

AN INTEGRATED STUDY OF
STRUCTURAL AND STRATIGRAPHIC DEVELOPMENT AND SOURCE ROCK
MATURATION HISTORY OF THE RIO MUNI BASIN, EQUATORIAL GUINEA

**A NON-EXCLUSIVE REPORT PREPARED IN COLLABORATION WITH THE
MINISTRY OF MINES AND ENERGY, EQUATORIAL GUINEA**

September 2001

Exploration Consultants Limited, now part of the RPS Group

309 Reading Road, Henley-on-Thames,
Oxfordshire, RG9 1EL, England
Telephone : 01491 415400
Facsimile : 01491 415415

GG7248

LIST OF CONTENTS

1. INTRODUCTION

- 1.1 Background
- 1.2 Scope of Study / Structure of Report
- 1.3 Report Formats

2. DATABASE

- 2.1 Historical Database
- 2.2 New Analytical Data

3. GEOTECTONIC FRAMEWORK, EVOLUTION, AND REGIONAL GEOLOGY EVOLUTION OF THE EASTERN GULF OF GUINEA

- 3.1 Regional Geotectonic Elements
 - 3.1.1 Introduction
 - 3.1.2 North Gabon Rifted Terrane
 - 3.1.3 Rio Muni / Cameroon Margin
 - 3.1.4 Calabar Flank / Douala Margin
 - 3.1.5 Benue Trough / Abakaliki Foldbelt
 - 3.1.6 Niger Delta
 - 3.1.7 Cameroon Volcanic Line
 - 3.1.8 Oceanic Domain / Fracture Zones
- 3.2 Plate Reconstructions
- 3.3 Break-up History
 - 3.3.1 Early Break-up – Rift Phases I and II (Neocomian – Barremian)
 - 3.3.2 Late Break-up – Rift Phase III (Late Barremian – Mid Aptian)
 - 3.3.3 Early Separation (Late Aptian – Late Albian)
 - 3.3.4 Volcanic Margin Development
 - 3.3.5 Late Separation (Cenomanian – Santonian)
 - 3.3.6 Unconstrained Separation

- 3.4 Petroleum Geology
 - 3.4.1 Source Rocks
 - 3.4.2 Reservoir Intervals
 - 3.4.3 Petroleum Systems

4. STRATIGRAPHIC REVIEW OF RIO MUNI

- 4.1 Offshore
 - 4.1.1 Introduction
 - 4.1.2 Aptian
 - 4.1.3 Aptian-Albian
 - 4.1.4 Pre-Santonian Upper Cretaceous
 - 4.1.5 Post-Santonian Upper Cretaceous
 - 4.1.6 Tertiary
- 4.2 Onshore
 - 4.2.1 Introduction
 - 4.2.2 Rio Leme Formation
 - 4.2.3 M'bini Formation
 - 4.2.4 Casablanca Formation
 - 4.2.5 Uloba Formation
 - 4.2.6 San Juan Formation
 - 4.2.7 Calatrava Formation
- 4.3 Stratigraphic Synthesis
 - 4.3.1 Onshore-Offshore Correlation
 - 4.3.2 Overview of Stratigraphic Development
 - 4.3.3 Tectono-Stratigraphy

5. STRUCTURAL INTERPRETATION OF RIO MUNI

- 5.1 Seismic Interpretation
 - 5.1.1 Seismic Horizons
 - 5.1.2 Interpretation

- 5.2 Structural Styles and Models
 - 5.2.1 Chronology of Ideas for the Structural Evolution of the Margin
 - 5.2.2 Tectono-Stratigraphy
 - 5.2.3 Structural Elements and Styles/Geometries
- 5.3 Structural Restoration
 - 5.3.1 Summary of Structural History
 - 5.3.2 Methodology
 - 5.3.3 Results

6. PETROLEUM GEOLOGY OF RIO MUNI

- 6.1 Source Rocks
 - 6.1.1 Introduction / Database
 - 6.1.2 TOC and Kerogen Type
 - 6.1.3 Source Rock Generation
 - 6.1.4 Source Rock Summary
- 6.2 Oils
 - 6.2.1 Introduction
 - 6.2.2 Bulk Properties
 - 6.2.3 Geochemical Composition
 - 6.2.4 Source Rock Characteristics
 - 6.2.5 Intra-Reservoir Alteration
 - 6.2.6 Summary
- 6.3 Reservoir Intervals
- 6.4 Petroleum Systems

7. THERMAL HISTORY RECONSTRUCTION

- 7.1 Introduction to AFTA and Thermal History Reconstruction
- 7.2 Data Quality
- 7.3 Identification of Paleo-Thermal Episodes
 - 7.3.1 Tertiary Episodes
 - 7.3.2 Late Cretaceous Episode
 - 7.3.3 Mid Cretaceous Episode
- 7.4 Present Day Temperature Regime
- 7.5 Paleogeothermal Gradients and Estimation of Removed Section

