In Progress

EGI Oceans | Evaluation of the Stratigraphy & Petroleum Systems of the Central & North Atlantic Ocean
Region 2 | Phase 1 | Addendum

Value

- Recalibration of the stratigraphy and evaluation of petroleum systems of the Central & North Atlantic Ocean conjugate margin.
- Timely opportunity to leverage a carefully selected array of 40 wells: COST – Continental Offshore Stratigraphic Test plus commercial wells and DSDP-ODP-IODP sites, recommended by EGI corporate members.
- Both in-house and affiliate scientist expertise and partnerships with 8 international institutes.
- Unique world class capability in high resolution chronostratigraphy via composite standards calibrated to the 2012 time scale, and novel analytical techniques in petroleum geochemistry (e.g., RockEval 6, kinetics, palynofacies).
- ArcGIS delivery platform.

Key Deliverables

1. Multi-disciplinary age and paleoenvironmental interpretation: Annotated graphic correlation charts for each study well.
2. Chronostratigraphic cross-sections: illustrating regional chronostratigraphy and distribution of paleofacies.
3. Integrated sedimentology data and paleofacies maps for key time horizons relevant to major source rock intervals.
4. Source rock characterization for richness, maturity, kerogen type, and kinetics
5. Source (kerogen) type, depositional environment, and petroleum systems integration
6. Anhydrous pyrolysis kinetic values for elected source intervals

Principal Investigators:

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Investment per Sponsor
$180K (USD) Total
$60k(USD) – Upon signing
$60k(USD) – Start of year 2
$60k(USD) – Start of year 3

Duration
30 months

Project I 01229

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RESEARCH RATIONALE

EGI convened a major workshop in Salt Lake City on March 23 and 24, 2014 designed to discuss the key opportunities for future exploration in the Central and North Atlantic Margin. Representatives participated from eight EGI corporate members (Anadarko, Chevron, ENI, ExxonMobil, Murphy Oil, Repsol, Statoil, and Total). This proposal, shaped directly by industry, is part of a global EGI initiative to recalibrate the stratigraphy and evaluate the perspective for petroleum systems of major ocean basins during the next decade.

Industry participants stated that EGI brings four unique capabilities to perform this research; (1) proven ability to access existing samples and obtain new samples to generate crucial data in the Atlantic Margin; (2) both in-house and affiliate scientist expertise in the evaluation of the Atlantic Margin combined with over 20 years of global margins research for industry; (3) a unique world class capability in high-resolution chronostratigraphy via graphic correlation and composite standards calibrated to the Global Time Scale 2012; (4) access to the integrated Continental Oceanic Research Data System software tool (iCORDS™) supported by 20 international petroleum companies, which was designed and constructed at EGI for global search and faster data access that the EGI research team will utilize to mine global data centers.

RESEARCH OBJECTIVE

EGI in collaboration with industry sponsors and eight identified research partners will generate new data and utilize a vast array of DSDP-ODP-IODP, COST (Continental Offshore Stratigraphic Test) and commercial well data to synthesize the stratigraphy and petroleum systems of the Central and North Atlantic Ocean. This will be done by an iterative process of revising existing age models and paleoenvironmental interpretation, followed by rigorous petroleum systems analyses and integration of new data generated by this research project. A key component of this project will be the integration of an extensive EGI database of over 10 previous studies carried out in the region and the inclusion of well data from multiple governmental bodies (e.g., United States Geological Survey) in the synthesis.

The main impact of this project lies in re-evaluating DSDP-ODP-IODP data comprising multiple vintages and inconsistent standards over the years, into an updated time scale (Geologic Time Scale 2012), combined with novel analytical techniques in petroleum geochemistry (e.g., palynofacies, bulk kinetics, etc.). The track record established in Region 1 (South Atlantic) will expand into Region 2 (Central and North Atlantic) with an efficient skills, workflow and dataset, that will assist sponsoring companies in multiple license round bids in the Central and North Atlantic Margin.

Significant license rounds have been announced within the forthcoming 1–6 years by various governments, who in many cases, operate a tax of royalty regime. This research project is therefore a timely opportunity to leverage critical well data and analysis in advance of evaluating new acreage in the region.

