Geological factors influencing gas production in the Tyne field (Block 44/18a), southern North Sea, and their impact on future infill well planning

From Earthwise

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From: Carboniferous hydrocarbon resources: the southern North Sea and surrounding onshore areas, edited by J. D. Collinson, D. J. Evans, D. W. Holliday, N. S. Jones. Published as volume 7 in the Occasional Publications series of the Yorkshire Geological Society,

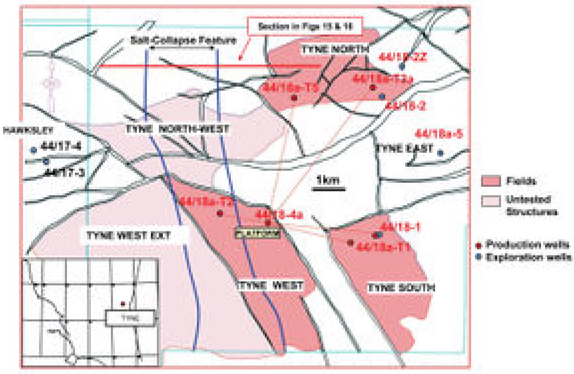

Figure 1 Tyne field: location, major structures and wells.

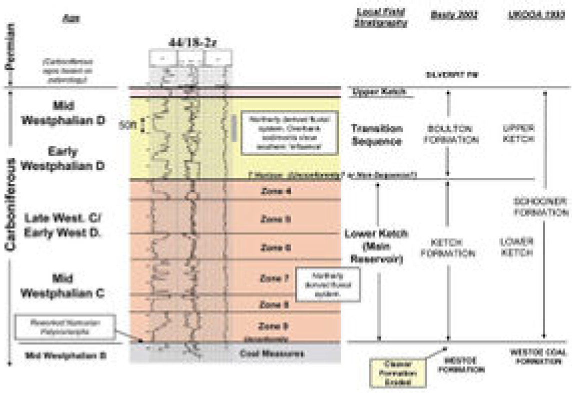

Figure 2 Tyne field: stratigraphy of 44/18-2z. Stratigraphical ages are from Duncan McLean (University of Sheffield). Suggested correlations are made with the UKOOA stratigraphy (Cameron 1993) and the recent proposed revision by Besly (2002).

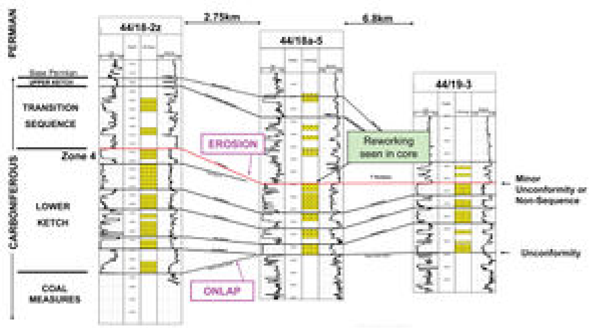

Figure 3 Well correlation from Tyne North–Tyne East–44/19-3. Most of Zone 4 at the top of the Lower Ketch appears to be missing in 44/18a-5 and 44/19-3. The cored junction with the overlying Transition Sequence shows evidence of erosion.

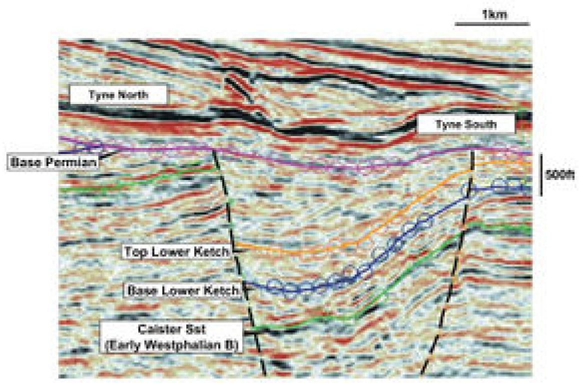

Figure 4 Seismic line showing a major east–west Carboniferous growth fault (see Figure 5 for location). Seismic picks: purple – top Carboniferous; orange – top Lower Ketch; blue – base Lower Ketch; green – top Caister Sandstone.

