin Modeling**

All inputs calibrated to wells and show database, multiple scenarios modeled





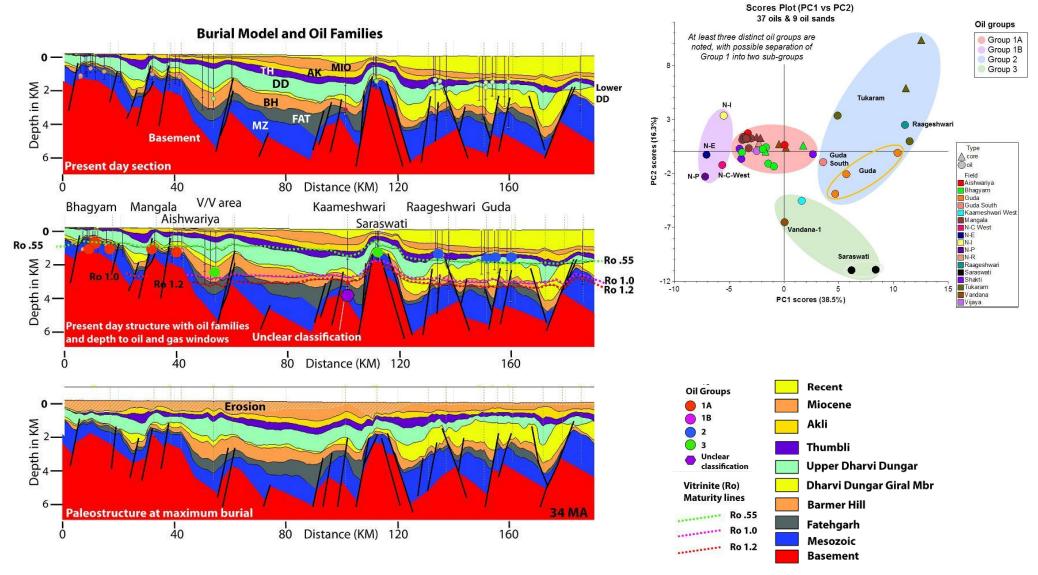




### **Prospectivity Re-assessment — Calibrated Basin Modeling**

Modeled outputs compared to field observations and laboratory results



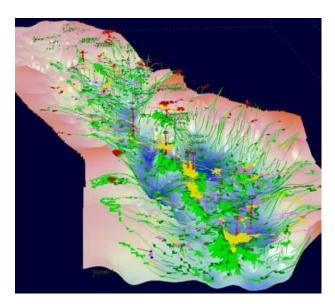


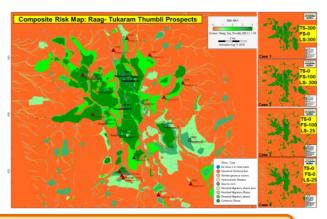
#### **Prospectivity Re-assessment — Migration & Charge**

Basin Modeling - Migration trends, fault seals and charge Risking

- Basin analysis amount, type and timing of generation
  - ✓ Regional tectonics, depositional history of sourcereservoirs and seal rocks
  - ✓ Trap formation and of hydrocarbon generation timing
  - ✓ Hydrocarbon expulsion and migration trends
  - World class oil prone lacustrine source rocks
  - Depositional history, trap formation and charge migration well understood
- □ Play & Prospect ranking and risking Trap Integrity modeling
  - ✓ Hydrocarbon charge volumes for each prospect predicted through time
  - ✓ Charge type and fill history predicted
  - ✓ Multiple top and lateral seal scenarios modeled
  - Innovative approach adopted for de-risking





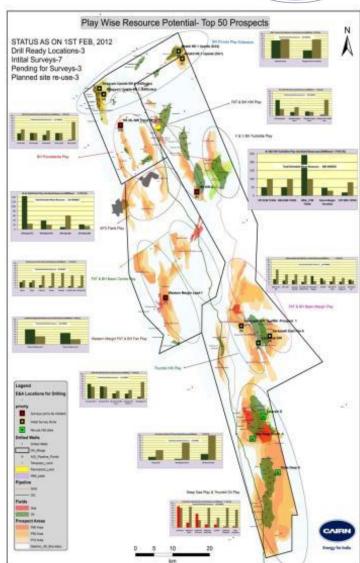


Multiple mature source rocks, no charge and timing risk – Huge volumes expelled



# BUILDING THE PROSPECTIVE RESOURCE BASE

2010 - 2012



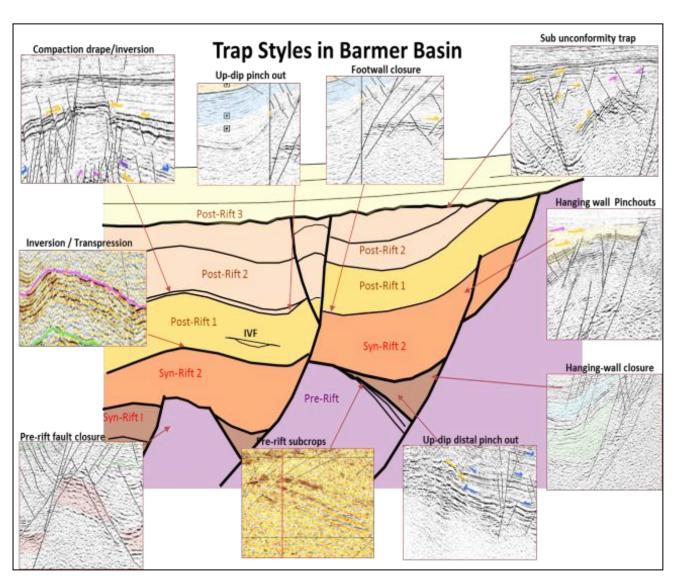
#### **Building the PR Portfolio – Available Play Types**

