The impact of varying clay content on the compaction characteristics of clastic sediments

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Introduction

Compaction in clean sandstones is well studied due to its importance in the hydrocarbon industry, especially in relation to porosity and permeability loss, cementation and burial depth (e.g. Paxton et al., 2002). However, very few clastic sediments are completely matrix-free and less is known about the effect of the clay content on compaction. Previous studies generally use synthetic sand/clay mixtures or a modelling approach to study the influence of clay. For example, Rutter and Wanten (2000) studied hydrostatic compaction of synthetic sand and illite/muscovite mixtures at high temperatures (300-450°C) while Crawford et al. (2008) used synthetic quartz/kaolinite mixtures to study the effect of sample composition on compaction, strength and fluid flow properties in fault zones. Both studies found that compaction was greater with an increase in the clay content. Revil et al. (2002) constructed a model for mechanical compaction of sand/clay mixtures showing, in addition to other findings, the dependency of compaction on the clay content and the effective stress history of the mixtures.

This project aims to increase the understanding of the control of clay content on the compaction of reservoir sandstones using a combined microstructural and laboratory approach on both natural clastic sediments and synthetic samples. Carefully controlled laboratory experiments will be carried out to simulate burial. Subsequent microstructural analysis will identify any changes in characteristics that could directly affect the reservoir quality potential of the sandstones, including porosity, permeability and composition.

Project Summary

This PhD project will provide a quantitative description of the compaction characteristics of sandstones with varying clay content and the impact on reservoir quality. Initially the work will consist of uniaxial compression tests that simulate shallow burial (up to 1500 m) of modern sediment collected from the Ravenglass Estuary in the Lake District (NW England), targeting sampling locations with known differences in clay content (e.g. M1-3, Image 1). Complementing these tests, synthetic mixtures of sand and clay will also be compacted. The compression experiments will be followed by microstructural analyses using several analytical techniques including standard petrographic methods and Scanning Electron Microscopy (SEM; Image 2).

The experiments described above provide the opportunity to investigate the following themes as part of this project:

- Examine the role of water saturation and water escape by studying samples with different saturation levels. Rutter and Wanten (2000) showed that wet, synthetic sand-clay mixtures exhibited more compaction compared to dry sand-clay mixtures and a recent study by Zadeh et al. (2016) also found that brine saturated samples with a higher clay-content were more prone to compaction, even at relatively low vertical effective stresses (up to 30 MPa).

- Investigate the time-dependency of compaction in clay-rich sandstones. Previous work shows evidence for time-dependent creep in both sandstones (Hagin and Zoback, 2004) and shales (Sone and Zoback, 2013).
- Not only study the effect of clay content, but also investigate the influence of clay type on compaction. Tembe et al. (2010) have shown that both clay content and type (illite and montmorillonite) affect the frictional sliding behavior in quartz-clay gouges, with a decrease in strength with increasing clay content and a linear (illite) or non-linear (montmorillonite) trend of strength reduction depending on clay type.

During the project the candidate will work in a multidisciplinary team with members of staff from the sedimentary geology, petroleum geology and rock deformation research groups within the Department of Earth, Ocean and Ecological Sciences. The PhD candidate will receive training in the design and running of compaction experiments using modern/loose sediments and the use of analytical techniques including standard petrography, SEM, X-ray diffraction (XRD), and automated mineralogical identification using SEM (QEMSCAN). Additionally, the candidate will be trained in scientific writing with the aim of publishing in international peer-reviewed journals. The project comprises both pure and applied aspects of (petroleum) geology and will therefore be suitable for candidates who wish to pursue a career in either academia or in industry.

The candidate should have an MSc in geology, earth sciences, geophysics or similar discipline. Knowledge of sandstone petrography and a basic understanding of rock deformation processes is desirable but not a requirement for application.

