Comparative analysis of the reservoir quality of the Sherwood sandstone and the Bridport sandstone, the Wessex Basin, UK

Y. BEKBEROV

Department of Earth, Ocean and Ecological Sciences, University of Liverpool, 4 Brownlow Street, Liverpool L18 1LX, UK

psybekbe@liv.ac.uk

Introduction

This work is going to make a compatible analysis of the two main reservoirs in the Wessex basin: the Sherwood sandstone and the Bridport sandstone. The Wessex basin was formed during Mesozoic extension and was modified by uplift in Cretaceous. This basin, that is located in Southern England, has been explored for hydrocarbons over 70 years. (Buchanan 1998) As a result, the Wytch Farm oilfield in 1973 was successfully proved to bearing hydrocarbon. Initially, the main reservoir was the Bridport sandstone that was produced the oil. However, after the exploration of the Sherwood reservoir below, production was changed from Bridport formation to Sherwood reservoir (Aplin and Coleman 1995). This work is going to assess both of the sandstone reservoir formations in terms of deposition, diagenesis and reservoir quality to understand what makes the Sherwood reservoir the main production system.

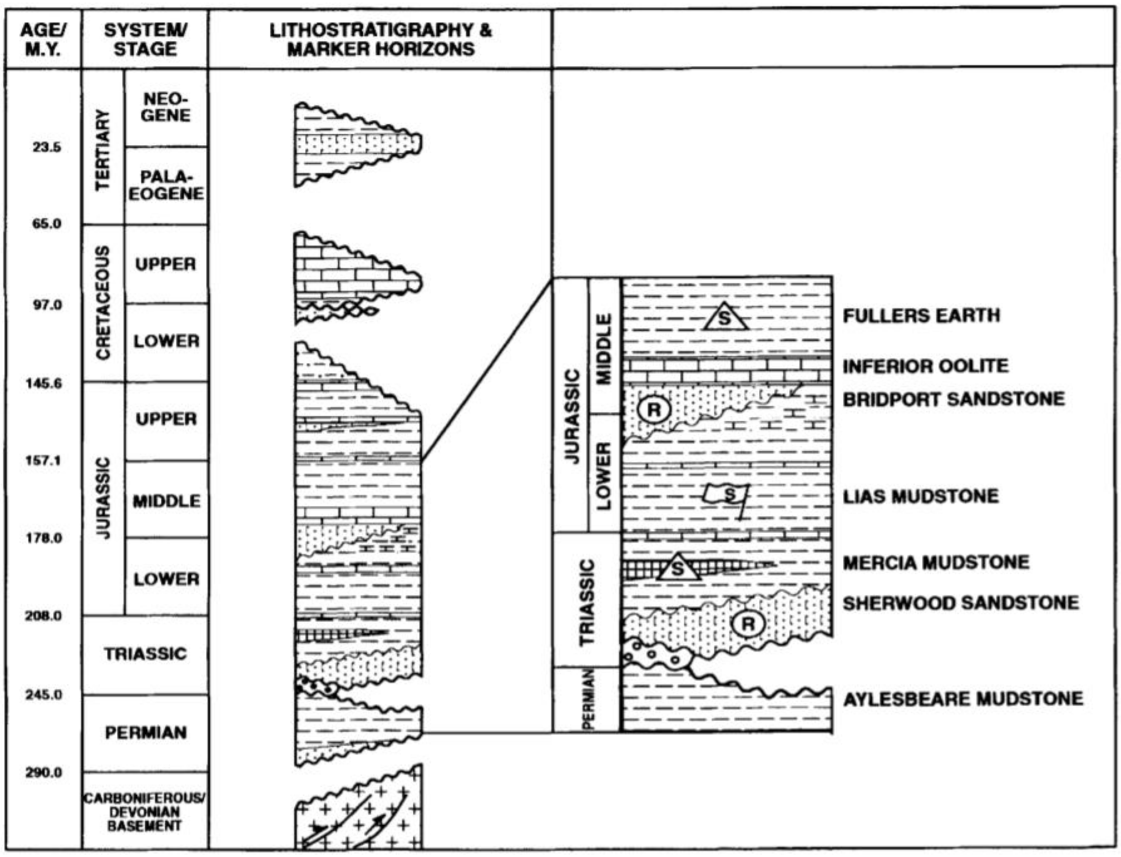

Figure 1. Stratigraphy of the Wessex Basin that represents the main reservoir formation by the geologic age (Buchanan 1998).

Geological background

Sherwood sandstone

Sherwood sandstone of Triassic age is the principal reservoir unit in the Wessex Basin. Outcrops of this sand unit are mostly presented in the western margin of the basin as it can be seen from figure 1. However, the main interest is concentrated on the eastern part of the basin. Wytch farm field is known by the production from these reservoir units.

