The Auk Field, Block 30/16, UK North Sea

NIGEL H. TREWIN[1], STEVEN G. FRYBERGER[2] & HELGE KREUTZ[2]

[1] *Department of Geology and Petroleum Geology, University of Aberdeen, Aberdeen AB24 3UE, UK (e-mail: n.trewin@abdn.ac.uk)*

[2] *Shell UK Exploration and Production, 1 Altens Farm Road, Nigg, Aberdeen AB12 3FY, UK*

Abstract: The Auk Field is located in Block 30/16 at the western margin of the Central Graben. Block 30/16 was awarded in June 1970 to Shell/Esso, and the discovery well 30/16-1 spudded in September 1970. The well found oil in a complex horst block sealed by Upper Cretaceous chalk and Tertiary claystones. The field contained an original oil column of up to 400 ft within Rotliegend sandstones, Zechstein dolomites, Lower Cretaceous breccia and Upper Cretaceous chalk. Production by natural aquifer drive commenced from a steel platform in 1976, initially from the Zechstein carbonates and now predominantly from the Rotliegend sandstone. Artificial lift was installed in 1988 helping to maintain production at economic levels past the year 2000. A complex reservoir architecture with cross flow between the Rotliegend and Zechstein reservoirs, a strong aquifer causing early water breakthrough via faults, and a limited seismic definition led to significant production variations from the initial forecasts. Equally important for the field, horizontal well technology opened up additional reserves and accelerated production from the complex Rotliegend reservoir; the most recent volumetric estimate for the total field predicts an ultimate recovery of 151 MMBBL for the existing wells from a STOIIP of 795 MMBBL. Full field reservoir simulation and 3D seismic data acquisition took place since mid 1980s but only recently resulted in a satisfactory understanding of the reservoir behaviour.

The field is situated about 270 km ESE from Aberdeen in 240–270 ft of water. It covers a tilted horst block with an area of 65 km^2, located at the western margin of the Central Graben. The Auk horst is bounded on the west by a series of faults with throws of up to 1000 ft, the eastern boundary fault has a throw of 5000 ft in the north reducing in throw southwards. The best reservoir lithology in the Zechstein is a vuggy fractured dolomite, and in the Rotliegend dune slipface sandstones provide the majority of the production. Both reservoirs and the overlying Lower Cretaceous breccia shared a common FWL at 7750 ft TVDss. The 38° API oil with a GOR of 190 SCF/STB was sourced from organic-rich Kimmeridge Clay.

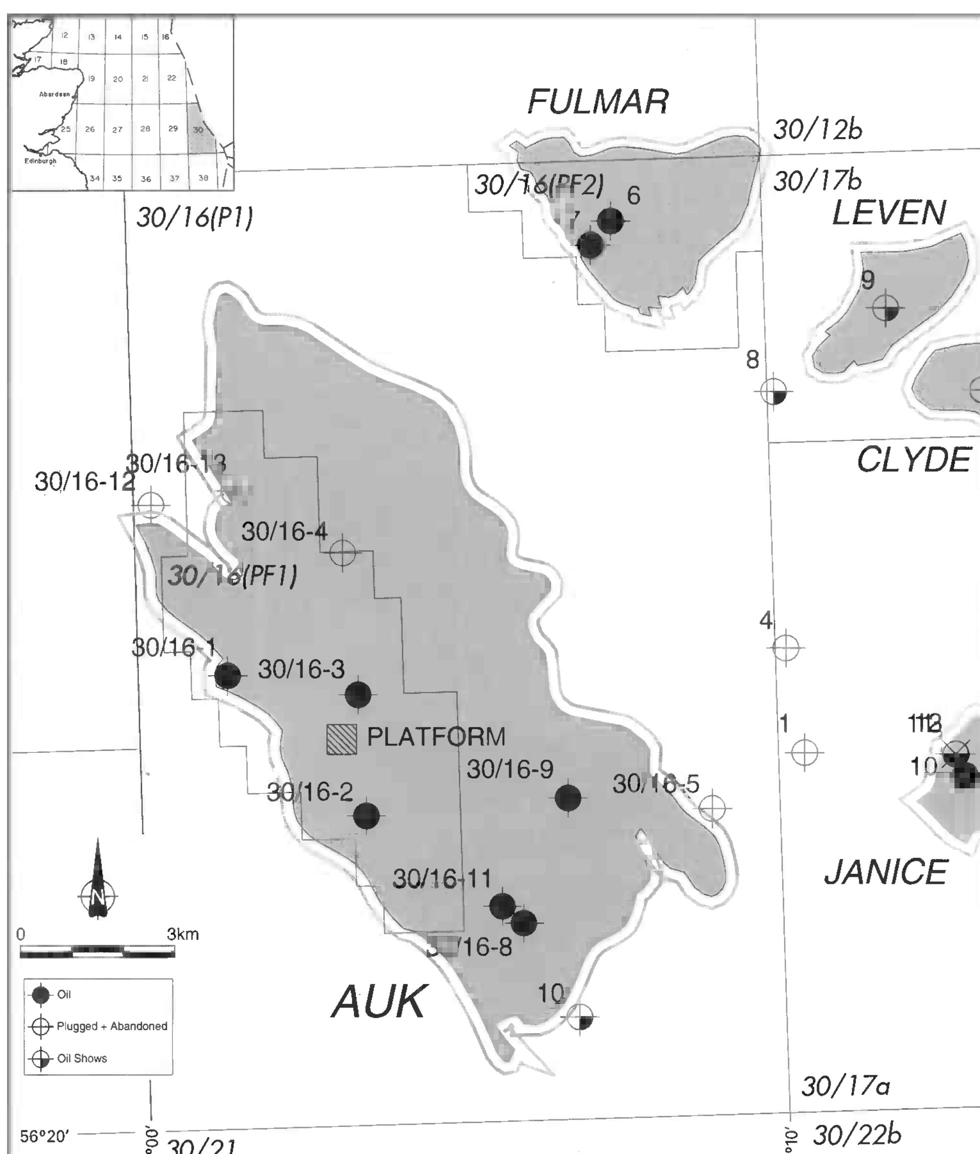

Fig. 1. Exploration and appraisal well locations in Block 30/16.

History

Pre-discovery and discovery

Licence P.116, initially comprising the Auk/Fulmar Block 30/16 (Fig. 1), the Kingfisher Block 16/8, and Block 22/2, was granted to Shell/Esso during the 3rd Round in 1970. Block 30/16 had been applied for to test the porous, but hitherto discarded as waterbearing, Rotliegend sandstones encountered in three wells previously drilled in the area. Due to the adjacent open acreage and upcoming licensing rounds, an exploration well proposal was approved within a month after licence acquisition on the basis of a sparse grid of 2D seismic data. Two months later, in September 1970, the semi-submersible rig 'Staflo' spudded the Auk discovery well, 30/16-1, as Shell Expro's sixth well in the Central North Sea. The well encountered only waterbearing sands in the Rotliegend, but tested oil from Zechstein carbonates at economic rates. As Shell Expro's first commercial oil discovery it was named 'Auk', starting the company's tradition that oil fields are named after seabirds.

Pre-development appraisal

The preservation of porous, fractured carbonates on the eroded horst block came as a surprise to Shell/Esso (Brennand & van Veen 1975). The thin Zechstein interval was not resolved on contemporary 2D seismic data, and prior to well 30/16-1 it was believed to be fully eroded from the structure. Subsequent appraisal wells 30/16-2 and 30/16-3, respectively up-dip to the east and southeast of the discovery well, again encountered Zechstein but also tested oil from Rotliegend. A drilling campaign of three wells was proposed to delineate the extent of the Zechstein aquifer and the oil–water contact (OWC). However, the next well (30/16-4) found the Zechstein eroded and only tight Rotliegend preserved below the chalk. Based on this well the decision was made in late 1972 to develop primarily the Zechstein and to provide water injection facilities. The Zechstein was correctly interpreted to lack its own aquifer due to erosion in the east and southeast (Fig. 2). The remaining two appraisal wells were cancelled, and 30/16-5 was unsuccessfully drilled as an exploration well targeting the Devonian, at the time found to be hydrocarbon bearing in the Argyll Field.

The large uncertainty in reserve estimates of 30–100 MMBBL at the time reflected the limited seismic resolution and the complex structural history indicated by the appraisal wells (Buchanan & Hoogteyling 1979). Below the Base Cretaceous unconformity the discovery well found Zechstein, the first appraisal well Triassic shales, the second appraisal well encountered Lower Cretaceous conglomerates, and the last pre-development appraisal well Rotliegend sandstones.

