“Diversion Design Guidelines and the Application of Advanced Diagnostic Tools for Field Evaluation”

Jointly presented by

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Kyle Haustveit, Devon Energy (SPE 184862)

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Poll Question

What is your primary discipline?

Poll Question

How many total years of experience do you have in the oil and gas industry?

Poll Question

How many years of experience do you have in the specific discipline of well stimulation?

Poll Question

What geographic region are you from?

Poll Question

Who is your employer?

Mary Van Domelen is an Engineering Advisor for the Northern Completions Team at Continental Resources.

She is a licensed Professional Engineer, a SPE Certified Petroleum Engineer, and has 35 years' experience in research and practical application of well completions.

Mary is a graduate of the University of Oklahoma with a bachelor's degree in Chemical Engineering who is actively involved in SPE via OKC Chapter Board Membership and participation in numerous committees for conferences, applied technology workshops, and forums.

She served as 2015-2016 SPE Distinguished Lecturer and was the recipient of the 2016 SPE Mid-Continent North America Regional Completions Optimization and Technology Award

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Engineering Advisor
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Kyle Haustveit is a completions engineer working in the completions technology group at Devon Energy, focused on completions design, modeling and diagnostics in the STACK.

He is a graduate from Montana Tech with a bachelor's degree in Petroleum Engineering.

Kyle currently serves on the Industry Advisory Board for Montana Tech and leads the SPE Future Trailblazers Program for OU and Montana Tech.

SPE 185120
A Practical Guide to Modern Diversion Technology

Mary S. Van Domelen
Continental Resources

Presentation Format

- Define the challenge
- Traditional approaches
- What is modern diversion
- Diverter design guidelines
- Conclusions

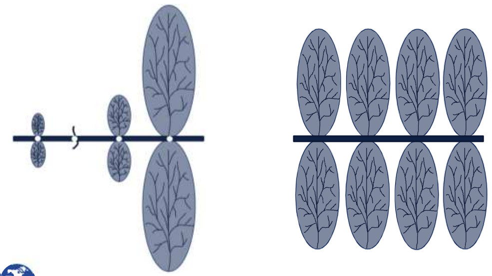
The Challenge

Optimize production from a horizontal well

- Success of a stimulation treatment often depends on complete coverage of all zones
- To accomplish complete coverage, some placement aid may be used to divert the treating fluid from one zone to another
- This is called “diversion”

What are we trying to accomplish with diversion?

Without diversion | Successful diversion



The most appropriate diversion method depends on:

Completion parameters

- Horizontal or vertical
- Zonal isolation method
- Perforation pattern
- Stimulation technique
- Well spacing

Reservoir characteristics

- Mineralogy
- Variations in permeability
- Stress contrasts along interval
- Temperature and pressure
- Reservoir fluids

Three broad approaches to achieving diversion

Mechanical

- Packers and Bridge Plugs
- Perforation Wash Tools
- Sliding Sleeves

Particulate diverting agents

Fluids and slurries follow the path of least resistance

- Matrix acidizing: fluids enter the zone of highest permeability
- Hydraulic fracturing: fractures propagate in zones of lowest stress

The particulates are deposited:

- Creating a low permeability filter cake resulting in:
  - → Additional pressure drop across the filter cake causing
    - → Increased flow resistance and
      - → Diversion of flow to other parts of the interval

Traditional particulate diverting agents

Should have low solubility in the treatment fluids and readily **dissolve** in the formation fluids, examples include:

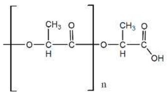
Type	Melting Point (ºF)	Solubility in Kerosene (lbs/bbl)	Solubility in Fresh Water (lbs/bbl)	Solubility in Saturated Salt Water (lbs/bbl)
Rock salt	1,472º	Nil	112	Nil
Benzoic acid	253º	6	0.75	0.25
Naphthalene	176º	42	Nil	Nil
Wax Beads	140 – 200º	70	Nil	Nil
Oil soluble resin	280º	Highly	Nil	Nil

Modern diverting agents

Degrade rather than dissolve; removal does not require fluid contact

Most common material is polylactic acid (PLA)

- Degrades via hydrolysis
- Rate is strongly influenced by temperature
- Certain fluids will catalyze the hydrolysis rate
- Degradation product is lactic acid