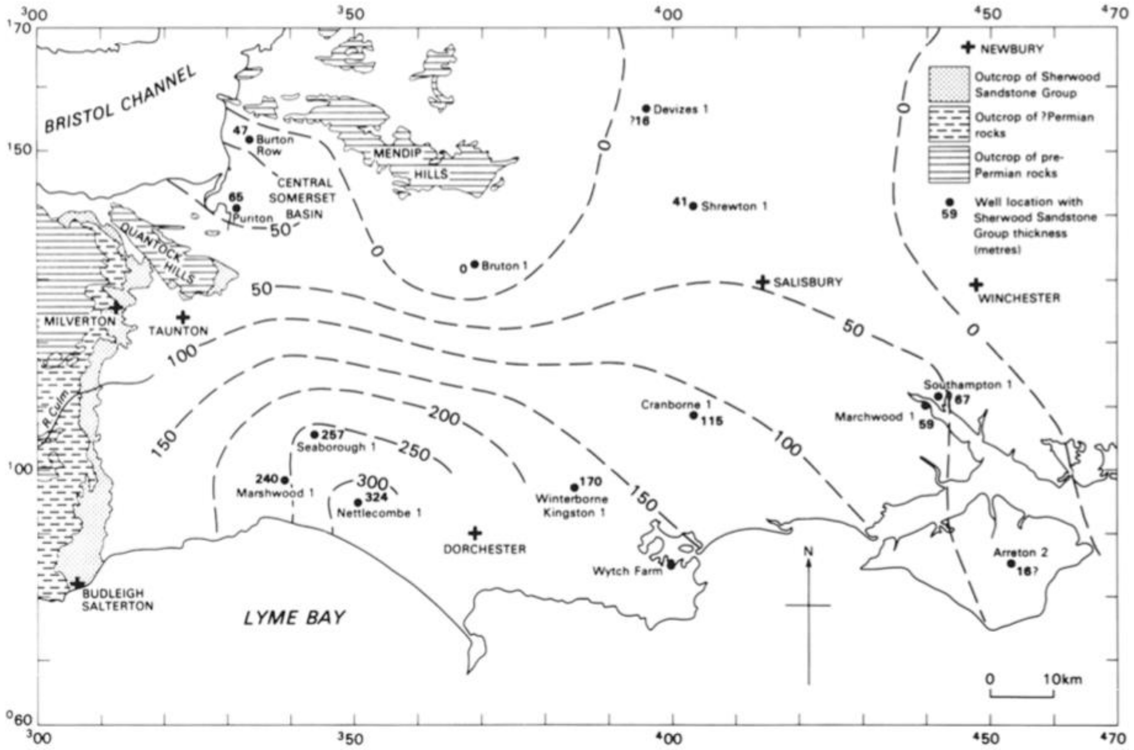

Figure 2. Isopach map of the distribution of the Sherwood sandstone within the Wessex Basin. Wells are also located. Isopach map can reveal the distribution of the thickness of this sandstone. The thickest location near the Nettlecombe 1 field, and thinning distally can explain the paleocurrent direction from the distal sediment supply in the basin center (Holloway et al. 1989).

Outcrops, that can be examined in the cost of Devon, have a presence of coarse conglomerates overlain by thick sandstone. It also can be named as Budleigh Salterton pebble bed due to local variation of the Sherwood sandstone (Otterton Sandstone formation above).

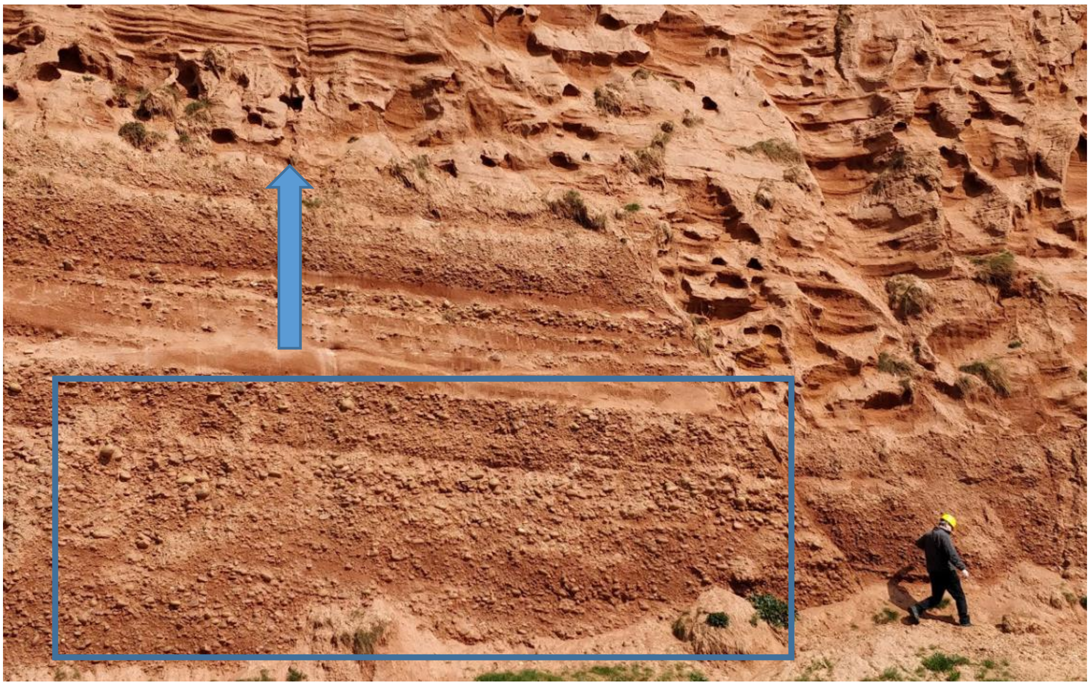

Figure 3. A photograph of the Budleigh Salterton pebble bed that was taken on the field trip. It is seen that grain size have a pattern of fining upwards (see an arrow) with some very-fine grained interbedded thin beds and cyclicity of deposition, where some of the events was deposited a thick layer of conglomerates (box shape). Additionally, there is a normal fault can be noticed, that is related to the extensional regime of rifting.

