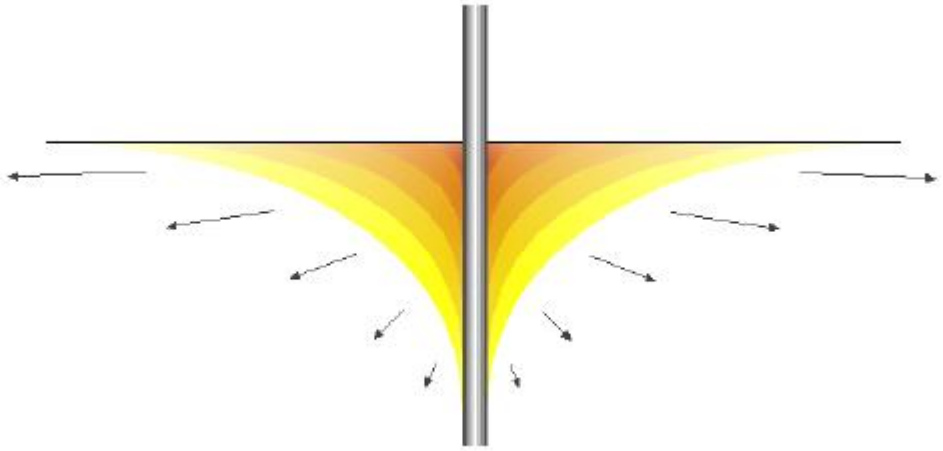
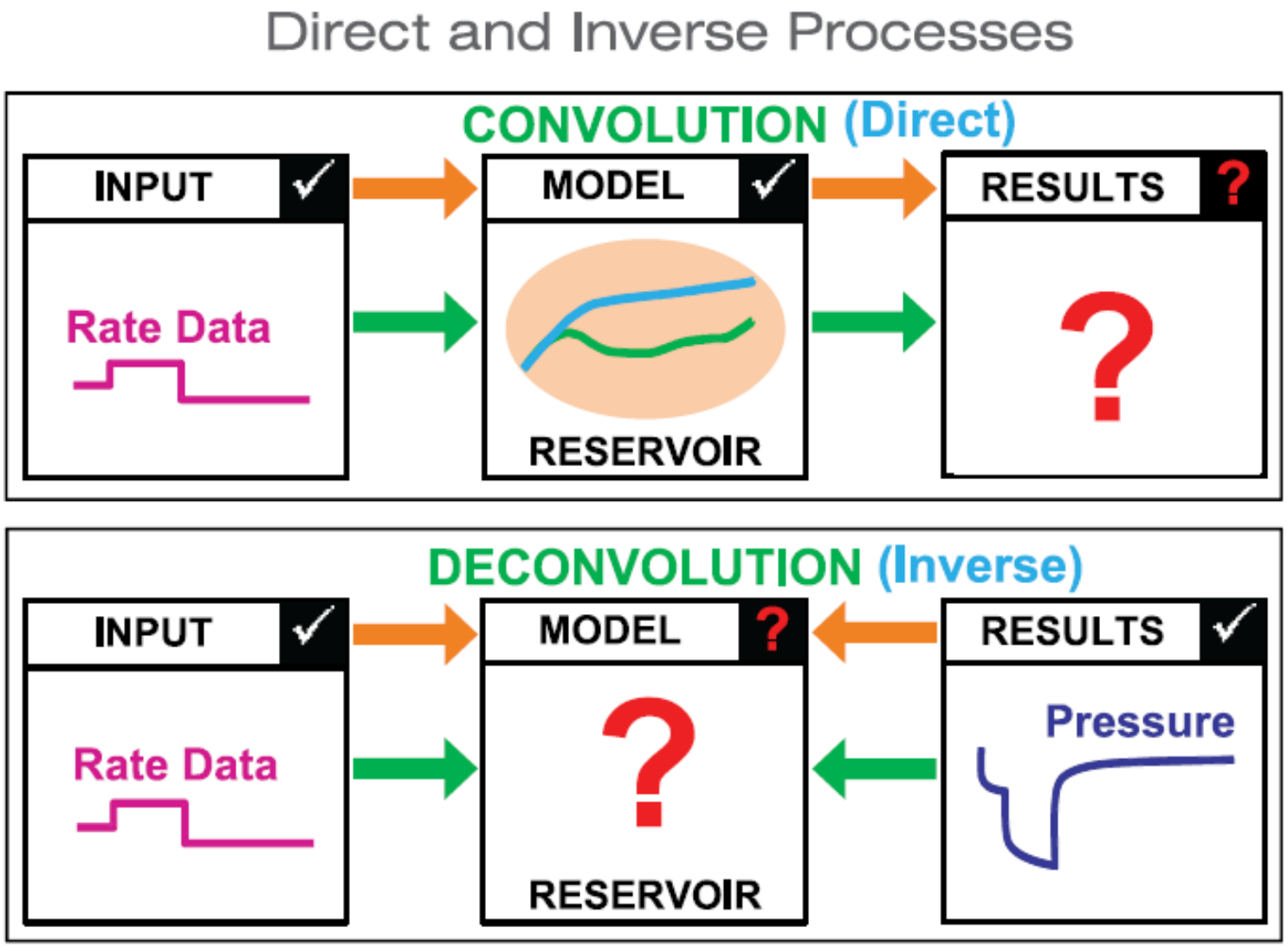
Advanced WellTest Analysis



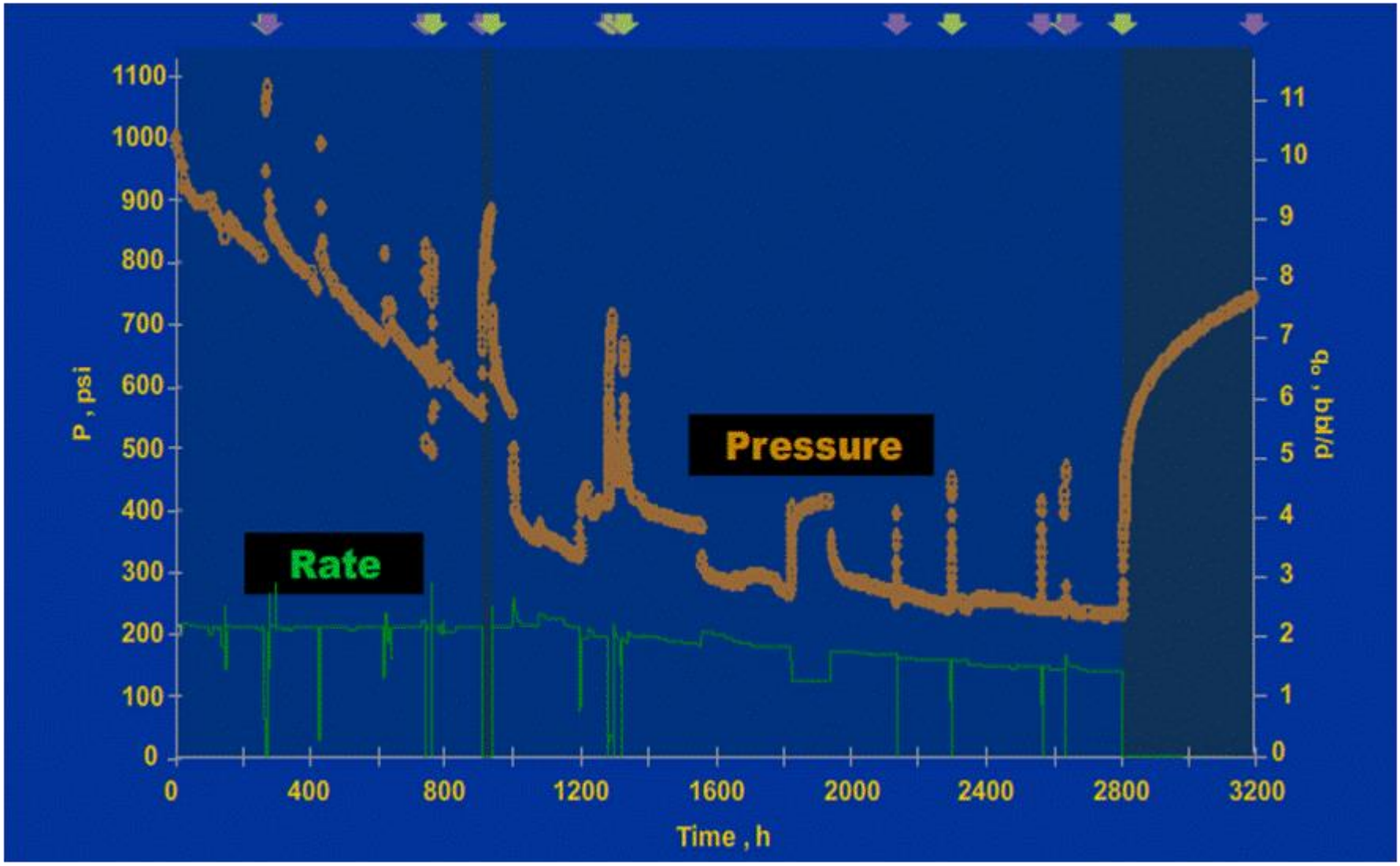
Deconvolution in Well Testing

By: Shahab Gerami

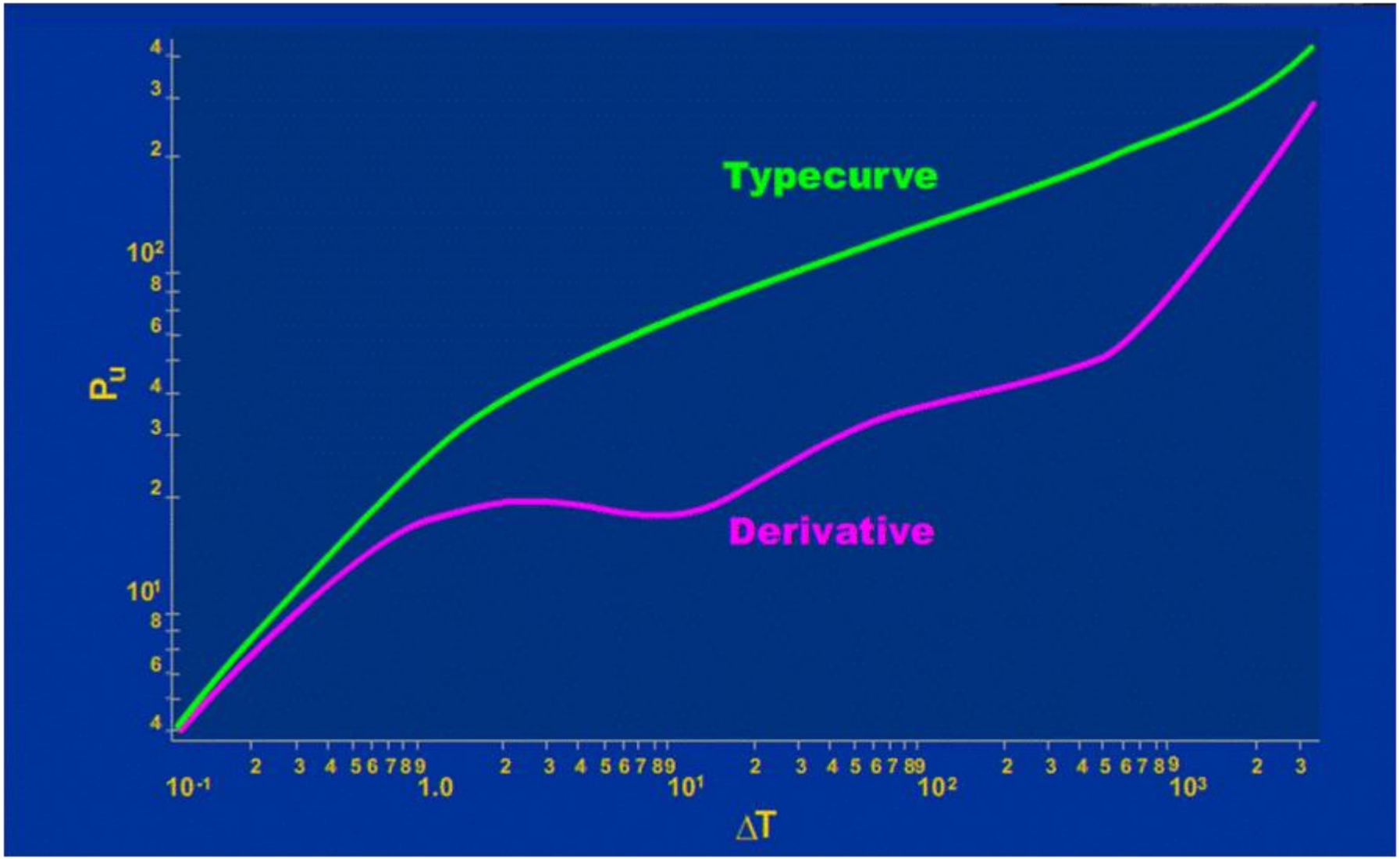
Convolution &Deconvolution



History Plot



Reservoir Charachteristics



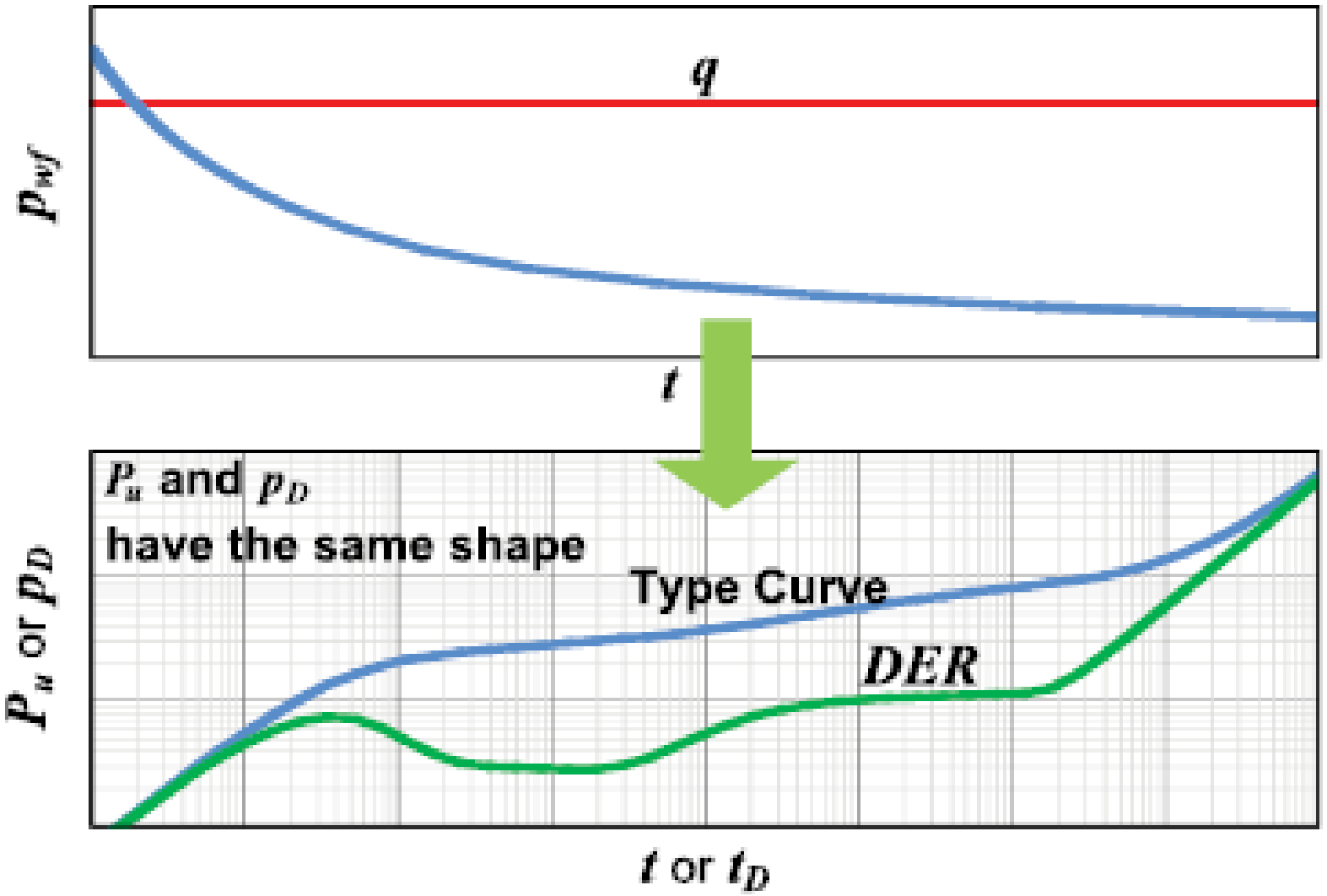
UNIT RATE FUNCTION

- Unit Rate Function, P_u, is defined as the pressure drop per unit constant flow rate : $P_u = (\Delta p/q)$
- It is the fundamental solution of the Diffusivity Equation used in Well Test Interpretation
- P_u is often expressed in dimensionless form

$$p_D = \frac{\Delta p k h}{141.2 q B \mu} \qquad t_D = \frac{2.637E{-}4\ kt}{\phi \mu c_t r_w^2}$$

- It is called a Type Curve when plotted on log-log coordinates, and is usually presented with the semilog derivative $DER = d(p_D)/d(\ln t_D)$
- Every reservoir has its own Unit Rate Function; the shape of its derivative reflects the reservoir model

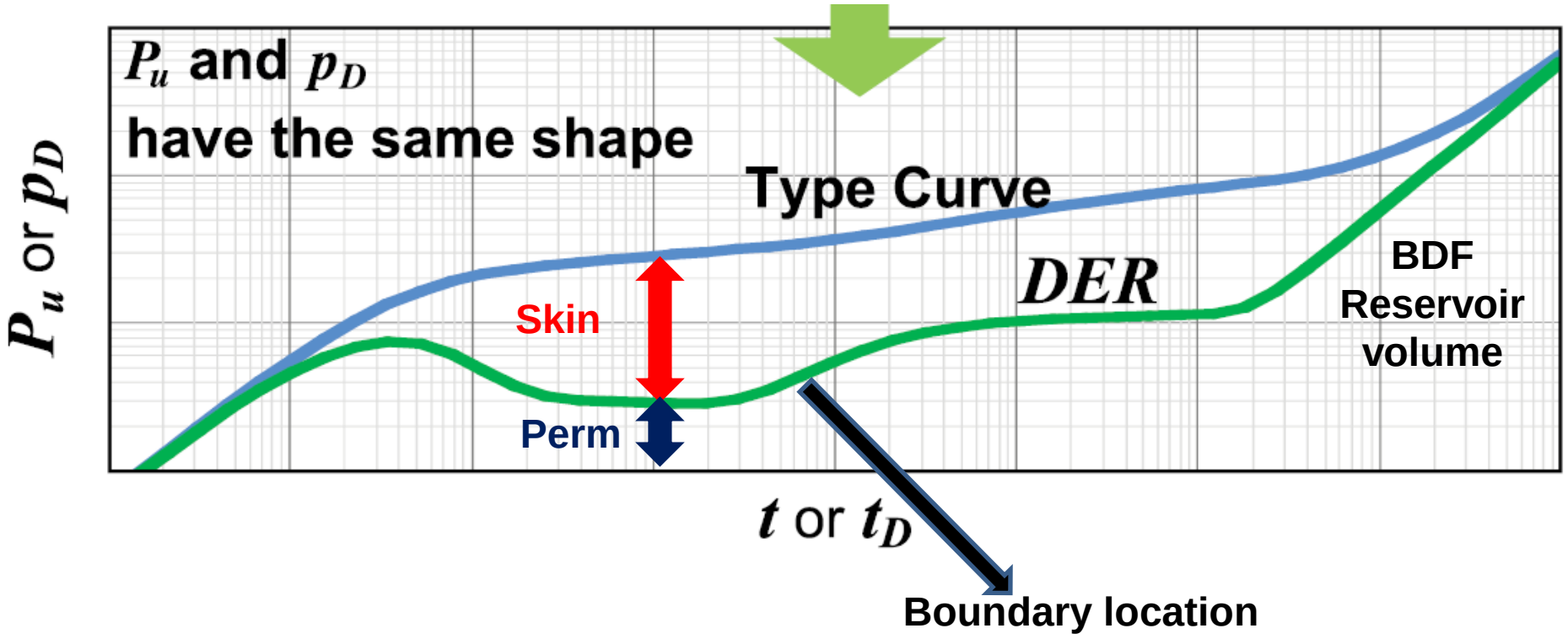
Unit Rate Function (Type-curve)



