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Predicting the Arrival of an Interference Response in a Direct Communication Test

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Society of Petroleum Engineers

Contents

- Types of Interference/Communication Tests
- Review of Reservoir Physics and Assumptions
- Two Methods to Estimate Time to Observe Interference
- Case Studies/Examples of Direct Interference Tests
- A Little Math (don’t worry, I’ll skip it)
- Conclusions

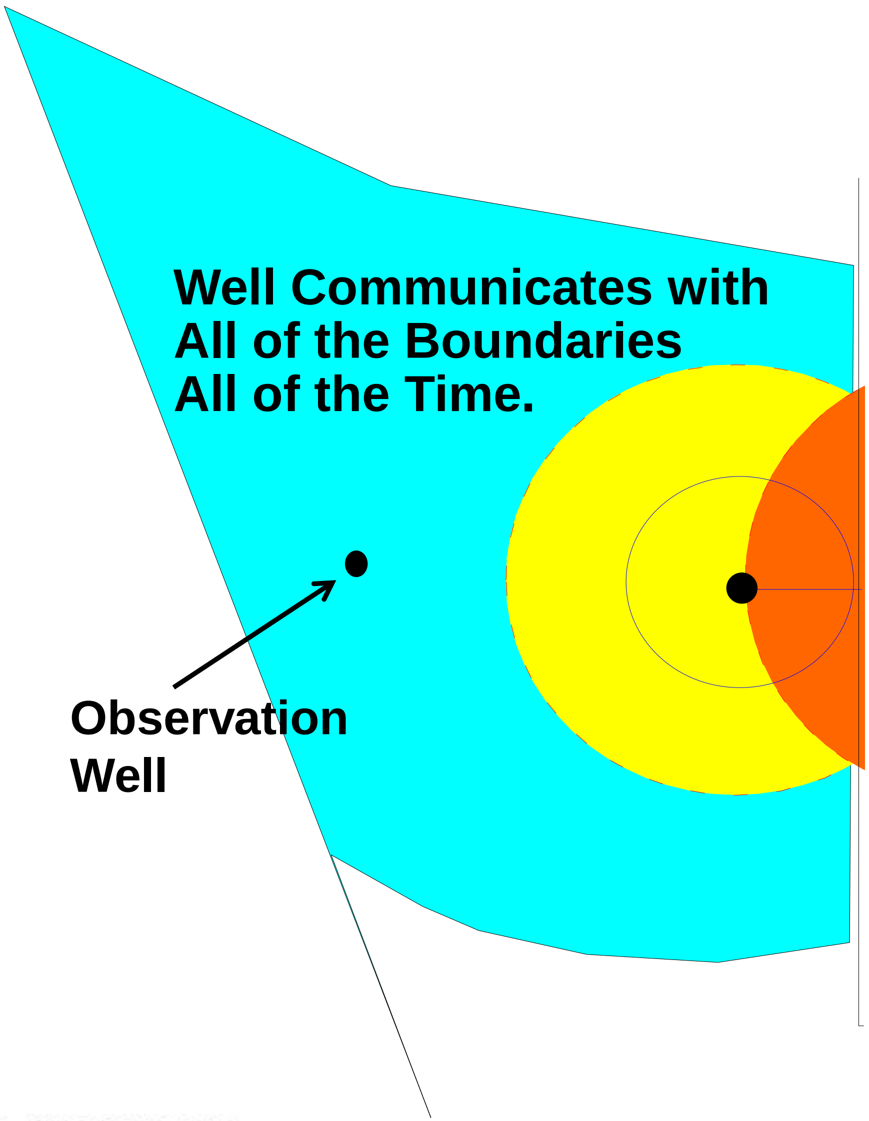
Types of Interference Tests

- **Direct - Flow one well and observe response in one or more wells (observation wells are shut-in)**
- **Indirect** - All wells are producers; all wells are put on production before direct communication is observed (ideally, all wells are placed on production simultaneously)
- **Inferred** - After establishing each well's drainage radius, one well's rate is changed & the response is observed in other wells
- **Pulse** - Alternating Series of build-ups and drawdowns in producer, response is observed in other wells

QUESTIONS:

- WHAT HAPPENS WHEN YOU FIRST TURN ON A WELL?
- WHAT DOES IT LOOK LIKE FROM A SHUT-IN OBSERVATION WELL?
- HOW LONG WILL IT TAKE TO OBSERVE COMMUNICATION?
- WHICH VARIABLES ACTUALLY MATTER & WHICH ONES DON'T?

Exponential Integral Model



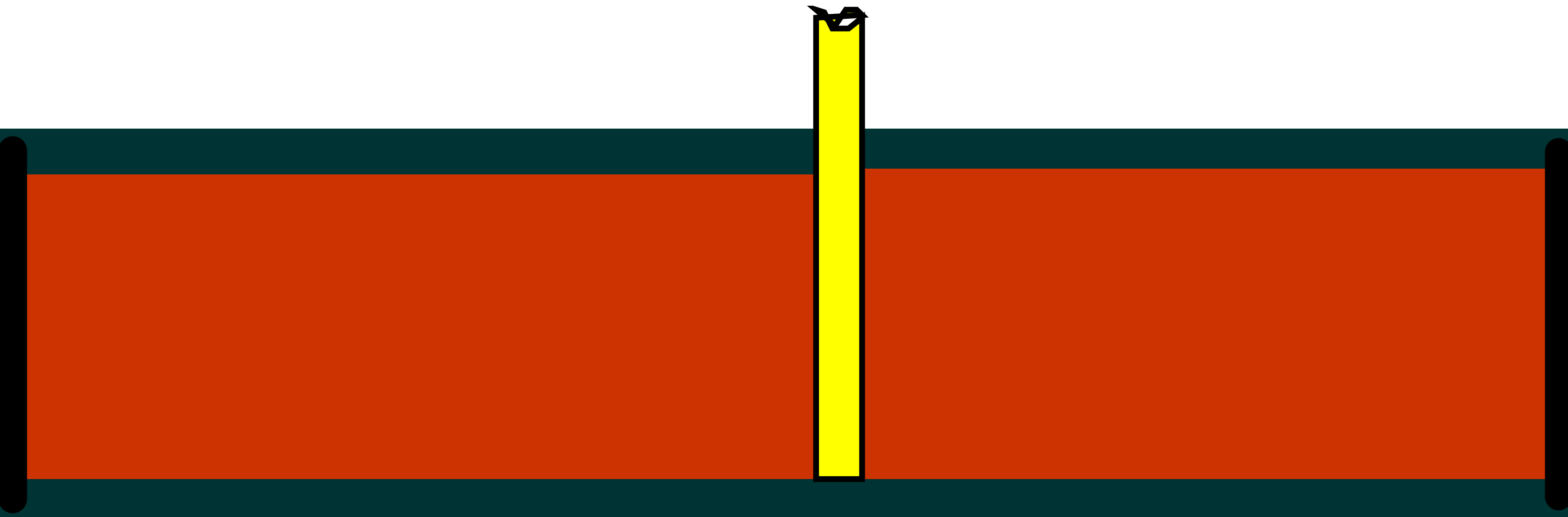
The Dashed Red Line Represents the Radius of Investigation. Rinv Is Based Upon the Hypothetical Effective Drainage Volume of the Well..

Exponential Integral Model

- Fixed Boundary (in communication instantly)
- Zero Potential Flow
- Relaxation of Field to Changes in Flow

Ei(x) Model

All Reservoir Volume Is Active All Boundaries Influence Model All of the Time



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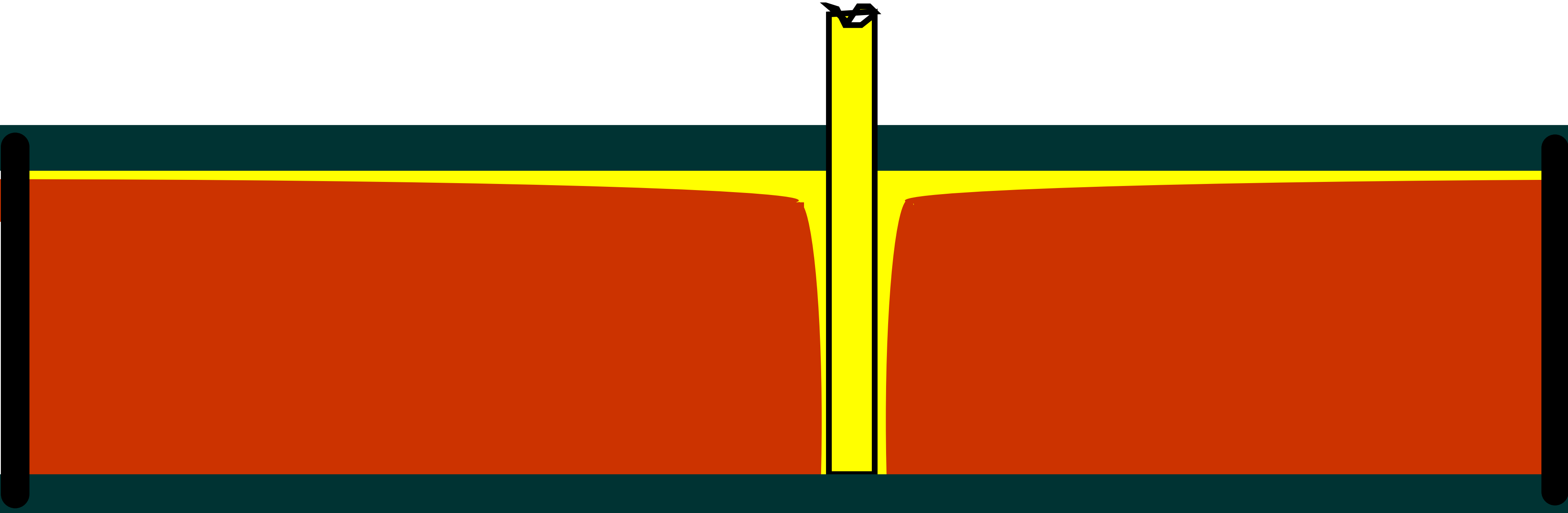

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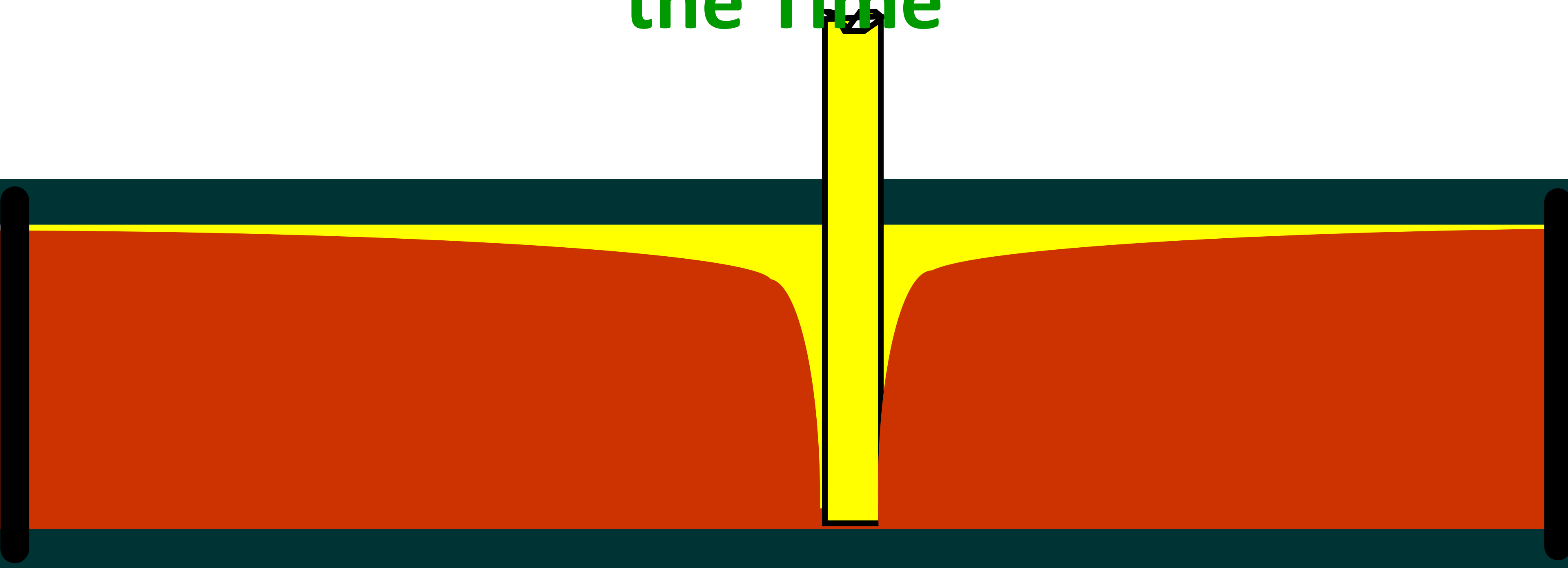

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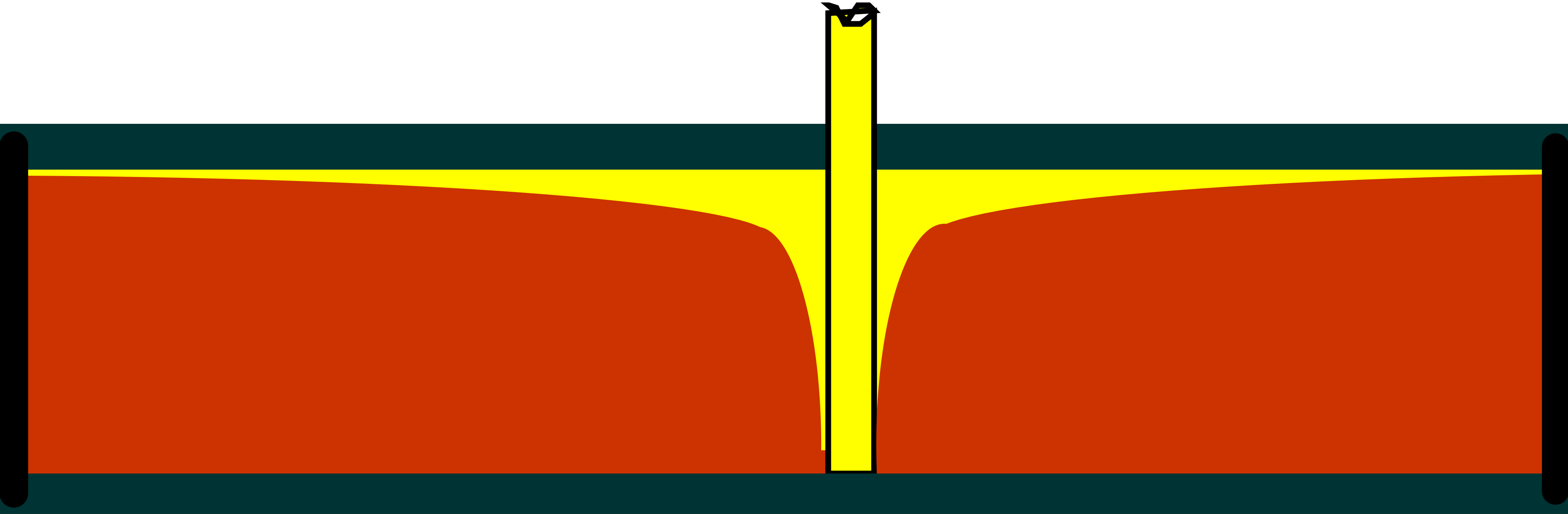

