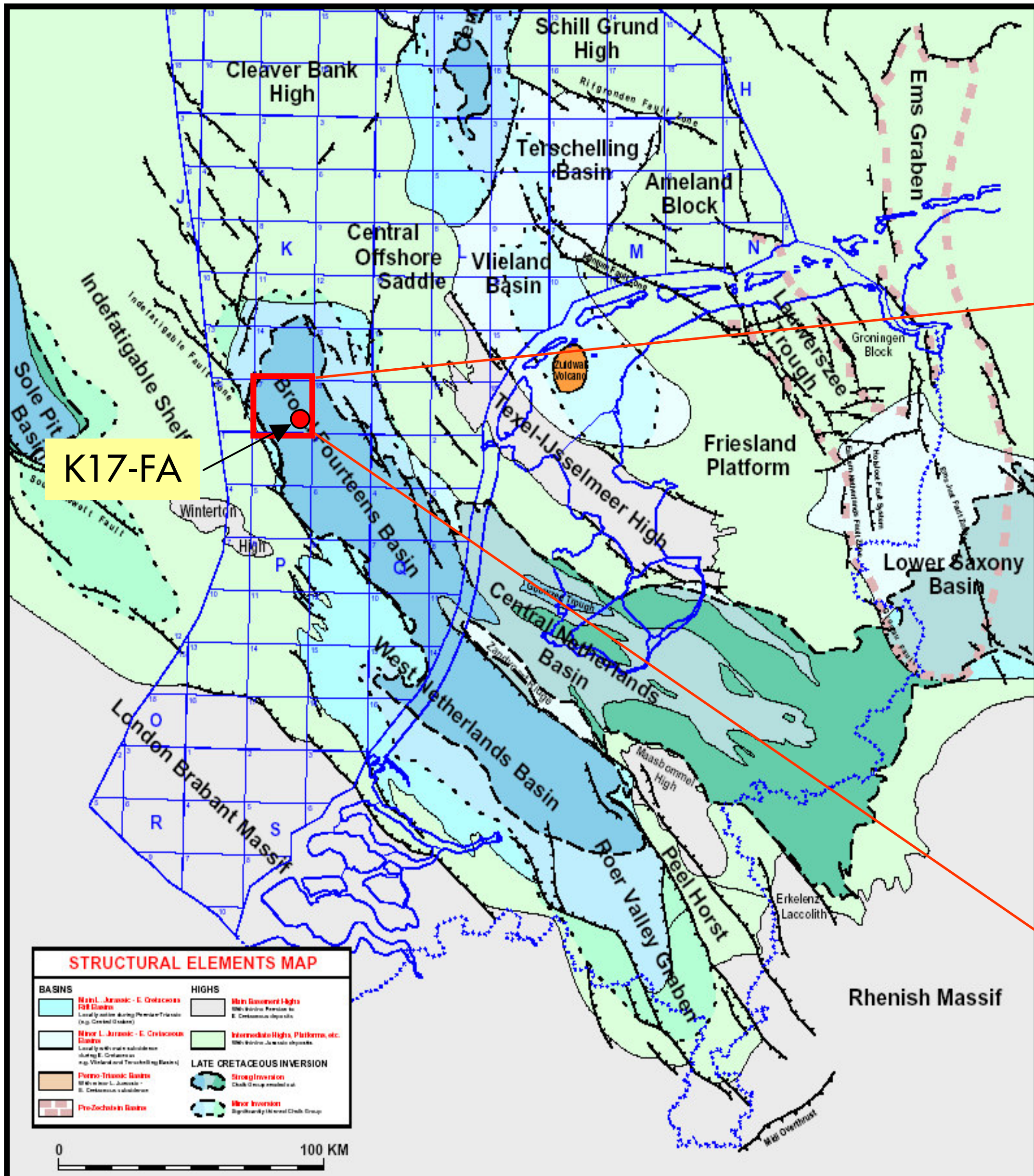
K17-FA Tight Gas Development

NAM-Shell EPE, Assen

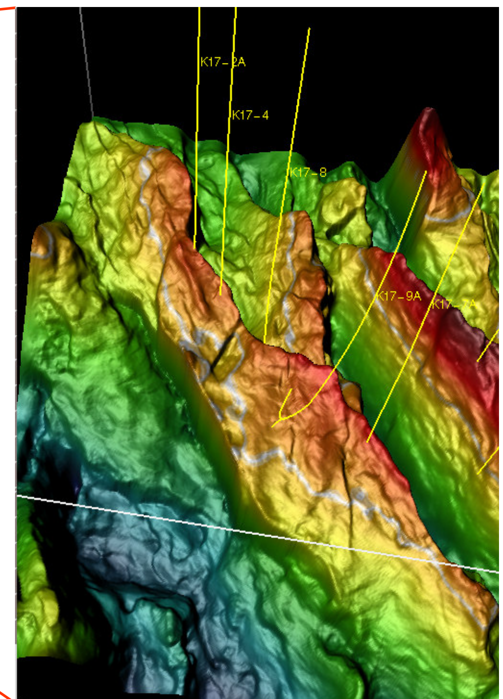
Tight Gas in NL/NL Offshore

- Tight gas defined as reservoir properties <1mD average insitu
- TG Volumes mostly contained in Rotliegend reservoir (Slochteren Sst)
  - Tight gas properties mainly due to diagenetic impairment of reservoir sandstones by combinations of grain coating and pore-filling clay minerals and carbonates
  - Flow during well testing/production logging observed to be derived from few thin zones
  - Large lateral and vertical variation of reservoir facies, difficulty to accurately predict presence/location/orientation/ dimensions of high flow features (fractures/HPS)
  - Absence or paucity of open natural fractures
  - Unusual combinations occur of low to high porosity and low permeability and limited height gas columns (often ~100m) characterised by thick transition zones and significant Sw
  - Compartmentalisation by faults common
- Well bore stability, sand production and risk of water influx are additional complications for TG field development
- Relatively modest in-place-volumes
  - Costs a major factor, cost control & reduction are a CSF
  - Ageing production systems, rising OPEX

K17-Location



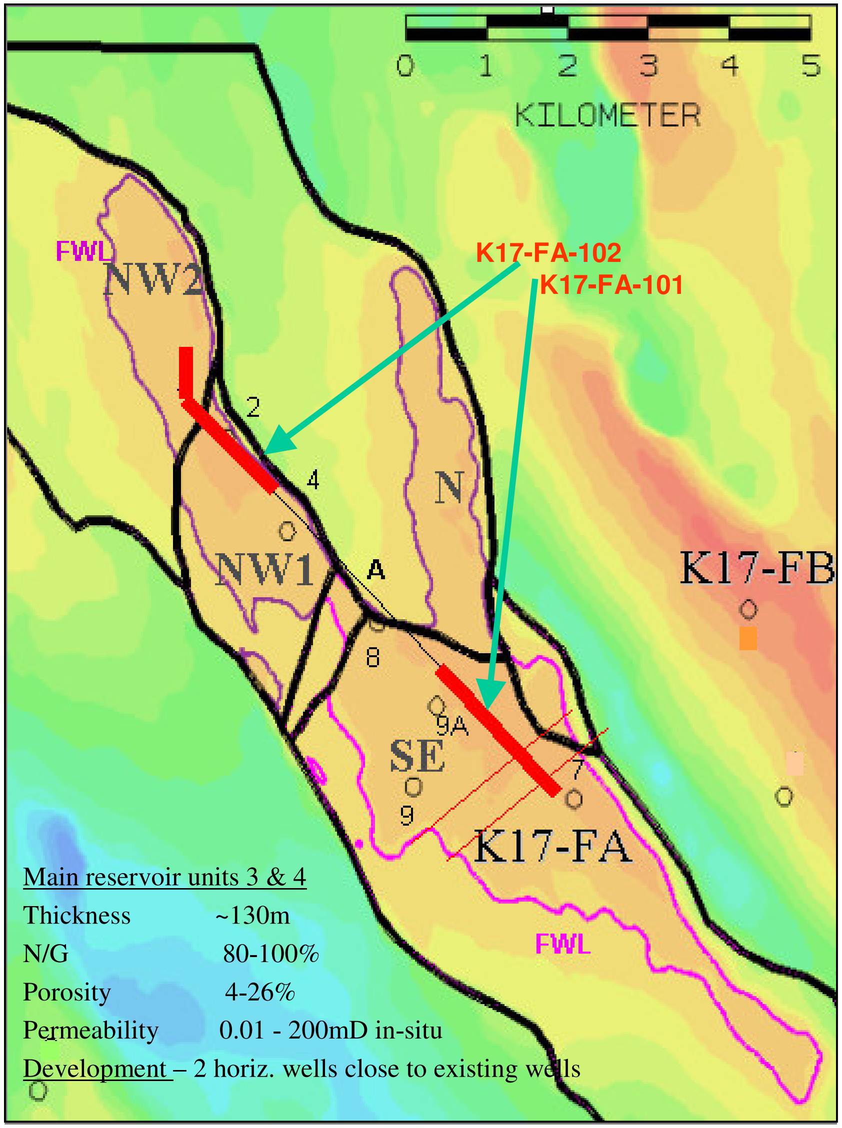
- Broad Fourteens Basin
  - ~80km west of Den Helder
- Complex structural history, tight reservoir