Development and early production

A 10-slot steel drilling/production platform and a single buoy mooring offloading system were installed in 1974 and the initial development wells drilled for a production start in late 1975. Their static results came in close to prognosis, but unexpectedly by mid-1976 the watercut in the first Zechstein producers started to increase, and it became evident that the reservoir was connected to a strong aquifer provided by Rotliegend sandstones. The water injection facilities were removed and used later on the neighbouring Fulmar platform.

Due to the rapid increase in watercut, the field only achieved a short peak production of 70 000 BOPD in May 1977 and reserves estimates decreased from an expectation of 60 MMBBL at the start of production down to 55 MMBBL in 1978 (Buchanan 1979). The estimated end of field life (1979 at the time of development consent) moved backward to end 1980 in estimates made during the late 1970s and was further postponed year-by-year due to updates in well performance. At this point in our discussion it may be useful to interrupt the historical description to look at the present knowledge about the reservoirs. The later development history is described at end of this chapter.

Structure

The Auk structure is the result of multiple periods of uplift and subsidence along two NW–SE striking faults. The eastern boundary fault (Figs 3 and 4) bounds the Auk horst against the Central Graben to the east, and the west boundary fault (WBF) (Figs 2 and 3) in most areas forms the western limit of the oil accumulation. Situated on the western edge of the Central Graben the structure at Rotliegend level is broken up into several blocks with different characteristics (Fig. 2).

The west flank of the field (Auk West) has preserved the most complete stratigraphic sequence due to westward tilting of the Auk High in the Early Cretaceous. Later, at the start of the Tertiary, this part of the field was uplifted and densely faulted by rejuvenation of the western boundary fault (WBF). Due to preservation of the overlying Triassic sequence the Zechstein and Rotliegend are located below the OWC.

The present crest of Auk (Auk Main West) is the result of the same Tertiary uplift and is as densely faulted as Auk West, but does not contain any Triassic sediments. The main reservoir in Auk Main West is the Zechstein dolomite, with only a thin oil column in the Rotliegend sandstone.

The east flank of the field has a low fault density. Two W–E trending faults split the east flank into three part blocks; Auk Main block, Auk Main North and Auk North blocks. Early Cretaceous uplift and erosion removed all of the strata between Zechstein and Upper Cretaceous chalk. In the eastern half of the flank towards the east boundary fault where erosion started first even the Zechstein is fully eroded. In some places Lower Cretaceous conglomerates have been deposited in isolated lenses.

The most recent fault interpretation described above was only resolved on the 1991 vintage 3D seismic survey (Fig. 4). Earlier 3D seismic (1985) and 2D lines (1976, 1979) had led to a significantly different fault interpretation. The correct interpretation of the main faults in Auk is the key to understanding the reservoir performance and drainage. Interference tests and watercut development has shown that faults are open; oil and water can cross-flow between the reservoirs in areas where Rotliegend and Zechstein are juxtaposed along the main faults. The strong aquifer observed in the Zechstein producers turned out to be the Rotliegend aquifer in Auk Main West juxtaposed against the Zechstein in Auk Main along the WBF. Zechstein producers near the boundary between Auk Main and Auk North on the other hand show an abnormally high oil recovery and late watercut development due to drainage of the Rotliegend oil via fault juxtaposition. Overall, Zechstein wells have produced 80 MMBBL of oil, of which 55 MMBBL are now believed to be Rotliegend oil drained via fault cross-flow, based on recently completed dynamic modeling studies. On the other hand, after increasing the offtake from the Rotliegend and shutting down watered out Zechstein producers the water flowed back from Zechstein to Rotliegend causing wells to water out that are completed far above the OWC.

Stratigraphy

The general stratigraphic sequence of the Auk Field is shown in Figure 5. Unconformities are present in the area at base Devonian, base Permian, base Trias, sub-Lower Cretaceous, sub-Upper Cretaceous, and sub-Palaeocene. These produce a considerable variation in stratigraphy in different parts of the field and in adjacent areas. Lower Palaeozoic basement was penetrated in well 30/16-5 and consists of steeply dipping low grade metamorphic siltstones and claystones with extensive quartz veining.

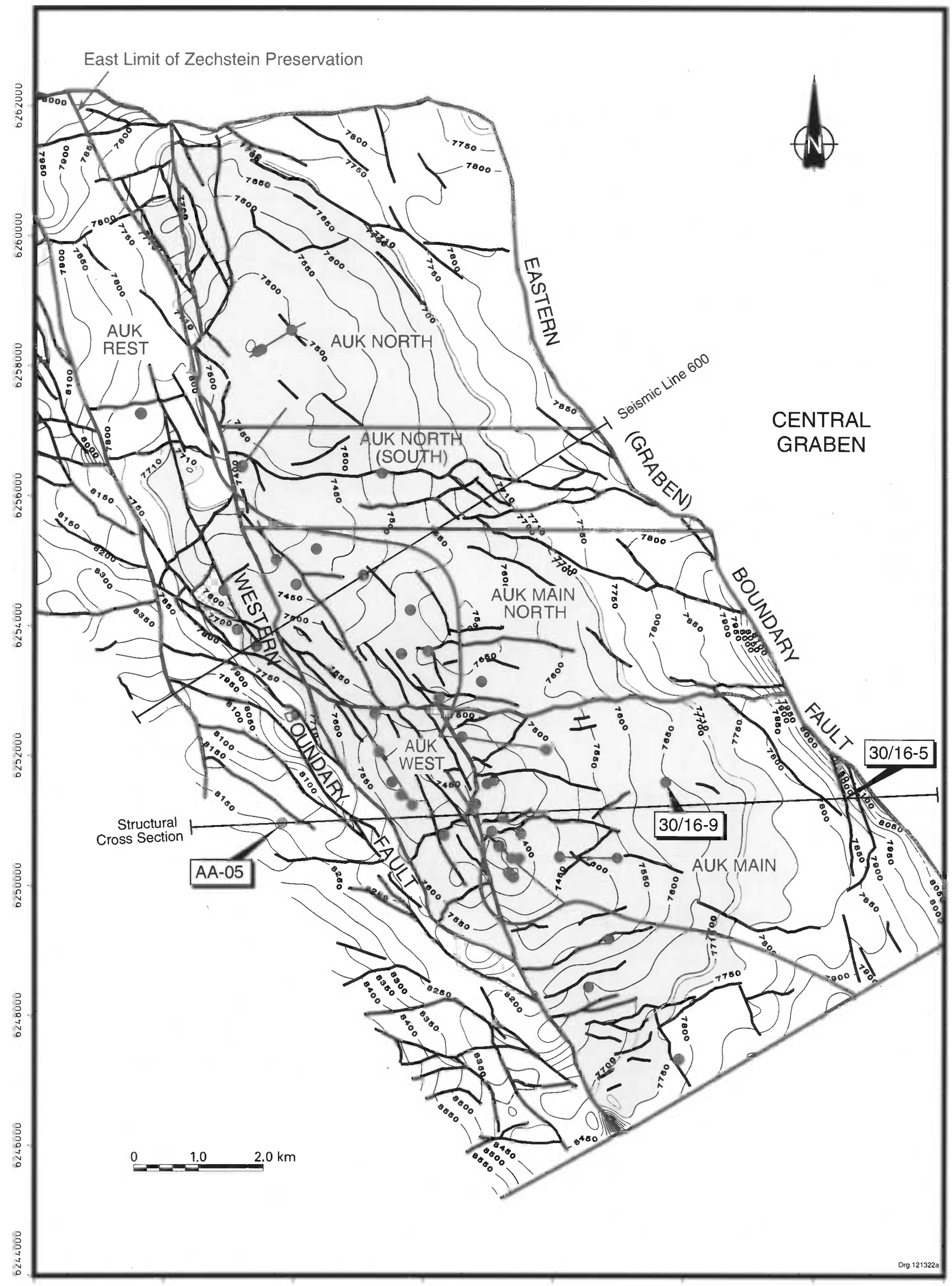

Fig. 2. Top Rotliegend structure map and well locations. The Zechstein is only preserved in the west part of the field, towards the east Early Cretaceous erosion has removed all of the Zechstein and cut into the Rotliegend reservoir.