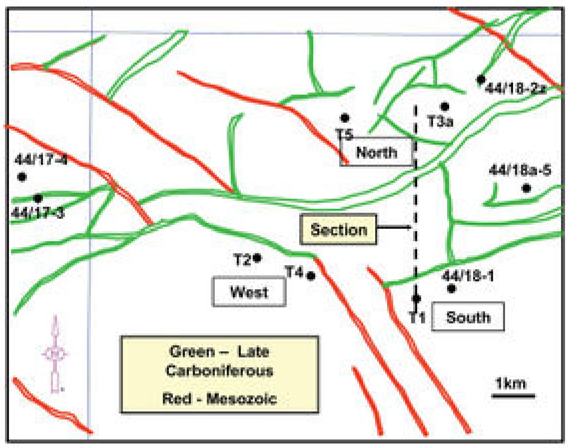

Figure 5 Tyne field: age of faulting. Late Carboniferous faults are shown in green. Younger faults (red) were active in the Mesozoic.

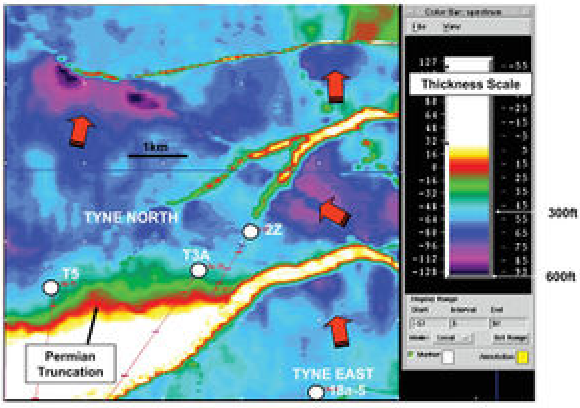

Figure 6 Thickness variations in the Lower Ketch from seismic data. The red arrows show areas thickening into growth faults. The maximum thickness (dark purple) is approximately 600 ft. The thinnest sequence (sky blue) is approximately 300 ft. Thinner sequences have been truncated by the Permian unconformity.

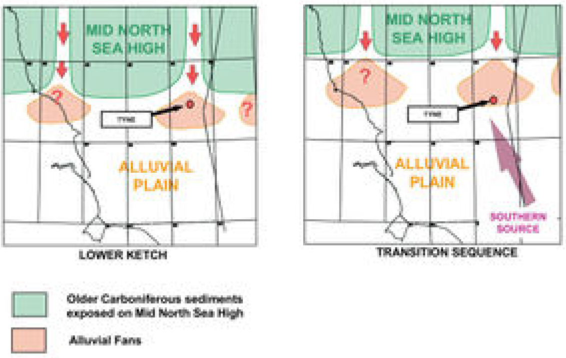

Figure 7 Tyne field: depositional model – (a) Lower Ketch, (b) Transition Sequence. The lower net-togross in the Transition Sequence is interpreted as resulting from a northwards retreat of the alluvial fan.

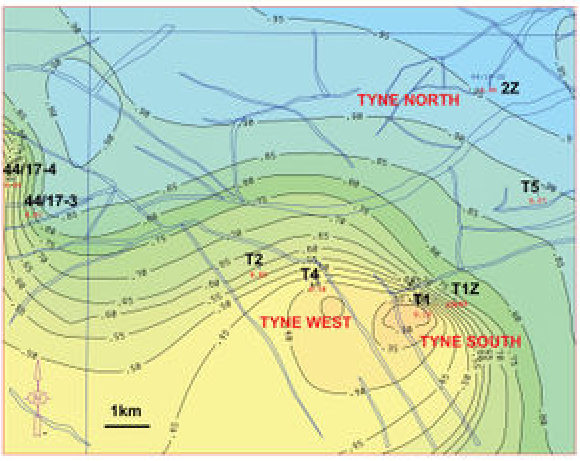

Figure 8 Tyne field: net-to-gross in Zone 5, Lower Ketch. Note the reduction from 0.9 to less than 0.5 over a few kilometres. Net-to-gross is equivalent to channel sandstone percentage.

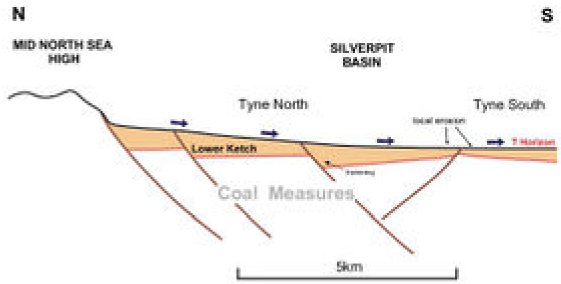

Figure 9 Simplified north–south cross section showing conceptual sedimentation in the Lower Ketch in relation to extensional faulting.

