

INJECTED SANDS RESEARCH CONSORTIUM

PHASE 2

Universities of Aberdeen and Cardiff

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WORK PROGRAMME
workflow, goals, deliverables



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BACKGROUND: RESULTS OF PHASE 1 OF ‘SAND INJECTITES’

Phase 1 of this consortium funded research project was conducted between 2001 and 2003, funded by ChevronTexaco, Norsk Hydro, Shell UK, Statoil, TFE and Kerr McGee UK Ltd.

The aims of Phase 1 were:

- to document the geological, petrophysical and geophysical characteristics of remobilised and injected sands and to understand their causes and consequences.

The main workflow was:

- to synthesise the vast amount of data already accumulated from reservoirs where the effects of remobilisation are well known.
- this included integration of 3D seismic, core and petrophysical data in a series of case studies selected by the sponsor companies.
- subsurface data were drawn largely from the Paleogene of the northern North Sea, which, at the time was the only petroleum province in the world where sand remobilisation and injection was considered a major issue for exploration and production.
- to support the subsurface interpretations of many previously undescribed phenomena, limited reconnaissance studies were undertaken to scope out analogues for interpreting geometries and processes that are only partially captured by subsurface datasets.

Theoretical modeling:

Theoretical models were developed in order to understand the physical processes associated with sand remobilisation, and to aid prediction of (1) timing, (2) depth and (3) prediction of the scale and geometry of the structures produced.

Results of Phase 1:

Phase 1 achieved all its main objectives, and significantly advanced our general understanding of the processes and products of sand remobilisation and injection. The access to key subsurface data and the opportunity to integrate this vast database provided by the sponsors gave the Injected Sands Group unparalleled advantage in developing this relatively unexplored subject. It is probably fair to say that the ISG is the leading research group in the world in this field, reflected in publications and conference keynote addresses, distinguished lectureships and the award of a medal from the EAGE.

While many of the results are confidential and embedded in the Phase 1 Final Report, the key published outcomes are listed below:

- *Defined classes of reservoir scale sandstone intrusion as conical sheets and wings, with seismic identification criteria for each class (Figs. 1 and 2)*
- *Defined core recognition criteria, with guides to separating injection and remobilization facies and discrimination from mass flow deposits (Fig. 3)*
- *Defined textural (poroperm) and petrophysical differences between injectite facies and depositional facies to aid in log interpretation and reservoir modelling*
- *Defined generalized basin models for remobilization-intrusion system to allow prediction in an exploration play context*
- *Defined role of injectites as long-term fluid migration conduits through isotope geochemistry and petrological analysis*
- *Defined relationships between intrusion and host caprock sequences especially in areas of polygonal faulting*