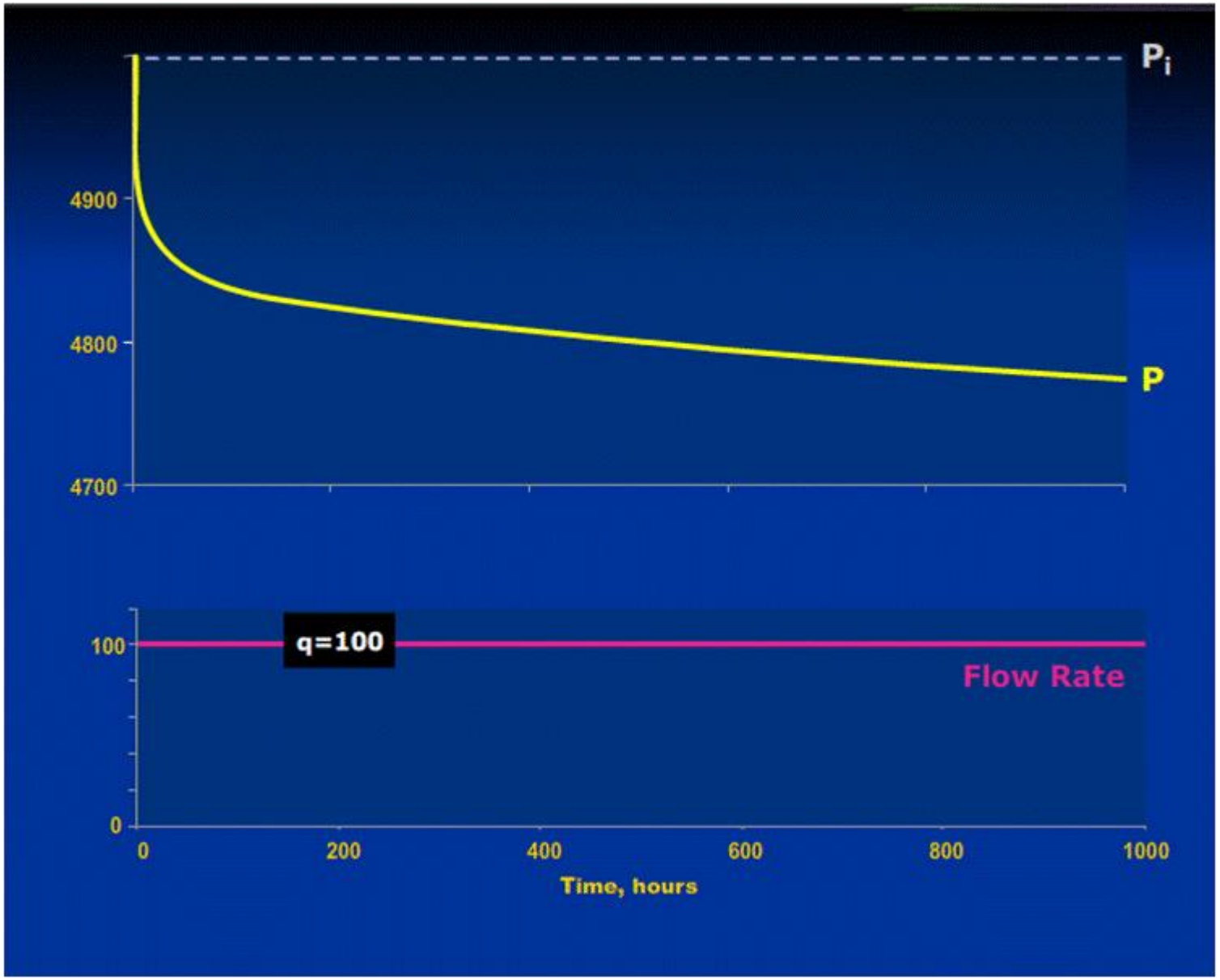
This type-curve describe the reservoir characteristics

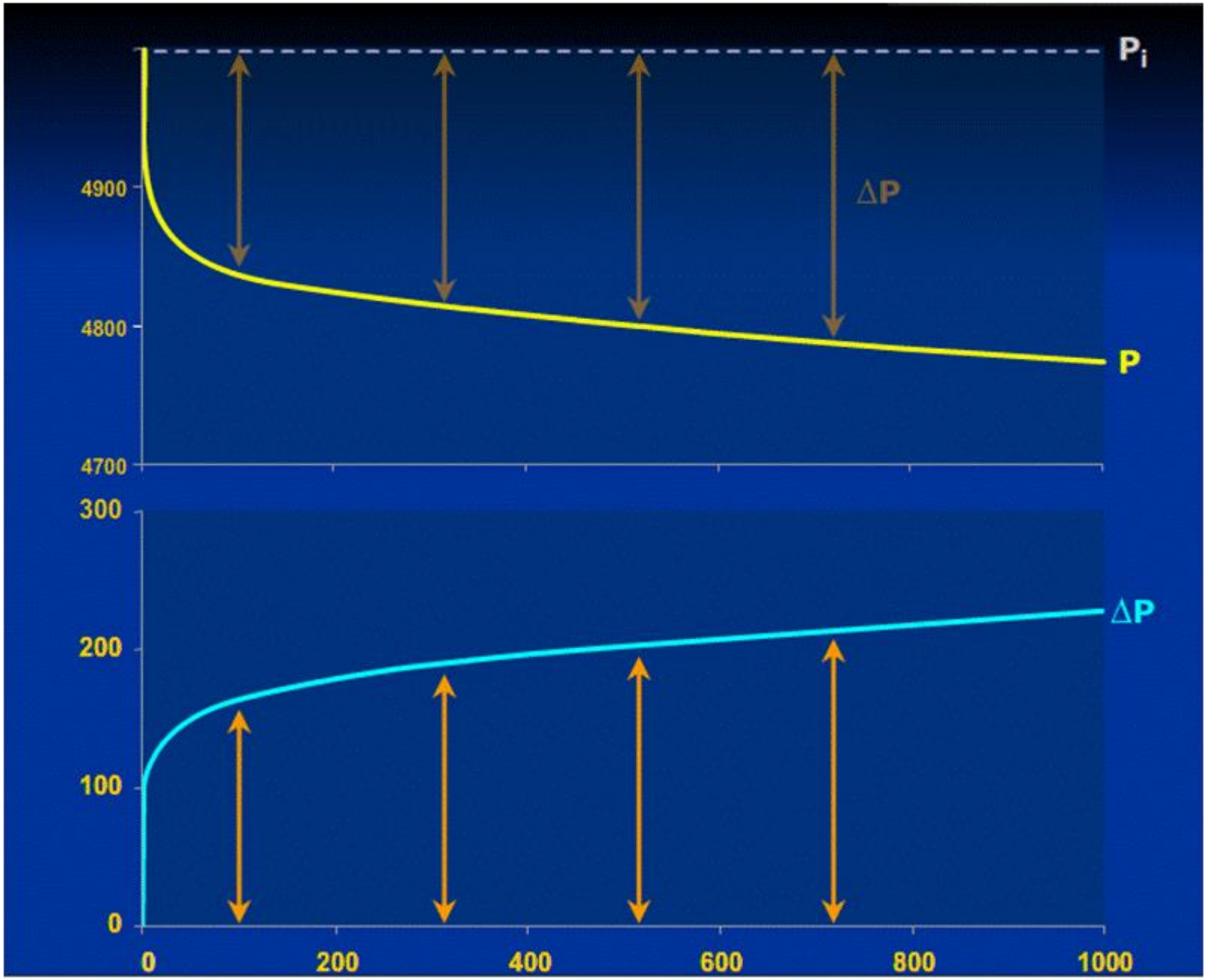
Importance of Reservoir Type-curve

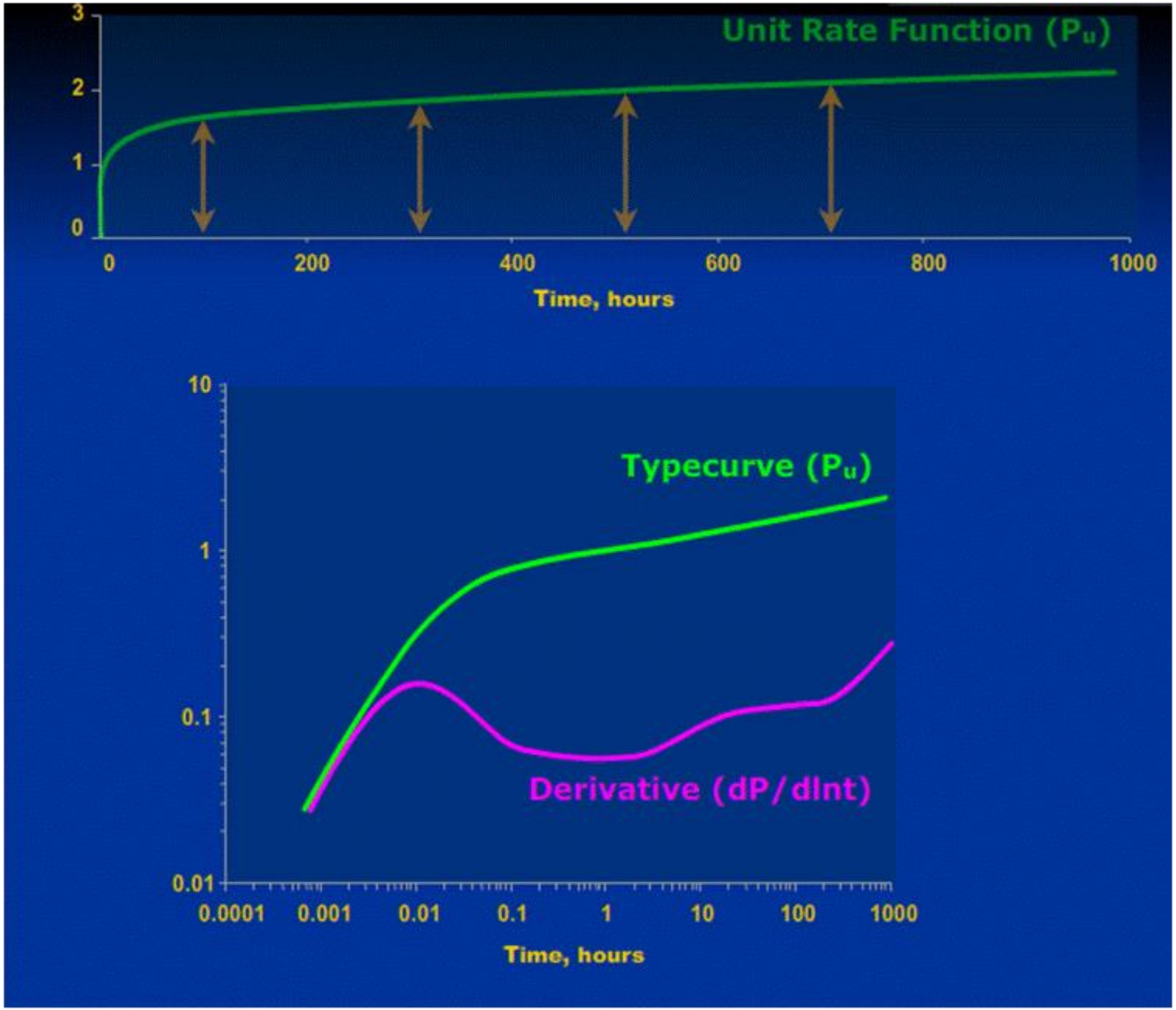
- ❑ Fundamental curve for well test interpretation
- ❑ Flow regime identification
- ❑ Reservoir description
- ❑Pressure behavior for constant rate



Unit Rate Function (Type-curve)

