The Heidrun Field, Offshore Mid-Norway

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ABSTRACT

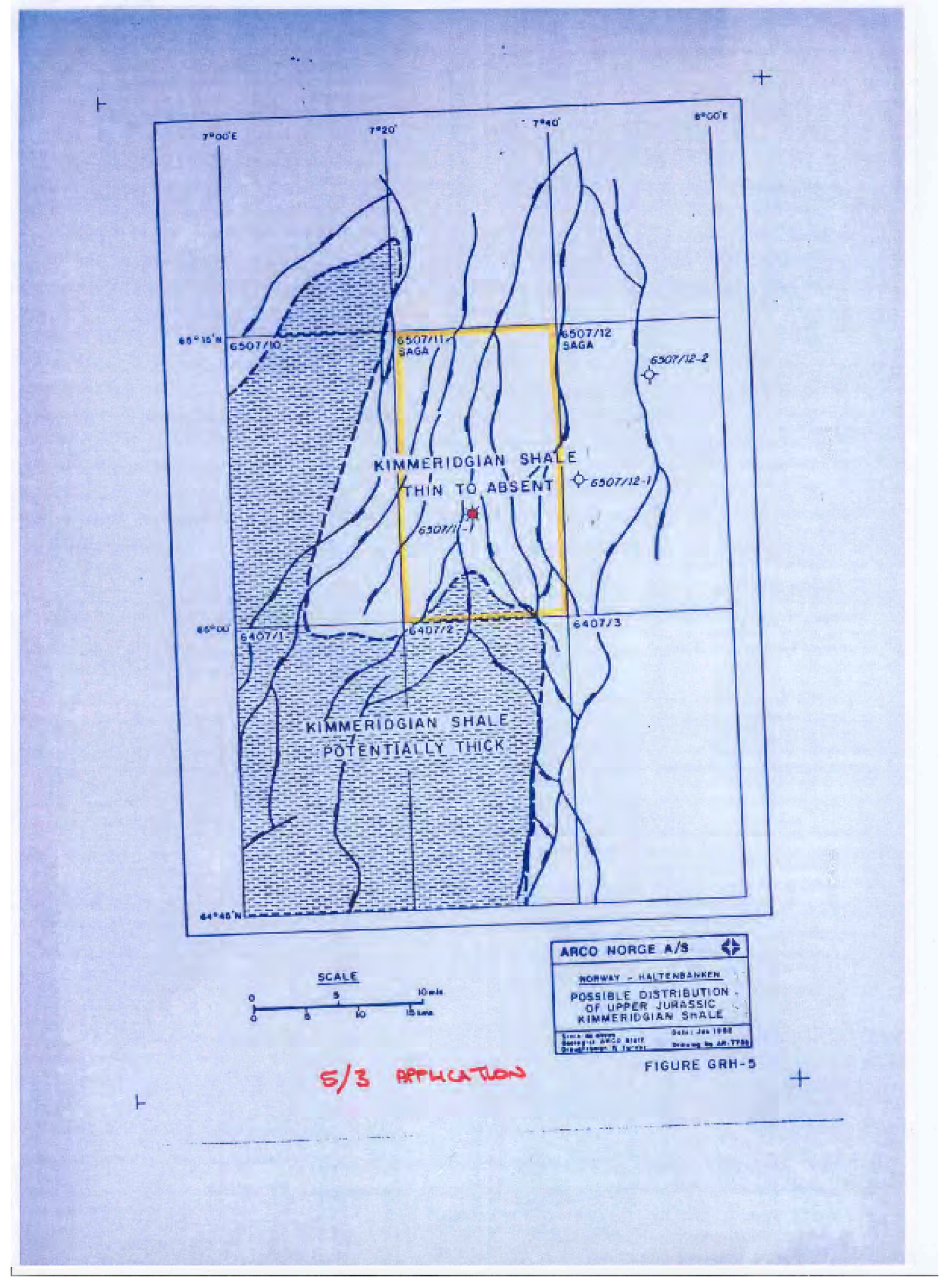
The Heidrun Field was discovered in 1985 by well 6507/7-2. Reserves are 180 million cubic meters oil and 42.70 billion cubic meters gas. Production commenced in 1995.The NPD offered block 6507/7 in the Eighth License Round, after three oil and gas fields were discovered on the Mid-Norway shelf.

The petroleum system was understood to include Lower and Upper Jurassic source rock intervals. Thick delta and shelf sandstones overlain by transgressive claystones formed laterally extensive reservoir-seal couplets within the Jurassic interval. Faulting during the Jurassic and early Cretaceous created large traps that were imaged on a 2 x2 km 2D grid of seismic data.

Well 6507/10-1 was drilled in 1982 on a location down dip of the later Heidrun discovery. The well encountered water bearing Jurassic sandstones. Traces of oil recovered from cores were interpreted by the operator not to represent migrated hydrocarbons. The operator concluded that faulting near the crest of the structure failed to create a viable trap.

ARCO Norway acquired a suite of seismic lines over the crest of the structure for use in the 8th Round evaluation. The lines were interpreted to demonstrate a valid trap on block 6507/7 up dip of well 6507/10-1. This was confirmed by the discovery well and the subsequent development program.

The Heidrun field demonstrates the importance of appropriate seismic data for trap definition. It also offers a caution against pessimistic interpretations of source rock geochemical data and highlights the importance of understanding any down dip hydrocarbon indications.



The first wells drilled in Mid-Norway were located on structural highs. A thin interval of Upper Jurassic claystones in one of these wells confirmed the presence of a source rock correlative with the North Sea Kimmeridgian shale.

Well 6507/11-1 encountered gas-bearing Jurassic sandstones in a horst structure. The sandstones were overlain by Cretaceous claystones.

Well 6507/12-1 encountered similar sandstones, which were water-bearing. These sandstones were overlain by a thin interval of Upper Jurassic Kimmeridgian claystones.

Seismic data was interpreted to indicate possible thickening of the Upper Jurassic interval to the south and west of these two wells.