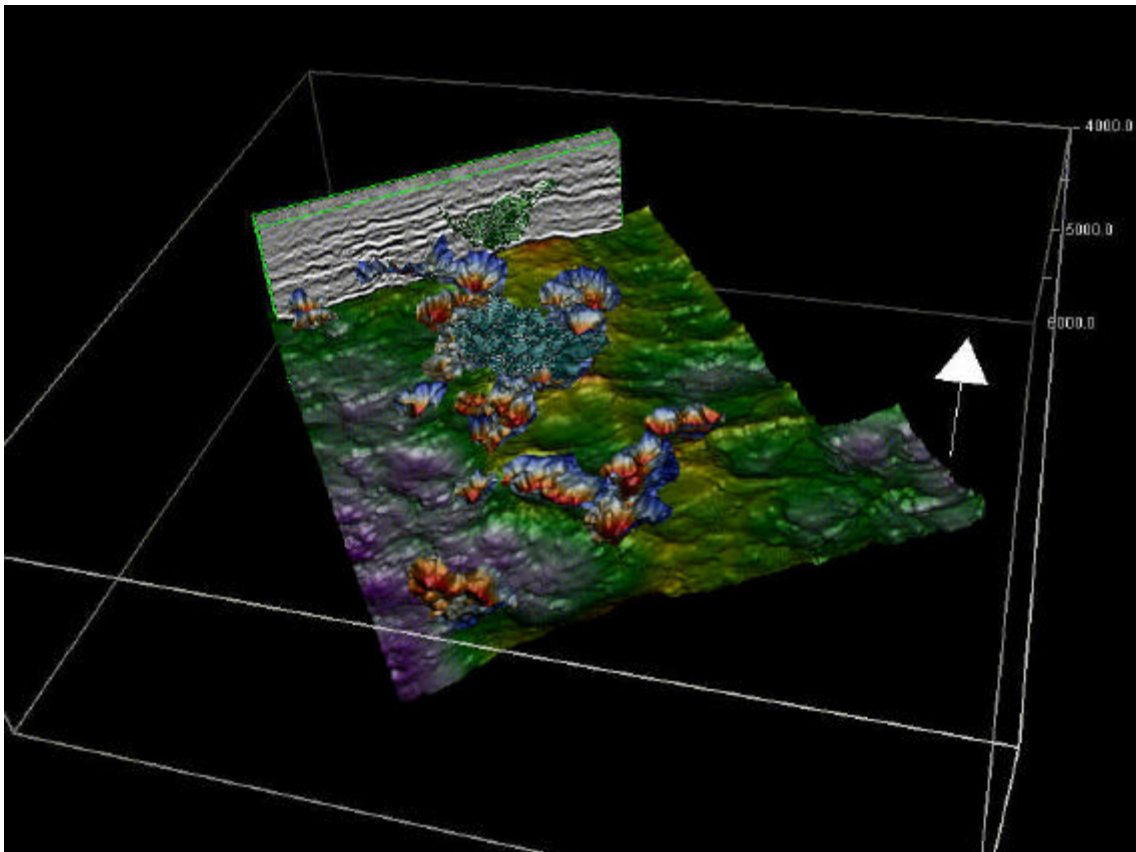


Fig. 1 Oblique view in GeoViz of system of conical sandstone intrusions each with c. 1km diameter in the Chestnut Field, UKCS From Huuse et al in press.

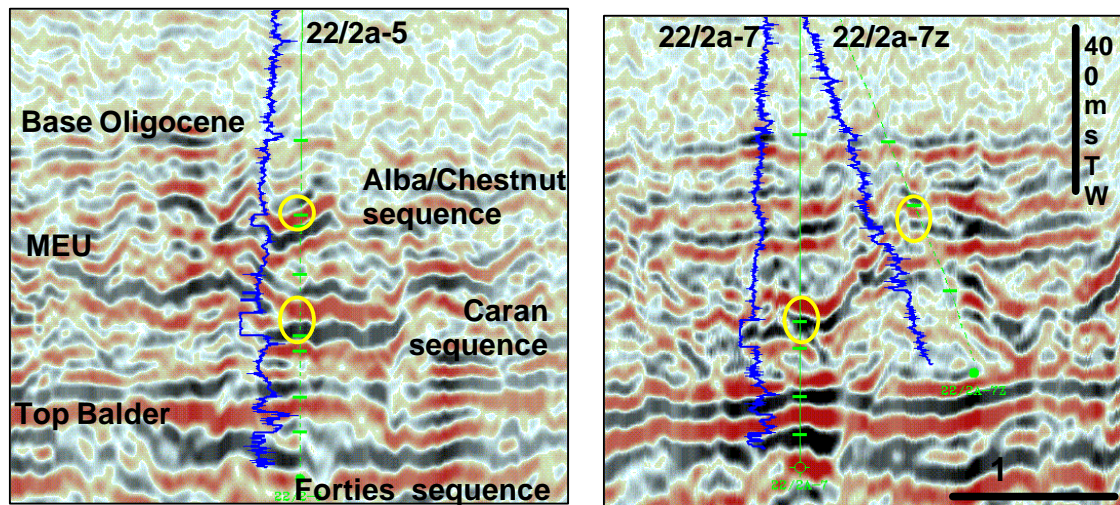


Fig. 2: Wireline log to seismic calibration for intrusive sandstones of reservoir scale: Chestnut Field UKCS from Huuse et al in press

