2019 Annual Technical SYMPOSIUM & Exhibition

Must have Values in Exploration:

- ***Concepts competency***
- ***Perseverance***
- ***Consistency***
- ***Collaboration & Stakeholders Awareness***
- ***Entrepreneurship***

Dr. Nadeem Ahmad

Where oil is first found
Is in the minds of 'humans'

Wallace Pratt, 1952

Seismic Stratigraphy for Prospect Mapping

New Plays and Unusual traps for Next Generation Exploration in Pakistan

Pre-conference Short Course – ATS2019

Nadeem Ahmad, Ph.D.

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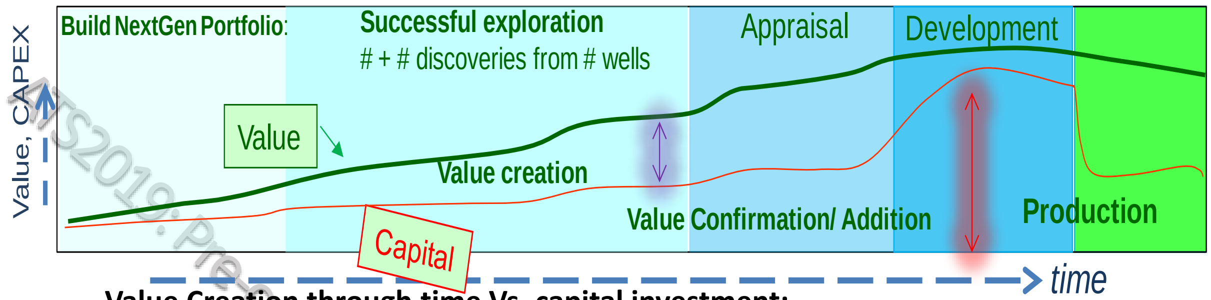
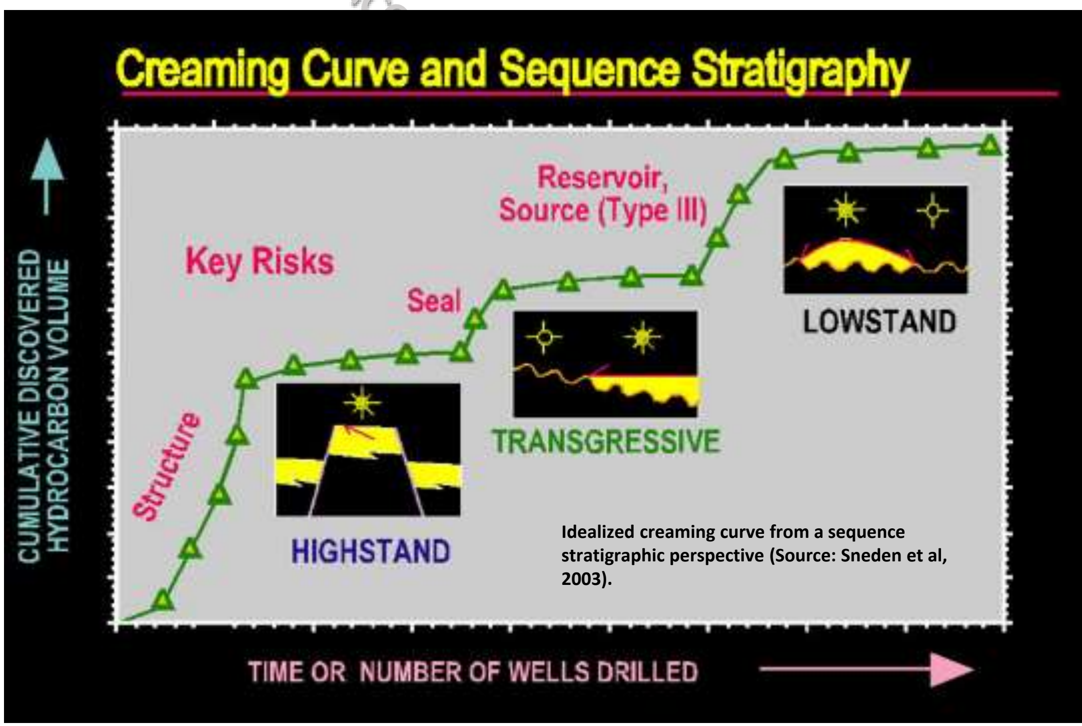
Business Context of Prospects: Petroleum Value Chain & Drilling opportunities for new reserves



Value Creation through time Vs. capital investment: Gap shows exploration performance and also the timing of farm-in/farm-out.



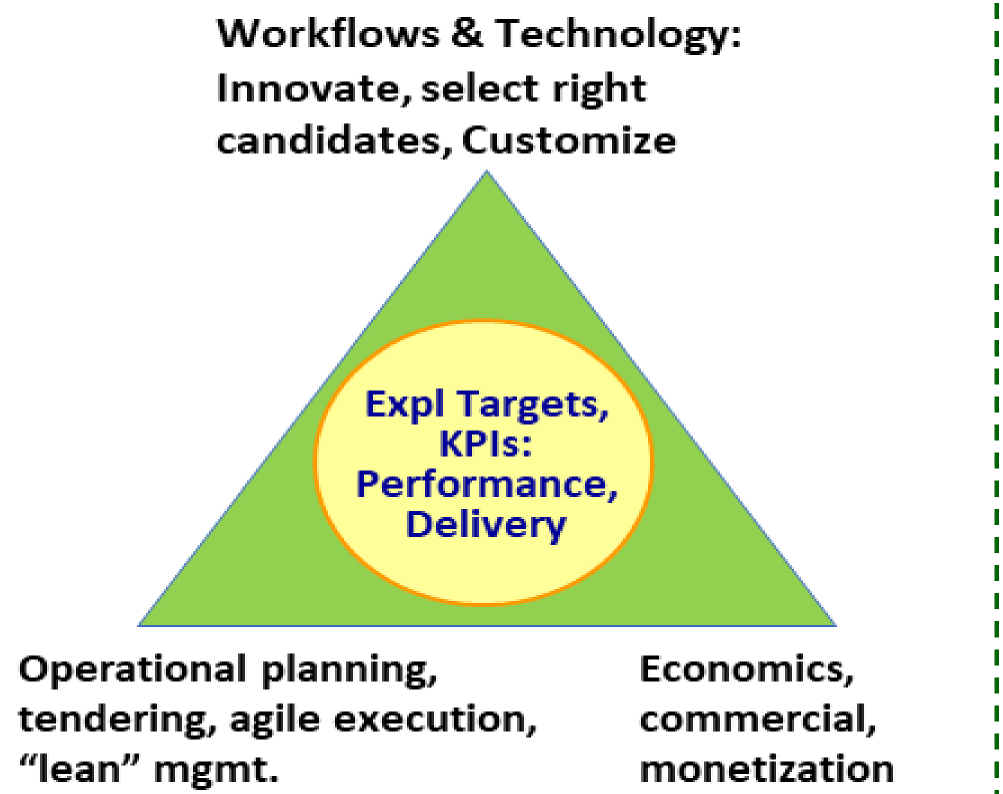
Idealized creaming curve from a sequence stratigraphic perspective (Source: Sneden et al, 2003).

- Powerhouse and Growth Center of an E&P company: Exploration Portfolio and Hopper (Plays & Prospects Inventory; PPI). Health Checks and Redressing the bottlenecks
- Exploration Performance of the basins has significantly improved in last 2 decades, mainly due to:
  - Early understanding of the target Plays, their key uncertainties and technologies needed for de-risking,
  - Deploying key technologies in timely and operationally effective manner. But: New Oil mostly in previously in inaccessible areas or unusual geological settings, and waiting to be developed!
- **'New value creation'** lies in Exploration and that with a very small Capex as compared to Appraisal & Dev. (ref. left side graph).
- Entry in new Basins & Plays which are in emergent phase means larger discoveries (right side graph). IOCs and NOCs with Giants in their portfolios use this approach to replace reserves.

Exploration Portfolio: Acreage, Inventory of Plays & Prospects, Skill Pools

- Acreage: Sedimentary basins with proven and yet-to-prove Petroleum Systems.
- Drivers of building acreage position: 1) Subsurface setting, 2) Market access, Geopolitical, 3) Emerging vs. Mature
- A deeper look into the drivers of exploration business and exploration planning & execution activities (ref. figure at right)

Key Drivers of Optimal Exploration

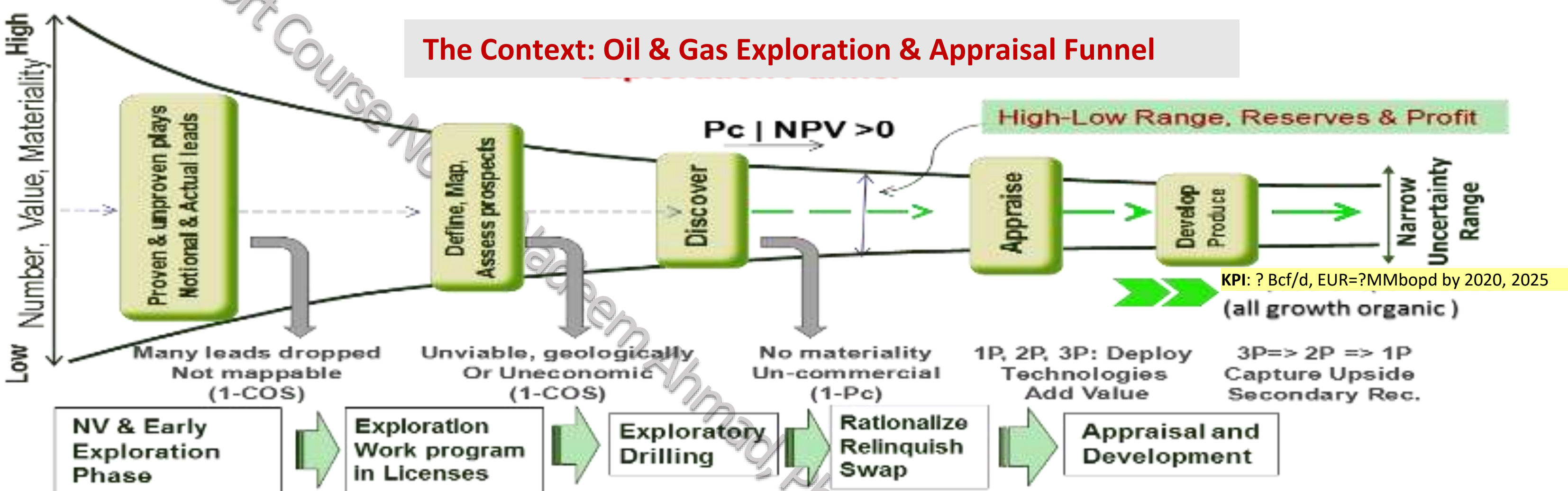


Exploration Portfolio: Business Framework, Acreage, Inventory of Plays & Prospects, Skill Pools

Value identification, phased de-risking, Farm-in/Farm-out or Swap, drill, discover, appraise, monetize!

Actions & Activities to achieve rationalized exploration portfolio, optimal operating performance and cost effectiveness can be grouped into three (3) areas:

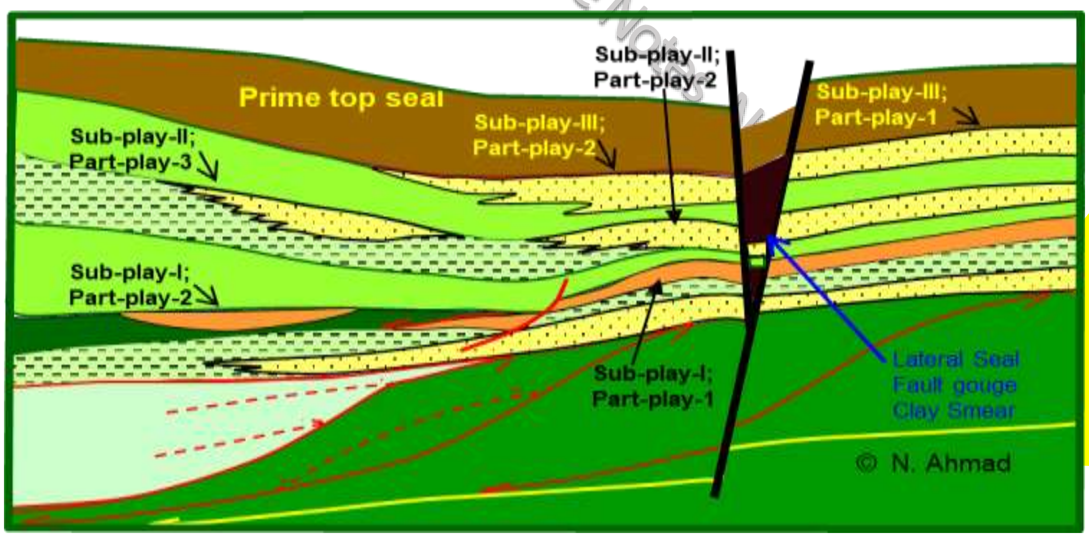
- Business Processes: **Controls & Assurance frame/Processes** customized to local challenges,
- **De-risking of exploration targets**: deploy customized workflows and technologies to match specific subsurface geological & engineering challenges. Target: technical, economic viability.
- Operations planning keeping in view surface bottlenecks, Surface Risks (Security, HSE, geopolitics, and access to facilities, infrastructure, market) and timely onset of Operations/continuity.

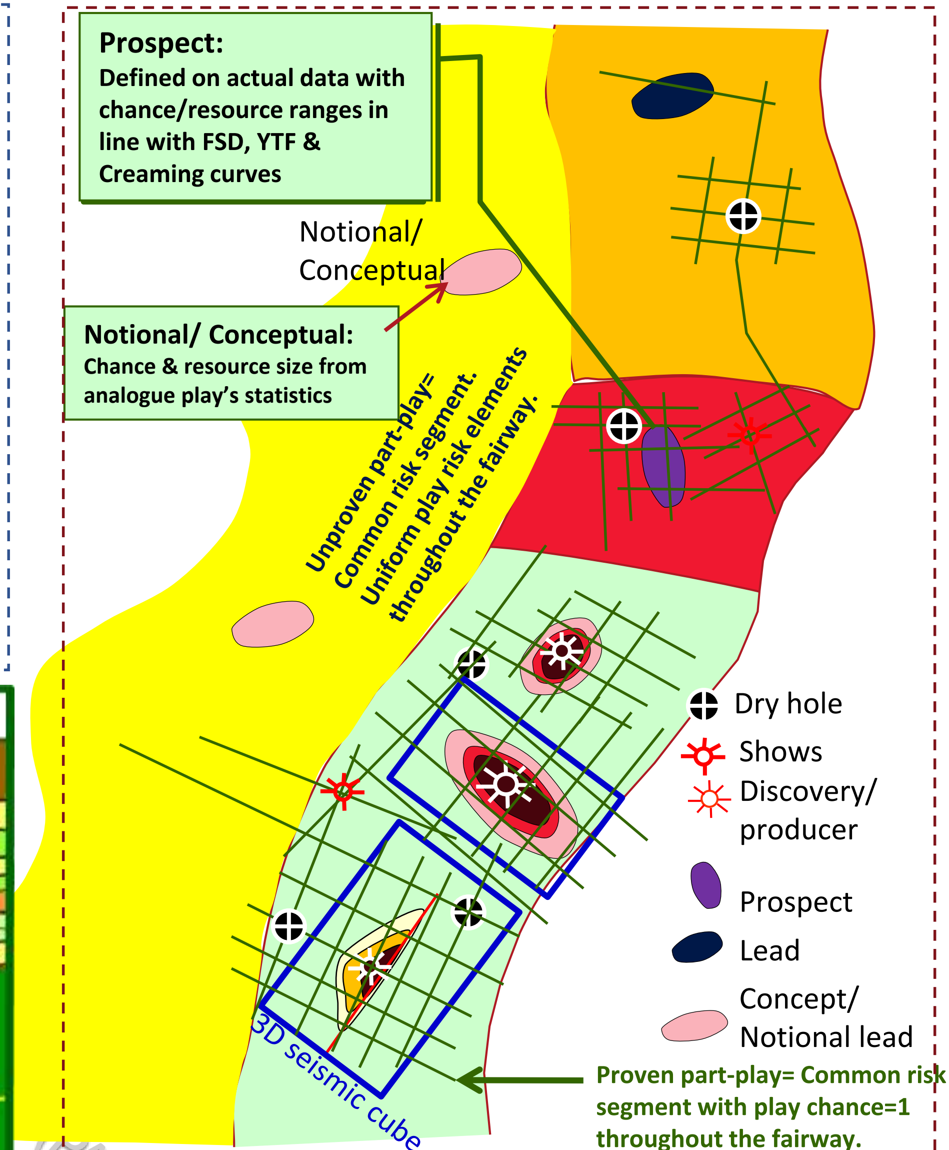


Quality & Value Assurance throughout the Exploration Funnel: Value identification, phased de-risking, Farm-in/Farm-out or Swap, drill, discover, appraise, monetize!

Inventory of Plays & Prospects: Play Concept & Definitions

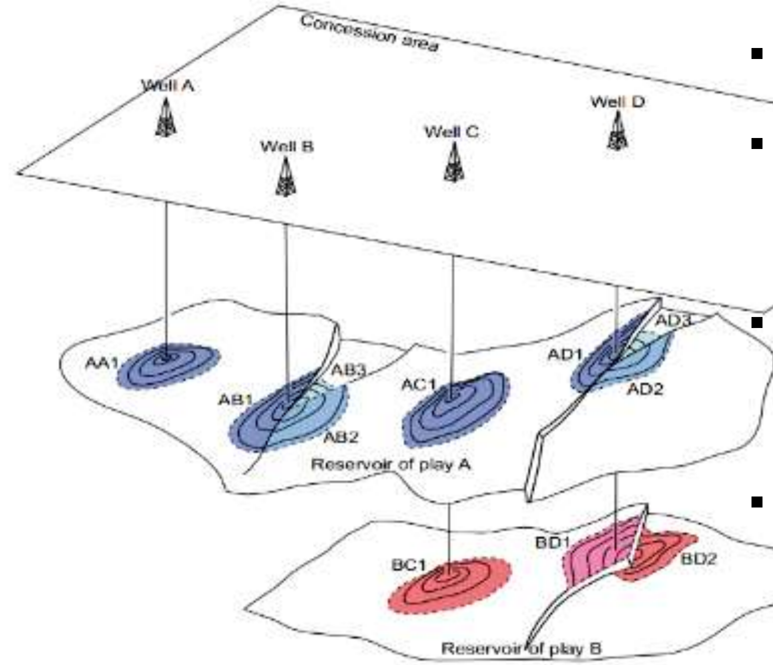
- **Play, conventional approach – Reservoir focus**
- **In hierarchical framework of petroleum system**
- **Play: a reservoir-seal Pair, stretched over basin:**
  - **Pair of Reservoir and its genetically associated top seal in hierarchical sequence stratigraphic framework**
  - **Specific spatial and 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**





Inventory of Plays & Prospects

- Plays & Prospects Inventory:
  - Play fairways in proven and yet-to-prove Petroleum Systems,
  - Prospects in Prove and yet-to-prove Play fairways (CRS maps).
  - Prospects with single vs. multiple trapping elements and reservoir-seal week links,



- **Well A:** Targets Single Segment prospect
- **Well B**: Multi-segments prospect comprising a single pot. accumulation with multiple risk segments
- **Well C:** Stacked multi-segments prospect: two single segment accumulations in two different plays
- **Well D:** Stacked multiple segmen prospect: two pot. accumulation each with +1 risk segments

Table 3 : Probablistic Resource and Risk Assessment of Stratigraphic Traps

			P90-P50-P10				Play Level Risking, Probability			L
			Area (km^2)	Net Sand (m)	Porosity	EUR, Bcf Sales Ga	Pl_Res GD	Pl_Top-seal GDE	Model Risk_	stı S
1	Prospect Z, Fig. 16-17	55	20-50-90	10-18-25	10-14-22	100-285-810	0.8	0.8	0.7	
1a	Prospect Z1_facies	50	25-50-80	10-18-25	10-14-22	120-302-760	1	1	1	
1b	Prospect Z2_facies+fault	36	16-30-50	8-14-22	8-13-18	46-110-272	1	1	1	
2	Prospect X, Fig. 17	8	1.5-8-16	10-15-22	8-12-18	24-45-120	1	1	0.8	
2a	Prospect X_facies-w	1.5		8-12-20	8-12-18	6-9-18	1	1	0.9	
2b	Prospect X_facies-E-W+fault	8	1.5-8-16	10-15-22	8-12-18	24-45-120				
3	Prospect Y, Fig. 17	13.1	10-13-20	10-15-22	10-13-18	38-77-155	1	1	0.9	
3a	Prospect Y1_2f(facies+fault)	6.3	4-6-10							
3b	Prospect Y2-south_2f (facies+thief-sd	6.8	4.5-7-11							

Petroleum system (source richness, maturity, migration pathways) are set to 1 (proven
3f=2 sides by facies change, 3rd by lateral fault seal
Bold font where weaker link used.
GIIP* : only the input parameters critical for this discussion are listed here.

