The Geological Framework and Economic Potential of the Coal-Bearing Karoo Strata in the Central Kalahari Basin, Botswana*

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Abstract

The Permian Karoo rocks in Botswana are little known with regards to their regional and local tectonic, climatic and depositional controlling mechanisms, and hence our understanding of the distribution, thickness and lateral continuity of the contained, economically important mineral resources (e.g., coal, coalbed methane, water) is hampered.

This MSc study of the coal-bearing Karoo strata in the Central Kalahari Sub-basin attempts to work out the dynamics of coal depositional environments, in particular the forces responsible for changes in the accommodation space (e.g., subsidence vs. sedimentation rates). This is hoped to be achieved by a detailed review of the temporal and spatial stratigraphic variation of the coal-bearing successions, including the analysis of facies changes based on over 800, widely distributed borehole records (e.g., core descriptions, gamma and spontaneous potential logs), field observations and palaeocurrent measurements. Utilizing RockWorks®, the subsurface data will be processed and results expressed in form of multi-log plots, cross-sections for correlation purposes (e.g., fence diagrams) and various maps (e.g., clastic to coal ratio contours, coal seam and sandstone isopach maps).

It is hoped that the results will lead to the development of regional tectonic and depositional models for the Permian Botswana Karoo sequences which will likely further enhance the exploration, exploitation and management of economic resources, especially that of coal, in the study area. Furthermore, it is anticipated that our results will be applicable as guidelines for future coal and stratigraphic correlation studies of the Permian Karoo strata in southern Africa.

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Review of the characteristics of Ecca facies associations

Comparison with modern examples

Characterisation of the processes & depositional environments during Ecca Group times
Notes by Presenter:

Two large basins recognized, namely:

- MKB: main basin & considered type basin – due to widely studied compared to its northern counterparts.
- GKB: considered the second largest basin north of MKB, NB.

=> merges eastward into the Tuli Basin and southeastward into the Ellisras Basin.
Notes by Presenter:

**KKB** ➔ covers ~ 70% of Botswana BUT totally buried by Recent Kalahari cover, e.g., sometimes as thick as ~ 200 m (western belt)

=> divided into four sub-basins, based on geological setting & facies changes:

**CKKB** ➔ *western, southeastern, southern & northern* belts ➔ Due large extent ~ division=>mainly for descriptive purposes

Stratigraphy ➔ all five groups present in CKKB & rest of KKB
Notes by Presenter:
To investigate the geological history, in particular the sedimentology & stratigraphy
~ i.e., investigate the influence of the depositional and post-depositional processes on the coal seam quantity (lateral & vertical distribution)
To work out the dynamics of coal depositional environments
~ in particular the forces responsible for changes in the accommodation space (e.g., subsidence vs. sedimentation rates) . Will start with a review of a deltaic system, as suggested being the depositional environ. responsible for the lower Karoo Supergroup deposition in the area.
A Deltaic System

A delta forms when a river deposits its transported sediments upon entering a standing body of water (e.g., sea or large lake).

Notes by Presenter:
Deltaic system ➔ Characterised by a number of sub-environments SEE next slide
Notes by Presenter:
This sub-environments give rise to different facies. See next slide for cross-section through A - B
Notes by Presenter:
Decrease in grain-size offshore ~ overall CUS, i.e., Coarser (a) ➔ medium (b) ➔ fine (c).
*NB: this will be explained further later, e.g., characteristics, facies, etc.)*

The sub-environments are associated with different processes that bring about different facies ~ SEE next slide
Notes by Presenter:
Just to show the relationship between the processes ➔ ➔ *further Explained in the coming slide*..................
Combination of **Tectonics** and **Eustatic** processes control

- Relative changes of sea level ➔ Control the space available for sediments to fill (= accommodation space)

Combination of **Tectonics** and **Climate** control

- The type and amount of **Sediment Supply**

The resulting Sediment Supply determines

- How much of the accommodation space is **consumed**
Notes by Presenter:

Tectonic movement ➔ slope gradient ➔ ➔ channel pattern (see next slide) ➔ ➔

discharge & sediment volume, grain size

NB: The interplay between tectonic and sedimentation ➔ ➔ ➔ shift in shoreline, i.e.,
transgression & Regression (~ explained coming slide)
Transgressions = creation of accommodation space >> consumption of accommodation space by sedimentation i.e., rates of base level rise > rates of sedimentation rates

⇒ retrogradation of facies + scour surface cut by waves during the shoreline transgression is onlapped by the aggrading & retrograding shoreface deposits.
Forced regressions = destruction of accommodation space by base level fall (irrespective of the sediment supply)

→ progradation of facies + erosion in both the nonmarine (fluvial incision) & shallow marine environments + offlap of the prograding shoreface deposits.
Normal regressions = consumption of accommodation space by sedimentation >> creation of accommodation space

i.e., rates of sedimentation >> rates of base level rise (during the early and late stages of base level rise) $\rightarrow$ aggradation (newly created accommodation filled) + sediment bypass + progradation of facies (sediment supply-driven regressions)
Subdivision of the Ecca Group

- Based on vertical grain size variations and facies associations of Ecca Group, such as:

1. Upward-coarsening successions (CUS)

2. Upward-fining successions (FUS)

3. Abundance of coal horizons

Notes by Presenter:
As shown in the next fig........
Subdivision of the Ecca Group

ECCA GROUP

Upper Part
- Unit B2
- Unit B1
- Unit A3
- Unit A2
- Unit A1

Basal Part
- Upper member
- Middle member
- Lower member

Each unit is divided into:
- Upper coal-bearing member
- Basal arenaceous member

Delta Plain
- Unit B2
- Unit B1
- Unit A3
- Unit A2
- Unit A1

Upper member
- Middle member
- Lower member

Distributary Mouth-Bar
- Distal Bar
- Prodelta Muds

CUS
- Delta Plain

FUS
Notes by Presenter:
Development of all five units A1-3 & B1-2 in the southern part & only unit B2 in the northern part. A3 is more persistent than B2.
Upward-coarsening successions (CUS)

- i.e., Prodelta & Delta front facies
Notes by Presenter:
Massive or structureless strata (Sm), Trough cross-bedding with rare low-angle cross-bedding (St, Sl), Planar cross-bedding (Sp), Ripple cross-lamination (Sr)
Just for explaining the division of the basal part based on facies analysis
Evidence for pd df see slide 5
The strongest thickness variation and pocket-like, sporadic occurrence of Dwyka Group and Basal Part of the Ecca Group

- In the Northern Belt where the Basal Part
  - Frequently absent or poorly developed (<40m thick)
  - Rests directly on pre-Karoo strata

  - Deposition on a basement ridge that formed during pre-Karoo times and persisted at least until early Karoo times (palaeo-morphology)

- Other parts of the basin (South-east, Southern & Western Belts) where the Basal Part
  - Well-developed (e.g., >60m thick - Southern Belt)
Thicker prodelta deposits in the South-east (~50m), Southern (~65m) & Western (~80m)

Thinner prodelta deposits in the Northern Belt (~20m)
- Thicker in the Western Belt (~ 300m max.)
- Condensed in the Northern Belt (~ 175m max.)
The delta plain is characterised by five sedimentary cycles:

- Unit B2
- Unit B1
- Unit A3
- Unit A2
- Unit A1
Delta plain facies association

Features in the Upper Part of Ecca Group:

- Erosive bases
- Associated sedimentary structures (Sm, St, Sl, Sp & Sr)
- Upward fining successions (FUS)
- Its stratigraphic position
  - Immediately overlying what is inferred as delta front succession

A delta plain depositional setting
Notes by Presenter:
~see coming slides for further explanation

➔➔➔ from this facies analysis and facies association =>=>=> sub-division of the Ecca
Group (~see next coming slides)
Base of each unit:
- Massive, medium- to coarse-grained to gritty feldspathic sandstone with thin interbeds of siltstones, mudstones and coal lenses forming either individual or stacked upward-fining successions (FUS)

Top of each unit:
- Carbonaceous, coaly mudstones & coals with thin upward-coarsening successions of sandstone bands or lenses

> Sub-division of the upper part of Ecca Group into
  - Basal arenaceous member
  - Upper argillaceous member

Notes by Presenter:
Results of facies analysis, associations ➔➔➔ sub-division of the Ecca Group
Notes by Presenter:
Braided(?) not conclusive because is only based only on few data, e.g. grain-size, suggested short distance, High relief & high energy ➔ this are usually conditions that promote braid development
Abundance & vertically multiple-stacking of sandstones with soured bases

Locally coarse- to pebbly grain-size

Fining-upward successions - FUS

~ High relief & high energy, fluvially influenced environments

Uplift (repeated ?) of the basin margins

Development of braided(?) distributary channels
Notes by Presenter:

massive, non-carbonaceous, coaly and carbonaceous mudstones and coals (Fm, Fsm, C) and massive, rippled or laminated siltstones (Fl).

waning floods = during and after the decline phase of flooding relatively quiet, low energy waters. Braided distributary channel morphology.
Notes by Presenter:

NB: it will be of great significance for coal developers to always drill few metres below the last coal seam as this will help researches in evaluating coal dep. Environ. due to differential compaction of the sandstones due to high rate of subsidence resulting into drowning of peat before great thickness can be achieved.
Notes by Presenter:
Currently working on resolving the issue, i.e., looking for distinguishing features for the two scenarios.
Notes by Presenter:
This was accompanied by intermittent uplift of pre-Karoo formations around the basin margin creating a higher energy environment with the consequent deposition of high proportion of arenaceous strata, variable in thickness & continuity.
Interdisciplinary approach to basin analysis

**Controls**
- Tectonics, Eustasy, Climatic changes

**Data & Techniques**
- Subsidence analysis
- Well logs, seismics, Biostratigraphy, etc.

**Exploration**
for natural resources, e.g., coal

**Basin Analysis**
Surfaces, system tracts, sequences (CORRELATION)

**Facies Analysis**
- Depositional systems
  - textures
  - structures
  - etc.

**Sedimentology**

Achieved
To present

Puzzle
To be unravelled

Catuneanu et al. (2002)
Selected References


THE END
THANK YOU