Introduction: Norway Fifth Round

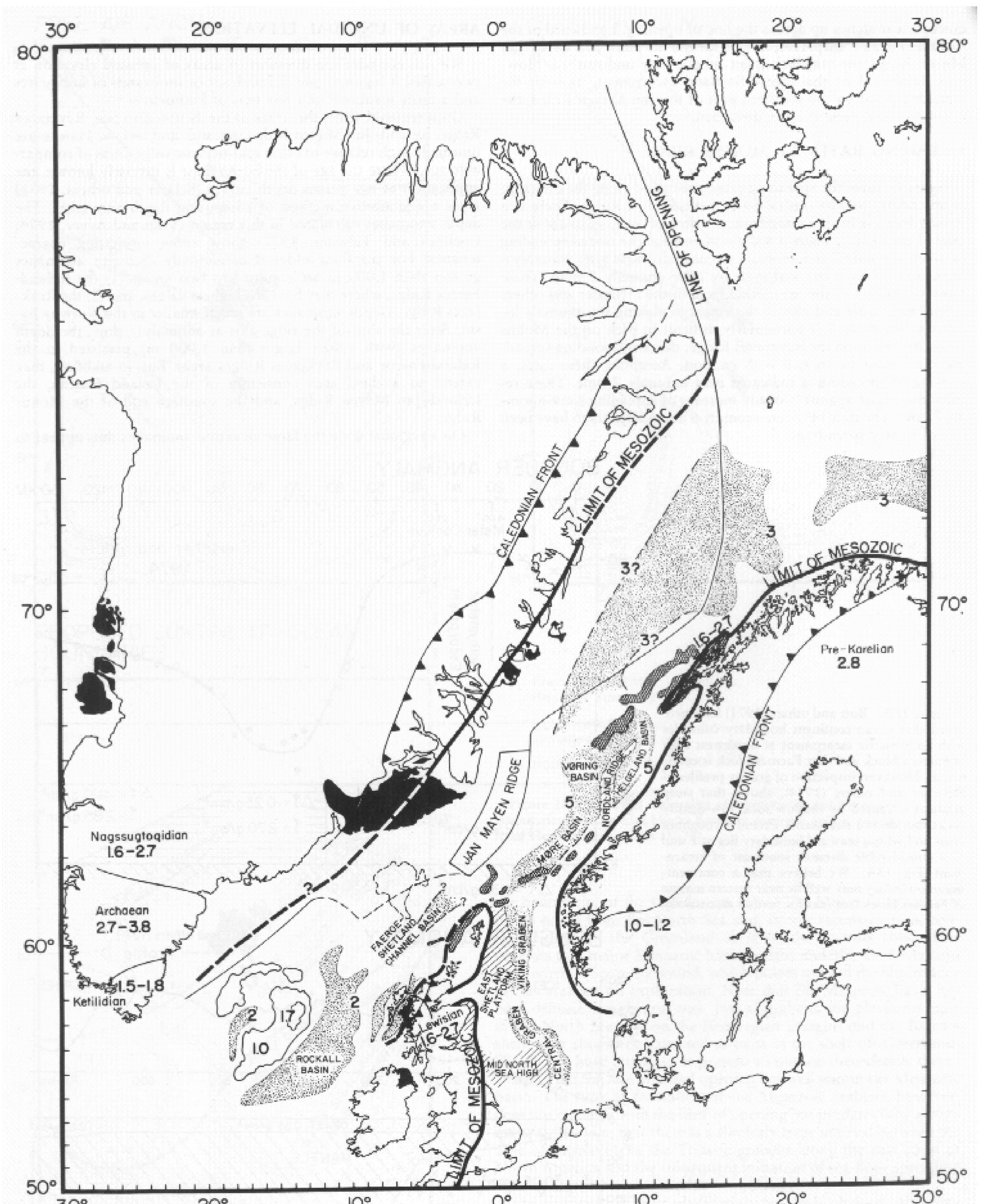
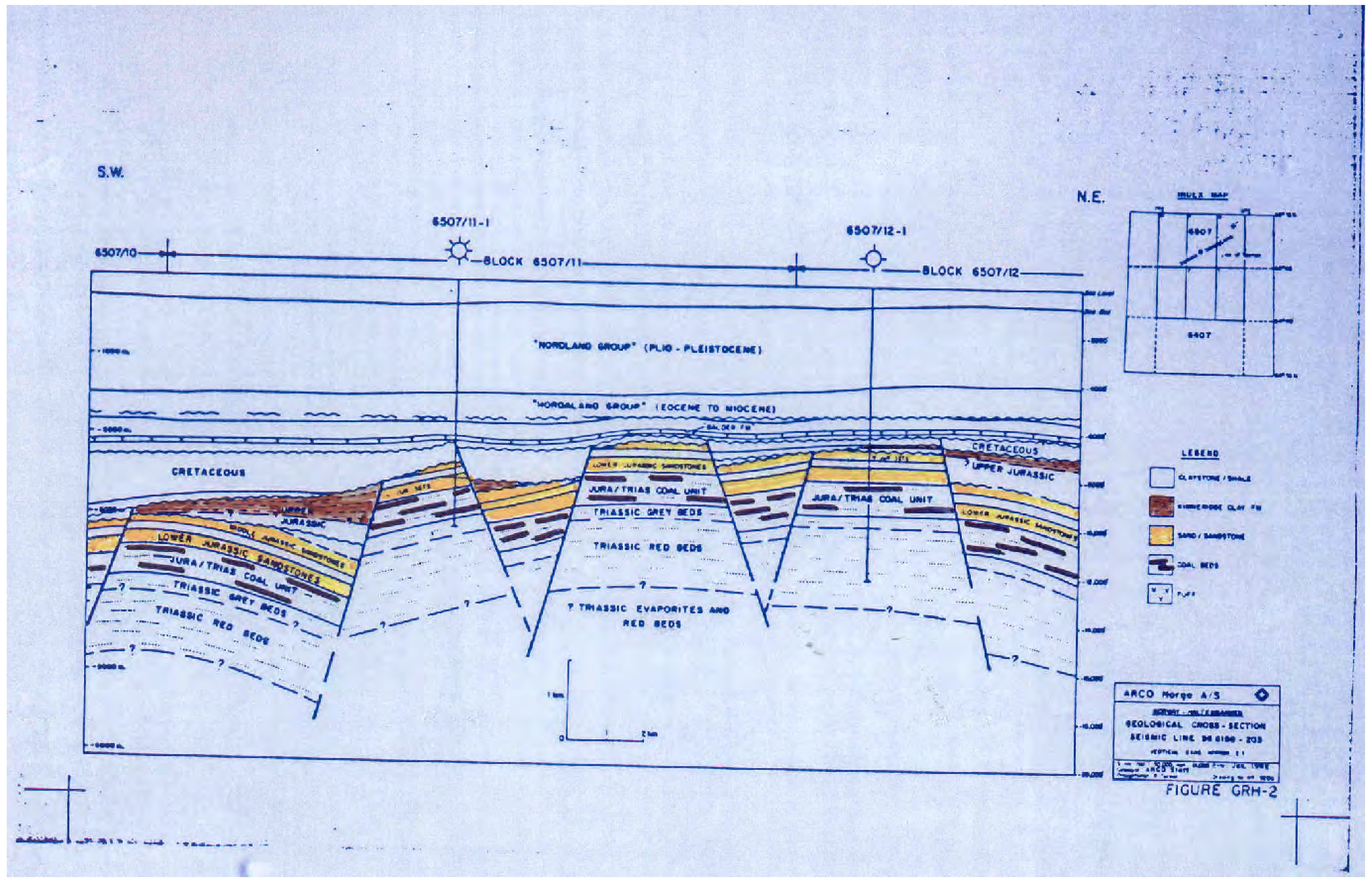


Figure 19, Talwani and Eldhom (1977)

The Norway Fifth Round initiated exploration north of 62° N in Northwest Europe. Academic and government studies demonstrated that the Jurassic depositional system found in the northern North Sea occurred in eastern Greenland. Reconnaissance seismic data tied to bottom core samples suggested Jurassic and younger sediments could occur beneath the Norwegian shelf between the Viking Graben and the Barents Sea. Talwani and Eldholm published several papers showing the magnetic anomalies of the North Atlantic oceanic crust and the inferred rifting history of the basin. Maps synthesizing these data and inferences suggested the petroleum system of the Viking Graben extended north, beneath the Mid-Norway shelf.

The Norwegian Petroleum Directorate opened the Mid-Norway shelf in 1980 with the Fifth License Round. Several exploration wells on Fifth Round blocks confirmed the presence of a Jurassic petroleum system analogous to the Viking Graben. The MIdgard Field discovered gas-condensate in middle Jurassic sandstone reservoirs.



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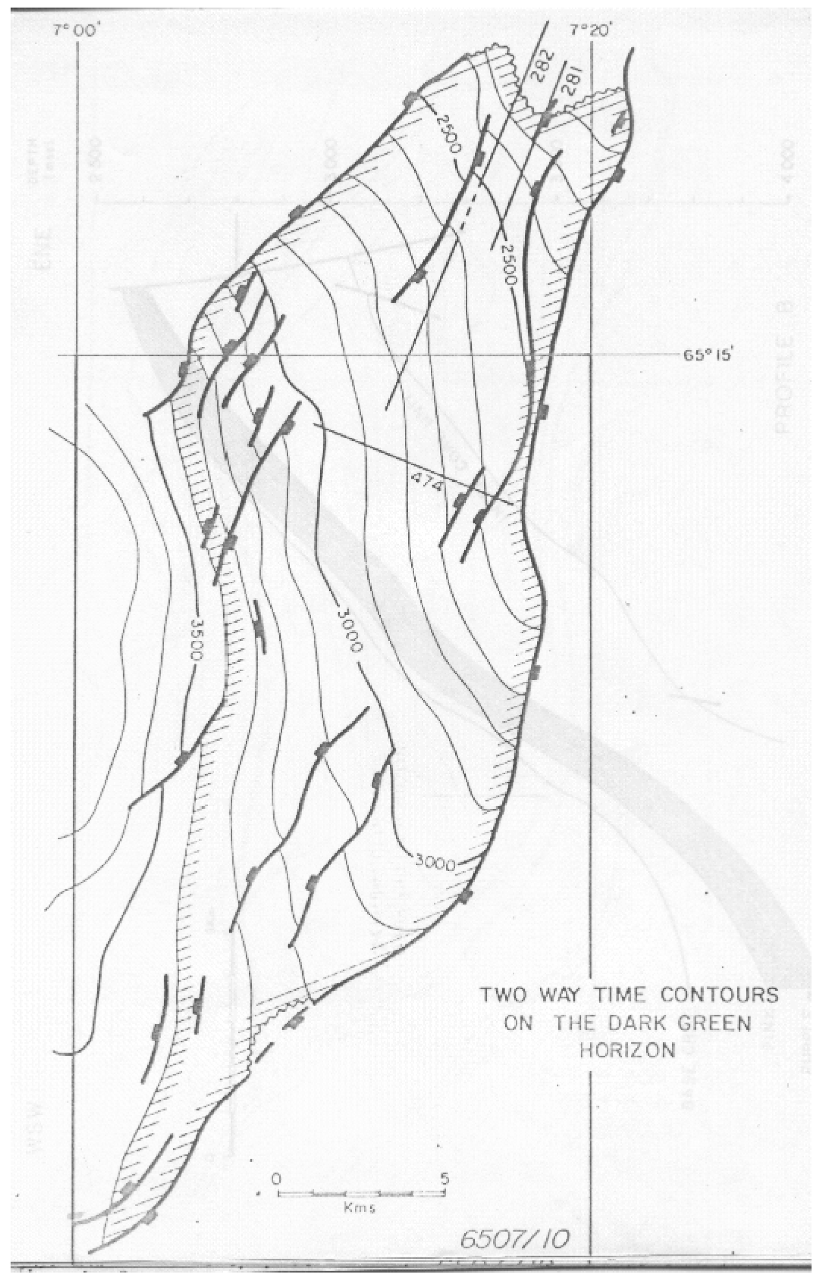
Well 6507/10-1

Block 6507/10 was awarded in 1981 as part of the Fifth Round Second Supplement.

A 4 x 4 km seismic grid acquired by the NPD was supplemented by a 4 x 4 km group shoot seismic grid to form a 2 x 2 km seismic grid over the block.

