Transient Pressure and Temperature Interpretation in Intelligent Wells of the Golden Eagle Field

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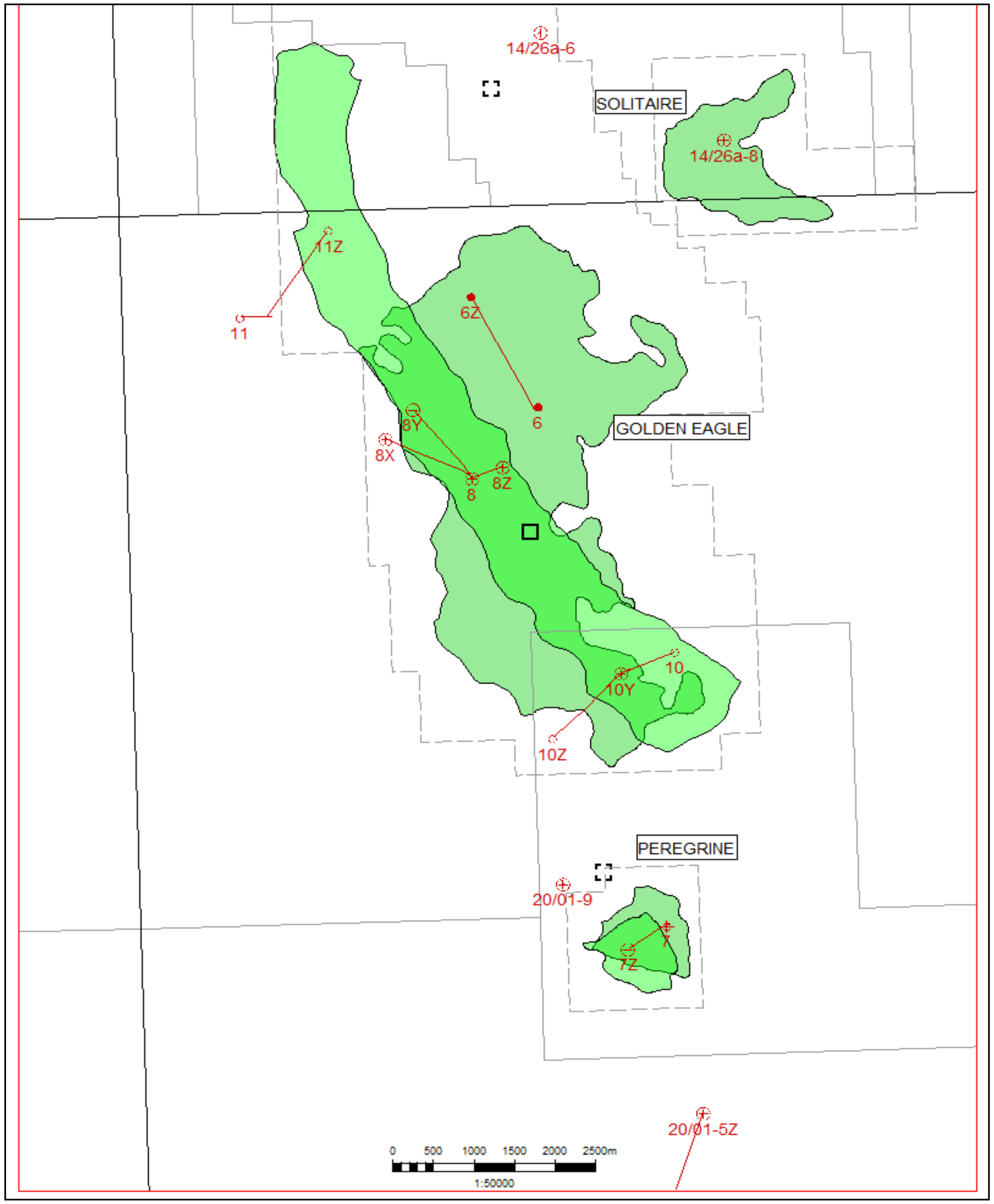
Outline

- Field and Well Description
- Temperature Transient Analysis (TTA) Basics
- Useful Events and Input Data
- TTA Selected Results
- Conclusions

The Golden Eagle Field

- The Golden Eagle Area is located 100 km NE of Aberdeen in the UKCS
- Production started in October 2014 with water injection some months later.
- The field produces a light, under-saturated black oil from the:
  - Lower Cretaceous Punt sandstone
  - Upper Jurassic Burns sandstone
- The two formations were, and possibly still are, in communication in at least one area of the field.

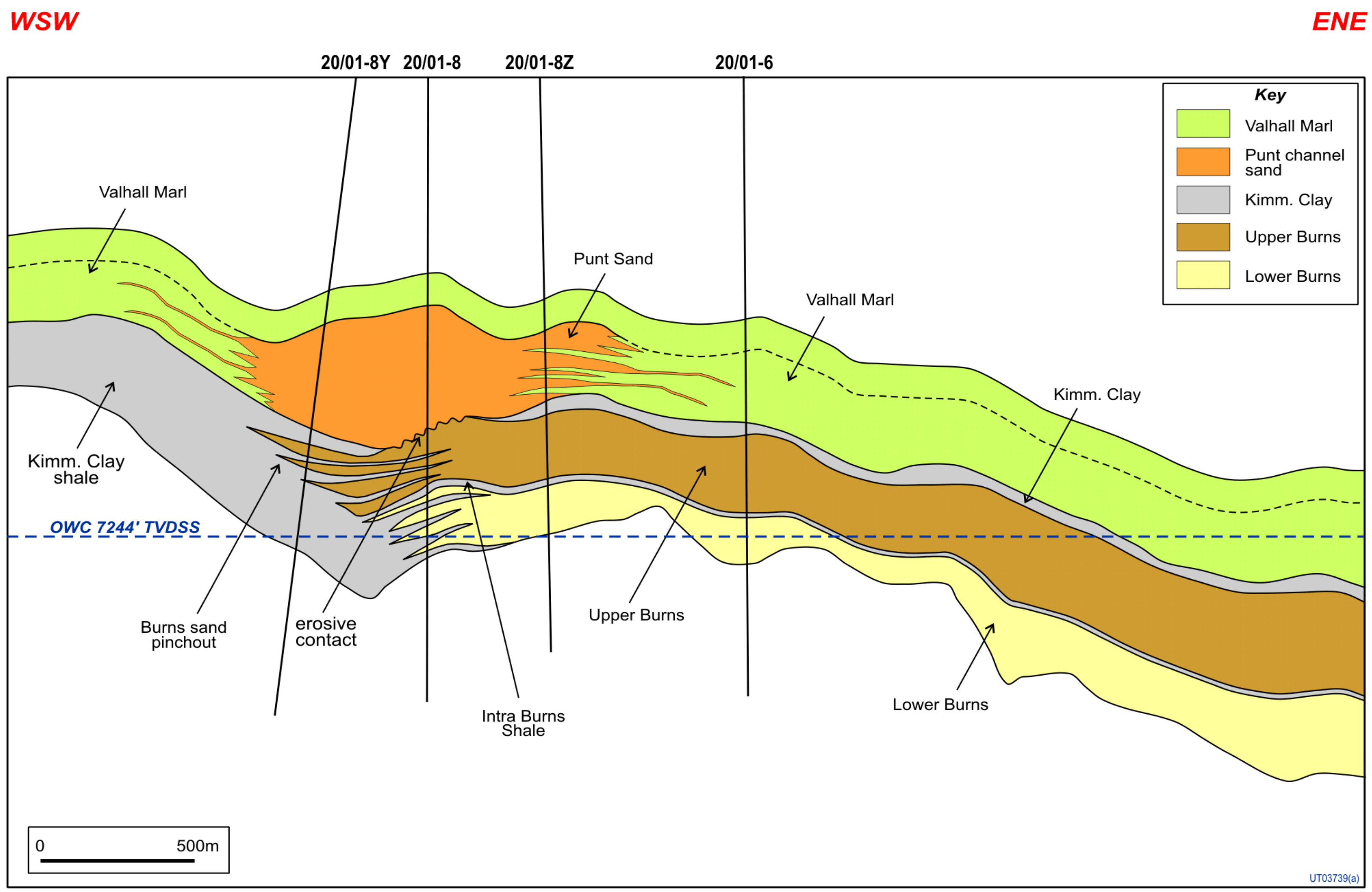
Golden Eagle Area Development Map



The Golden Eagle Field

- I-well technology installed in most of the 14 production and 5 injection wells
- ICVs manage the production from up to 3 zones/per well
  - Produced separately or comingled in any combination.