Typical Rift Basin - Structural & stratigraphic in Pre-, Syn- & Post-rift plays available



Analysed the global analogues for possible plays

- 10 different Trapping styles and 4 major reservoir units together give rise to 20 entrapments in 7 major categories
- Frontier MesozoicExploration and FracturedBasement plays included
- Play wise portfolio risked and ranked on play maturity and recoverable volumes



#### **Building the PR Portfolio – Available Play Types**

**Play Types Identified** 



- **☐** Footwall Plays:
  - Thumbli Oil\*
  - DD & DDCS Oil\*
  - Barmer Hill Porcellanite
  - > Fatehgarh (High NTG)\*
  - Fatehgarh (Low NTG)
  - Fractured Basement
- ☐ Hangingwall Plays:
  - > Thumbli Oil
  - DD Fan Delta
  - Barmer Hill Porcellanites
  - Fatehgarh (High NTG)
  - Fatehgarh (Low NTG)
  - Fatehgarh Strati-structural
- Basin Margin Fan Delta Plays:
  - Barmer Hill Eastern Margin Fan Delta\*
  - Barmer Hill Western Margin Fan Delta
  - BH Basin Margin Alluvial Fans

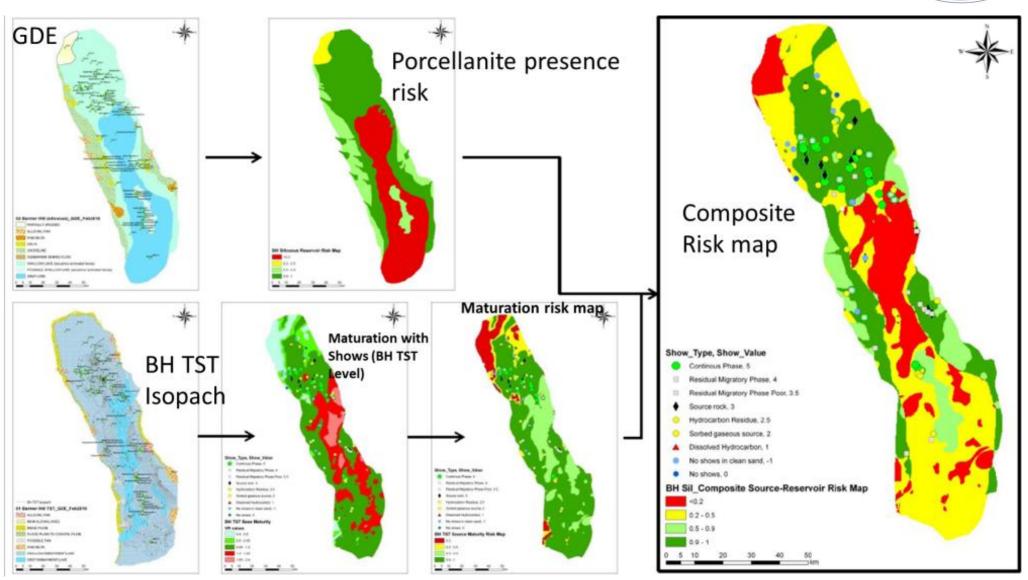
- □ CBH Horst Play:
  - CBH Horst Basal Thumbli Oil
- ☐ Stratigraphic Plays:
  - DD Turbidites Oil Play
  - Barmer Hill Turbidites (Strati-structural)\*
  - Fatehgarh (Downflank or Bald Highs)
- Basement Plays:
  - Deep Gas (Fatehgarh + Basement)
- Mesozoic Play
  - Tilted Footwall Closures
  - Sub-conformity Traps
  - Horst Blocks

