Basin-scale assessment of the potential CO$_2$ storage of the offshore Durban Basin, KwaZulu-Natal, South Africa

Geological development of the Durban Basin

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Presentation forms part of a PhD Thesis in Geology undertaken at the University of KwaZulu-Natal, in conjunction with a statutory programme undertaken by the Council for Geoscience on behalf of SACCCS
The Objectives of this thesis are as follows:

• To assess and define the stratigraphy and sedimentology of the Mesozoic Durban Basin, with specific emphasis upon the mineralogy of potential sand-rich horizons and their association with overlying shale caprocks.

• To identify and quantify potential CO$_2$ storage sites/areas through seismic and stratigraphic interpretation

• To assess and map the areal extent of potential sand-rich horizons within target areas identified from seismic and stratigraphic interpretations

• To define a capacity estimate for the safe storage of CO$_2$ in subsurface aquifer rocks in the Durban Basin.
Position of the offshore Durban Basin in relation to other Mesozoic sedimentary basins in South Africa
Offshore Durban Basin

- 10 000km$^2$ along the continental shelf between Durban in the south and Richards Bay in the north.
- Durban Basin extends to the 2500m isobath
- Offshore Zululand Basin separate from offshore Durban Basin
- Separated by the Naude Ridge – a palaeo-basement high

Figure 1.2. The northern Natal Physiographic Provinces after Dingle et al. (1978). The continental shelf (1 - 3), continental slope and rise (4), Thukela Cone (5 - 11), Central Terrace (12), Mozambique Ridge (13), deep ocean basin (14 - 16). The bathymetric contours of the northern Natal Valley after Dingle et al. (1979) are overlaid as an orthorectified raster image.

after Young, 2009
Although targeted for oil and gas exploration, has not been well studied.

Explored by SOEKOR in late 1970’s and early 1980’s

Sparse seismic coverage of ~7000km of 2D seismic profiles completed – centred around the Tugela Cone in the Durban Basin.

Four wildcat wells drilled mainly on the continental shelf.

No detailed exploration has been undertaken in the Zululand Basin and therefore limiting the project to the Durban Basin.
Viljoen et al., (2010) combined Durban and Zululand Basins during country-scale screening and CO₂ storage capacity calculations.
- Suggested a combined potential storage capacity of 42Gt, over ~81 000km².

Offshore Durban Basin covers area of ~10 000km² down to the 2500m isobath
- Therefore hosts theoretical saline aquifer storage capacity of ~5Gt.
- Excludes ~200Mt potential Oil/Gas reservoir storage postulated by Roux, (2009)
• 2\textsuperscript{nd} highest emission value in SA outside of the Gauteng hub.
• \(\text{CO}_2\) emissions due to SAPREF oil refinery

• Existing oil and gas pipelines between Sasol-Secunda, Richards Bay and Durban Harbour
• Oil pipeline operated by Petronet
• Gas pipeline operated by SASOL
Map of earthquake magnitudes inferred from modified Mercalli-scale intensities (CGS)

Map of recorded earthquakes in Southern Africa (USGS database)

Map of seismic risk in South Africa (CGS)

Map of earthquake magnitudes inferred from modified Mercalli-scale intensities (CGS)
Available Seismic Data

- 2D data
- Moderate resolution
  - can identify large regional-scale unconformities
  - Cannot identify individual sandstone packages less than ~20m thick
- Seismic data suggests a total thickness of >4000m for the Jurassic-Cretaceous basin-fill succession
- Includes a thick Cenozoic succession of sandstone, and marine claystone forming the Tugela Cone
  - Oligocene channels have been identified in seismsics
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x = desirable; xx = required; n.a. = not applicable
**Durban Basin Formation - Gondwana break-up**

**Early Jurassic (180 – 175Ma)**

**Karoo volcanism**
- Drakensberg volcanics
- Dyke swarms
- Early rifting in Mozambique

**Mid to Late Jurassic (175 – 155Ma)**

**Plate separation**
- Indian Ocean opens from north
- Extension on Maurice Ewing Bank – pull-apart basins form
- Strike-slip movement on AFFZ
- Syn-rift sedimentation begins

- Strike Slip fault defines northern termination of AFFZ
- Marks the boundary between the Natal Valley to the south and the Durban Basin to the north
- Durban Basin formed on South Tugela Ridge micro-plate
**Late Jurassic – Early Cretaceous (155 – 135Ma)**

**Natal Valley opens**
- Falkland Plateau moves - Strike-slip faulting
- Formation of rift basins on Agulhas Bank
- Syn-rift sedimentation

**Early – Mid Cretaceous (135 – 115Ma)**

**Drift stage**
- Extraction of Falkland Plateau
- Formation of Natal Valley
- Coast-parallel faults form onshore
- Durban Basin forms as localised depocentres

- Normal Faulting manifested onshore and offshore KZN
- Type I – Early arcuate faulting
  - Early Arcuate fault represents northern termination of Natal Valley and AFFZ
- Type II – Late coast-parallel faulting
- **Late Cretaceous (115 - 90Ma)**
- **Drift stage**
- Extraction of Falkland Plateau - Natal Valley forms
- Coast-parallel faults form onshore
- Durban Basin forms one singular depocentre
- Distal offshore deposition of synrift and drift sediments – similar to Zululand Basin
Stratigraphy of the Durban Basin

- Consists predominantly of marine claystones and siltstones with some intercalated sandstone horizons

- **Basement to 6At1** (*Late Jurassic ~157Ma to Barremian 129Ma*)

- Stage I - Basal syn-rift sediments:
  - Late Jurassic (157Ma) - late Valanginian (133Ma).
  - Correlated with continental red bed successions identified in the ZU well in Zululand.

