Midwest Geological Sequestration Consortium

Overview of Illinois Basin-Decatur Project Site and Microseismicity

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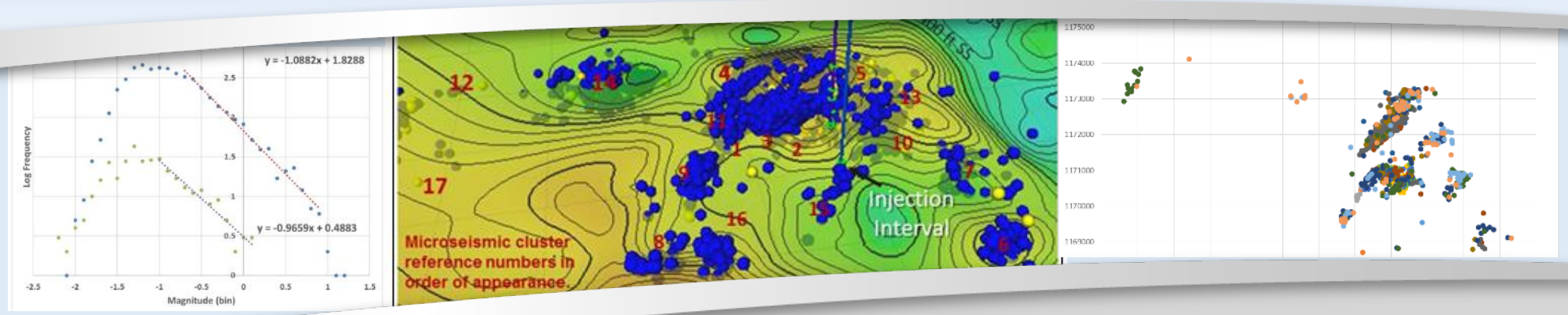
Schlumberger Carbon Services
Paul Jaques, Systems Engineer, Microseismic Processing
Robert Will, Reservoir Engineer
Wade Zaluski, Geologist



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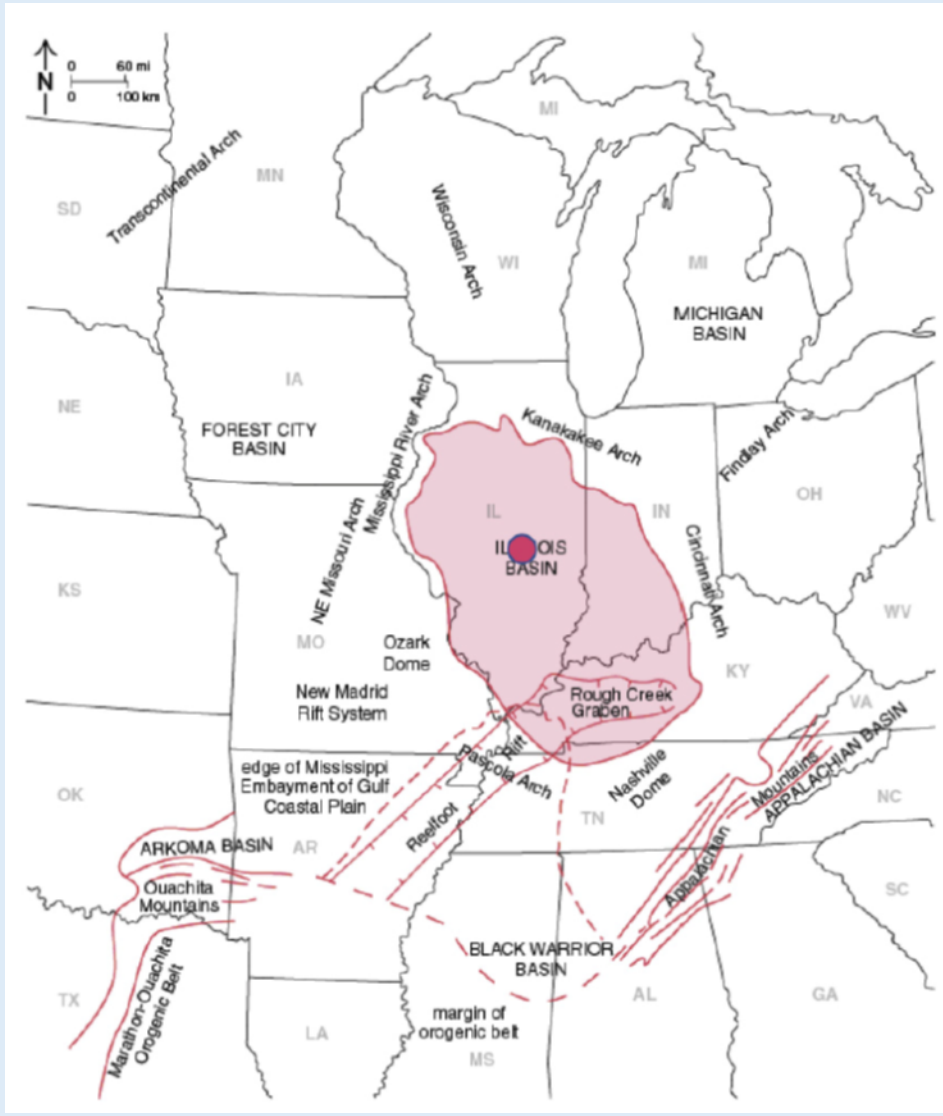
Overview of the IBDP microseismicity:

Setting – formation characteristics
Stratified pressure response
Stress directions & influence on microseismic cluster sequence
Monitoring arrays
Pre-Injection Seismicity
Injection & Post-Injection Seismicity
Comparison to other injection sites and types


N
0 60 mi
0 100 km
Transcontinental Arch
Wisconsin Arch
MICHIGAN BASIN
FOREST CITY BASIN
Mississippi River Arch
NE Missouri Arch
Kanakakee Arch
Findlay Arch
ILLINOIS BASIN
Cincinnati Arch
Ozark Dome
New Madrid Rift System
Rough Creek Graben
Rough Rift
Pascola Arch
Nashville Dome
edge of Mississippi Embayment of Gulf Coastal Plain
Reelfoot
APPALACHIAN BASIN
Mountains
Appalachian
ARKOMA BASIN
Ouachita Mountains
BLACK WARRIOR BASIN
Marathon-Ouachita Orogenic Belt
margin of orogenic belt
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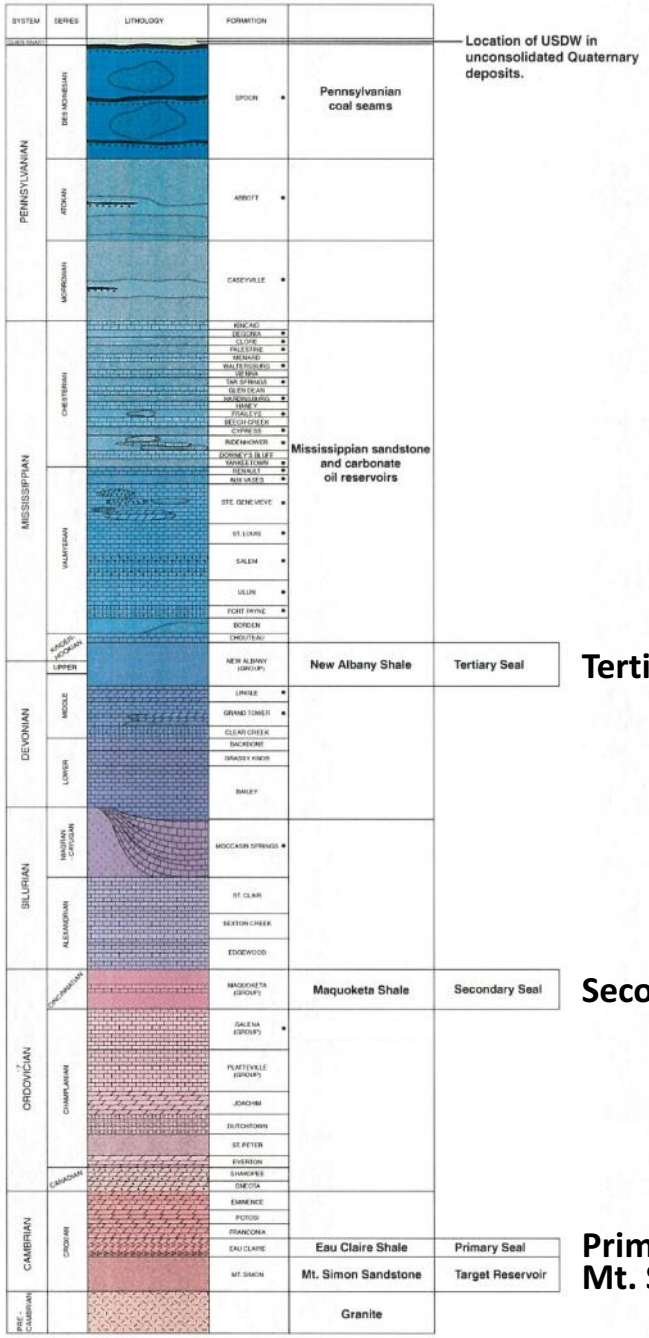
STRATAGRAPHIC COLUMN OF THE ILLINOIS BASIN

