Shale Gas Potential of Lower Cretaceous Sembar Formation in Middle and Lower Indus Sub-Basins, Pakistan*

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Abstract

Natural gas production from tight shale formations, known as "shale gas", has become an important source of natural gas in the world due to technological advances and rapid increases in natural gas prices as a result of significant supply and demand pressures. Pakistan is facing big challenges in meeting its ever growing energy needs due to an expanding population and economic growth. It is necessary to exploit unconventional energy resources along with conventional ones to meet the country's energy requirements.

Here we investigate shale gas potential of the Lower Cretaceous Sembar Formation within a large area of the Middle and Lower Indus Basin. The study includes the organic richness, hydrocarbon generative potential, shale thickness and distribution, subsurface depth of studied interval, maturity, volume of hydrocarbon generated and retained per section, and reservoir characteristics of the Sembar shales.

Geochemical data show that the TOC of the formation ranges from 0.55 wt.% to 9.48 wt.% with present day generation potential of 0.14-18.69 mg HC/g rock. The average TOC of immature samples is 1.0 wt.% with a generation potential of 2.88 mg HC/g rock and hydrogen index (HI) of 240 mg HC/g TOC (type III & II/III).

Gross thickness of the formation ranges from less than 50 m to more than 1000 m with an average of 300 m in the study area. Subsurface depth (top of the formation) varies between 1000 to 5000 m in platform to foredeep areas. Overburden thickness, geothermal gradient, Tmax and Vitrinite Reflectance data place the formation in oil, wet and dry gas windows at the depths of 2500 m, 3200 m and 3400 m respectively. Based on original generation potential, and average source rock thickness, volume of generated hydrocarbon (gas equivalent) is 242 bcf/section. By taking expulsion (50% of the generated volume) into account and conversion of retained oil into gas through secondary cracking, the retained volume is 103 bcf/section. Average porosity of the formation at reservoir level (3400-4000 m) is 6.0%.

Mineralogically, the formation is composed of an average of 42% quartz, 47% clay, 3% calcite and 1% pyrite. Depth for shale gas exploitation in platform areas is about 3500 m, whereas in foldbelt regions, it varies between 1000 to 3000 m.

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Shale Gas Potential of Lower Cretaceous Sembar Formation in Middle and Lower Indus Sub-Basins, Pakistan

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INTRODUCTION

- Natural gas production from tight shale formations, known as "shale gas", has become an important source of natural gas due to technological advances and rapidly increasing gas prices as a result of significant supply and demand pressures;

- Pakistan is facing big challenges in meeting its ever growing energy needs due to expanding population and economic growth;

- It is necessary to exploit unconventional energy resources along with conventional ones to meet the country's energy requirement.

SHALE GAS

- Shale gas refers to as in situ hydrocarbon gas present in organic rich, fine grained, sedimentary rocks (shale and associated lithofacies);
- Gas is generated and stored in situ in shales;
- Shale gas is typically a dry gas composed primarily of methane but some formations do produce wet gas;
- Gas is stored in shale source rocks in two principal ways;
  - As adsorbed and absorbed (sorbed) to or within the organic matrix;
  - As free gas in pore spaces or in fractures.

SHALE GAS

Key parameters for gas shale deposits include:

- Total Organic Carbon (TOC);
- Thermal maturity;
- Shale thickness;
- Shale characteristics (brittleness / mineralogy, porosity / permeability);
- Free gas fraction within pores and fractures, and adsorbed gas fraction within the organic matrix.

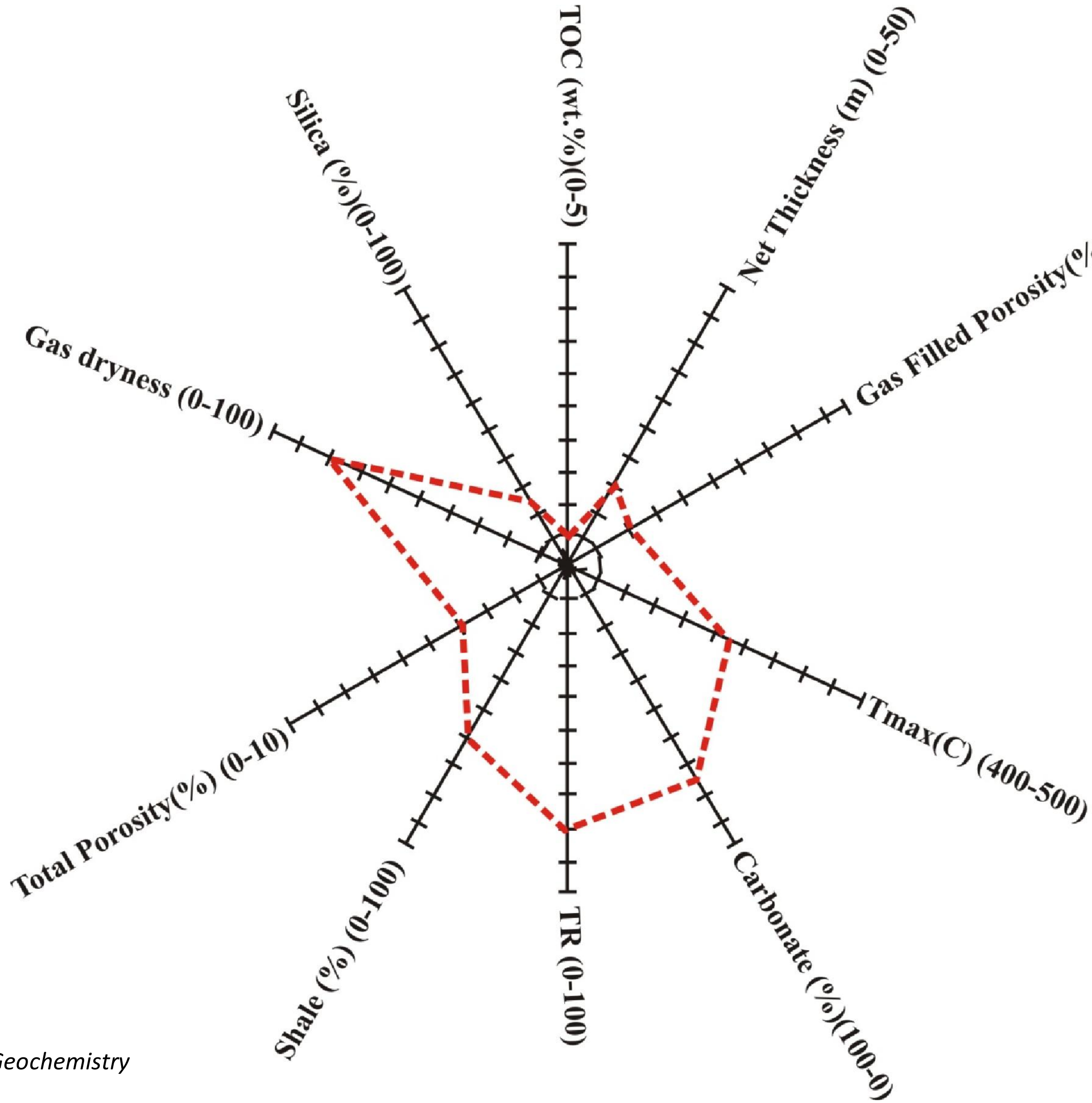
Shales that host economic quantities of gas are:

- Rich in organic material (0.5wt. % to 25wt. %), ;
- Usually thermally mature;
- Sufficiently brittle and rigid enough to maintain open fractures.

POLAR SHALE-GAS RISK PLOT

Any shale to qualify as a shale gas reservoir should fall outside the red boundary.

TOC (wt.%)	0.50
Tmax (C)-Ro(%)	455, 1.0
Transformation Ratio	80
Gas Dryness (%)	80
Total Porosity (%)	4
Gas Filled Porosity(%)	2
Net Thickness(m)	15
Shale (%)	60
Silica (%)	25
Carbonate (%)	<25



D M. JARVIE, 2008; *Energy Institute, TCU / Worldwide Geochemistry*
D M. Jarvie et.al, 2007; AAPG Bulletin, v. 91

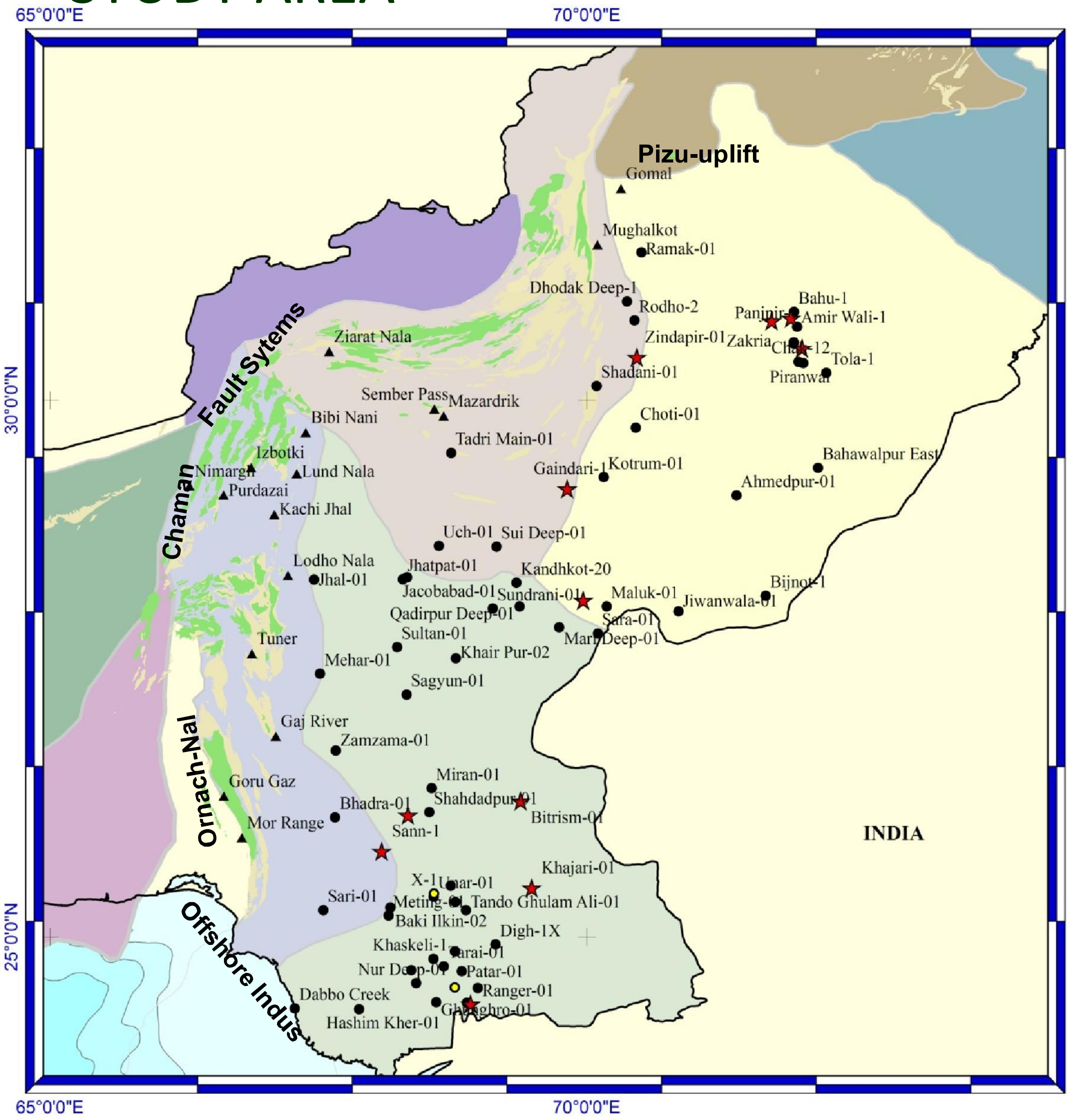
OBJECTIVES

The objectives of this paper are to assess the Sembar Formation as shale gas reservoir and to priorities the areas in term of:

- Shale thickness;
- Its hydrocarbon generation potential;
- Current depth and maturity;
- Reservoir characteristics.

STUDY AREA

- Study area ~ Middle and Lower Indus sub-Basins.
- Bounded by;
  - Pizu-uplift to the north;
  - Offshore Indus Basin ~ south;
  - Ornach-Chaman Fault systems to the west,
  - Easternmost drilled wells mark the eastern limit.



DATA SETS

- Total Organic Carbon (TOC) and Rock-Eval pyrolysis data of 11 wells, 135 data points;
- Well data (depth & thickness);
- Rock-Eval Tmax, Vitrinite Reflectance and Thermal Alteration Index (TAI) data;
- Conventional logs (GR, NPHI, RHOB, PEF & DT).