K17-FA

EBN/TNO Tight Gas workshop, 19Sept 2006, Utrecht

K17-FA UBD : Background

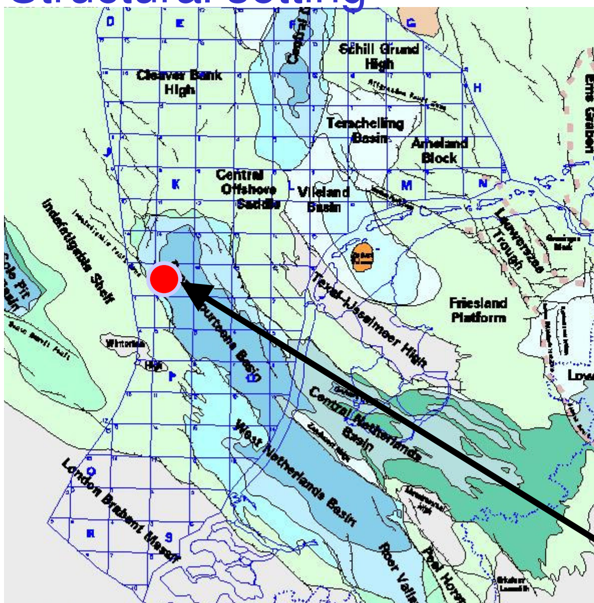


K17-FA discovered in 1972 (#2 well).

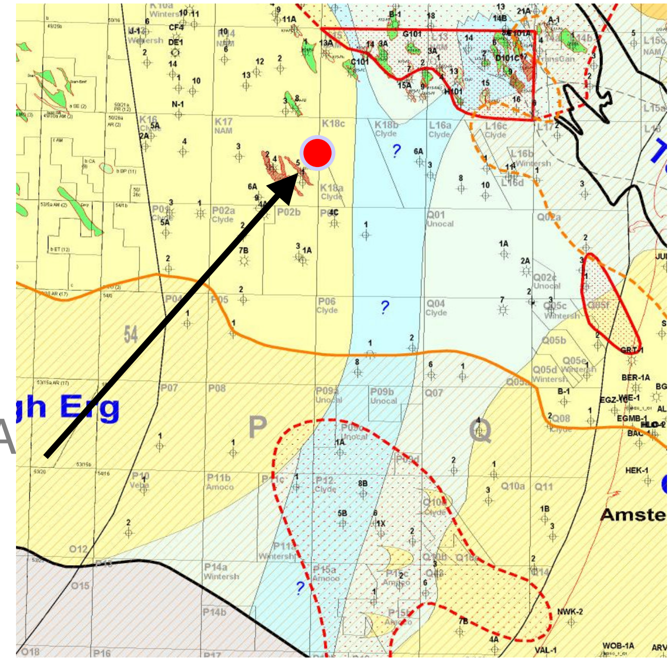
- NAM 60%, EBN 40%
- 1 Exploration and 3 Appraisal wells drilled 1977-1998
- 3D seismic;
  - Excellent to good quality. Complex overburden
- Rotliegend reservoir
  - Predominantly aeolian,with fluvial sandstones
  - Very heterogeneous
  - Paleo burial caused severe reservoir deterioration (hairy illite)
  - Poor well test results (also fracced wells) – tight reservoir

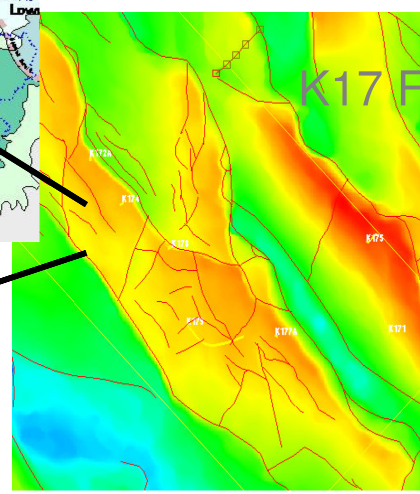
K17-FA – Location and Geological Setting

