Unconventional Hydrocarbon Resource Plays in Pakistan: An Overview Awakening a South East Asian Sleeping Giant-Technological Solutions to Unlock the Vast Unconventional Reserves of Pakistan*

S. Areeba Ayaz¹, Batool Arhamna Haider², Kiran Ismail³, and Peter Mark Smith⁴

Search and Discovery Article #80216 (2012)**
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*Adapted from oral presentation given in Singapore at the Geoscience Technology Workshop (GTW) on Unconventional Hydrocarbons, 15-16 March 2012
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²Application Engineer, Weatherford, Singapore
³Operations Assistant, Weatherford, Singapore
⁴Presenter; Weatherford Singapore (PeterMark.Smith@ap.weatherford.com)

Summary

Sedimentary basins of Pakistan, on broad scale, are: Indus (upper, central southern [and lower]) in the east, Baluchistan, and Pishin. Upper Indus basin is geologically complex and oil-prone. Central Indus is the major gas producing area of Pakistan; it has unconventional plays. Southern Indus has both oil- and gas-prone areas, with unconventional resources. Thar Coal in the lower Indus basin contains great potential as CBM reservoir.

Baluchistan basin is thought to be prospective both in conventional and unconventional resources. Offshore Makran coast is considered to have significant hydrate potential.

Selected References


Website

Unconventional Hydrocarbon Resource Plays in Pakistan: An Overview

S. Areeba Ayaz, PhD Candidate at University of Queensland, Australia.

Awakening a South East Asian Sleeping Giant- Technological Solutions to Unlock the Vast Unconventional Reserves of Pakistan

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Kiran Ismail, Operations Assistant
Presented by Peter Mark Smith – Weatherford Singapore

Pakistan has:
- 2nd largest salt mine
- 5th largest gold mine
- 9th largest coal reserves
- 7th largest copper mine

Pakistan is:
- 11th largest wheat producer
- 12th largest rice producer
- 5th largest milk producer
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Introduction of Authors

Syeda Areeba Ayaz has served Weatherford Oil Tool Middle East Limited for one year as Petroleum Geologist. She has worked actively in the fields of geology and geochemistry for Coal Bed Methane (CBM) and shale gas projects in Pakistan. Ayaz is currently a PhD candidate at the University of Queensland, working on CBM basin studies in Australia. In addition, she holds a master’s degree in geochemistry from the University of Karachi. During the 2009-2010 school year, she served as president of the University of Karachi’s AAPG student chapter and has received various awards, including Weatherford’s Innovation Award on shale gas and two gold medals for excellence in academics.

Batool Arhamna Haider is currently working as the Application Engineer for Artificial Lift Systems at Weatherford Oil Tool Middle East Ltd. She has authored several papers and has been awarded various honors, awards and distinctions on both national and international levels. Batool has served as the Chief Editor of Petrospective, the annual magazine of the Petroleum Department, NED University of Engineering & Technology. She is also a member of the prestigious Network of Excellence in Energy Development NED Research Association, Pakistan. Batool is a graduate of NED University with a degree in Petroleum Engineering.

Sedimentary Basins of Pakistan

- Indus basin
- Baluchistan basin
- Pishin basin
Conventional Exploration Status

- Total explored area in Pakistan = 2,750,000 sq. km
- Unexplored area in Pakistan = 5,500,000 sq. km

Geology & Play Fairway Maps of Unconventional Hydrocarbons in Different Basins of Pakistan
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30 tcf conventional gas

Geology & Play Fairway Maps of Unconventional Hydrocarbons in Different Basins of Pakistan
**Upper Indus Basin**

- Upper Indus basin is further divided into Potwar sub-basin in the east and Kohat sub-basin in the west
- Geologically complex area
- Possesses rocks from Precambrian era to recent times
- Challenging drilling environment due to abnormally high pressure sands
- Oil-prone basin
- Unconventional hydrocarbon resources present (not tested yet)

**Central Indus Basin**

- Major gas producing area of Pakistan
- Rocks from Precambrian to recent times are present
- Possible regions of tight and shale gas
- Shales with swelling and cave-in tendency
- Highly jointed and fractured formations
- Hot sands are also present
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Unconventional Hydrocarbon Plays in Central Indus Basin