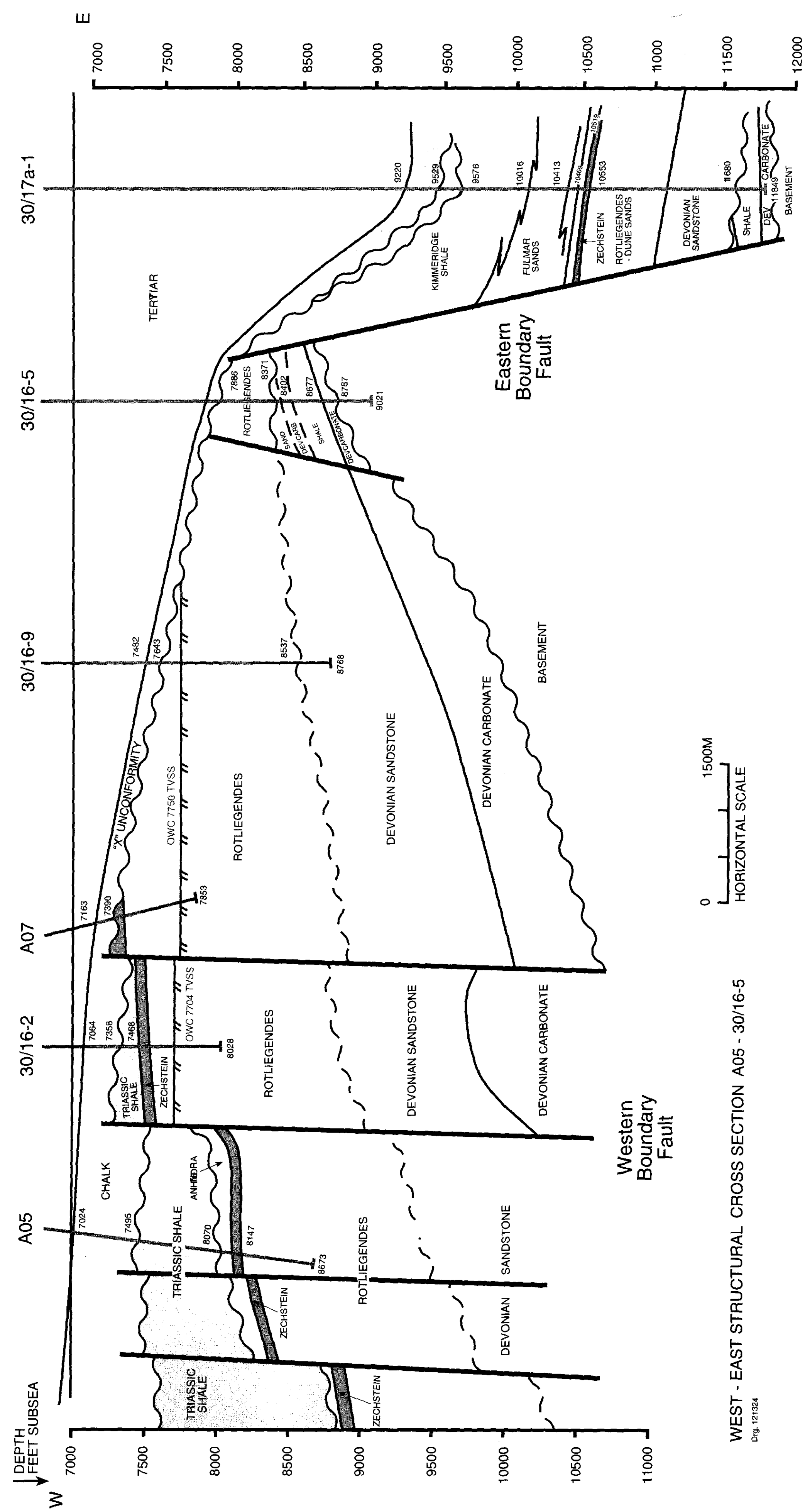

Fig 3. Geological cross-section in W–E direction through the Auk Main block and into the Central North Sea Graben, illustrating the trapping of hydrocarbons to the west against Triassic shales.

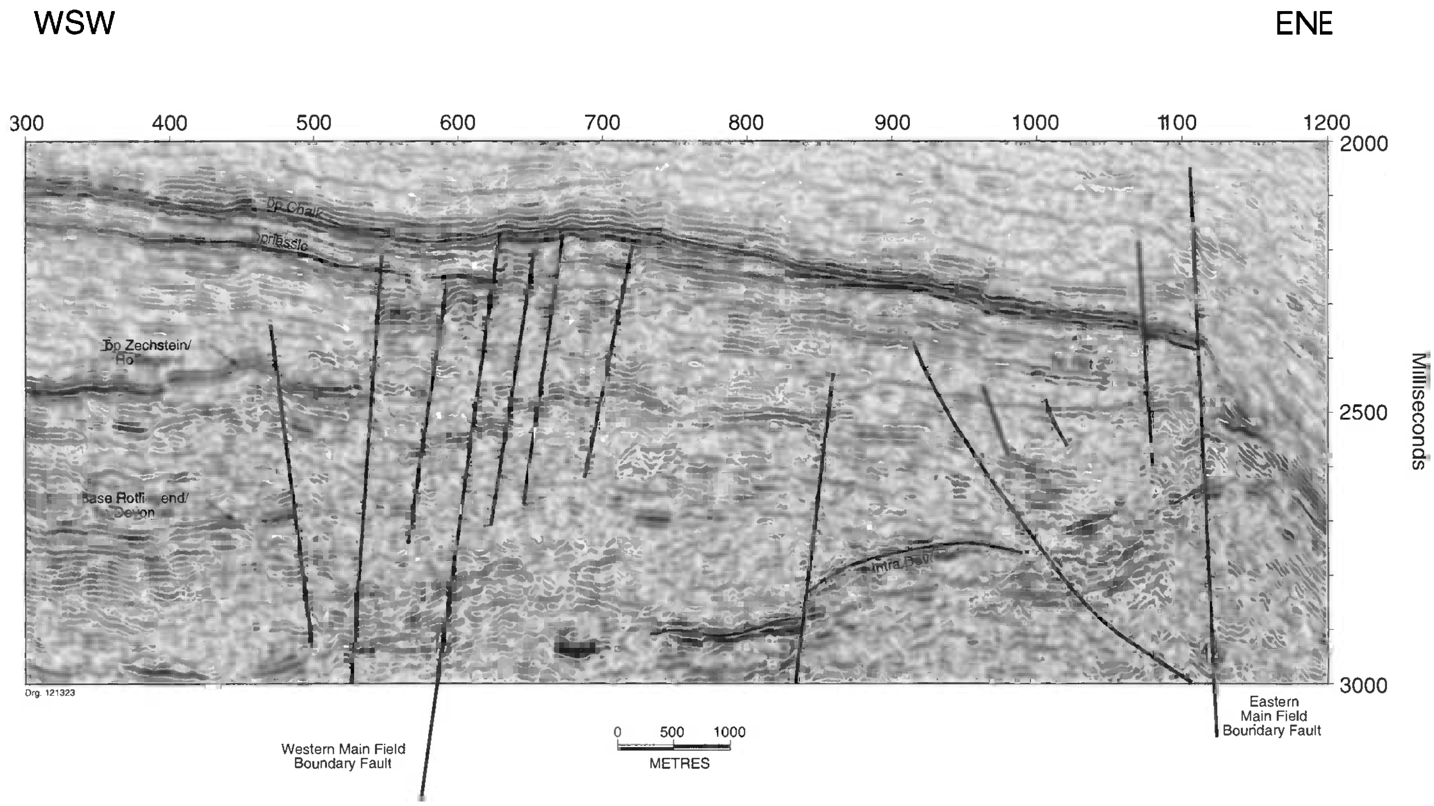

Fig. 4. Seismic cross-section in SW–NE direction through the Auk Main North block. The quality of the 1991 3D seismic survey in the latest reprocessing, shown in this figure, is now sufficient to interpret reservoir juxtapositions reliably.

Devonian

Two Devonian carbonate units each up to 100 ft in thickness and separated by 200 ft of red–brown claystone rest unconformably on the basement with a thin basal conglomerate of locally derived material (Heward 1991). The carbonates are laminated peloidal calcareous dolomites and dolomites which have been reported to yield tabulate and rugose corals indicative of shallow-marine origin. Similar coral-bearing limestones in the Argyll Field are considered to be of Middle Devonian age (Pennington 1975). However, the finely laminated limestones resting on the basement in the core from well 30/16-5 could be of marginal lacustrine origin (Bessa 1991). Succeeding the carbonates with apparent conformity are up to 3000 ft of porous sandstones and shales of inferred Devonian age that are probably of floodplain origin.

