The Dynamic Tamar Reservoir: Insights from Five Years of Production*

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Abstract

The Tamar Field was discovered offshore Israel in early 2009 and proved the presence of a new gas play in the Miocene-aged sediments of the deep Levant Basin. Subsequent discoveries in this "Tamar Sands" Play (e.g. Leviathan, Aphrodite, Karish, and Tanin) total over 40 Tcf of recoverable resources. Tamar is an elongated anticline, trending NE-SW. The field consists of three vertically stacked gas bearing reservoir intervals (A, B, and C Sands), which are separated by shale-dominated zones (AB and BC Shales). Seismic and well data confirm the lateral continuity of the major sand and shale units. The high-quality reservoirs were deposited in a relatively unconfined environment as compensationally-stacked basin floor fans and are juxtaposed across post-depositional NW-SE striking normal faults. The reservoir intervals have a very high net-to-gross (75% to 95%), in predominantly fine-grained sands. Average total porosity ranges from 21% to 23%, and gas core permeability values average 600 to 1200 mD. Thin shale beds are also present within the reservoir intervals and have the potential to baffle fluid flow. Many of these thinner shale beds are debritic in nature, while others are laminated components of heterolithic packages. Prior to production, all reservoir penetrations encountered a single Gas-Water-Contact (GWC), strongly suggesting hydraulic-connectivity over geologic timescales. To date, six high-rate (~250 MMscf/d) production wells have been drilled and completed in the field. The wells are equipped with downhole pressure-temperature (DHPT) gauges located approximately 250 meters above the completed sand face, which provide high frequency production data for reservoir monitoring and performance analysis. The subsea wells are tied back to the Tamar Platform via a subsea manifold and two 150km gathering lines. Since Tamar is presently the sole supplier of natural gas to the Israeli market (excluding minor LNG imports and production from the nearly depleted Mari-B Field), the production rates are directly driven by market demand. This dependency creates a cyclic pattern of production rates on a daily, weekly, and seasonal basis. These cycles challenge both operations and conventional methods of reservoir performance analysis. Well pressure data are collected continuously from the DHPT gauges and provide a history of pressure/temperature drawdowns and buildups throughout the life of each well. Pressure Transient Analysis (PTA) of the buildup data is used to monitor completion efficiency as well as to constrain and forecast reservoir performance. PTA-derived permeability, well interference signature, and reservoir pressure decline are all used to study a reservoir's dynamic properties. This study integrates these dynamic methods with the geological database, and particularly with data from the recent Tamar-8 well. Tamar-8 was drilled in late 2016, close to 4 years after first gas. Tamar-8 was drilled to a TD below the lowest reservoir and then plugged back, sidetracked, and completed as a high

rate producer. The pilot hole allowed full evaluation of partially depleted sands and a water-encroached swept zone. Wireline logs, pressure tests, and fluid sampling from this well provided valuable insights into reservoir dynamics and enabled an improved calibration of both geologic and reservoir engineering models. The PTA and Material Balance results indicate that the wells are draining large extents of the reservoir, and that all wells are in communication either through the gas and/or through the aquifer. These conclusions are supported by pressure data from Tamar-8. Furthermore, the datasets confirm cross-fault communication, some degree of stratigraphic baffling, and a combination of both volumetric depletion and aquifer support. The integration of "dynamic data" (continuous production parameters) with "static data" (seismic, well logs, cores) indicates that the reservoir is indeed continuous and exhibits a high degree of hydraulic connectivity. Additionally, small scale features that impact flow on production timescales are now better understood. These types of insights may inform development decisions such as the timing and location of future wells. At Tamar, geoscientists and engineers continuously reevaluate both static and dynamic reservoir models. This collaboration is enhancing the original concepts for reservoir connectivity and performance and is expected to result in an optimized development plan for the management and production of the field.

The Dynamic Tamar Reservoir

Insights from Five Years of Production

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Isramco

noble energy

Delek Drilling

Tamar Petroleum

Alon Natural Gas Exploration Ltd

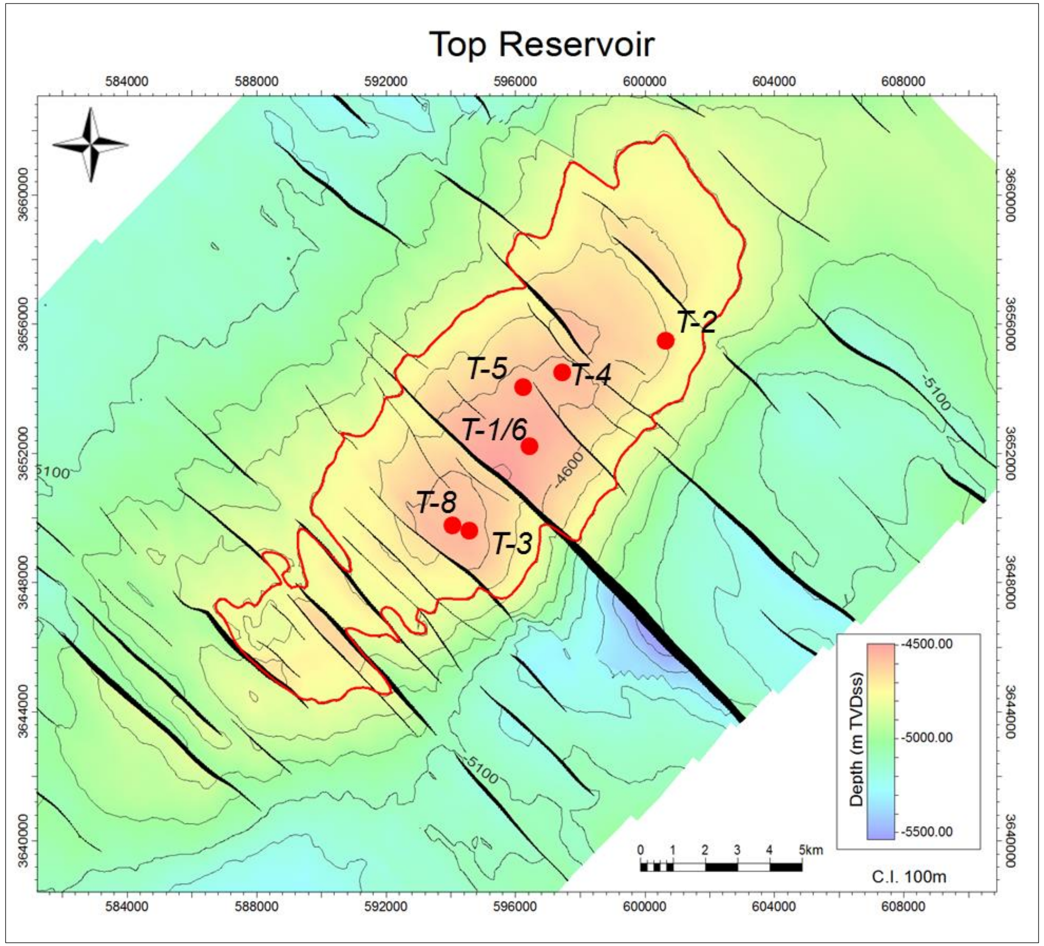
EVEREST INFRASTRUCTURES

Objective and Outline

Objective:

Demonstrate how the integration of static and dynamic data has enhanced the original concepts for reservoir connectivity and performance at Tamar.

- **Outline**
  - Field Overview
  - Geological Background
  - Pre-Production Observations
  - Initial Production Analysis
  - Recent (Tamar-8) Well Results
  - Current Understanding of Connectivity
  - Summary and Conclusions



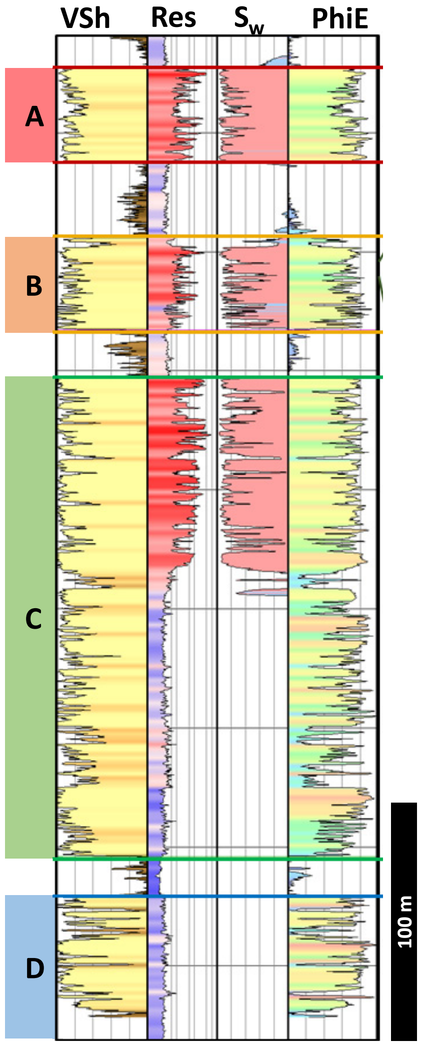
Four-way faulted anticline & six producing wells