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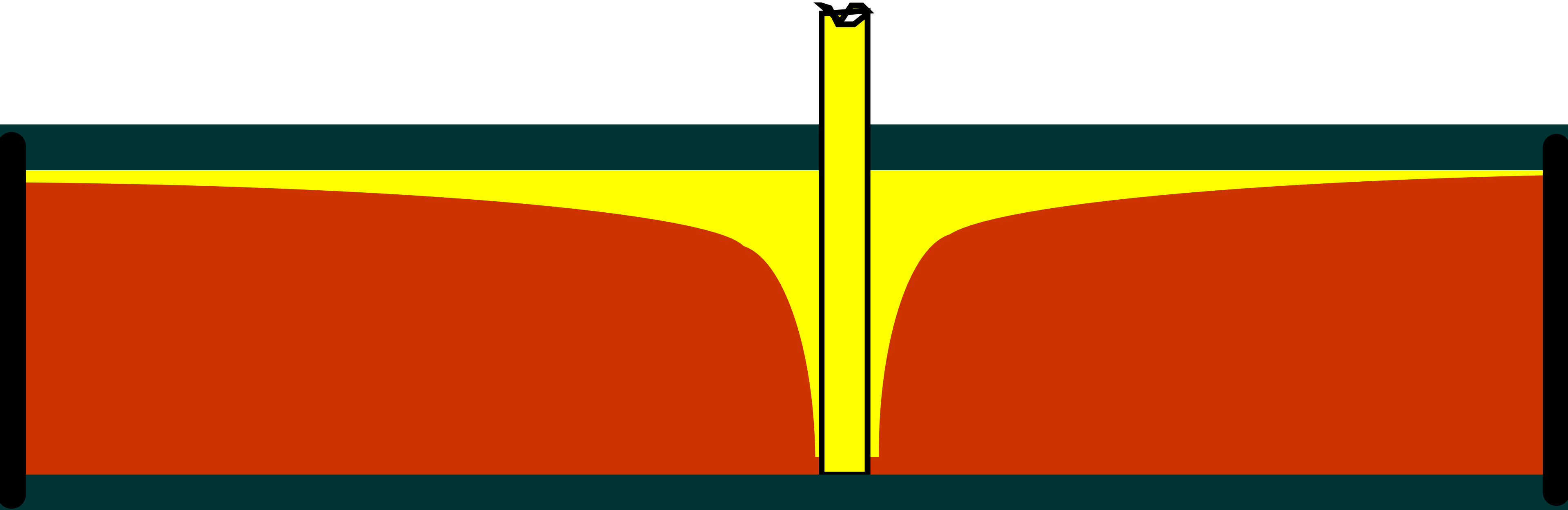

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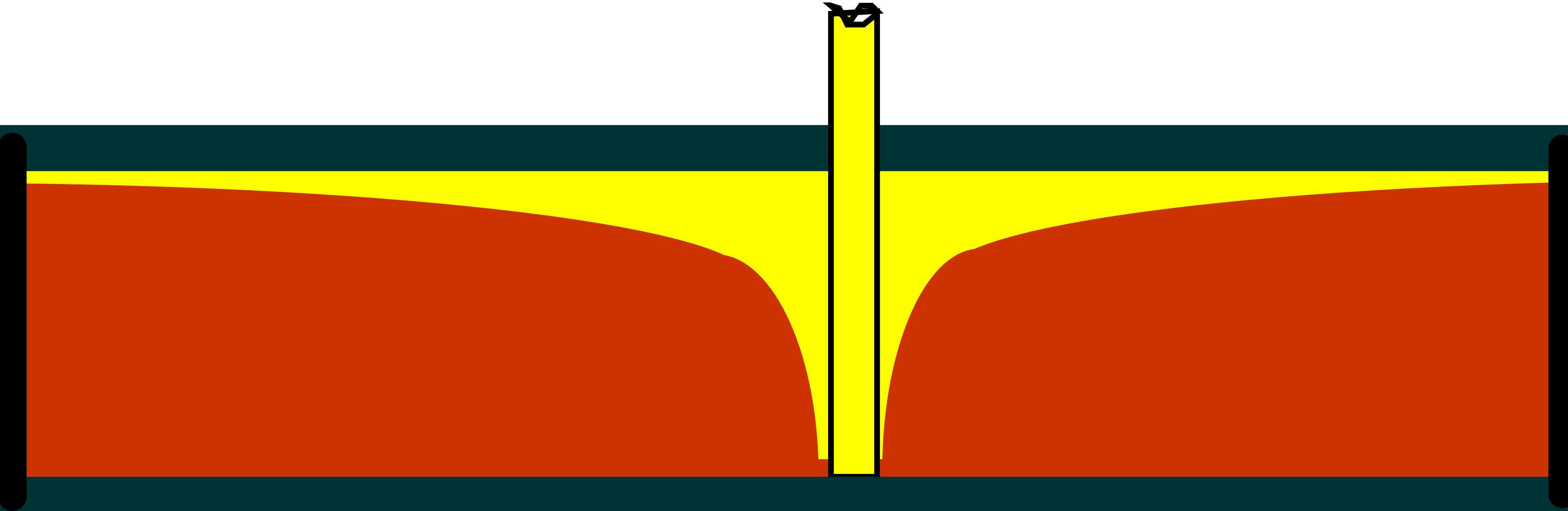

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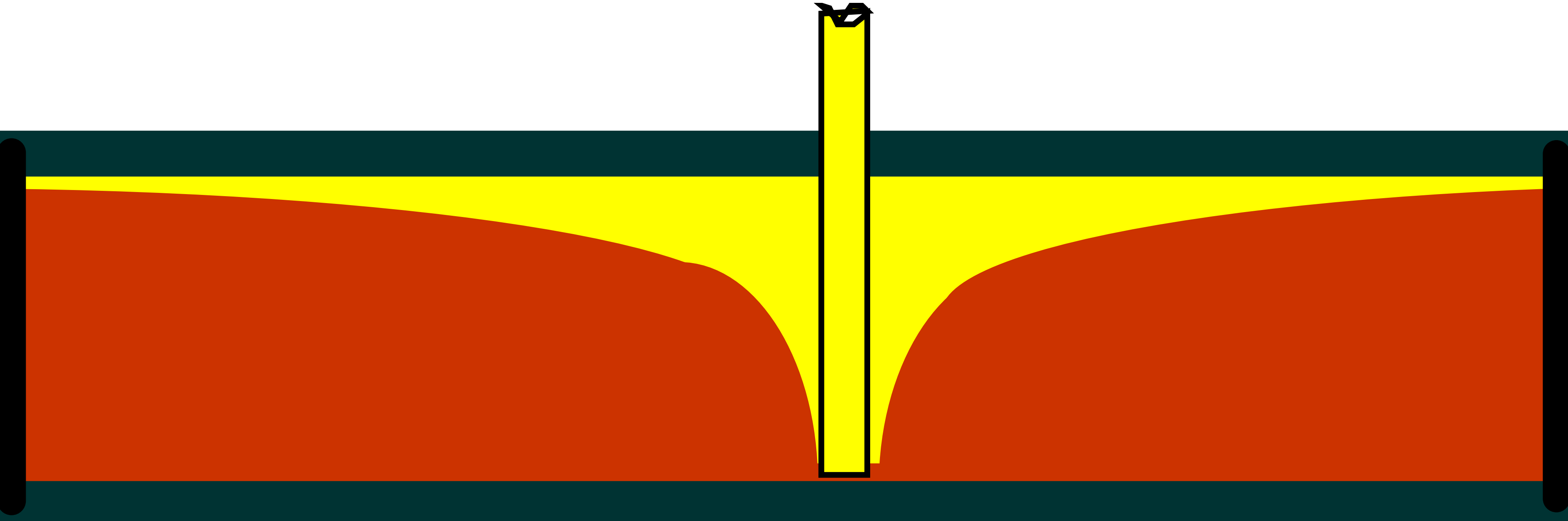

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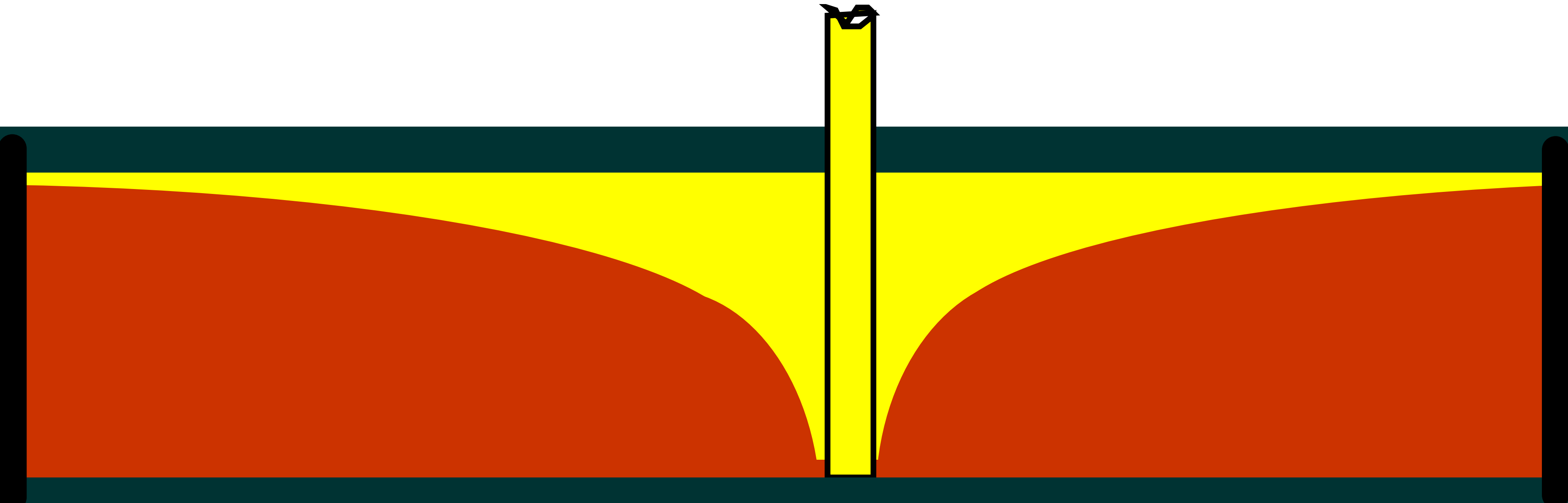

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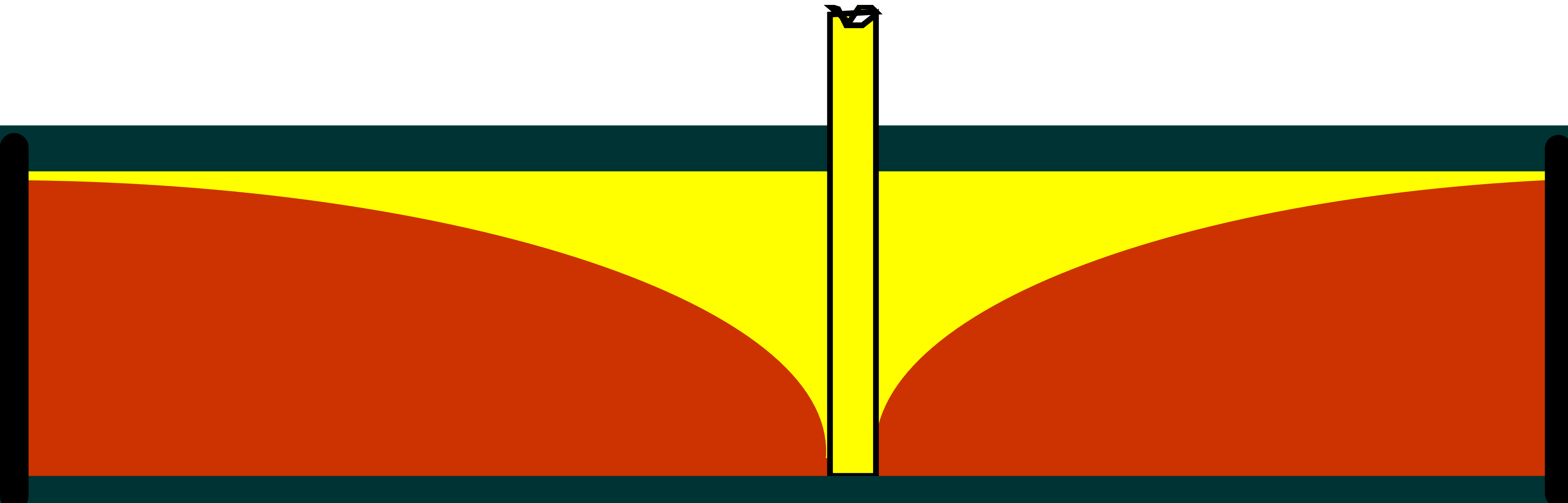

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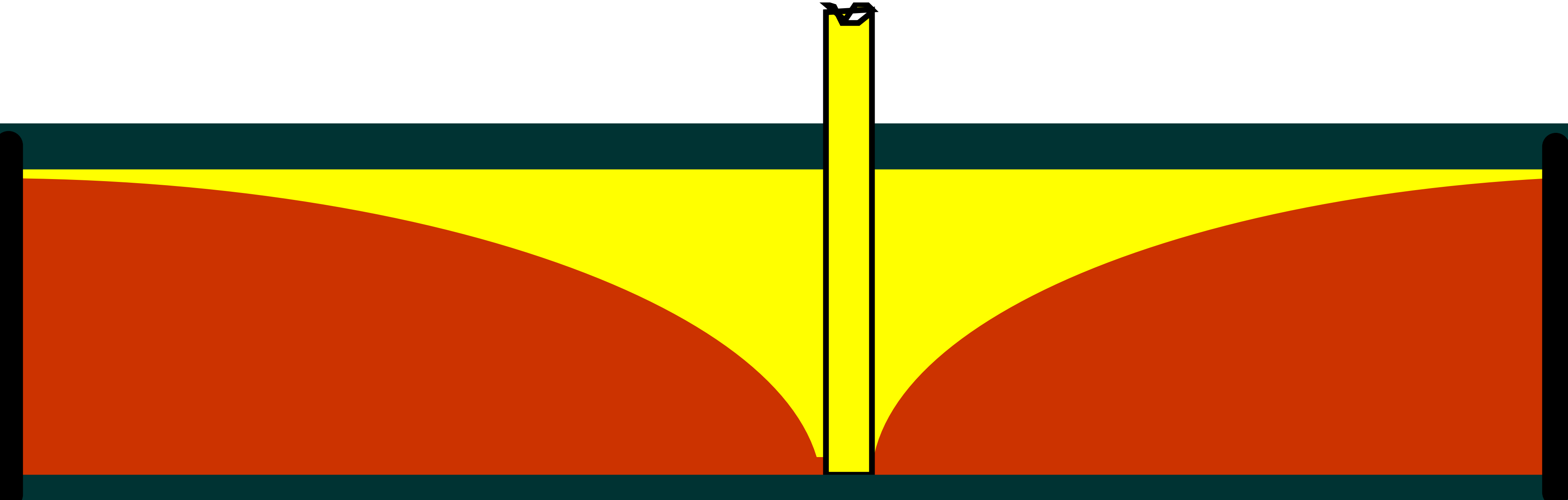