METHODOLOGY

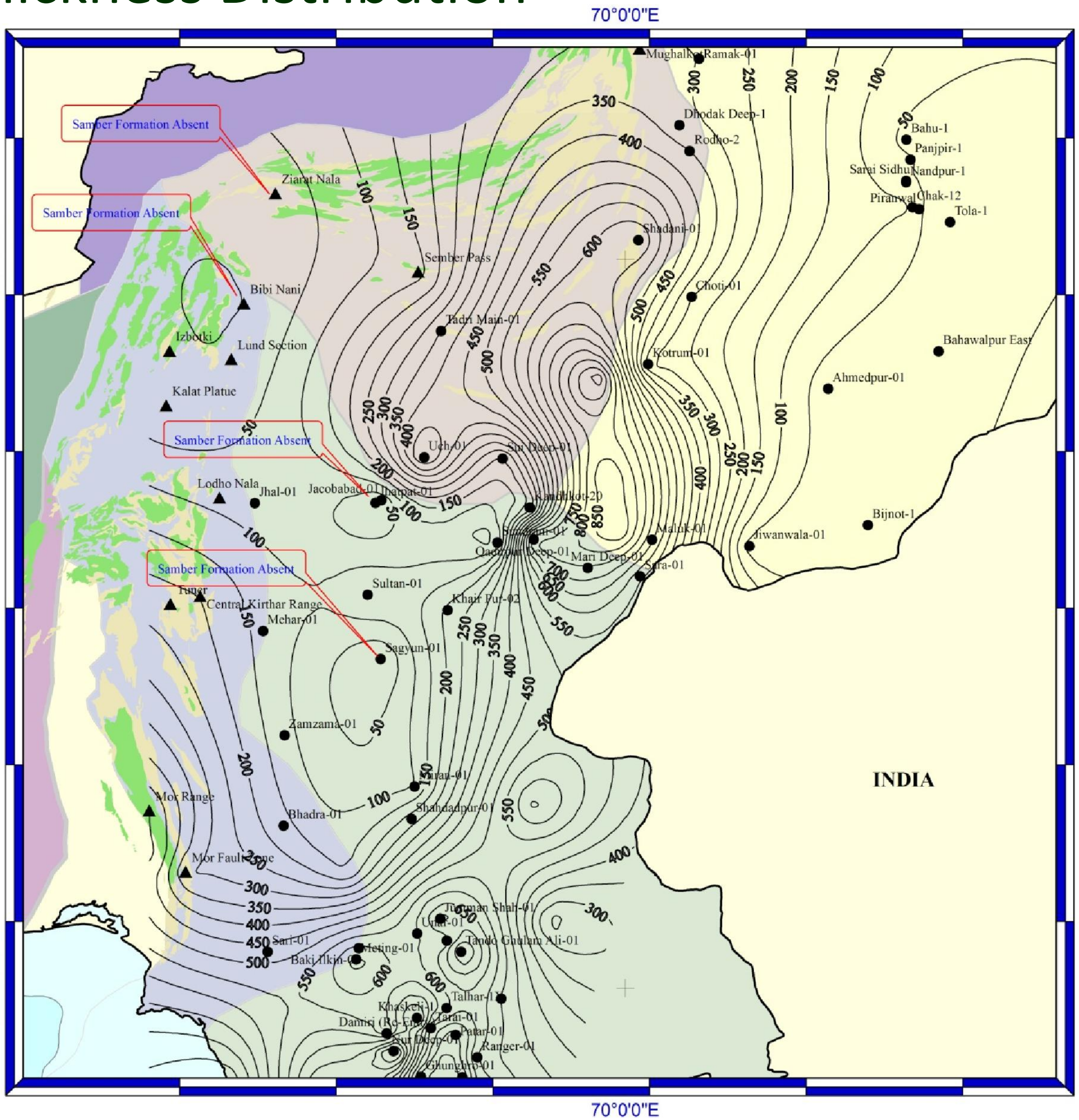
- Cross-plots of TOC vs. S2 were prepared to assess the source potential and type of organic matter;
- Well data were utilized to prepare thickness, top and base depth maps;
- Rock-Eval Tmax, Vitrinite Reflectance and Thermal Alteration Index (TAI) data were utilized to assess the maturity levels of the Formation;
- Volume percentages of minerals from a single well(X1) were computed by Spectrolith Quantitative lithology interpretation based on elemental concentrations:
  - Conventional logs (GR, NPHI, RHOB, PEF & DT) were loaded into Geoframe;
  - ELanplus module of Geoframe was used to analyze formation components;
  - Total rock volume of Sembar Formation is divided into five lithologic fractions: clay, carbonate, pyrite, siderite, and Quartz+feldspar+mica.
- Porosity was calculated by using neutron, density and sonic logs combination.

GEOLOGY OF SEMBAR FORMATION

- Sembar Formation was deposited in a passive margin setting with sediments supplied from Indian continent to the southeast;
- It is composed dominantly of clastic rocks, mostly shale with lesser quantities of sandstone and siltstone in the Lower Indus. The sand content increases towards southeast in Lower Indus basin;
- In Middle Indus Basin, the formation is composed of shales and siltstone with some marl. In eastern part of Sulaiman Foldbelt, it becomes sandy within the lower part;
- Glauconite is commonly present;
- In the basal part, pyritic and phosphatic nodules and sandy shales are developed locally;
- Shale is medium hard, moderately indurated, pyritic, silty and slightly calcareous in the study area.