<sup>\*</sup> Plays established in First Phase of Exploration

#### **Building the PR Portfolio – Prospect Risking**

Consistency in Risking Methodology – CRS maps for each reservoir level prepared



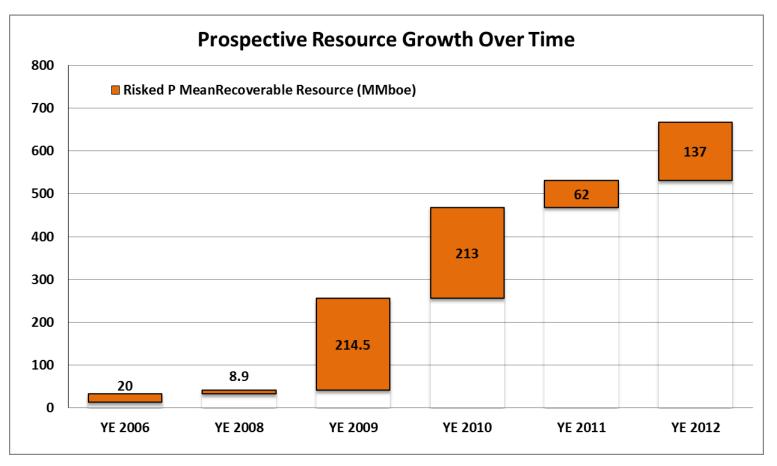


#### **Building the PR Portfolio – Prospect Level Scrutiny**

#### **Portfolio Growth through Time**



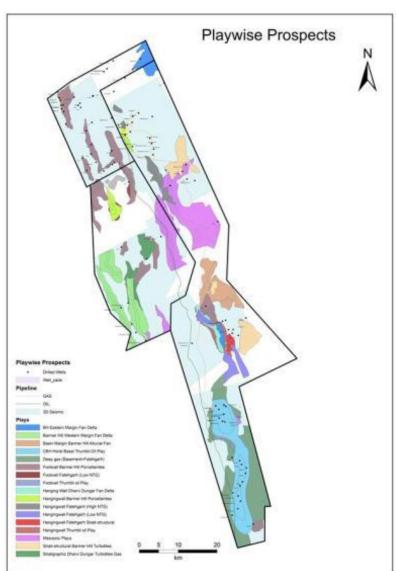
- >550mmboe of P50 risked prospective resource added during the drilling holiday
- Considered in-house and external independent Expert opinion on the plays, prospects
   and attached risks all priority prospects thoroughly scrutinized before release



#### **Building the PR Portfolio – Risked Resource**



- ➤ 83 prospects added to Exp portfolio by 2012, in 20 different plays
- ➤ 2012 Portfolio has about >550 mmboe risked EUR, approx. 40% gas
- ➤ In addition approx. 110 mmboe of discovered yet to be appraised 2C CR
- Mix of Wildcat 'high risk-high reward' and lower impact Near Field prospects
- Need to convince own management and JV partner on the remaining prospectivity
- Needed policy clarification on continuing exploration in mining lease areas



#### **Exploration Strategy Adopted**

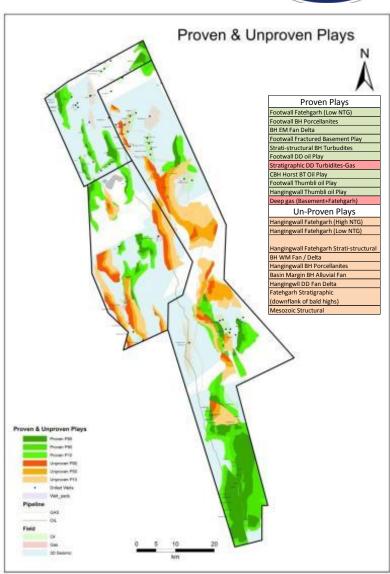
#### Proven Play extension

- Drill prospect with largest risked volumes first
- Drill out total prospect inventory above commercial threshold, if success ratio supports
- Prioritize wells in key clusters or 'hub' areas, consider rate in addition to volumes

#### Unproven Plays

- De-risk the play first best play opener and least risky prospect as the play opener
- Drill at least 2 prospect in each play
- If de-risked, drill out all the prospects above commercial threshold
- If first 2 wells are unsuccessful; suspend play and analyze the cause of failure

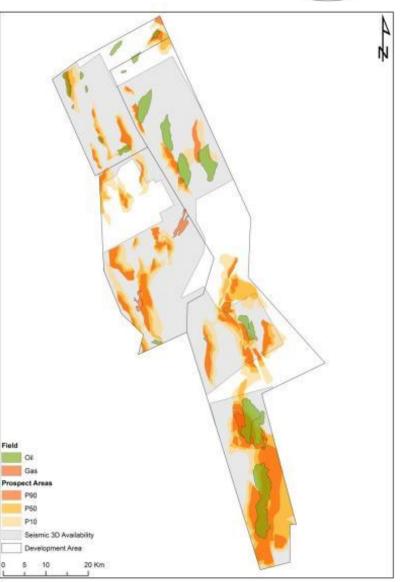




#### Realizing the Portfolio – Campaign Preparation

- ☐ Conducted a 3 Day Basin Workshop in May 2012 all involved external experts invited to resolve the unanswered questions and ambiguities
- ☐ Aggressive Exploration & Appraisal campaign
  - Approx. 40 E&A wells per year
  - 4 year exploration campaign
  - Planned appraisal to new discoveries
- Drilling Rigs, Services and Consumables
  - > Four Exploration rig campaign
  - Provision for additional rigs
- Land acquisition & site construction for first 34 E&A wells
- New 3D Seismic in gap area 1800 SqKm to generate additional leads and prospects.