Cross Section Through Central Golden Eagle Field



Completion:
In-well Monitoring & Flow Control

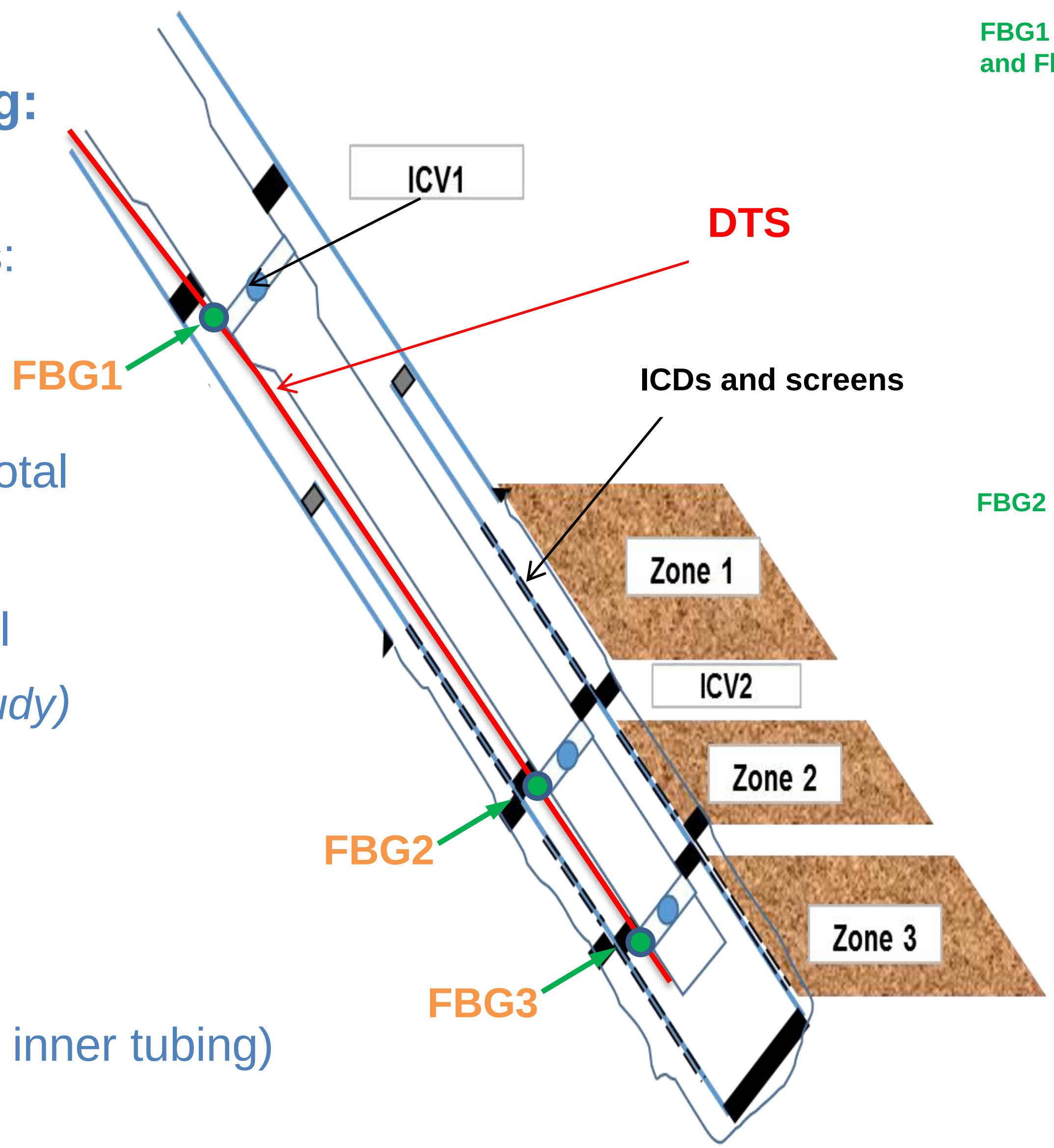
Well A: A 60º deviated, high PI, 3-zone, intelligent, oil production well

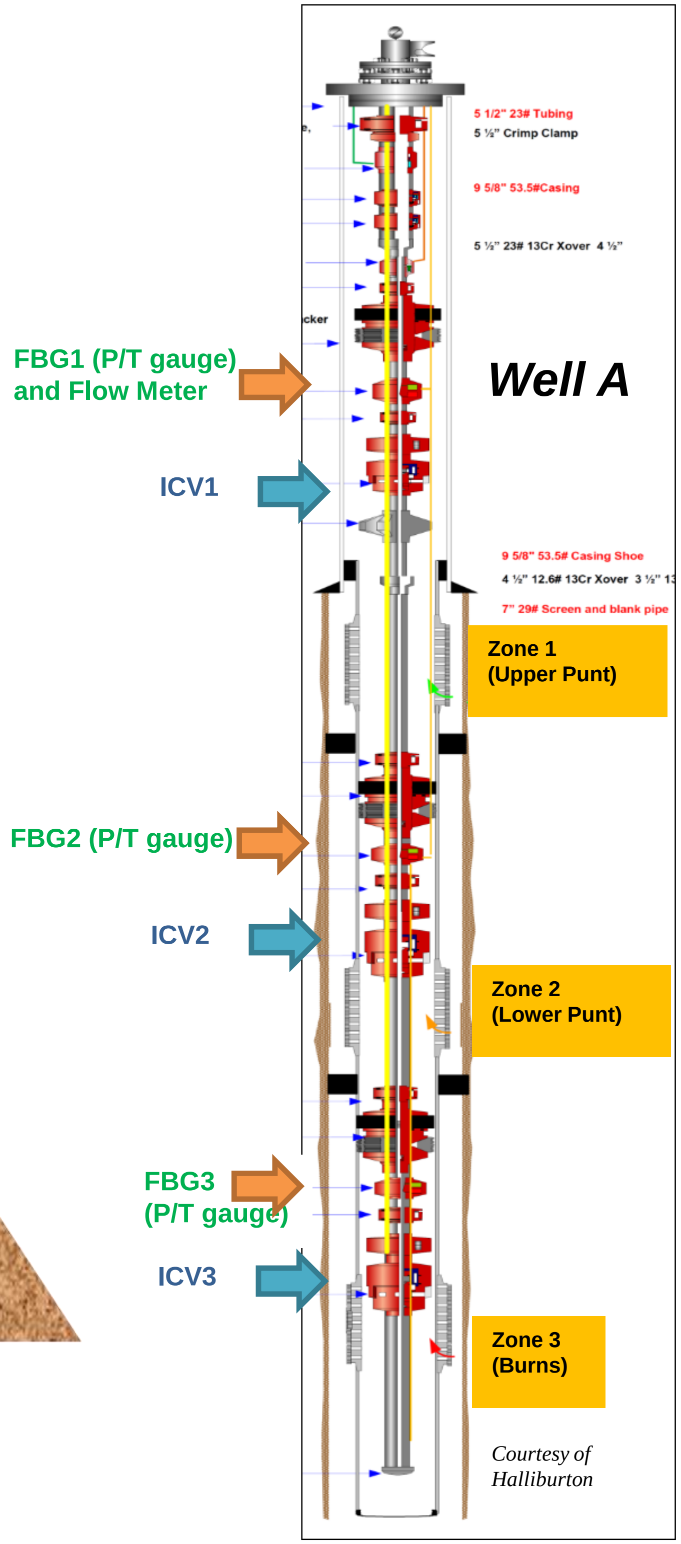
Fibre-optic In-well Monitoring:

- FBG - high precision (within 1.5psi and 0.02ºC) P/T gauges: 1 per zone
- 2-phase flowmeter measures total well rate and Water Cut
- DTS across completion interval *(insufficient resolution for this study)*

Zonal Control:

- 10-position, hydraulic ICVs (on inner tubing) and ICDs (on outer screens)





Problem Statement

1. In-well flowmeters measure total well rate *and*
   - Pressure & Temperature data measured by permanent, high-precision gauges *but*
   - Workflow required to turn measured data into information on zonal flow rate allocation, reservoir monitoring, history matching, etc.

2. ICVs are regularly cycled.
   - Provides zonal flow-rate build-up and drawdown *(transient)* data *as part of routine operations for:*

     i. Pressure Transient Analysis (PTA)
       - Well-developed with high quality analysis software available

     ii. Temperature Transient Analysis (TTA)
       - Novel
       - Golden Eagle Field provides a unique set of data to extend and verify industry knowledge in this area

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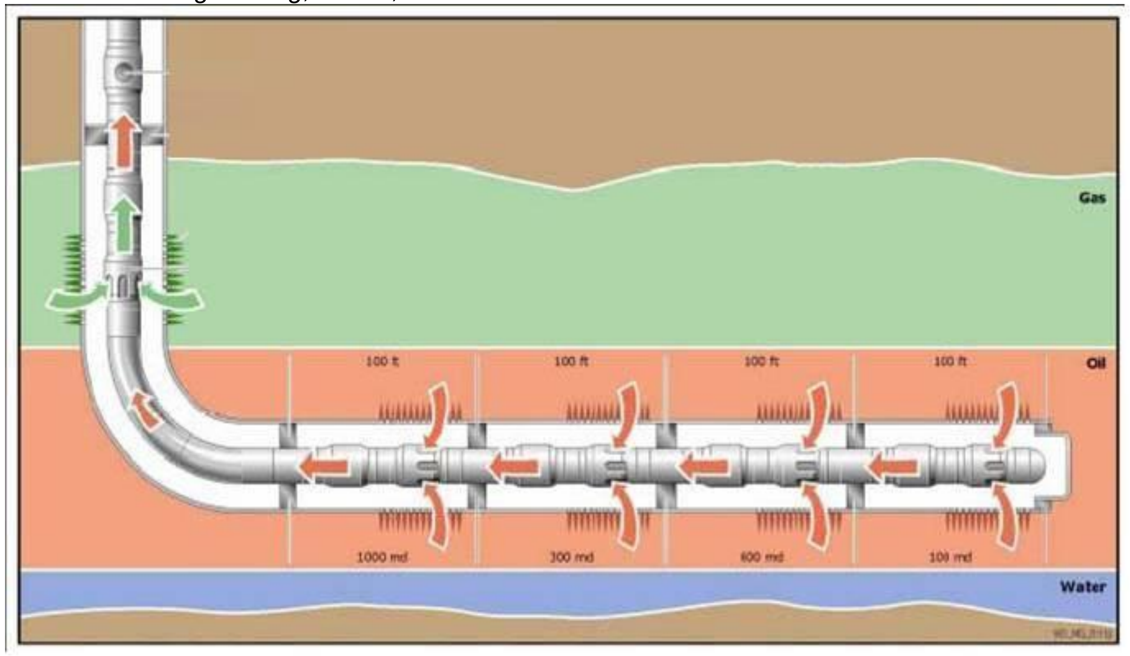
Transient Temperature Analysis
A Game Changer for Multi-zone Wells

Example from: MURADOV, K. & DAVIES, D. 2012b. Temperature transient analysis in horizontal wells: Application workflow, problems and advantages. Journal of Petroleum Science and Engineering, 92–93, 11-23



Discrete and Distributed TTA analysis:

An attractive source of information:

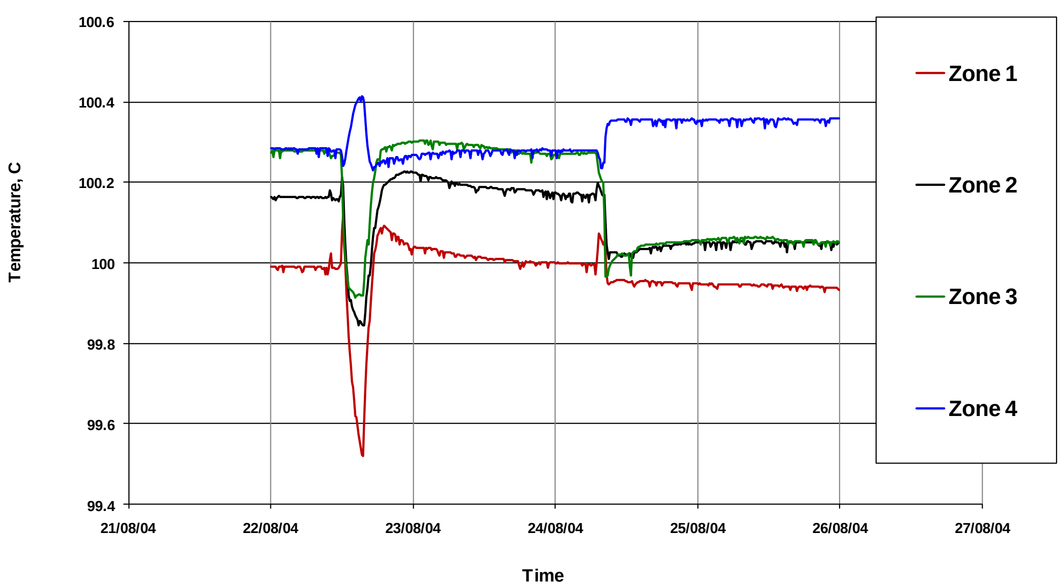
1. Differentiates zones
2. Layer-by-layer testing no longer required