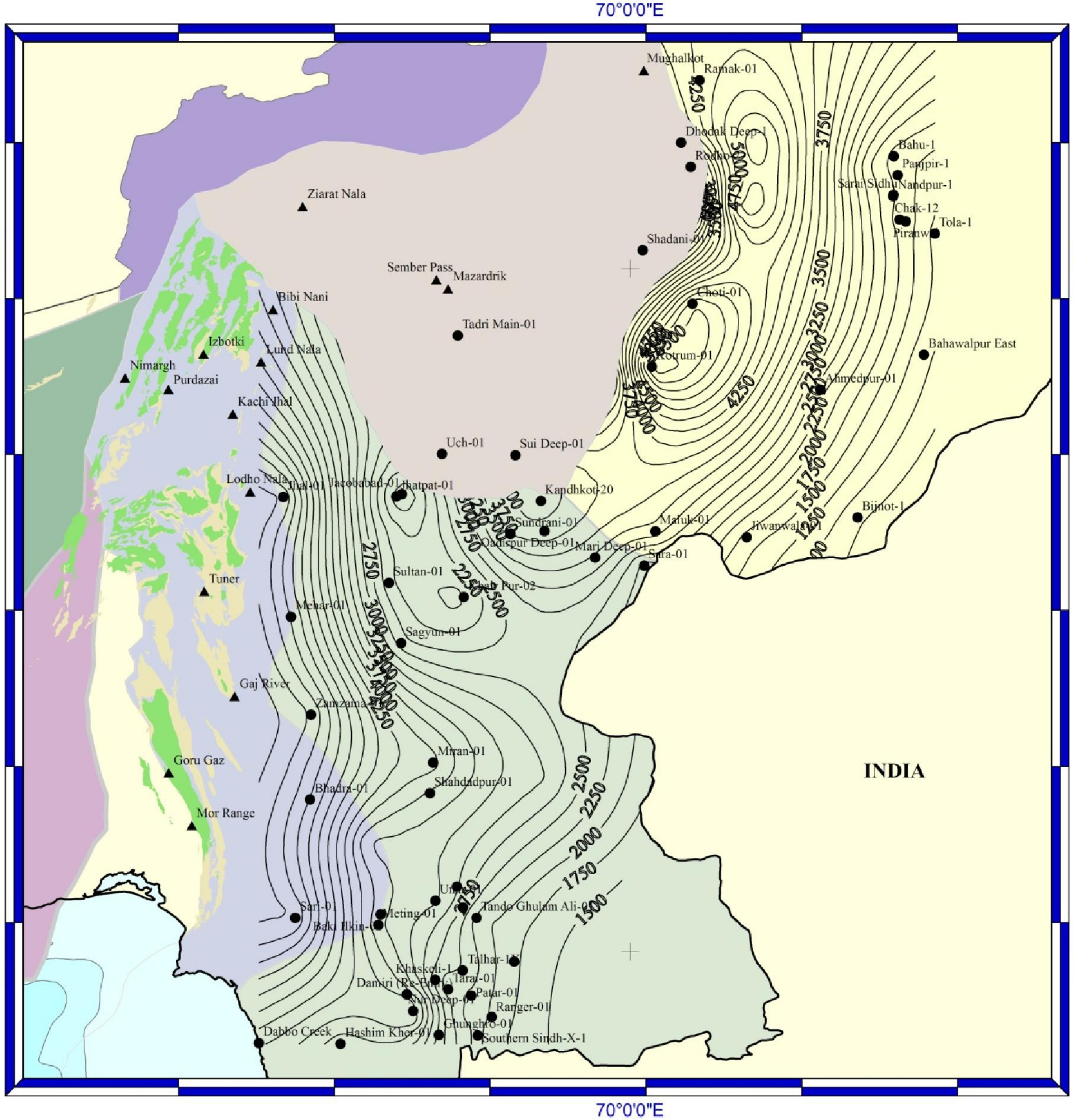
Thickness Distribution

- Gross thickness ranges from less than 50 m to more than 800 m;
- Thickness increases from east and west towards depocenters;
- Sediments are missing in western Sulaiman Foldbelt and northern Kirthar FB;
- Sediments are missing on Jacobabad and Sagyun Highs in Lower Indus Platform.



SUBSURFACE DEPTH

- Subsurface depth ranges from less than 1000m to more than 5000 m in the study area;
- Depth increases towards foredeeps;
- In Lower Indus and Punjab Platforms, depth of the formation ranges from 1000m to 4000m;
- In Sulaiman and Kirthar Foredeeps, depth is more than 5000m;
- In Kirthar and Sulaiman Foldbelts, depth varies between 1000 to 3000m.