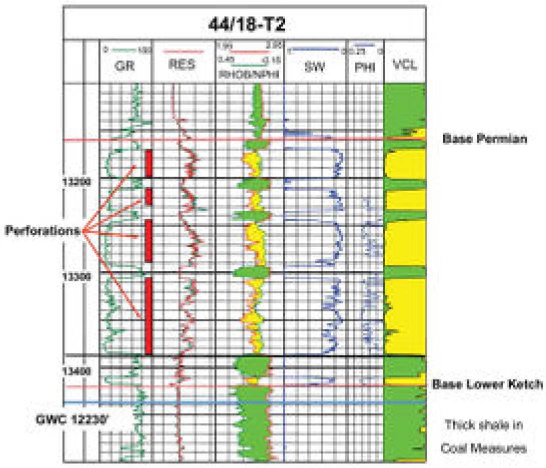

Figure 10 Well 44/18-T2 (Tyne West): petrophysical log through the Lower Ketch. The gas leg extends to the base of the reservoir. Beneath is a thick shale-prone Coal Measures section; Only the top 80 ft is shown. The nearest water in the reservoir is approximately 1000 ft down dip

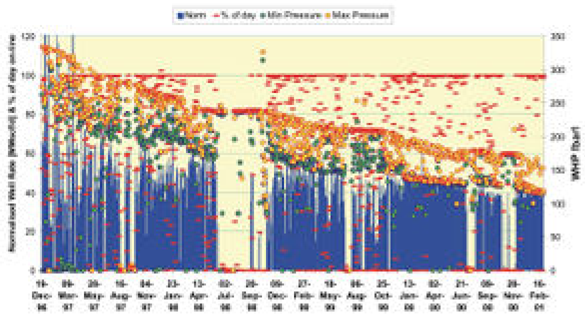

Figure 11 Well 44/18-T2 (Tyne West): early production history.

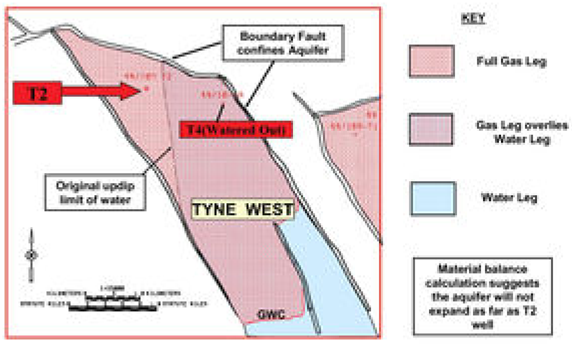

Figure 12 Tyne West field, showing the location of the gas- and water-bearing sections in relation to the two production wells. Well T4 watered out comparatively early; Well T2 is still on production after more than 5 years.

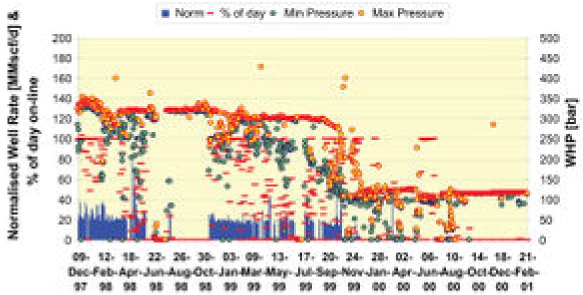

Figure 13 Well 44/18a-T5 (Tyne North): production history. Note the very sudden end to production between September and November 1999.

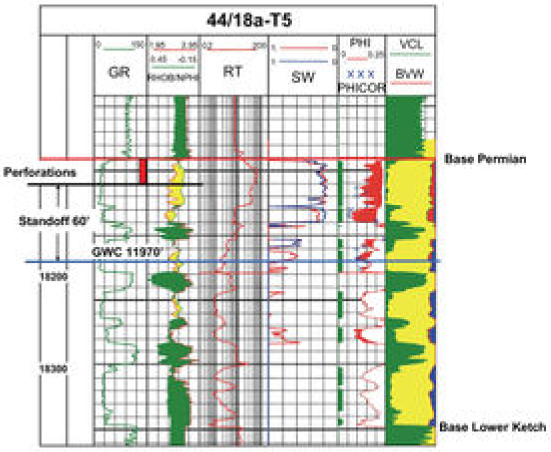

Figure 14 Well 44/18a-T5 (Tyne North): petrophysical log through the Lower Ketch. There is only a 60 ft standoff between the perforations and the gas/water contact, which lies in the lower part of the reservoir.