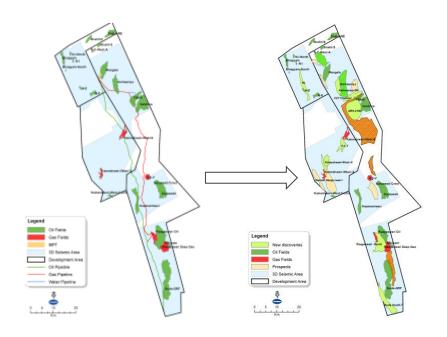






# SECOND EXPLORATION CAMPAIGN

2013 - 2016

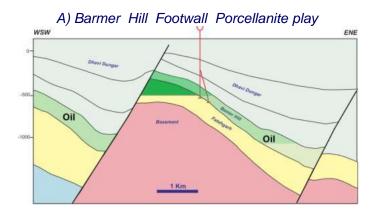


Policy clarification by Government of India on 2<sup>nd</sup> Feb 2013

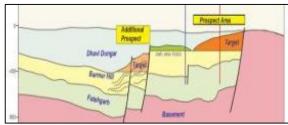
Cairn India commenced the drilling of its first Exploration well, Raageshwari-South-1, on 25 February, 2013 located in the southern part of the block.

## **Core Areas Identified – Key Plays Targeted**

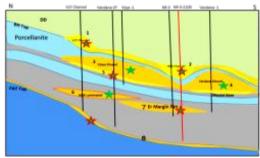




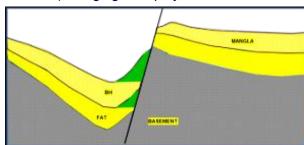
B) Barmer hill Deltaic play



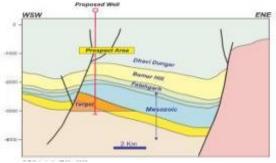
C) Barmer Hill turbidite play



E) Hanging Wall play



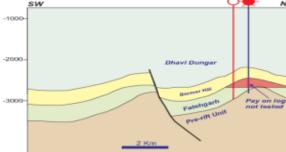
C) Mesozoic play



F) DDCS- Basal thumbli Play



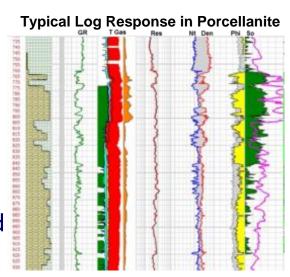
D)

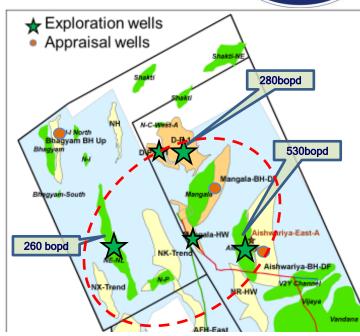


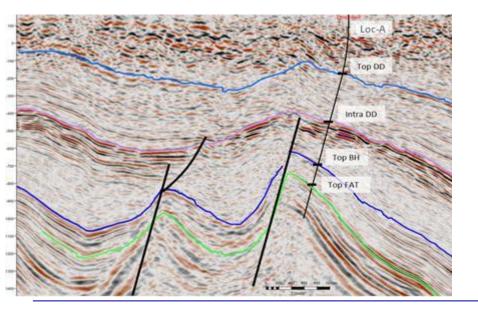
D) Fategarh- Volacanics Gas play

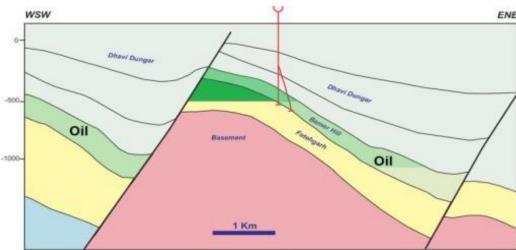
## **2nd Exploration Campaign: Porcellanite Play**

- Tight laminated diatomites in Barmer Hill Formation
- Milimeter scale laminae alternating with shale, but good total thicknes (~200m)
- Require fraccing to flow
- Initial flow rates 250-500bopd with single frac





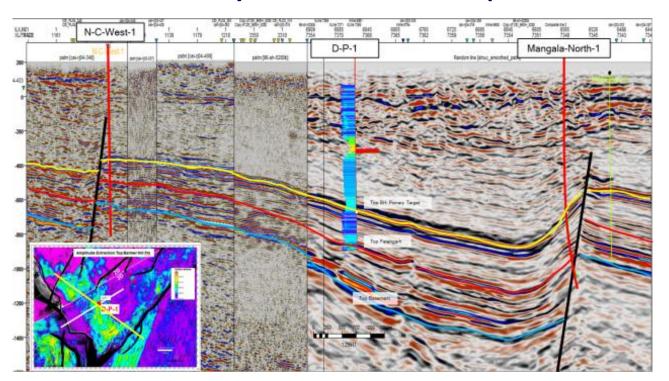




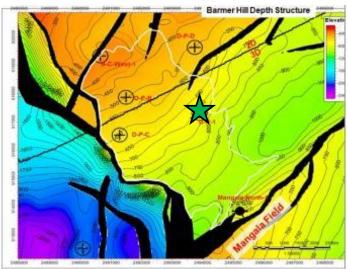
### 2nd Exploration Campaign: Risk v/s Reward

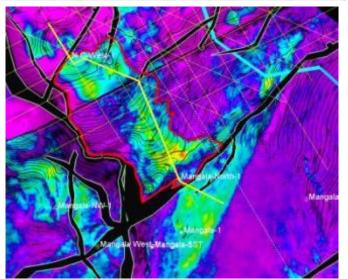
- Bright amplitude anomaly over the rising flank
- Extends beyond the 3D limit into old legacy 2D data
- Crestal well flowed very little gas
- ➤ No structural conformance in 3D data set but possible lateral facies changes high risk trap.