The world-class data combined with EGI's formidable expertise in chronostratigraphy and geochemistry will enable an informed integration of the carefully selected Central and North Atlantic Ocean basins on a robustly linked ArcGIS platform.
Regional Coverage with Conjugate Margins

On the basis of the EGI-industry workshop, a real focus was achieved on the area of interest for the study. The Central and North Atlantic Ocean (Figures 1 and 2) can be divided into two sectors based on the Newfoundland Azores Fracture Zone (NAFZ). This boundary, initiated as a fracture zone due to the western spreading of the Tethys Ocean, separates the Central and North Atlantic Ocean petroleum systems. The boundary, therefore, requires detailed investigation in the course of this study from both stratigraphic and geochemical perspectives. Each of these two sectors and their conjugates are described below, highlighting the key exploration-related issues that will be addressed (Figures 3–7).

Sector I: Central Atlantic Ocean

Boundary and definition: Delimited by the Sierra Leone Fracture Zone in the south, and the Newfoundland Azores Fracture Zone (NAFZ) in the north. Includes conjugate margins of the east coast of the USA and West Africa (Morocco to Senegal).

Age of oceanic crust: Bathonian (Middle Jurassic)

Focus Area 1A: East coast of the USA

The interest in this area is driven by the indication that the offshore area between Virginia and Georgia will be put up for lease sale in 2020-21.

Key issue to be addressed:
1. Age and distribution of Mesozoic source rocks: The central Atlantic petroleum systems are understood to be driven by Middle Jurassic and Upper Cretaceous source rocks. The analysis of the selected COST wells and the DSDP sites will identify the age and spatial/temporal distribution of all Mesozoic source rocks, including the Triassic, as suggested by Triassic rifting.

Study sites and wells chosen: 17
- DSDP Sites 105, 144, 391C, 534, 603B; ODP Sites 1257, 1258; IODP Site U1407
- COST Wells: COST B-2, COST G-2, COST GE-1

Focus Area 1B: West Africa (Morocco-Mauritania-Senegal)

Key issues to be addressed:
1. Jurassic source rocks: A number of deep sea drilling sites have penetrated Jurassic strata along this margin. These wells will be analyzed, in particular, to determine how far the Jurassic source rocks extend, both basinward and along the margin. Potential Jurassic source rocks (DSDP Sites 367 and 368) will be investigated.

2. Cenomanian-Turonian (C-T) source rocks: The presence of C-T source rocks are well-known from the Tarfaya Shelf. The maturity of C-T source rocks will be investigated.

Study sites and wells chosen: 7
- DSDP Sites 137, 367, 368, 369, 415, 416, 547
Sector II: North Atlantic Ocean

Boundary and definition: Delimited by the NAFZ in the south, and the Davis Strait/Greenland Iceland Faroe Rise in the north. Including key areas of offshore eastern Canada (Scotian Margin, Newfoundland & Labrador Sea) and its conjugate in the Rockall/Porcupine Trough, Iberia and Bay of Biscay, this is a subsequently rifted segmented of Jurassic age dominated by Upper Jurassic (Kimmeridgian) source rocks.

Age of oceanic crust: Aptian (Bay of Biscay oceanic crust)

Focus area 2A: Eastern Canada (Scotian Margin, Newfoundland and Labrador Sea)

Key issues to be addressed:

1. Upper Jurassic (Kimmeridgian) source rock: The Labrador Margin is data-rich with extensive drilling from Hibernia, Orphan Basin, Scotian margin, etc., but its conjugate margin is relatively data-poor. The Labrador margin is the southern part of a major Kimmeridgian epicontinental anoxic seaway that spread from the NAFZ (southern boundary of anoxia) through the Norwegian-Greenland Sea, Barents Sea and into western Siberia. It is a regional source rock. The goal is to classify and confirm the anoxia model and understand the impact of the Early Cretaceous rifting that broke up the distribution of the Kimmeridgian source rock. In some places it is regional, but in many places it was compartmentalized by Early Cretaceous rifting. An understanding of the gaps in Kimmeridgian source rocks by analyzing wells constraining and controlling the present day distribution of Kimmeridge Clay Formation equivalent is critical.

2. Early Cretaceous rifting: Another challenge is the Early Cretaceous rifting in relation to identifying source rocks within the region. Key sites/wells throughout this area will be investigated for supposedly Albian source rocks, e.g., DSDP Site 111, and other equivalent sections along the margin. The idea of an Early Cretaceous source rock and rifting phase, especially where the Jurassic is either absent, fragmented or at greater depths, with a thick Tertiary sediment overload forming a play field is attractive.