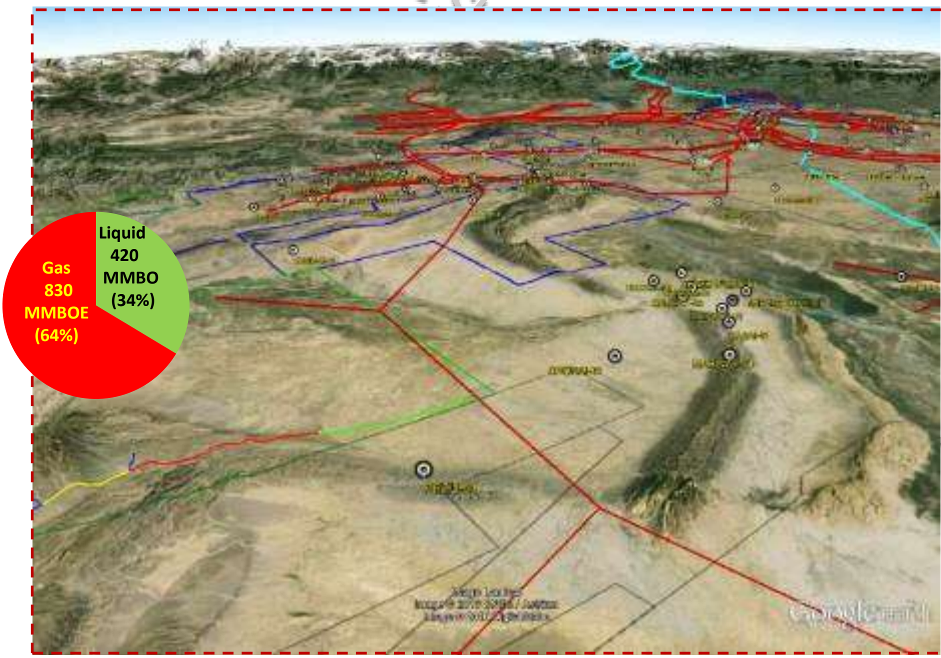
2. Types of Data, Materials and Maps as used to find and define exploration opportunities:

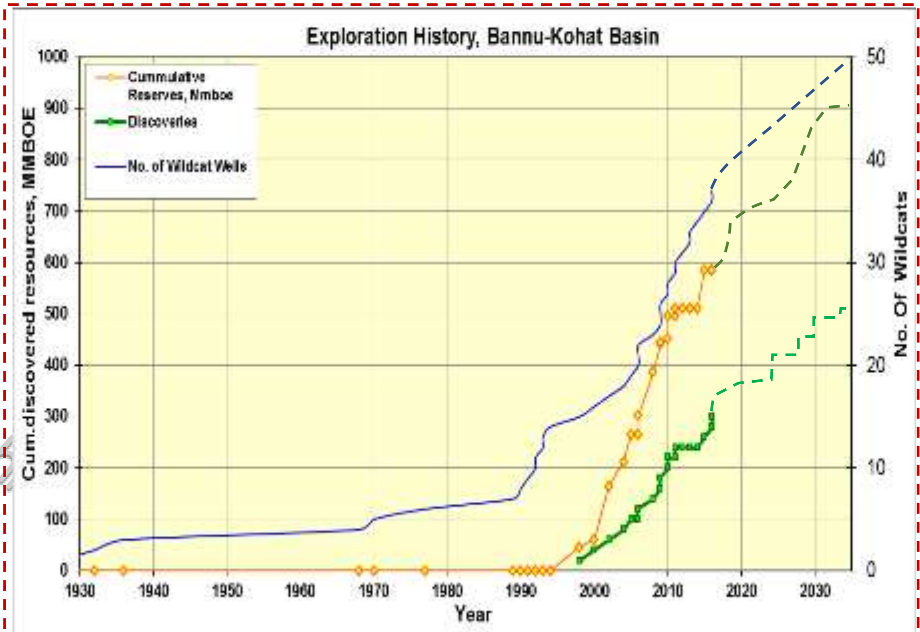
a. Historical data, Contemporary data sources, Expert groups
b. Top-down forecasting: Basin statistics, yet-to-find resources (YTF).
c. Bottom-up approach. Steps of Play fairway and Common Risk Segment (CRS) mapping.
d. Selection & Deployment of different Methods, Tools and Technologies in different stages of exploration
e. Identification of new reservoirs & seals and reservoir-seal pairs as new prospective plays in mature basins and in frontier emerging basins of Pakistan.

Basin Stats: (1) Basin-wise and (2) Play-wise within a basin

Upper Indus Bannu-Kohat Sub-basin – story of perseverance. Opening of a New Basin, New Play

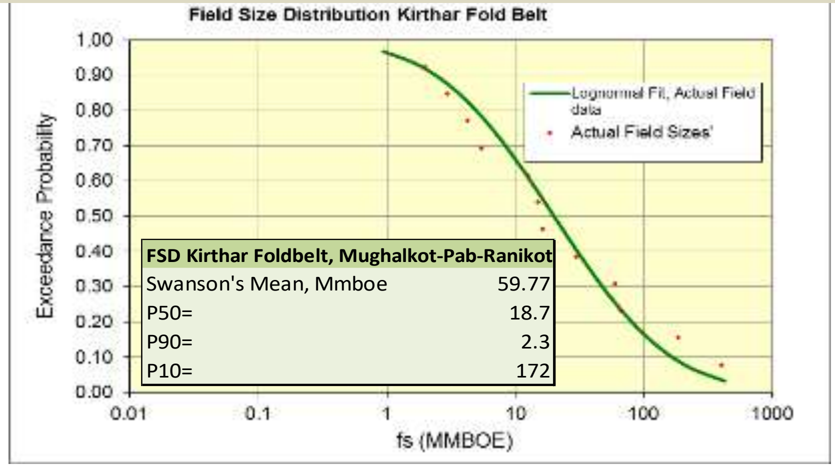
- A story of perseverance! First well: Dalwati-1 in 1937, First discovery in 1999 in the 15th well!
- 1957-1980: 2 seismic surveys, 3 wells, all dry. First generation seismic used- Karak-1 (1977).
- 1980-1990: > 10 seismic surveys, 3 wells, all dry,
- 1990-1998: > 5 seismic surveys, 5 wells, all dry. 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!



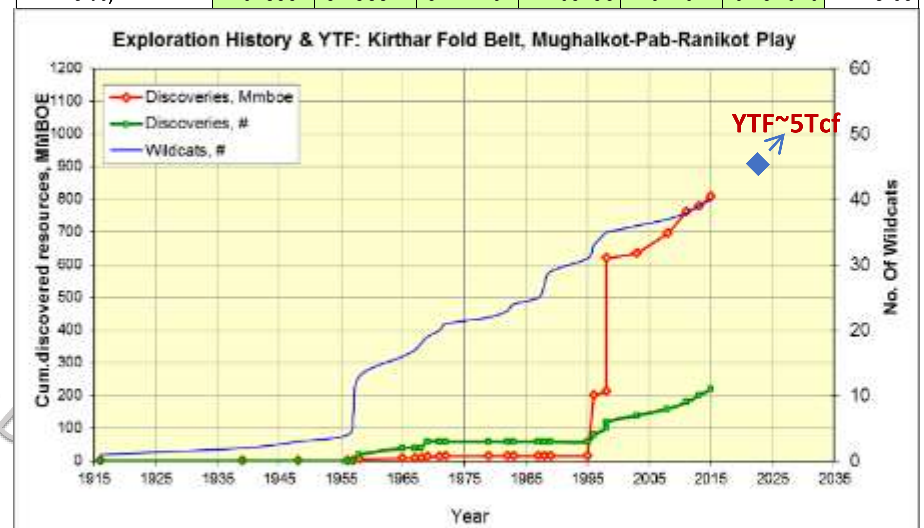


Basin stats: Play-wise: Field Size Distribution (FSD) & Creaming Curves for Yet-to-find (YTF)

U. Cretaceous/Paleocene Play

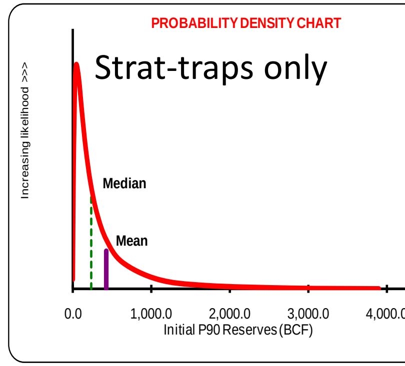


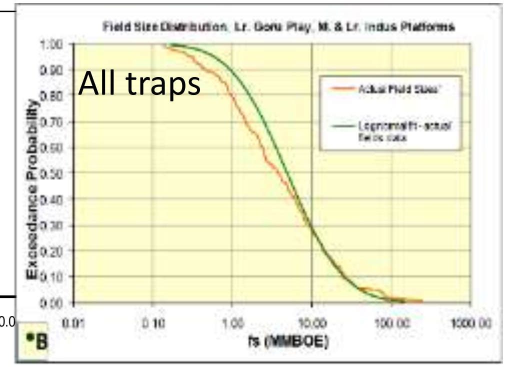
Classes/ range	1 - 5	5 - 10	10 - 50	50 - 100	100 - 200	200 - 300	
Modelled volumes	16.58578	29.86316	307.9125	211.5772	404.5675	672.9374	
Actual volumes discovered	9.27	5.53	74.10	126.70	186.50	406.58	
YTF, Mmboe	7.32	24.33	233.81	84.88	218.07	266.36	**834.77**
Modelled discoveri.	6	4	12	3	3	2	
YTF fields, #	2.648334	3.258841	9.112167	1.203493	1.617042	0.791626	**18.63**



Basin stats: Play-wise: Field Size Distribution (FSD) & Creaming Curves for Yet-to-find (YTF)

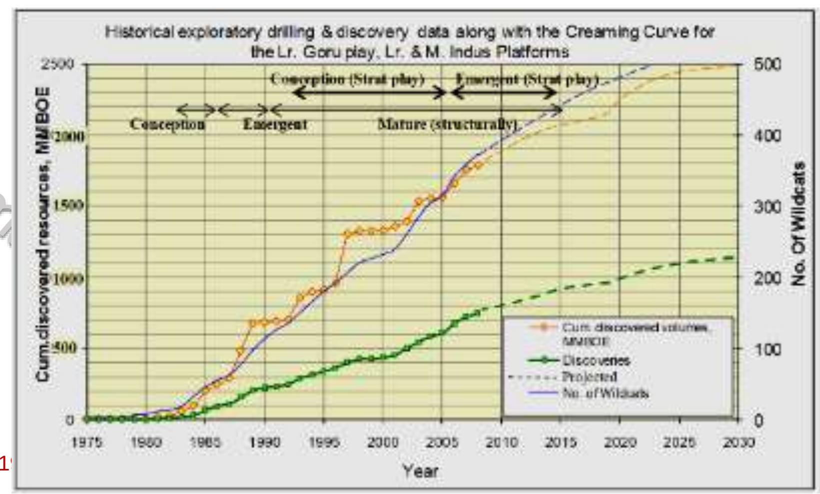
Lr. Cretaceous, Lr Goru Play. YTF in Comb. & Strat traps





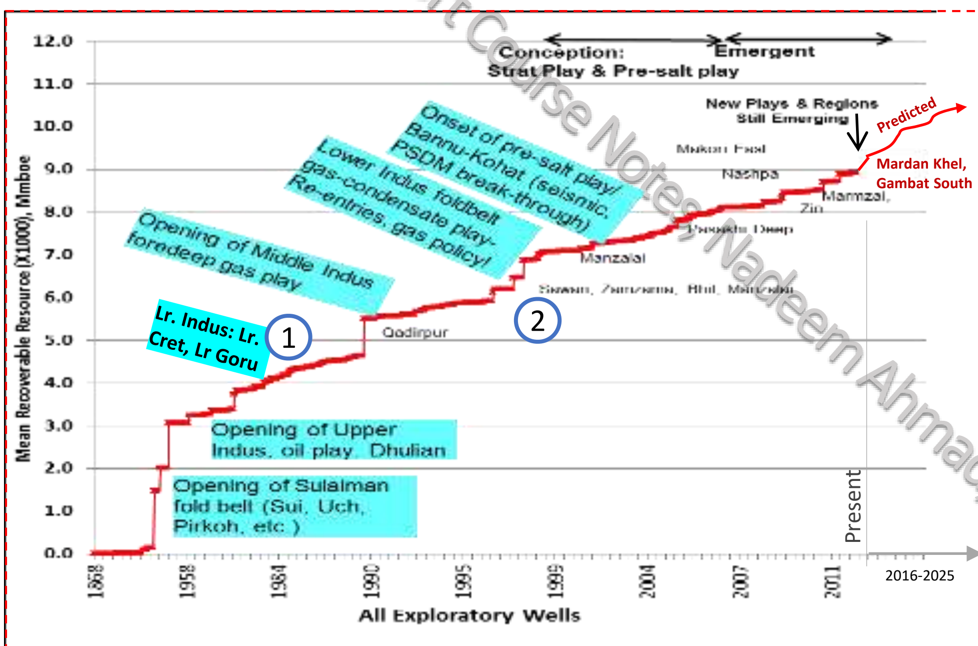
Strat-traps only

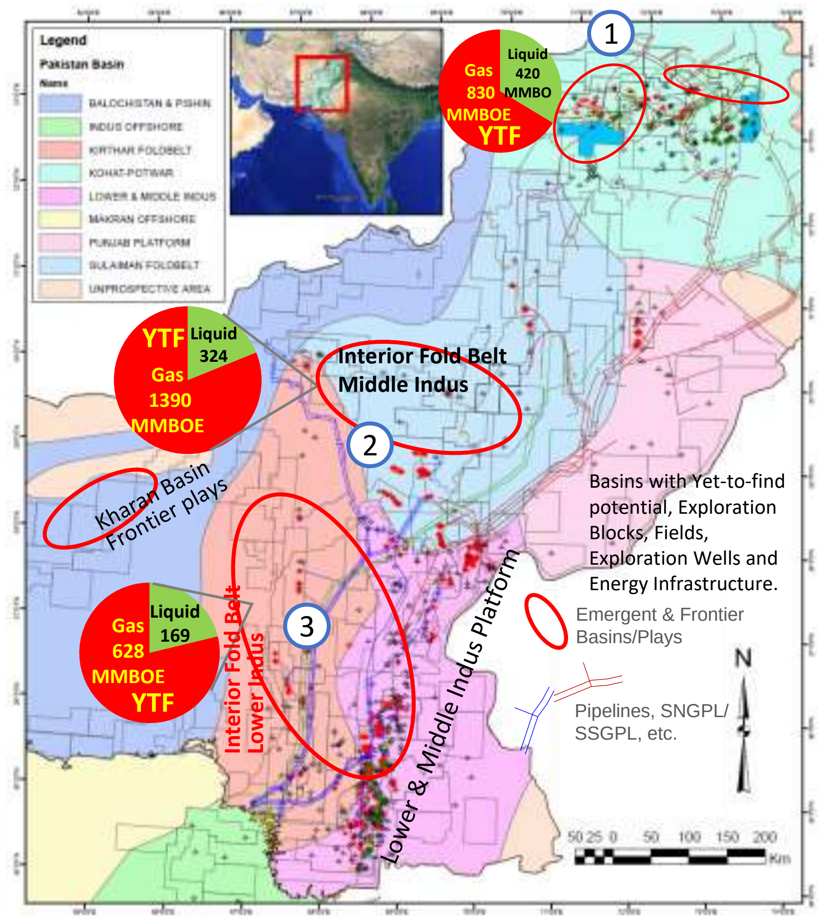
Classes, MMBOE	1 - 10	10 - 50	50 - 100	100 - 200
Actual found	0	57.25	159.80	250.00
Modelled, MMBOE	7.22	280.18	283.00	575.59
# of Finds, actual	0	3	2	1
# of Finds, Modelled	1	10	4	4
YTF, MMBOE		222.93	123.20	325.59
New Pot. Finds	1	7	2	3



YTF, next question; Where is room? Bottom-up approach, source-to-sink evaluations

- Acreage: Sedimentary basins with proven and yet-to-prove Petroleum Systems. Drivers of building acreage position (Subsurface setting, Market access, Geopolitical, Emerging vs. Mature)
- Plays & Prospects Inventory:
  - Play fairways in proven and yet-to-prove Petroleum Systems,
  - Prospects in Prove and yet-to-prove Play fairways (CRS maps).
  - Prospects with single vs. multiple trapping elements and reservoir-seal week links,





1. ~ 800MMboe (gas) and +400MMboe (oil) –U. Indus
2. Nearly1,400 MMboe gas and Over 300MMboe liquids - Middle Indus Sulaiman Foldbelt area,
3. Over 600MMboe gas and nearly 170MMboe liquids - Kirthar fold belt

Identifying New Reservoir-Seal pairs as prospective plays in mature (old) & emerging basins

ACCESS to the Basin / its Play Fairway controls Exploration activity & Exploration Performance / Success in Pakistan. Critical factors for the opening of new basins/plays are:

Early versus late Access, Geographic access (terrain, security, geopolitics, etc), Access to technology.

❑ Proven Plays

- Matured plays or sub-basins
  - ✓ Accessible terrains,
  - ✓ Technology access ok. Problem: appropriate technology selection, project management.
- Emergent plays or sub-basins (incld. Tight Gas)
  - ✓ Difficult access: Terrain difficulty, Security & Geopolotical issues.
  - ✓ Technology deployment late, and slow. Need optimization!

❑ Unproven Plays and Basins

- **Unconventional Resources**: Shale Gas (challenge: identify sweet spots, drill/Frac, establish producibility)
- **Bannu-Kohat basin (NW part),** Geographic access in Tribal belt.
- **Interior of Sulaiman fold belt** (Geographic Access issue).

❑ Unproven Plays and Basins (contin…)

- **Indus Offshore:**
  - ✓ Eocene Carbonate build-up plays: 1) Attached carbonate ramp margin buildup play, 2) Isolated carbonate platforms in Deep-water,
  - ✓ Delta toe-thrust plays, sub-basalt Cretaceous play, Mud diapirs play on/beyond Murray Ridge.

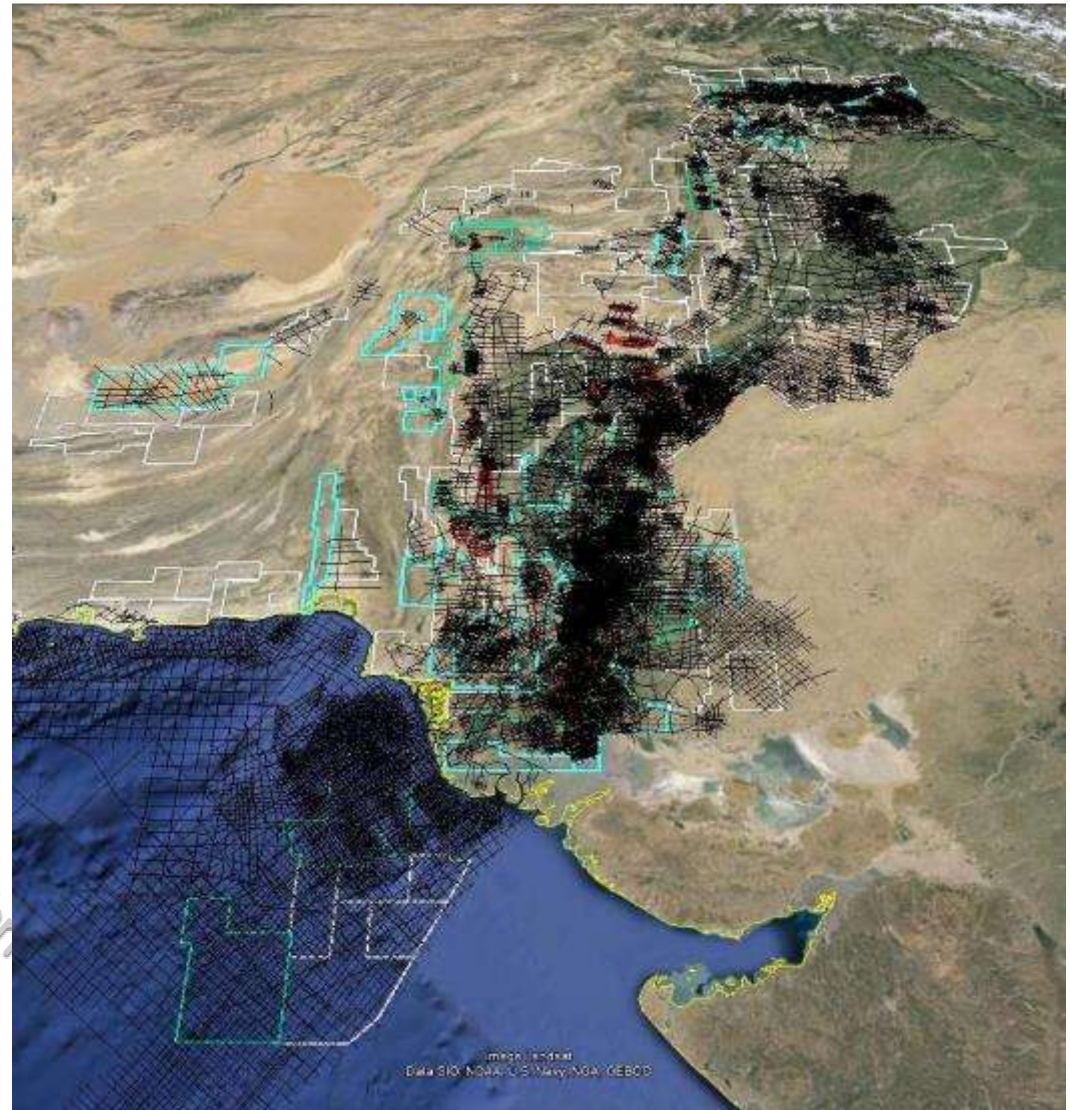
  Issues: 1) Flawed Play concepts, Identifying & appraising Combination traps for drilling 2) Identifying the right technology and its access, e.g., Deep drilling, Deep-water drilling, Sub-basalt seismic imaging.
- **Kharan Basin** (Being explored, no success yet).
- **Brown-field Infrastructure-led exploration in Platform areas.** Appropriate Technology selection & optimization issue, Project management issue to lower the drilling to first production cycle.