- *ALSO* Tolerant to gauge drift & accuracy

BUT ***analysis workflow not widely adopted yet***

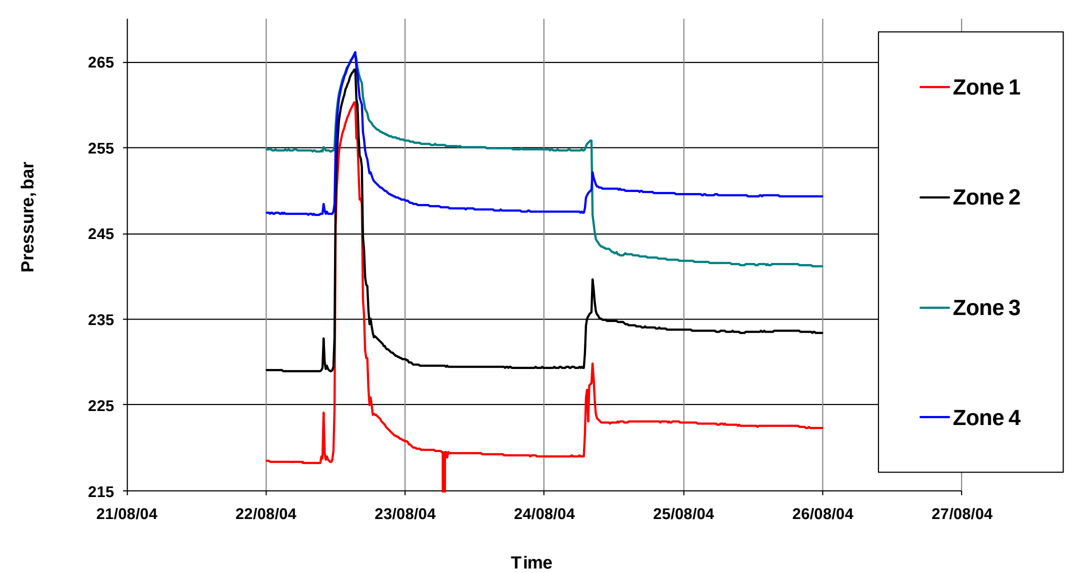
A 4-zone intelligent well shut-in & start-up

zonal temperatures ***– discriminates zonesones***



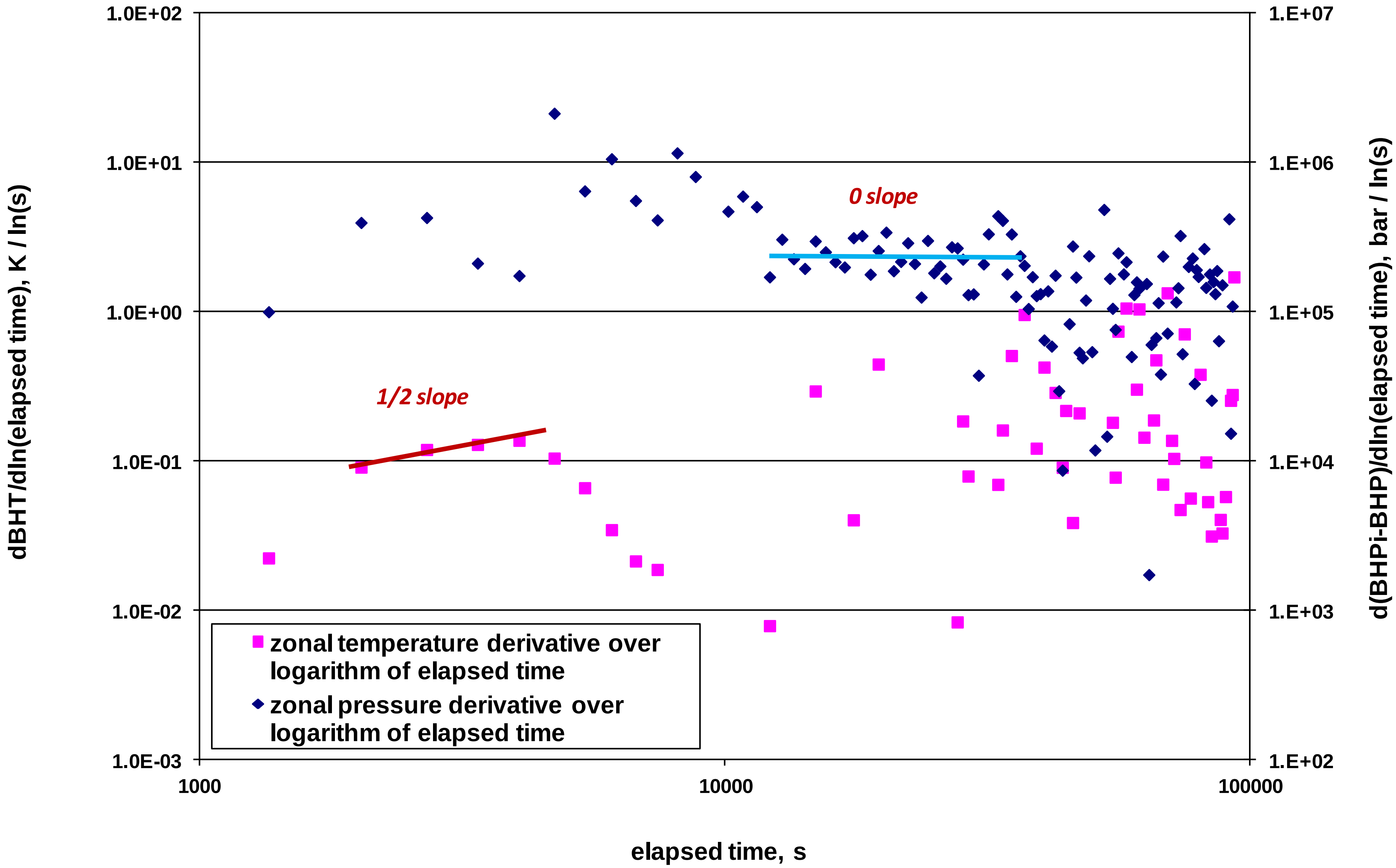
VS

zonal pressures - ***indiscriminate***



Potential Benefits of Transient Pressure & Temperature Data

1. P data is better at describing the reservoir at a distance
2. T recognises the near-wellbore effects much better than P
   T signal propagates much slower than P signal



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Physics of Pressure & Temperature changes

Pressure Model (Diffusivity equation)*

$$\frac{\partial}{\partial t}(\phi\rho) + \nabla\cdot\left(-\rho\frac{\overline{\overline{\boldsymbol{K}}}}{\mu}\nabla P\right) = 0$$

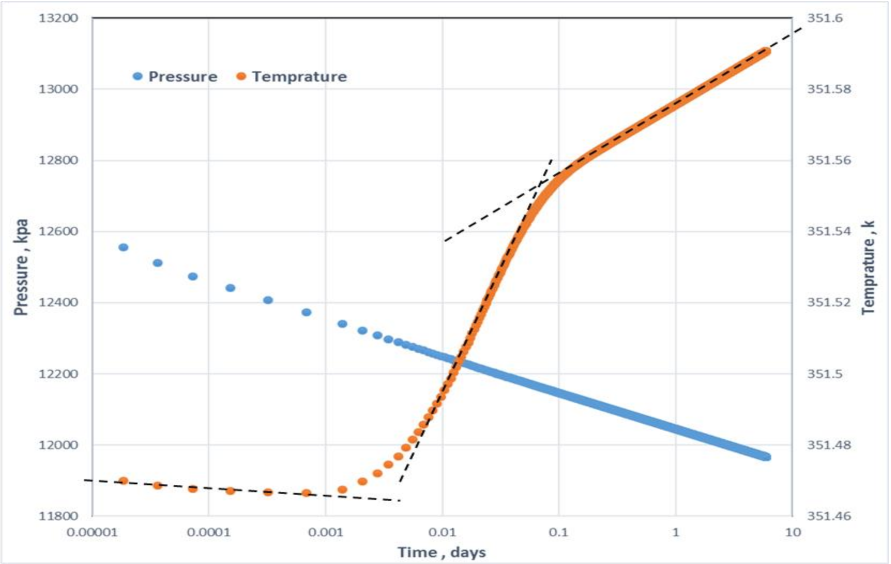
Transient pressure change — Divergence of mass flux