Structural setting

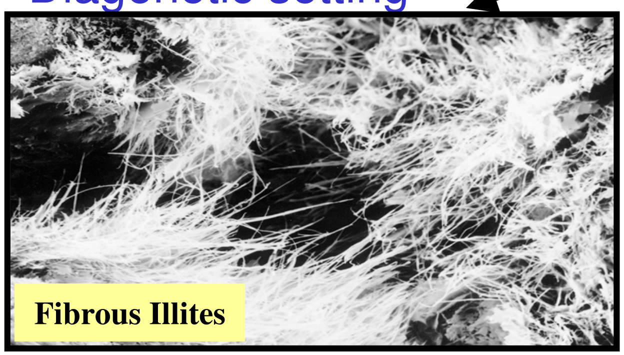


Depositional setting





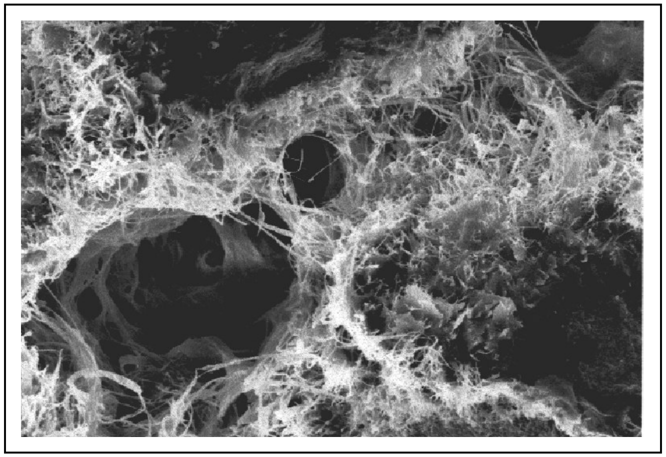
Diagenetic setting

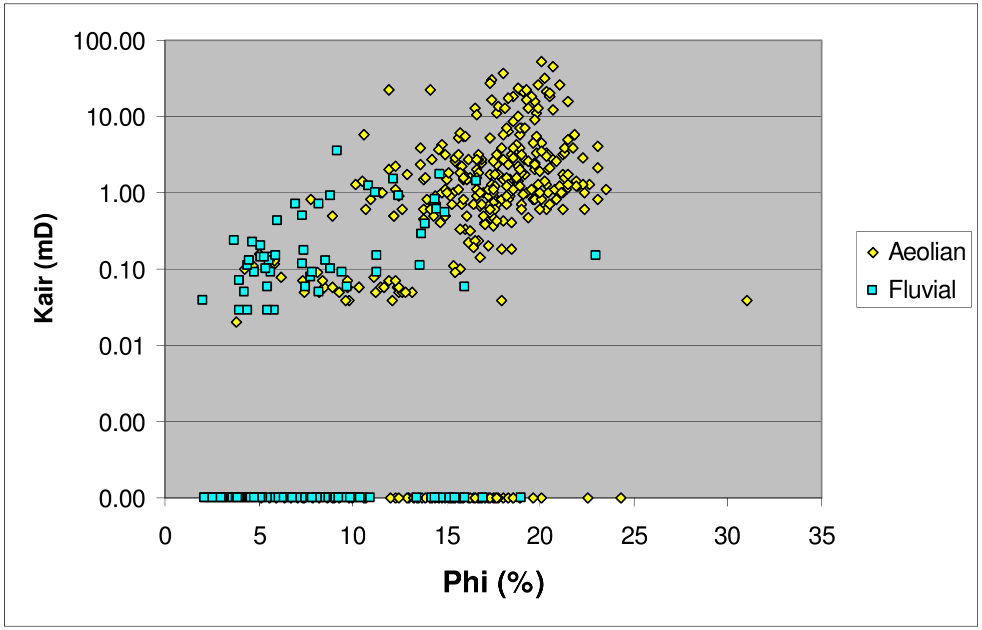


At the SW edge of the inverted Broad Fourteens Basin
Located in Erg setting adjacent to major fluvial system
Reservoir severely illitised

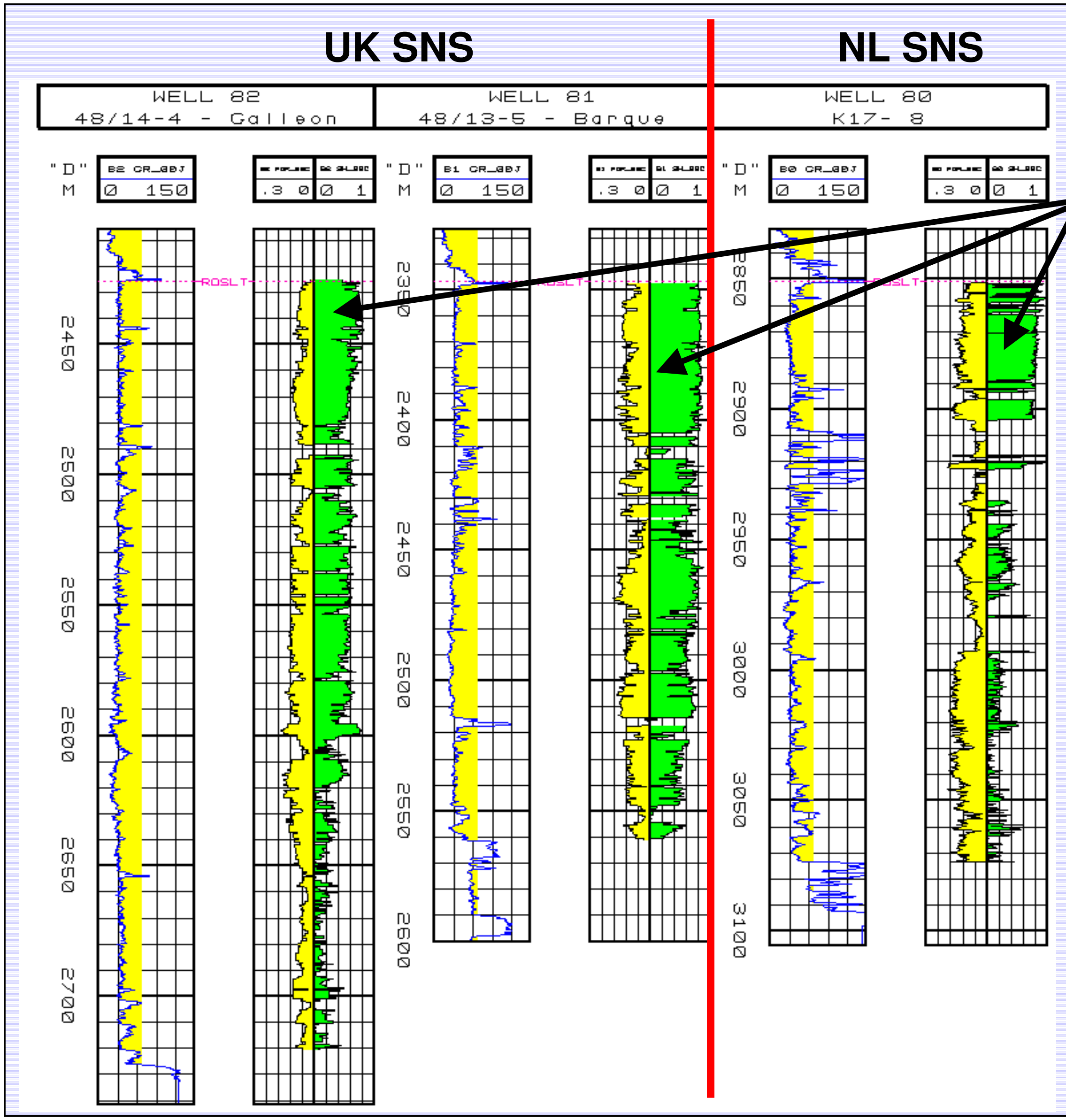
K17-FA diagenesis

- Key reservoir issue on K17-FA: Reservoir pervasively illitised
  - No relation with
    - Structural position
    - Sedimentology
  - Permeability effect largest on poorly sorted fluviatile sands