A large tilted fault block created the primary prospect on the block. The operator interpreted an on-lapping seismic reflector package to be an Upper Jurassic sand-prone interval. This was identified as the primary target of well 6507/10-1. It was considered a likely analog to the Magnus Field of the Viking Graben.

Note that this interval is truncated at the crest of the structure in an adjoining block. The operator preferred a well location down dip from the block boundary that would test a closure of 10 billion barrels.



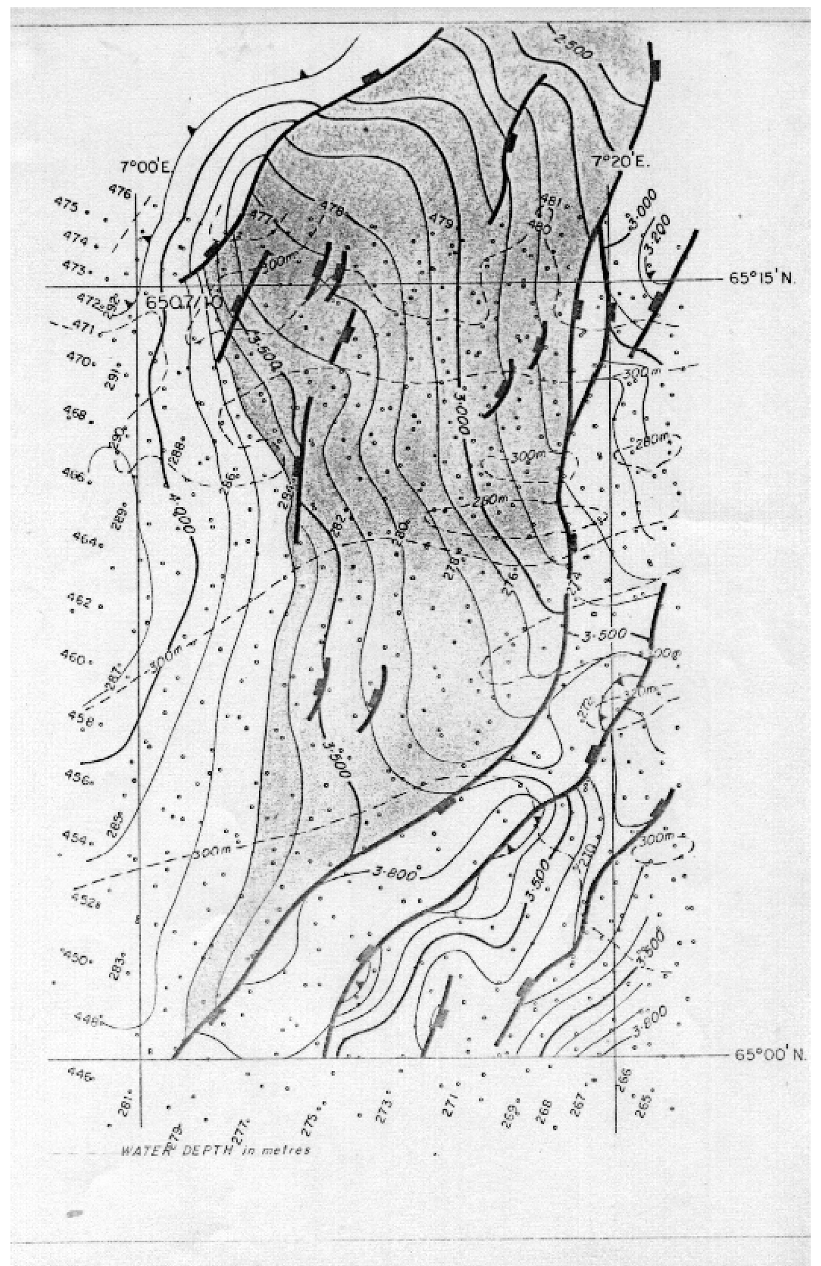
Operator's 6507/10-1 Pre-drill Map

ARCO interpreted the 4 x 4 km grid to show a tilted fault block on Middle Jurassic and deeper horizons. The overlying Upper Jurassic interval was considered a secondary objective.

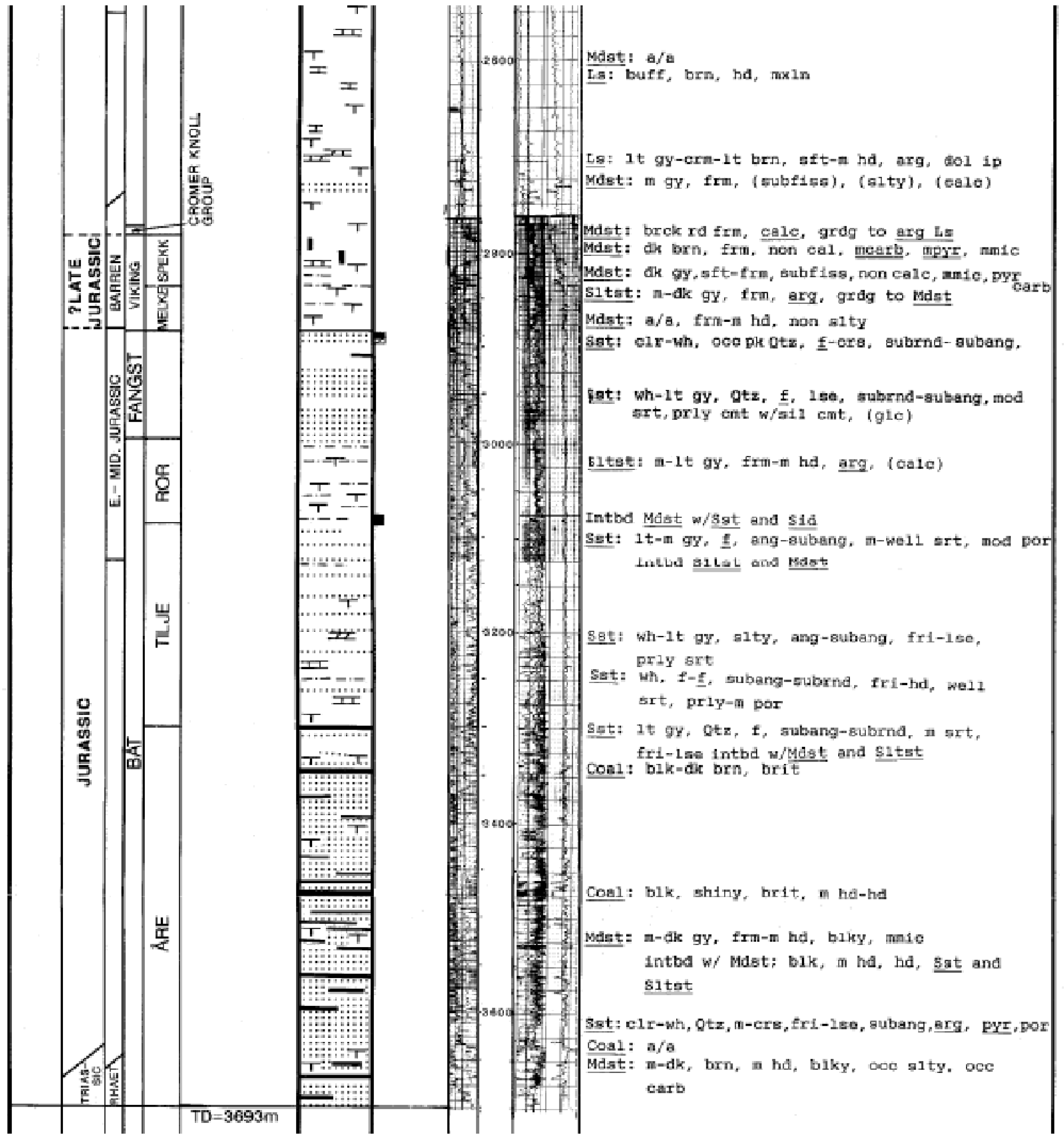
ARCO's preferred location was up dip of the operator's proposal, due to concerns the eastern bounding fault might leak where potentially thick reservoirs sands would be juxtaposed across the fault.

Note that ARCO's Fifth Round map does not show the northern limit of the structure, which was located on the adjoining block.

Partners agreed to drill well 6507/10-1 at the operator's location.



ARCO 6507/10-1 Pre-drill Map



Completion Log Well 6507/10-1 Jurassic Interval

Well 6507/10-1 was drilled in 1982. It encountered Middle and Lower Jurassic sandstones beneath a thin interval of Upper Jurassic claystones. The prognosed Upper Jurassic sandstones were not present.

Vitrinite reflectance measurements of well samples indicated the top of the oil window (Ro=0.55%) in the range 3674 +/- 341 meters.

Upper Jurassic Kimmeridgean clays were "extremely rich" in oil-prone organic material. The Lower Jurassic silstones and shales have "good" organic richness, with oil and oil/gas potential.

Trace samples of oil were recovered from cores within the Jurassic interval. The operator analyzed these and offered three interpretations of their potential source:

1. The oils of maturity and type to be "locally" derived
2. The oils DID NOT correlate with major source interval analyzed in this well
3. The oils "could be contaminant from handling or preservation of the samples".

The operator concluded these oils "are not from a major migration route".

