Deep-Water Sequences in Static and Dynamic Basin Margin Accommodation*

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Abstract

Sedimentary sequences deposited in deep-water basins contain a variety of reservoir-prone units separated by fine-grained intervals. We have compared deep-water sequences from a post-rift passive margin Paleogene of the West of Shetlands, syn-deformational Miocene of the NW Borneo fold-thrust belt, and intra-cratonic Cretaceous clinoforms of the West Siberian basin to examine distribution of reservoirs and seals in the environments of different tectonic settings. On passive margins, transition to post-rift thermal subsidence is often associated with increased sand supply and smoothing of rift topography. An overall progradational trend is reflected by superposition of channels over lobes. There are commonly persistent point source feeder systems, controlled by the underlying structure. Due to efficient sand transport, the drape development may be limited and the effective seal is typically only developed at significant sea-level rise episodes, or due to changes in tectonic subsidence pattern. Sequences deposited in toe-set portions of clinoforms prograding into relatively shallow intra-cratonic basins experience limited lateral and downdip confinement, resulting in an overall progradation within and between sequences. The shelf edge often develops multiple feeder systems, which tend to alternate in supplying sand into deep water. As a result, autocyclic drapes related to lateral shift of deposition define more localized sequences, which partly overlap to stack into linear belts. In compressional settings, folding is initially subtle, mainly providing lateral confinement in tortuous corridors. Progradation and draping of the systems are commonly linked to sea-level change controlling sediment supply. Progressive linkage of structures creates more disconnected slope accommodation. The confining structures often grow near equilibrium with sedimentation rate, and a switch from ponding to bypass may happen repeatedly and in random order. Bypass and updip trapping of sediment is the key control in a development of drapes. Geometry and vertical stacking of deep-water sequences depends on whether the receiving accommodation is static or dynamically changing due to substrate deformation. The slope gradient variation controls relative proportion of channelized and sheet-like deposits. The drapes may result from autocyclic lateral shifts or from an allocyclic supply switch-offs, due to rejuvenation of updip topographic sills or a eustatic sea level rise.
References Cited


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Reserves: Our use of the term "reserves" in this presentation means SEC proved oil and gas reserves.

Resources: Our use of the term "resources" in this presentation includes quantities of oil and gas not yet classified as SEC proved oil and gas reserves. Resources are consistent with the Society of Petroleum Engineers (SPE) 2P + 2C definitions. Discovered and prospective resources: Our use of the term "discovered and prospective resources" are consistent with SPE 2P + 2C + 2U definitions.

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Is there a distinctive architecture in DW sequences of different settings?

**DW depositional sequences:** genetically linked turbidite deposits draped by a significant shale of auto- or allocyclic origin (sediment supply or bypass related)

**Controlling factors**
- 4D character of slope accommodation: static or dynamic
- Slope profiles – active deformation, healing of inherited topography, graded

**Compared parameters**
- Geometry – size of depositional elements, width vs thickness (confinement)
- Architecture - proportion and stacking of channelized vs lobe elements

**Implications**
- Stratigraphic trapping potential
- Stacked pay potential
- Reservoir risk and volumetric prediction in partly or poorly imaged DW plays

[Image: Diagram showing various depositional elements and their architectural implications]
Examples of static and dynamic basin accommodation

Case study 1: West Siberia
- Intra-cratonic thermal sag basin
- Rapid progradation of clinoforms

Case study 2: West of Shetlands
- Passive margin with rejuvenated rift topography
- Healing of an ‘above-grade’ slope

Case study 3: NW Borneo
- Deep-water fold-thrust belt
- Evolution from basin floor to episodically deforming slope

Eustasy

Sediment supply

Subsidence/Uplift

STATIC to DYNAMIC
Meretoyakhinskiy block
West Siberian basin, Russia

An intra-cratonic sag basin with rapidly prograding clinoforms
Lower Cretaceous clinoforms

- Triassic rifting followed by a thermal sag. Only minor deformation subsequently.
- Max subsidence and sedimentation rates in the early Cretaceous (uplift and erosion of the basin margins).
- High progradation rate (mean of 61 km/My)
- Eustatic cycles - primary control on deposition.
- Basin depth: 300–1,200 m
- Grain size: fine – medium
- Wide shelf (10’s – 100’s km)
Sequence architecture & sand distribution

- Regressive wedges during both highstand and lowstand, with DW sand deposited in both HSS and ISS
- Toe-set sands commonly detached along steeper foresets (strat. trapping)
- Intra-formational seals also by draped ravinement
Basin-floor & slope turbidites

- Basal extensive basin-floor fans overlie composite sequence boundary
- Following sequences have less sandy toesets, but sand is present on the slope and at their shelf-edge
- Apparent pinch-outs/toplaps draped by mud-prone transgressive deposits
Lateral & vertical heterogeneity

- Sequences are represented in the toesets by turbidite fans (lobe complex sets) 80-120m thick
- Lobe complexes (50-60m thick) are passing up-slope to 20-30m thick channel belts
- Sand bodies are separated by 5-10m thick muddy drapes, with thickness increasing in the foresets
- Drapes are laterally persistent, acting as effective intraformational seals
- Slump facies observed in the core from the upper slope setting
Architectural evolution

- Initial wide channel belt evolves into multiple short lived slope channels with higher sinuosity
- Active channels alternate along the slope, but more than one is active at a time
- Lobe complexes overlap but exert little lateral confinement on their neighbours

Limited influence of currents on shallow (inner) subaqueous delta, increasing towards outer shelf. Waves might bring sediment to outer shelf. With straight shelf edge, shelf edge propagation dependent on sediment input at shoreline?