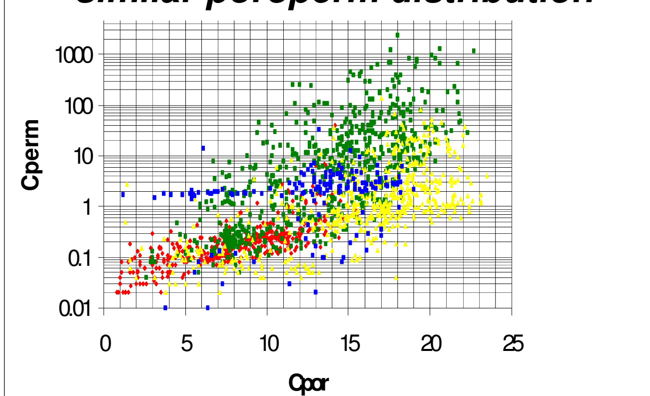


Rotliegend SNS analogues
Similarities/differences



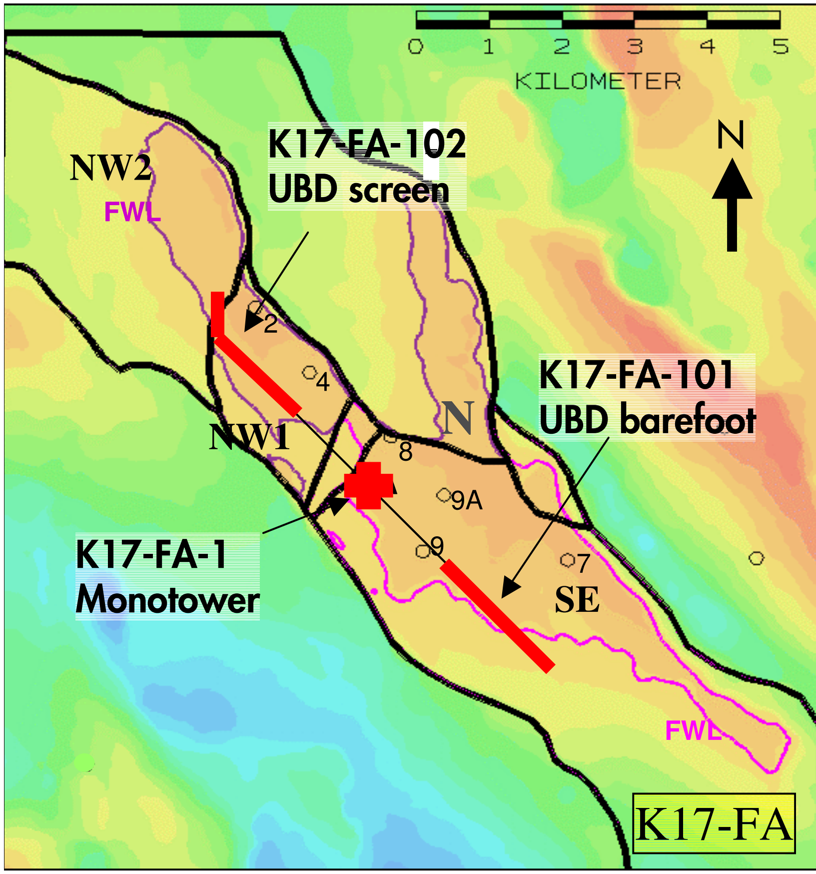
K17	*UK SNS analogues*
SIMILARITIES	
Rotliegend -Slochteren	Rotliegend
Illite/Fibrous illite	Fibrous Illites
Core perm=<0.01-10'smD	Core perm=<0.001-10'smD
Porosity=(5)10-26%	Porosity=(5)10-22%
High permeability streaks (from PLT)	Some high permeability streaks (cores & PLT)
?Natural fractures/matrix	(Natural) fracs/matrix
DIFFERENCES	
Stacked fluvial/dune sets (20-35m)	Same, but thicker dune sequence (45-60m)
Small column (≈ 165m)	Large column (≈ 250m)
UBD only tried in 1997	UBD the norm

K17 vs UK Rotliegend TG
similar poroperm distribution

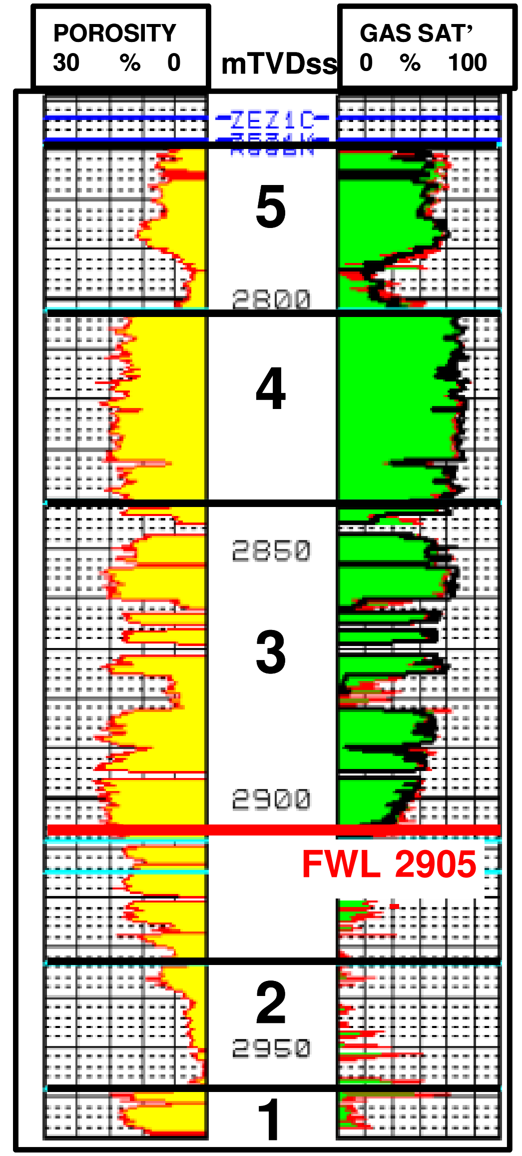


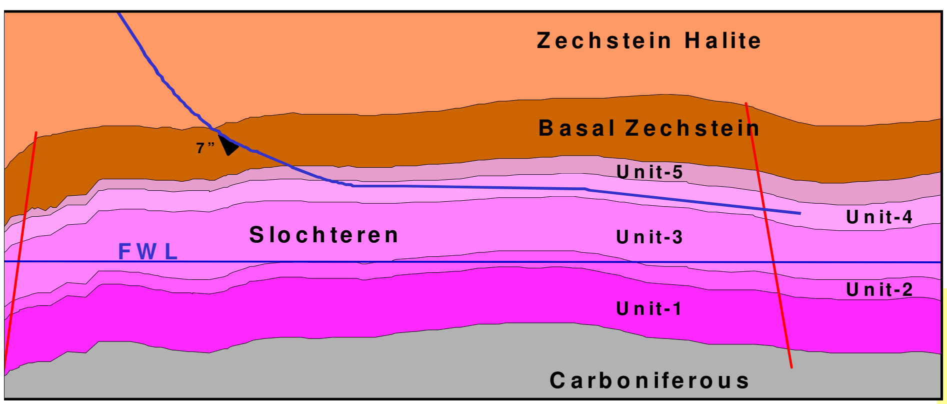
K17-FA Main Development Risks

- Project cost
  - Drilling operations
  - Diving operations (weather risk)
  - Concurrent drilling, tie-ins, hookup & commissioning
- Well performance
  - Underbalance operations
    - Operational execution is critical (experience)
    - Relative lack of data (GR/Dir) and tool reliability
    - Well productivity prediction (initial)
      - Comparable to UK analogues?
  - Sand control required?
  - Deployment and cleanup of sand screens
  - Reservoir quality
- Pipeline & Facilities
  - Minimum facilities



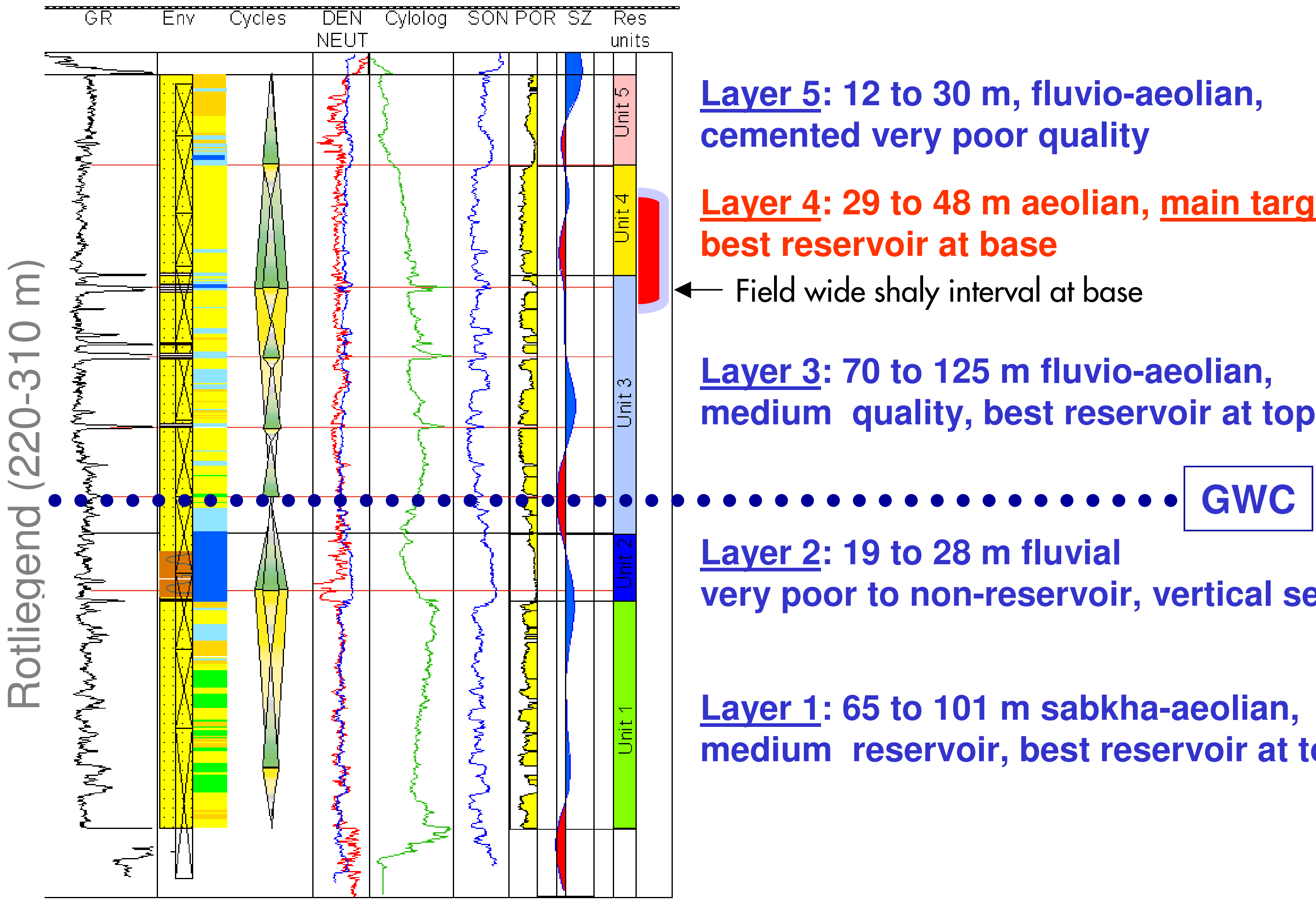
- K17-FA-101 plan to develop SE Block via 1700 m sub-horizontal placed in 40 m thick Unit 4
- K17-FA-102: plan to develop NW Block via 1900 m sub-horizontal placed in 40 m thick Unit 4