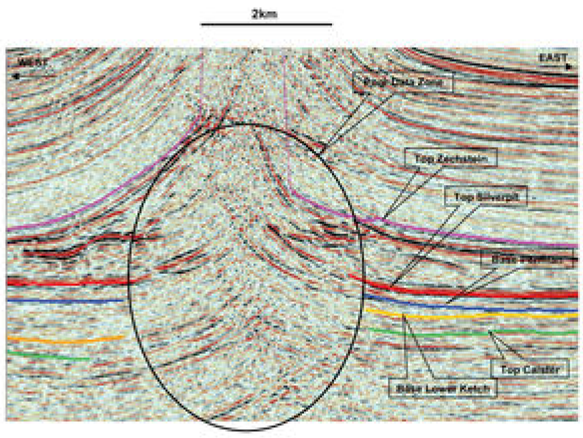

Figure 15 Seismic line across salt collapse feature: post-stack depth migration (see Figure 1 for location).

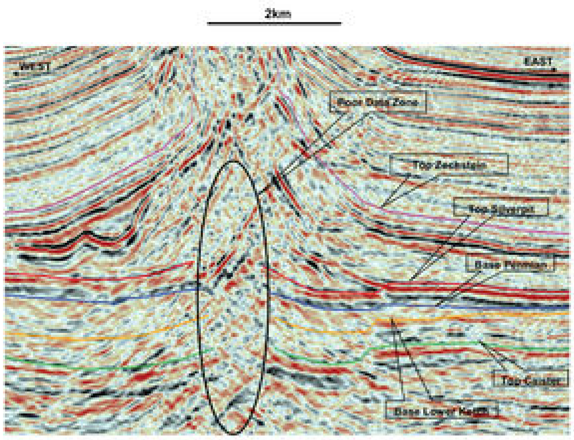

Figure 16 Seismic line across saltcollapse feature: pre-stack depth migration (see Figure 1 for location).

Interval	Net-to-gross	Channel type	Thickness range (ft)
Transition Sequence	0.1–0.3	Mainly single storey	10–30
Lower Ketch (Tyne South and West)	0.3–0.65	Mixed, multi- and single-storey	10–70
Lower Ketch (Tyne North)	0.7–0.8	Mainly multi-storey	25–70

Table 1 Comparison between the Lower Ketch and Transition Sequence in the Tyne area.
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By Colin M. Jones,Philip. J. Allen, Neville H. Morrison

From: Pages 183–193 of *Carboniferous hydrocarbon geology: the southern North Sea and surrounding onshore areas*, edited by J. D. Collinson, D. J. Evans, D. W. Holliday, N. S. Jones.

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Summary

The Tyne field was discovered in 1992 and came into production in late 1996. It comprises three separate fields and some smaller accumulations. It produces to a central platform from the Lower Ketch Member of the Schooner Formation (Westphalian C). Of five original development wells, only one is still on production. Geological factors that may influence ultimate recovery include field compartmentalization, generally thin gas columns, high reservoir permeability, variable reservoir thickness, low connectivity in the upper reservoir and, in parts of the field, complex overburden. Production data have been combined with the geological interpretations to enable a better understanding of the variable well performance to be gained. This is critical to future well planning if well performance is to be improved and field recovery optimized.

Introduction

The Tyne field was discovered by well 44/18-1 (Tyne South) in 1992 by Arco British Ltd and partners. Further wells discovered the Tyne North and Tyne West structures (O'Mara et al. 1999). The field came onto production in late 1996 through an unmanned central platform situated over Tyne West (Figure 1). Five production wells were drilled (Figure 1); four of these were highly deviated long-reach wells with drilled lengths of up to 21600ft. Not all parts of the field can be reached from the platform. Only one of the original development wells (T2) is still on production. Three of the other four wells produced no more than 15 billion cubic feet (bcf) each, and recovery factors were considerably less than originally anticipated.

British Petroleum (BP) took over the operatorship in 1999. In September 2000 a combined Production Geoscience Ltd/BP team was set up to manage the field and find new infill well locations. Details of the general stratigraphy and structure are given in O'Mara et al. (1999). This paper reviews the production history and discusses some of the more recent geological, geophysical and reservoir engineering work on the field.

1. Stratigraphy and correlation

The stratigraphy of the Tyne field is illustrated by well 44/18-2z (Tyne North), which contains one of the most complete sections through the sequence (Figure 2). Three units are recognized – Lower Ketch, Transition Sequence and Upper Ketch – with ages based on palynological criteria. The main producing reservoir is the Lower Ketch (Westphalian C). This reservoir is a high netto-gross fluvial sequence and has been informally subdivided into six reservoir zones. Chemostratigraphy has played a key role in reservoir subdivision and correlation, although its resolution is insufficiently detailed to identify individual reservoir zones.