- 7.5.1 Observations from VR/Tmax Data
- 7.5.2 AFTA Results
- 7.6 Regional Trends and General Discussion

8 BASIN MODELLING, MATURITY DEVELOPMENT AND HYDROCARBON GENERATION HISTORY

- 8.1 Basin Modelling Approach
- 8.2 Basin Modelling Results
- 8.3 Source Rock Maturity Development
- 8.4 Hydrocarbon Generation

9 PLAY ANALYSIS

- 9.1 Play-Types
- 9.2 Play Fairway Analysis

REFERENCES

APPENDICES

1. Field Trip Notes
2. Onshore Biostratigraphical Analysis Results
3. Geochemical Analysis Results
4. Vitrinite Reflectance Measurements
5. AFTA - Analytical Data, Procedures, Principles of Interpretation
6. Fluid Inclusion Analysis Results
7. Basin Modelling Plots
8. Magnetic Modelling Results
9. Well Analytical Results Logs

FIGURES

After Page No.

1.	Study Area Location Map	3
2.	GIS Structure	5
3.	Database Map	6
4.	Regional Geological Setting	9
5.	Project Probe Regional Seismic Profile 5	10
6.	Alternative ‘fits’ for Equatorial Atlantic Reconstructions	14
7.	Optimum ‘fit’ for Equatorial Atlantic Reconstruction	14
8.	Close-up of ‘fit’ for Equatorial Atlantic Reconstruction	14
9.	Regional Tectono-Stratigraphy	16
10.	Plan Cartoon of Margin Evolution	19
11.	Cross-Section Cartoon of Margin Evolution	23
12.	Regional Petroleum Geology	25
13.	Petroleum Systems on West African Side	33
14.	Petroleum Systems on South American Side	33
15.	Offshore Well Synthesis	35
16.	Onshore Geological Outcrop Map	40
17.	Onshore Synthetic Stratigraphic Column	40
18.	Stratigraphic Synthesis	46
19.	Tectono-Stratigraphy	49
20.	Stratigraphic Relationships	49
21.	Seismic Markers	51
22.	Geoseismic Profile of the Ceiba Slide Complex	53
23.	Geoseismic Profile from the Eviondo Slide Complex	53
24.	Geoseismic Profile of the Pongue Slide Complex	53
25.	Study Area Structural Elements	59
26.	Onshore Structural Elements Map	59
27.	Structural History / Deformational Styles	63
28.	Structural Cartoon Showing Santonian Deformation	63
29.	Structural Restoration Sequence for the Ceiba Slide (Profile 4)	63
30.	Structural Restoration Sequence for the Matondo Slide (Profile 5)	63

31.	Structural Restoration Sequence for the Eviondo Slide (Profile 7)	63
32.	Structural Restoration Sequence for the Pongue Slide (Profile 9)	63
33.	Distribution of TOC Values from Rio Muni Wells and Outcrops	75
34.	TOC vs S2 Plot for Rio Muni Wells and Outcrops	75
35.	Hydrogen Index vs T-max Plot for Richest Samples from Rio Muni Wells and Outcrops	76
36.	Van-Krevelen Plot showing Well and TOC from Rio Muni Wells and Outcrops	76
37.	Van-Krevelen Plot showing Well and Stratigraphy from Rio Muni Wells and Outcrops	76
38.	Hydrogen Index vs Depth Plot for Rio Muni Wells and Outcrops	77
39.	Hydrogen Index vs T-max Plot showing Well and Stratigraphy from Rio Muni Wells and Outcrops	77
40.	Hydrogen Index vs T-max Plot showing Well and TOC from Rio Muni Wells and Outcrops	77
41.	Production Index vs T-max Plot from Rio Muni Wells and Outcrops	77
42.	Stratigraphy - Source Rocks	78
43.	Stratigraphic Relationships - Source Rocks	78
44.	Whole Oil Stable Carbon Isotopes of the Principe and Sao Tome Seep Oils	80
45.	Carbon Isotopes for Saturate and Aromatic Fractions of the Principe and Sao Tome Seep Oils	80
46.	The m/z 217 Mass Fragmentogram Traces showing Steranes of the Principe and Sao Tome Seep Oils	81
47.	Sterane Isomer Ratios of the Principe and Sao Tome Seep Oils	81
48.	The m/z 218 Mass Fragmentogram Traces showing Steranes of the Principe and Sao Tome Seep Oils	81
49.	Sterane Carbon Number Distributions (m/z 218) of the Principe and Sao Tome Seeps compared with Gabon and Nigeria Oils	82
50.	C ₃₀ n-propyl Sterane Abundance of the Principe and Sao Tome Seep Oils	82
51.	The m/z 191 Mass Fragmentogram Traces showing the Terpanes of the Principe and Sao Tome Seep Oils	82
52.	Abundance of Oleanane in Principe and Sao Tome Seep Oils	83
53.	Hopane/Sterane vs C30/29 Hopane Ratios for Principe and Sao Tome Seeps compared with Gabon and Nigeria Oils	83