Thermal Model*

$$\overline{\rho\widehat{C_P}}\frac{\partial T}{\partial t} - \emptyset\beta T\frac{\partial P}{\partial t} - \emptyset C_f\left(P + \rho_f\widehat{C_{Pf}}T\right)\frac{\partial P}{\partial t} = -\rho v\widehat{C_p}\cdot\nabla T + \beta T v\cdot\nabla P - v\cdot\nabla P + K_T\nabla^2 T$$

Transient temperature change — Transient fluid expansion — Transient formation rock compression — Heat convection — Joule-Thomson effect — Heat conduction

Pressure and **Temperature** response compared for a numerical model of a vertical, oil production well



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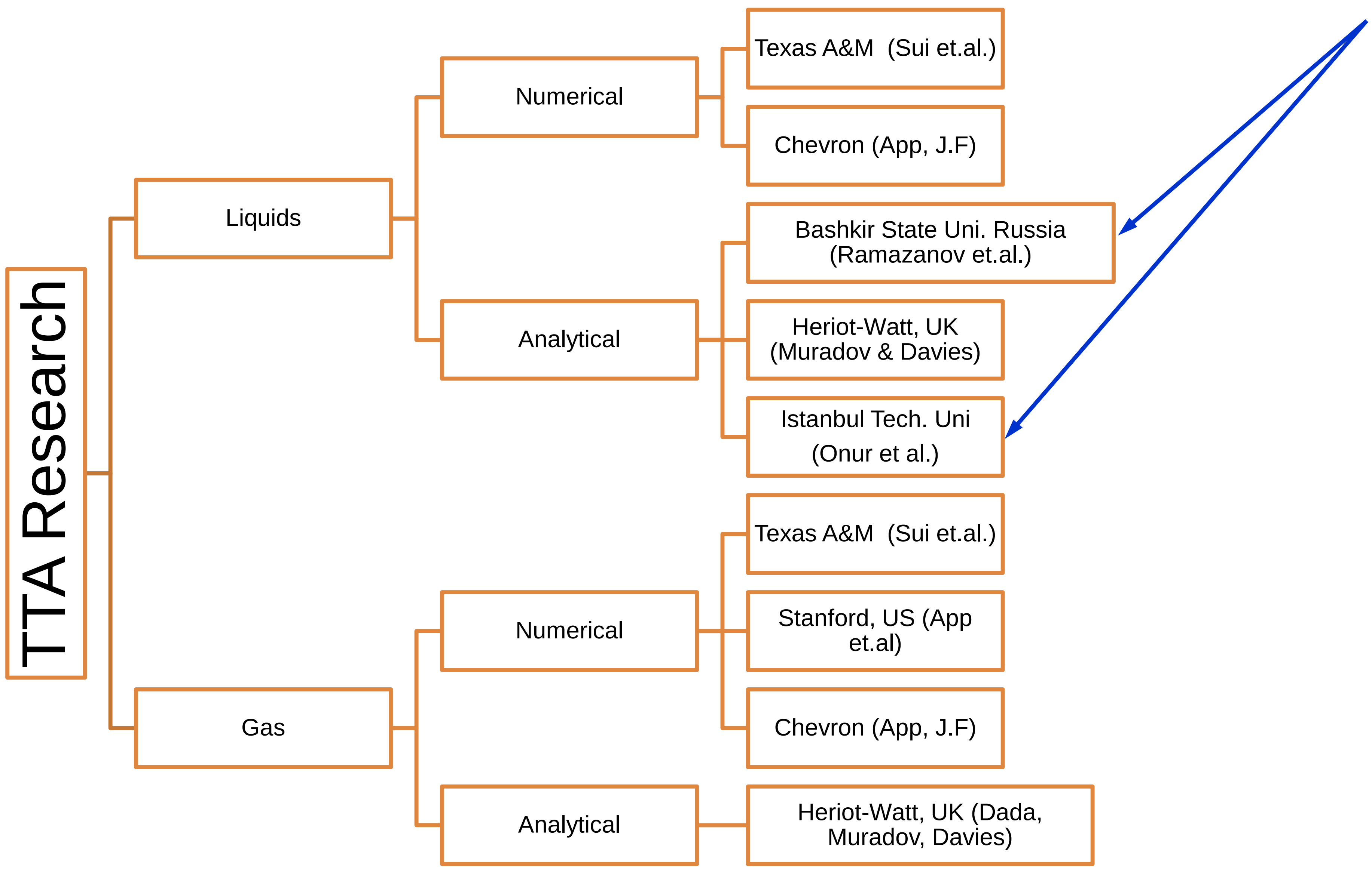
TTA Research is relatively new (since 2008)



Used here for data interpretation of:

1. Late-time **TDD in damage zone**
2. Late-time **TDD beyond damage zone**
3. Late-time **TBU**
4. **Multi-zone** late-time **TDD**

**TDD - Temperature Draw Down*
**TBU - Temperature Build-Up*
(Equations derived in SPE 136256 and SPE 180074)

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Select Well A Data for TTA interpretation after 5 months:

Routine ICV cycling/testing

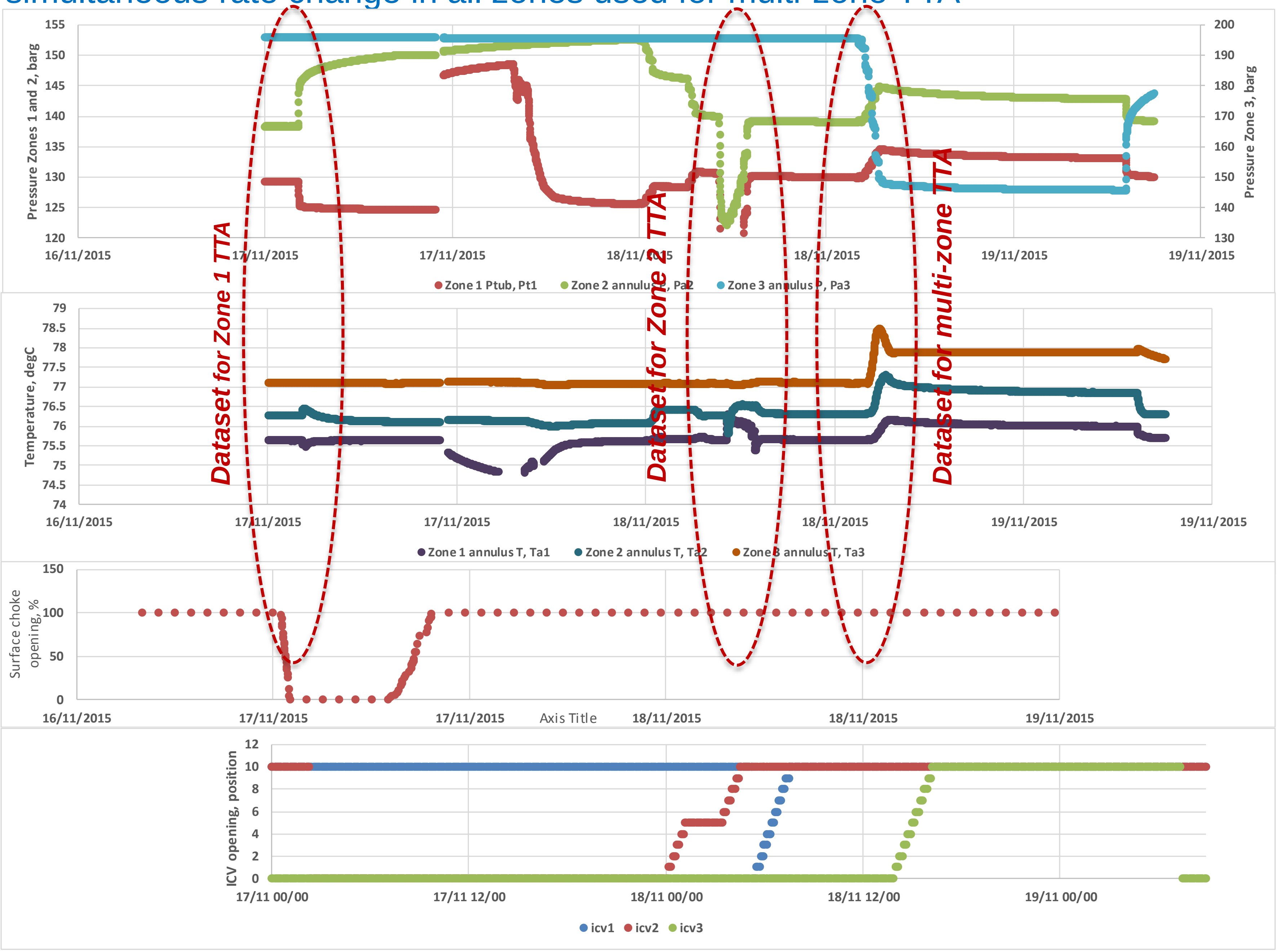
1. Zone 1 and 2 TTA events due to rate change in another zone selected
2. ICV3 cycling: simultaneous rate change in all zones used for multi-zone TTA