The stratigraphy of the Late Carboniferous presented here differs slightly from that in O'Mara et al. (1999: fig. 3). No "Lower Schooner" is recognized, and biostratigraphical data (D. McLean, personal communication) show that the Lower Ketch, which has been dated palynologically as mid-Westphalian C, sits unconformably on a Coal Measures sequence of mid-Westphalian B age, termed the Westoe Coal Formation (Figure 2). The unconformity is regional (Besly 2002) and, in the Tyne field, the basal Lower Ketch sandstone (Zone 9) commonly contains reworked Namurian palynomorphs (D. McLean, personal communication), suggesting a deeper level of erosion elsewhere in the basin. Compared to the succession seen in the southern part of Quadrant 44 (Schooner Ketch area) and northern part of Quad 49, several hundred feet of late Westphalian B and early

Westphalian C Coal Measures, including the Aegiranum Marine Band (equivalent to most of the Cleaver Formation of Besly 2002), have been eroded in the Tyne field area. This interpretation is supported by regional well-log correlations and seismic data, which locally show faulted Westphalian Coal Measures overlain by unfaulted Lower Ketch.

The top of the Lower Ketch (T-Horizon) is very sharp and in well 44/18a-5, where it was cored (Figure 3), it shows evidence of reworking, with small sandstone pebbles derived from the Lower Ketch scattered within the overlying mudstones at the base of the Transition Sequence. This Transition Sequence of Westphalian D age is also fluvial in origin, but in all wells the net-to-gross is considerably lower (Template:Anchor Figure 2, Figure 3). The channel-fill sequences are of similar appearance to those of the Lower Ketch and, like the latter, are believed to be of northerly derivation (see detailed discussion of depositional model below). However, the finer-grained non-channel sediments are geochemically distinctive and show the first evidence of the reworked low-grade metasediments that characterize the southern sediment source that predominated in later Westphalian times (Besly et al. 1993, Morton et al. 2001, Besly 2002, Pearce et al. 2002). It is because of these mixed geochemical signatures that the interval was termed the transition sequence (Chemostrat Consultants 1995), as it was unclear whether it correlated with the Lower or Upper Ketch of the UKOOA scheme (Cameron 1993). The Westphalian D age, together with the evidence for some southerly derived sediment, suggests a correlation with the newly defined Boulton Formation (Besly 2002: table 2).

The junction with the Lower Ketch (T-Horizon) is a distinctive chemostratigraphical marker in the Tyne field area. The time gap is small and the palynological data show no obvious missing section. However, well-log correlations (Figure 3) suggest that Zone 4 is probably missing in several of the wells in Tyne West, South and East. This fact, together with the reworking and sharp change in net-to-gross, suggests that there may be a small unconformity or non-sequence at this level.

The channel sandstones in the Transition Sequence are also gas-bearing. They were tested in well 44/18-2z (Figure 2) and there has been limited production from other Transition Sequence sandstones in the Tyne West field (Figure 1).

The Upper Ketch proper (as defined by chemostratigraphy in the Boulton field reference well 44/21-3), and now termed the Boulton Formation by Besly (2002), has been recognized at the top of the Carboniferous sequence in wells 44/18-2z (Figure 2) and 44/18a-5 (Figure 3). However, over much of the Tyne field, the general level of erosion at the base Permian level is such that this interval is very poorly preserved in all of the wells drilled. However, thick undrilled sequences are seen on seismic lines shot across downfaulted Carboniferous sections between the producing fields (Figure 4). In the limited thickness of succession drilled in wells, the sequence predominantly comprises claystone and siltstone, with thin gas-bearing sandstones. These sandstones contain low-grade metasedimentary rock fragments (Chemostrat Consultants 1995). These are of probable southerly derivation and compare closely with those in the 44/21-3 reference well (Pearce et al. 2005). Similar southerly derived sediments have been described by Morton et al. (2001).

The stratigraphical intervals recognized above can be correlated through all of the Tyne field wells. In some wells the deeper section (Zone 9) of the Lower Ketch is missing (Figure 2, Figure 3). This is probably a result of the irregularity of the basal unconformity. Erosion of the older Coal Measures sequence created a slightly irregular topography, which was then filled in by the alluvial Lower Ketch sequence, with the oldest section (Zone 9) preserved in depositional lows. This process, together with the possible local unconformity at the T-Horizon, plus several variations in thickness within the other reservoir zones, leads to considerable thickness variations in the Lower Ketch, even in the small area of the Tyne field.

