The Dynamic Tamar Reservoir: Insights from Five Years of Production

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Search and Discovery Article #20465 (2019)**
Posted October 7, 2019

*Adapted from oral presentation given at AAPG Geoscience Technology Workshop, Exploration and Development of Siliciclastic and Carbonate Reservoirs in the Eastern Mediterranean, Tel Aviv, Israel, February 26-27, 2019
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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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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.

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

![Pre-Production Tamar Pressures (psi)](image)

TVDss (m)

<table>
<thead>
<tr>
<th>Pre-Production Tamar Pressures (psi)</th>
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<tbody>
<tr>
<td>Tamar 1</td>
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<td>Tamar 2</td>
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<td>Tamar 3</td>
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<td>Tamar 5</td>
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**Gas Water Contact**

*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:
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Graph showing reservoir pressure data for TAMAR-2, TAMAR-3, TAMAR-4, and TAMAR-5 with a common datum of -4727 m tvdss.
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)

![Graph showing observed P/Z in T-3 and expected P/Z from depletion drive, with additional energy from aquifer highlighted.](image)
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

Wireline Pressure Data:

Pressure Data:
- Initial Gas
- Initial Water
- Tamar-8 (all)

~425 psi
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

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**Pressure Data:**
- Initial Gas
- Initial Water
- Tamar-8 (all)
- Gas
- Water
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.
Dynamic Connectivity: Direct connection (T-4 & T-6)

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![Diagram of dynamic connectivity with T-4, T-6, T-8, and T-3 wells showing completions and stratigraphic baffles.](image-url)

![T4 & T6 Production Rate graph showing significant production differences.](image-url)
Dynamic Connectivity: Far-field connection (T-8)

- Does the interpretation of a baffled reservoir fit with the interference testing observations?
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  - T-8 and T-6 show a more subtle interference response during build-ups.
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Dynamic Connectivity: Tortuous connection (T-3)

- 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.
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Dynamic Connectivity: Interaction along single line

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V.E. = 8

Pre-Production GWC

Completions
Stratigraphic Baffles
Pre-Production GWC
T-4 AND T-6 Comp Interval
T-8 Comp Interval
T-3 Comp Interval
T-8 and T-3 Juxtaposition
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.
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The Dynamic Tamar Reservoir

THANK YOU!

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