K17-FA Rotliegend Development

K17 FA – Vertical facies distribution



Layer 5: 12 to 30 m, fluvio-aeolian, cemented very poor quality

Layer 4: 29 to 48 m aeolian, **main target**, best reservoir at base

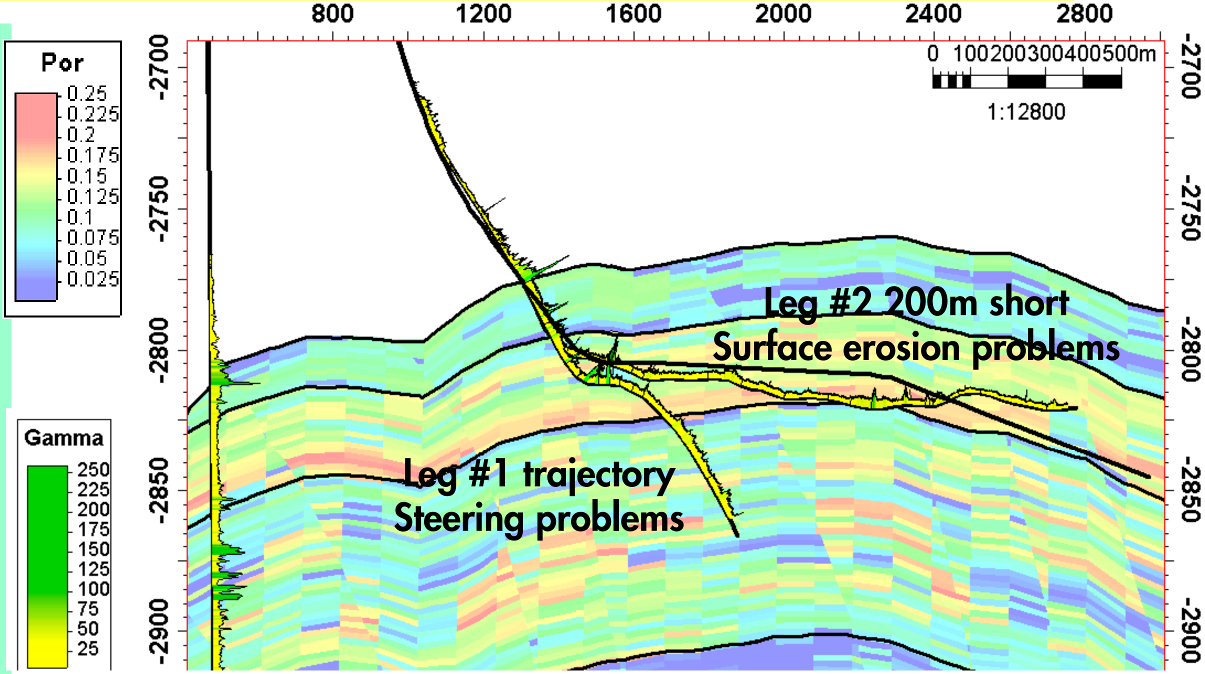
Layer 3: 70 to 125 m fluvio-aeolian, medium quality, best reservoir at top

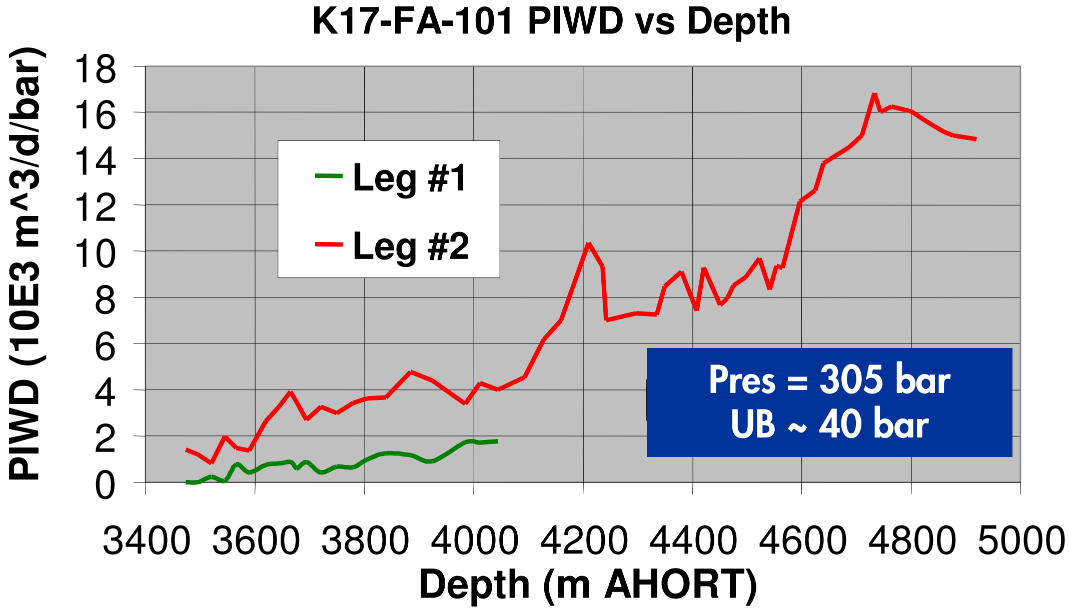
Layer 2: 19 to 28 m fluvial very poor to non-reservoir, vertical seal