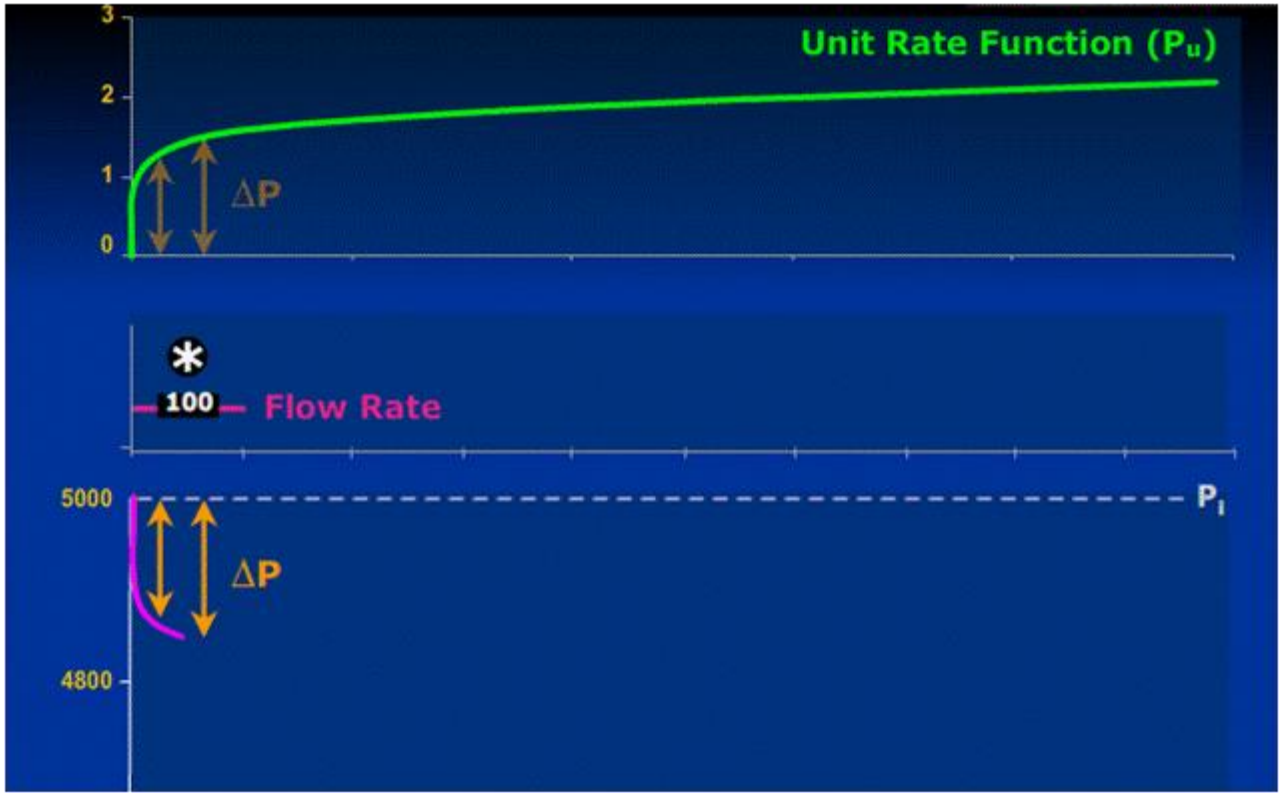


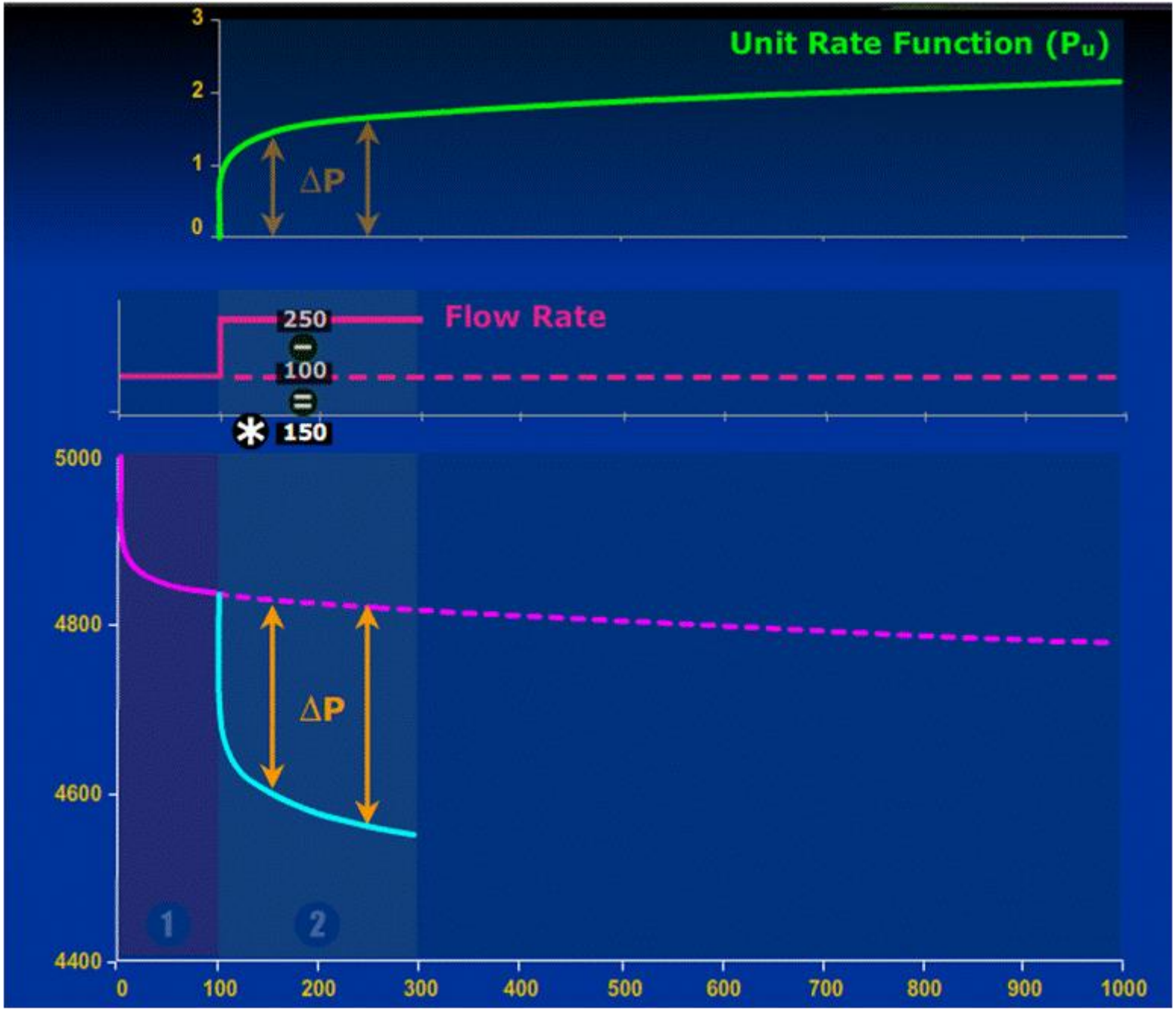

Pi
ΔP
P
4900
4800
4700
300
200
100
0
ΔP
0
200
400
600
800
1000

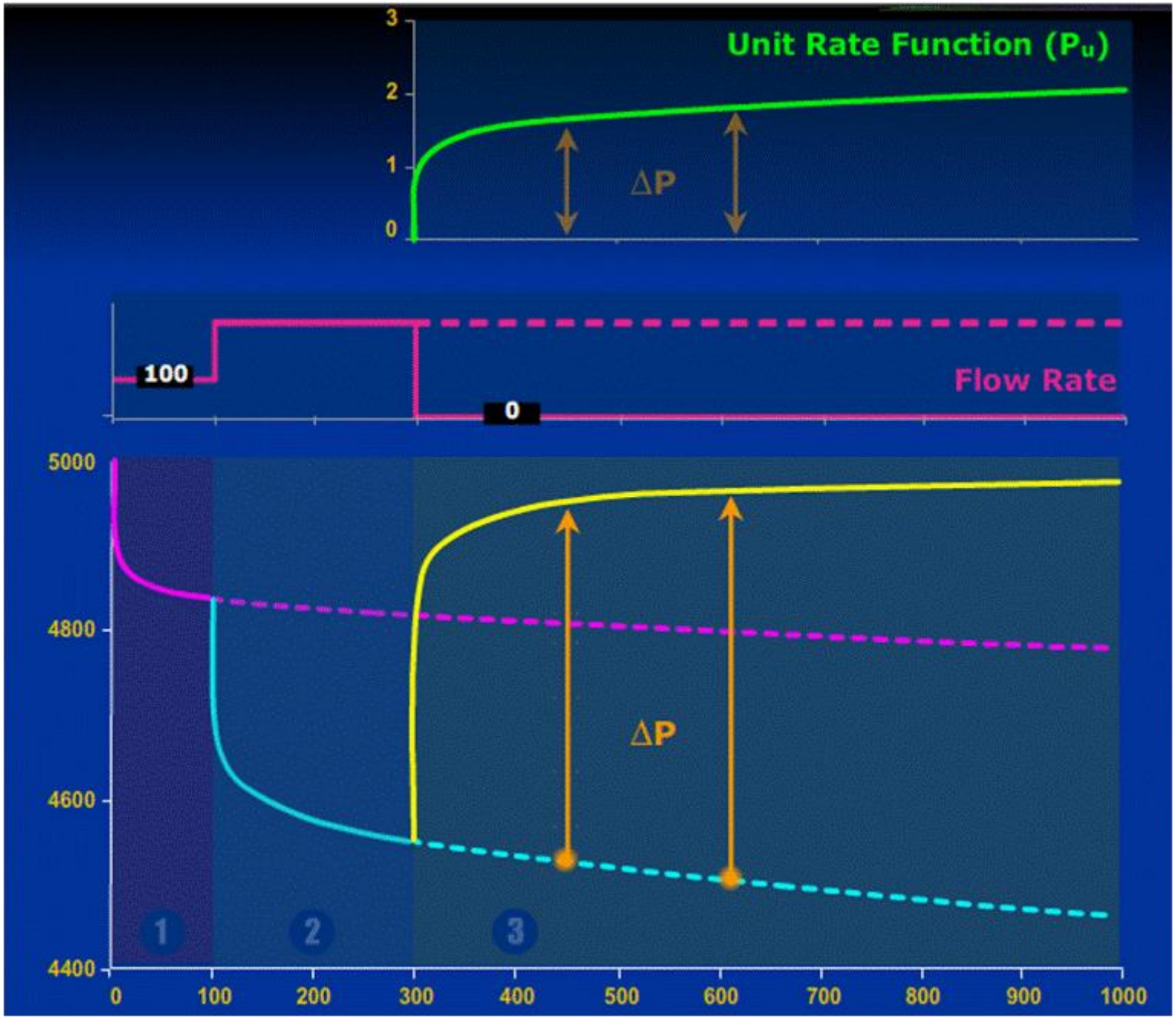

Unit Rate Function (P_u)
3
2
1
0
0
200
400
600
800
1000
Time, hours
Typecurve (P_u)
Derivative (dP/dlnt)
10
1
0.1
0.01
0.0001
0.001
0.01
0.1
1
10
100
1000
Time, hours

Multi Rates

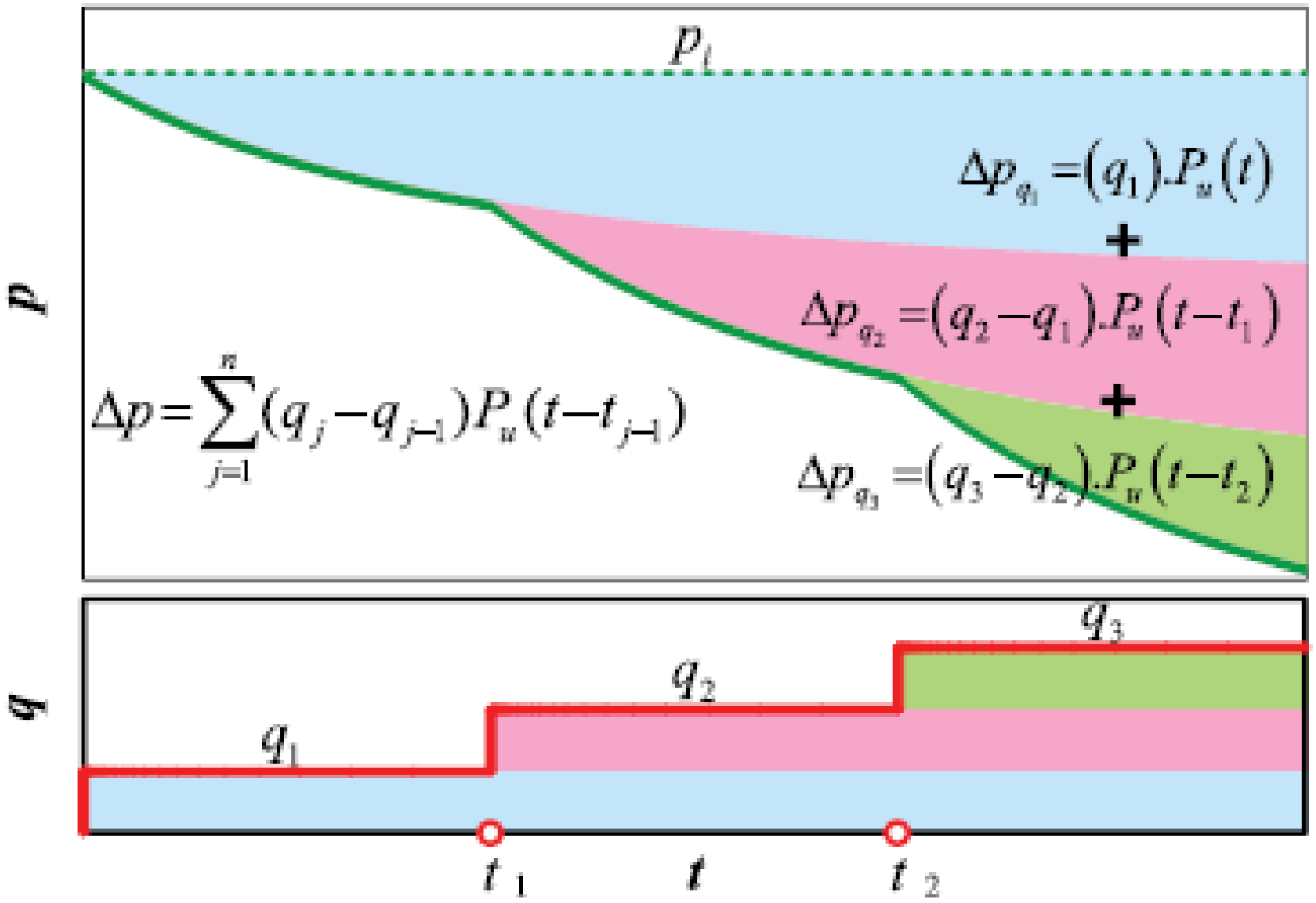

250
100
Flow Rate
0


3
2
1
0
Unit Rate Function (P_u)
ΔP
*
100
Flow Rate
5000
P_I
ΔP
4800

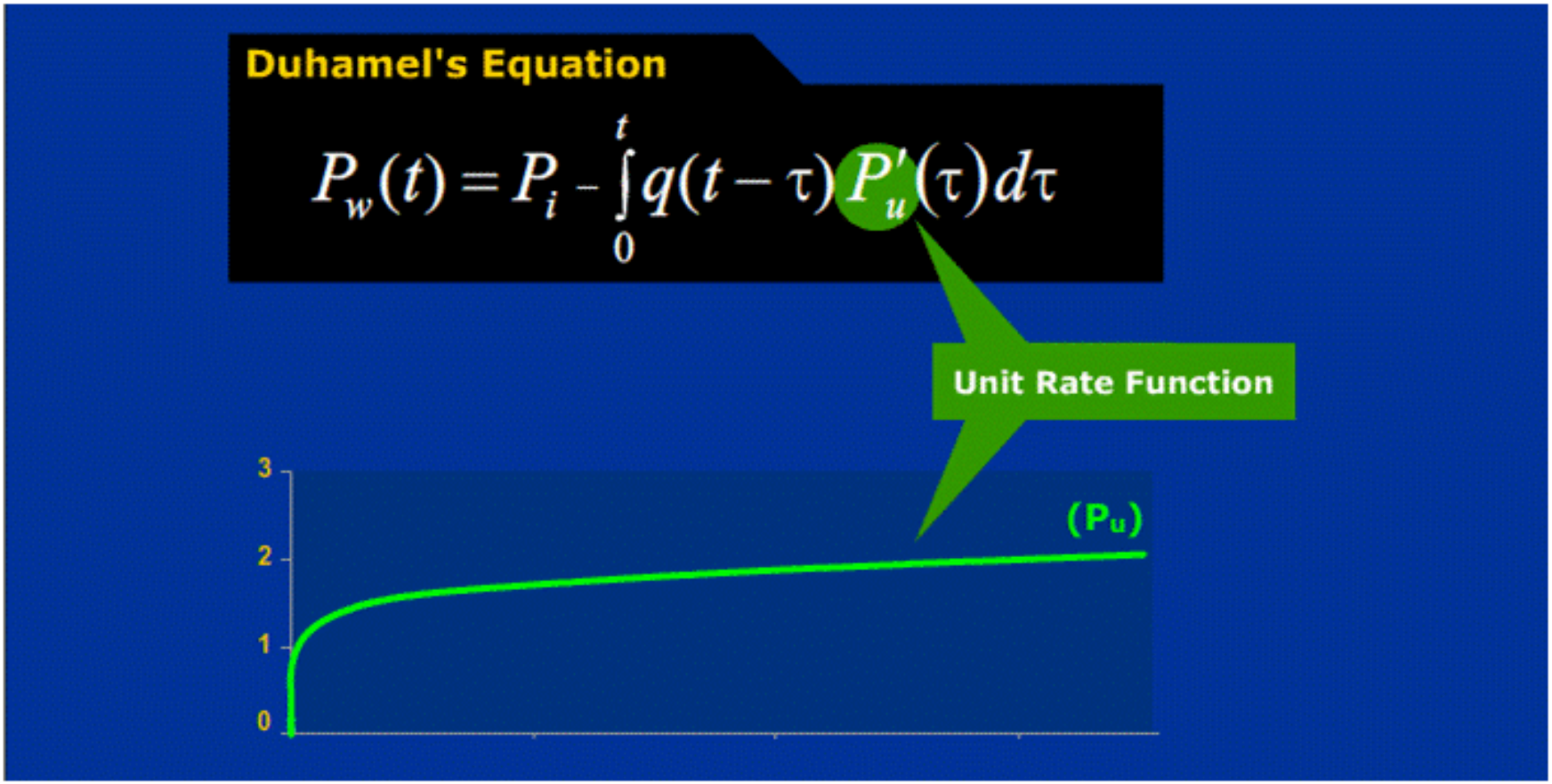

Unit Rate Function (P_u)
3
2
1
0
ΔP
Flow Rate
250
100
150
5000
4800
4600
4400
ΔP
1
2
0
100
200
300
400
500
600
700
800
900
1000


Unit Rate Function (P_u)
3
2
1
0
ΔP
100
0
Flow Rate
5000
4800
4600
4400
ΔP
1
2
3
0
100
200
300
400
500
600
700
800
900
1000

Superposition-in-Time



Duhamels Equation



Duhamel's Equation (deals with continuously changing rate)

$$p(t) = p_i - \int_0^t q(t-\tau) \frac{dp_u}{d\tau} d\tau$$

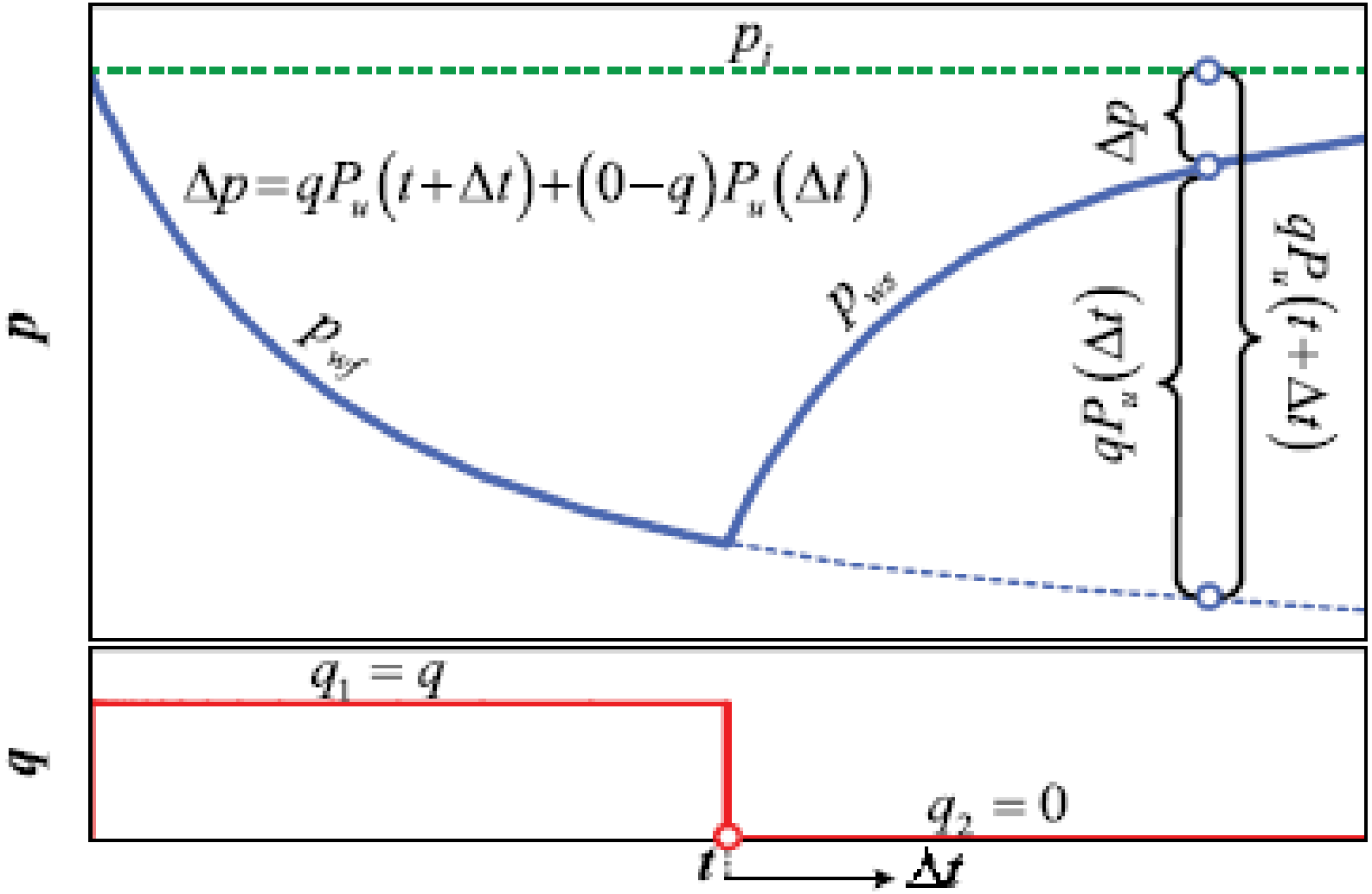
CONVOLUTION

- Superposition is also known as Convolution
- In simple terms, the Principle of Superposition states that the total pressure drop is simply the summation of the individual pressure drops
- It is applied ***in time*** to account for rate changes, and ***in space*** to account for multiple wells and boundaries

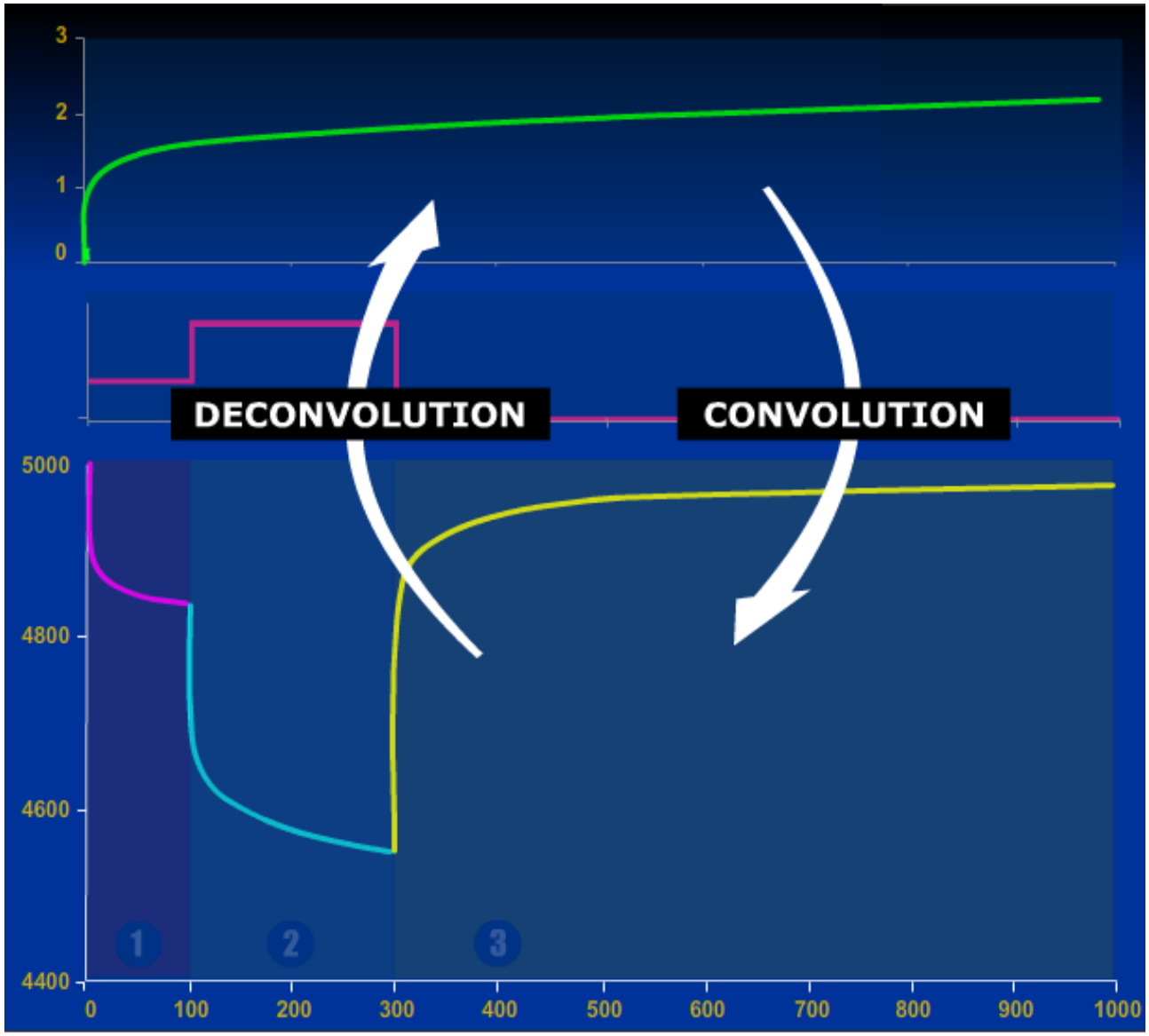
SUPERPOSITION-IN-TIME

- Superposition-in-time is used to convert the constant rate solution (Pu) to a multi-rate solution
- The rate used for each step is the difference between the current rate and the previous rate
- A rate changing from q_1 to q_2 at time t_1, is treated as q_1 continuing forever plus (q_2-q_1) starting at t_1