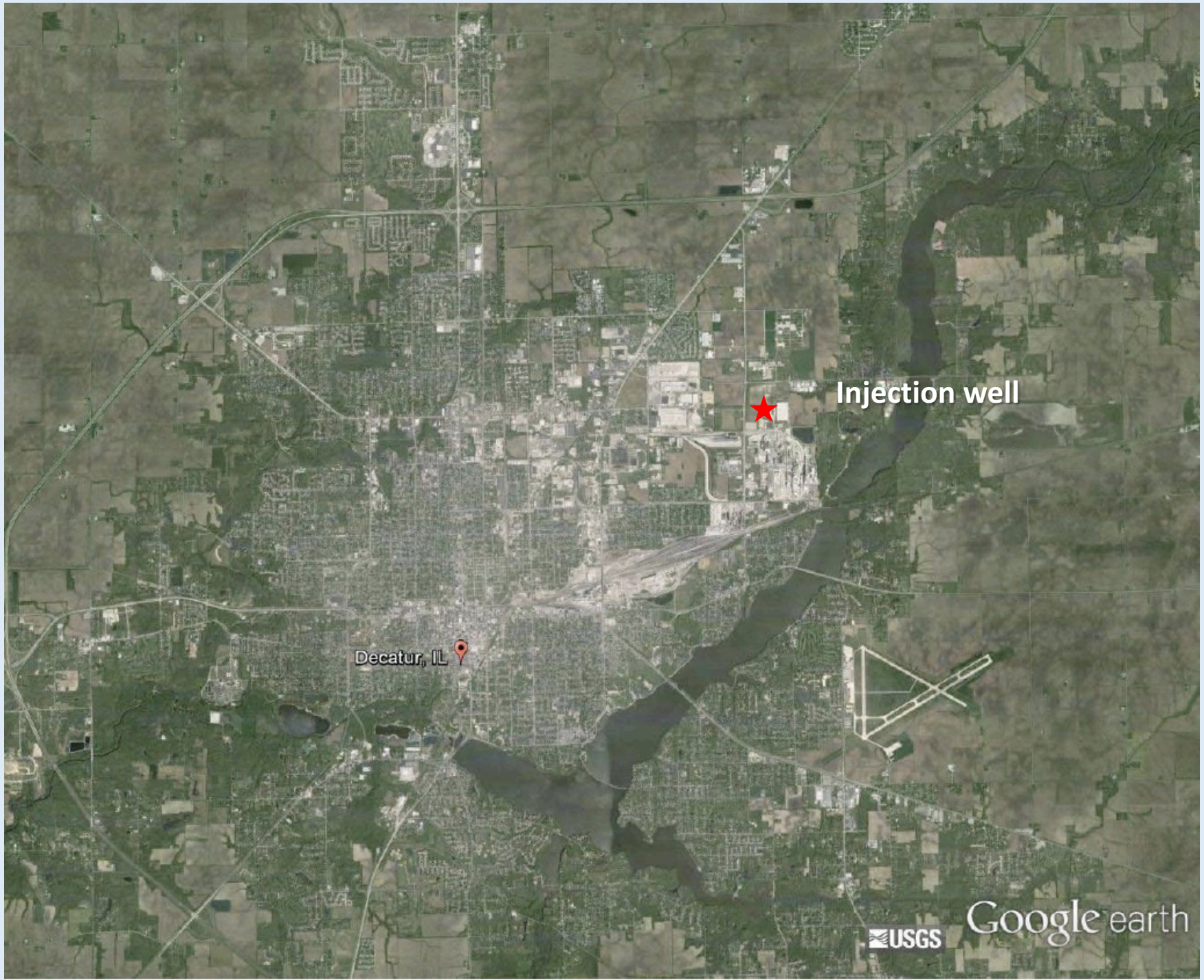


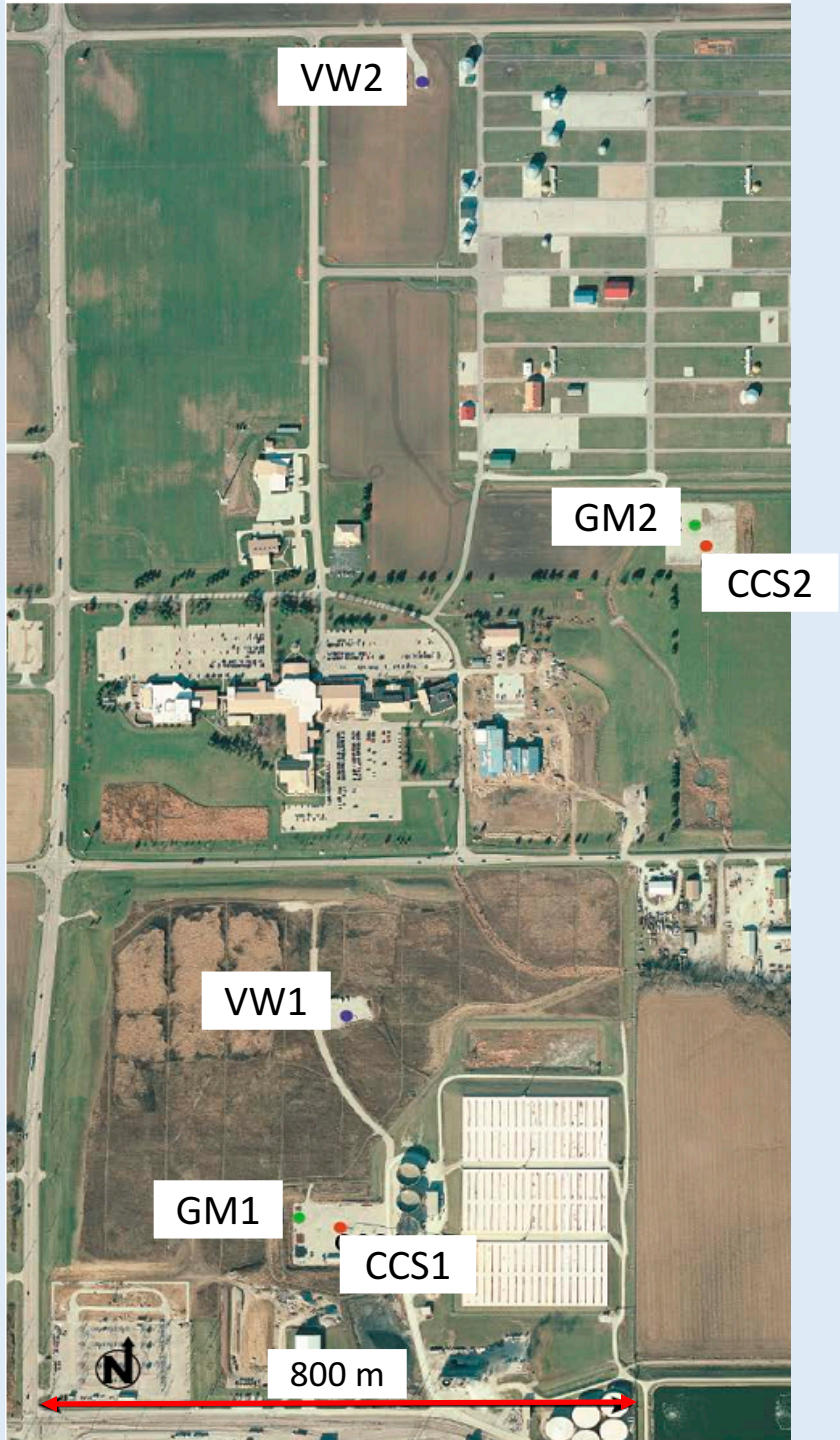
Tertiary seal

Secondary seal

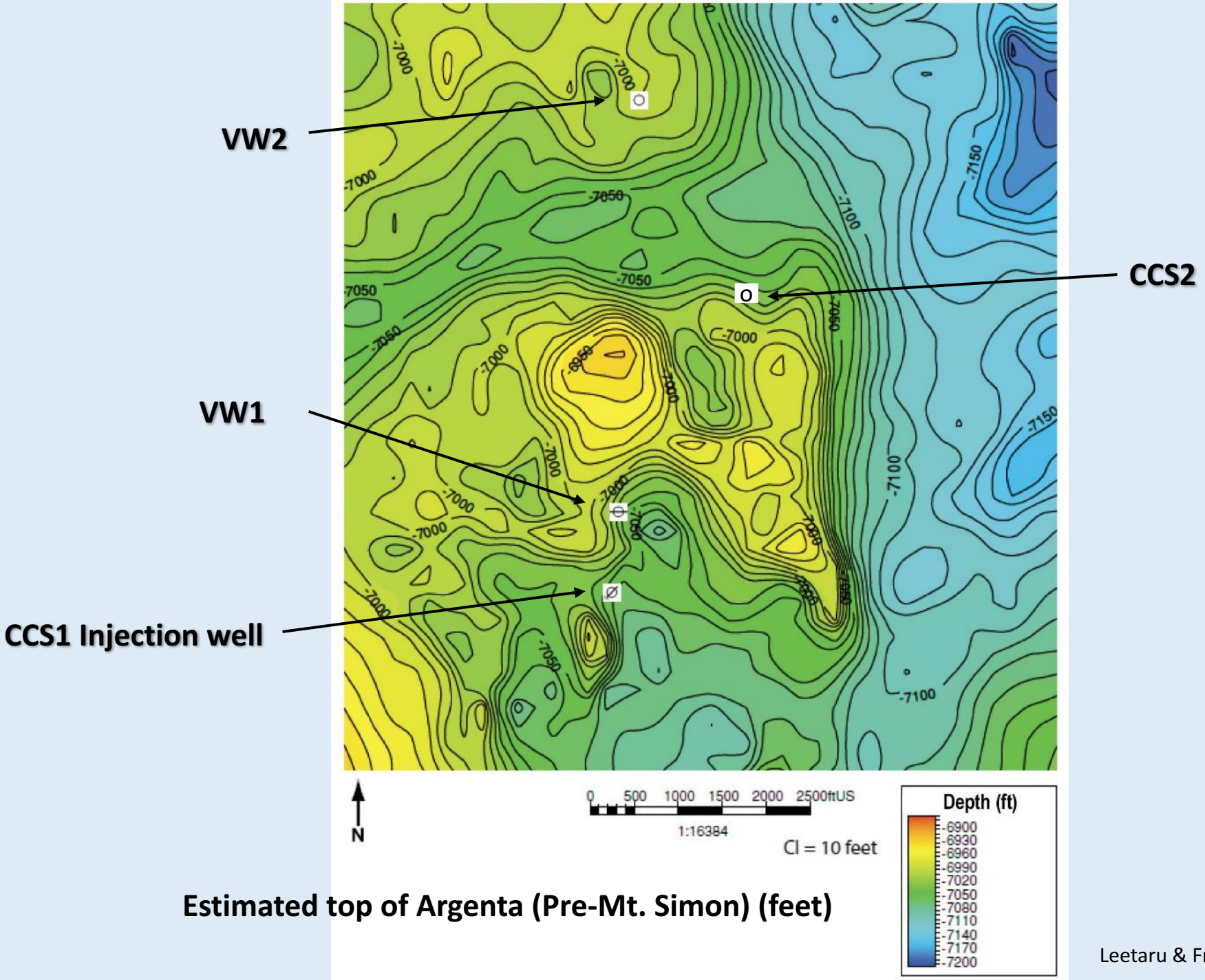
Primary seal
Mt. Simon – 500 meters thick

Injection at
2.1 km – 7,050 ft


Injection well
Decatur, IL
USGS
Google earth

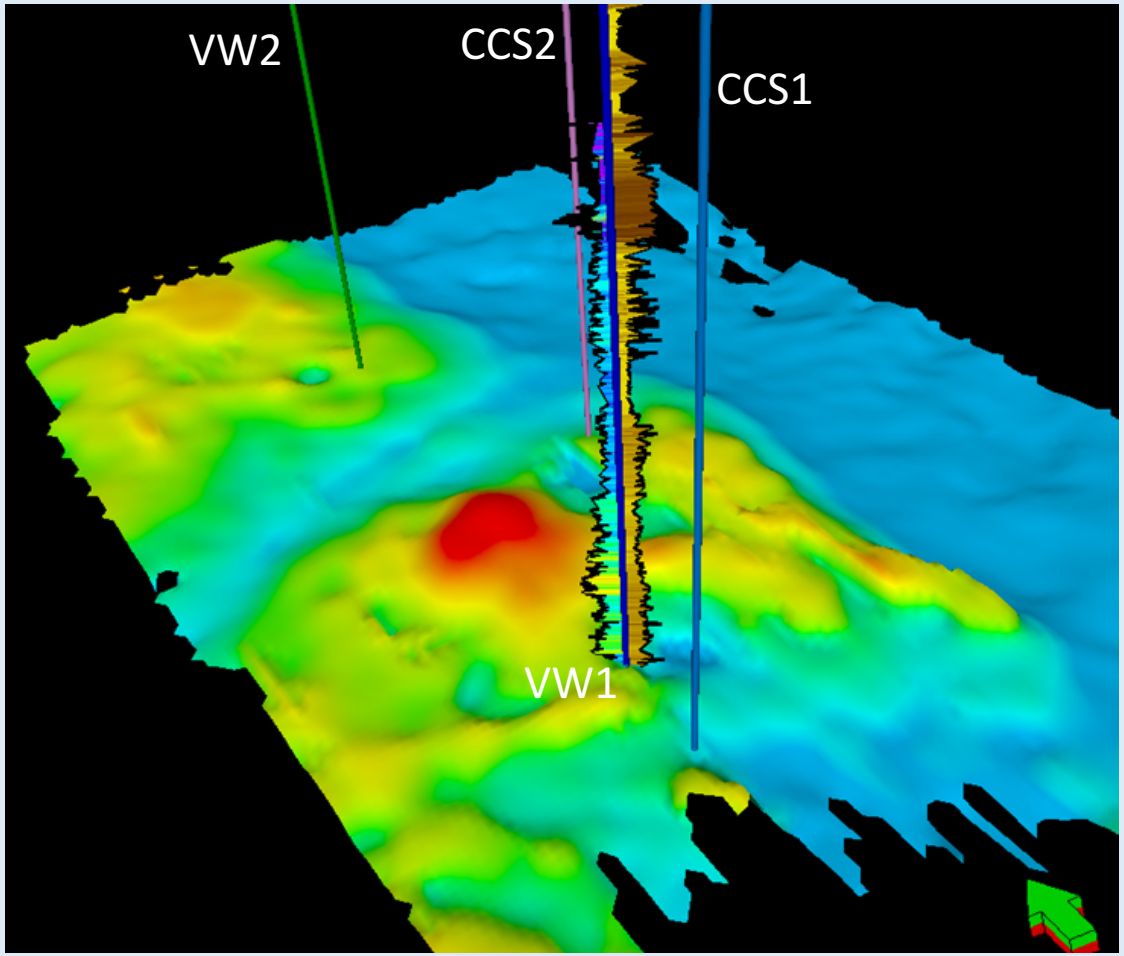

VW2
GM2
CCS2
VW1
GM1
CCS1
N
800 m

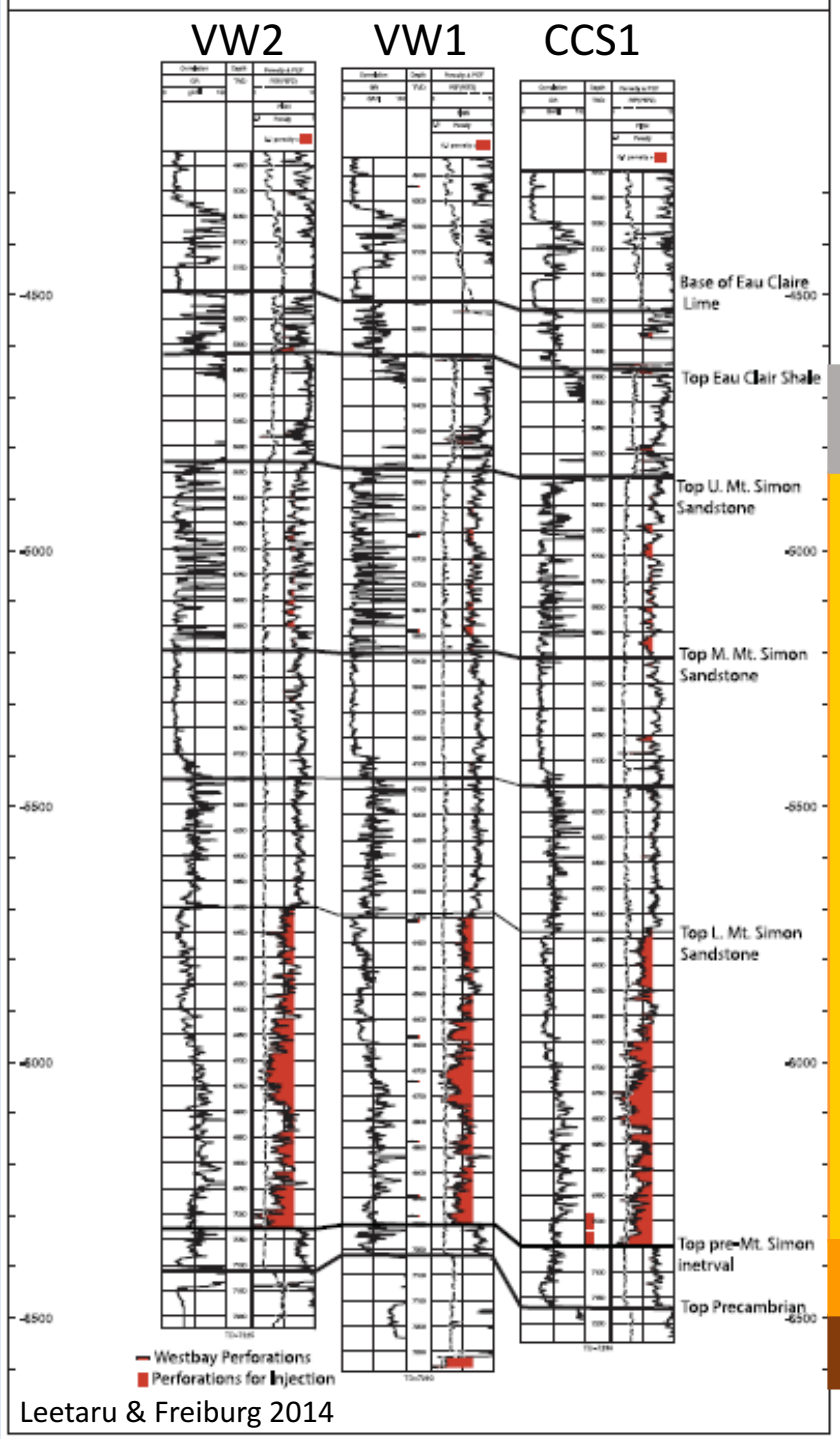
Map View of IBDP wells



Estimated top of Argenta (Pre-Mt. Simon) (feet)

Leetaru & Freiburg 2014


VW2
CCS2
CCS1
VW1



Leetaru & Freiburg 2014

Red= Porosity > 10%

Eau Claire Shale

Mt. Simon Sandstone

Injection zone

Argenta

Precambrian

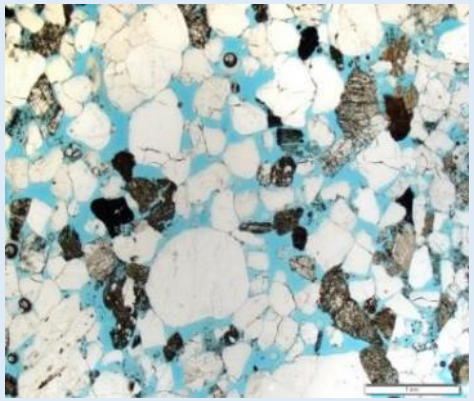
Thickness @ CCS1

492 ft (150 m)

1640 ft (500 m)

50-115 ft (15-35 m)

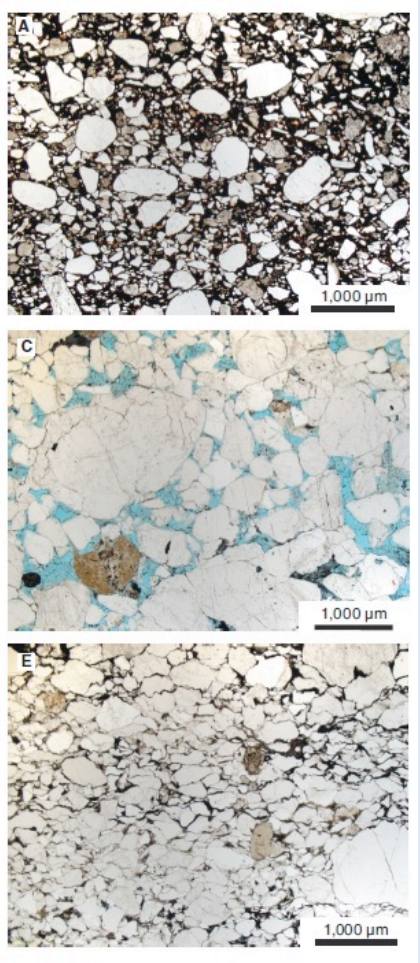
Mt. Simon



1mm

Highest Log Porosity = 27%
Highest Log Perm = 1066 mD

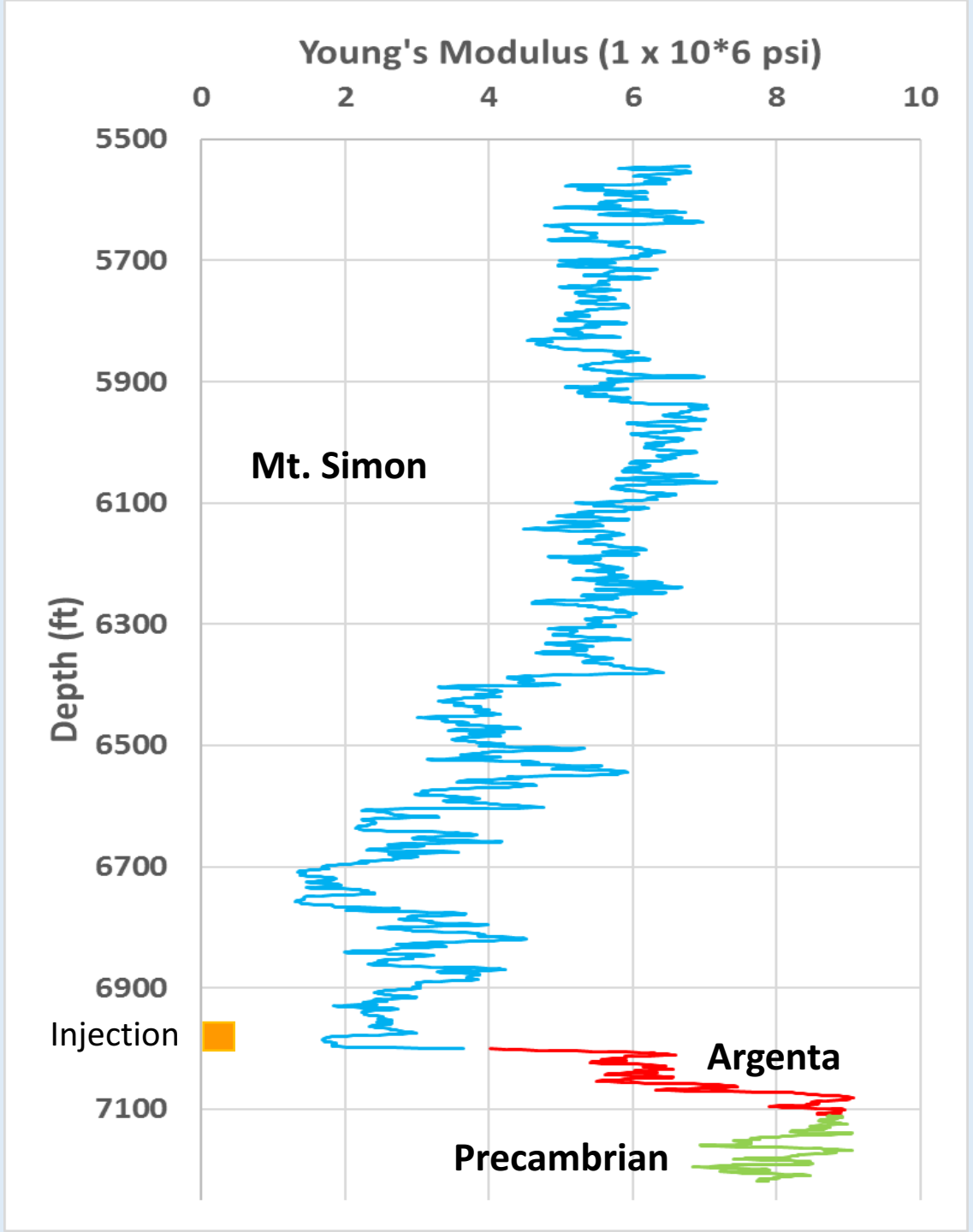
Argenta (Pre-Mt. Simon)