Layer 1: 65 to 101 m sabkha-aeolian, medium reservoir, best reservoir at top

K17-FA-101 Well Results

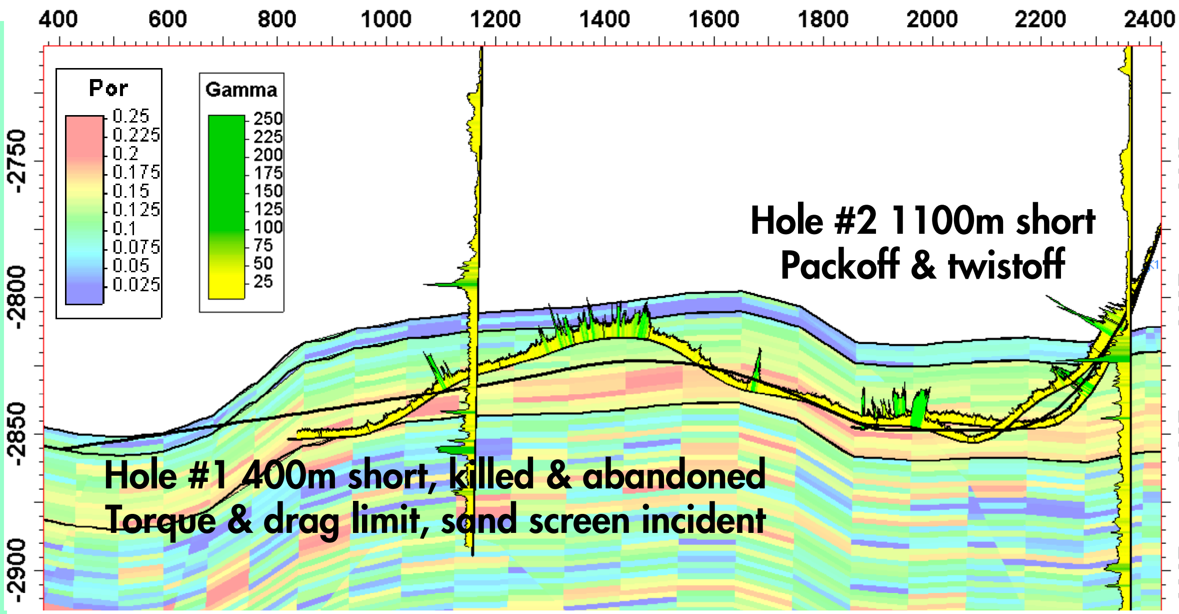
- Best reservoir across bottom half Unit 4 in line with E&A
- Difference between PIWD for Leg #1 and Leg #2 illustrates heterogeneity and benefit of long horizontal wells in TG reservoir
- No indications of natural fractures from either drilling or productivity data - but present in core

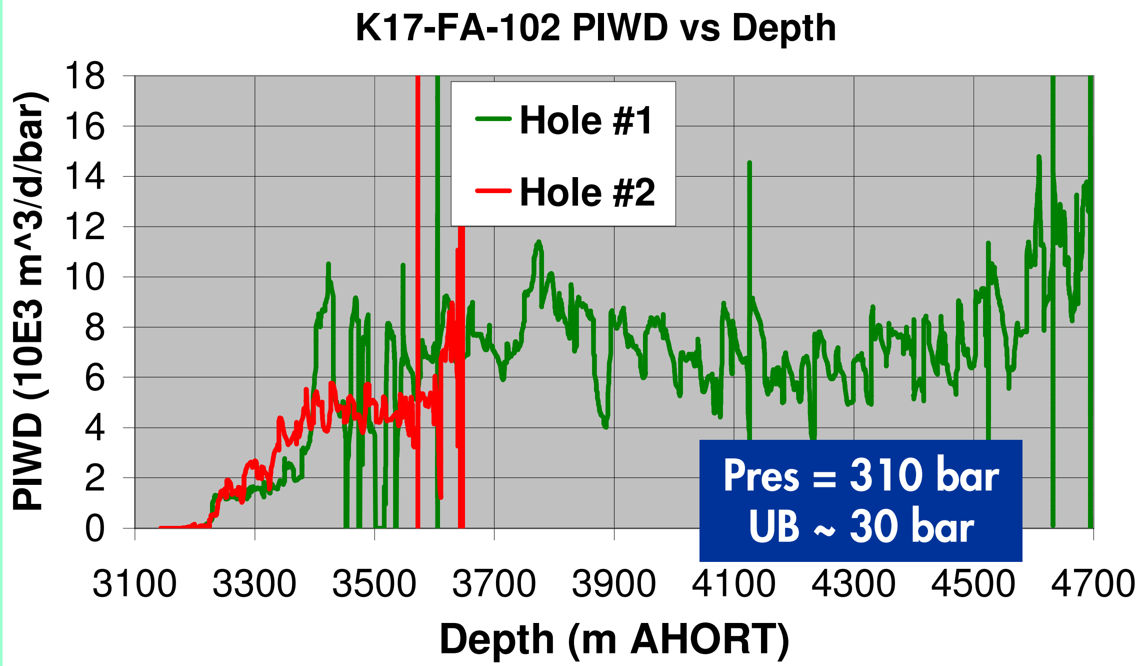




K17-FA-102 Well Results

- Unit 4 less clean than expected: NTG 85% vs 98% in E&A wells
- Best reservoir across bottom half Unit 4 in line with E&A data
- No indications of natural fractures from either drilling or production
- PIWD very helpful in steering well
- Shorter well than plan due to drilling difficulties