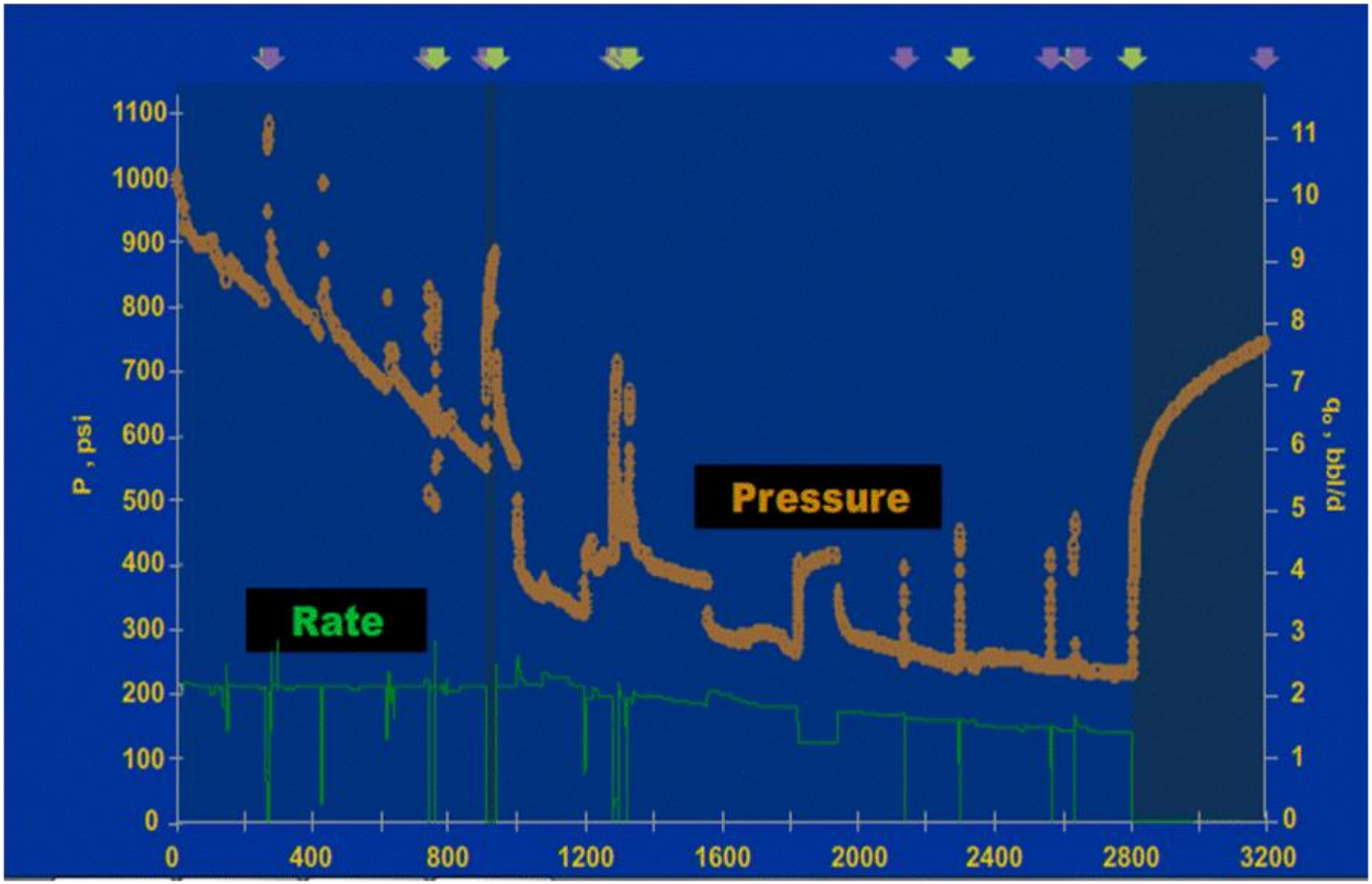
Buildup as Example of Superposition



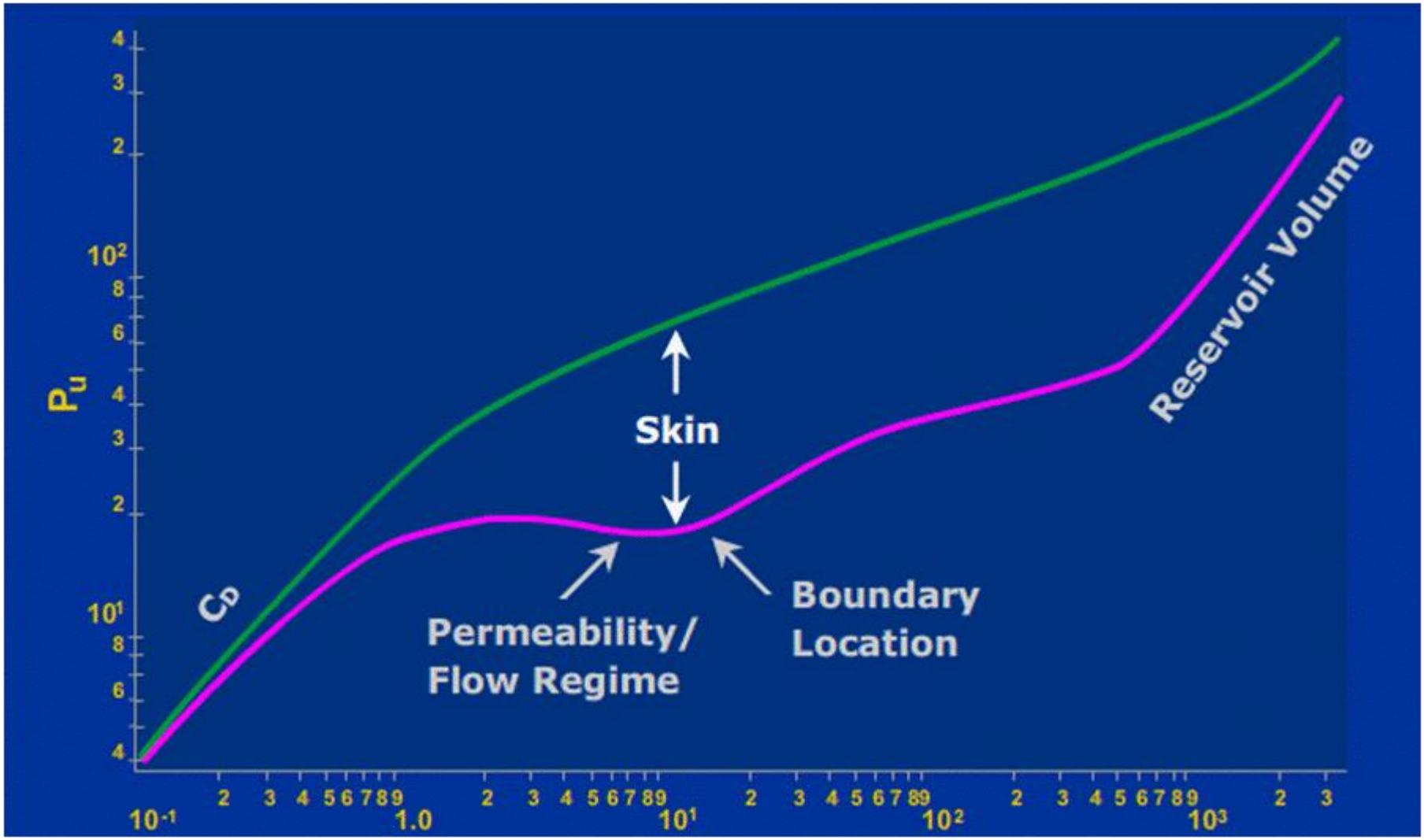
Convolution vs. Deconvolution



History Plot

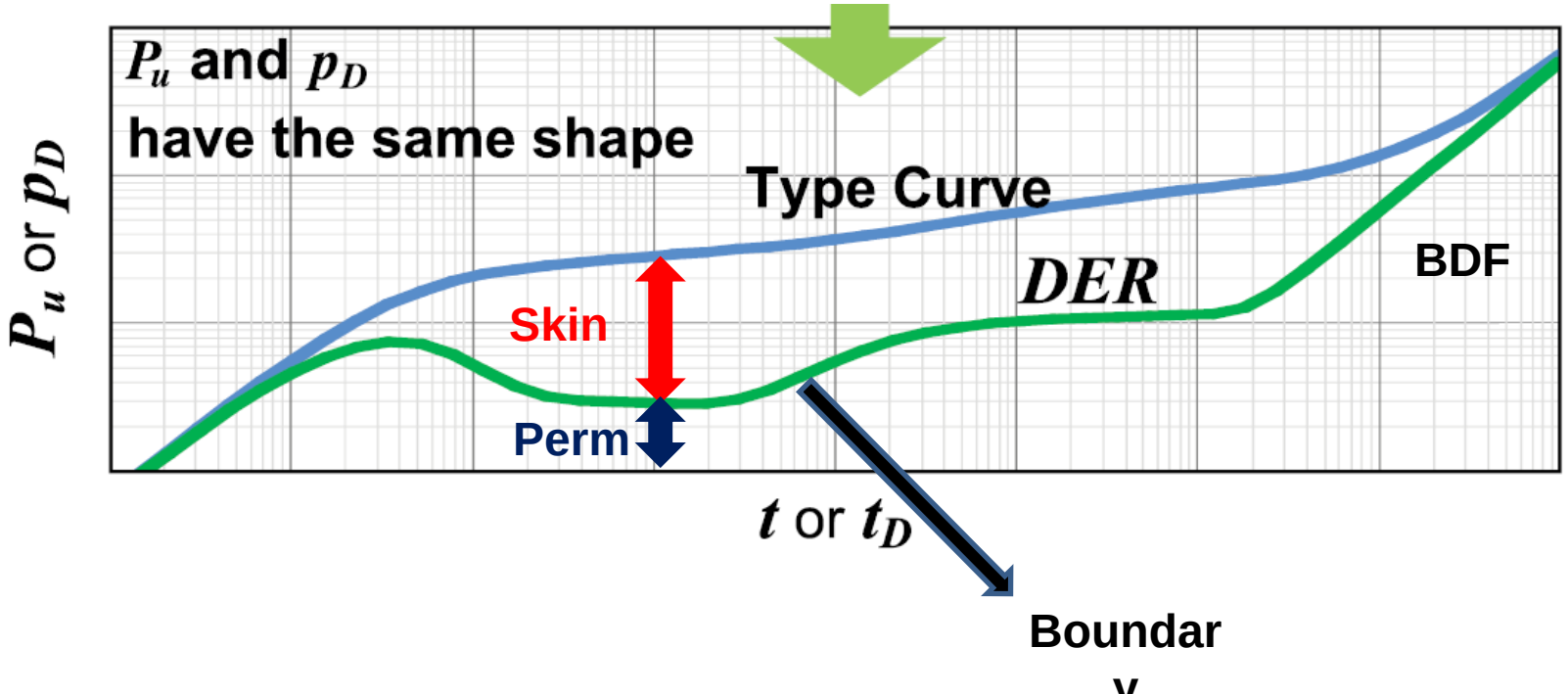


Reservoir Type Curve



Deconvolution Process

Deconvolution provides an alternative to conventional diagnostic analysis and **can show additional flow regime information that would not normally be seen within the specified time frame of the buildup test**.