#### New Discovery with >300 MMBbl In-place oil





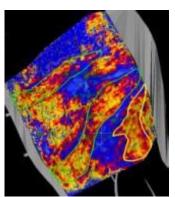


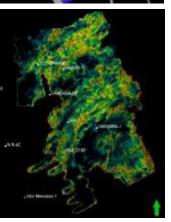


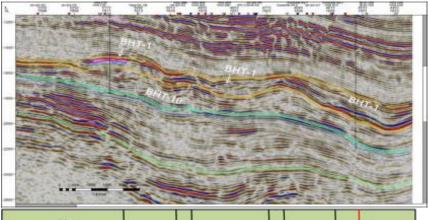
RMS amplitude of top 50ms window in BH

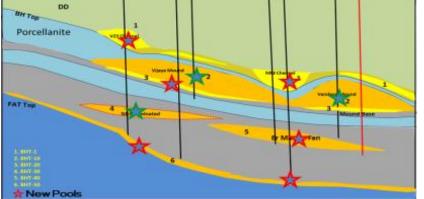
## **2nd Exploration Campaign: BH Turbidite Play**

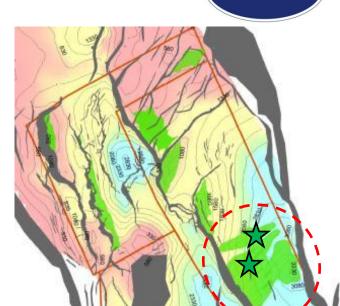
- CFCs, MTCs and debrites in deeper lake environment
- Huge Inplace established (> 1Billion bbl) trapped stratigraphically in turbidite channel & fans
- Require fracking for commercial rates
- Initial flow rates 250-450bopd post-frack.

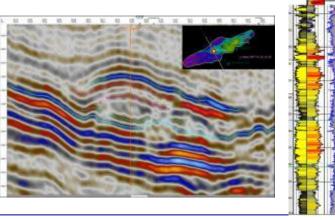










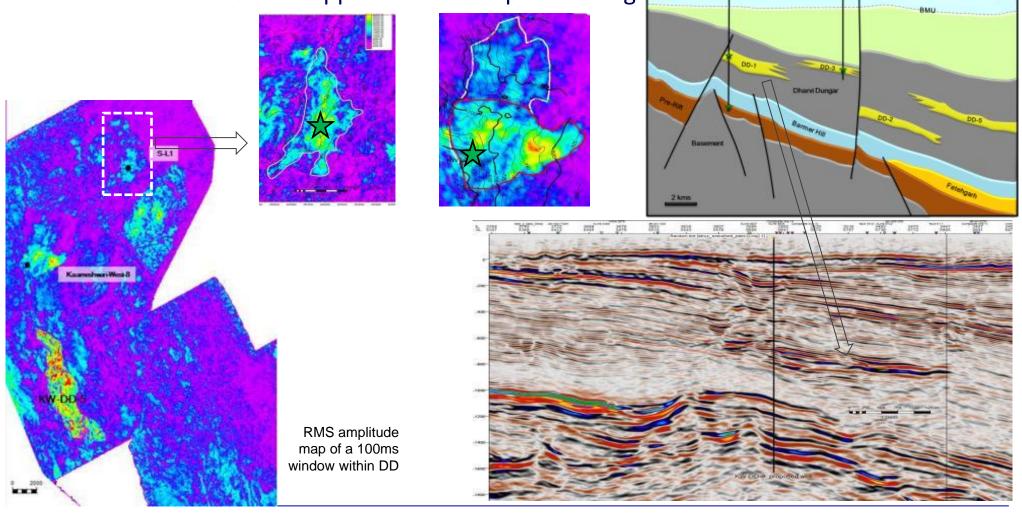


## **2nd Exploration Campaign : DD Turbidite Play**



- Bright amplitude anomalies deposited as turbidites encased in shales
- ➤ Two successful exploration wells drilled others high graded

Additional anomalies mapped and lined up for drilling

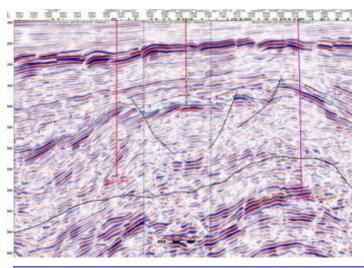


### 2nd Exploration Campaign: DD Deltaic Play

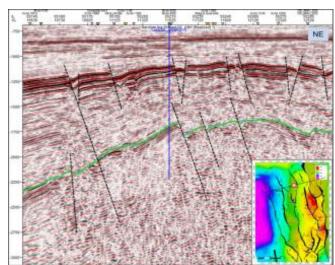


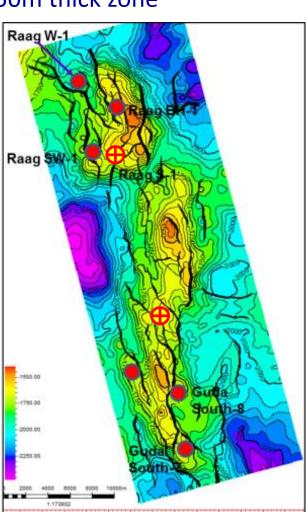
- Discovered in 1<sup>st</sup> campaign in Guda area but largely ignored.
- Individually thin sands with silts/shales and coal streaks but 150m thick zone
- Now pool extended over the entire Central Basin high.
- Emerging to be close to a billion barrel in-place oil.
- Tighter towards north 350 bopd after single frack.
- Better reservoirs in south 500bopd without frack.
- 9 successful appraisal wells drilled so far.