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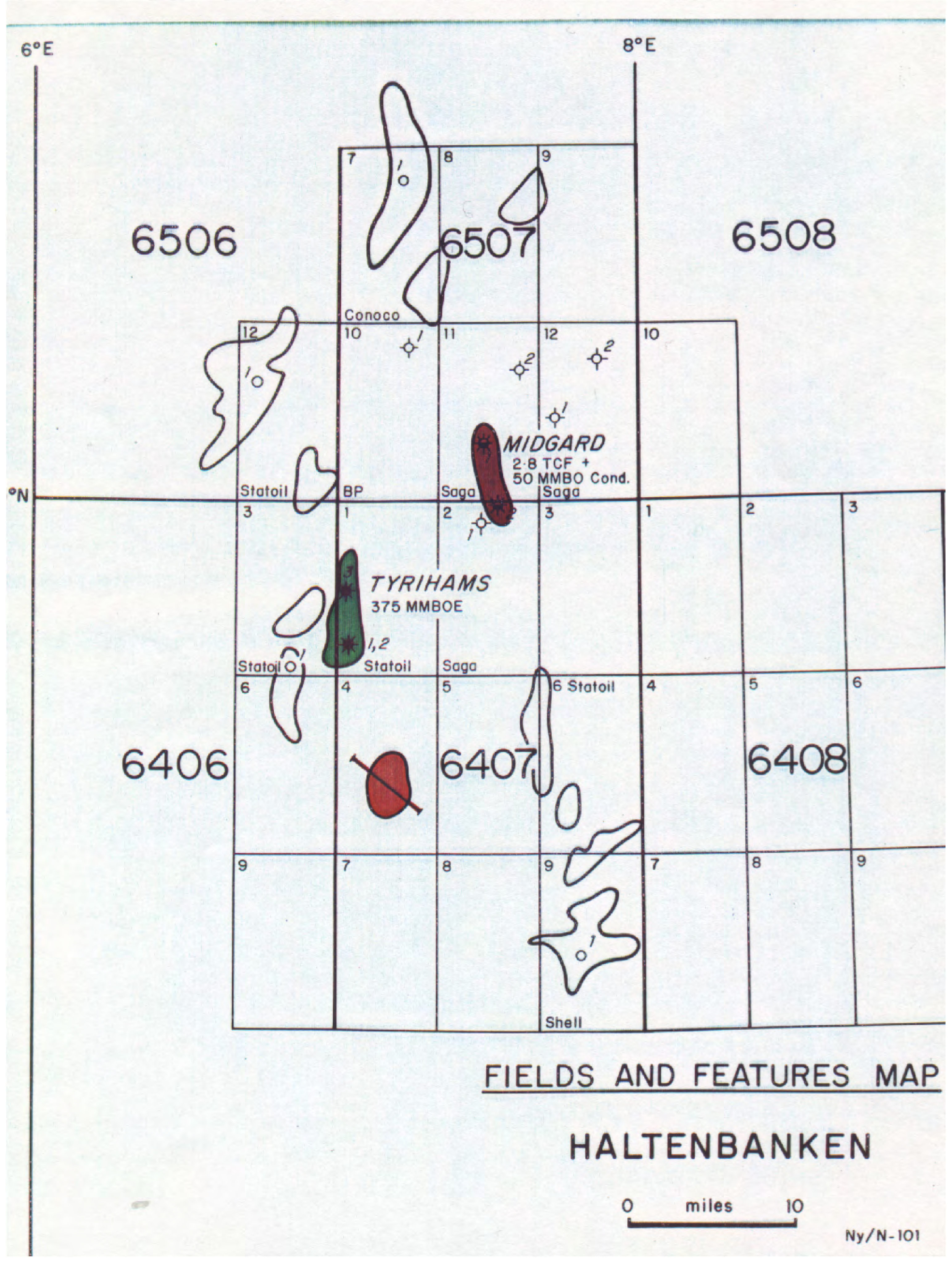
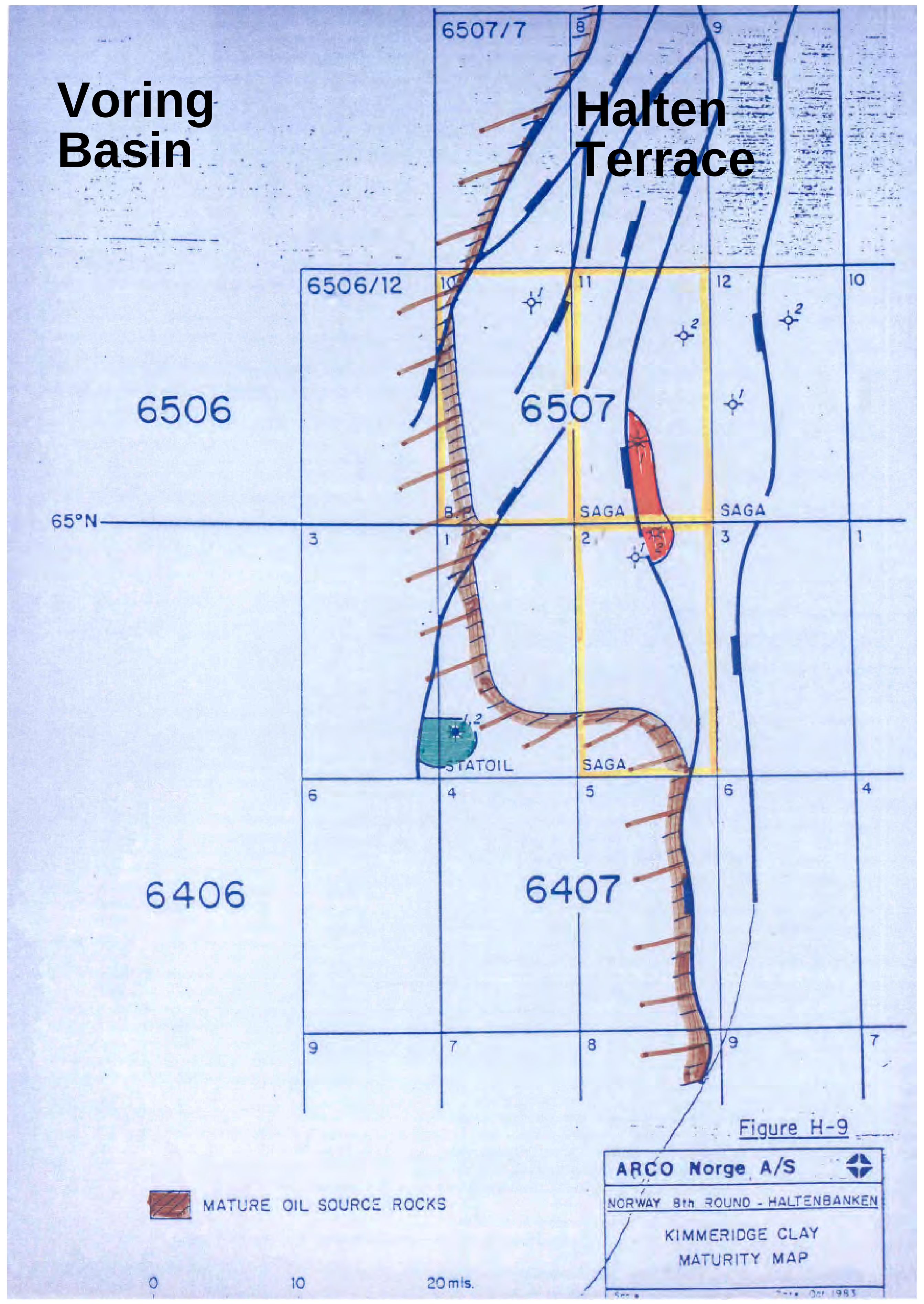
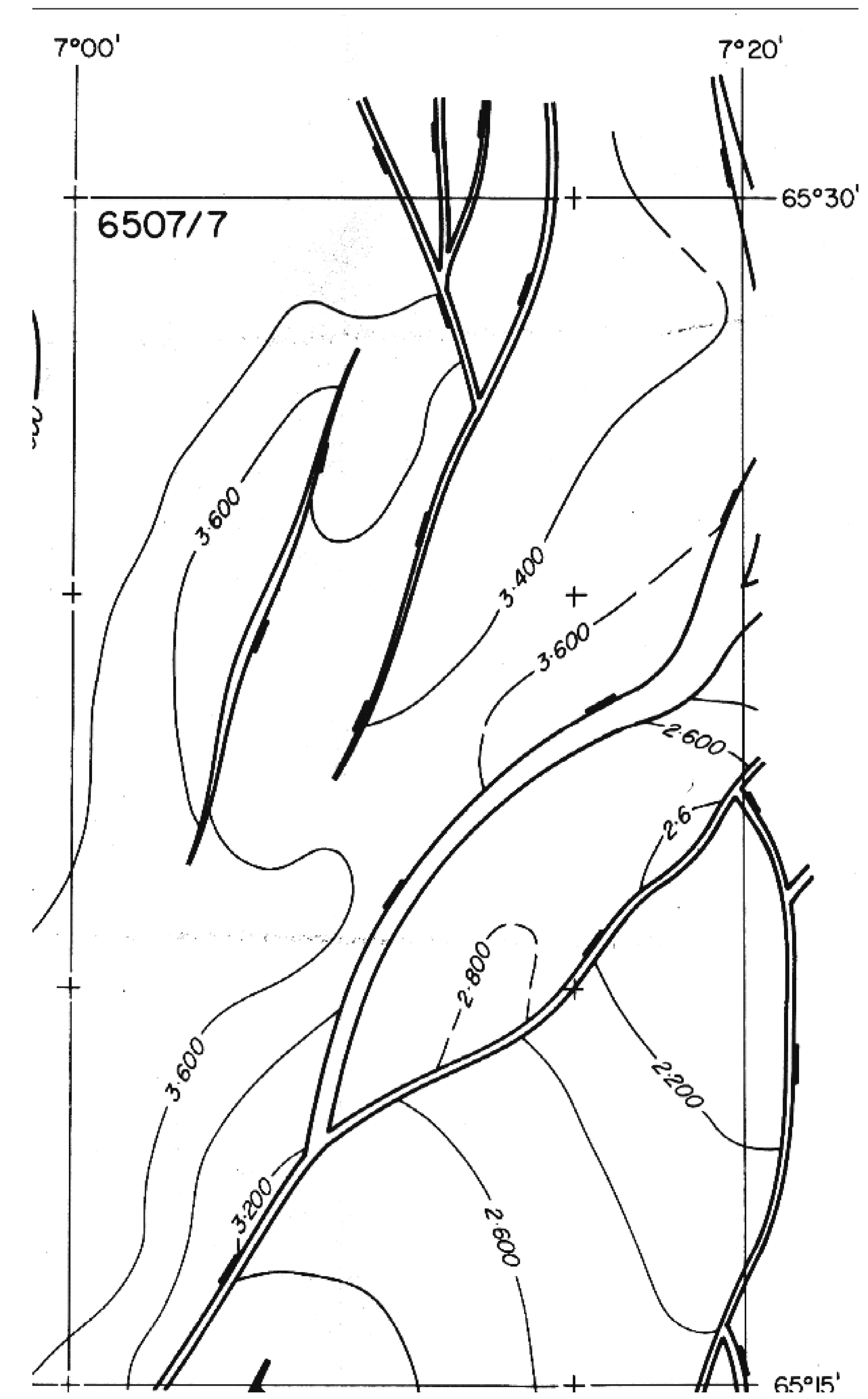
Norway Eighth Round







