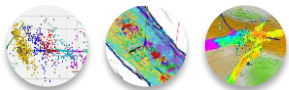


Northeast Natural Energy MIP 3H / 5H

Adrian Morales
Microseismic Services
January 11, 2016

Project ID 2015HOU0098



MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

Quick Bio

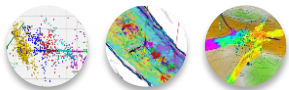
Adrian Morales

amorales24@slb.com

281-285-1298

MSE, PSE, Field Engineer, Process Engineer

M.Sc. Petroleum Engineering



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Outline

Objectives

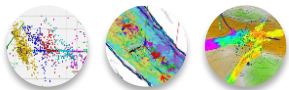
Overview

Completion & Stimulation Summary

Microseismic Interpretation

Well Comparisons

Conclusions



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Objectives

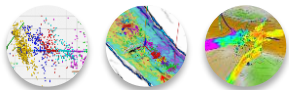
To understand the complexity of the stimulation in the lower Marcellus

Understand frac stimulation complexity and stimulated reservoir volume as well as to understand vertical and horizontal progression of the frac as it advances.

Maintain stimulation within zone, minimize over/under stimulation.

Understand number of stages and stage sizes.

Understand well interaction.

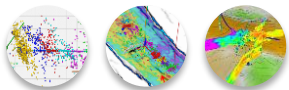


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Executive Summary

- MIP 3H Average Half Length: 784ft, Average Height: 496ft, Average Azimuths N76°E
- MIP 5H Average Half Length: 618ft, Average Height: 540ft, Average Azimuths N63°E
- Similar fracture geometries and pressure responses were observed.
- Normalized production comparison recommended in order to determine the effect of slight fluid and completion alteration



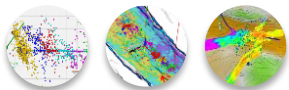
MICROSEISMIC SERVICES
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Executive Summary

MIP 5H displays a higher fracture height growth.

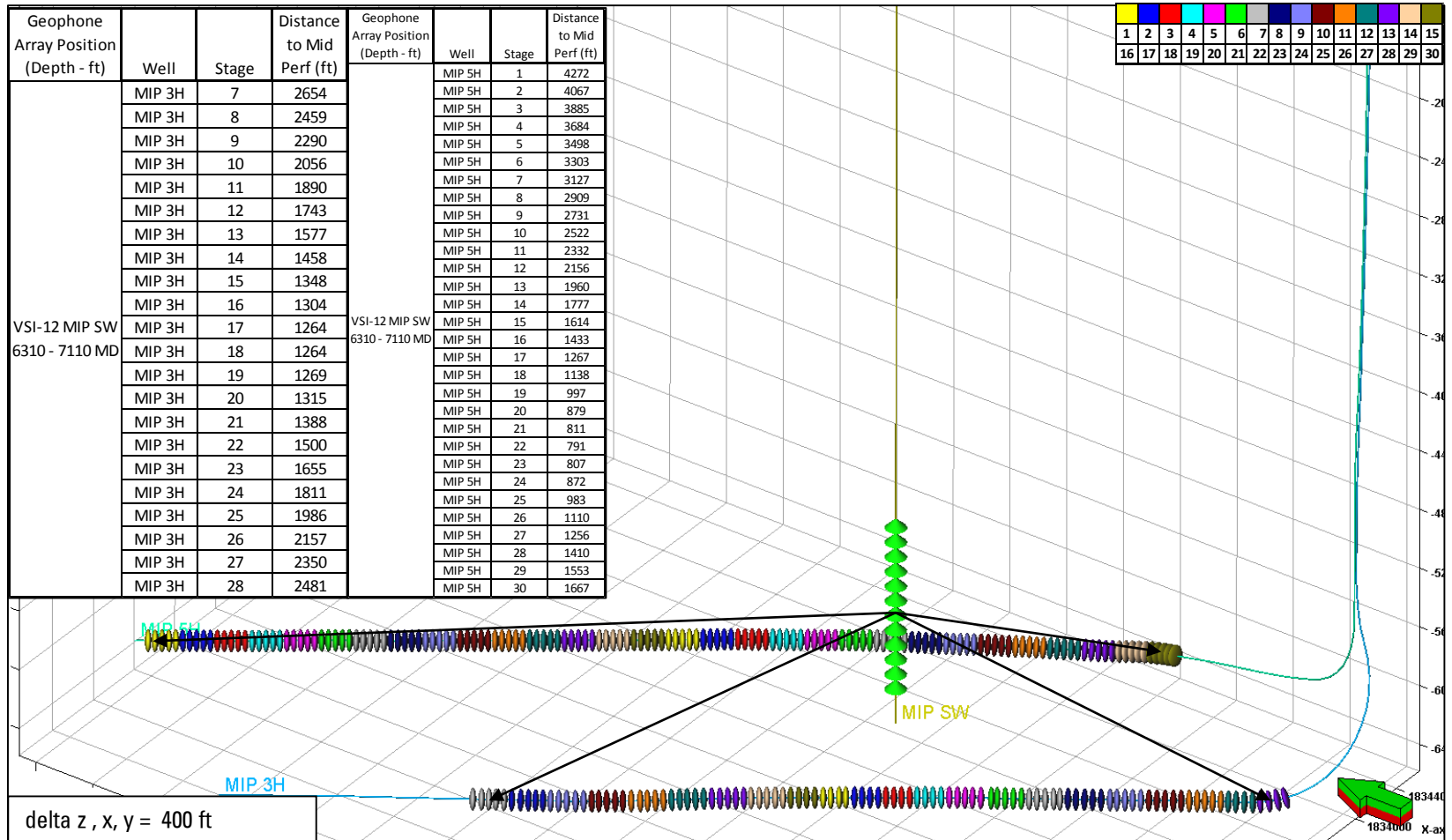
Sapphire VF appears to have more constrained height growth when compared to SW treatments.



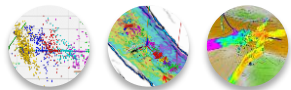
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MIP 3H & 5H Monitoring Configuration



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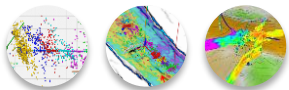
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Completion & Stimulation Summary

	MIP 3H	MIP 5H
Lateral Landing	Upper Marcellus	Upper Marcellus
Lateral Length	~5,800	~6,000
Monitored / Total Stages	22 / 28	30 / 30
Perf Design	Multiple	5 Clusters, 40' Spacing
Fluid & Prop	Multiple	SW, 100-Mesh and 40/70 White

Schlumberger-Private

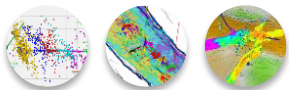


MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

Completion & Stimulation Summary – MIP 3H

- Four pump schedules
- Three shot densities
- Two cluster configurations
- Multiple perforation orientation



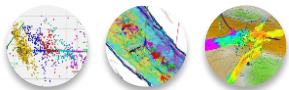
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Completion & Stimulation Summary – MIP 3H

Section		Stage	Pump Schedule
A	NNE Standard 35% 100-Mesh	1 – 6	A – NNE 440K 35% 100-Mesh
B	NNE 75% 100- Mesh	7 – 12	B – NNE 440K 75% 100-Mesh
C	Perforation Design	13 – 14	A – NNE 440K 35% 100-Mesh
		15 – 19	C – NNE 360K 35% 100-Mesh
D	Sapphire VF	20 – 21	D – SLB VF 440K 35% 100-Mesh
E	Best Practices	22 – 23	C – NNE 360K 35% 100-Mesh
		24 – 28	A – NNE 440K 35% 100-Mesh

Schlumberger-Private



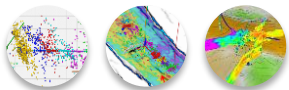
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Completion & Stimulation Summary – MIP 3H

Section		Stage	Pump Schedule	Clusters	Shot Density
A	NNE Standard 35% 100-Mesh	1 – 6	A	5	10
B	NNE 75% 100-Mesh	7 – 12	B	5	10
C	Perforation Design	13 – 14	A	5	6
		15 – 16	C	4	6
		17 – 19	C	4	8
D	Sapphire VF	20 – 21	D	5	10
E	Best Practices	22 – 23	C	4	10
		24 – 28	A	5	8

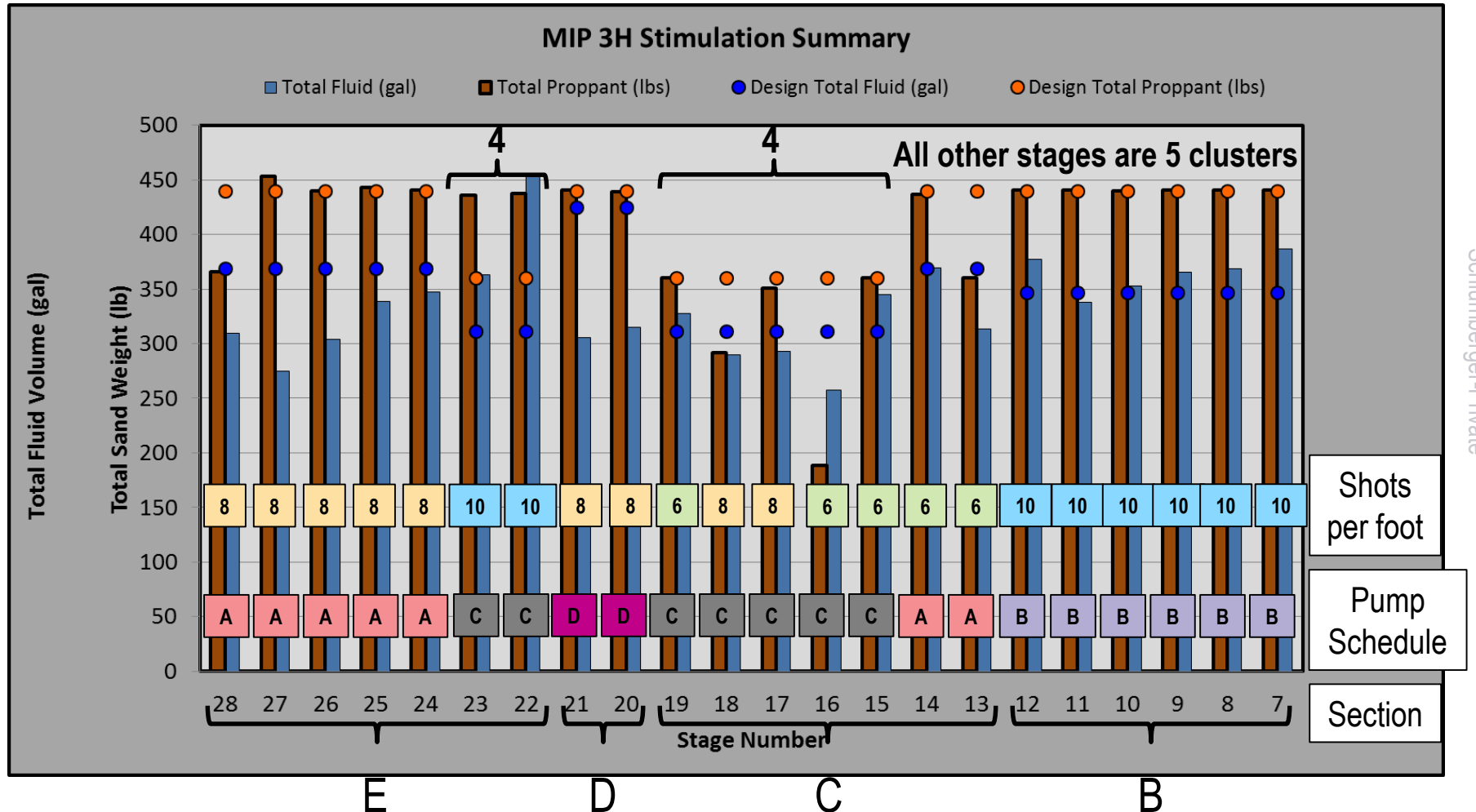
Schlumberger-Private



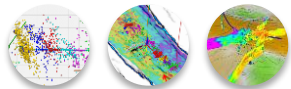
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Completion & Stimulation Summary – MIP 3H



Schlumberger-Private



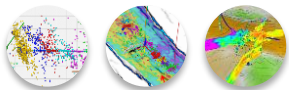
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE



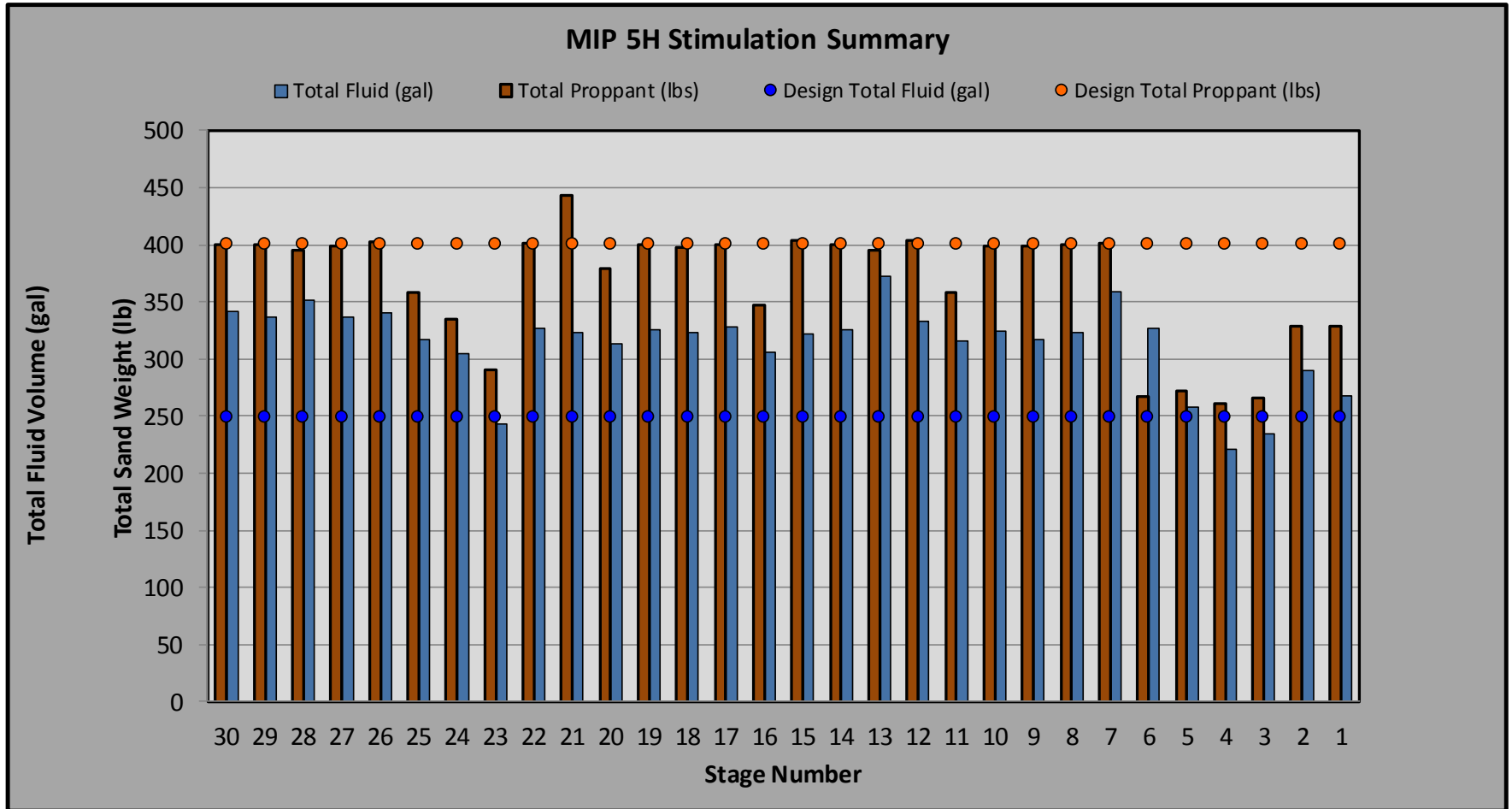
Completion & Stimulation Summary – MIP 5H

Slickwater

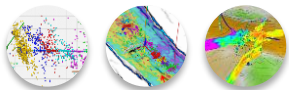
- Smaller Pump Schedule A
- 400,000 lbm, 35% 100-Mesh
- 200 ft Stage
- 5 Clusters, 40 ft spacing
- 8 Shots per Cluster



Completion & Stimulation Summary – MIP 5H



Schlumberger-Private

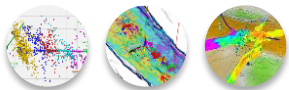
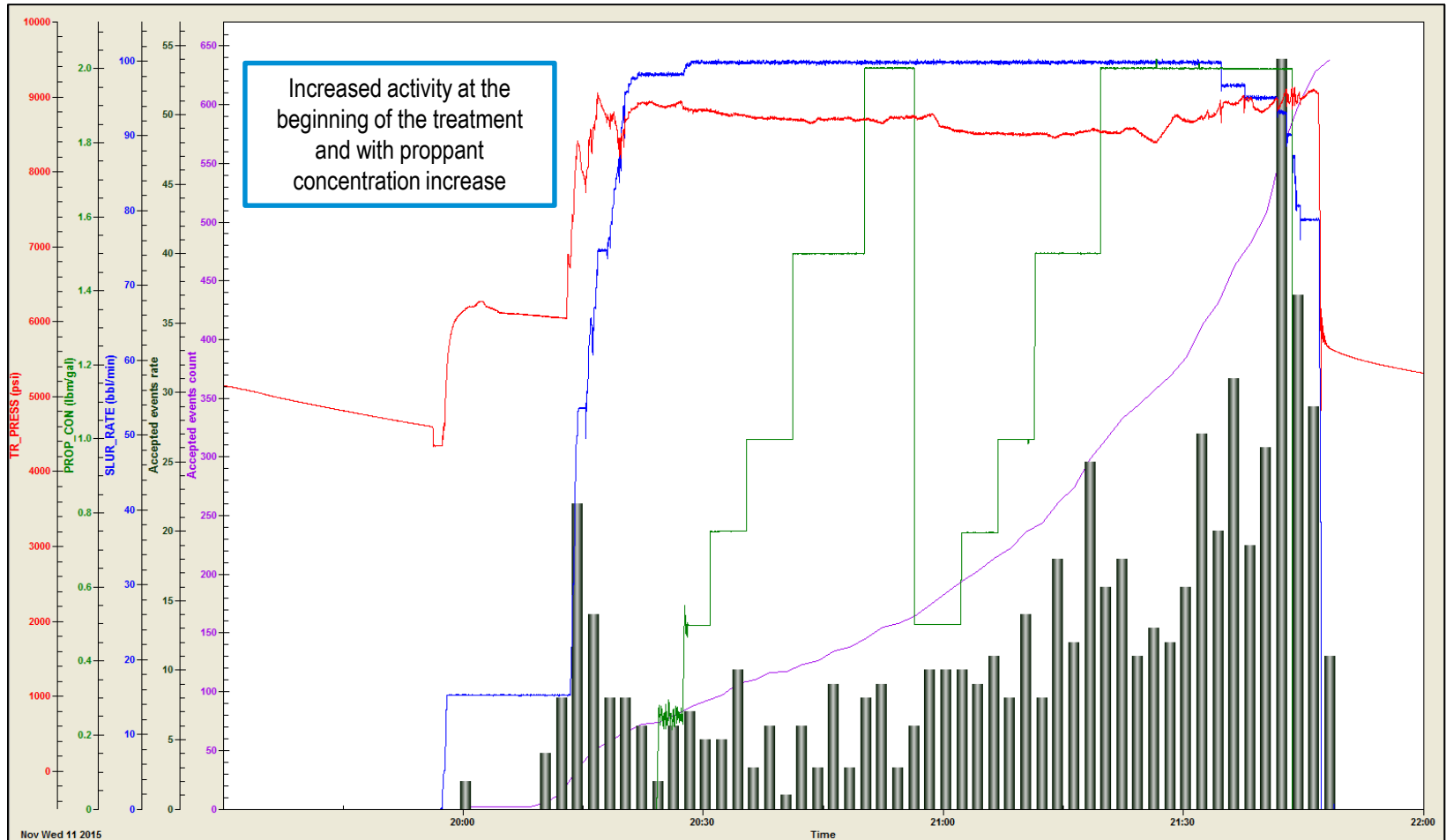


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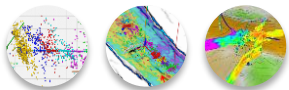
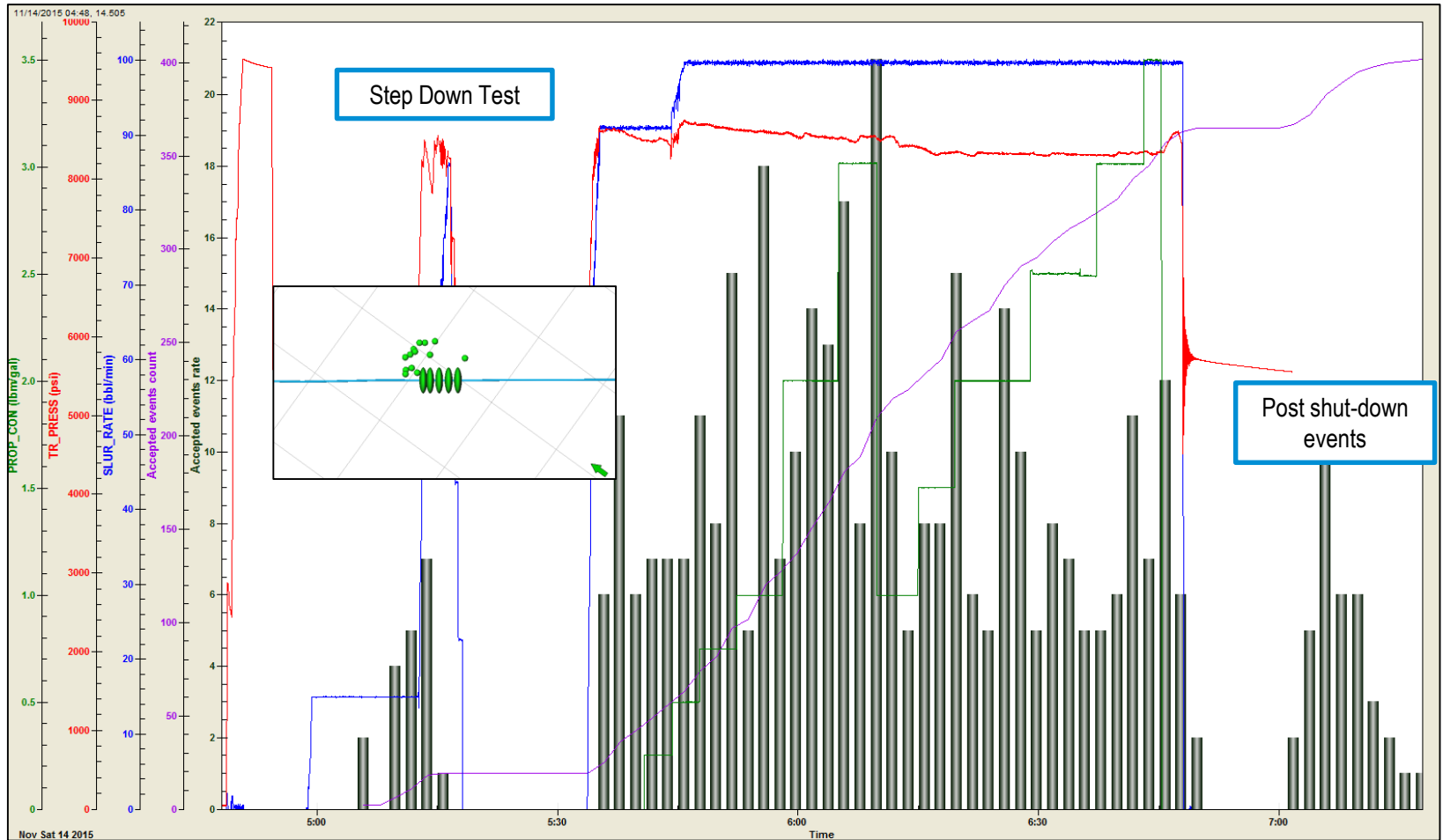


MIP 3H Typical Pump Schedule – Stage 14

Pump Schedule A

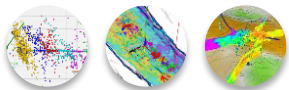
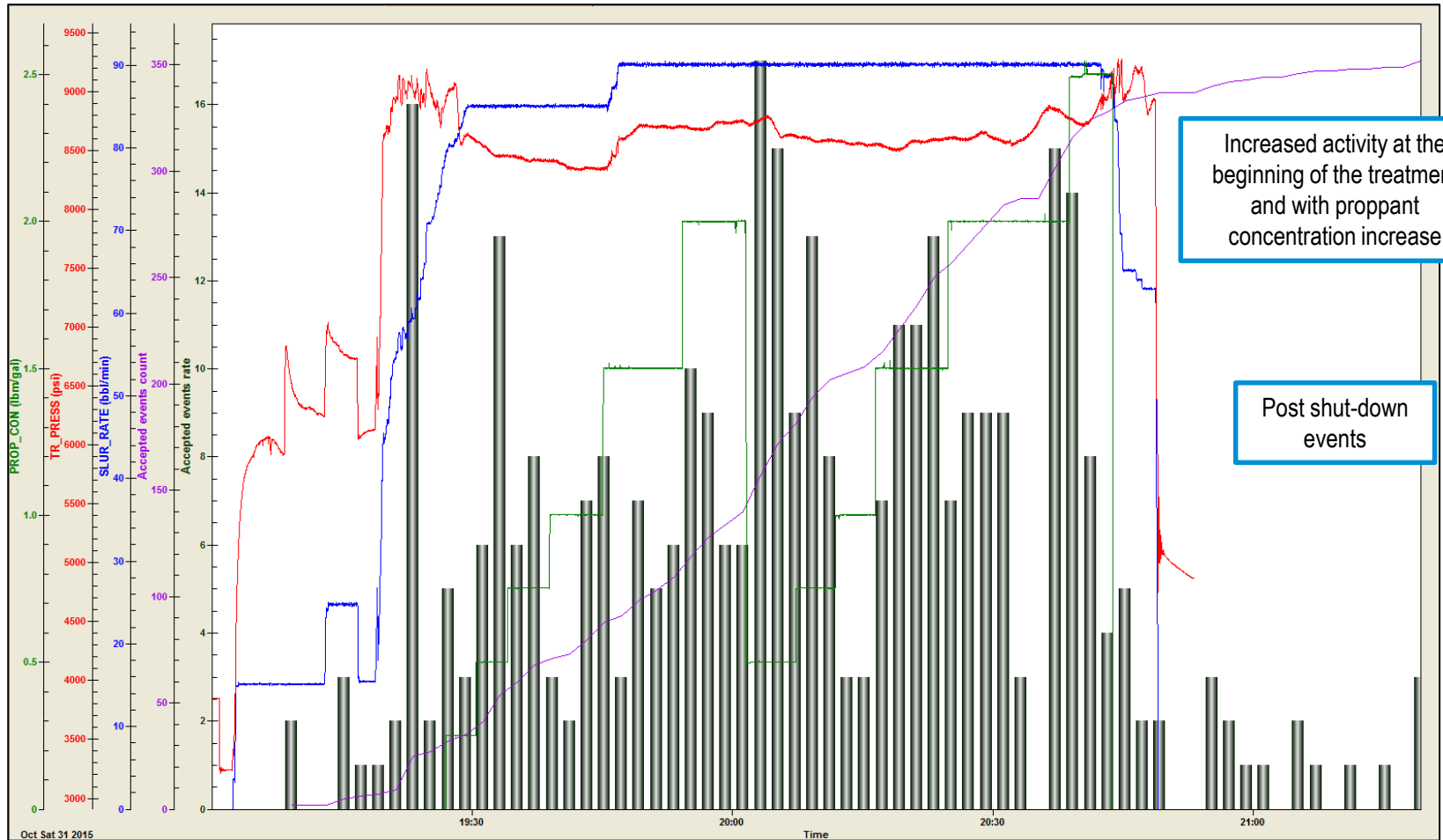


MIP 3H Typical Pump Schedule – Stage 21 Pump Schedule D

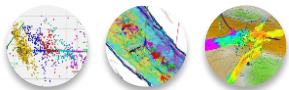
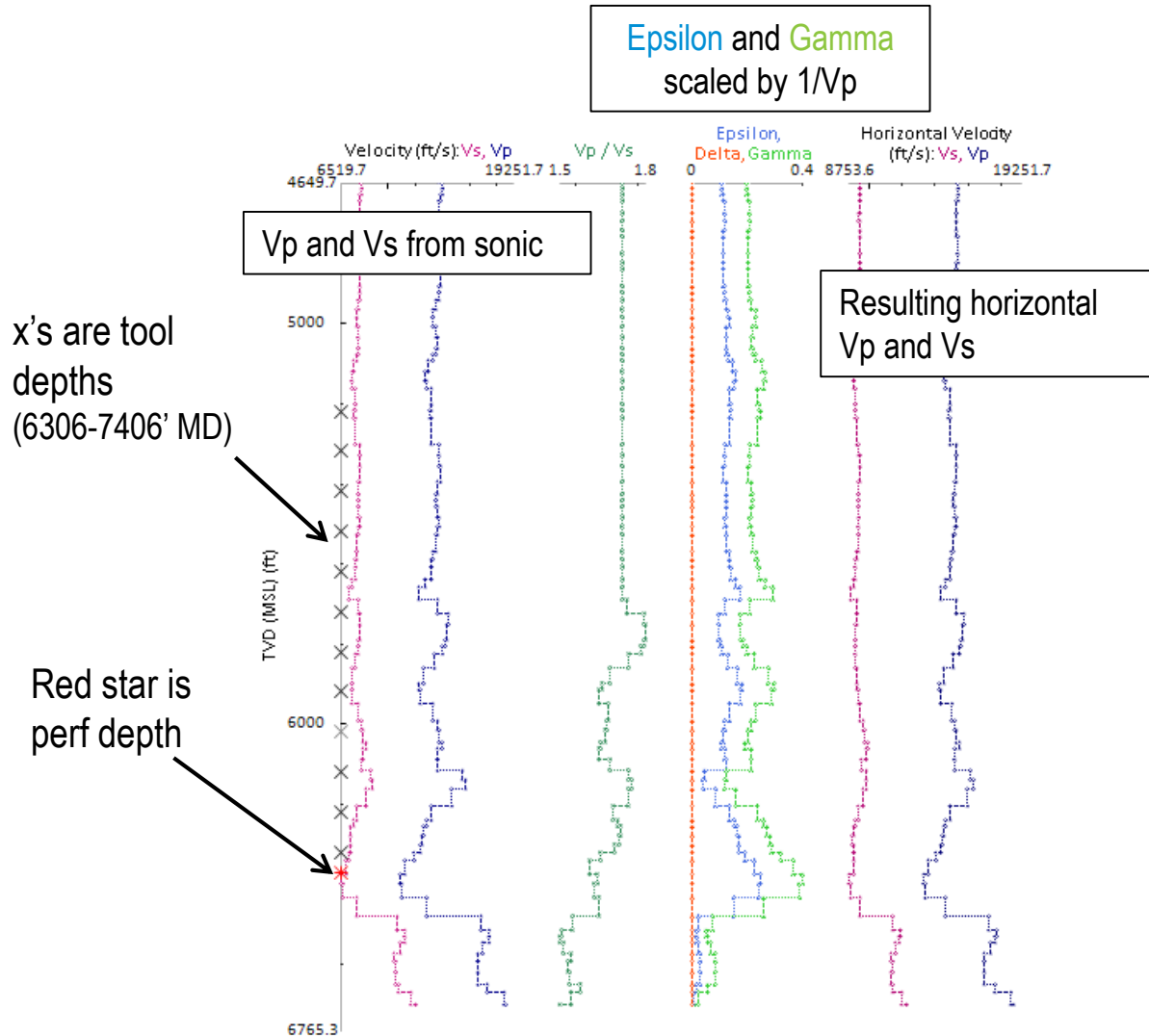


MIP 5H Typical Pump Schedule – Stage 21

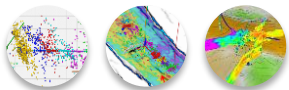
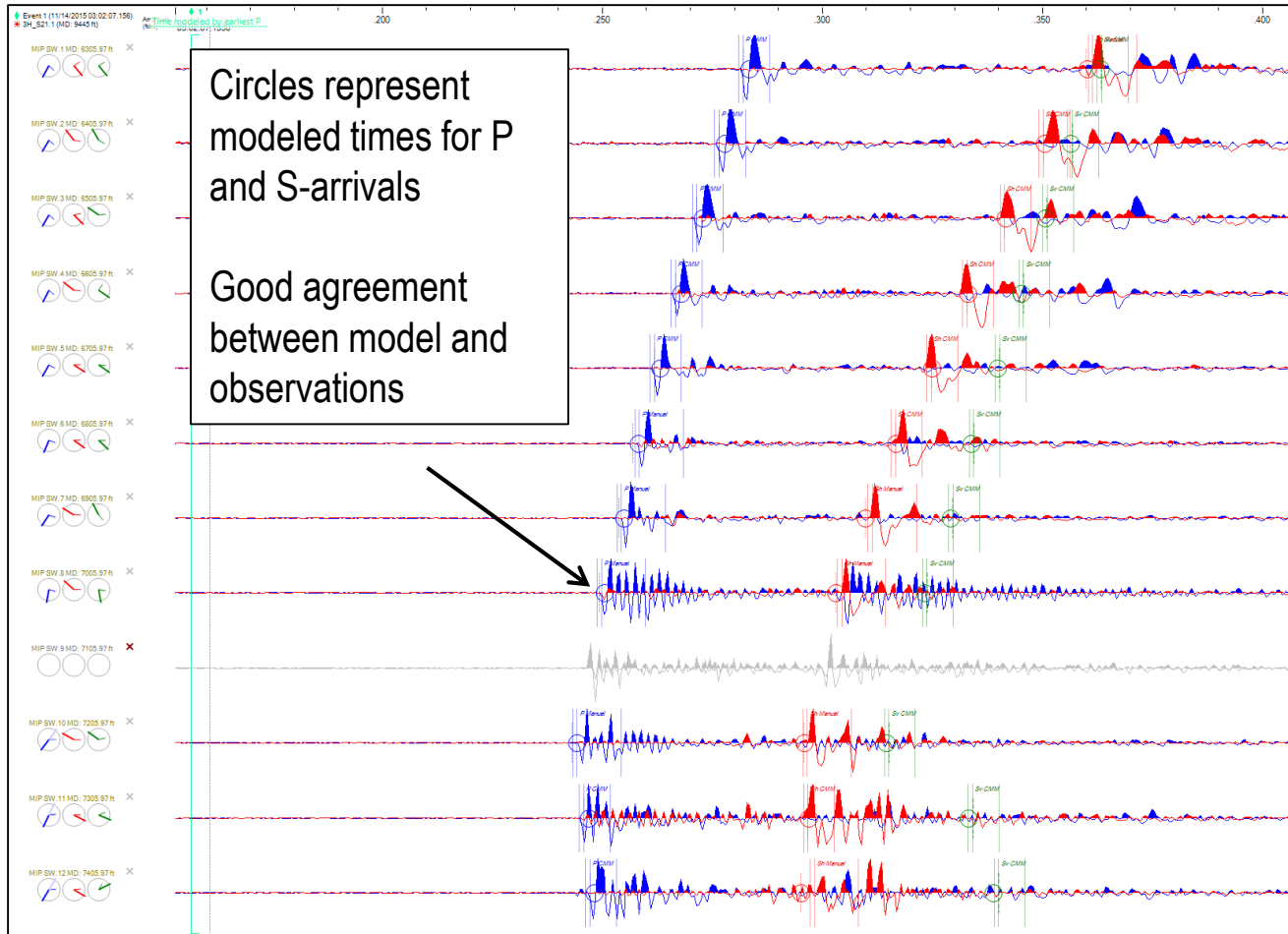
Pump Schedule A



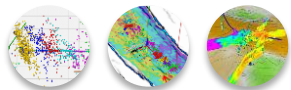
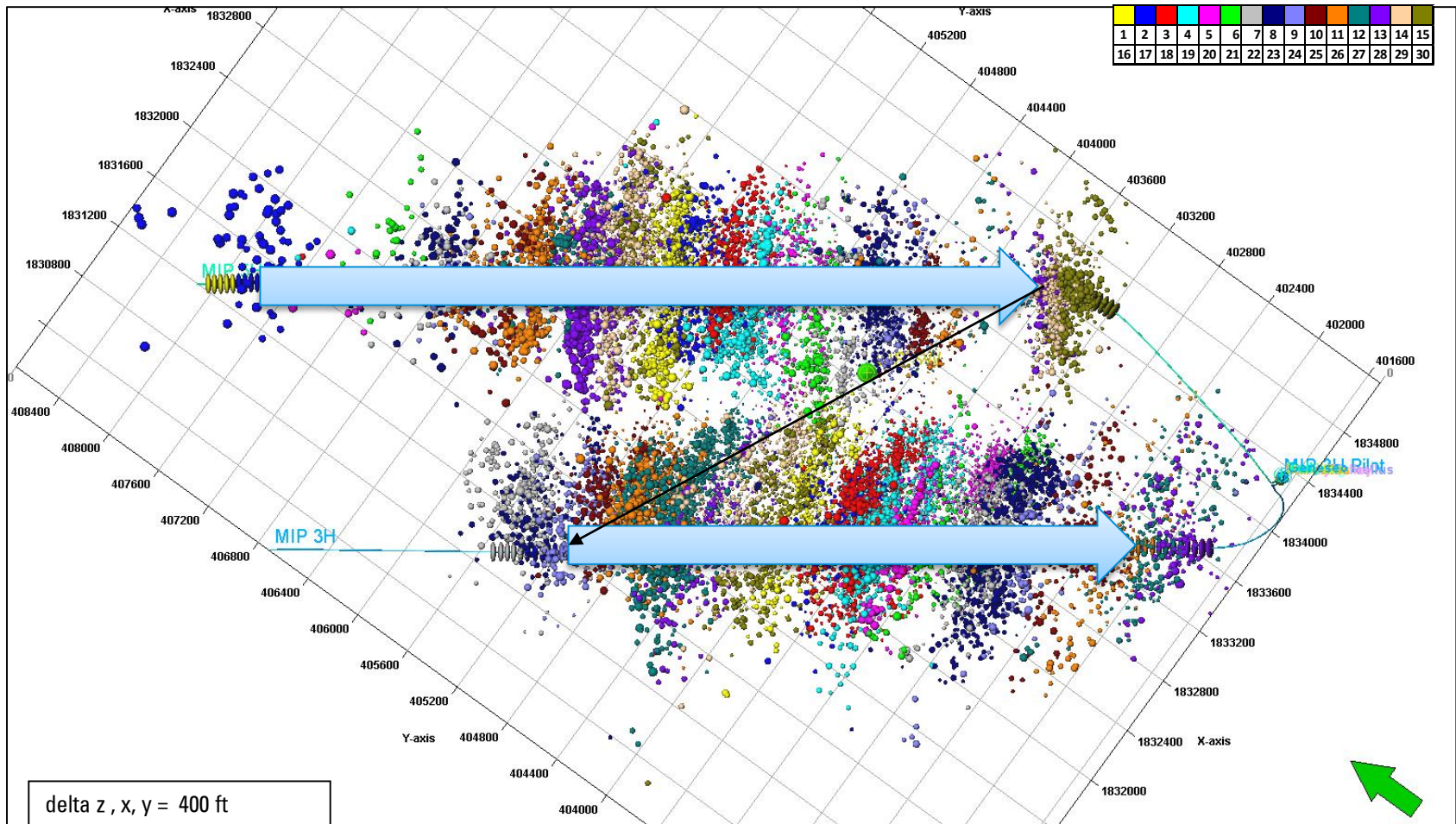
Velocity Model – 3H Stage 21 Model



QAQC Example – Times



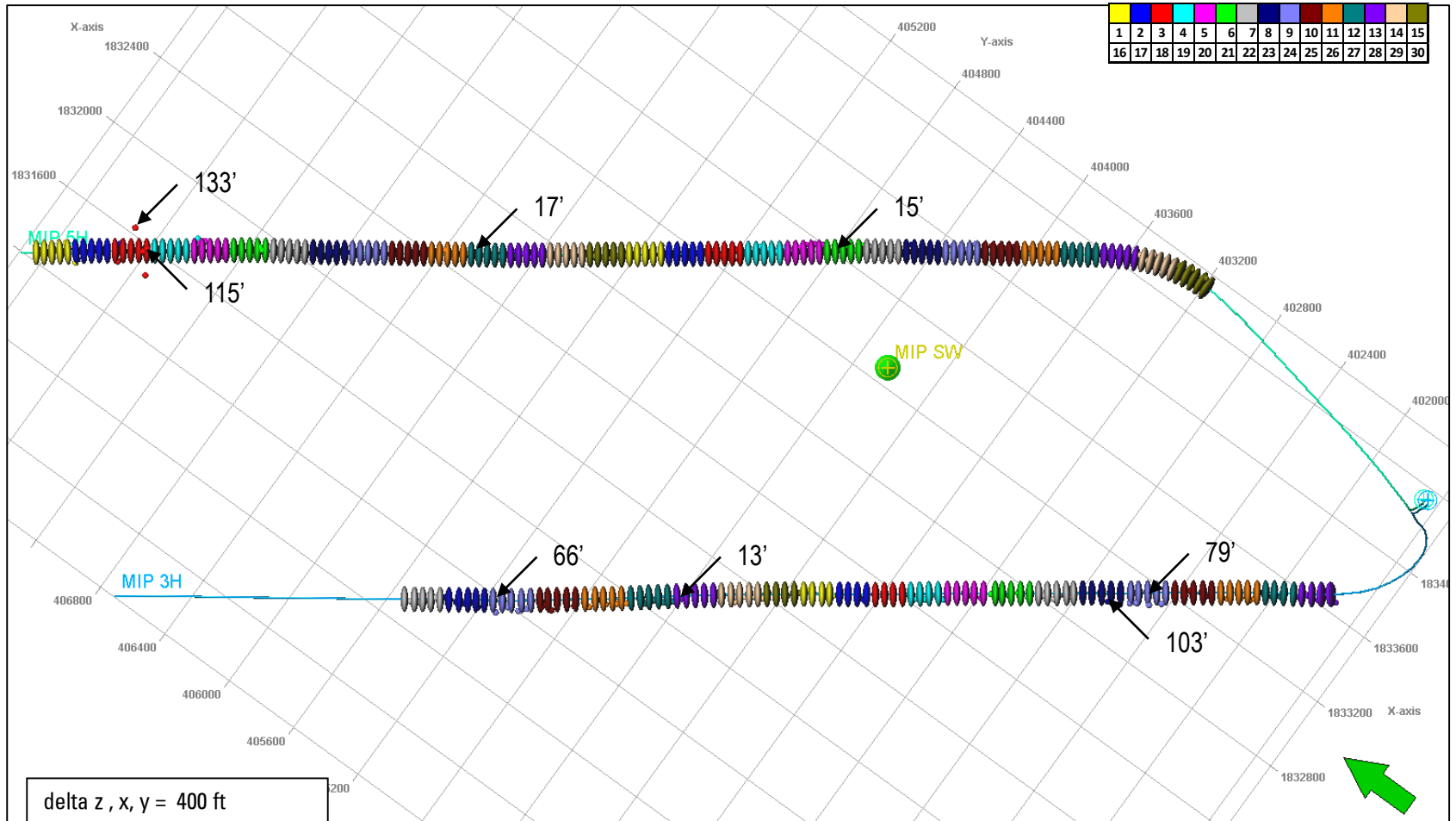
Pump Sequence



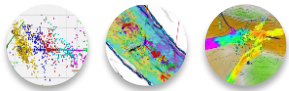
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Perf Locations – Map View