2. Structure and trapping mechanism

The Tyne field is subdivided into separate fault blocks. Two major sets of faults occur (Figure 5):* *West-southwest–east-northeast faults.* These faults are of late Carboniferous age. There is little or no displacement of the Permian unconformity surface (Figure 4).

- *North-northwest–south-southeast faults.* These displace the Lower Permian succession. Fault movement occurred during the Mesozoic.

Faults within the Tyne North and Northwest blocks dip northwards. The southern boundary of these blocks is marked by a major east–west trending fault complex of late Carboniferous age. The Tyne South and Tyne West fault blocks dip southwards away from this complex. They are separated by a northwest– southeast orientated graben of younger, Mesozoic age (Figure 1).

According to Knipe et al. (1998), an important period of Late Carboniferous extension preceded the end-Variscan compression. The west-southwest–east-northeast faults, showing only Carboniferous movement, date from this period. Many faults that show evidence for post-Carboniferous reactivation were also initiated during this time. Although most of this extension postdated deposition of the Lower Ketch, careful analysis of the 3-D seismic data shows there was also some early syn-sedimentary movement (Figure 5, Figure 6). The result was a thickening of the Lower Ketch into hanging-wall sections of active faults and erosion of section at the T-Horizon near the fault-block crests, causing local unconformities. Seismic mapping suggests that the thickness of the Lower Ketch ranges from about 600ft to just under 300ft. Most of this is attributed to the impact of synsedimentary faulting.

As pointed out by O'Mara et al. (1999), the trapping mechanism in the Tyne field is unusual in that there is no structural closure at the base Permian level. The traps in all of the accumulations are complex and rely on a combination of topseal provided by the unconformably overlying Permian Silverpit Formation and the shale-prone Upper Ketch on the dip slope.

There is also an element of fault seal in some fields, where the reservoir is juxtaposed against the shale-prone Upper Ketch. An important consequence of this is that, in contrast to the majority of the southern North Sea Carboniferous gasfields, which have base Permian closures typically several hundreds of feet thick, the gas-column thicknesses in all of the Tyne fields are considerably less. Seismic mapping shows that the typical thickness ranges between 100ft and 200 ft over most parts of the field.

3. Depositional model

Gamma-ray log character and core descriptions from the Tyne field wells suggest that deposition of the Lower Ketch occurred within pebbly braided rivers dominated by longitudinal bars. These are interpreted to form part of a low-relief fluvially dominated alluvial-fan system (Figure 7), which to the north was probably incised into older Carboniferous sediments on the Mid North Sea High (Collinson Jones Consulting 1997, Stone and Moscariello 1999, Moscariello et al. 2002). There may have been several such systems in the Southern North Sea Basin (Figure 7).

The Tyne field is thought to have been located near the apex of one such fan and hence comprises some of the most sand-prone sequences within the offshore Ketch (Barren Red Beds) sequence. In Tyne North, net-to-gross exceeds 0.7 and is even higher in well 44/13-1, a few kilometres to the north. Southwards, net-to-gross reduces to less than 0.4 in Tyne West and South over only a few kilometres. The reduction in net-to-gross is seen in all six reservoir zones, and an example from Zone

5 is shown in Figure 8. This consistent southerly reduction in netto-gross over such a comparatively short distance is taken to indicate a fairly small-scale fan system, which may not have extended as far as other Ketch Formation fields that are farther south.

In contrast to the Ketch and Schooner fields, overbank sediments, where preserved, tend to have less pedogenic alteration. This is attributed to more frequent channel reworking, particularly in the more proximal areas (Tyne North), therefore reducing the opportunities for extensive pedogenesis.

Deposition of the Lower Ketch probably occurred during the early stages of a period of late Westphalian extension (Figure 9). This accounts for the thickening into active faults. At the end of Lower Ketch deposition, during a possible short-lived period of more active fault movement, erosion of the hanging-wall fault- block crests led to the formation of small local unconformities at the T-Horizon.

Within the younger Transition Sequence, similarity of the channel-fill sequences suggests a continuation of braided fluvial sedimentation, but with a much greater preservation of the over-bank sediments. A similar upward decrease in net-to-gross occurs in the Ketch and Schooner fields, and has been attributed to increased fluvial incision (Stone & Moscariello 1999). In the Tyne field area, the channel-fill sequences are generally much thinner than in the Lower Ketch and commonly only single-storey channel fills occur (Table 1). This suggests that channel incision was not a factor in allowing greater preservation of the floodplain sediments here. A northward retreat of the alluvial fan, so that the Tyne area occupied a more distal position, seems a more likely explanation for the much lower net-to-gross (Figure 7). This retreat was accompanied by the incoming of a drainage system flowing from the south, which by late Westphalian times completely dominated the basin (Besly et al. 1993).