ARCO Eighth Round Lower Jurassic Time Map

The Eighth Round offered blocks contiguous with discoveries that followed earlier block allocations by the NPD. The Tyrihans oil discovery followed the Midgard, confirming the basin's potential for oil as well as gas discoveries.

As with earlier rounds, the NPD acquired a 4 x 4 km seismic grid over the offered blocks, and a group shoot acquired in-fill data to create a 2 x 2 km grid.

The seismic data showed a prominent marker at the base of the Cretaceous interval. The Trondelag Platform on the east was seen to step down to the west through the Halten Terrace, a zone of north- and northeast-trending faults to the Voring Basin on the west (Gabrielsen et al 1984). The two fields occupied blocks within the Halten Terrace.

Well data was traded widely among companies with interests in existing licenses. Source rock analysis, performed on all wells, demonstrated the presence of two wide spread source intervals: the Upper Jurassic oil-prone Kimmeridgian interval and the Lower Jurassic gas-prone "coal unit". Well data indicated these would be mature for hydrocarbon generation in the basinal area west of the Halten Terrace.

Reservoir quality sandstones were identified in the Middle and Lower Jurassic intervals. The Upper Jurassic in the Halten Terrace comprised claystones and rare siltstones.

The Middle Jurassic sandstones were overlain by Upper Jurassic or Lower Cretaceous claystones. Intra-formational claystones within the Lower Jurassic were interpreted to provide potential seals of a local extent, but were not considered reliable regional seals.

Interpretation of seismic data on Block 6507/7 identified two prospects within the Jurassic interval.

A faulted domal closure was interpreted on the northwestern quadrant of the block at 3.4 s twt. This prospect was considered to have both oil and gas potential due to the depth of burial of both source rock intervals.

A tilted fault block, previously tested by well 6507/10-1 was interpreted on the southeastern quadrant of the block. This prospect was thought to be at the apex of a large source rock kitchen located in block 6507/10. The Upper Jurassic was thought to be within the oil window in the kitchen area, and the Lower Jurassic was thought to be marginally within the gas window. Reservoir quality sandstones encountered in well 6507/10-1 were anticipated to occur throughout the prospect, although it was possible these would be truncated near the top of the structure.

A major concern remained: did the faults bounding the structure create a closure at its apex? To address this issue, ARCO acquired a suite of proprietary lines.

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ARCO Interpretation of 6507/10-1 Oil Data

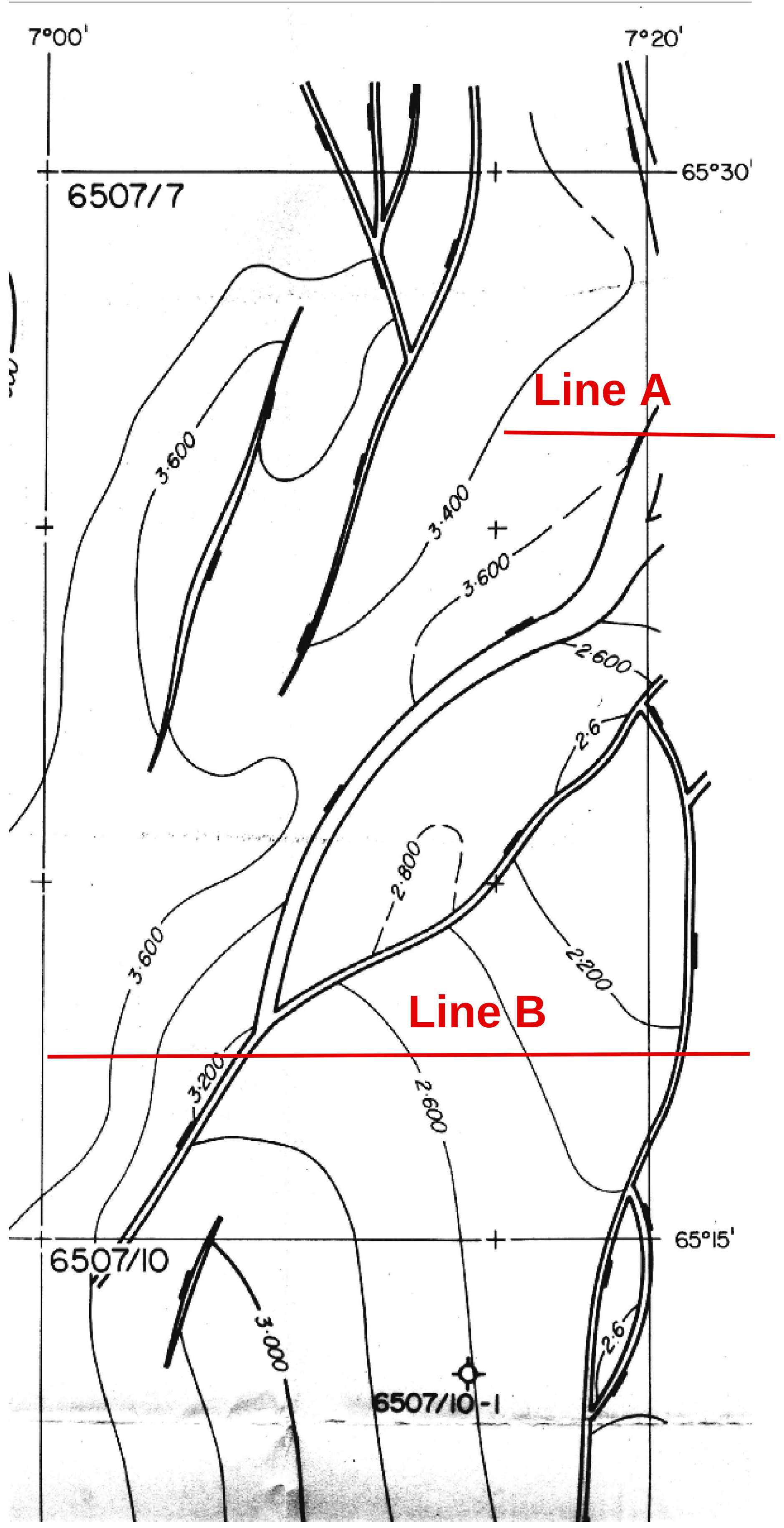
In preparation for the Norwegian Ninth Round in 1984, ARCO geochemists reviewed all of the source rock and oil samples analyses obtained for samples from wells drilled in Mid-Norway (Horsefield, internal ARCO Report). This review refined ARCO's model of source rock maturation for the Halten Terrace and the Voring Basin. The fluids collected from well 6507/10-1 were interpreted to represent oils similar to those generated by the Kimmeridgian interval in the Viking Graben. The maturity of these fluids was interpreted to reflect their migration from a kitchen area located down dip of the well location.

Well 6507/10-1 was not considered to lie upon a major migration route. The Base Cretaceous Unconformity was interpreted to show a plunging nose located near the eastern border fault of the structure. This was considered a likely migration route for hydrocarbons generated in the kitchen area south of the structure. A more problematic migration pathway was interpreted for the fault zone on the northwest side of the structure.