Permian

The Rotliegend in the Auk area was deposited in a broad, shallow basin that sloped gently southwest before thinning against the Mid North Sea High. The maximum thickness south of the field exceeds 1000 ft whilst in Auk itself the Rotliegend is up to 900 ft thick. A conglomerate with basalt pebbles locally marks the base and a possible *in situ* flow of porphyritic leucite–nepheline basalt was encountered by one well. Thin conglomerates and sandstones of alluvial origin are followed by pinkish to red–brown dune sandstones with large scale cross-bedding. The main aquifer above this alluvial sequence consists of high net-to-gross barchanoid dune bodies, which in the top of the sequence grade into more complex and heterogeneous sands interpreted as a dunefield with more complex bedforms. The Rotliegend sequence is capped by waterlain massive mass flow and stratified sandstones, intraformational conglomerates and thin lacustrine shales, which yield an Upper Permian flora (Pennington 1975).

The sandstones show only minor reworking at the top prior to deposition of the Kupferschiefer, a 3–5 ft thick bituminous shale deposited below wave base in the restricted marine setting of the Zechstein basin. The succeeding Zechstein dolomites/carbonates were deposited in a shallow marine to sabkha environment across the whole area. Zechstein dolomites, where preserved, average 28 ft in thickness and are probably a time equivalent of the Z1 carbonates of northern England. The dominant lithology in cores is a laminated dolomicrite with sub-parallel organic-rich laminae on a millimetre scale. Solution vugs after evaporite minerals occur, some of which are confined by organic laminae. Ghosts of peloids, indeterminate fossil material, and scattered quartz grains occur in the dolomite. Pervasive brecciation is present, probably due to collapse of the more evaporite-rich lithologies. The top of the incomplete Zechstein sequence is formed by a massive anhydrite.

Triassic

Red–brown to grey–green silty claystones of Early Triassic (Scythian) age, based on palynology, are thickest in the west of the field (500 ft), but have been extensively eroded on the top of the block. These rocks are interpreted as the flood plain deposits of a fluviatile system and are probably a part of the Smith Bank Formation.

Cretaceous

The four Lower Cretaceous lithological units recognized in the field are the Upper Carbonates breccia, a Hauterivian basalt flow, an Albian–Aptian conglomerate, and a marl. The Upper Carbonates breccia consists of Zechstein dolomite and possibly Triassic clasts in a matrix which includes rounded (Rotliegend derived) sand grains, and an open marine fauna of probably Neocomian age. This breccia only occurs in structurally low blocks between Zechstein and other Cretaceous deposits. Deposition of this breccia was associated with erosion, karstification and faulting of the horst in Early

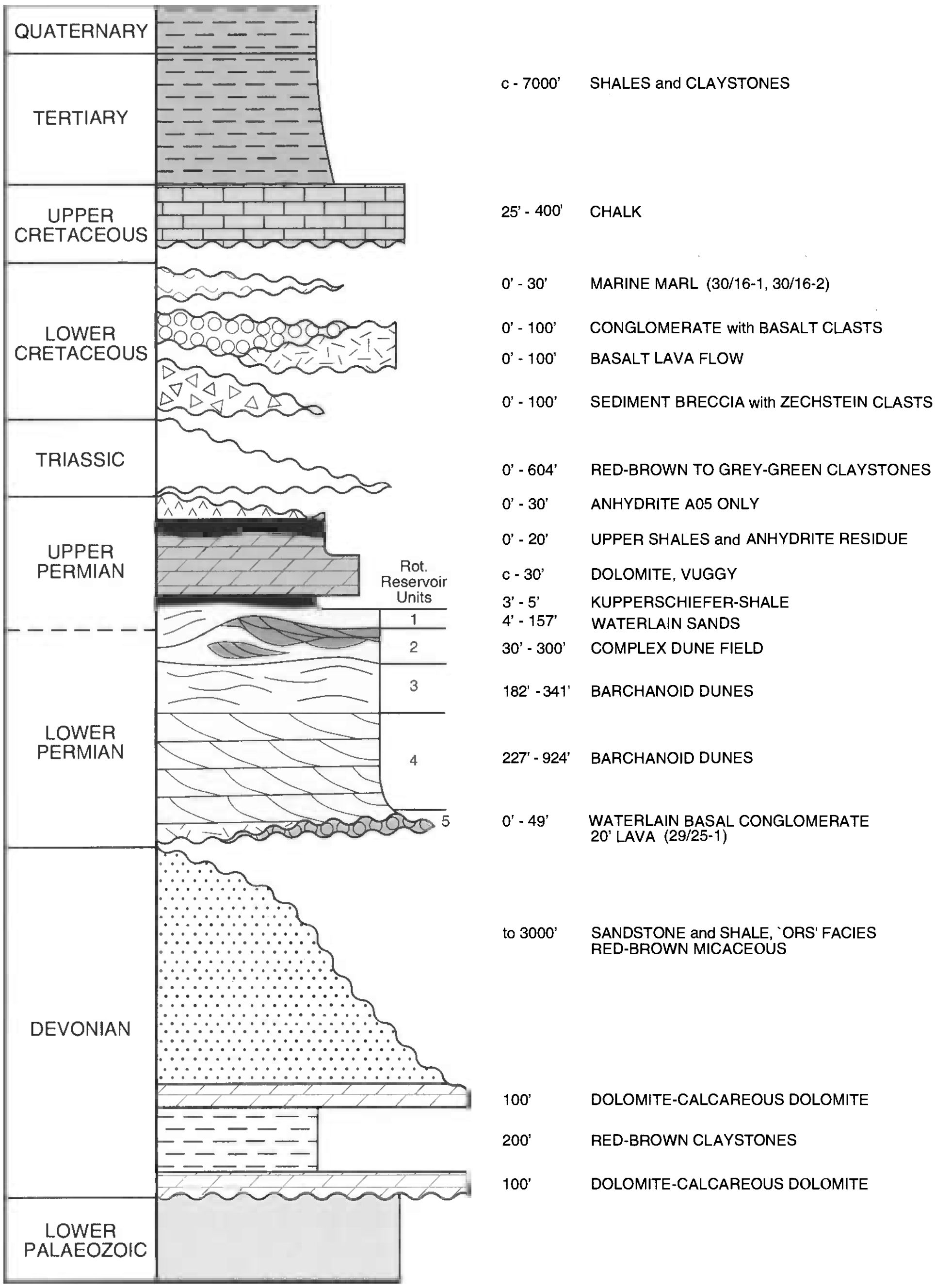

Fig. 5. Lithostratigraphic summary for the Auk Field.

Cretaceous times. A basalt flow occurs in the northeast of the field and radiometric dating suggests a Hauterivian age. The Albian–Aptian conglomerate fringes the basalt flow and contains rounded basalt and Zechstein pebbles in a matrix of sand. Shell fragments of an open marine fauna (Aptian–Albian) are present and bivalve borings are preserved in larger Zechstein clasts. A Lower Cretaceous marl was penetrated by some wells on top of the breccia or older Triassic sediments. Deposited in an open marine environment it illustrates the increasing subsidence of the area, and the end of the Jurassic/Early Cretaceous period of aerial exposure.

The Upper Cretaceous chalk in the Auk Field is fully autochthonous and has been dated as Coniacian to Santonian. Lower parts are oil stained, but the denser upper parts form the main top seal of the field.

Tertiary

Rapid subsidence during the Tertiary and especially during the Palaeocene pulled the east flank downwards, rotating the structure into its current position. A 7000 ft thick sequence of mudstones, siltstones and shales was deposited in the area. Deep marine conditions prevailed during Tertiary times.

Trap

The tilted horst block containing the Auk accumulation is capped by an asymmetric anticlinal structure at chalk level. Triassic shales seal the accumulation to the west with fault closure prevailing in the northwest and dip closure in the southwest. To the east and south the virtually impermeable upper parts of the chalk provide the top seal with a simple dip closure. In the extreme north, where the chalk is eroded down to a thickness of less than 50 ft and reservoir quality in the Rotliegend deteriorates, hydrocarbons are probably spilling slowly into low permeability Tertiary sediments. In most parts of the field the basal 30 ft of chalk is porous and contains some hydrocarbons thus providing a waste zone between the main reservoir and the Tertiary overburden. This explains the shallower OWC in the north part of the field (7710 ft TVDss) compared with 7750 ft TVDss in the Auk Main block, a feature which led to the proposal of a stratigraphic trap in an earlier paper (Trewin & Bramwell 1991).