= Field Outline

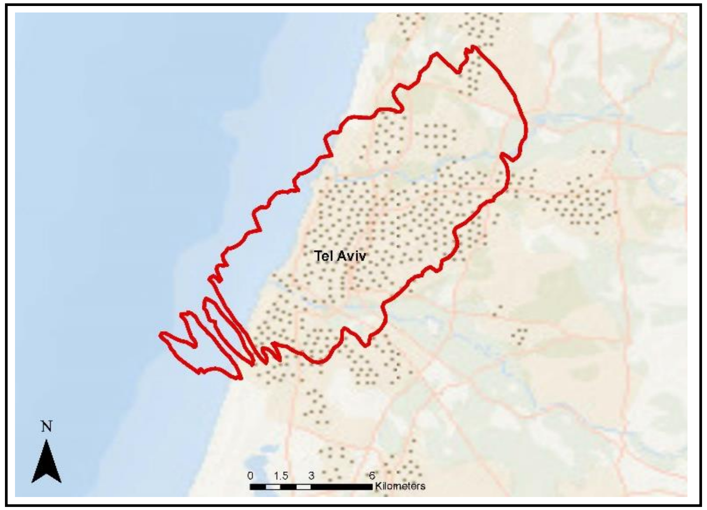
Field Overview

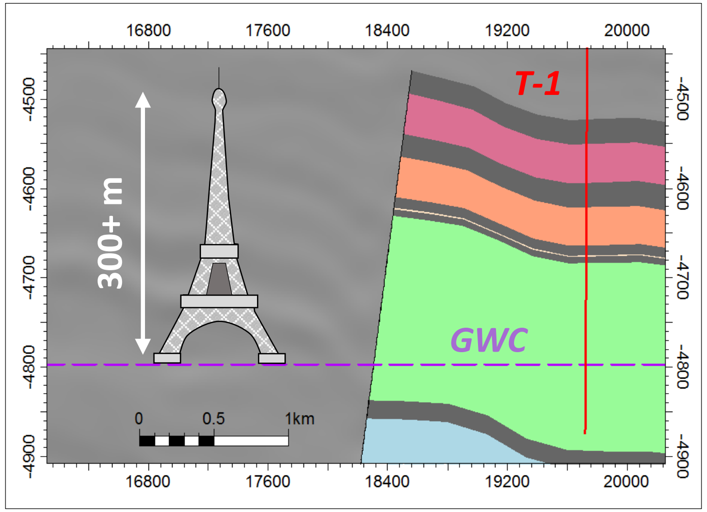
- **Four-way dipping closure, field area of 115 km²**
- **Three producing reservoirs (A, B, & C Sands)**
  - Lower Miocene
  - Deposited in a basin floor environment
  - High quality sands
    - Average permeability: 600-1200mD
    - Average Porosity: 21-23%
  - Lean, biogenic gas
  - Maximum Gross Column Height of 305m
- **Six producing wells**
  - 1 billion cubic feet of gas per day (BCF/D)
  - Total Produced Volumes (as of March 31st, 2018)
    - 5 years of production
    - 1.5 Trillion cubic feet of gas (TCF)
    - Less than 10% of Gas-Initially-In-Place (GIIP)

Tamar Well



Scale Check



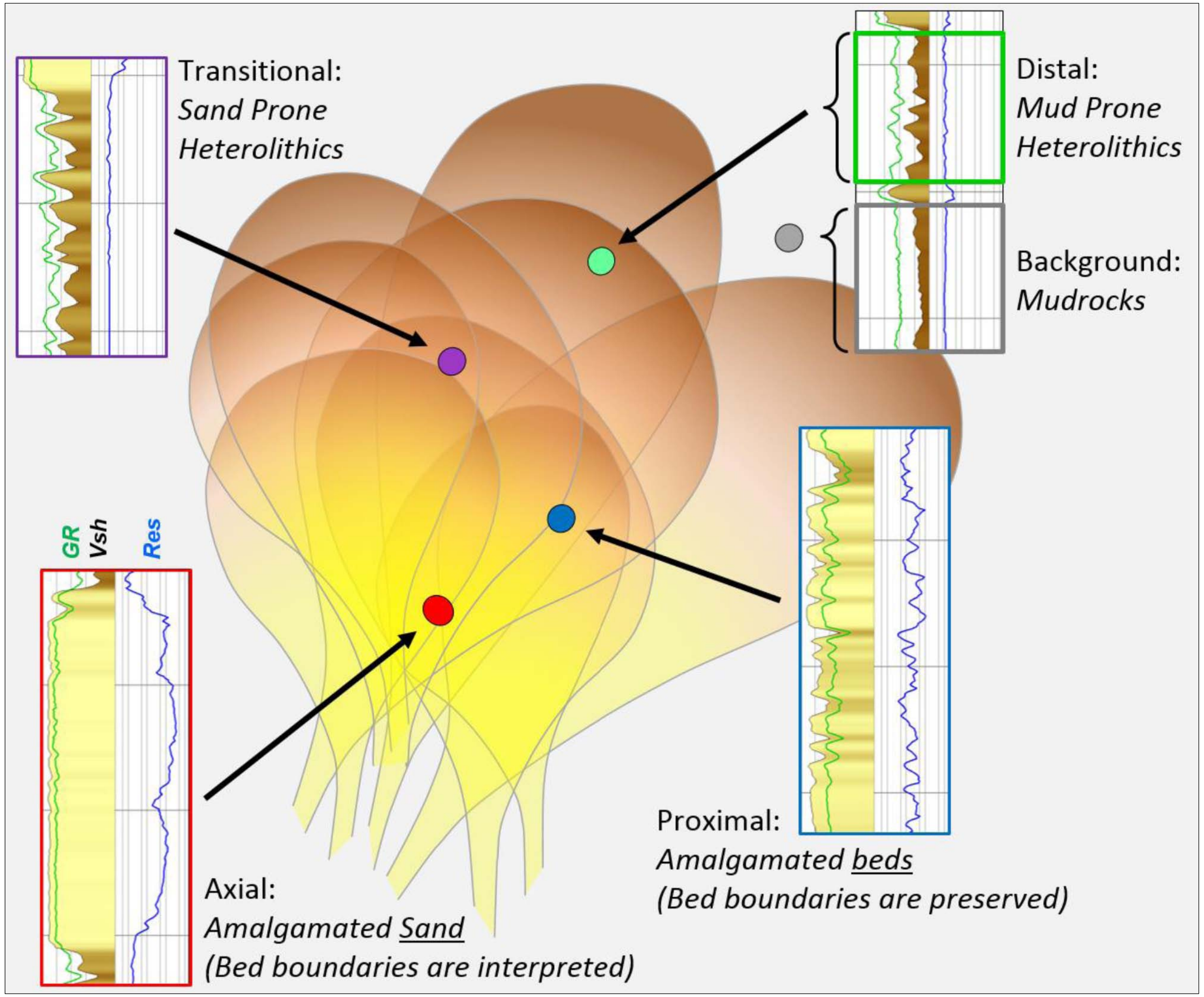


Tamar Reservoir: Facies interpretation

- **Depositional System**
  - Deepwater / Basin-floor environment
  - Relatively unconfined & sand-rich
  - Compensationally stacked deposits

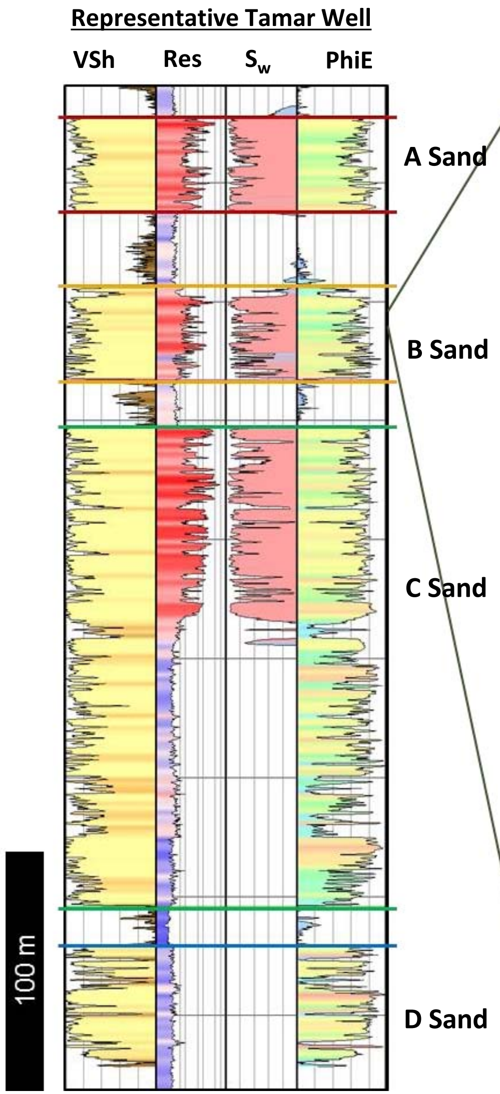
- **Five major facies**
  - Axial
  - Proximal
  - Transitional
  - Distal
  - Background

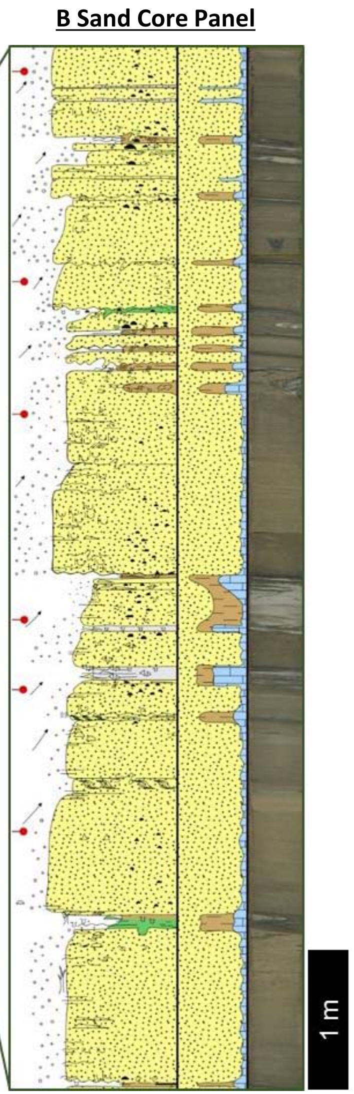
- **Interpreted from core and logs**
- **Guide reservoir properties in models**
- **Heterolithic packages (Transitional/Distal facies) can be correlated across the field**

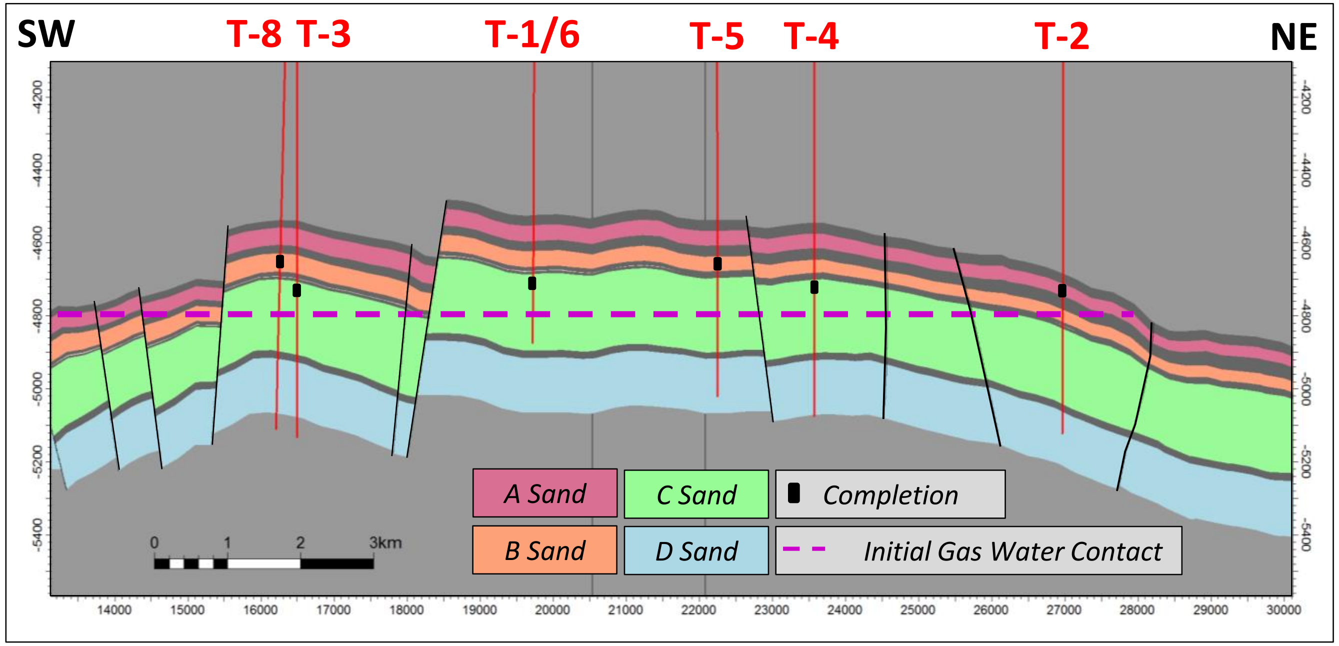


Modified after Needham, et al. (2017)