Possible fairway map of tight gas sands and shale gas in Lower Goru

Southern Indus Basin

- It possess both oil and gas prone areas
- Rocks from Triassic to recent times are present in the basin
- Compact sands and fractured limestones
- Shales with swelling ability
- High pressure zones in southwestern part of basin
- Tight sands, shale gas and CBM resources are present
Unconventional Hydrocarbon Plays in Central Indus Basin

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Unconventional Hydrocarbons in Southern Indus Basin

Possible Fairway map of Unconventional gas in Southern Indus Basin
Fairway map of tight gas and shale gas in Lower Goru
Fairway of CBM in Bara Formation

Geology of Baluchistan Basin

- Bounded by Chaman transform fault in the east, Iran in west, offshore Makran in south and Afghanistan in north
- Basin is thought to be prospective for oil/gas and minerals, but there had been no discoveries yet due to lack of geological understanding, sparse drilling and lack of available infrastructure
- Oil and Gas seepages in various areas show that hydrocarbons have been generated in basin
- Sedimentary rocks exposed in basin ranges from Cretaceous to recent
- Possible reservoirs of methane hydrates near Makran coast
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Exploitation & Development Challenges

- Evaluation Uncertainties
- High Investment
- Longer Production Time
- Longer Payout Time
- High Density of Wells
- Skilled Manpower
- Environmental Issue
- Political Stability
- Willingness to Accept Challenges

Shale Gas in Pakistan
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![Resolvable](Image1)

**Shale Gas in Pakistan**
48 Shale gas basins, 32 countries

EIA Report, April 2011

EIA Estimates - Technically Recoverable Shale

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<tr>
<th>Continent</th>
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Potential Shale Basins in Pakistan

Number of shale formations are prospective with various challenges:

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- Prospective formations include:
  - Lower Goru, shale members
  - Sembar Formation
  - Ghazij Formation
  - Mughal Kot Formation
- Prospective formations are:
  - Patala Formation
  - Hangu, Chichali, Datta formations
  - Sardhai Formation

Shales in Lower Indus basin

- Sembar Shale
  - Early Cretaceous shale
  - Proven source rock in the lower Indus basin
  - Grayish black colored silty shale
  - Organic richness and maturity varies with region
  - Kerogen type and maceral varies with region

- Lower Goru shales
  - Early Cretaceous shale, overlain by Sembar
  - Lower Goru is alternating shale and sands
  - It is very brittle as shales have more than 60% silt and lesser amount of clays.

- Other shales
  - Ghazij is Paleocene shale and restricted in few regions with good thickness > 1000m
  - Mughal Kot formation of late Cretaceous, restricted in few areas of Lower Indus basin.
  - Above mentioned shale formations in offshore region can be prospective as well
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This is a generalized distribution. TOC sometimes vary drastically within nearby wells.

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Avg. distribution of Patala and other potential shale formations based on TOC and Ro.

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Challenges of the Potential Shale formations in Pakistan

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| 1. Lower Goru formation | - Shale member is deep in various regions  
                          - Geological heterogeneity is present |
| 2. Sembar formation     | - Extremely deep in various region  
                          - Coring issue due to large thickness |
| 3. Patala formation       | - Accessibility problems in some areas |

Number of Upper Indus shales like Sardhai, Datta, Chichali, Hangu etc could be prospective shales depending upon their prerequisite geochemical data.
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Pakistan can develop shale resources in a number of ways:

- Targeting existing source rock for shale gas
- Attempting to analyze samples of old wells for shale gas characters
- Re-entry of old wells and re-planning of current wells for shale core
- Integration of data and interpreting the best possible zones in country

**US – Pak Shale Comparisons**

![Shale formations comparison chart](chart.png)

- **Legend parameter**:
  - TOC %
  - Ro %
  - Depth*1000 (ft)

  Shale formations:
  - Barnett
  - Marcellus
  - Fayetteville
  - Haynesville
  - Eagle Ford
  - Horn River
  - Woodford
  - Lower Goru
  - Sembar
  - Hangu
  - Chichali

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<td>Green chemicals, salt water fracs, low disposal volume, reduced truck traffic, pad</td>
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#### Multilateral Wells

- Dual
- Stacked
- Trilateral Fork
- Herringbone
- Backbone and Rib
- Radial

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Shale Summary of Upper and Lower Indus Basin

**Lower Indus Basin**
- Detailed reservoir studies have not been performed yet.
- Shale Beds are thick: over 80m.
- Relatively less heterogenous as compared to the Upper Indus.
- Water cut very high - Over 50%.

