Deciphering deltas: Mapping environmental change in time and space where rivers meet the sea

University of St Andrews
In partnership with University of Glasgow

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biogeochemistry, biomarkers, chemostratigraphy, Earth history, stable isotopes

Overview

Deltas – landforms created where sediment is deposited at the mouth of a river – bury vast amounts of organic carbon, thereby playing a central role in the biogeochemical carbon and sulphur cycles (Fig. 1). Delta sediments are highly heterogeneous, varying over space and time, with important consequences for the interaction of sediments with biogeochemical processes. Understanding this complexity is a challenge for biogeochemists, Earth historians, and petroleum exploration.

Information about these biogeochemical interactions is recorded through geochemical proxies such as the ratios of elements, isotopes or compounds in sedimentary material. Geologists have long recognised that through Earth’s history many isotopic and elemental ratios appear to have varied in a manner that is globally synchronous. For example, geologists use $^{12}$C/$^{13}$C ratios and other proxies to correlate rock layers across key Earth history events such as mass extinctions, or between oil wells. However, a range of recent evidence suggests these signals are complex, and heterogeneity in coeval signals exists over the scale of a sedimentary basin. Furthermore, modern sediments that have been variably reworked record different degrees of scatter in the stratigraphic isotope profiles for sulphur (Fig. 2). Thus, such geochemical variability may be magnified in complex environments such as deltas. This variability poses challenges for correlation, but provides information about the deposition of a sedimentary basin and its enclosed petroleum systems.

Aim

We aim to investigate carbon and sulphur isotopic records, along with biomarkers, and determine how they vary in space and time across a marine delta. We will develop an integrated geochemical mapping project that can offer insight into the complex history of a continental margin, and be applied to
understanding how stable isotope and biomarker variation in offshore Atlantic margin basins.

On the spatial scale of a sedimentary basin, we will examine the sedimentology and geochemistry of the Sobrarbe Delta, Ainsa Basin, Spain. We will address the questions: How has the physical and chemical environment of this delta changed over space and time? What controls the spatial variation of geochemical proxies? How are these geochemical signatures incorporated and preserved in the rock record?

**Importance**

This work will provide fundamental new insights into the generation, preservation, and interpretation of stable isotope and biomarker records from sedimentary rocks of all ages, with a focus on the relationship between depositional setting and geochemical characteristics. The results will impact the interpretive framework used by geoscientists to reconstruct environmental changes recorded in sedimentary rocks.

**In petroleum exploration**, basin-scale variability poses challenges to the economic development of a petroleum system. Correlation from well to well is a critical aspect of developing petroleum systems. Furthermore, characteristics of petroleum may vary across a basin, with different organic accumulations, source rock quality, thermal maturity and oil biodegradation. This meter-scale biogeochemical variability may be influenced by subsequent sediment compaction, early diagenetic biogeochemical reactions, and bioturbation. Understanding the physical controls and geochemical manifestations of intrabasinal differences is critical for exploring and exploiting petroleum resources.

**In Earth history**, sedimentary rocks contain physical, chemical, and biological records through time. These packages are frequently interpreted as archives that record global geochemical signals. However, in recent years it has become apparent that the stratigraphic variability of stable isotopes is often greater than expected between coeval locations\(^3,4\) – presenting challenges to stratigraphic correlation. Alternative interpretations suggest that geochemical variability integrates chemical and physical parameters of sediment deposition, such as physical reworking\(^5\) or secondary alteration of mineral phases after deposition and lithification\(^6\). These processes have been observed in modern environments, yet careful time-resolved demonstration of their significance in ancient sediments needs to tested.

**Methodology**

The research team will map the geochemical variability in the well-characterized Eocene Ainsa Basin in northern Spain. This delta is a longstanding type location for the petroleum industry and is ideally suited for this study due to its extensive, excellent exposure across environmental gradients spanning shelf to deepwater facies, allowing high-resolution stratigraphy and sample collection following well-resolved timelines.

The geology of this depositional system allows for correlation of sediments deposited simultaneously. Therefore, these outcrops provide an ideal model system in which to investigate the geochemical variability among syngenetic rocks - including across a gradient of paleo water depths from shallow nearshore environments to the deep offshore settings. The findings can be applied to other settings that lack sedimentological constraints of the delta and require other correlative methods.

**Fieldwork:** Four detailed stratigraphic sections will be measured across the delta with samples collected from outcrop at ~100 cm resolution over select stratigraphic intervals during two field seasons. We will map out timelines to generate coeval analyses in different paleo water depths. Samples will be placed in a sedimentological context, and facies determinations based on lithology, texture, fossil content, sedimentary structures, and bioturbation index.

**Analyses:** Carbon and oxygen isotope analysis at the St Andrews geochemistry laboratories will follow detailed petrographic analyses. Ratios of carbon isotopes in bulk organic matter will be analysed at St Andrews. S isotope analysis of carbonate associated sulphate and pyrite will occur at St Andrews. Biomarker analysis will be conducted on selected sections at Washington University, including compound specific analysis of \(^{13}\)C content of individual organic compounds.

**Timeline**

Year 1: Literature review, field season and preparation of samples.
Year 2: Field season and analysis of sediments, papers 1-2.
Year 3: Analysis of outcrop samples, synthesis, papers 2-3.
Year 4: Thesis, further papers.

**Training & Skills**

The studentship will be housed in the School of Earth and Environmental Sciences at the University of St Andrews, where research interests focus around environmental change through Earth’s history, and economic geology and resources.
The project will involve fieldwork allowing training in mapping and logging techniques. In addition, there will be laboratory work and geochemical analyses, and hence the student will gain theoretical and experimental training in a wide variety of geochemical techniques, as well as quantitative skills in interpreting geochemical data.

The student will join Dr Rose who is a field geologist whose research focuses on understanding key Earth history events using a range of geochemical proxies, particularly C and S stable isotopes. Dr Bradley is a biogeochemist specialising in organic geochemistry. He will provide the student with training to prepare and analyse organic samples. In addition, Prof Boyce has extensive experience leading the Stable Isotopes Facility at the SUERC, University of Glasgow.

The student will additionally be trained in transferrable skills such as critical thinking, oral and written science communication, through manuscript preparation and presentation of work at scientific conferences.

**References & Further Reading**


**Further Information**

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