3. Mapping of plays and prospects - Beyond usual Well Tops and prominent seismic reflectors:

a. G&G data: Potential field data & Remote Sensing data, Wells data and Seismic data, Basemaps and data quality maps
b. Log correlations – well-based sequence stratigraphic surfaces & units,
c. Geoseismic sections: Sequence stratigraphic packages with distinct source-reservoir-seal and charge pathways.
d. Drawing Wheelers and Magoon Diagrams, Play Schematics (icons) with Entrapment concept diagrams. 1D Basin modeling of wells to get major hiatuses along seq boundaries & condensed sections, and chronologically caliberating key surfaces in chronostrat chart.
e. Decision of picking additional well Tops and seismic Horizons, using manual vs. auto-tracking (ASAP), use of attributes for expedient picking, fault correlation and fault geometries. Gridding algorithms.

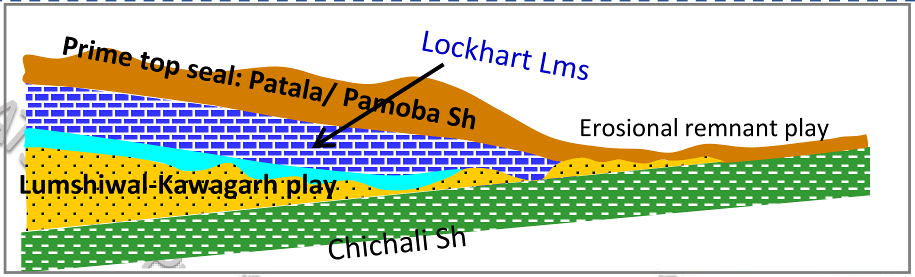
Key Data and Selecting/ Deploying different Methods, Tools, Technologies for different Expl stages

- Seismic Coverage – shows activity areas,
- Extensive seismic in the Plains with some blanks,
- Sparse in rugged terrain,
- Little to no seismic in many blocks,
- Doability is high in platform areas. No security or infrastructure bottlenecks.

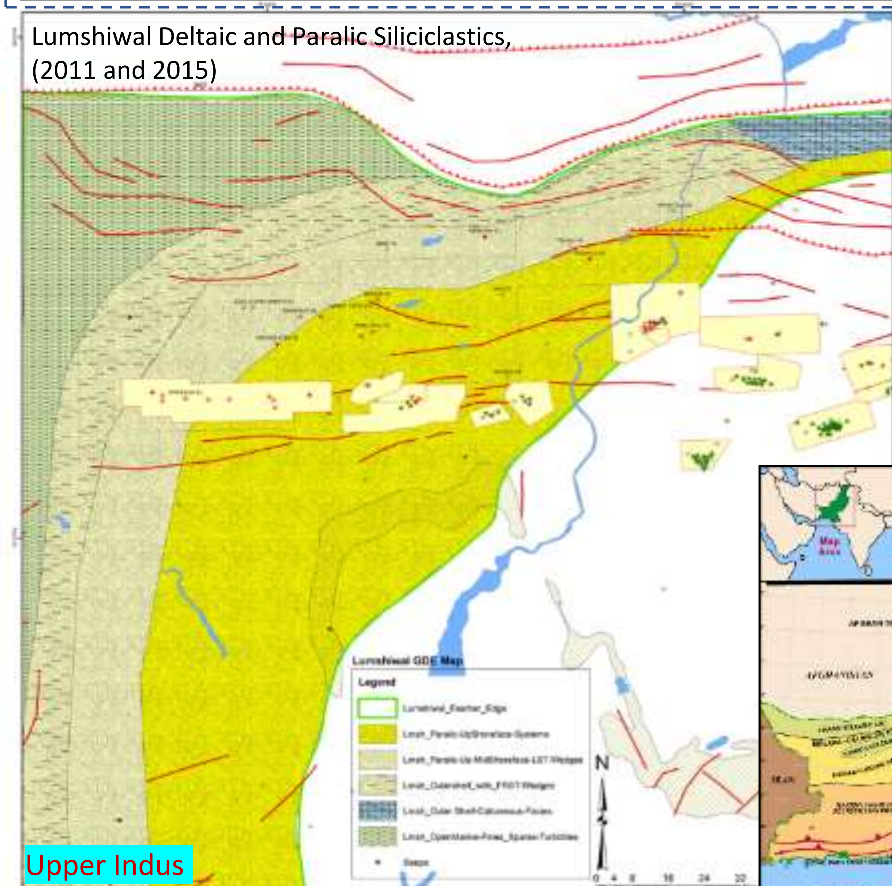


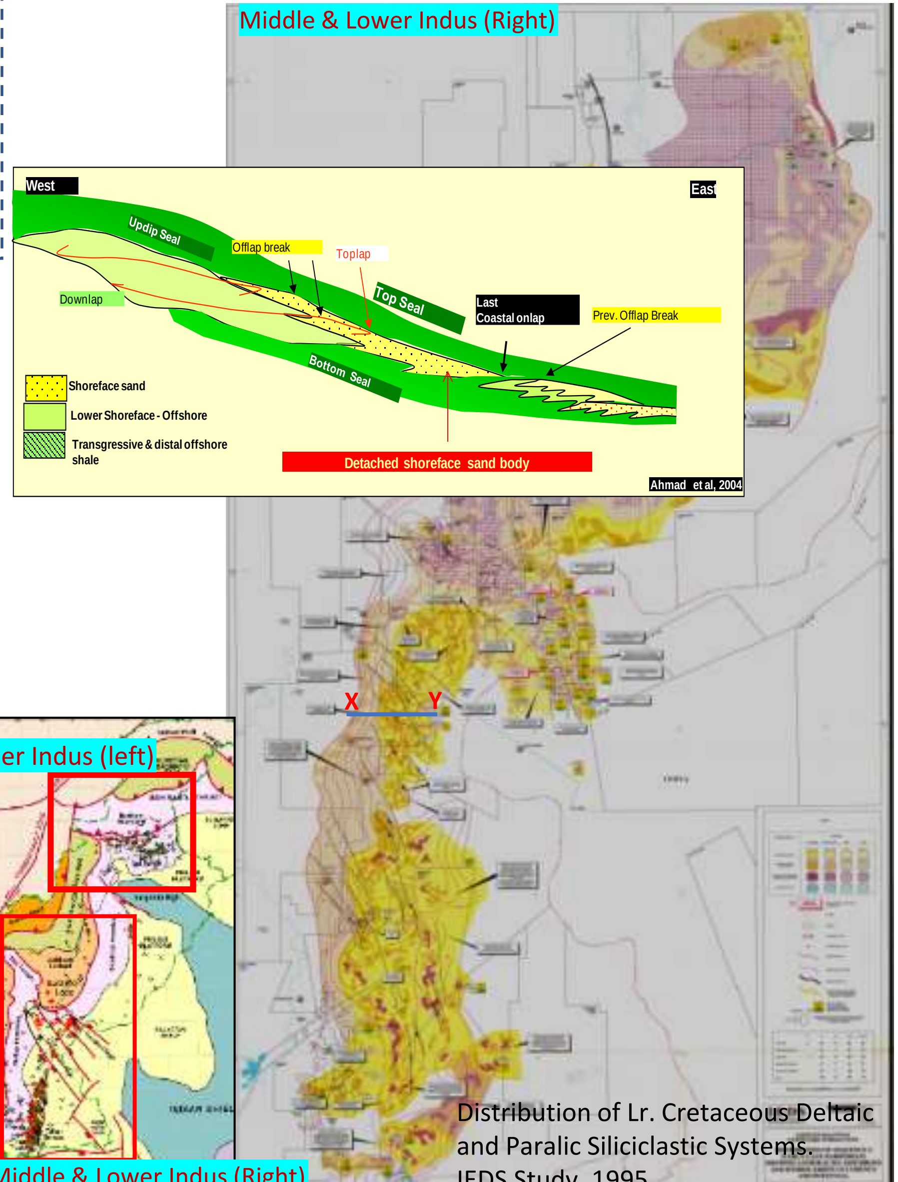
- Seismic: 2D seismic, Fat/Wideline, 3D seismic (sparse vs narrow grid, short vs long offset), Multicomponent Seismic, 4D seismic
- Seismic processing, Specialized processing (AVO, Spectral decomp, etc), Inversion
- GIS & Remote Sensing data sets
- Cores, Cuttings. Core analysis (hotshot) & SCAL
- Potential field data
  - Conventional Grav-Mag
  - Aero Gradiometry – Falcon and SFD
  - CSEM
- Specialized Logging & log processing:
  - LWD, OH Wireline logging, CH Logging,
  - HMI/FMI,
  - Sonic imaging (
  - NMR/CMR

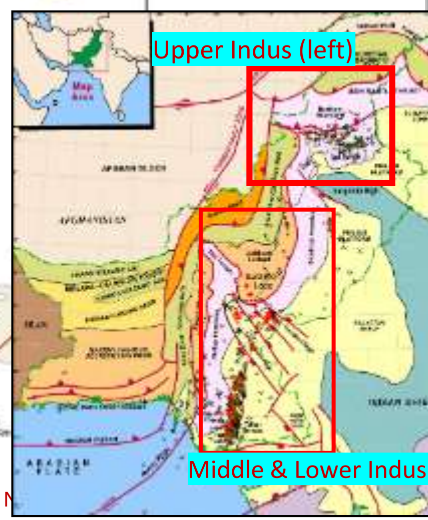
Paly Conceptuals: Drawing schematics of the key elements of trap and reservoir-seal pair



Lumshiwal Deltaic and Paralic Siliciclastics,
(2011 and 2015)







Distribution of Lr. Cretaceous Deltaic and Paralic Siliclastic Systems.
IEDS Study, 1995

Play Fairway Analysis (PFA) for Portfolio based Exploration: Definitions, Workflow

- Data & reports review, loading/QC
- Tectonic elements map. Tect.history
- HC Occurrence map. Incld wells, seeps, chimneys
- Exploration history, FSD, Play statistics

- Success & failure wells' analyses
- Field and reservoir analogues' review (modern & ancient)
- Core-Log-seismic calibration.

Play definitions, Establish proven & unproven, and Part-plays, Sub-plays

- Regional well log & seismic sequence stratigraphy. Correlate mfs, SB/mrs
- Geoseismic sections, Log correlation panels with facies continuity/transitions
- Wheeler diagrams. Biometric calibration using available biostrat. Single out sequences containing reservoir, regional seal and source w/ their spatial & temporal interrelationships
- Basin modeling, Palinspastic restoration. Define & mark Kitchens, Lows & Highs
- Regional Facies Distribution Maps for each play's reservoir & seal element
- Gross Depositional Environment Maps

Quantification of uncertainties using wells' success/ failure analysis & basin stats, Risking model

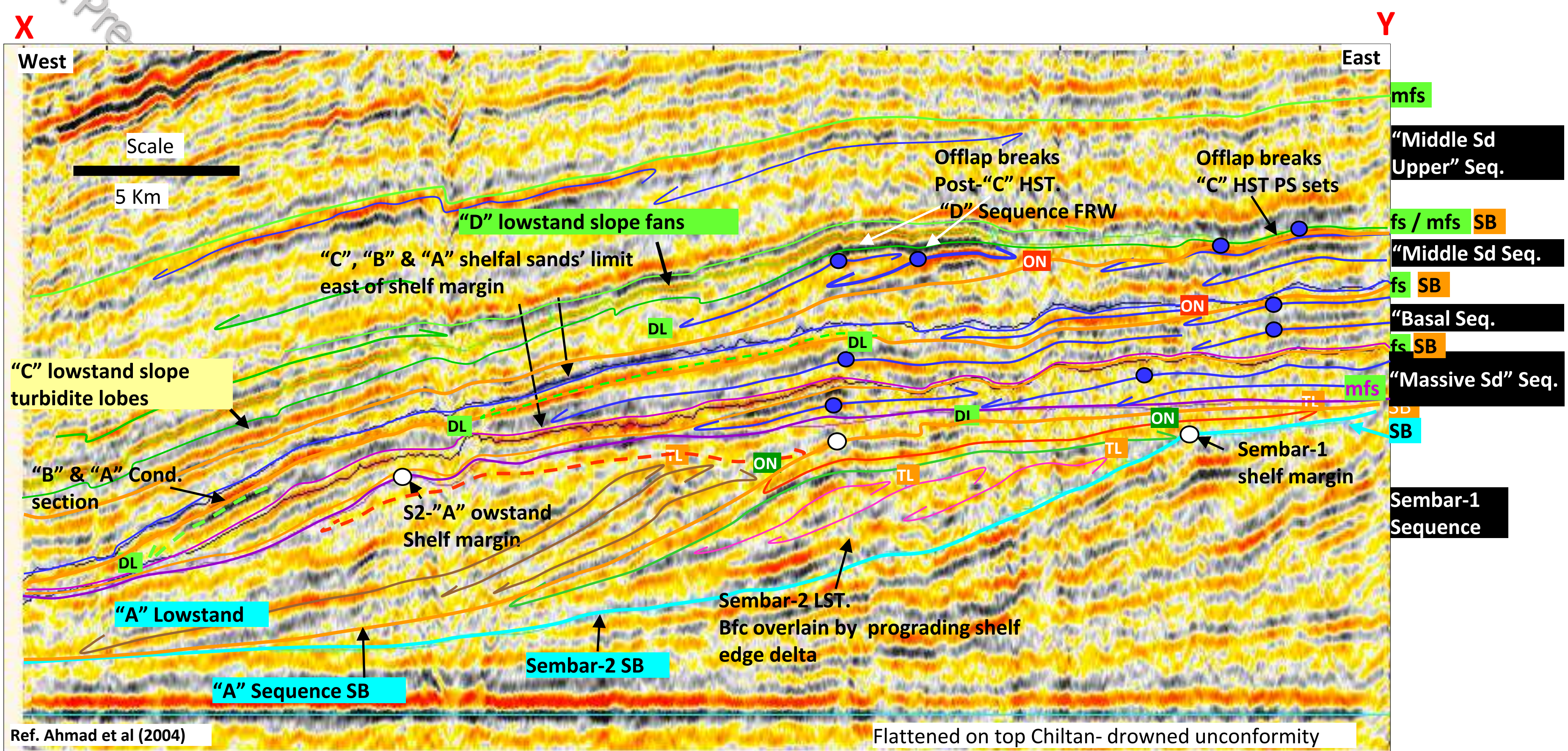
- Source CRS map
- Reservoir CRS map
- Top Seal CRS map

Overlay analysis

- Composite CRS (CCRS) map
- - Ranking of blocks/licenses
- - Traffic light maps

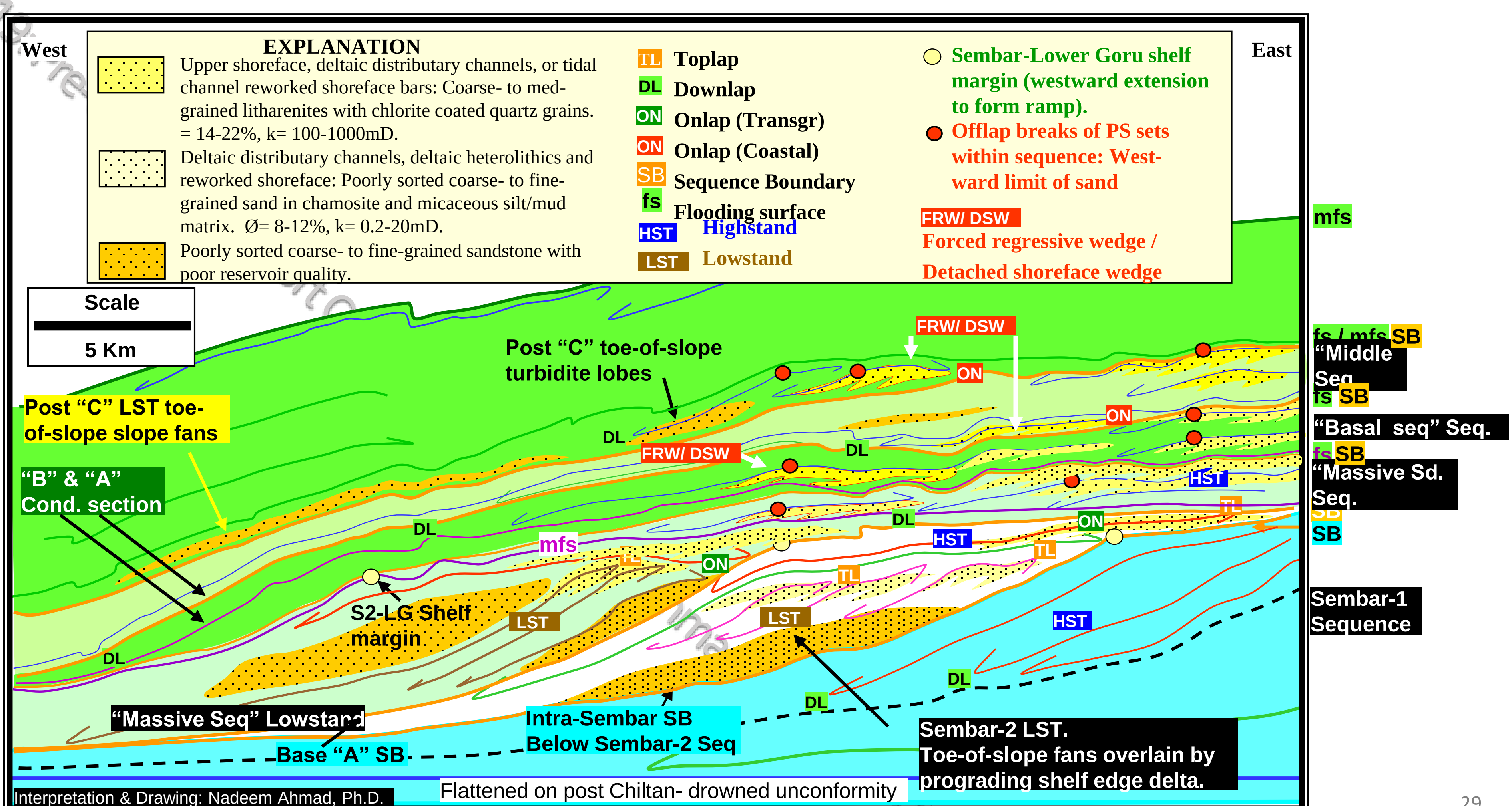
Geoseismic Section: fundamental frame of identifying regionally extensive surface, seal-reservoir pairs

- 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



Geoseismic Section: Extensive surfaces, regionally extensive top seal intervals sand bodies, and seal-reservoir pairs

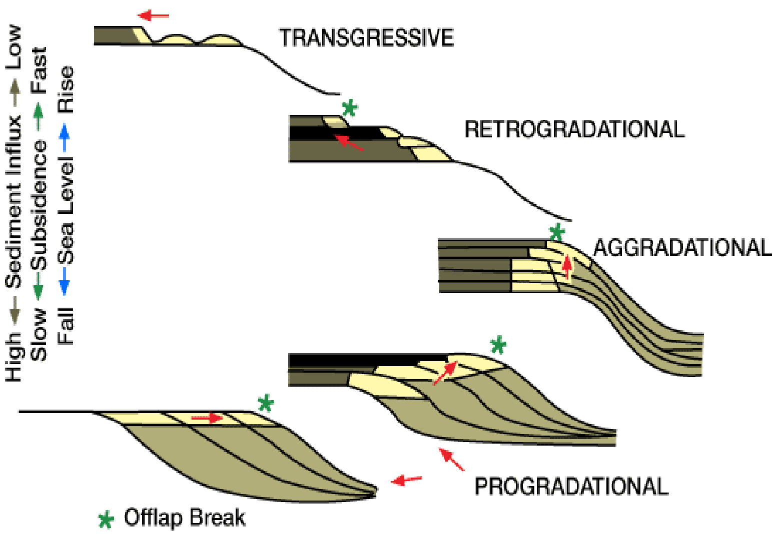
- Depositional systems and sand body interpretation from seismic section
- Sequence stratigraphic framework and temporal and spatial relationships of the interpreted sand bodies