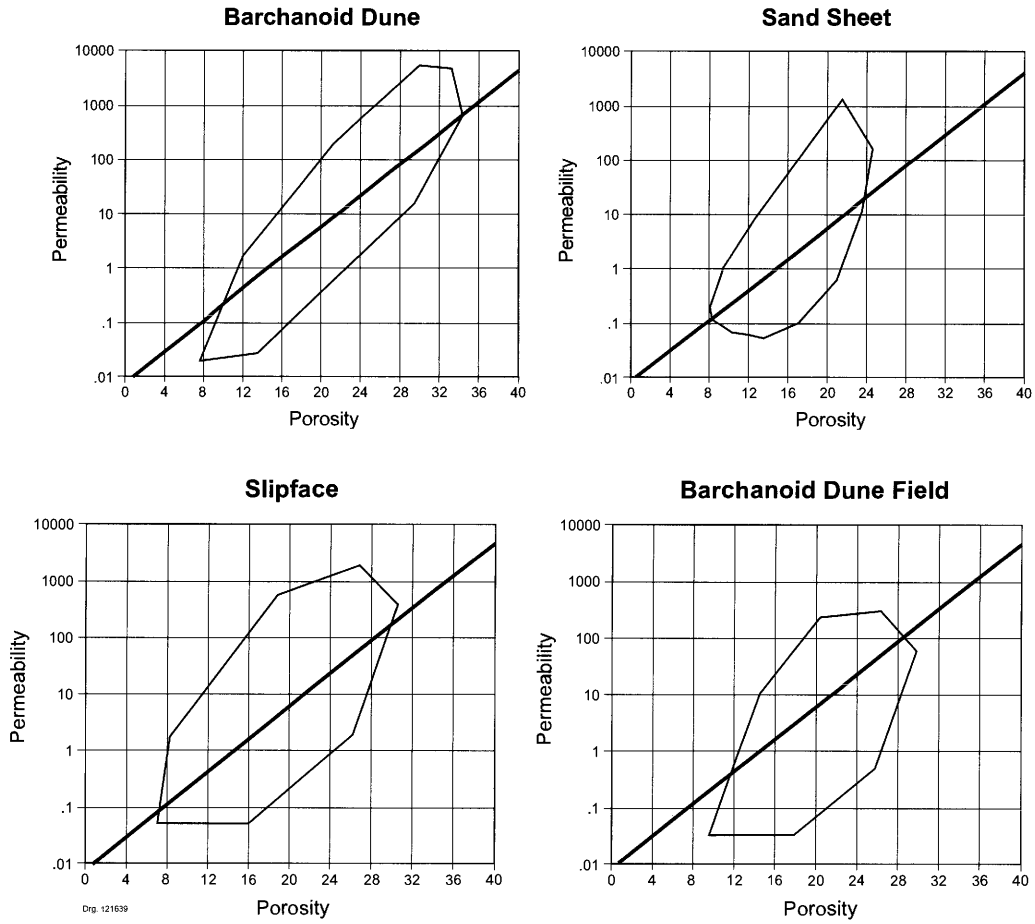

Fig. 6. Porosity/permeability relationship for the different lithofacies in the Rotliegend unit 2 main reservoir. The permeability rarely exceeds 1000 mD, in barchanoid dunes.

At the OWC, the field has a length of 16 km in a NW–SE direction with an average width of 5 km. The crest at Top Zechstein is around 7300 ft TVDss giving Auk a maximum hydrocarbon column of 450 ft.

Reservoirs

Rotliegend

Rotliegend sediments in the Auk area were deposited unconformably onto Devonian and older basement rocks. The deepest Rotliegend unit in Auk (unit 5) consists of basal fluvial conglomerates, transported by ephemeral streams into the newly formed basin from the west or southwest. The sediments are indicative of the initial rapid subsidence north of the Mid North Sea High, with simultaneous movements along Auk's west boundary fault controlling local thickness variations. The overlying sandstones of units 4 and 3 represent thick dune deposits and are interpreted as a stack of barchanoid bed forms. They form the main aquifer for the field. Within the Rotliegend unit 2 reservoir quality is more variable, ranging from very marginal (<1 mD) to good, but values are rarely greater than 1000 mD (see Fig. 6). A complex assemblage of different dune forms succeeds the better quality barchanoid dunes. In the youngest Rotliegend unit (unit 1) fresh water flooding of the area has resulted in widespread slumping and subaqueous reworking of the dunes. Figure 7 illustrates the vertical variations in reservoir quality within Rotliegend units 2 and 3.

Cores from Auk wells exhibit two types of aeolian primary strata: ripple and avalanche. These strata dominate in the Rotliegend units 2, 3 and 4. Ripple strata in Auk has fair to poor reservoir quality whilst avalanche strata due to a coarser grain size and better sorting comprises the best reservoir. The Rotliegend unit 1 consists of slumped avalanche and ripple strata along with some subaqueous strata and shale. Cross-stratification styles and primary strata types were used to identify lithofacies associations with different rock properties (see Figs 8 and 9). Variations of properties within a single lithofacies are fairly wide due to differences in grain size and sorting.

The drive mechanism in the Auk Field in most areas can be best described as a complex, indirect bottom water drive caused by high permeability barchanoid dune sands in the Rotliegend unit 3 aquifer and large variations in permeability within the Rotliegend unit 2 oil zone. In addition, water cross-flows between Zechstein and Rotliegend reservoirs along fault juxtapositions in crestal areas. In line with the heterogeneous reservoir the productivity of vertical Rotliegend producers varies widely with PI's ranging from 0.5 to 18 BBL/psi. This is the main reason why horizontal well technology had a major impact on the field. The scale of the permeability variations is such that a medium reach or long reach horizontal well can slant through many productive sand bodies (Fig. 7) and is thus more predictable in PI than a vertical well. On the other hand, such a horizontal well requires a large undrained area to be successful, but the complex water drive makes the prediction of such areas difficult. Transient sand failure right from the start of production necessitates sand control by gravel pack (vertical wells) and/or prepacked screens (horizontal wells) thus further limiting the ability to control water production.

Zechstein

A more detailed description of the Zechstein reservoir can be found in Vahrenkamp (1995). At the base of this formation a 1 ft thick layer of Kupferschiefer rests conformably on Rotliegend unit 1 sandstones, indicating the transition to restricted marine, anoxic conditions during the early Zechstein period. The thin, grey dolomite above the Kupferschiefer is characterized by current ripples and capped by a subaerial exposure surface. Above this surface a 30 ft thick sequence of stromatolites and dolo-mudstones have been