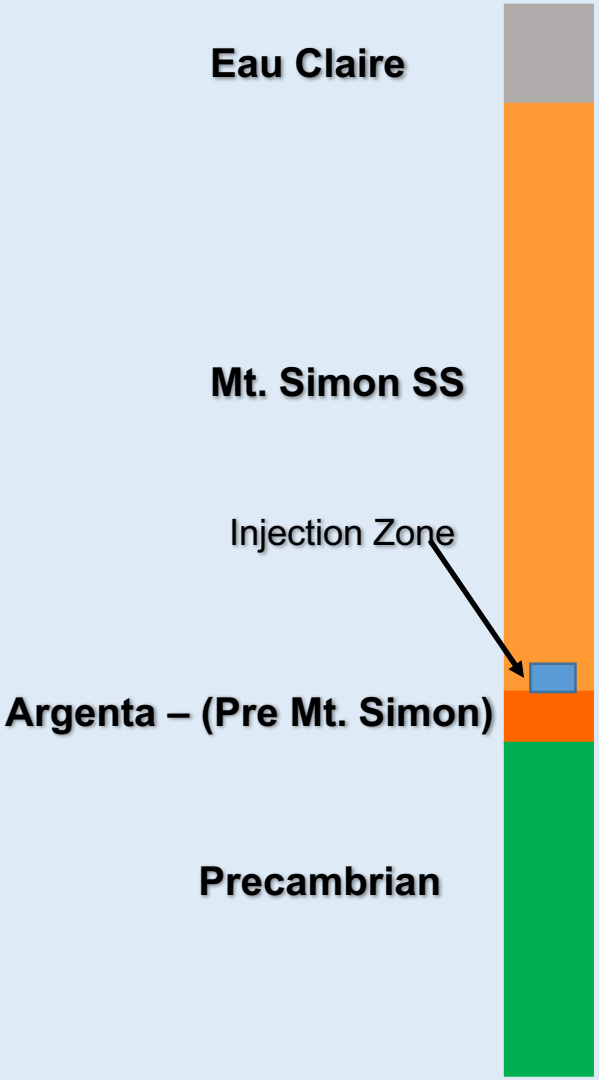


Highest Log Porosity = 14%
Highest Log Perm = 36 mD

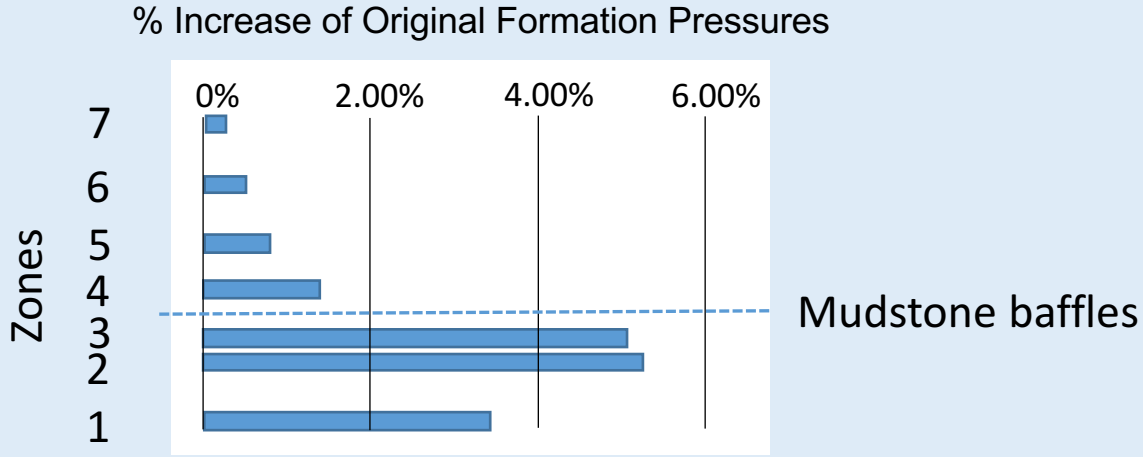
Fractured Precambrian

VW1 Log Derived



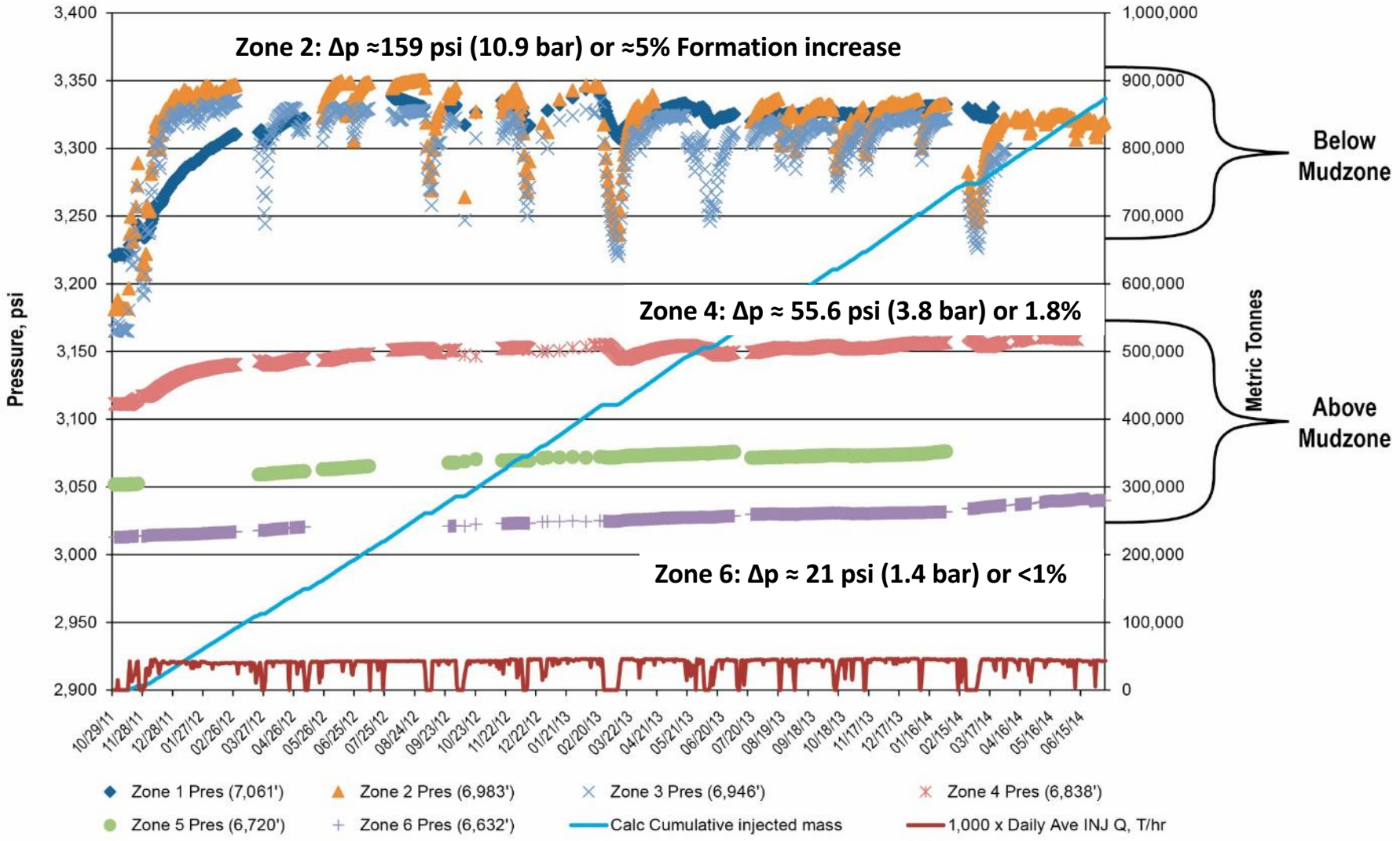


VW1
Formation pressure readings
900 feet from Injection borehole



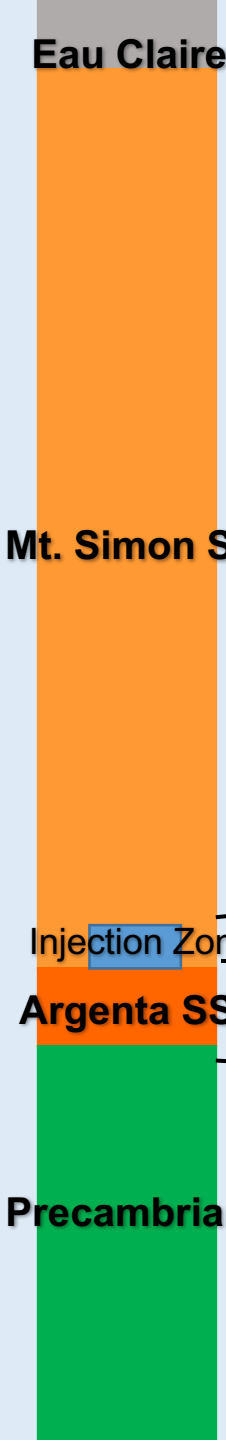
Down hole Injection pressure @ CCS1
14% to 16% increase above original formation pressure

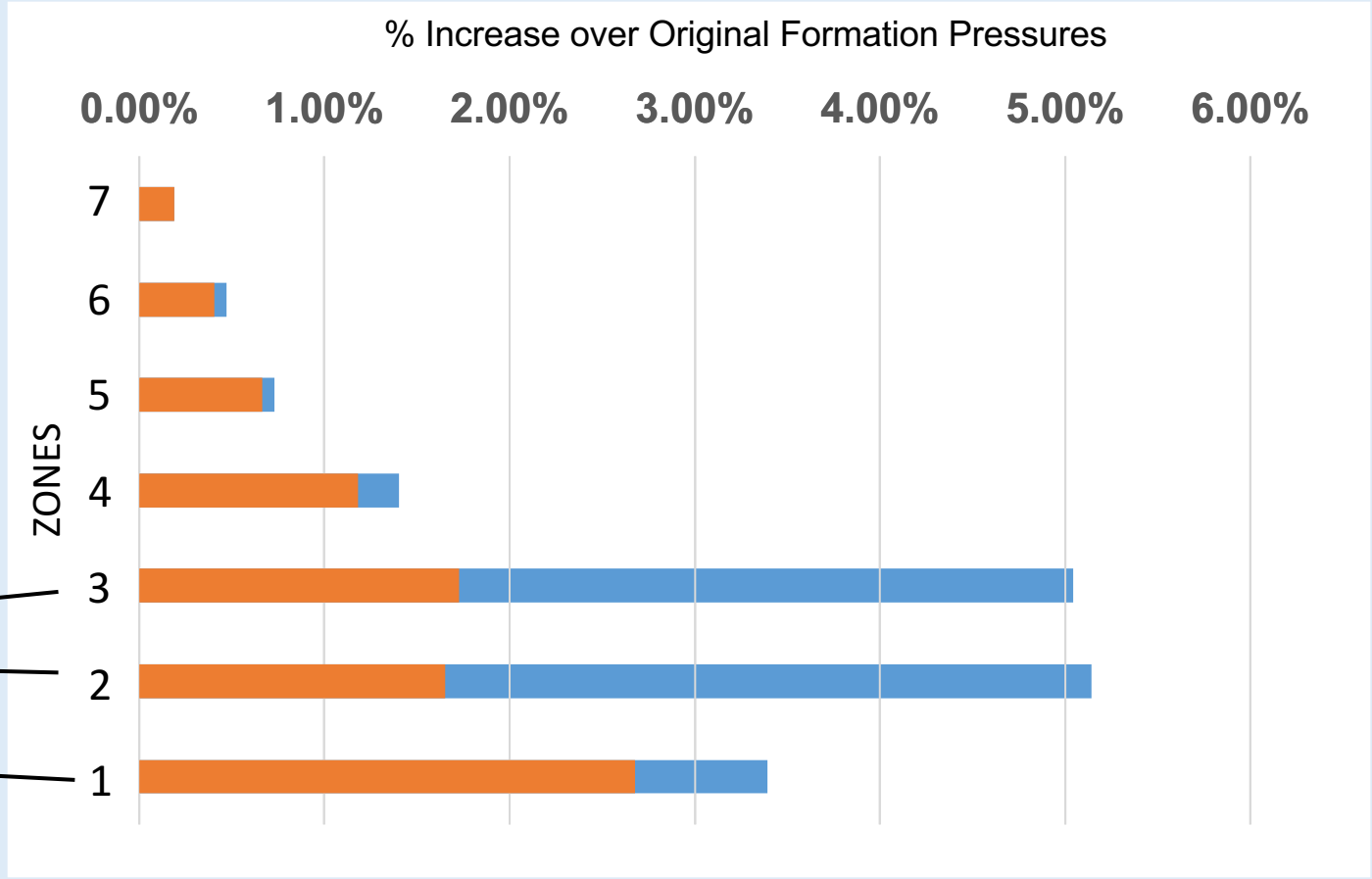
VW1 - Verification Well Pressure Monitoring Data



from Schlumberger Carbon Services

Zone Reactions to 2 week shut in





CCS1 Bottom Hole Pressures as % of Original Pressures dropped from 14% to 3.8%

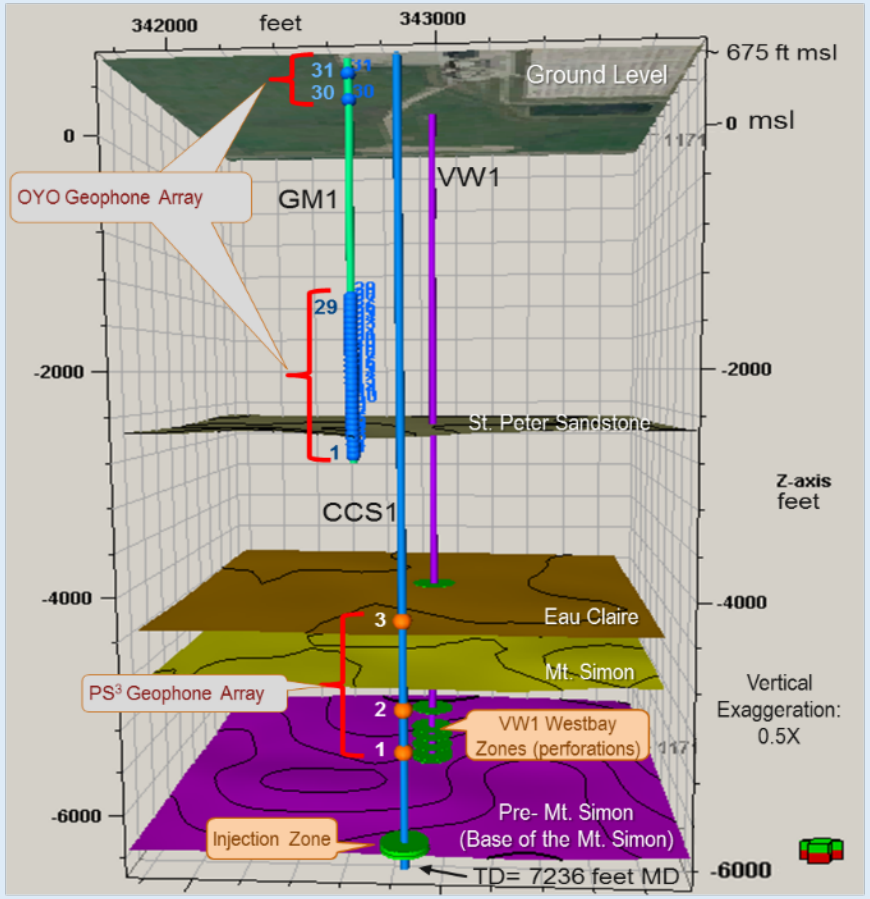
∆ P max at VW1 = 5.2% over original formation pressures for Zone 2

64% to 73% of fracture pressures of Mt. Simon at Injection well

Pressures are stratified and upwards movement influenced by very thin mudstone layers 300 feet above injection zone