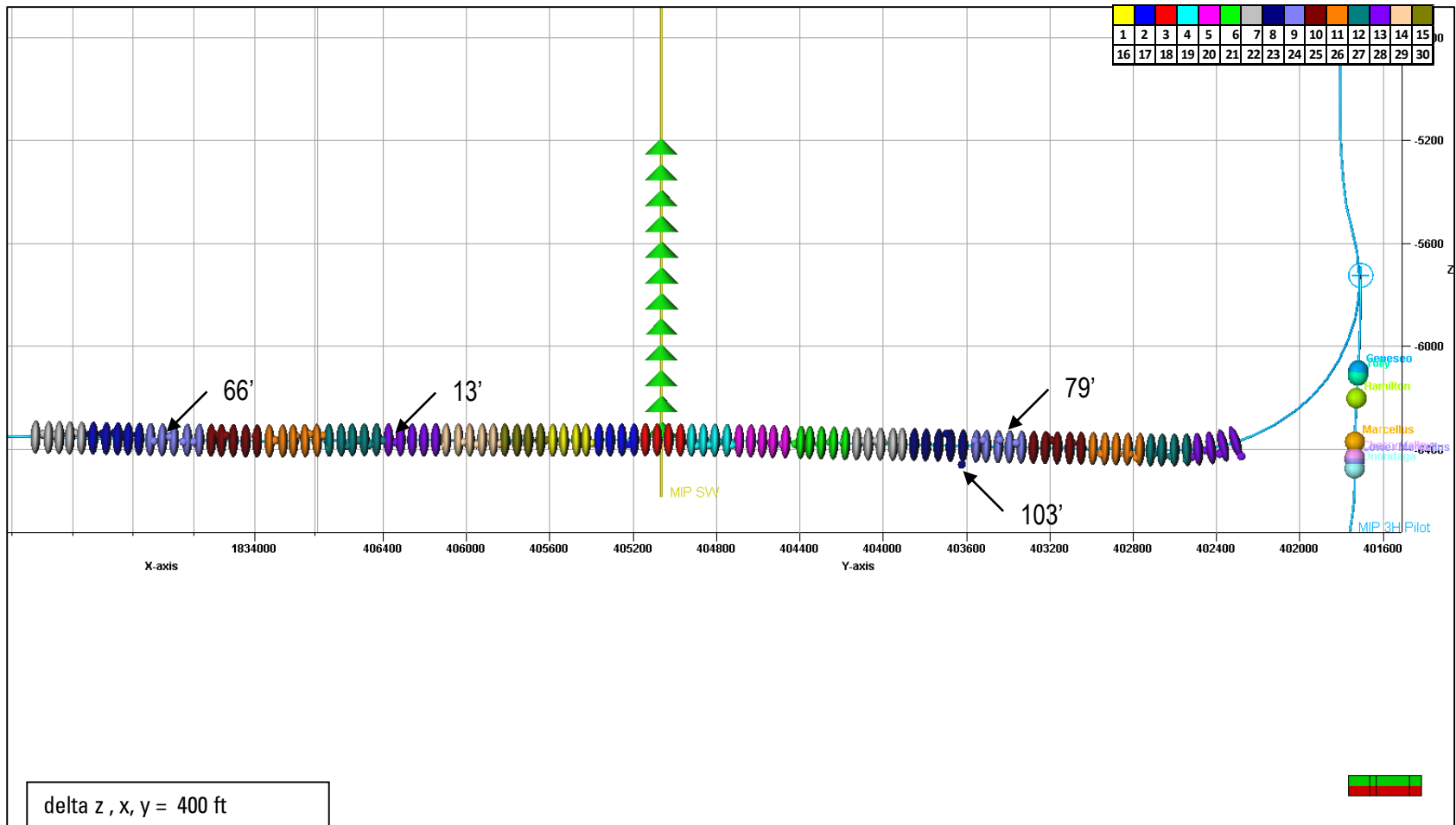
Schlumberger-Private



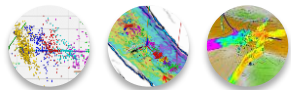
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Perf Locations – Depth View MIP 3H



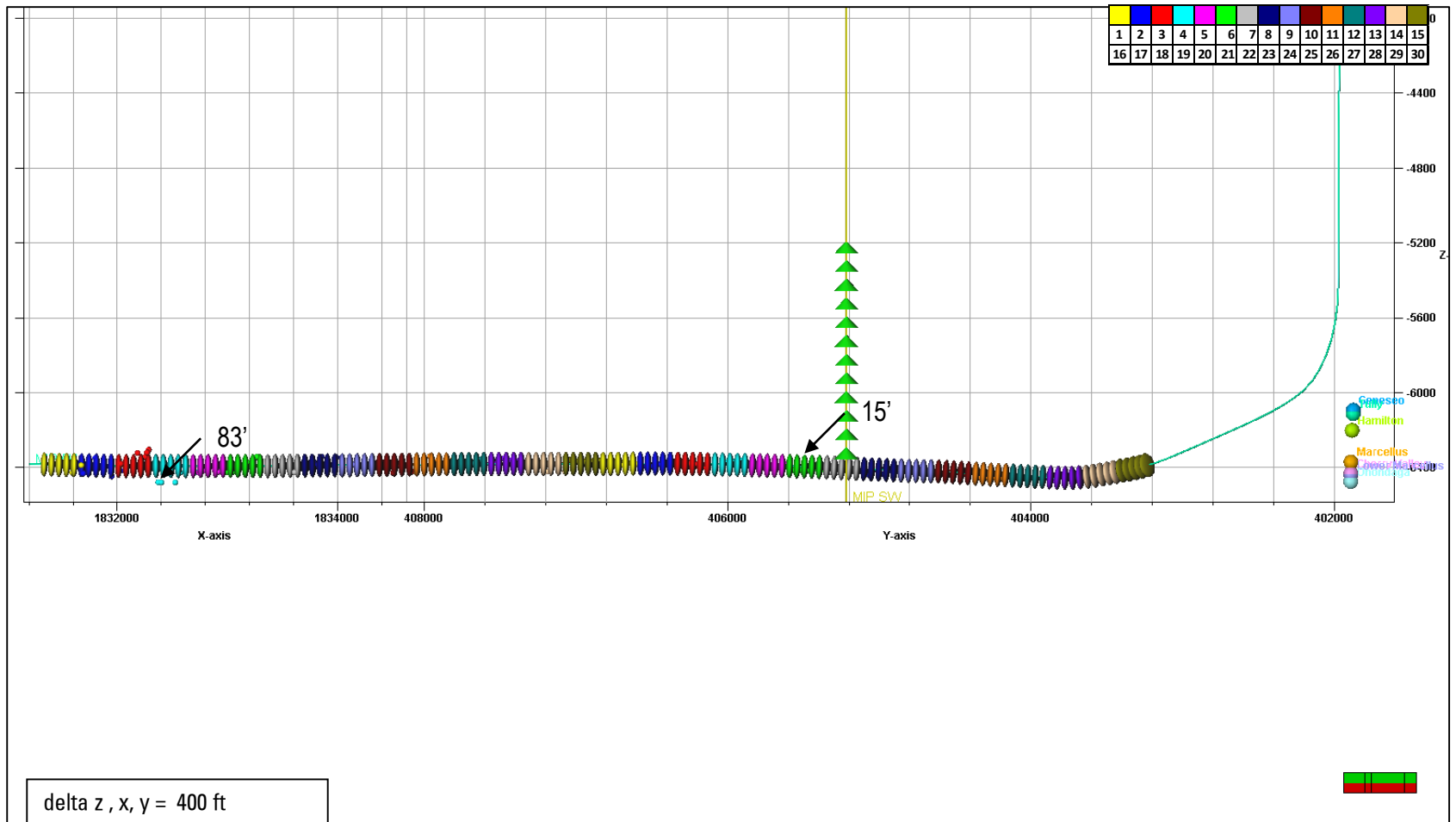
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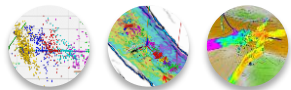
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

Perf Locations – Depth View MIP 5H



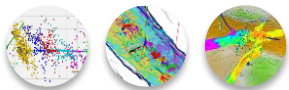
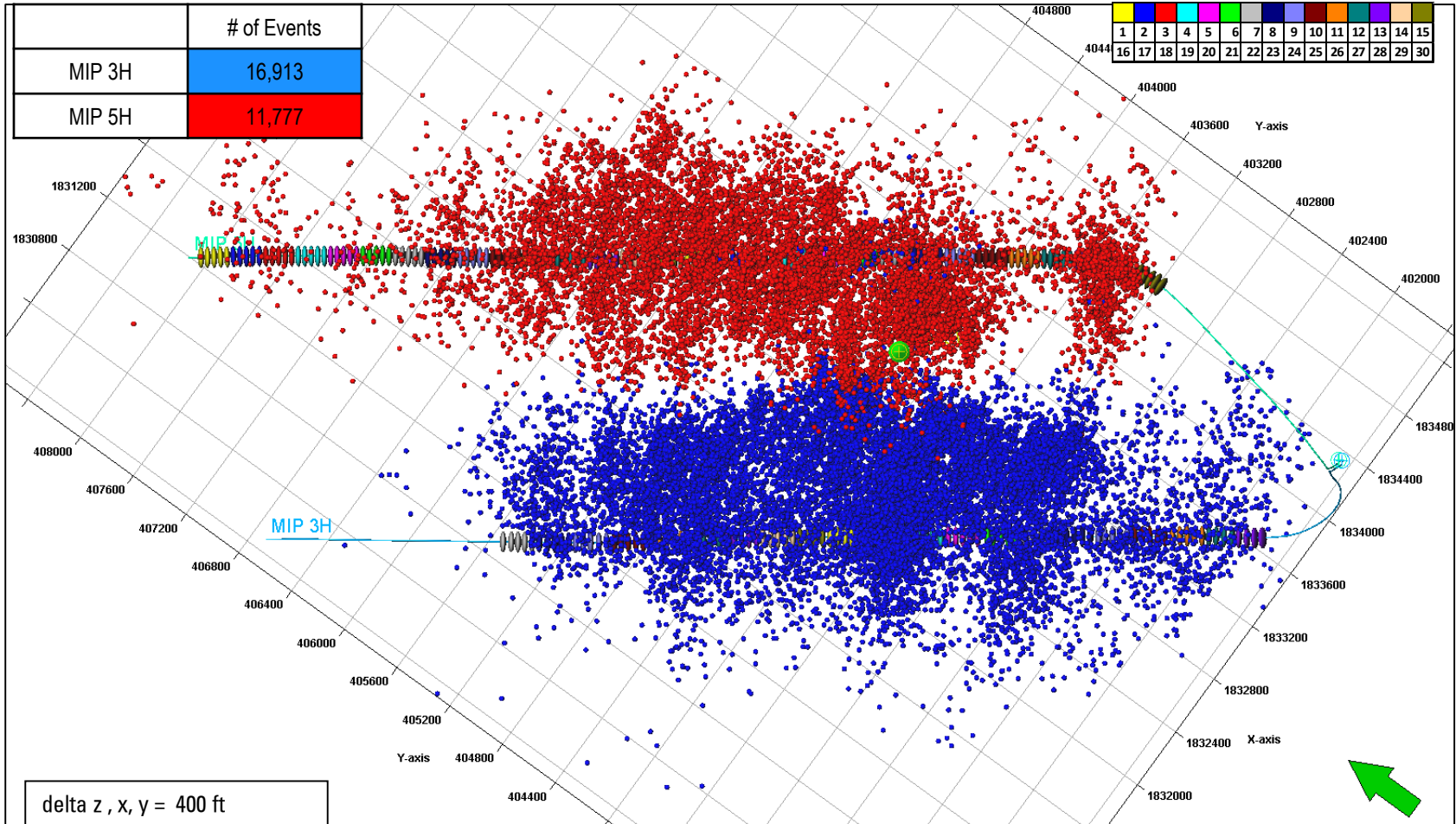
Schlumberger-Private



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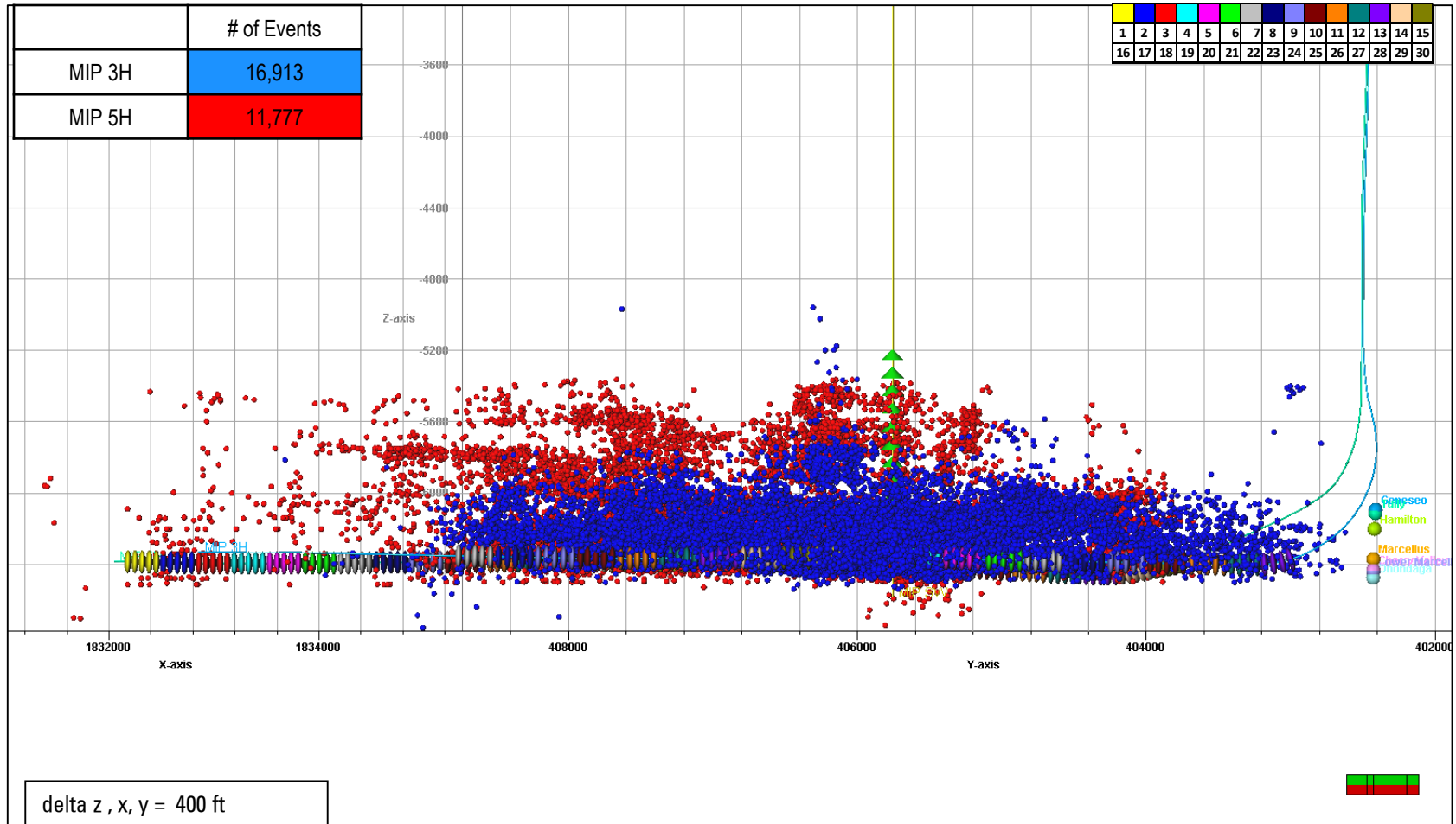
Events Summary (Unfiltered) – Map View



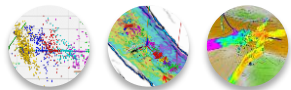
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

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Events Summary (Unfiltered) – Depth View



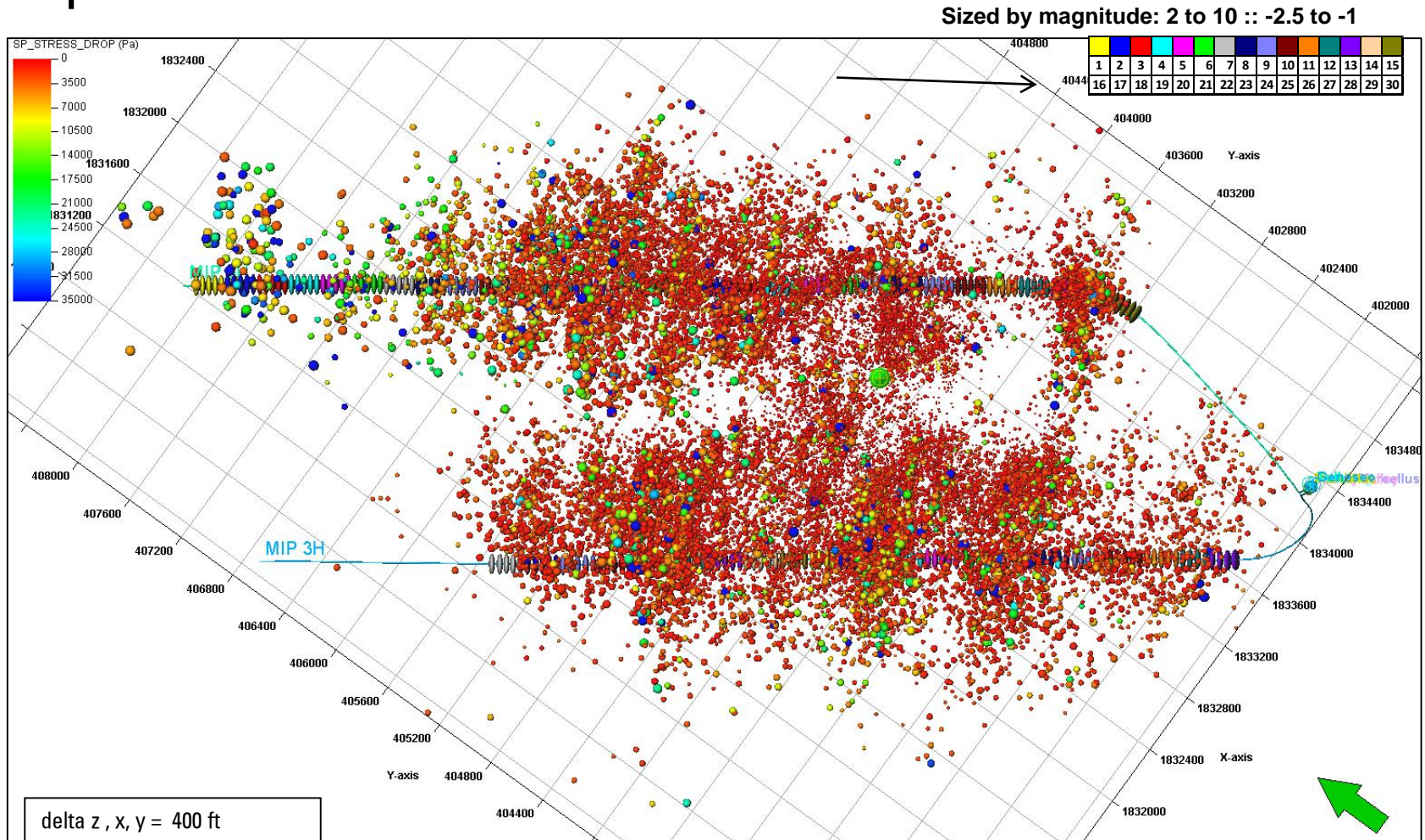
Schlumberger-Private



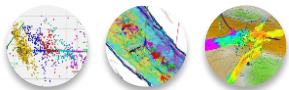
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

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Offset Vertical Well Interference (Unfiltered) Map View



Schlumberger-Private

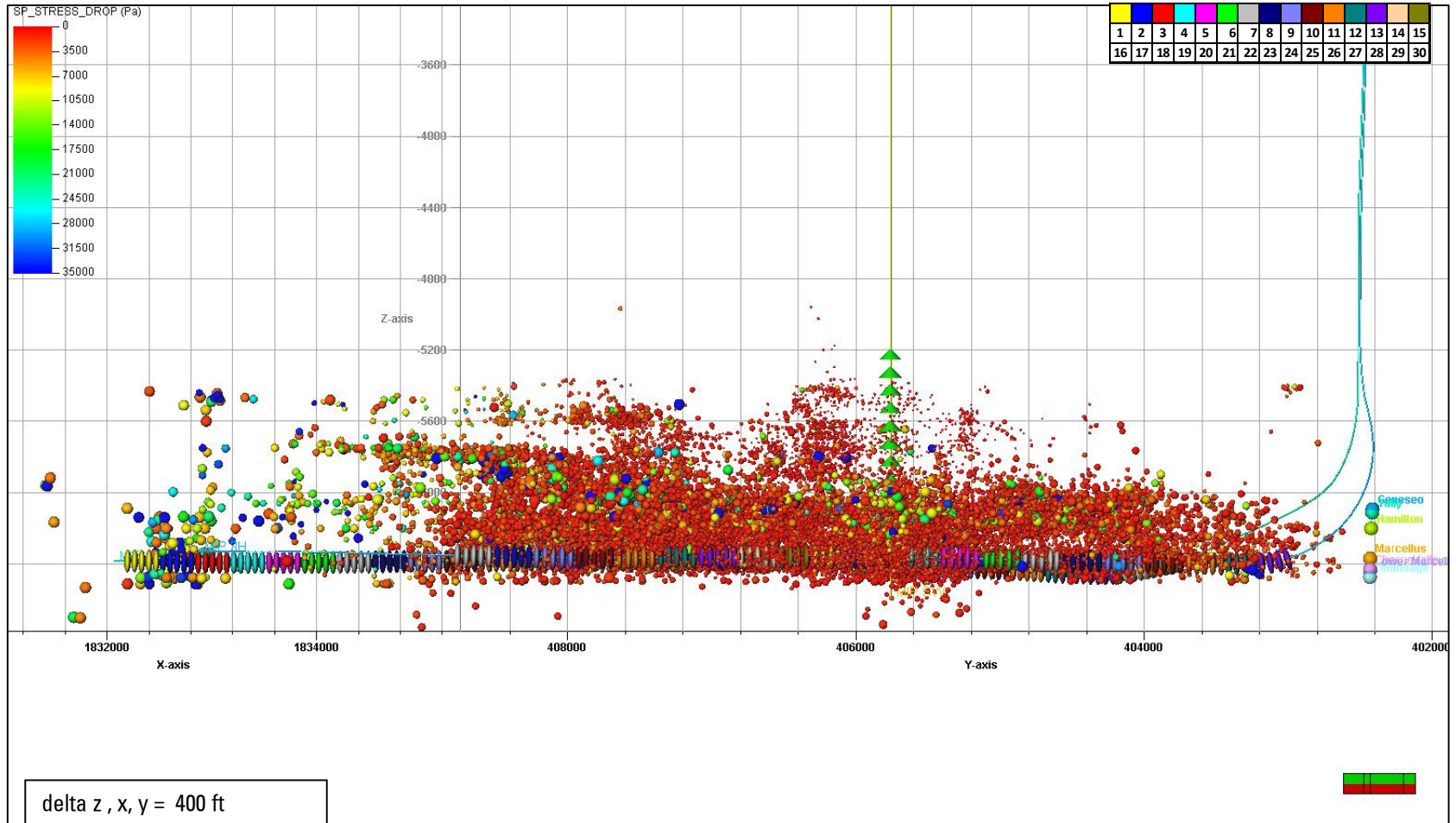


MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

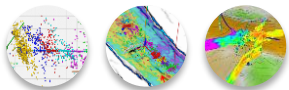
Schlumberger

Offset Vertical Well Interference (Unfiltered) Depth View

Sized by magnitude: 2 to 10 :: -2.5 to -1



Schlumberger-Private



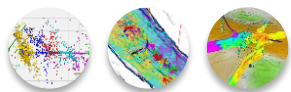
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

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Applied Filters

	MIP 3H	MIP 5H
Unfiltered	16,913	11,777
Pumping Only	14,529 (86%)	10,088 (86%)
SP_Magnitude > -2.5	12,807 (76%)	8,880 (75%)
QC_Confidence > 2.8	12,092 (72%)	8,203 (70%)

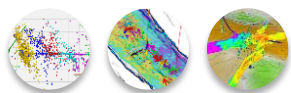
Schlumberger-Private



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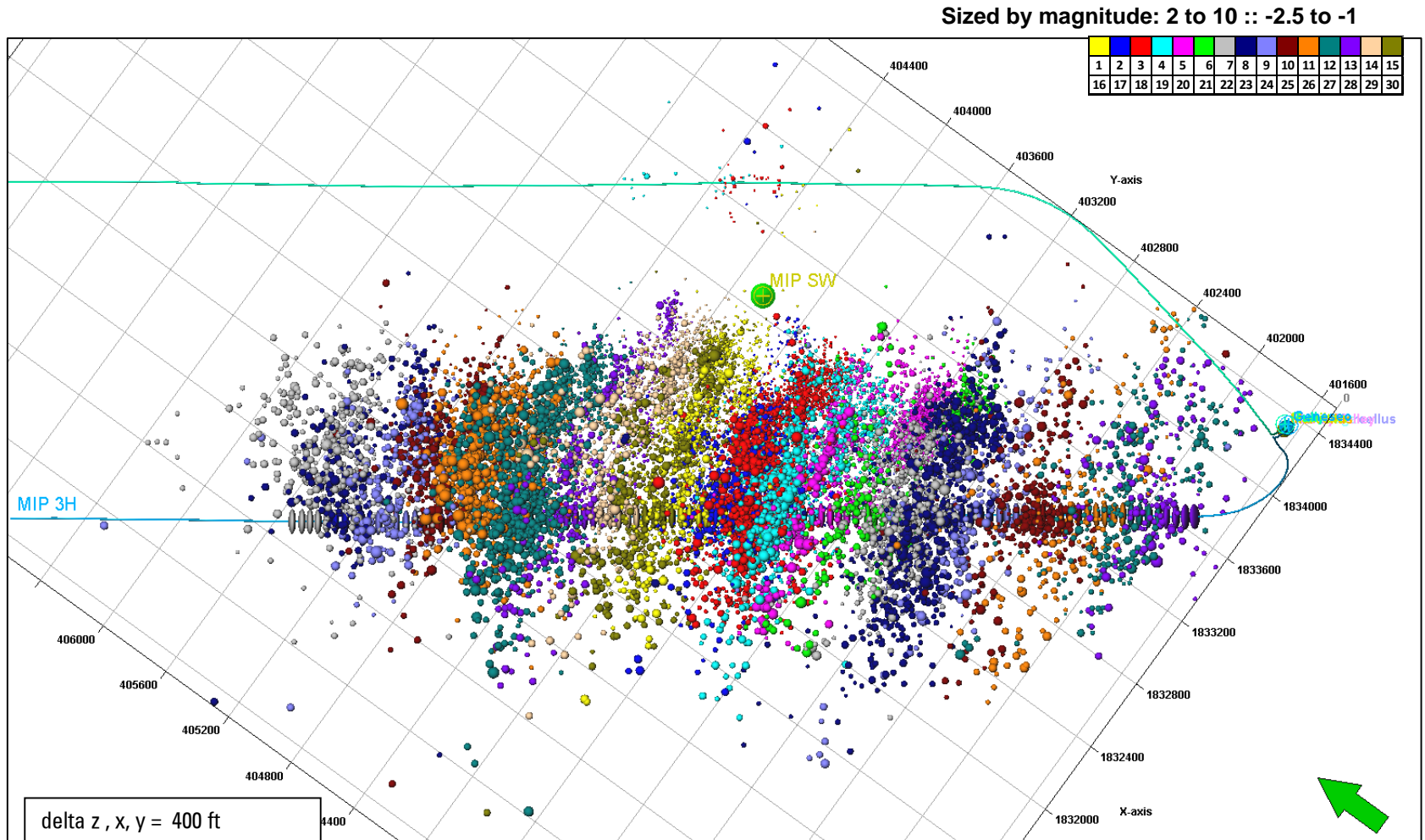
MIP 3H Cherry Valley



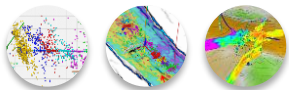
MICROSEISMIC SERVICES
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MIP 3H Unfiltered – Map View



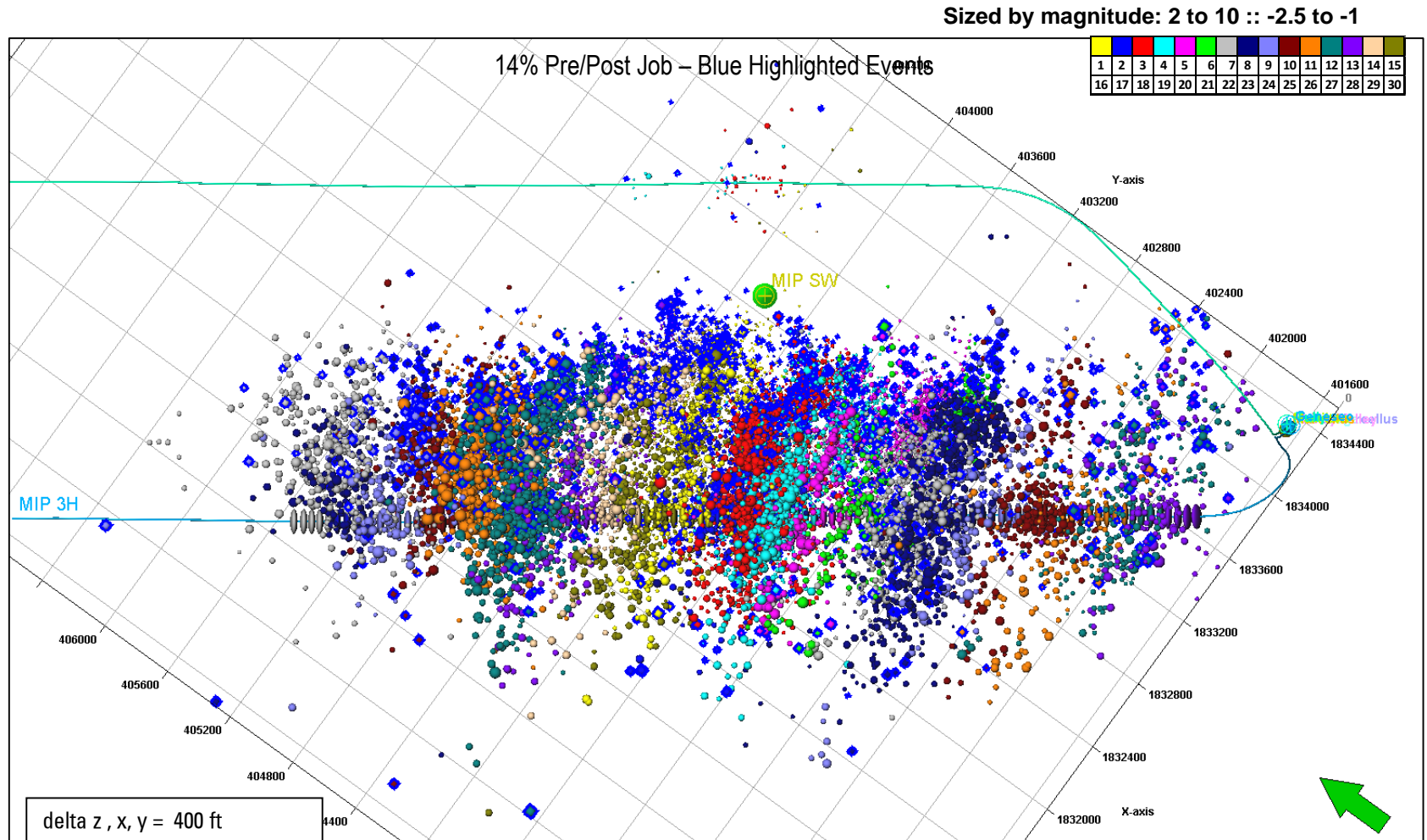
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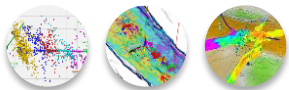
MICROSEISMIC SERVICES
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MIP 3H Post Job – Map View



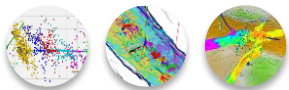
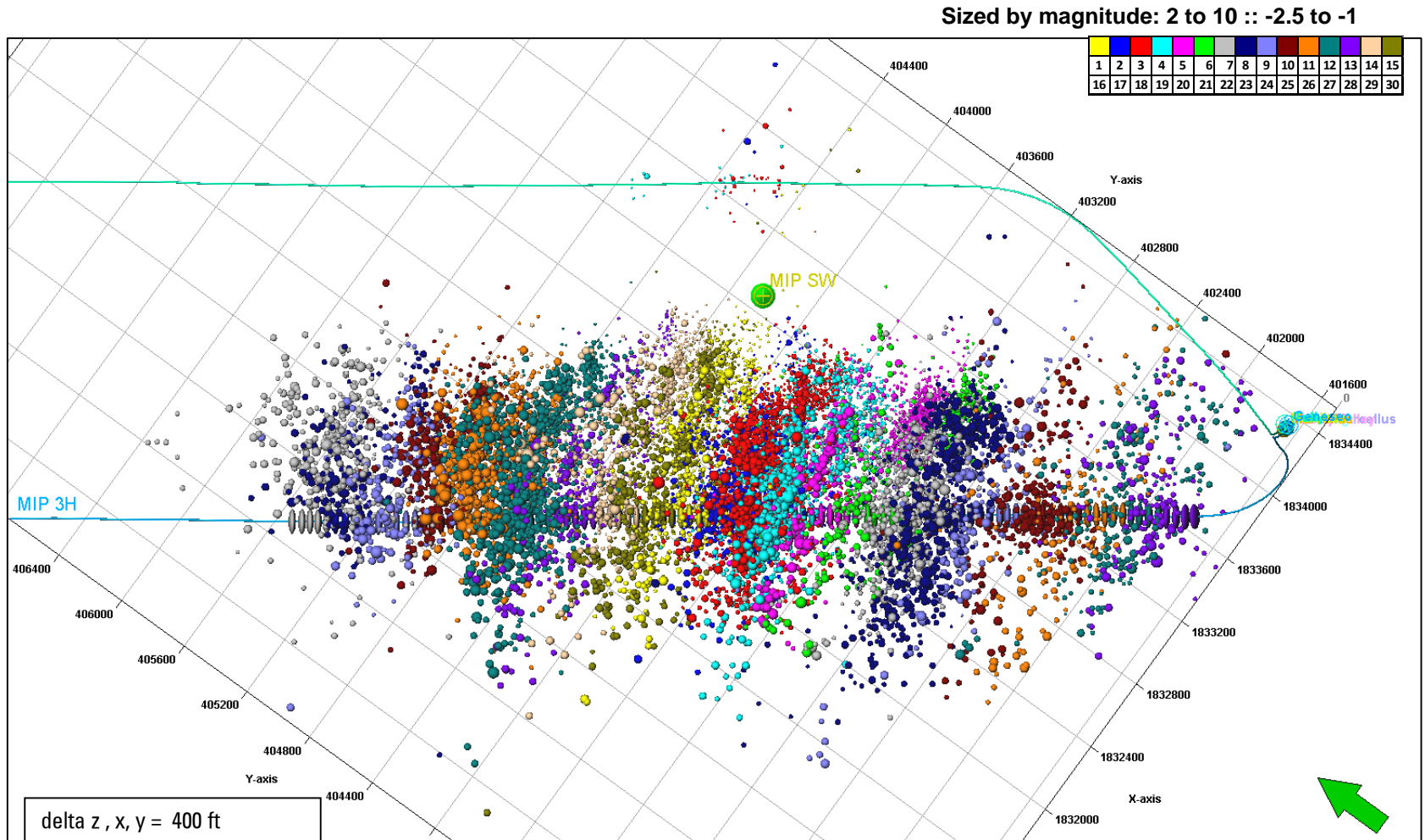
Schlumberger-Private



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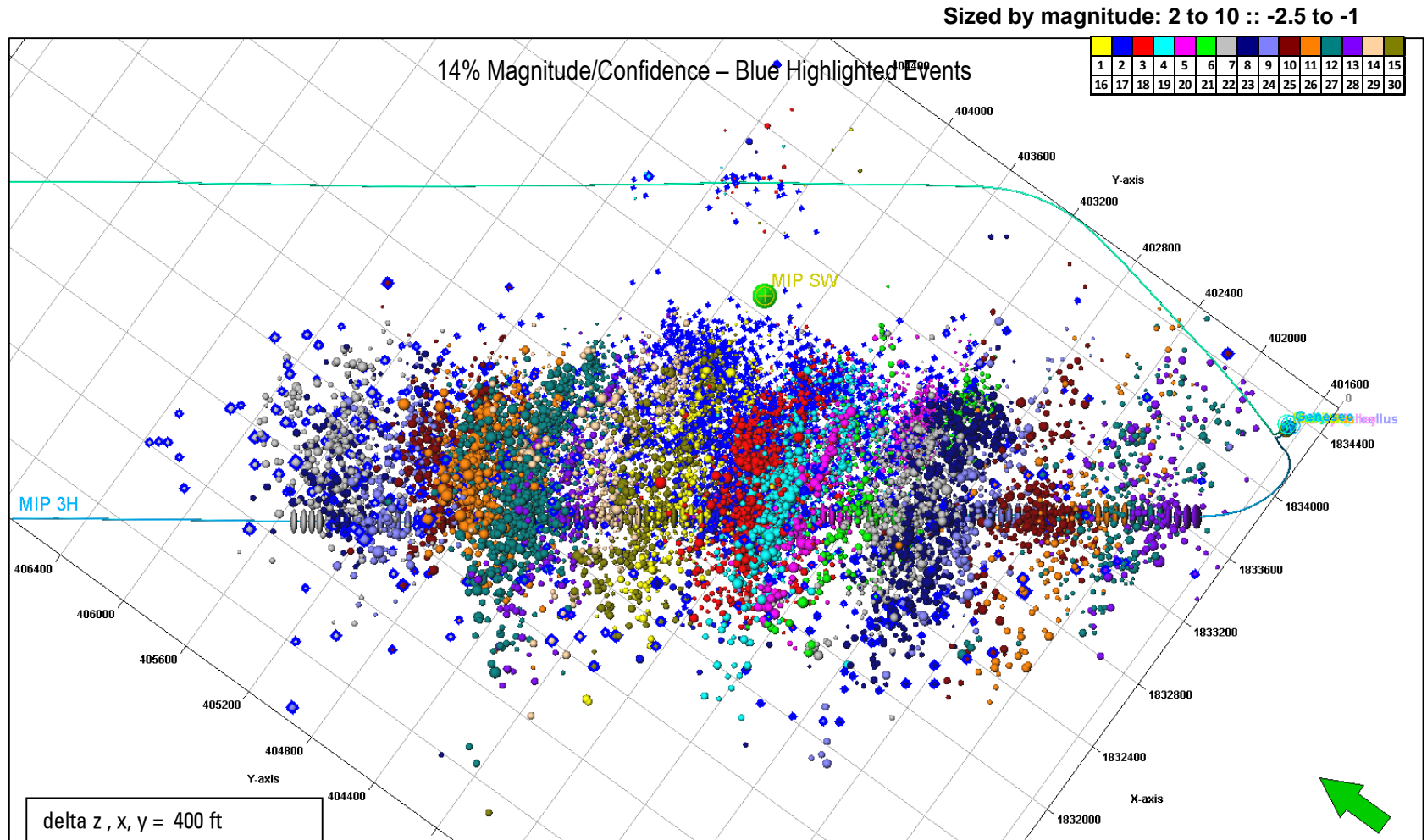
MIP 3H Rate Filtered – Map View



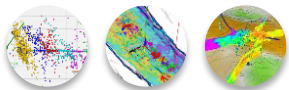
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

MIP 3H Magnitude and Confidence – Map View



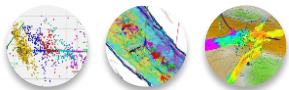
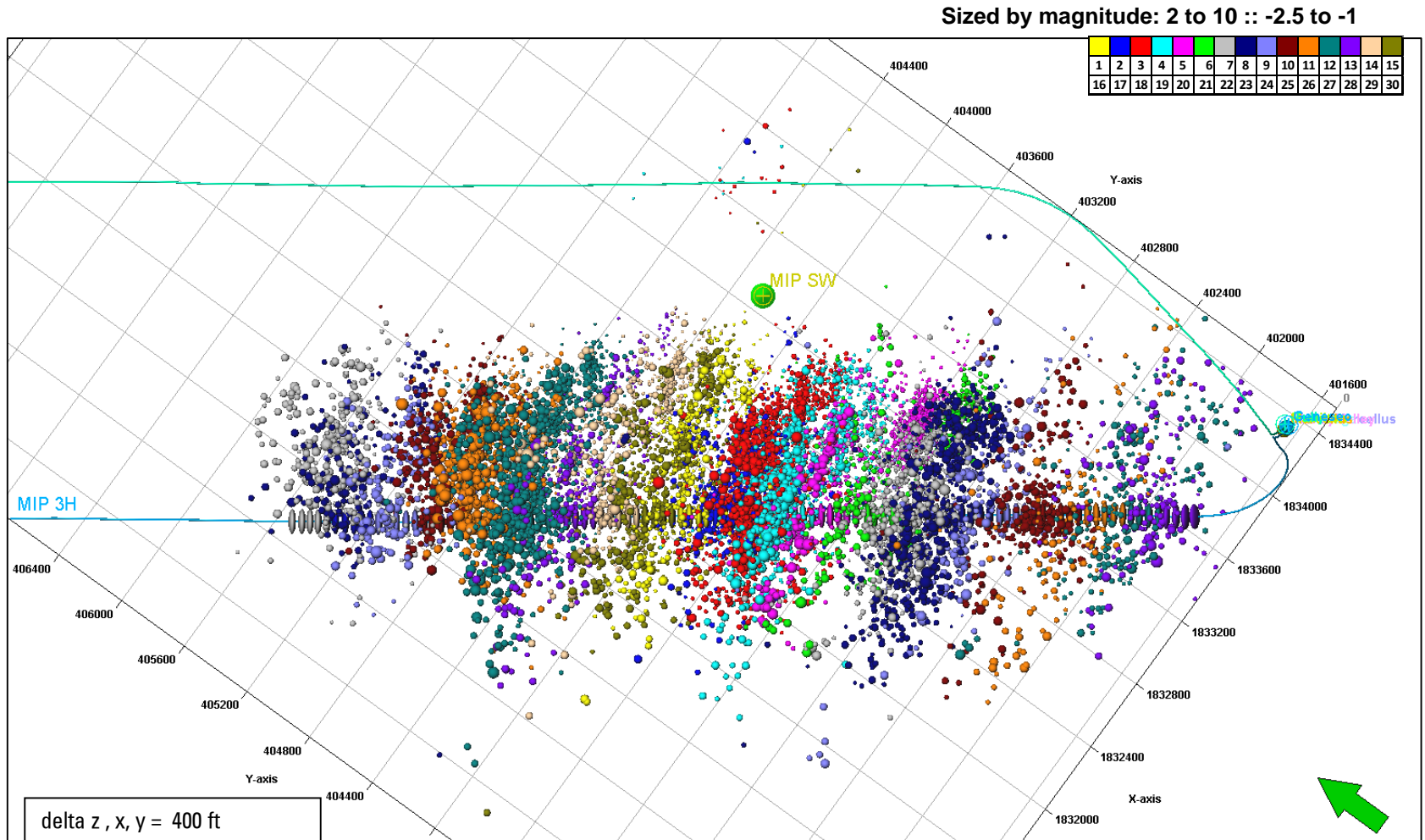
Schlumberger-Private