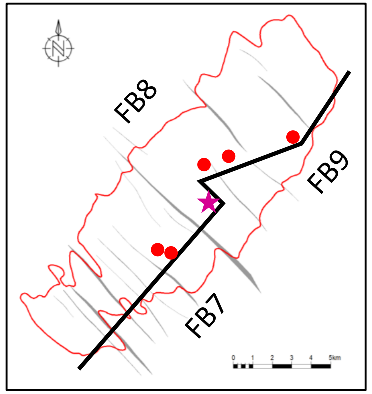
Tamar Reservoir: Potential for complexity







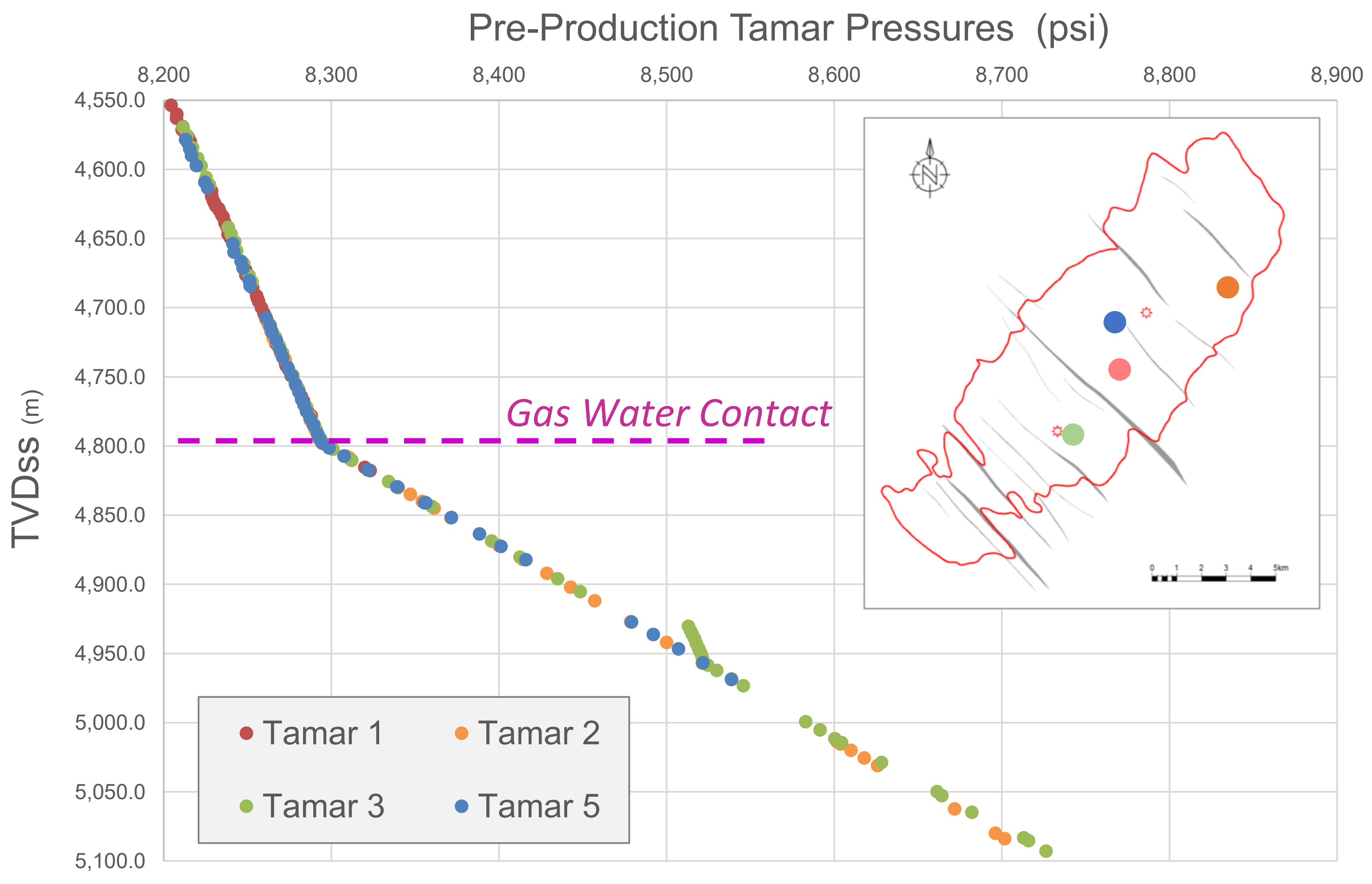
- Core panel shows thin intervals with lower vertical permeability interbedded within high quality sands
- Post-depositional NW-SE striking normal faults juxtapose producing sands
- Completions set in three primary fault blocks
- Completions set in the A, B, and C Sands



noble energy

Pre-Production Pressures: Field is well-connected

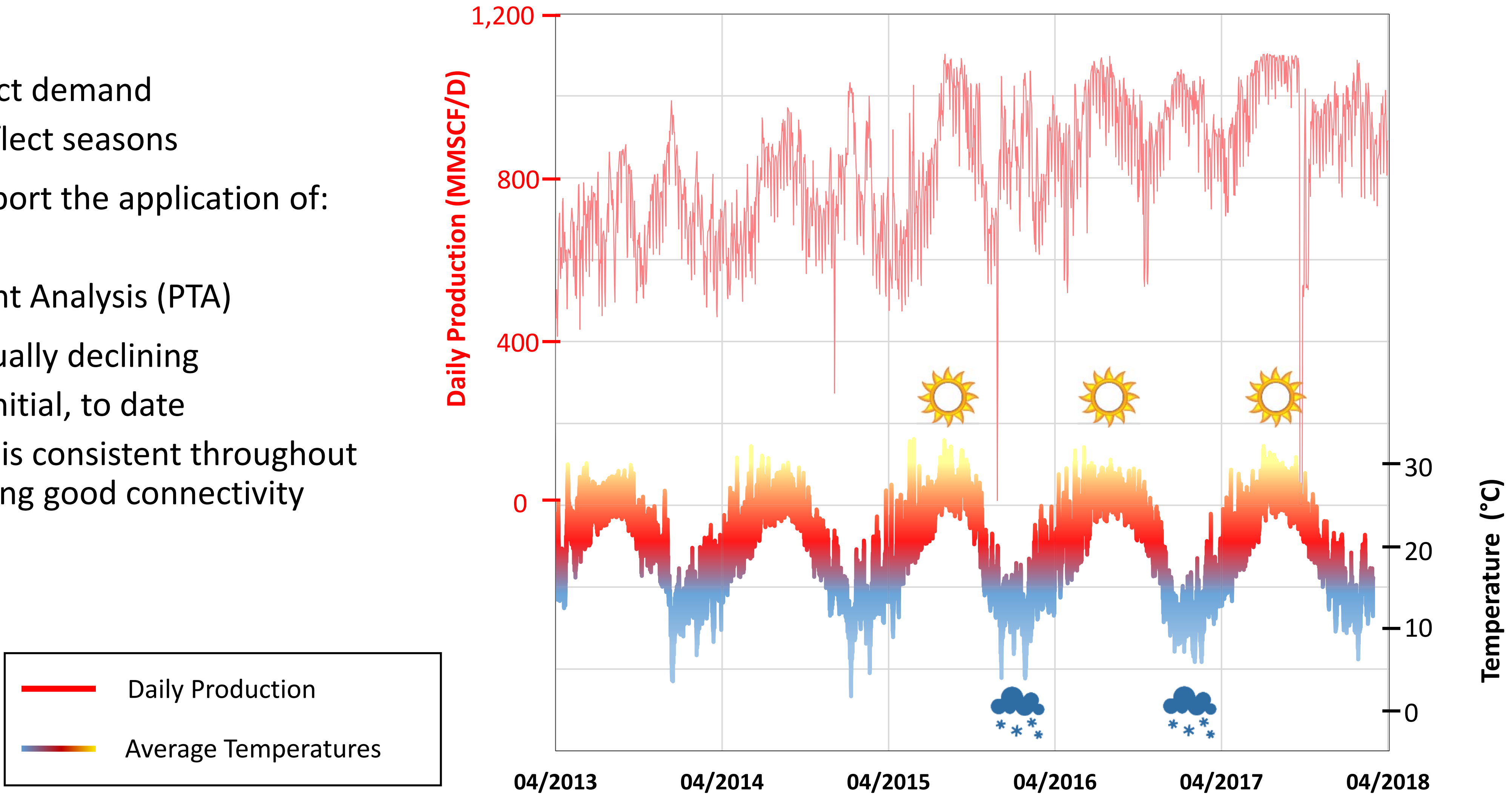
- **Potential for complexity:**
  - Large field
  - Multiple sands
  - Multiple fault blocks
- **Pressure Data show:**
  - Common gradients
  - Common Gas-Water Contact
- **Interpreted as a continuous and well-connected reservoir (over geologic time)**



Pressure data collected using wireline-conveyed downhole tools

Production Analysis: Variable rates reflect demand

- Rate fluctuations
  - Daily cycles reflect demand
  - Annual cycles reflect seasons
- Multiple shut-ins support the application of:
  - Material Balance
  - Pressure Transient Analysis (PTA)
- Field pressure is gradually declining
  - ~550 psi below initial, to date
  - Pressure decline is consistent throughout the field, indicating good connectivity



