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A Source-to-Sink and Reservoir-Quality Prediction Workflow: The Offshore Nile Delta

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Abstract

We outline a novel workflow for utilising hinterland datasets to predict reservoir quality and distribution in frontier exploration regions and apply this methodology to a case study in the Nile Delta. Geochemical data are intersected with drainage areas to derive first-order bulk chemical compositions. Drainage polygons are modified using thermochronological data and paleocurrent information to create paleo-drainage areas. Volume of denuded sediment is then estimated from uplift data and integrated with stratigraphies to verify the link between hinterland and offshore geology. Finally, inorganic geochemical data are used to predict the modal composition of sediment within key reservoir and seal horizons.

The workflow presented utilises datasets otherwise overlooked in the exploration process and reduces the reliance on more speculative inputs such as paleogeographic reconstructions and paleoclimate modelling. The workflow provides quantitative predictions with percentage certainties, allowing explorers to understand the degree to which results can be relied upon.

To demonstrate this workflow, we look at the offshore Nile Delta sediments in the Eastern Mediterranean. The Nile's vast hinterland is comprised of sediments derived from the Congo Craton and Saharan Metacraton, Cenozoic Flood Basalts and Phanerozoic sediments from the Ethiopian Highlands, and Phanerozoic sediments and Cenozoic carbonates from the Egyptian Red Sea Hills. Recent detrital studies on the offshore Nile Delta have shown the provenance of the Oligocene-to-Pleistocene sediments remained the same since the Rupelian, 31 Ma (Fielding et al., 2018). Fluctuations in the amount of mafic material recorded in the delta during the Oligocene and Pliocene versus the Miocene and Pleistocene have implications for discontinuous reservoir quality in the basin. Using the workflow outlined above and incorporating additional datasets and methods, we aim to quantify this variation in mafic sediments and its implications for predicting reservoir quality in the offshore Nile Delta.

Introduction

We present a worked example on data from the Nile Delta cone and hinterlands using the Petryx Data Lens. A source-to-sink study to help determine the reservoir quality of the Oligocene-to-recent cone sediments was carried out as part of a PhD project from 2011 to 2015 (Fielding, 2016). Samples from the Nile cone were compared to hinterland data collected from four main potential source areas.

Hinterland Selection

After studying the literature, the Red Sea Hills (Egypt), Ethiopian Highlands (the Blue Nile), Western Desert (Egypt) and the Congo and Saharan Metacraton (White Nile) were targeted for hinterland characterisation. Each of these source areas have unique provenance signatures and therefore differing reservoir quality potential. The study by Fielding (2015) and subsequent papers (Fielding et al., 2017 and Fielding et al., 2018) address the evolution of paleo-drainage to the delta over time but do not look at the potential impacts that this may have on reservoir potential.

