Exploration Strategies for Frontier Hydrocarbon Plays in the Western basins of South Asia in low price environment

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August, 2016
New Millennium's Exploration Paradigm and Performance

Exploration Performance: Success/Failure History and Lessons Learnt

- Seven long years of $80-100/bbl oil price -> lucrative economics of prospects/ projects,
- Exploration ventures in geologically complex, environmentally sensitive, technology intensive, and geographically remote & difficult areas at high finding costs ($6 - $15/boe),
- Exploration Performance of the basins significantly improved in last 2 decades. Factors:
  - Early understanding of the Play, its key uncertainties and technologies needed to de-risk/ discover,
  - Deploying key technologies in timely and operationally effective manner.
- Success of Deepwater exploration and North American Tight Oil/Shale Gas Plays increasingly flooded the markets - oil glut of over 3 Billion barrel,
- Predicted time of Hubert’s peak passed? New Oil- abundant, waiting to be developed!
  - 350 Billion boe discovered in last decade as compared to 120Bboe in 1991-2001.
  - 200Bboe in 91 Elephants. Mostly in previously inaccessible areas or geological settings.
Modern Exploration History – What it means for Future Exploration Performance & Targets

- Implications for the Future, Window of Opportunity:
  - Must redefine efficiency in terms of operating performance, building resilient portfolio and robust economics projects (vis-à-vis neutral cash flows),
  - Like the Unconventionals’ exploitation starting in early 2000s (low oil price times), opportunity to exploit previously less understood Plays having smaller Prospect sizes due to lower operating cost, improved operating efficiency and technologies availability (at lower cost).
  - Identify (differentiate) the maturing and emergent Plays & Basins – use wells’ statistics and Success-Failure Analysis, Early acreage capture, and periodic relinquishments
  - Diversify portfolio, JV Partnerships, Technology Partnerships (IOCs & Service Companies),

The Context

Exploration Funnel

The Context

Exploration Funnel

- Proven & unproven plays
  - National & Actual leads
- Define, Map, Assess prospects
- Discover
- Appraise
- Develop Produce

High-Low Range, Reserves & Profit

Many leads dropped
Not mappable
(1-COS)

Unviable, geologically
Or Uneconomic
(1-COS)

No materiality
Un-commercial
(1-Pc)

1P, 2P, 3P: Deploy Technologies
Add Value

3P⇒ 2P ⇒ 1P: Capture Upside Secondary Rec.

NV & Early Exploration Phase
Exploration Work program in Licenses
Exploratory Drilling
Rationalize Relinquish Swap
Appraisal and Development

Exploration Strategies for Frontier HC Plays in the Western basins, in low price environment, SAARC Conference, Nadeem Ahmad, Ph.D. Aug-2016. (MOL Pakistan)
Basins and Plays of Interest with Creaming Curve and Yet-to-find (YTF)

1. **Lr. Cretaceous, Lr. Goru Play** (Detached shoreface regressive sands (proven))
2. **Upper Cretaceous – Lr. Paleocene Progradational Deltas and Turbidite Lobes** (proven)
3. **Lr. Eocene Lowstand Carbonate wedges** (unproven)
   - Significant Yet-to-find, (Map)
   - North: mainly oil & gas-condensate, Mid: mainly gas, South: oil & gas with condensate
Upper Indus: Bannu-Kohat Basin

Opening of a New Basin, New Play: Cream of the Crop

- A story of perseverance! First well: Dalwati-1 in 1937, First discovery in 1999 in the 15th well!
- 1980-1990: > 10 seismic surveys, 3 wells, all dry,
- 1990-1998: > 5 seismic surveys, 5 wells, all dry. AMOCO deployed 2nd Generation seismic with PreSTM processing and workstation based workflows,
- First discovery at Chanda-1, followed by Manzala!
- PSDM, imaging below thick salt /diapiric mudstones!
### Play Statistics, Yet-to-find (YTF)

#### U. Cretaceous/Paleocene Play

**Field Size Distribution Kirthar Foldbelt**

- **FSD Kirthar Foldbelt, Mughalkot-Pab-Ranikot**
- **Swanson’s Mean, Mmboe**: 59.77
- **P50**: 18.7
- **P90**: 2.3
- **P10**: 172