Production Analysis: Decline indicates connectivity

- Rate fluctuations
  - Daily cycles reflect demand
  - Annual cycles reflect seasons
- Multiple shut-ins support the application of:
  - Material Balance
  - Pressure Transient Analysis (PTA)
- Field pressure is gradually declining
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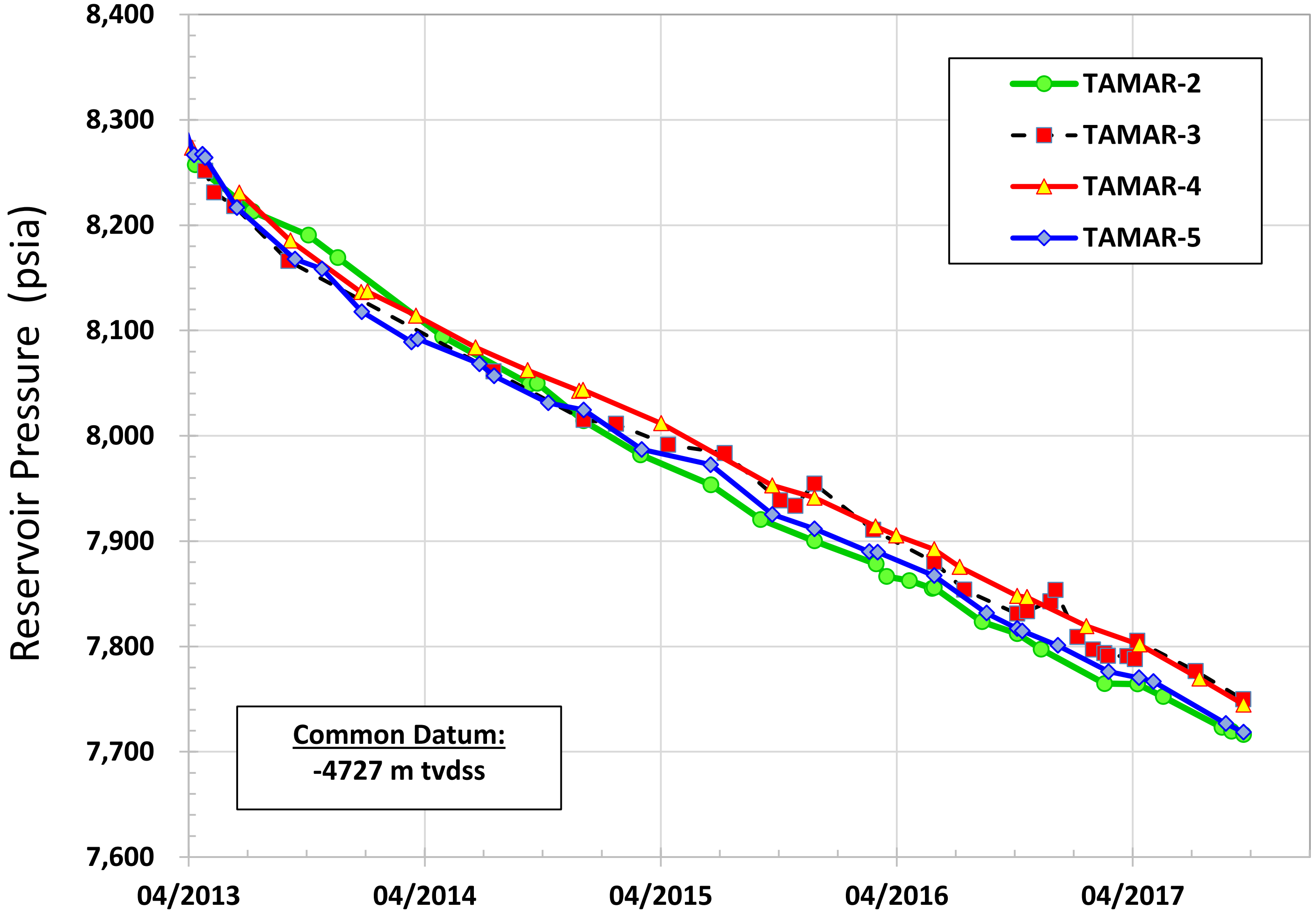
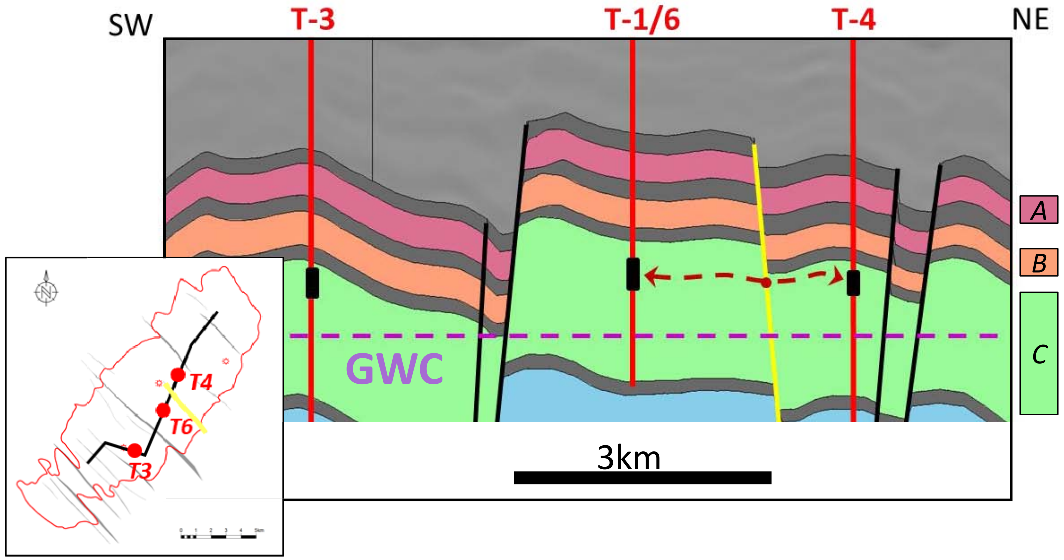
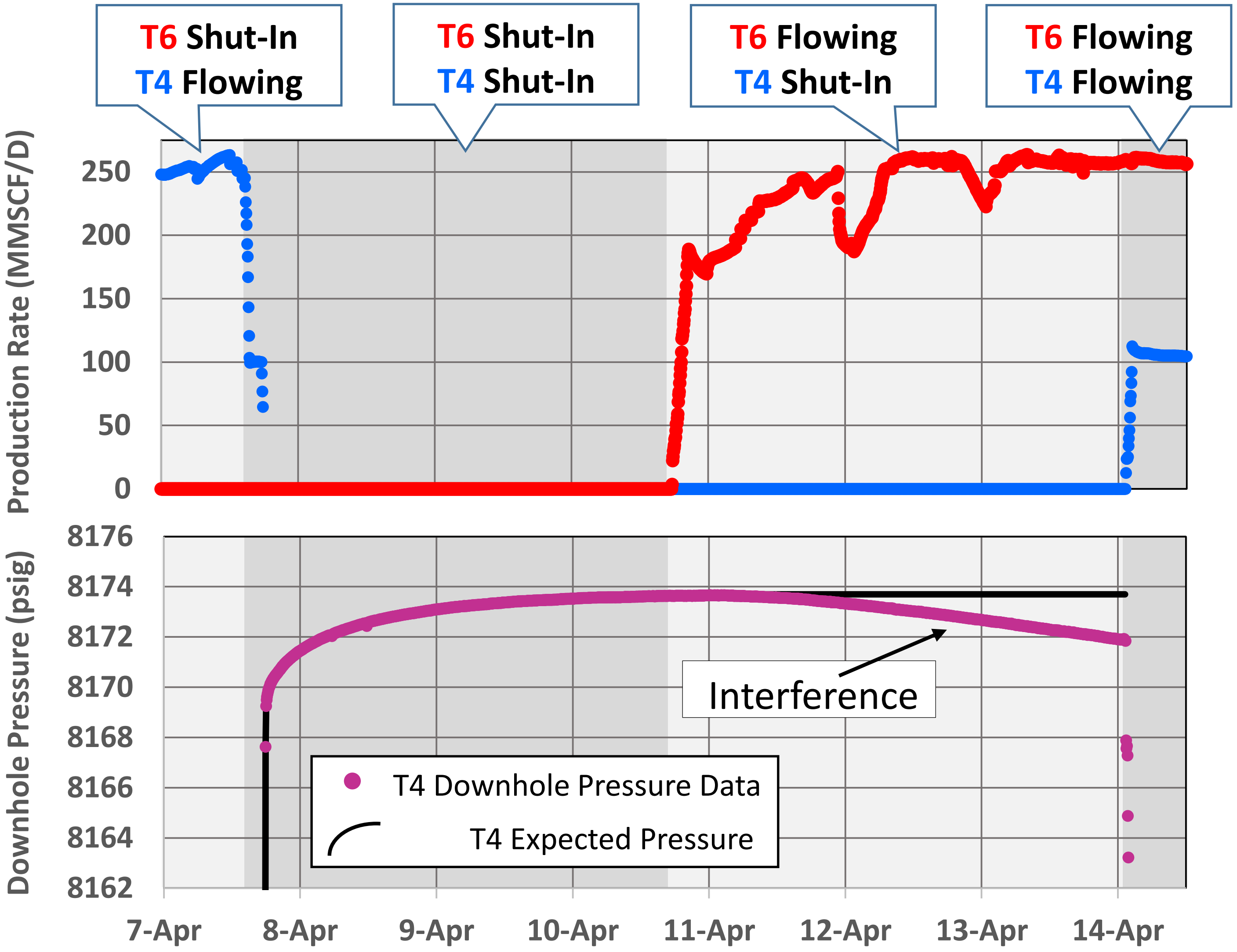


Production Analysis: Direct connection (T-4 & T-6)

