Wo FTS 11

Structural Modelling and History Matching to Understand Aquifer Behaviour in the Hewett Field, UK Southern North Sea

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SUMMARY

The Hewett Gas Field is located in the Southern North Sea and is being considered for carbon storage. This study uses production and pressure data to validate a structural model of the field. A thorough understanding of aquifer behaviour observed throughout production is necessary to correctly manage the Hewett Field's potential future use as a carbon storage site. Material balance methods and Cole plots are used to estimate aquifer strength. A conceptual model of aquifer behaviour is developed to explain the observed pressure communication between the Hewett Field and the nearby Little Dotty Field via the shared Bunter aquifer. Within this conceptual model, estimates of changes in hydraulic head between the two reservoirs are made over their productive lifetimes to establish the direction of aquifer movement. Finally, estimates of hydraulic diffusivity are made to establish a characteristic diffusion time for a pressure pulse to be transmitted between the two reservoirs. This was cross-checked with pressure data. A short migration pathway could be observed across the North Hewett Fault that runs between the two reservoirs, which wouldn't have been realised without history matching the pressure and production data to the structural model, although secure storage of CO2 could still be achieved.

Introduction

The Hewett Gas Field is located in the UK Southern North Sea, situated 16 km NE of Bacton on the Norfolk Coastline (Figure 1). The field has been in production for over 40 years from four reservoirs: the Triassic Hewett Upper Bunter Sandstone reservoir, the Triassic Hewett Lower Bunter Sandstone reservoir, the Rotliegendes sandstones and the Zechstein dolomites. This study uses production and pressure data from the main Hewett Upper Bunter Sandstone reservoir to illustrate the importance of detailed structural modelling coupled with history matching to understand pressure communication and aquifer movement throughout production. A thorough understanding of this behaviour is of great importance to correctly manage its potential future use as a carbon storage site following the cessation production.

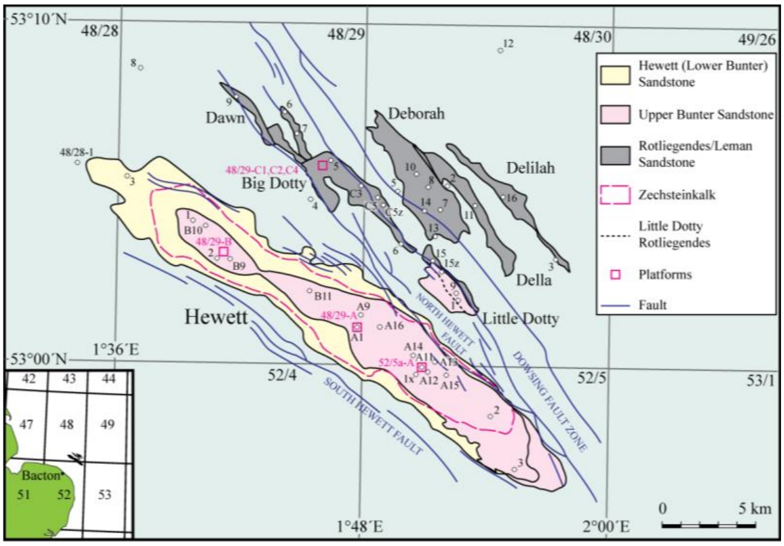

Figure 1 *The location and structure of the Hewett Unit, UK Southern North Sea. Only major faults and their trends are displayed. The original gas water contacts of the reservoir play areas are shown. Wells and platforms are displayed for reference. Adapted from Cooke-Yarborough and Smith (2003)*

3D Structural Modelling and Fault Seal Analysis

A 3D structural model was constructed using fault and horizon interpretations made on a 3D seismic volume covering the Hewett Field and six surrounding "D" fields using T7 software. The Hewett Upper Bunter Sandstone reservoir was found to be a three-way dip-closed trap, with fault closure provided by the North Hewett Fault of the central section on its eastern flank (Figure 2). It was known from historical records and production and pressure data that the Hewett Upper Bunter Sandstone reservoir was in pressure communication with the Upper Bunter Sandstone reservoir in the neighbouring Little Dotty Field (Cooke-Yarborough and Smith 2003). The Little Dotty Field is located directly east of the North Hewett Fault and therefore it was necessary to use the model to find potential migration pathways from the Little Dotty Field to the Hewett Field via the shared Bunter aquifer.