Z1 Tubing Pressure
Z2 Annulus Pressure
Z3 Annulus Pressure

Z1 Annulus Temperature
Z2 Annulus Temperature
Z3 Annulus Temperature

Surface Choke opening: from 0 to 100%

Zonal ICVs opening: positions from 0 to 10
ICV1
ICV2
ICV3



Fluid and Formation Properties

1. Conventional PVT properties available.

2. In-situ Thermal fluid properties are unknown, however there are multiple ways to estimate them cheaply and accurately. From instance in this work:

   Specific heat capacity, **Cp**

   - estimated using black oil correlations

   Adiabatic (η) and Joule-Thomson (ε) coefficients:

   - estimated directly from the pressure and temperature measurements

** See paper SPE-185817 for more detail*

Solutions and Workflows Used*

Radial flow models applied to well A. The corresponding TTA solutions were used as follows:

1. The temperature slopes were used to estimate the kh values for each zone
2. The damage radius and permeability kdam were also reliably estimated using temperature, because the rate at which the radius of investigation for temperature increases in well A is ~200 times slower than for pressure.
3. These parameters were then used in a zonal Productivity Index model to calculate zonal Pis

Further, combined with the basic wellbore pressure measurements (no PTA) the above estimates of zonal PIs were used to

4. Estimate zonal pressures (zonal shut-in is not required)
5. Reliably allocate zonal flow rates or flow rate changes

** See paper SPE-185817 for more detail*

"Traditional" Pressure based Well Surveillance that was Used in Well A to confirm TTA results

Combining TTA with "Traditional PBU/PDD" methods "Adds Value" by:

1. Confirmation of TTA results.
2. Well monitoring, reservoir characterization & flow rate allocation, e.g.:
   a. Zonal PBUs
   b. Nodal analysis, multi-layer/zone, wellbore model used routinely.

      Measure stabilised pressures and total Q_{well} for various combinations of ICV positions and estimate:

      Zonal PI or P_{res} for each zone & solve $Q_{well} = \sum_{i=1}^{3} PI_i(P_{res,i} - P_{ann,i})$

   c. ΔP_{ICV}* used for virtual flow metering: $\Delta P_{ICV} = \frac{\gamma \cdot q^2}{C_V^2}$

      where C_V for each ICV position provided by the ICV manufacturer

*ΔP_{ICV} must be sufficiently large.

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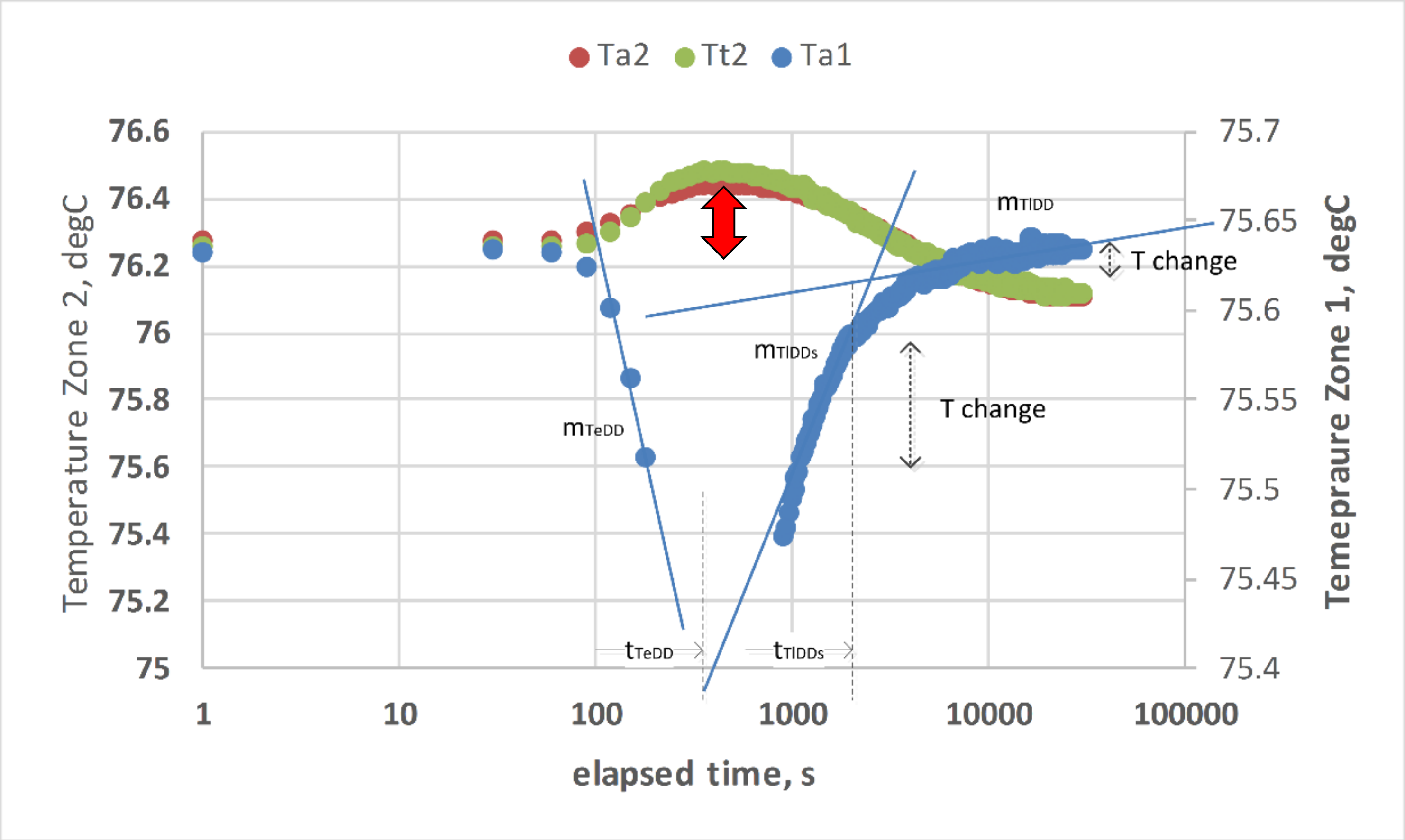
Top Zone (Zone 1) TTA: an event (instantaneous increase in q1) generated by Zone 2 closure