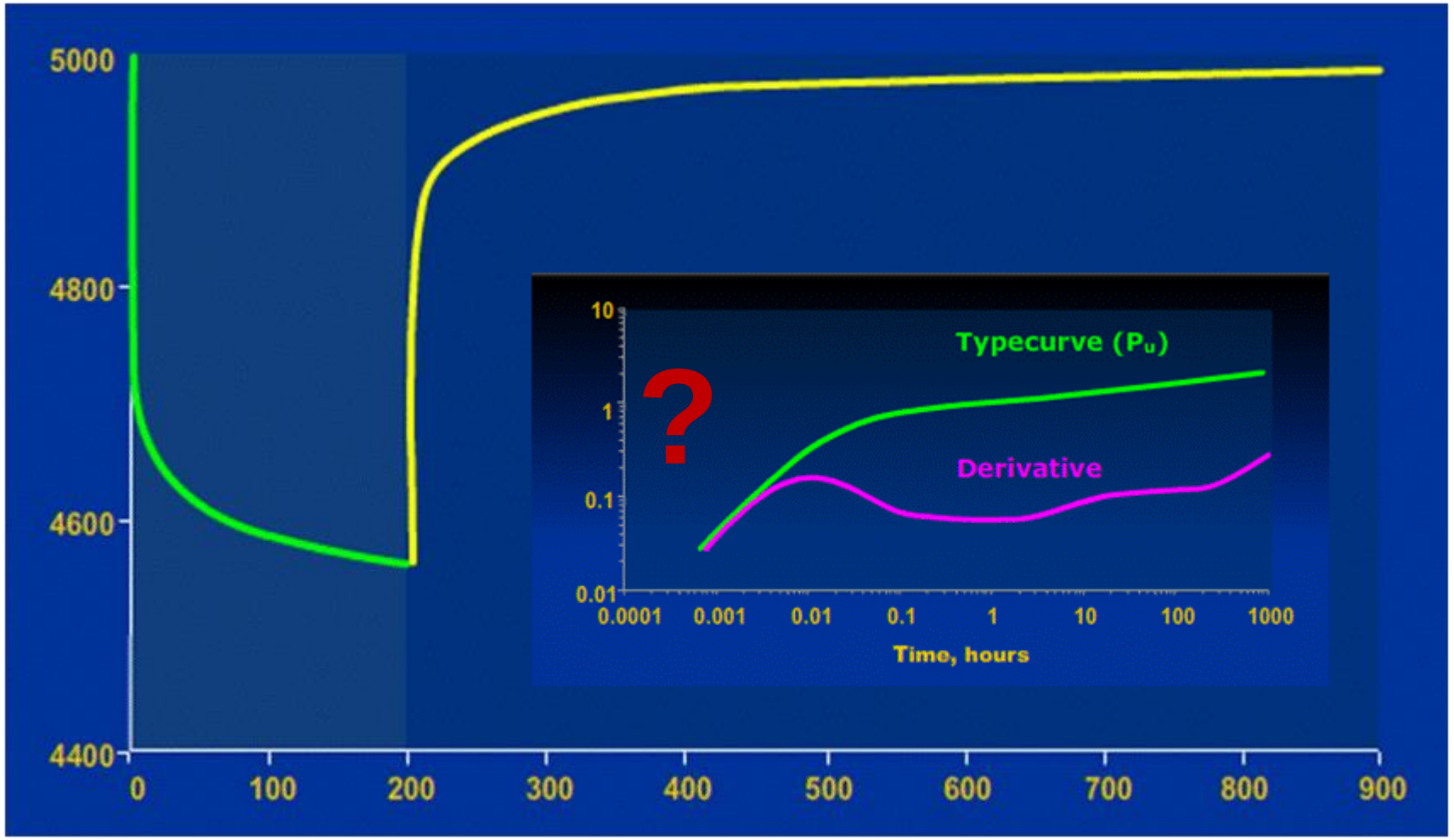


Deconvolution

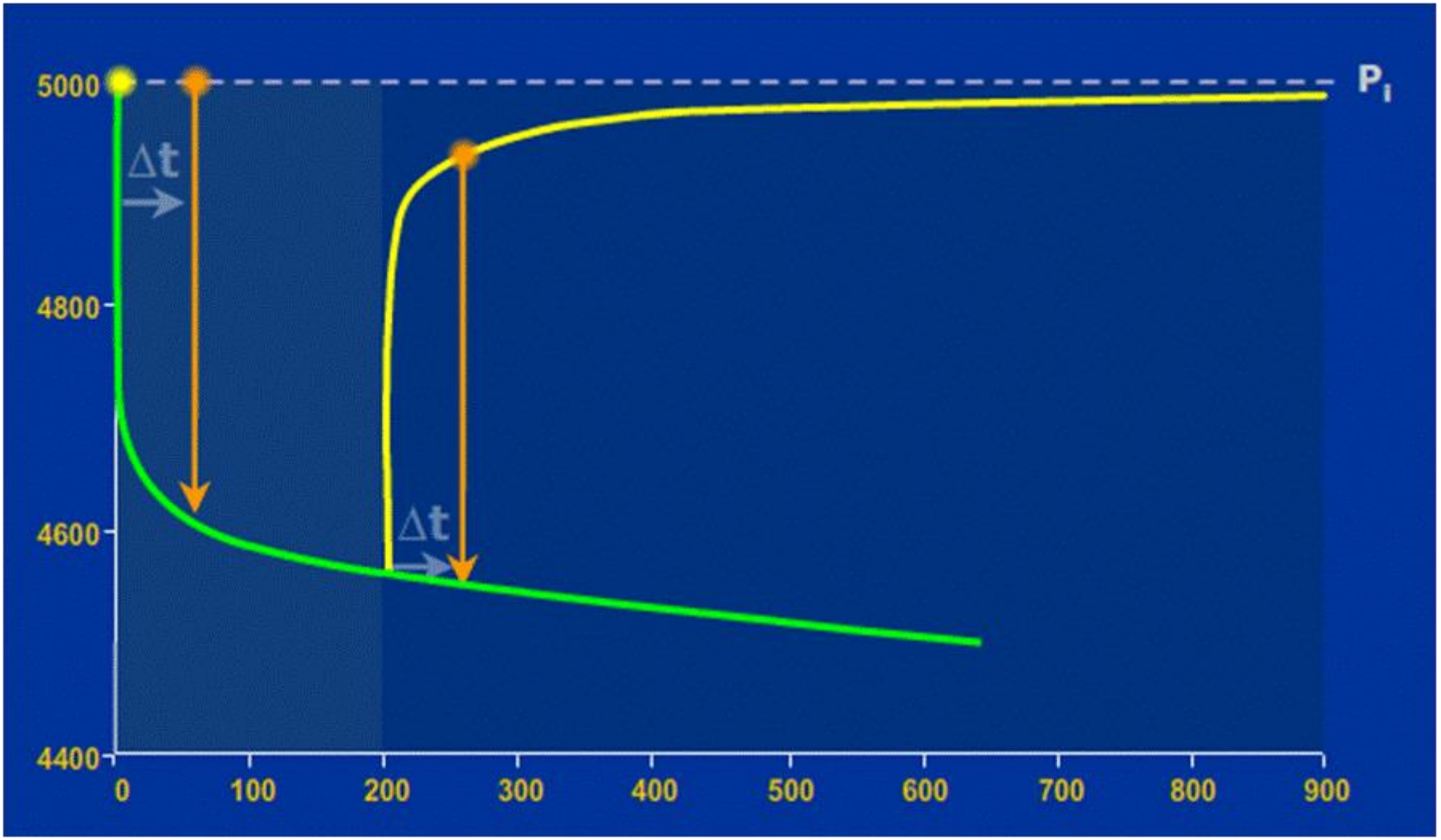
DECONVOLUTION

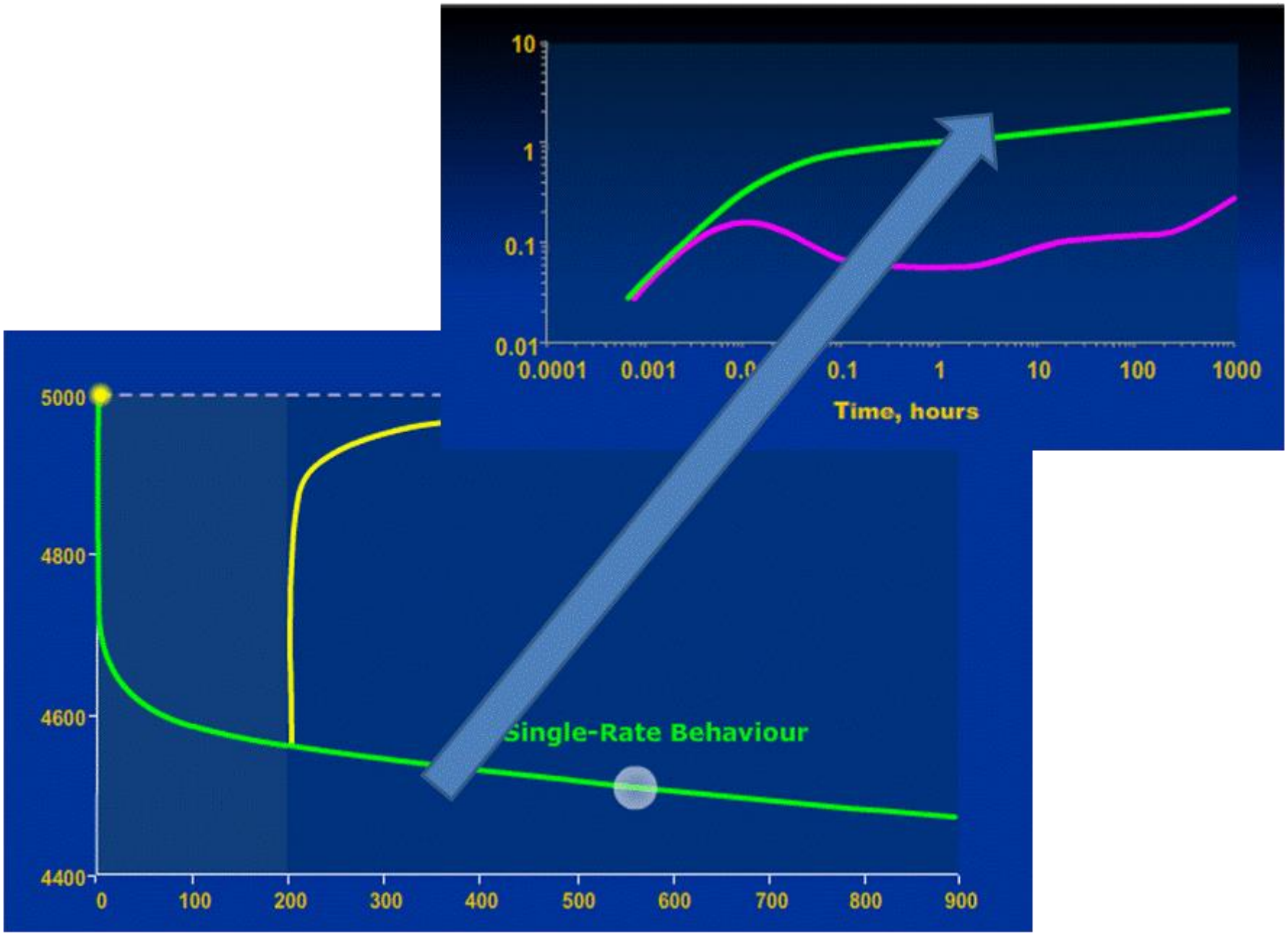
- Deconvolution is the reverse of superposition
- Its purpose is to extract the Unit Rate Function from pressure data in multi-rate tests
- This Unit Rate Function is in fact the reservoir Type Curve; it facilitates identification of the reservoir model
- It does NOT require a pre-conceived reservoir model; rather, it is used to determine what the reservoir model might be
- It is used to convert buildup or multi-rate data into the corresponding constant rate Drawdown Type Curve

Deconvolution of a Buildup Test



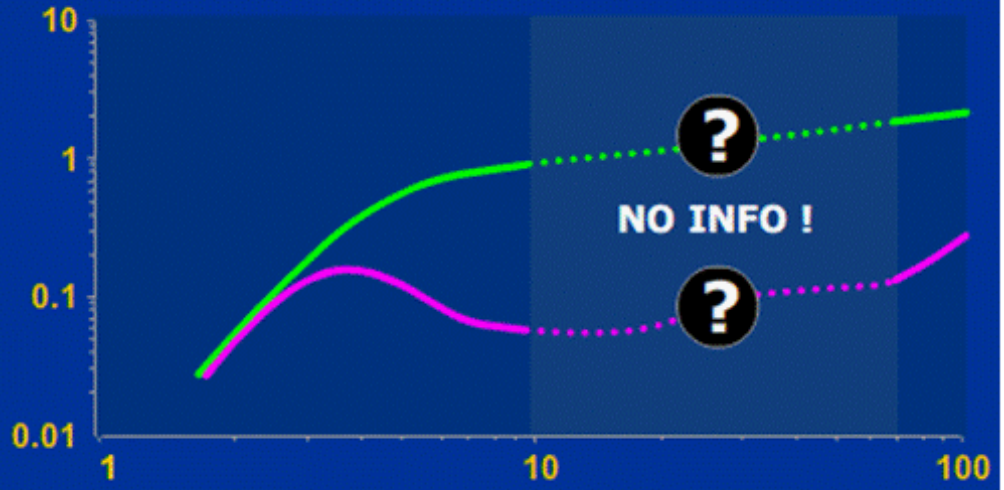
Deconvolution of a Buildup Test



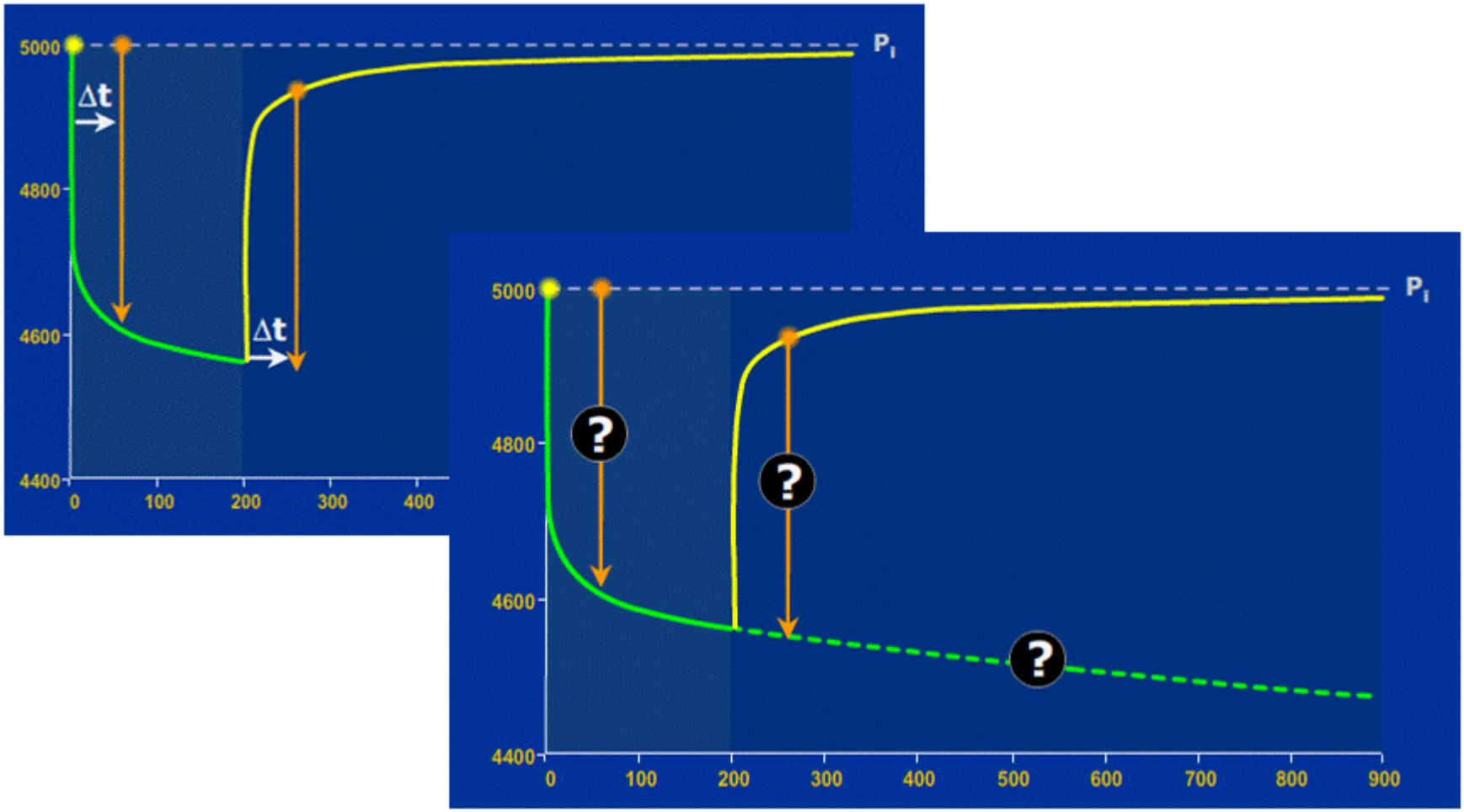

10
1
0.1
0.01
0.0001
0.001
0.1
1
10
100
1000
Time, hours
5000
4800
4600
4400
0
100
200
300
400
500
600
700
800
900
Single-Rate Behaviour

Limitations

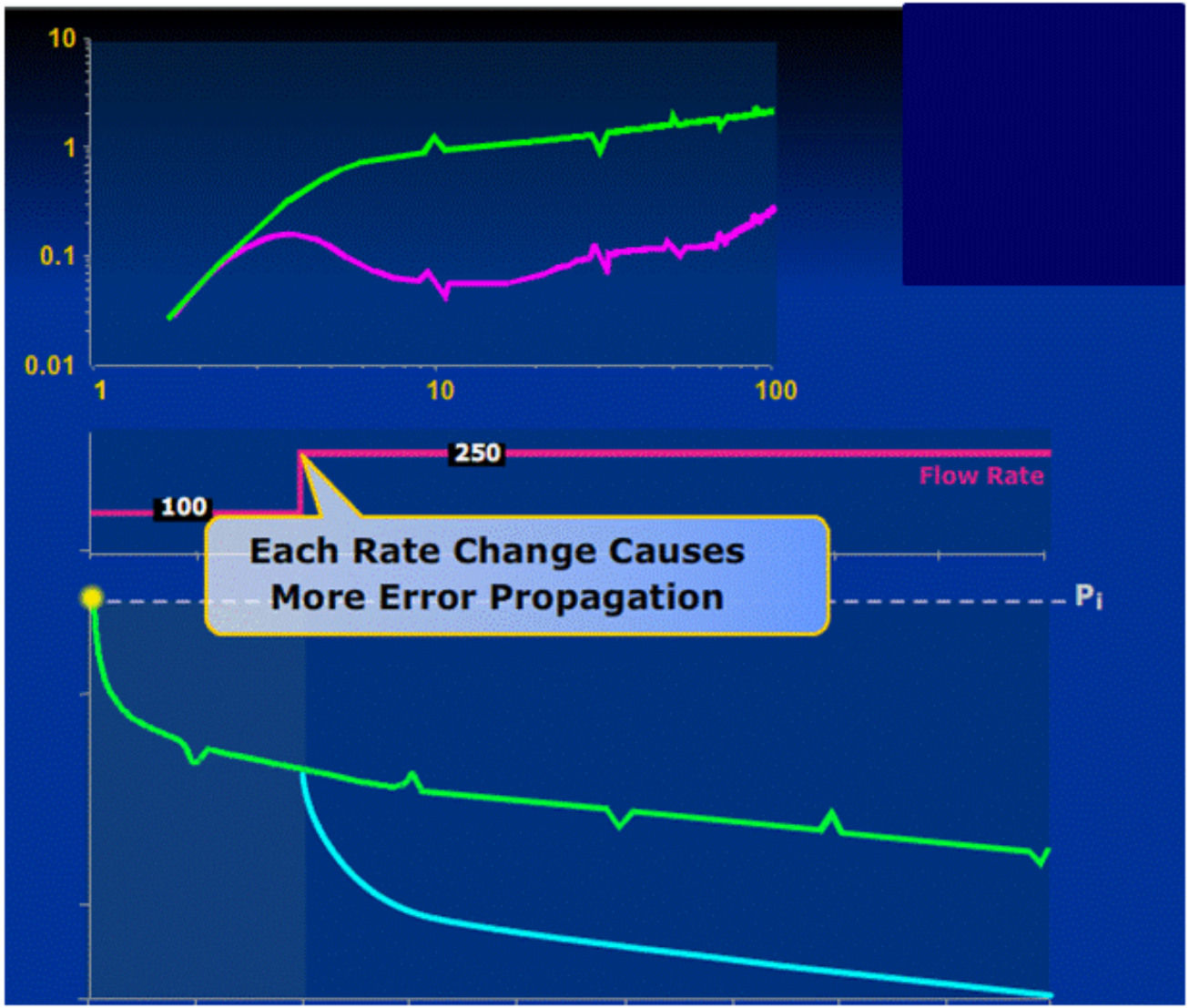
1. All Pressures Must Be Available
2. Errors Propagate:
   Pressure data must be "good" quality
3. Buildup Data Only
4. Initial Pressure Unknown



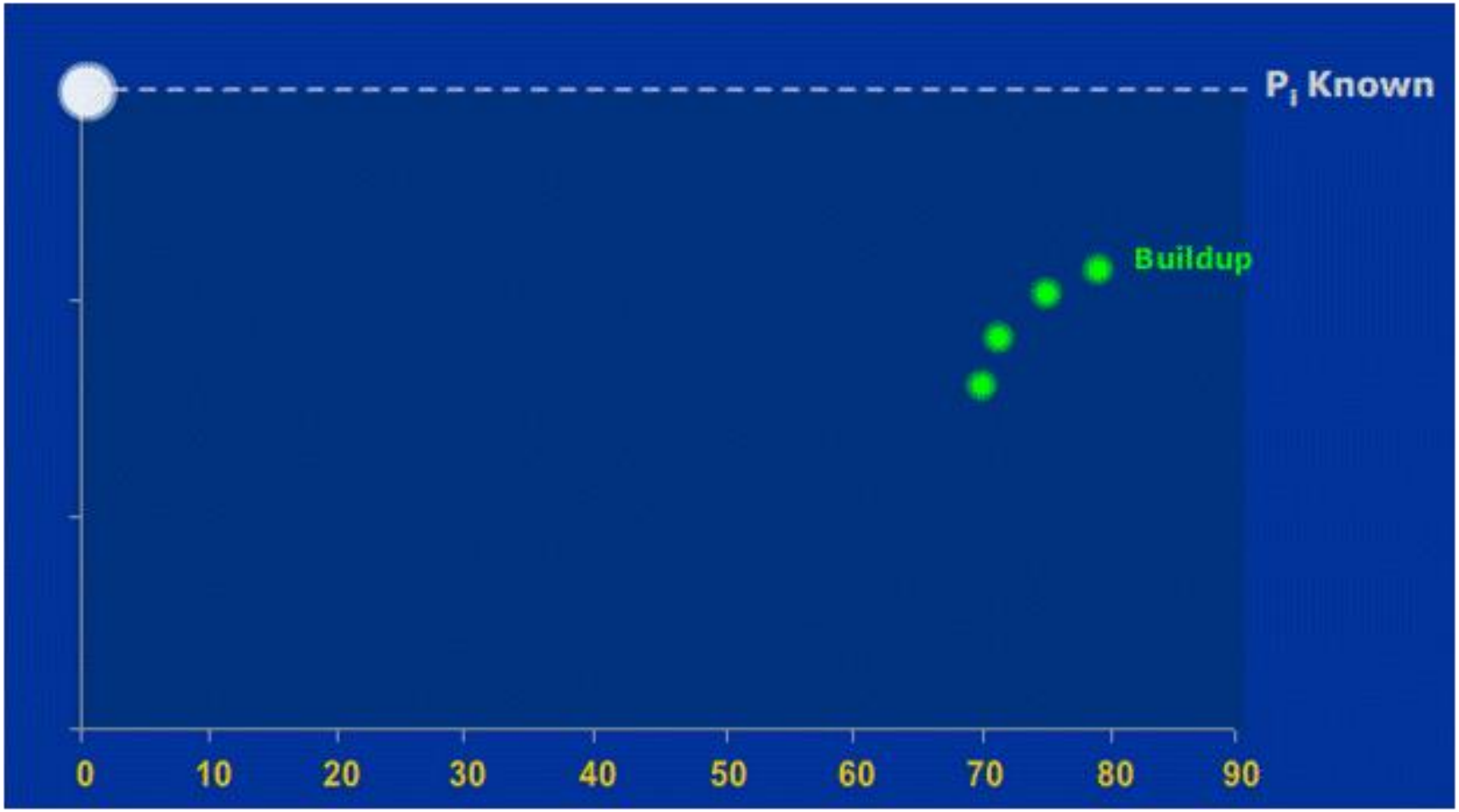
Limitations
Availability of All Pressure Data