One obvious main migration pathway could be seen travelling up-dip from the Little Dotty Field around the tip of the North Hewett Fault and into the Hewett Upper Bunter Sandstone reservoir. Fault seal analysis was then conducted within T7 on the North Hewett Fault to investigate the potential for across-fault flow/transmission of a pressure pulse. The Shale Gouge Ratio (SGR) algorithm, after Yielding et al. (1997), and Freeman et al. (1998), was used to predict fault zone composition and the likelihood of fault seal. From the initial interpretations it was found that the Bunter sand intervals in the footwall and hanging wall were separated along the length of the North Hewett Fault, except towards the north-westerly tip of the fault where reservoir juxtaposition occurred. As such, there was a high probability of fault seal along the majority of the fault where the Bunter reservoir is juxtaposed against sealing units. However, the SGR values in the area of sand-juxtaposition were predicted to be low, therefore it was likely that a second migration pathway was possible in the northwest tip of the North Hewett Fault.

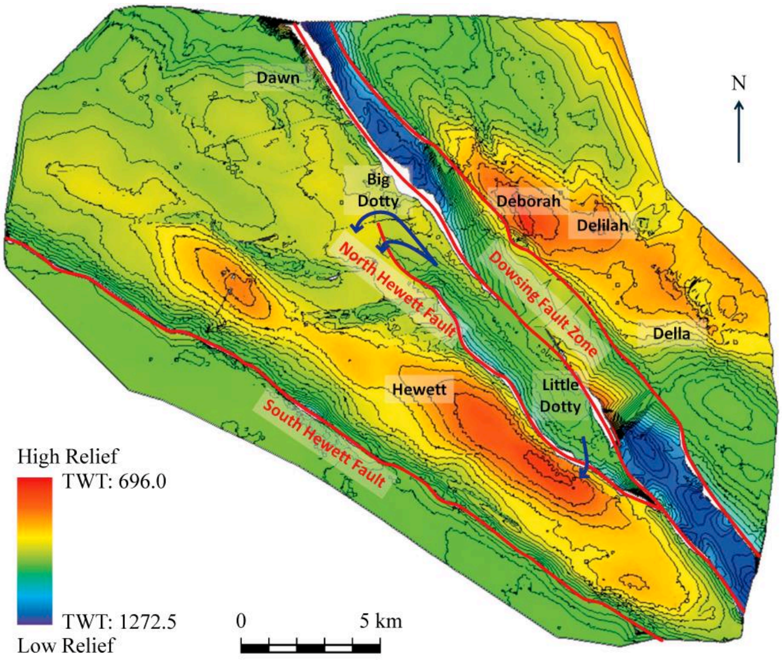

Figure 2 *Annotated time structure map of the top Bunter Sandstone Formation within the Hewett Unit. Potential pressure communication pathways, via the regional Bunter aquifer, are illustrated as dark blue arrows. Interpreted in T7*

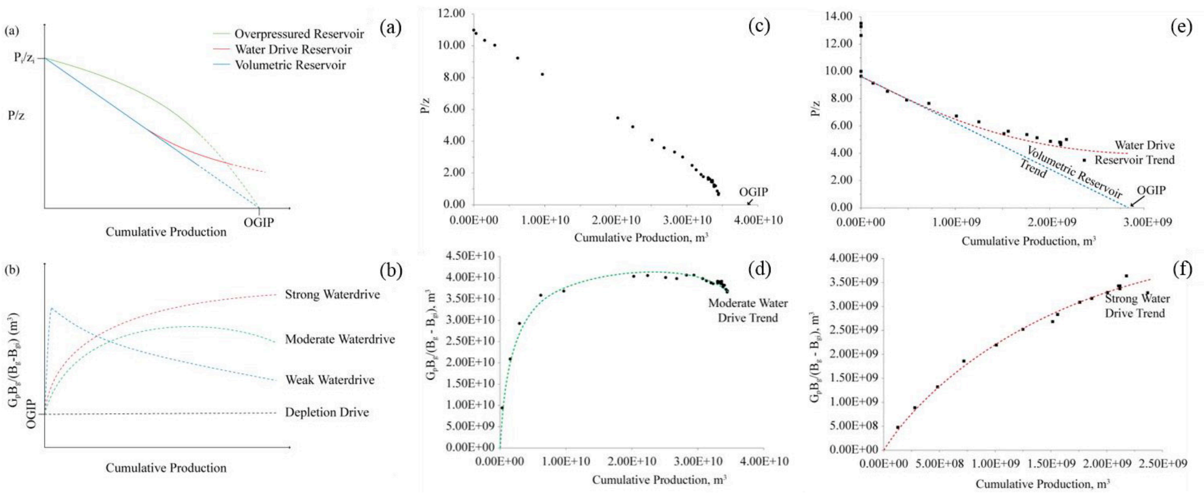

Figure 3 *Material balance and Cole plots of production and pressure data: (a) Typical material balance plot trends for overpressured, water drive and depletion drive reservoirs, (b) Cole plot curve shapes as a function of aquifer strength, adapted from Pletcher, 2002, (c) Material balance plot for the Hewett Upper Bunter Sandstone reservoir, (d) Material balance plot for the Little Dotty Upper Bunter Sandstone reservoir, (e) Cole plot for the Hewett Upper Bunter Sandstone reservoir, and (f) Cole plot for the Little Dotty Upper Bunter Sandstone reservoir*