Raageshwari seismic Line



Guda seismic Line

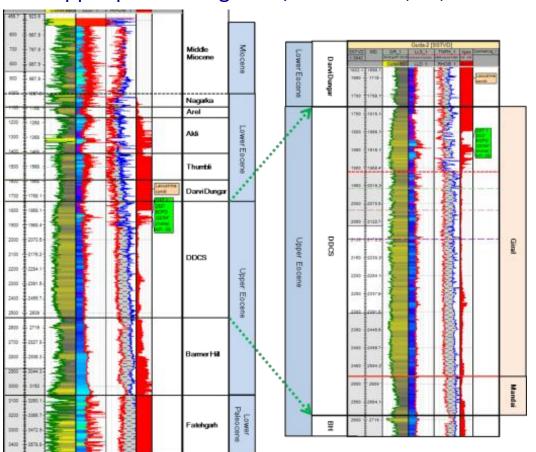


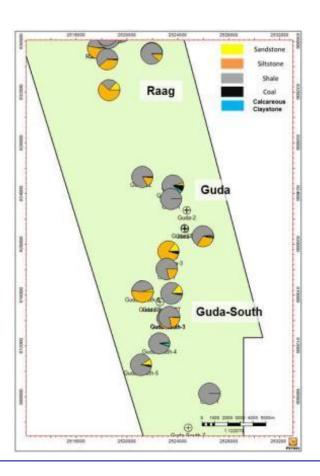


### 2nd Exploration Campaign: DD Deltaic Play



- Over 600m thick sequence with erosional unconformity on top.
- Palynological data suggest a lacustrine setting with marine incursions.
- Low energy delta plain /swampy depositional environment evident from FMI logs
- The individual sand generally between 3-8 m thick, laminated nature on image logs.
- Upper part has higher N/G of 5-15 %, Av, Phi-e 8 -10 % (total porosity range 18 to 22%).



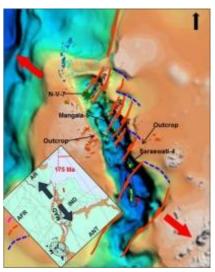


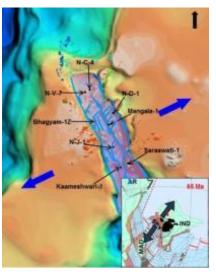
## 2nd Exploration Campaign: Possible Mesozoic Basin?











se Gravity Modeling

**Mesozoic Outcrops** 

Te/Tim (%) vis Dia81 (%)

Two oils with very high maturit

Paleo-Tectoring Reconstitution mode so a vandana

Mesozoic Prospect Northern Africa Malani Igneous Basement Loutit et al., 2001

Oil Geochemistry

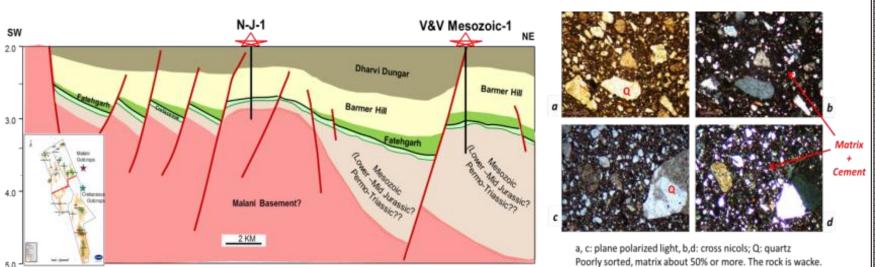
Mesozoic Basin beneath Tertiary basin?

**Global Analogues** 

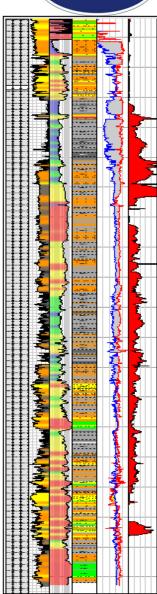
## 2nd Exploration Campaign: Possible Mesozoic Basin?

- Drilled about 1000m of Mesozoic sediments
- Very hard compact sandstones with tuffs, and claystones
- ➤ A new deeper source rock identified thermally mature, sapropelic (?) probably deposited in swampy lacustrine environment
- Good gas shows encountered during drilling but the reservoirs have very low porosity and are cemented with hematite.