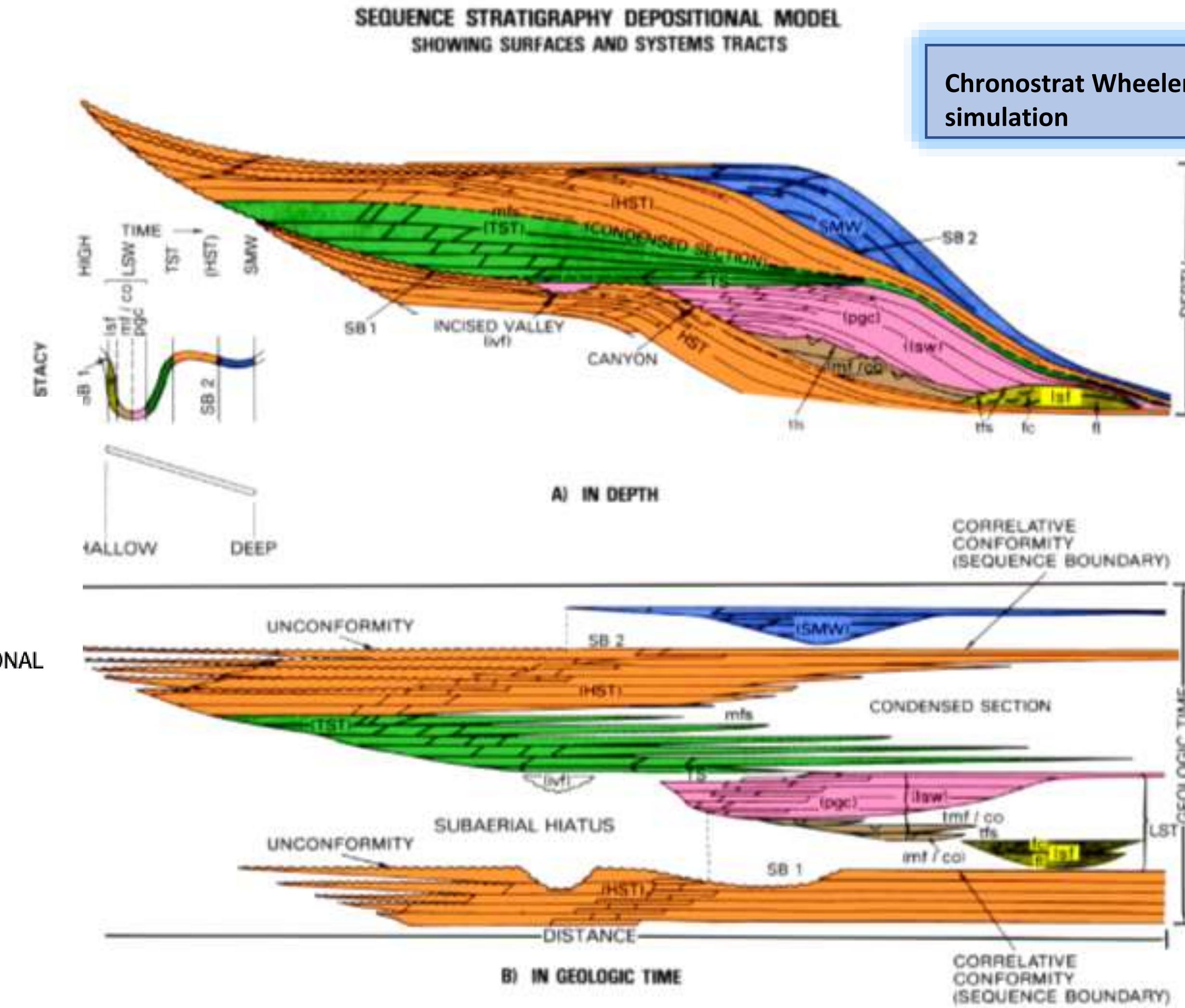
Chronostrat Chart, Coastal onlap curve, Magoon diagram: in single well and for a 2D section

a. Drawing Wheelers log correlation charts and geoseismic sections
b. 1D Basin modeling of wells to get major hiatuses along seq boundaries & condensed sections, and chronologically caliberating key surfaces in chronostrat chart.
c. Magoon Diagrams,

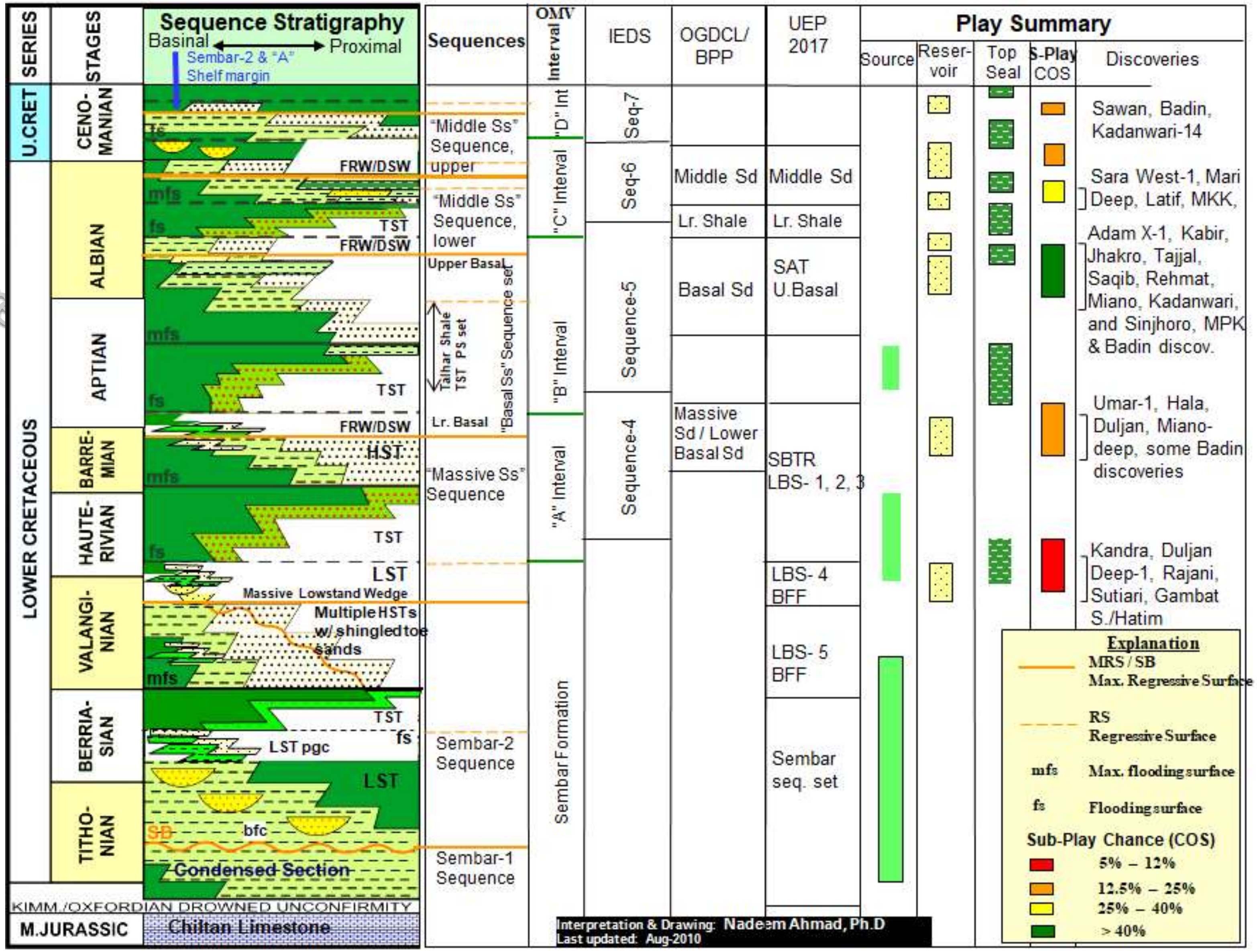
Chronostrat Wheeler simulation



(From Galloway, 1989a)



Chronostrat Chart, Coastal onlap curve, Magoon diagram: in single well and for a 2D section



Shale Gas Play Concepts: require innovative approach of combining multiple possibilities

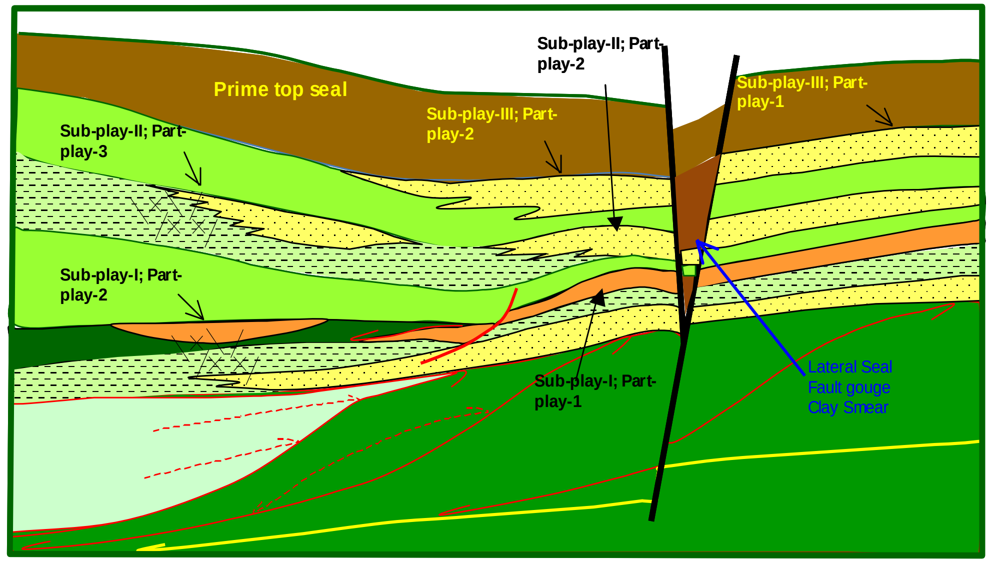
Conventional Shale Gas formation-misunderstood

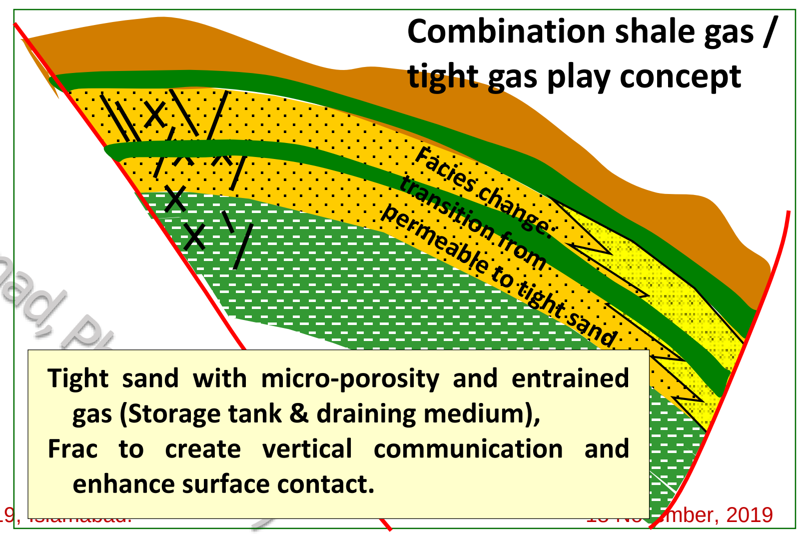
- ❑ Depth of burial - Candidate formations deep in some parts (Sulaiman Foredeep, Karachi Trough)
- ❑ Lateral and vertical continuation of organic-rich shale Facies not properly constrained – need regional maps of source rock parameter

Combination play: tight gas + shale gas

- ❑ Tight sand relatively brittle and Fracs easily
- ❑ Organic-rich Shale – gas sink but lacks permeability and low in brittleness
- ❑ Play works by matrix porosity tank stacked on top of the Gas Shale. Once free gas drained, ‘adsorbed’ gas from shale liberated to feed the ‘tight gas’ tank. Also suitable for the formation thicknesses encountered in Lower Goru

Definition of play fairway, sub-plays & part-plays (proven and unproven). Cross-sectional view to explain sub-play concept





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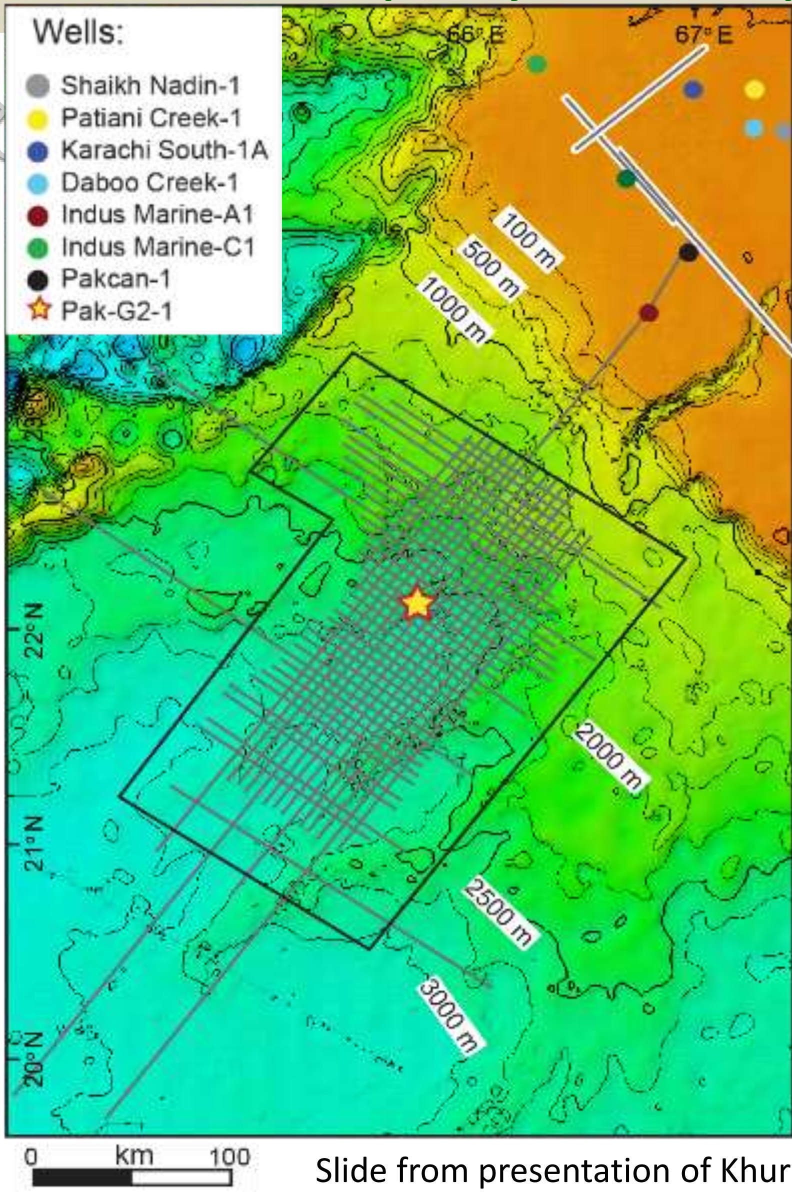
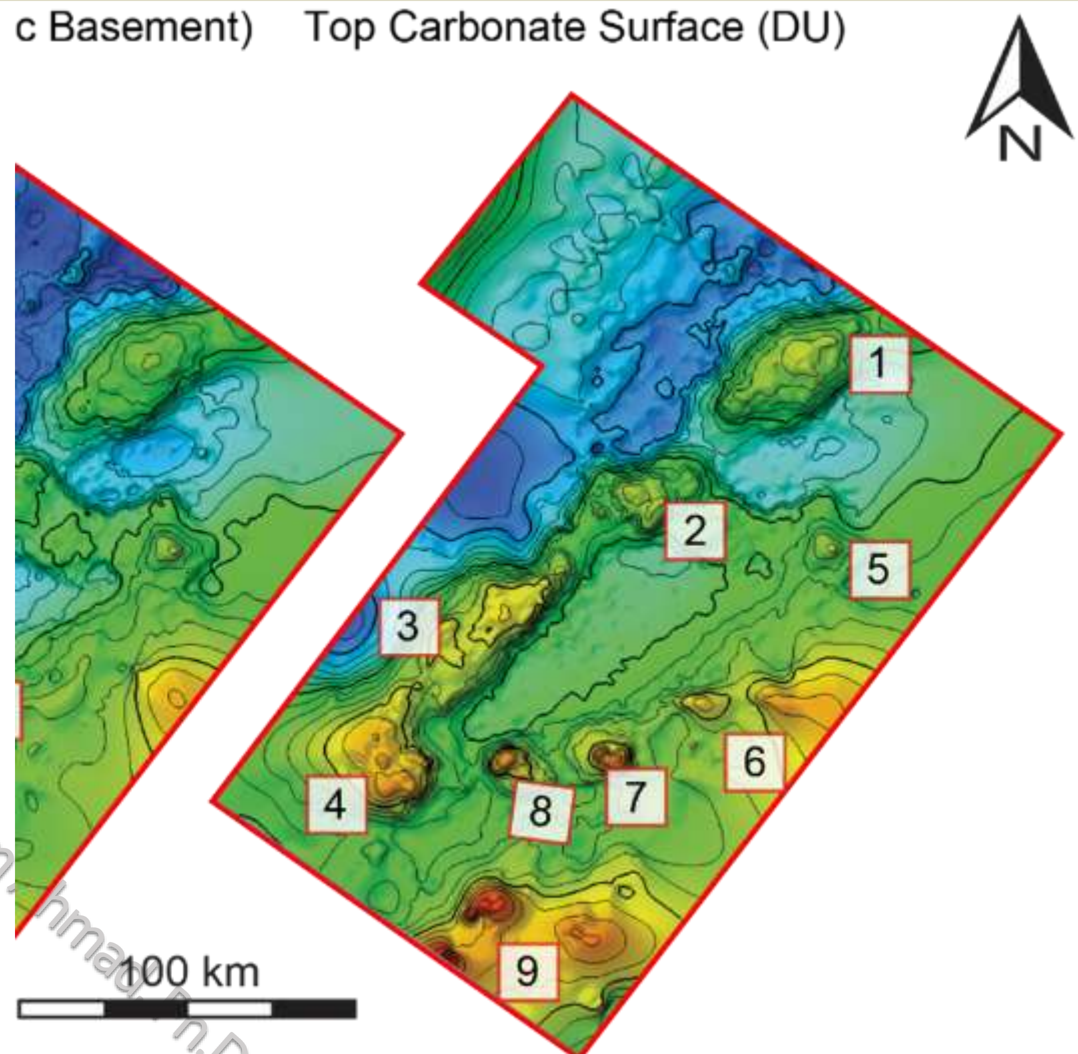
Carbonate Buildups Plays: Indus Deepwater Offshore



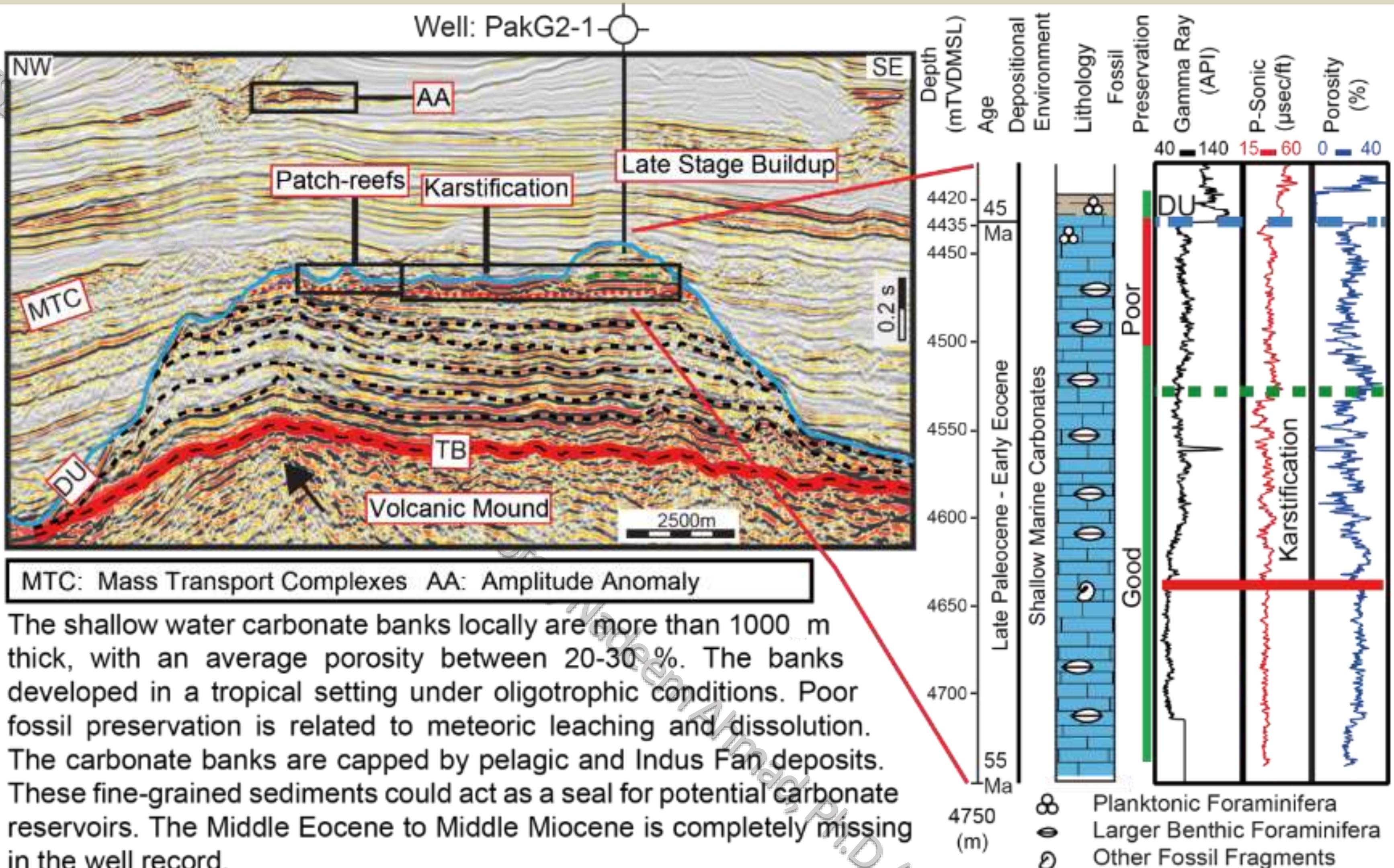


*1-9 Isolated Carbonate Banks (ICBs)

Slide from presentation of Khurram Shahzad, 2019 (Ph.D. work at Univ. of Hamburg)

A

Carbonate Buildups Plays: Indus Deepwater Offshore



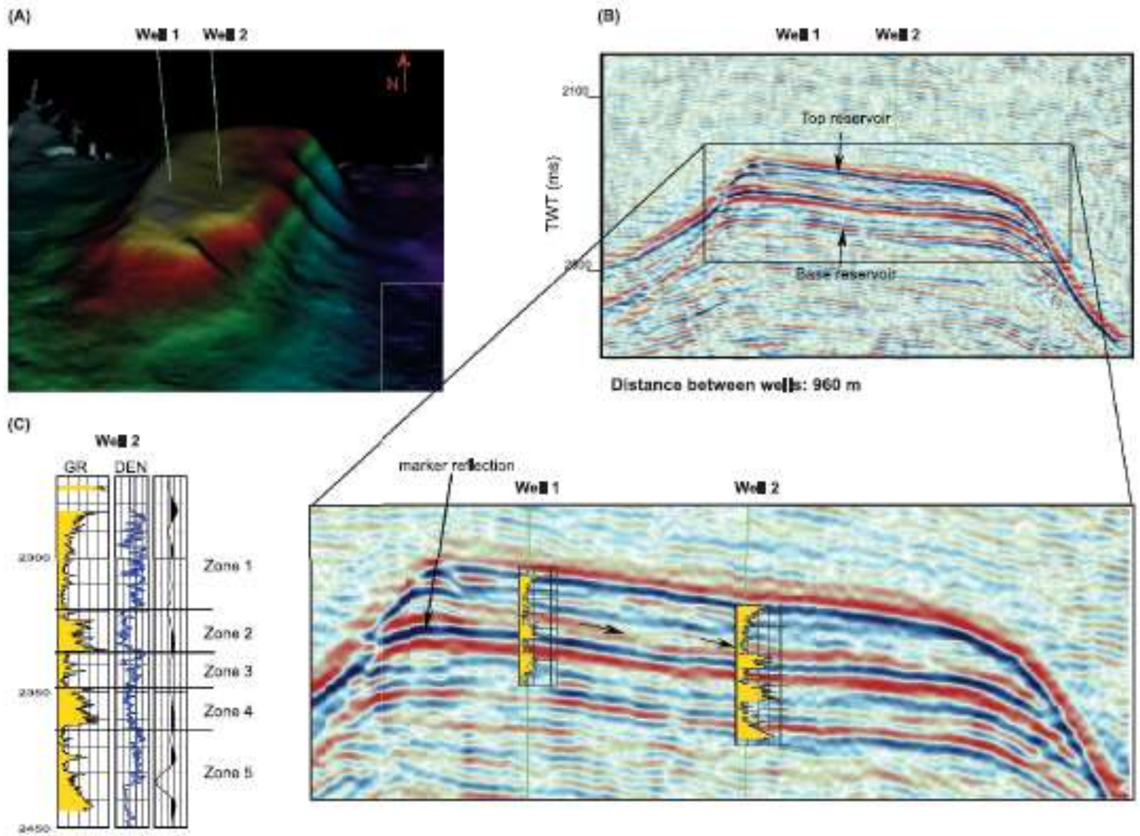
MTC: Mass Transport Complexes AA: Amplitude Anomaly

The shallow water carbonate banks locally are more than 1000 m thick, with an average porosity between 20-30 %. The banks developed in a tropical setting under oligotrophic conditions. Poor fossil preservation is related to meteoric leaching and dissolution. The carbonate banks are capped by pelagic and Indus Fan deposits. These fine-grained sediments could act as a seal for potential carbonate reservoirs. The Middle Eocene to Middle Miocene is completely missing in the well record.