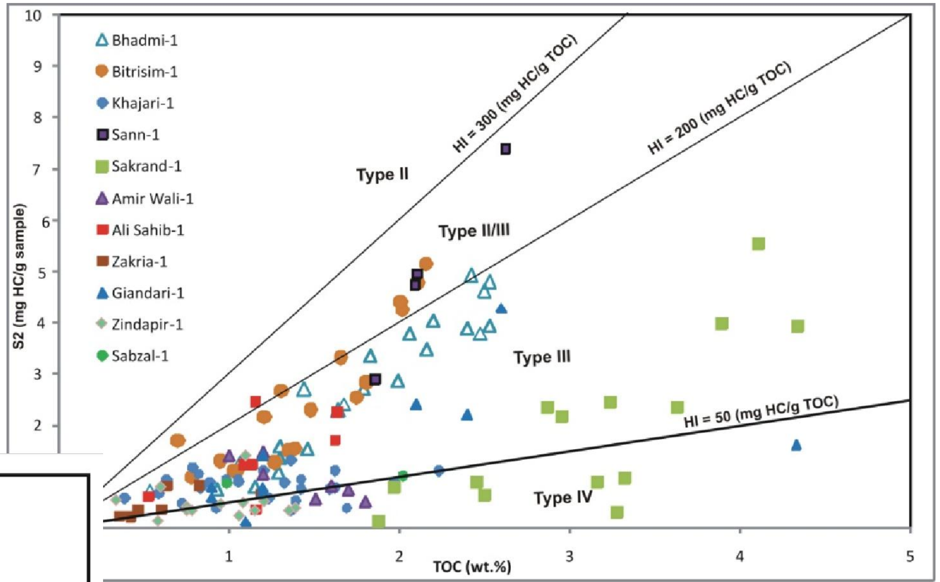
SOURCE POTENTIAL

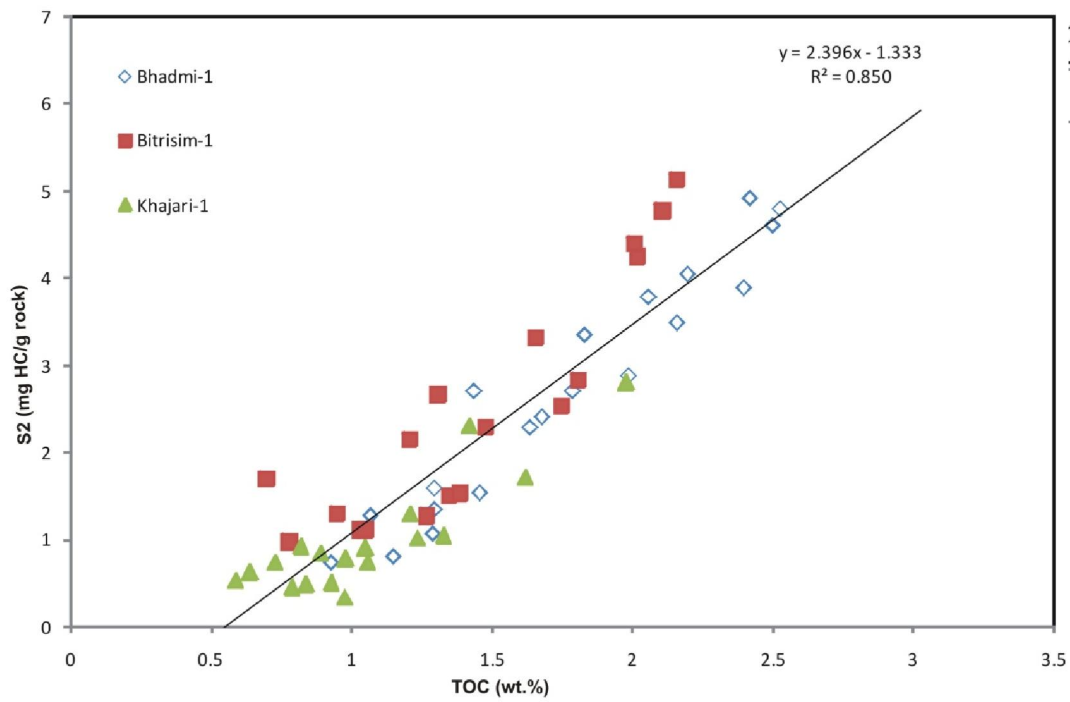
Punjab Platform, TOC <0.5 - 1.64wt.% ;HI ~212

Sulaiman Foldbelt, TOC~ 0.56 - 4.33 wt.%

Lower Indus Platform, TOC <0.5 to 4.15 wt.%

Kirthar Foldbelt, TOC ~ 0.83 - 3.0 wt. %





- Plot of S2 verses TOC of immature to early oil-mature samples
- The slope of the regression line gives an average (HI) and percentage of pyrolyzable hydrocarbon in TOC
- Average TOC ~ 1.0 wt.%
- Convertible OM ~ 24%
- HI ~ 240 mg HC/g TOC

HYDROCARBON GENERATION, EXPULSION AND RETAINED POTENTIAL

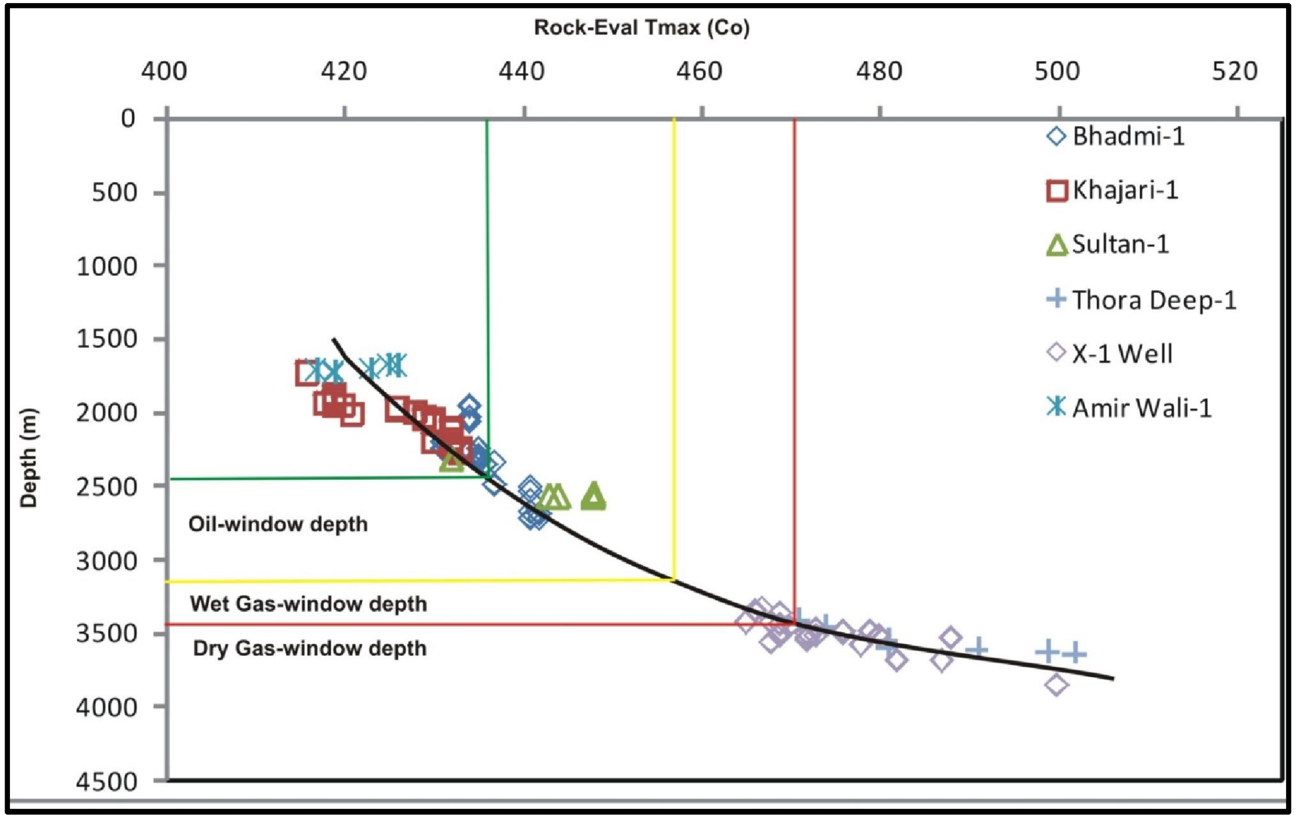
TOCC (wt.%)	0.24
Original generation potential (mg HC/g rock)	2.88
Estimate of amount of oil generated from kerogen (30% of original HC potential)(bbloil/ac-ft)	19
Estimate of amount of gas generated from kerogen (70% of original HC potential)(mcf/ac-ft)	265
Source rock thickness (ft)	1000
Primary oil generated from kerogen with above thickness (mmbo/section)	12
Primary gas generated from kerogen f with above thickness (bcf/section)	169
Total hydrocarbons (gas and oil) generated from primary cracking of kerogen(gas equivalent bcf/section)	242
Expulsion factor	0.50
Oil expelled (bbl oil/ac-ft)	9
Gas expelled (mcf/ac-ft)	132
Retained hydrocarbons	
Primary oil retained in shale (bbl oil/ac-ft)	9
Primary gas retained in shale (mcf/ac-ft)	132
Correction factor for insufficient hydrogen in oil	0.49
Gas yield from secondary cracking of oil (mcf/ac-ft)	28
Total retained gas (primary gas plus secondary gas from oil cracking) (mcf/ac-ft)	160
Total retained hydrocarbons under these assumptions (bcf/section)	103