3. Biogenic vs. thermogenic hydrocarbons: Labrador Sea is still an enigma with many small discoveries along the east coast of Canada. But the geochemical source rock signature of thermogenic vs. biogenic hydrocarbons is key to understanding the future potential with future licensing rounds anticipated in the region.

Study sites and wells chosen:

- DSDP Site 111; IODP Site 1276
- Commercial wells: Baccalieu I-78, Great Barasway F-66, Hopedale E-33, North Bjarni F-06

Focus area 2B: Rockall-Porcupine Trough, New Grange Basin, offshore Ireland

A working petroleum system from the Corrib gas condensate field (Triassic age) is well-known from offshore Ireland. The focus area is the deep water Rockall and Porcupine Trough, which extends southward into the New Grange Basin, and further into the Bay of Biscay.

Key issues to be addressed:

1. Upper Jurassic (Kimmeridgian) source rock: There are suggested Kimmeridgian source rocks deposited in this area. The problem again is subsequent Early Cretaceous rifting that has broken up this regional source rock. Therefore an understanding of (1) was the Jurassic ever deposited in the Rockall/Porcupine/Bay of Biscay region, and (2) if it was, where it is still preserved, is timely.
The biostratigraphic and geochemical analysis of the selected wells will give insights into this major question.

**Study sites and wells chosen:**
- DSDP Sites 549, 550
- **Commercial wells:** 83/24 - sb 02; 83/20 sb-01

**Focus area 2C: Iberia and Bay of Biscay**

**Key issue to be addressed:**
1. **Upper Jurassic source rock:** Confirm presence of a Kimmeridgian source rock and its maturity, especially with a much larger and voluminous river drainage system coming from the hinterland. Heat flow data is essential to understand the thermal maturity.

**Study sites/wells chosen:**
- DSDP Sites 398, 401, 402; ODP Sites 638, 901; IODP Site 1069.

In summary, the following themes recur for the basins that were identified as critical to the proposed study:

- Chronostratigraphy
- Paleoenvironment
- Palynofacies
- Source rock age, distribution and maturity

**SITE/WELL SELECTION**

Guided by the workshop, a focused selection of 40 key sites and wells was achieved for detailed analysis and investigation (Table 1). Three types of subsurface stratigraphic data and samples will be utilized in the study:

- DSDP, ODP, and IODP sites
- Continental Offshore Stratigraphic Tests (COST) wells
- Petroleum exploration or industry wells

Additional reports available through data partners and public domain will be integrated with the results from the analysis, including reports from EGI’s archive.

Discussions on the scope of the project guided the decision that wells targeting only the Tertiary section would be excluded, and only deeper DSDP/ODP/IODP sites and COST wells, with penetration of older Mesozoic (Jurassic or Triassic) sediments would be included to achieve the agreed objectives. Also, the Barents Sea (western Arctic Ocean), Baffin Bay and Norwegian/Greenland Sea were shelved from the scope of work due to the problem of Recent Cenozoic uplift. It was questioned whether the type of analysis proposed would be of much value in resolving the complexity of these areas.

Table 1 shows the distribution of wells selected for the regional study.
Collaboration & Partnerships for Data

Relevant data, including samples, and completed reports will be integrated via the following collaborating eight data partners:

- British Geological Survey (BGS)
- Bureau of Ocean Energy Management (BOEM), USA
- Canada-Nova Scotia Offshore Petroleum Board (CNSOPB)
- Canada-New Foundland Offshore Petroleum Board (CNOPB)
- Geological Survey of Denmark and Greenland (GEUS)
- Geological Survey of Canada (GSC)
- United States Geological Survey (USGS)
- Petroleum Infrastructure Program (PIP), Rockall Group, Ireland

Research Team

<table>
<thead>
<tr>
<th>Staff</th>
<th>Expertise/Affiliation</th>
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<tbody>
<tr>
<td>Sudeep Kanungo, Ph.D.</td>
<td>Chronostratigraphy, Research Assistant Professor; EGI, University of Utah</td>
</tr>
<tr>
<td>Eiichi Setoyama, Ph.D.</td>
<td>Paleoenvironments, Research Instructor EGI, University of Utah</td>
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<td>Sylvain Garel, Ph.D.</td>
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</tr>
<tr>
<td>Júlia Kotulová, Ph.D.</td>
<td>Petroleum Geochemistry, Research Scientist EGI, University of Utah</td>
</tr>
<tr>
<td>Alastair Fraser, Ph.D.</td>
<td>Project Advisor &amp; EGI Chair in Petroleum Geoscience, Imperial College, London</td>
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<tr>
<td>Jonathan Bujak, Ph.D.</td>
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<td>Supporting Research Staff (3)</td>
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KEY ARCGIS PLATFORM ENABLED DELIVERABLES