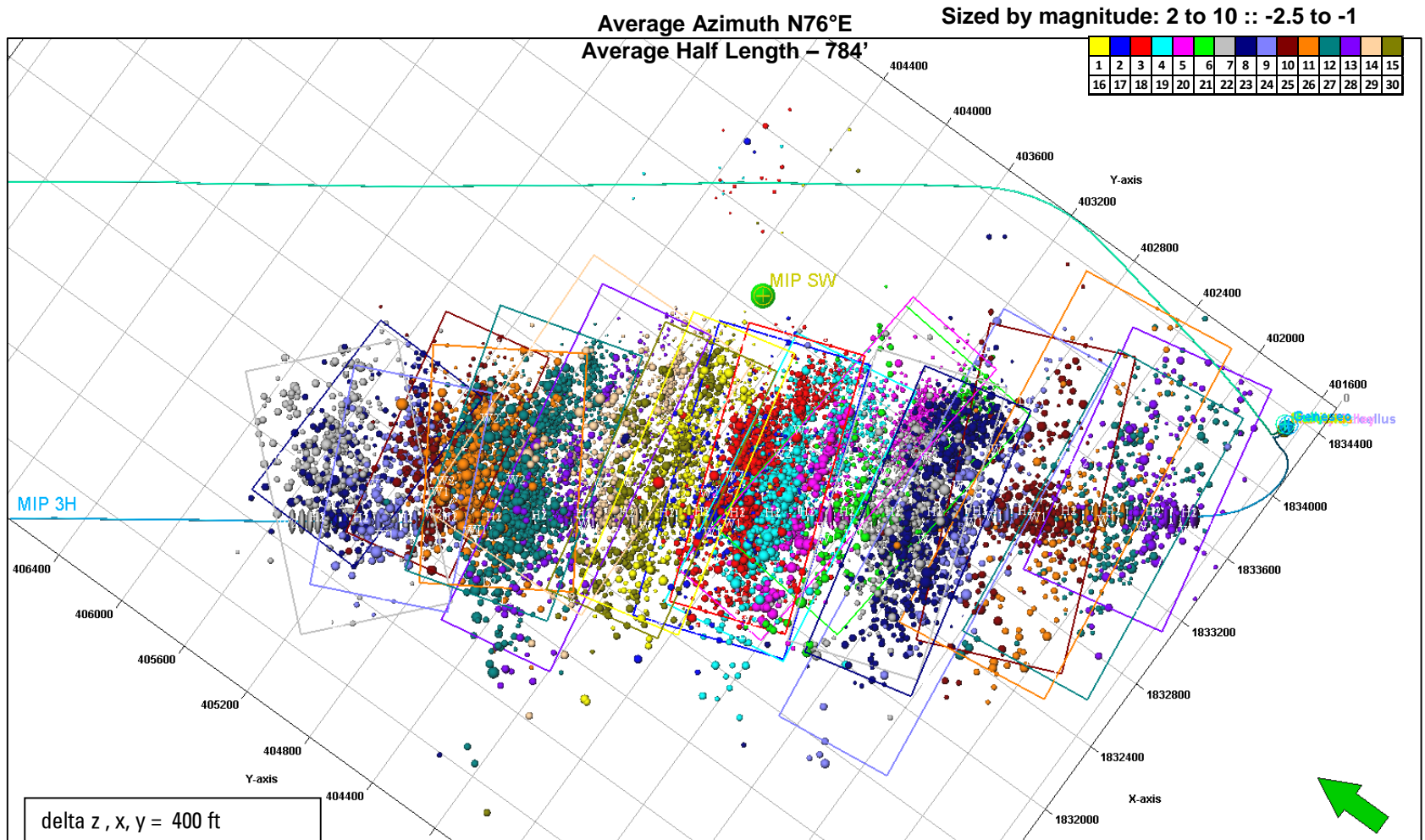
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

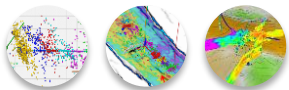
MIP 3H Filtered – Map View



MIP 3H Microseismic Dimensions – Map View



Schlumberger-Private

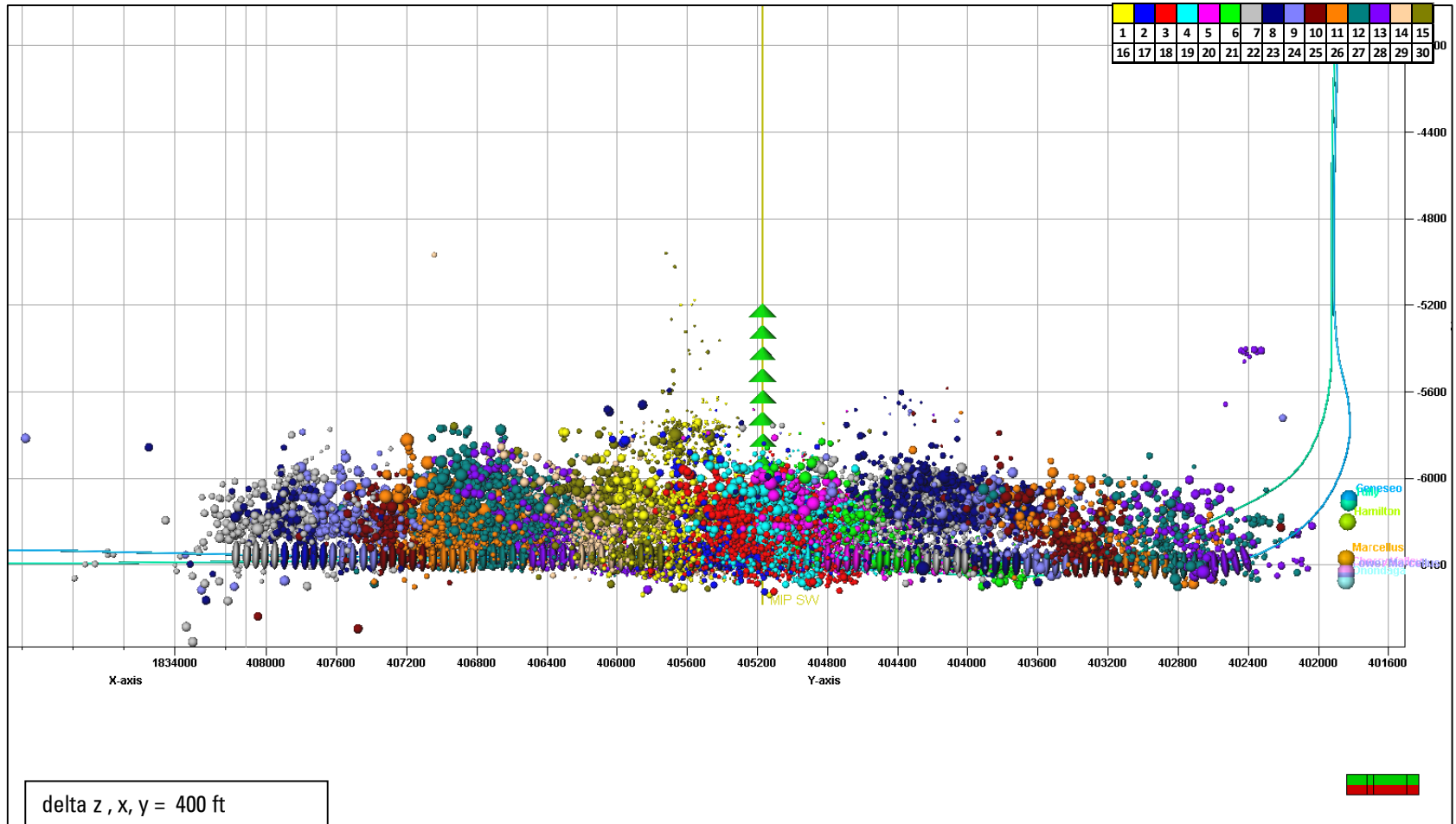


MICROSEISMIC SERVICES
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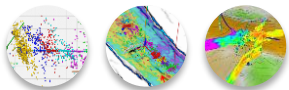
Schlumberger

MIP 3H Unfiltered – Depth View

Sized by magnitude: 2 to 10 :: -2.5 to -1



Schlumberger-Private

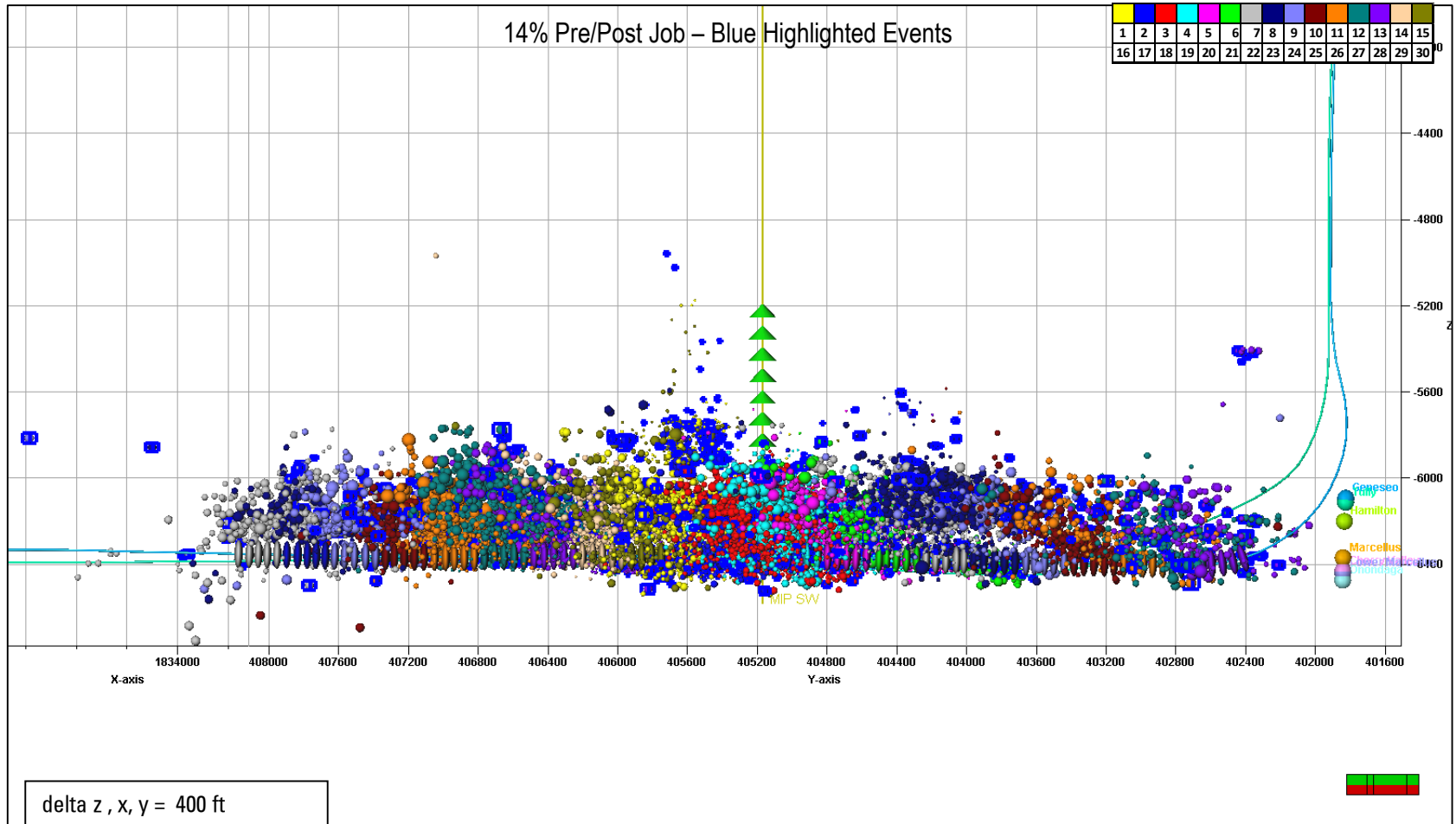


MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

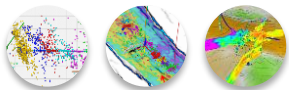
Schlumberger

MIP 3H Post-Job – Depth View

Sized by magnitude: 2 to 10 :: -2.5 to -1



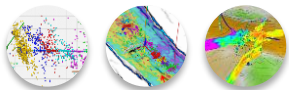
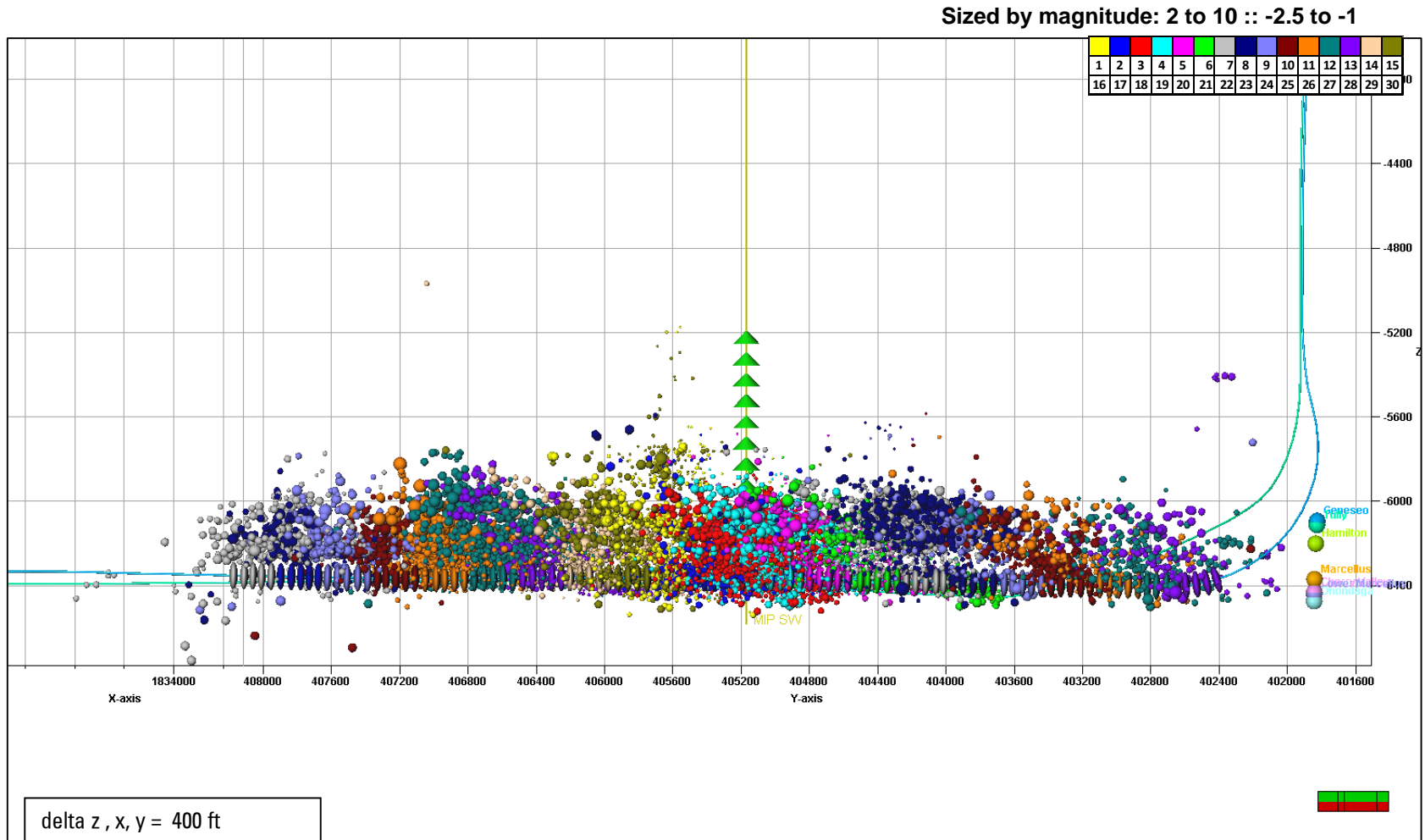
Schlumberger-Private



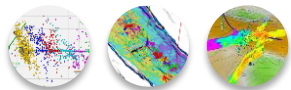
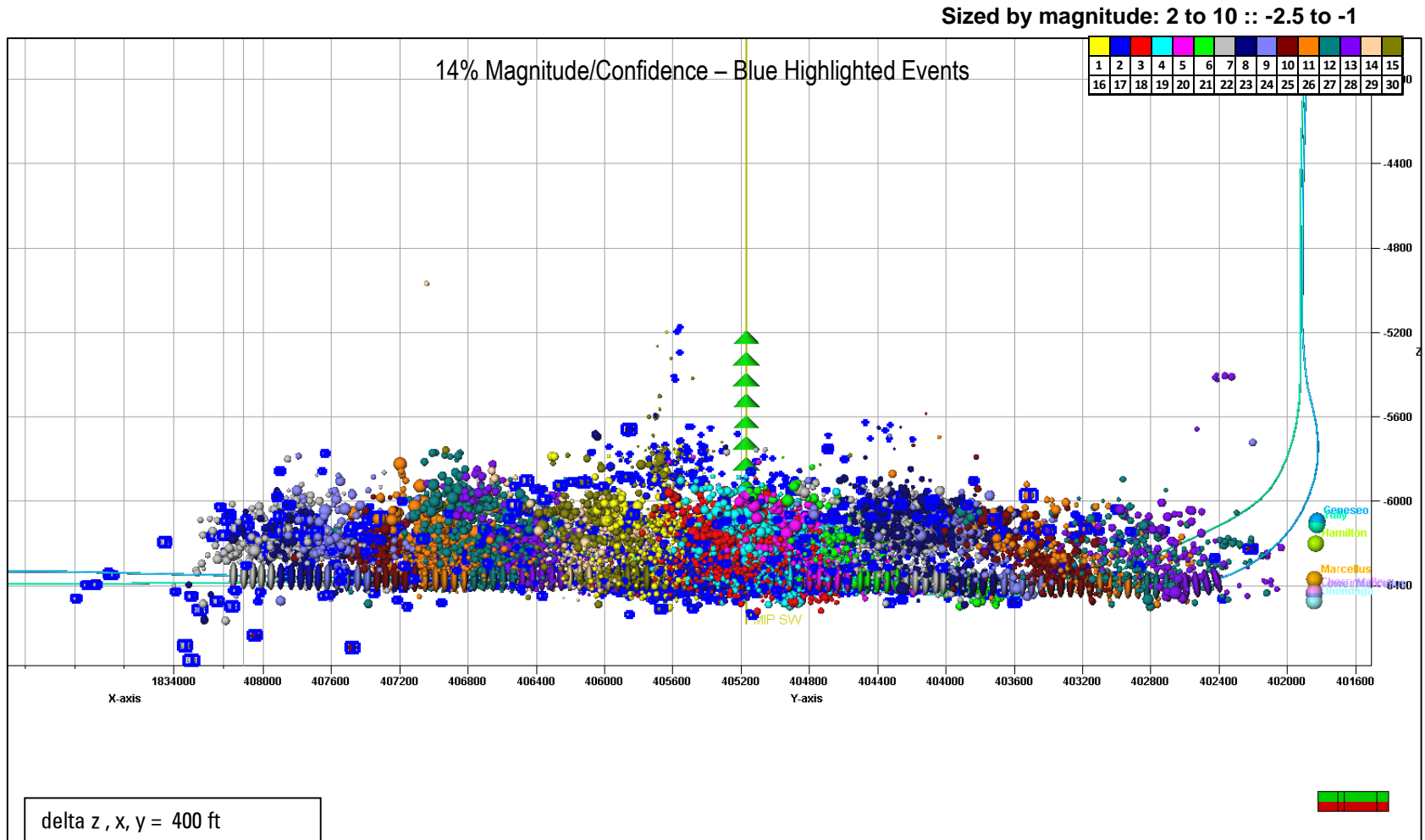
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

MIP 3H Rate Filtered – Depth View



MIP 3H Magnitude and Confidence – Depth View

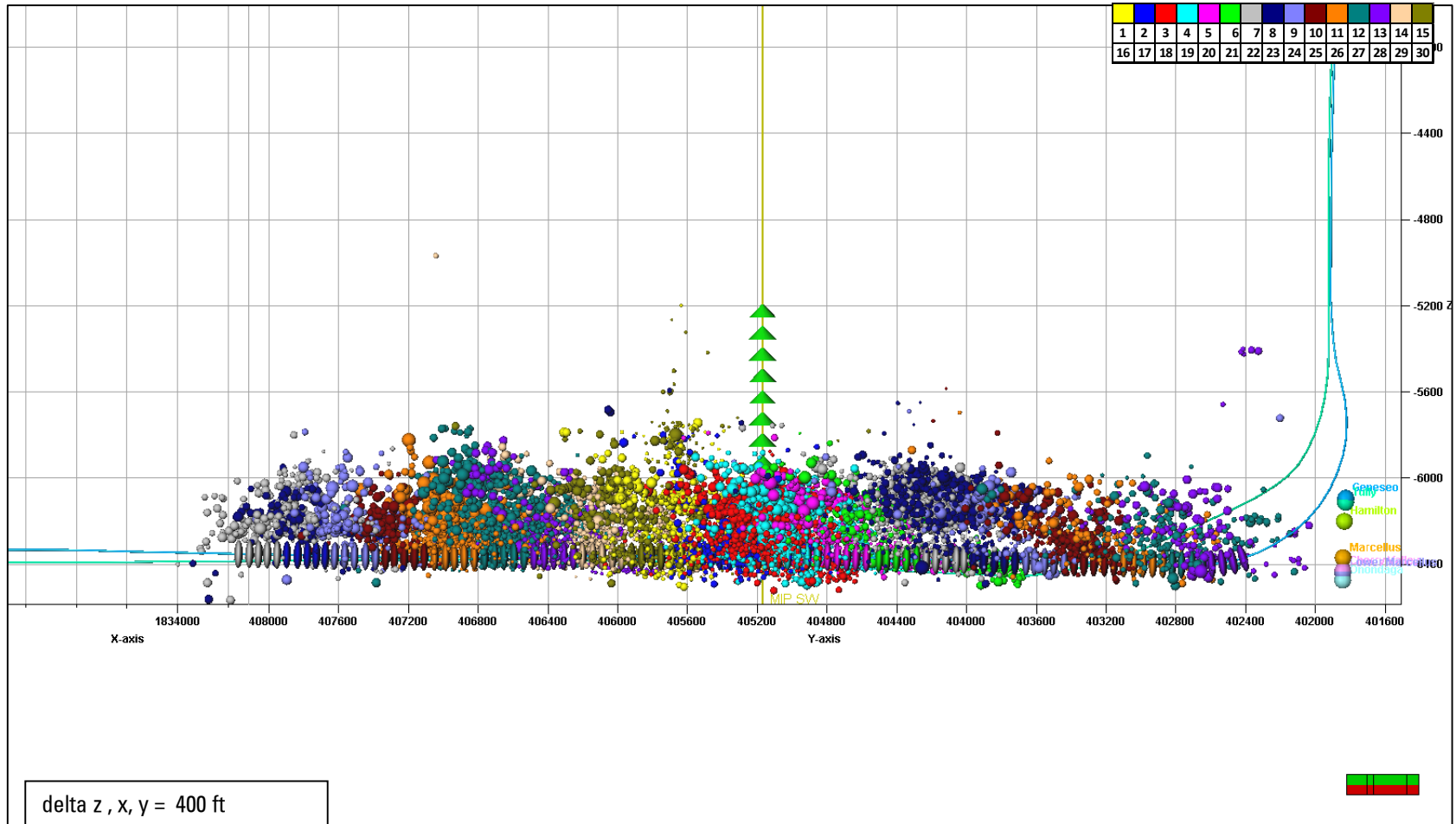


MICROSEISMIC SERVICES
 IMAGE INTERPRET INTEGRATE

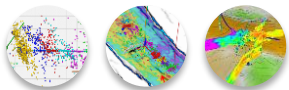
Schlumberger

MIP 3H Filtered – Depth View

Sized by magnitude: 2 to 10 :: -2.5 to -1



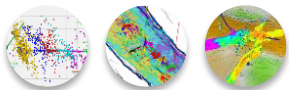
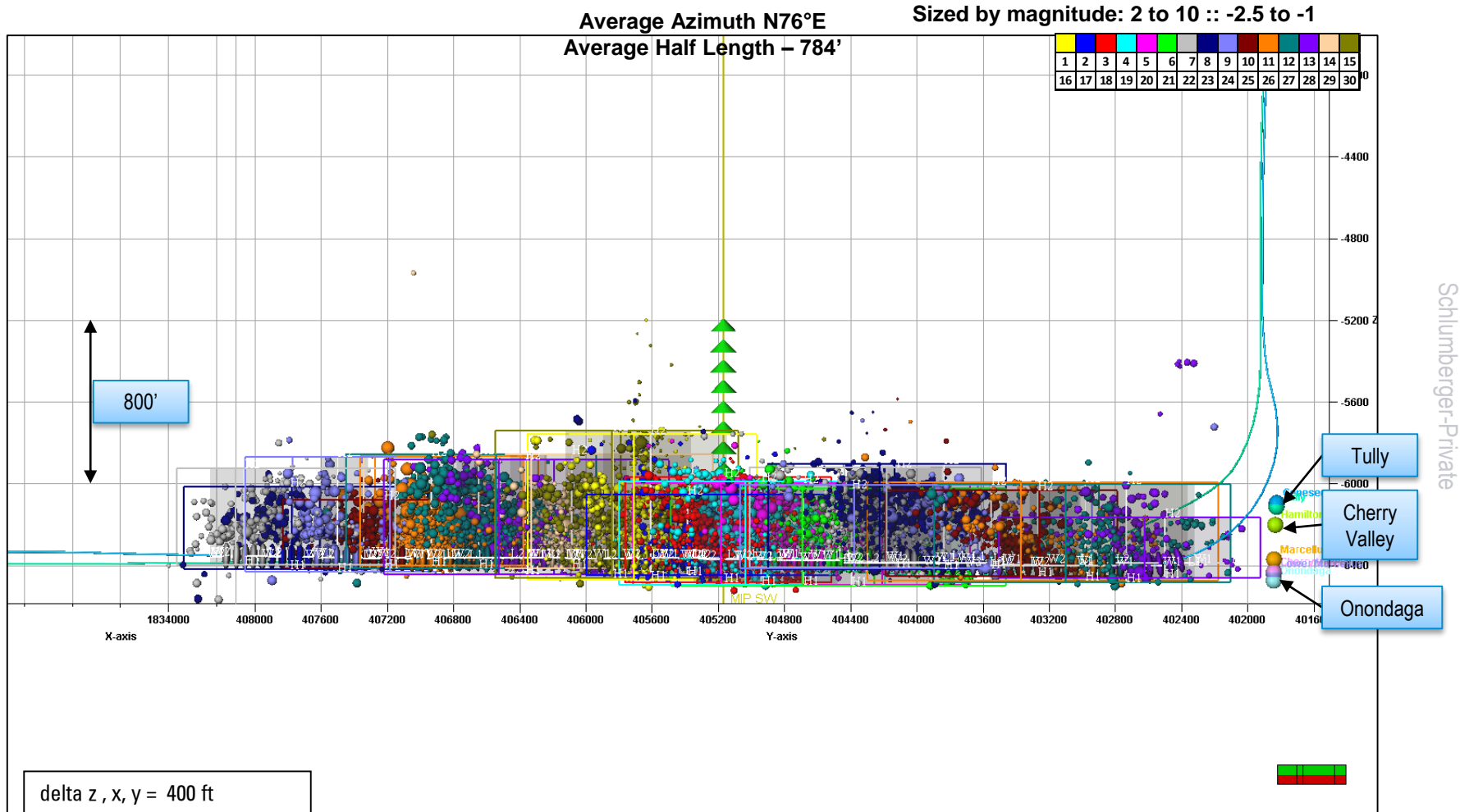
Schlumberger-Private



MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

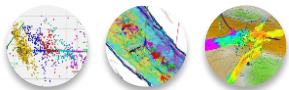
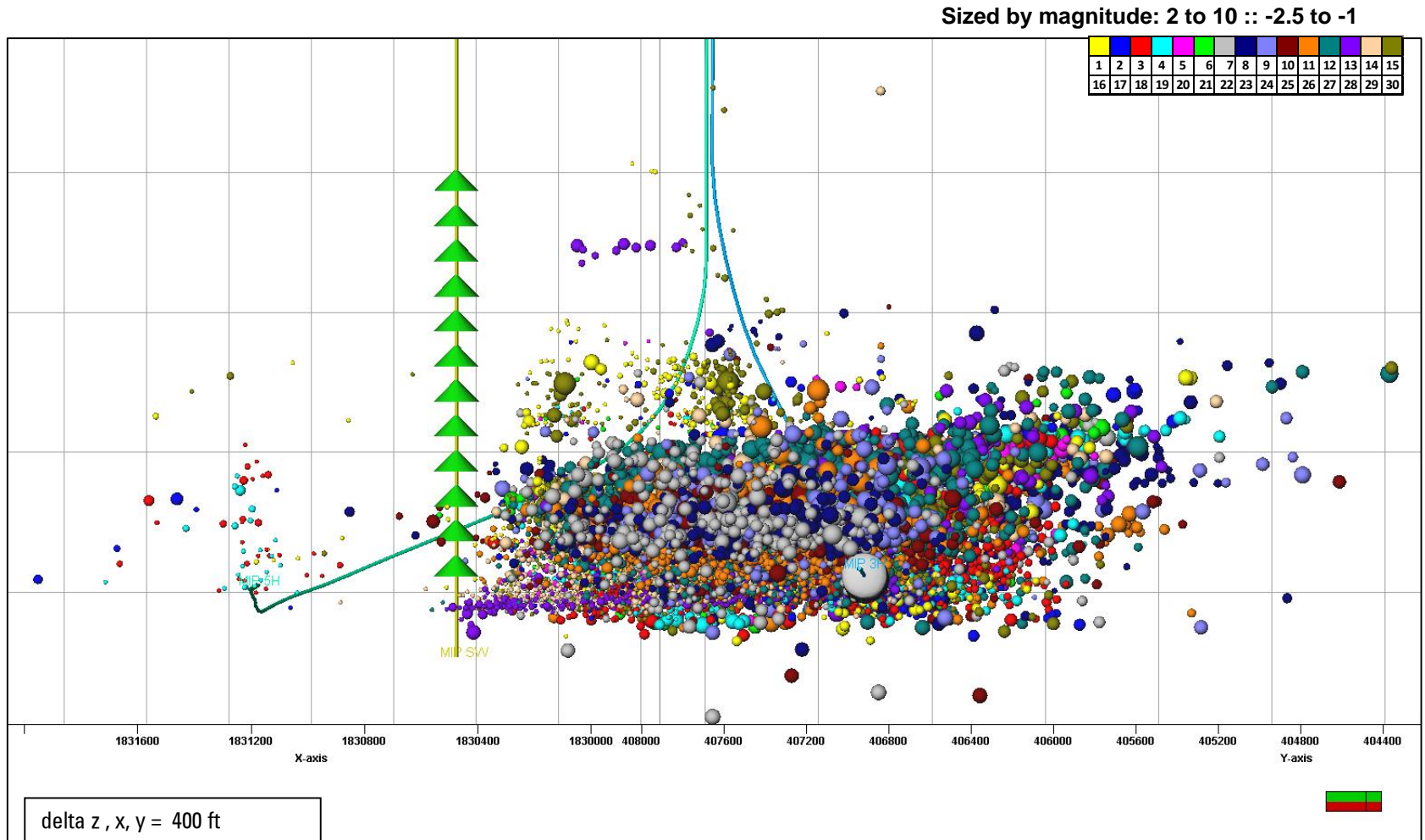
MIP 3H Microseismic Dimensions – Depth View



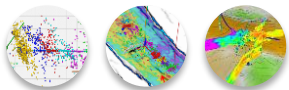
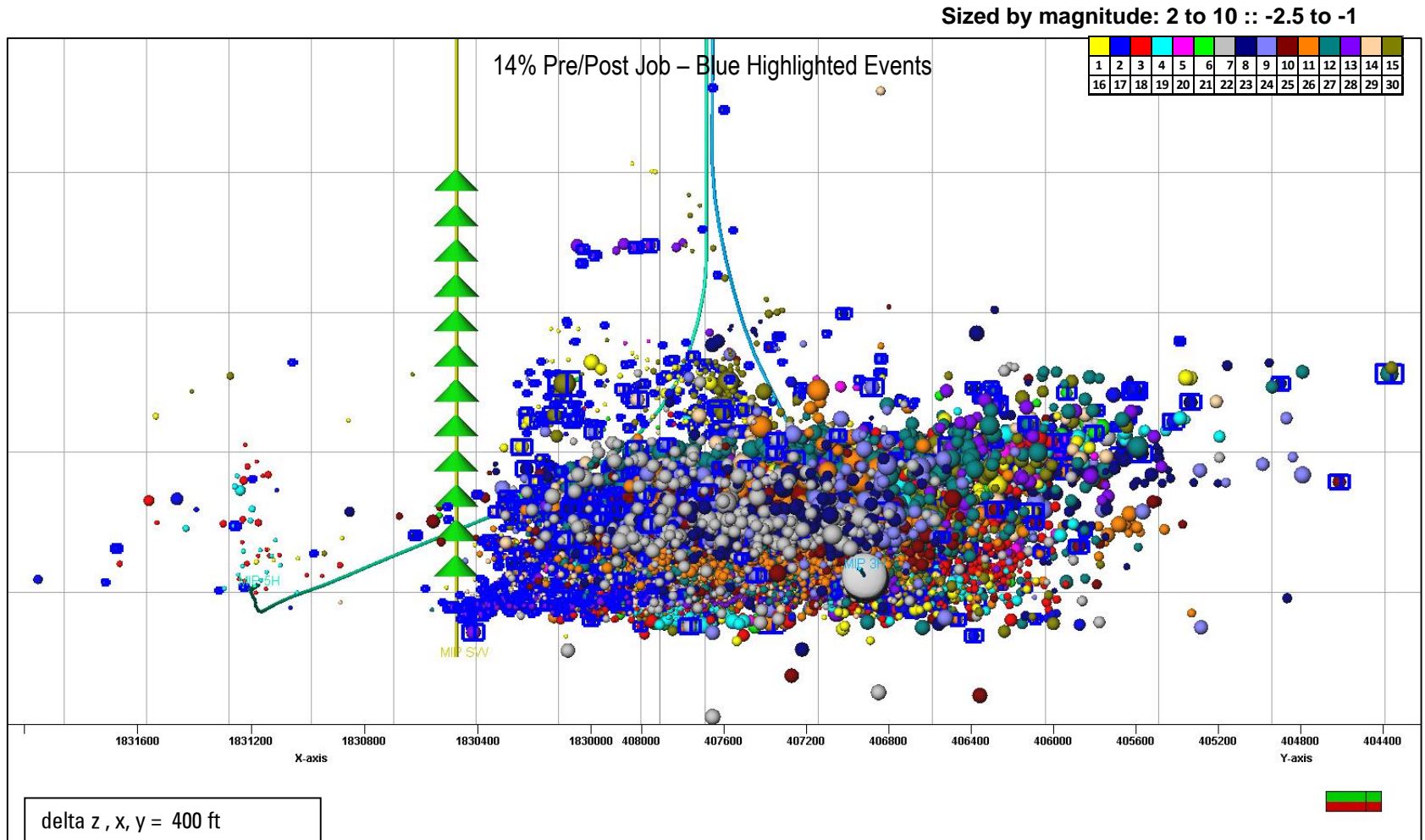
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

MIP 3H Unfiltered – Toe View



MIP 3H Post-Job – Toe View

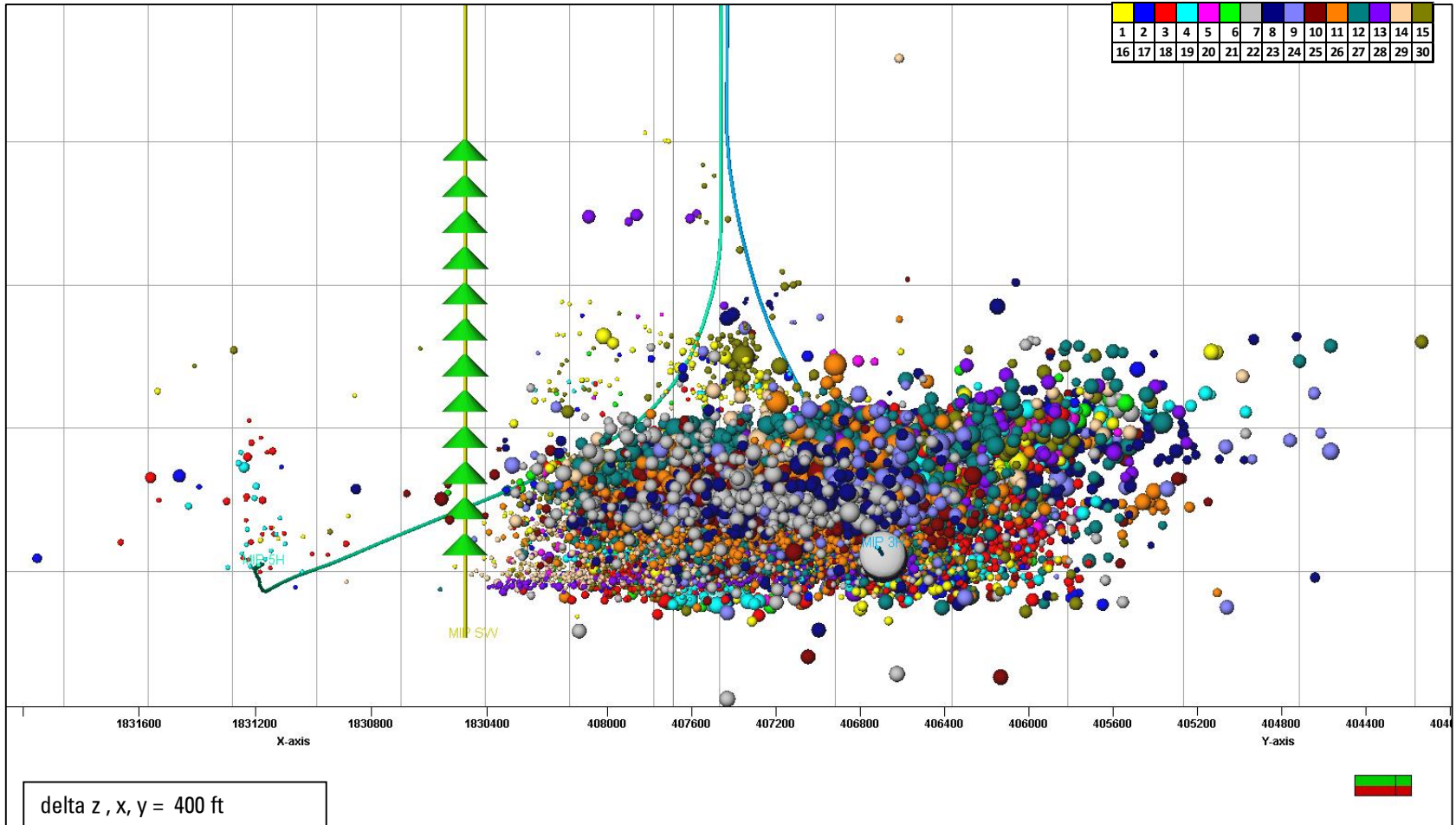


MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

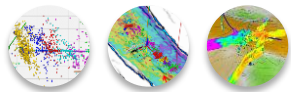
Schlumberger

MIP 3H Rate Filtered – Toe View

Sized by magnitude: 2 to 10 :: -2.5 to -1



Schlumberger-Private

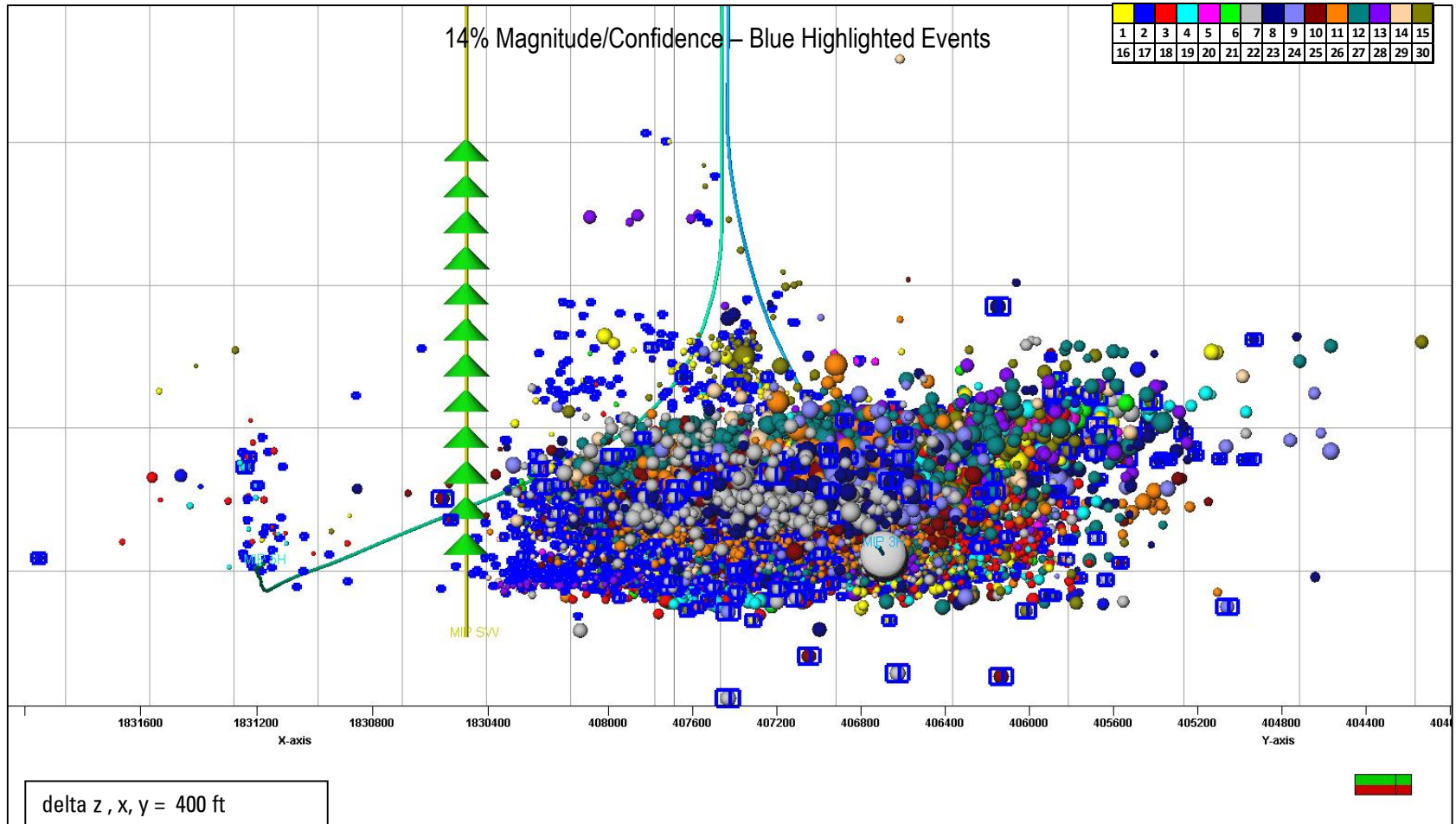


MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

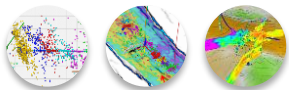
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MIP 3H Magnitude and Confidence – Toe View

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Schlumberger-Private

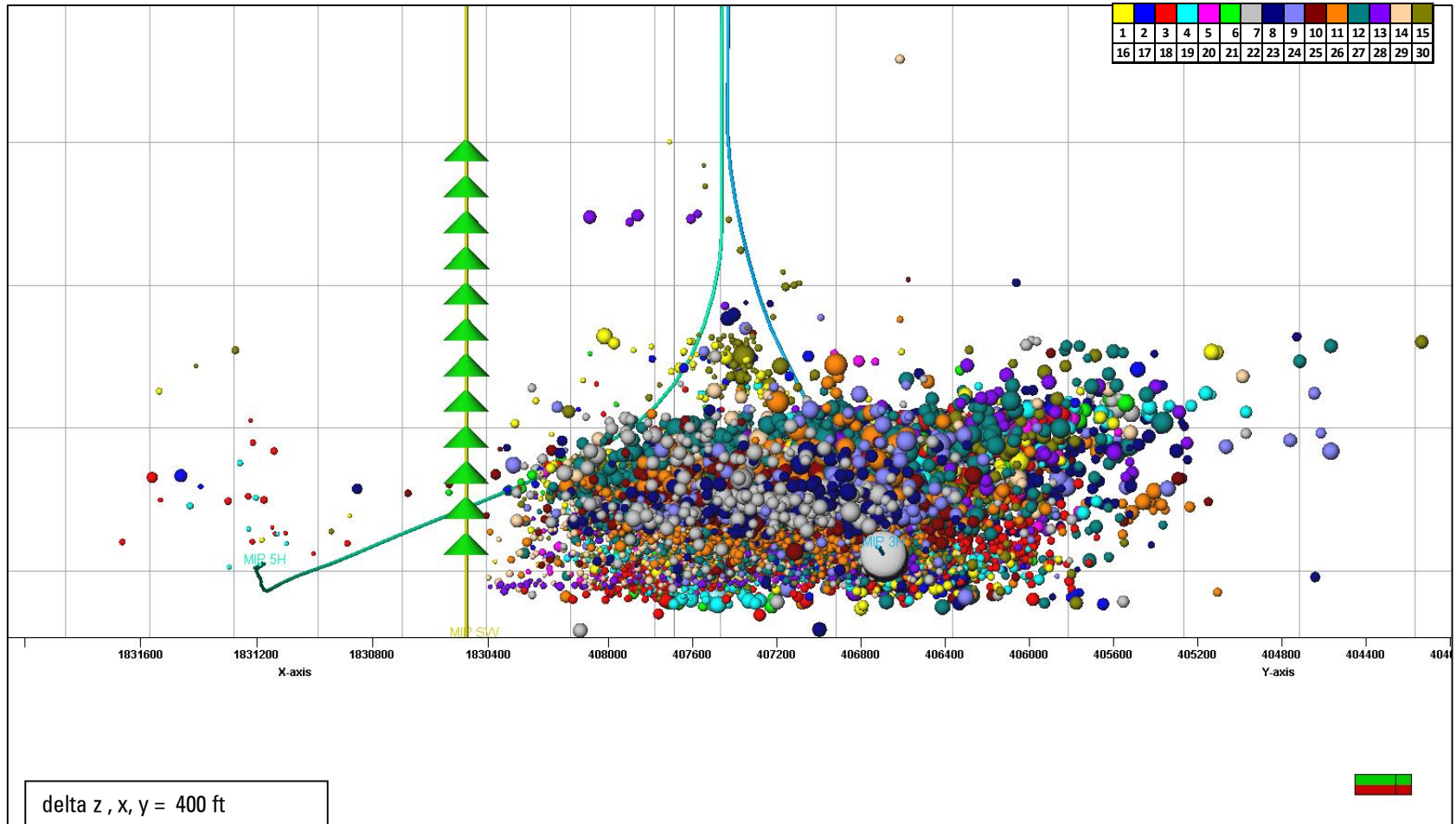


MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

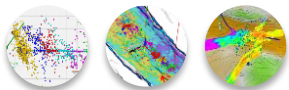
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MIP 3H Filtered – Toe View