IBDP Well configuration and geophones

Oblique View looking north



SMC 1850 10 Hz

Omni 2400 15 Hz

Valerie Smith
Schlumberger Carbon Services

1.5 Years of Pre-Injection Seismic Monitoring

May 2010-Nov 2011

7,894 events detected – 86% related to drilling and well activities

1,100 distant events – most related to distant quarries in southern Illinois

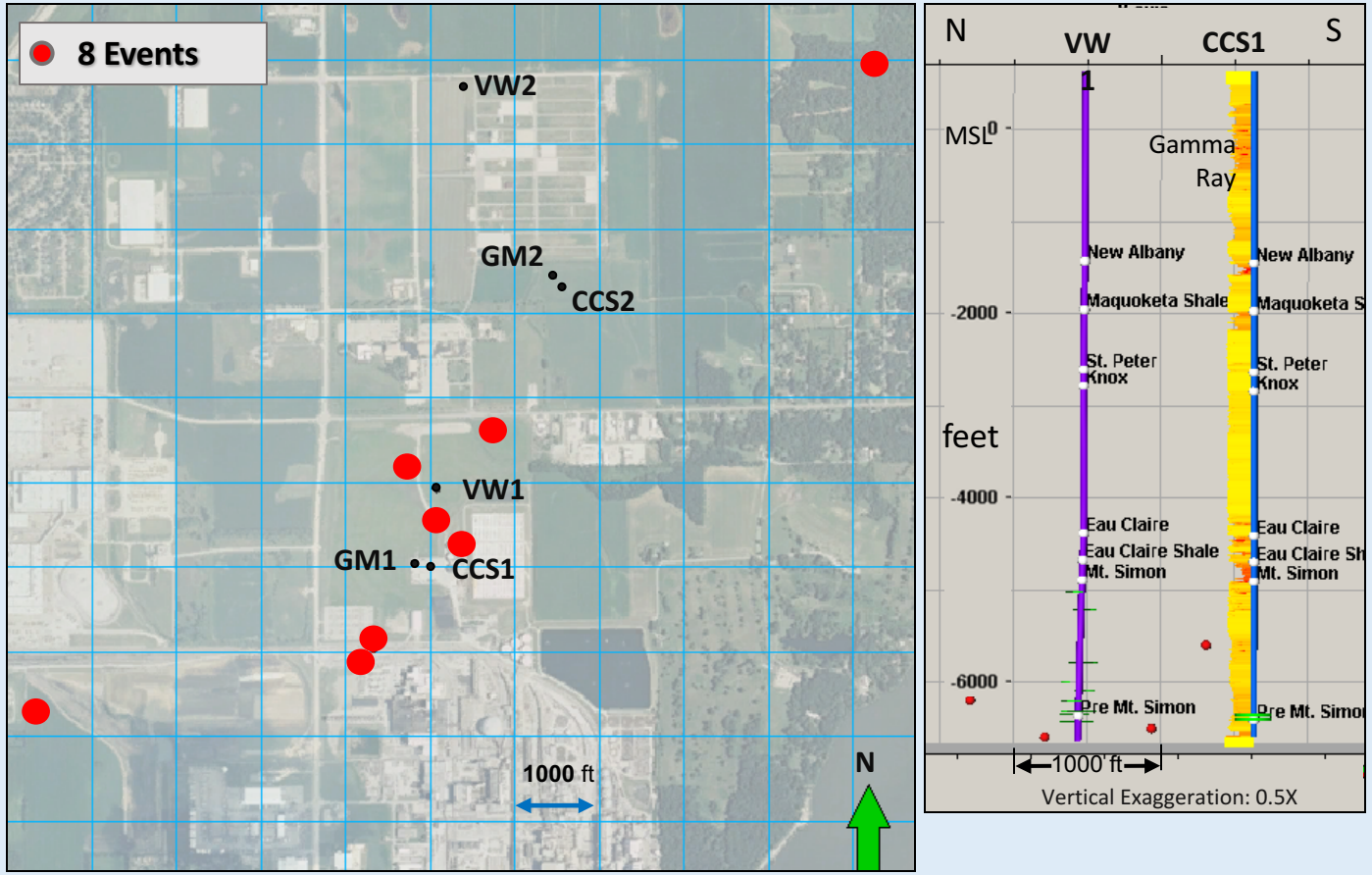
8 local events unrelated to drilling and well activity

Smith 2016

Local Microseismic Events: Pre-Injection

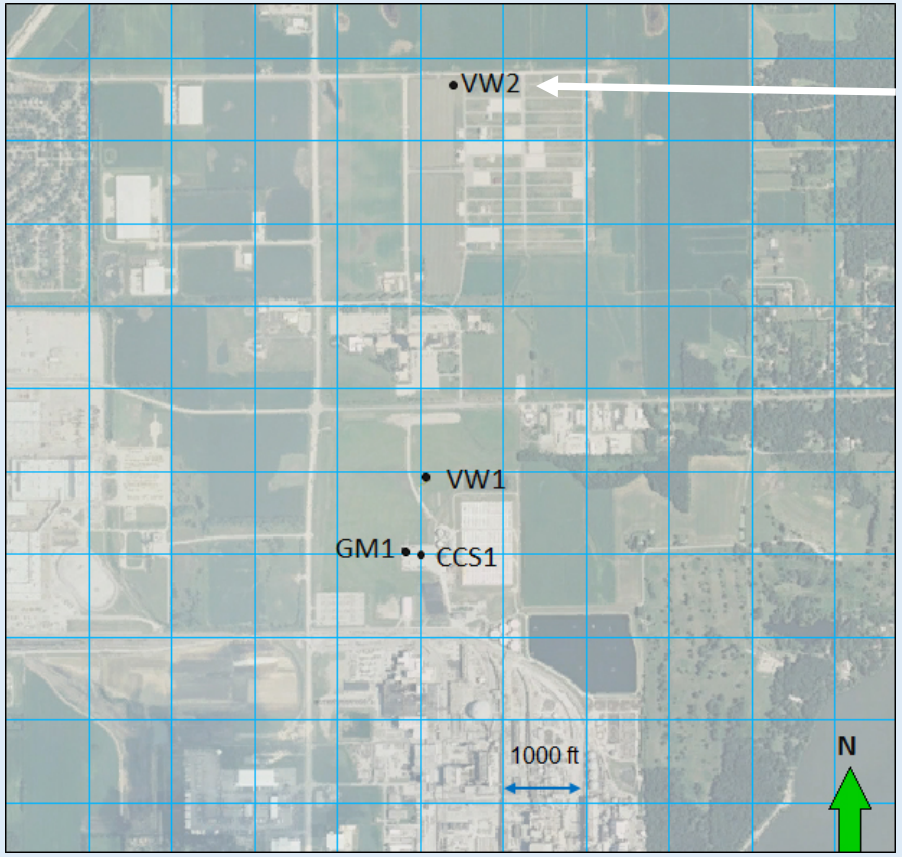
1.5 years of Pre-Injection Monitoring

Max: -1.52
Avg: -1.83
Min: -2.16



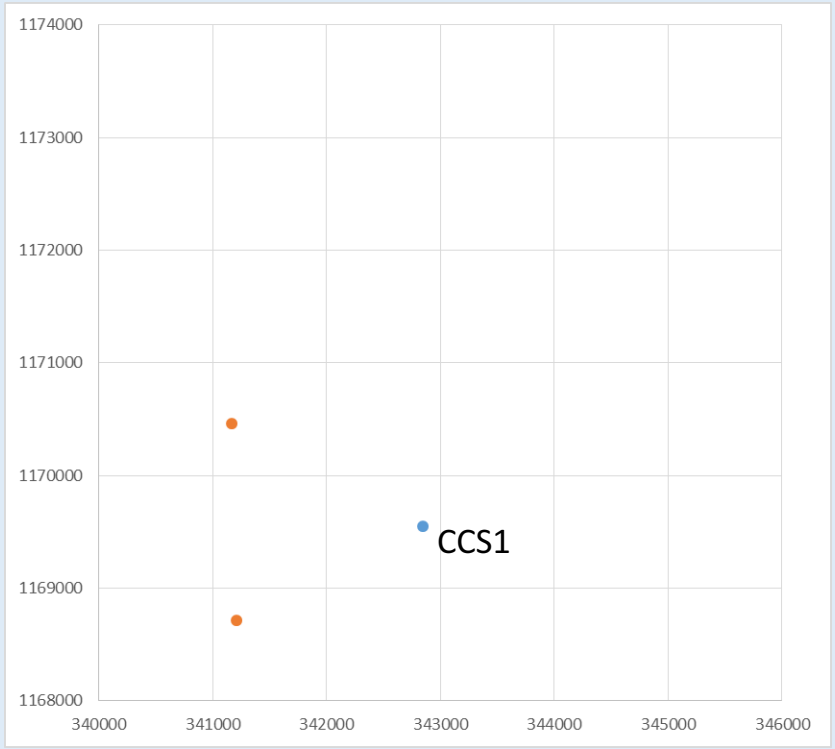
Valerie Smith
Schlumberger Carbon Services

Additional Temporary Geophones in VW2 from 26 Sept 2013 to 25 Feb 2015



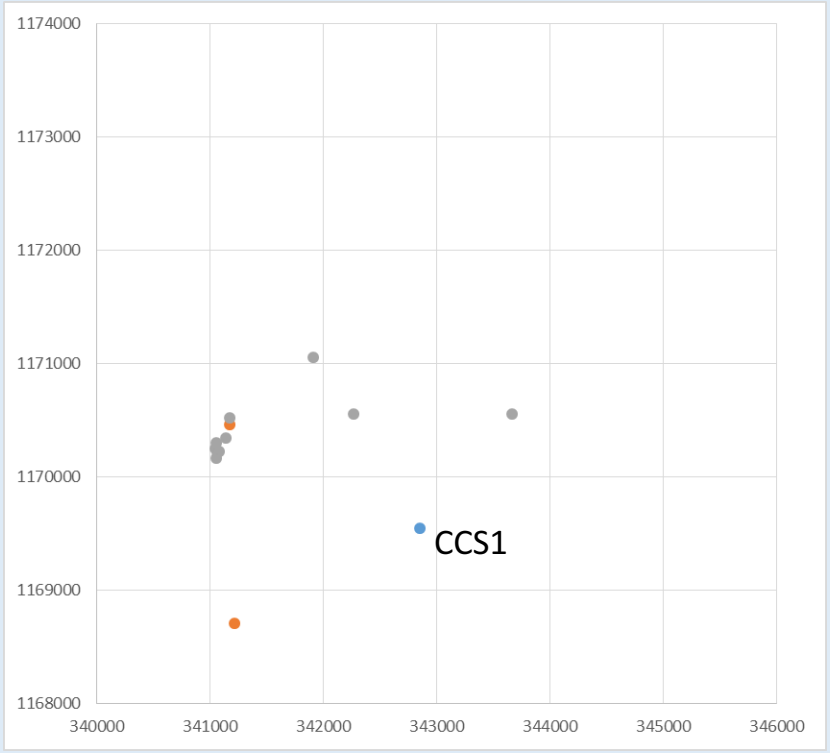
Five Omni 2400 15 Hz 200 ft apart from depths of 6,150 ft to 6,950 ft