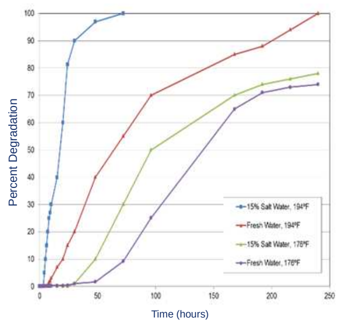


Diverter design guidelines

1. Choose the most appropriate base material
2. Determine the correct particle size distribution
3. Determine the amount of diverter required
4. Monitor the injection well
5. Monitor the offset wells

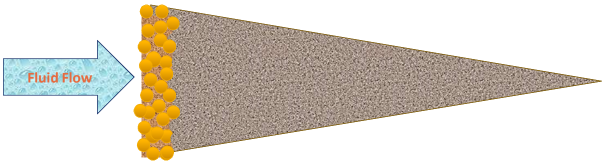
Step 1
Choose the appropriate base material

Understand the effect of temperature and fluid



Step 2
Determine correct size distribution

- Coarse particles ***bridge*** on proppant pack or an open fracture
- Medium particles ***pack*** inside larger particles
- Fine particles ***seal*** the pore throats



Commercially available PLA diverting agents

Example of bimodal PLA diverting agents

To calculate correct particle size distribution:

"Invert" established gravel pack rules

- A broad particle size distribution is required
- Use Saucier's rule (1974) to determine the lower limit for the larger ***"bridging"*** particulates
- Use Abrams' rule (1977) to determine the upper limit for the smaller ***"sealing"*** particulates

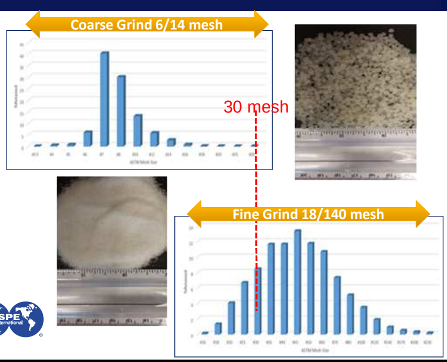
Flow chart to determine particulate size distribution

Coarse
- **BRIDGING PARTICLES (BP)**
- Should have a median diameter (BP_{50}) 6x greater than the median diameter (FS_{50}) of the proppant

Medium
- **PACKING PARTICLES (PP)**
- Should have a median diameter (PP_{50}) 1/5th of the median diameter of the bridging particles (BP_{50})

Fine
- **SEALING PARTICLES (SP)**
- Should have a median diameter (SP_{50}) 1/3rd of the median diameter of the packing particles (PP_{50})

Diverter for 20/40, 30/50, and 40/70 proppant



Step 3
Determine the amount of diverter required

Amount required will vary depending upon where the diversion is to take place:

- On the perforations
- In the perforations
- In an open hole

There are guidelines for traditional diverters

Rules of thumb have not yet been established for PLA diverting agents

Process to determine guidelines for the Williston Basin

- Review relevant SPE papers
- Query pumping service providers
- Data mine FracFocus
- Track diverter requirement for Company's wells

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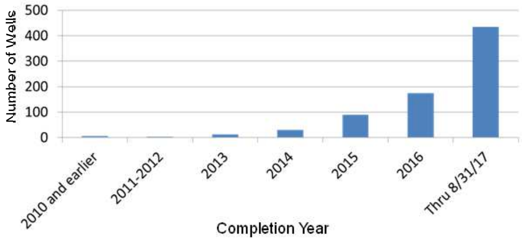
Data mining FracFocus for PLA use in Williston Basin

- Establish search parameters
- Perform mass balance
- Merge with completion parameters
- Calculate the average mass of PLA per stage
- Quality control with a set of known wells
- Analyze the variations based upon
  - Completion method
  - Formation
  - PLA supplier

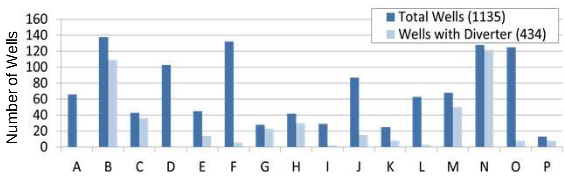
Williston Basin wells identified using PLA diverting agents



PLA diverter application in the Williston Basin

Total Number of Wells with Diverter		**434 (of 1135 wells)**	
Williston Basin Companies Identified		**16**	
Average Completion Parameters			
	Lateral Length	9,623	ft
	Normalized Proppant	833	lb/ft
	Normalized Fluid	19.5	bbl/ft
	Stage Spacing	247	ft
Average Diverter (PLA) per stage – by completion type			
	OH-Swell Packer Completions	144	lbs/stage
	Cemented Laterals	66	lbs/stage
Average Diverter (PLA) per stage – by formation			
	Middle Bakken	107	lbs/stage
	Three Forks	57	lbs/stage