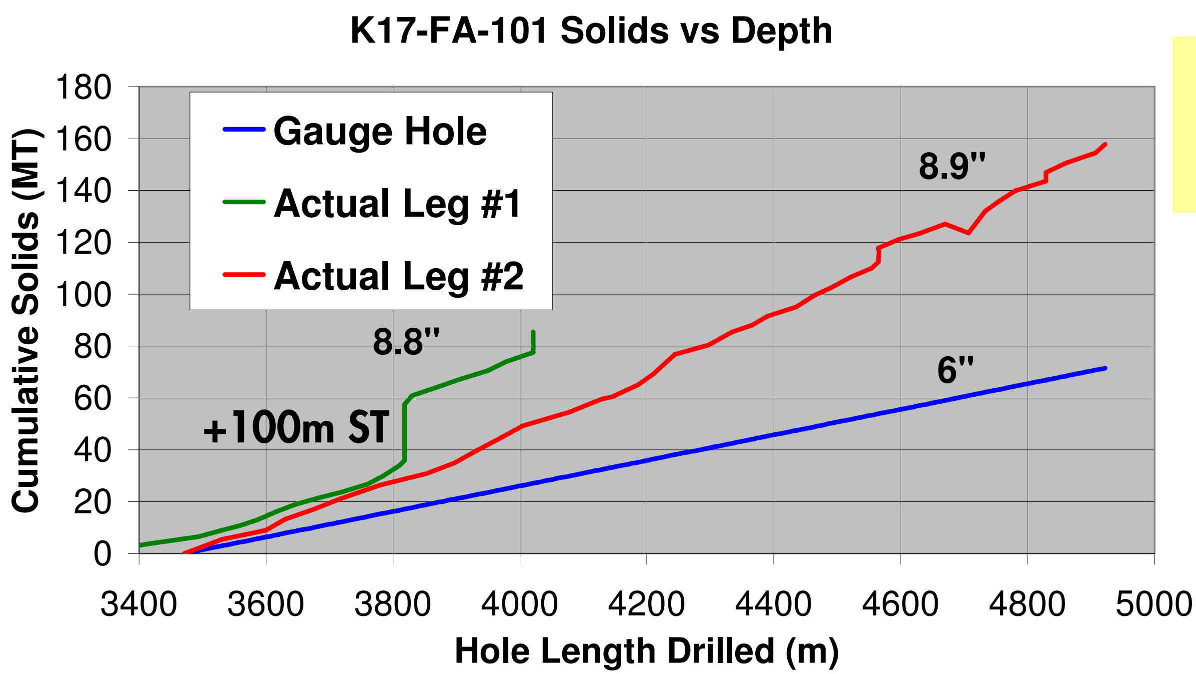


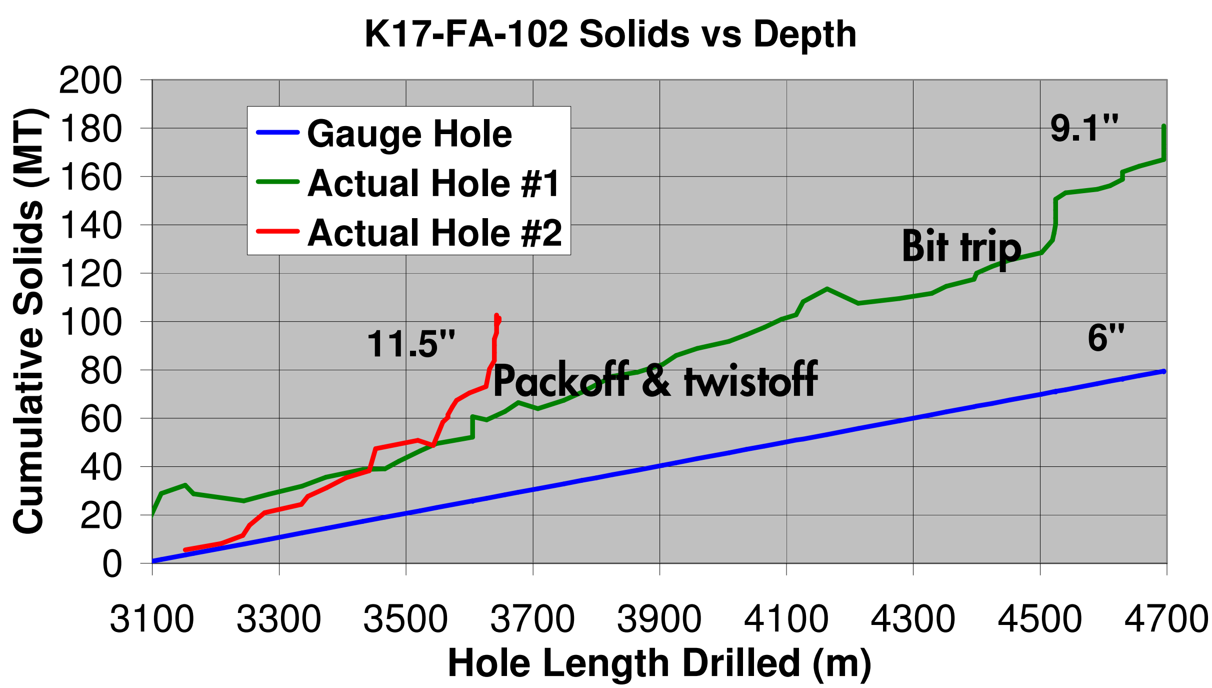


Initial Well Performance

- Very rapid clean-up – typical for UBD wells
- Transient PI about 50% of instantaneous PI due to rapid depletion of thin high perm streaks
  - high PI's 10-20Km3/d/bar
- Initial well performance suggests tortuous communication in reservoir
  - Corresponds with heterogeneity of reservoir
  - Connected volume increases with time
- Wellbore PI ≠ Reservoir RI

K17-FA Hole Size

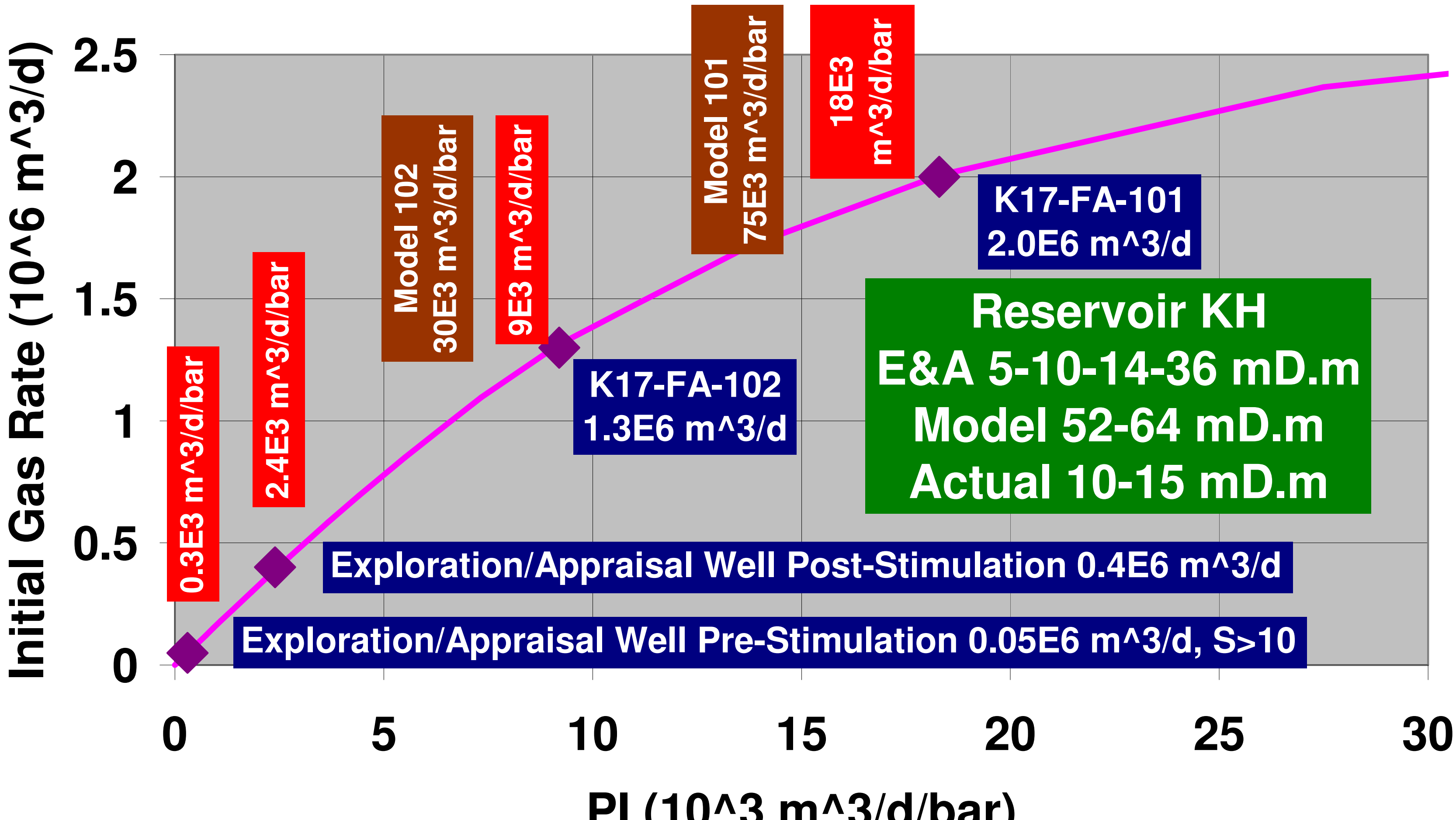




- Average hole size 9" vs 6" gauge
- Extreme 12" hole size in K17-FA-102 sidetrack may have caused a drilling trouble spot
- Large volume of "whole grain" solids main cause of erosion of surface equipment