Dec 2011



Each Division in X & Y
= 1,000 Ft or
≈ 300 m

Jan 2012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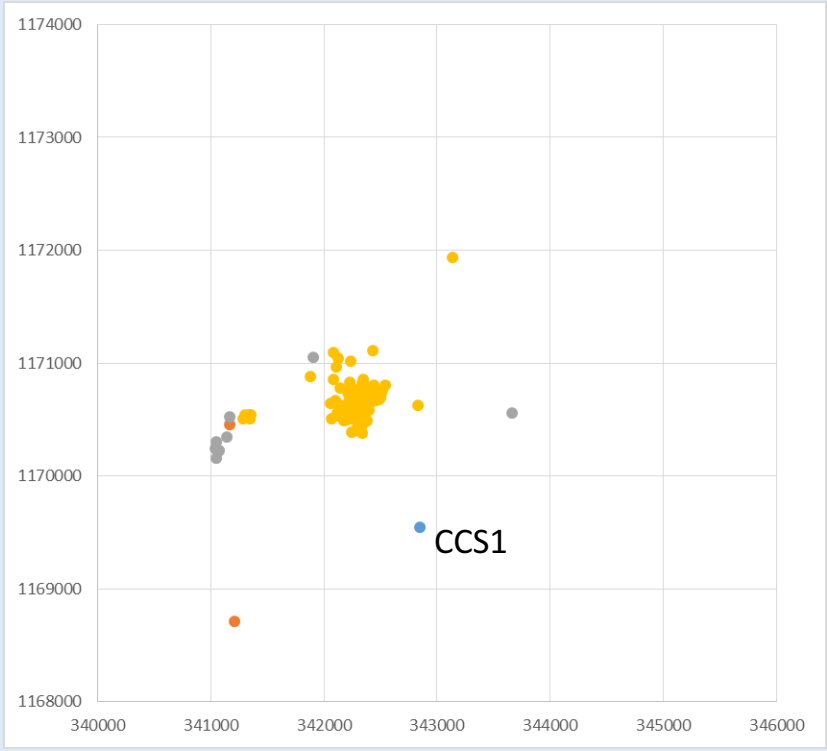
Feb 2012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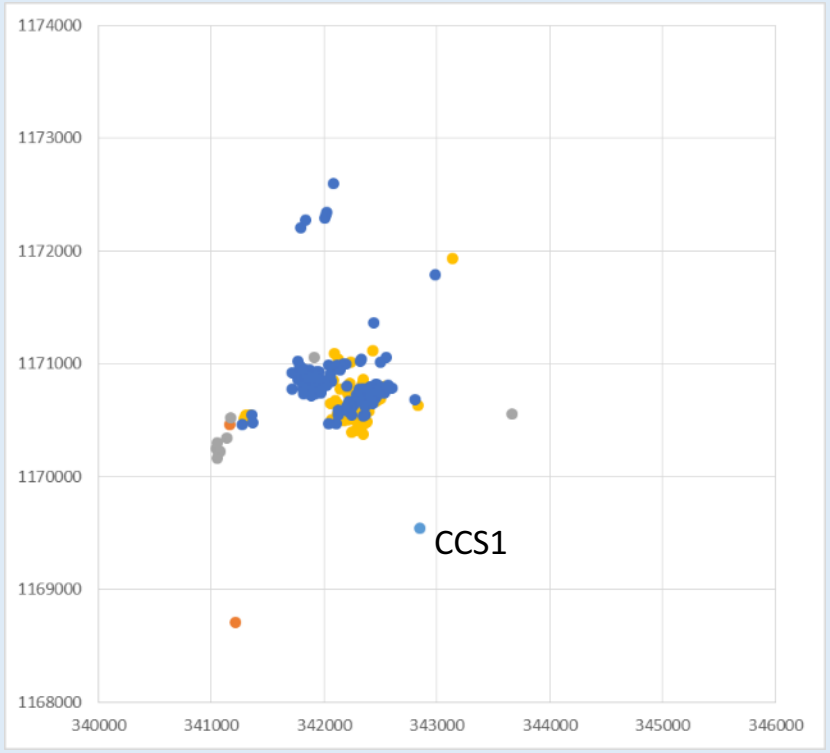
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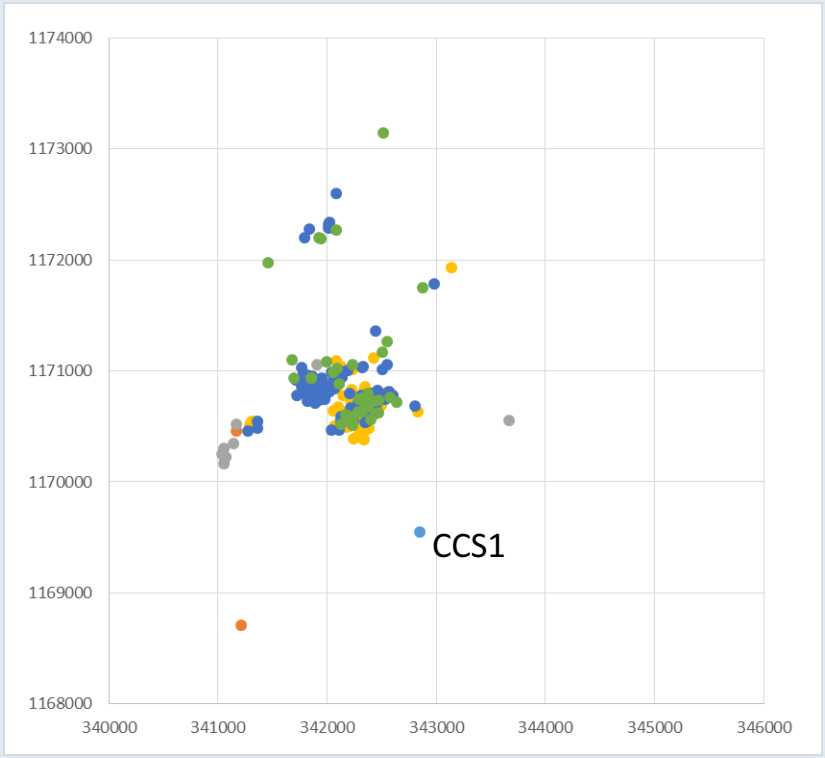
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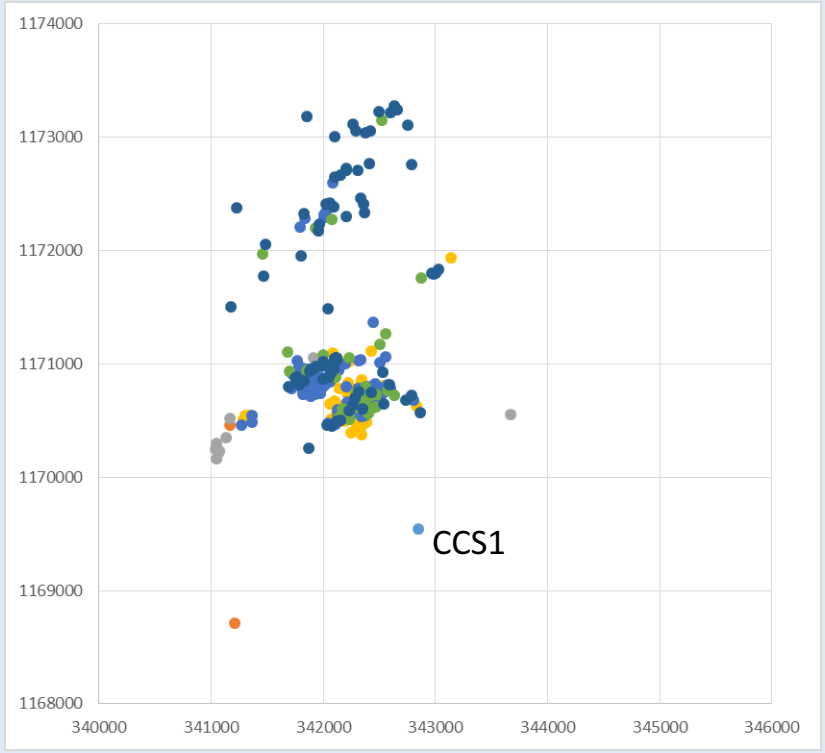
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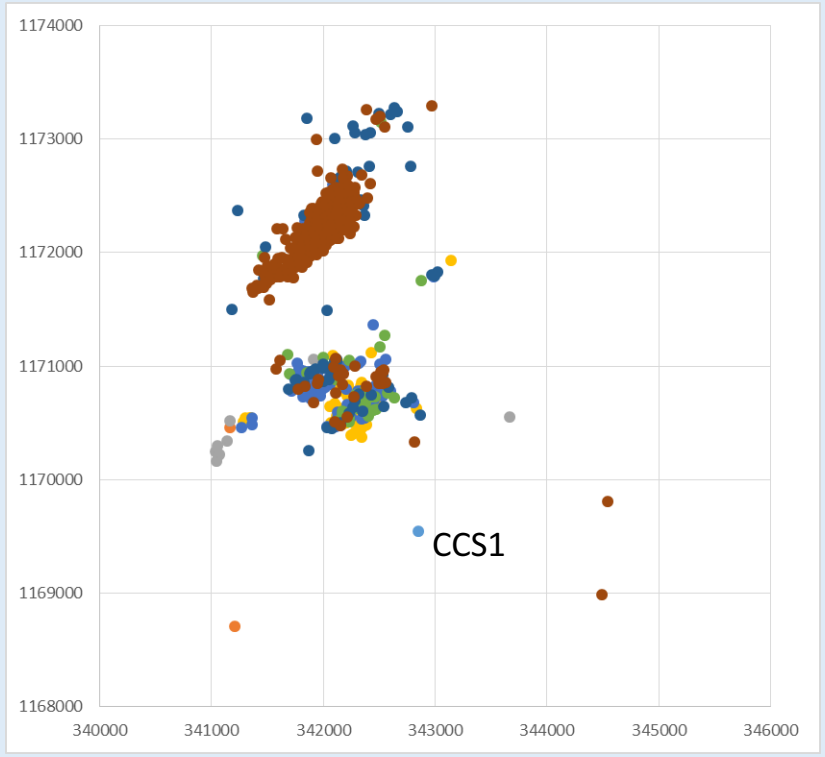
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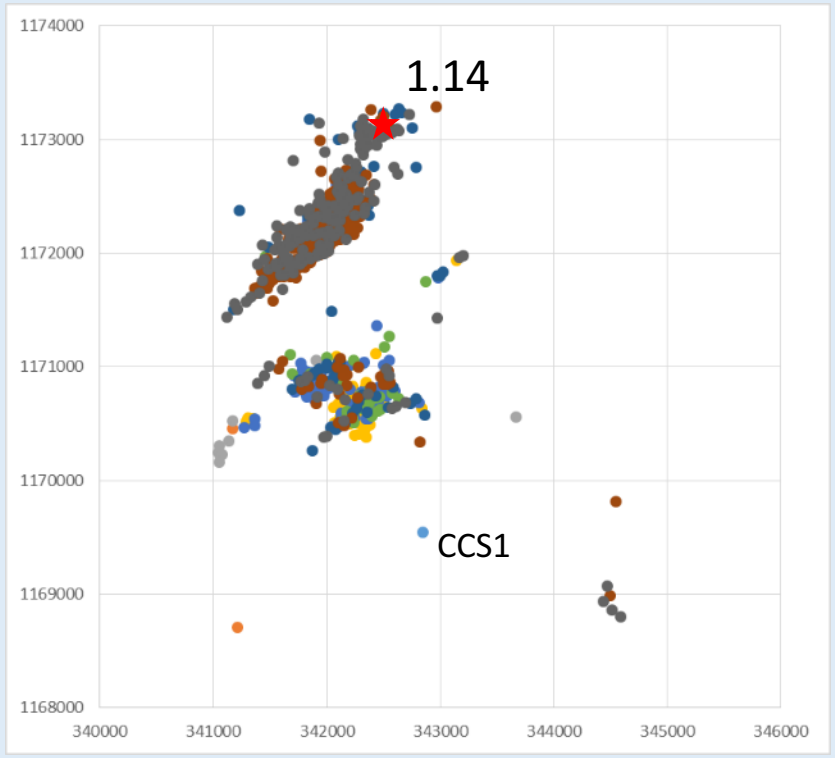