- Stage II syn-rift sediments:
  - Hauterivian (132.9Ma) to Barremian (127Ma).
  - Sediments to the north of basin - grey-green and red-brown claystone and silty sandstone - devoid of fauna
  - 40m thick upward coarsening packages identified – coarsen from clay to 10m thick sandstone units
  - Continental origin to the north,
  - Upper slope origin suggested for the south
  - Succession is capped by an erosional unconformity (Horizon 6At1) formed during regional uplift.
  - Pre-6At1 successions are not identified in 2 of the wells drilled in the basin.

- Basal units in Jc-B1 intruded by dolerite sills of late Cretaceous age (Broad et al., 2006).
Stratigraphy continued …

- **6At1 to 13At1 (Barremian 129Ma to Aptian 125Ma)**
- Early Cretaceous Drift succession very localised
- Thick (920m) succession of grey claystones and minor sandstones identified in Jc-C1.
  - Deposited in outer shelf environment
- Facies change to the north – becomes more sand-rich
  - Thinner
  - Deposited in an innermost shelf environment
- Sand-rich units can be correlated with the Marginal and Basal (Aptian) sandstones identified in the Zululand Basin.
- Interval is terminated by a transgressive unconformity.
• **13At1 to 15At1 (Aptian 125Ma to Late Cenomanian 93Ma)**
  
  • Defined by siltstones with interbedded sandstone stringers.
  
  • In Jc-B1 the lower portion of the unit is not preserved.
  
  • Siltstones in Jc-C1 to the southwest suggest inner shelf deposition.
  
  • In places in the basin the entire interval has been removed by erosion.

• In most basins the 15At1 horizon marks a hiatus for most of the Late Cenomanian and Turonian.
  
  – defined as the Mid Cretaceous unconformity (Klinger and Kennedy) identified in outcrop in Zululand.
  
  – Mid-Cenomanian unconformity underlying Late Cenomanian-Early Turonian sandstones in deep Zululand Basin.
• **15At1 to ”K” (Turonian 93Ma to Santonian 86Ma)**
  
  • Only portions of this interval are known to be preserved in the Durban Basin.
    – Late Cenomanian to Early Turonian intervals are not developed in Durban Basin
    – Has been postulated to exist in deeper portions of the Durban Basin (PASA 2012)
  
  • Lower portion of this interval is represented by extensive clean gritty quartz sandstone (the “11” sandstone)
    – Identified in all southern African basins except the Durban Basin
    – Equivalent of the Grudja Formation (Domo) sandstone in Mozambique, and the Middle (Cenomanian) sandstone in Zululand.
    – Represents a forced regressive shoreline deposit
  
  • “11” to “K” interval intersected by boreholes in the Durban Basin
    – Late Turonian interval
    – Dominated by deep marine claystone
    – Represented by deeper water deposition – outer shelf
    – Jc-B1 intersected a 17m thick “tight” calcareous sandstone interbedded within this interval
    – Overlain by Late Coniacion deep marine claystones
Stratigraphy continued …

- "K" to 22At1 (End Coniacian 86Ma to Maastrichtian 66Ma)

- Durban Basin - interval separated into 2 by
  - Early Campanian (83.5 to 76.5Ma) unconformity “X”

- Lower interval
  - Lower units not preserved in the offshore Durban Basin
  - Outcrops are present at Mzamba and Trafalgar
  - Suggests period of erosion rather than non-deposition

- Unconformity “X” eroded down to:
  - Coniacian in Jc-B1 - Turonian in Jc-A1
  - Cenomanian in Jc-C1

- Upper interval
  - Identified in all Durban Basin wells
  - Regressive sequence of interbedded claystone, siltstone and sandstone
  - Deposited as a shallowing upwards sequence from slope to outer slope
• **22At1 to Seafloor (Cenozoic – 65Ma to Present)**
  
  22At1 represents the boundary between the Cretaceous and Cenozoic.

  • Cenozoic interval over 1500m in Durban Basin.
  
  • Comprises interbedded claystone and sandstone with occasional coquina beds.
    - Forms overall coarsening upwards succession becoming more sand-rich upwards.
    - Depositional environment shallows upwards from outer shelf to present mid shelf environment.

  • Dominated by Tugela Cone which formed by mid-Cretaceous times.
    - Although not drilled, upper fan, turbidite sand packages are expected on levees and in channel infill in the delta.
    - Middle fan should host supra-fan lobes and proximal turbidite facies.
    - Lower fan potentially hosts bedded distal turbidites.
    - Oligocene (~30Ma) channels identified by seismic mapping (PASA)

• **Tugela Canyon formed in recent times.**
  - Mapped bathymetrically (Young, 2009)
Conclusions and future work

- Durban Basin formed through extension tectonics related to Gondwana breakup
- Syn rift and Drift phase sediments have been identified
- Sediments range in age from Late Jurassic (157Ma) to Cenozoic
- Dominated by marine claystones with some sandstone horizons evident
- Tugela Cone forms a large progradational delta fan complex that may host sandstone packages with potential CO$_2$ storage capabilities.

- Further mapping of seismic profiles with the assistance of Petroleum Agency SA will help to delineate potential reservoir packages
- Re-mapping and analysis of existing legacy well data housed at PASA may identify potential sandstone units with CO$_2$ storage prospectivity.
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Thank You