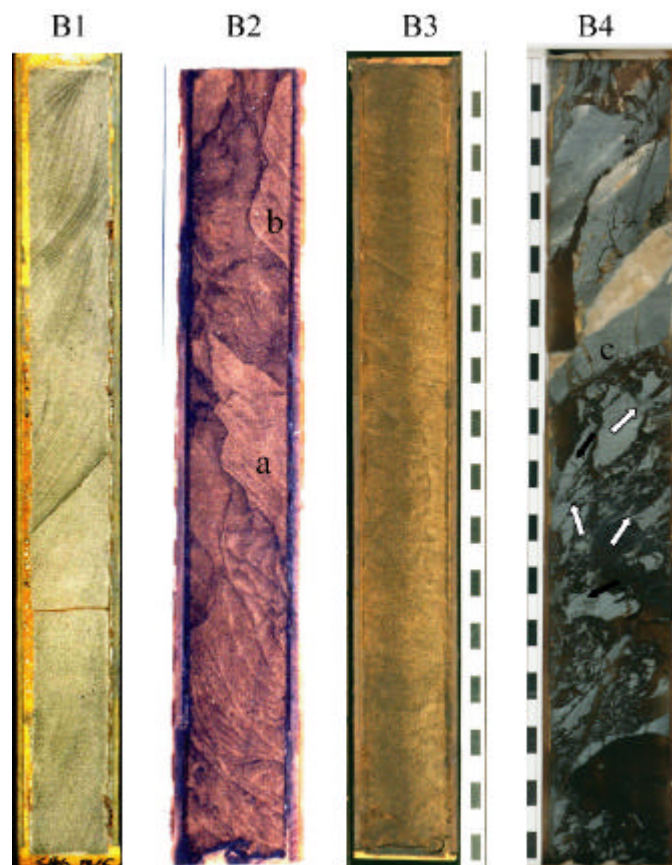


Fig. 3. Sand injectite (unstratified) facies from the Alba Formation (N Sea): B1 oversteepened laminae; B2 giant pillars; B3 structureless sandstones; B4 mudstone-clast breccia. B4 in its various forms is commonly confused with debrites (after Duranti & Hurst (2004) *Sedimentology* 51, 503-531).

WHY THE NEED FOR PHASE 2?

Sand injectites are increasingly being recognized to be of far greater significance in the context of hydrocarbon exploration and production worldwide. From the essentially NW European focus of Phase 1, we see a need to expand the scope of injected sands research to a more global footing because of the much wider recognition of injected sands in hydrocarbon systems from many other deepwater settings.

The increased recognition stems partly from greater awareness of diagnostic features on seismic and in core. Increased resolution of 3-D seismic data, for example, allows features associated with sand injection to be identified, both in producing fields and as potential exploration targets (earlier this year Marathon and their partner Lundin drilled the first ever deliberate exploration well into an injectite complex, Norway 24/9-7, discovering a >100m oil column).

Phase 1 concentrated on classification and definition of genetic models. The logical extension of this primary work is to apply this new understanding of the context of intrusion/remobilization to reservoir characterization and modeling.

Many of the challenges associated with their hydrocarbon prospectivity and productivity are related to understanding their rock properties – are they sand-prone? – what is the N/G? – what is the lateral continuity? – how well are sand bodies connected? – how can the sand bodies be represented in geomodels? - can pre-drill facies prediction be improved? All these issues are intractable using subsurface data (seismic, borehole and dynamic data) in isolation, however, by acquiring appropriate outcrop data and applying these data to subsurface modeling, we believe that more robust prediction will be possible.

Because of the increasing awareness of the significance of sand injectites in turbidite¹ reservoirs globally, we focus primarily on deep-water clastic environments. When present, sand injectites will almost certainly have a profound affect on reservoir character and behaviour: these need to be included in the appraisal and development of all reservoirs affected or formed by injectites.

Equally, as development proceeds there is substantial evidence that a failure to recognize the importance of sand injection may compromise the optimization of recovery. As sand injectites often extend 10s to 100s meters above “conventional” top reservoir maps (as picked on seismic) substantial reserves may be overlooked. In this context, top reservoir seals are often much higher in the stratigraphy than originally conceived, which leads to reconsideration of hydrocarbon migration pathways and the integrity of top seals, for example.

¹ We recognize that sand injectites facies may often be significant in other depositional environments (aeolian in particular). Depending on sponsor interest non-turbidite facies can be included in our proposed research.

The activities tackled in Phase 1 have provided a solid foundation for the recognition of remobilization phenomena using seismic data, but there is only limited understanding of the affects of subseismic-scale features on reservoir behaviour. There are still major problems too with identifying specific geometries on seismic data and relating these to physical properties. Phase 2 is thus designed primarily to bridge the scale gap between seismic and outcrop scales and to downscale our predictive understanding to the reservoir.