Slide from presentation of Khurram Shahzad, 2019 (Ph.D. work at Univ. of Hamburg)

Analogue Carbonate Buildups Plays: Miocene Isolated Carbonate Platforms, Malaysia

- Top reservoir 3-D graphs showing distinctive characteristic relief of the Luconian middle Miocene buildup.
- Seismic section across the two drilled wells with superimposed gamma ray logs. Black arrows are interpreted downlap reflections. TWT = two-way traveltime.
- Gamma ray (GR), density (DENS), and synthetic seismogram showing the five reservoir zones.



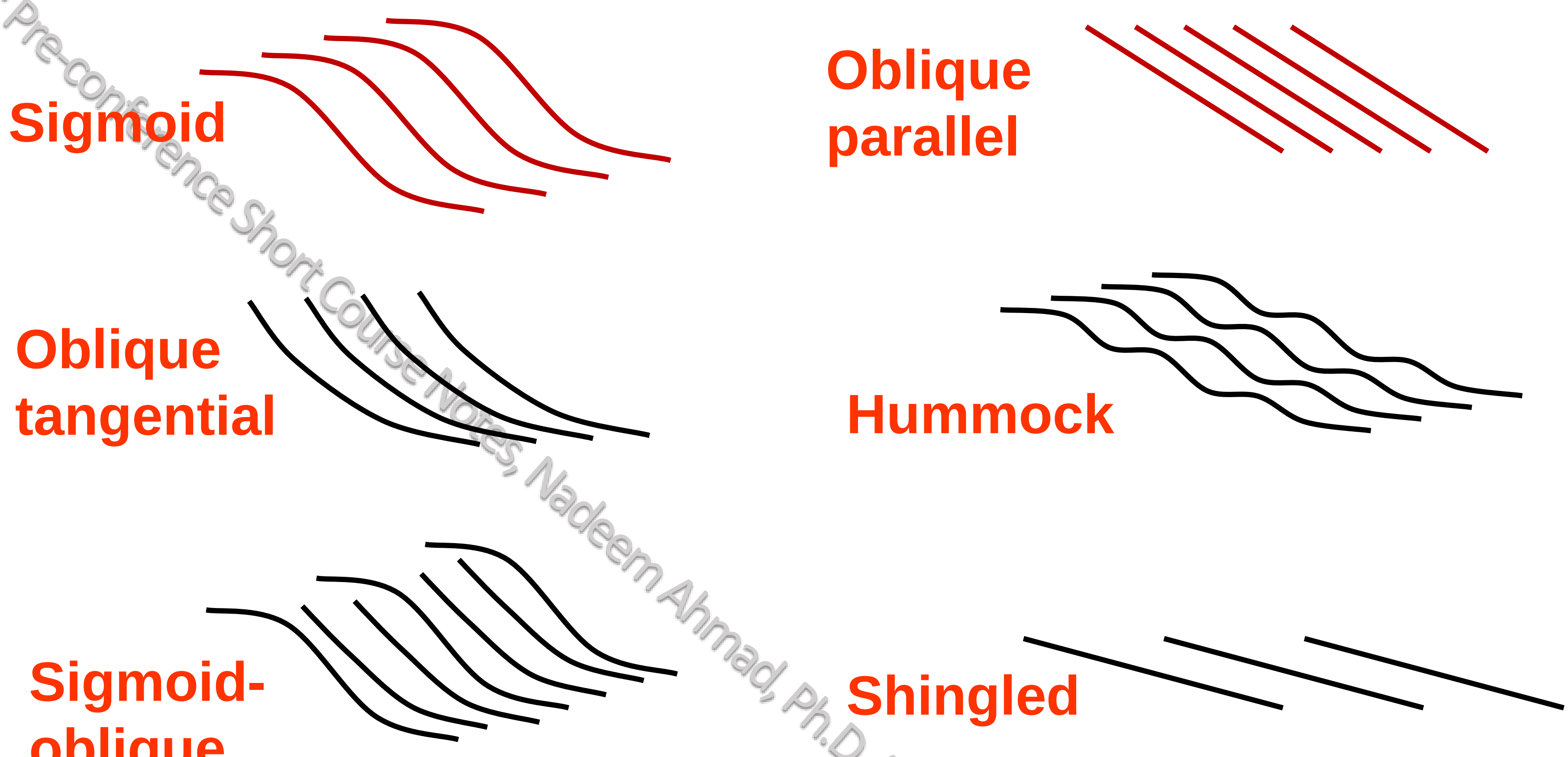
Masaferro, J. L., R. Bourne, and J. C. Jauffred, 2004, Three-dimensional seismic visualization of carbonate reservoirs and structures, in Seismic imaging of carbonate reservoirs and systems: AAPG Memoir 81, p. 11– 41.

4. Seismic stratigraphy for reservoir, seal and trap Characterization.

a) Seismic as a tool for reservoir and seal identification and mapping. Reservoir heterogeneity and compartments
b) Facies maps and property maps of the identified reservoir and seal formations. Isopach maps. Paleogeographic and GDE maps. CRS maps.
c) Migration- charge. Petroleum system/ Magoon diagram … under GIS Spatial Analyst – Hydrology toolkit. Ref. Buyancy quant assessment… capil entry pressure vs. oil column height and depth vs. porosity. Paleodepth/bathymetry from coastal onlap curve/seal level, Pressures, seals & traps in Biteau, Apr 2018.

Tool of Seismic Stratigraphy for Seal & Reservoir Delineation & Characterization

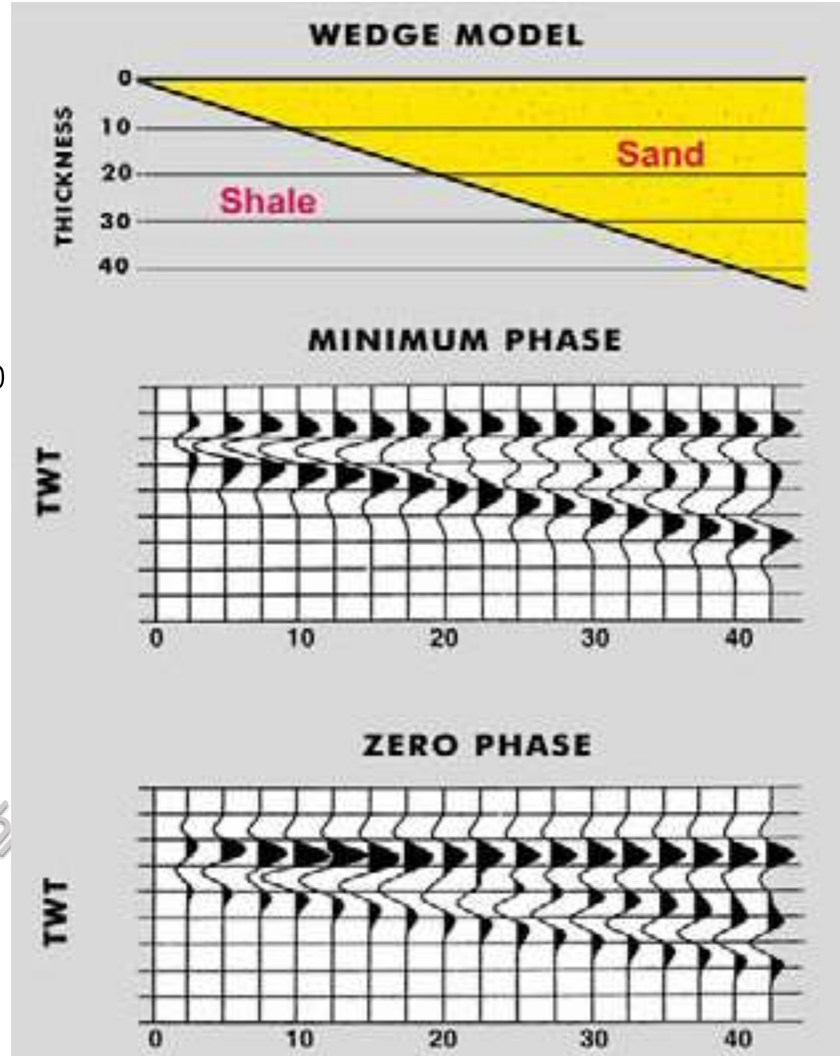
- SEISMIC FACIES Classification
  - Reflections motifs,
  - Sismic waveform classification thru neural networkPlays & Prospects Inventory:
- Seismic Waveform classification



After Mitchum, 1977

Tool of Seismic Stratigraphy: artifacts, pitfalls

- Drive seis-strat interpretation using forward models:
- Example: Wedge-shaped body. Lateral change in amplitude of the individual reflections
  - The wedge has a 2500 m/s interval velocity. A 50 Hz wavelet is equivalent to 50 cycles/sec and results in a 20 milliseconds basic waveform with a wavelength of 50 metres. The time lines are 10 ms apart (after Sheriff 1977)



Home Exercise:

Use Seismic Modeling software as provided, and set up your own geological models. Investigate the seismic responses using different frequencies and phases. Present results in class.

Seismic attribute analysis- key part of Seis-strat work

- Fundamental requirement: a surface. Science of surfaces? **Sequence stratigraphy**.
- Extract attributes constrained or bounded by Genetically related packages or surfaces… **seismic stratigraphy!**
- Seismic data: **time, amp, freq, attenuation**. Alistair Brown's book a good ref.
- A Seismic Attribute is any information that is obtained from seismicdata, either bydirect measurement, or based onlogicalthinking and/or experience. T.Taner
- Specific measurements of geometric, dynamic, kinematic orstatistical properties obtainedfromseismic data. (L. Liner)
- A Seismic Attribute is any measurement made on seismic data that could help us to better visualize and quantify events of interest. (K. Marfurt)
- Classes of attributes:
  - Physical attributes: e.g., Mag of envlp trace, freq related to bed thickness, absorption/disp. Vel & dens dependence on rock props -> lithology classific & res charactrz
  - Geom attributes or struc atts: spatial & temporal relations of other attrbts. Lateral contnty measured by Semblace or Coherency (shows discount).
  - Refl attributes: interface characteristics. Amps, Phase, AVO,
  - Interval or transmissivity attributes: interval b/w two interfaces. RMS or avg Vel, Q absorption, dispersion, inverted impedance

Seismic Stratigraphy: Stratigraphic Interpretation via Neural Net driven Seismic Trace Shape classification

- Observation: Each Facies assemblage /stratal stack has a characteristic ’log motif’ (represents a geomorphic feature: channel, bar, etc).
- Assumption: Sonic properties of facies & its assemblage and reflectivity series of this ‘stack’ has a comparable to seismic reflections/ seismic geometries and a “characteristic waveform shape”.
- Establish representative Facies Assemblages & Key Stacks of Facies and Stratal stacking patterns. Petrophysical and petro elastic of each ‘stack’.
- Model seismic waveform for each stack (***recall ‘facies stacks’ & log motif discussion***). Perform forward modelling for each interval of facies stacks under discussion.
- Generate a seismic facies (similarity) map by correlating the modelled wave forms with the actual traces
- Compare neural network facies traces with the above ‘characteristic waveforms’ of each facies stack. Correlate synthetic seismic response to field seismic data.
- Change reservoir properties. Interactively observe changes in synthetic seismic response.
- Re-run / converge neural networks to re-classify data based on above comparisons, and produce property maps (“facies stacks” away from wells). Assign each zone/sector a geomporphic element (channel, bar, deltaic heterolithics, etc.)

Facies Maps & Seismic Attribute Maps - Integrate

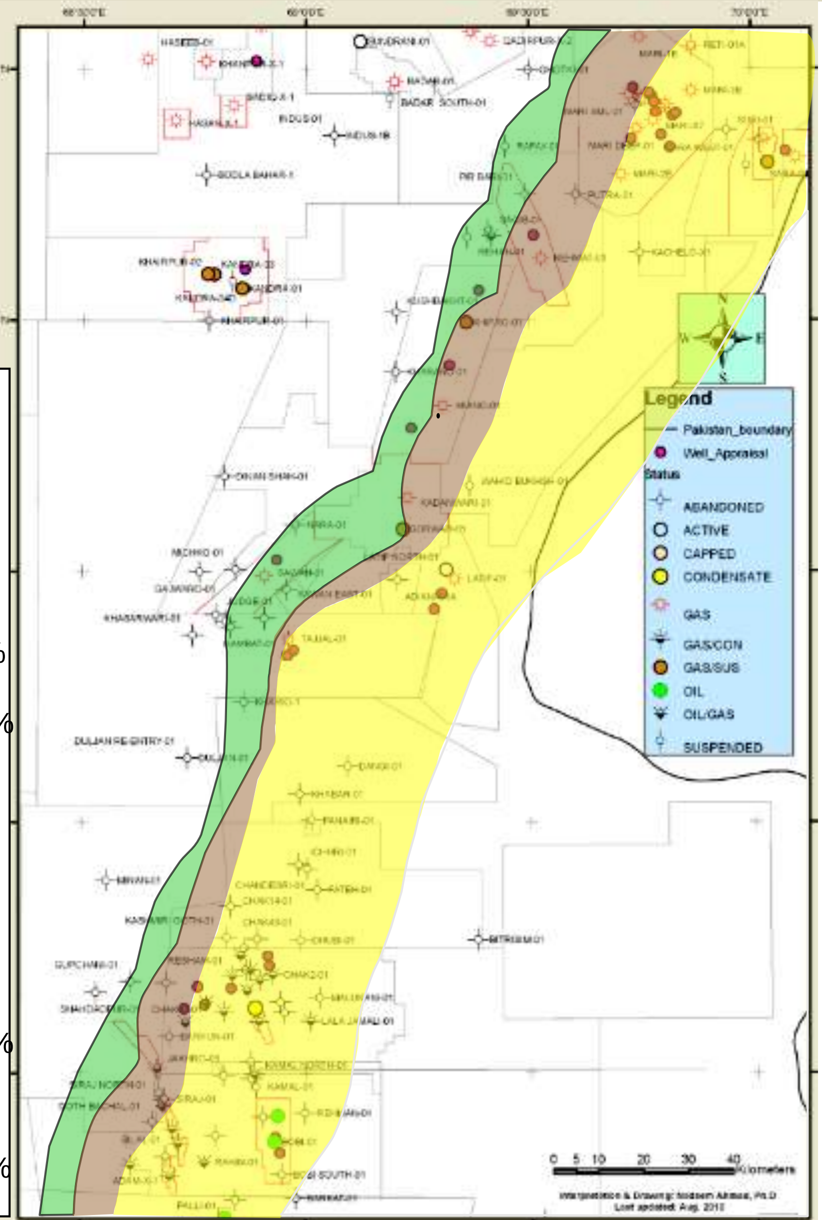
Gross Facies map of the sand-prone PS sets -3 and -4, Basal Ss Sequence set

Based on core-calibrated log motifs, correlation and seismic stratigraphic evidence

Western limit of shoreface controlled by the older shelf margin built by the Sembar deltaic progradation

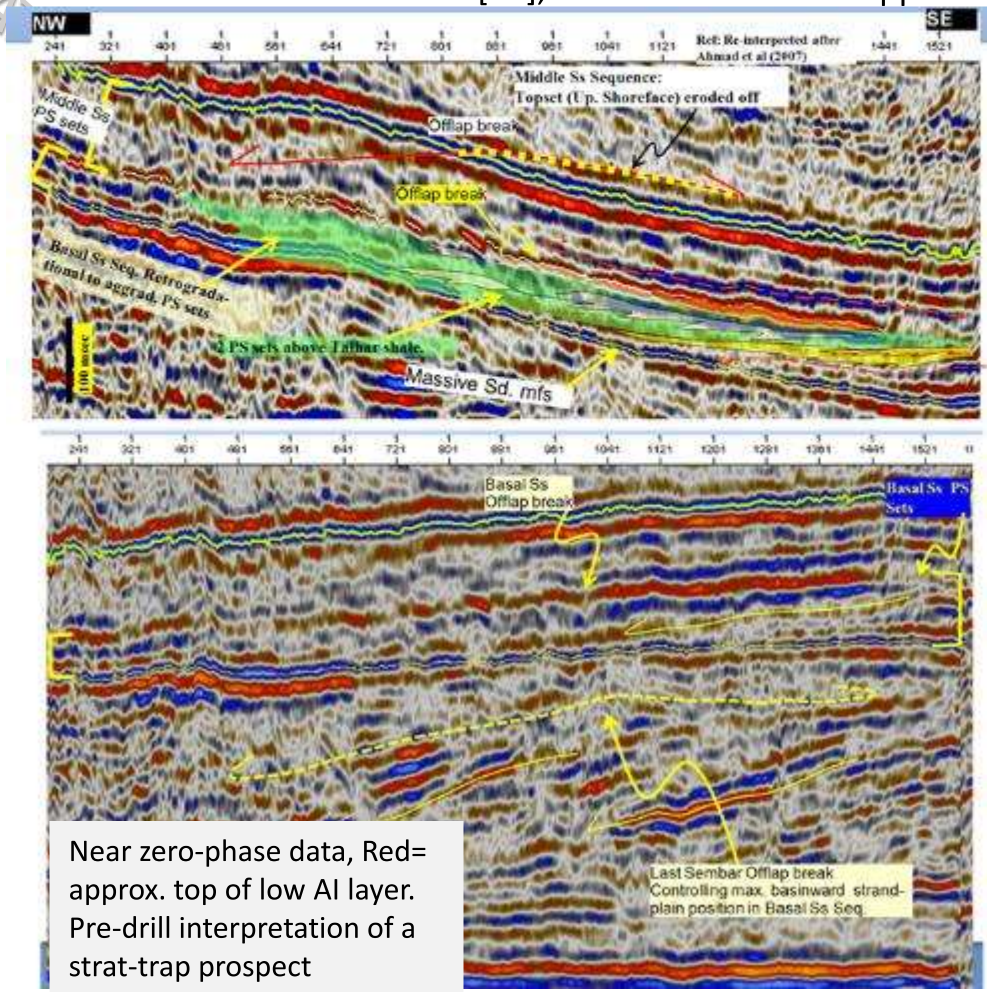
Facies Definition:

White	USH_Smc, TID-Ch_Smc Others N:G = 80%	>80% >20%
Yellow	USH_Smc, TID-Ch_Smc LAG_Sf-M; LSH_Sf. OFF_M and Pelagic shale N:G = 60%	= 50-60 % = 20-30% = 10-20%
Brown	USH_Smc, TID-Ch_Smc LSH_Sf OFF_M	= 30% = 50% = 20%
Light green	TID-Ch_Smc lobes LSH_Sf and OFF_M TURB_Sfm lobes	= 20% = 60% = 10-20%
Dark green	LSH_Sf and OFF_M TURB_Sfm lobes	= 80% = 10-20%



Seismic attribute analysis- 3D Seismic Geomorph

Present-day counter-regional dip conducive for strat-traps.
Seismic line PG04-101 from [13], after JV and DGPC's approval.