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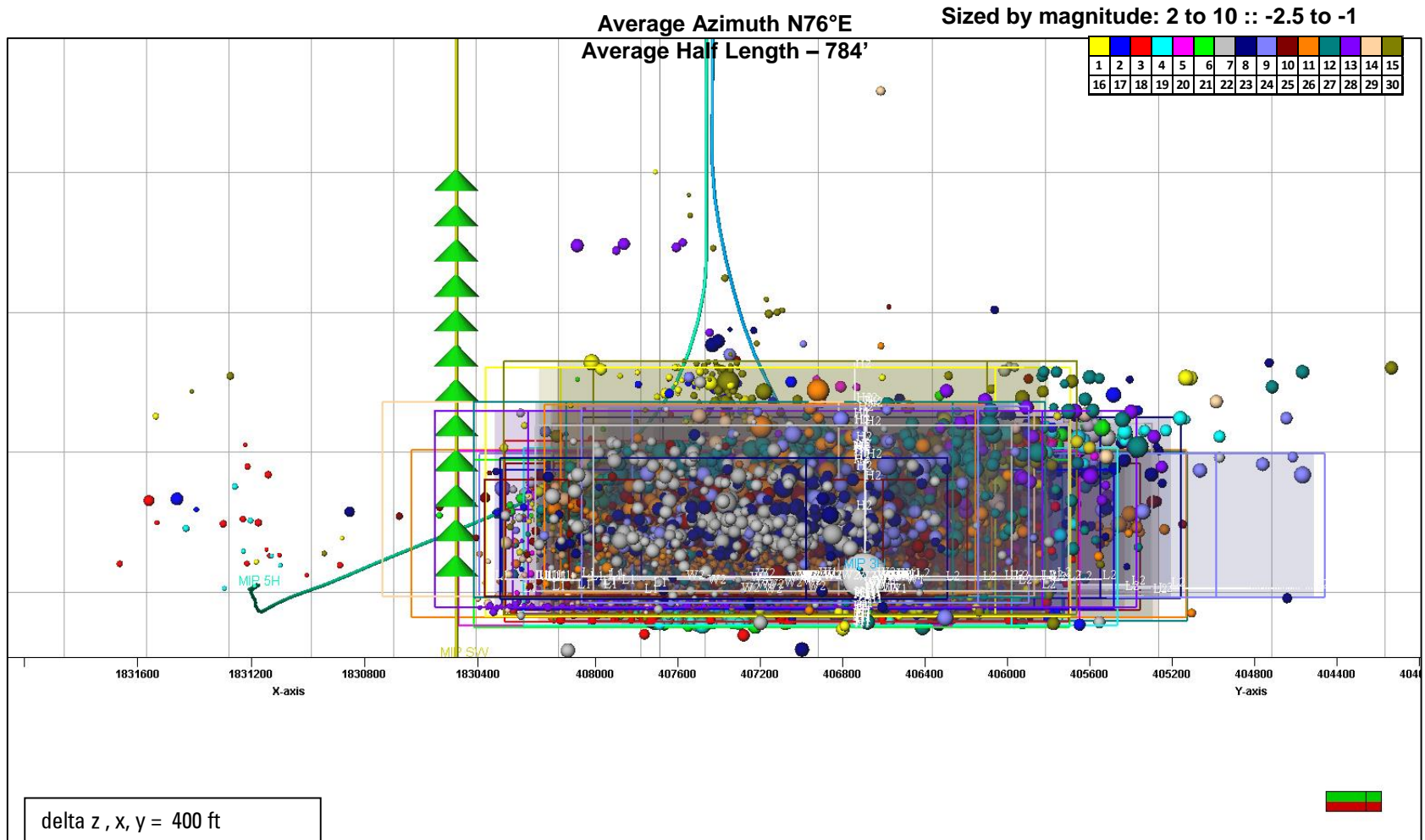
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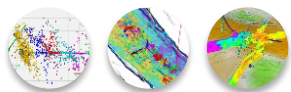
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

MIP 3H Microseismic Dimensions – Toe View



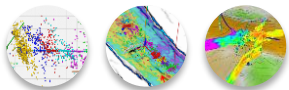
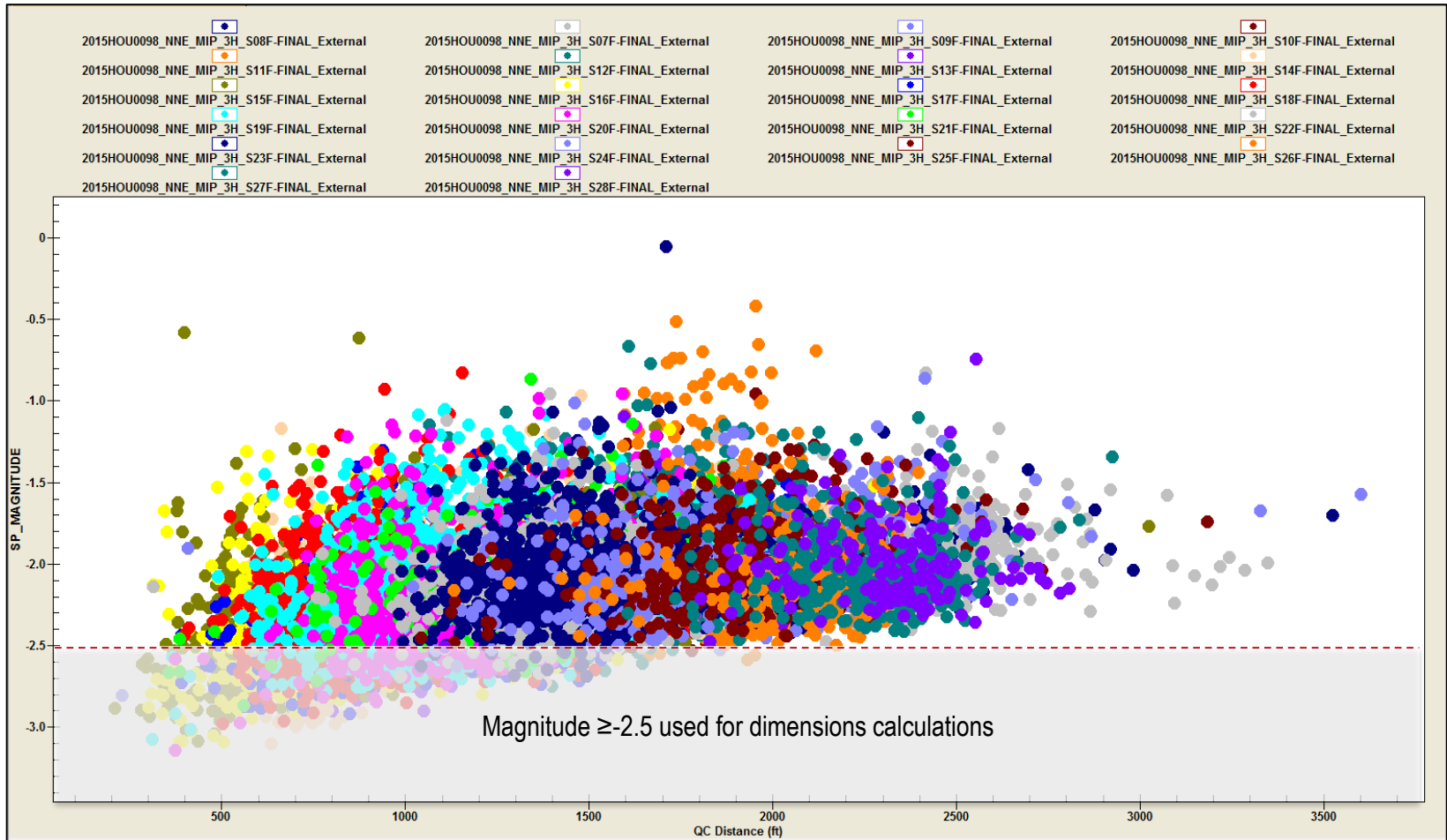
Schlumberger-Private



MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

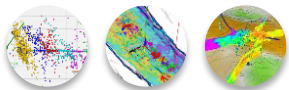
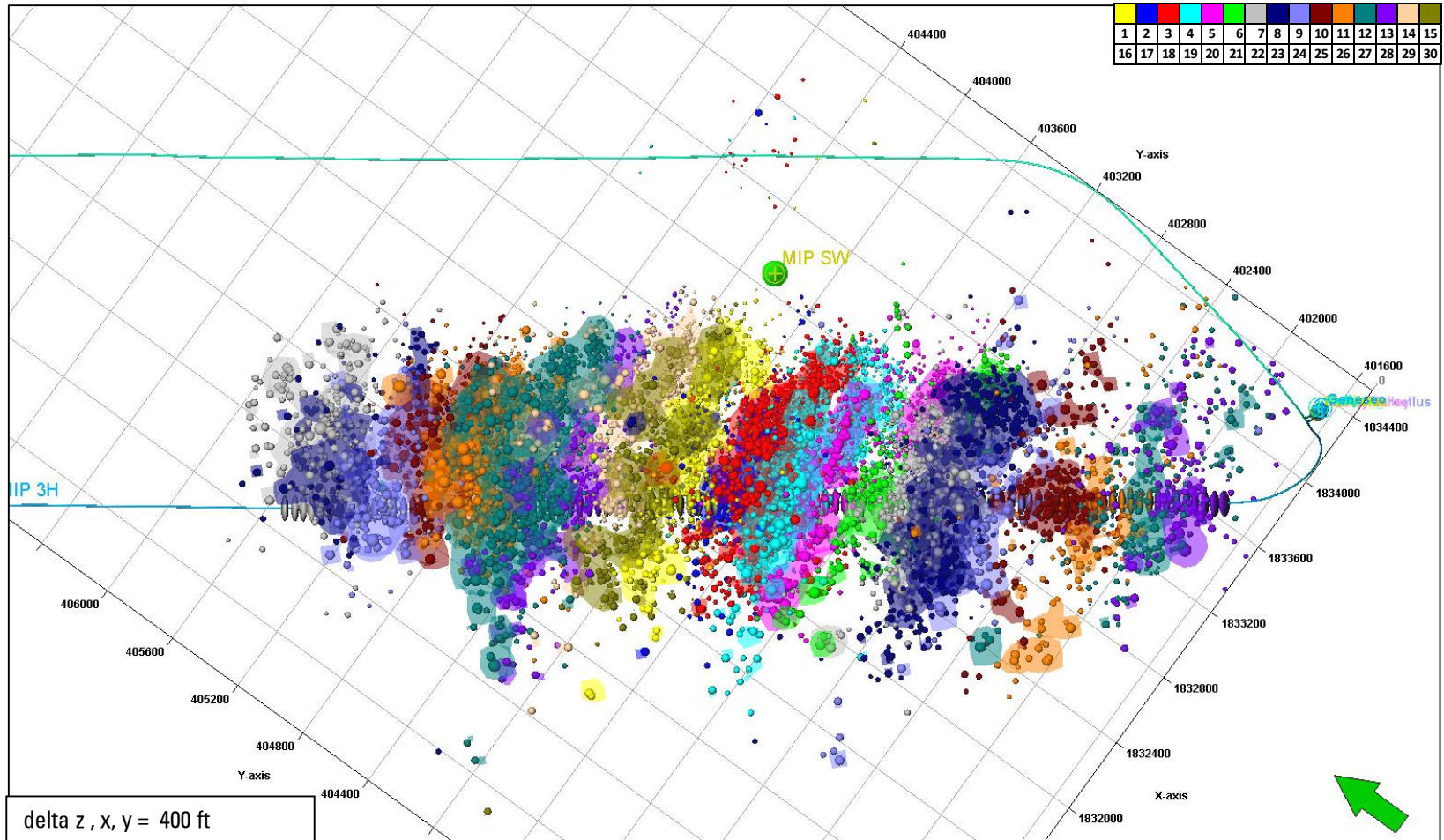
Schlumberger

MIP 3H Magnitude vs. Distance



MIP 3H Microseismic ESVs – Map View

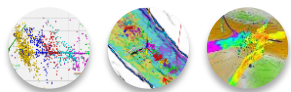
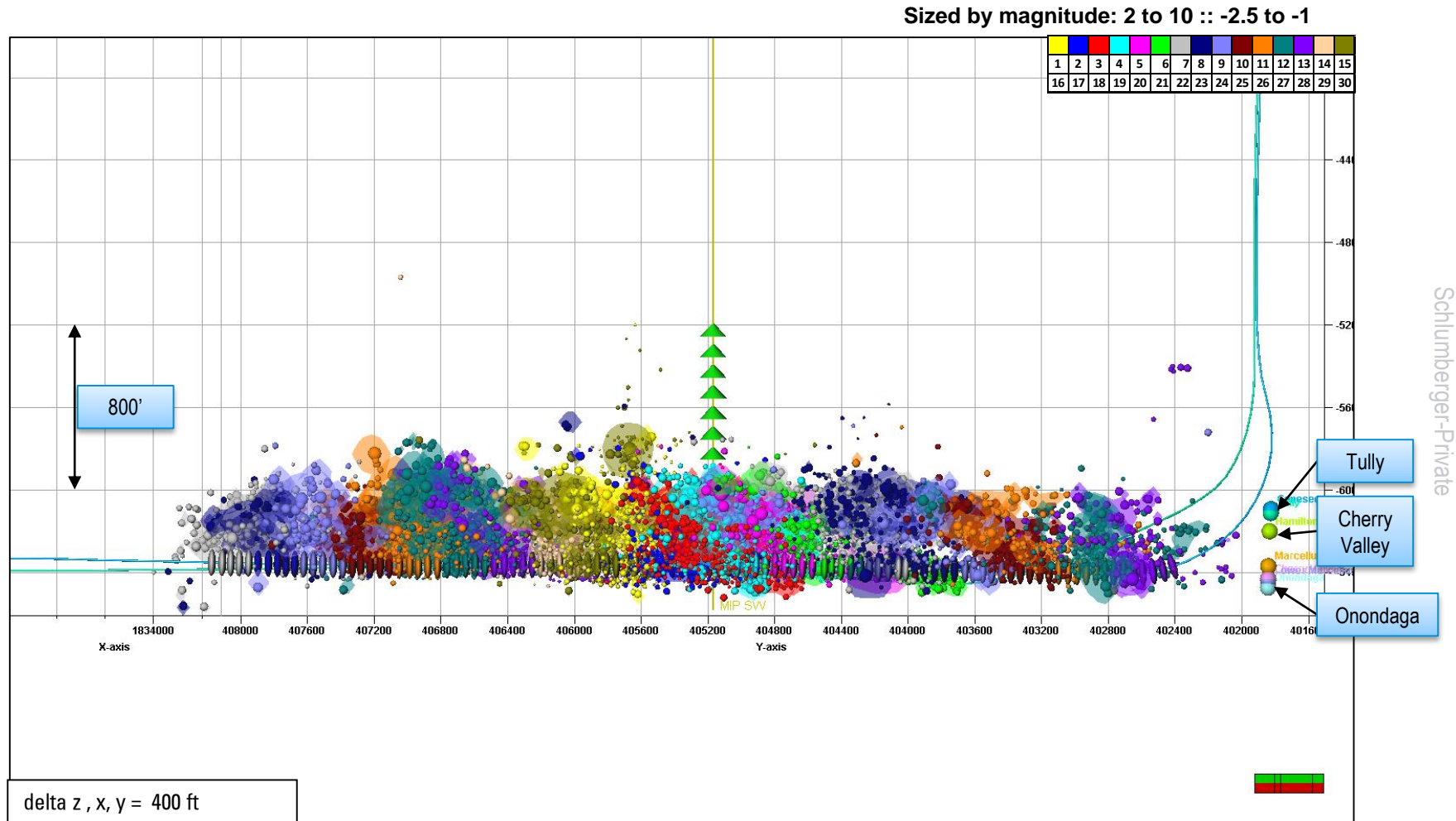
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MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

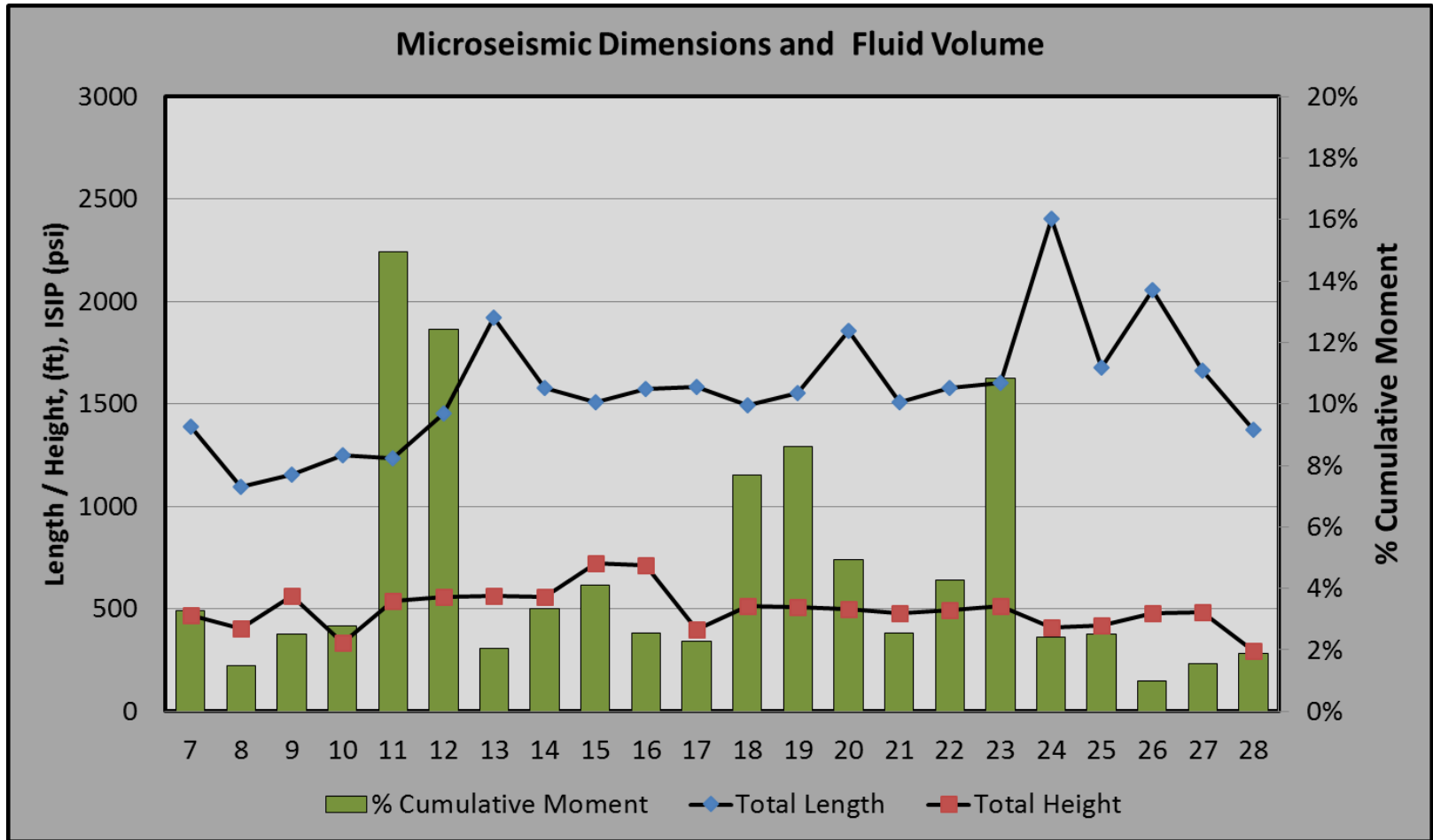
MIP 3H Microseismic ESVs – Depth View



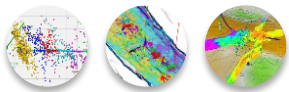
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

MIP 3H Cumulative Moment



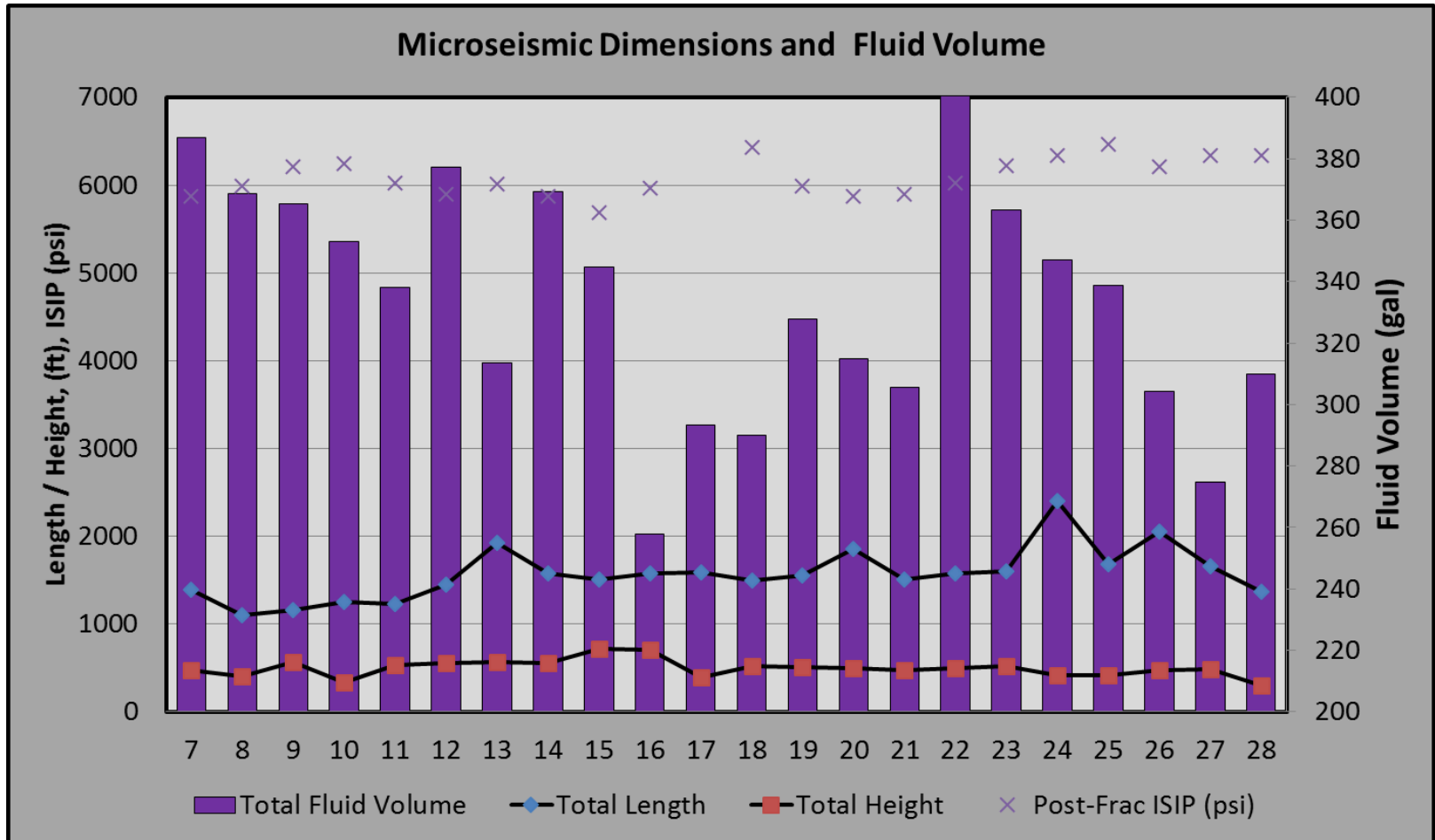
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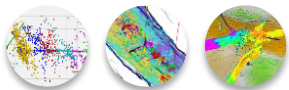
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE



MIP 3H Dimensions and Fluid Volume



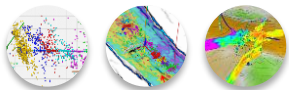
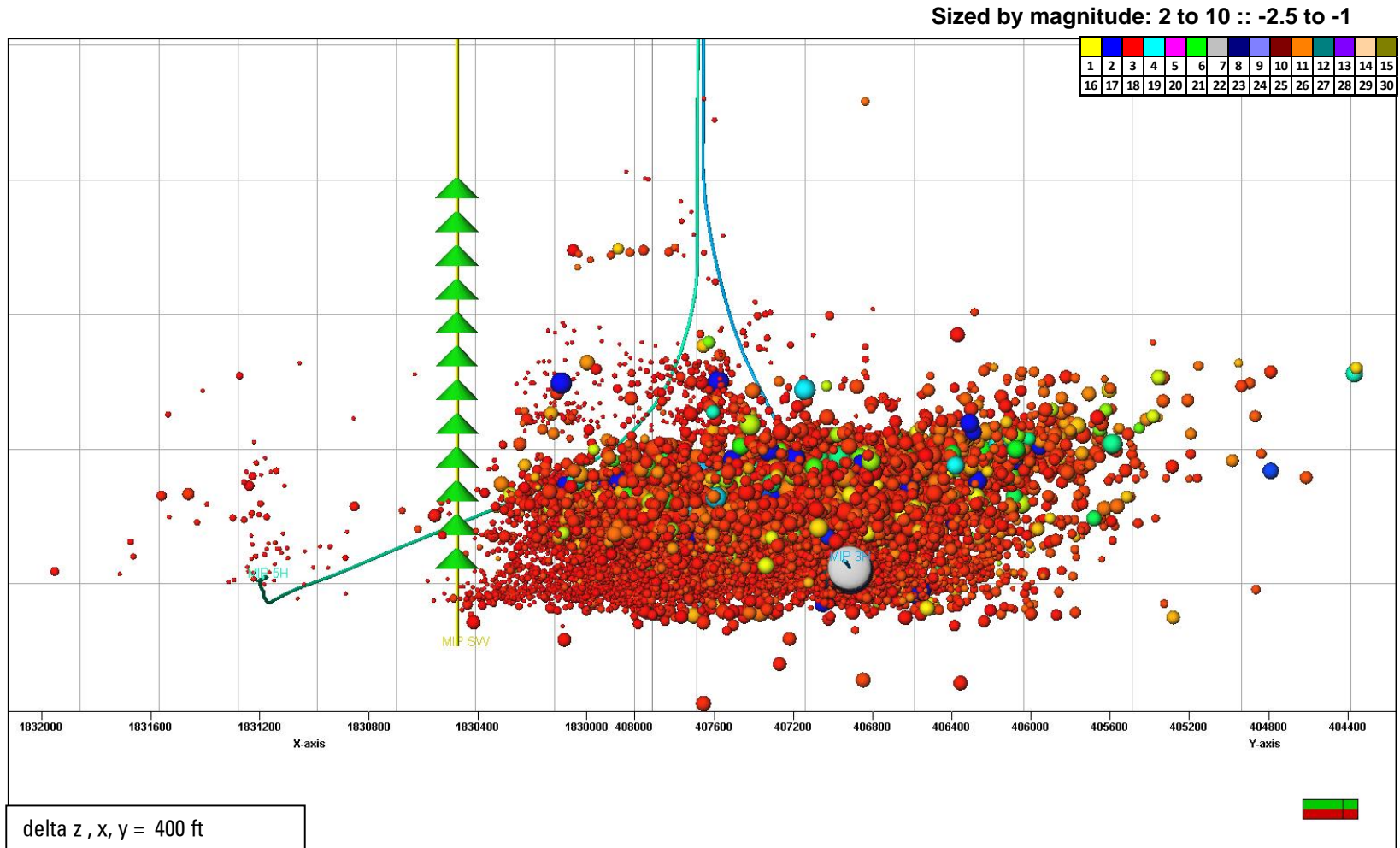
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MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

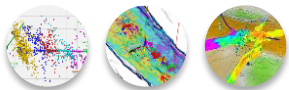
Schlumberger

Stress Drop 3H – Depth View

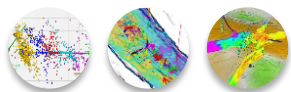


Observations

- MIP 3H Average Half Length: 784ft, Average Height: 496ft, Average Azimuths N76°E.
- Low inter-stage interference was observed, indicating good stage isolation.
- Overall fracture geometries do not vary significantly based on microseismic. A detailed comparison of the multiple fluid systems are compared in a subsequent section.



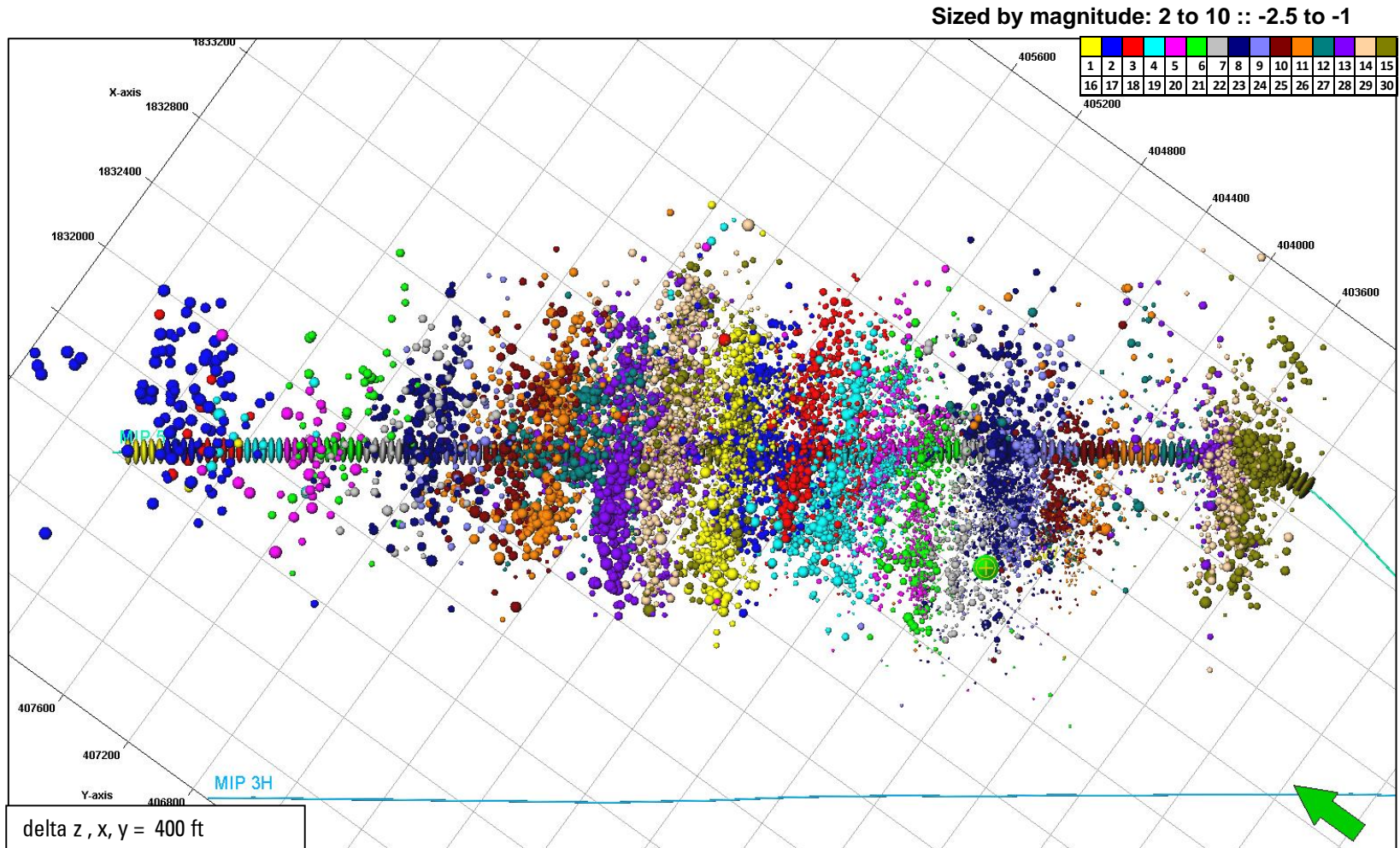
MIP 5H Cherry Valley



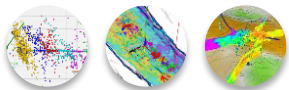
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

MIP 5H Unfiltered – Map View



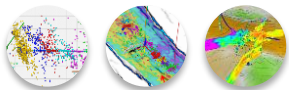
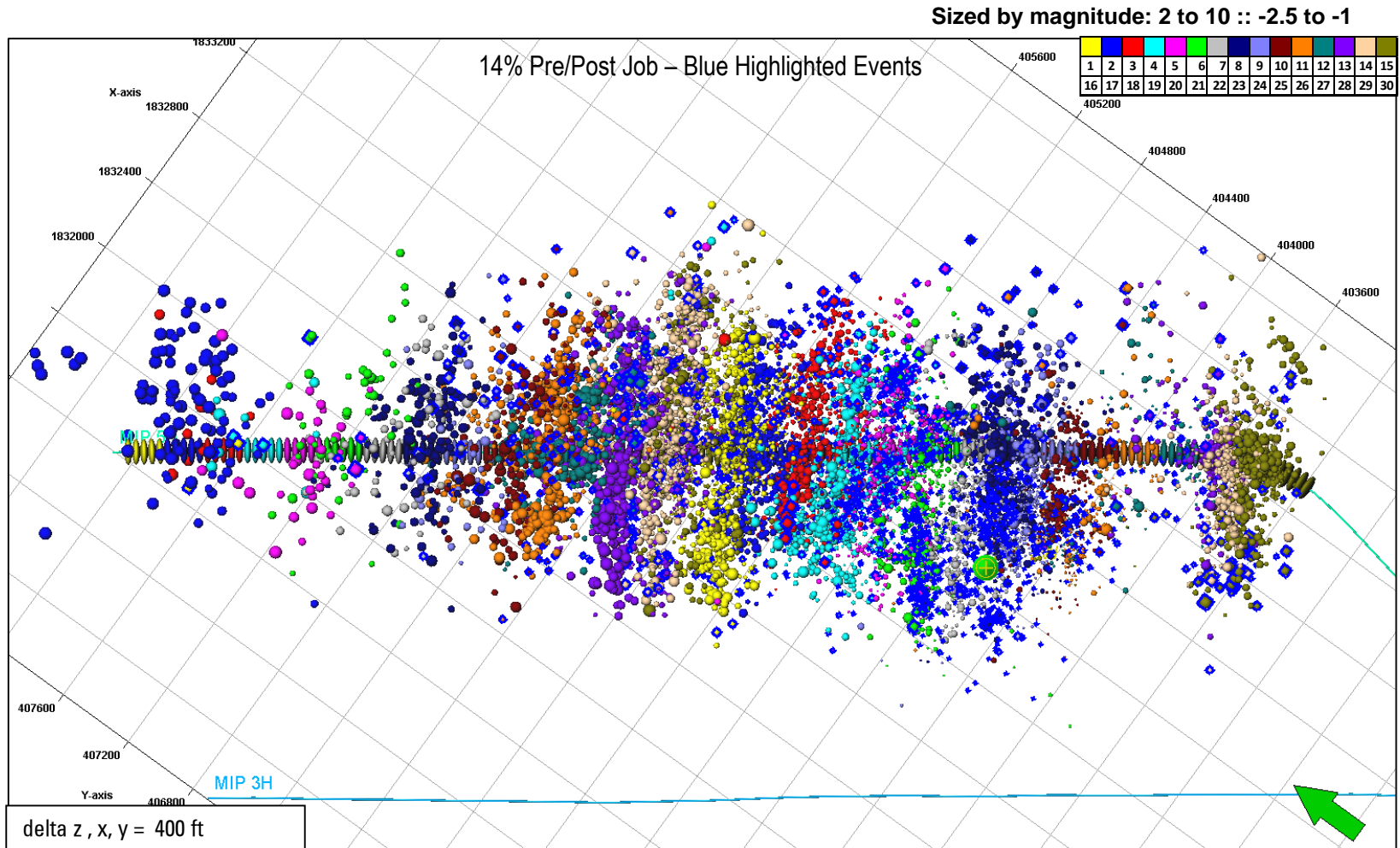
Schlumberger-Private



MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

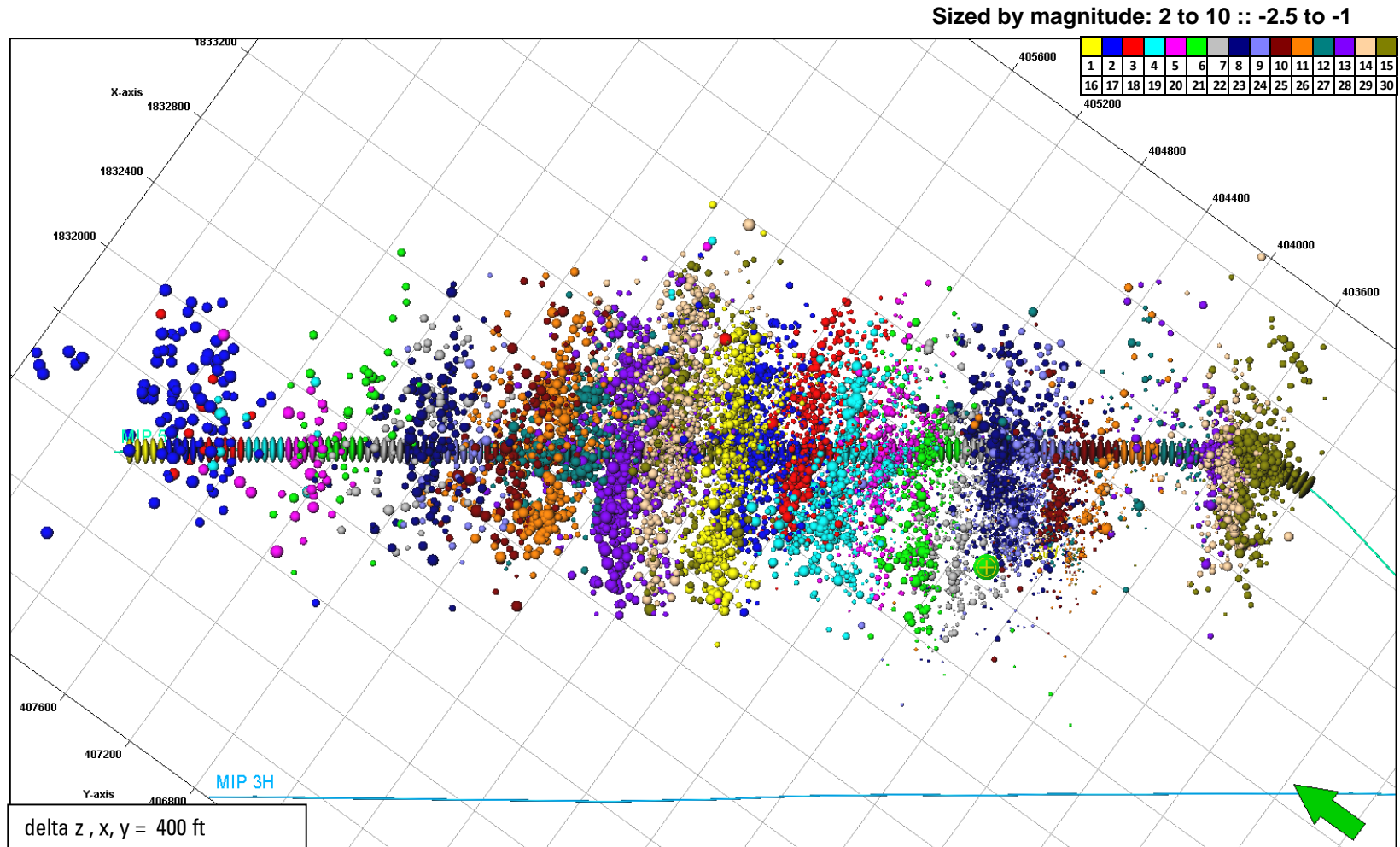
MIP 5H Post Job – Map View



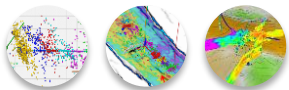
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

MIP 5H Rate Filtered – Map View



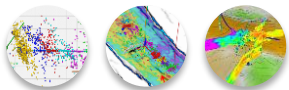
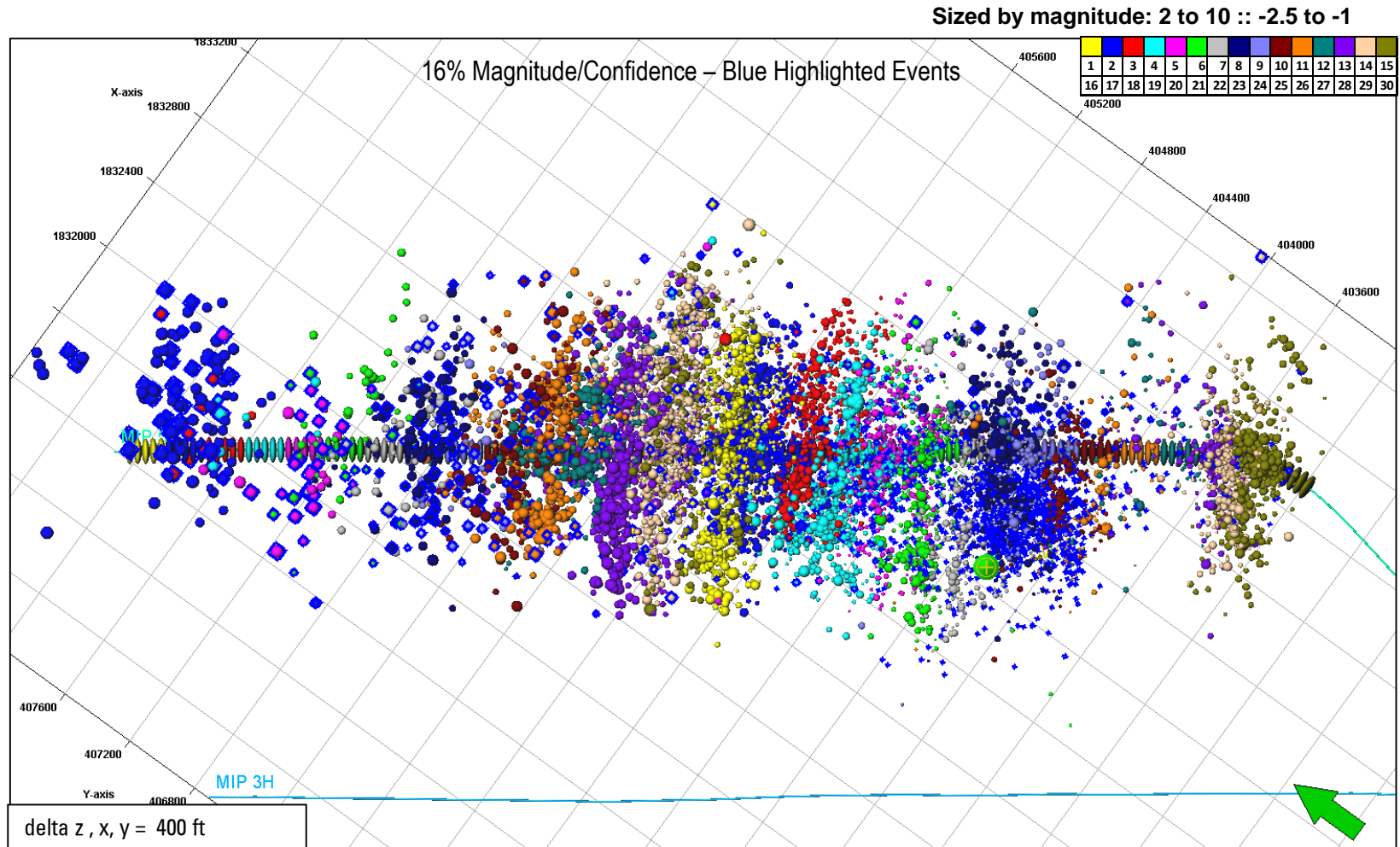
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MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