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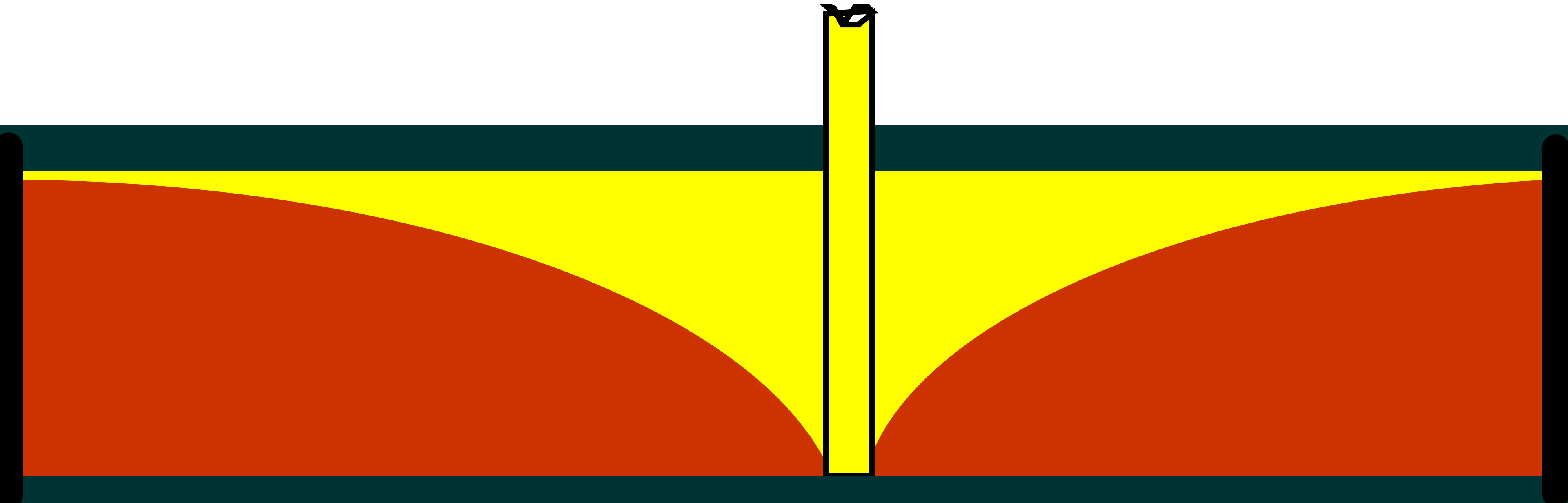

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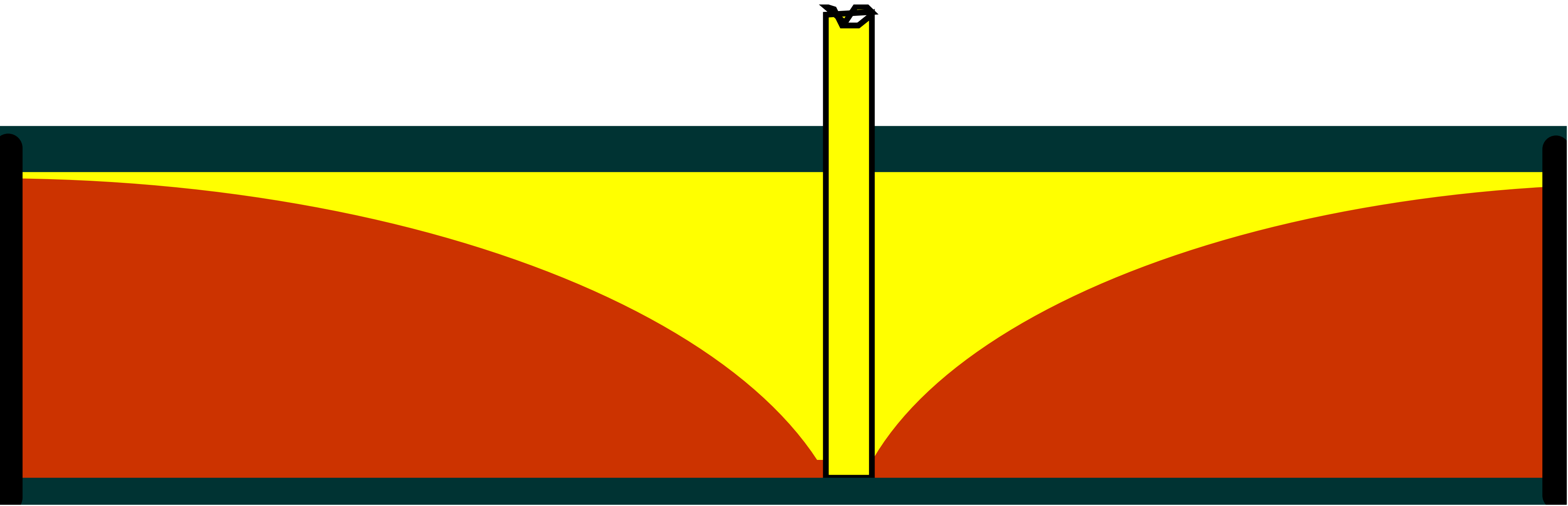
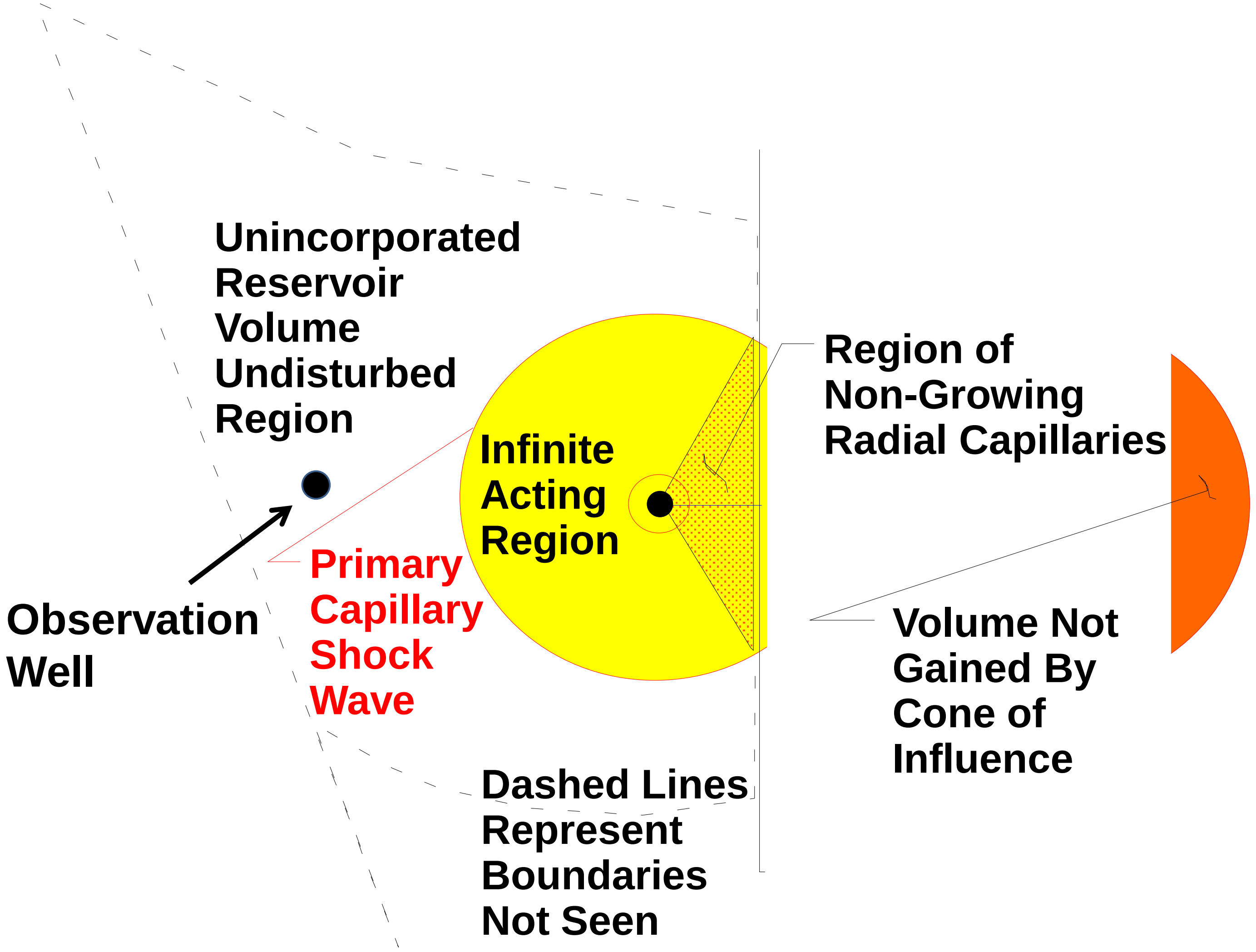
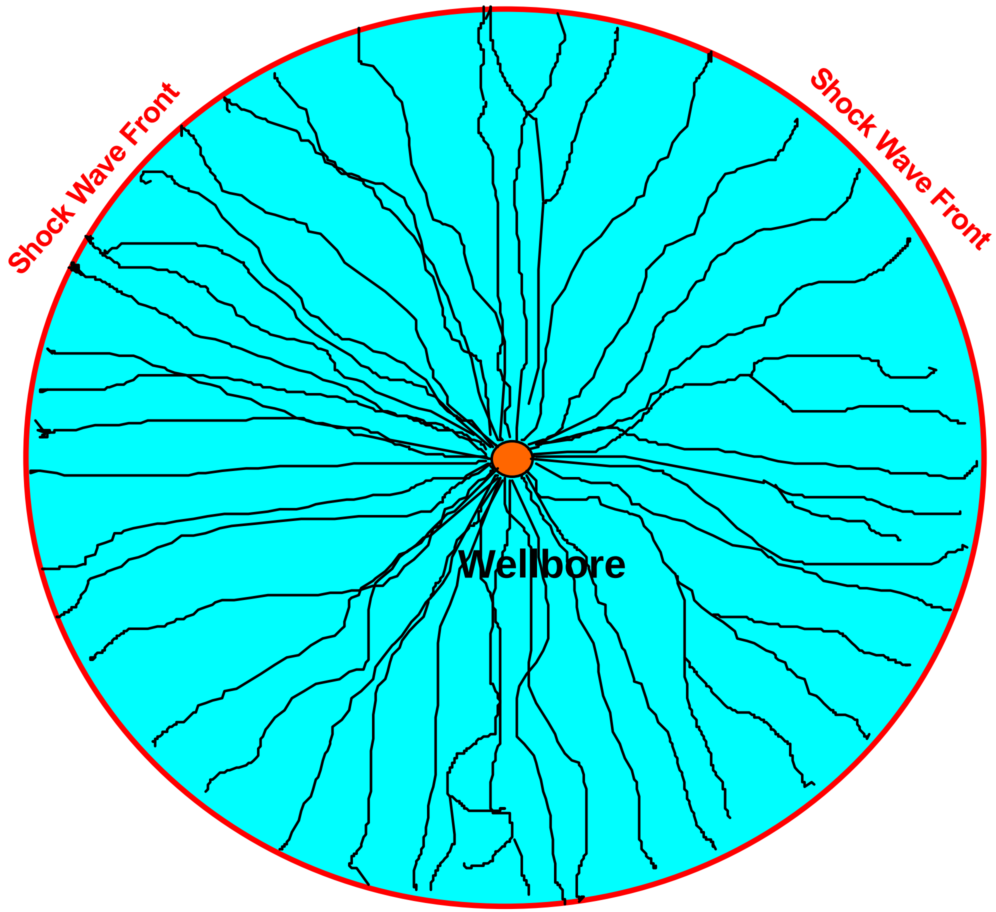