Near zero-phase data, Red= approx. top of low AI layer. Pre-drill interpretation of a strat-trap prospect

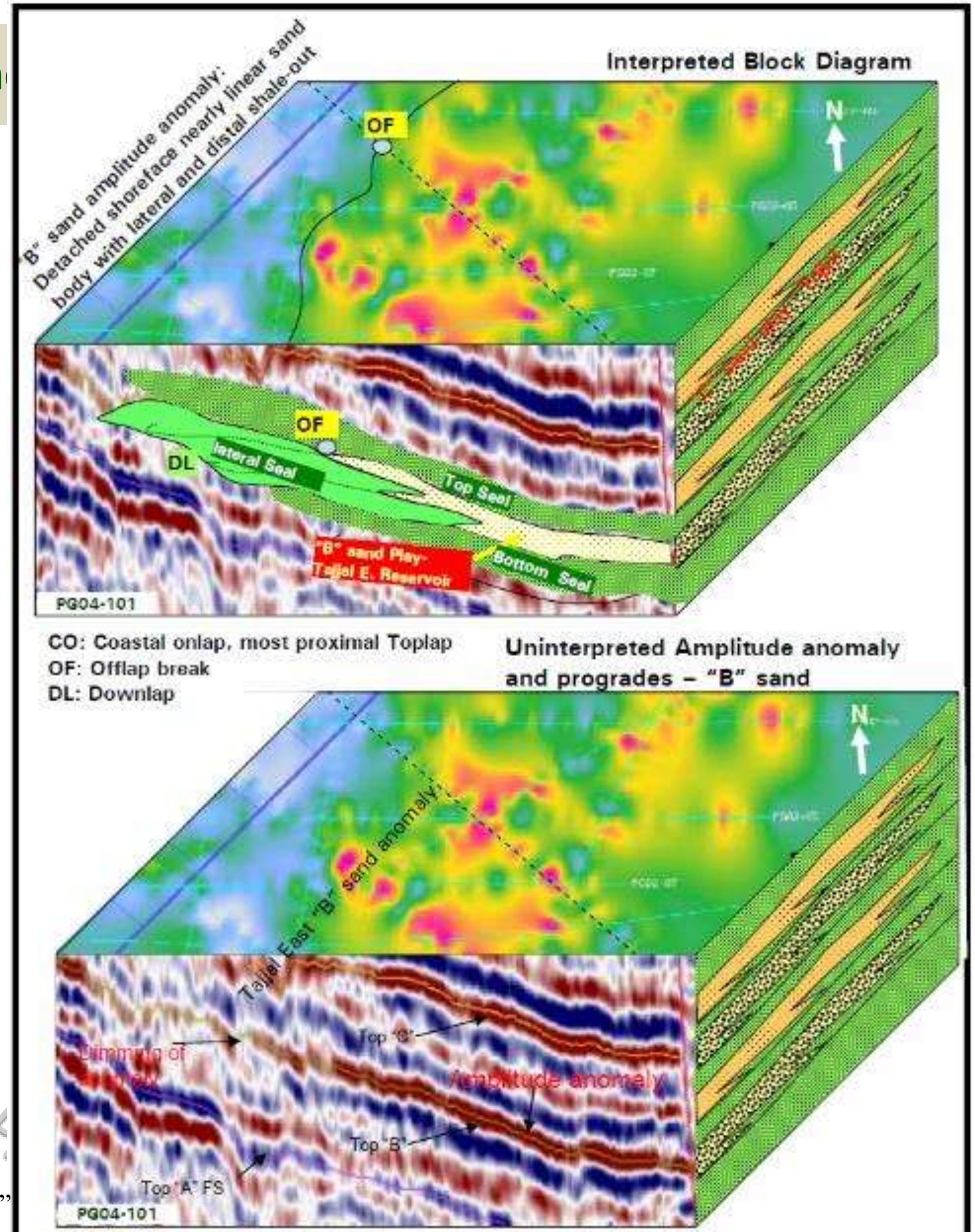


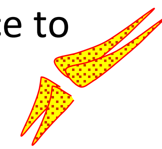
Figure 14. Pre-drill 2D seismic based reconstruction of Upper Basal Sand ("B" sand) depo-systems to define a stratigraphic trap (say, Prospect "Z"). Uninterpreted seismic reflectors and with interpretation (shale-out towards west).

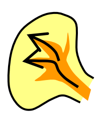
Reservoir GDE Map: Integrating Seismic attribute maps & well-based facies maps

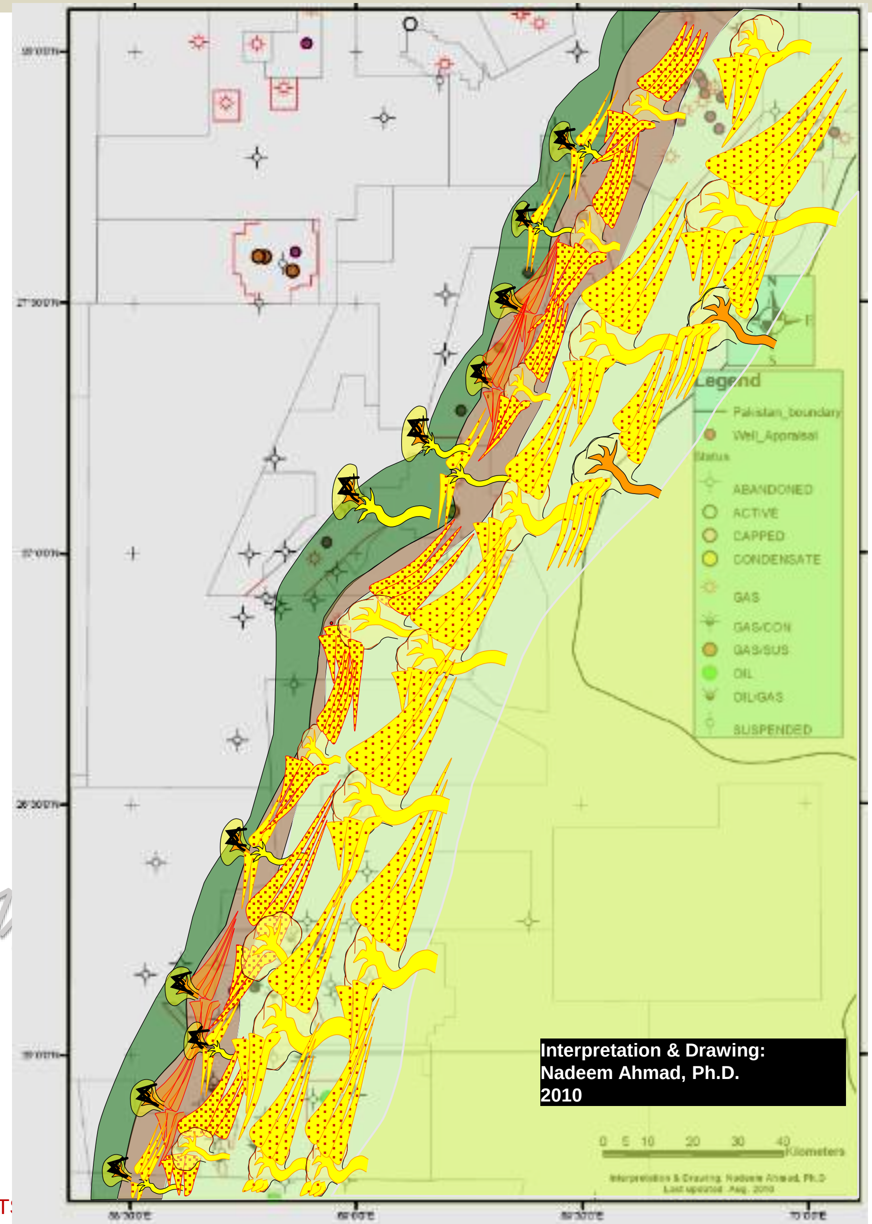
- Gross Depositional Environments map (GDE) based on depo-systems reconstruction for key geomorphic elements - PS Sets-3 and -4 Basal Ss Seq.
- Three phases of strandplain-barrier bar down-stepping towards west and sand emplacement on to the lower shoreface to offshore siltstone-shale.


Feeders: Delta plane distributary channels, mouth bars & heterolithics


Longshore drift.

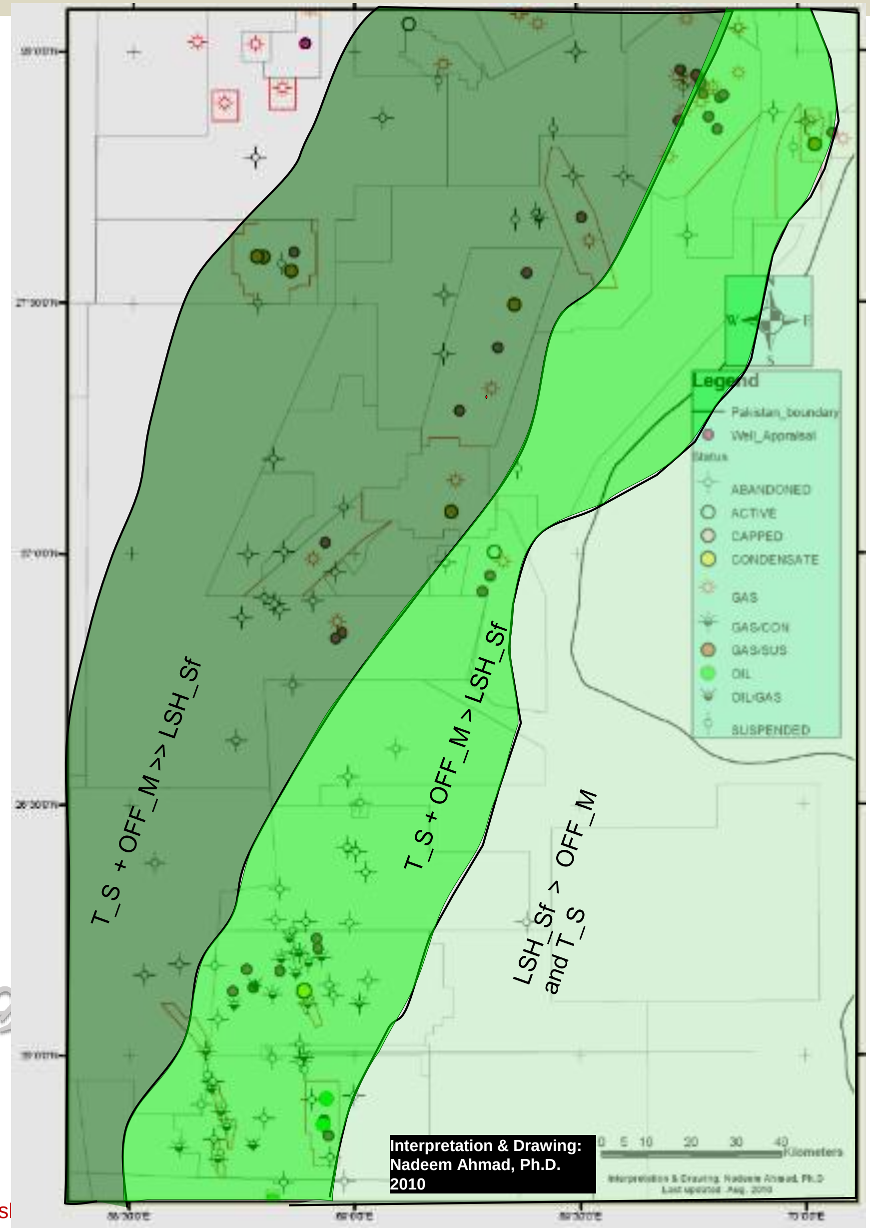

Strandplains & Shoreface bars under mixed wave & tide effect.
Waves actively back-piling sands. Tides spreading fines around and laying sand onto the back-barrier lagoons.


Rip current or Ebb flood deltas attached to the Tidal inlets cutting across the shoreface bars and even strandplains

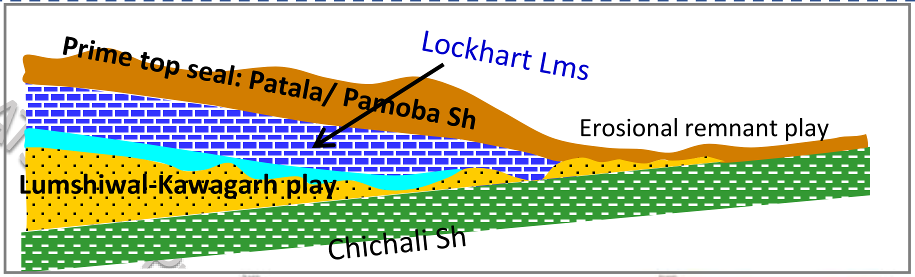


Seal Facies Map for Seal CRS Map. To combine with the Reservoir GDE Map for making Play Fairway Map

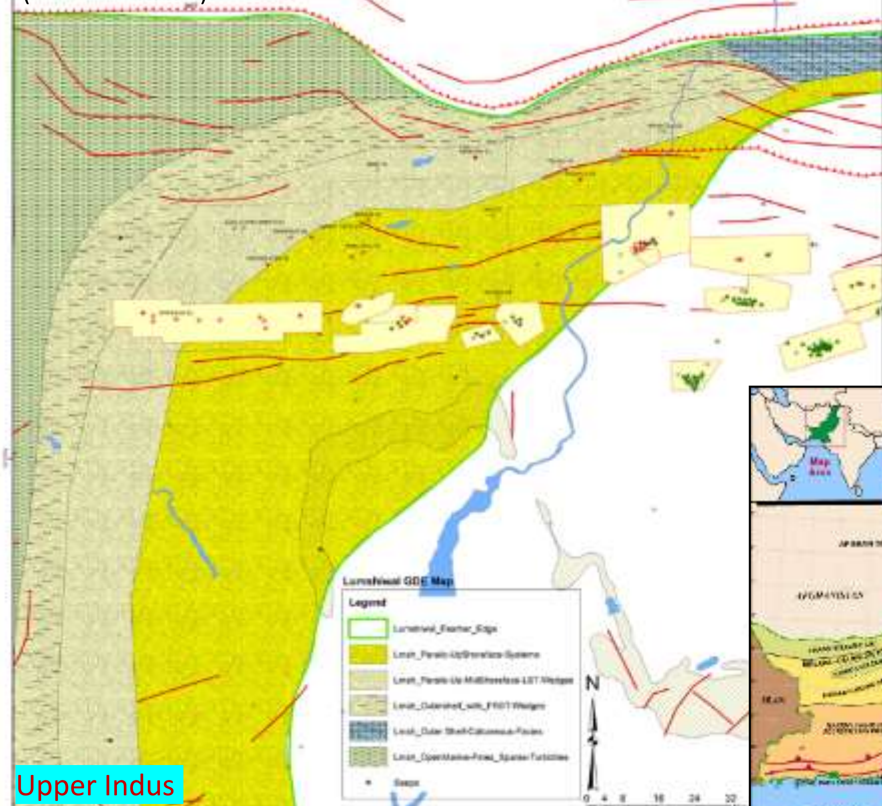
- Gross Facies map of the sealing rock facies within and above the Basal Sandstone Sequence set
- Prime top seal: Upper Goru marls. Considered uniform throughout the platform for the purpose of GDE and CRS maps
- Outer ramp deeper water environment

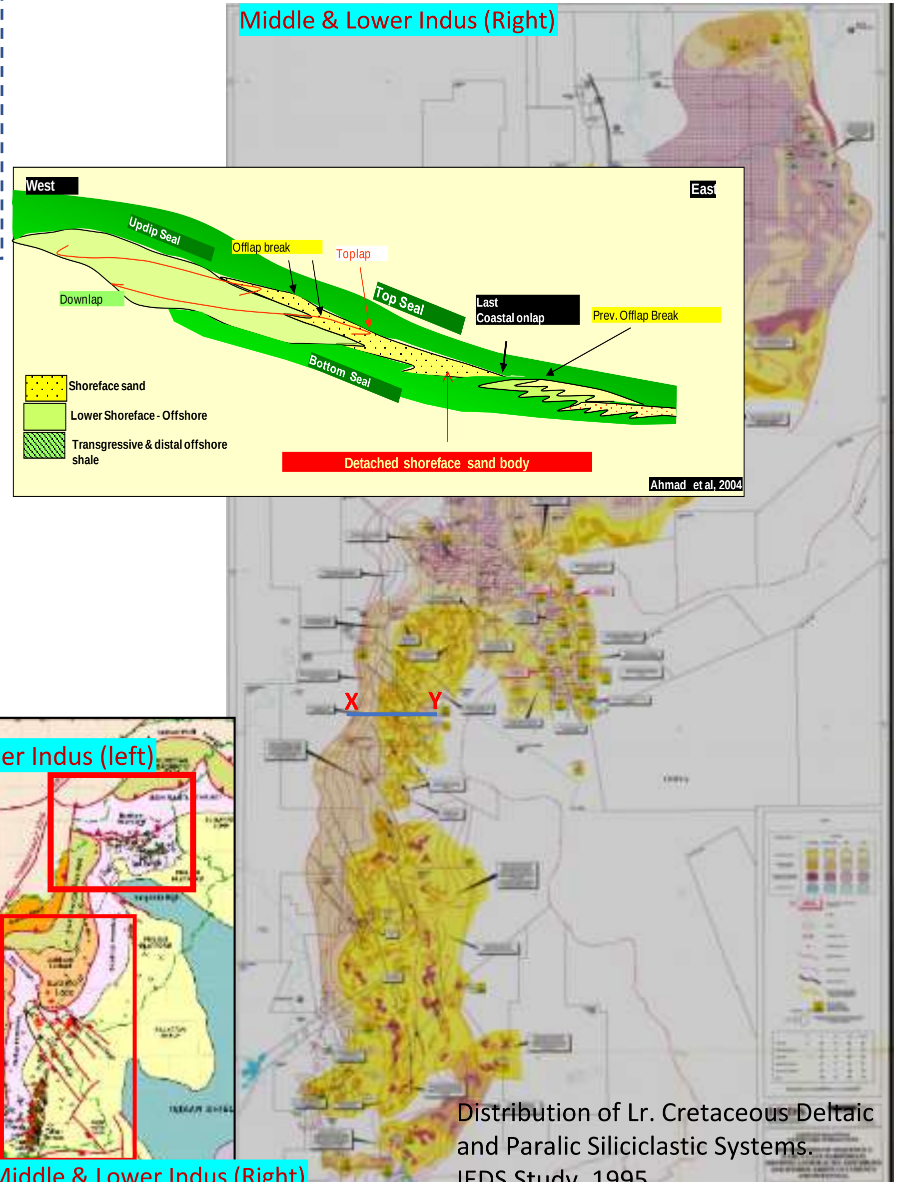


1 PFA – Mapping, Extending from the same age analogue Play Fairway in South: Lr. Goru and Lumshiwal Reservoir CRS, Upper Goru marls and Kawagarth Marl-Limestone Seal CRS



Lumshiwal Deltaic and Paralic Siliciclastics, (2011 and 2015)





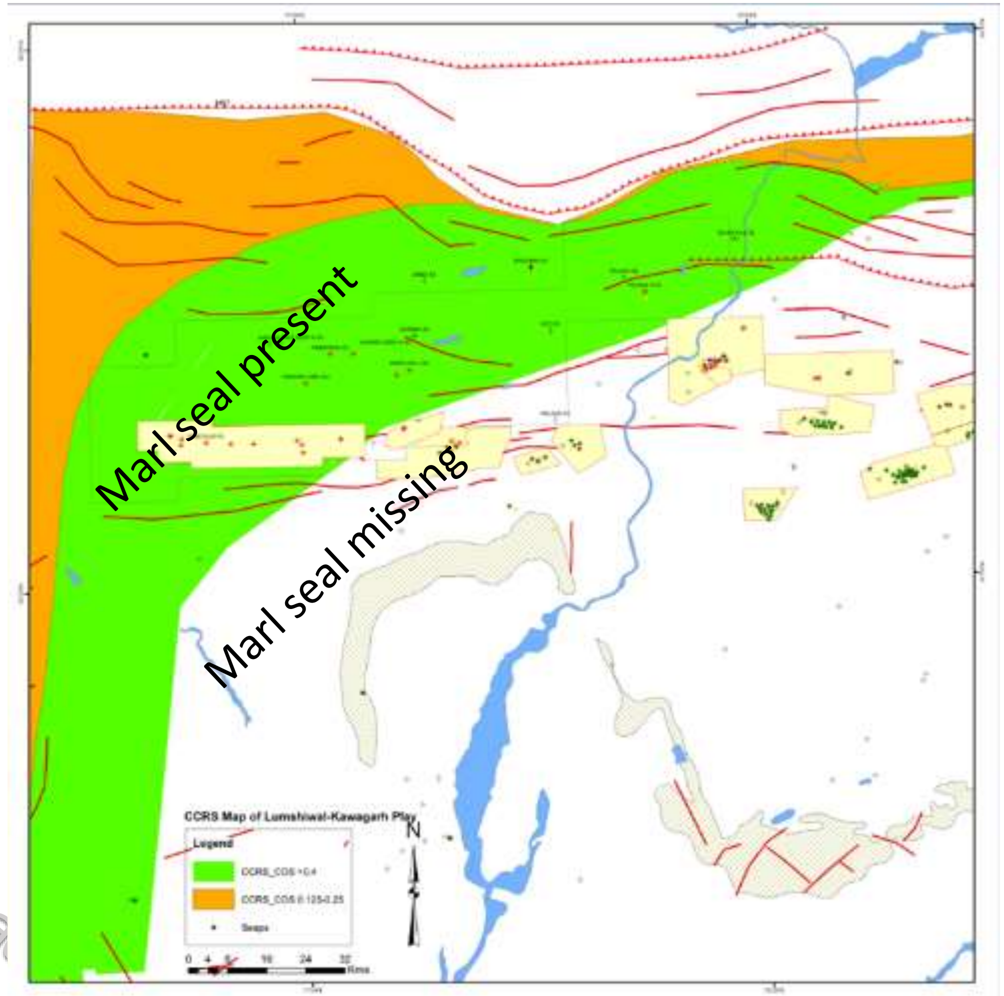
Distribution of Lr. Cretaceous Deltaic and Paralic Siliciclastic Systems. IEDS Study, 1995

North: Lumshiwal-Kawagarh Reservoir-Seal Pair: Play's CCRS Map

New Play Concepts & Approaches to capture Upside

- Regionally extensive thick Panoba-Mamikhel shales / evaporites provide effective top & lateral seal in highly tectonized culminations.
- Deposition of the Kawagarh's shale/marl-prone facies and Chichali's organic-rich anoxic facies are controlled by the reactivated paleo-high/ thermal bulge.
- Key geological uncertainties: 1) Mapping of top Seal, 2) Reservoir quality,

- Next Steps:
- Regional scale structural and sequence stratigraphic interpretations to reconstruct ancient structural setting, paleo-highs, depocenters and depo-systems,
- Inherent issues of diachronous Formations to be resolved through Sequence stratigraphy,
- Only if the structural and stratigraphic framework are consistent at regional scale, the success-failure analysis of correlative reservoir & seal intervals is possible.
- An adequate relationship between charge timing and structuration can then be established.



