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Research paper

Porosity, permeability and compaction trends for Scandinavian regoliths

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A R T I C L E I N F O

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A B S T R A C T

Weathered crystalline and metamorphic basement are proven as hydrocarbon reservoir rock in many areas of the world, including the Norwegian Continental Shelf. The reservoir properties of these rocks vary laterally and vertically as a function of the burial history, initial basement lithologies, sub-aerial exposure to weathering processes, chemical weathering, fault patterns, and these properties are relatively unknown. In this work, laboratory measurements are performed on different regolith types applying varying confining pressures representative for different degrees of basement weathering and burial depth. Porosity and permeability are measured on coherent samples (altered basement) and incoherent samples (disintegrated basement rock and saprolites) from the Utsira High (offshore Norway), and outcrop samples from Bømlo (southwestern Norway) and Ivö Klack (southern Sweden). Coherent samples from Utsira High (well 16/1-15 and 16/1-12) give porosities between 5.10% and 7.95% and permeabilities between 1.08 and 3.30 mD at 5.1 MPa, and indicate a relation between observed micro-fractures and decreasing permeabilities. In general, permeability increases with increasing amount of micro-fractures. The permeability is varying from 0.15 mD at 30 MPa to 3.30 mD at 5.1 MPa. This work presents the first published compaction curves for weathered basement (saprock and saprolites), and to our knowledge first permeability-porosity relationships for saprock and saprolites from three locations (Bømlo, Ivö Klack and Utsira High). The new porosity and permeability measurements of weathered basement rocks can be used as input parameters for reservoir modelling, basin modelling, field planning and hydrocarbon exploration in areas with regoliths. It can also serve as important input into hydrogeology, geothermal modelling, planning of tunnels, and as help to understand landslides and hillslope gullies in weathered basement.

1. Introduction

During the last years, fractured and weathered crystalline and metamorphic basements along the continental margin of Norway have become a substantial focal point for hydrocarbon exploration in new areas. The recent discoveries on the Utsira High (Fig. 1a) with the Edvard Grieg, Rolvsnes and Johan Sverdrup fields show that deeply buried regolith profiles with weathered and fractured Caledonian granitic and gabbroic rocks can act as petroleum reservoirs (Riber et al., 2015, 2016, 2017). These phenomena are not restricted to the Norwegian continental shelf. Naturally fractured and weathered basement reservoirs occur globally (Petford and McCaffrey, 2003), as proven by many discoveries, e.g., the Lancaster field west of Shetland (Trice, 2014), the La Paz field in Venezuela (Koning, 2003) and the Bach Ho field in Vietnam (Cuong and Warren, 2009).

In general, the basement-cover-interfaces in the upper crust can contain regoliths, which are composed of weathered residuum of the underlying basement rocks. At present day surface conditions, commonly a few metres to over 150 m thick lateritic regoliths are widespread in inter-tropical regions of the world (Butt et al., 2000). The thickness and degree of weathering depends on the age of the land surface, tectonic activity, climatic history and the nature of the bedrock (Butt et al., 2000). This lateral and vertical inhomogeneity of regoliths makes any kind of exploration challenging (Butt et al., 2000). In a petroleum system, a regolith might serve as a carrier, a reservoir and/or as a sealing unit. The migration operates on scales ranging from micro- to basin-scale (Bethke, 1985; Ge and Garven, 1994). Furthermore, the petrophysical, morphological, mineralogical and geochemical characteristics of the regolith might differ with respect to the degree of weathering (e.g., depth in weathering profile) and its burial and exhumation history (Riber et al., 2017). Riber et al. (2015) found that reservoir quality in crystalline rocks from 18 different wells located on the Utsira High (Fig. 1c) varied greatly as a function of type and degree of alteration. Moreover, it is well known that a petroleum system involving weathered basement (e.g., Lancaster Field) is dominantly controlled by the fracture systems (Trice, 2014). Thus, the study of the