Selected Findings and Observations:

- Instantaneous temperature jump in Zone 2 after shows that the zone is cleaned up. It is also used to estimate fluid thermal props
- The Zone 1 slopes ratio is used to estimate fluid thermal props
- Further, the Zone 1 T slope analysis gives kh estimate of 75 D*ft. *(matches the (earlier) PBU result of 71 D*ft!)*
- The damage zone (radius, permeability) is also described using TTA (unique result)

Zone 2 TDD ***and*** *Zone 1 TBU*



Well A Results:

Zonal PBU results:

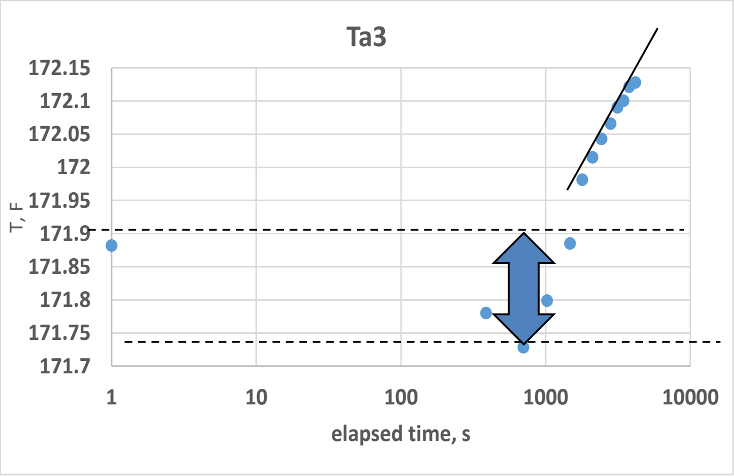
	Zone 1 (Upper Punt)	Zone 2 (Lower Punt)	Zone 3 (Burns)
kh, mD.ft	71,000	19,000 – 29,000	3,000 – 15,000
Total skin	+0.9	approx. -1	+ 2 to -3
PI, bbls/day/psi	34.6	15.4	4.3

Zonal TTA results:

	Zone 1 (Upper Punt)	Zone 2 (Lower Punt)	Zone 3 (Burns)
kh damage zone, mD.ft	7,000	2,000	1,000
kh original, mD.ft	75,000	22,000	n/a
Damage radius	1ft	1ft	> 3 ft
Damage skin	3	6	n/a
Zone clean during test?	Yes	Yes	No

Zone 2 TDD

Zone 3 TDD



Major results:

a. KH values from TTA & PBU data analyses agree
b. TTA uniquely provides depth and permeability of formation damage zone
c. Zonal shut-ins also used for well clean-up quality monitoring

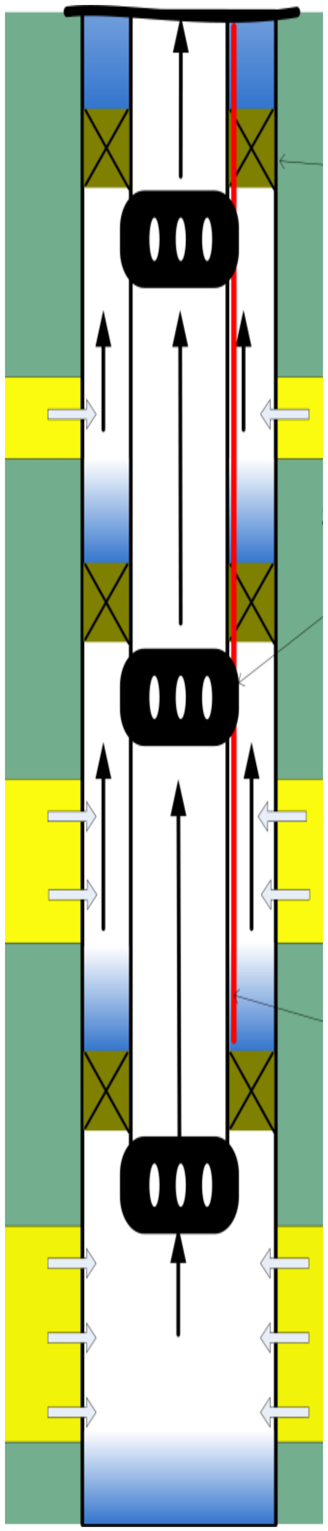
Formed the basis of comprehensive guidelines for implementing TTA *(+data sampling, metrology & test design)* by project sponsors

Simultaneous, Multi-zone TTA

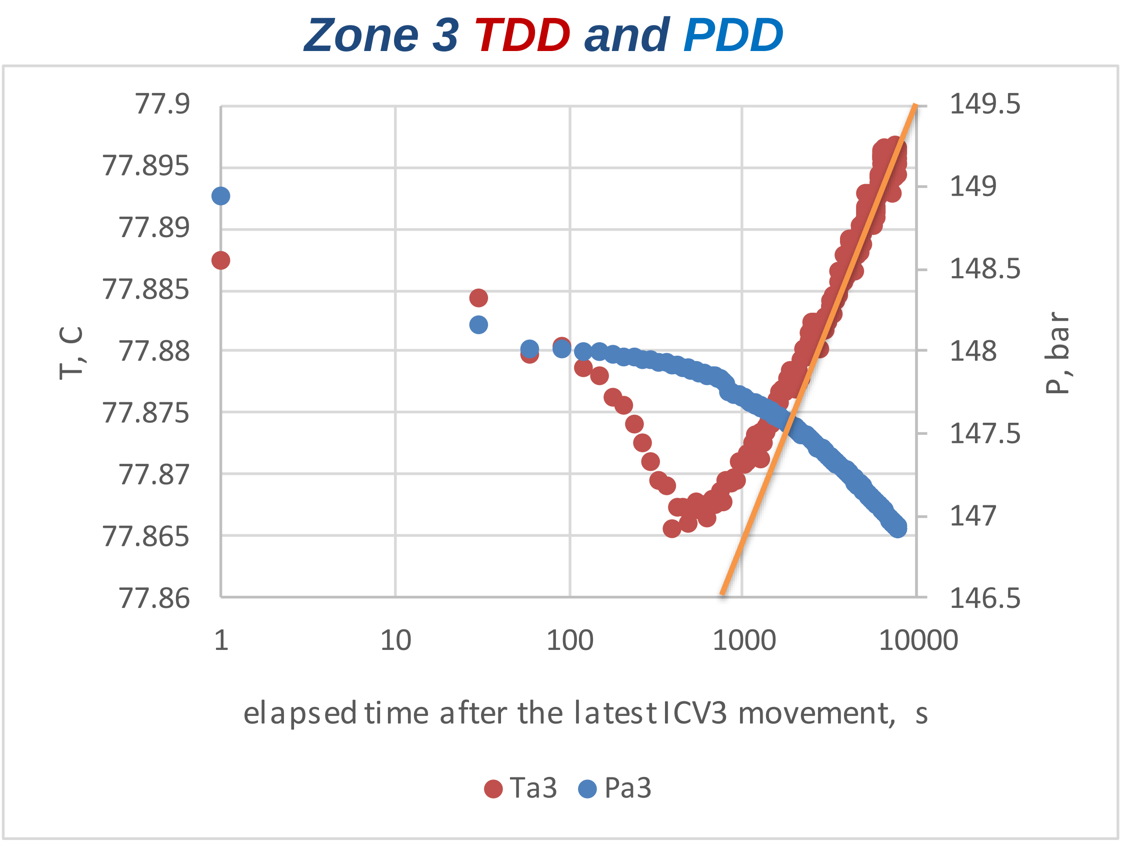
1. Simultaneous analysis *(flow profiling)* of multiple zones from a single transient is a unique to TTA.
   - Downhole flow control (incl. zonal shut-ins) is **not required**
2. Thermal contribution of each zone =