Prospect COS = P(play) x P(seal) x P(trap) x P(cont) x P(Model-U-Sh)

Whereas, **COS**= chance of success, **P(seal)** is the chance for local top seal and fault seal but excluding the bottom-seal and lateral shale-out seal, **P(Model-U-Sh)** is probability of model (e.g., detached shoreface, lateral shale-out, structural setup, etc).

5. **Plays & Prospects' Resource & Risk Assessment,** and Metrics for Opportunity selection for drilling:

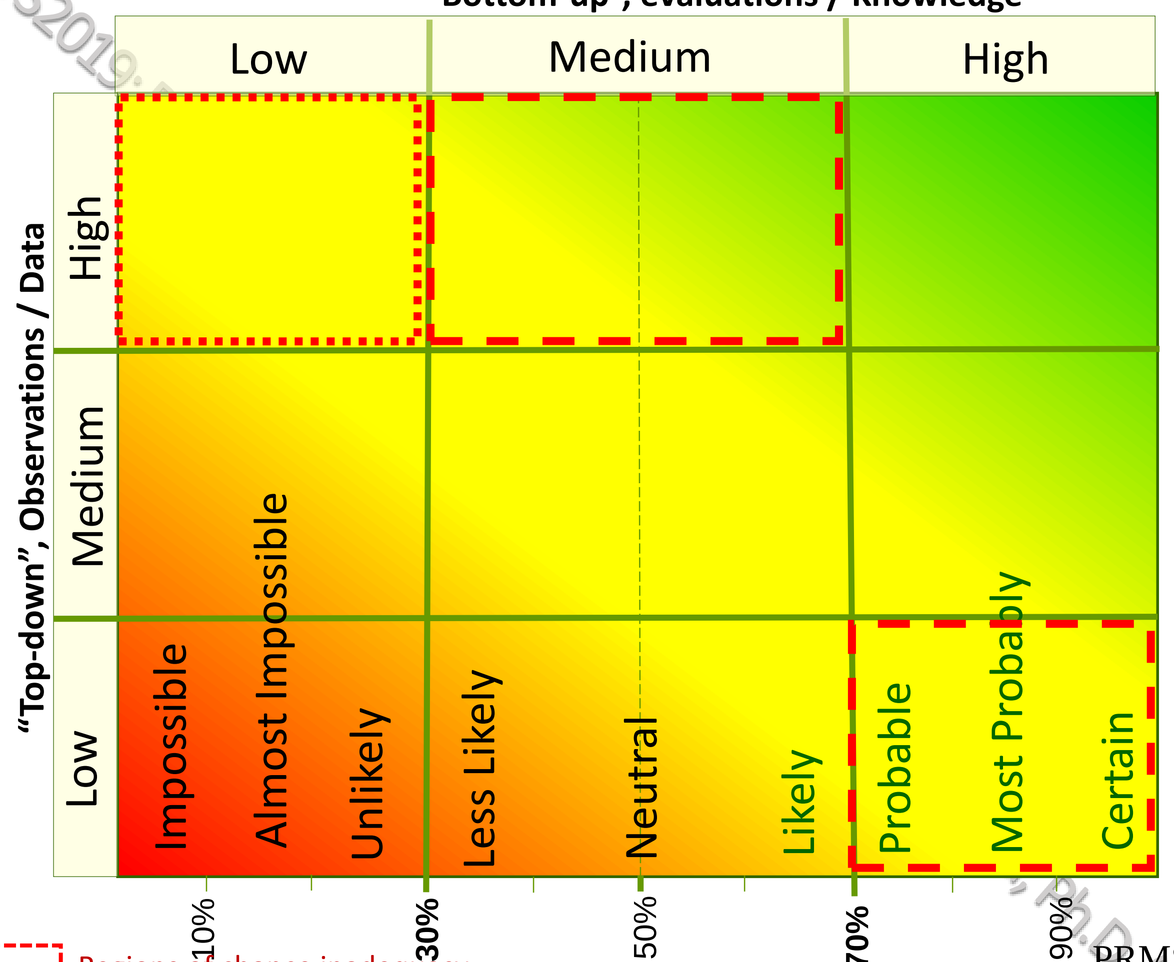
A. Quantification of geological Uncertainties (reservoirs, seals, source rock & its maturity, charge access and preservation, lateral seal).

B. Risk & Resource assessment models and approaches.

A. Frontier basin wildcats, Greenfield exploration and Brownfield exploration inventories, and respective geological risk models and success rates. Accordingly designing multiple exploration campaigns with success/failure criteria & indicators.

PRMS Guidelines, Chance Adequacy matrix for 'Risk Model'

- Plot of "Observations / Data" (top-down) vs. current level of knowledge from evaluations (bottom-up)

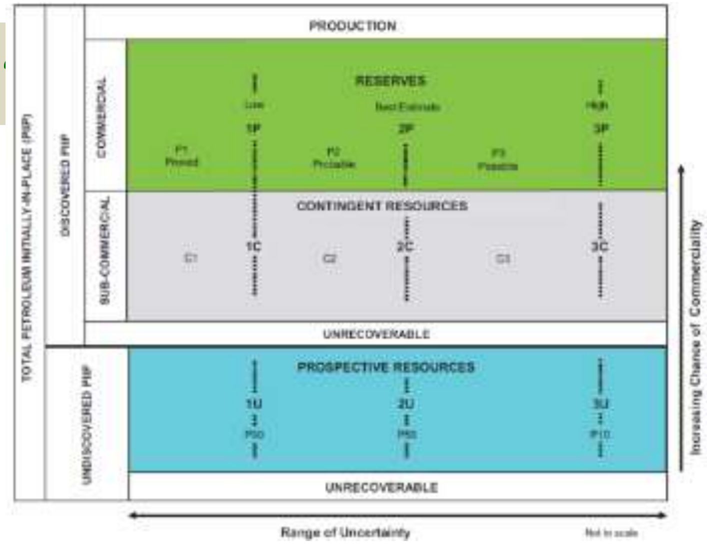


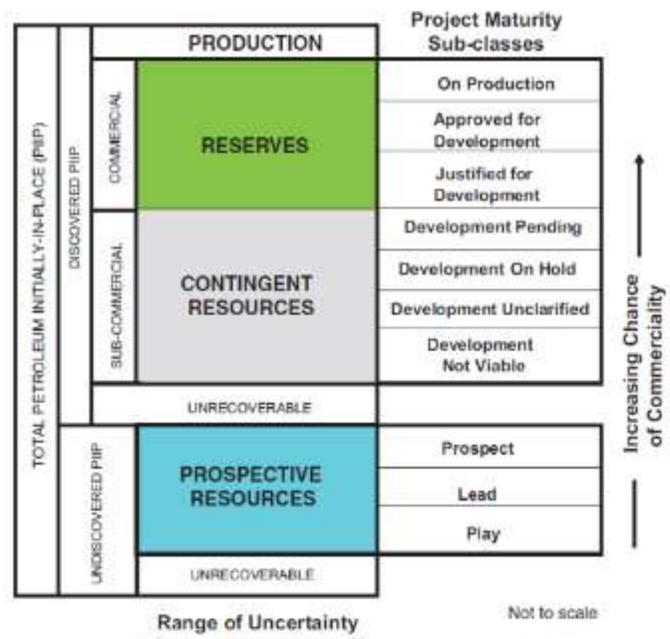
Regions of chance inadequacy

Region of 'data' inadequacy

Chance (adequacy)

Risk





PRMS resources classification framework and project maturity sub-classes as a function of decreasing uncertainty and increasing commerciality. SPE PRMS revision-2018.

Geological Uncertainties and Resource Potential – From Problem Definition to Solution

- Peculiar issues around Strat-barriers: change in depositional or diagenetic fabric or stratal termination -- neither abrupt nor so obvious on seismic data (Examples- fig-3)
- Added challenge: very few well documented analogues, little/no information on their geological & geophysical (G&G) aspects, mapping workflows,
- A wide range of resource sizes
- How to handle? 1) use wide range of GRV (gross rock volume) or its input parameters. Result: even wider range of probablistic estimates
- Post-drill 'look-backs' of what and where an under-estimation or over-estimation was made and how to get it right in the next prospects
- Requirement of a baseline & bench-marking,
- Need of a range of probabilistic volumes as opposed to one or three deterministic estimates or scenarios,

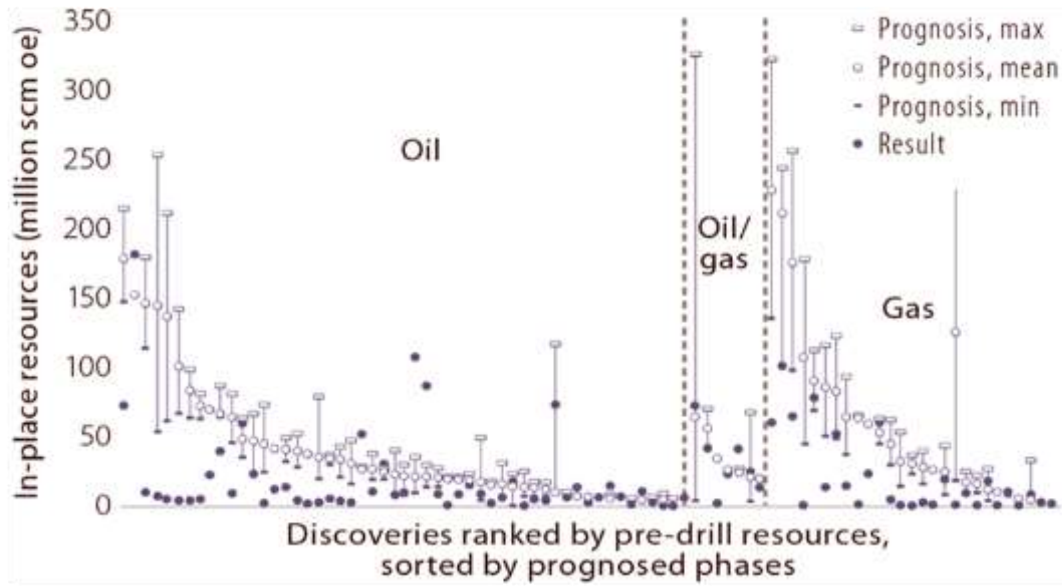
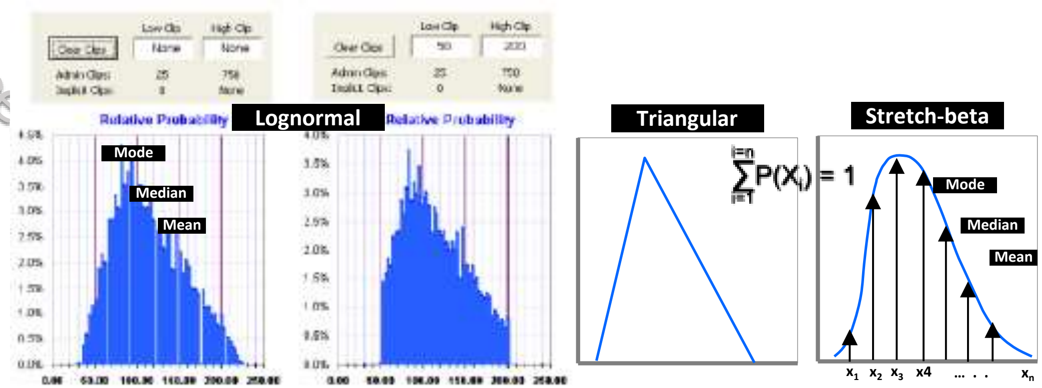
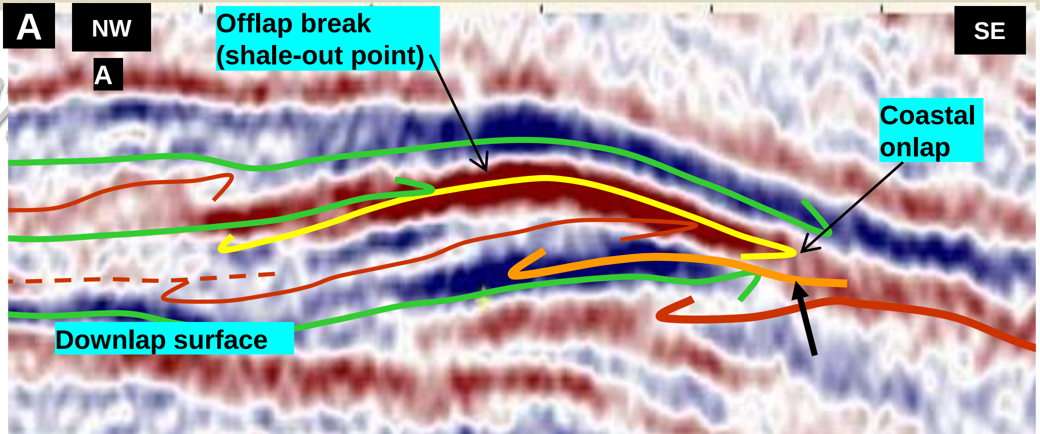


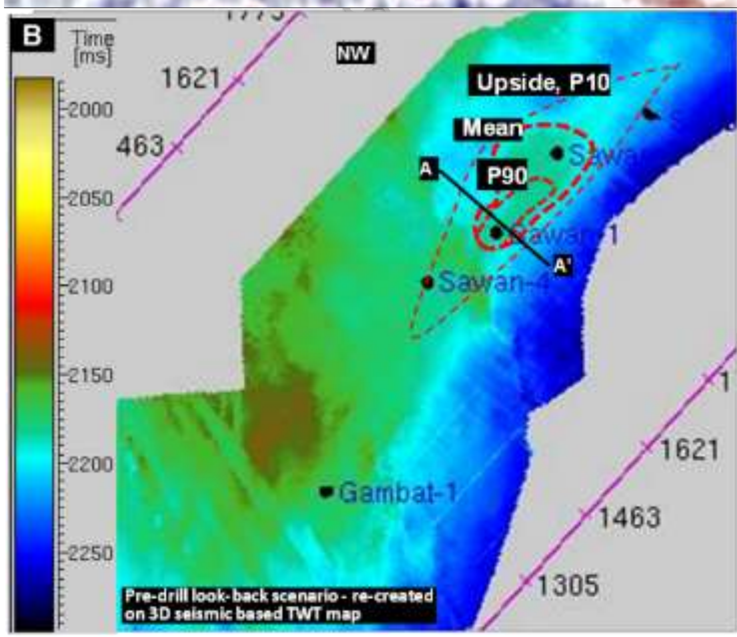
Figure 8. Overestimating the pre-drill prospective resources and underestimating the "chance of success" (for P90 volumes). Such inflated exploration portfolios under-deliver against the allocated capital. Data from Norwegian Offshore [15].



Reference: N. Ahmad, 2018 (ATC publ)

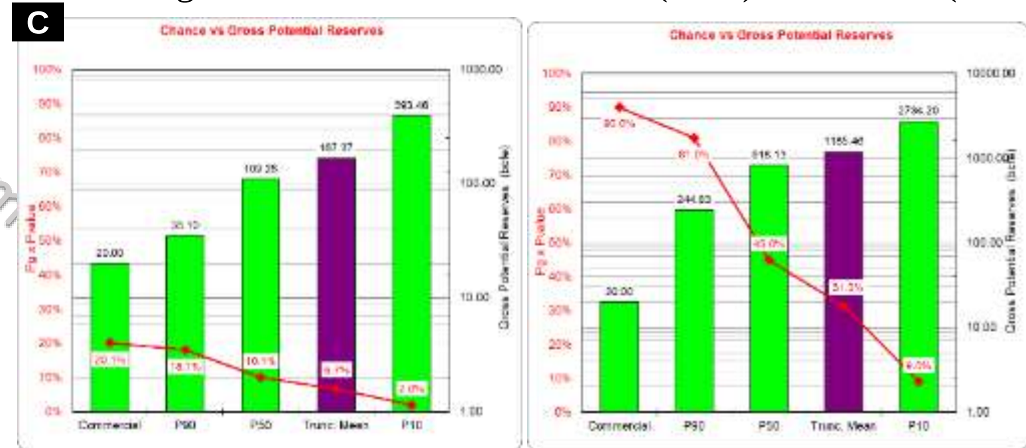
Rebuilding the Resource & Risking approach: Pre-drill vs. Post-drill





- A pre-drill trap scenario 're-created' for comparing the pre- and post-drill uncertainties as wells as prospective resources (1U, 2U, 3U) versus reserves. Progradational geometry on seismic makes linear belt of bright amplitude.
- B: Pre-drill outlook of Sawan Trap. Pre-drill concept of rollover structural closure as drawn on post-drill 3D seismic based TWT map of Top-C sand. Area polygons on TWT map of Top C Sand for GRV and in-place resources.
- Low, base and high cases (P90, Mean, P10) trap areas' definition is based on assumptions under pre-drill conditions.

Probablistic resources and COS (Pg) based on the polygons defined above using the method described in Rose (2001) and Ahmad (2001)



Prospect "S", Prospective resources (sales gas)

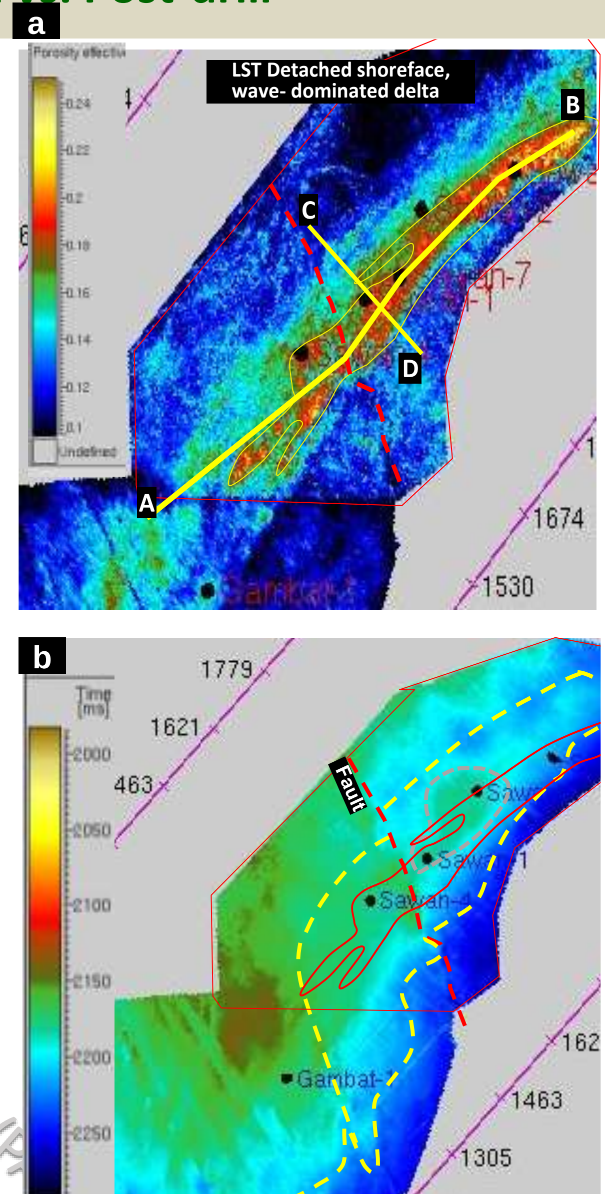
Prospect "S", Prospective resources (sales gas)

"S" field, EUR bcf sales, post-3D post-appraisal

Reference: N. Ahmad, 2018 (ATC publ)

Rebuilding the Resource & Risking approach: Pre-drill vs. Post-drill

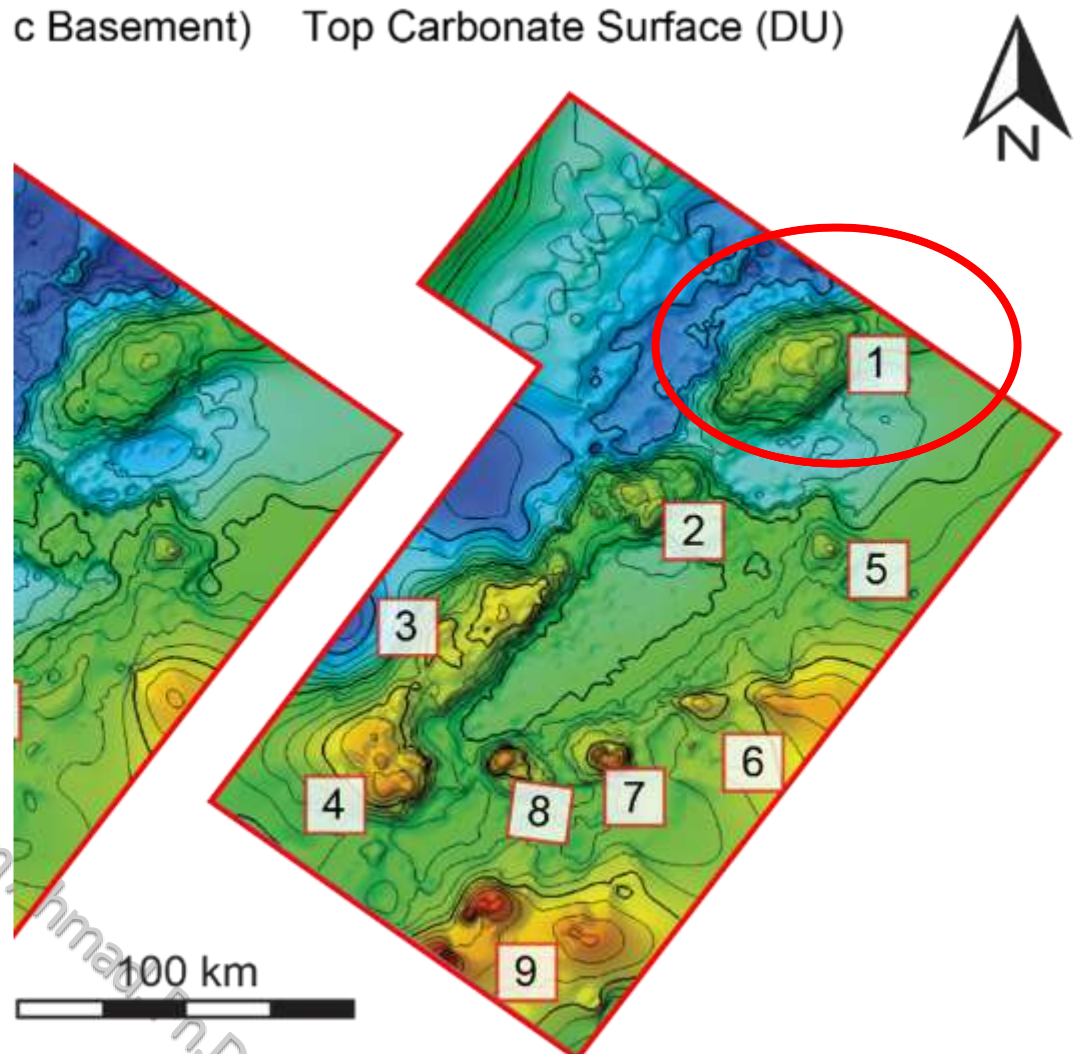
- Key entrapment elements of "S" stratigraphic trap, a post-drill outlook.
  - a) Seismic-derived "acoustic impedance" (AI) deriven porosity map showing strong depositional control (ref. Fig. 11A) on reservoir distribution and trap geometry. Trap outline for base case (Mean) drawn after the maps in Fink et al. (2004) and Ibrahim & Ahmad (2005).
  - Post-drill Mean (base case) and Upside (P10).
  - In post 3D seismic Appraisal and early development stages, wider GRV and GIIP ranges
  - Result of geological uncertainties related to the lateral extent of reservoir facies; effective porosity, net pay and technical recovery from certain high porosity (12-18% but low permeability) reservoir facies.