Regarding of the Budleigh Salterton pebble bed deposition, it probably was deposited from a semi-arid braid fluvial environment in the hot continental system. The absence of marine fossils and some occurrence of the non-marine vertebrate fossils can confirm this as well as the presence of anhydrite (Milodowski et al. 1986).

Generally, the Sherwood sandstone has two intervals: lower part of the high net to gross ratio of fluvial deposits and upper part of more mixed with lacustrine and floodplain mudrocks. (McKie *et al.* 2008) Supply for this sandstone came by the transportation of arkosic sediment from the Variscan highlands or from the Brabant Massif by complex braided alluvial systems (Holloway *et al.* 1989).

To better represent the stratigraphy and explain the depositional environment within the whole formation, the Sherwood sandstone will be divided into the facies associations within these two sections:

Facies association	Product	Process
Floodplain	Up to 10m of thinly interbedded very fine / fine grain sandstones and mudstone with mudclasts, root traces	Episodic sediment supply by sheetfloods or overbank flooding
Sandflat and lacustrine deposits	Fine-grain sandstone dominated by interbedding of the fine plane, ripple-laminated and adhesion-laminated fabrics. Lacustrine deposits more heterolithic with abundant wave ripple forms	Ubiquitous presence of wave ripples and burrows in the heterolithics leads to a lacustrine environment. Ephemeral, saline lakes.
Sheetflood deposits	Thinly bedded, fine-grained sandstones that interbedded with mud-prone floodplains.	Upper flow regime conditions by shallow, episodic sheet floods. Ephemeral channel-fills
Channel-fill deposits	Fine to very coarse grains, mostly cross-stratified sandstone 1-5m thick. Fining upwards trend	Confined channel with no clear original planform geometry. Amalgamated vertically and laterally. Sand-rich - Low sinuosity.
Aeolian deposits	Up to 8 m thick fine-grained and well sorted, lack of mudclasts.	A fluvial origin (gradational contacts with flood-plain deposits) that was affected by the aeolian environment

Table 1. Facies association of Sherwood sandstone by the study of the Wytch farm field core (McKie et al. 2008, Hamblin et al. 1992, Hardie et al. 1978).

In the south west part of England, where the Otter sandstone variation of Sherwood sandstone group is also present, carbonate cementation occurs in two distinct forms. Vertical and large concentrically zoned cylinder shapes and subhorizontal thin sheets. First one represents rhizocretions (process of root systems that has been encased in mineral matter) of the tap roots of phreatophyte plants. Second one represents cementation of water-tables (Purvis & Wright 1991).

The channel facies of the Sherwood sandstone are recorded the best reservoir properties (Quantitative settings will be present in Results section). However, vertical permeability can be reduced by calcrete horizons (Bowman et al. 1993). In addition, permeability of the sandstone can be affected by the presence of the mud-prone units and poorly sorted conglomerates.

In terms of the sealing potential, overlaid Mercia Mudstone formation are well developed and have approximately 100-600 meters of thickness. Source rock for the Sherwood sandstone only can be the Liassic mudstones, where the possibility of Kimmeridge Clay and Oxford Clay were rejected

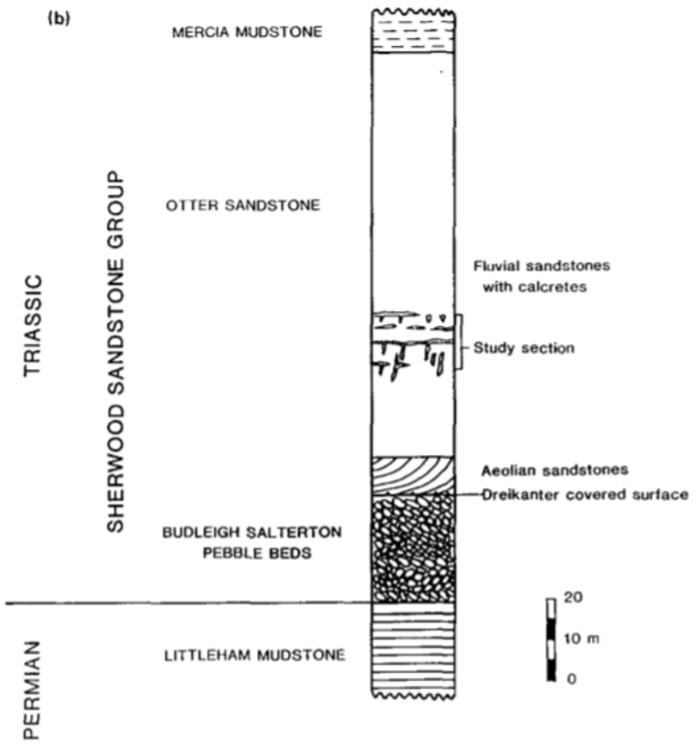

Figure 4. Scheme of the sedimentary log that represents the variation of Sherwood sandstone within the Wessex basin. A key feature such as this local calcretes is shown. It should be noticed that this sandstone overlaid by massive Mercia Mudstone that is generated a good seal unit for this reservoir.