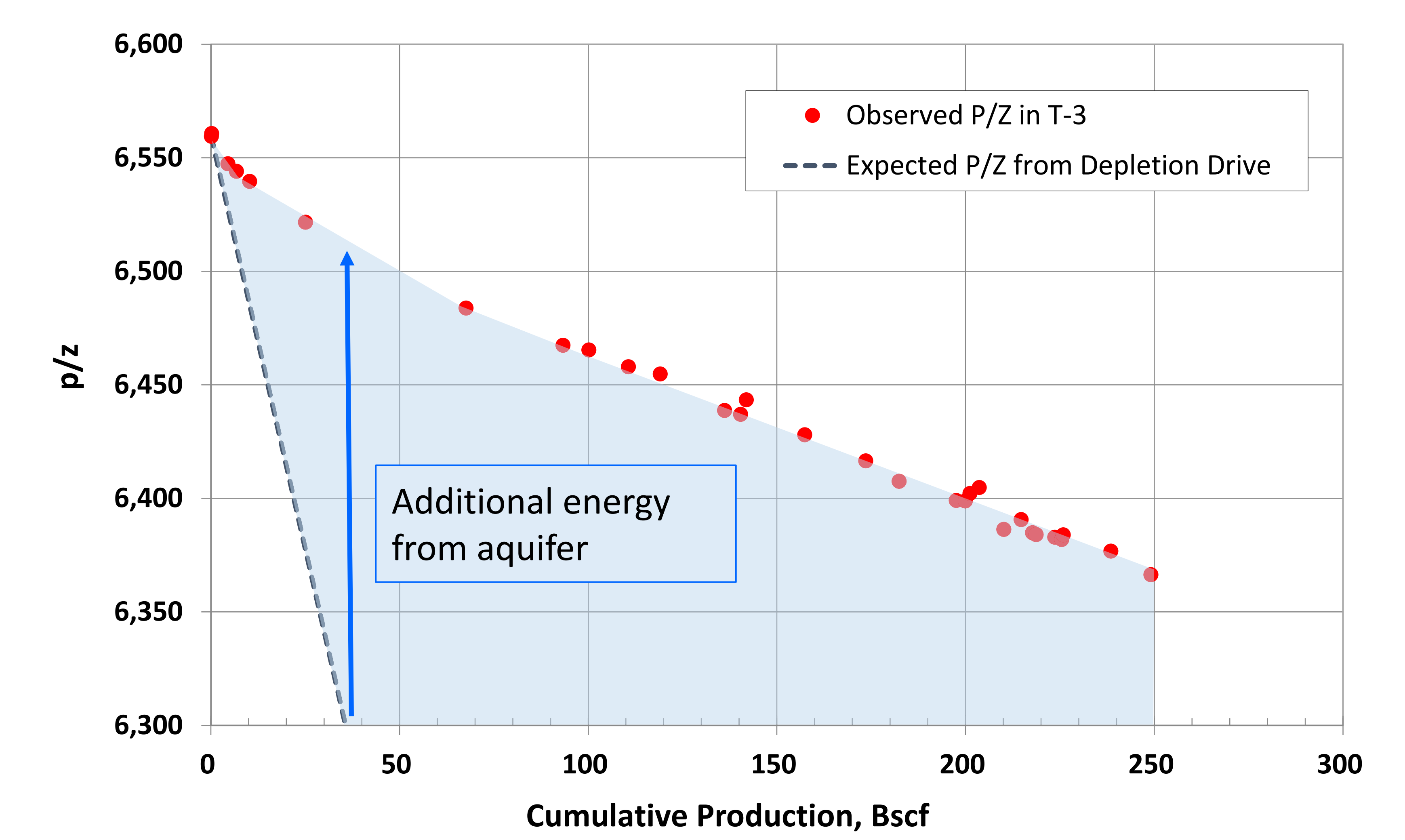
- Tamar-4 and Tamar-6 demonstrate a clear connection during well interference testing
  - Both completed in the C Sand, ~3km apart
  - Both are located in same fault block
  - A relatively small fault exists between the wells, but C-C juxtaposition is maintained
- T-3 does not show a similar connection





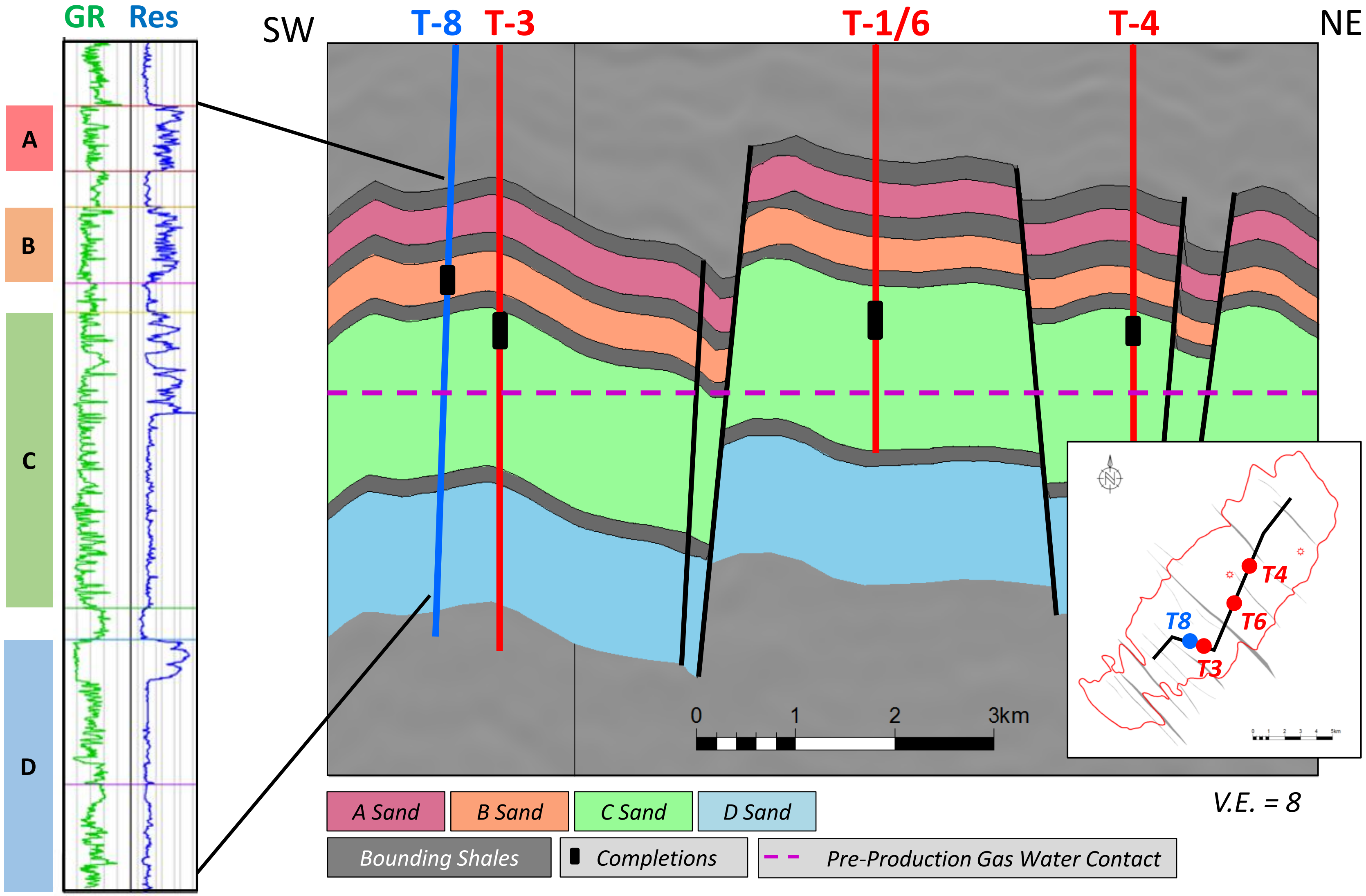
Drive Mechanism: Evidence for aquifer support

- Pressure Transient Analysis (PTA) indicate a dominant **depletion drive** mechanism for the field.
- Material balance techniques and recent well results provide evidence for **aquifer support.**
- P/z is a material-balance based method for investigating drive mechanism and estimating ultimate recovery.
- When referenced to the expected tank volume, this analysis indicates additional aquifer support (blue polygon)



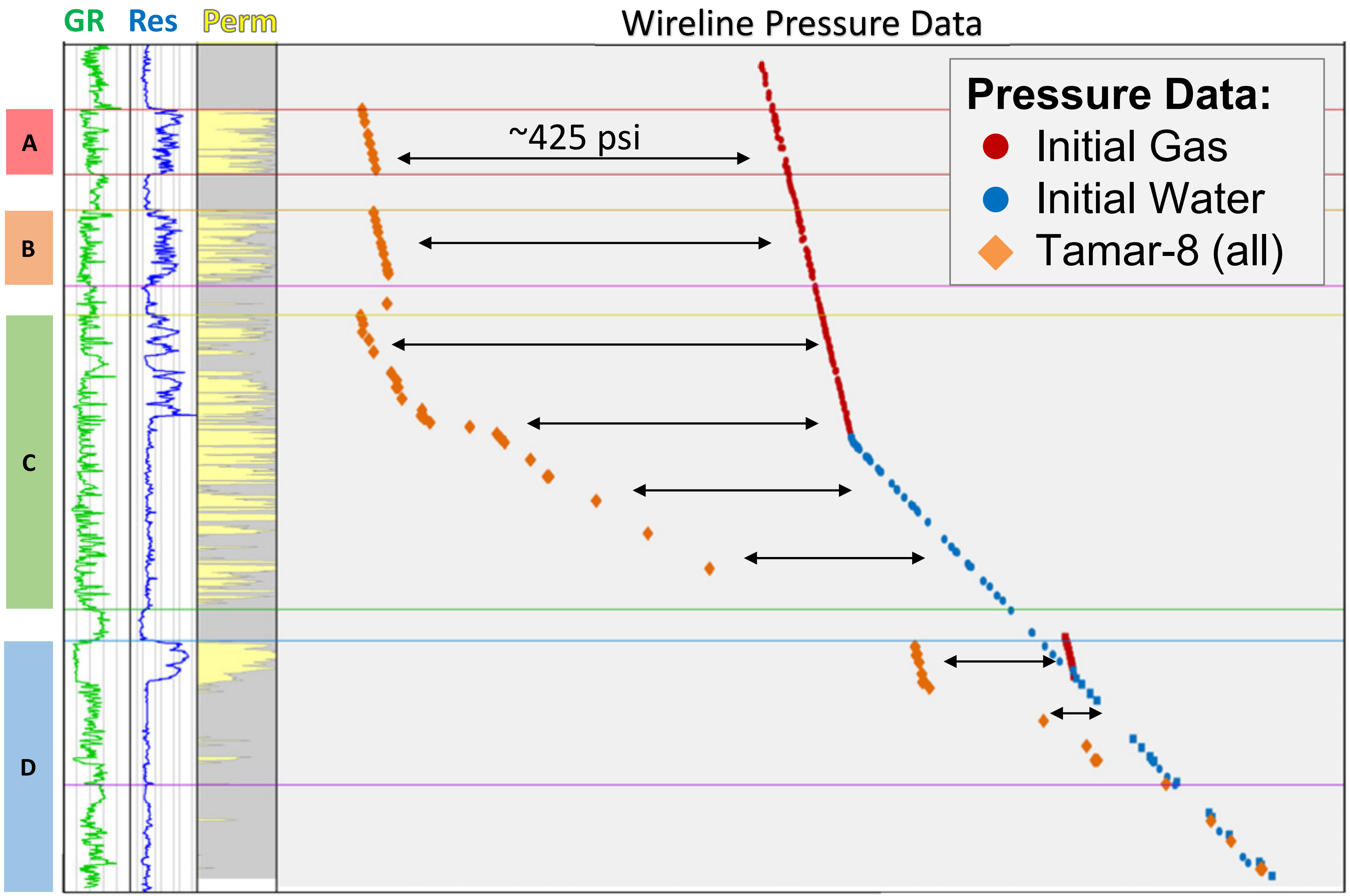
Tamar-8 Summary: Drilled 2016

- **Well Purpose:**
  - Security for gas supply (redundancy)
  - Uncertainty reduction
  - Comprehensive evaluation
- **Pre-Drill Uncertainties:**
  - Fault & shale behavior
  - Aquifer behavior
  - Depletion mechanism
  - GWC movement
- **Tamar-8 Evaluation Program**
  - One conventional core
  - Fluid samples and pressures
  - LWD and Wireline logs