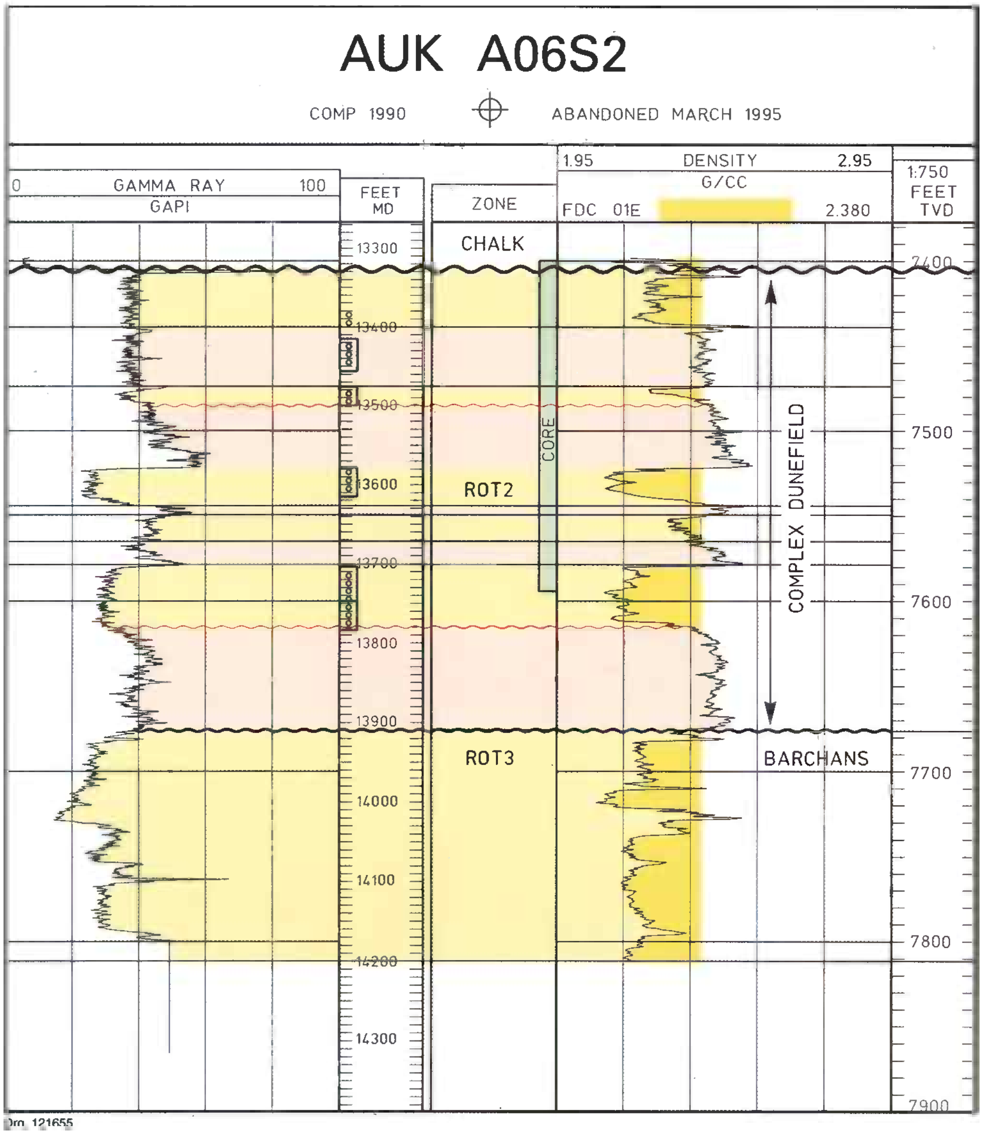

Fig. 7. Typelog for the Rotliegend unit 2 reservoir and Rotliegend unit 3 aquifer, yellow indicates net reservoir whilst orange–brown indicates waste zones. The Rotliegend unit 1 and the Zechstein is eroded in this well.

deposited in an inter- to supratidal, highly saline environment. The dolomites form the main Zechstein reservoir. Their predominantly secondary moldic pore space originated from leaching of evaporites and fossils by Jurassic–Cretaceous subaerial exposure. Stylolites bridge some vugs indicating that compaction predated leaching, which in some parts of the rock is so extensive that it has caused mechanical collapse. The rock was further fractured during later faulting and uplift. Above the dolomites an organic-rich shale of 5–10 ft thickness was deposited with gypsum bands, now replaced by calcite, dolomite, and silica. A massive anhydrite, interpreted as the equivalent of the Z1 (Werra) anhydrite, completes the sequence.

The only reservoir rock within this sequence is the fractured dolo-mudstone described above. Primary porosity in this rock has been completely destroyed during early dolomitization. The secondary porosity consists of vugs created by the dissolution of evaporite material and intercrystalline porosity in micro-crystalline dolomite. According to Vahrenkamp (1995) the porosity ranges from 1.8 to 26% and core permeability is between 0.02 and 620 mD. The calculated average porosity (13%) and permeability (53 mD) from cores is unlikely to be representative for the total reservoir. The core recovery is low and biased towards zones that are less fractured and therefore better conserved. This selective core recovery might explain why no core encountered significant flushing in the Zechstein despite early water breakthrough. The drainage of the reservoir is confined to intensively fractured zones and does not continue far into the unfractured dolomite due to poor connectivity of the vuggy pore space.

Lower Cretaceous

The Lower Cretaceous breccia consists mainly of dolomitic clasts in a sandy to marly matrix (Vahrenkamp 1995). Local variations in clast and matrix composition cause large poroperm variations, ranging from 0.5 to 25% porosity and from 0.01 to 100 mD permeability. The Lower Cretaceous is only locally developed and has been produced commingled with the Zechstein in a few wells.

Hydrocarbons

The source for the 38° API, low GOR and low sulphur oil is the Upper Jurassic Kimmeridge Clay in the Central Graben. Maturation took place from Late Tertiary times. The migration path is not fully resolved. One possible interpretation is that oil spilled over from the Fulmar area to the north, with gas leaking into the overlying Tertiary sediments where it is partly entrapped in Oligocene sediments (Trewin & Bramwell 1991).

Reserves and later development

The latest estimate of ultimate recovery for the Auk Field is 151 MMBBL. Since the first official estimate in 1976 (30–100 MMBBL) reserves have increased continuously (Fig. 10), the main contributing factors being:

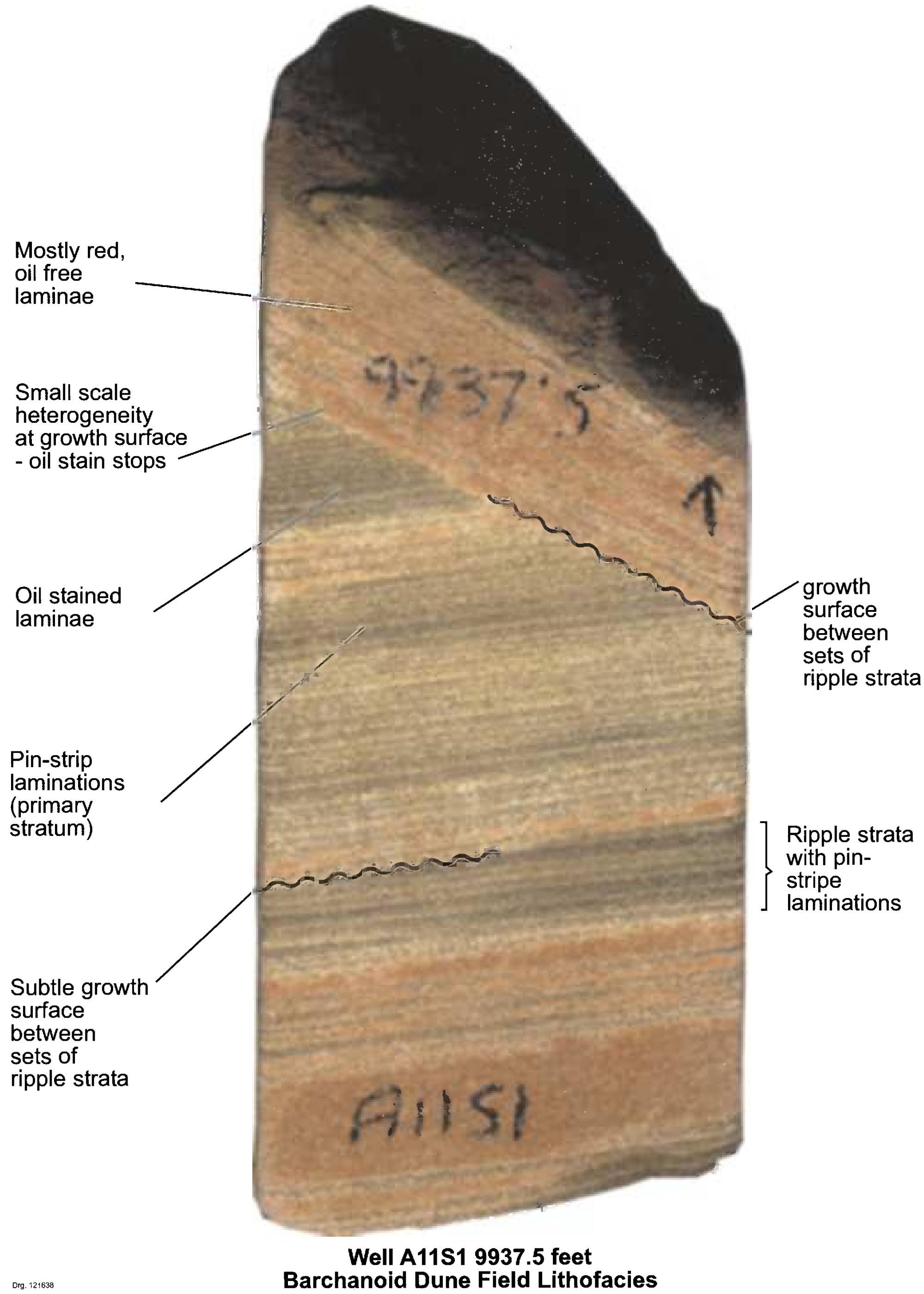

Fig. 8. Example for lithofacies identification in cores. Note fine scaled intercalations of oil stained (brown) and oil free reservoir (red).

Drg. 121638

Development plans for the Rotliegend. The exploration and pre-production appraisal wells encountered either a water bearing Rotliegend reservoir or marginal reservoir quality in the oil bearing interval. Initial estimates of ultimate recovery did not foresee a development of this formation.