Bridport sandstone

Bridport sandstone was the first reservoir formation that was found in the Wytch field and thought to be the main hydrocarbon bearing formation until the Sherwood sandstone was detected in early strata.

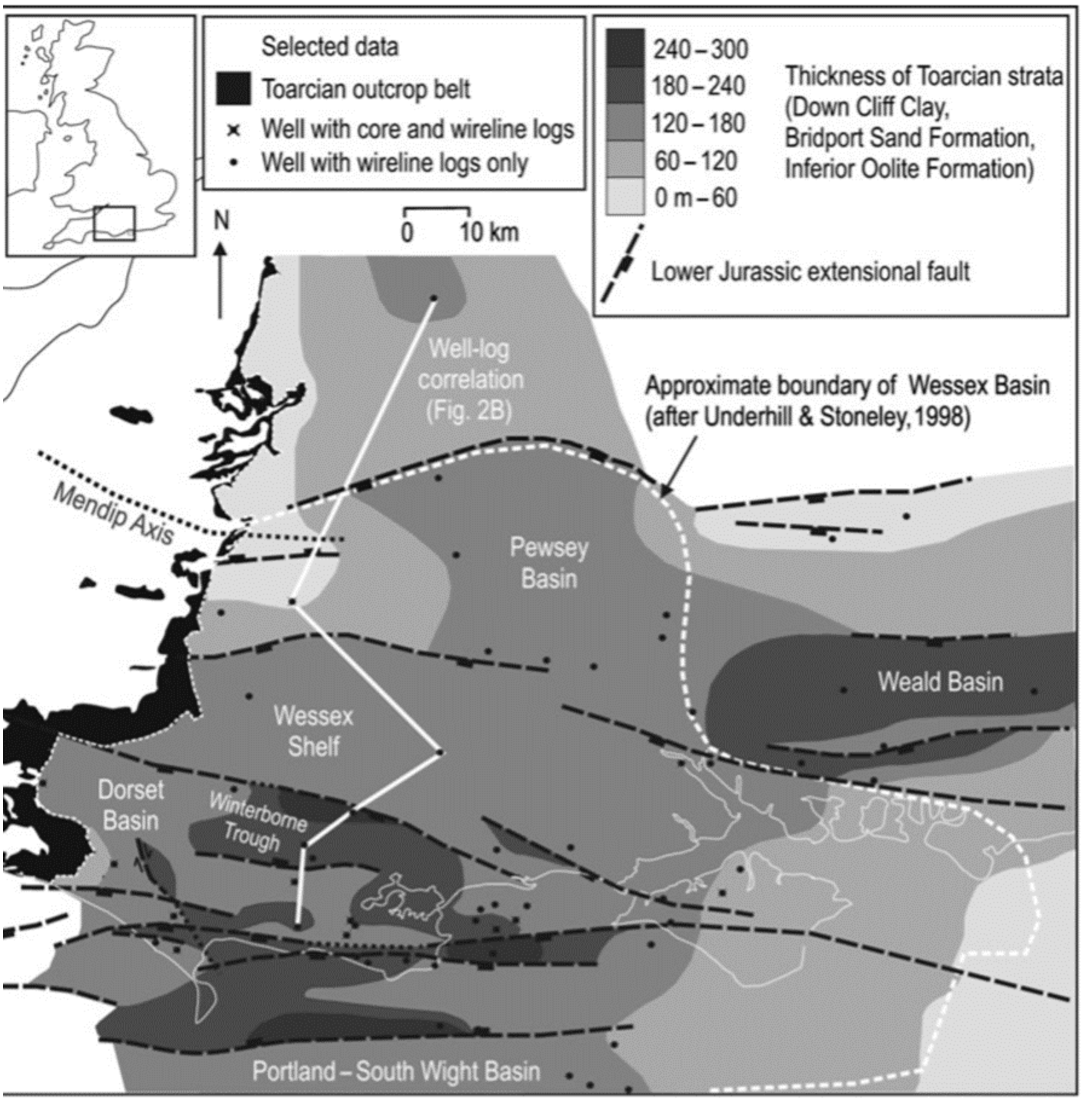

Figure 5. Isopach map of the Toarcian strata distribution (Bridport sandstone) in the Wessex basin. Note the East-West trend of faults direction that is part of extensional regime of the basin towards the south.