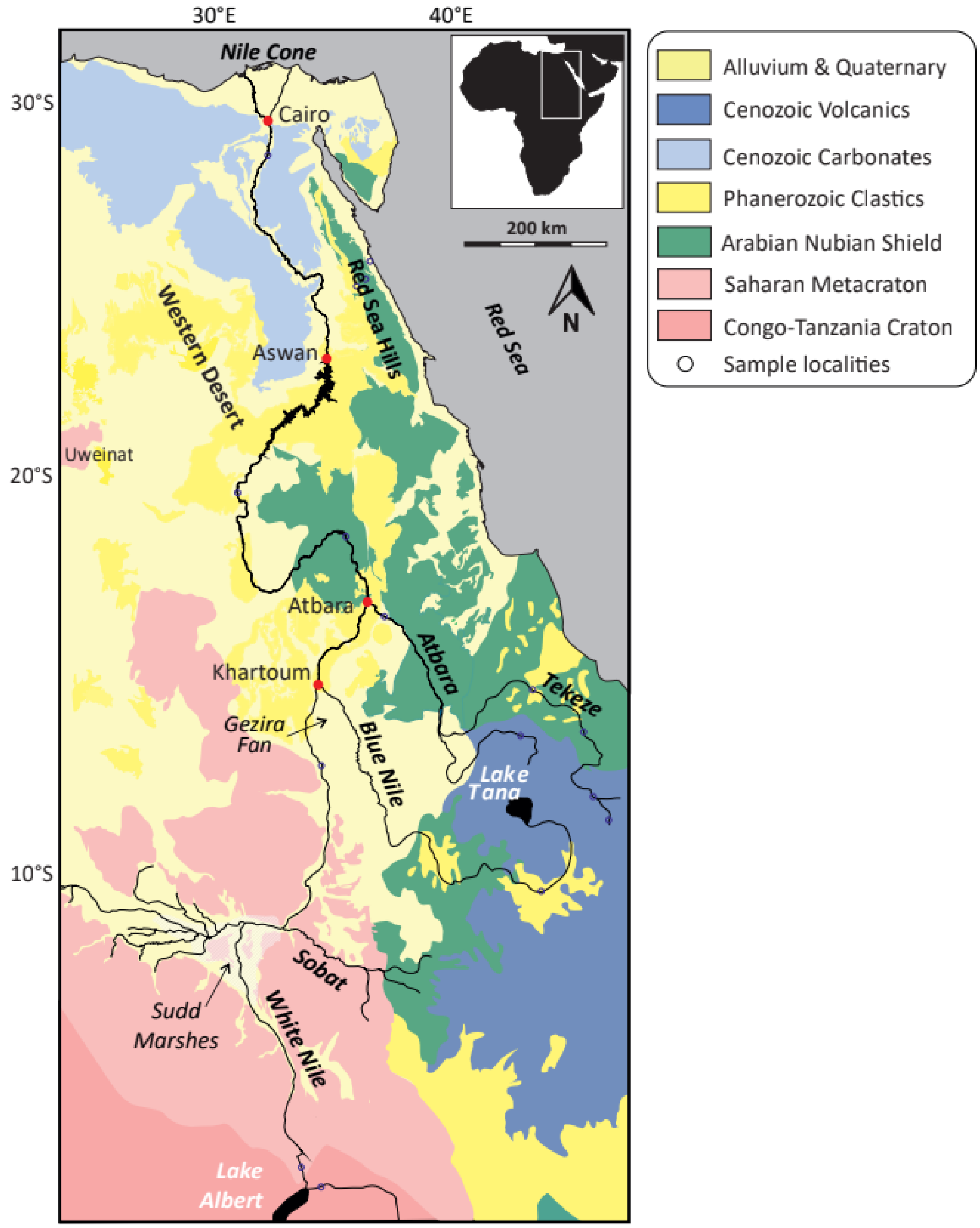

Figure 1 Geological map of the Nile catchment area taken from Fielding et al. (2018).

Sediment Fertility

After selecting potential hinterland areas, the next step of the workflow is to estimate sediment fertility in each catchment area both with Present Day geometries and paleo-extents. Mineralogical estimates are intersected with petrographic data in the offshore to calibrate sediment mixing and recycling effects. This technique can be valuable when no 'sink' or offshore samples are available as it uses the mineralogy of the hinterland as a precursor for sands downstream. In the case of the Nile hinterland, both the Egyptian Red Sea Hills and Western Desert demonstrate the greatest sediment fertility and therefore the greatest reservoir quality potential. Whereas the volcanic component of the sediments from the Ethiopian Highlands has the effect of reducing sediment fertility due to the overwhelming component of plagioclase highlighted in the data, resulting in poor reservoir-quality potential.

Sediment Supply

Now that the source area with greatest reservoir potential has been identified, the next step is to determine when sediment was being supplied from this area and being delivered to the sink to create our reservoir. This is best done using a multi-disciplinary approach. Data types proven to be key when reconstructing sediment provenance include:

- U/Pb/Hf zircon geochronology
- Ar/Ar or K/Ar plagioclase, biotite and mica geochronology
- U/Pb rutile geochronology
- Rb/Sr and Sm/Nd whole rock radiogenic isotope analyses of muds
- Apatite and zircon fission track analyses
- Whole rock XRF major and trace element analyses
- Heavy mineral and petrographic analyses.

Fielding et al. (2018) paired U/Pb and Hf zircon geochronology with radiogenic isotope analyses of muds from the hinterland and offshore Nile Delta. The result was a clear reconstruction of the timing of sediment delivery to the Nile Delta cone. U/Pb zircon data showed Oligocene-to-recent sediments in the delta have much the same signature regardless of age (Fielding et al., 2018), receiving sediment from all source areas except the Saharan Metacraton. All samples were dominated by a 600 Ma grain population representing the Pan African Orogeny that was ongoing at this time whilst subordinate 1000 to 2600 Ma grain populations show subtle variations over time. What is clear is that a c.30 Ma grain population present in all samples points to a connection with the Ethiopian Highlands since the formation of the Nile Delta cone in its current offshore location (Fielding et al., 2018).