# Presence of Mesozoic Basin beneath the Tertiary Rift established; impact and remaining prospectivity analyses being carried out





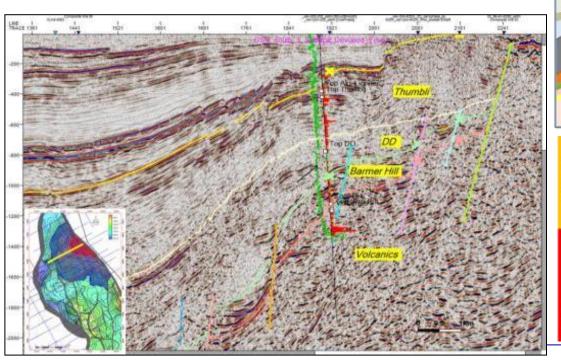


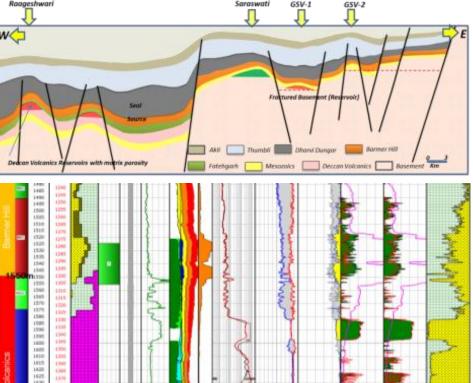
## 2nd Exploration Campaign: Fractured Volcanic Play

- Proven gas in CBH area matrix porosity and good frack response
- Basement play gradually unfolding in Saraswati GSV area
- Two wells drilled to test the fractured volcanic play
- Encouraging observations during drilling
- Yet to be tested : potentially a large resource









## 2nd Exploration Campaign: Paleosols over the CBH Unconformity surface on top of DD Shales. Good gas shows in all wells drilled over CBH MDT tested oil in 1 well Total area of 180 sqkm with a huge in-place potential. Tight reservoir - will require fracking. -1400.00

## 2nd Exploration Campaign: Deep Gas Exploration

Good Gas potential in the southern part – Multi-TCF potential to be unlocked



Raageshwari Deep-North & Extension: BH+Fat+Vol+Mes

#### Raageshwari Main High

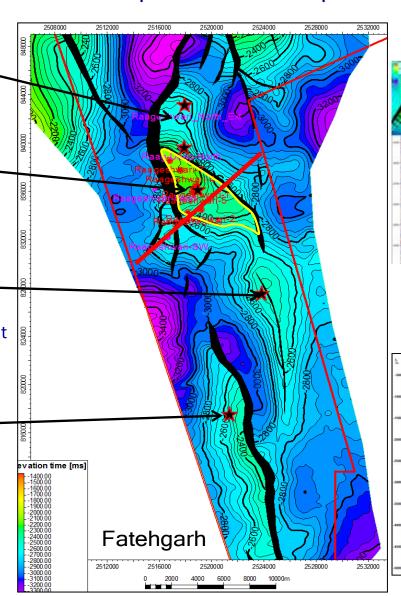
Proven ~1 TCF field, No contact established so far, Gas in Fatehgarh & Volcanics

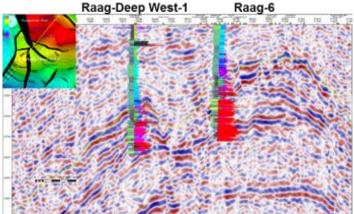
#### **Guda Deep Prospect**

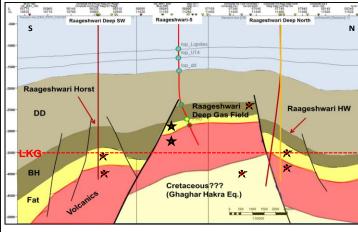
Currently under completion, Good petrophysical pay on logs, thicker Fat

#### **Guda South Deep Gas**

Taken up for drilling







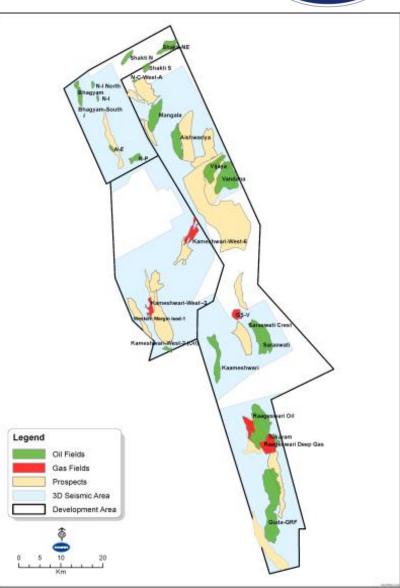
## 2nd Exploration Campaign: Status August 2014



- ➤ 19 Exploration prospects drilled
- 11 Play types probed
- 7 discoveries announced.
- 4 wells were dry Plugged & abandoned
- 4 well are under testing good shows during drilling, MDT oil + Petrophysical pays
- 4 well are lined up for testing good shows.

Total In-place established - 1.8 bn boe.