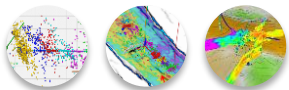
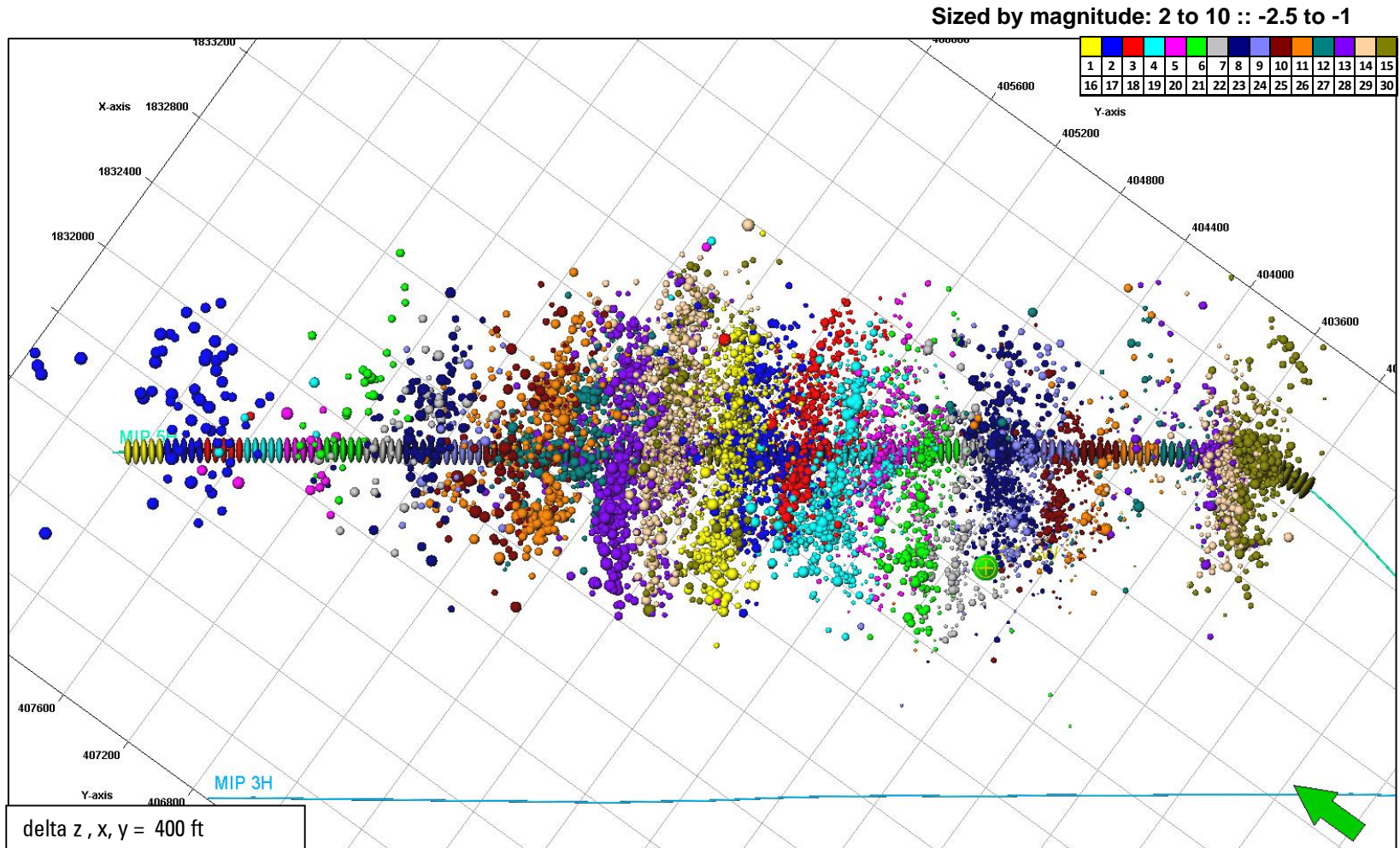
MIP 5H Magnitude and Confidence – Map View



MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

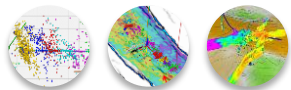
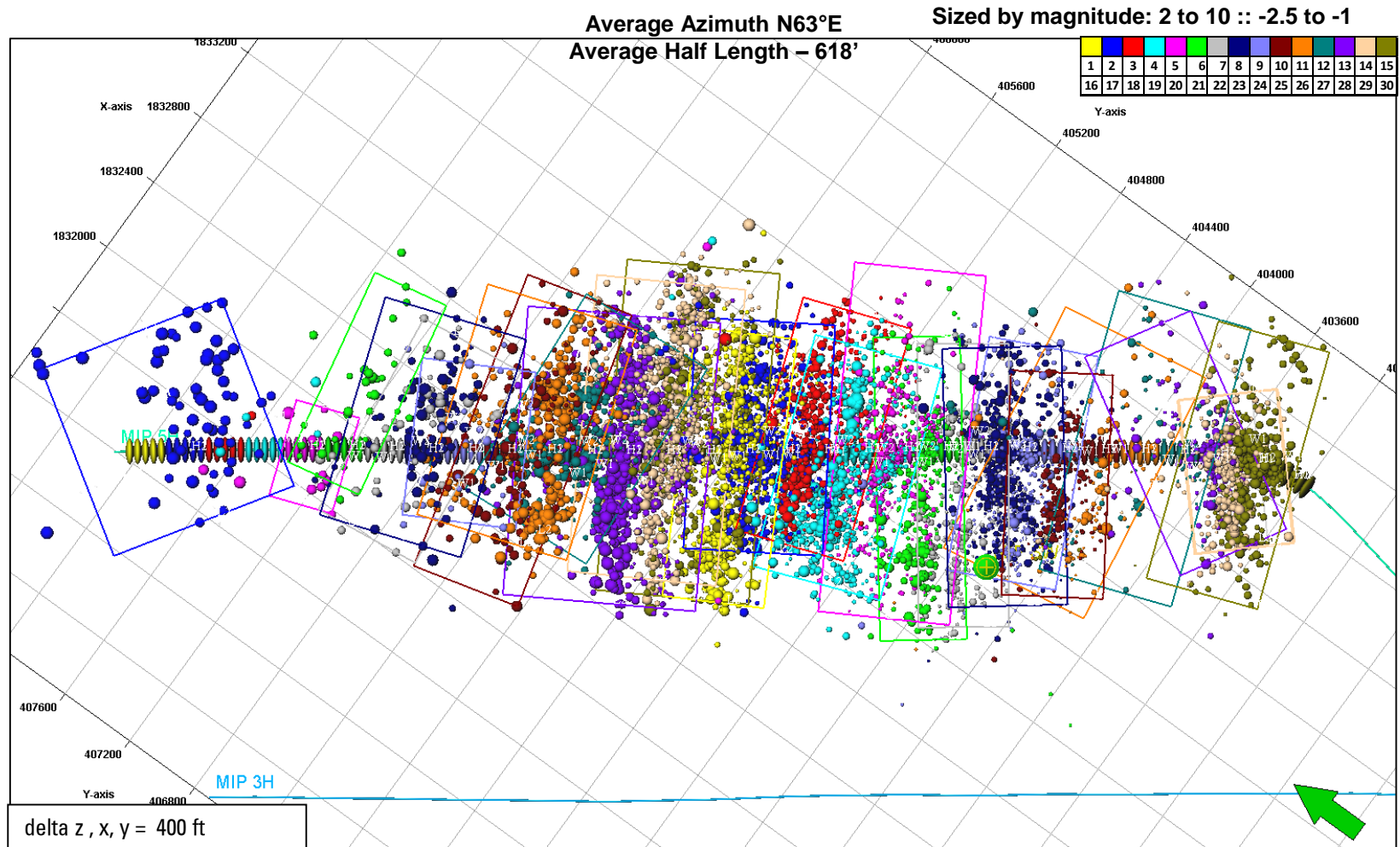
MIP 5H Filtered – Map View



MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

MIP 5H Microseismic Dimensions – Map View

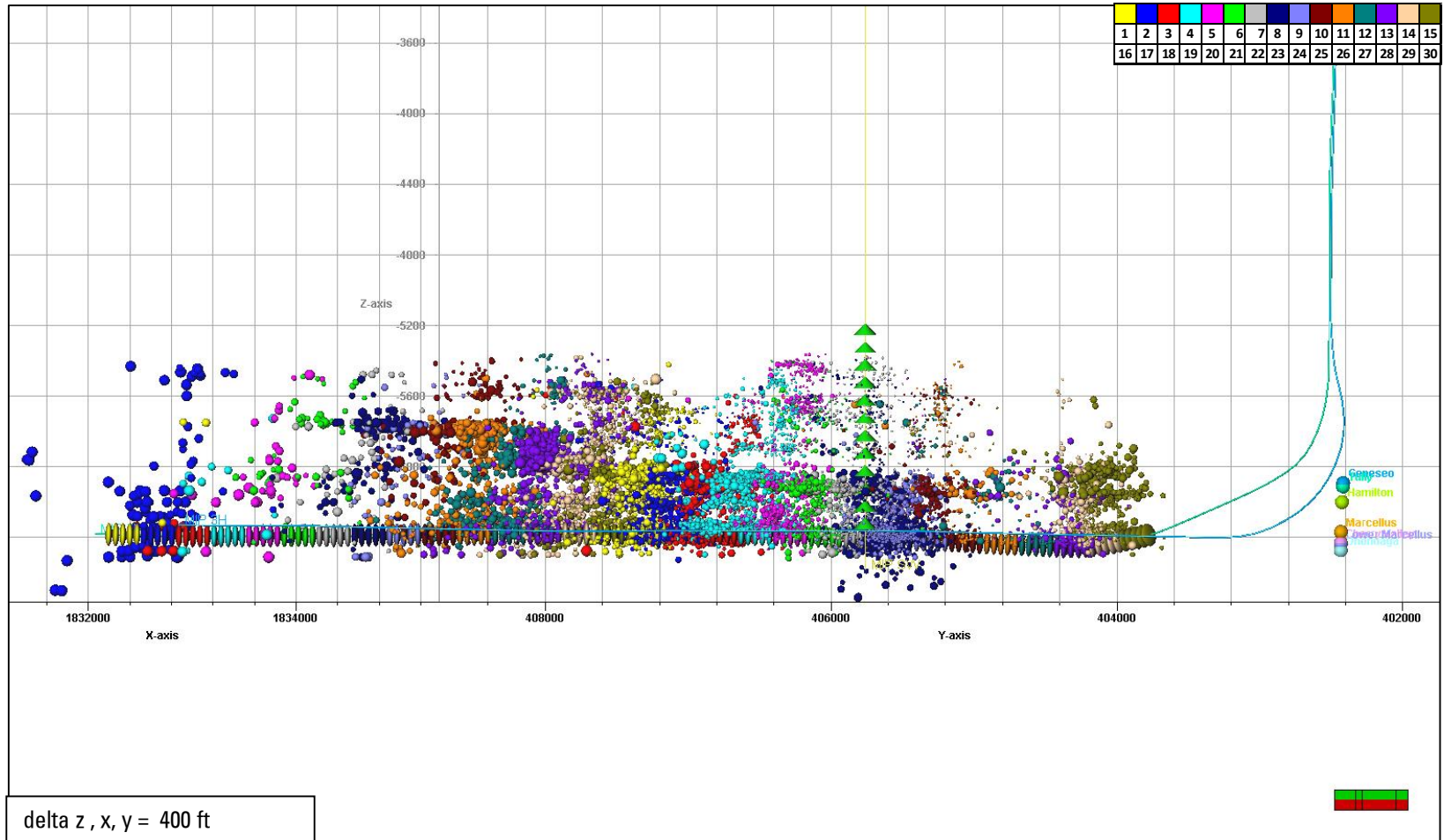


MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

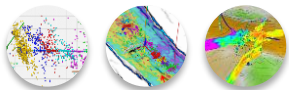
Schlumberger

MIP 5H Unfiltered – Depth View

Sized by magnitude: 2 to 10 :: -2.5 to -1



Schlumberger-Private

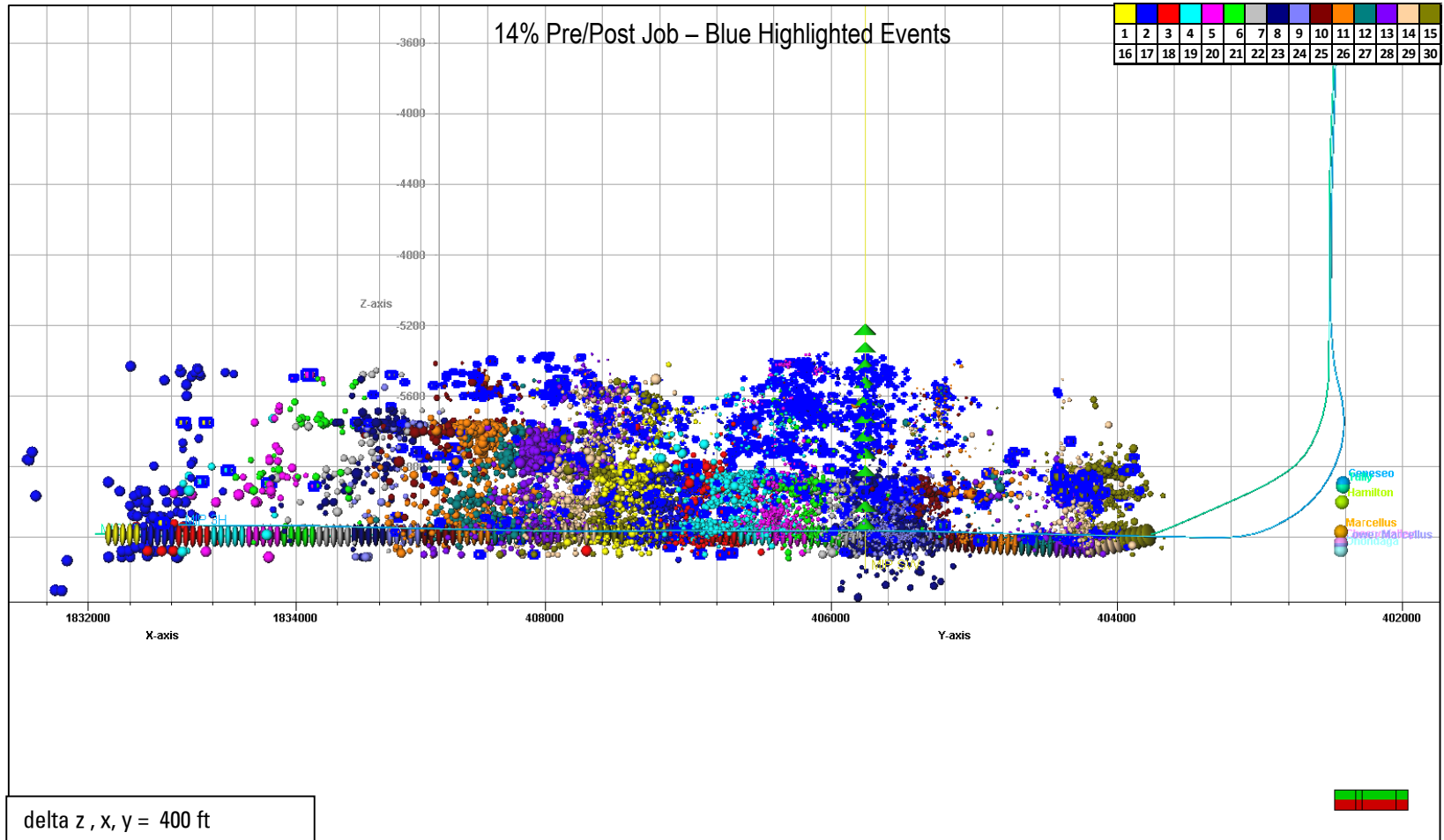


MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

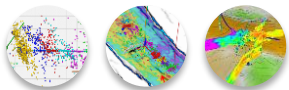
Schlumberger

MIP 5H Post-Job – Depth View

Sized by magnitude: 2 to 10 :: -2.5 to -1



Schlumberger-Private

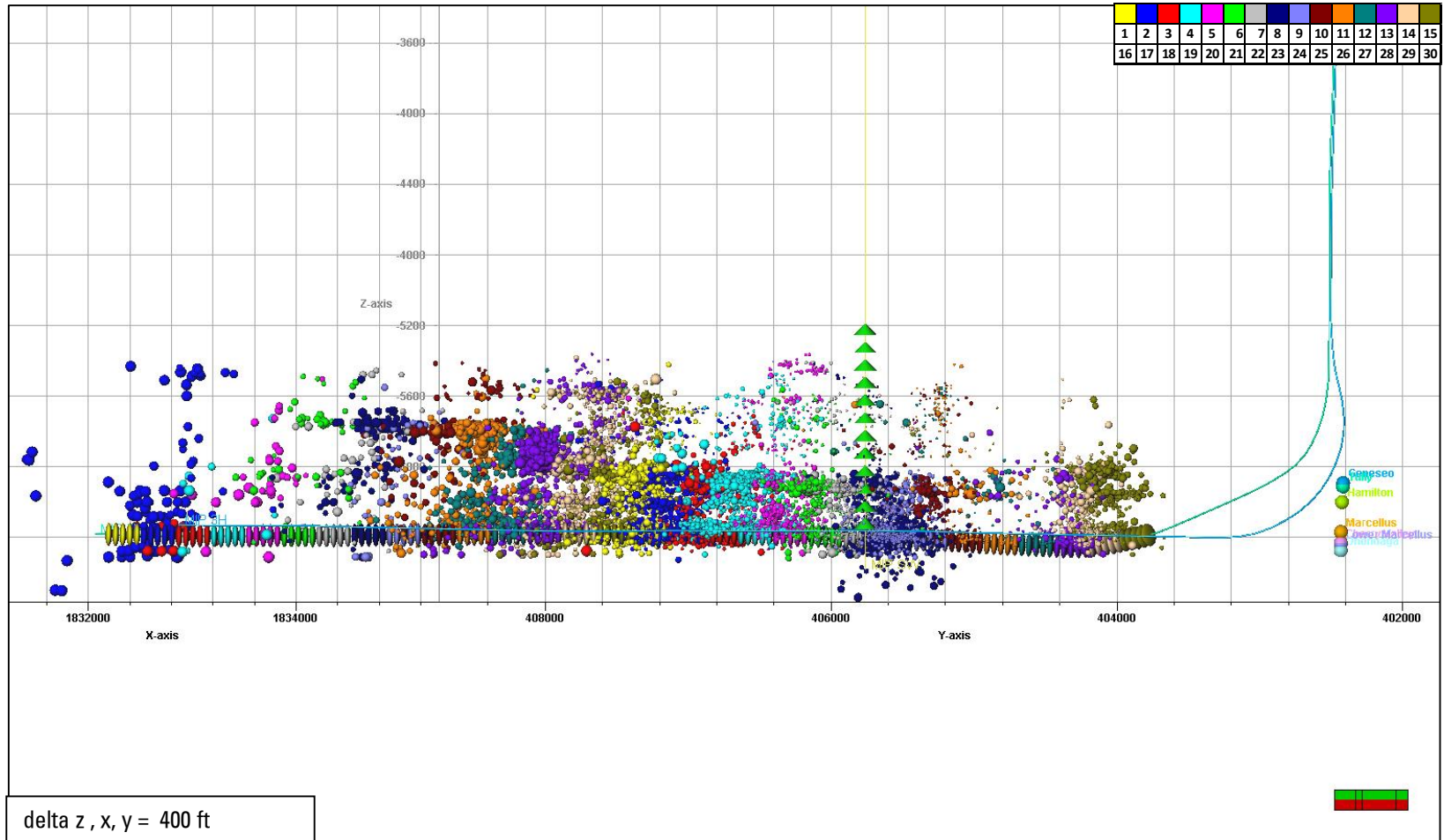


MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

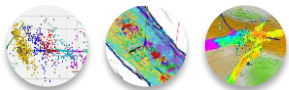
Schlumberger

MIP 5H Rate Filtered – Depth View

Sized by magnitude: 2 to 10 :: -2.5 to -1



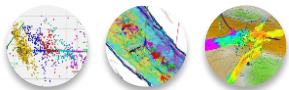
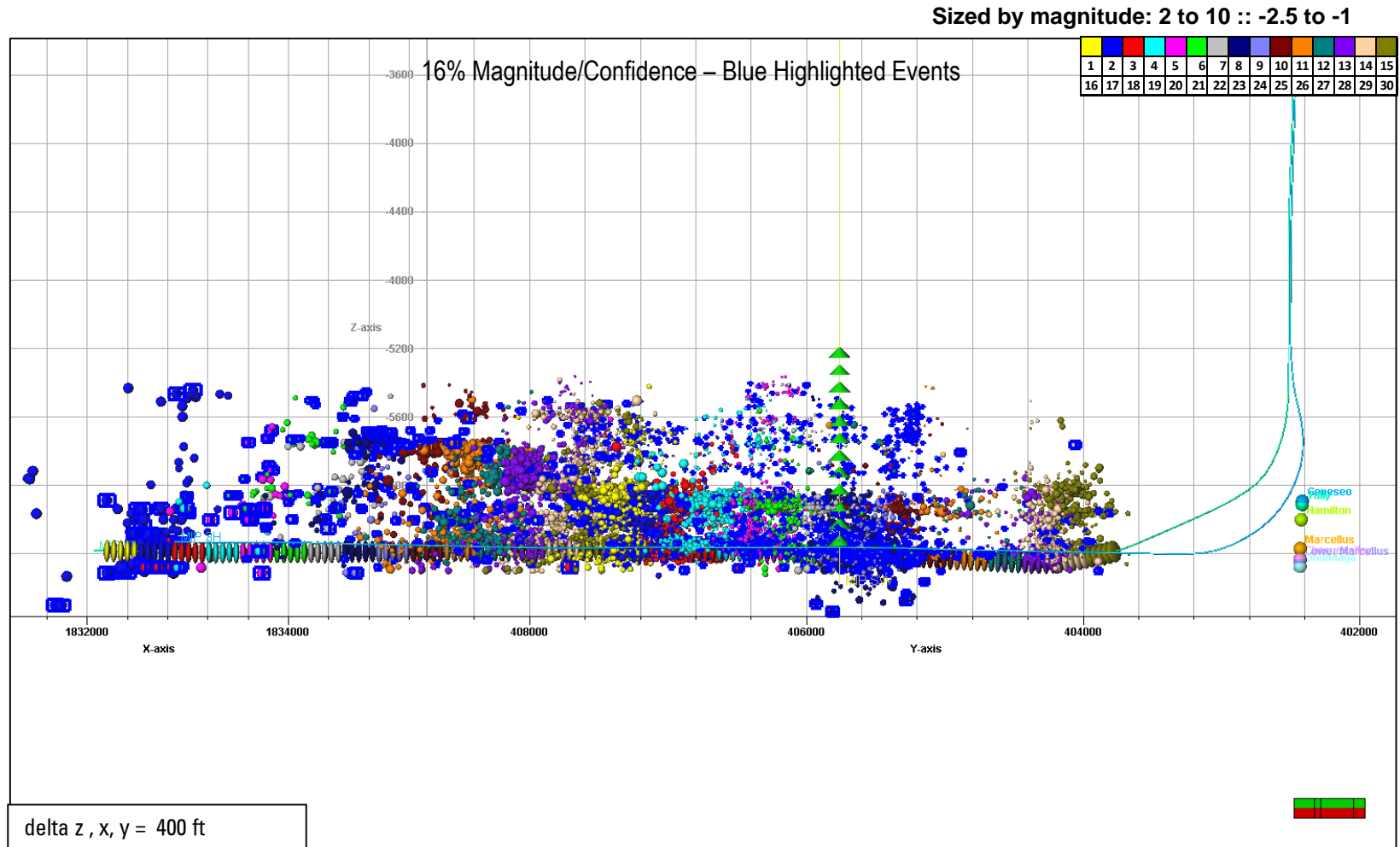
Schlumberger-Private



MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

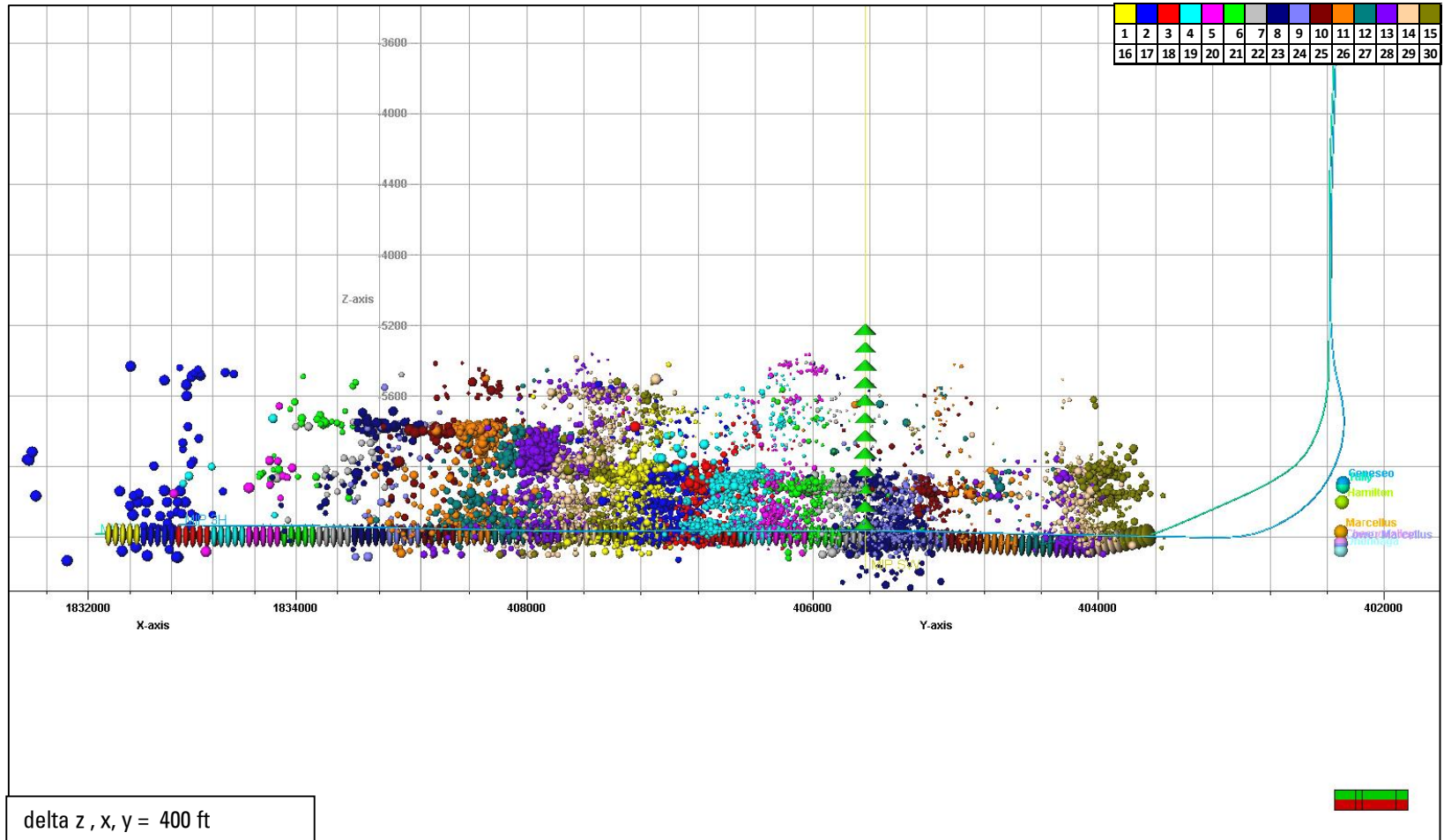
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MIP 5H Magnitude and Confidence – Depth View

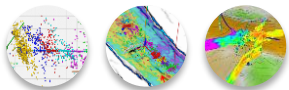


MIP 5H Filtered – Depth View

Sized by magnitude: 2 to 10 :: -2.5 to -1



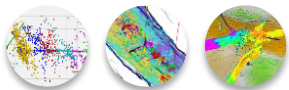
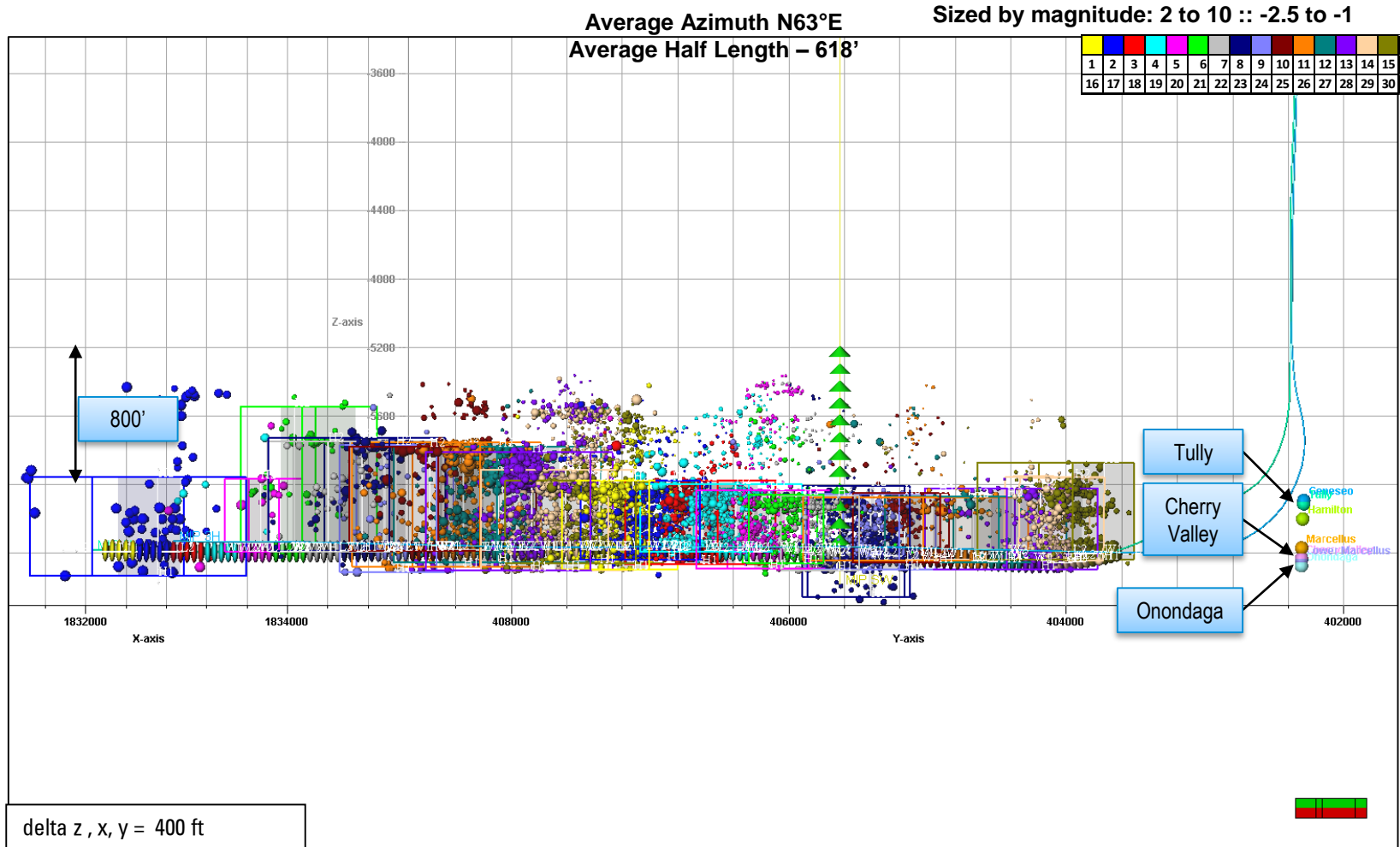
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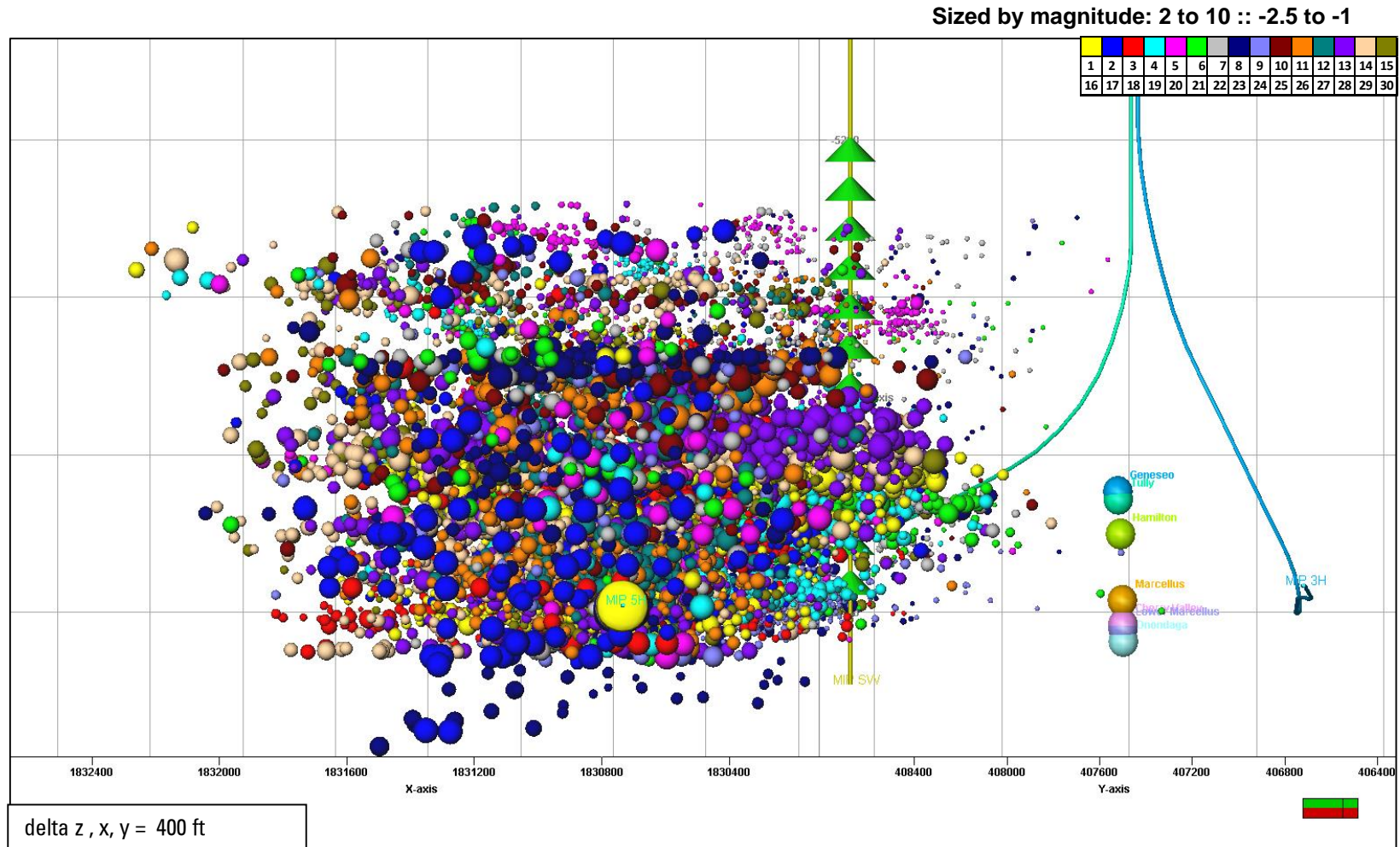
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

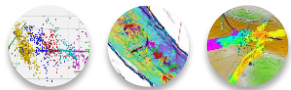
MIP 5H Microseismic Dimensions – Depth View



MIP 5H Unfiltered – Toe View



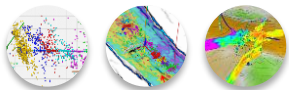
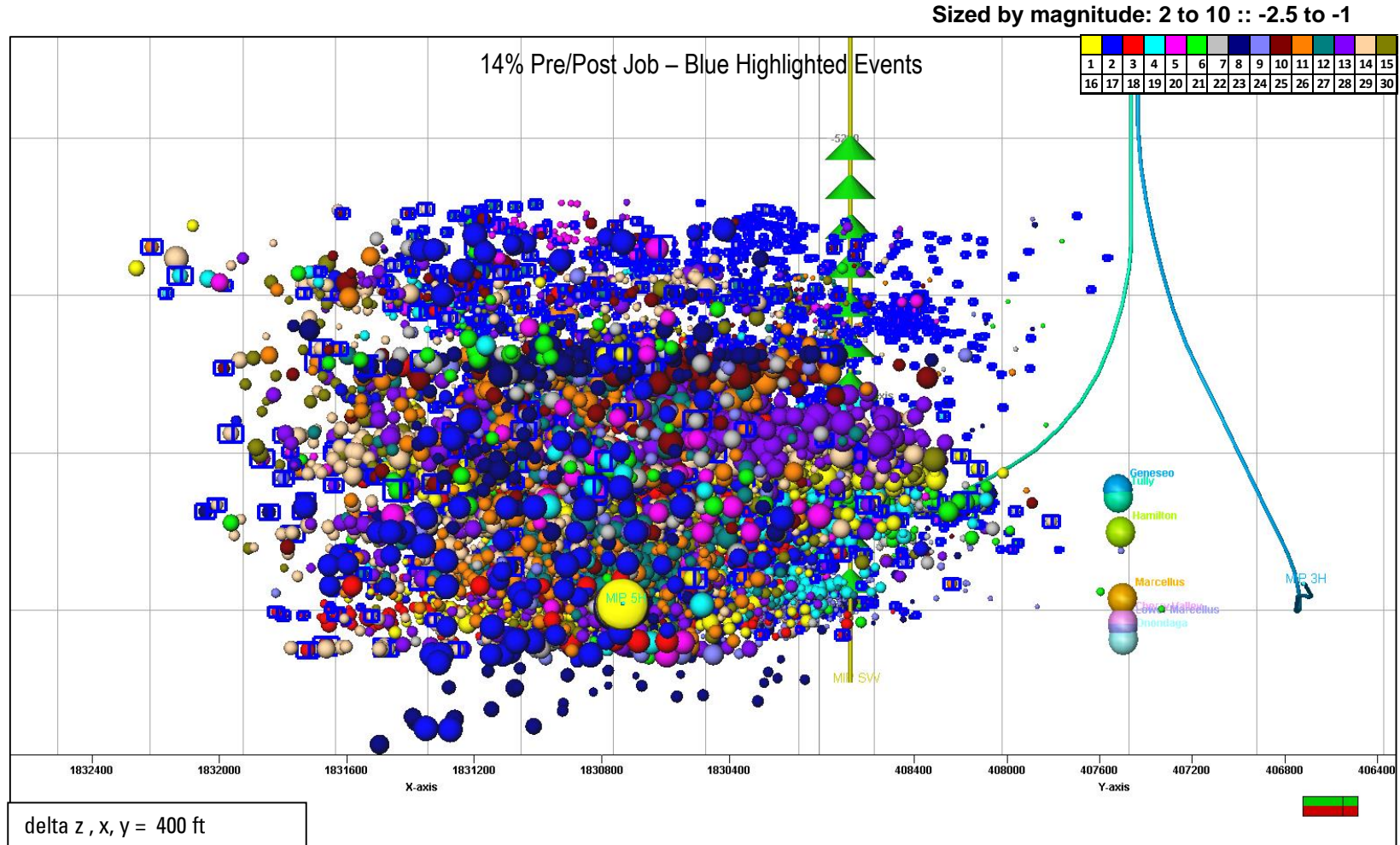
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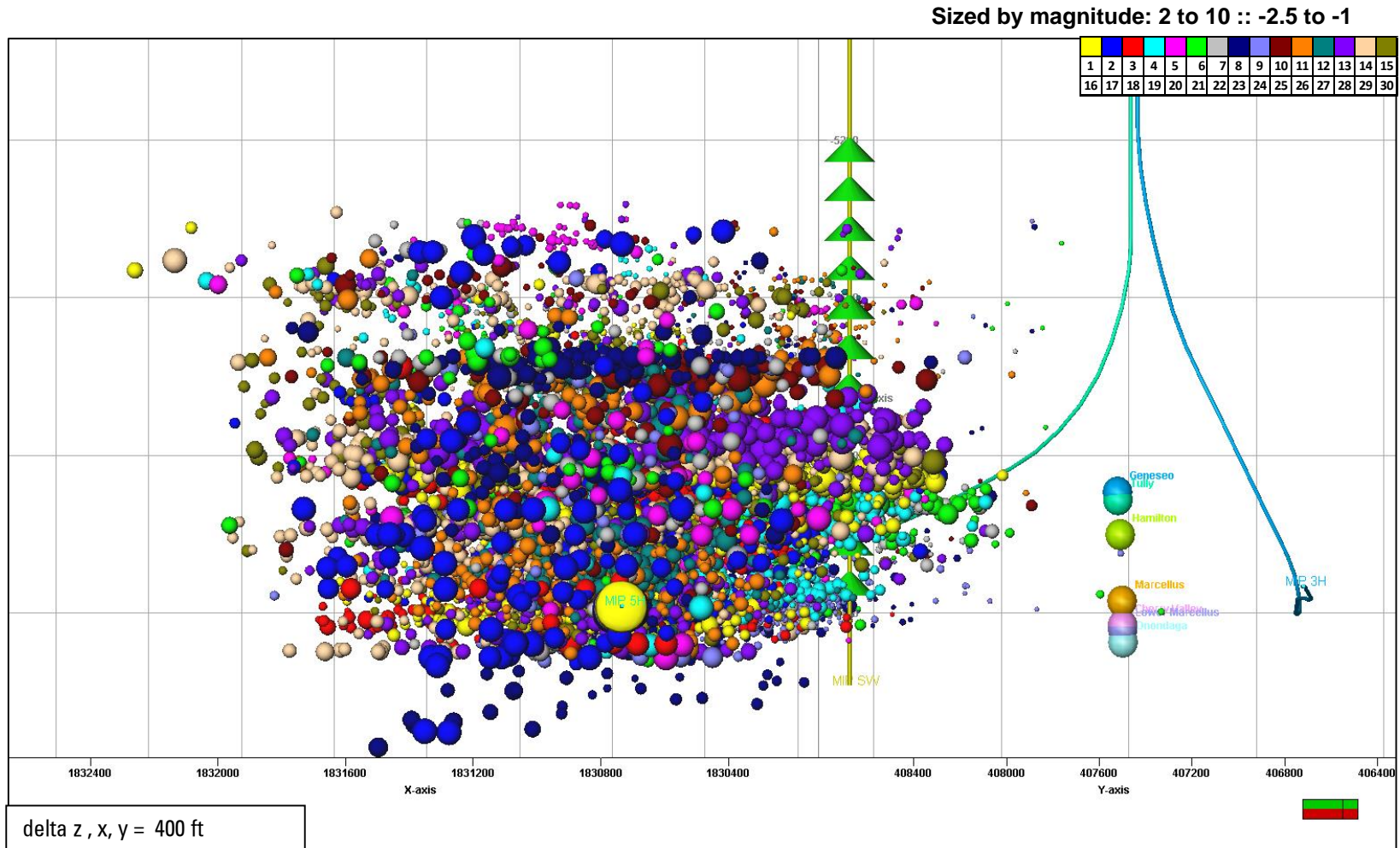
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

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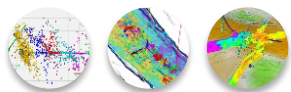
MIP 5H Post-Job – Toe View