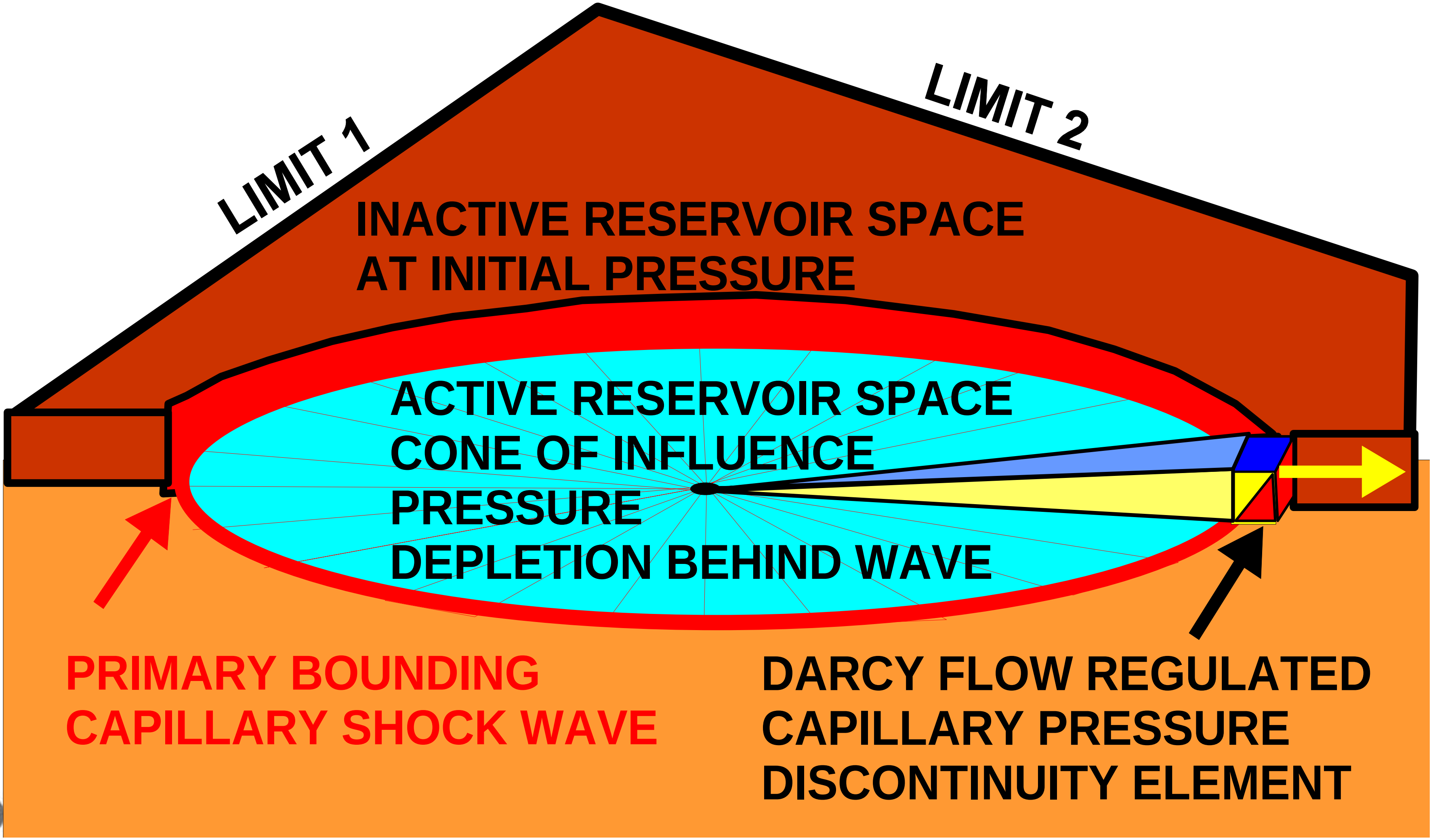
Capillary Shock Front Model



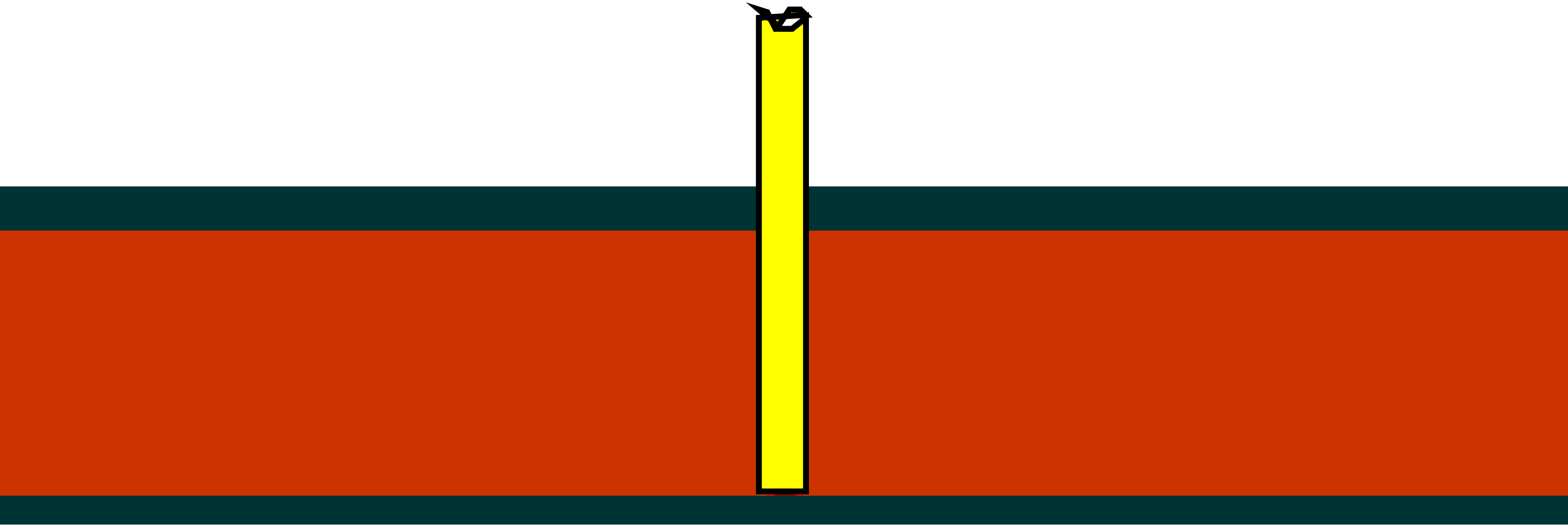
Clusters of Growing Capillaries



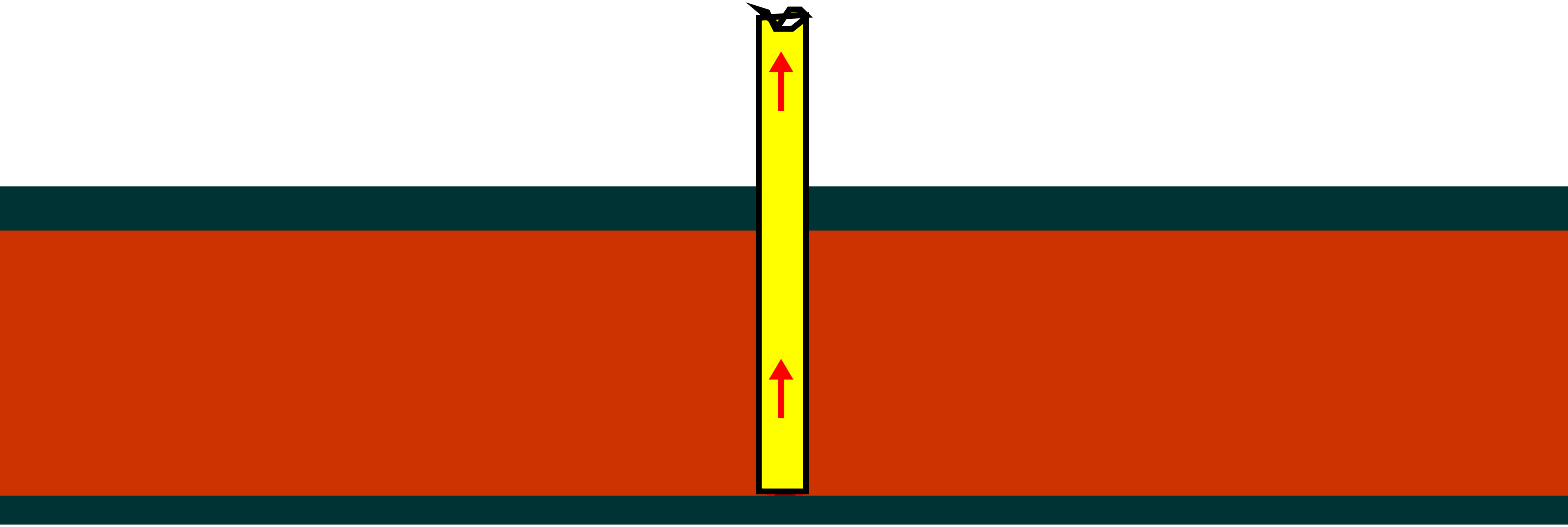
Moving Capillary Shockwave Boundary



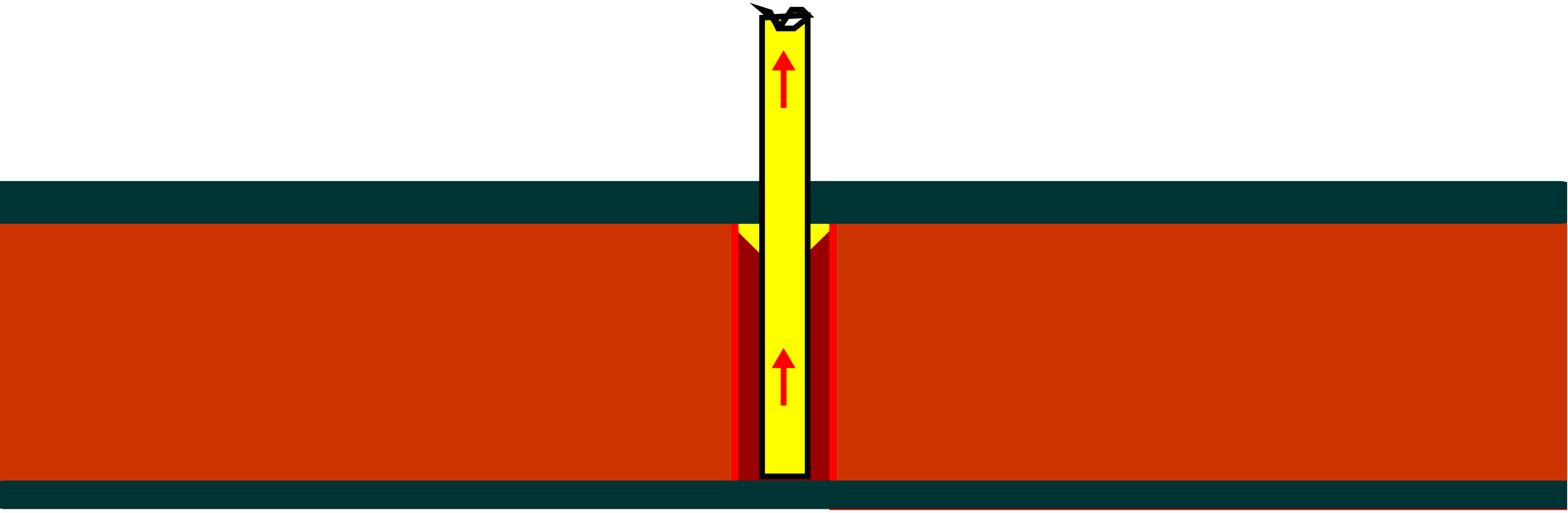
Static Reservoir



Well Turned On



Shock Front Advances and Creates Active Reservoir Volume Pressure Depletes Behind Shock Front



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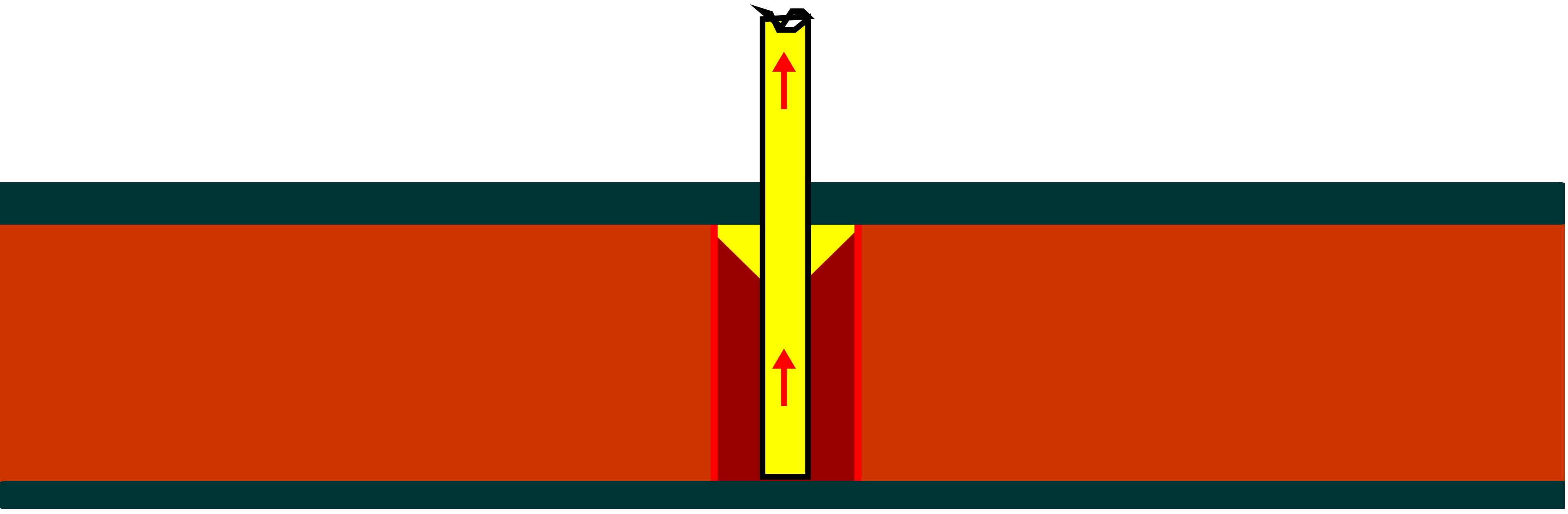

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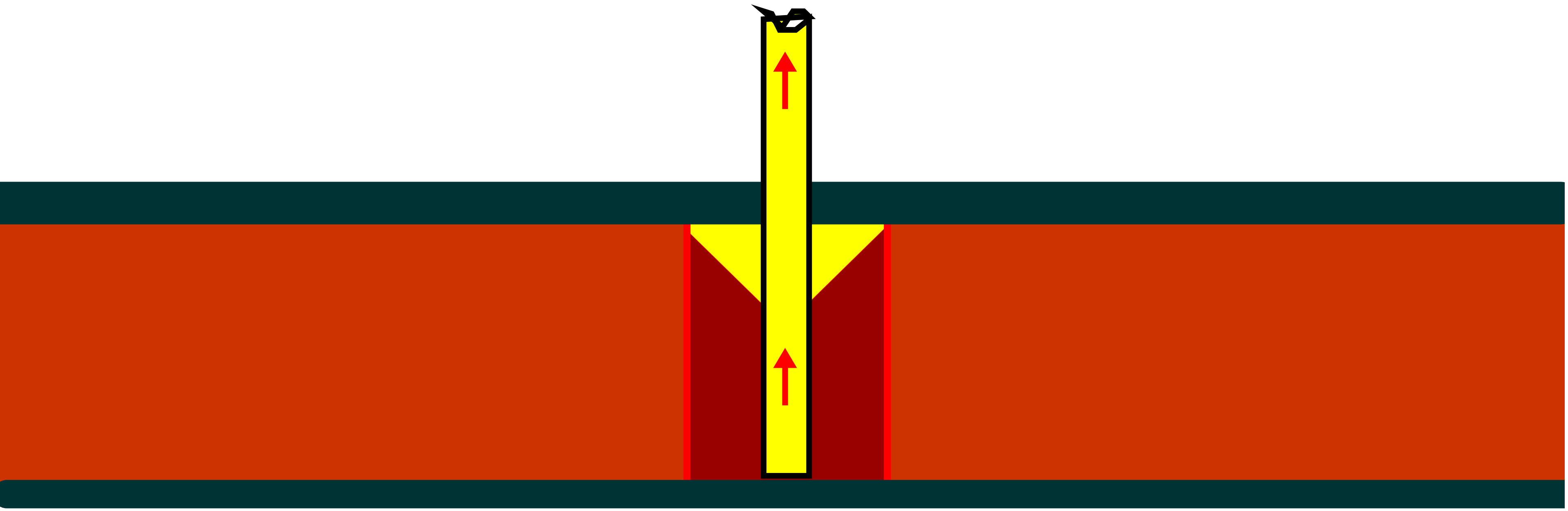