The recent FORCE conference (Stavanger, April 2004) highlighted the lack of synthesis of injectite subsurface data, for example, relating production history (well productivity) to specific sedimentary and/or injectite facies. The paucity of cores from key sand injectite features, the limits of seismic resolution, and the limited integration of microscale data into seismic models limits all aspects of their interpretation and modelling. Consequently, the main focus of this research programme is to expand the outcrop database and to utilize these data for seismic and geological modelling of sand injectites, and their associated turbidite reservoirs.

SUMMARY

This document defines in detail the proposed activities for Phase 2 of the Injected Sands Research consortium. In our base model it is assumed that the consortium will support two full-time research fellows for three years and a minimum of two PhD students for the same period.

Phase 2 has two main components, **reservoir characterization** and **reservoir modelling**. Gantt charts showing the distribution of workload between the two postdoctoral research fellows (PDRFs) are attached. A further chart displays a reporting schedule for the first two years of the project. Individual elements such as fieldwork and specific results of seismic modelling will be reported at the conclusion of particular phases of the work as and when appropriate. A final report will be submitted at the end of year 3. The PDRFs will be based in Aberdeen but jointly administered by U's Aberdeen and Cardiff. Andrew Hurst will be project manager.

We will work closely with sponsors on company-specific mini-projects whenever possible to facilitate maximum return on your research investment.

Gantt charts do not specify a start date but it is our aim to start the project in December 2004/January 2005. The programme of outcrop data acquisition will require minor adjustment dependent on the start date and the number of sponsors.

Cost

£30k per year, per sponsor for 3 years.

Reservoir characterisation

This module has two inter-related strands, seismic characterization and reservoir prediction, which are relevant both the exploration and field development. The work is underpinned by acquisition of outcrop analogue data that, together with subsurface data, are used to create seismic and reservoir models.

Seismic character and modelling

Present-day practice in reservoir prediction and characterization of injectite reservoirs is strongly dependent on the ability to recognize macro-scale features on seismic data and to infer lithology and N/G. Despite the increasing experience of drilling into well-defined seismic (often acoustic impedance) features there are invariably surprises with the thickness of sand present and the N/G. Clearly, there is a need for more robust prediction. We believe that risk reduction regarding prediction of gross sand and N/G by improving the understanding of the affects of micro-scale injectite features on seismic response.

As features resolved by seismic data tend to be macro-scale or larger there is a tendency to ignore smaller-scale features as they are “below the scale of seismic resolution.” We believe that the key to accurate prediction of reservoir distribution is to develop models that incorporate features that occur below the scale of seismic resolution into models. Such features are known from cores and outcrops but, to our knowledge, not included in seismic models or interpretations.

The fundamental step in the modelling process is to acquire appropriate core/borehole data and create 2D and 3D interpolations of these data using outcrop analogues. The paucity of quantitative outcrop description of sand injectites was demonstrated in Phase 1, and is a fundamental activity of Phase 2. Seismic modelling software will utilize existing in-house facilities at Aberdeen and Cardiff, including new developments of the RokDoc suite. We plan to examine core/borehole data from sponsor-held wells and to conduct sponsor-specific studies based on these data.

Reservoir prediction

Subsurface workers continue to struggle with the distinction between depositional units and injectites. Further, there is a strong tendency to adopt conservative interpretations of injectite abundance, distribution and geometry, using dated concepts and models for the genesis of sand injection. We will address these issues both by providing a more robust and broader-based analogue database and by providing alternative reservoir models that can be used to test the sensitivity of dynamic models to the presence of injectites, i.e. “what if the depositional units are injectites – would it make a difference?” Particular confusion remains when differentiating between debris flow facies, including “linked debris flows,” and injectites (specifically breccias with a sand-supported matrix). We will link this work with sponsor-specific case studies.

A second element of this module is the role of *in situ* stress on the formation and propagation of sand injectites. This work will be carried out in parallel with the rock description studies and will be incorporated in to a PhD study (co-supervised by

Professor Peter Cobbold, U Rennes). *In situ* stress has a fundamental control over the geometry, orientation and timing of sand injection. By improving the fundamental understanding of stress relationships we believe that the prediction of occurrence of injectites in deep-water clastic successions will be improved.