ARCO Eighth Round Seismic Data

In preparation for the Norwegian Eighth Round, ARCO acquired a 585 km of proprietary seismic data to supplement the existing 2 x 2 km grid. The ARCO data was located to create local 1 x 1 km grids over features considered critical to prospect evaluation of several blocks offered in the Eighth Round.

The 6507/7 tilted fault block prospect is formed by the intersection of two normal faults at the northern end of the structure. The 2 x 2 seismic grid did not conclusively demonstrate the critical intersection of the bounding faults. The in-fill ARCO lines did show the intersection of these faults.



Lower Jurassic Time Structure Map

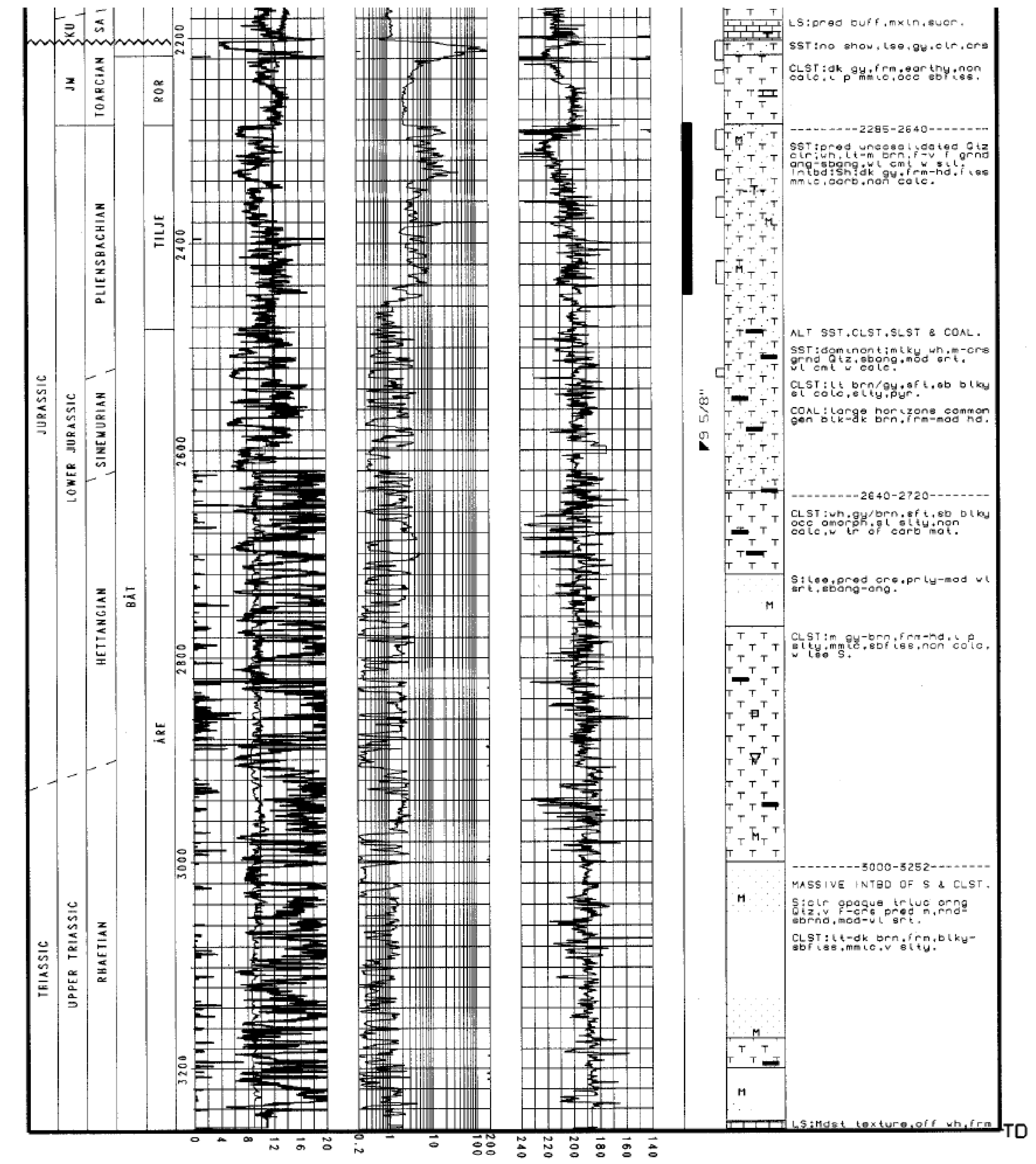
Norway Eighth Round Award

Licenses were awarded by the NPD on a discretionary basis. Individual companies carried out their own evaluations and applied individually with a proposed work program. The NPD then decided which companies would be offered a share in the block, and what percentage they would each be offered. Norwegian companies were always favoured. The NPD also selected the operator.

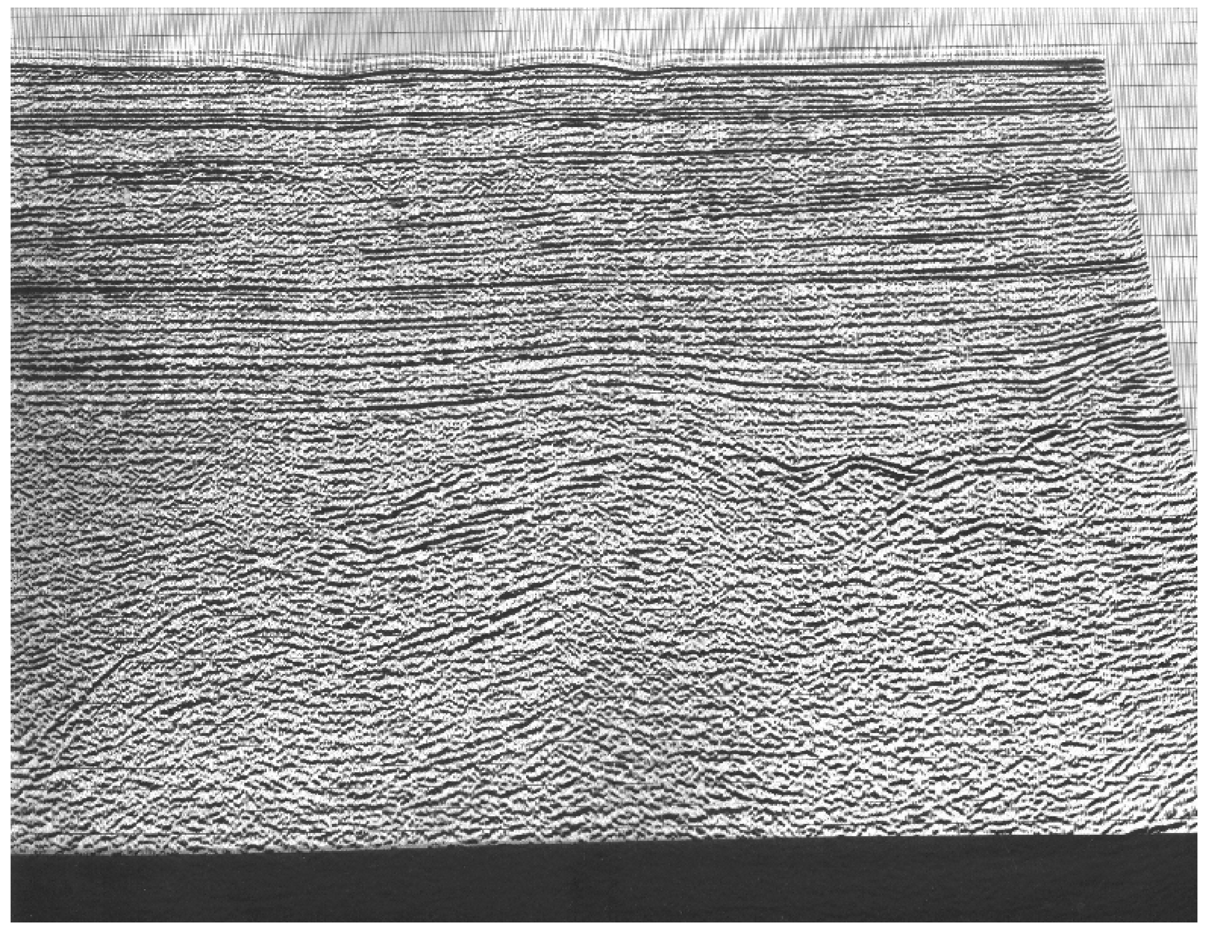
The NPD awarded block 6507/7 to a new consortium of companies, some of which did not participate in well 6507/10-1. This group chose to drill well 6507/7-1 on the domal prospect located in the northwest quadrant of the block. This well found water-bearing Jurassic reservoirs.

The Operator suggested a second well on the block would be unsuccessful. Partners, including ARCO, and the NPD noted that the license award entailed a second commitment well.