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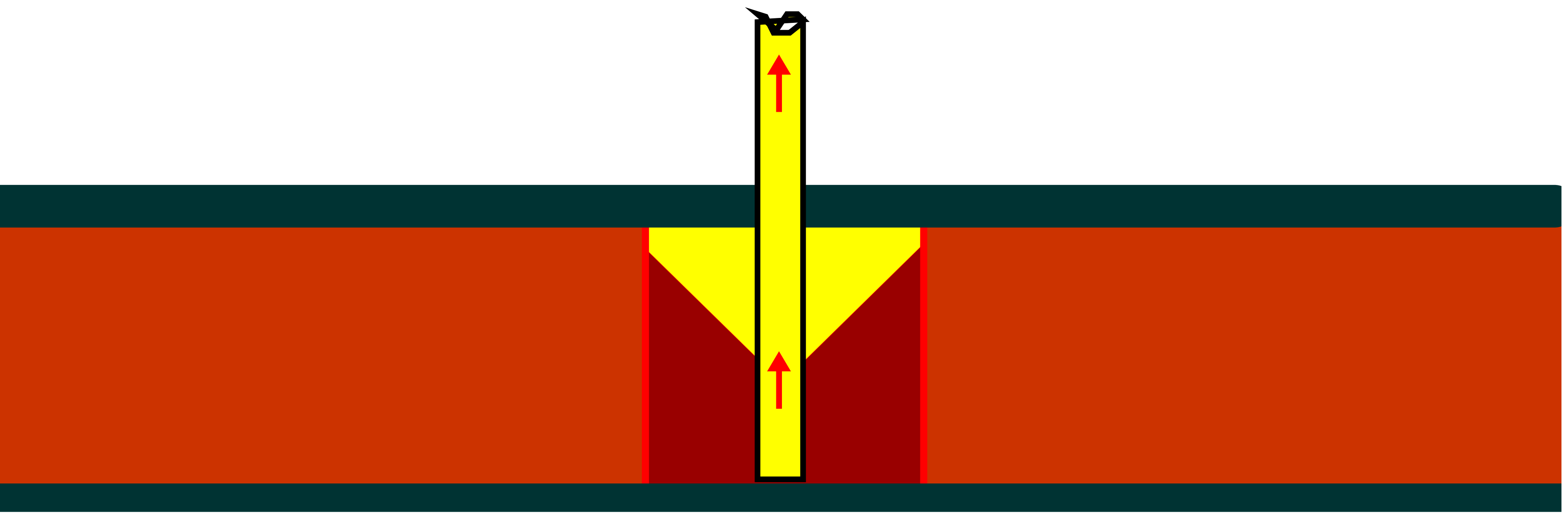

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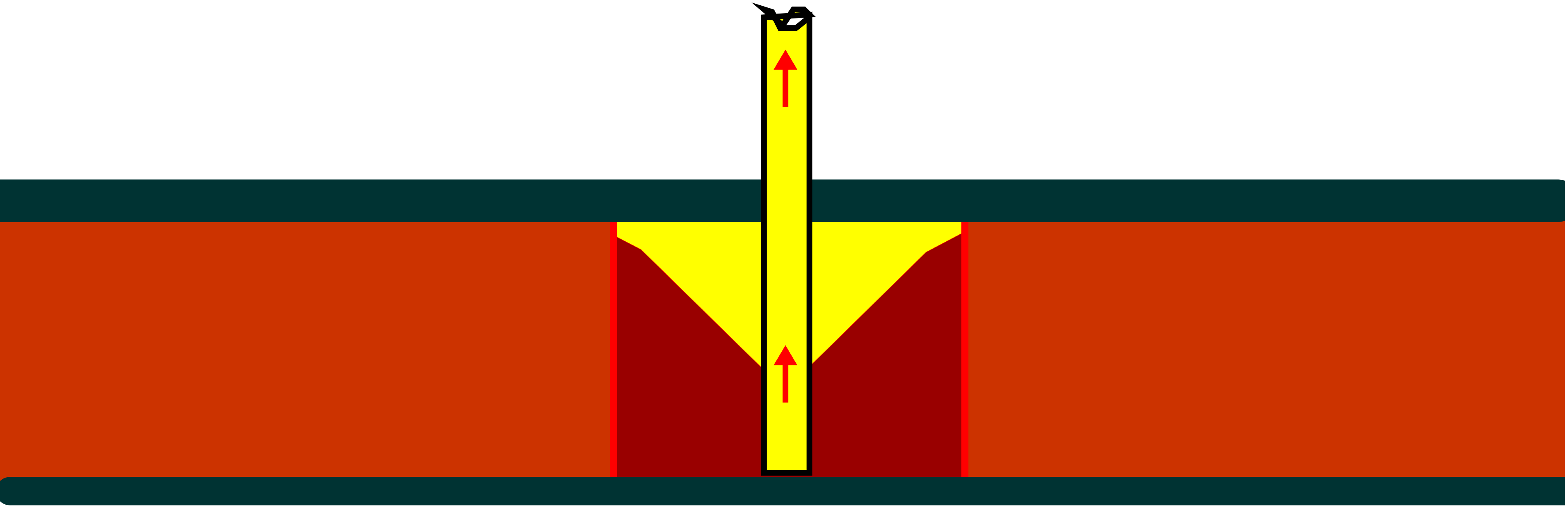

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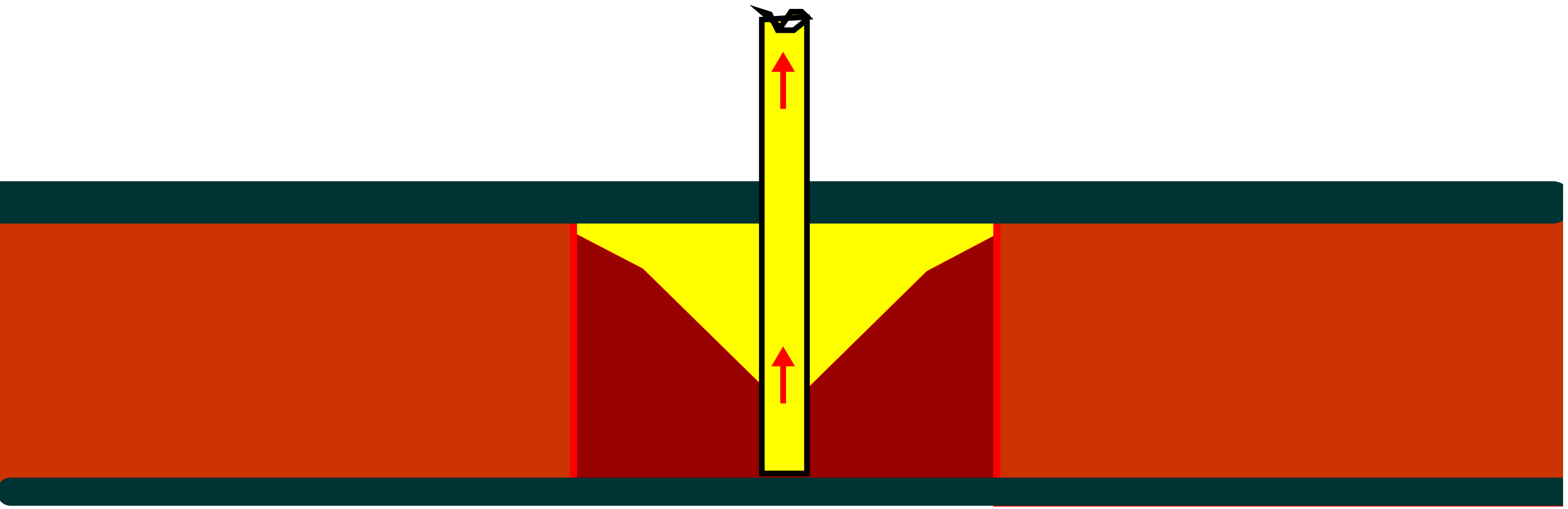

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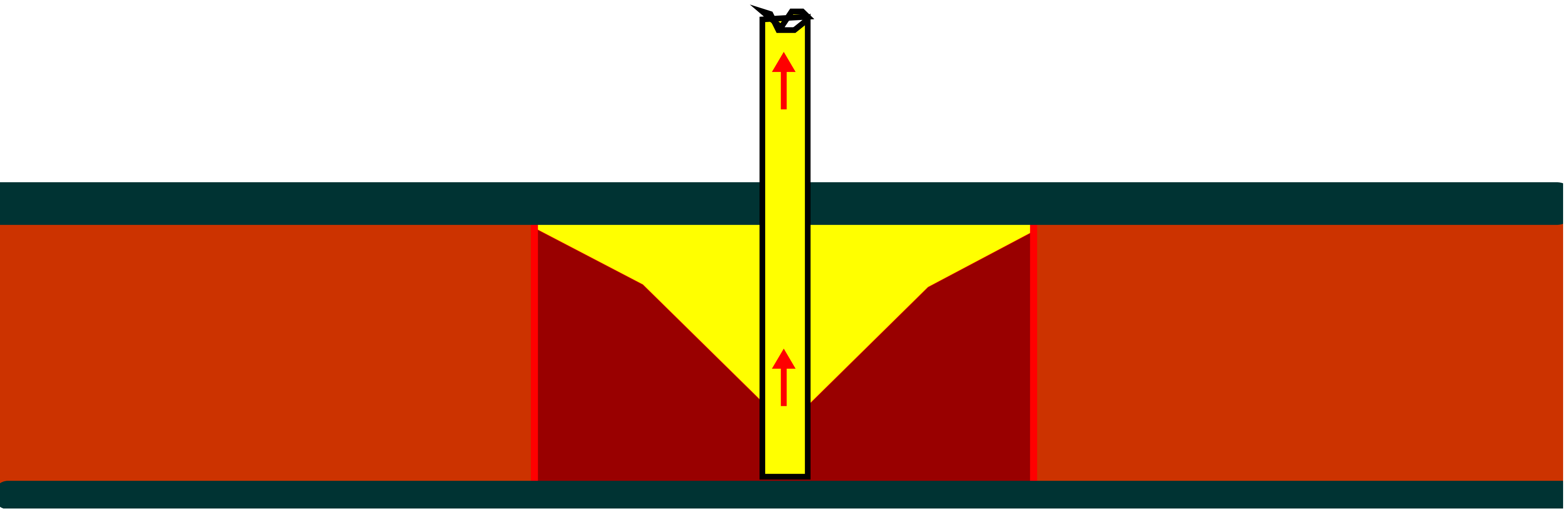

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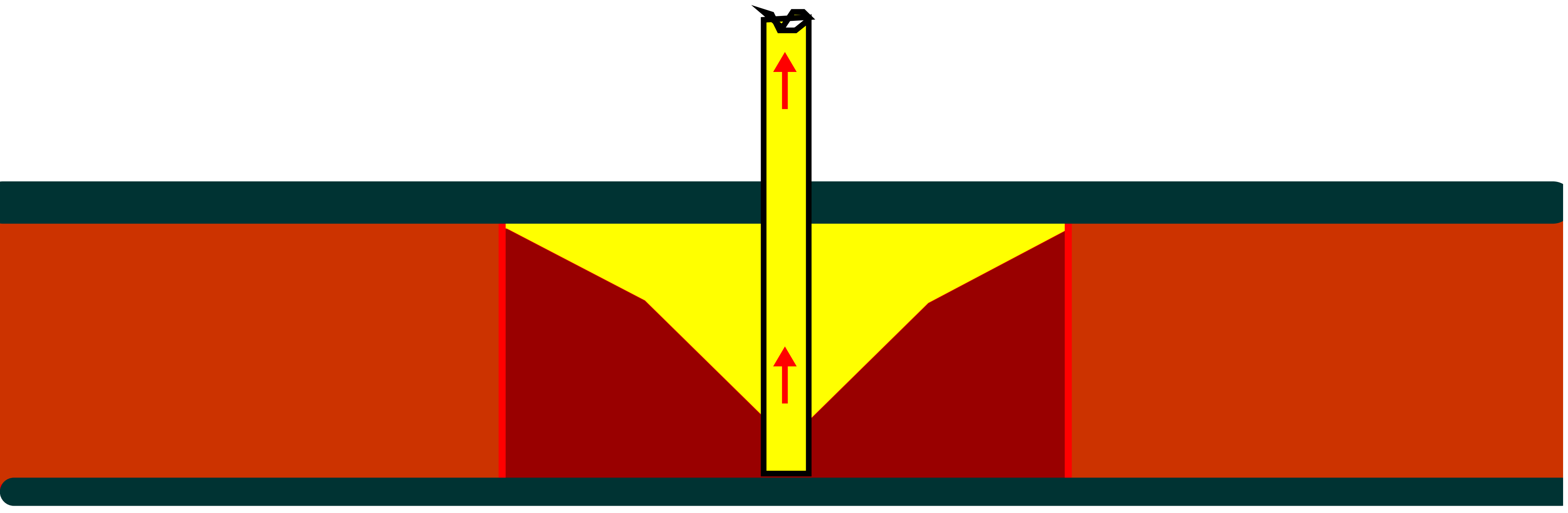

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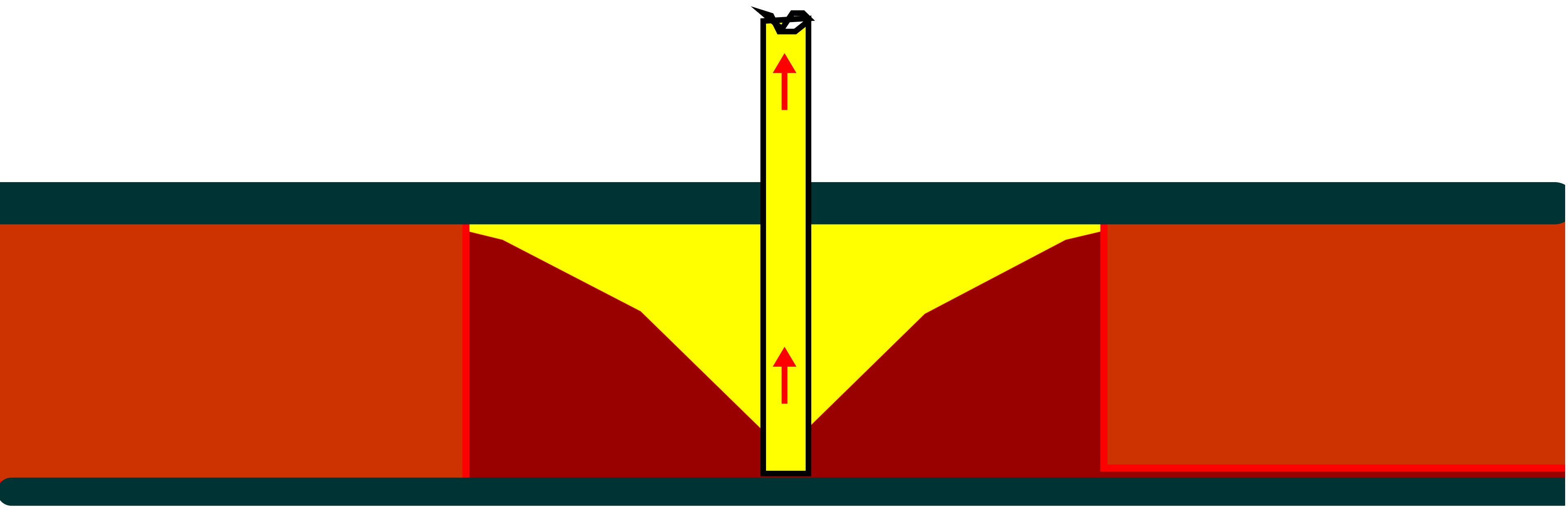