<table>
<thead>
<tr>
<th>Classes/ range</th>
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<th>5 - 10</th>
<th>10 - 50</th>
<th>50 - 100</th>
<th>100 - 200</th>
<th>200 - 300</th>
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<td>16.58578</td>
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<td>Actual volumes discovered</td>
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<td>84.88</td>
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<td>Modelled discoveri.</td>
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<td>4</td>
<td>12</td>
<td>3</td>
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<td>2</td>
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<tr>
<td>YTF fields, #</td>
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<td>3.258841</td>
<td>9.112167</td>
<td>1.203493</td>
<td>1.617042</td>
<td>0.791626</td>
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</tbody>
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#### Lr. Cretaceous, Lr Goru Play. YTF in Comb. & Strat traps

**PROBABILITY DENSITY CHART**

- **Strat-traps only**
- **All traps**

<table>
<thead>
<tr>
<th>Classes, MMBOE</th>
<th>1 - 10</th>
<th>10 - 50</th>
<th>50 - 100</th>
<th>100 - 200</th>
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<tbody>
<tr>
<td>Actual found</td>
<td>0</td>
<td>57.25</td>
<td>159.80</td>
<td>250.00</td>
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<tr>
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<td>7.22</td>
<td>280.18</td>
<td>283.00</td>
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<tr>
<td># of Finds, actual</td>
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<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td># of Finds, Modelled</td>
<td>1</td>
<td>10</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>YTF, MMBOE</td>
<td>222.93</td>
<td>123.20</td>
<td>325.59</td>
<td></td>
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<tr>
<td>New Pot. Finds</td>
<td>1</td>
<td>7</td>
<td>2</td>
<td>3</td>
</tr>
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#### Exploration History & YTF: Kirthar Fold Belt, Mughalkot-Pab-Ranikot Play

- **Cum. discovered volumes, MMBOE**
- **Cum. discovered resources, MMBOE**
- **No. Of Wildcats**

### Historical exploratory drilling & discovery data along with the Creasing Curve for the Lr. Goru play, Lr. & M. Indus Platforms

- **Cum. discovered volumes, MMBOE**
- **Cum. discovered resources, MMBOE**
- **No. Of Wildcats**
Play and Play Fairway for Portfolio based Exploration: Definitions, Workflow

- **Play**, conventional approach – Reservoir focus
- In hierarchical framework of petroleum system
- Play: a **reservoir-seal Pair**, stretched over basin:
  - Pair of Reservoir and its genetically associated top seal in hierarchical sequence stratigraphic framework
  - Specific spatial and temporal arrangement
  - Prospects have a shared mechanism/ arrangement of migration pathways, Containment
- **Part-play**: Proven & Unproven
- **Sub-play**: Proven & Unproven
- Common Risk Segment (CRS) maps of each element
- Composite CRS (CCRS) map of a Play Fairway, to prioritize areas, focus exploration work programs.

**Prospect:**
- Defined on actual data with chance/resource ranges in line with FSD, YTF & Creaming curves
- Notional/Conceptual: Chance & resource size from analogue play’s statistics

**Unproven part-play=** Common risk segment with play chance <1. Petroleum system proven or not.
Risk & Resource Assessment Approaches in Stratigraphic and Combination Trap Plays, Nadeem Ahmad, Ph.D (MOL Pakistan)

Distribution of \( Lr \). Cretaceous Deltaic and Paralic Siliciclastic Systems. IEDS Study, 1995

Lumshiwal Deltaic and Paralic Siliciclastics, (2011 and 2015)

PFA – Mapping, Extending from the same age analogue Play Fairway in South: \( Lr \). Goru and Lumshiwal Reservoir CRS, Upper Goru marls and Kawagarth Marl-Limestone Seal CRS

Lumshiwal GDE Map

Prime top seal: Patala/ Pamoba Sh
Erosional remnant play
Lumshiwal-Kawagarh play
Chichali Sh

Upper Indus (left)
Middle & Lower Indus (Right)

Offlap break
Downlap
Last Coastal onlap
Toplap
Shoreface sand
Lower Shoreface - Offshore
Transgressive & distal offshore shale
West
Prev. Offlap Break
Detached shoreface sand body
East
Ahmad et al, 2004

Erosional remnant play

Detached shoreface sand body

Strategic steps: Capture, Create Value

Modern Exploration History & Plays of Interest
Play Statistics, YTF & Case Studies
Play-based Exploration & Risk Models
Strategic steps: Capture, Create Value

Play Statistics, YTF & Case Studies

Play-based Exploration & Risk Models

Strategic steps: Capture, Create Value

Lumshiwal GDE Map

Legend
- Lumshiwal_Father_Edge
- Lock_Paralic-UpShoreface Systems
- Lock_Paralic-MultShoreface UST_Wedges
- Lock_Colonnak_Latero UST_Wedges
- Lock_Outlet_Calcicarbonate Faces
- Lock_CoralMarine_Facies_Starke Turbids
- Seals