Outcrop of the Bridport sandstone formation is also can be found on the western margin of the basin in the outcrop belt system that is prolonged from Gloucester to the coast of Dorset. The latter part are famous for the outcrop in Burton Bradstock that have a distinct geological presence. The Bridport sandstone has a thickness 50-80m. The general trend is the coarsening upwards from the claystone of the Down Cliff Clay Member to the transgressive limestone of the Inferior Oolite (Hesselbo & Jenkyns 1998)

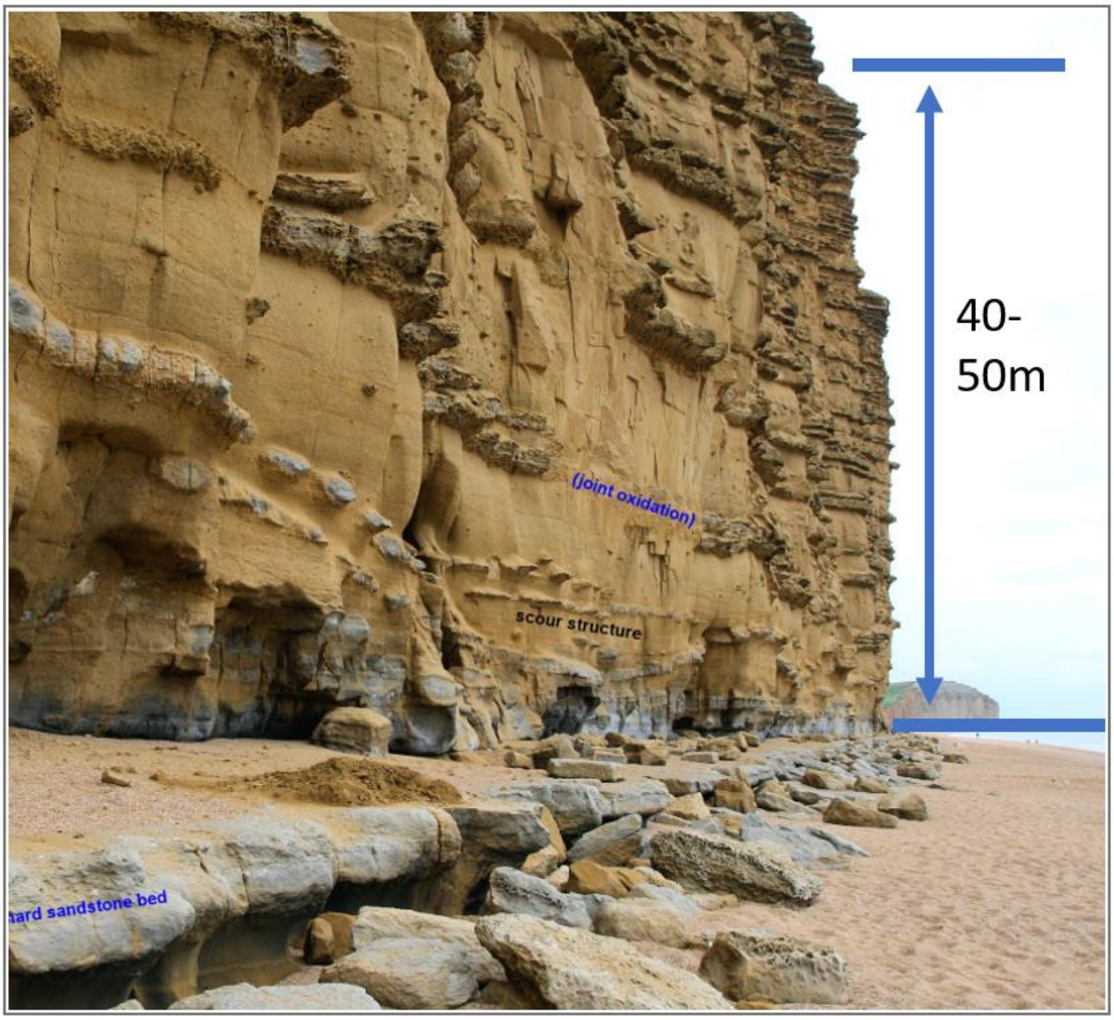

Figure 6. A photograph of Burton Bradstock hill that has distinguishable characteristics of the Bridport sandstone. Thick yellow friable sandstone (up to 3 meters) that is interbedded with thin hard band carbonate cemented sandstone (up to 75 cm). A trend of thinning upwards of this friable sandstone are seen. Yellow colour of sandstone due to oxidization of pyrite, originally was blue-grey colour.

Deposition. Early Jurassic of the Wessex Basin was the extensional subject of rifting with the east-west oriented faults and a regional subsidence (Hawkes et al. 1998). The environment of the deposition was that the basin was occupied by a shallow sea surrounding by low-relief landmass. The overall progradation setting of the Bridport sandstone was from north to south by a tortuous route from the source in Britanny, France (Morris *et al.* 2006). The local progradation can be seen from west to east by clinoforms in Wytch Farm field.

Because an outcrop is only part of the formation, to reveal whole sandstone unit all types of products should be determined. Facies association is also efforted to represent variation of these sandstone.