Williston Basin wells with and without diverter *(1/1/16 – 8/31/17)*



Williston Basin trend (lbs/stage)

by formation and completion type (2013-2016 vs 2017)

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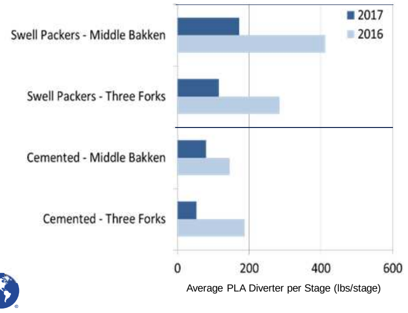

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What is the criteria for successful diversion?

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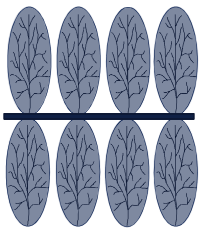
Most common method used to evaluate diversion effectiveness is to monitor the pressure response during pumping

Sophisticated techniques include:

- Microseismic monitoring
- Distributed temperature surveys (DTS)
- Distributed acoustic surveys (DAS)
- Chemical and radioactive tracers
- Flow profiling during flowback



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Step 4
Monitor the injection well

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What are the expected pressure responses?

- Overall increase in bottom hole treating pressures at a constant injection rate
- Instantaneous pumping pressures as the diverter enters the perforations
- Net pressure increase ($\triangle$ISIP) from the beginning to the end of the treatment

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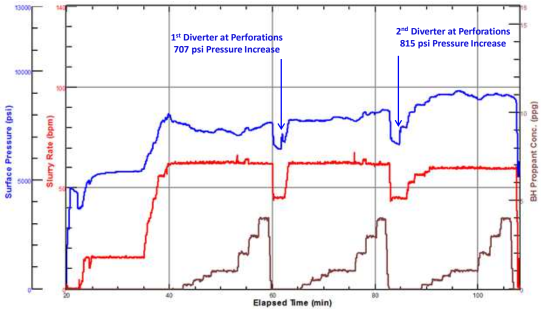
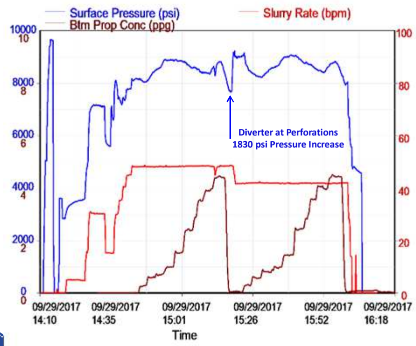
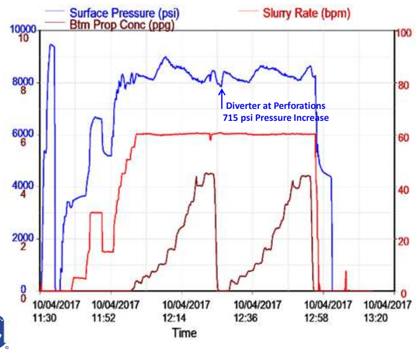
Three-cycle diversion, well #1, stage #37



Dual-cycle diversion, well #2, stage #21

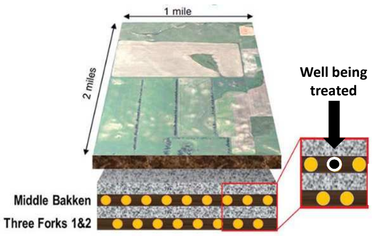


Dual-cycle diversion, well #2, stage #52

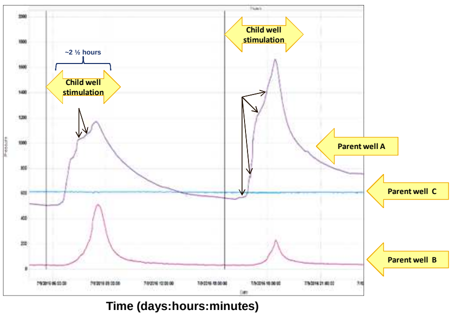


Step 5
Monitor the offset wells

Frac hits, frac bashing, offset well communication can result in ineffective stimulation and by-passed reserves