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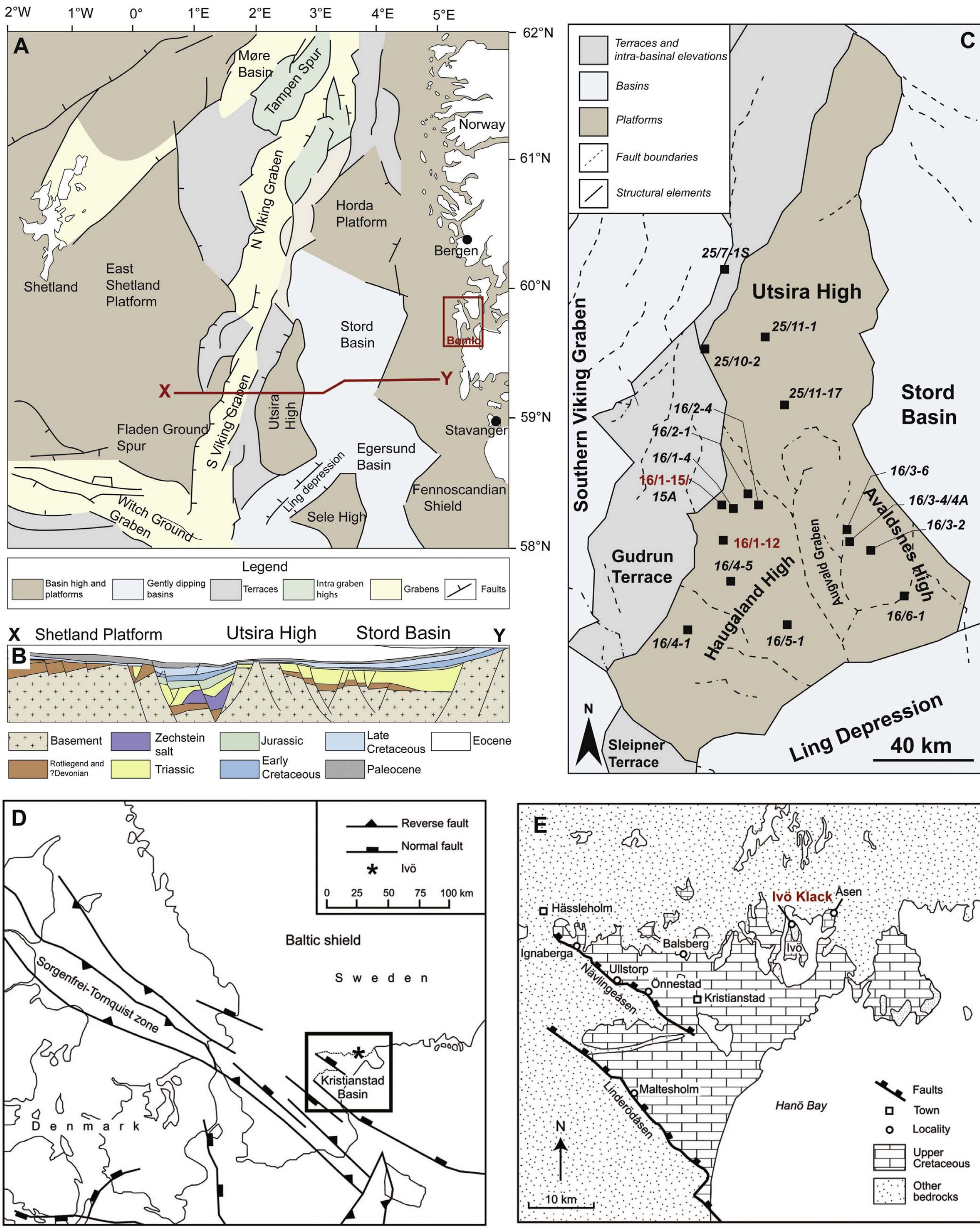

Fig. 1. Regional geology and sample locations a) Structural elements in the North Sea area. The Bømlo island study area is highlighted with a red box. b) A regional geo-seismic cross-section across the southern Viking Graben. The location (X–Y) in the cross-section is shown in (a). c) Major structural elements of the Utsira High with sample locations of two explorations wells (in red) used in this study. d) Simplified location and tectonic map overview of the eastern part of the Danish Basin with a detailed geological map (e) of the north-eastern Skåne, showing the location of Ivö Klack (modified from Riber et al., 2017; Surlyk and Sørensen, 2010 and references therein). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)