Comparison Against E&A Wells and Model

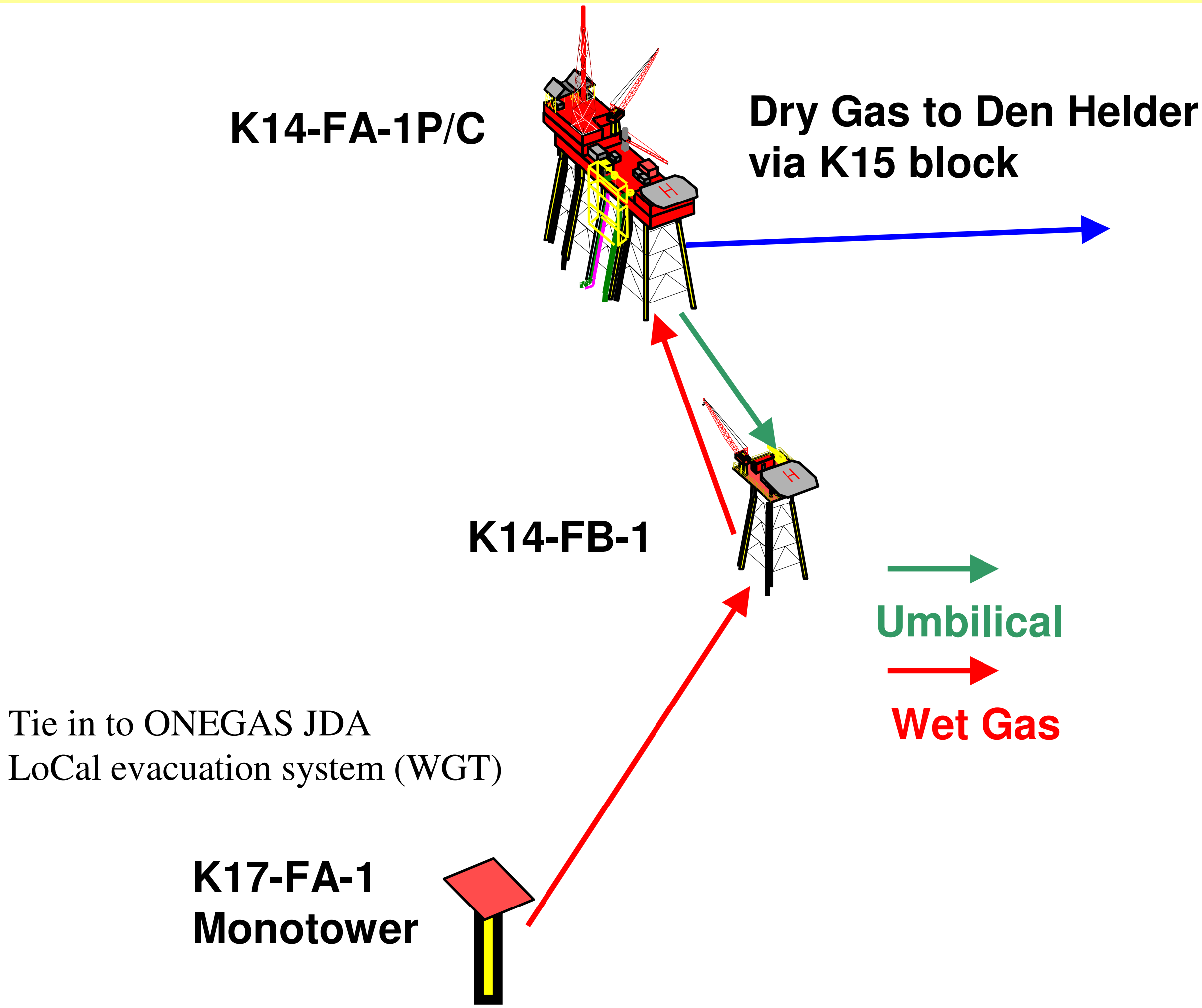
- Excellent inflow compared to E&A wells: horizontal & UBD success story
- Less inflow than modelled: model optimistic, impact of diagenesis difficult to model



Current View

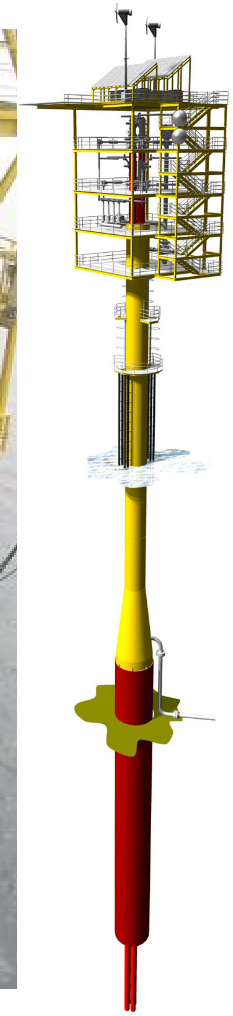
- Biggest gain from drilling horizontals
- UBD enables horizontals in fractured reservoir
- UBD Qi benefit:
  - 1.5x-2.5x OK for damage
  - 6x-8x due to fractures
- Kill can be worse than drilling OB, in-line with general industry experience
- K17-FA performance in line with UK analogue wells

Evacuation system

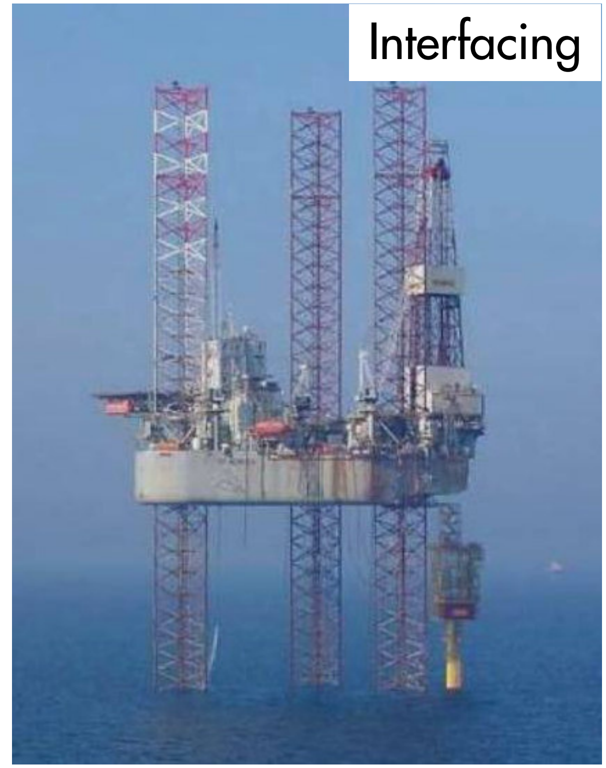


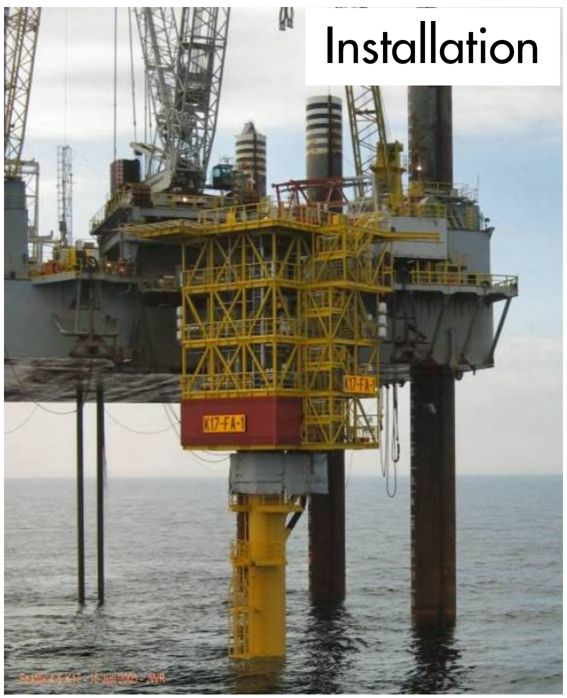
Novel type of surface facilities: T2 monotower design

minimal facilities, remotely operated, 4 well slots, boat access, renewables (wind, solar) provide power




Installation


Interfacing


Installation
K17-FA-1


Drilling

K17-FA - Lessons Learned

- ✓ Multi-discipline, multi-functional effort with great attention to detail is critical
  - ✓ To get it right-first-time is difficult
  - ✓ Subsurface heterogeneity confirmed by drilling, difficult to model
  - ✓ Minimum facilities - installation successful
- ✓ Reproduced success of horizontal drilling in UK offset tight gas fields
  - ✓ Similar tight reservoir type – 'horses for courses' approach
- ✓ Maximised well capacity by underbalanced drilling (geosteering, impairment)
- ✓ Reaped benefits of oil-based underbalanced drilling fluid
- ✓ Installed sand screens underbalanced – but with a lot of difficulties/learnings
- X Experienced integrity problems (BOP's and surface erosion)
- X Drilling trouble spots - need further investigation