Offset well monitoring shows response to diverter drops



Conclusions

- Degradation tests should be performed with treatment and reservoir fluids
- Select particulate size distribution based upon proppant size
- Consider historical diverting practices in any area
- The amount of diverting agent required varies based upon
  - a) Zonal isolation method in the lateral
  - b) Formation being treated
  - c) Most important, supplier of material
- Surface pumping pressures are used to evaluate the effectiveness of a diverter, but can sometimes be misleading
- Monitoring offset wells can provide valuable information on the diverter performance

Completions Diagnostics

Diagnostics

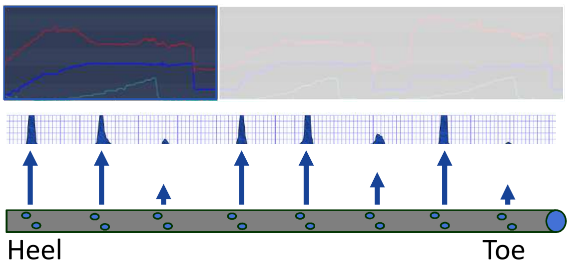
- Tracer
  - Radioactive proppant tracer
- Pressure
  - Surface treating
  - Offset poroelastic responses
- Fiber Optic
  - Intra well
  - Cross-well strain

Why Invest in Diagnostics?

- Cost of Diverter
  - Product
  - Time
  - Operational risk
- Geometry Effects
  - Interference
  - Non-uniform drainage

Proppant Tracer

RA Proppant Tracer



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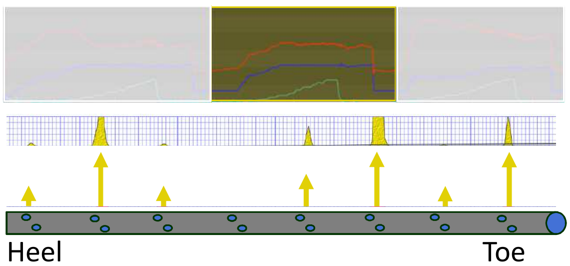
RA Proppant Tracer



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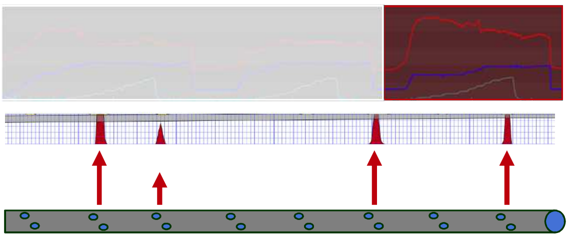

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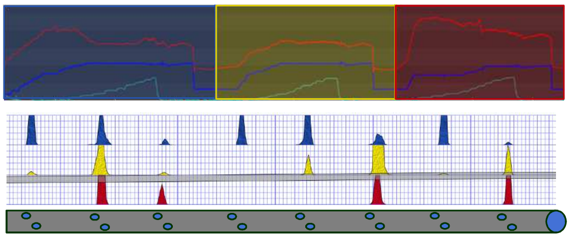
RA Proppant Tracer



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Fiber Optics

Installing Fiber Optic Cable

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- Secured to exterior of casing
- Cemented in place
- Permanent installation
- Oriented perforating
- Monitor subject well
- Monitor offset wells

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What is Fiber Optic Sensing?

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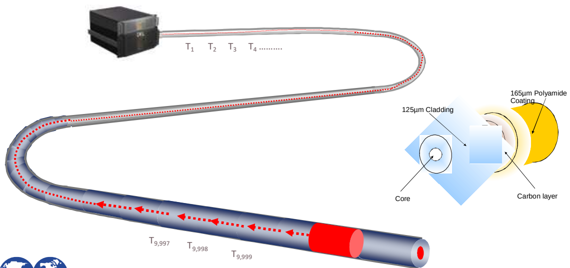
Measurement every 3-ft along the fiber



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Fiber Optic Monitoring

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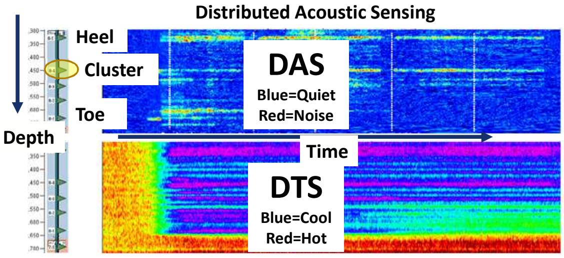
Distributed Acoustic Sensing