Limited seismic resolution. The structural interpretation at field development was based on limited 2D seismic data. Faults were mainly interpreted from well penetrations and were not reliable. Structural interpretations outside of the core area were equally unreliable and appraisal results turned out to be unpredictable. Even on the first 3D seismic survey (1985) the fault pattern was too poorly resolved to be useful for reservoir simulation, but the data helped to identify additional reserves in the southeast flank of the field. After acquisition of better quality 3D seismic data (1991) the overall structural resolution improved and well 30/16-13 (1992) discovered a significant field extension to the north. However, only in the most recent reprocessing is the quality of the survey high enough to resolve the internal fault pattern of the field, and the juxtaposition of the reservoirs.

Reliable full field simulation. As mentioned above, a full understanding of the reservoir performance in the Auk Field is only possible with a full field simulation model that realistically models reservoir juxtaposition and heterogeneity. Full field simulation was attempted as early as 1982, but none of the models built in the past achieved a satisfying history match mainly due to shortcomings in the fault interpretation. A sophisticated 3D simulation model for the Zechstein, built in 1992, resolved the fluid movements within this dual-porosity reservoir but could not identify additional infill locations since the juxtaposition with Rotliegend aquifer could not be located accurately. Field forecasts were therefore constructed from decline curves which in Auk leads to a pessimistic assessment of remaining reserves. Only with the most recent seismic reprocessing could a reservoir model be built that yields a satisfactory history match, and hence is suitable to identify smaller infill

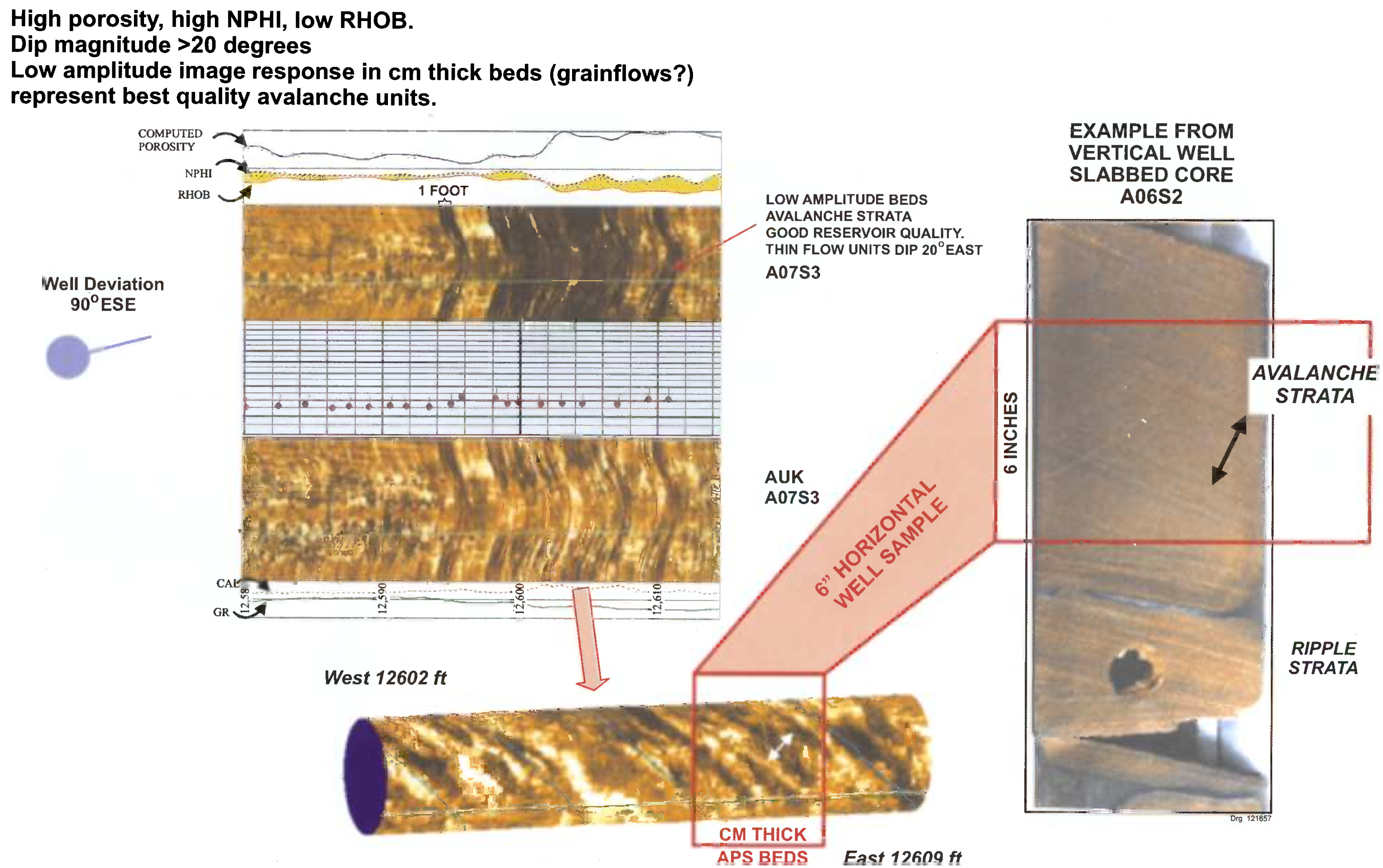

Fig. 9. Identification of avalanche strata in UBI images of a horizontal well. See Follows (1997) for full description of core/UBI log interpretation in this well.

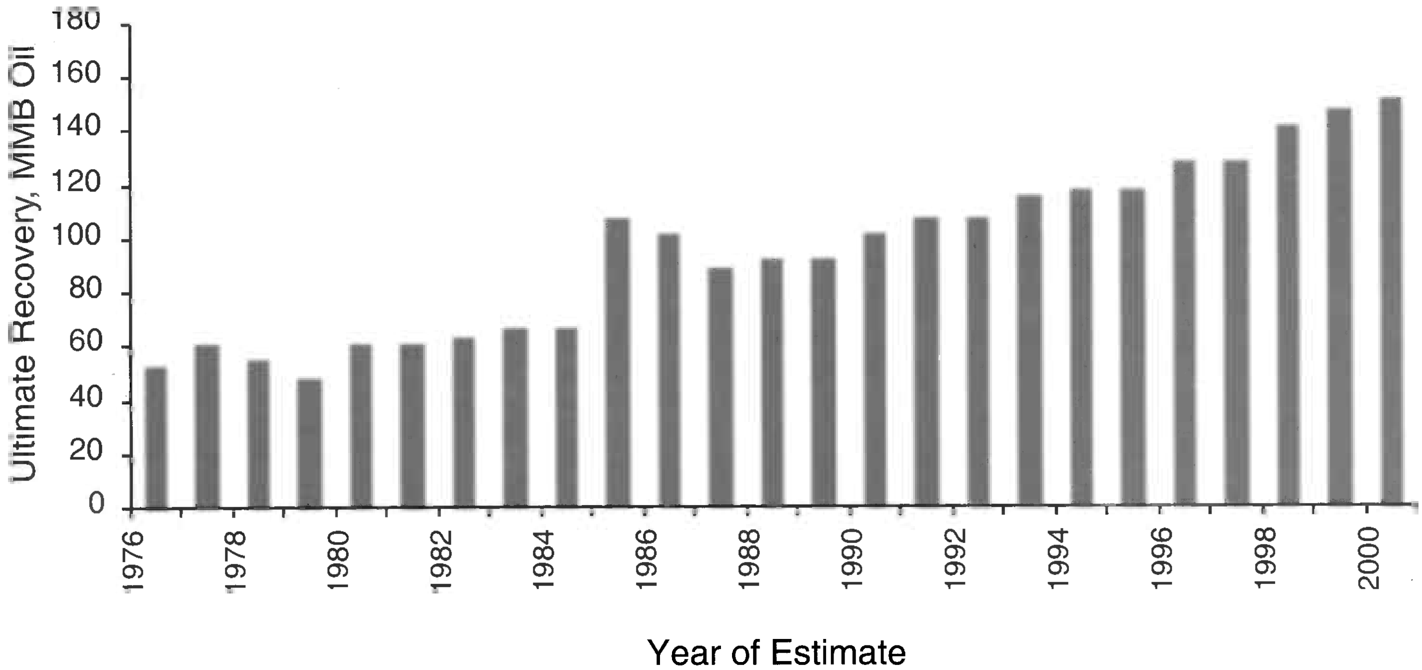

Fig. 10. Changes of resreves estimates in the Auk Field were dictated by early water-break-through (1979), plans for installation of artificial lift (1985–1988), and horizontal well and seismic imaging technology (1990s).