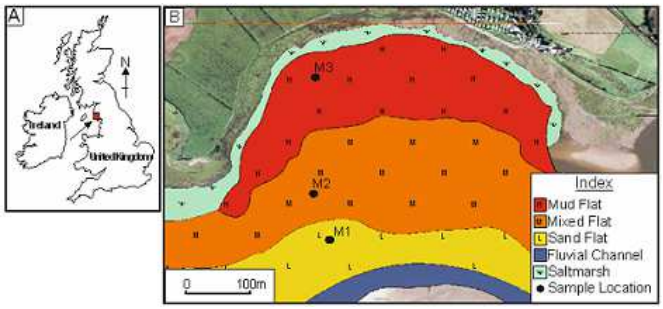

Image 1 *A) Location map highlighting the Ravenglass Estuary in the Lake District (NW England). Map courtesy of M. Noel. B) Detailed map of the north-east part of the Ravenglass Estuary showing three potential sampling sites M1-3 (see Image 2). Colours relate to different clay fraction content varying from 0-10% (L, sand flat) to 30-80% (H, mud flat). Image modified from Wooldridge et al. (2017).*

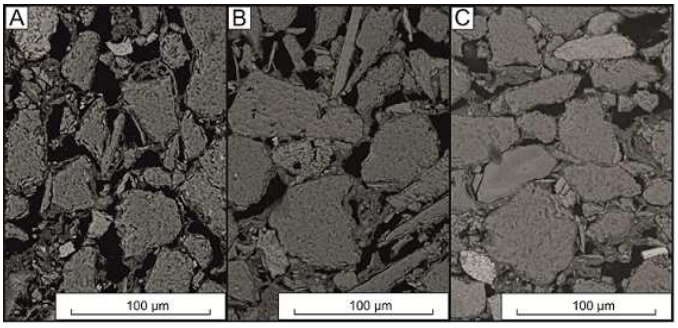

Image 2 *Examples of SEM photomicrographs showing the shallow burial (compaction) of modern sediment from sample site M3 in the Ravenglass Estuary (Image 1) with A) no compaction, B) 500 m (12.5 MPa) and C) 1500 m (37.5 MPa). Image courtesy of M. Noel.*

References

Crawford, B. R., Faulkner, D. R. and E. H. Rutter, E. H., 2008. *Strength, porosity, and permeability development during hydrostatic and shear loading of synthetic quartz-clay fault gouge.* J. Geophys. Res. Earth, 113, B03207, doi:10.1029/2006jb004634

Hagin, P. N. and Zoback, M. D., 2004. *Viscous deformation of unconsolidated reservoir sands—Part 1: Time - dependent deformation, frequency dispersion, and attenuation*. Geophysics, 69(3), 731-741.

Paxton, S. T., Szabo, J. O., Ajdukiewicz, J. M., and Klimentidis, R. E., 2002. *Construction of an intergranular volume compaction curve for evaluating and predicting compaction and porosity loss in rigid-grain sandstone reservoirs*. AAPG Bulletin, 86, 2047-2067

Revil, A., Grauls, D. and O. Brevart, O., 2002. *Mechanical compaction of sand/clay mixtures.* J. Geophys. Res. Earth, 107, B11, 2293, doi:10.1029/2001jb000318.

Rutter, E. H. and Wanten, P. H., 2000. *Experimental study of the compaction of phyllosilicate-bearing sand at elevated temperature and with controlled porewater pressure*. J. Sediment. Res., 70(1), 107–116

Sone, H. and Zoback, M. D., 2013. *Mechanical properties of shale-gas reservoir rocks — Part 2 : Ductile creep, brittle strength, and their relation to the elastic modulus*. Geophysics, 78(5), 393–402

Tembe, S., Lockner, D., A., and Wong, T. F., 2010. *Effect of clay content and mineralogy on frictional sliding behavior of simulated gouges: Binary and ternary mixtures of quartz, illite, and montmorillonite*, J. Geophys. Res. Earth, 115, B03416, doi:10.1029/2009jb006383

Wooldridge, L. J., Worden, R. H., Griffiths, J., & Utley, J. E., 2017. *Clay-coated sand grains in petroleum reservoirs: understanding their distribution via a modern analogue*. J. Sediment. Res., 87, 338-352

Zadeh, M. K., Mondol, N. H. and Jahren, J., 2016. *Experimental mechanical compaction of sands and sand-clay mixtures: a study to investigate evolution of rock properties with full control on mineralogy and rock texture.* Geophysical Prospecting, 64, 915-941