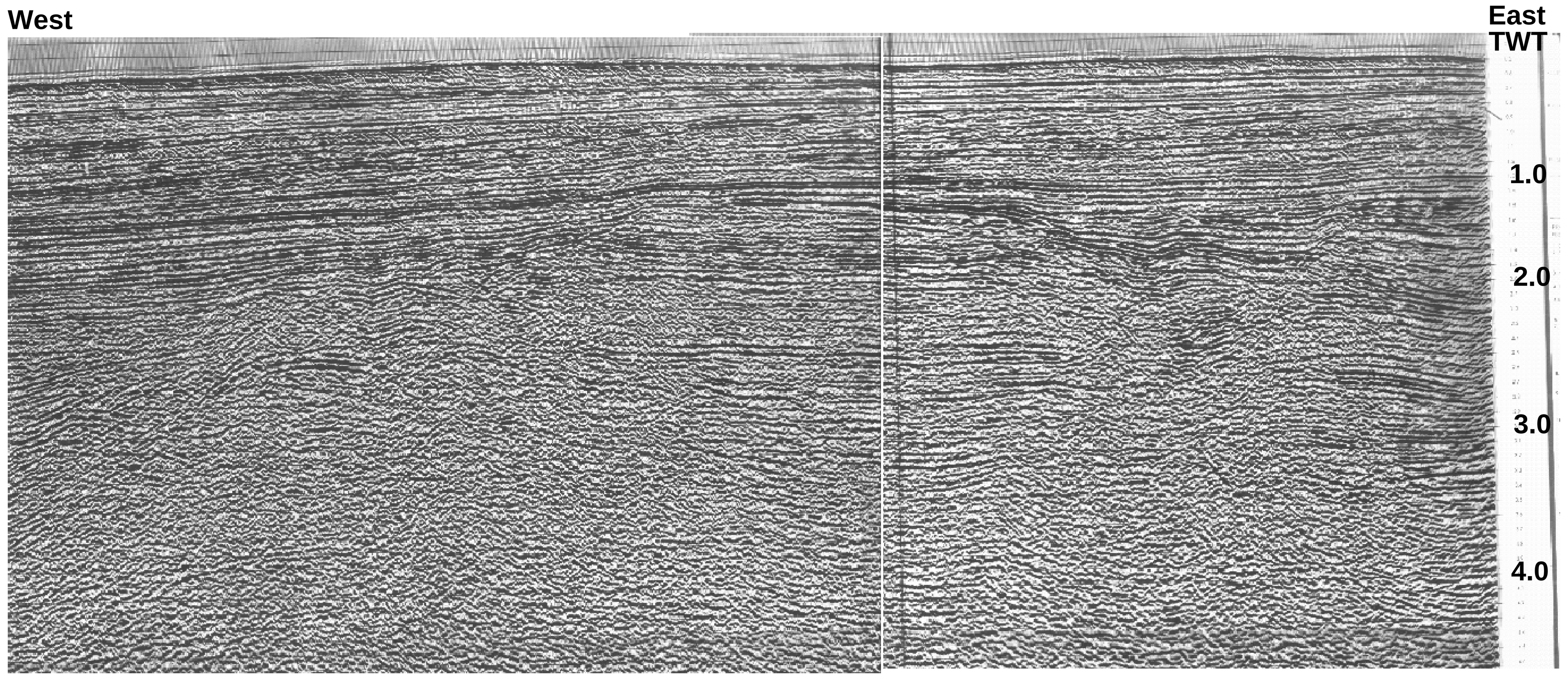
The consortium then chose to drill well 6507/7-2, which tested oil from a Middle Jurassic reservoir. Success with this well led the consortium to acquire a 3-D seismic survey over the trap.



Line A



Line B



Completion Log Well 6507/7-2 Jurassic Interval

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Heidrun Field Development

ARCO Well and Field Prognosis

Well data from the eight wells drilled prior to 6507/7-2 were used to develop reservoir parameters for the well prognosis. The 2 x 2 km seismic grid supplemented by the ARCO proprietary seismic data were employed to create structure maps on the Base Cretaceous Unconformity and on the Lower Jurassic“Coal Unit” reflector.

The well was prognosed to encounter the Lower Jurassic “Coal Unit” at approximately -9500 feet. A major issue for reservoir characterization was the thickness of Middle Jurassic sandstone preserved beneath the Base Cretaceous Unconformity. This was further complicated by cross-fault sealing along the eastern boundary fault, where down thrown Middle Jurassic sandstones might be placed against Lower Jurassic sandstones.

The upper section of the Middle Jurassic sandstone typically had a net-to-gross ratio close to 1, while the lower section typically had a net-gross-ration close to 0.5. Average porosities for Jurassic sandstones at the target depth ranged between 20 and 26 percent.

The following parameters were used in ARCO’s evaluation:

	10%	Mean	90%
Area	4570 Acres	6465 Acres	9215 Acres
Net Pay	100 Feet	330 Feet	900 Feet
Recovery Factor	255 b/ac-ft	445 b/ac-ft	700 b/ac-ft

Predicted reserves if the well was successful:

	10%	Mean	90%
	165 MMBO	944 MMB0	2050 MMBO

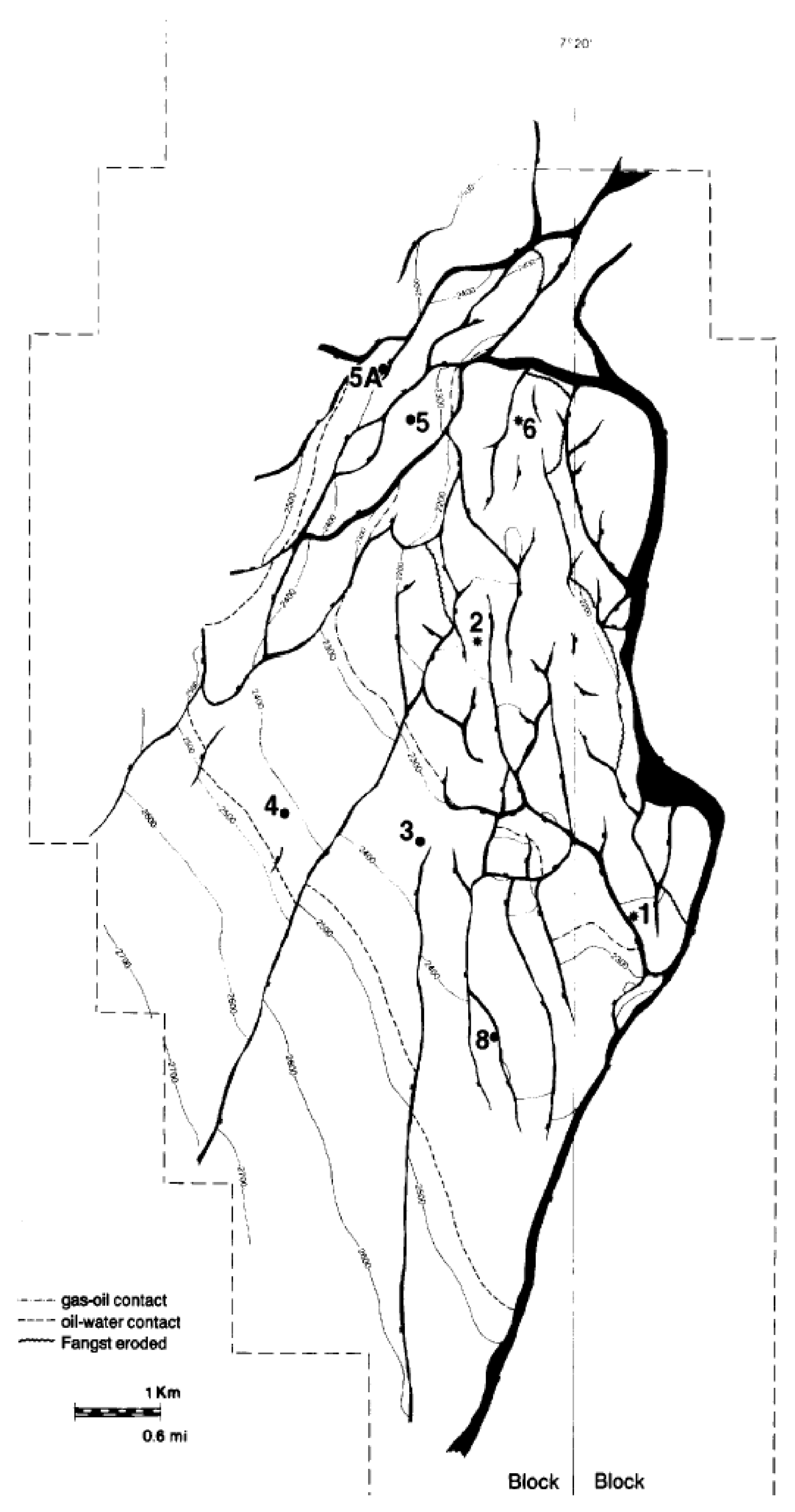
ARCO engineers anticipated the peak field production for the success case would be 290,000 BOPD or 105,850,000 barrels per year (16.8 million cubic meters per year).

Following the successful test of well 6507/7-2, oil was found to be down to -8090 feet. The operator estimated that with a 30 % recovery factor, the field would produce 863 MMBO. It further estimated that with a recovery factor of 40% the field would produce 1,150 MMBO.