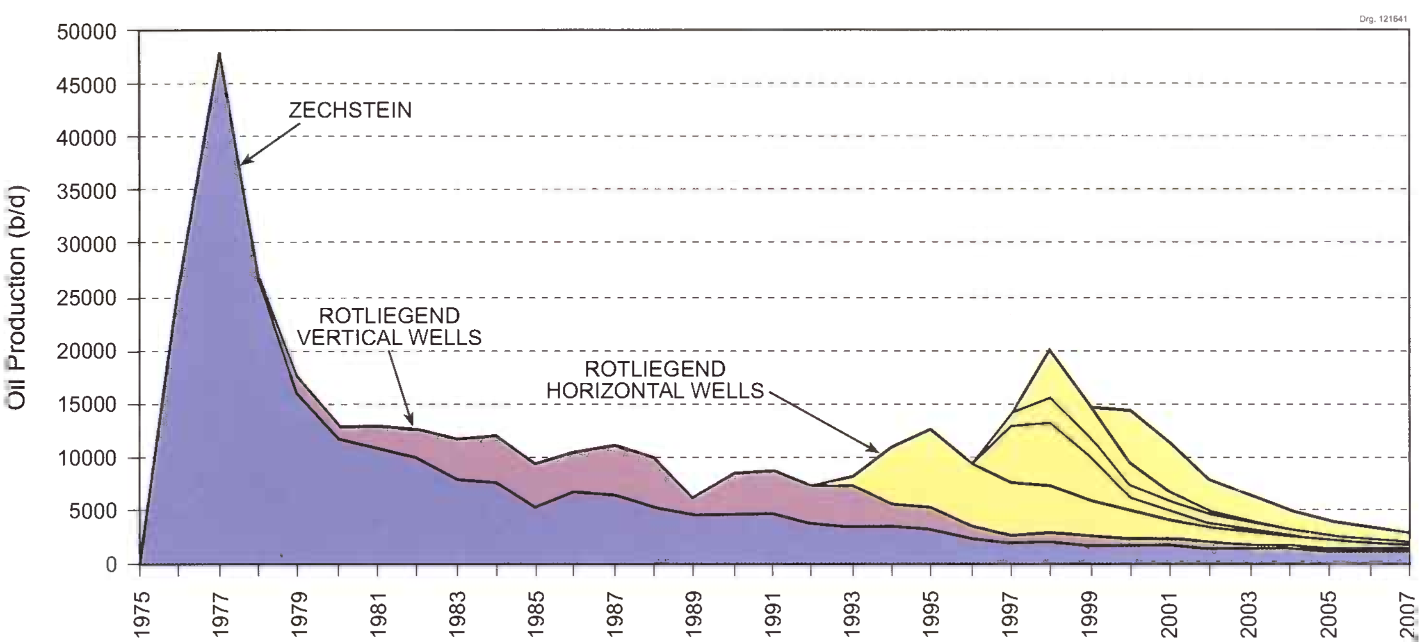

Fig. 11. Production contribution of the individual reservoirs and well types in the Auk Field. Note that the amount of oil produced from Zechstein wells includes cross-flow from the Rotliegend reservoir.

locations. The recently drilled well 30/16-A25 is the first well in Auk located mainly on reservoir simulation.

Artificial lift. In 1988, when artificial lift was installed, the estimates of ultimate recovery for the first time exceeded the pre-development high estimate. The conversion of wells to electro-submersible pumps is still ongoing, constrained by the power capacity of the platform.

Horizontal drilling. Due to heterogenity of the Rotliegend reservoir the deliverability of vertical wells ranges from marginal to poor and the number of geological sidetracks drilled to improve well performance is high. Many low-relief infill locations were uneconomic before horizontal well technology emerged. In addition, since the Auk platform was built for the Zechstein only, there are only a limited number of slots available and well deliverability is key to the fast drainage of reserves. Horizontal well technology, implemented in Auk since 1992, has increased reserves by approximately 30 MMBBL to date. The impact of this technology on the production history of the field is illustrated in Figure 11.

Since the first edition of the Memoir in 1991 several geologists and geophysicists have improved our understanding of the field. This summary would not be possible without the work of Janet Almond, who constructed the present reservoir model and analysed the production history. Elaine Scott planned and drilled the majority of the recent infill wells and Charlie Ash's seismic interpretation forms the basis for the current structural model. The authors wish to thank Sid Jain for the permission to use his reservoir engineering analysis and finally, we would like to thank Shell UK Exploration and Production and ExxonMobil International Ltd for the permission to publish this paper.

Auk Field data summary

Trap	
Type	structural
Depth to crest	7300 ft TVDss
Lowest closing contour	7750 ft TVDss
GOC or GWC	n/a
OWC	7750 ft TVDss
Gas column	0 ft
Oil column	450 ft
Pay zone	
Formation	Auk Formation
Age	Rotliegend (Early Permian)
Gross thickness	1000 ft
Net/gross ratio	0.85 (0.46–0.92)
Porosity average (range)	19% (11–27%)
Permeability average (range)	5 mD (0.2–125 mD)
Hc saturation average (range)	55–80%
Productivity index	1 BOPD/psi (vertical well average)
Formation	Zechstein dolomites
Age	Late Permian
Gross thickness	30 ft
Net/gross ratio	1.0 (fractures)
Porosity average (range)	13% (2–26%)
Permeability average (range)	53 mD (0.02–620 mD)
Productivity index	50–159 BOPD/psi
Petroleum	
Oil density	38° API
Oil type	volatile oil, low sulphur (0.4%)
Gas gravity	solution gas only
Viscosity	0.9 cP
Bubble point	700 psi
Dew point	n/a
Gas/oil ratio	190 SCF/BBL
Condensate yield	n/a
Formation volume factor	1.154 RB/STB
Gas expansion factor	n/a
Formation water	
Salinity	105 000 ppm NaCl equivalent
Resistivity	0.025 ohm m @ 205°F
Field characteristics	
Area	93 km^2
Gross rock volume	28 MM acre feet
Initial pressure	4067 psi @ 7600 ft TVDss
Pressure gradient	0.33 psi/ft (oil)
Temperature	215°F
Oil initially in place	795 MMBBL
Gas initially in place	133 BCF
Recovery factor	19%
Drive mechanism	natural water drive/artificial lift
Recoverable oil	151 MMBBL
Recoverable gas	n/a
Recoverable NGL/condensate	n/a
Production	
Start-up date	January 1976
Production rate plateau oil	70 000 BOPD peak rate
Production rate plateau gas	n/a
Number/type of well	10 exploration/appraisal 23 deviated development wells/production sidetracks 8 horizontal sidetracks

References

BESSA, J. L. 1991. *A re-interpretation of Devonian carbonates found in well 21/16-5, Auk Field, North Sea.* Petroleum Geology MSc Thesis, University of Aberdeen.

BRENNAND, T. P. & VAN VEEN, F. 1975. The Auk Field. *In*: WOODLAND, A. W. (ed.) *Petroleum Geology and the Continental Shelf of NW Europe.* Applied Science Publishers Ltd., Barking, Essex, 271–281.

BUCHANAN, R. 1979. Auk Field development: A case history, illustrating the need for a flexible plan. *Journal of Petroleum Technology*, **31**, 1305–1312.

BUCHANAN, R. & HOOGTEYLING, L. 1979. Auk Field development: a case history, illustrating the need for a flexible plan. *Journal of Petroleum Technology*, **31**, 1305–1312.

FOLLOWS, E. 1997. Integration of inclined pilot hole core with horizontal image logs to appraise an aeolian reservoir, Auk Field, Central North Sea. *Petroleum Geoscience*, **3**, 45–55.

HEWARD, A. P. 1991. Inside Auk – the anatomy of an aeolian reservoir. *In*: MIALL, A. D. & TYLER, N. (eds) *Three-dimensional facies architecture of clastic sediments.* SEPM Concepts in Sedimentology and Paleontology, **3**, 44–56.

PENNINGTON, J. J. 1975. The geology of the Argyll Field. *In*: WOODLAND, A. W. (ed.) *Petroleum Geology of the Continental Shelf of NW Europe.* Applied Science Publishers Ltd, Barking, Essex, 285–291.

TREWIN, N. H. & BRAMWELL, M. G. 1991. The Auk Field, block 30/16, UK North Sea. *In*: ABBOTTS, I. L. (eds) *United Kingdom Oil and Gas Fields: 25 Years Commemorative Volume.* Geological Society, London, Memoirs, **14**, 227–236.

VAHRENKAMP, V. C. 1995. The post-Rotliegend reservoirs of Auk Field, British North Sea: subaerial exposure and reservoir creation. *In*: BUDD, D. A. *et al.* (eds) *Unconformity and porosity in carbonate strata.* American Association of Petroleum Geologists, Memoir, **63**, 191–211.