4. Reservoir characteristics

The Lower Ketch is a complex fluvial reservoir that exhibits considerable variation in permeability. Coarser-grained facies, such as matrix-supported conglomerates and coarse pebbly sandstones, have permeabilities that can exceed 1000 millidarcies (mD). In other channel facies, typical permeabilities are hundreds of millidarcies, but reduce severely in the finer-grained sediments at the tops of the channel-fill sequences. The high-permeability sections provide the potential for very high gasflow rates, with consequent rapid payback of the development well costs. They could also provide pathways for water influx, as the relatively small gas-column thicknesses in all of the Tyne field structures mean that in most development wells the gas/water contact is never very far from the perforated intervals.

Table 1 Comparison between the Lower Ketch and Transition Sequence in the Tyne area

Interval	Net-to- gross	Channel type	Thickness range (ft)
Transition Sequence	0.1–0.3	Mainly single storey	10–30
Lower Ketch (Tyne South and West)	0.3–0.65	Mixed, multi- and single-storey	10–70
Lower Ketch (Tyne North)	0.7–0.8	Mainly multi-storey	25–70

Although no three-dimensional facies modelling has been carried out, well test and production data together give some guide as to likely connectivity. Plots of pressure versus cumulative production (p/Z) provide reasonable estimates of the volumes of connected gas in individual development wells. Comparing these values with mapped gas-in-place suggests that connectivities in the higher net-to-gross Lower Ketch interval are in the order of 60 per cent. Production data from wells T5 and T3a on

Tyne North showed that these wells were not in communication with one another. A combination of fault seal (shale smears) and horizontal barriers provided by interchannel over-bank sediments is believed to reduce this connectivity. However, these seals appear to have broken down over geological time, as each field has a single or very similar gas/water contact and RFT pressure profile.

In the low net-to-gross Transition Sequence, connectivity is likely to be much lower. Indeed, analysis of well test data has shown severe depletion, with small volumes of connected gas. This suggests that individual channel sandbodies are mostly isolated.

5. Production history

The Tyne field development wells have exhibited large variations in recovery. Gas production from individual wells has ranged from as little as 6bcf (<10%) to over 55bcf (*c.* 60%). The amount of recovery is controlled primarily by water production. Four of the five wells are now shut in because of early water breakthrough. In all of these wells, because of the relatively thin gas columns, the perforations were, of necessity, set fairly close to the water leg.

There are several ways in which water breakthrough may have occurred:* coning

- updip water movement along high-permeability layers
- general rise in the gas/water contact because of aquifer expansion
- water breakthrough behind casing.

Well T2 (Figure 10) has produced the most gas by far (>55bcf) and shows a pressure-decline curve typical of a well that is being blown down without pressure support (Figure 11). The *p*/*Z* (connected gas) at about 90bcf is also greatest for this well. The well is unique in the Tyne field for two reasons: first, the gas column extends through the entire Lower Ketch sequence and, secondly, there is no water leg in direct communication, as the underlying Coal Measures sequence contains a thick shale section. The Carboniferous sequence dips southeast at only 2° and the lowest perforated interval is approximately 1000ft up dip from the gas/water contact (Figure 12).

The aquifer in Tyne West is quite small (Figure 12). The field is bounded by faults and, farther south, the Lower Ketch reservoir is truncated by the Permian unconformity. A simple material-balance calculation has been used to estimate the amount of aquifer expansion that has occurred as a result of pressure decline following gas production from the two development wells. It suggests that aquifer expansion has been insufficient to allow water to enter the T2 well bore.

In contrast, Well T5 (Figure 13, Figure 14) produced only 6bcf. The wellhead pressure plot shows little early decline followed by a very rapid fall in November 1999. This occurred after water entered through the perforations, filled in the well bore and shut off gas production. Comparison with the p/Z plot shows that the well produced only a very small proportion of the connected gas. Dynamic reservoir-modelling studies indicate the most likely mechanism is a general rise in the gas/water contact in the near vicinity of the well. Shale beds below the well, which are generally considered to have limited areal extents, should act as a baffle and delay water influx. Aquifer expansion is considered unlikely to be the main reason for water production, because of the limited aquifer volume.