Assumed sediment input point north of model, resulting in higher shelf propagation in this area. Southward, only minor propagation due to limited sediment delivery. Island source/terraced area becomes preferred area of deposition at basin floor.

Reduced sed. supply to shelf edge (e.g. due to decrease in shelf accommodation).

Current strength and direction, sediment input, high sed. supply, maintained high sed. supply, southward shift in main dep. over time.

Achimov 2

Lobe complexes 8-12 km wide
Upper Achimov fan >20 km wide
Channels 0.3-0.6 km wide (widening downslope)
Sinuosity ~1.25-1.3 (peak mid-slope)
Greater Schiehallion area
Faroe-Shetlands basin, UK

Passive margin with inherited, episodically re-juvenated rift topography
Paleogene stratigraphy

- Major hinterland uplift triggers sand input into the basin
- Rift topography present long into thermal subsidence phase
- Basin accommodation progressively filled by deep-water deposits, but episodic deformation triggers slope gradient changes

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Schiehallion field located between a major underlying faulted horst and a transfer zone
- Syn-depositional E-W faulting occurred in response to their episodic movement
- Fault accommodation zones created corridors capable of confining turbidite fairways
- Initial Paleocene slope depocenter at their intersection progressively filled before gradual back-stepping and onlap of the basin margin in the subsequent phase
Depositional sequences

- Individual sequences grouped in sequence sets, recording evolving slope accommodation
- Initial extensive sheet-like ponded aprons vertically succeeded by perched lobe complexes with distributary channels, followed by slope valley complexes
- Lateral confinement in the E persists
- Vertical amalgamation of sequences through channel incisions
Schiehallion reservoirs and seals

- The main producing interval spans four amalgamated sequences containing both lobe and channel complexes
- Lobes typically thicker than channels, with channel complexes showing more aggradation upward
- Drapes thin (10-20m) and/or containing thin sands and silt
- Trapping aided by fault offset and slump scars
Geometry

- A N-S confined fairway developed at the end of the ponded phase
- Narrower and straighter channels at the onset of the back-filling lobe-dominated perched sequence
- Channel belts become wider and extend further basinward as the bypass progressively develops
- The prograding clinoform sequence contains multiple straight gullies feeding coalescing toeset aprons
Sabah
NW Borneo, Malaysia

Deep-water fold & thrust belt with syn-depositional turbidites
Tectonics & sedimentation

- Basin margin succession deposited within an intermittently active foreland fold/thrust belt
- Outboard propagation of thrusting and associated folding
- Frequent shelf-edge sediment instability
- Pre-kinematic turbidite sequences followed by syn-kinematic ones
Mass wasting, incisions, ponding and healing

- Anticlines generated by thrust propagation link into a series of shelf-parallel ridges
- Parts of anticline trends progressively buried by slope segments reaching equilibrium profile
- Active deformation frequently triggers mass wasting
- Steep slopes are dissected by incised submarine valleys feeding perched and ponded slope aprons
- Different architectural elements co-exist laterally along the same slope position

Active processes:
- Regional-scale mass wasting of shelf edge/upper slope
- Local instability of anticline flanks
- Submarine valley incision on high-gradient slope
- Slope apron deposition on localized flats/basins
Fill of a ponded accommodation

- Forced sinuosity of feeder systems as the anticlines grow and overlap
- Shape of the apron defined by syncline
- MTCs intercalated with turbidite units
- Channelization & bypass as updip depocentre fills and gradient increases
Mud-prone units slumped in core and BHI, showing variable thickness in depocentre

- Lobes offset stacked, showing some compensation with underlying MTD thick
- Sand-rich distributary channels
- No lobe-complex amalgamation across MTDs – four reservoir-seal pairs in place
Confined geometry & forced stacking

- A shallower better imaged interval used as a geometric analogue for the reservoir
- Reduced length/width ratio of the lobes possibly due to syncline confinement
- Lateral stepping of successive lobe storey sets creating a wide lobe complex
- Thin and straight channels loosely organised into belts also show periodic lateral steps
Summary & conclusions
Lobes and lobe complexes show a degree of confinement even in prograding clinoforms and in passive margins – a role of depositional topography in the multi-feeder slope systems as opposed to point-source basin-floor fans?

Mixed to sand-rich channel systems in the shown examples are straight to sinuous, rather than meandering.

Healing of the above grade slopes in studied passive margins is accompanied by progressively widening and more sinuous channel belts.

Highest sinuosity seen in isolated channels of the multi-feeder clinoform slopes, or where channel belts are tortuous due to confinement.
Key characteristics of DW sequences in static & dynamic basins

**Intra-cratonic sag basin with prograding clinoforms**
- Rapid progradation fed by significant long-shore currents
- Multiple isolated sinuous channels originate at shelf break
- Steep slopes allow sand bypass of the upper slope – trap creation
- Limited erosion prevents amalgamation – multiple RSPs
- Adjacent lobes provide lateral confinement through their topography

**Passive margin with inherited rift topography**
- Underlying faulted grabens initially create ponded accommodation
- Episodic fault reactivation focuses subsidence and confines fairways
- Progressive healing leads to back-stepping of perched aprons followed by an incision of channels within graded slope valleys
- Perched to graded sequences amalgamate – vertical connectivity

**Fold & thrust belt with syn-depositional turbidites**
- Fold linkage may evolve tortuous fairways into ponded depocentres
- Widths of feeder systems is variable – determined by confinement
- Lateral offset of lobes is common, creating wide shingled complexes
- Onset of spill from filled depocentres abrupt – late bypass channels
- Frequent degradation of fold flanks produces MTDs – effective seals

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**STATIC to DYNAMIC**

West of Shetlands

Sabah

**STATIC**

West Siberia

**DYNAMIC**
References