Facies association	Product	Process
Bioturbated sandstone	Light to dark grey, highly bioturbated silty very-fine sandstone; siltstone	Low energy lower shoreface and offshore transition
Weakly bioturbated sandstone	Fine-grained sandstone with interbedded mudstone and grey clay drapes	Limited storm activity in sheltered shallow-marine environment
Bioclastic limestone	Cross-bedded bioclastic (skeletal) limestone	Carbonate channel-fills and shoals, highly reworked
Oolitic ironstone	Fine-grained sandstone and limestone of iron-coated ooids, peloids and bioclasts (>15%)	Condensed deposits

Table 2. Facies association table of the Bridport sandstone core analysis from the Wytch Farm field.

One of the main controls on the Bridport sandstone is the carbonate cemented hard bands. This carbonate minerals occur by cementation during the diagenesis of shallow-marine sandstone. Origin of cement includes precipitation from sea water, the dissolution and then, precipitation again of bioclastic aragonite and calcite as well as precipitation during bacterial processes (Kantorowicz *et al.* 1987).

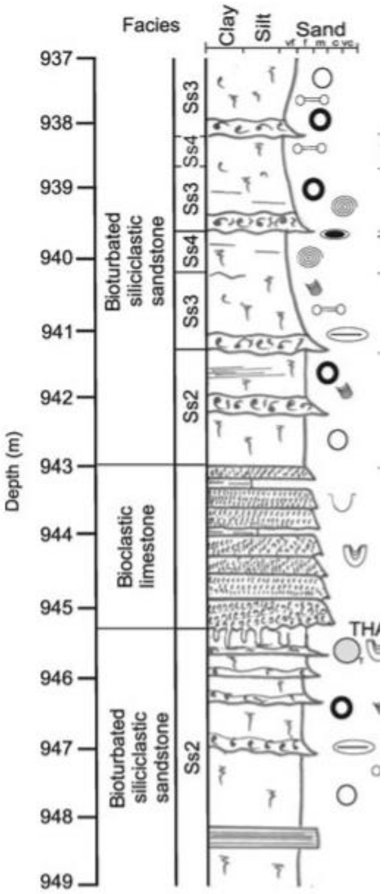

Figure 7. Section of the core log from Winterborne Kingstone borehole that represents bioturbated siliciclastic sandstones with interbedded carbonate cemented hard bands and a bioclastic limestone bed.

The Bridport sands have good reservoir properties in the western part within the basin, because it dominates with siliciclastic deposits. However, in the east part of the basin, non-reservoir mud prone sediments are present. The quality of the reservoir is also reduced by the presence of well-cemented layers that can play the permeability barrier to hydrocarbon flow. Fuller's Earth formation mudstone is a seal unit for this reservoir that is laterally extended and forming a good capping mechanism (Buchanan 1998).

Results (well data)

Wytch Farm Field is the main area of interest to make comparative analysis of the Sherwood and Bridport sandstones. This oilfield is the largest oilfield on the south of England and has a reserve more than 330 million barrels. Production from the Bridport Sands started in 1979. This horizon was the first major reservoir, and the Sherwood sandstone reservoir was discovered later. The Bridport sandstone contains 30 million barrels of oil, while the Sherwood reservoir estimated to have 300 million barrels (Aplin and Coleman 1995).