Conversion of wt.% CC to mg HC/g rock, divide by 0.08333.
Conversion of Rock-Eval S2 in mg HC/g rock to bbl oil/ac-ft, multiply by 21.89.
Conversion of Rock-Eval S2 in mg HC/g rock to mcf/ac-ft, multiply by 131.34
Section = 640 acr or 2.59 sq.km

SOURCE ROCK MATURITY

- Ro data ranging from 1.0% to 3.9% in Sulaiman FB
- Lower Indus Basin, Ro~ 1.0% @ 3000m (Tarai-1 well)
- In Kirthar Trough, TAI ~ 2.9(Sann-1 well), place the Sembar Formation in gas window at the depth of 3530m

- Maturity of organic matter increases with increase in Tmax;
- Oil genesis > 435ºC;
- Cond. zone > 455°C;
- Dry Gas > 470°C.



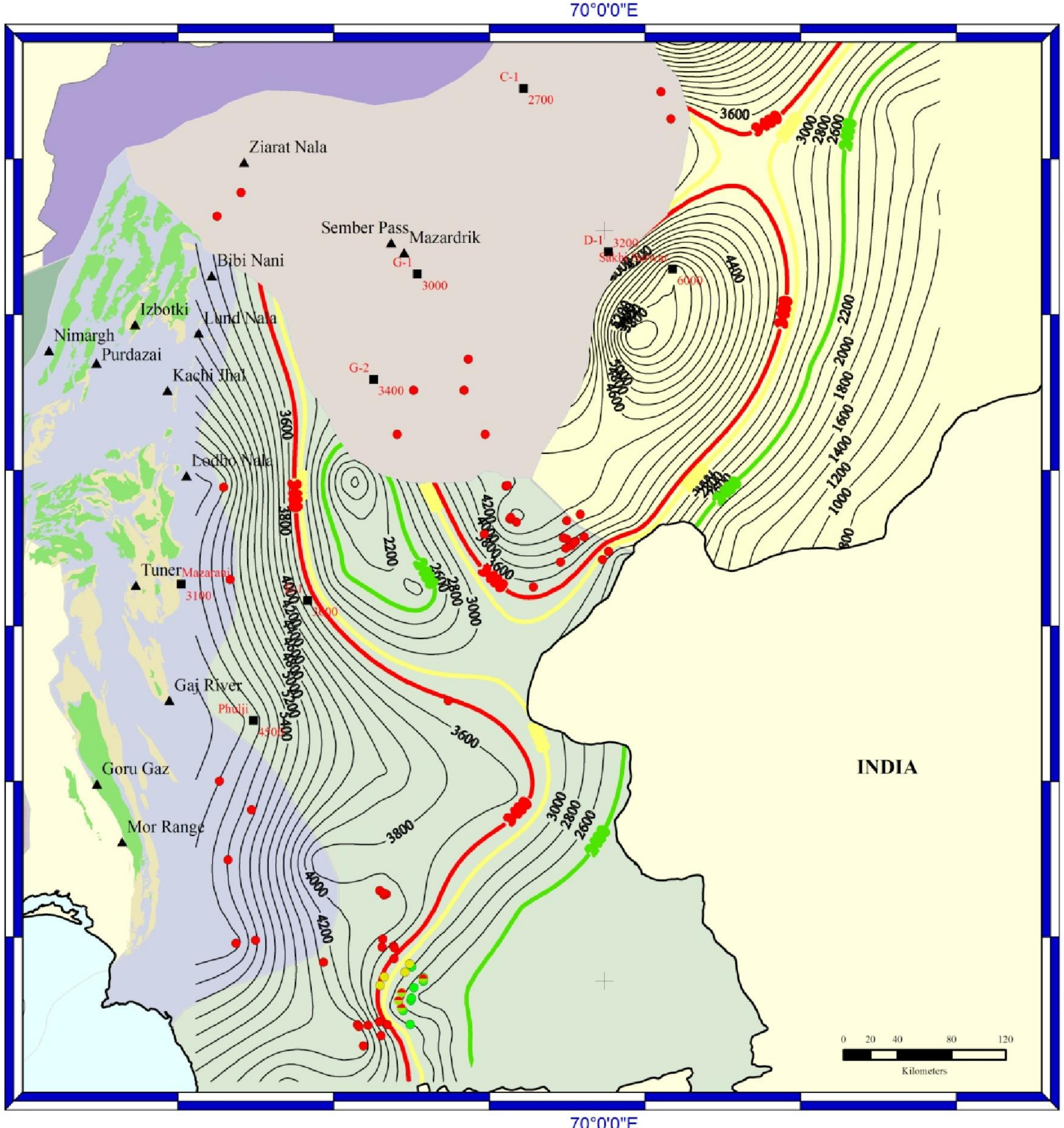
MATURITY MAP

- Maturity increases, east to west;
- Formation is Gas mature in Foredeeps, foldbelts, and Lower Indus Platform:

Oil depth

Condensate depth

Dry gas depth



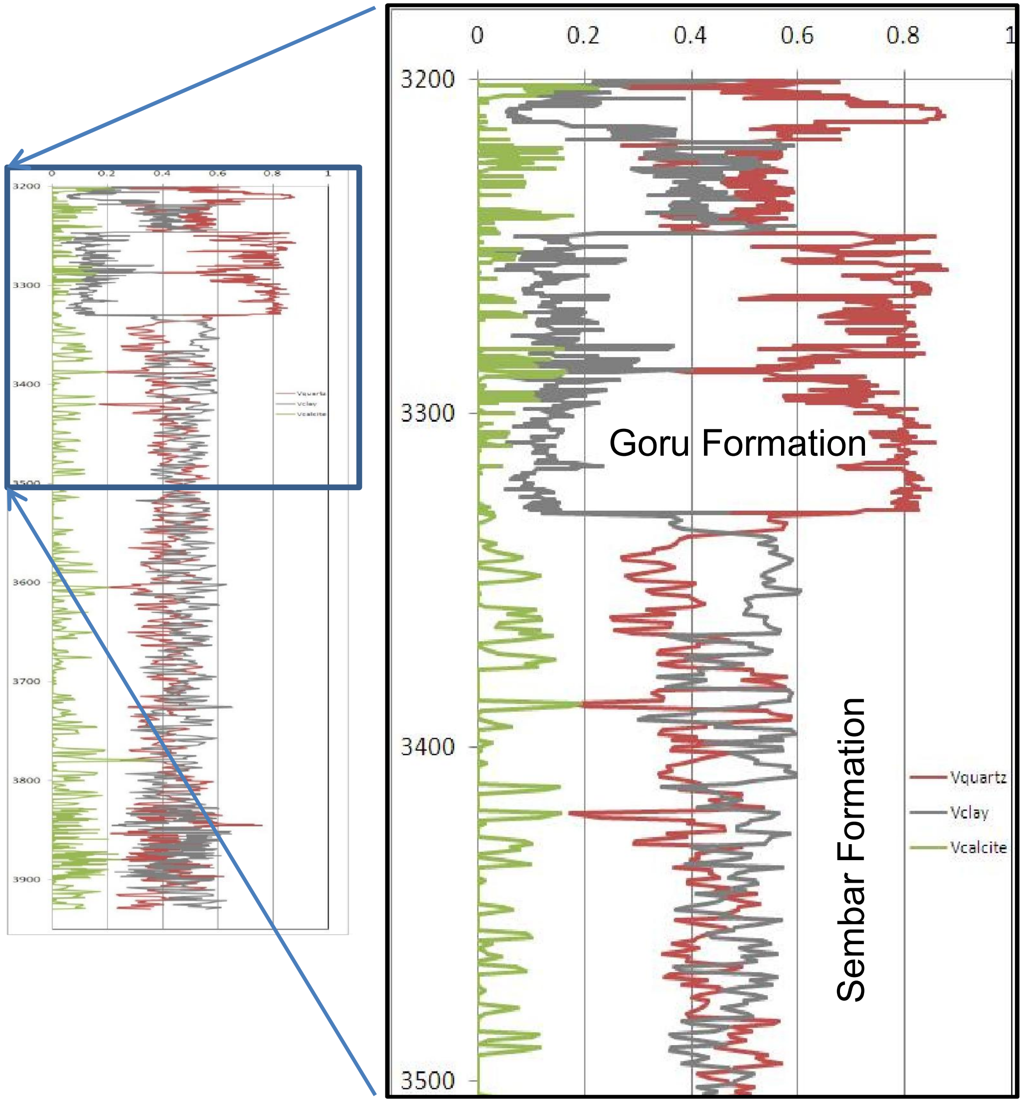
RESERVOIR CHARACTERISTICS

Mineralogy

- Volume percentages of clay, quartz and carbonate contents were calculated from well X-1 in the Lower Indus Basin;

- Fractional volumes of these minerals were plotted against depth:

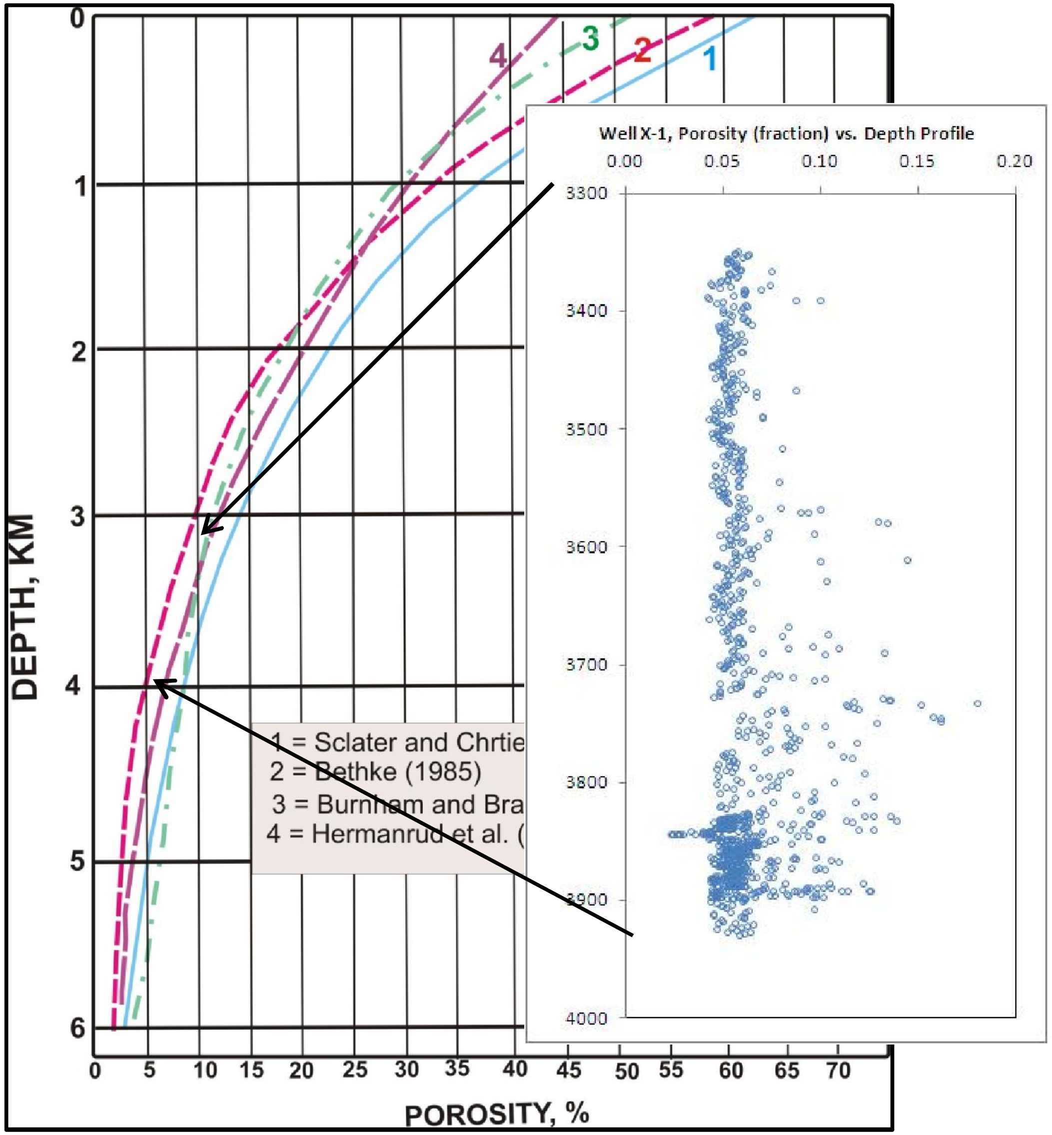
  - Quartz 30 – 50%;
  - Clay minerals 35 - 60%;
  - Calcite 00 - 12%.