Upper Indus

Risk & Resource Assessment Approaches in Stratigraphic and Combination Trap Plays (MOL Pakistan)
Seismic stratigraphic interpretation of E-W regional seismic line from across the Sawan area
Subtle seismic reflection geometries, truncation patterns and dimming & brightening of amplitudes help infer coastal onlaps and offlap breaks -> sand bodies’ proximal and distal extents

Middle & South: Play Fairway Mapping: Extending from the same Play Fairway in south Lr. Goru and Lumshiwal Reservoir CRS, Upper Goru marls and Kawagarth Marl-Limestone Seal CRS

Top ‘B’ Sequence: Interpreting sand body distribution, uppermost sand 1-2 packages

- Key Uncertainties:
  - Seismic tuning, composite response - Artifacts
  - Reservoir quality prediction,
  - Lateral seal (shale-out or fault seal),
  - Bottom seal
  - Deeper Plays: Preservation against leakage along faults into the shallower sand bodies - b

Source: N. Ahmad et al., Geol. Society London (2007)
Quantification of Uncertainties, Risk Models

Chance adequacy matrix
- Information: Data, observations
- Knowledge is interpretation in the form of evaluations
- Elements plotting in top left corner & mid bottom area have large room for de-risking.

### Chance (adequacy)

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<th>Information</th>
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<th>Chance (adequacy)</th>
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<td>Low</td>
<td>10% - 20%</td>
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<tr>
<td>Low</td>
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<td>60% - 80%</td>
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<td>80% - 100%</td>
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<td>20% - 40%</td>
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<td>40% - 60%</td>
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<tr>
<td>High</td>
<td>High</td>
<td>60% - 80%</td>
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</table>

- **EXPLORATION PROSPECT Chance Success**
  - SOURCE COMPONENTS
    - Quantity/ Volume (Include Marketable Product)
    - Quality/ Richness
    - Maturity
    - MINIMUM FACTOR: 100.0% 89.8% 89.8%
  - TIMING/ MIGRATION COMPONENTS
    - Timing of Closure/ Trap
    - Timing of Expulsion
    - Effective Migration Pathway
    - MINIMUM FACTOR: 100.0% 90.0% 90.0%
  - RESERVOIR COMPONENTS
    - Presence
    - Quality
    - Reservoir Performance
    - MINIMUM FACTOR: 100.0% 90.0% 90.0%
  - CLOSURE COMPONENTS
    - Map Reliability & Control
    - Presence
    - Data Quality
    - MINIMUM FACTOR: 100.0% 80.0% 80.0%
  - CONTAINMENT COMPONENTS
    - Top / Base Seal Effectiveness
    - Lateral Seal Effectiveness
    - Preservation from Spillage or Depletion
    - Preservation from Degradation
    - MINIMUM FACTOR: 100.0% 90.0% 90.0%

- **PLAY SEGMENT**
  - PROSPECT
  - TOTAL
  - Confidence of P3P Resource: 61.00 MMBDF

- **Final Chance of Success**
  - Shared: 51.3%
  - Local: 51.9%
  - Total: 51.9%

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Exploration Strategies for Frontier HC Plays in the Western basins, in low price environment, SAARC Conference, Nadeem Ahmad, Ph.D.

MOL Group

Aug-2016. (MOL Pakistan)
Quantification of Uncertainties, Play level Risking

- Quantify uncertainty, Establish classes/bins
- Draw risk segment polygons on top of GDE maps.

### Proven Part-play:

**Play chance** = \( P(R) \times P(S-e) \times P(C-e) \)

Where, \( R = \) Reservoir presence, \( S-e = \) top Seal effectiveness, \( C-e = \) Charge Effectiveness

### Unproven part-play

**Play chance** = \( P(R) \times P(S-e) \times P(C-e) \times P(\text{model}) \)

Where, \( P(\text{model}) \) is Probability of the model given alternate possibilities and available data & knowledge in the un-drilled part of the Play (part play).