**Upper Indus Basin**
- Detailed reservoir studies have not been performed yet.
- Shale Beds are thickness vary greatly & ‘pinch out’ effect is common.
- Very heterogenous as compared to the Upper Indus.

**LIB** - Ideal place to start with the shale gas exploitation.

**Vertical Multiple Stack Fracturing** - A suitable candidate.
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Real Time evaluation of Shale Gas

**Most Critical Problem of Shale Development in Pakistan** - Lack of Data

Real time Evaluation can:
- Improve the pace of shale exploitation.
- Increase data base.
- Cut shot analysis time.
- Effectively point out the sweet spots.

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Lower Indus Basin -
- Detailed reservoir studies have not been performed yet
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- **Exploration Companies- Consortium**
  - Work Program for next 3-4 years
  - Drilling of vertical, horizontal & multilateral
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- **Service Providers- Consortium**
  - Bring relevant technology
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- Mostly the deep sand formations with very low permeability as low as 0.01 mD can be considered as tight gas sands
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- Early Cretaceous and highly prolific silty sands
- The region has extensional deformation, followed by active compressional movement

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- Late Cretaceous sands, restricted in some regions of lower Indus basin
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Way forward to Tight gas Exploitation in Pakistan

- Core Analyses
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- **Number of wells:** 25
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- **Gas Flow Rate:** 5MMSCFD
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Satellite Map of Sindh

Character of Sindh Coal Fields

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- Coal seams present within the Bara member of Ranikot Formation belong to Paleocene age.
- Coal seams are underlain by thick sand dunes.
- Coal beds are divided into three seams.
- There are three aquifers, one above coal, one within coal and one below seam.
- The basement rock is very shallow and in some areas it is 300m deep.

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Fig. 3.3 Generalized cross-section of Thar (Jaleel et al., 1999). (Block-1, IV, II and III)
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Natural fractures in coal: Cleats

Orthogonal orientation of face and butt cleats

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Thar Analogue

Barmer coal, Cambay basin in India is the extension of Thar coal in Pakistan.

- Thar desert comprises different coal fields of Tertiary times
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- Greater depths are better; however 150m is enough
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(Indian Experience)

Air drilling is suitable for drilling in Thar’s lignite due to its intrinsic properties of being soft in nature and more susceptible to changes.

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Value of Investment on the Prolific Thar

Why Thar?

- Large deposit can provide fuel for power generation 5000 MW at least
- High and constant lignite quality; one of the best lignites in the world
- Domestic fuel. Independence from imports
- Creation of 4000 direct jobs and 15,000 indirect jobs for phase I
- Generation of 1200 MW power generation at least for 50 years
- Competitive cost through other fuels like imported hard coal
- Fossil fuels will continue their dominance accounting for 65% of all the electricity generated in the world, with coal dominating at 44%
- Pakistan could meet the above mentioned world target having Thar as the largest lignite deposit. *Case Study Block II for power generation*
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- Coal seam permeability & gas content
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- Well bore stability
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Technology Selection for CBM Production in the Region - FLOW CHART

[Diagram showing Technology Selection Flowchart]

- **Proximate Analysis & Low depth**
  - (go for Canister gas analysis (Desorption analysis))

- **Permeability Testing**
  - Injection Fall off test

- **Vertical well with single sand completion**
  - Permeability

- **Net economic under current technology**
  - Medium, low, high (>) 30 ft

- **1st Seam - 125m (410ft)**
  - Vertical well with single sand completion

- **2nd Seam - 150m (492ft)**
  - Combined Thickness of all the 3 layers is 75m ( bifurcated seams with varying thickness)

- **3rd Seam - 200m (656ft)**

- **THAR PAKISTAN**

- **Net economic under current technology**
  - Medium, low, high (>) 30 ft

- **Net sand thickness**
  - Very high (> 150 ft)

- **Gas content**
  - High

- **Depth**
  - Shallow, low (< 1,500 ft)

- **Permeability**
  - Medium, high (> 1,500 ft)

- **Coal embedded in sand layers**

- **Vertical distance between seams is approx 62 ft**

- **Vertical well with single sand completion, horizontal fracture stimulation**

- **1st Seam, 2nd Seam, 3rd Seam**

- **Combined Thickness of all the 3 layers is 75m ( bifurcated seams with varying thickness)**

- **Very few (< 3 ft)**
Technology Selection for CBM Production in the Region - FLOW CHART

THAR PAKISTAN

Combined Thickness of all the 3 layers is 75m (bifurcated seams with varying thickness)