RESERVOIR CHARACTERISTICS (Cont.)

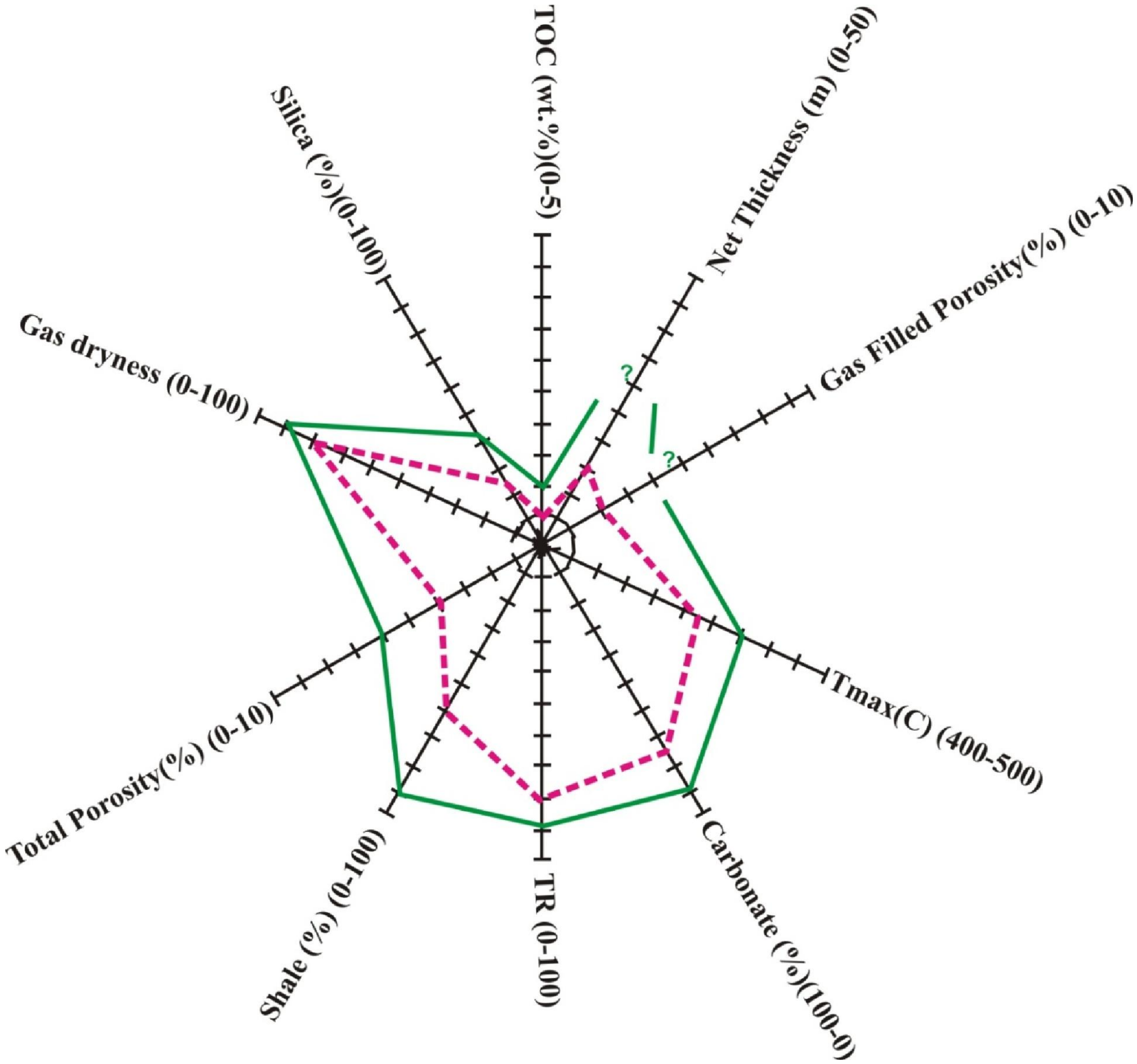
Porosity

- Estimates of porosity from logs suggest that normally pressured sediments exhibit an exponential relationship of the form $\Theta = \Theta o e^{-cy}$;
- The porosity-depth relationship Curves by various authors show Shales at surface porosities 46 - 65%, Reduced to 3% at the depth of 6 km;
- Porosity of Sembar shale ~ 5-7% .



POLAR RISK PLOT - SEMBAR SHALE

TOC (wt.%)	1.00
Tmax (C)-Ro(%)	470, 1.0
Transformation Ratio	90
Gas Dryness (%)	90
Total Porosity (%)	6
Gas Filled Porosity(%)	?
Net Thickness(m)	?
Shale (%)	>90
Silica (%)	42
Carbonate (%)	12



Threshold values

Sembar shale values

RESULTS & CONCLUSIONS

- Sembar Formation is widely distributed in the Middle and Lower Indus Sub-basins;
- Thickness of the formation ranges from less than 50m to more than 800m;
- Subsurface depth of the formation ranges from less than 1000m to more than 5000m;
- It has good organic richness with mixed (type III, II/III) organic matter. An average TOC is 1.0 wt.% with generation potential of 2.88 mg HC/g rock and hydrogen index of 240 mg HC/g TOC;
- The computation of original generation potential yields about 378 mcf gas equivalent/ac-ft.

RESULTS & CONCLUSIONS

- It is thermally mature (gas) below the depth of 3400m;
- Mineralogically, it comprises an average of 42.0 % quartz, 47.0 % clay, 3.0 % calcite and 1.0 % pyrite;
- In platform areas, the depth to exploit shale gas is about 3500m while in foldbelts, depth varies between 1000m to 3000m;
- Geochemical parameters, physical characteristics and mineralogical composition make it potential candidate for gas shale play in Lower Indus Platform, in foredeeps and in foldbelt areas.

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