Estimation of Aquifer Strength using Production and Pressure Data

Pressure and production data was used to estimate aquifer strength in the Hewett Upper Bunter Sandstone reservoir. Traditional material balance methods were used, however, the results on the P/z plot were inconclusive and suggested a depletion drive reservoir which was known from historical records to be inaccurate. The problems with solving the material balance equation in the presence of a water drive have long been known (Bruns et al. 1965, Chierici et al. 1967, Dake 1978, Tehrani 1985, Vega and Wattenbarger 2000). Instead, the data was re-plotted on a Cole plot (Pletcher 2002). The results were more conclusive and suggested the reservoir experience a moderate water drive (Figure 3).

A Conceptual Model of Aquifer Behaviour

A conceptual model to explain the pressure communication between the Hewett and Little Dotty Upper Bunter Sandstone reservoirs via the regional Bunter aquifer was then developed. The hydraulic (or piezometric) head (a measurement of liquid pressure above a geometric datum) was determined for the two reservoirs, both initially and throughout their productive lifetimes (after Ingebritsen and Sanford (1999)). Prior to production, both reservoirs had similar values. When production initiated in the Hewett Upper Bunter Sandstone reservoir, its head declined as a result of a reduction in reservoir pressure. The decline in head in Hewett exceeded the decline in head in the non-producing Little Dotty Field, resulting in an increase in hydraulic gradient between the two reservoirs, consistent with the movement of formation water through the shared Bunter aquifer from Little Dotty (H_{res} = high) towards the Hewett Upper Bunter Sandstone reservoir (H_{res} = low). After the onset of production from Little Dotty, head continued to fall in Little Dotty, whereas the rate of decline slowed in Hewett. Near the end of their productive lifetimes, a lower, almost equal hydraulic gradient was established between the two reservoirs.

Estimating a Characteristic Diffusion Time for Pressure Pulse Transmission

A key question arising from the results of the structural model and fault seal analysis is whether the main pathway for pressure communication and fluid flow is either through the reservoir juxtaposed area on the North Hewett Fault or around its northwest tip. The hydraulic diffusivity of the Bunter aquifer was estimated (after Wibberley, (2002)) in order to evaluate an order of magnitude estimate for the characteristic diffusion time for a pressure change within the Hewett Upper Bunter Sandstone reservoir to influence pressure within the Little Dotty Upper Bunter Sandstone reservoir via the regional Bunter aquifer. Results showed a characteristic diffusion time within the order of hundreds to thousands of years.

From the measured pressure changes it is clear that the pressure in the Little Dotty Upper Bunter Sandstone reservoir was perturbed by the pressure decline in the Hewett Upper Bunter Sandstone reservoir over a 13 year period. If this pressure decline was solely associated with pressure diffusion away from Little Dotty around the northwest tip of the North Hewett Fault, the estimated lag time (in the order of hundreds of years) would be far too long to achieve the rapid pressure decline observed in Little Dotty. The observed decadal timescale implies that a shorter migration pathway exists.

On this basis the structural model was re-assessed. There had been difficulties in establishing picks with a degree of confidence in the south east section of the North Hewett Fault where it branches with the Dowsing Fault zone. In this region, the Hewett Upper Bunter Sandstone reservoir relies on fault seal for closure of the trap, and the Little Dotty Upper Bunter Sandstone reservoir lies immediately to the east. There are substantial velocity affects in this region, however on re-interpretation it was possible to model a small area of reservoir juxtaposition. When the SGR algorithm was applied, the fault was found to be leaky in this area. Substitution of a shorter diffusion pathway of 3.5 km (the approximate distance from Little Dotty to the Hewett Field across the North Hewett Fault via the reservoir juxtaposed region) yielded a characteristic diffusion time in the order of years, a result that is more consistent with the historical pressure data. As such, this shorter across-fault pathway is the most likely pathway for pressure communication and fluid flow between the two reservoirs.

Conclusions

This study has shown the importance for history matching pressure and production data to structural modelling, without which the third and most important migration pathway would not have been realised. It is important to properly understand the dynamic behaviour of depleted gas fields that are being considered as carbon storage sites so that they can be properly managed throughout and post-CO_2 injection. Despite the three migration pathways, proven in this study to exist between the Hewett and Little Dotty Upper Bunter Sandstone reservoirs, effective management during CO_2 injection will mean that they should not affect the secure storage of CO_2 within the Hewett Upper Bunter structural closure. Successful, secure storage of CO_2 can be achieved through careful management during CO_2 injection within the Hewett Upper Bunter Sandstone reservoir alone.

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