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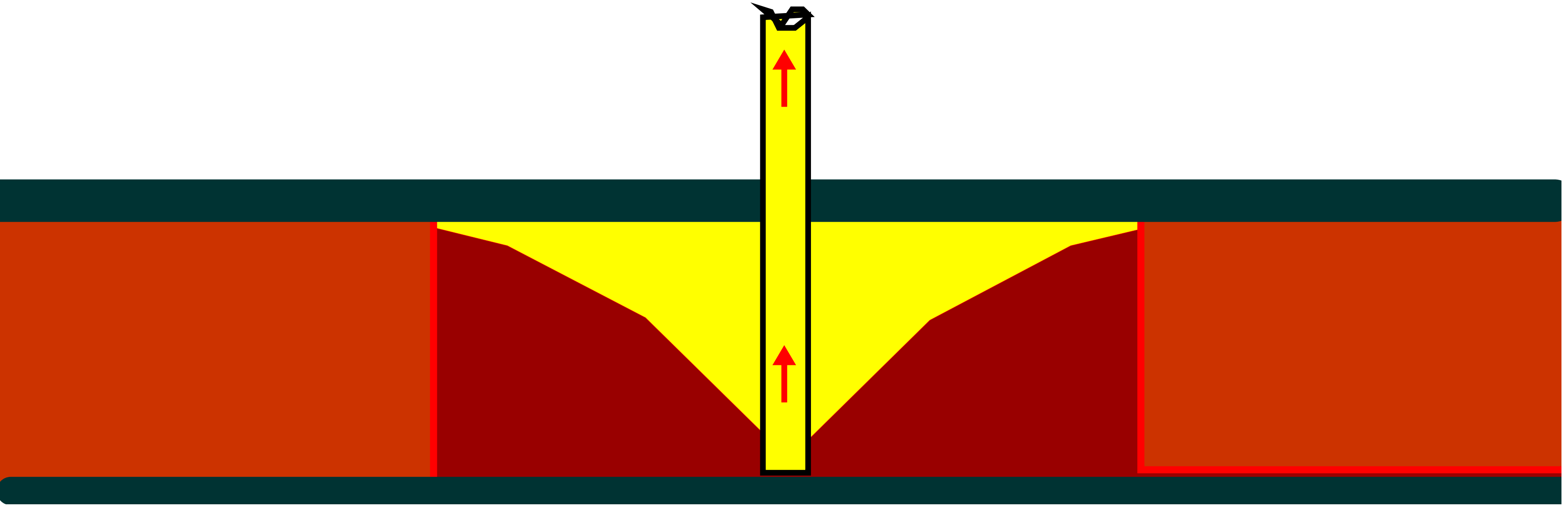

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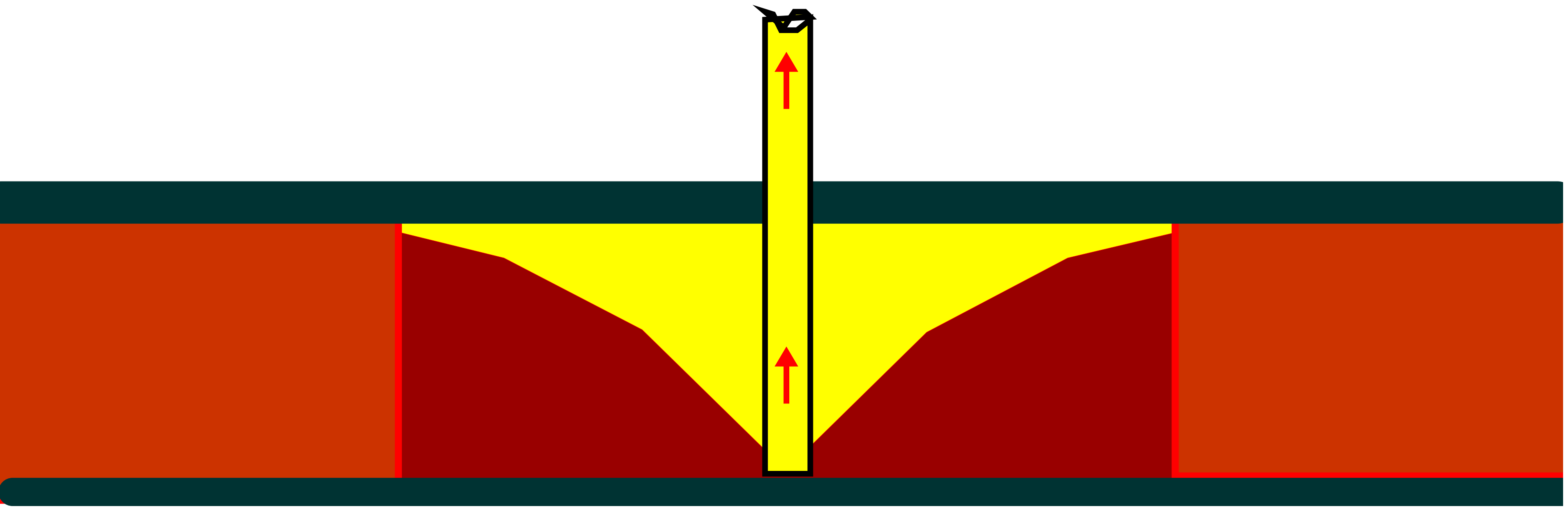

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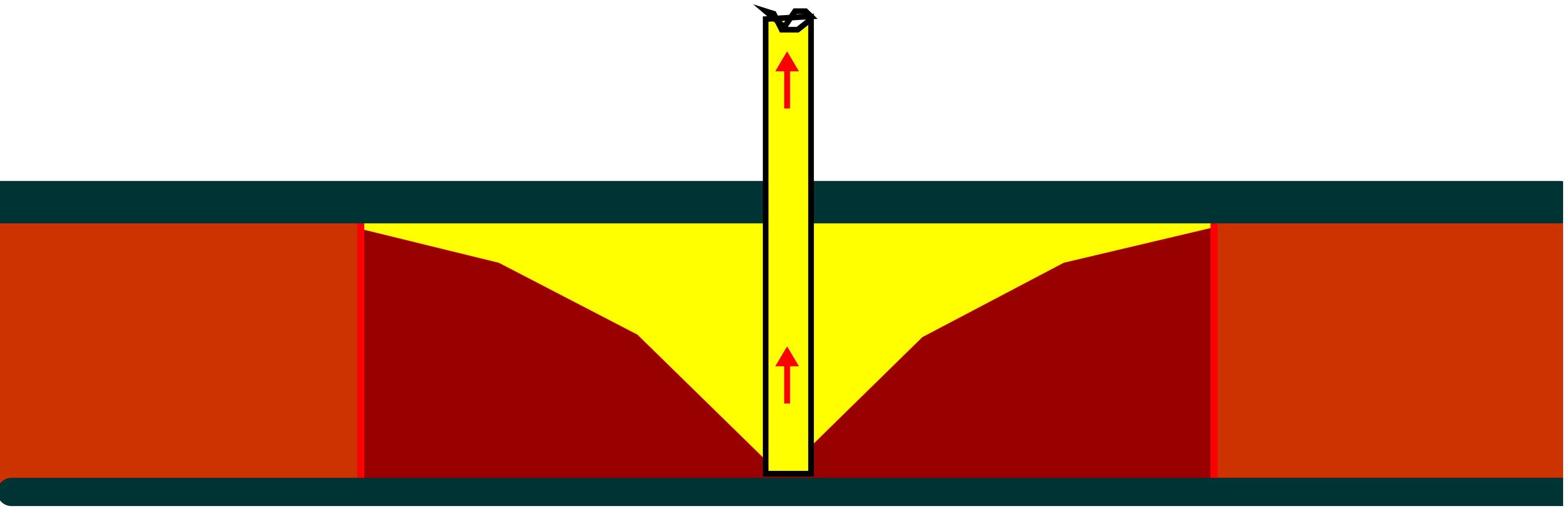


WHAT'S THE DIFFERENCE BETWEEN THESE TWO SOLUTIONS?

Solution to Diffusivity Equation

- Classic (Exponential Integral) Infinite Acting

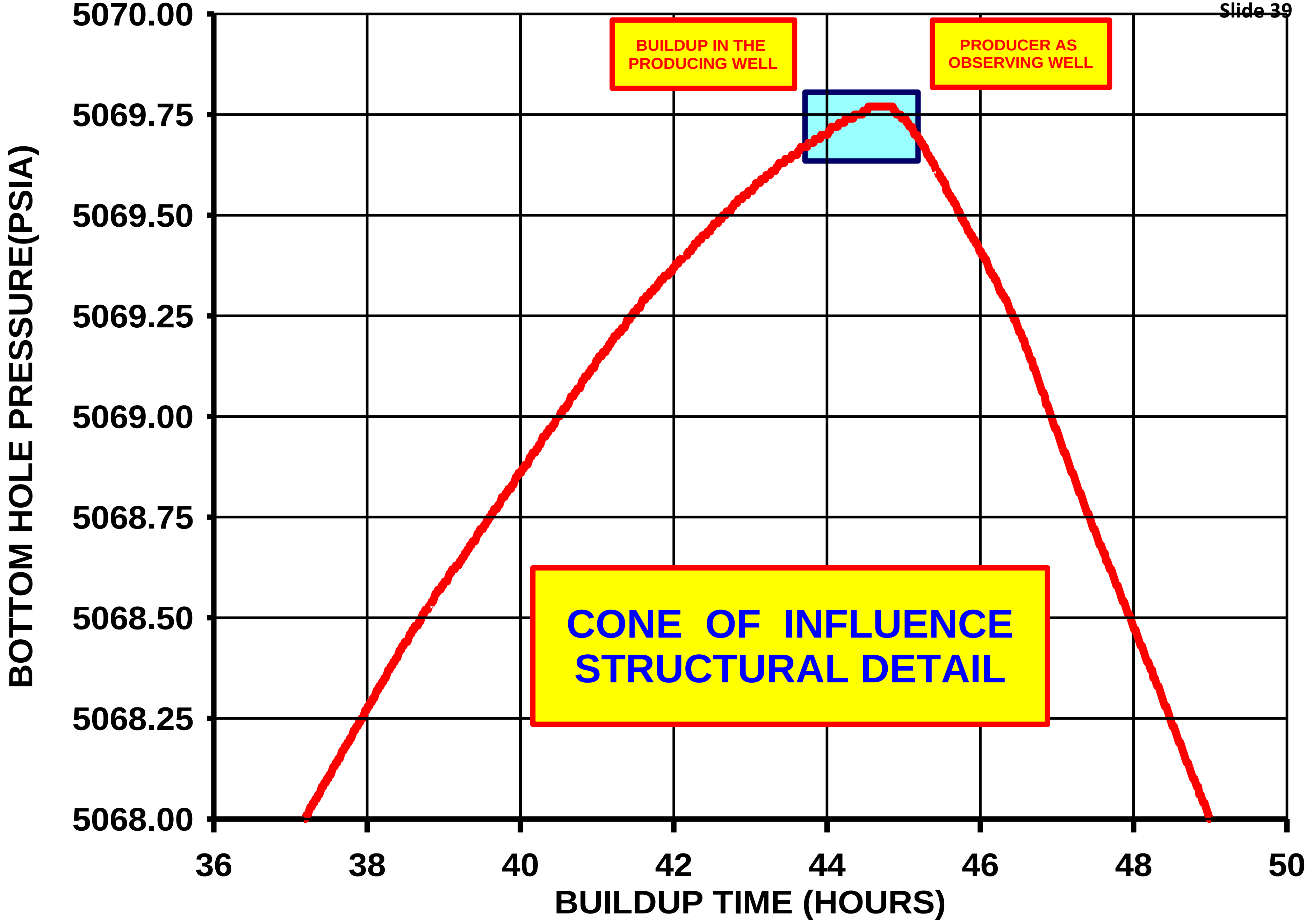
$$P(r,t) = P_i - \frac{q\mu B}{4\pi kh} * \ln \frac{4kt}{\gamma\mu\phi c_t r^2}$$