Chronostratigraphy:
- Multidisciplinary age synthesis: The one problem with data from the past is that it has multiple vintages and standards, neither of which is consistent or modern. Using the GTS 2012 calibrated composite standard, we will achieve a standardized and up-to-date age synthesis of the chosen basins and study sites/wells. Annotated graphic correlation charts for each study site/well will show key biostratigraphic datums (foraminifera, nannofossils, palynomorphs, siliceous microfossils). A chronostratigraphic summary illustrating absolute age limits of depositional packages and hiatuses discovered will be plotted on every graphic correlation chart.
- Paleoenvironments: Charts will include paleoenvironmental interpretations (paleobathymetry, paleoecology/organic productivity and recognition of displaced sediments).
- Wheeler diagrams (chronostratigraphic cross-sections) illustrating the regional chronostratigraphy and distribution of biofacies.
- Paleofacies maps for key time horizons relevant to major source rock intervals including expected kerogen types.
- Age-top depth tables (in xls) will be provided for every study site.
- List of chronostratigraphic markers used to calibrate ages in myr (composite standard calibrated) with recommendations/comments on their applicability.
- Renewed comprehensive chronostratigraphic glossary to facilitate the understanding of chronostratigraphic and paleoenvironmental interpretation.

Geochemistry deliverables:
- Source rock characterization for richness, maturity, kerogen type, and kinetics
- Comparison of Rock Eval data with correction values from historical datasets
- Source (kerogen) type integrated with depositional environment and palynofacies
- Petroleum systems integration
- Bulk and compositional kinetics for genetic potential assessment

PROJECT TIMELINE & INVESTMENT

The project is proposed to be 2.5 years in duration starting Q4 2015. Project tasks will be divided into three phases along the following lines:

Year 1: Sampling and data collection
- Focused sampling of study sites and wells for biostrat, geochem and fission track analysis
- Integration and review of data and reports from EGI archives
- COST wells analysis
- Sample processing and analysis (biostratigraphy, geochemistry)
- Initialization of Graphic Correlation to wells
Year 2: Data Interpretation and soft integration of results

- Graphic correlation and paleoenvironmental interpretation
- Geochemical interpretation

Year 3: Hard integration of results and data

- Integration of biostratigraphy and geochemistry analyses
- Paleofacies maps reconstructions

Investment: The total investment per sponsor for the project is $180k (USD) for 2.5 years, payable in 3 yearly installments.
  - $60k(USD) – Upon signing
  - $60k(USD) – Start of year 2
  - $60k(USD) – Start of year 3

STEERING COMMITTEE & ANNUAL WORKSHOP

- Sponsor input and participation will be critical to the progress of the project. An annual workshop will be conducted during the course of the project to review progress and fine-tune future work, guided by sponsor input.
- Each sponsoring company can nominate two representatives on the steering committee for the project.
- Three yearly project updates will be provided to the sponsors for regular and timely feedback.
- Bi-annual and a final project ArcGIS delivery for results and data.

EGI TECHNICAL CONTACTS

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EGI SPONSORSHIP & CONTRACT INFORMATION

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APPENDIX

Figure 1: Map showing sectors and focus areas (Central and North Atlantic) with five focus areas outlined (1A-2C).

Figure 2: Map showing sectors and focus areas with the site/well locations chosen.

Figures 3–7: Key issues to be addressed in each focus area of study

Table 1: List of Sites/Wells selected for study

Figure 1: Map showing sectors and focus areas (Central and North Atlantic) with five focus areas outlined (1A-2C). (Newfoundland Azores Fracture Zone (NAFZ); Sierra Leone Fracture Zone (SLFZ))
Figure 2: Map showing sectors and focus areas with the site/well locations chosen.
Focus Area 1A: East coast of the USA

Figure 3: Key Issue – Age and distribution of Jurassic source rocks.

Focus Area 1B: Northwest Africa

Figure 4: Key Issues: 1) Distribution of Jurassic source rocks, 2) Maturity of Cenomanian-Turonian source rocks.
Focus Area 2A: Eastern Canada

Figure 5: Key Issues – 1) Upper Jurassic (Kimmeridgian) source rocks, 2) Early Cretaceous rifting, 3) Biogenic versus Thermogenic hydrocarbons.