When paired with a technique focusing on the mud fraction of the detrital sediments, it is possible to make further interpretation as to the reservoir quality of the sediments. On initial inspection, Sr/Nd analyses show the delta cone samples behave in much the same way over time as shown in the U/Pb zircon results. However, it is also possible to see fluctuations in the proportions of mafic sediment being received from the Ethiopian Highlands over time. Miocene and Pleistocene samples have lower radiogenic Sr values and more positive εNd values, suggesting a greater mafic input than during the Oligocene and Pliocene. This technique can be used to predict the composition of sediment downstream if no samples are available in the sink. The proportions of each end member can be adjusted according to the denudation rates reported in each area over time.

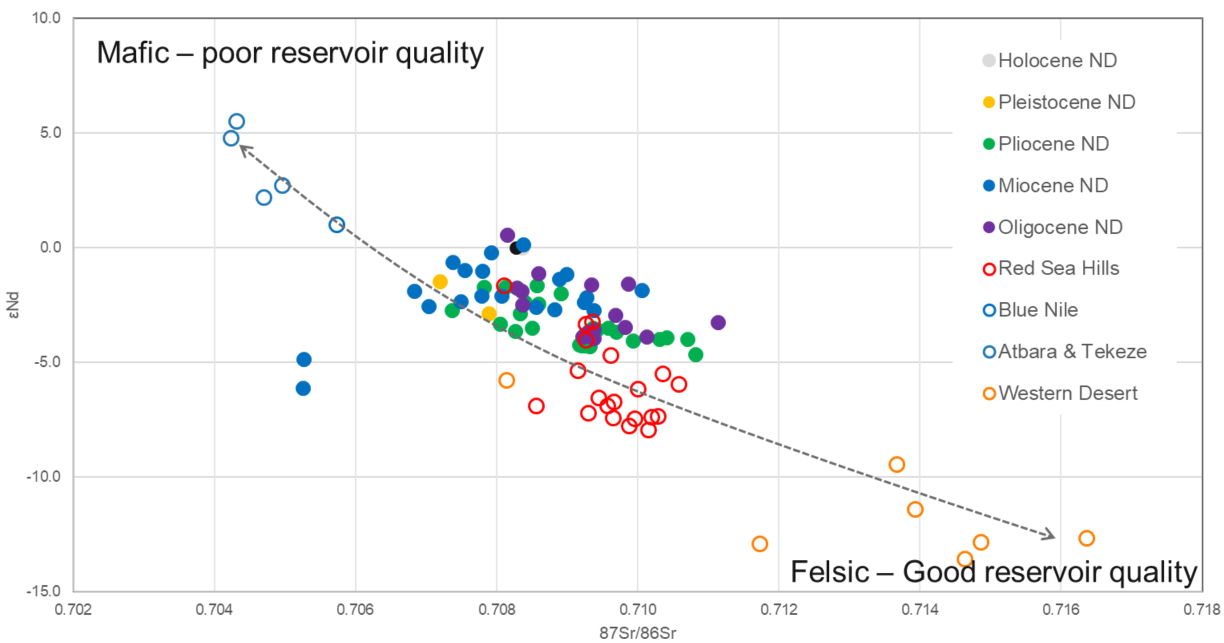

Figure 2 Sr/Nd radiogenic isotope analyses of Nile Delta (ND) cone (solid circles) and Nile hinterland samples (open circles) taken from Fielding et al. (2018).

Conclusion

The final stage of the workflow is piecing together the data and interpretations made at each stage of the workflow. In this case:

1. **Hinterland selection**
   The four main source areas in question are the Red Sea Hills, Western Desert and Ethiopian Highlands.
2. **Sediment fertility**
   The source area with the greatest reservoir potential is the Red Sea Hills and Western Desert.
3. **Sediment supply**
   Sediment supply has remained largely unchanged since 30 Ma, with subtle increases in the mafic content of Miocene and Pleistocene sediments in comparison to the Oligocene and Pliocene.
4. **Reservoir-quality prediction**
   Nile Delta sediments showing the most promising reservoir potential occur during the Oligocene and Pliocene.

References

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