MIP 5H Rate Filtered – Toe View



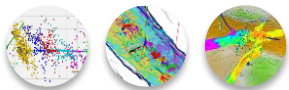
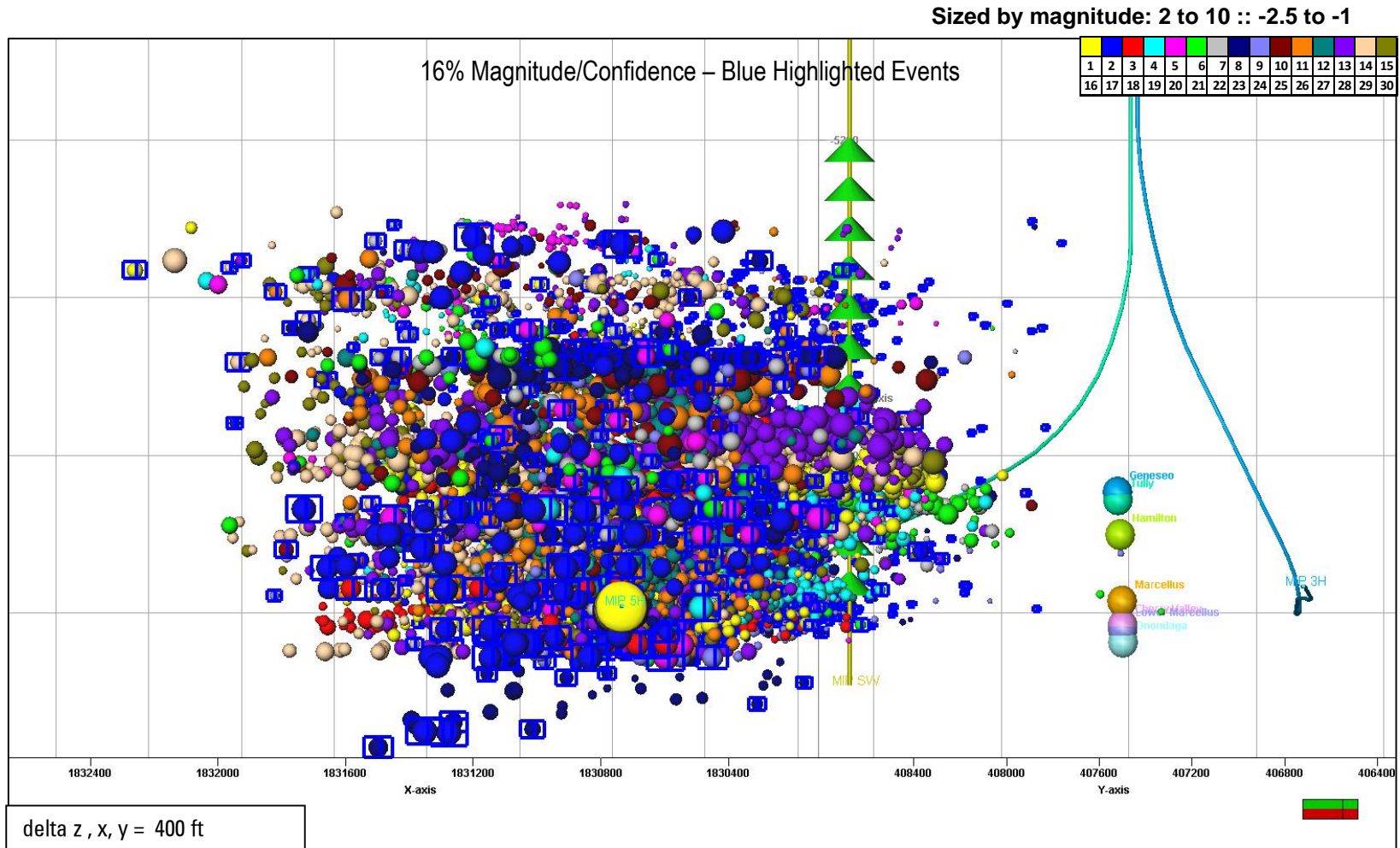
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MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE



MIP 5H Magnitude and Confidence – Toe View

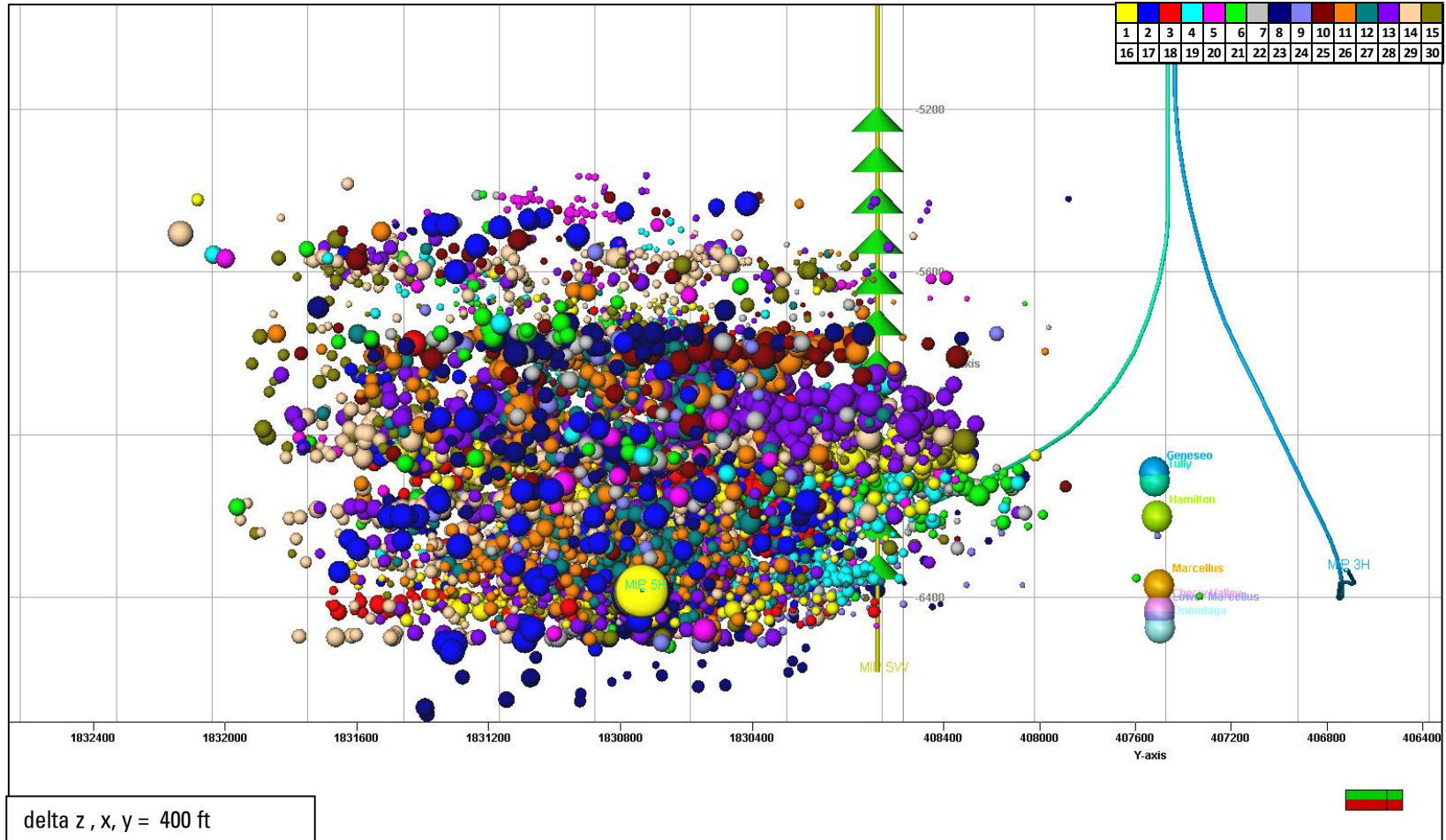


MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

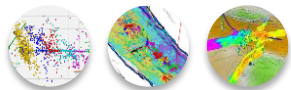
Schlumberger

MIP 5H Filtered – Toe View

Sized by magnitude: 2 to 10 :: -2.5 to -1



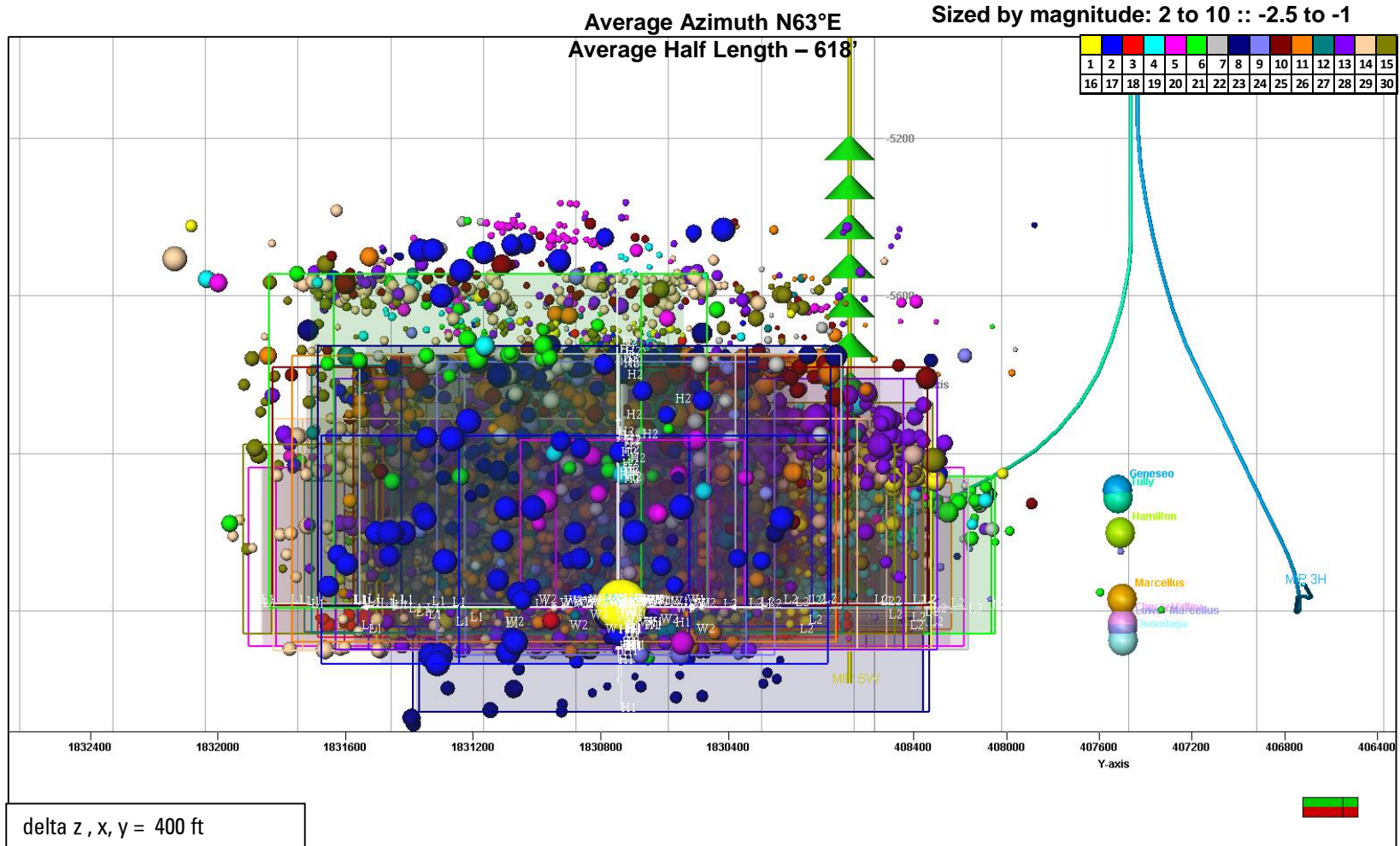
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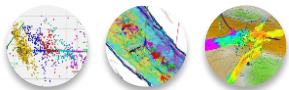
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

MIP 5H Microseismic Dimensions – Toe View



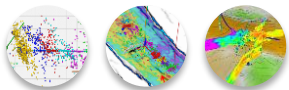
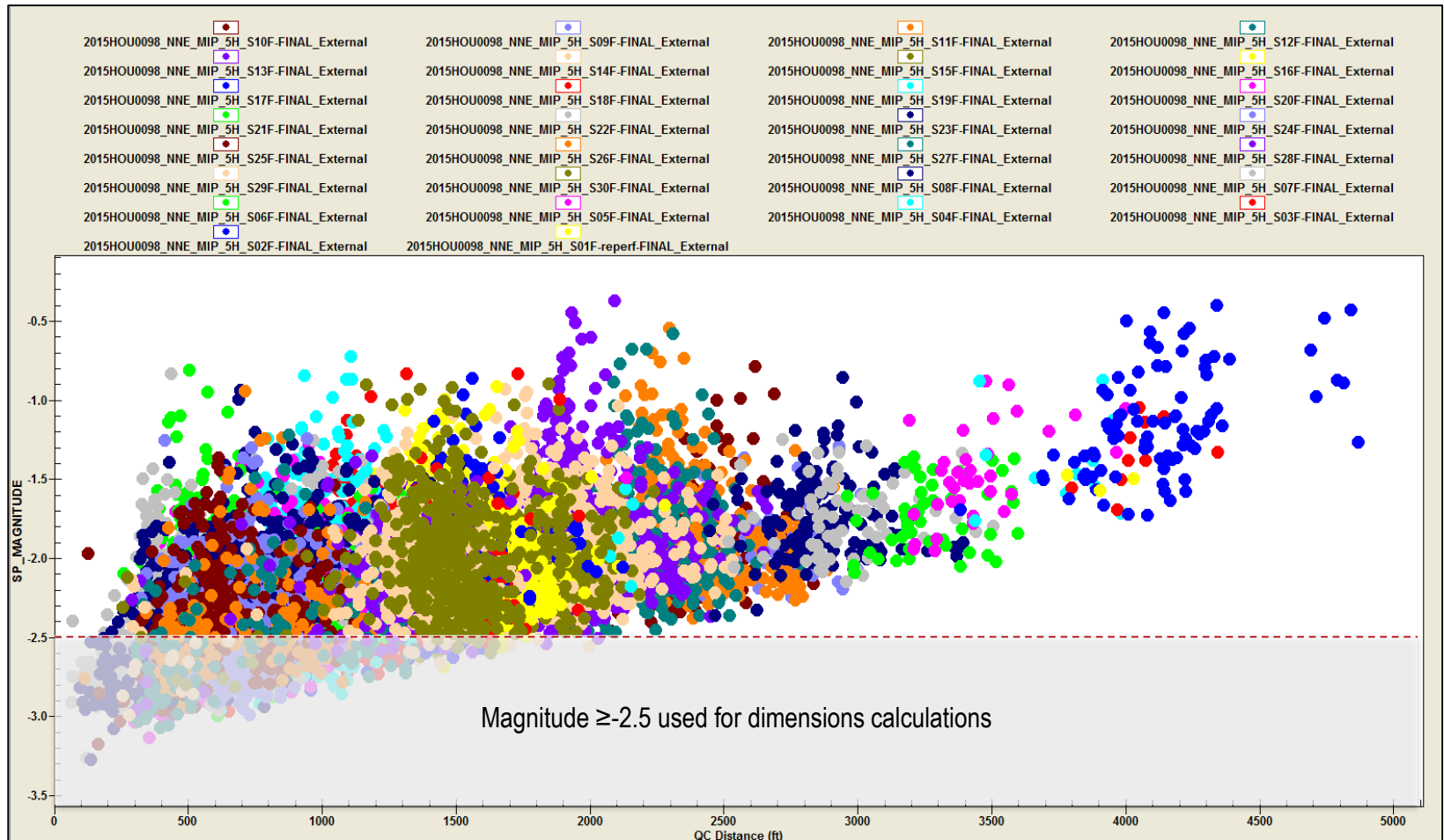
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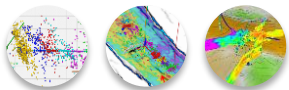
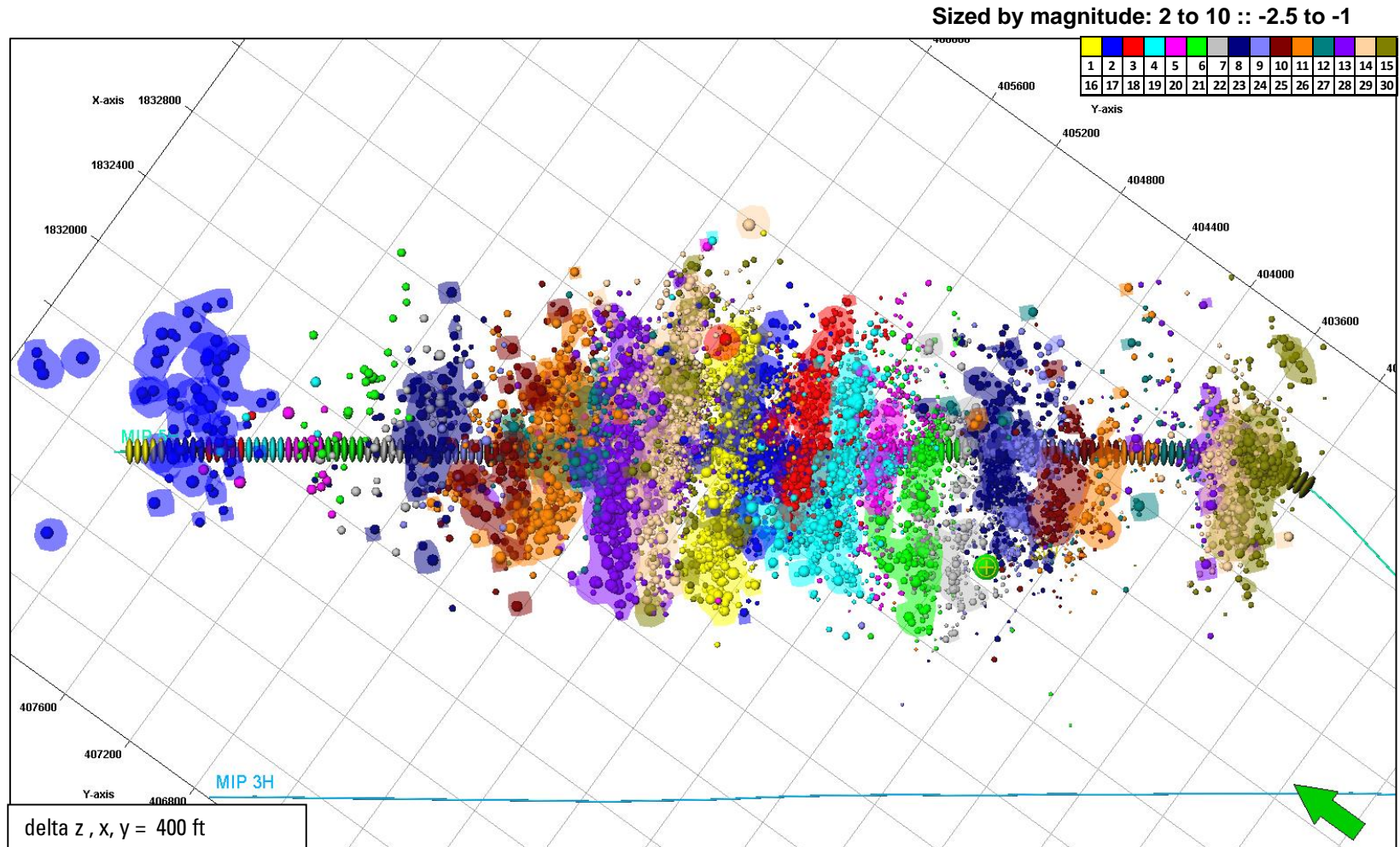
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

MIP 5H Magnitude vs. Distance



MIP 5H Microseismic ESVs – Map View

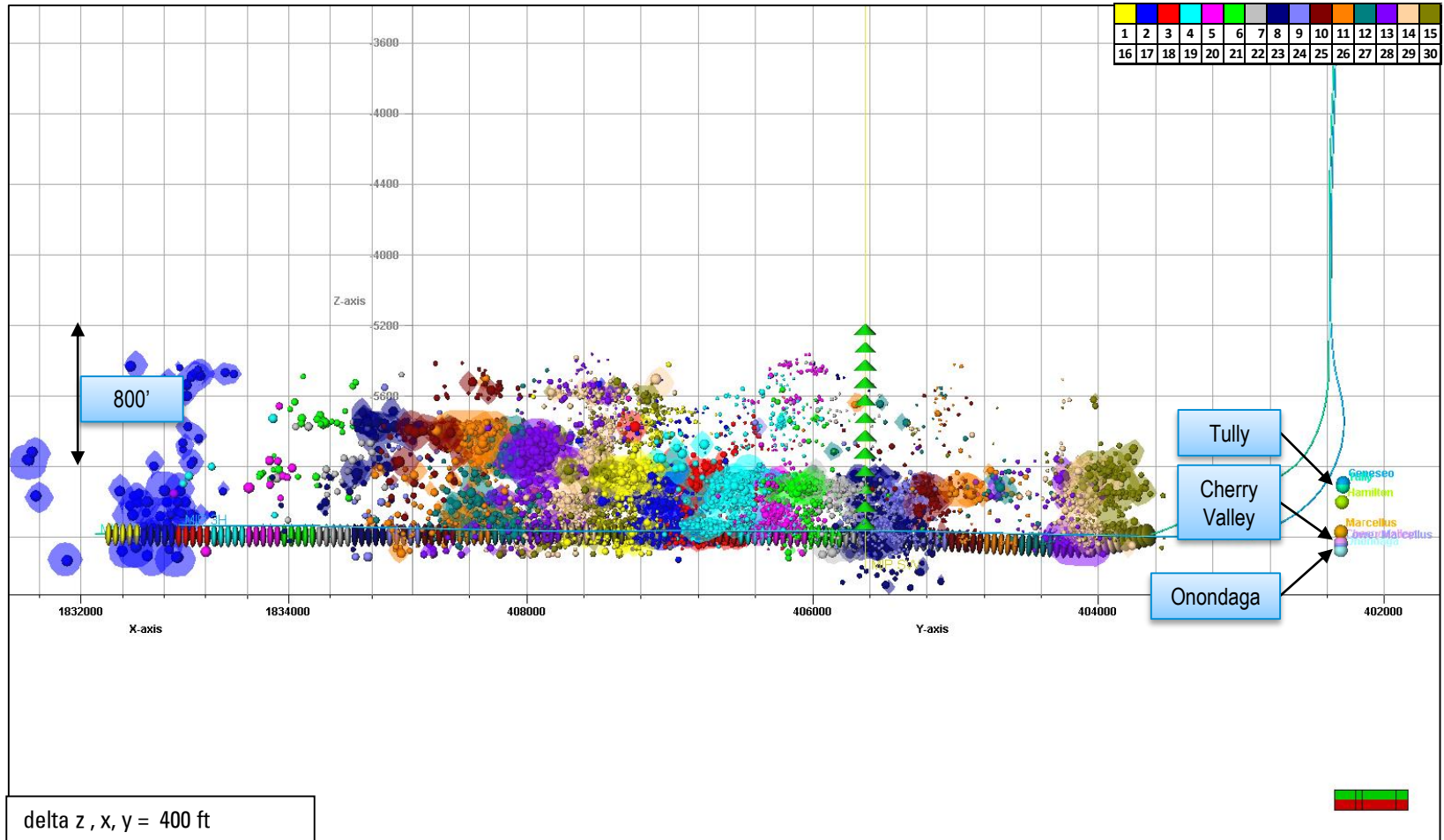


MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

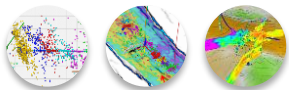
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MIP 5H Microseismic ESVs – Depth View

Sized by magnitude: 2 to 10 :: -2.5 to -1



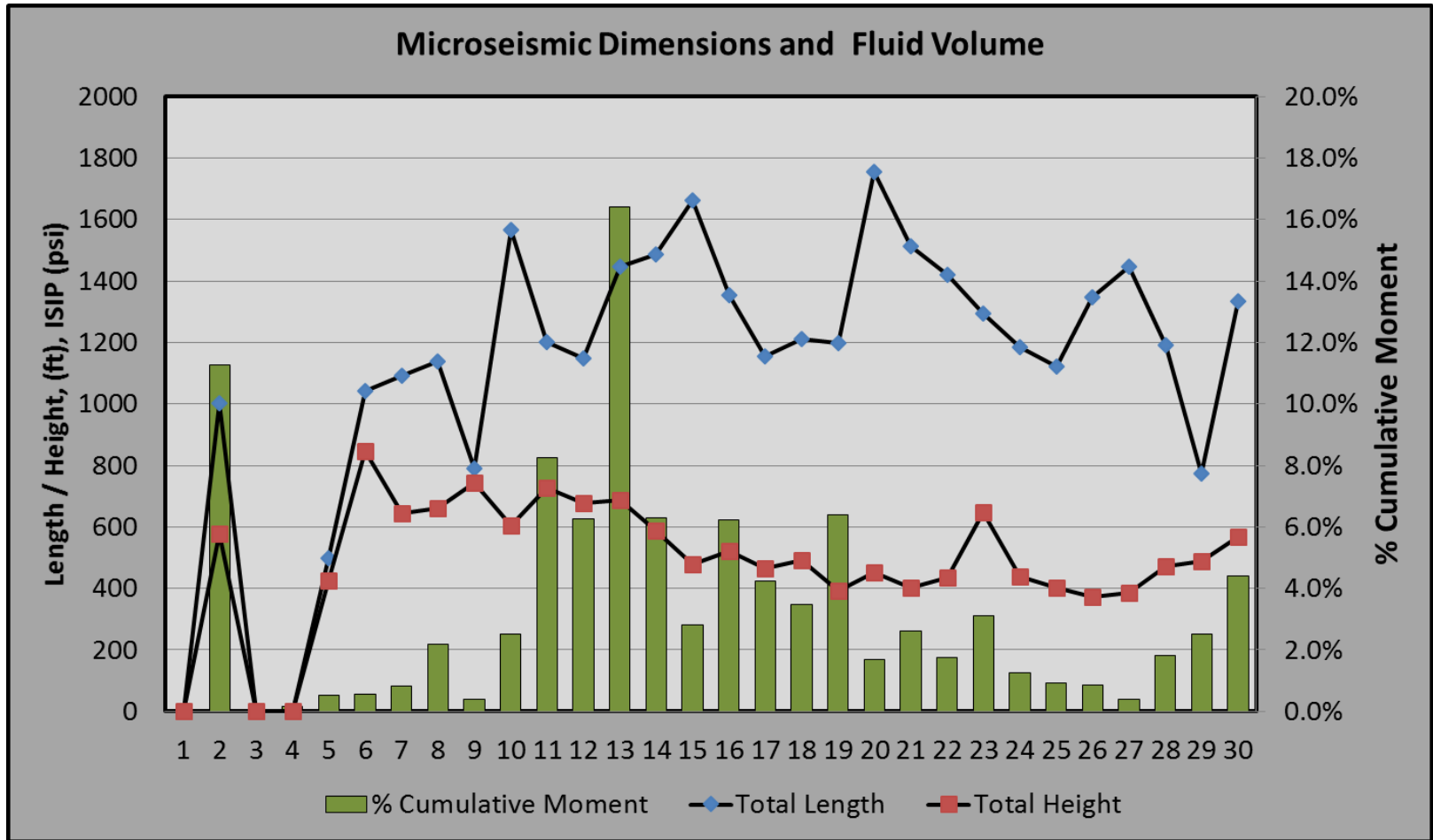
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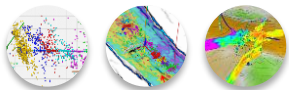
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

MIP 5H Cumulative Moment



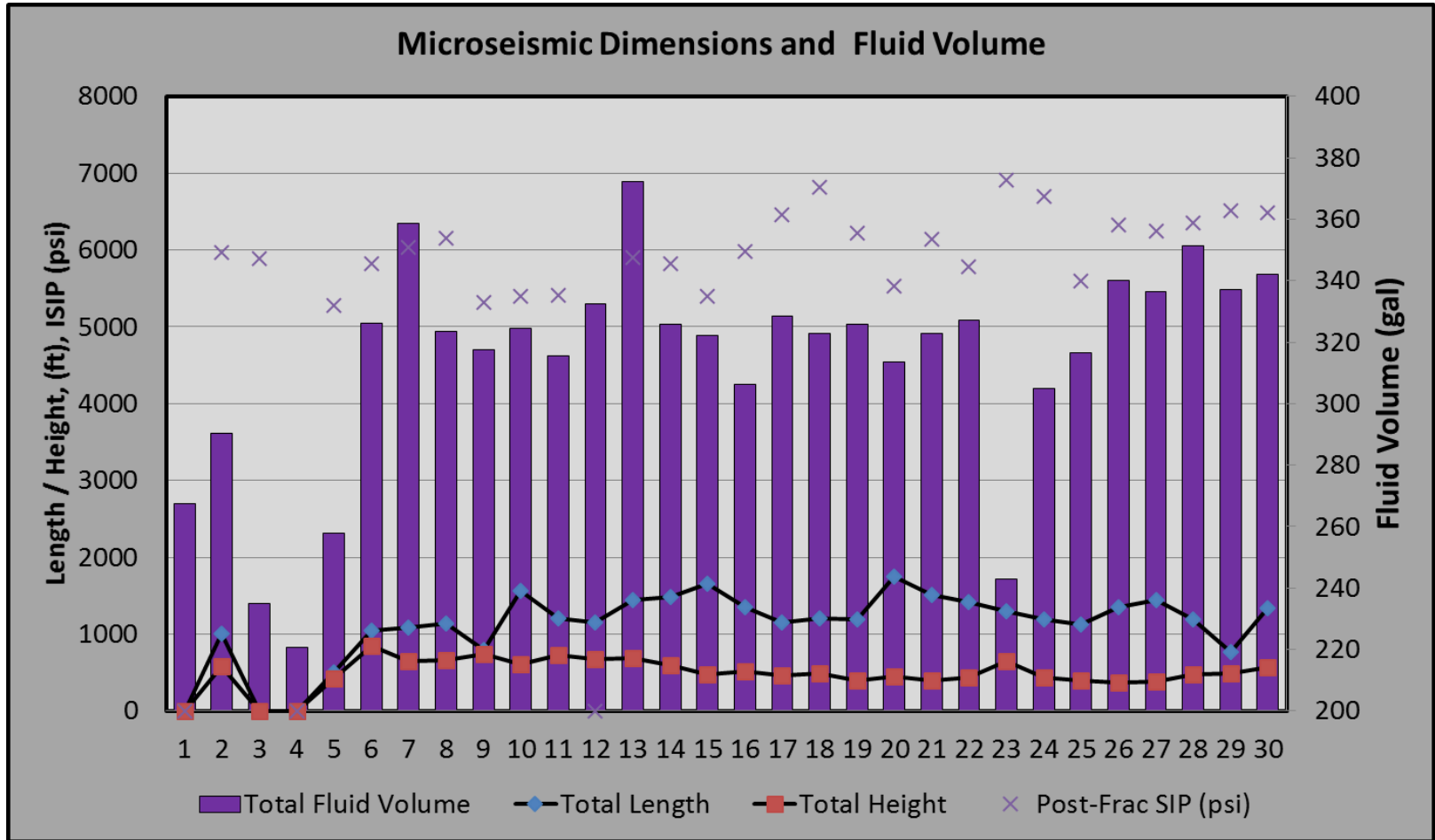
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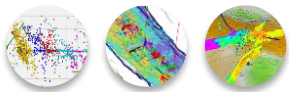
MICROSEISMIC SERVICES
IMAGE INTERPRET INTEGRATE

Schlumberger

MIP 5H Dimensions and Fluid Volume



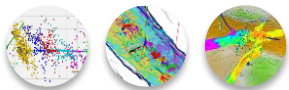
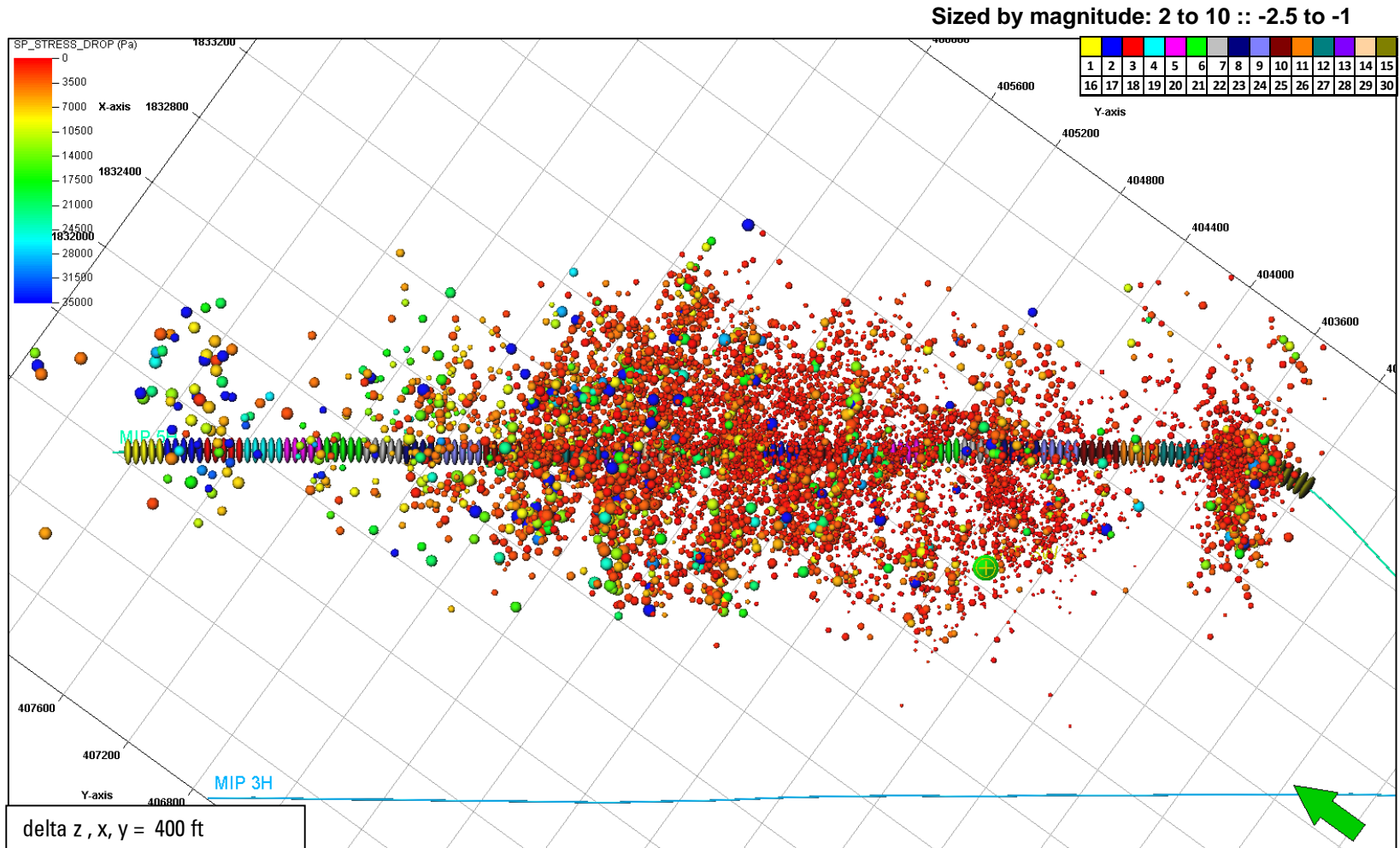
Schlumberger-Private



MICROSEISMIC SERVICES
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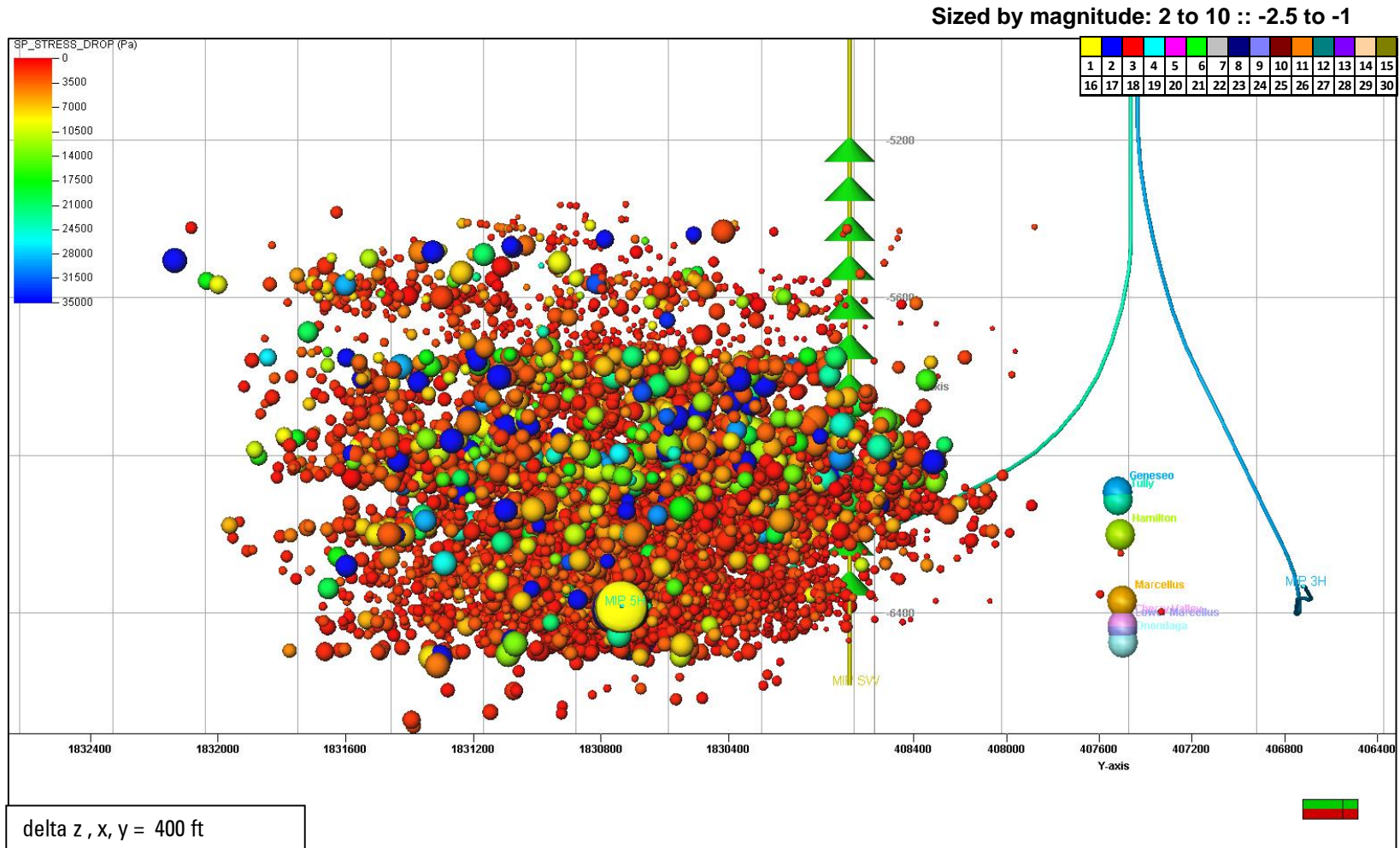
Stress Drop 5H – Map View



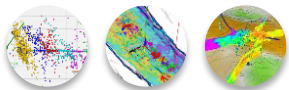
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Stress Drop 5H – Depth View



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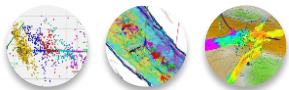


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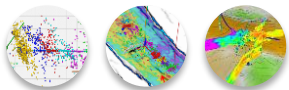
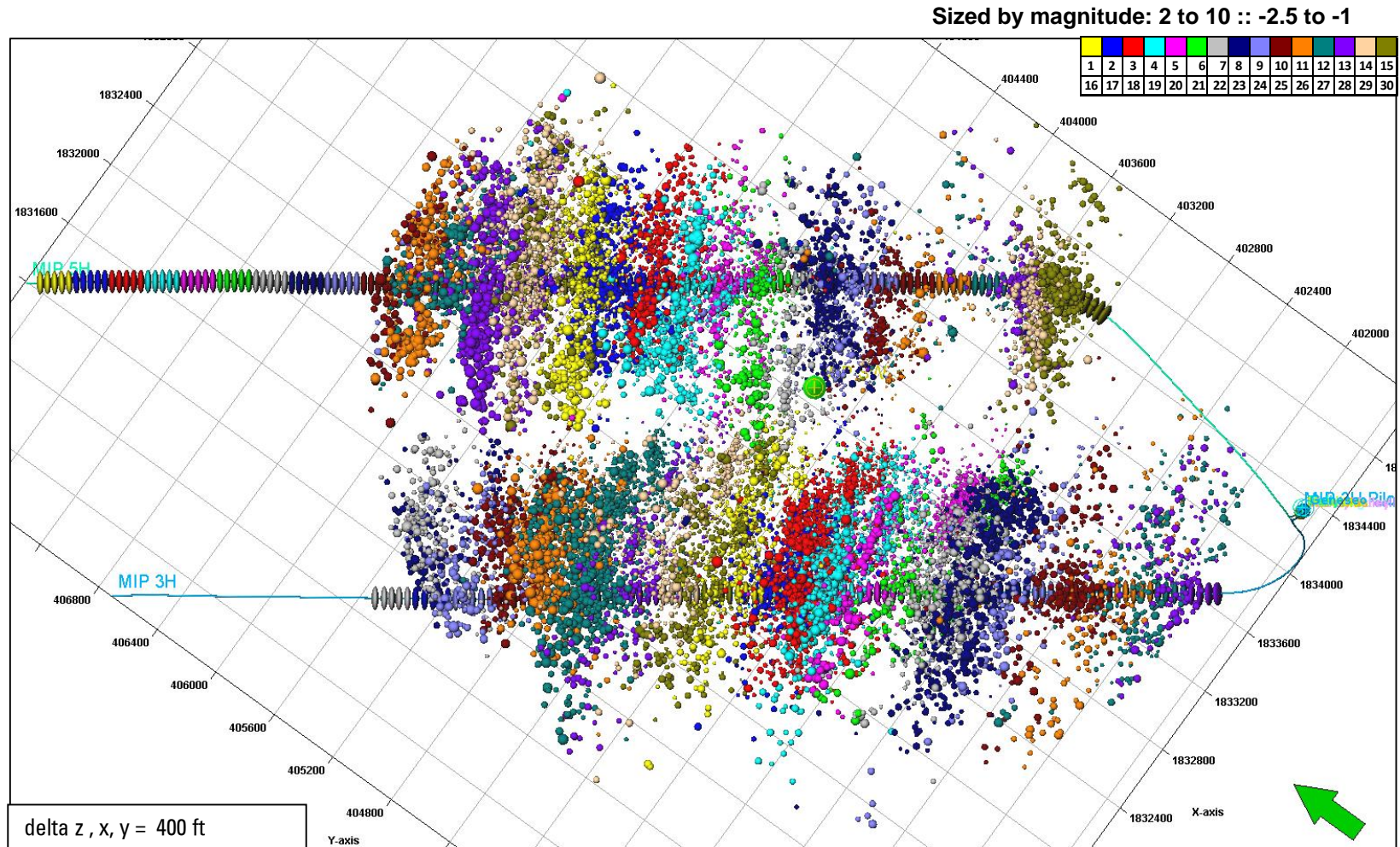
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Observations

- MIP 5H Average Half Length: 618ft, Average Height: 540ft, Average Azimuths N63°E
- There is a higher stress drop in the upper height growth boundary when compared to MIP 3H.