### Unconventional Traps (e.g., strat trap) in proven part-play:

**Prospect COS** = \( P(\text{play}) \times P(\text{seal}) \times P(\text{trap}) \times P(\text{cont}) \times P(\text{Model-U-Sh}) \)

Whereas, \( \text{COS} = \) chance of success, \( P(\text{seal}) \) is the chance for local top seal and fault seal but excluding the bottom-seal and lateral shale-out seal, \( P(\text{Model-U-Sh}) \) is probability of model (e.g., detached shoreface, lateral shale-out, structural setup, etc).
Middle & South: Play Fairway Mapping: Extending from the same Play Fairway - Lr. Goru and Lr. Goru paralic sand Reservoir, Upper Goru marls as prime top Seal

**CCRS Map - Lr. Goru play**

- **CCRS = > 0.4**
- Low to v. low risk
- **CCRS = 0.25 – 0.4**
- Medium low risk
- **CCRS = 0.125 – 0.25**
- Medium high risk
- **CCRS = 0.05 -0.125,**
- High to v. high risk

- Feeders: Delta plane distributary channels, mouth bars & heterolithics
- Longshore drift.
- Strandplains & Shoreface bars under mixed wave & tide effect. Waves actively back-piling sands. Tides spreading fines around and laying sand onto the back-barrier lagoons.
- Rip current or Ebb flood deltas attached to the Tidal inlets cutting across the shoreface bars and even strandplains

**Gross Depositional Environments map (GDE)**

- Depo-systems reconstruction for key geomorphic elements; PS Sets-3 and -4 Basal Ss Seq.
- Three phases of strand plain-barrier bar down-stepping - sand emplacement on to the lower shoreface

- Overlay Analysis of key CRS maps.
- Multiplication of individual risk polygons.
- Removed shattered glass effect. Minimize classes – simplify binning

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Risk & Resource Assessment Approaches in Stratigraphic and Combination Trap Plays, Nadeem Ahmad, Ph.D (MOL Pakistan)
Strat-trap Prospects definition in Cretaceous Play; Risks

- Thief sand risk towards hinterland; success-failure analysis from analogues
- In Cretaceous systems of Lower & Middle Indus, no such success despite multiple wells (Karachi South 1A, Chnoai-1, Lundo-1, etc).
- Fewer examples exist of strat-traps in sandstone pinchouts updip towards hinterland (sand source, fluvial inputs).
- East Texas, Cretaceous Woodbine sandstone play. Porosity preservation mechanism similar to Lr. Goru with porous-permeable sand at >6000m in a number of fields. Works with Buda Lms as bottom seal, thick Austin Chalk as updip and top seal.
- Buzzard Field, Moray Firth Basin, UK North Sea: U. Jurassic Turbidite sandstone reservoir, Thick Cretaceous chalk on top, Tight limestone underneath. Complete detachment of sand (fault escarpments).
Strat-trap Prospects; Resource & Risk Assessment Strategies

- Exploration work programs to be designed to cover Play Fairways in contiguous blocks using CCRS maps
- Strat-traps/ Combination traps to be added to a Prospect Inventory to diversify & spread risk,
- Play and Portfolio based de-risking means Consistent resource & risk assessment across the blocks, forecasting on the bases of Portfolio instead of individual Leads/Prospects’ COS, and achieving matching results at the end of Exploration Effort vis-à-vis initial planning & forecast,
- Due process of successive de-risking to be:
  - Gauge the room for de-risking (COS improvement) through available technologies/ methodology,
  - Select appropriate technology specific to critical uncertainties, pre-assess future risk revision with increased or decreased GCOS,
  - Before ranking / maturing to drill, determine maximum number of high risk elements acceptable (per prospect) and residual risk vis-à-vis ALARP framework of the company; we recommend two (2).
  - Set up accordingly the Decision Tree and back-calculate the expected value (EMV, ENPV) by taking into account “cost of de-risking” while making risk investment decisions.

Exploration License-1
3 Leads

VOI FROM SEISMIC (CHANCE,%) YES
80%

No de-risking, no VOI – Drop License
20%

Drill Lead-1
Discovery

Post-seismic de-risking
Revised COS: 35%

Dry Well
Chance of Failure
DHC, US$ MM
Do not drop License, Drill 3rd Lead

Drill Lead-2
Discovery

Post-seismic
Revised chance: 65%

Dry Well

G.COS NPV US$ MM

MOL GROUP

Risk & Resource Assessment Approaches in Stratigraphic and Combination Trap Plays, Nadeem Ahmad, Ph.D (MOL Pakistan)
Future Challenges and Strategies

- Field size and Finding cost ranges: 1-5MM boe (Million Barrels of Oil Equivalent) at an exorbitantly higher finding cost of +$10/boe, others continue to discover larger gas and oil fields (5-50 MMboe) at a cost less than $5/boe,
- Creaming Curve of three (3) proven basins of Pakistan: Rising trend on creaming curve and geological Play Fairway and Common Risk Segment (CRS) maps suggest Basins are still in emergent or yet-to-mature stage,
- Significant yet-to-find due to yet-to-mature sub-plays within the already discovered Plays
- Over 800MMboe (gas) and +400MMboe (oil) in the Upper Indus (Figure 1).
- Nearly 1,400 MMboe gas and Over 300MMboe liquids are expected from the Middle Indus Sulaiman Foldbelt area,
- Over 600MMboe gas and nearly 170MMboe liquids are expected from the Kirthar fold belt