Tamar-8 Pressures: Partial depletion in all sands

- Partial depletion in all sands
  - Evidence for cross-fault communication
- Dynamic nature of reservoir observed in C Sand
  - Additional evidence for lateral communication
  - Shallower Gas water-Contact
- Pressures progressively approach pre-production values towards the base of the well
  - This implies a stratigraphic or temporal limit of the effective aquifer; and…
  - Baffling



Tamar-8 Pressures: Stratigraphic baffles

- Partial depletion in all sands
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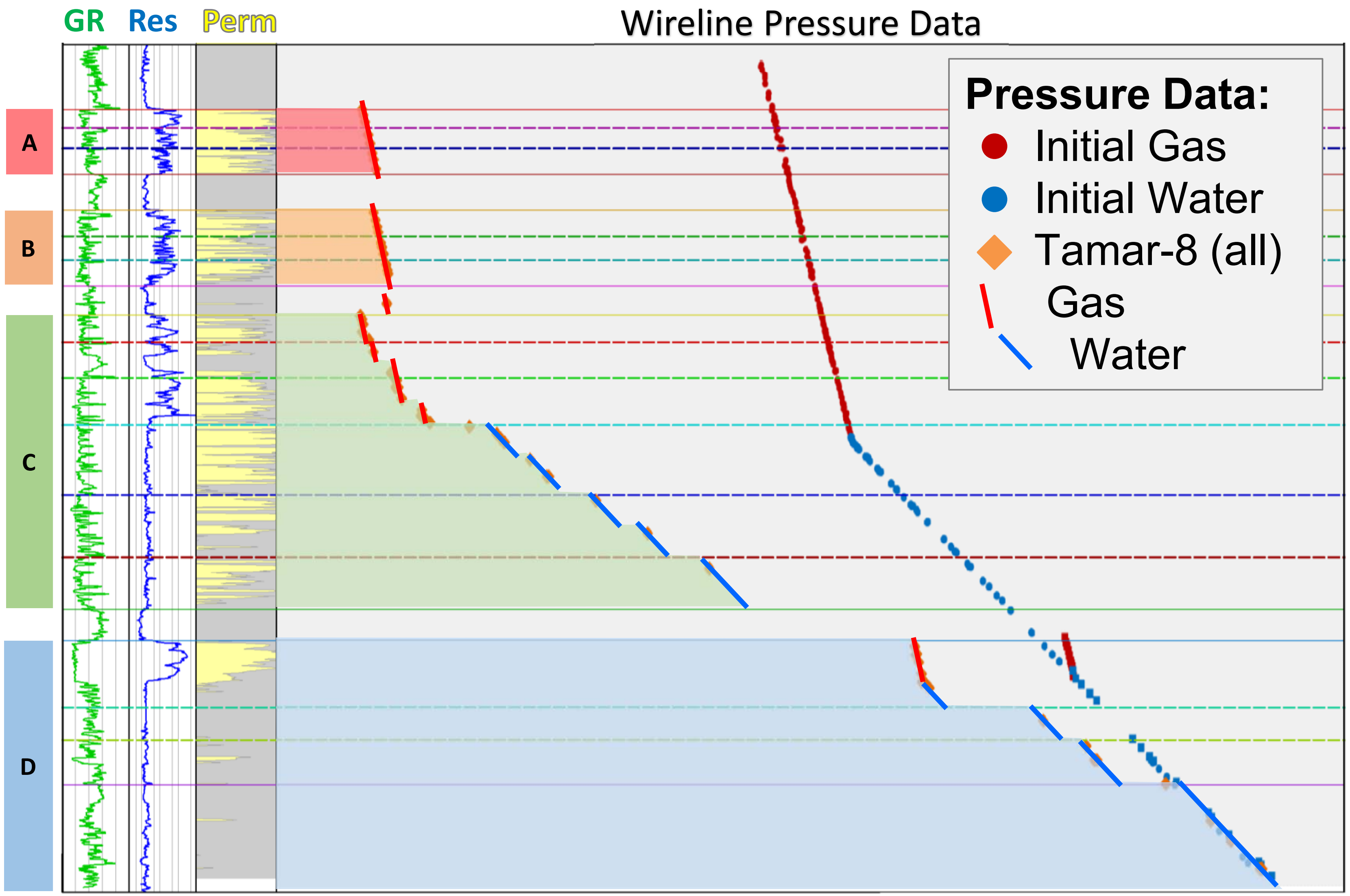
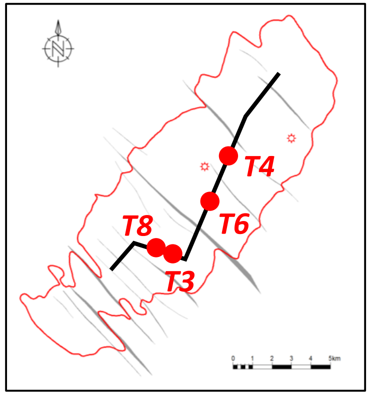
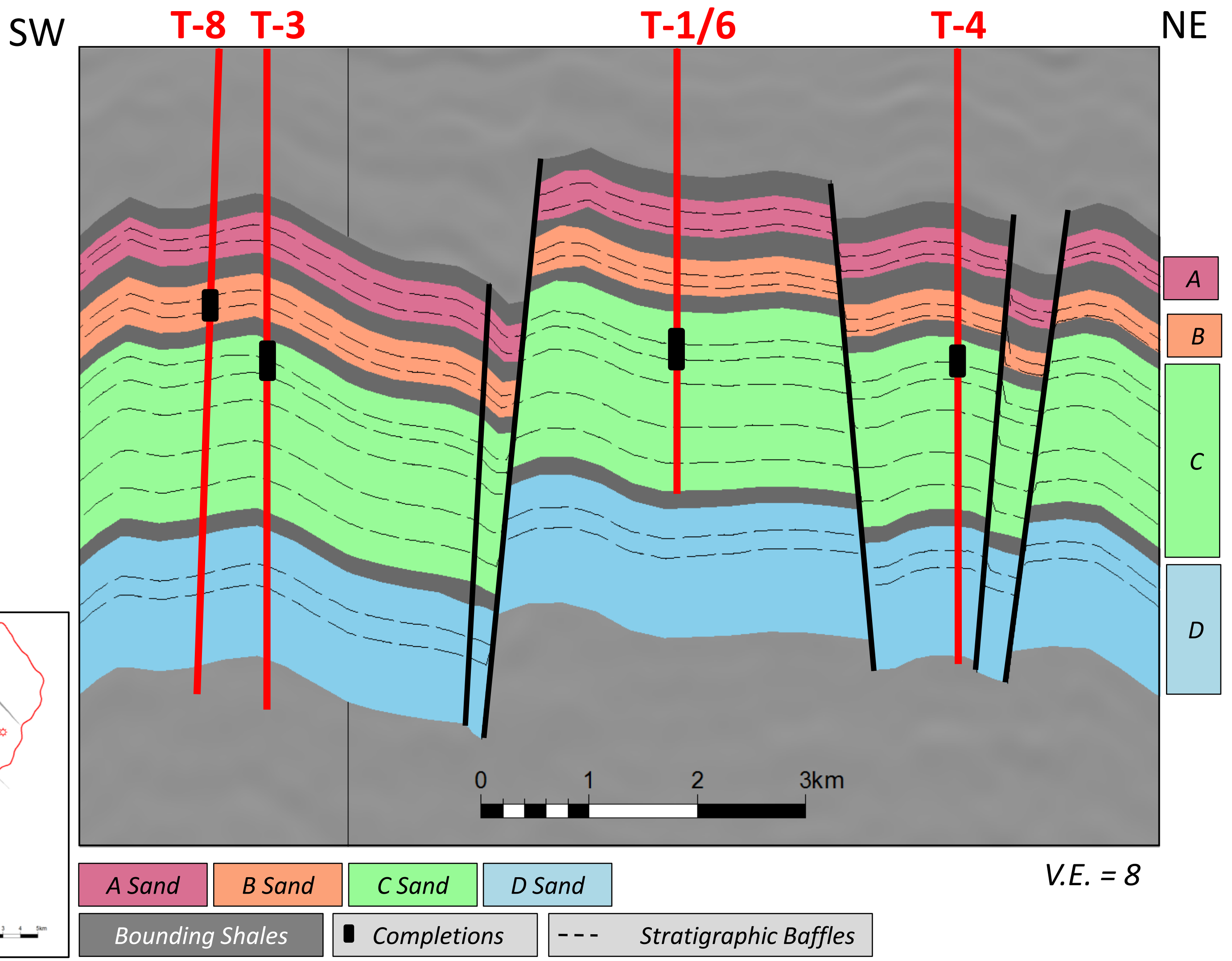


Dynamic Connectivity: Do Baffles fit?

- **Does the interpretation of a baffled reservoir fit with the interference testing observations?**
  - T-4 and T-6 show excellent connection, and an immediate interference response.
  - T-8 also showed depletion between logging, testing, and initial production.
  - T-8 and T-6 show a more subtle interference response during build-ups.
  - T-3 does not show immediate interference with any other well, but is likely connected through more tortuous paths.