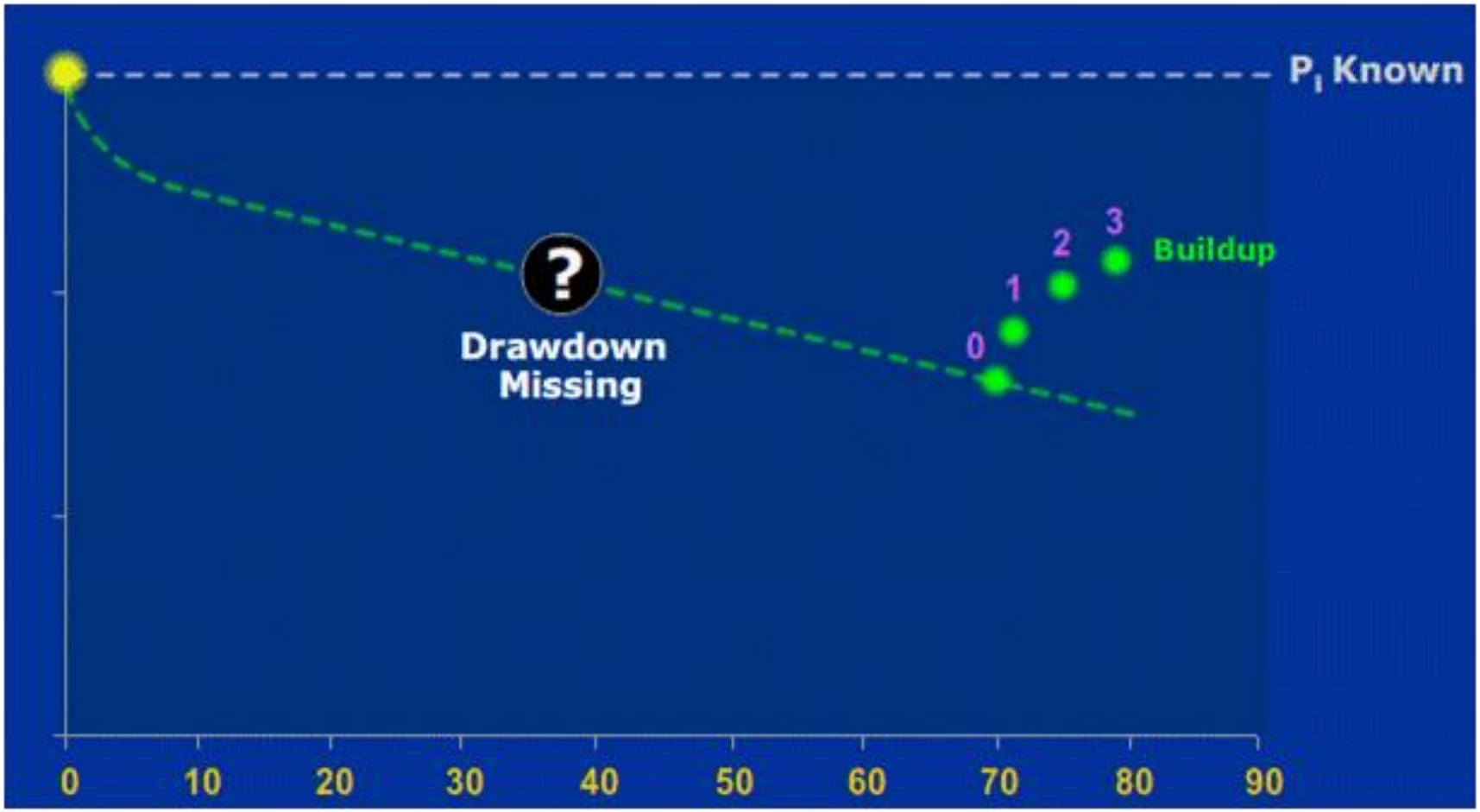
Limitations
Error Propagation



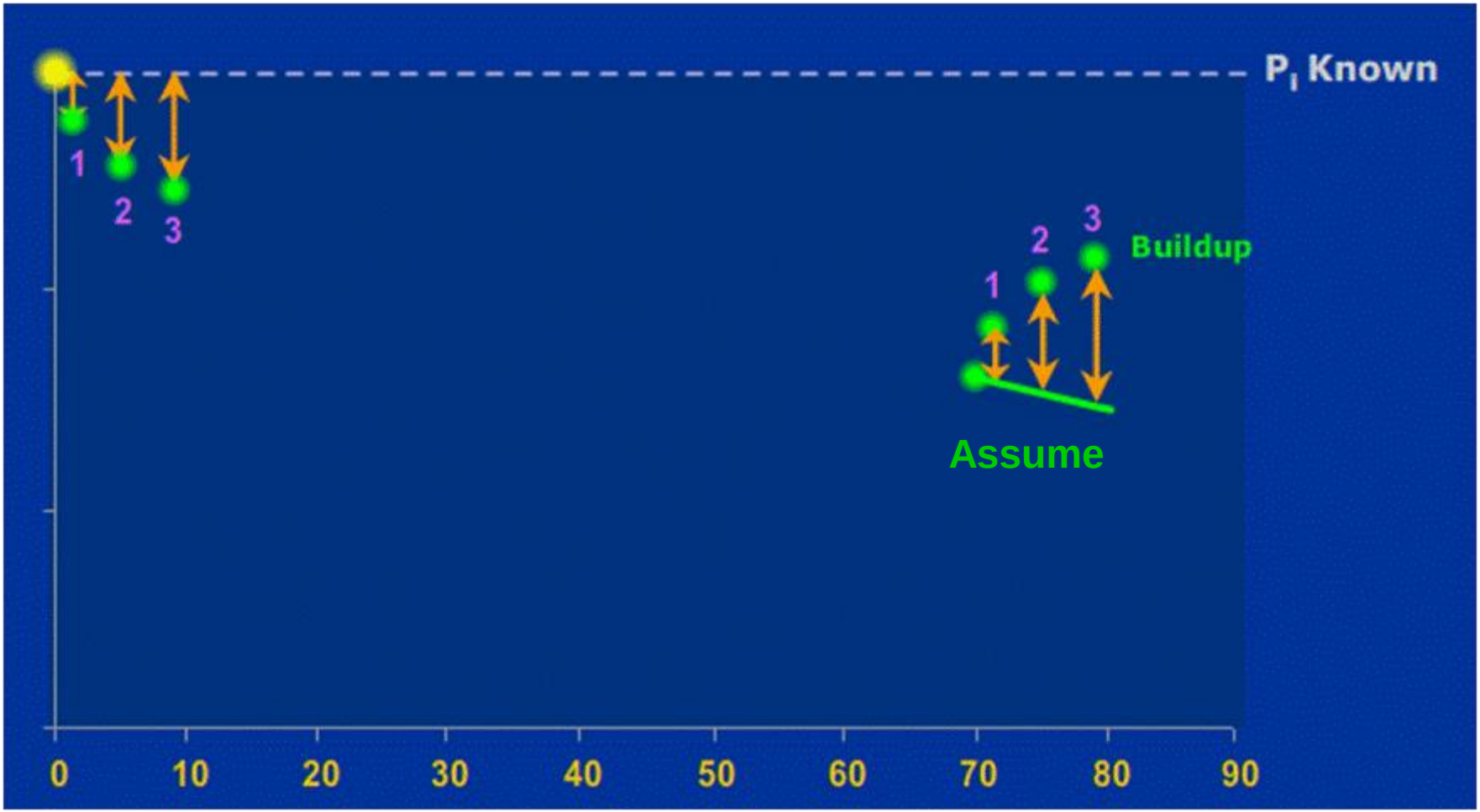
Limitations
Buildup Data Only- Pi Known



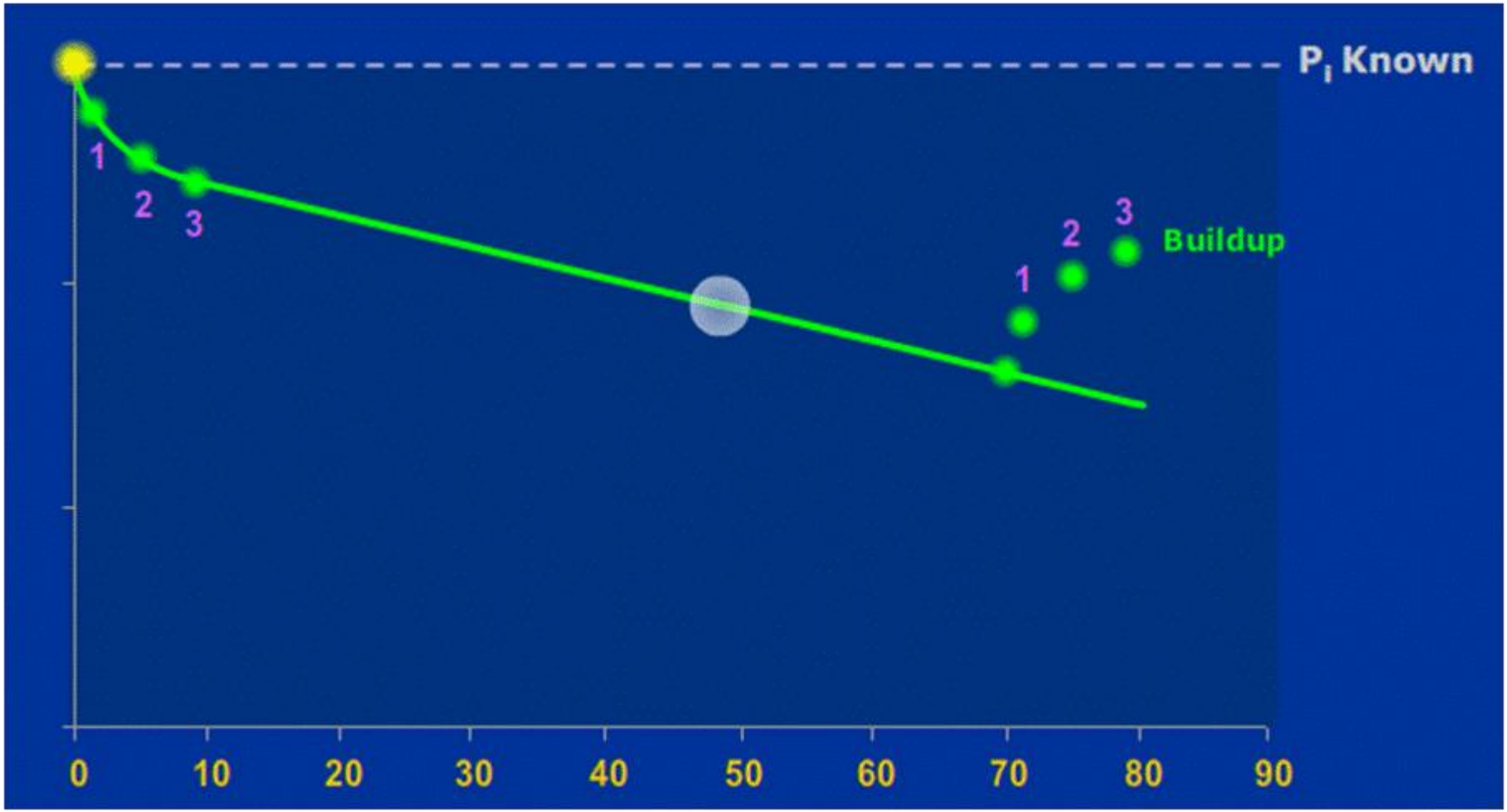
Limitations
Buildup Data Only- Pi Known



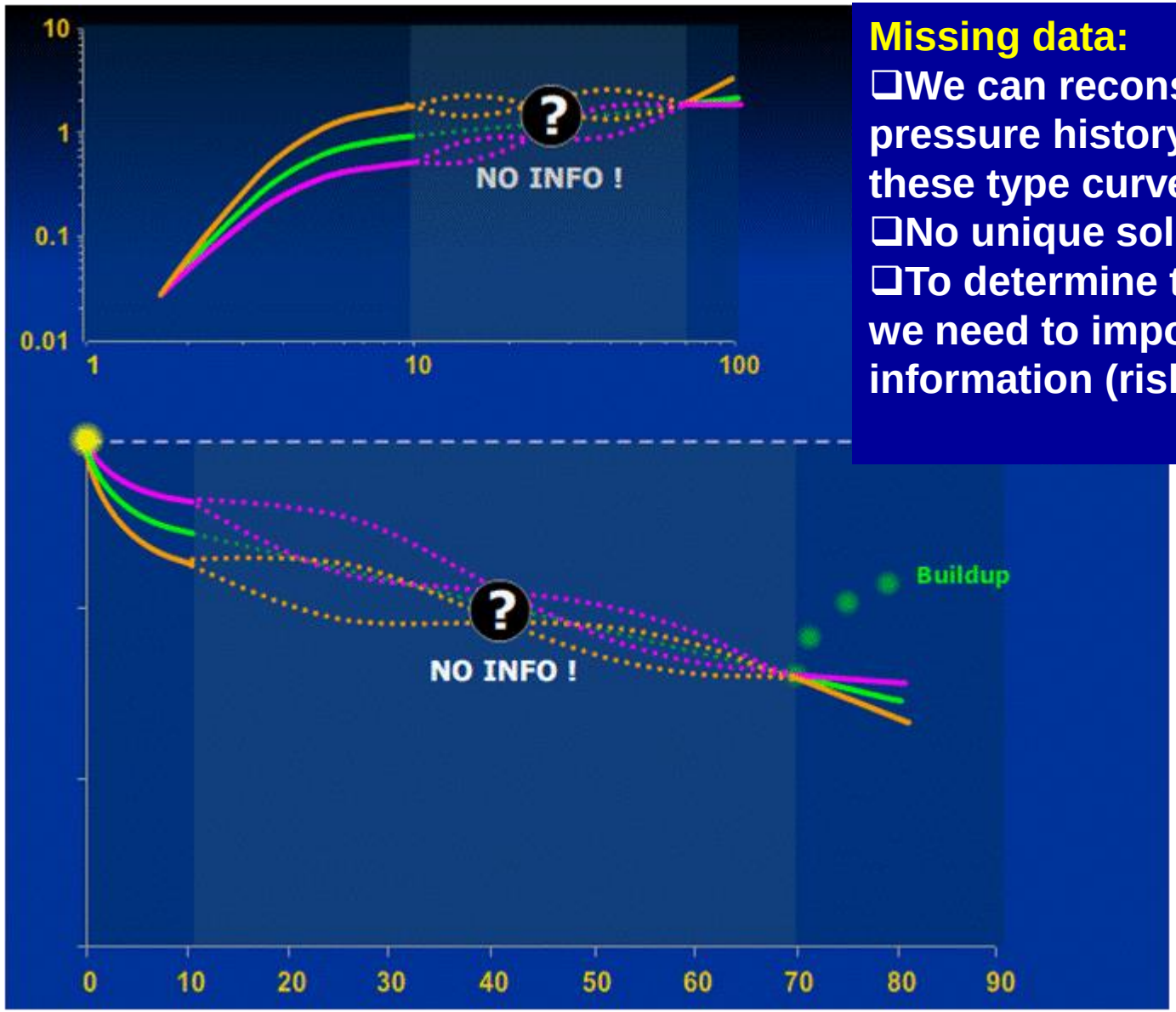
Limitations
Buildup Data Only- Pi Known



Limitations
Buildup Data Only- Pi Known



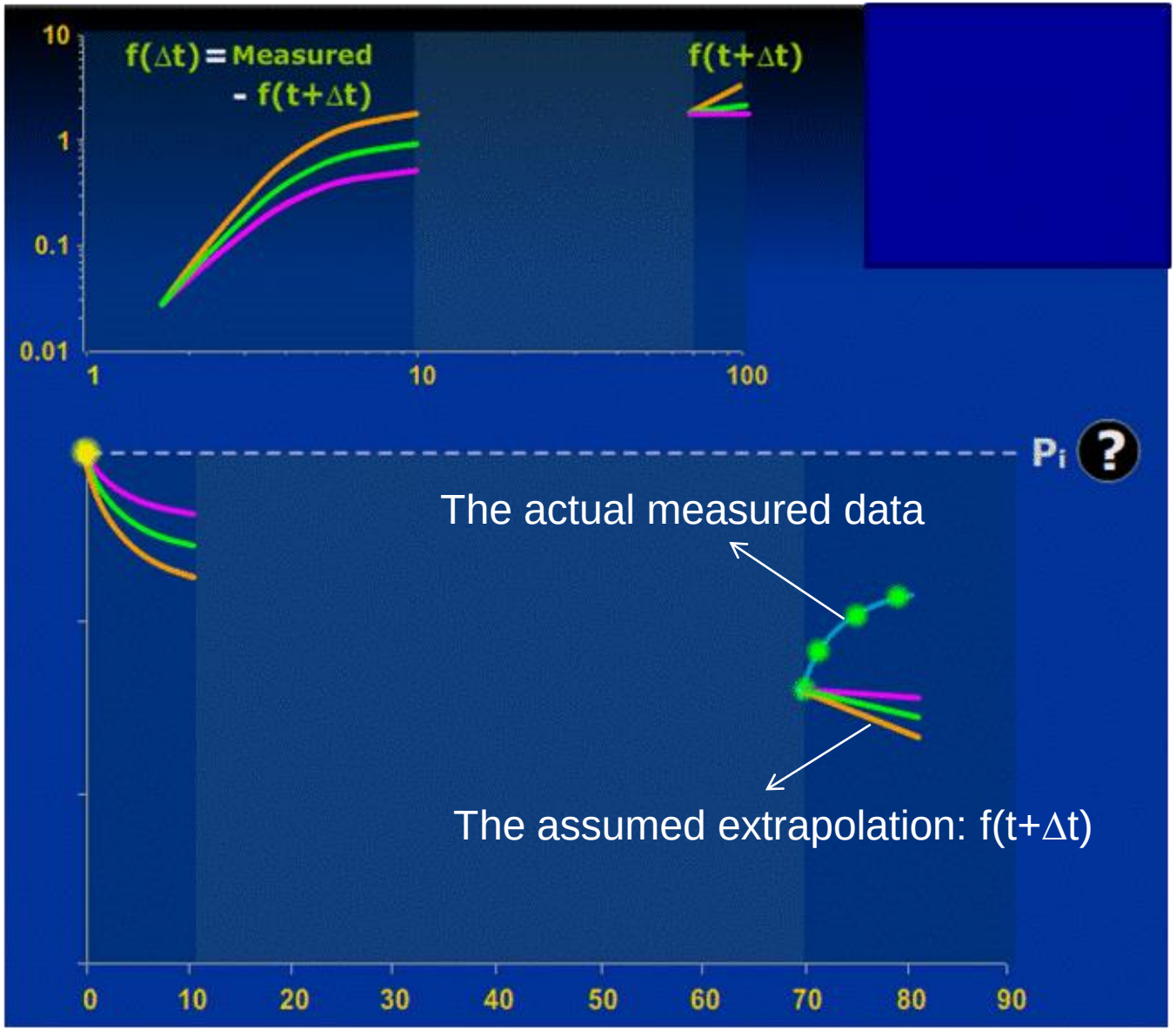
Limitations -Buildup Data Only- Pi Known



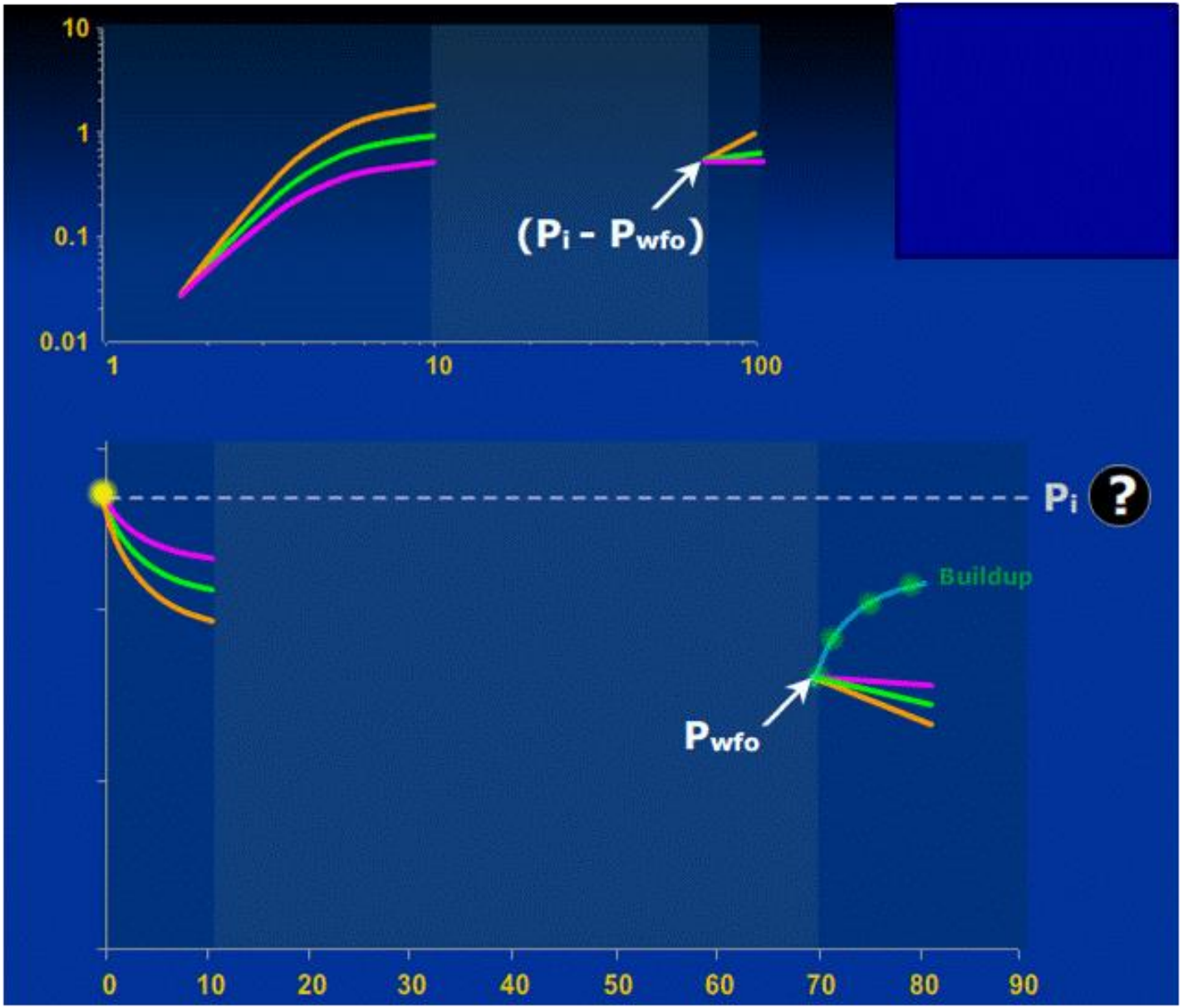
Missing data:

- We can reconstruct the pressure history With any of these type curves.
- No unique solution.
- To determine the correct one we need to impose external information (risk of bias)