Very low (< 3 ft)

Proximate Analysis & low depth, (go for Canister gas analysis (De-adsorption analysis))

Permeability Testing- Injection Fall off test

Vertical well with lenticular seam completion

Very high (> 150 acf)

Permeability

Medium, low, high (> 30 ft)

Net economic under current technology

Low (< 140 Btu/ft³)

Not economic under current technology

Net economic under current technology

1st Seam- 125m (410ft)
2nd Seam- 150m (492ft)
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High, high, low

Low (10 mD)

Less overburden & shallow depth

High (1,000 psi)

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Medium, high (> 1 mD)

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Coal embedded in sand layers

Vertical well with lenticular seam completion or canister completion with hydraulic fracturing stimulation

Very deep (> 40 ft)

No. of stacked stages

Medium, high, low

Low (< 140 Btu/ft³)

Net economic under current technology

Net economic under current technology

High (10 mD)

Very deep (> 6,000 ft)

Vertical well with lenticular seam completion or canister completion with hydraulic fracturing stimulation

Very deep (> 40 ft)

No. of stacked stages

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Proppant Selection For Hydraulic Fracturing

**Engineering Practices**

<table>
<thead>
<tr>
<th>Engineering Practice</th>
<th>Key Reservoir Parameters</th>
<th>Cut off Values</th>
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<td>Top set under ream</td>
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<td>&lt;1,800ft</td>
</tr>
<tr>
<td></td>
<td>Coal Seam thickness</td>
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<td>Dip of Coal Seam</td>
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<tr>
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<tr>
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<td></td>
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<td>stimulation (multi-stage)</td>
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Gas Hydrates in Pakistan

ICE that burns!!

Figure 2. Global map of recovered and inferred gas hydrates, modified from Collett et al. (2009). The color coding refers to drilling programs highlighted in the gas hydrates research timeline shown in Figure 5. This map includes gas hydrates recovered from both shallower depths, which are generally not considered relevant for resource studies, and greater depths. For full discussion see Ruppel et al. (2011).
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Makran Coast in Pakistan

- Makran microplate is situated on the south western boundary of the Indo-Australian plate
- This is the coastal region of Baluchistan with a diverse geology
- A chain of approx. 18 mud volcanoes is distributed on the coastal belt both on- and offshore. There relief is around 250 feet above sea level. They are formed due to the subduction of Makran plate into Arabian plate.
- It has been expected that Makran offshore (continental slope and rise) and the mud volcanoes region might contain gas hydrates.

Mud Volcano Near Coastal Belt of Baluchistan

- Gas bubbles
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Figure 5: (a) Stability Thickness Map of GH in the Continental Margin (Kvenvolden & Barnard, 1982) and (b) Phase Curve for GH Stability (Sloan, 1998)

Seismic Identification of Gas Hydrates, BSR in Continental Margin off Pakistan

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Favorable Controls for Gas Hydrates

- Convergent boundary – Makran subduction zone
- Low temperature and high pressures in past – Pleistocene glacial period
- Mud volcanoes along the coast – approx. 18 mud volcanoes are present near Makran coast. They are emitting gas continuously.
- Depth range in marine setting around 1000-1600m below sea surface with temperature conditions max. up to 20°C
Lateral Variation of Gas Hydrates and Free Gas

(Ojha, Sain and Minshull, 2010, Geophysics).

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De-Pressurization Hydrate Production

Thermal-Injection cycle Gas Hydrate production

Hydrate Drilling Challenges That Might Be Faced in Offshore Pakistan
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Hydrate Drilling Challenges That Might Be Faced in Offshore Pakistan
Challenges Associated with Hole Enlargement

More Challenges…
Challenges Associated with Hole Enlargement

More Challenges...
SUMMARY

- Enough unconventional reservoirs exist in the country
- Unconventional reservoirs are required to be evaluated by collection of more data by initiating pilot projects in shale gas as early as possible
- Exploration blocks may be awarded for unconventional reservoirs
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- Unconventional reservoirs are required to be evaluated by collection of more data by initiating pilot projects in shale gas as early as possible
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Thank you

Queries can be made directly to authors

For geological aspects, geochemical analyses and mapping, direct questions to:

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Syeda.ayaz@uqconnect.edu.au

For technological perspective, direct questions to:

Batool Arhamna (Author: Technological Solutions to Unlock Unconventional Potential of Pakistan)
Batool.haider@me.weatherford.com