A statistical analysis of the distribution of intruded sands within the reservoir complex will also form part of this module. This will be based on subsurface reservoirs known to have a well developed intrusion halo. This analysis will be used to tighten the constraints on recognition of intruded facies from wireline logs.

We will construct static models, with seismic analogues, and are amenable to up-scaling into dynamic models. Given the likely diversity of sponsor geo-modelling procedures and requirements we intend generating generic templates that are amenable to integration into any modelling package. As with all other aspects of this research, we will carry out sponsor-specific studies using, or collaborating with, modellers in each sponsor company.

Campaigns of outcrop data acquisition are a priority from the outset. Although some flexibility is retained regarding the location and timing of data acquisition, at least seven outcrop campaigns are planned during the first two years with provision for additional campaigns during year 3. Prime areas for data acquisition are California, Greenland, Tunisia and Argentina/Chile. Subsurface case studies (some of which are sponsor-selected) will be carried out to test and support the validation of subsurface interpretation with analogue data. Extensive use of seismic modelling will be undertaken to translate outcrop data into a subsurface format.

Reservoir modelling

This is a smaller module than reservoir characterization and builds on data from that module.

Dynamic models will be constructed to test the effects of injectites on hydrocarbon recovery. The work will focus on small-scale architectural elements, based largely on outcrop analogue data that are calibrated against subsurface data. Small-scale models will be used as a basis for the input to reservoir engineering up-scaling (to be carried out in collaboration with a 3rd party academic collaborator). An important aspect of the modelling will be to relate physical models of sand body geometry and distribution to seismic models of the same, and to use these relationships to support and enhance seismic interpretation of reservoir quality.

As sand injectite reservoirs have strong vertical anisotropy, at all scales of investigation, they present a series of challenges in reservoir development that may be distinct from those encountered when dealing with depositional sandstones. In particular the drilling of development wells into inclined, multi-layer sand bodies, which are connected by sub-vertical dykes, presents a new scenario for optimal positioning and completion. In this

context, particular attention will be given to estimation of vertical permeability and optimal well positioning and perforation.

It is not the intention of this module to carry out sponsor-specific studies, however we welcome sponsor input regarding specific development problems.

Manpower

Two dedicated post-doctoral research fellows will undertake the main technical programme of the project with additional projects carried out as PhDs. Academic staff from both universities (and Peter Cobbold, U Rennes) will be engaged in a wide range of supporting activities.

Reporting

Interim reporting will be made as indicated on the Gantt charts. Sponsor-specific studies will be reported on an exclusive basis. Annual sponsor meetings/workshops will be convened to monitor progress and to facilitate networking between sponsors.

As outcrop studies were only a minor part of Phase 1, all available data will be reviewed prior to new data acquisition. A summary classification of geometries, sizes, etc. together with an analysis of the geological setting in which injection occurred will provide a prelude to the first campaign of outcrop data acquisition and initial input to seismic modelling. Interim reports from all outcrop studies will be provided.

Final report A fully illustrated database and classification of sand injectites will be presented together with comparisons of subsurface occurrences of similar features. Particular attention will be given to the spatial distribution of injectites, variations in their volumetric distribution and their geometry, and the relationship to depositional and tectonic setting. PhDs undertaken in the context of this research, 1) the role of *in situ* stress regime on injection style and geometry and, 2) the rock-fluid interactions associated with sand injectites, will be integrated into this part of the final report. PhDs will be reported independently to all sponsors following their completion.

A workflow for integrating outcrop data into seismic, and static and dynamic reservoir models will be provided together with the results of selected case studies. All appropriate outcrop data will be presented as 3-D geo' models.

Software requirements

Existing software held by both universities will be used by the project. Interpretation of subsurface data and geo' modelling will whenever possible be made using in-house software within sponsor companies.

Assembling a library of reservoir geometries for reservoir modelling will probably use GOCAD, however, this is an issue that is open for discussion and may need to be handled differently for different sponsors. GOCAD is not yet available to the project.

Reservoir modeling will make use of the software used in-house by our collaborators (as yet undefined), and sponsors in-house modelling software. Wherever possible we will seek to avoid duplication of routines and focus on developing transferable, generic procedures for 3-D modelling, up-scaling, etc.

Andrew Hurst & Joe Cartwright, September 2004

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