Initial success Ratio: ~80%



## **2nd Exploration Campaign: Results in Core areas**

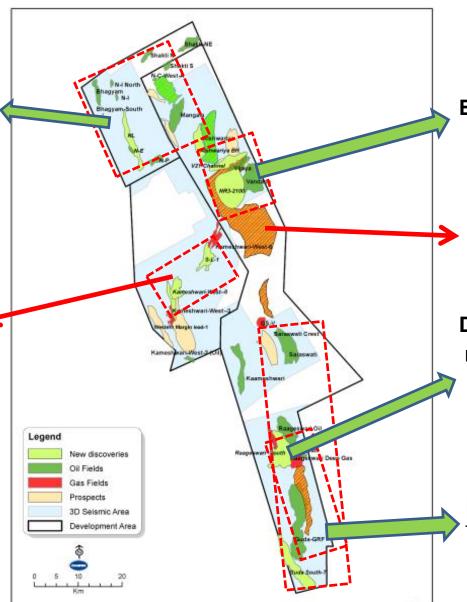


## Barmer Hill Porcellanite play

- DP-1
- NL-2
- DP West-1
- Mangla-HW-1

#### Dharvi Dungar play

- KW-8 & SL-1 Discoveries
- Significant new play in Dharvi Dungar turbidite
- Many prospects de-risked



#### **Barmer Hill Turbidites**

- V2Y Channel & NR3 2100
- Significant volumes added

#### **Mesozoic Play**

Significant new play introduced

#### **DD Deltaic Play**

Major success in DDCS and BTplay

- Raag-S-1 Discovery
- Guda South-7 Discovery
- Play extended over entire CBH (180 sqkm)

#### **Deep Fategarh+BH Gas**

Two wells Guda Deep-1 & Raag DW-1

 Thick column encountered in Guda Deep

## 2nd Exploration Campaign: Plays Yet to be Tested





Legend

New discoveries Oil Fields

3D Seismic Area Development Area

Gas Fields Remaining Prospects

#### **Turbidites Strat Pool**

 Juxtaposed to prodelta shales, Porcellanites and turbidites are the key targets

#### **Mesozoic Play**

 Presence of source established, basin-wide search for good reservoirs and traps

#### **Fractured Volcanic Play**

Evaluate new wells, extend the play

#### Deep Fategarh+BH Gas

Thick column (400+m) in Guda Deep

## **2nd Exploration Campaign : Unconventional Resource**

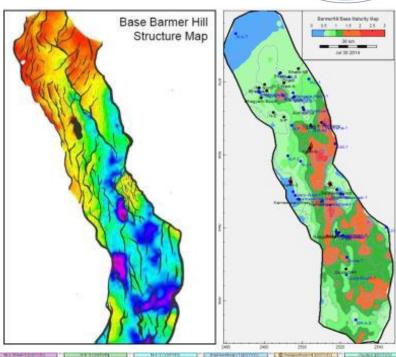
# CAIRN

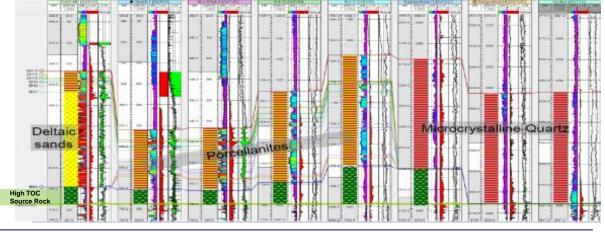
#### **Preparedness:**

- ☐ Studies at very initial stage
- Workflows for Storage Determination,Fraccability & Producibility
- ☐ Oil mature kitchen in the north
- Gas mature source rocks in the south

#### **Key Challenges:**

- ☐ 30-50m thick main source rock
- ☐ Resting over gas / oil/ Waterbearing high permeability rocks
- Overlain by Porcelanites rocks often oil bearing

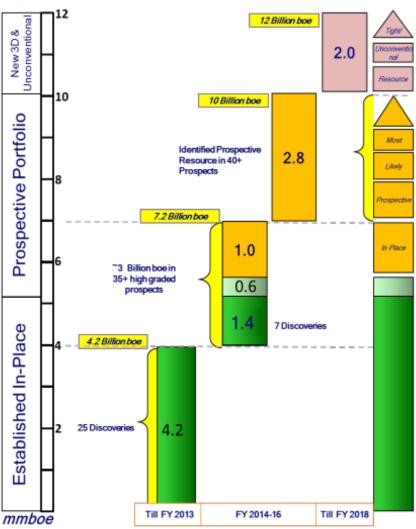




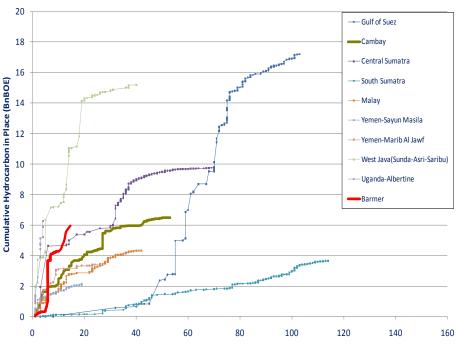
## 2nd Exploration Campaign: Plays Yet to be Tested







#### Creaming Curves (normalised by volume productive basin)



#### **Basin Potential is enormous**

- Only syn-rift structural play chased
- Post rift plays initial exploration
- Pre-rift plays initial exploration
- Stratigraphic Plays Initial Stage



"Twenty years from now you will be more disappointed by the things you didn't do than the things you did. So throw off the bowlines, sail away from the safe harbour, catch the trade wind in your sails.

Explore..... dream..... discover".

Mark Twain.