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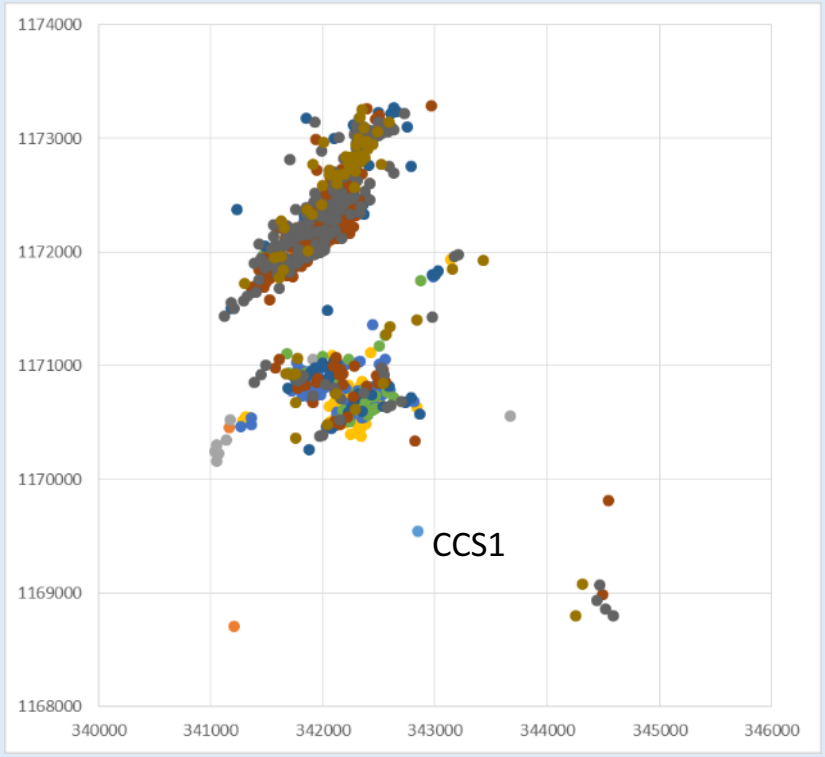
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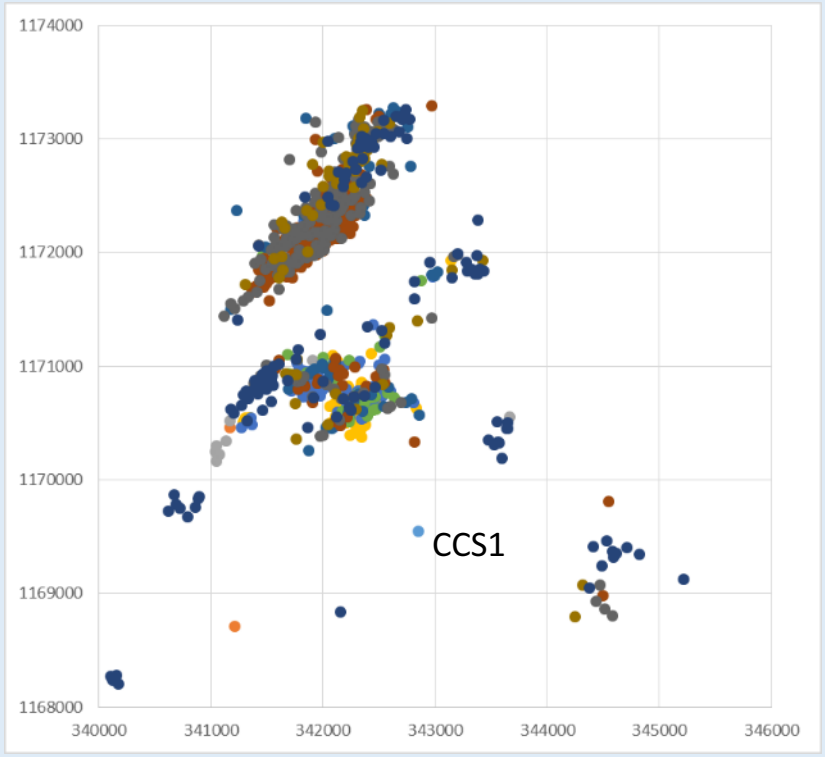
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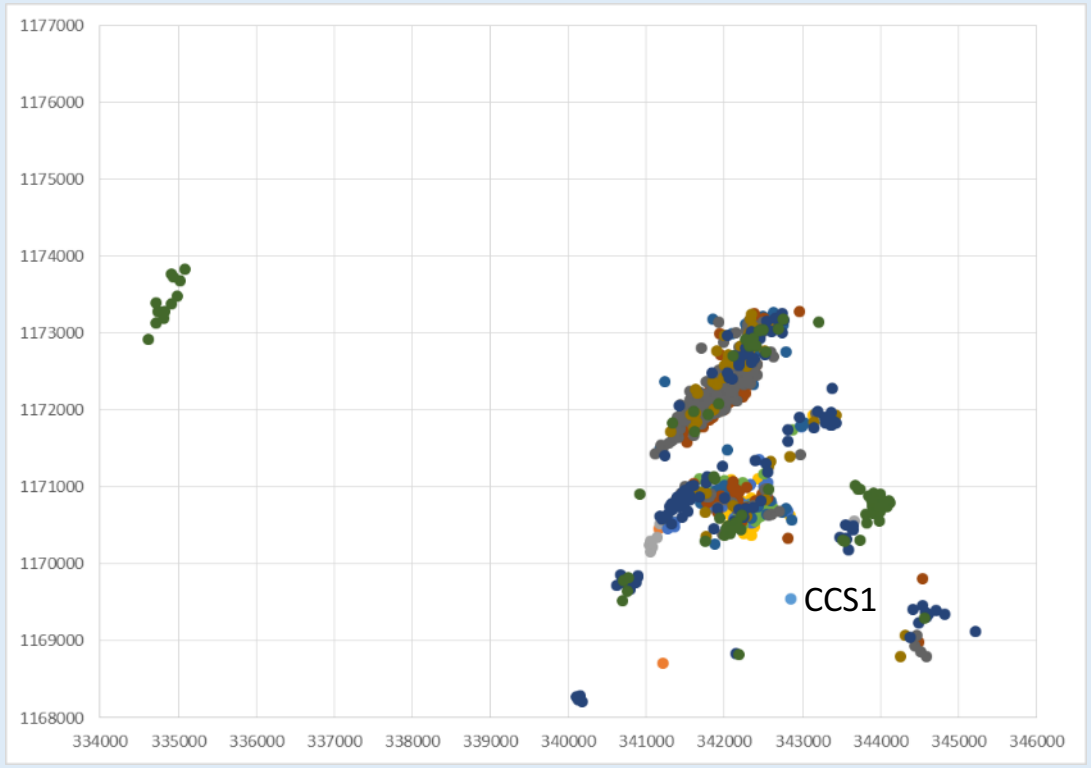
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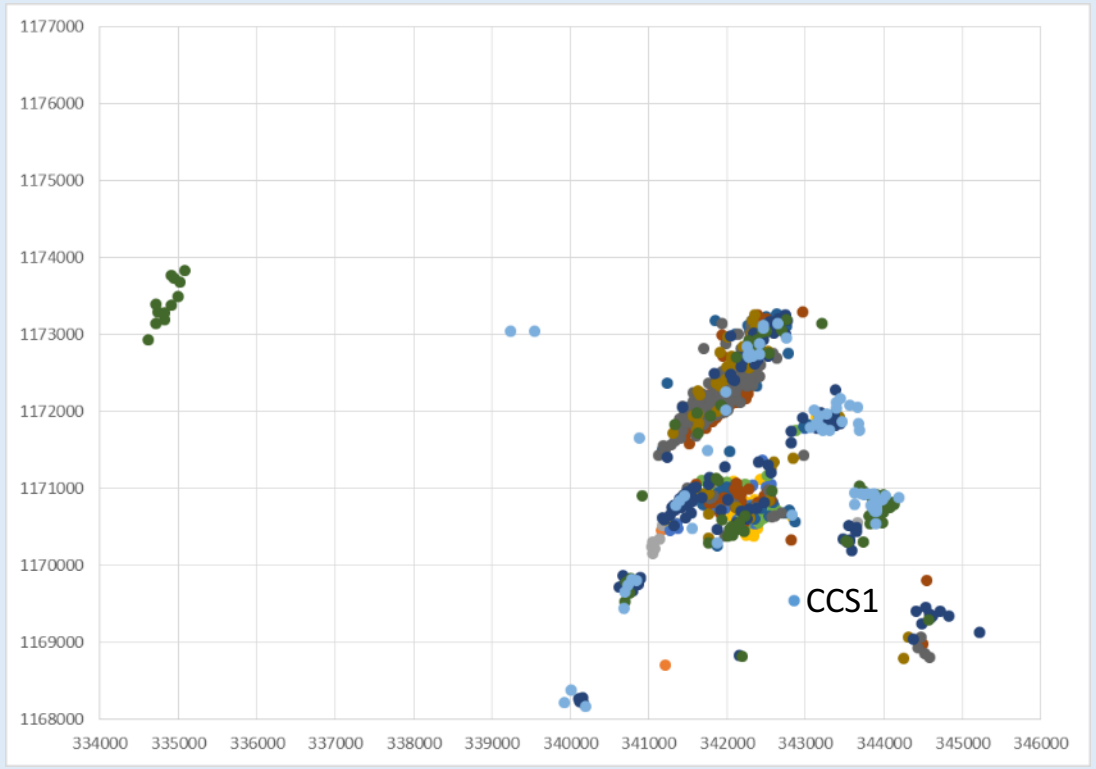
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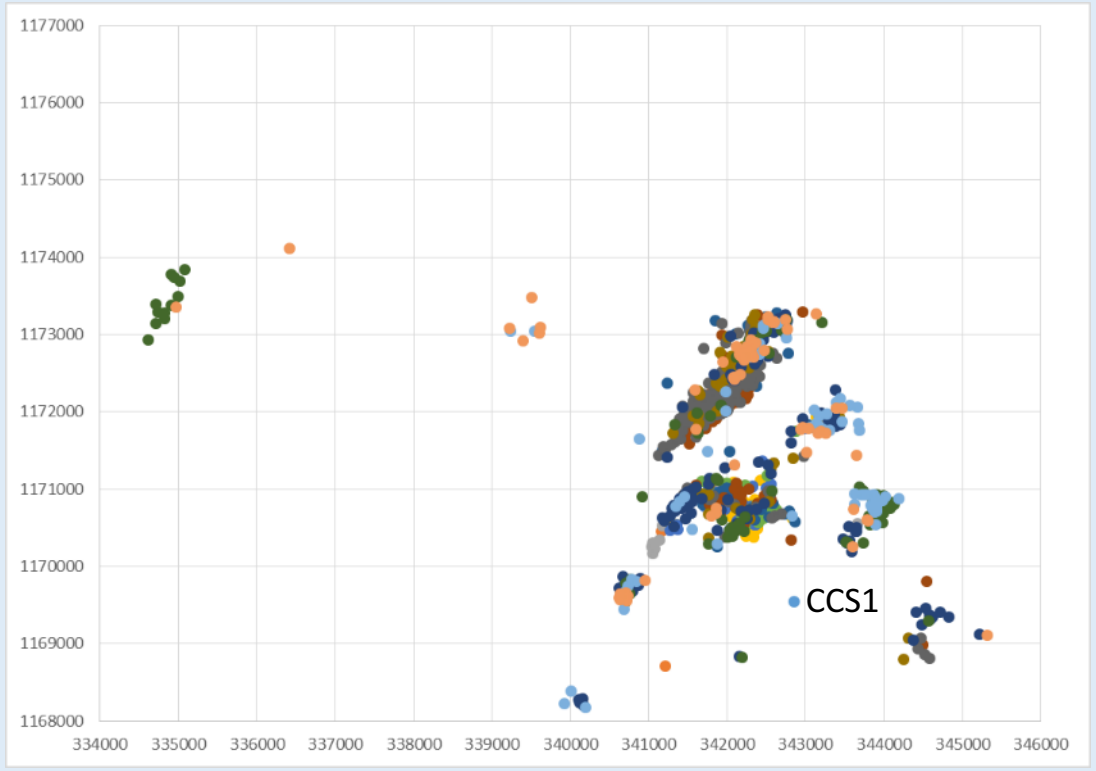
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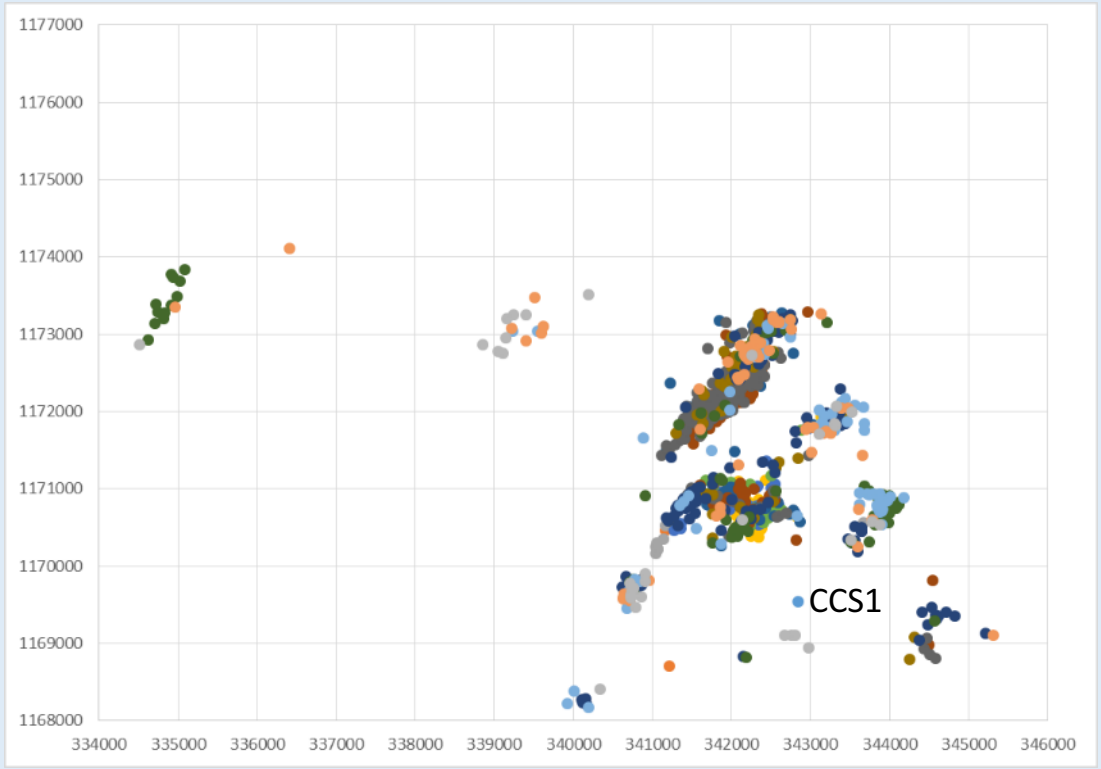
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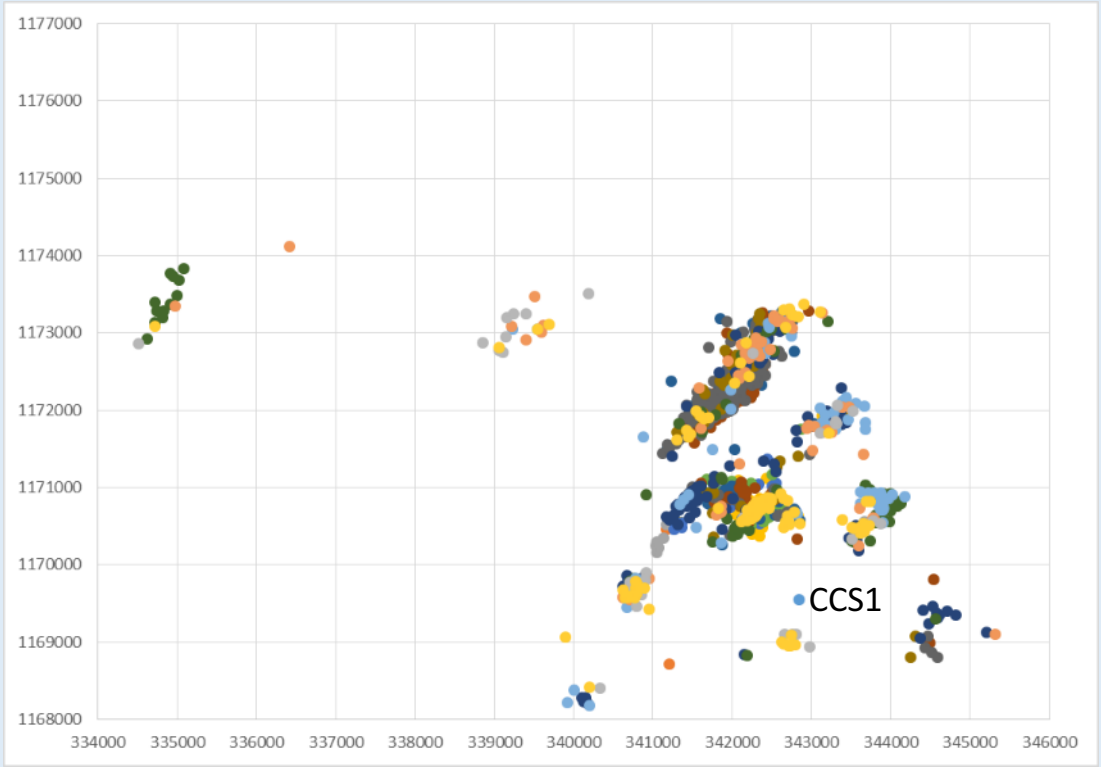