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<th>Wells</th>
<th>Exploratory Completed</th>
<th>App/Dev Completed</th>
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<tr>
<td>OGDCL</td>
<td>17</td>
<td>2</td>
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<td>PPL</td>
<td>14</td>
<td>2</td>
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<tr>
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<td>23</td>
<td>5</td>
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<td>Total</td>
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Table 1. Status of exploratory and A&D drilling in the country for 2015-16. Source: PPIS Online and Scout Check reports.

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Table 2. Upper Indus Basin, Average costs, US$ Million.

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Table 2. Upper Indus Basin, Average costs, US$ Million.

Seismic cost; 300sq-km 3D, or 400 L.km 2D 10-14
Well Cost, 3,000- 35,000m deep 18-25
G&A Cost (1 yr, 1 block) 1.5-2
Typical resource size, MMBOE 10-50
Finding Cost, $/BOE 1.5 – 7.0

Seismic cost; 300sq-km 3D, or 400 L.km 2D 10-14
Well Cost, 3,000- 3,500m deep 18-25
G&A Cost (1 yr, 1 block) 1.5-2
Typical resource size, MMBOE 10-50
Finding Cost, $/BOE 1.5 – 7.0
Strategic Options for Pakistan

- Technology selection and timely deployment: 2D and 3D Seismic surveys & Processing
- Global spending on seismic reached $7 Billion in 2011, and exceeded $12 Billions in 2013. In Pakistan, during last 8 years, over 20,000 sq.Km 3D seismic (~ $0.5 Billion) and over 100,000 L.Km 2D (> $1.5 Billion) have been acquired.
- Potential Field surveys especially Gravity (rather Gravity Gradiometry) and Magnetic mainly for rather frontier basins.
- Brownfield and greenfield infrastructure-led exploration of smaller prospects,
- Explore frontier basins & plays: Public sector companies to engage IOCs to explore remote and unproven basins like interior fold belts, Kharan basin. Must define New play concepts, use innovative approaches.
- Add Unconventional play types to the portfolio,
- IOCs having Giant fields in their portfolios continuously add new countries and basins to their portfolios to access new emergent basins (larger field sizes). Recent examples are: Petrochina, Petronas, ONGC Videsh. Accessing E&P projects in the neighboring oil & gas rich countries: Secure energy at the source.

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<td>PPL</td>
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<td>2</td>
<td>10</td>
<td>1</td>
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<tr>
<td>Private</td>
<td>23</td>
<td>5</td>
<td>16</td>
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<tr>
<td>Total</td>
<td>54</td>
<td>9</td>
<td>40</td>
<td>7</td>
</tr>
</tbody>
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**Table 2.** Upper Indus Basin, Average costs, US$ Million.

| Seismic cost; 300sq-km 3D, or 400 L.km 2D | 10-14 |
| Well Cost, 3,000-3,500m deep | 18-25 |
| G&A Cost (1 yr, 1 block) | 1.5-2 |
| Typical resource size, MMBOE | 10-50 |
| Finding Cost, $/BOE | 1.5 – 7.0 |
Strategies for Times of Low Oil Prices – Closing Remarks

- Basin’s exploration performance linked w/ Play characteristics & right techniques/workflow deployed,

- But also linked with Company’s operating performance which is determined by:
  - Portfolio mix (diversity of basins & play types and prospect sizes and their risks),
  - Managing the Operations onset or scheduling risk, contracts management,
  - Stakeholders’ management including the local communities and security risks, and
  - Controls and Assurance processes the company runs for prioritizing its capital allocations to the new projects/acquisitions and an agile and disciplined execution of projects.

- A low oil price of $45-$65/bbl is anticipated for next few years -> Companies must redefine efficiency in terms of:
  - Operating performance, Securing sustained financial inflows while maintaining certain debt ratio, building resilient portfolio and robust economics projects in the face of their neutral to slightly negative cash flows,
  - Portfolio mix of diverse Plays and prospect sizes: these low times also offers window of opportunity to capture promising acreage from cash-strapped companies, restructuring and repositioning, and exploiting smaller Prospect sizes based on lower operating cost, improved operating efficiency and technologies developed and learned in last decade.