Distributed Temperature Sensing

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Fiber Optic Monitoring

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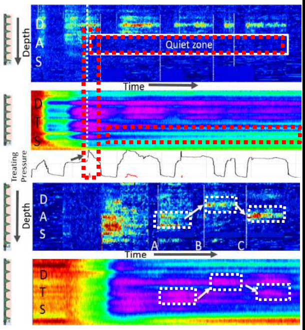
- Unintended diversion
- Surface pressure and fiber
- Difficult to reinitiate
- Effective diversion
- Redistributed treatment



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Cross Well Strain

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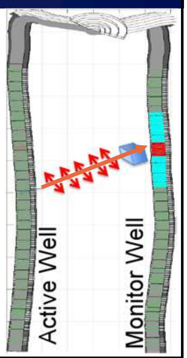
- Pressure change in fracture
- Stress change deforms rock
- Low frequency DAS measures strain
- Measures temperature effects



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Cross Well Strain

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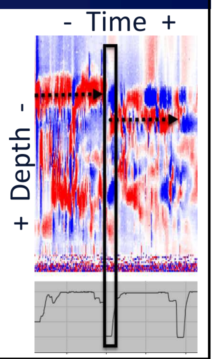
- Pressure change in fracture
- Stress change deforms rock
- Low frequency DAS measures strain
- Measures temperature effects
- Change in strain location after drop



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Pressure Monitoring

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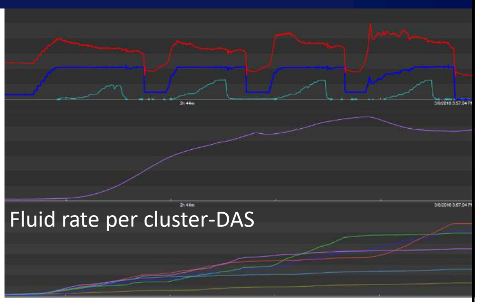
Combination View

Treating Pressure
Treating Rate
Prop Con

Offset Pressure

Cluster 1-Toe
Cluster 2
Cluster 3
Cluster 4
Cluster 5
Cluster 6-Heel



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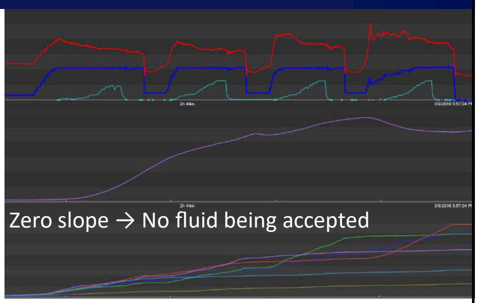
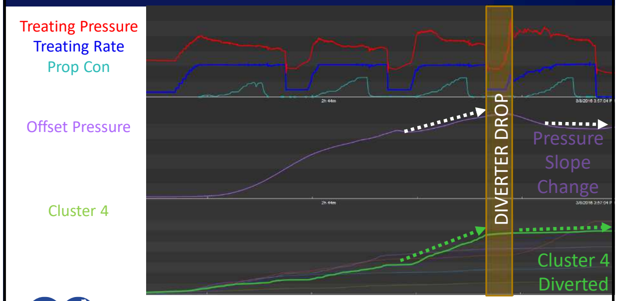
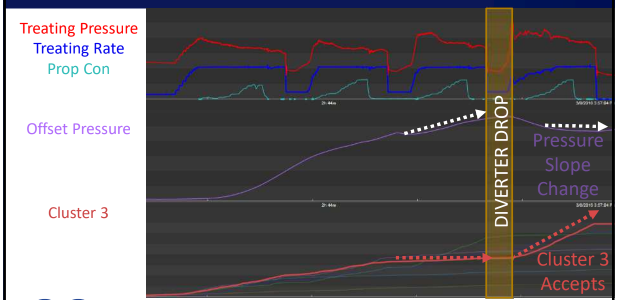


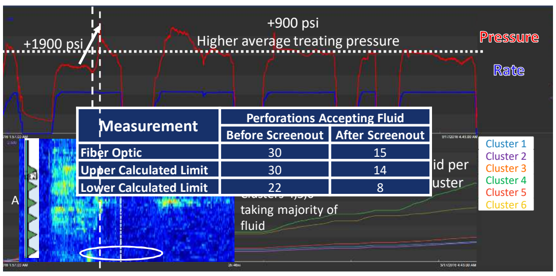
Combination View



Combination View



Surface Treating Pressure



Measurement	Perforations Accepting Fluid	
	Before Screenout	After Screenout
Fiber Optic	30	15
Upper Calculated Limit	30	14
Lower Calculated Limit	22	8

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Summary

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- Multiple diagnostic tools available
- Value in correlating responses
- Variations in response to diverter

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Webinars

Thank you!

Questions?

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