Focus Area 2B: Rockall Basin, Offshore Ireland

Figure 6: Key Issue – Confirm the presence and distribution of Upper Jurassic (Kimmeridgian) source rocks.
Focus Area 2C: Iberian Margin

Figure 7: Key Issues – Presence of Upper Jurassic (Kimmeridgian) source rocks.

Sponsors

[List of Sponsor Logos]
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Sudeep Kanungo, PhD, MBA
RESEARCH ASSISTANT PROFESSOR

Sudeep Kanungo is a micropaleontologist / nannofossil biostratigrapher recognized for his work in applied chronostratigraphy through the graphic correlation methodology and composite standard database technology. The foundation of this method is the former Amoco Composite Standard. Sudeep uses novel, analytic approaches to enhance biostratigraphic data and transforms the data into meaningful decision making tools for E&P companies. Sudeep leads his team in integrative, multi-disciplinary chronostratigraphy projects to identify periods of rock accumulation, unconformities and depositional environments in absolute time. The research he conducts produces high-resolution correlations that are reproducible on a basin or regional scale. This aids in creating data for improved spatial and temporal calibration of anoxic events, which are important for source rock studies. Sudeep specializes in Cretaceous nannofossils, and integrating them with planktonic foraminifera and palynomorphs through the graphic correlation methodology. Sudeep recently received the Best Scientific Poster Award at the 15th Annual Houston Geological Society Africa Conference in September 2016.

Regional Experience in Biostratigraphy:

- South Atlantic: Conjugate Margin
- Equatorial Transform Margin: Côte d'Ivoire – Ghana Transform Margin
- Central and North Atlantic: Conjugate Margin
- East and West India Passive Margin: 16 onshore to offshore basins
- East Africa: Somalia to Mozambique basins (onshore to offshore)
- Onshore India: Damodar, Cambay and Himalayan Foreland Basin
- Onshore Argentina: Neuquén and San Jorge Basin
- Gulf of Mexico
- North Africa: Sirte Basin, Libya
- Caribbean: Trinidad

Education:

- M.B.A., 2014. David Eccles School of Business, University of Utah, USA
- Ph.D. Micropaleontology, 2005. University College London, UK
- M.Sc. Geology, 1999. University of Delhi, India

Research Interests

- Integrated microfossil chronostratigraphy
- Paleoenvironmental interpretation
- Nannofossil biostratigraphy
Eiichi Setoyama, PhD

FORAMINIFERAL BIOSTRATIGRAPHER

Dr. Eiichi Setoyama's expertise is in benthic foraminifera, a microfossil group that is critical in the industry and academia for paleoenvironmental reconstructions to underpin the understanding of the distribution of source and reservoir sediments and margin paleogeography. Dr. Setoyama joined EGI in 2014 as a paleoenvironment and biostratigraphy expert with the Chronostratigraphy Team.

Dr. Setoyama earned his Ph.D. from the Institute of Geological Sciences in Kraków, Poland (2012), followed by a post-doctoral research position at the King Fahd University of Petroleum and Minerals in Dhahran, Saudi Arabia where he focused on the project “Pliocene to Pleistocene benthic foraminifera from IODP Expedition 323 Cores in the Bering Sea: The role of sea-level change, oxygenation, productivity, and volcanism.”

He also received his MS in Paleobiology from University College London, UK. In addition to authoring multiple peer-reviewed publications, he is the proud recipient of several academic awards and grants related to ocean research drilling, and notably from the Paleontological Society. Dr. Setoyama is bilingual in Japanese and English.

Dr. Setoyama started his research at EGI on the iCORDS South Atlantic Regional Synthesis project. His role includes conducting paleoenvironmental evaluation of intervals representing the oceanic anoxic events (OAEs) and high resolution chronostratigraphy of Mesozoic and Cenozoic sections of the DSDP/ODP/IODP sites. His research focus areas include:

- Taxonomy of benthic foraminifera
- Paleobathymetric modeling
- Biofacies modeling
- The use of foraminiferal assemblages for analysis of displaced sediments
- Integrated, multi-disciplinary biostratigraphy

Research Interests

- Application of foraminifera for paleoenvironmental and paleobathymetric estimation
- High-resolution biostratigraphy

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