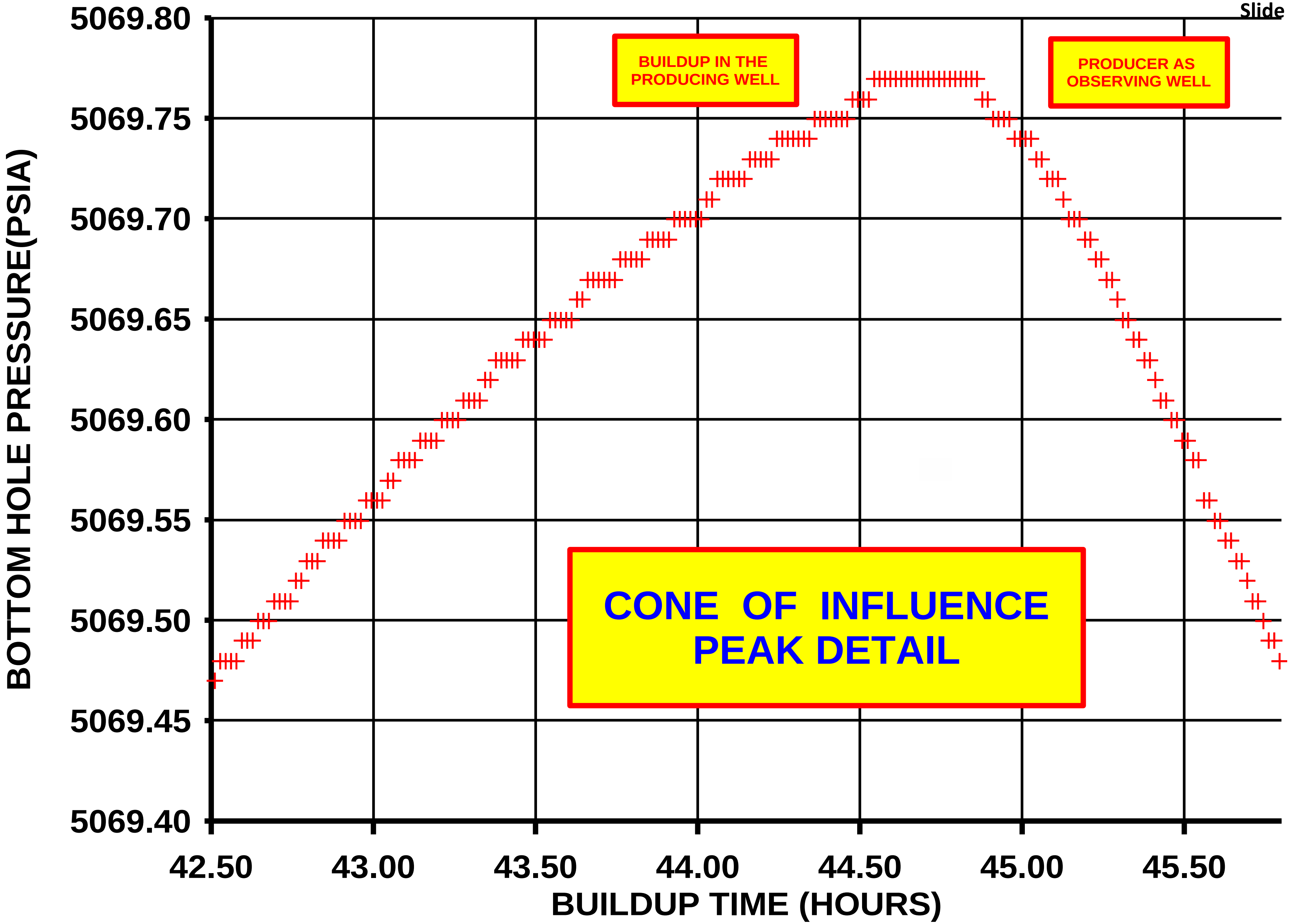
- Shock Front “Infinite Acting” Model

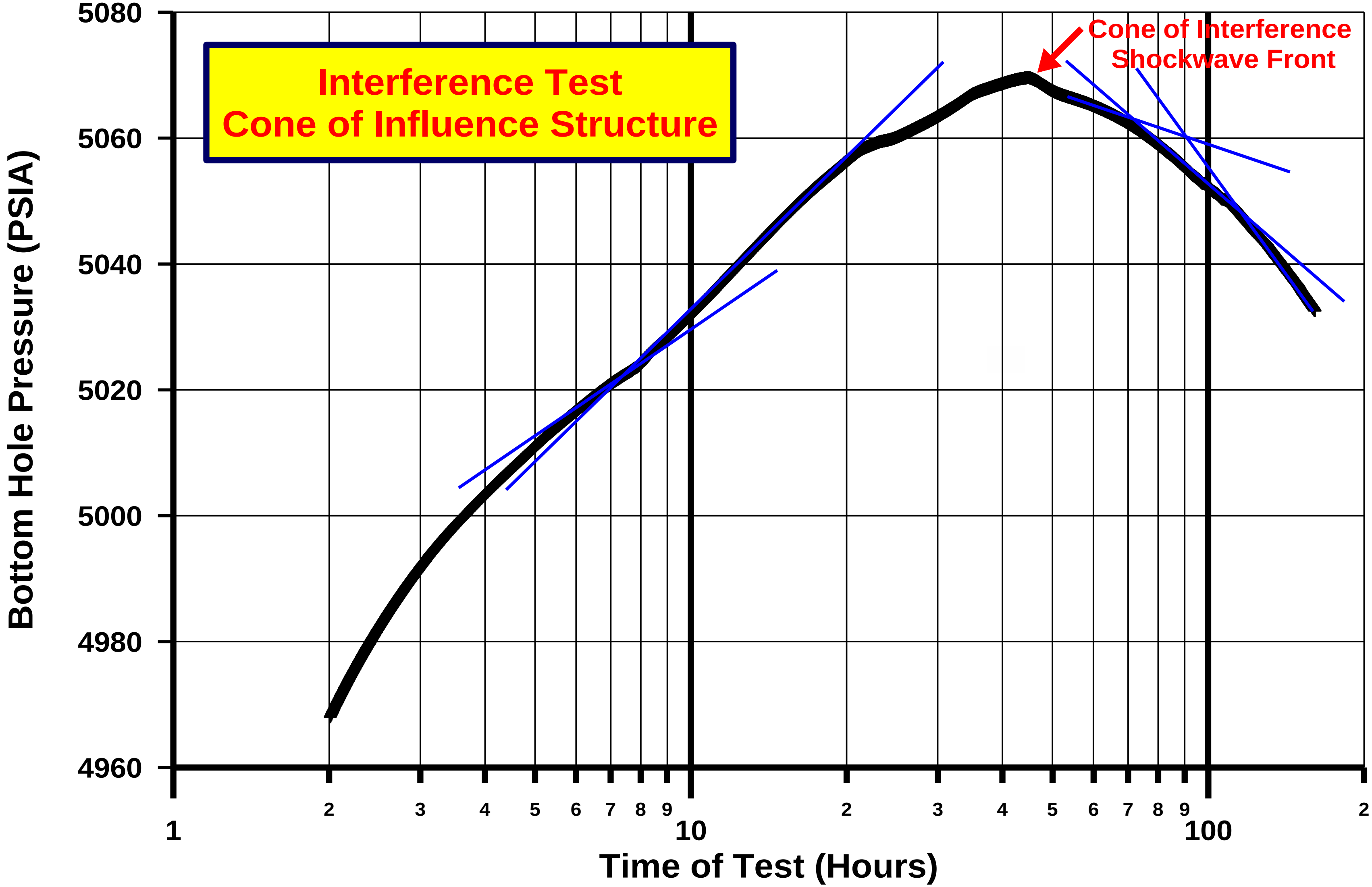
Same as above if $r < r_i$

$P(r, t) = P_i$ if $r > r_i$

WHAT DOES INTERFERENCE LOOK LIKE AT THE OBSERVATION WELL?


BUILDUP IN THE PRODUCING WELL
PRODUCER AS OBSERVING WELL
CONE OF INFLUENCE STRUCTURAL DETAIL
BOTTOM HOLE PRESSURE(PSIA)
5070.00
5069.75
5069.50
5069.25
5069.00
5068.75
5068.50
5068.25
5068.00
36
38
40
42
44
46
48
50
BUILDUP TIME (HOURS)


5069.80
5069.75
5069.70
5069.65
5069.60
5069.55
5069.50
5069.45
5069.40
BOTTOM HOLE PRESSURE(PSIA)
42.50
43.00
43.50
44.00
44.50
45.00
45.50
BUILDUP TIME (HOURS)
BUILDUP IN THE PRODUCING WELL
PRODUCER AS OBSERVING WELL
CONE OF INFLUENCE PEAK DETAIL


Interference Test
Cone of Influence Structure
Cone of Interference
Shockwave Front
Bottom Hole Pressure (PSIA)
5080
5060
5040
5020
5000
4980
4960
1
2
3
4
5
6
7
8
9
10
2
3
4
5
6
7
8
9
100
2
Time of Test (Hours)

Two Methods to Calculate Time to Observe Interference

- **Exponential Integral Method:**

$$t = \exp\left[\frac{4\pi h * \Delta P}{q\mu B}\right] * \frac{r^2 \mu \phi c_t}{2.25\ k}$$

ΔP is effective gauge resolution

- **Radius of Investigation**:

$$r_i = 2(\eta t)^{1/2}$$

$$t = r_i^2/(4\eta)$$

Where $\eta = 2.637 \times 10^{-4}\ k/(\phi \mu c_t)$ in Oilfield Units

Dimensionless Method for Time – Ex(i)

1. $\Delta P_D = \frac{Gauge\ Resolution * kh}{141.2\ q\mu B}$
2. $t_D/r_D^2 = \frac{2.637x10^{-4}\ kt}{\phi\mu c_t r_w^2}$
3. $r_D^2 = r^2/r_w^2$

- Determine 1 & 3
- Determine 2 (Exponential Integral Solution)
- Solve for t

Variables that Affect the Results

Exponential Integral Method

- Gauge resolution
- Rate
- FVF (B_x)
- Wellbore Radius
- Permeability
- TVT Thickness
- Viscosity
- Porosity
- Total System Compressibility

Variables that Affect the Results

Radius of Investigation Method

- Permeability
- Viscosity
- Porosity
- Total System Compressibility

Note: Hydraulic Diffusivity, $\eta = k/(\phi\mu C_t)$

Case Study #1 - Parameters

- **Case 1: High Perm Oil Well**
- Distance between wells (r): 1381 feet
- Wellbore Radius (r_w): 0.71 feet
- Permeability from Observation Well: 675 md
- Pay Thickness: 164 feet
- Porosity: 0.093
- Total Compressibility: 10.16 microsips (1.016 x 10-5/psi)
- Gauge Resolution (High-End Dual Quartz): 0.01 psi
- Rate = 900 STB/D
- Formation Volume Factor (Bo) = 1.08 RB/STB
- Viscosity = 2.18 cp
- Hydraulic Diffusivity (h)= 86,400 ft2/hr

Case Study #1 - Predictions

Exponential Integral Method:

a) Resolution = 0.01 psi, t = 0.84 hr

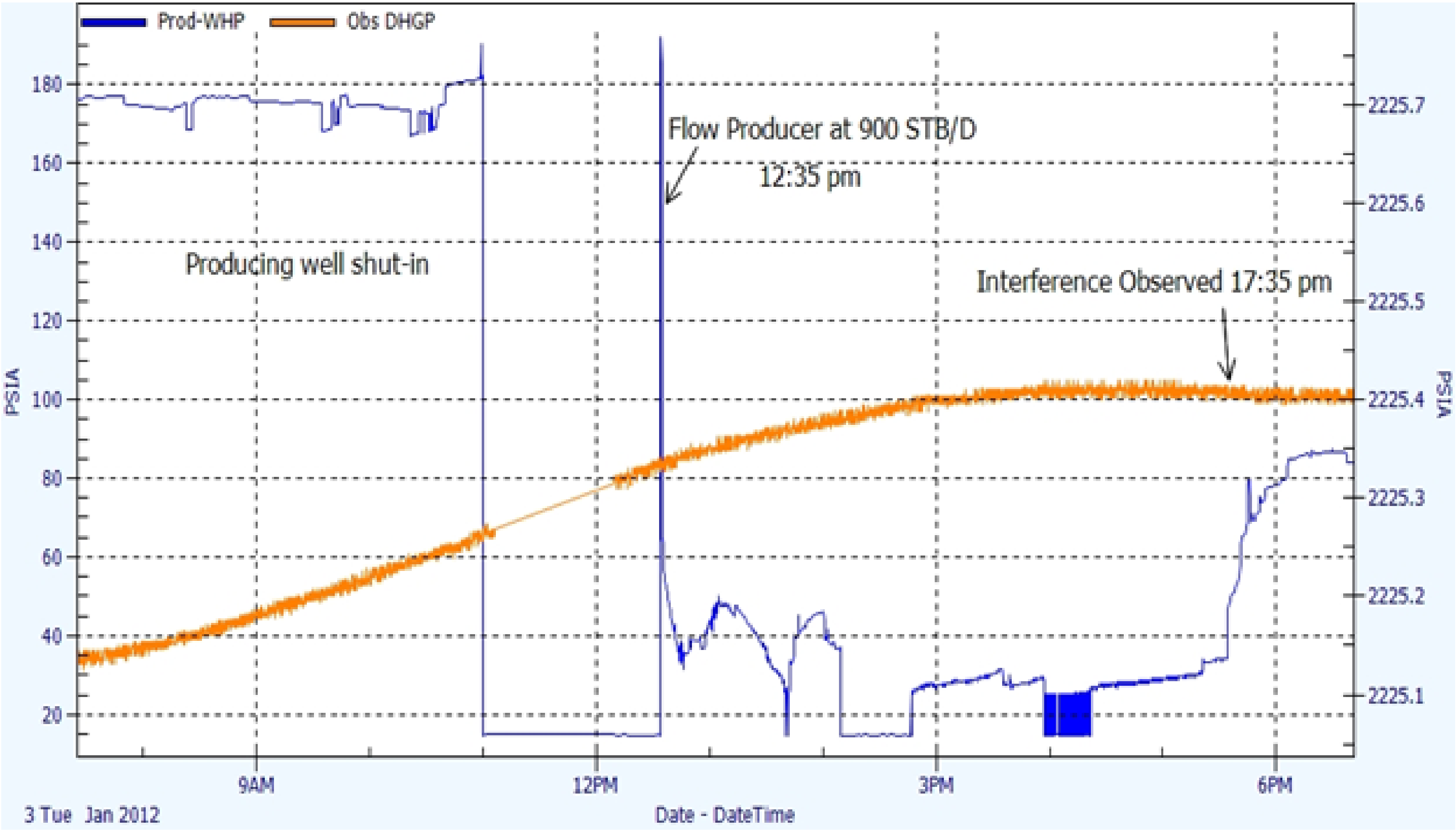
b) Resolution = 0.10 psi, t = 3.1 hr

c) Resolution = 1.00 psi, t = 14.4 hr

Shock Front Method:

t= 5.5 hr

Case Study #1 – Real Data



Case Study #1 - Results

Exponential Integral Method:

a) Resolution = 0.01 psi, t = 0.84 hr

b) Resolution = 0.10 psi, t = 3.1 hr

c) Resolution = 1.00 psi, t = 14.4 hr

Shock Front Method:

t= 5.5 hr

Actual Arrival Time = 5.0 hr

Case Study #2 - Parameters

Case 2: Moderate Perm Gas/Condy Well

- Distance between wells (r): 6623 feet
- Wellbore Radius (r_w): 0.5 feet
- Permeability from Observation Well: 12.2 md
- Pay Thickness: 244 feet
- Porosity: 0.17
- Total Compressibility: 21.46 microsips (2.146 x 10-5/psi)
- Gauge Resolution (High-End Dual Quartz, but with some noise): 0.10 psi
- Rate = 81,000 Mscf/D
- Formation Volume Factor (Bg) = 0.576 RB/Mcf
- Viscosity = 0.075 cp
- Hydraulic Diffusivity (h) = 11,760 ft^2/hr

Case Study #2 - Predictions

Exponential Integral Method:

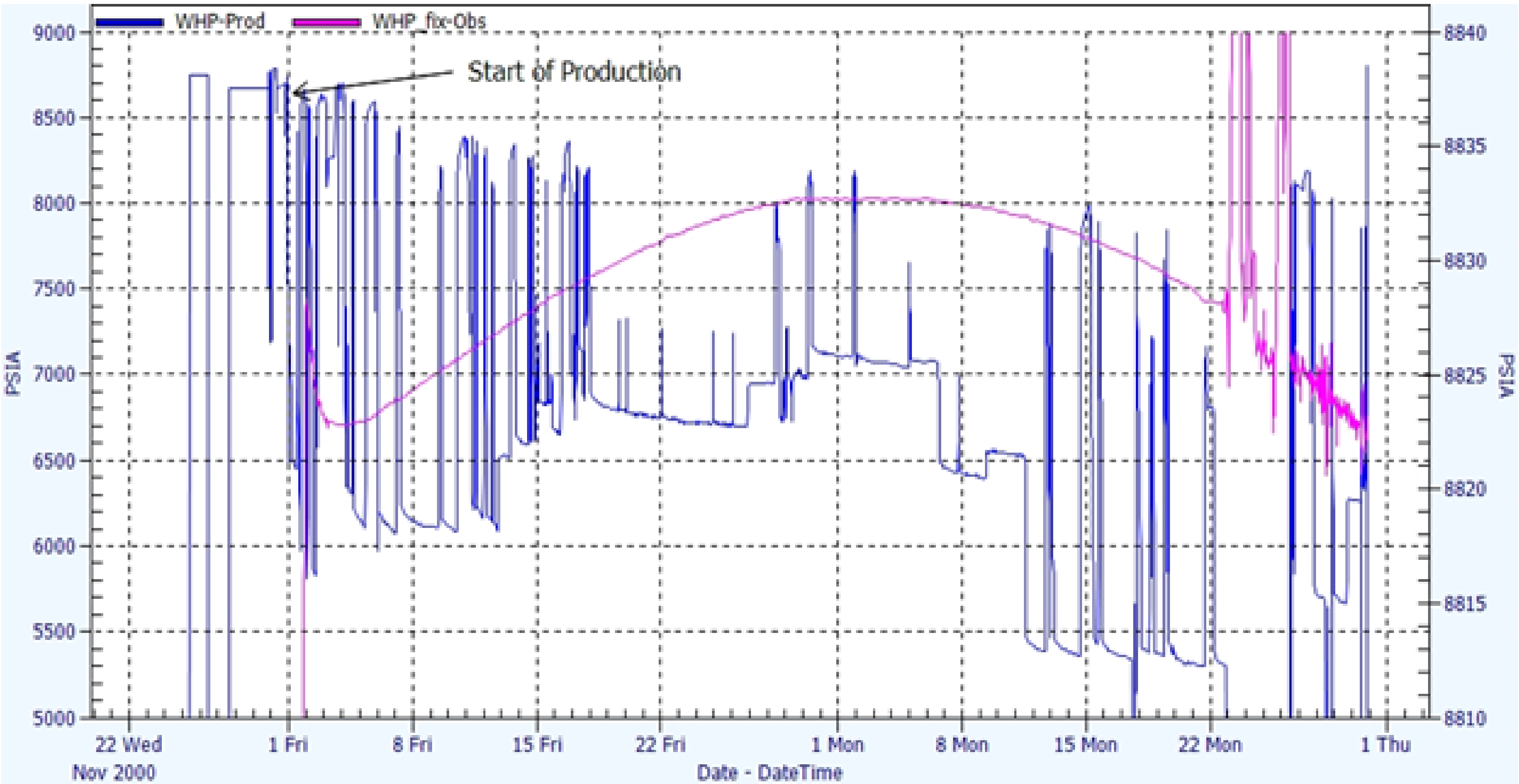
a) Resolution = 0.10 psi, t = 198 hr

b) Resolution = 1.00 psi, t = 314 hr

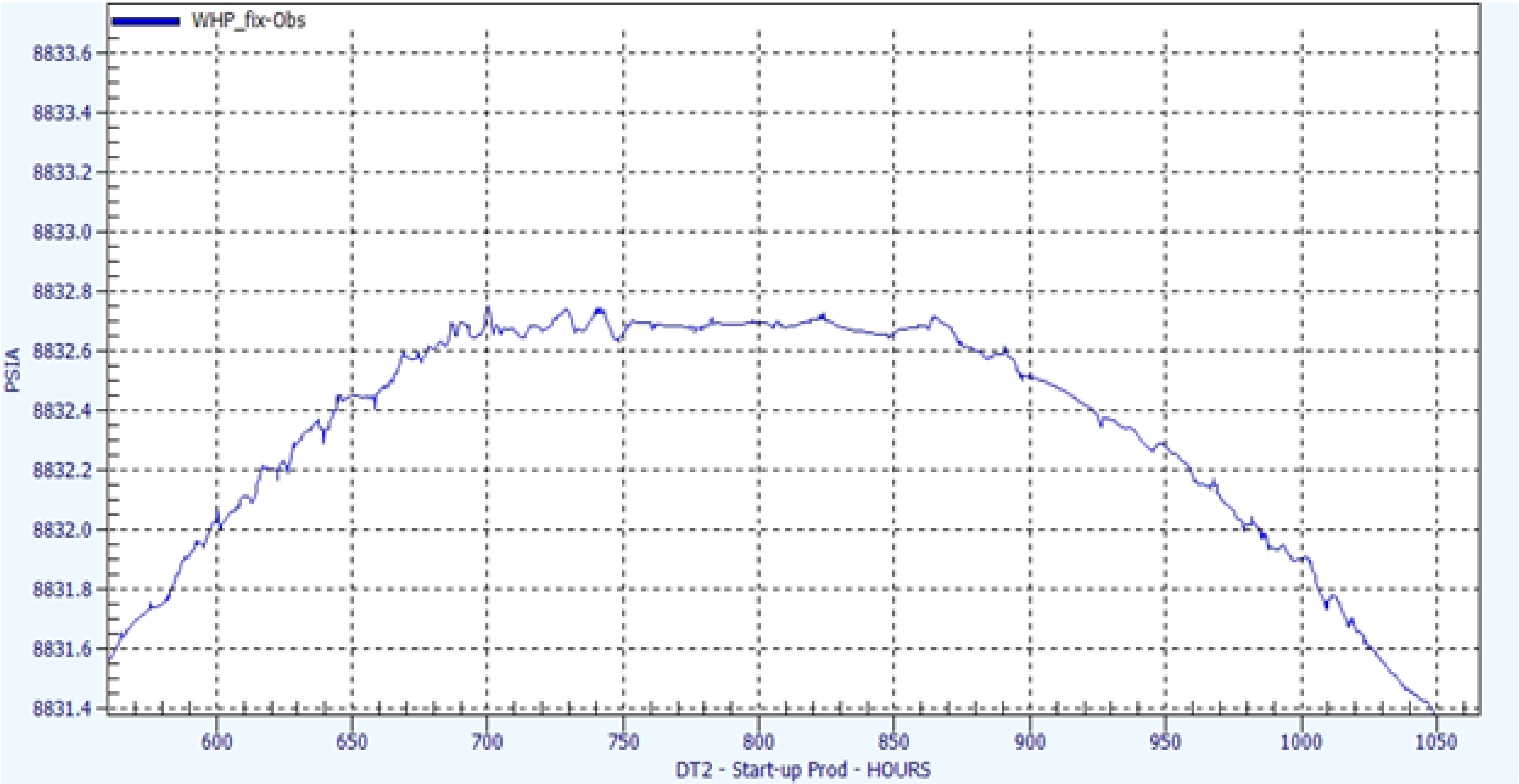
Shock Front Method:

t= 933 hr

Case Study #2 – Real Data



Case Study #2 – Real Data Zoom



Case Study #2 - Results

Exponential Integral Method:

a) Resolution = 0.10 psi, t = 198 hr

b) Resolution = 1.00 psi, t = 314 hr

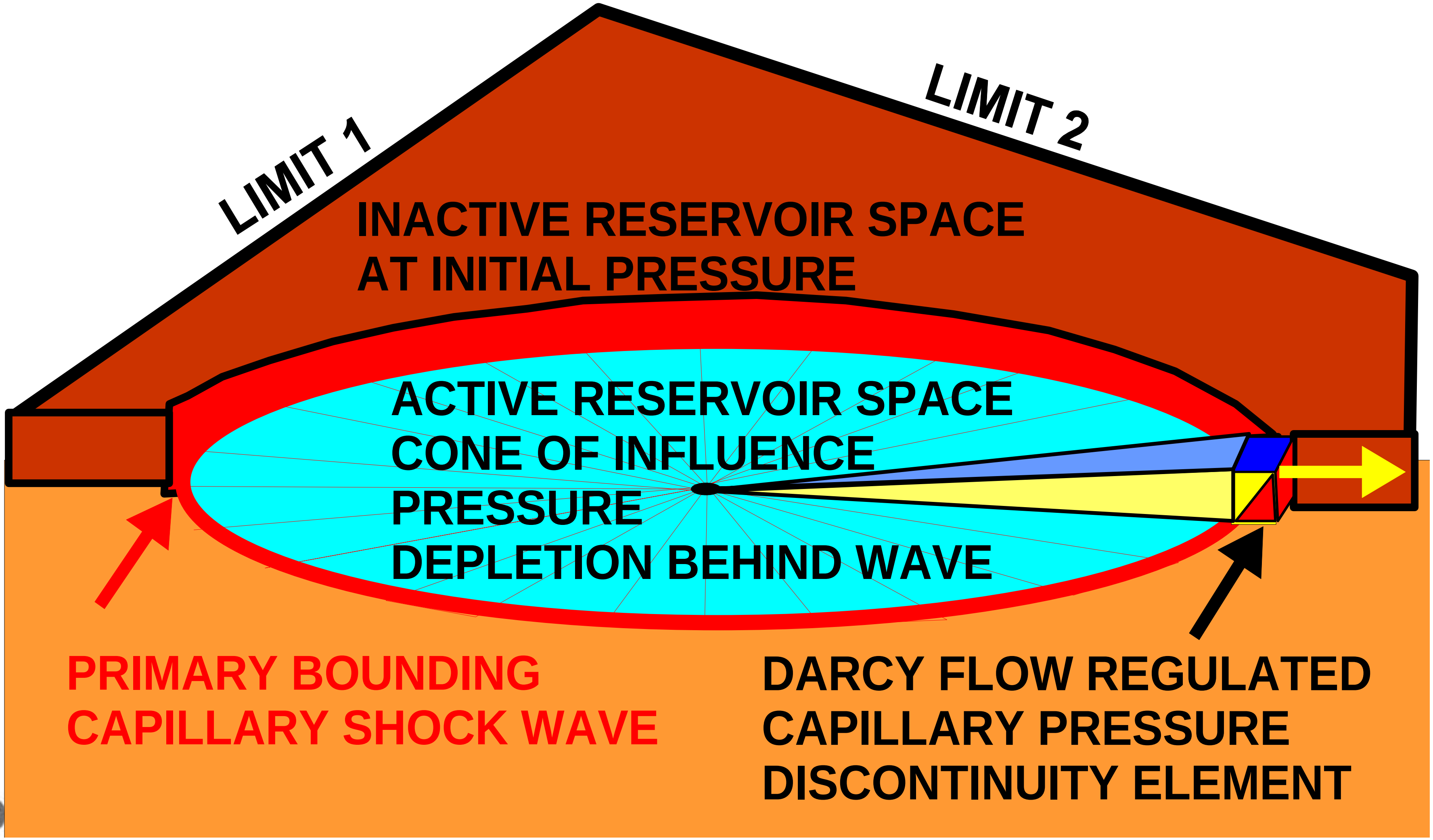
Shock Front Method:

t= 933 hr

Actual Arrival Time: 700-850 hr

AND NOW…
…A LITTLE MATH

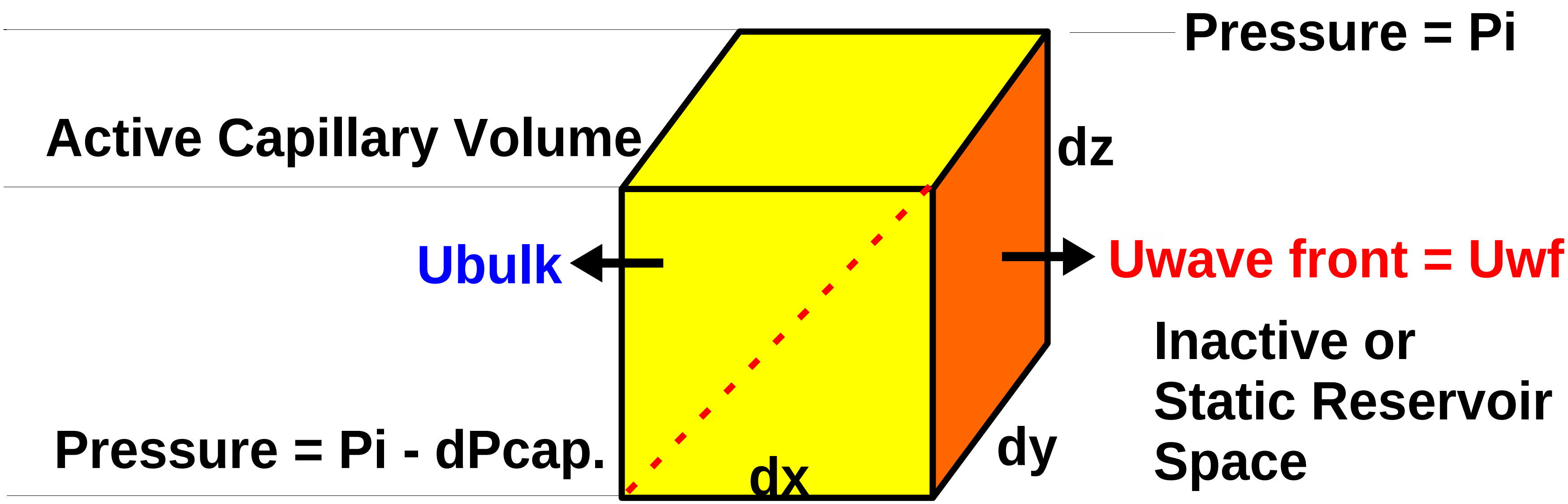
Moving Capillary Shockwave Boundary



Laws and Principles

- **Continuity Principle** is What Flows Into the Element Must Flow Out…Or More Accurately, What the Box Flows Into It Must Flow Out Of or Must Flow Out of Its Own Defined Space
- **Darcy's Law** is the **Steady State Resistance** of Flow Through Porous Media is Related to Bulk Velocity
- **Conservation of Energy** (Elastic) Within the Element Must Be Conserved

The Moving Shock Front Element



Gradient = -dPcap./dx

Ubulk = Fluid Flow into Active Capillary Bundle

Ubulk = ϕ* (Uwf) = q/(dy*dz)

Continuity: Accounting for Fluid Added to the Cone of Influence

The Flow from the Well is the Bulk Fluid Rate. The Flow of Fluid into the System is the Element Volume Times Porosity.

Darcy's Law

$$U_{bulk} = -\left(k/\mu\right) * \left(dP/dx\right)$$

- Bulk Velocity … Not Acutal
- Steady State Resistance to Flow
- Single Phase
- Constant Pressure Head Experiment

The Energy Equation

$$dPc/dV = -1/(Ct*V)$$

OR

$$dPc/dx = -1/(t*Ct*Uwf)$$

Equating Fluid Growth of Cone in Terms of Bulk Fluid Velocity

$$q \,/\, \text{Tube Area} = U_{Bulk} = \phi * U_{Wave\ Front}$$

Fluid Continuity… Darcy's Law………Energy Equation

$$\phi * Uwf = -(k/\mu) * dPc/dx = -(k/\mu)*(-1/(t*Ct*Uwf))$$

Combining Relationships

in Terms of Uwf and Eliminating dPc/dx

$$\phi * Uwf = -(k/\mu) * dPc/dx = -(k/\mu) * (-1/(t * Ct * Uwf))$$

$$Uwf^2 = k/(\phi * \mu * t * Ct)$$

$$Uwf = \sqrt{k/(\phi * \mu * t * Ct)} = \sqrt{\eta / t}$$

<u>Note:</u> The Velocity of the Shock Front is a Function Solely of *Hydraulic Diffusivity* and *Time of Wave Initiation.*

$$Uwf = \sqrt{\eta It}$$

Capillary Path Length Traveled by the Shock Wave Element

$$\text{Line Integral Path Length} = \oint_0^t \text{Uwf}\, dt$$

$$L = \oint_0^t \text{Uwf}\, dt = \oint_0^t \sqrt{\eta / t}\, dt = 2\sqrt{\eta\, t}$$

Conclusions: Predicting Arrival Time

$$t = \frac{r_i^{\,2}}{4\eta}$$

In Oilfield Units:

$$t = \frac{r_i^{\,2}}{4} * \frac{\mu\phi c_t}{2.637x10^{-4} * k}$$

Conclusions: Which Variables Matter?

- **Hydraulic Diffusivity**
  - –Perm
  - –Porosity
  - –Viscosity
  - –Total System Compressibility

Conclusions: Which Variables **Don't** Matter?

- Gauge resolution
- Rate
- FVF (B_x)
- Wellbore Radius
- TVT Thickness

Conclusions

- Exponential Integral Solution works very well during IARF…AT THE PRODUCING WELL
- With Modern Gauges, Predictions of Interference Observation time using the Ei(x) Solution usually UNDERESTIMATE actual arrival time
- Radius of Investigation/Shock Front Solution is much more accurate method to predict Observation time (more accurate the more homogeneous the reservoir)
- The arrival of the interference effect is an event, not a mathematical construction

Acknowledgements / Thank You / Questions

The authors would like to thank Stacy Newman for his review and editing of the material presented in this paper, as well as the anonymous contributing operators for allowing us to use their data.