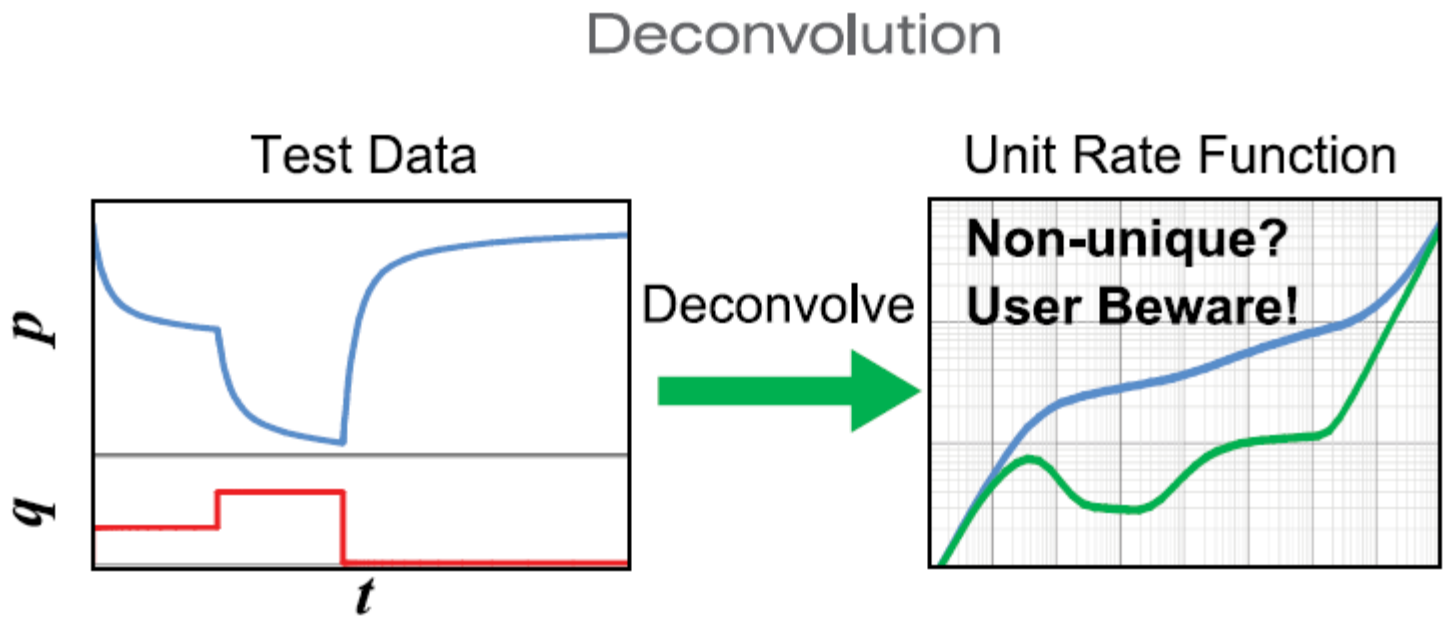
Limitations -Buildup Data Only- Pi Unknown



Limitations -Buildup Data Only- Pi Unknown



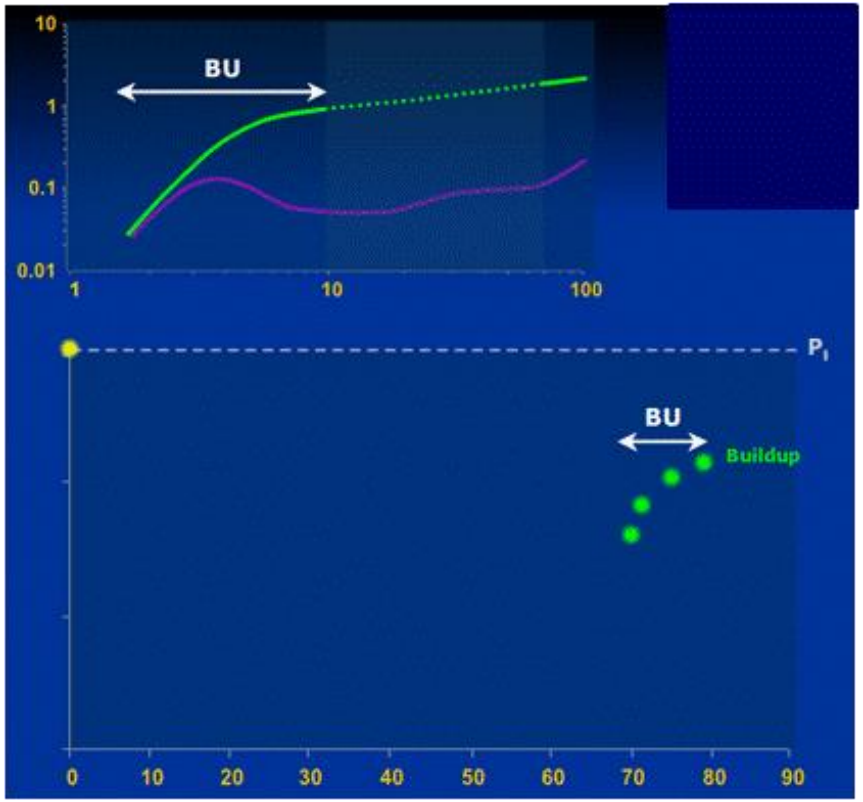
Deconvolution

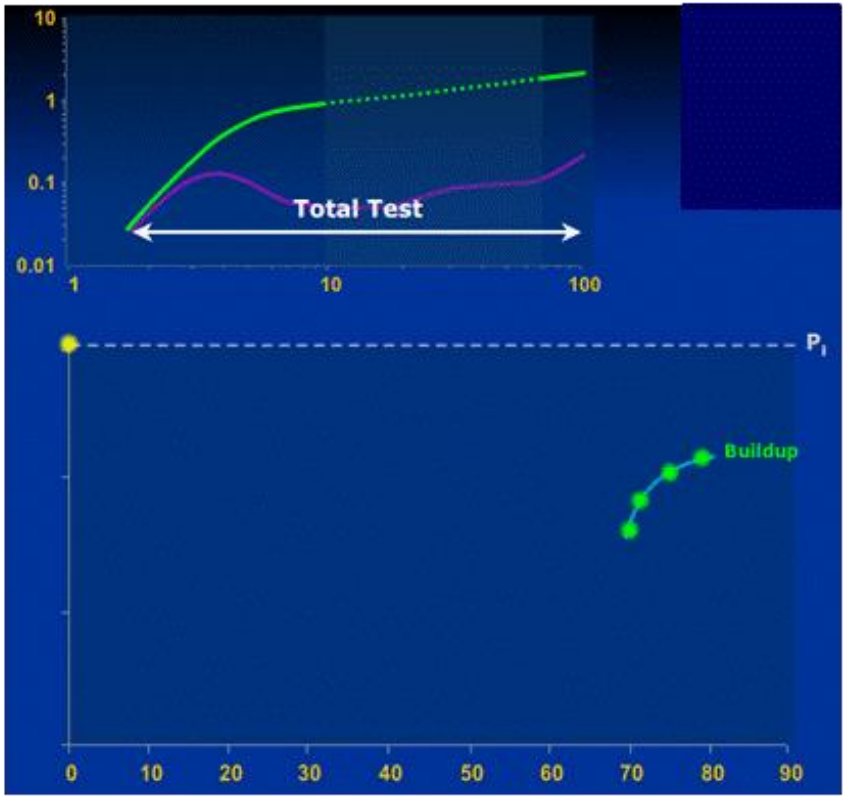


Limitations

- Very sensitive to data quality
- Changing skin, changing wellbore storage, missing/ incorrect initial pressure and gaps in data can have a significant effect on the shape of the deconvolved Type Curve

Deconvolution
Increasing the Radius of Investigation





Deconvolution- Modern Methods

- Van Scheroter et al (Imperial College, 2002)
  - Solved for Derivative, Not Type curve (Pu)
  - Non-linear Regression to minimize error : TLS (p,q)
  - Early time: wellbore storage
  - Integrate derivative to get type curve(Pu)
  - Curvature control- regularization (TLS)

- **Non-Linear Regression: TLS (p, q)**

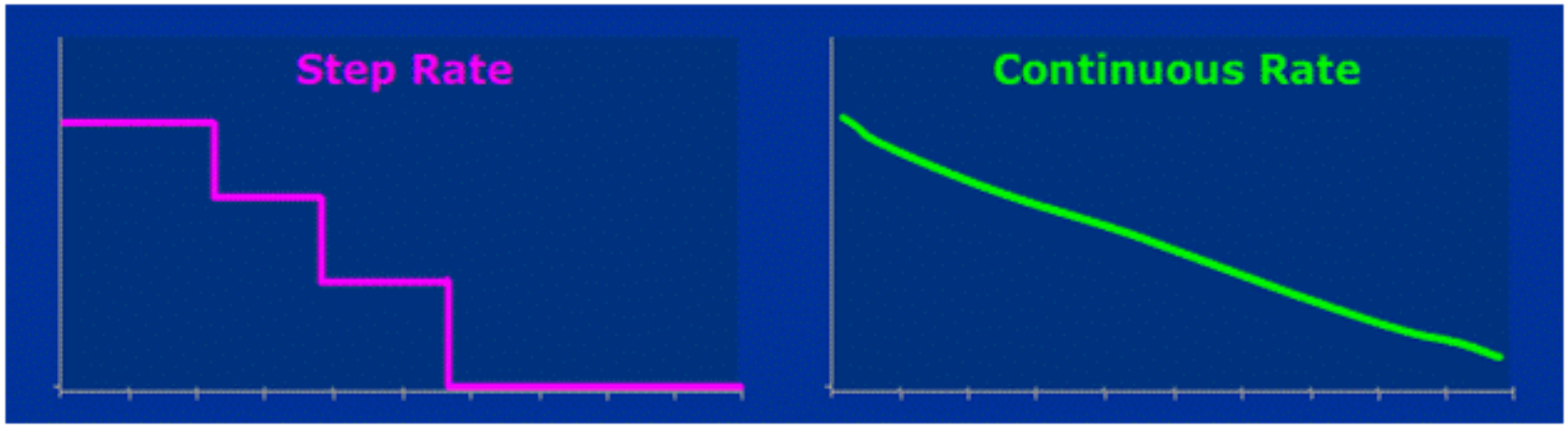
$$E = W_p^2 \times (P_{meas} - P_{calc})^2 + W_q^2 \times (q_{meas} - q_{calc})^2 + W_c^2 \times E_{curv}^2$$

Deconvolution- Modern Methods

- Levitan (bp, 2005)
  - Removed assumption of early time wellbore storage
  - Identified problem when Pi is unknown

Deconvolution- Modern Methods

- Ilk et al (Texas A&M, 2006)
  - B-spline basis function to create derivative (instead of assuming point on derivative, he assumed continues curve)
  - Contineus rate change not step change
  - Solved problem in Laplace space

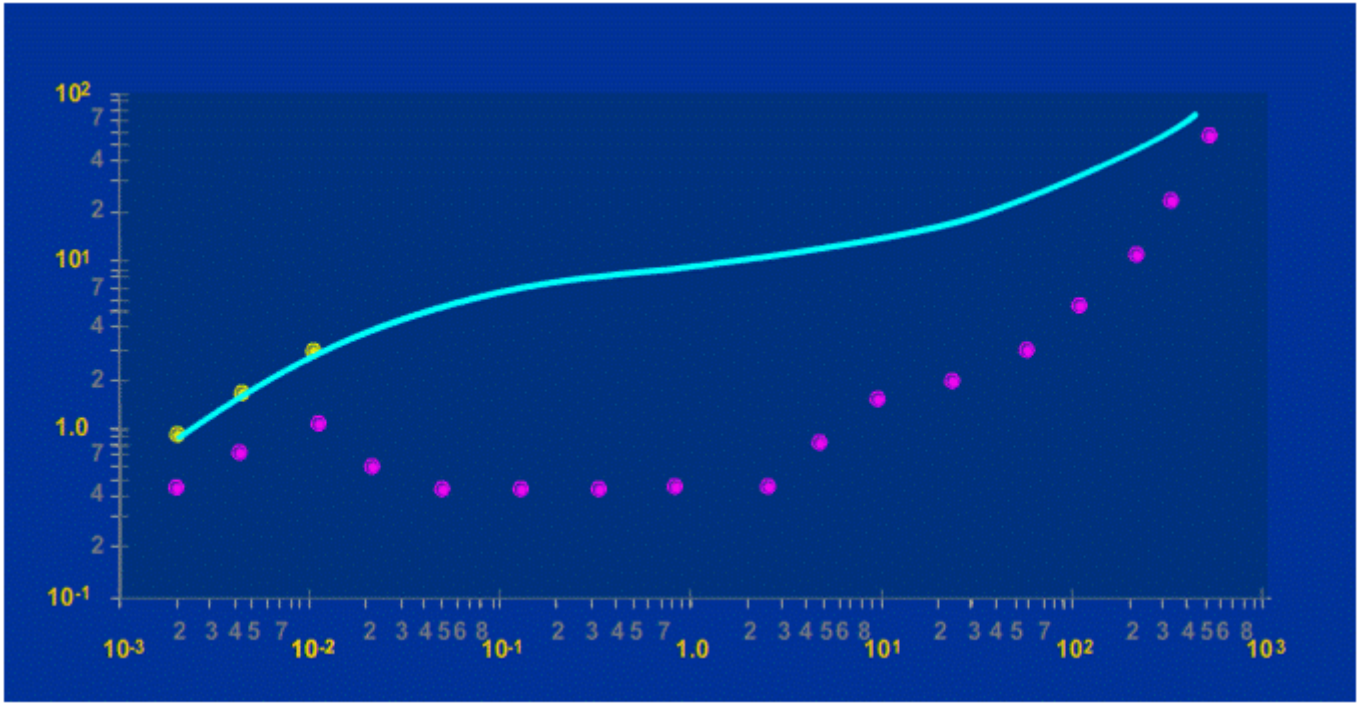


Deconvolution
Modern Methods Procedure

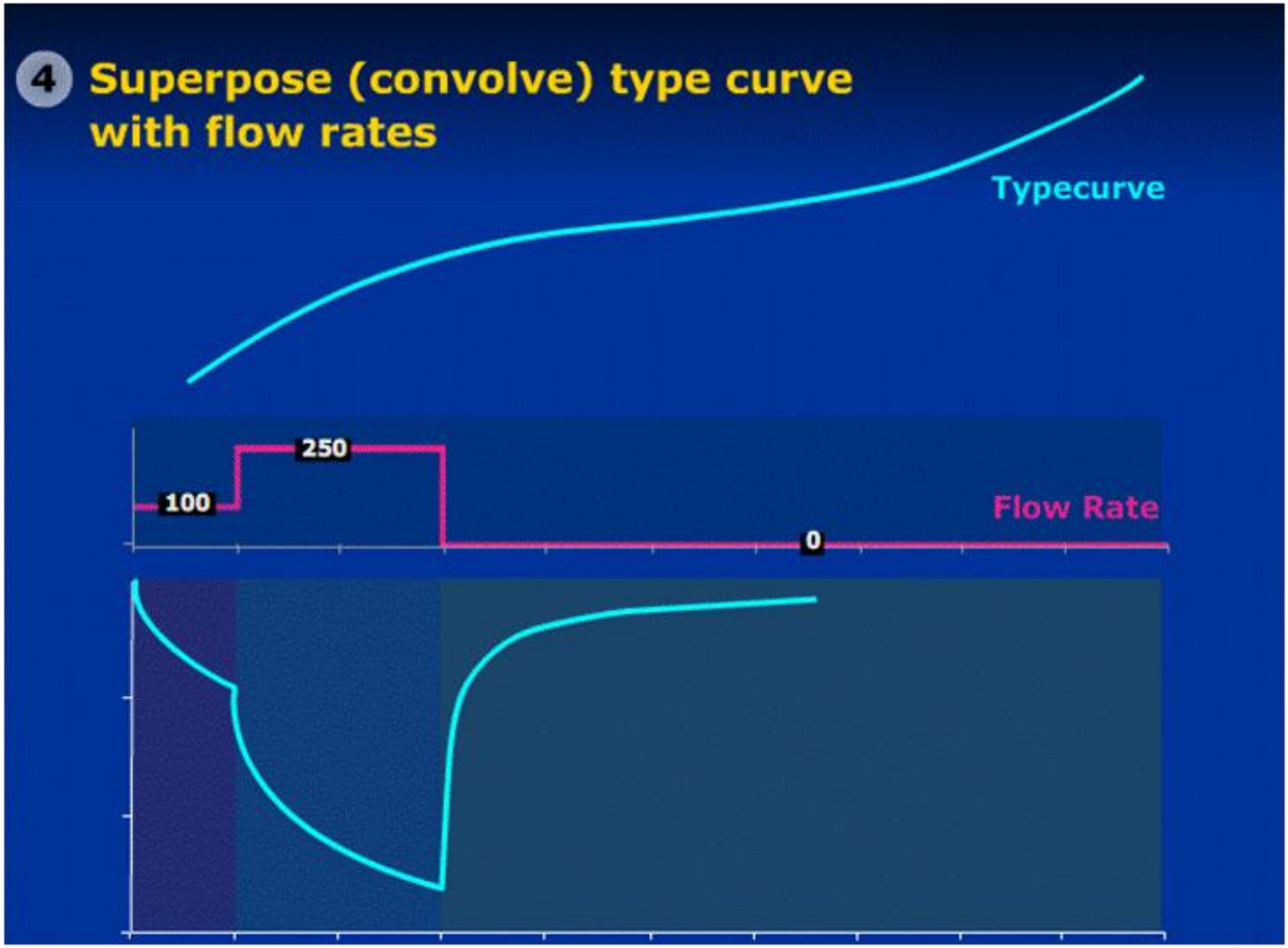
1. Assume derivative
2. Assume starting point on type curve
3. Integrate derivative to obtain the type curve
4. Superpose (convolve) type curve with flow rates
5. Compare calculated results with measured data
6. Quantify total error
7. Modify derivative and repeat until minimum error: Total Least Squares (TLS)

Modern Methods Procedure

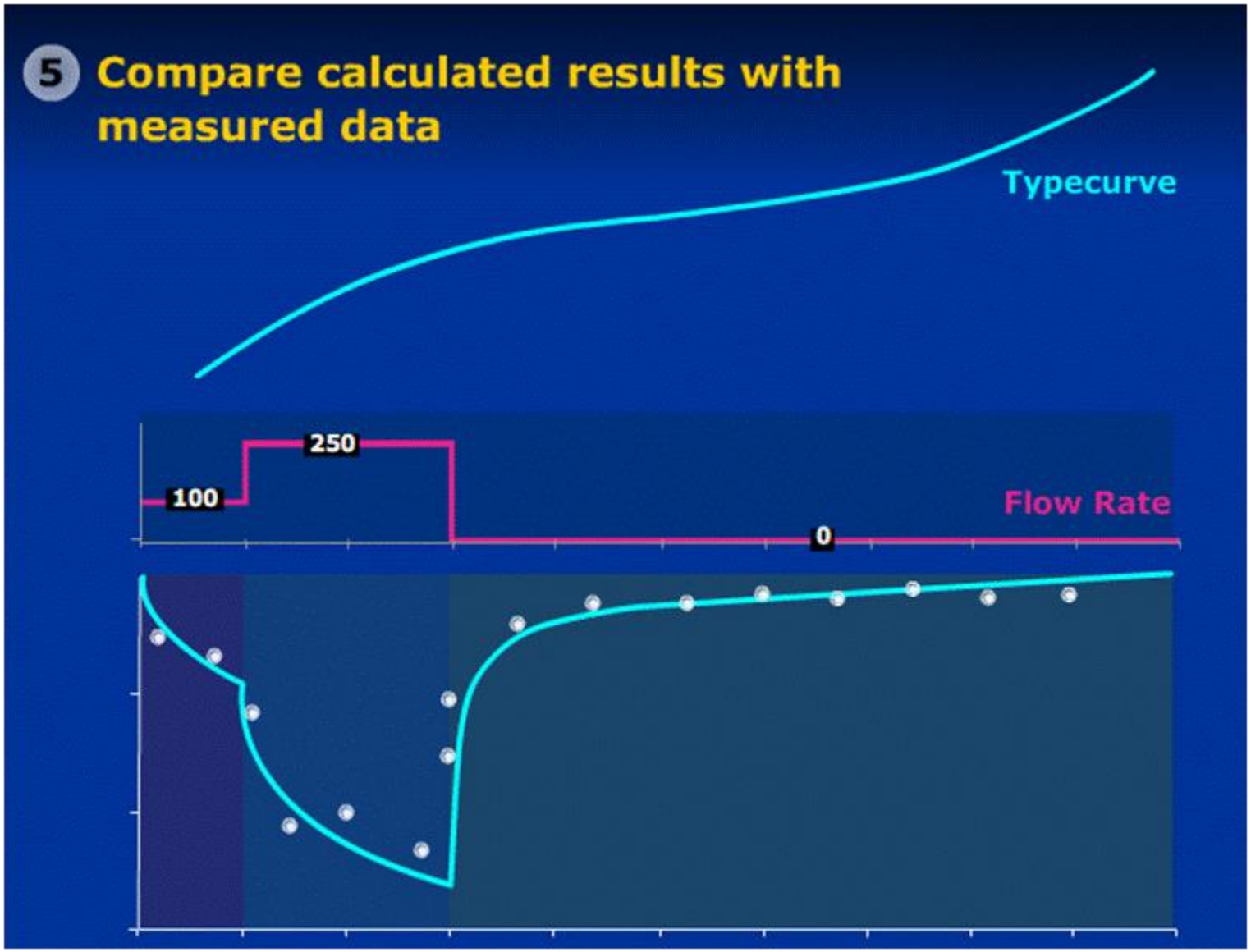
1. Assume derivative
2. Assume starting point on type curve
3. Integrate derivative to obtain the type curve