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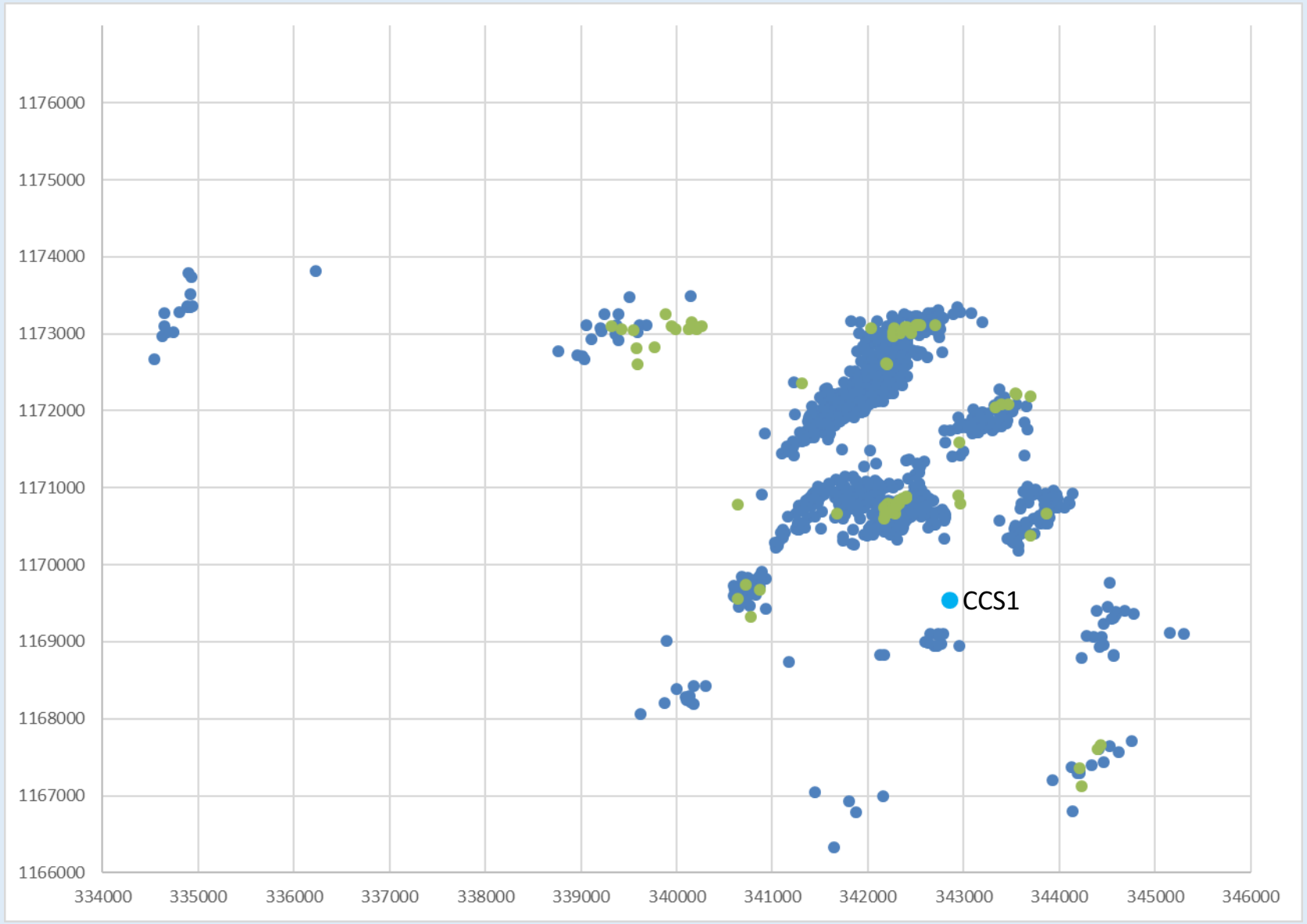
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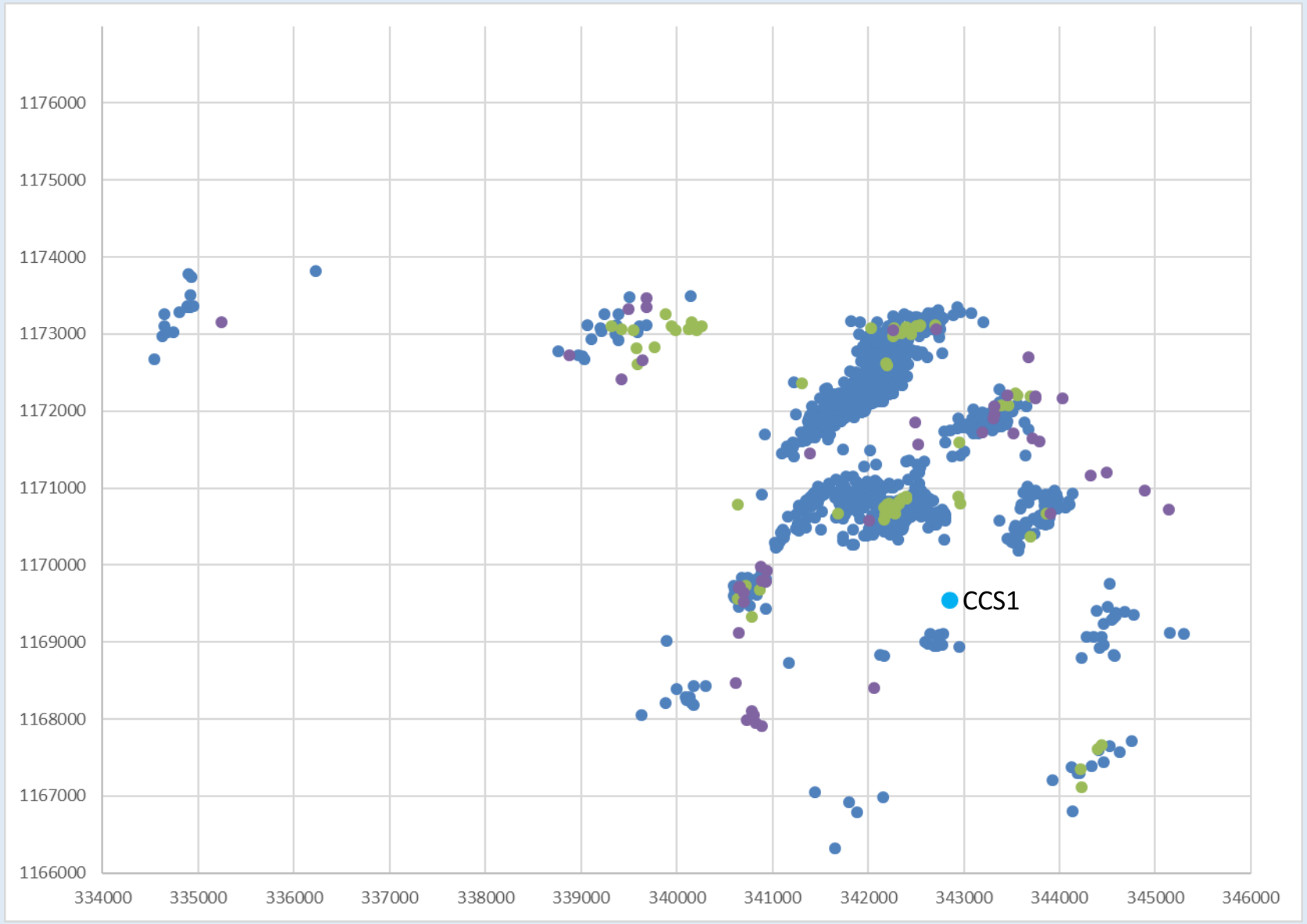
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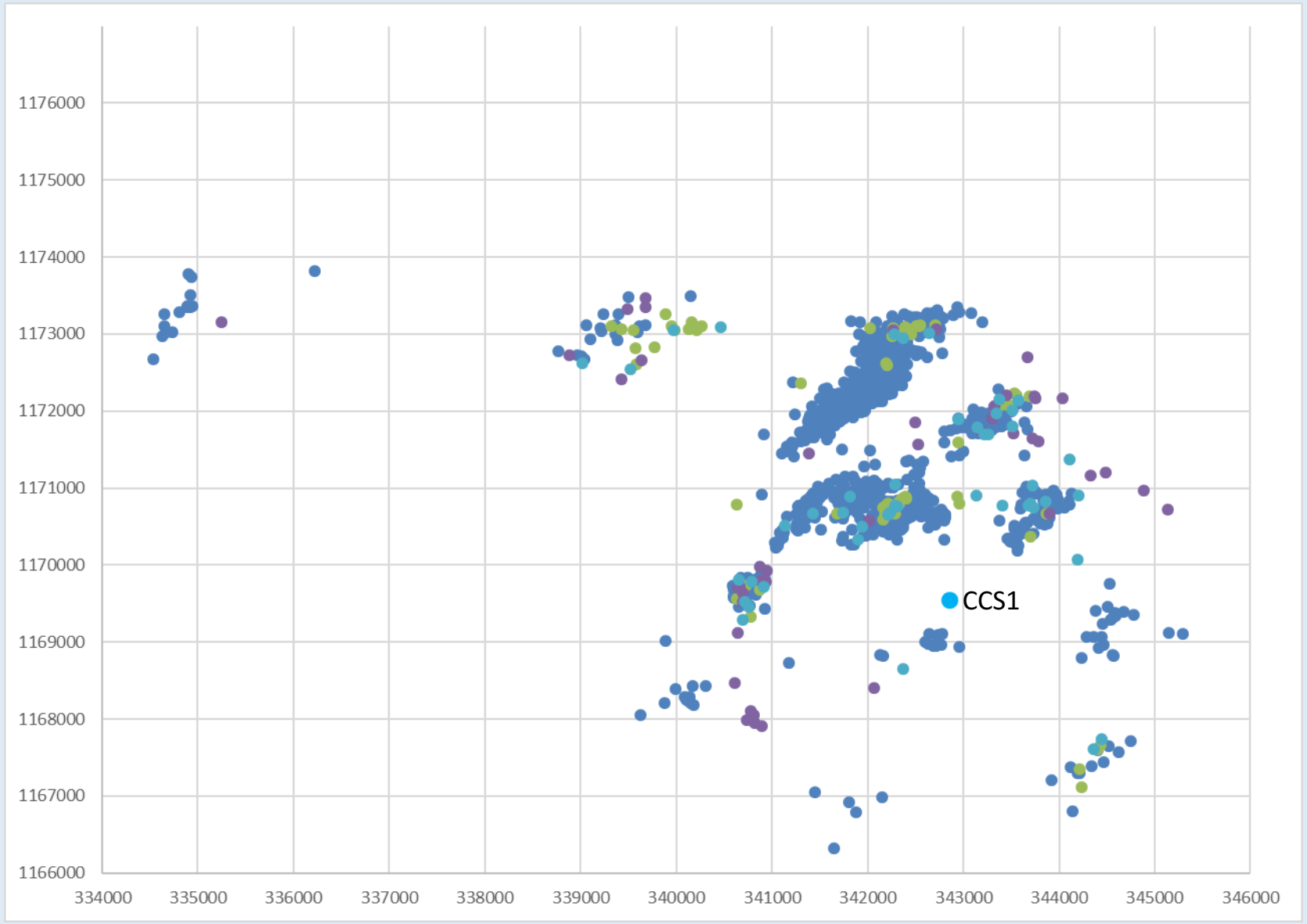
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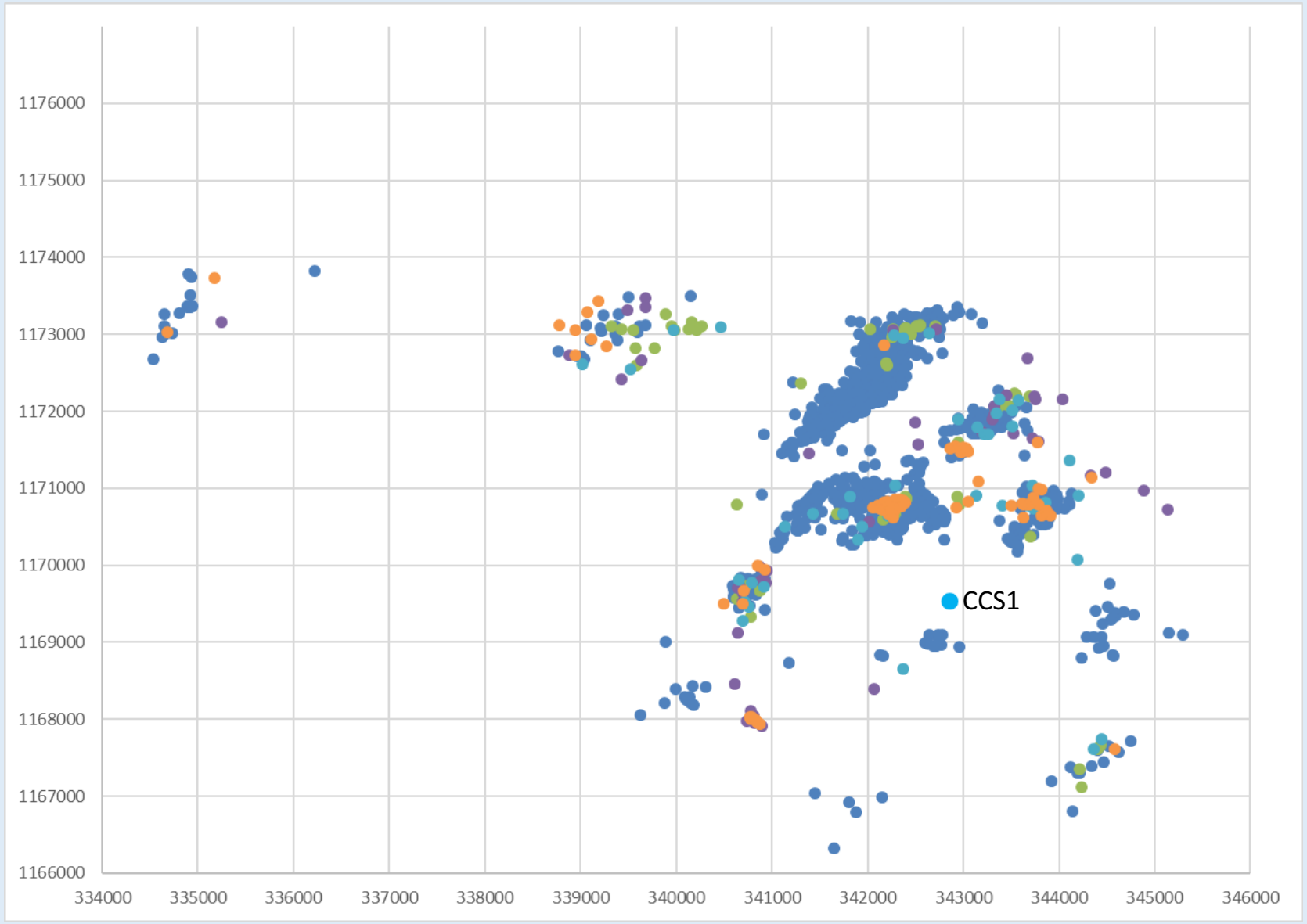
June 2013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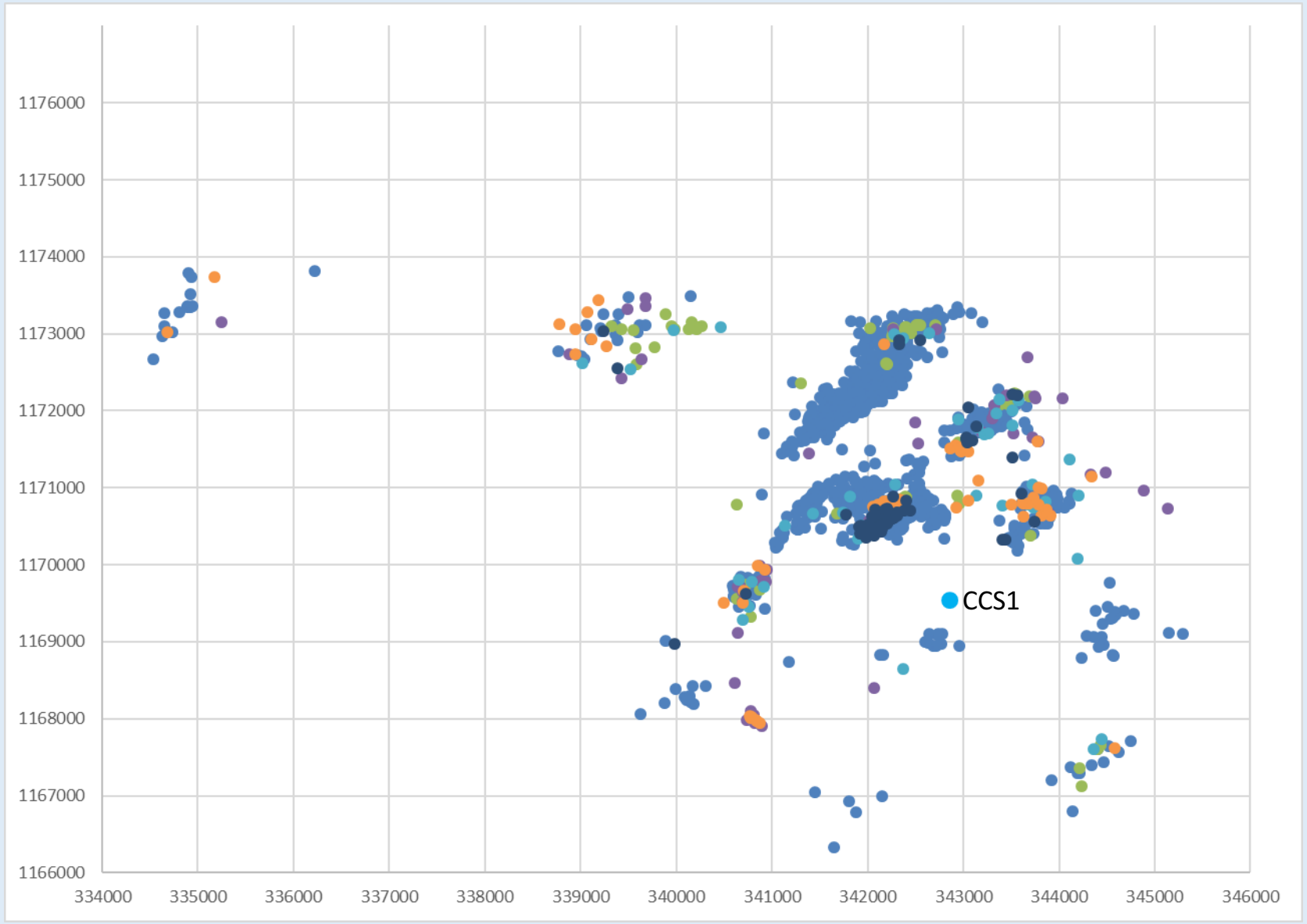
July 2013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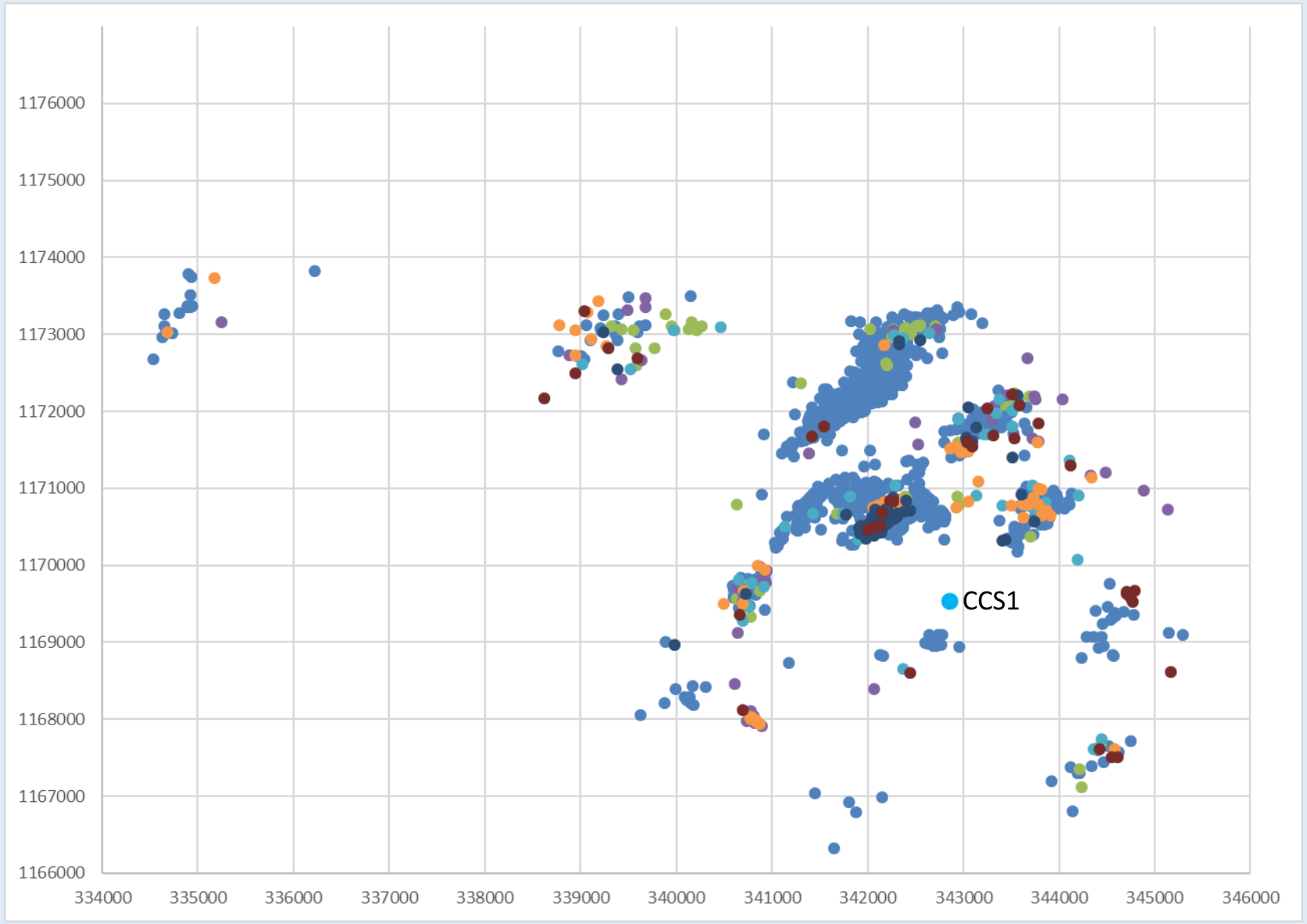