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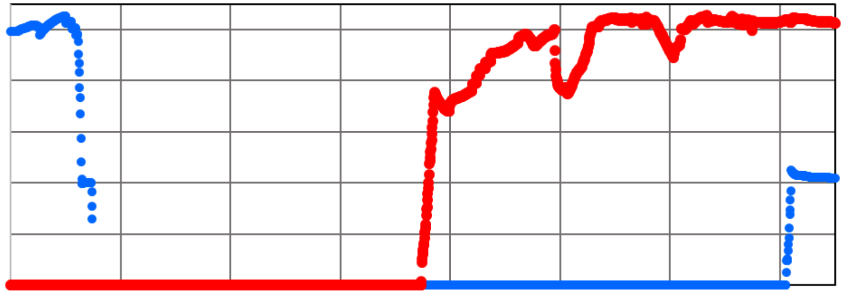
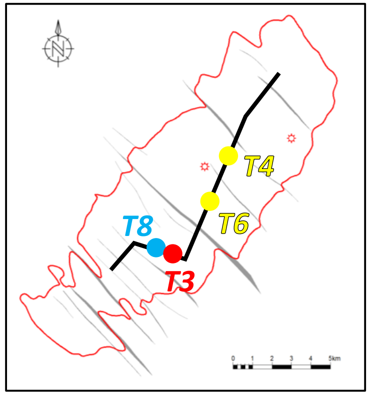
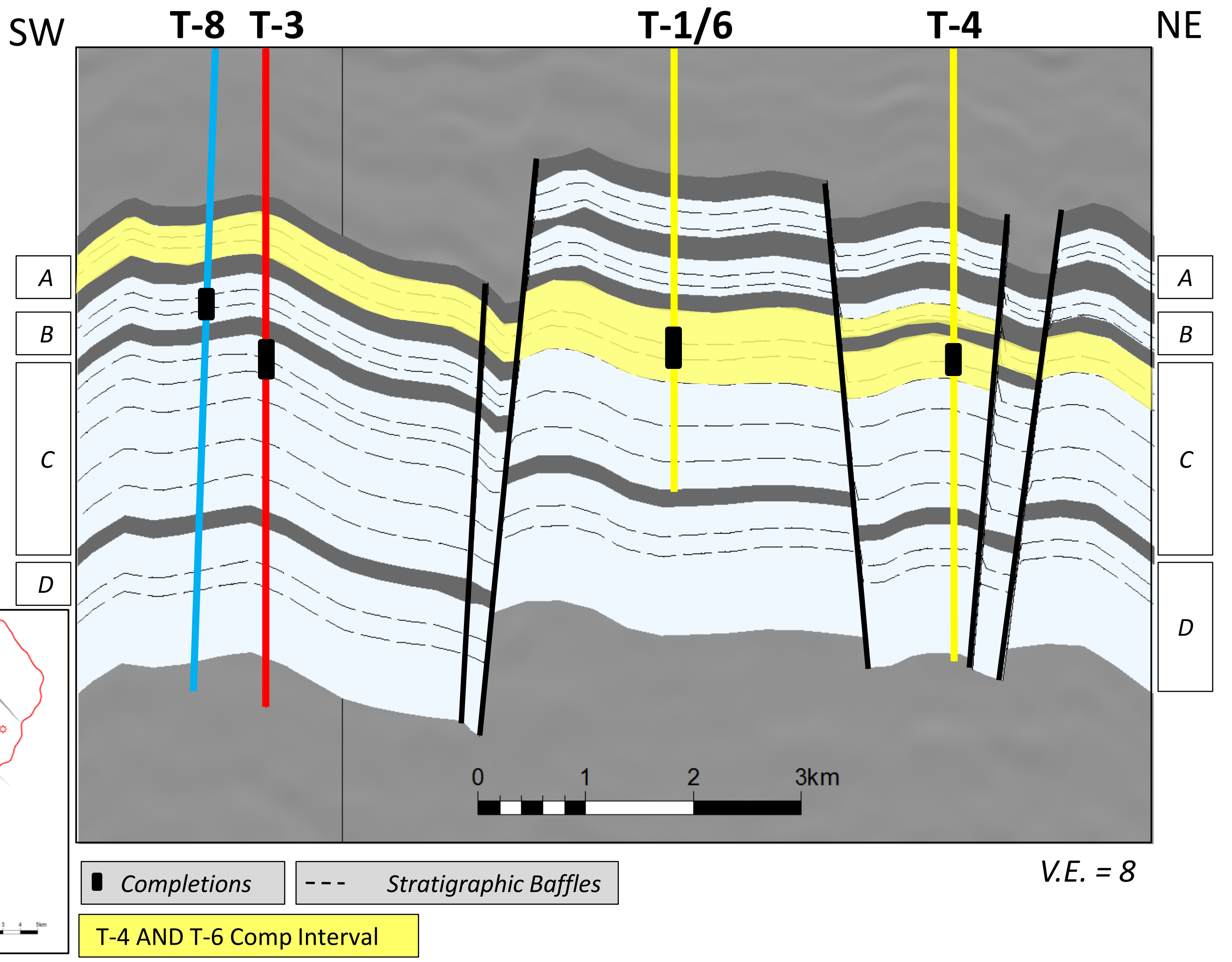


T4 & T6 Production Rate





Dynamic Connectivity: Far-field connection (T-8)

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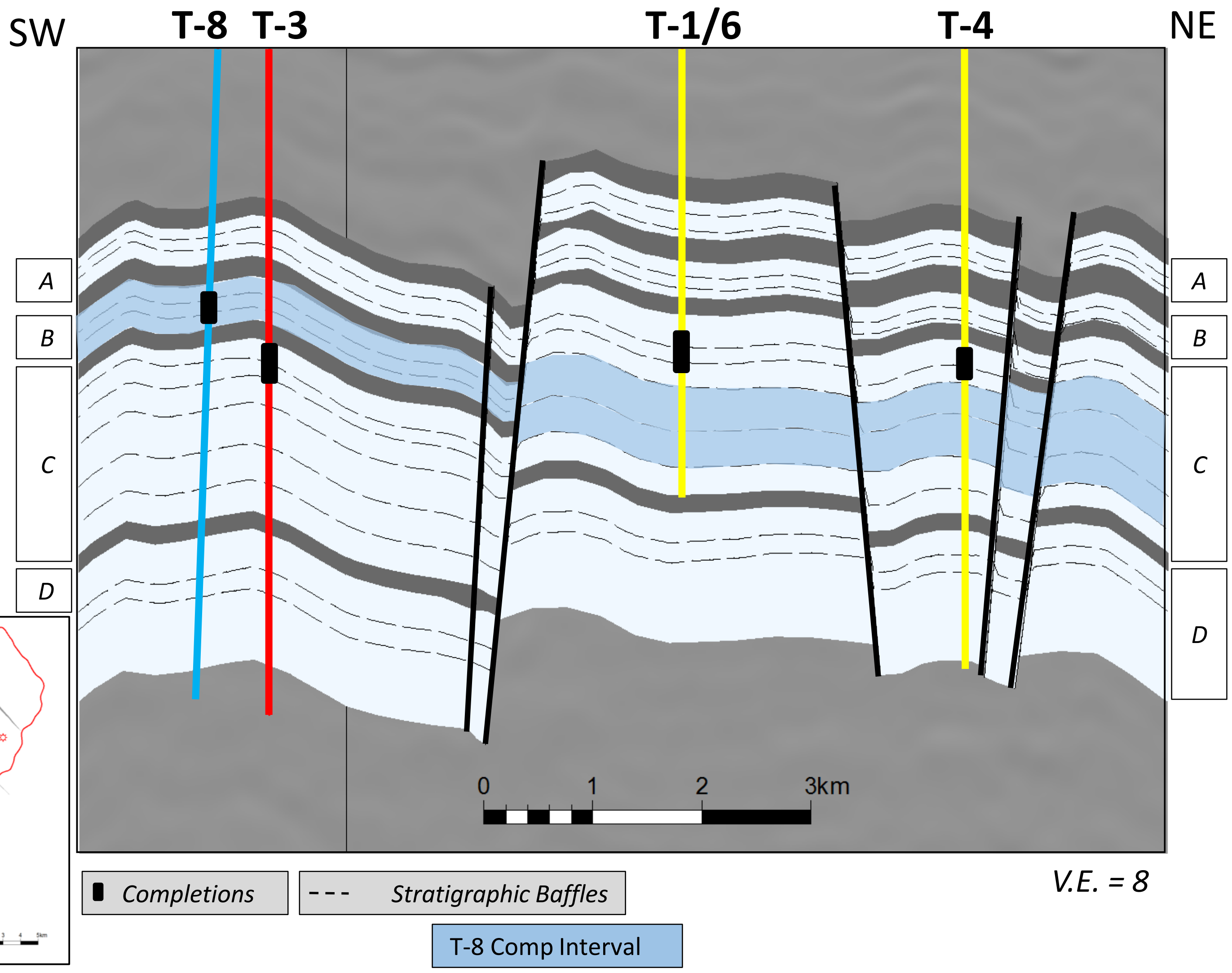

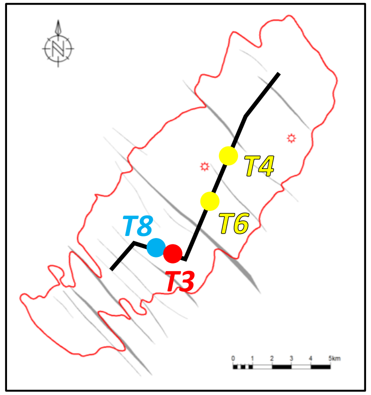

Dynamic Connectivity: Tortuous connection (T-3)

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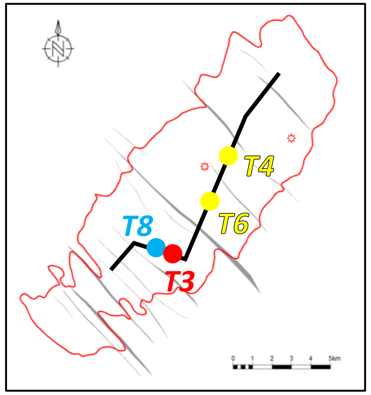