Map View Radius Filtered Events – 2,500 ft

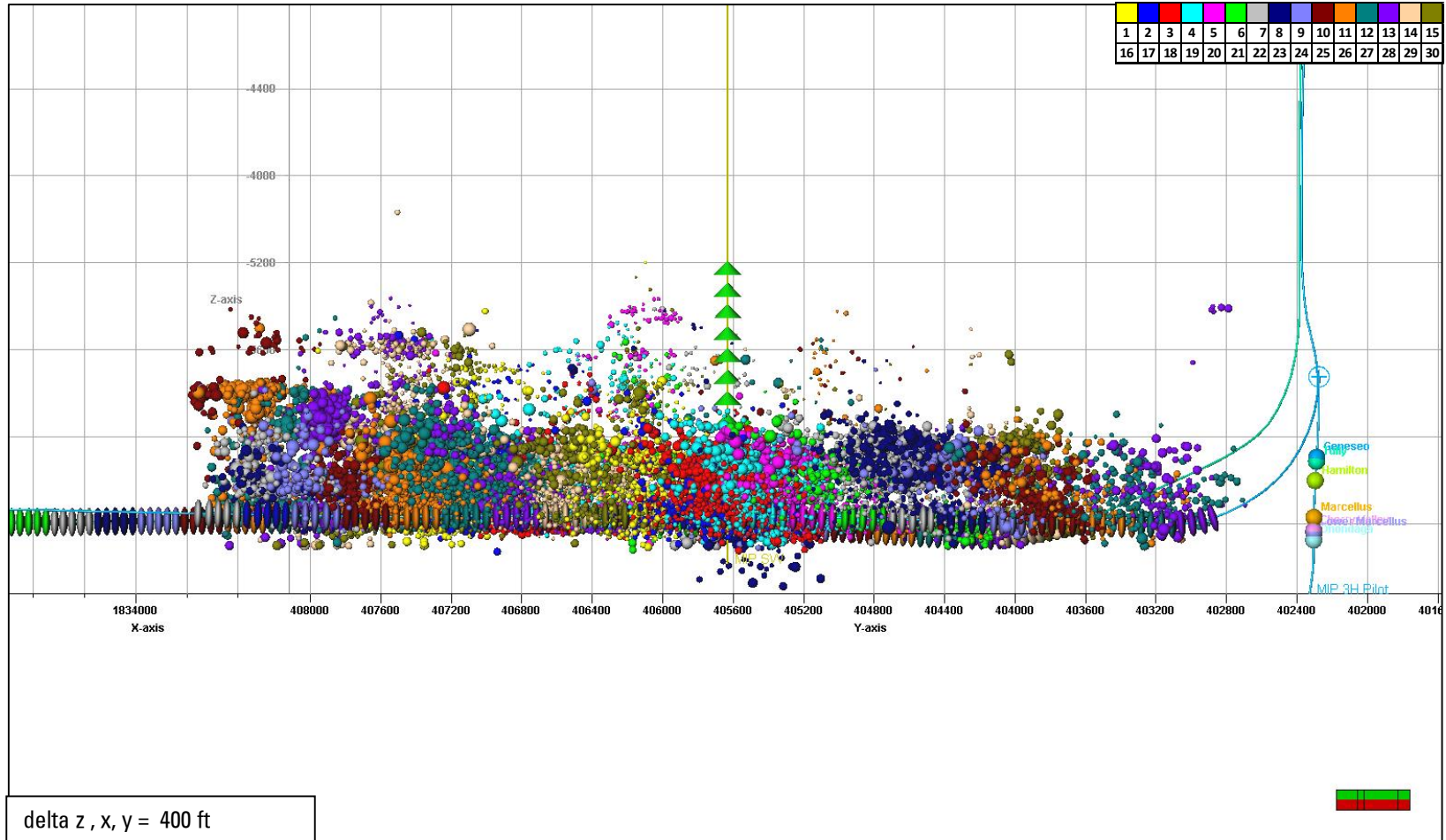


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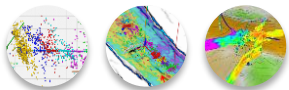
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Side View Radius Filtered Events – 2,500 ft

Sized by magnitude: 2 to 10 :: -2.5 to -1



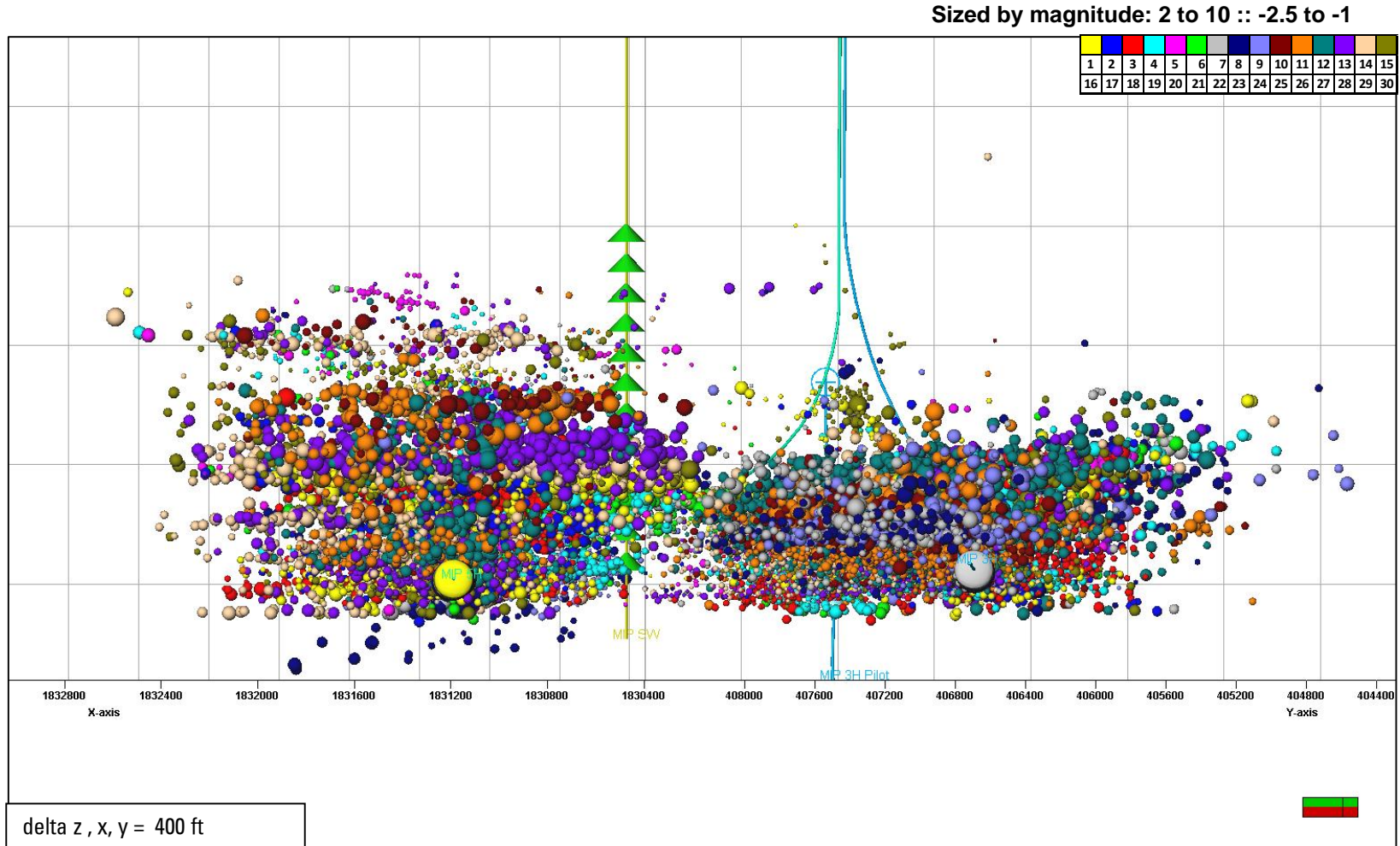
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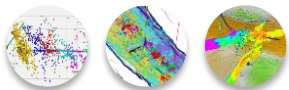
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Toe View Radius Filtered Events – 2,500 ft



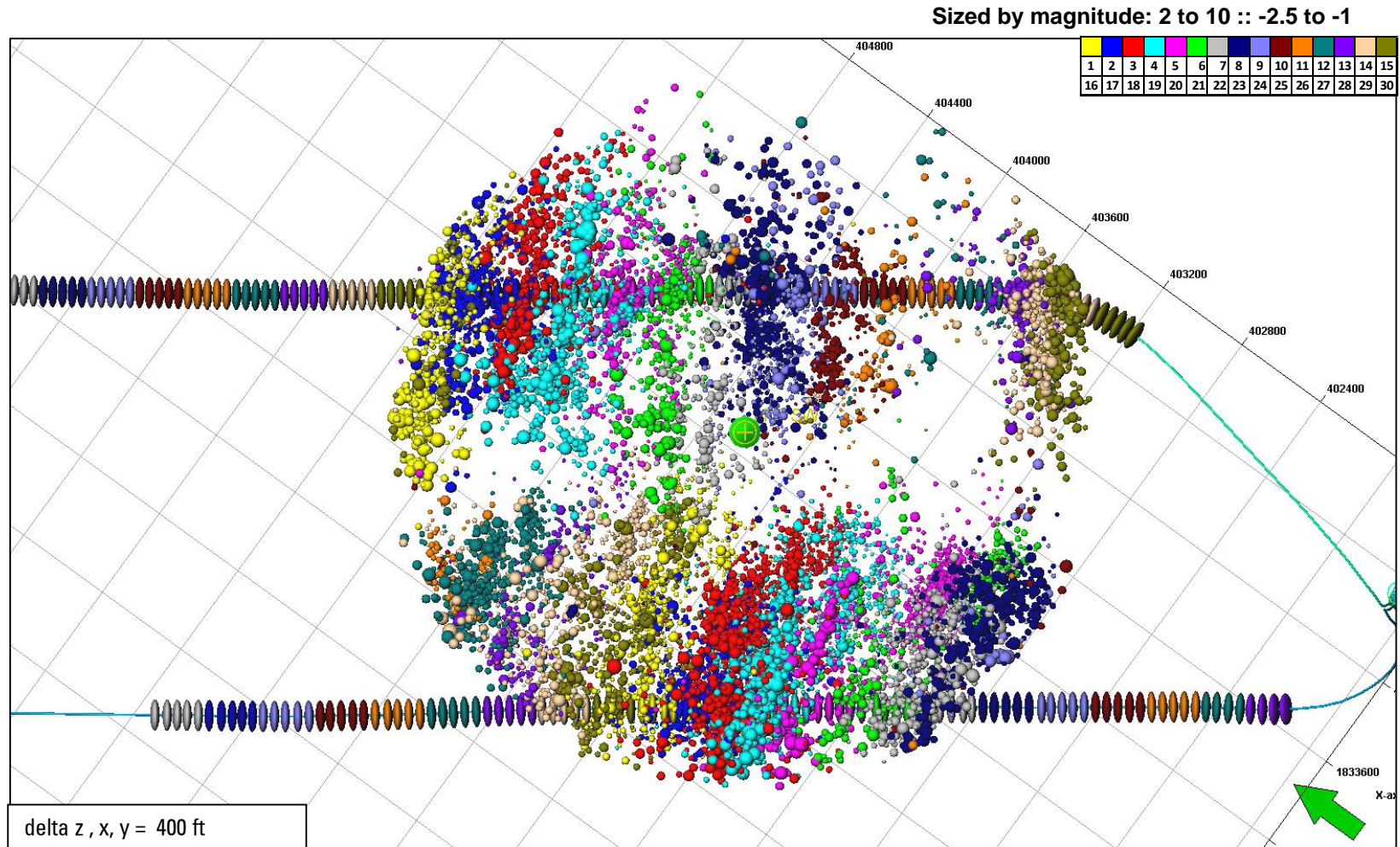
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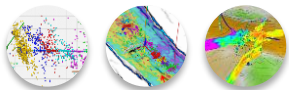
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Map View Radius Filtered Events – 1,500 ft



Schlumberger-Private

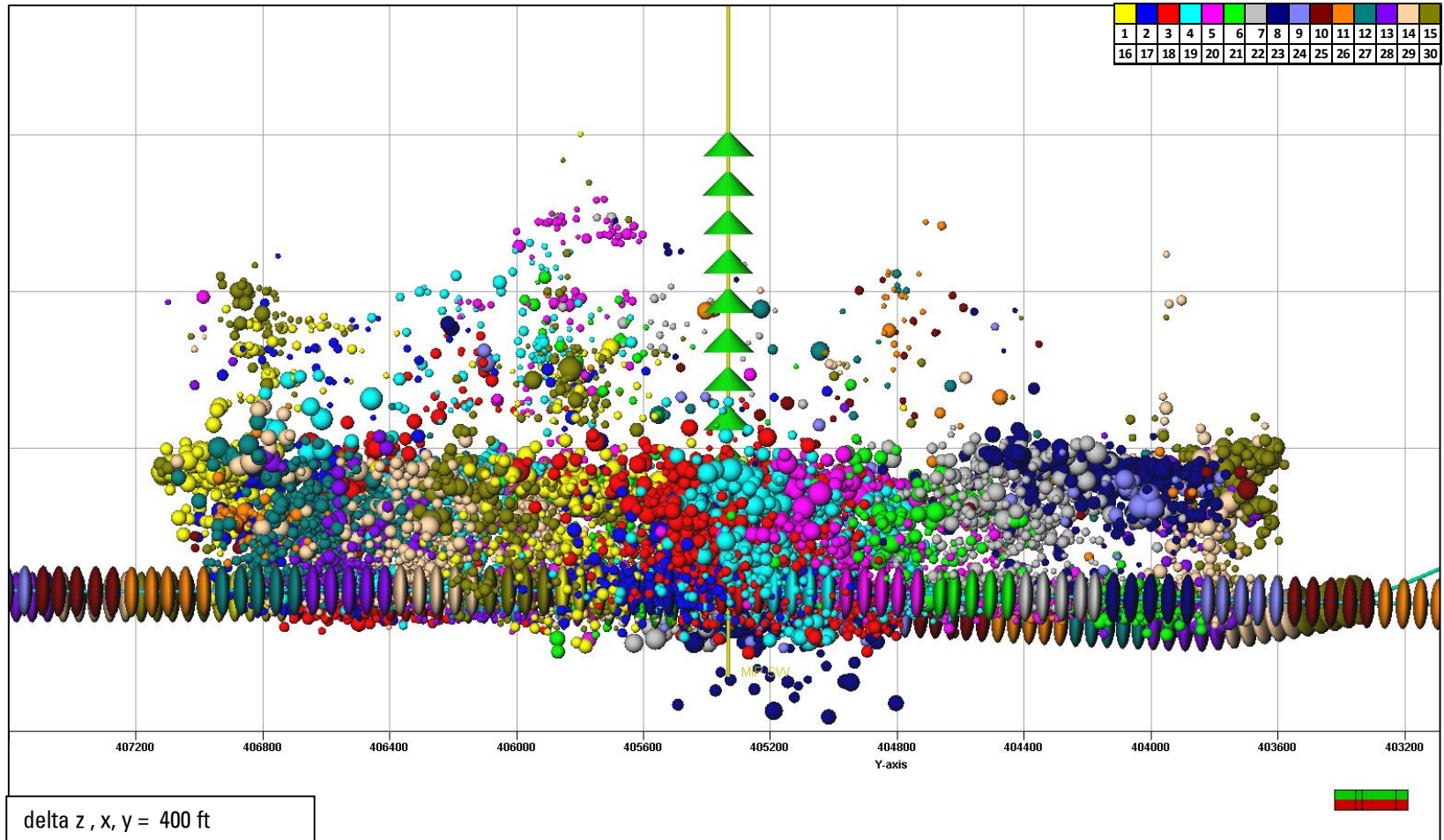


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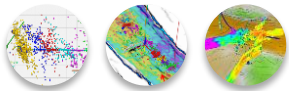
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Side View Radius Filtered Events – 1,500 ft

Sized by magnitude: 2 to 10 :: -2.5 to -1



Schlumberger-Private

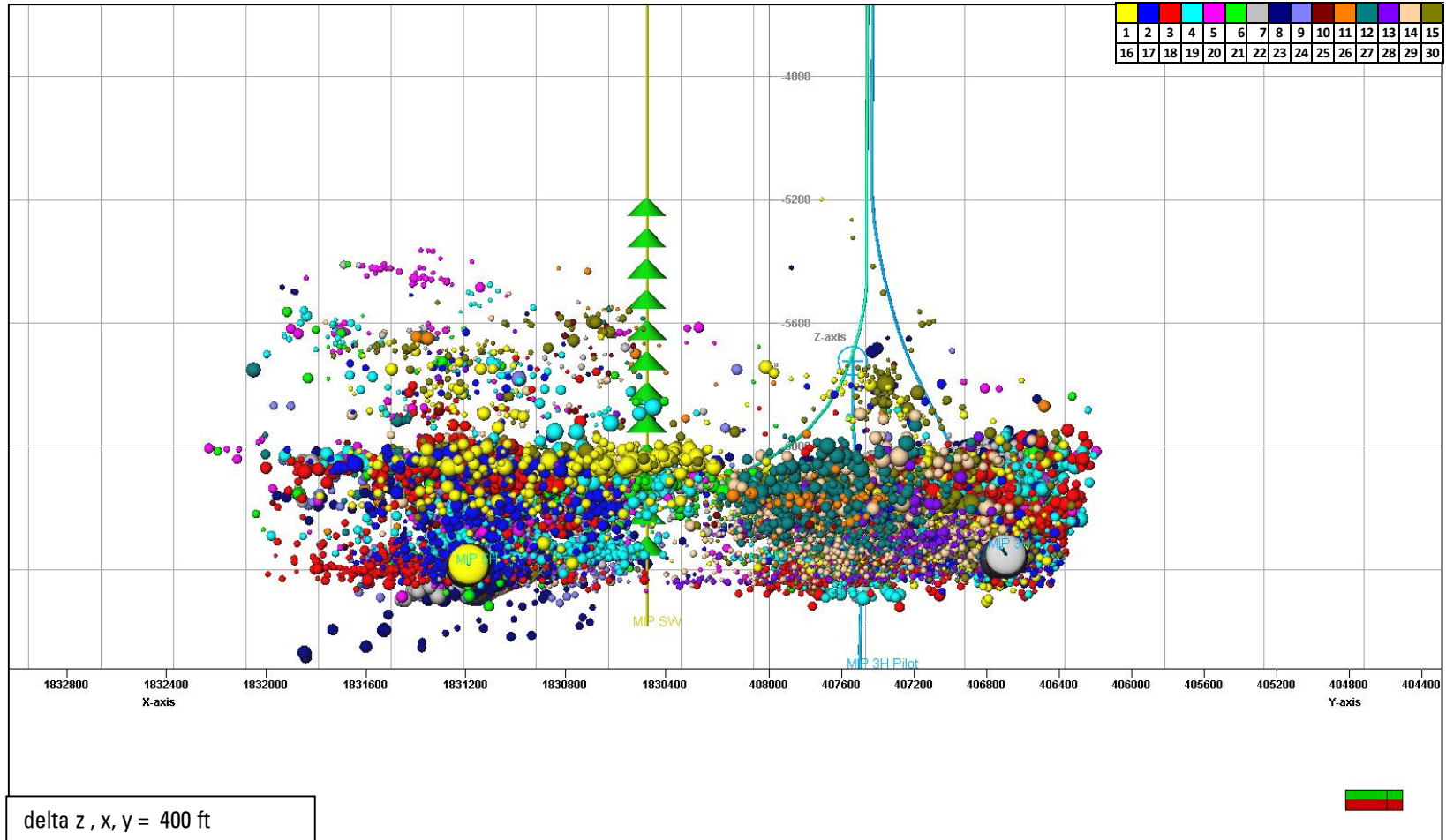


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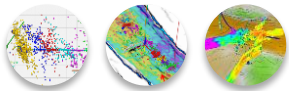
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Toe View Radius Filtered Events – 1,500 ft

Sized by magnitude: 2 to 10 :: -2.5 to -1



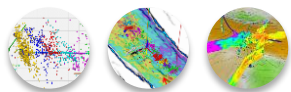
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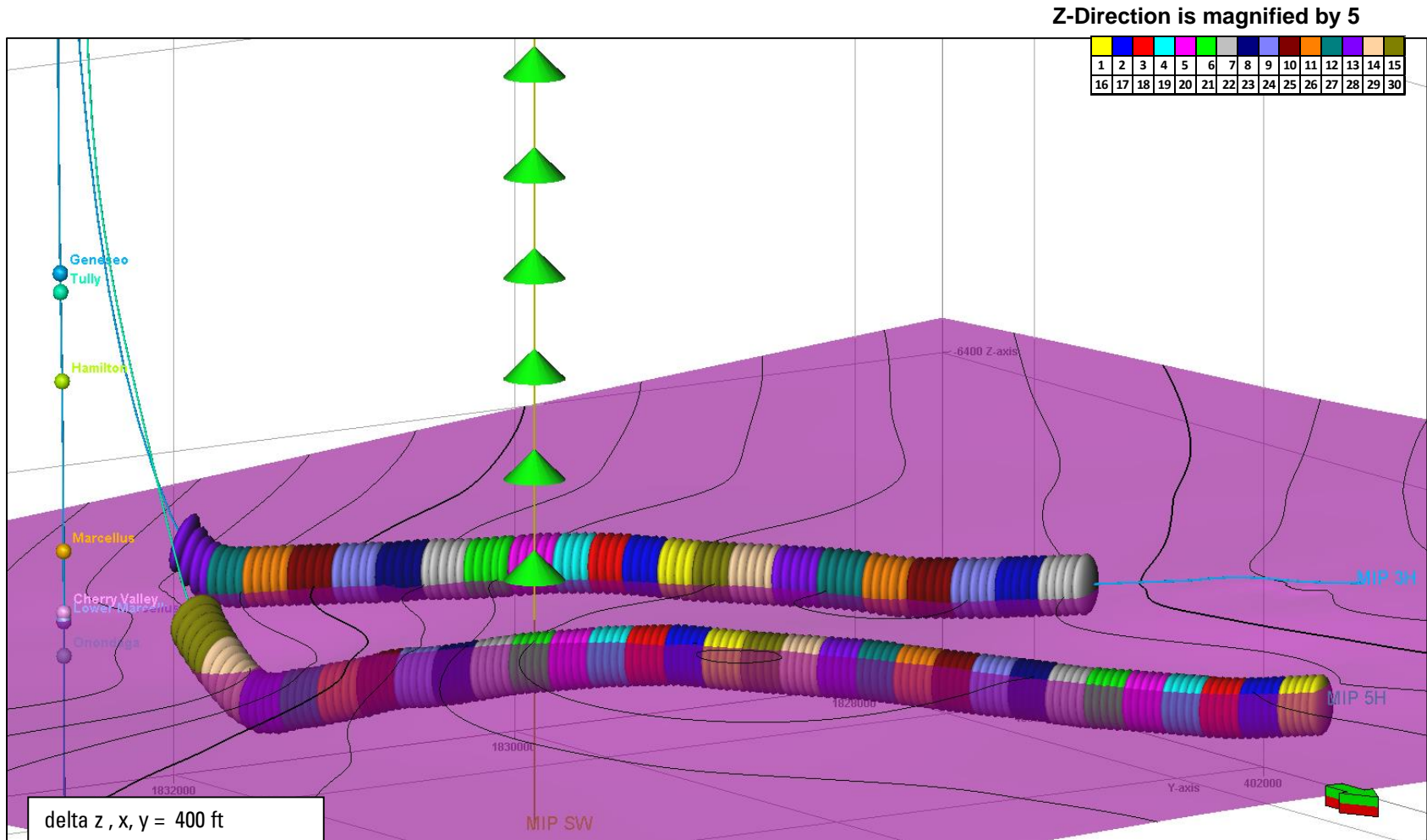
MIP 3H / MIP 5H – Well Comparisons



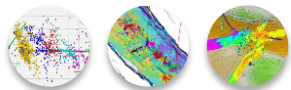
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Landing Points



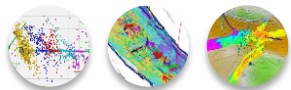
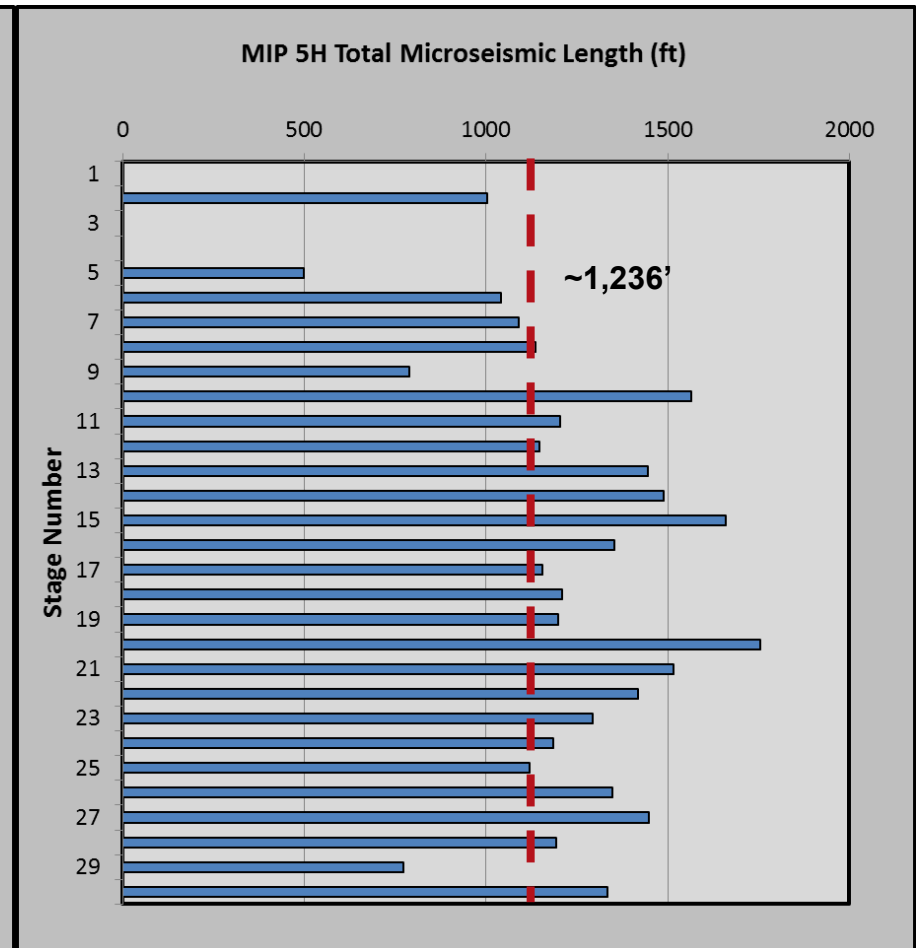
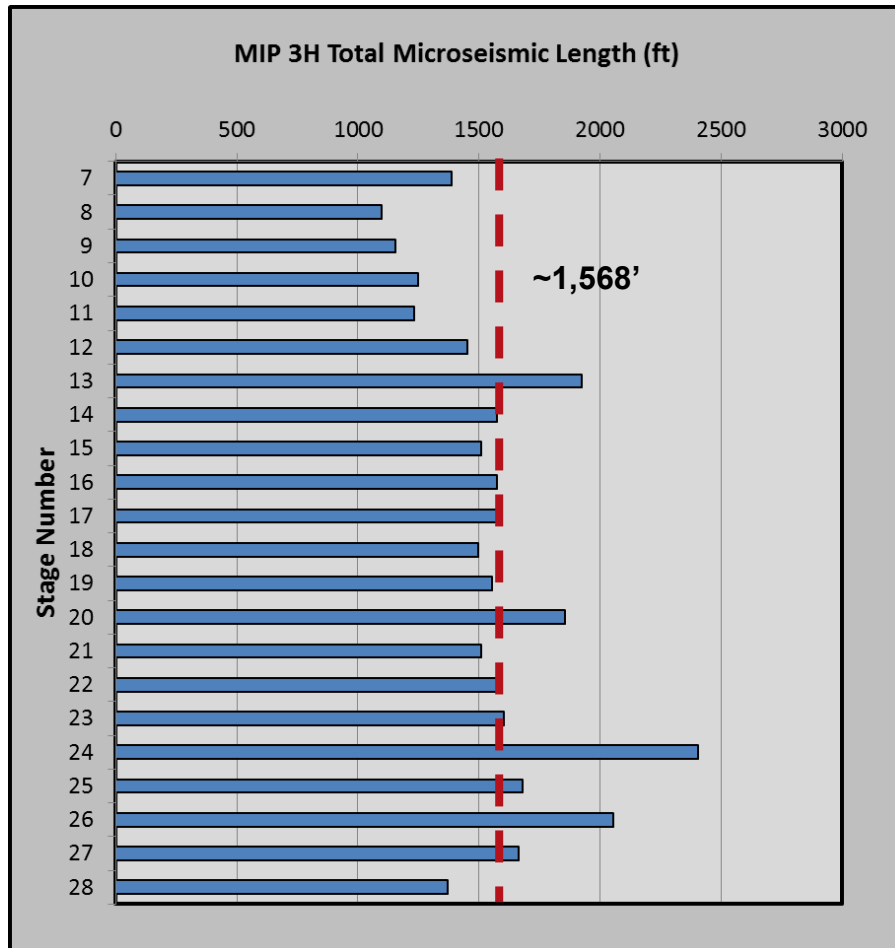
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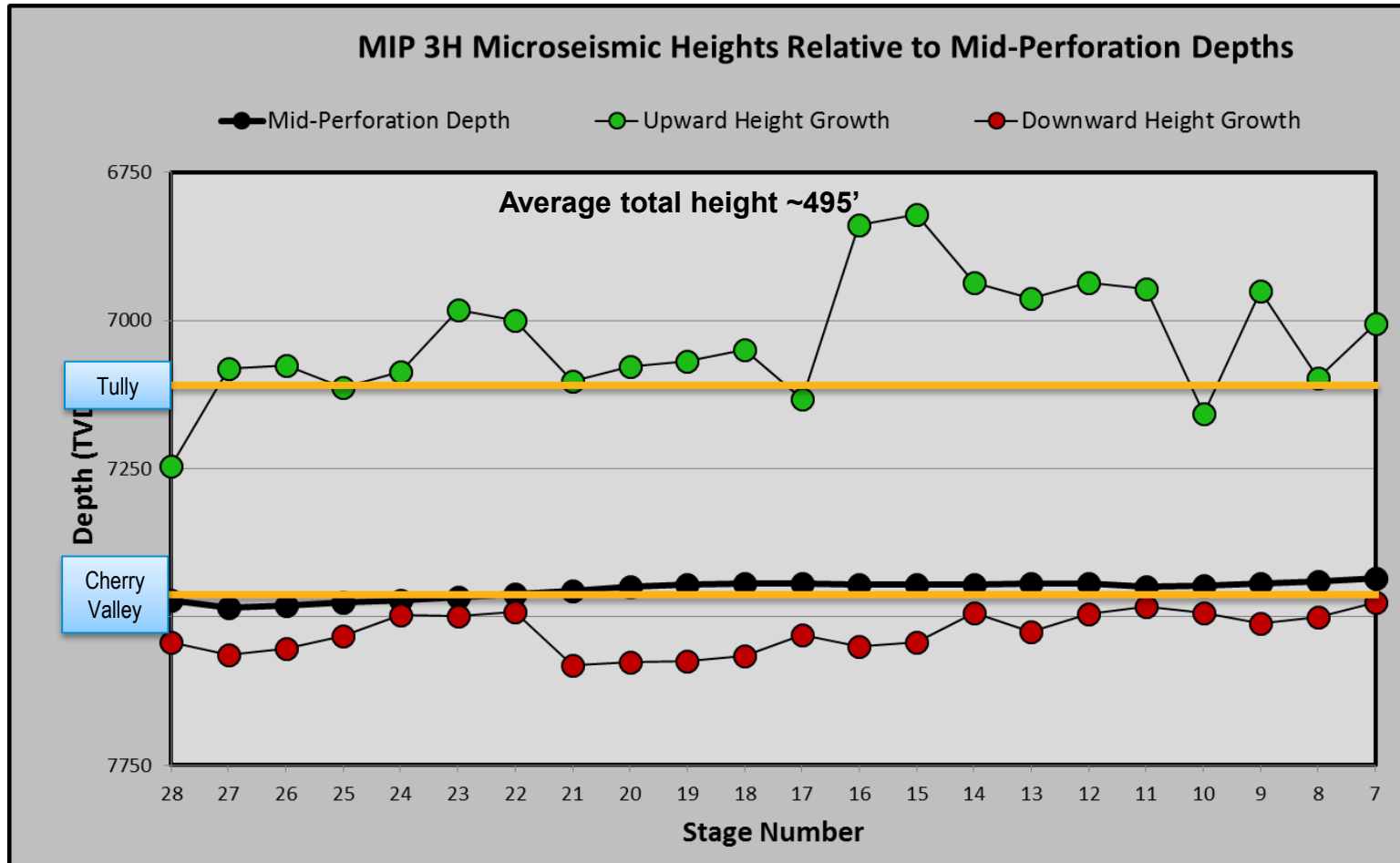
Microseismic Lengths



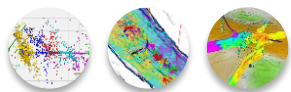
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Microseismic Heights – MIP 3H



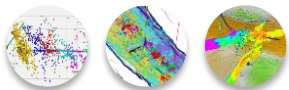
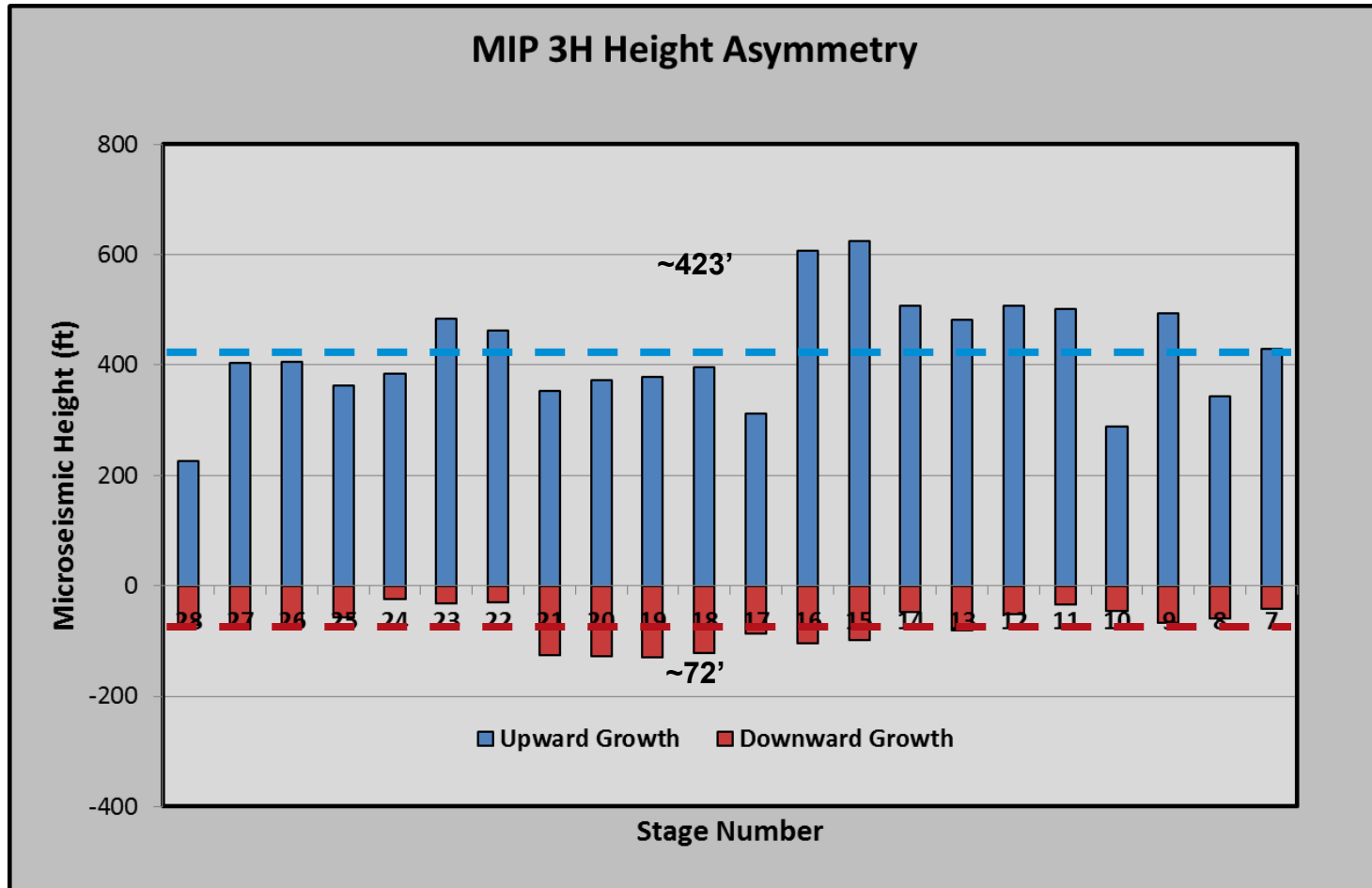
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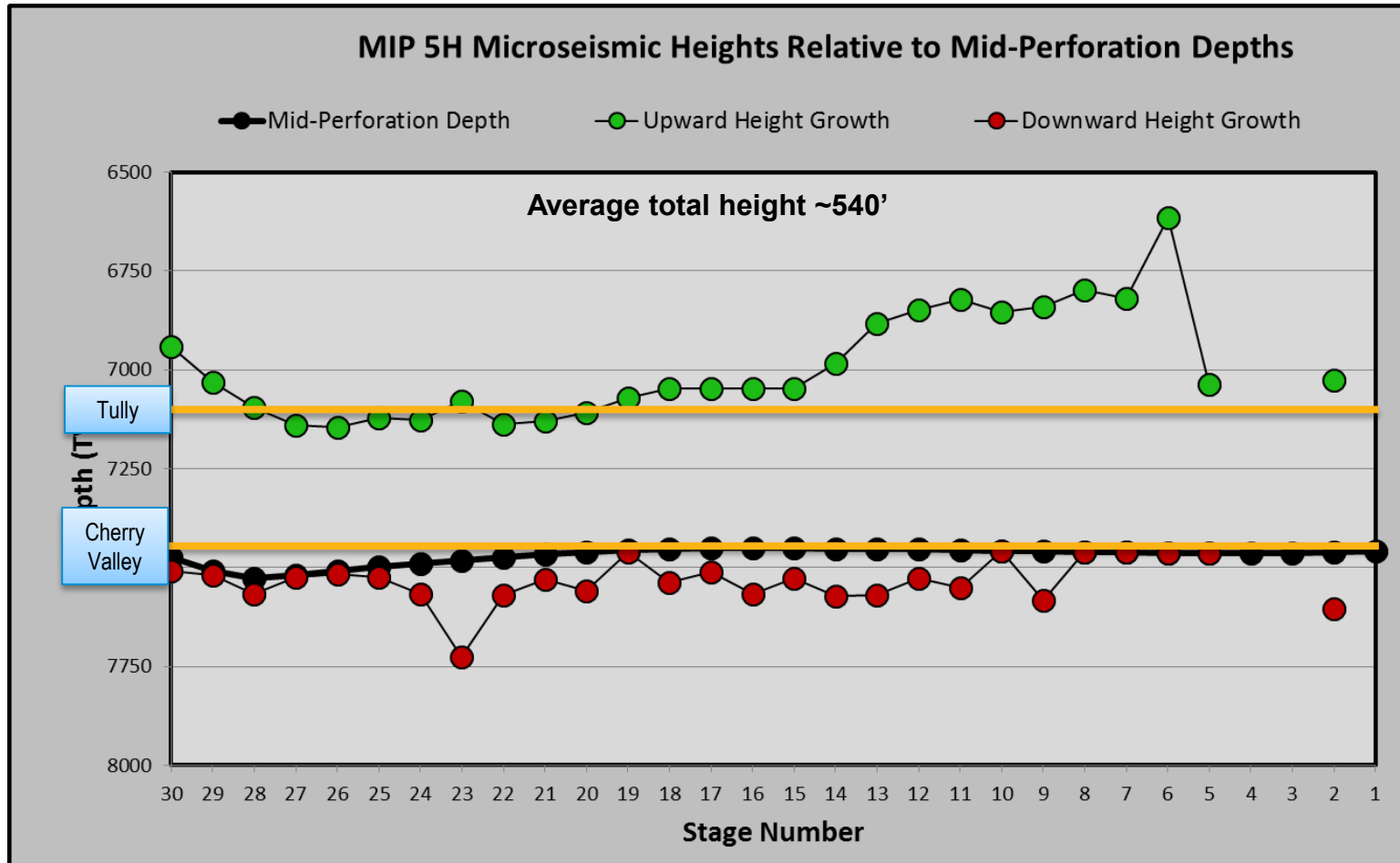
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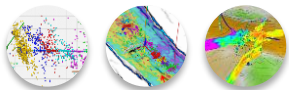
Microseismic Heights – MIP 3H



Microseismic Heights – MIP 5H



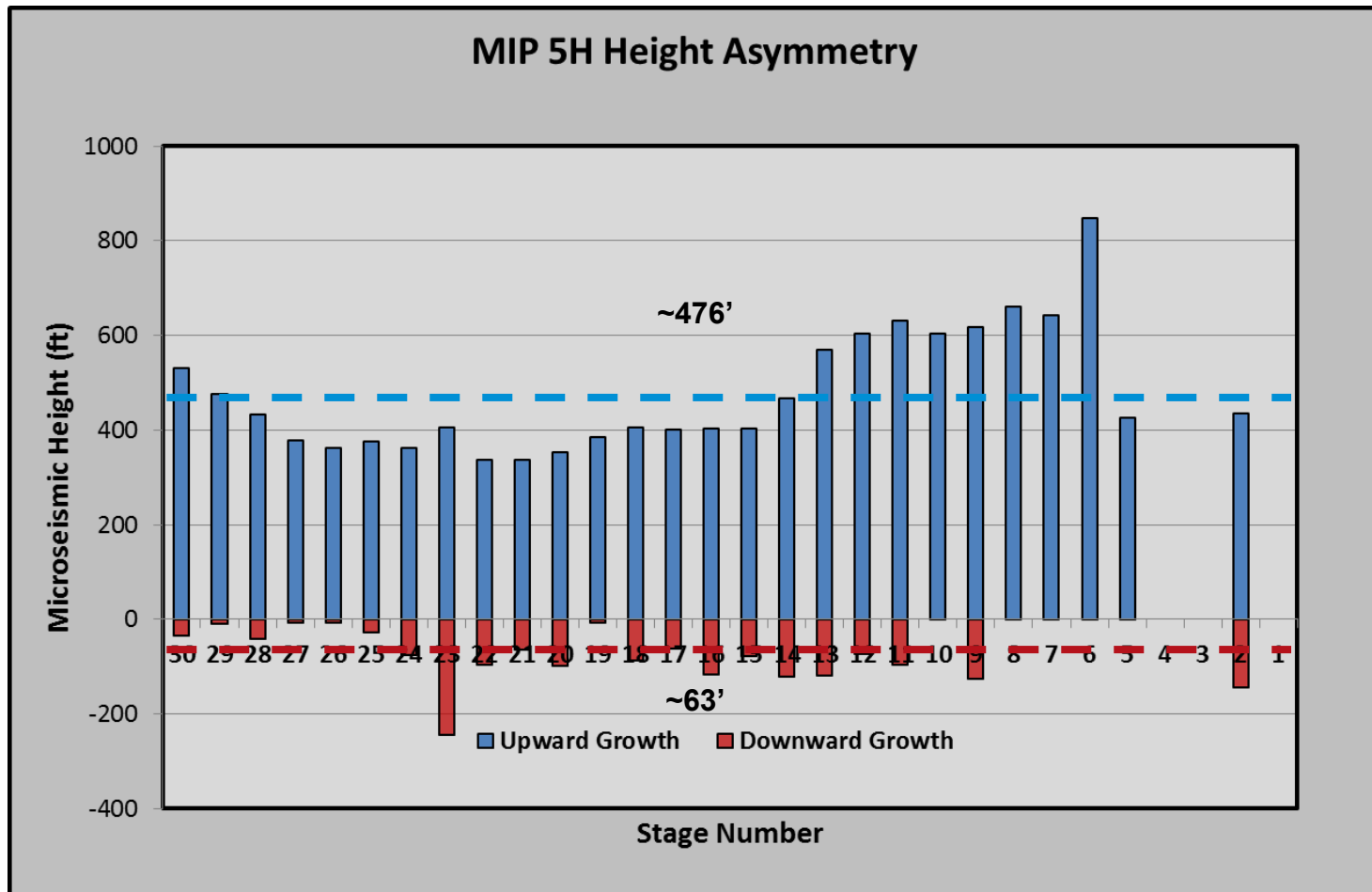
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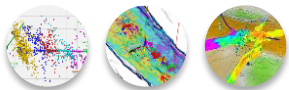
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Microseismic Heights – MIP 5H