The possibility of water production coming up behind the outside of the casing has also been considered. This should be prevented by cementing, which plugs any gaps that may develop between the outside of the casing and the formation. Cement-bond logs, run at well completion, do indeed indicate poor bond over reservoir intervals. However, water production did not occur for some two years after production began in most wells. The fact that there was no initial water production tends to suggest that this mechanism is less likely.

High permeability intervals have been identified from core and inferred from logs. The lateral extent of these is probably limited given the complex nature of the channel fill sequences in a braided alluvial system. However, it is likely that any water coming up from below will tend to be accelerated to the well via any such high permeability intervals.

6. Overburden – the seismic challenge

Over the western half of Block 44/18 there is strong geological deformation associated with the partial collapse of a north–south trending salt wall. This complexity makes it difficult to determine seismic velocities accurately in this area and hence it is difficult to carry out normal seismic processing techniques, leading to substantial distortion of the subsalt seismic data. On the conventionally processed, time-migrated data, the Carboniferous reflections are very poor, or non-existent, under much of this structure.

The seismic data were reprocessed using pre-stack depth migration (pre-SDM), with a view to improving the imaging beneath the salt disturbance. The technique required the construction of an accurate depth and velocity model followed by time-to-depth conversion using image-ray tracing and the application of a Kirchhoff depth-migration algorithm which attempts to place each subsurface point in its correct subsurface location.

The principal reprocessing challenge was the estimation of salt thickness, especially in areas of near-vertical dip and possibly salt overhang. Five key horizons were used in building a model of the overburden. These were top and base Chalk, top Triassic, top Zechstein and top Rotliegendes. The velocity model was constructed by taking each layer in turn, starting with the surface to top Chalk. For each layer, an initial velocity gradient was derived from well control. The interval was then “flooded” with these velocities and an updated stacking velocity map was created after correcting for residual move-out.

The upper surface of each interval was converted to depth using image-ray migration. A tomographic approach then used 3-D ray tracing to identify an interval velocity that best matched the hyperbola associated with the picked stacking velocity. The output of tomography was used to update the depth horizon at the base of the interval. This surface then became the starting point for the next iteration.

The technique enabled better imaging of the deeper structures under the salt wall. Improvements under the thickest salt were less dramatic. However, compared with the conventional time-migrated data, the width of the zone of uncertainty was reduced from about 2km to about 0.75km. Figure 15 shows an east–west dip line before pre-SDM. The no-data zone is indicated by an ellipse; this zone was significantly narrower on the pre-SDM data (Figure 16). The remapping has allowed new potential targets beneath the salt to be evaluated.

7. Infill drilling

No development wells have been drilled on the Tyne field since 1997. In assessing future potential, attention has continued to focus on the main Lower Ketch reservoir. The Transition Sequence is not seen as a target because of the likely poor connectivity in the low net-to-gross sequence. A further constraint is that the main potential areas of interest within this interval (in the northern part of the Tyne North field and undeveloped Tyne East field;) are not within reach of the platform and would require costly sub-sea tieback wells in order to be developed.

The first infill well target was chosen on Tyne North in an area outside the salt-collapse structure. Field mapping has shown that significant in-place-gas exists here. A revised geological model (incorporating new seismic interpretation and depth conversion) was used to construct a 3-D reservoir model for the field. This model was the basis for a history match of production wells, forecasting and evaluation of potential infill opportunities. A range of development options was considered, including multi-lateral wells with sub-sea tieback, and sidetracks to existing wells.

Lessons learned from previous drilling and the insights from the new reservoir model were critical to maximizing recovery in the proposed new well. Reservoir modelling and the production history of the older wells had shown that, because of relatively low gas-column thicknesses at the available infill locations, early water breakthrough could limit gas recovery. Key concerns were therefore to maximize stand-off from the gas/water contact, minimize drawdown, and avoid penetration of any water-bearing sand.

The first proposed infill well (T6) will address the above concerns. It is planned as a *c.* 500ft near-horizontal producer in the upper part of the Lower Ketch. The extended-reach well will be drilled as a sidetrack to T5 to a total length of about 21000ft. In the final stages of drilling, geosteering will be used to optimize the location in the upper part of the Lower Ketch reservoir, as high as possible above the gas/water contact.

Acknowledgements

This paper is published with the permission of BP Exploration Ltd. We thank former Tyne Team members Chris Cassop, Graham Hulbert, Rachel McRonald, Mark Tringham and Appia Kyei for discussions and contributions. Duncan McLean (University of Sheffield) and Tim Pearce (Chemostrat Consultants) have provided data on stratigraphical ages and correlations.

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