54.	C ₂₆ /C ₂₅ Tricyclic Terpanes for Principe and Sao Tome Seep Oils interpreted in terms of other oils on the West African Margin	84
55.	Summary of Key Principe and Sao Tome Seep Properties compared with other West African Oils	84
56.	Terpane Maturity Ratios in Principe and Sao Tome Seep Oils	85
57.	Stratigraphy – Reservoirs	87
58.	Stratigraphic Relationships – Reservoirs	87
59.	Established Petroleum Systems	91
60.	Predicted Petroleum Systems	91
61.	Vitrinite Reflectance Depth Trends for Rio Muni Wells and Outcrops	105
62.	T-max Depth Trends for Rio Muni Wells and Outcrops	106
63.	Paleotemperature Constraints Derived from AFTA and VR in Rio Muni A-1	106
64.	Paleotemperature Constraints Derived from AFTA and VR in Rio Muni-1	106
65.	Paleotemperature Constraints Derived from AFTA and VR in Benito-1	106
66.	Paleotemperature Constraints Derived from AFTA and VR in Matondo-1	106
67.	Paleotemperature Constraints Derived from AFTA and VR in Eviondo-1	106
68.	Stratigraphy - Erosional Events	110
69.	Burial History and Maturity Calibration Plots for Well Rio Muni A-1	115
70.	Burial History and Maturity Calibration Plots for Well Rio Muni-1	115
71.	Burial History and Maturity Calibration Plots for Well N'dote-1	115
72.	Burial History and Maturity Calibration Plots for Well Benito-1	115
73.	Burial History and Maturity Calibration Plots for Well Matondo-1	115
74.	Burial History and Maturity Calibration Plots for Well Eviondo-1	115
75.	Source Rock Maturity Map - SR3 End Rift	115
76.	Source Rock Maturity Map - SR3 Pre-Santonian Erosion	115
77.	Source Rock Maturity Map - SR3 Late Cretaceous	115
78.	Source Rock Maturity Map - SR3 Present Day	115
79.	Source Rock Maturity Map - SR2 Pre-Santonian Erosion	115
80.	Source Rock Maturity Map - SR2 Late Cretaceous	115
81.	Source Rock Maturity Map - SR2 Present Day	115
82.	Source Rock Maturity Map - SR1 Pre-Santonian Erosion	115
83.	Source Rock Maturity Map - SR1 Late Cretaceous	115
84.	Source Rock Maturity Map - SR1 Present Day	115

85.	Structural Restoration and Maturity/Migration Sequence for the Ceiba Slide (Profile 4)	115
86.	Structural Restoration and Maturity/Migration Sequence for the Matondo Slide (Profile 5)	115
87.	Structural Restoration and Maturity/Migration Sequence for the Eviondo Slide (Profile 7)	115
88.	Structural Restoration and Maturity/Migration Sequence for the Pongue Slide (Profile 9)	115
89.	SR3 - Max. Paleotemperature Map	115
90.	SR2 - Max. Paleotemperature Map	115
91.	SR1 - Max. Paleotemperature Map	115
92.	Rio Muni Play-Types	126

ENCLOSURES

1. Database Map
2. Regional Geological Setting
3. Coastal Cross-Section
4. Onshore and Offshore Stratigraphic Synthesis
5. Regional Seismic Profiles 1 & 2
6. Seismic Profiles 3, 4, 5 & 6
7. Seismic Profiles 7, 8, 9, & 10
8. Seismic Profiles 11 & 11a
9. Study Area Structural Elements
10. Onshore Structural Elements
11. Structural Restoration Sequence for Ceiba Slide (Profile 4)
12. Structural Restoration Sequence for Matondo Slide (Profile 5)
13. Structural Restoration Sequence for Eviondo Slide (Profile 7)
14. Structural Restoration Sequence for Pongue Slide (Profile 9)
15. Thermal History Synopsis
16. Structural Restoration and Maturity/Migration Sequences for Ceiba Slide (Profile 4)
17. Structural Restoration and Maturity/Migration Sequences for Matondo Slide (Profile 5)
18. Structural Restoration and Maturity/Migration Sequences for Eviondo Slide (Profile 7)
19. Structural Restoration and Maturity/Migration Sequences for Pongue Slide (Profile 9)
20. Play Fairway Map – Post-Santonian Unconformity
21. Play Fairway Map – Deformational Carapace
22. Play Fairway Map – POC Fundamental Features
23. Play Fairway Map – Santonian Deformational Features

TABLES

1. Data Listing for Composite Seismic Profiles
2. Sample Record for Offshore Wells
3. Sample Record for Outcrop Locations
4. Bulk Properties of the of the Sao Tome and Principe Seep Oils
5. The Degree of Bacterial Degradation for the Sao Tome and Principe Seep Oils
6. Estimates of Paleogeothermal Gradients and Removed Section form AFTA