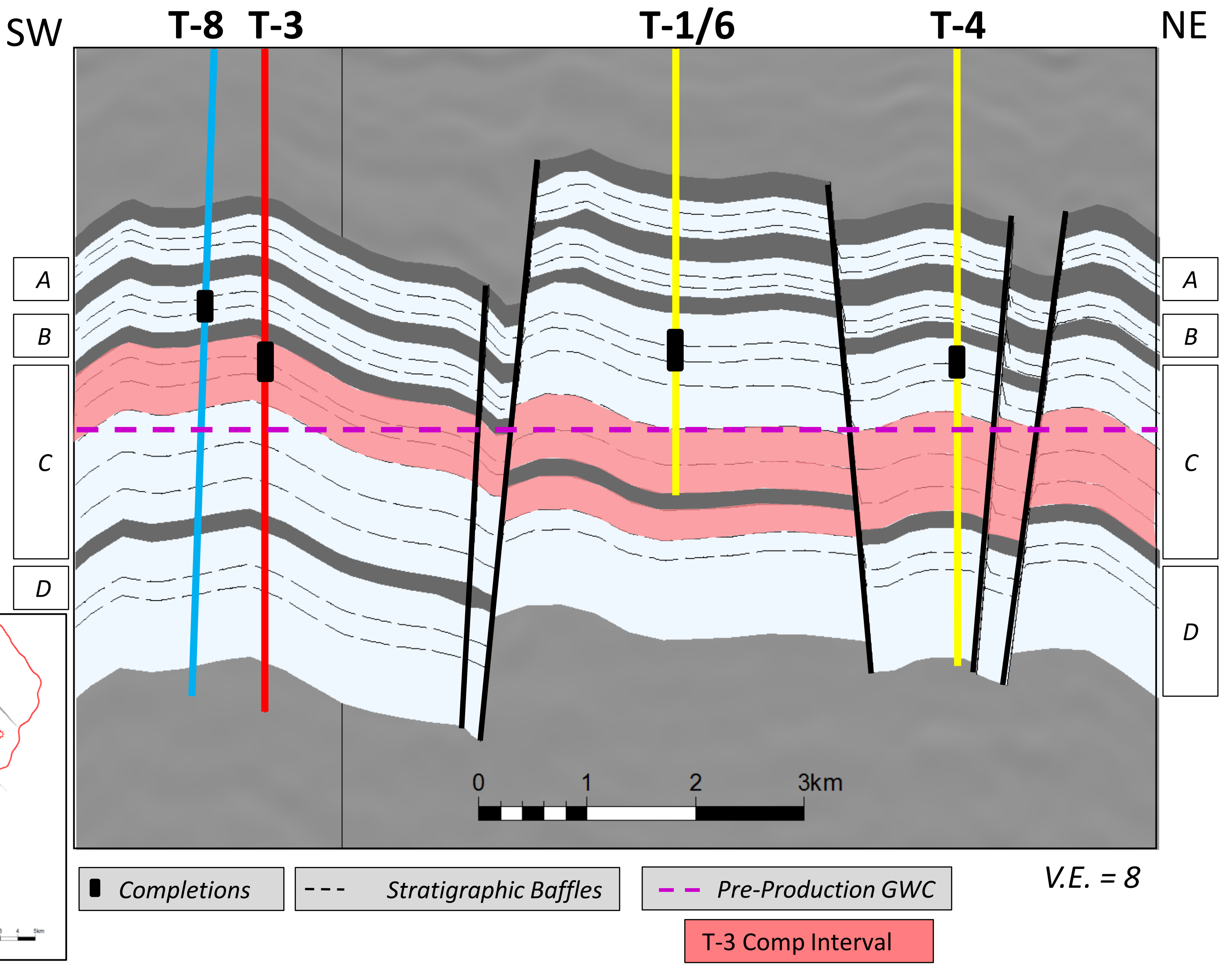

Dynamic Connectivity: Interaction along single line

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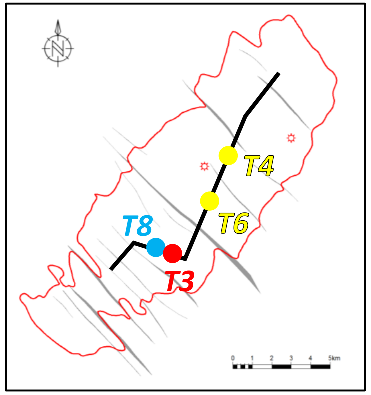

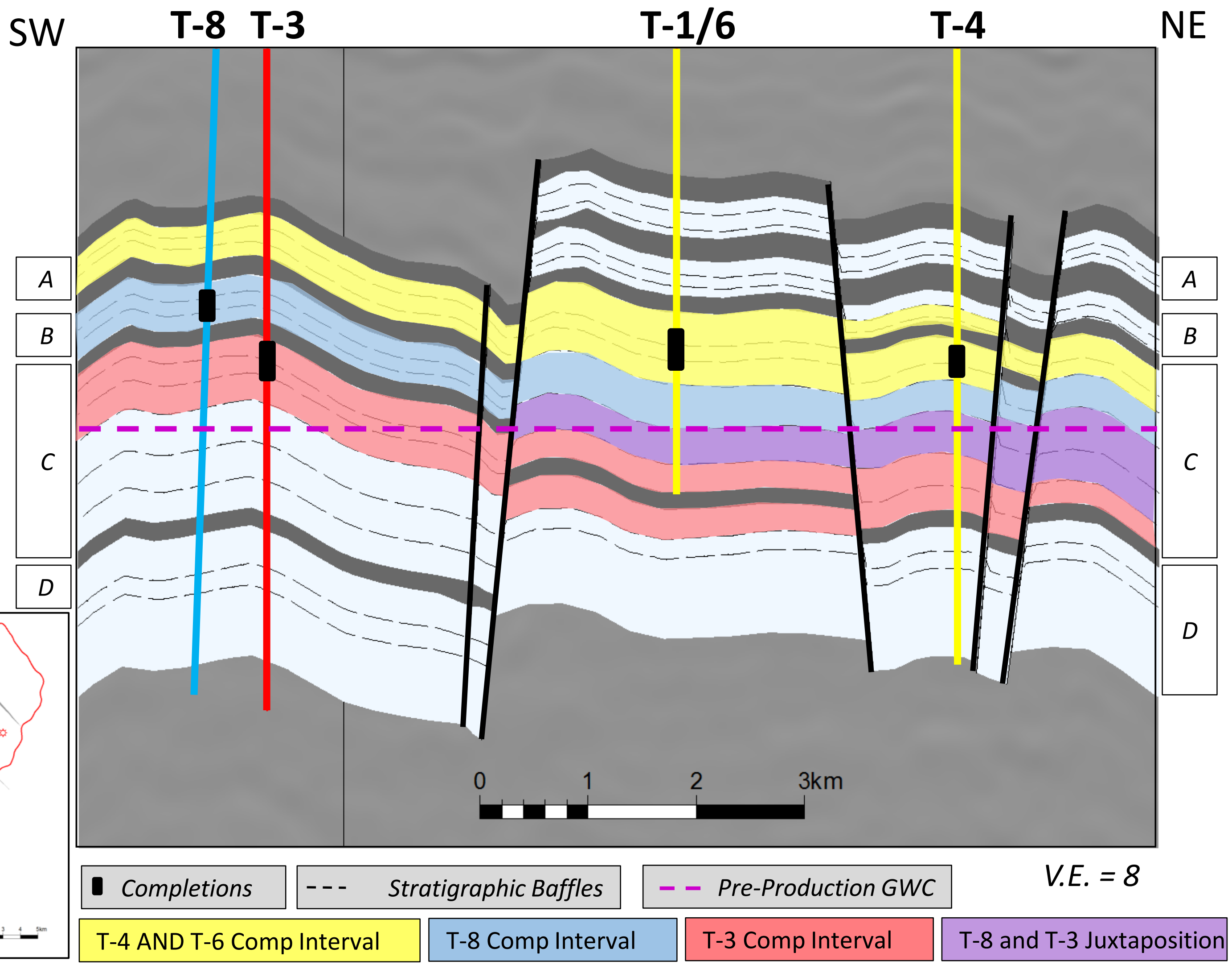

Complex AND Connected

- The integration of dynamic and static data indicates that the reservoir
  - Is continuous with some internal complexity
  - Exhibits a high degree of hydraulic connectivity

- The combination of T-8 results with PTA, Material Balance, and interference testing has provided:
  - Improved calibration for reservoir dynamics
  - Verification of cross-fault communication (sand-sand)
  - Indication of stratigraphic baffling
  - Demonstration of both volumetric depletion and aquifer support.
  - Evidence that all wells are in communication (to varying degrees)

- At Tamar, interdisciplinary collaboration is enhancing the original concepts for reservoir connectivity and performance, and will result in an optimized development plan for field management.

Forward-Looking Statements and Other Matters

This presentation contains certain "forward-looking statements" within the meaning of federal securities laws. Words such as "anticipates", "believes“, "expects", "intends", "will", "should", "may", and similar expressions may be used to identify forward-looking statements. Forward-looking statements are not statements of historical fact and reflect Noble Energy's current views about future events. Such forward-looking statements may include, but are not limited to, future financial and operating results, and other statements that are not historical facts, including estimates of oil and natural gas reserves and resources, estimates of future production, assumptions regarding future oil and natural gas pricing, planned drilling activity, future results of operations, projected cash flow and liquidity, business strategy and other plans and objectives for future operations. No assurances can be given that the forward-looking statements contained in this presentation will occur as projected and actual results may differ materially from those projected. Forward-looking statements are based on current expectations, estimates and assumptions that involve a number of risks and uncertainties that could cause actual results to differ materially from those projected. These risks and uncertainties include, without limitation, the volatility in commodity prices for crude oil and natural gas, the presence or recoverability of estimated reserves, the ability to replace reserves, environmental risks, drilling and operating risks, exploration and development risks, competition, government regulation or other actions, the ability of management to execute its plans to meet its goals and other risks inherent in Noble Energy's businesses that are discussed in Noble Energy's most recent annual reports on Form 10-K, respectively, and in other Noble Energy reports on file with the Securities and Exchange Commission (the "SEC"). These reports are also available from the sources described above. Forward-looking statements are based on the estimates and opinions of management at the time the statements are made. Noble Energy does not assume any obligation to update any forward-looking statements should circumstances or management’s estimates or opinions change.

The SEC requires oil and gas companies, in their filings with the SEC, to disclose proved reserves that a company has demonstrated by actual production or conclusive formation tests to be economically and legally producible under existing economic and operating conditions. The SEC permits the optional disclosure of probable and possible reserves, however, we have not disclosed our probable and possible reserves in our filings with the SEC. We may use certain terms in this presentation, such as “net unrisked resources”, which by their nature are more speculative than estimates of proved, probable and possible reserves and accordingly are subject to substantially greater risk of being actually realized. The SEC guidelines strictly prohibit us from including these estimates in filings with the SEC. Investors are urged to consider closely the disclosures and risk factors in our most recent Form 10-K and in other reports on file with the SEC, available from Noble Energy’s offices or website, http://www.nblenergy.com.

This presentation also contains certain non-GAAP measures of financial performance that management believes are good tools for internal use and the investment community in evaluating Noble Energy’s overall financial performance. These non-GAAP measures are broadly used to value and compare companies in the crude oil and natural gas industry. Please see the attached schedules for reconciliations of the differences between any historical non-GAAP measures used in this presentation and the most directly comparable GAAP financial measures.

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THANK YOU!

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