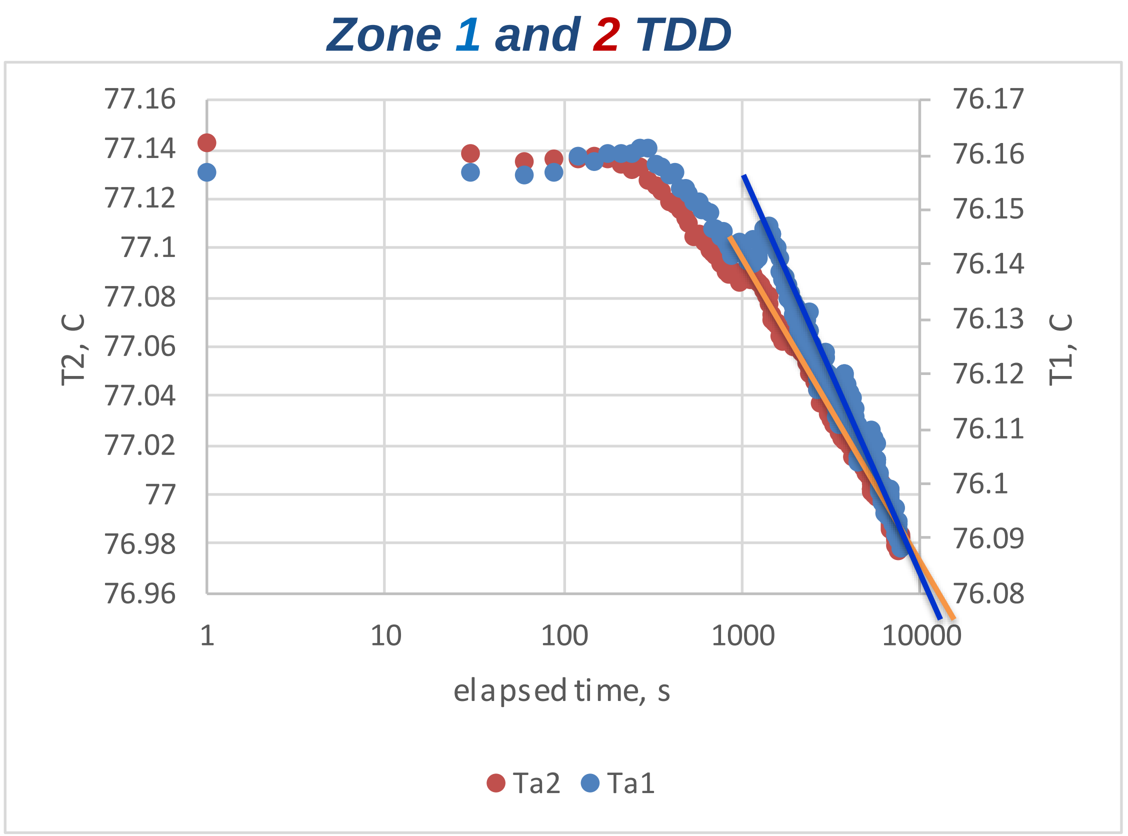
   the total, thermal contribution –

   the combined contribution of all upstream zones.
3. Solutions for temperature slopes allows:
   - Ignoring thermal mixing and wellbore heat flow effects
   - Extracting sand face slopes for each zone from one event



Verification of simultaneous analysis of multiple zones - by comparing zonal derivatives





TTA predicted ratio of zonal rates: $\mathbf{\Delta q_1:\Delta q_2:\Delta q_3 = 19:7:20}$

PBU predicted ratio of zonal rates: $\mathbf{\Delta q_1:\Delta q_2:\Delta q_3 = 20:8:20}$

This unique ability of TTA to profile reservoir properties, or rates, **from a single transient without the need for zonal closure** *also applies to conventional wells*

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Conclusions

1. Practical field application of TTA solutions to wells equipped with high-precision in-well monitoring and zonal control confirmed

2. Input fluid property data derived directly from TTA data set

3. TTA reliably estimated zonal flow rates, formation damage zone properties and well clean-up parameters.

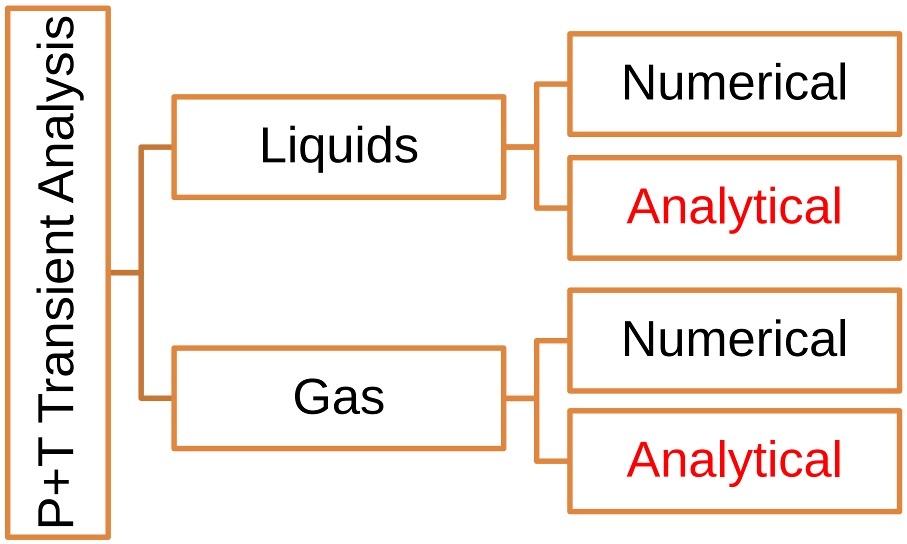
4. TTA solution accuracy of ± 5-20% *for this field's data set*
    - Results uniquely verified by other data sources.

5. TTA also suited to interval-by-interval Temperature analysis for flow and Kh profiling of conventional wells.

6. TTA has "stand-alone" workflow or combined with PTA
    - TTA can reduce the number of well or zonal flow tests by ≥ 50%
    - Compensates for failed ICVs / sensors.

Analysis of In-Well Temperature Data: The Future

Multiple methods for interpretation and well test design steady-state (DTS) and transient (FBG, PDG, ATS) pressure & temperature (both) for smart and conventional wells producing either liquids or gas.



Latest "Value from Advanced Wells" JIP starting shortly, will develop:

1. ***In-well monitoring and data interpretation Theme***

- Integrated, Pressure and Temperature Transient data analysis for gas-liquid production wells
- DTS interpretation methods for oil and gas wells
- Data mining of in-well measurements *and*

2. ***Modelling and Optimisation Theme***

- Maximise "Added Value" from downhole flow control completions

Acknowledgements / Thank You / Questions

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