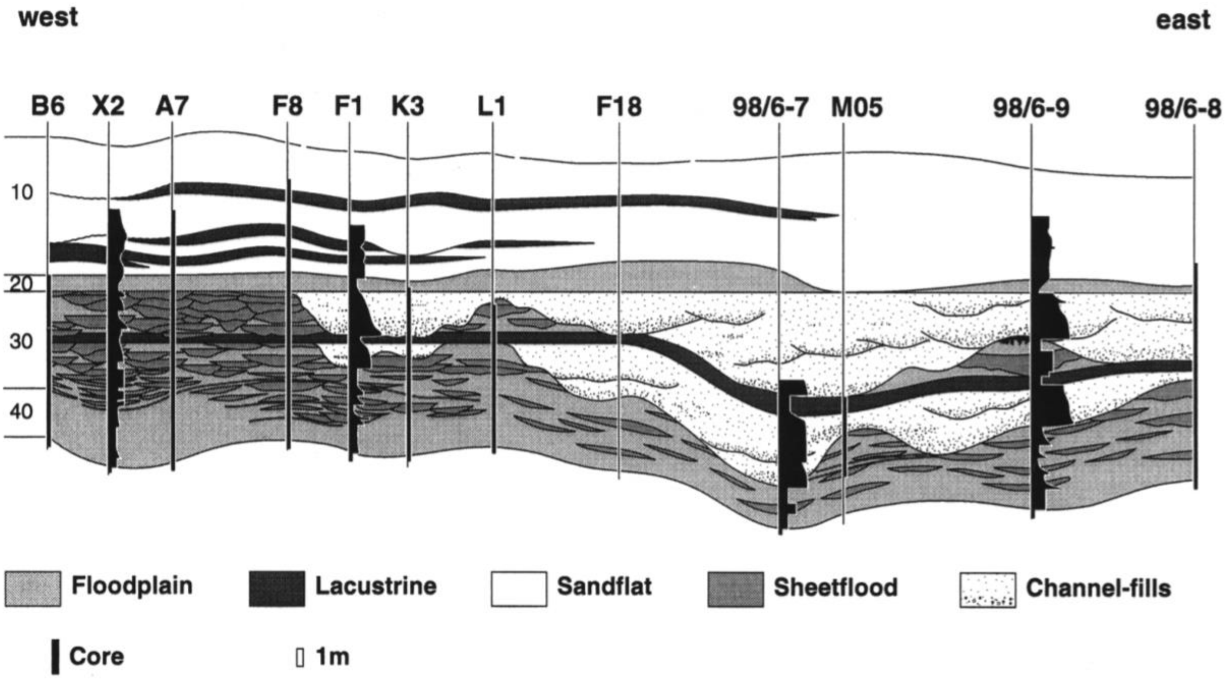

Figure 10. Representation of the Sherwood zone within the oilfield. Note the homogeneous massive sandflat with channel-fills (McKie et al. 2008).

Average porosity (range)	18% (14-23%)
Permeability range	1-1500
Gas/oil ratio	357 scf/stb
Net to gross	0.7
Water saturation	0.44

Table 4. Wytch Farm Sherwood sandstone data summary (Bowman et al. 1993)

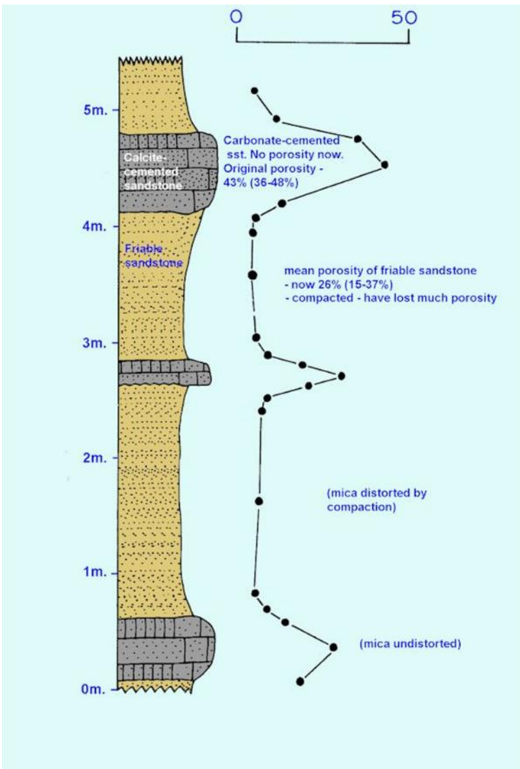

Figure 8. Vertical variation in carbonate in the Bridport sandstone. Scale on the top shows the $CaCo_3$ content in per cent (Davies, 1967).

Average net porosity	20-27%
Average net permeability	5 mD at the base, 64 mD on top
Clay content	10%
Gas/Oil ratio	150 scf/bbl

Table 3. Bridport reservoir data from the Wytch Farm oilfield (Davies, 1967).

