COMPARISON OF INITIAL STRESS STATE AND ROCK-FAILURE RISKS FOR FIVE PROSPECTIVE CO_2 STORAGE SITES

John Williams[a], Philip Ringrose[b]*, Nicholas Thompson[b], Zoya Zarifi[b], Kevin Bisdom[c], Tom Kettlety[d], Susann Wienecke[e], Jung Chan Choi[f], Elin Skurtveit[f], Michael Bryld Wessel Fyhn[g], Devendra Narian Singh[h], Reddi Srinivasa Rao[h] and Volker Oye[i]
SHARP Project with authors from [a]BGS,UK; [b]Equinor, Norway; [c]Shell, Netherlands; [d]University of Oxford, UK; [e]ASN, Norway; [f]NGI, Norway; [g]GEUS, Denmark; [h]IITB, India; [i]NORSAR, Norway
Corresponding author's e-mail address: phiri@equinor.com

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ABSTRACT

We report initial assessments of the state of stress and the estimated conditions for rock failure at five prospective CO_2 storage sites which are being considered in the ACT SHARP Project. This multinational project aims to improve understanding of stress history and reservoir pressure to enable improved quantification of CO_2 storage containment risks. The goal is to improve the accuracy of subsurface CO_2 storage containment risk management through the improvement and integration of subsurface stress models, rock mechanical data and seismicity observations. The case studies considered in this assessment are:

- Norway – Horda/Smeaheia region;
- UK – Southern North Sea, Bunter storage play;
- Netherlands – Aramis site, Rotliegend pre-salt;
- Denmark – Lisa Structure;
- India – Bhagewala Heavy Oil Field, Rajasthan.

These case studies have different levels of maturity of site development and data availability, which is useful for understanding what data is needed at different stages of a project. While detailed site characterisation and rock failure studies have been conducted for the Horda/Smeaheia region offshore Norway and for parts of the UK Southern North Sea (SNS) Bunter storage play, rock failure characterisation studies at the Aramis site and Lisa Structure are limited to regional studies. The Bhagewala Heavy Oil Field in India is the least mature of the case studies in terms of storage assessment.

For each of the sites we first review the structural and basin setting of the prospective stores, and then review available datasets describing the *in situ* stress conditions. The available rock mechanical core measurements (Youngs Modulus, poisons ratio, friction angle, etc.) and dynamic formation tests (e.g. FIT, minifrac, XLOT) provide an initial indication of the depth-dependent state of stress and likely conditions for rock failure in the reservoirs and sealing units. We then review the available seismicity data, inferring current levels of earthquake occurrence and, where possible, summarize the state of stress inferred from fault-plane solutions.

Although each case study is unique, for example the Bunter storage play is very affected by salt tectonics, general insights can be drawn on the data types needed to form an understanding of the state of stress and the likelihood of rock failure for a given change in fluid pressure. The sites are also different in terms of project maturity, and to organize these questions in terms of maturity of knowledge we have placed these geomechanical assessments in the Storage Readiness Level

(SRL) Framework proposed by Akhurst et al. (2021). Our preliminary assessment is shown in Table 1.

Our aim in the SHARP project is to further develop this initial understanding of the rock failure risks summarized here. Subsequently we will develop 'smarter' targeted monitoring strategies, leading to more precise estimates of stress states and rock failure modes, both within the storage complex and regionally. The new/emerging monitoring methods include smart arrays of broadband seismometers, novel downhole gauges, and optimal use of Distributed Acoustic Sensing (DAS), both as vertical downhole optical fibres and as horizontal fibres (e.g. located within submarine telecom and power cables of infrastructure that is already in place). This rapidly developing technology has multiple applications and can often be deployed at lower cost than current technology. Benefits include improved spatial resolution of seismic imaging in the overburden, time-lapse seismic monitoring (of changes in saturation, pressure and rock strain), and microseismic event detection.

Table 1. *Preliminary mapping of geomechanical requirements within the Storage Readiness Level (SRL) Framework.*

SRL	Descriptive title	Rock failure/geomechanical activities likely to be required to meet SRL	SHARP case studies
SRL 1	First pass assessment of storage capacity at country-wide or basin scales		
SRL 2	Site identified as theoretical capacity	Initial collation of existing information and identification of activities required to progress the site	Bhagewala Heavy Oil Field
SRL 3	Screening study to identify an individual storage site and initial storage concept updated	Collation of regional data related to structure (major fault/fracture systems), *in situ* stress, earthquake focal mechanisms and rock mechanical property data	Aramis site & Lisa Structure
SRL 4	Storage site validated by desktop studies and storage project concept updated	Interpretation of site-specific data and development of a detailed 1D geomechanical model	UK SNS Bunter Sandstone storage play, and Horda Platform storage play
SRL 5a	Storage site validated, firstly by detailed analysis, then in a relevant 'real world' setting	Detailed risk assessment-led rock failure investigations and risk reduction activities to inform a storage permit application - including 3D geomechanical modelling	
SRL 5b		New data is acquired where needed, including acquisition of *in situ* stress measurements and/or laboratory measurements from downhole samples.	
SRL 5c		All storage site data will have been acquired, analysed and technical appraisal completed - updated 3D geomechanical modelling	
SRL 6	Storage site integrated into a feasible CCS project concept or portfolio of sites (contingent storage resource)	Any remaining concerns addressed, and residual risks effectively managed	Aurora site (part of Horda play) and Endurance (part of the UK SNS Bunter play)
SRL 7	Storage site is permit ready or permitted		
SRL 8	Commissioning of the storage site and test injection		
SRL 9	Storage site on injection	Updated insights from operational data	Snøhvit CCS project

Ref: Akhurst, M., Kirk, K., Neele, F., Grimstad, A.A., Bentham, M. and Bergmo, P., 2021. Storage Readiness Levels: communicating the maturity of site technical understanding, permitting and planning needed for storage operations using CO2. *International Journal of Greenhouse Gas Control*, *110*, p.103402.