Reference: N. Ahmad, 2018 (ATC publ)

Rebuilding the Resource & Risking approach:
Follow-up strat-traps – Isolated Carbonate Buildups Exploration in Indus Offshore

- **What's different in proven plays?**
  Thick regionally extensive plastic seal (both top and lateral) in analogue plays
- Thick & laterally extensive source rock and maturity to generate and expel sufficient hydrocarbons are lacking (HC shows in overlying silty rocks are absent).
- Or Source/ Kitchen is not optimally situated relative to the reservoir/ buildups to allow effective charge throughout the geological history
- Porous permeable skeletal grainstone and bafflestone facies form the buildups – reservoir confirmed.
- This is only one of several plays that exist in Indus Offshore. Its kitchen and top seal are not shared by the other Plays. Therefore, its result does not downgrade rest of the 70-80% offshore

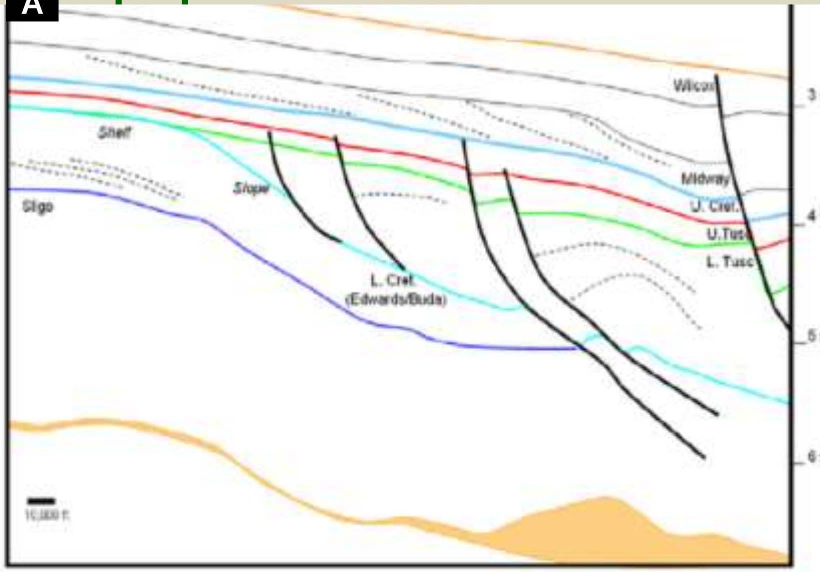


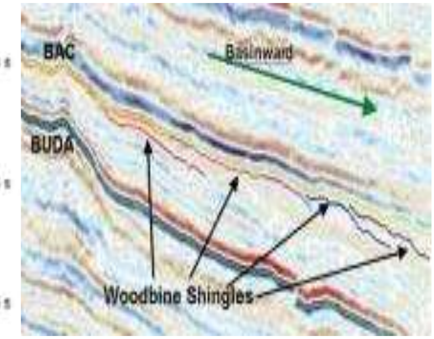
*1-9 Isolated Carbonate Banks (ICBs)

Rebuilding the Resource & Risking approach: Follow-up strat-traps – Issue of "updip towards hinterland" seal

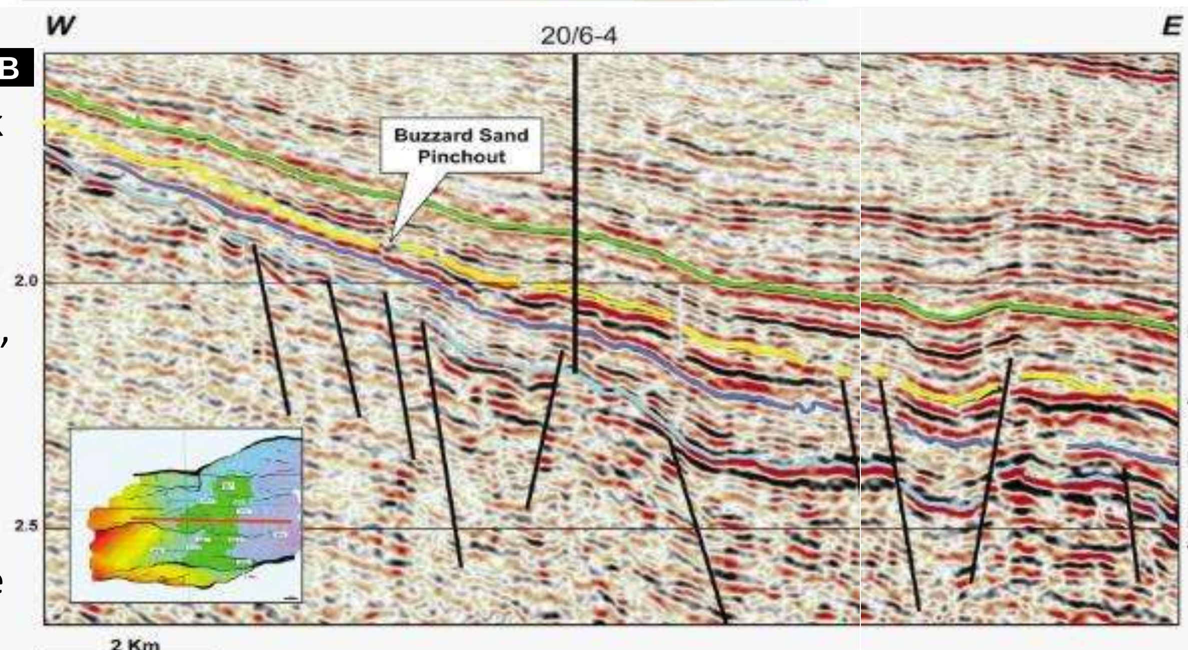
- Globally, fewer examples Works where plastic ductile lithology (thick salt, marls, argillaceous limestones or shales) underlie and overlie the reservoir,
- The Upper Cretaceous Woodbine Formation in East Texas and the Tuscaloosa Formation in Louisiana (Bunge, 2011). Spread over a large area, fluvio-deltaic to paralic progradational wedges across Edwards and Sligo ramp margins act as reservoirs (Figure 18A). The Upper Cretaceous Austin Chalk and Eagle Ford Shale act as a thick regionally extensive top seal. Several pools at 3,500-4,500m. Key risk is diagenesis of reservoir.
- Buzzard field in Outer Moray Firth, Central North Sea, operated by Nexen Petroleum (Doré and Robbins, 2005).
- Deep marine turbidite sand encased in U. Jurassic Kimmeridge

A





B



Rebuilding the Resource & Risking approach: Risking Model for Strat-traps

- Multiple lateral seals in two directions by the two independent geological features;
- Uncertainty around each to be quantified separately. Multiply two probabilities following the Bayesian approach to get an overall revised lateral seal risk.
- If a smaller GRV is constrained by one lateral seal, this may be treated as P90. However, the incremental GRV associated with the next lateral seal (whether fault or sand pinch-out) would require a risk revision of overall COS (Figure 10B).
- Exceedance probability for the incremental volume would have to be quoted, separately with the revised COS.
- Incremental volume to be reported as 2U with an increased risk or lower COS after Bayesian revision.

	Geological Elements of Play & Prospct	Linkage	Assessed for	**Play elements**	**Prospect**	Net
5	**Charge Effectiveness (C_eff)**		P90 in-place			
	Expel, Migrate, Pathway			100%		
	Trap's timing vs. Charge			100%		
				100%		100%
4	**Containment**		P90 in-place			
	Top/ Bottom Seal effectives (Seal_eff)			80%		
	Lateral seal- Fault				80%	
	Lateral seal- Stratigraphic*				45%	
	Preservation **				100%	
				80%	***60%	48%
3	**Trap Integrity**		P90 trap area			
	Closure/ Shale-out present/ mappable				70%	
	Data quality & coverage				80%	
					70%	70%
2	**Reservoir**		P90 net sand, pay			
	Presence, R_pres			80%		
	Quality - Effectiveness, R_eff				70%	
				80%	70%	56.00%
1	**Source Effectiveness (S_eff)**		P90 in-place			
	Source: richness & volume			100%		
	Maturity			90%		
				90%		90%
			Play Chance:			
	Chance of finding minimum volume at a sustained flow rate.		Prospect COS:			48.00%

Table 2 : Geological risk model customized to the subtle traps [16]. Refer to Chance adequacy matrix in Figure 10A.

* Stratigraphic lateral seal: truncation, shale-out or diagnostic barrier

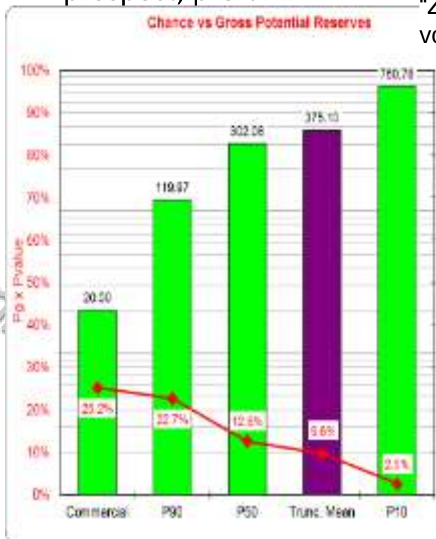
** Preserved thru geologic history against trap breach, spill, biodegradation.

*** Bayesian risk revision

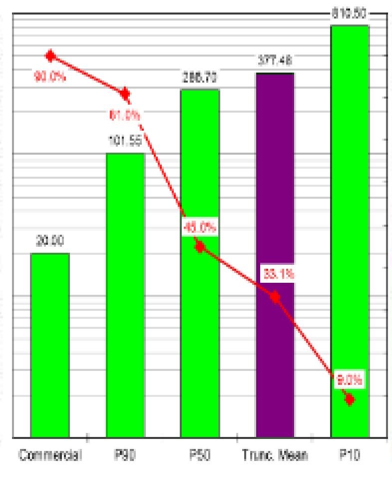
Reference: N. Ahmad, 2018 (ATC publ)

Rebuilding the Resource & Risking approach:
Risk and Resource Assessment of follow-up traps, post Z2 discovery

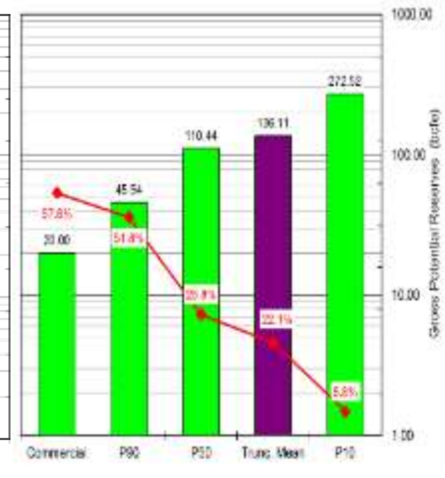
"Z" prospect, pre-drill



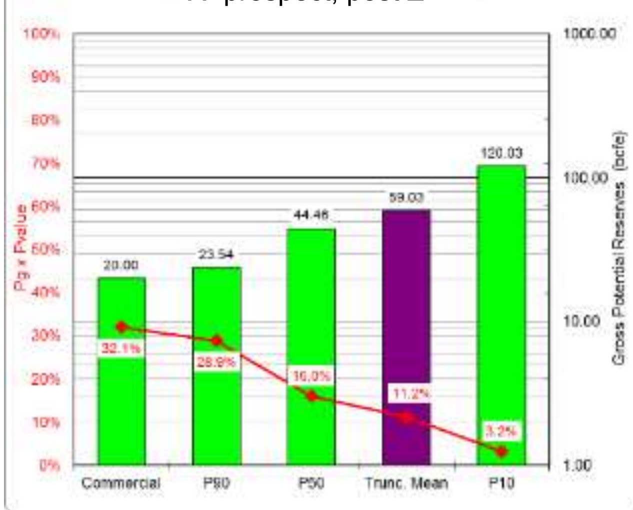
"Z2" (discovery) area's post-drill volumes & risking after 1st expl well.



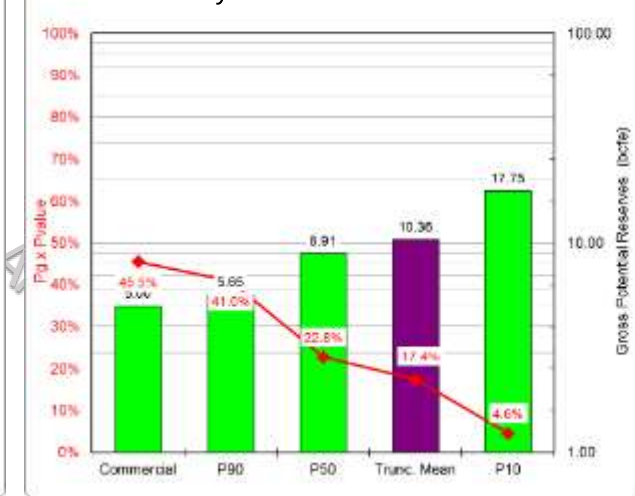
Z1 area's Post-Z2 appr well volumes & risking. Result: Found non-sealing fault



"X" prospect, post Z



Incremental case, "X-1" post Z discovery & shallower GWC



Reference: N. Ahmad, 2018 (ATC publ)

Rebuilding the Resource & Risking approach:
Risking approach and Learnings for calibrating next prospects

			P90-P50-P10				Play Level Risking, Probability				L
			Area (km^2)	Net Sand (m)	Porosity	EUR, Bcf Sales Ga	Pl_Res GD	Pl_Top-seal GDE	Model Risk_	stı	S
1	Prospect Z, Fig. 16-17	55	20-50-90	10-18-25	10-14-22	100-285-810	0.8	0.8	0.7		
1a	Prospect Z1_facies	50	25-50-80	10-18-25	10-14-22	120-302-760	1	1	1		
1b	Prospect Z2_facies+fault	36	16-30-50	8-14-22	8-13-18	46-110-272	1	1	1		
2	Prospect X, Fig. 17	8	1.5-8-16	10-15-22	8-12-18	24-45-120	1	1	0.8		
2a	Prospect X_facies-w	1.5		8-12-20	8-12-18	6-9-18	1	1	0.9		
2b	Prospect X_facies-E-W+fault	8	1.5-8-16	10-15-22	8-12-18	24-45-120					
3	Prospect Y, Fig. 17	13.1	10-13-20	10-15-22	10-13-18	38-77-155	1	1	0.9		
3a	Prospect Y1_2f(facies+fault)	6.3	4-6-10	12-16-22	8-13-18	17-36-75	1	1	0.9		
3b	Prospect Y2-south_2f (facies+thief-sd	6.8	4.5-7-11	12-18-25	8-13-18	20-42-90	1	1	0.7		
	Prospect "S", pre 3D, pre-drill. Fig. 11.	Mean	16	24	13	167	0.8	0.7	0.7		
	P90	1U	5	10	8	35					
	P50	2U	12	21	13	109					
	P10	3U	32	50	20	393					
	"S" field, Post-drill, Post 3D. Fig. 12.	Mean				1200	0.9	1	1		
	S1	1U -> P1	32.5	100	20	244	0.9	1	1		
	S1+S2	2U -> P1+P2	46.5	35-100	14-21	818	0.9	1	1		
	S1+S2+S3	3U -> P1+P2+P3	120	15-100	8-20	2734	0.9	1	1		

Table 3 : Probablistic Resource and Risk Assessment of Stratigraphic Traps (continues on next page).

Petroleum system (source richness, maturity, migration pathways) are set to 1 (proven

3f=2 sides by facies change, 3rd by lateral fault seal

Bold font where weaker link used.

GIIP* : only the input parameters critical for this discussion are listed here.

Reference: N. Ahmad, 2018 (ATC publ)

Rebuilding the Resource & Risking approach: Risking approach and Learnings for calibrating next prospects

		Local, Prospect Level Risking, Probability							
		st Seal-top	Reservoir_	Lateral fault	Lateral Se	Charge_loca	COS_play	COS (playxlo	COS (week li
1	Prospect Z, Fig. 16-17	0.9	0.6	1	0.6	1	0.448	0.145152	0.2268
1a	Prospect Z1_facies	1	0.9	0.9	0.9	1	1	0.729	0.729
1b	Prospect Z2_facies+fault	1	0.9	0.7	0.9	1	1	0.567	0.567
2	Prospect X, Fig. 17	1	0.9	0.6	0.6	1	0.8	0.2592	0.432
2a	Prospect X_facies-w	1	0.9	0.8	0.8	1	0.9	0.5184	0.648
2b	Prospect X_facies-E-W+fault								
3	Prospect Y, Fig. 17	1	0.9	0.6	0.6	1	0.9	0.2916	0.486
3a	Prospect Y1_2f(facies+fault)	1	0.9	0.6	0.7	1	0.9	0.3402	0.567
3b	Prospect Y2-south_2f (facies+thief-sd	1	0.9	0.6	0.4	1	0.7	0.1512	0.252
	Prospect "S", pre 3D, pre-drill. Fig. 11.	1	0.7	1	1	0.9	0.392	0.24696	0.441
	P90								
	P50								
	P10								
	"S" field, Post-drill, Post 3D. Fig. 12.	1	0.9	1	1	1	0.9	0.81	0.9
	S1	1	0.9	1	1	1	0.9	0.81	
	S1+S2	1	0.7	1	0.7	1	0.9	0.441	
	S1+S2+S3	1	0.9	1	1	1	0.9	0.81	

Table 3 : Probablistic Resource and Risk Assessment of Stratigraphic Traps (...continued from last page).

Rebuilding the Resource & Risking approach: Recommended Approach

- A smaller GRV, constrained by one lateral seal, should be treated as P90.
- The incremental GRV associated with the next lateral seal (whether a fault or a sand pinch-out) should require a risk revision of overall lateral seal risk following the Bayesian approach; the two probabilities should not be simply multiplied, neither a "weaker link" approach should be used unless dependency can be demonstrated.
- This lateral risk element should then be used for calculating an overall COS.
- Sawan and Miano like large volumetrics make P10 or P1 part of a play or region's field size distribution.
- P90 to Mean field size is otherwise in the range of only 20-200 bcf or its oil equivalent (Ahmad and Khan, 2010). Truncate tails. Use Stretch-beta distrib.
- First build a customized risk model based on pre- versus post-drill assessments and learnings. Consistent risk & resource assessment across the portfolio.
- Use of "weaker link" approach is recommended where a local prospect-scale risk element is a subset of the respective Play element.
- If using one depositional model for reservoir presence and lateral facies change (lateral seal), use only one 'probability factor', avoid double-dipping.
- Lateral seal integrity of the sandstone pinch-out (coastal onlap) toward hinterland is key risk, except in the area of faulting similar to that described in Section Sec. 5.2 (Figure 17).
- Identify 'residual risk' source and establish at business level its appetite,
- Decision Tree for VOI

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Nadeem Ahmad, Ph.D