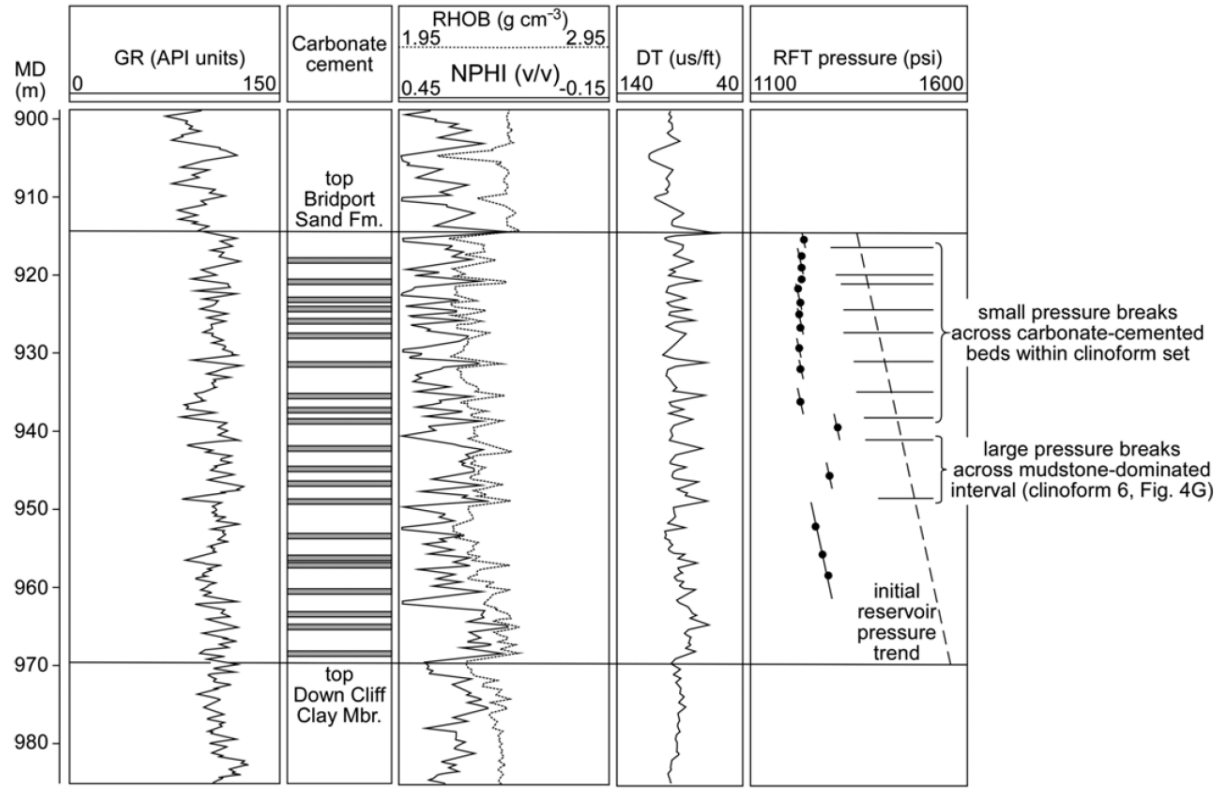

Figure 9. Wireline log for Bridport sandstone section from the well A-09, Wytch Farm field. Note the relatively high gamma response, peaks in sonic travel time and difference in formation pressure (Hampson et al. 2015).

Discussion

The Sherwood sandstone and the Bridport sandstone are the main reservoir units in the Wessex basin. Comparison between them will be in this section following the key characteristics.

Distribution. Sherwood and Bridport are relatively similar in terms of the geographic presence in the Wessex basin. Both have outcrops in the western margin of the basin. However, due to the time of deposition (Sherwood – Upper Triassic; Bridport – Lower Jurassic) local sedimentation thickness trended from west to east. The amount of thickness for each sand formation is diverse. The Sherwood sandstone thickness is clearly bigger: up to 300m, while the Bridport sands have a thickness 50-80m.

Deposition. Difference in the environment of deposition separates these two sandstone formations. Sherwood sandstone was deposited earlier in time, when local environment was in hot continental settings. Sediments deposited in the semi-arid braided system close to alluvial/fluvial environment. Some of aeolian deposits is also determined. Continuation of a local rifting and extension created regional subsidence and environment close to the open ocean. The Bridport sandstone was deposited in a setting of shallow sea/upper shoreface with carbonate/siliclastic interaction. In terms of the source for siliciclastic deposition, Bridport sandstone supplied from a tortuous complex route from Britanny, France by creating local clinoforms from west to east, while Sherwood sandstone sourced by arkosic routes from the Variscan highlands or the Brabant Massif.

Facies. The Sherwood sandstone has 5 facies association with corresponded products. Sandflats with channel-fills have prevailed that have fine-medium grains on top with coarsening downwards. Bridport sandstone facies association divided for 4 types. However, it is better to distinguish two of them: friable bioturbated sandstone with very fine to fine grains and carbonate cemented hard beds with some variation of bioclastic limestone.

Reservoir quality. It is important to start with the assessment of diagenetic features among these sandstones. Sherwood and Bridport sandstone interact with carbonate cementation. But the scale and impact for the reservoir quality are fundamentally different. In Sherwood sandstone carbonate cementation occurred locally in roots and subhorizontal thin sheets. The former does not have an impact on reservoir quality, while the latter affects the vertical permeability minimally. In contrast, the carbonate cemented hard bands in Bridport formation have a thickness up to 75 m that significantly reduce the vertical permeability. It can be proved by the compartmentalisation analysis of formation pressure in figure 9. Also, tables 3 and 4 show the variation in permeability that was affected by this feature. However, the reduction of the permeability in Bridport sandstone is also affected by high clay content (10%) that is also can be seen by high gamma response in figure 9.

Although the sorting is relatively poor in Sherwood sandstone, the overall quality of the Sherwood sandstone is good due to grain size (fine to coarse), connectivity and homogeneity of the reservoir that can be seen in figure 10. High net to gross and water saturation is also proving that the quality of the Sherwood sandstone is better than in Bridport sandstone. However, the main limitation for Bridport sandstone is the size of the reservoir that is ten times less than Sherwood in Wytch Farm field.

Conclusion

1. The main reservoirs in the Wessex basin are the Sherwood sandstone (Upper Triassic age) and the Bridport sandstone (Lower Jurassic age).
2. The Sherwood sandstone consisted of the Budleigh Salterton pebble bed deposition and Otterton formation, which were deposited in semi-arid braid fluvial environment in the hot continental system. Facies association was assessed with the explanation of products and processes.
3. The Bridport sandstone was deposited in shallow marine environment with carbonate interaction that was affected the reservoir quality. Two main facies are the friable bioturbated sandstone with high clay content and the carbonate cemented hard bands that reduces the vertical permeability.
4. According to the results of the well data that was taken from the Wytch Farm field, both of sandstones were assessed by reservoir quality
5. The overall better quality of the Sherwood sandstone than Bridport sandstone is due to several factors such as the connectivity within the reservoir, absence of significant barriers, less clay content and the size of the formation is the key in the assessment of the best reservoir in the Wessex basin
6. However, it cannot be denied that the potential of Bridport sandstone is very high and the possibility to produce from this reservoir can be done using technologically developed (horizontal) drilling and petroleum geology re-assessment.

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