Results of Initial Appraisal Work

The success of well 6707/7-2 lead to a acquisition of a 3-D seismic data volume and an extensive appraisal drilling program. Drilling confirmed erosion of the Middle Jurassic sandstone at the crest of the structure, as well as the high net-to-gross ration of that interval. Porosity was found to average 30 percent, significantly greater than prognosed by ARCO.

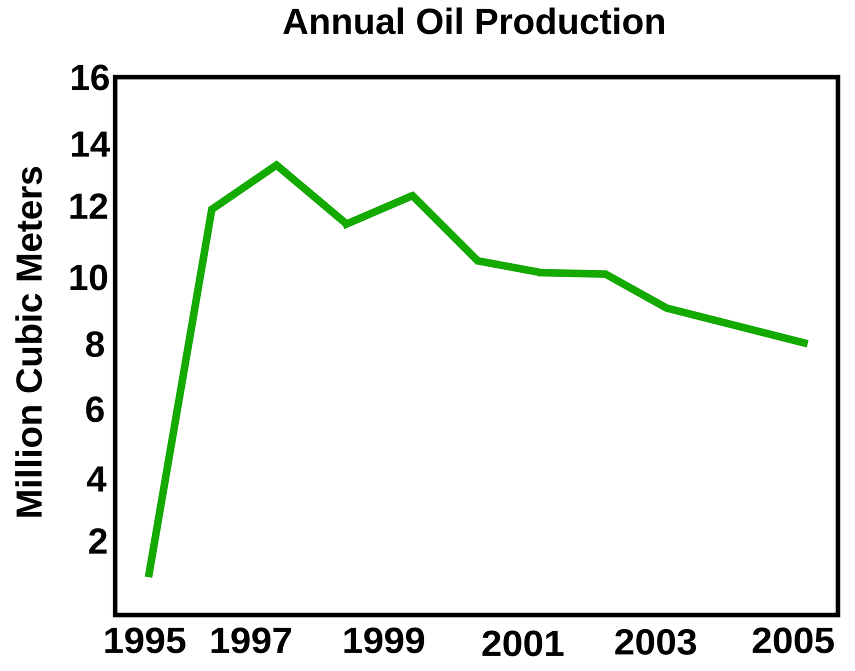
3-D Seismic Data Field Map

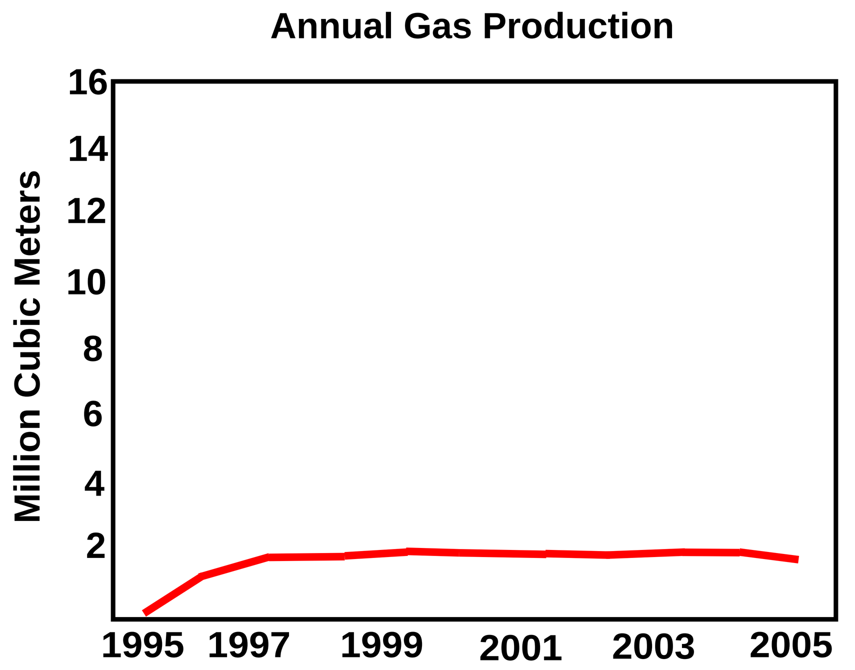


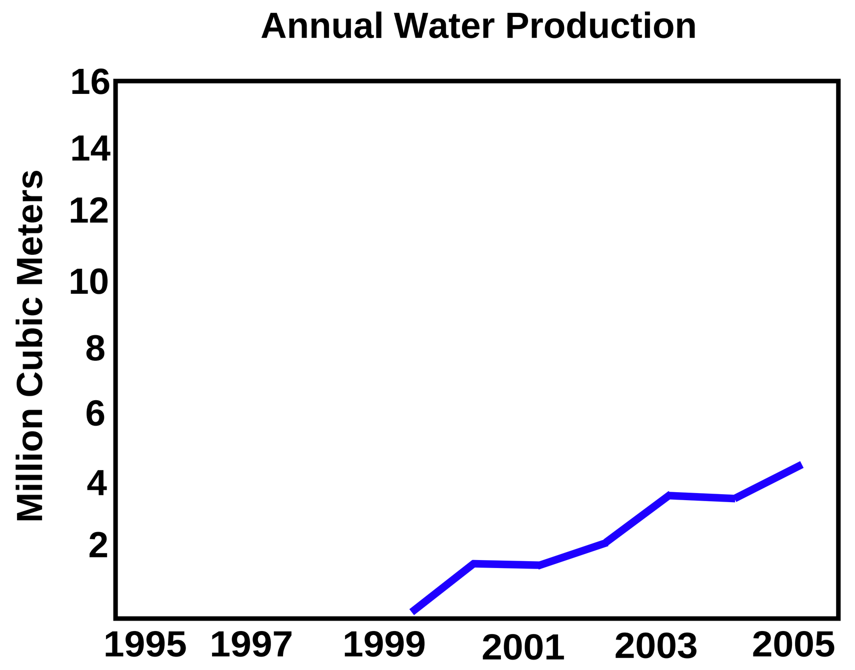
(Figure 3 Harris 1989. See also Figure 2 Schmidt 1992)

The 3-D seismic data showed the field to be bounded on the east by both northeast and north trending faults, while the interior of the fault block was a mosaic of smaller blocks near its crest. The northwestern boundary of the field was formed by a relay of northeast trending faults. Altogether the structure was much more complex near its crest than indicated by the 2-D seismic data acquire before the discovery well was drilled.

Production Profile







Heidrun Field was estimated to hold 1,132,165,900 barrels of recoverable oil (180 million cubic meters) when it began production in October, 1995 (Norwegian Petroleum Directorate). It was also estimated to hold 150 billion cubic feet of gas (42.7 billion cubic meters).

The Heidrun Field, Offshore Mid-Norway-6

Discussion

1. The use of analogs: early exploration of Mid-Norway was motivated by success in the UK and Norwegian sectors of the North Sea. The Viking Graben hosted tilled fault blocks formed during Triassic and Jurassic rifting. Lower, Middle, and Upper Jurassic sandstones served as reservoirs for oil and gas generated primarily from Upper Jurassic claystones. Intra-formational claystones and Lower Cretaceous claystones created seals to underlying reservoirs.

Each play in the Viking Graben was initially discovered by wells testing play concepts somewhat or very different from their actual discovery (Woodland 1975). Delineation drilling typically showed unexpected reservoir and structural complexity (Dore and Vining 2005). One early well drilled on the Heidrun discovery structure was interpreted by several companies to condemn the feature when it failed to conform to a Viking Graben model play.

Focus on narrowly defined model plays tends to obstruct the role of serendipity in exploration.

2. The use of seismic data: a dense grid of seismic data was needed to confirm the structural closure at Heidrun. Early reconnaissance data acquired by academic and government surveys identified normal faults on the Mid-Norway margin, including major faults on the Heidrun structure. A 4 x 4 km seismic grid was subsequently interpreted to show an array of fault blocks on the Halten Terrace, however it was not sufficient to demonstrate closure at the apex of the Heidrun structure. Additional seismic data created a 2 x 2 km grid over the Heidrun structure which left interpretation of the closure problematic. Acquisition of additional supplemental lines to create a 1 x 1 grid permitted interpretation of the structural apex with some confidence. Nonetheless, many features interpreted from the field-wide 3-D survey were not seen on these earlier surveys.

3. The use of organic geochemistry: the first eight wells drilled in Mid-Norway discovered a large gas-condensate field and could be interpreted to show an gas-prone petroleum system was present. A narrow interpretation geochemical data for oils extracted from early wells discouraged some companies from pursuing exploration in Mid-Norway. Recognition that these oils were within the full range of oils recovered in the Viking Graben played a major role in ARCO's persistence in Mid-Norway exploration. Source rock analysis of Kimmeridgian claystones encountered in the first Mid-Norway wells confirmed the presence of a major oil-prone source interval that was analogous to the Viking Graben's main source rock interval.

4. The use of core data to constrain reservoir parameters: early wells in Mid-Norway were extensively cored in Middle and Lower Jurassic sandstones. These cores provided valuable insights into the reservoir potential of the Jurassic which was amply confirmed by subsequent oil field developments. These cores, however, were not sufficient to anticipate the reservoir heterogeneity found in each field.

5. Early estimates of Heidrun's in-place and recoverable reserves were made with a conservative bias. Development drilling and early production demonstrated the field was significantly larger than first indicated. This follows a trend seen in many large fields across many basins: the big fields get bigger.

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