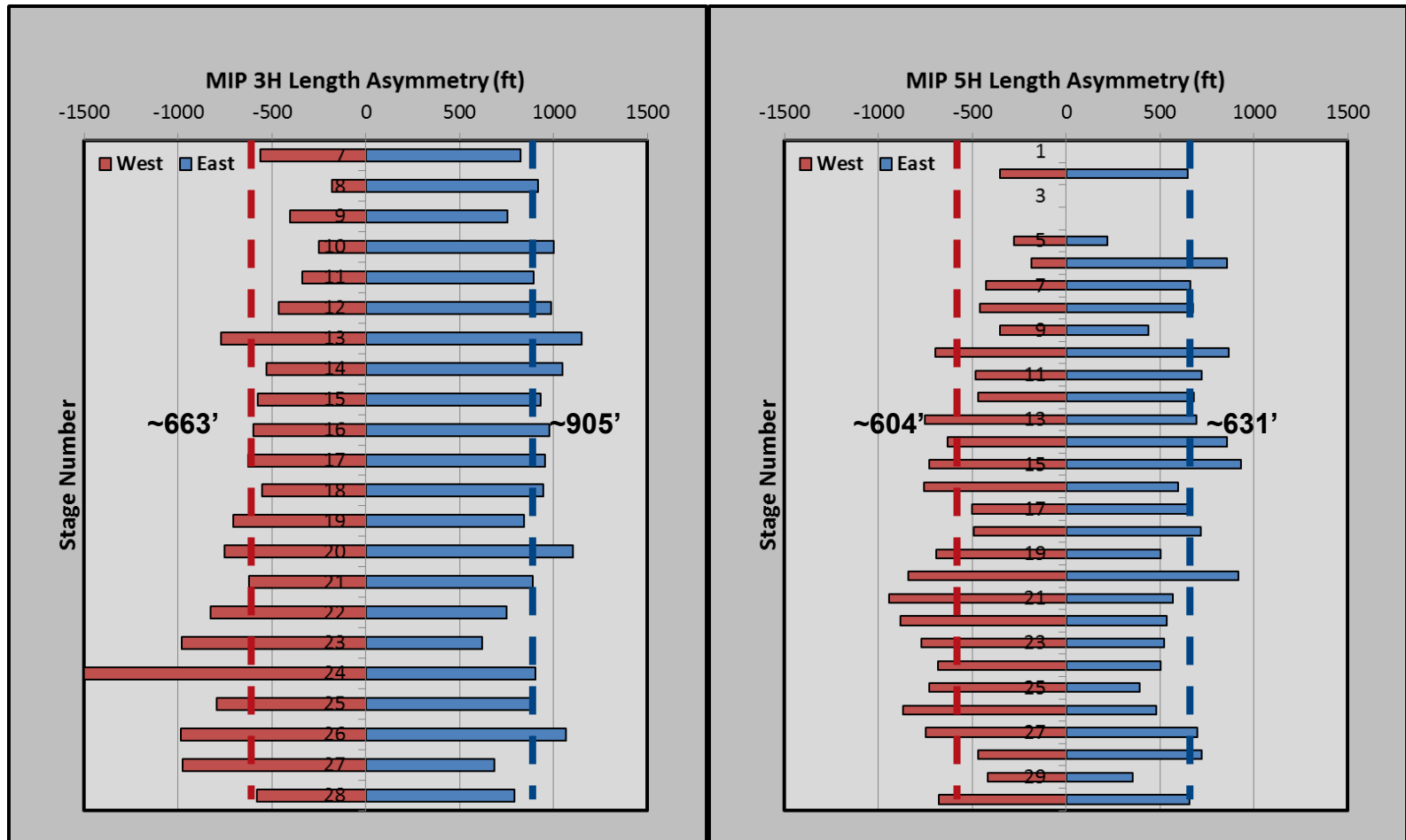
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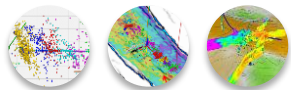
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Microseismic Length Asymmetry



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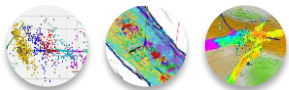


Completion Comparison

Multiple completion strategies are studied

	MIP 3H	MIP 5H
Lateral Landing	Upper Marcellus	Upper Marcellus
Lateral Length	~5,800	~6,000
Monitored / Total Stages	22 / 28	30 / 30
Perf Design	Multiple	5 Clusters, 40' Spacing
Perf Orientation	Multiple	Unknown

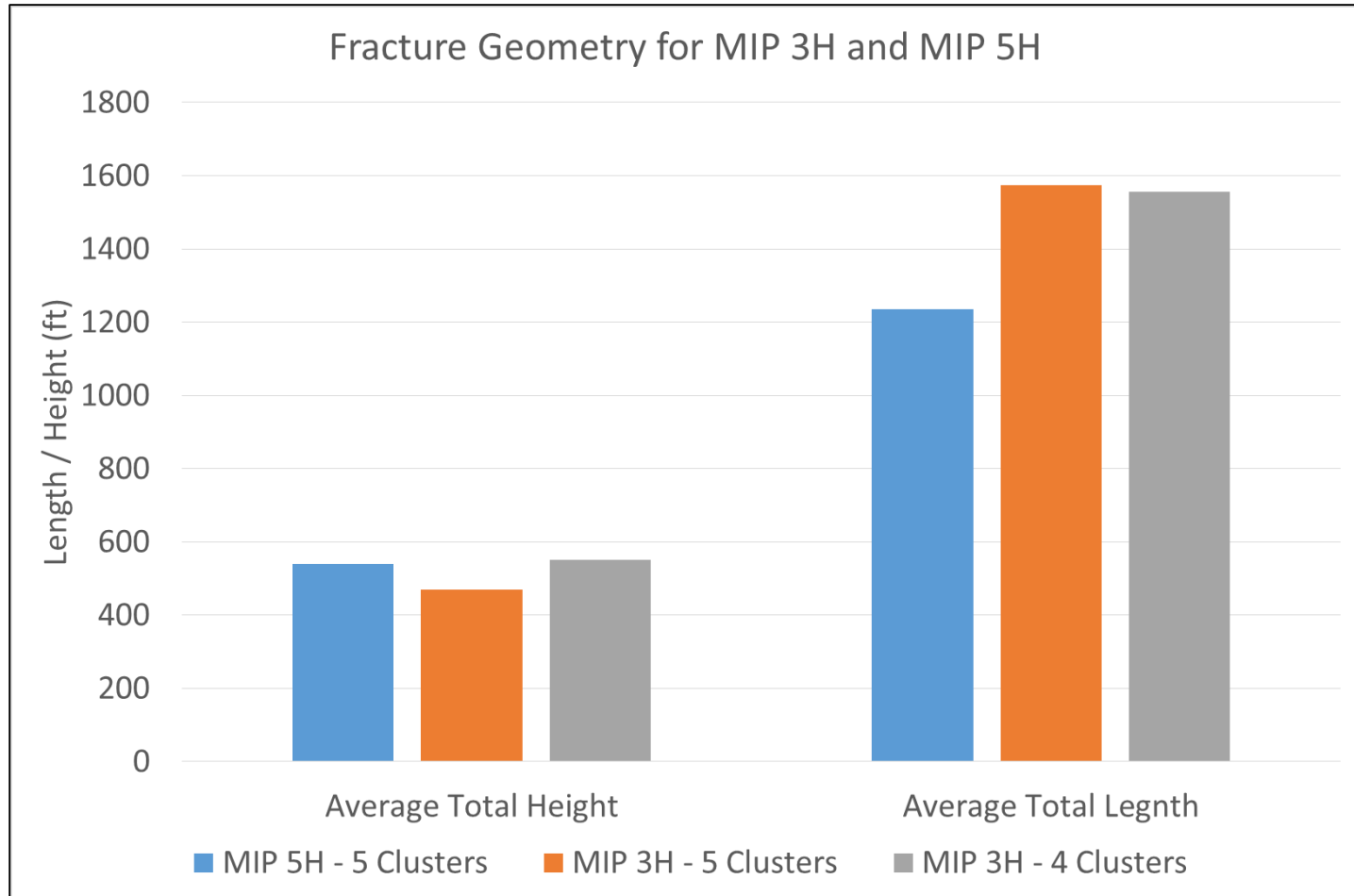
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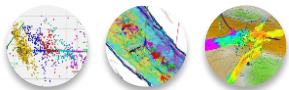
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Fracture Geometry Comparison



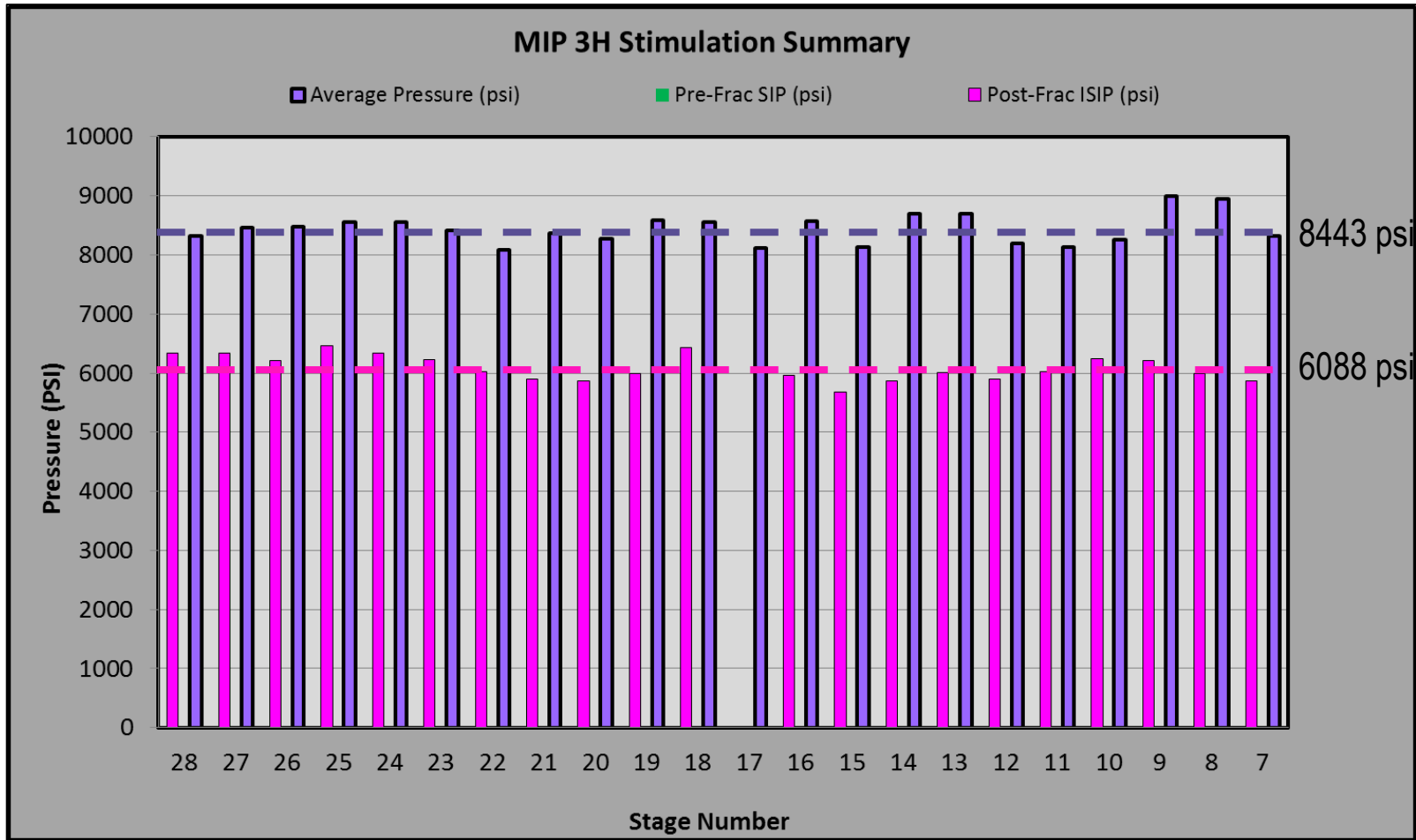
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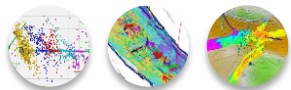
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MIP 3H Pressures



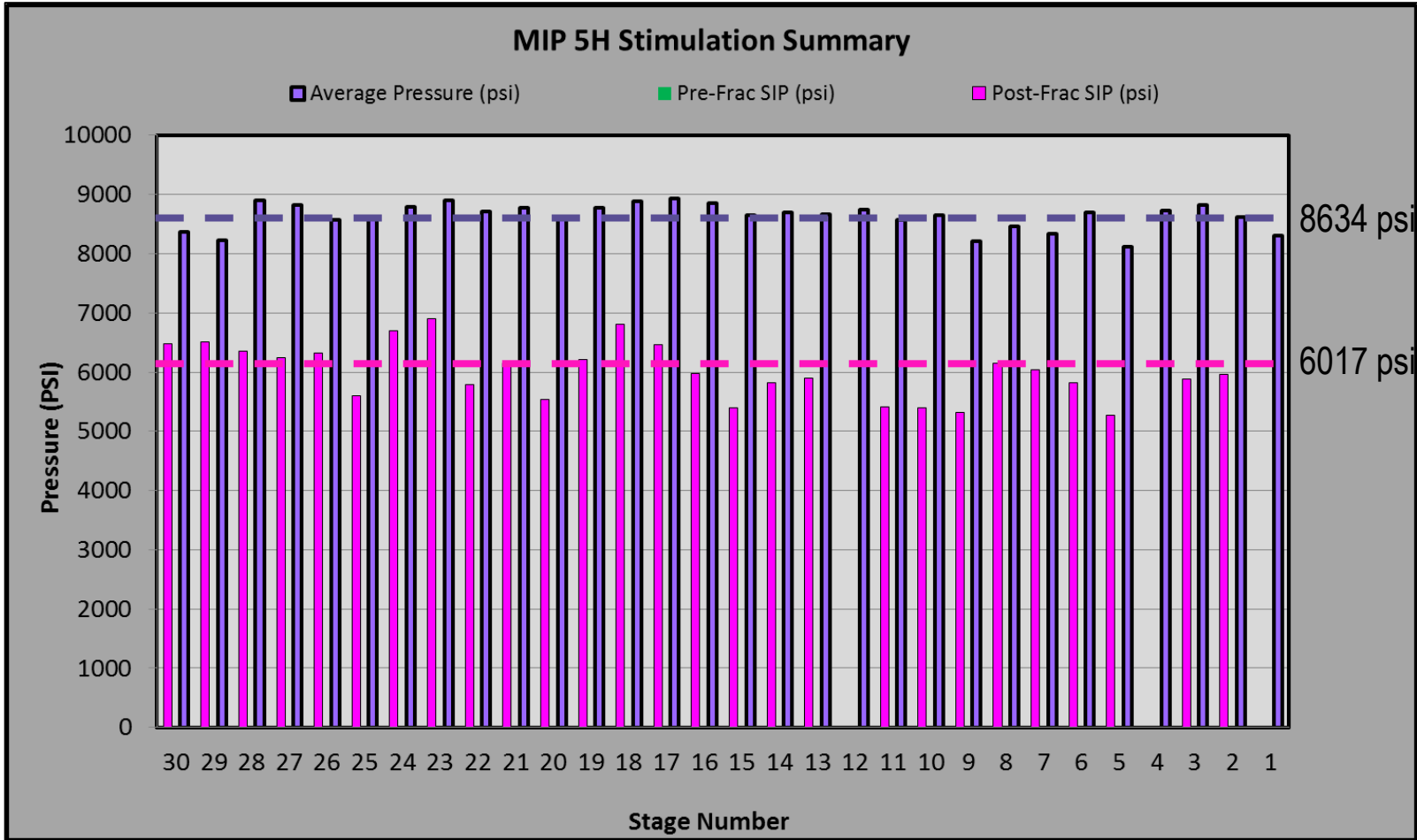
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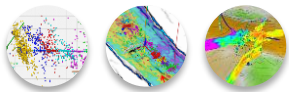
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MIP 5H Pressures



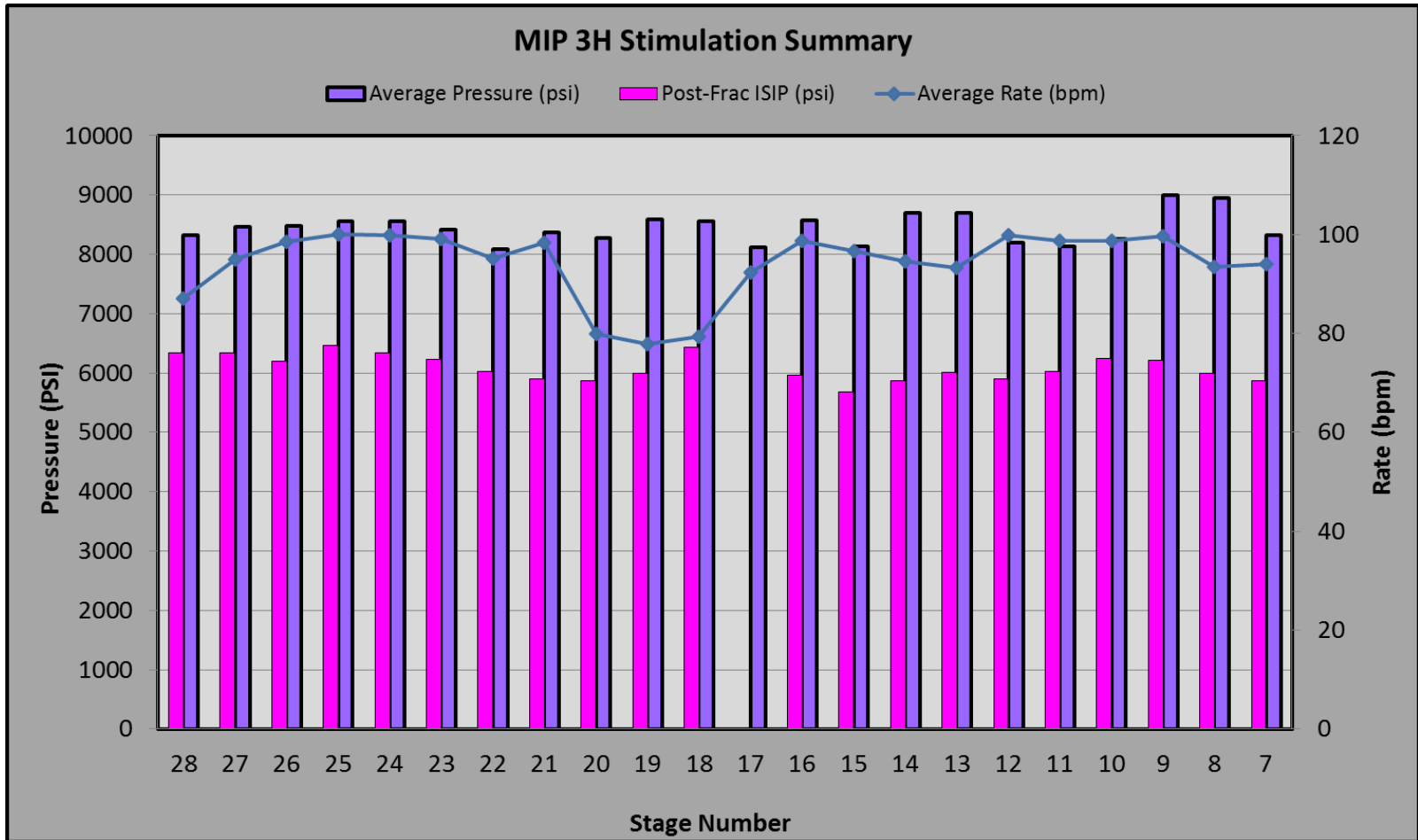
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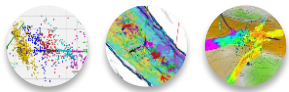
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MIP 3H Rates and Pressure



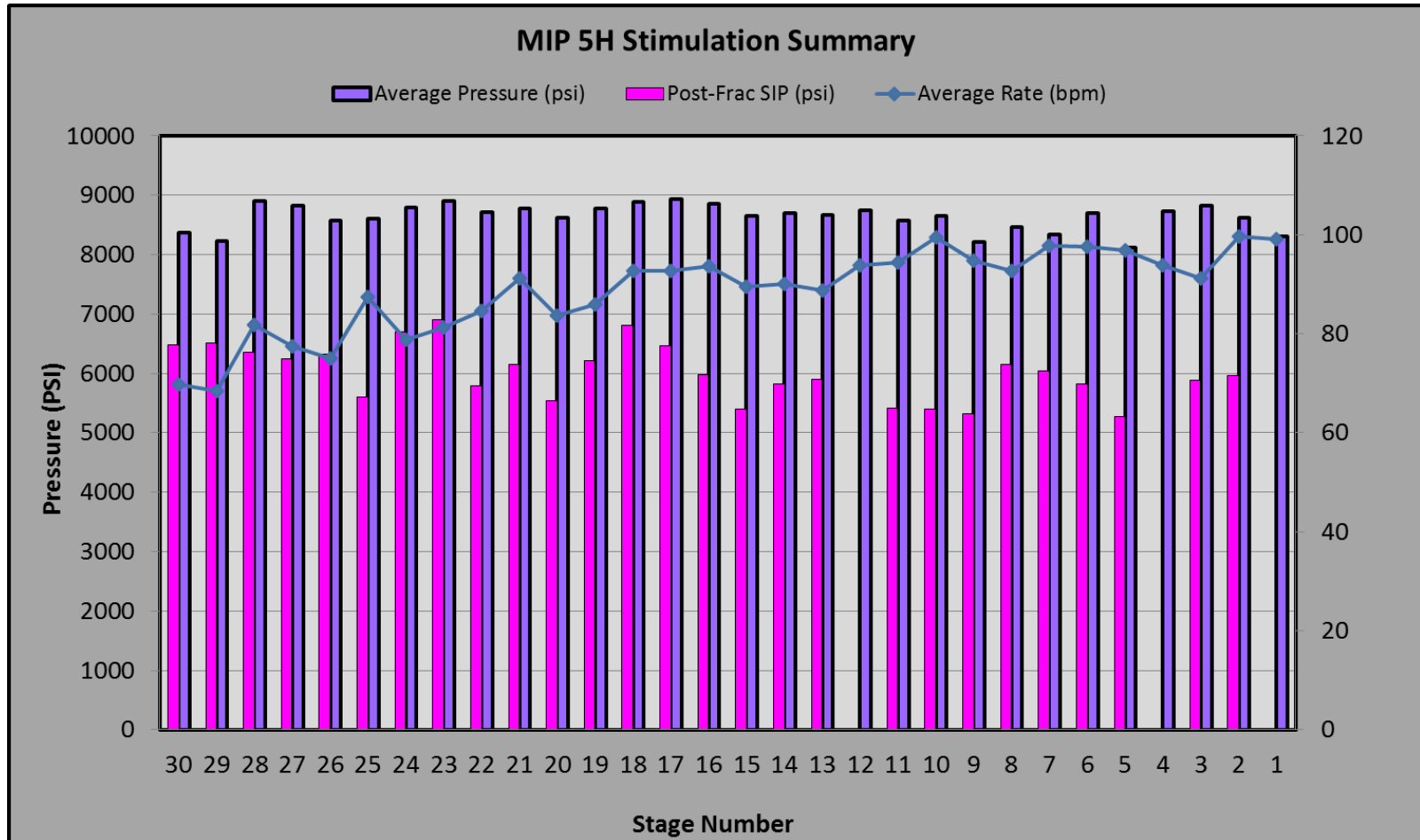
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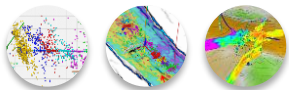
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MIP 5H Rates and Pressure



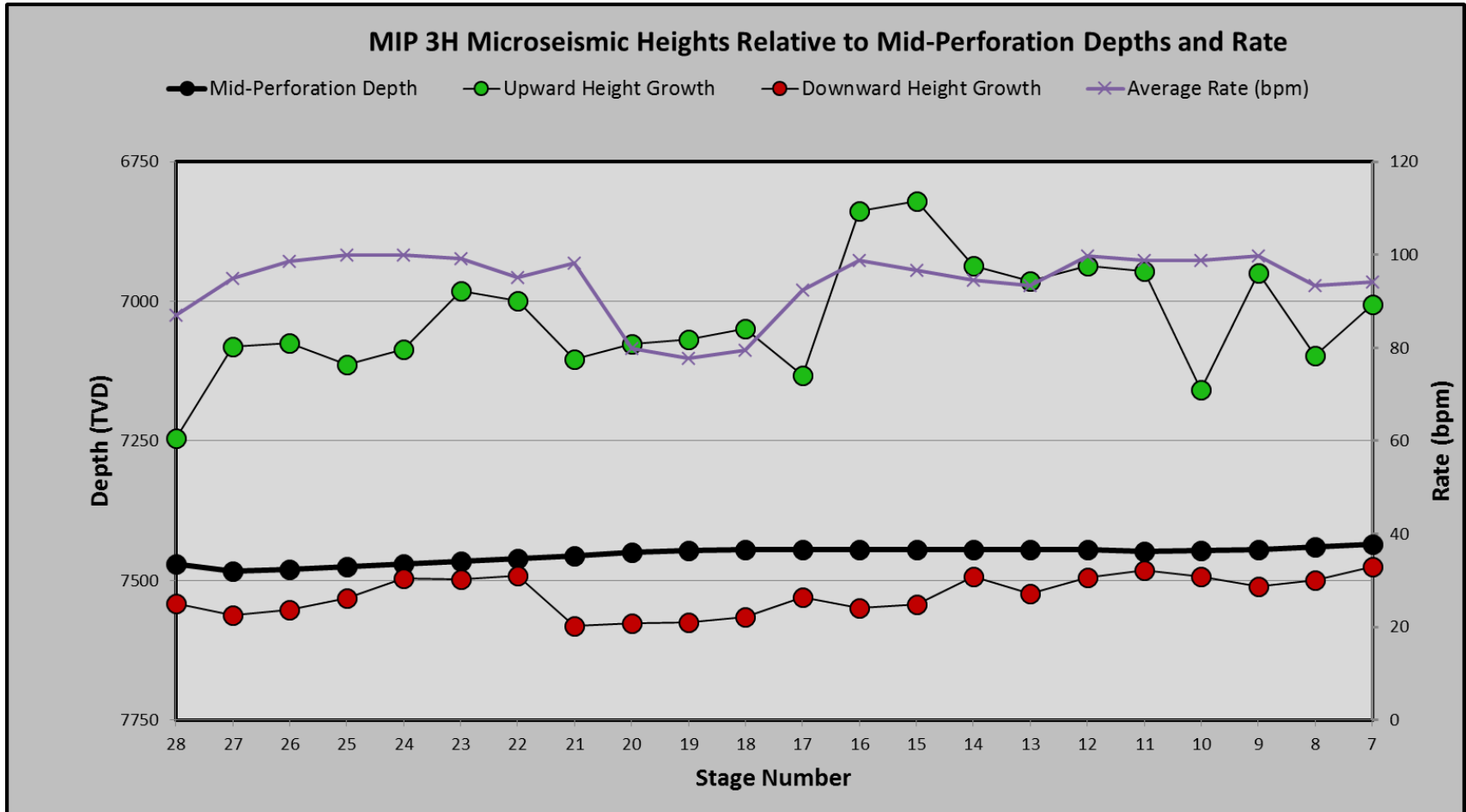
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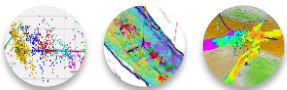
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MIP 3H Rates and Geometries



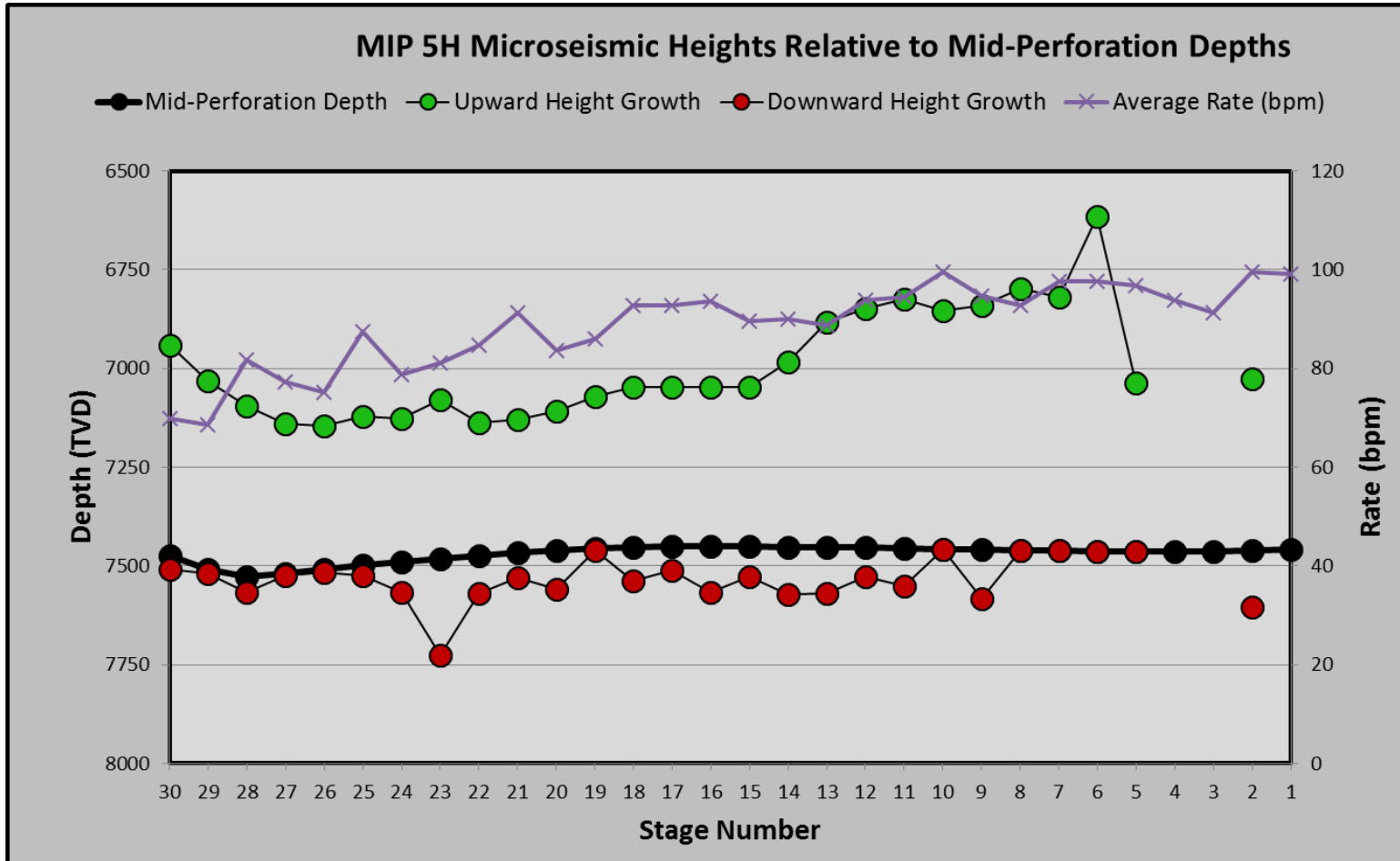
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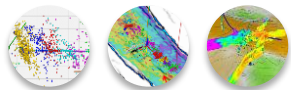
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MIP 5H Rates and Geometries



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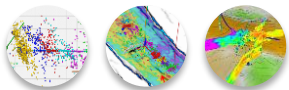
Pressure Notes MIP 3H and MIP 5H

The average treating pressure for MIP 3H was 8,443 psi

The average treating pressure for MIP 5H was 8,634 psi

The change in treating pressures is about 2%. This is an indication of similar geologic constructs although the surface was built using MIP 3H pilot log data.

The ISIP difference is even lower, at 1%. ISIP data can only be used in a qualitative manner. This indicates similar pressure buildup, not to be confused with net pressure.



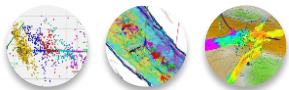
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Pump Schedule Comparison

Well	Section		Stage	Pump Schedule
MIP 3H	A	NNE Standard 35% 100-Mesh	1 – 6	A – NNE 440K 35% 100-Mesh
	B	NNE 75% 100- Mesh	7 – 12	B – NNE 440K 75% 100-Mesh
	C	Perforation Design	13 – 14	A – NNE 440K 35% 100-Mesh
			15 – 19	C – NNE 360K 35% 100-Mesh
	D	Sapphire VF	20 – 21	D – SLB VF 440K 35% 100-Mesh
	E	Best Practices	22 – 23	C – NNE 360K 35% 100-Mesh
24 – 28			A – NNE 440K 35% 100-Mesh	
MIP 5H	N/A		1 – 30	Smaller A – NNE 400K 35% 100-Mesh

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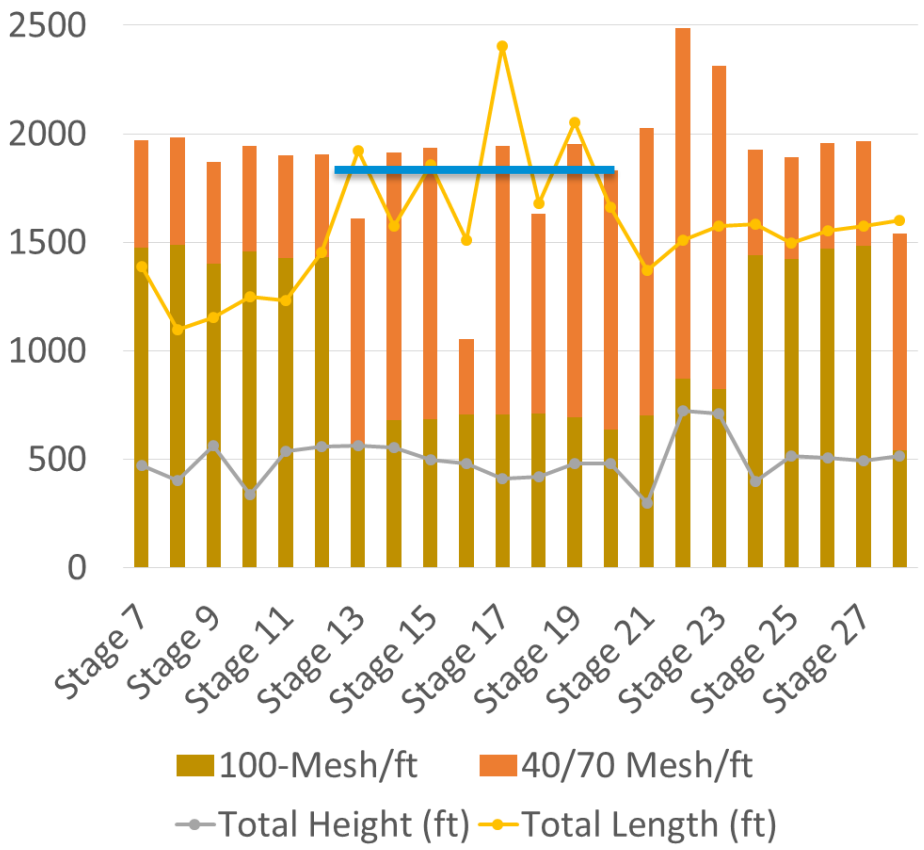


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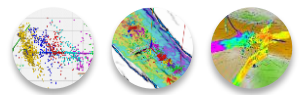
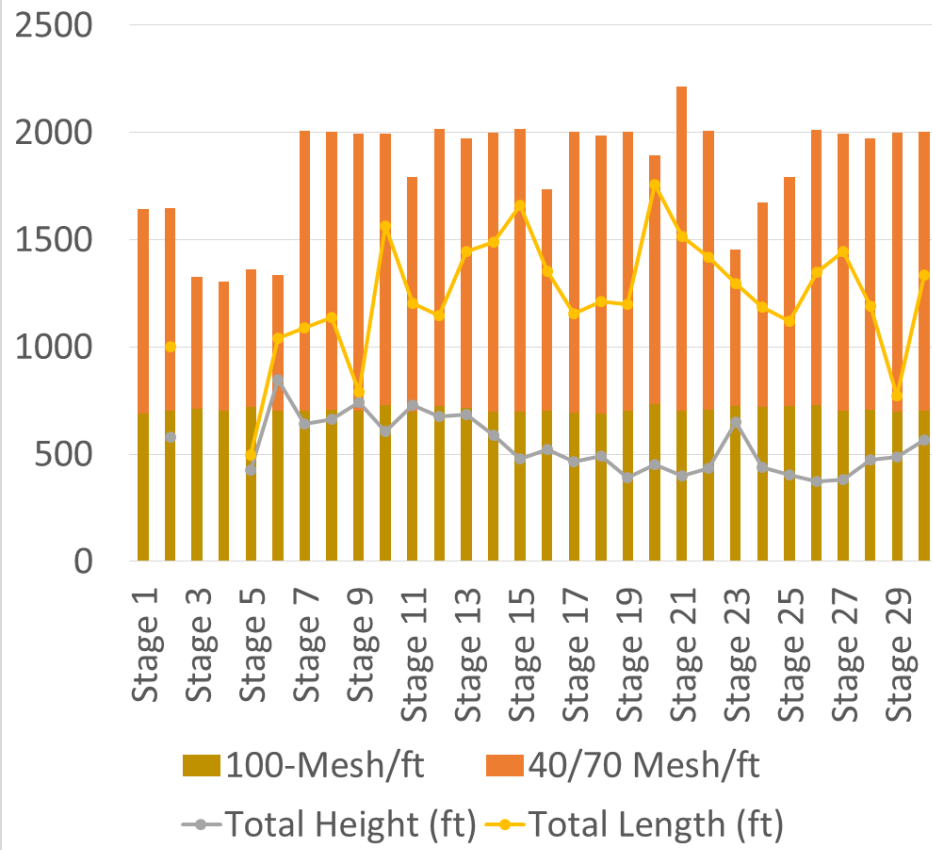
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Proppant vs Fracture Geometry Comparison

MIP 3H Proppant vs Fracture Geometry



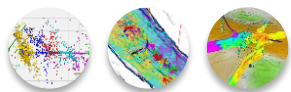
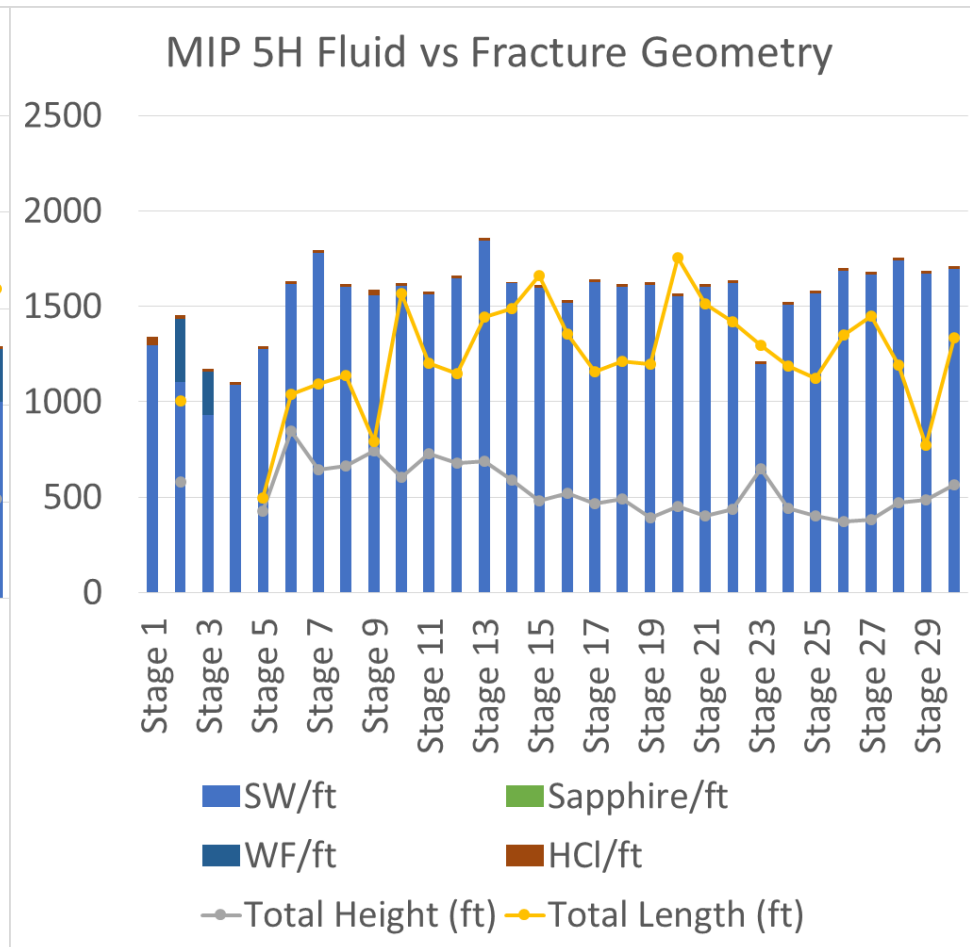
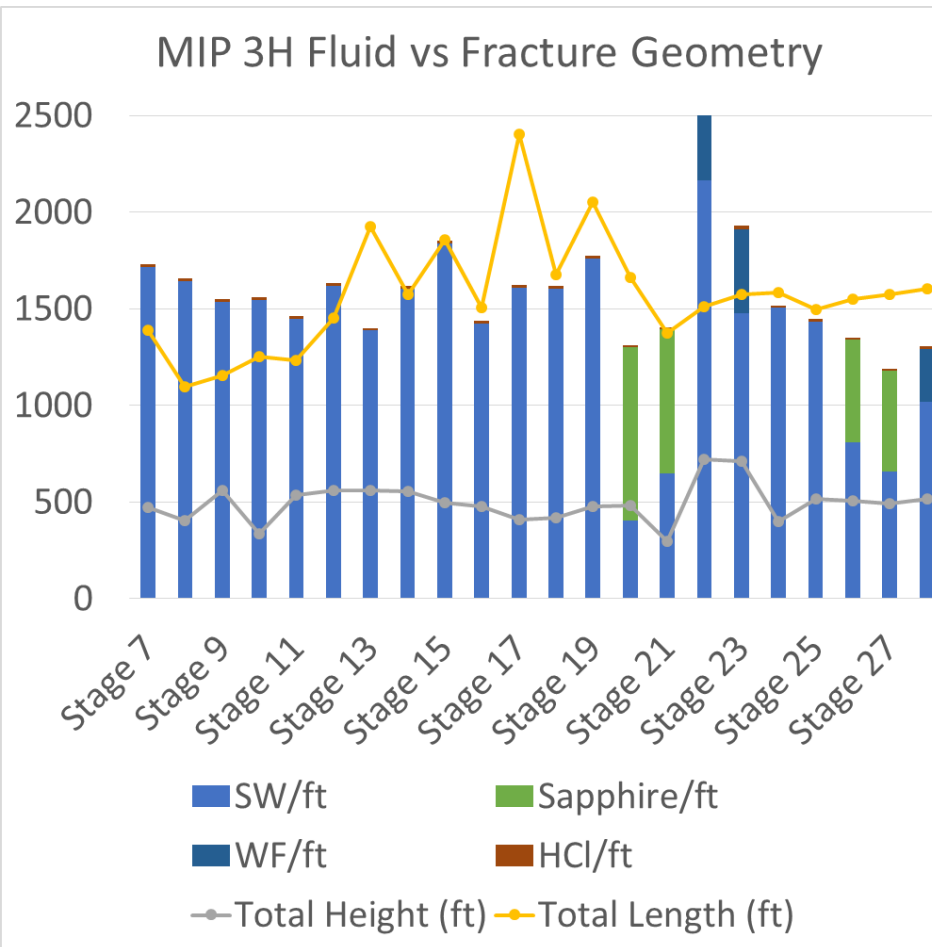
MIP 5H Proppant vs Fracture Geometry



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Fluid vs Fracture Geometry Comparison

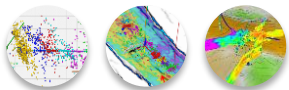


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Discussion and Observation

- MIP 3H Average Half Length: 784ft, Average Height: 496ft, Average Azimuths N76°E
- MIP 5H Average Half Length: 618ft, Average Height: 540ft, Average Azimuths N63°E
- Overall similar pressure responses from various sources indicates the jobs were placed in geologically similar zones, as well as creating similar geometries.

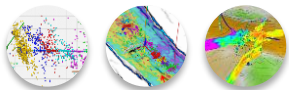


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Discussion and Observation

- A proper comparison among an array of pump schedules and completion strategies will be a normalized production comparison.
- A 40' or smaller cluster spacing has a tendency to create stress shadow effects. This coupled with the altered stress regime created by MIP 5H stimulation, will create larger number of events. Reinforcing the need of larger lateral lengths dedicated to a single variation in order to detect significant differences.

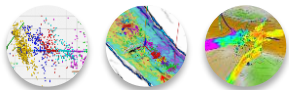


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Conclusions

- Overall event complexity indicates higher stress anisotropy when compared to other unconventional plays.
- Higher amounts of 40/70 sand resulted in larger fracture geometries.
- Higher viscosity fracturing fluid leads smaller fracture height growth, although it will deliver better proppant transport properties.
- The large fracture height growth is an indication of low stress barriers.
- Overall, the differences among the two fracture geometries is not significant.
- Microseismic, lateral logs, and pumping data can be used to create a calibrated DFN model with synthetic microseismic.



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