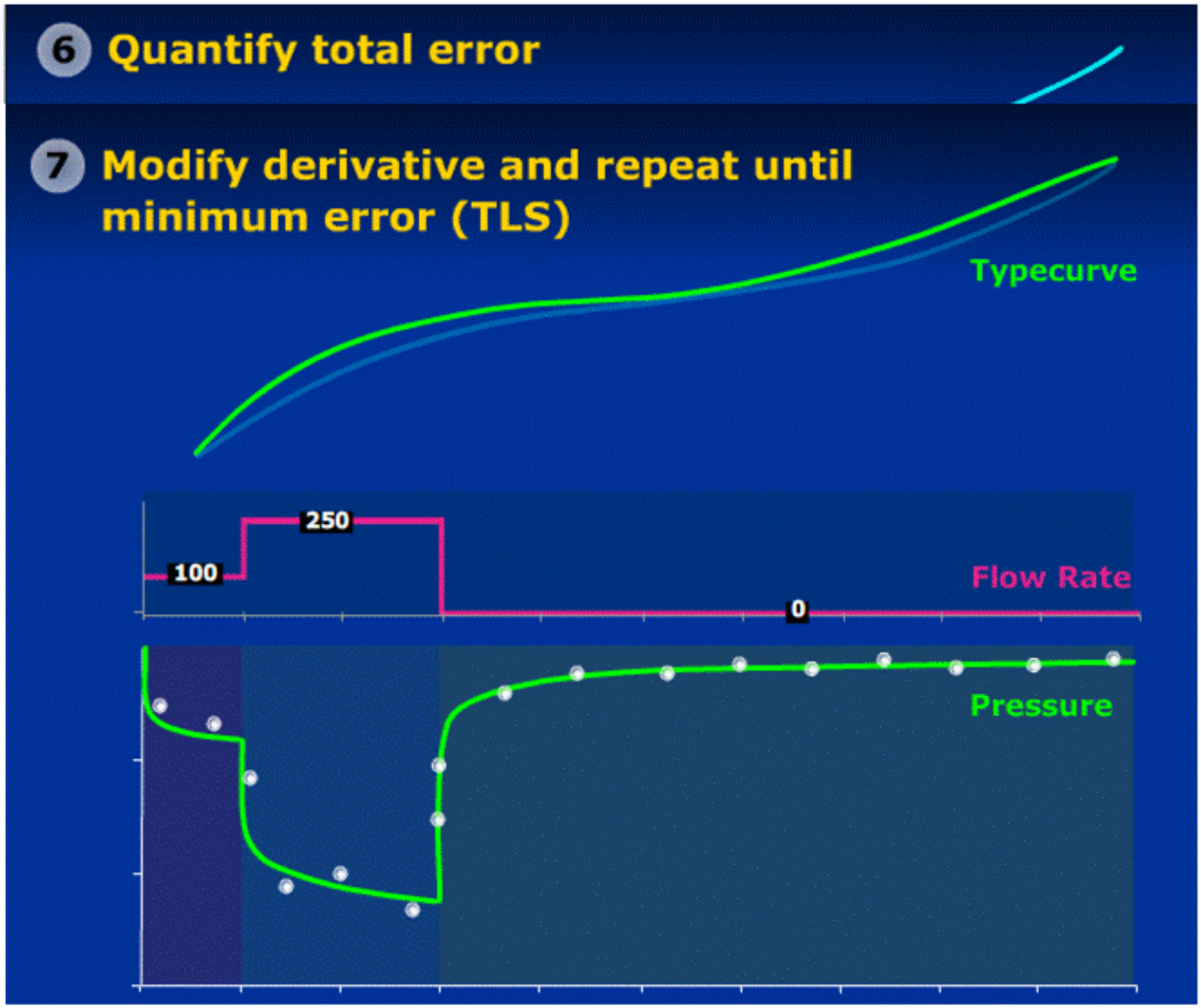
Modern Methods Procedure



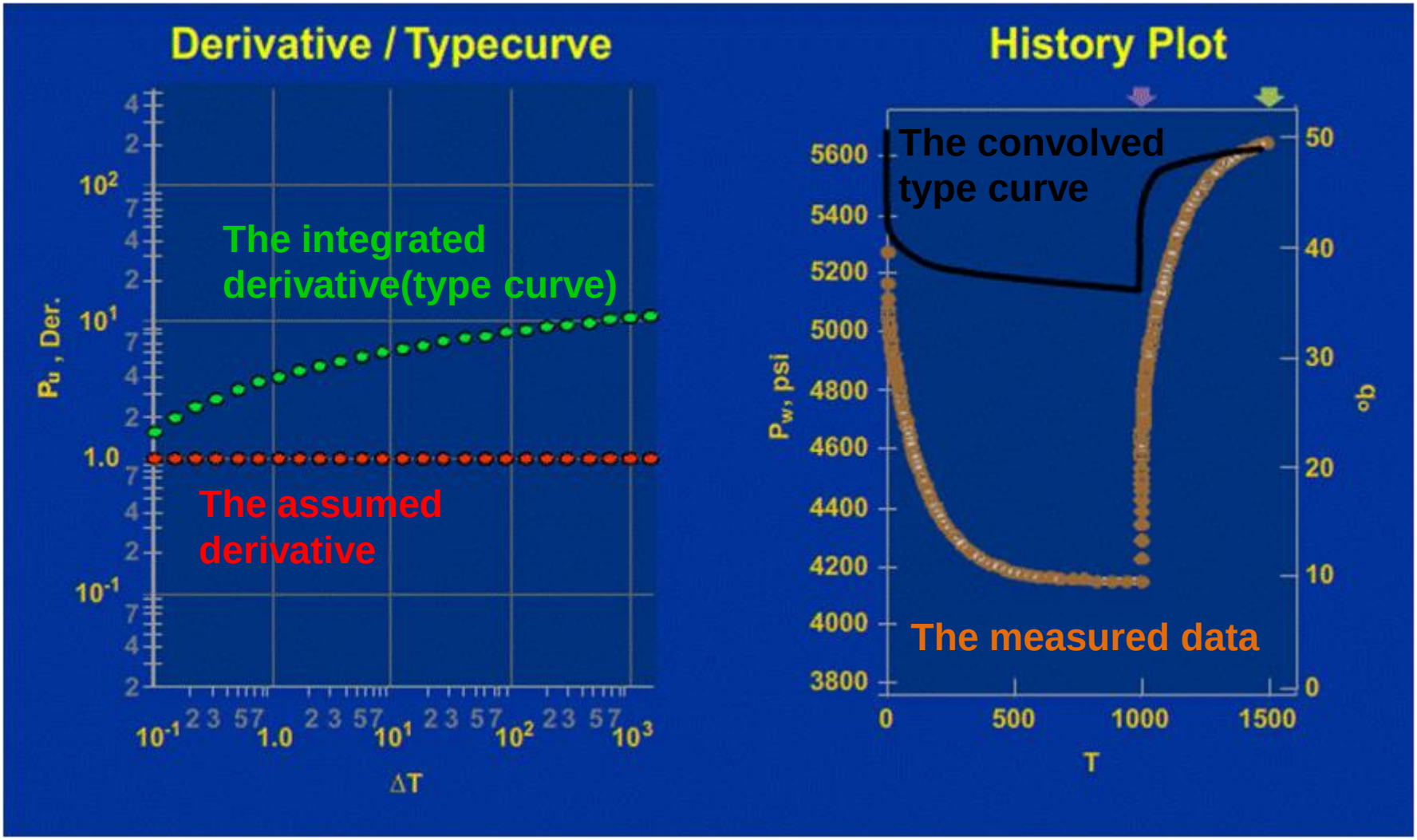
Modern Methods Procedure

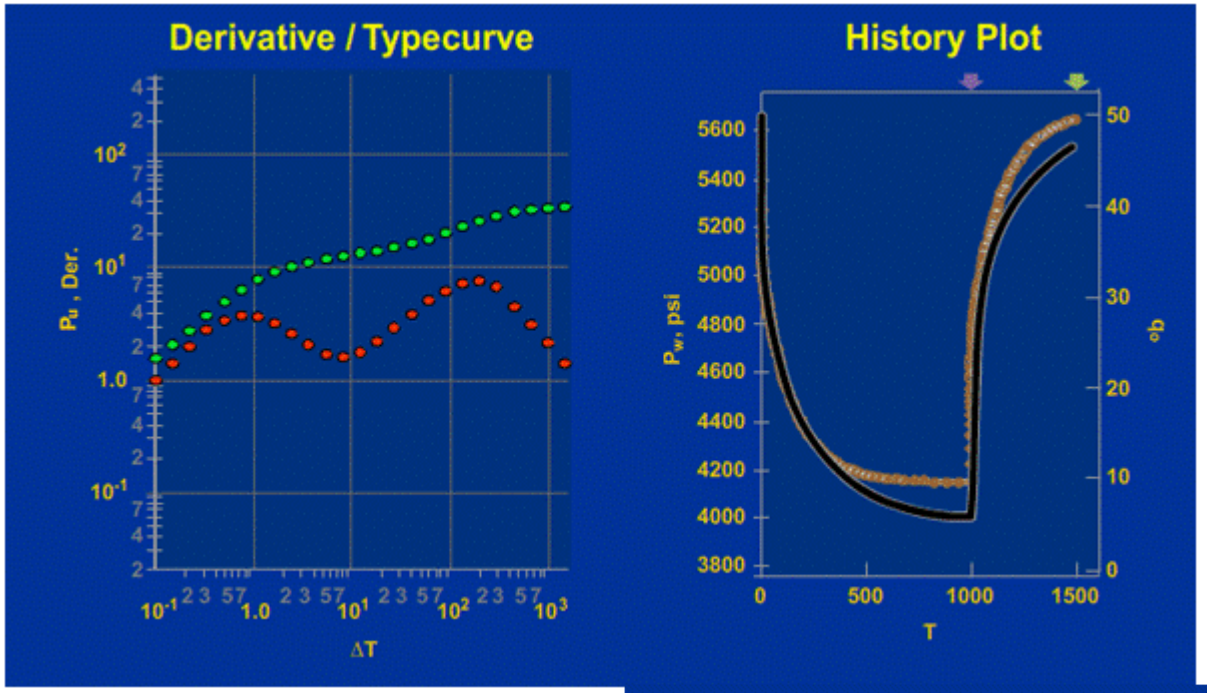


Modern Methods Procedure

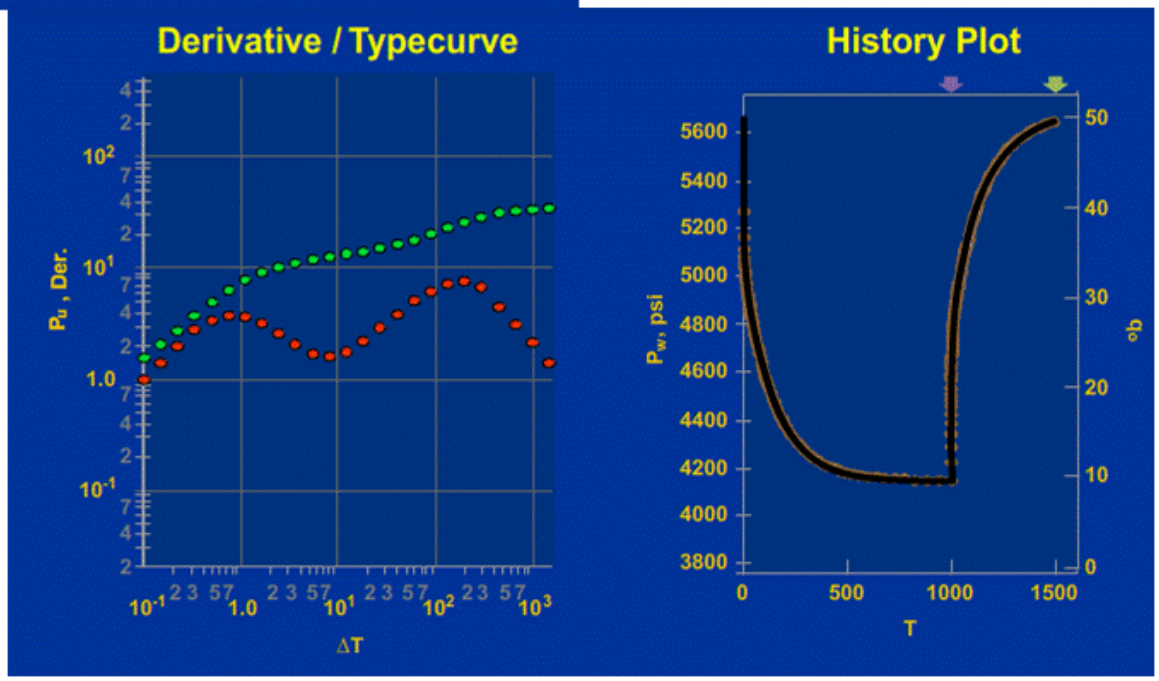


Manual Deconvolution





By changing the derivative we can get a good match



Deconvolution Process

Deconvolution is a mathematical tool that extracts the drawdown typecurve from the rate and pressure history. Essentially the deconvolution process consists of the following steps:

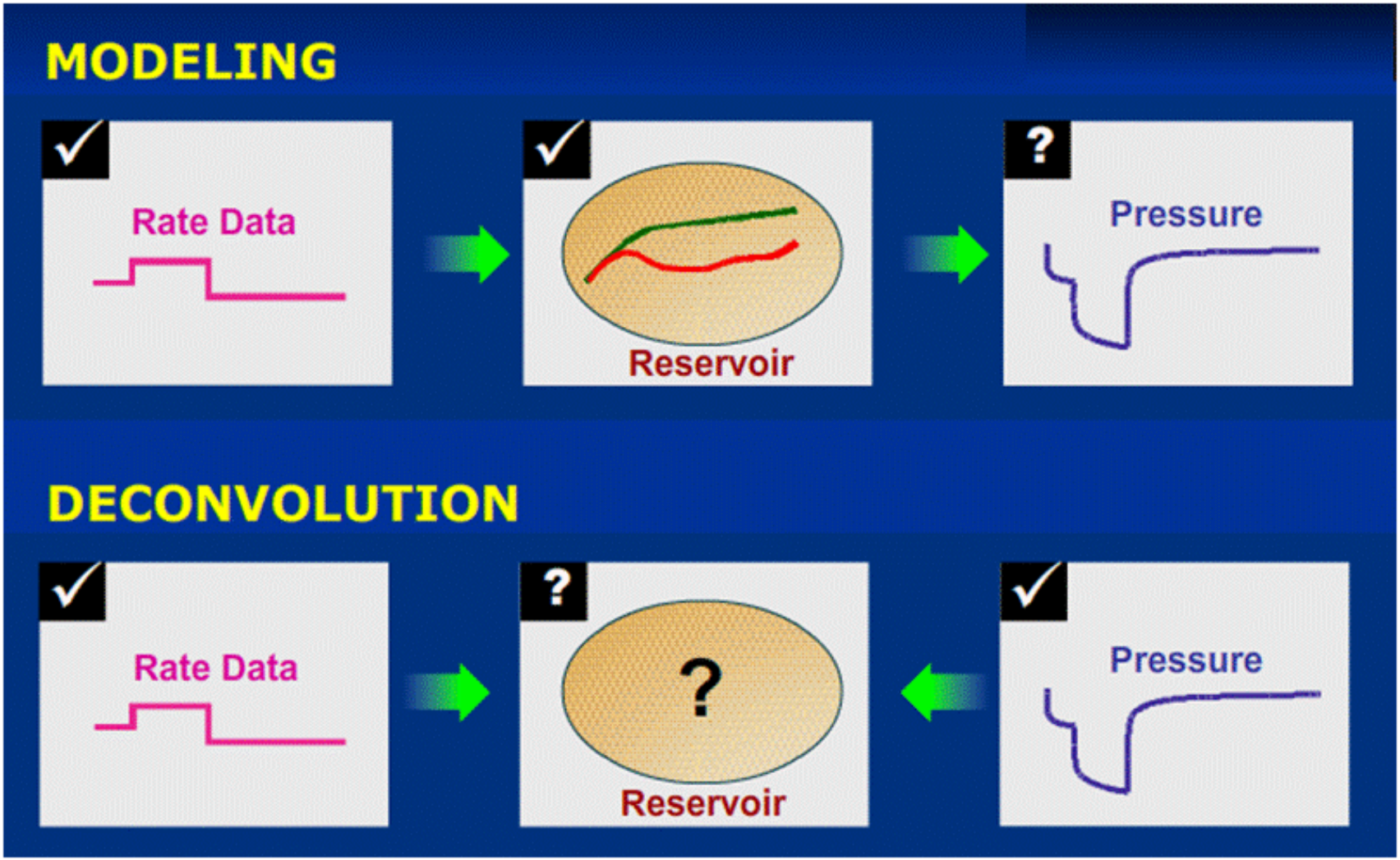
- Generate a typecurve as an initial guess
- Superpose this typecurve with historical rate data to calculate synthetic pressures
- Calculate the error between the calculated pressures and the measured pressures
- Generate a new typecurve and repeat the process until the error between calculated and measured pressures is minimized

Deconvolution-Guidelines

Please note that deconvolution is a purely mathematical process and should be used with caution. The following guidelines show the ideal conditions for deconvolving data to obtain the best possible results

- ❑Data does not contain a lot of noise
- ❑Data is free from outliers in both rate and pressure
- ❑Rate history is reliable
- ❑Buildup typecurves used for deconvolution are consistent with each other
- ❑Wellbore and reservoir properties do not change significantly with time
- ❑A good estimate of initial pressure (p_i) is available

Deconvolution vs. Modeling



Deconvolution vs. Modeling

1	Deconvolution extracts the underlying Drawdown Type Curve from Multi-Rate data	✓ So Does Modeling
2	Deconvolution generates the "Total Test Duration" Type Curve using ONLY Buildup data	✓ So Does Modeling
3	Deconvolution INCREASES the radius of investigation	✓ So Does Modeling
4	Deconvolution can (?) determine the Initial Reservoir Pressure, when it is missing	✓ So Does Modeling
5	Deconvolution eliminates the need to use superposition time functions (Σlog, Σ√, or Material Balance time etc.)	✓ So Does Modeling
6	Deconvolution does NOT assume a "Reservoir Model"	INSTEAD it assumes a "Mathematical Model"

Useful References for Deconvolution

- SPE 71574,
- SPE 77688,
- SPE 84290,
- SPE 90680.