Aug 2013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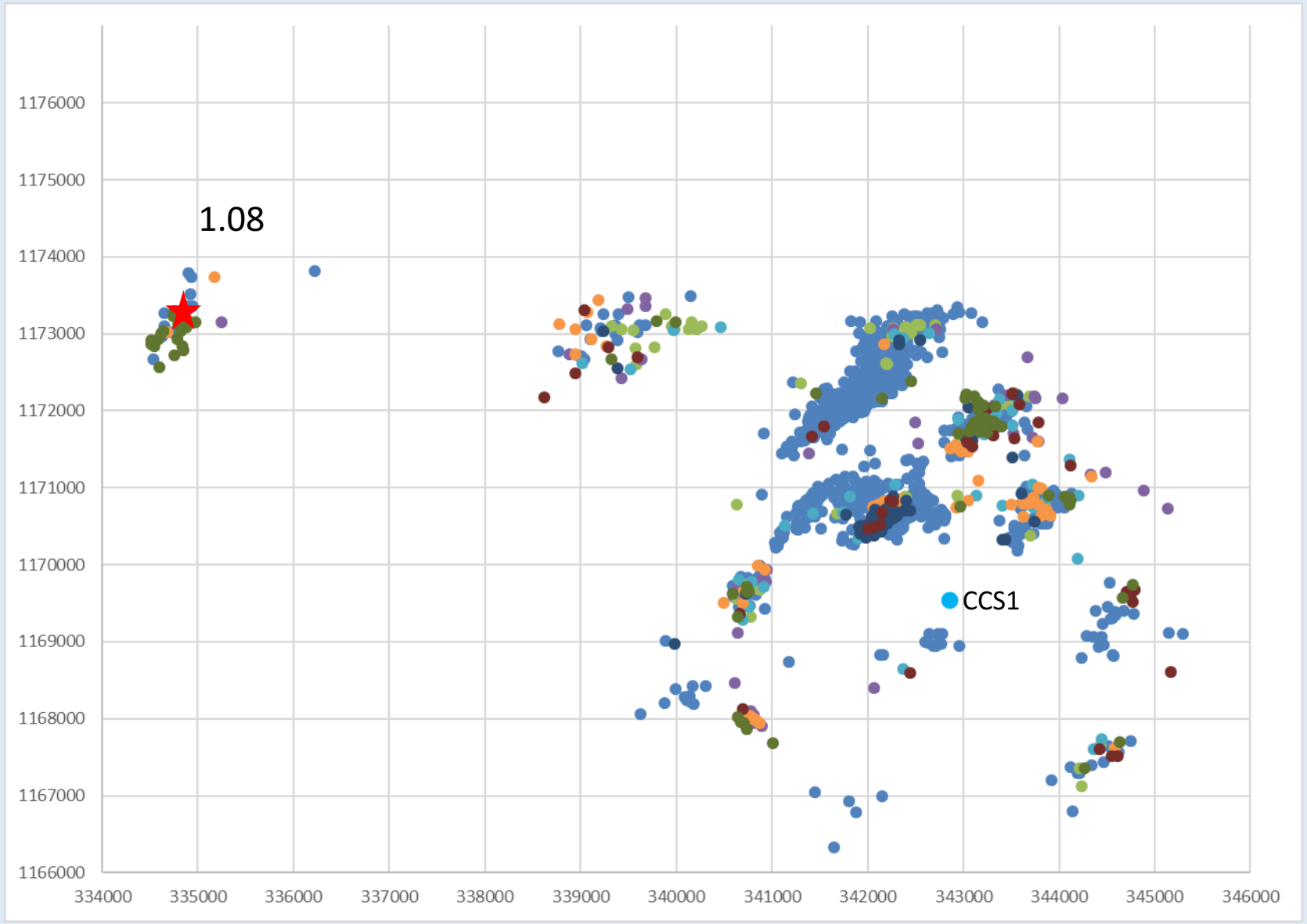
Sept 2013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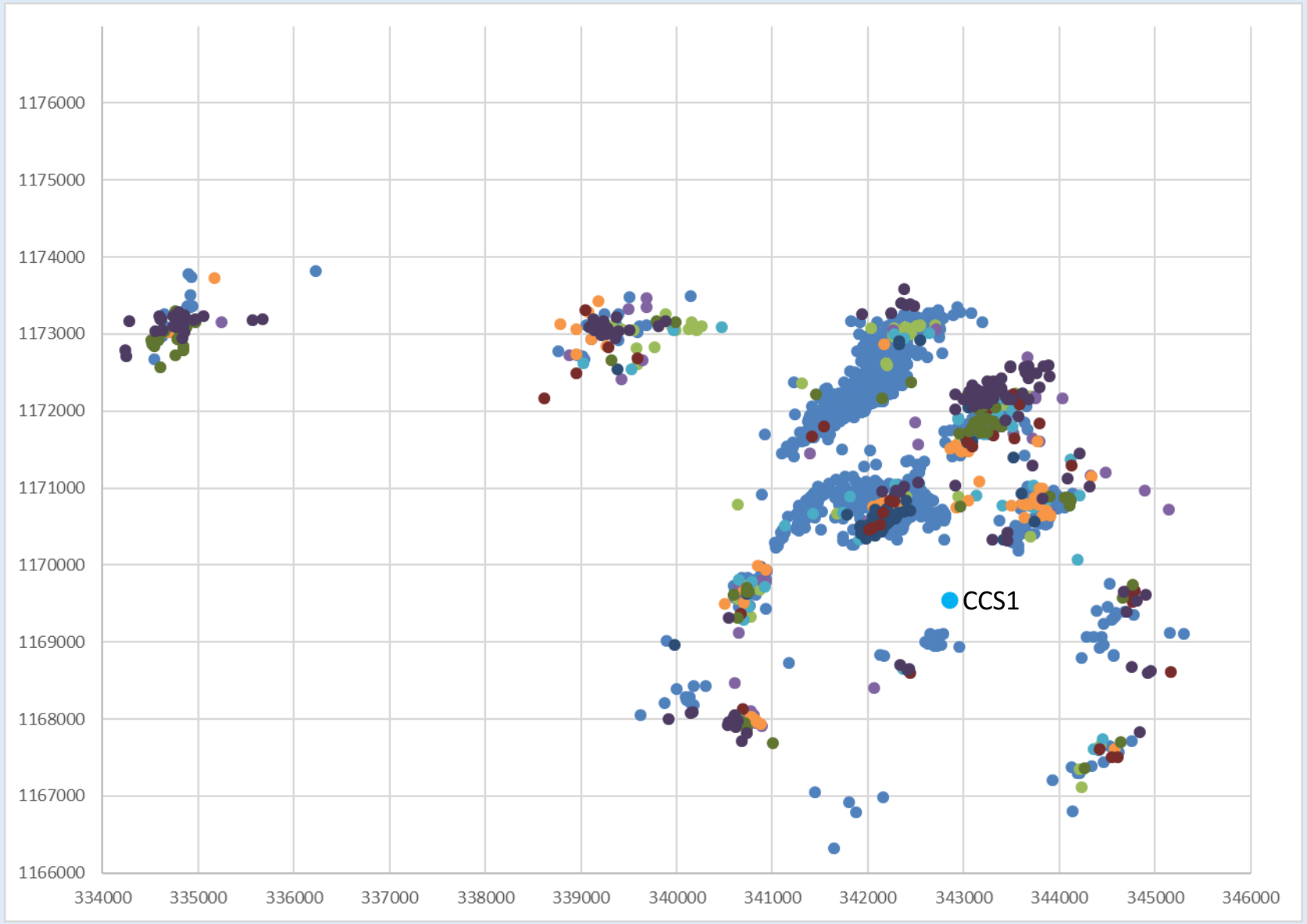
Oct 2013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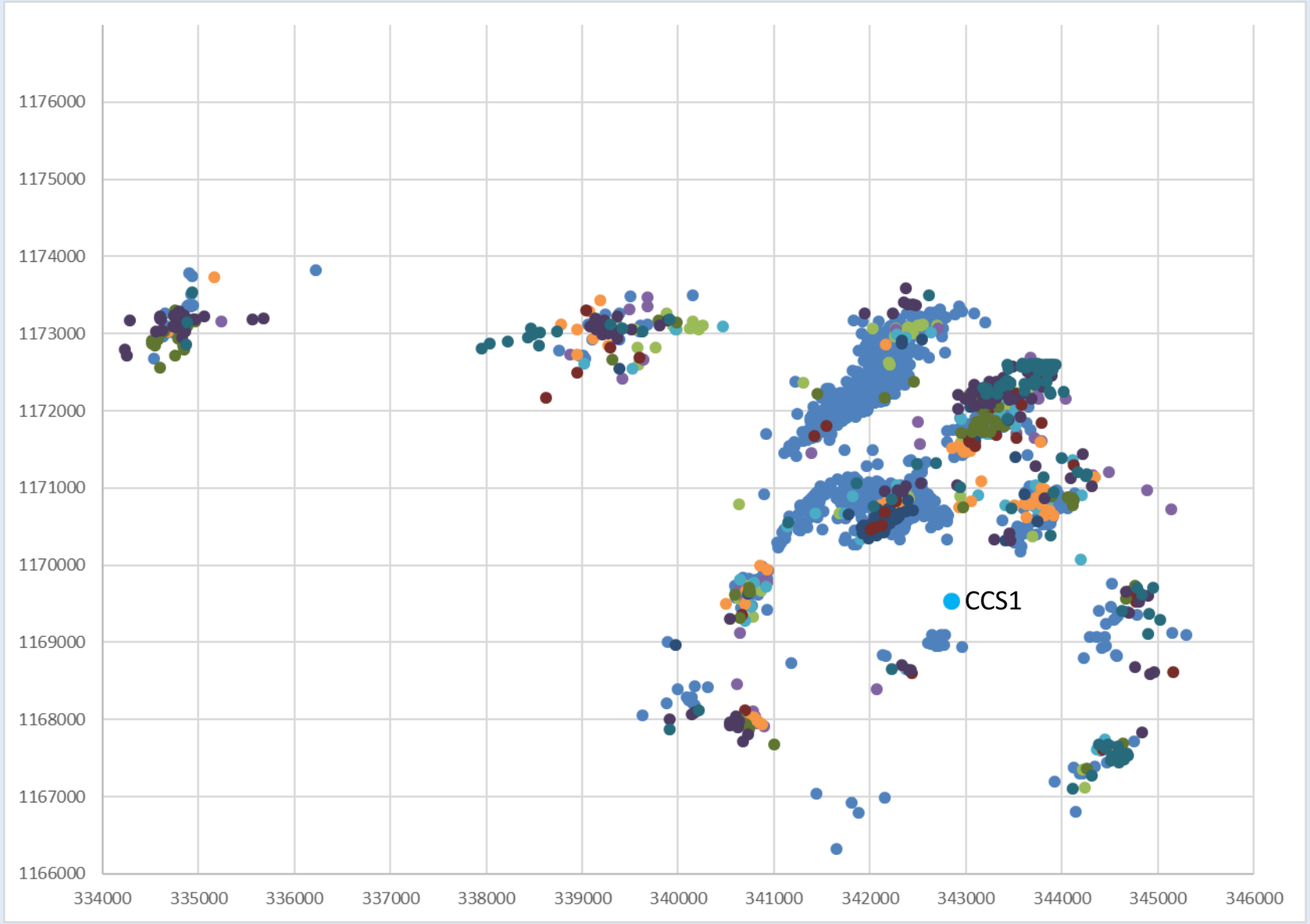
Nov 2013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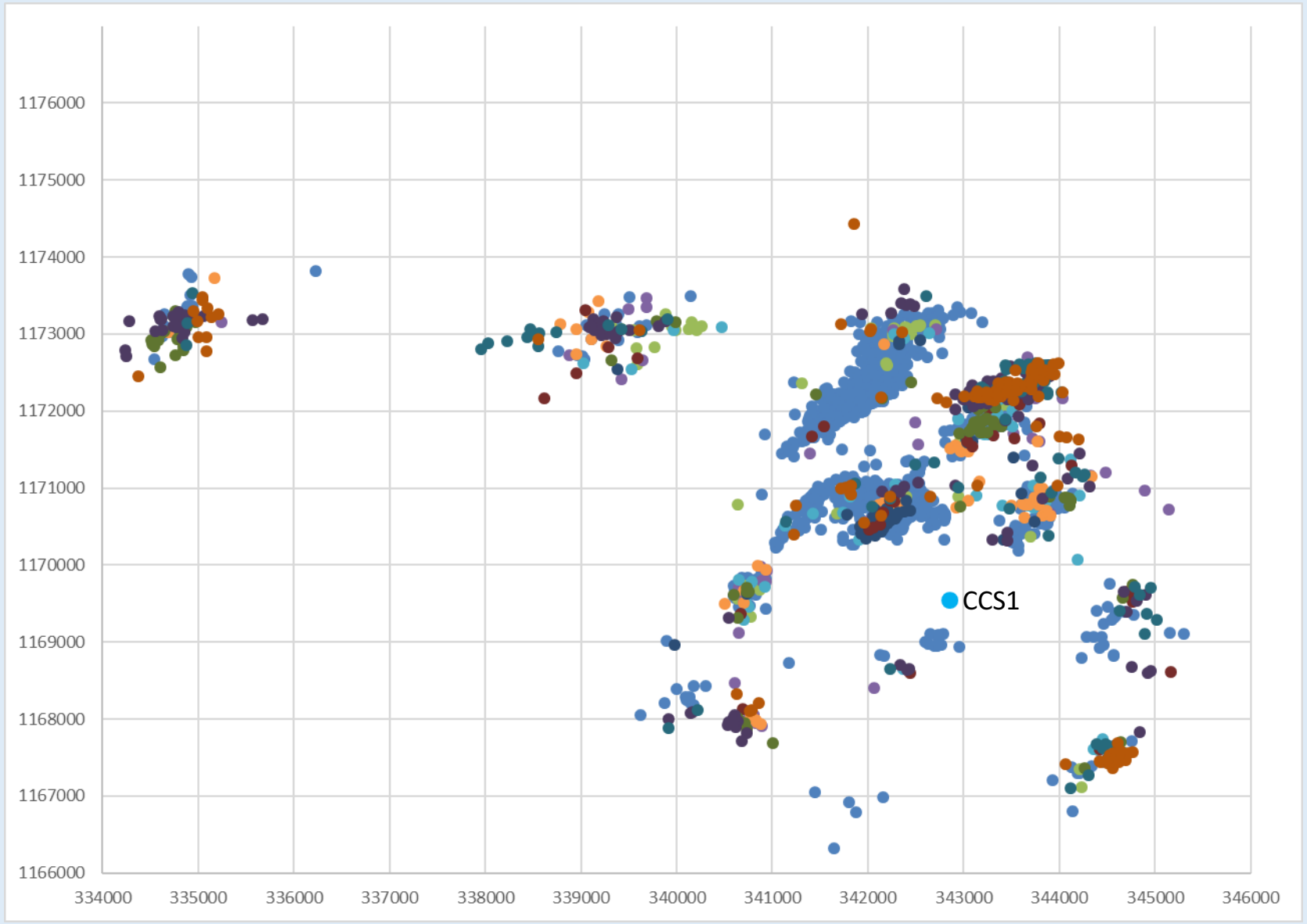
Dec 2013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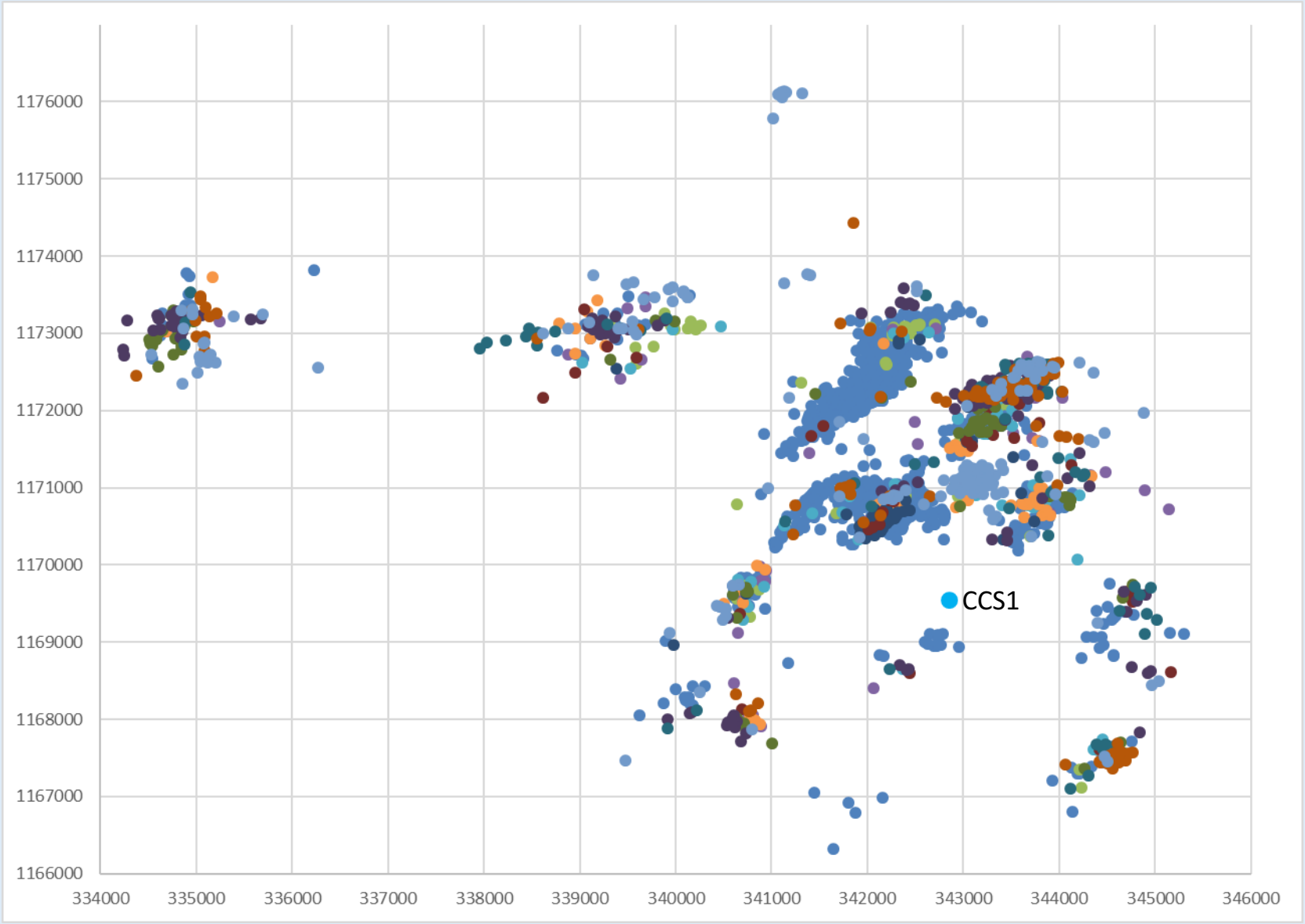
Jan 2014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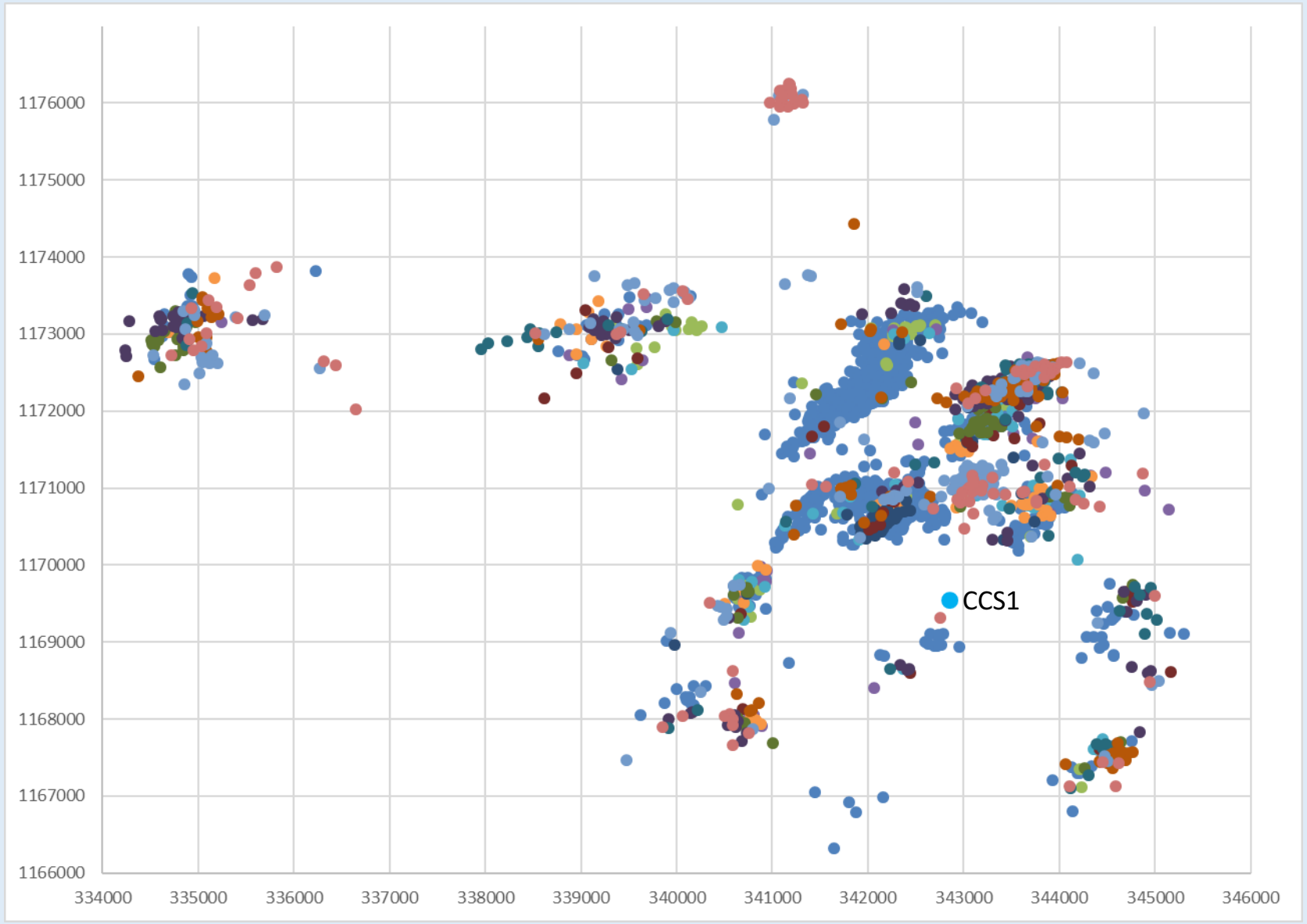
Feb 2014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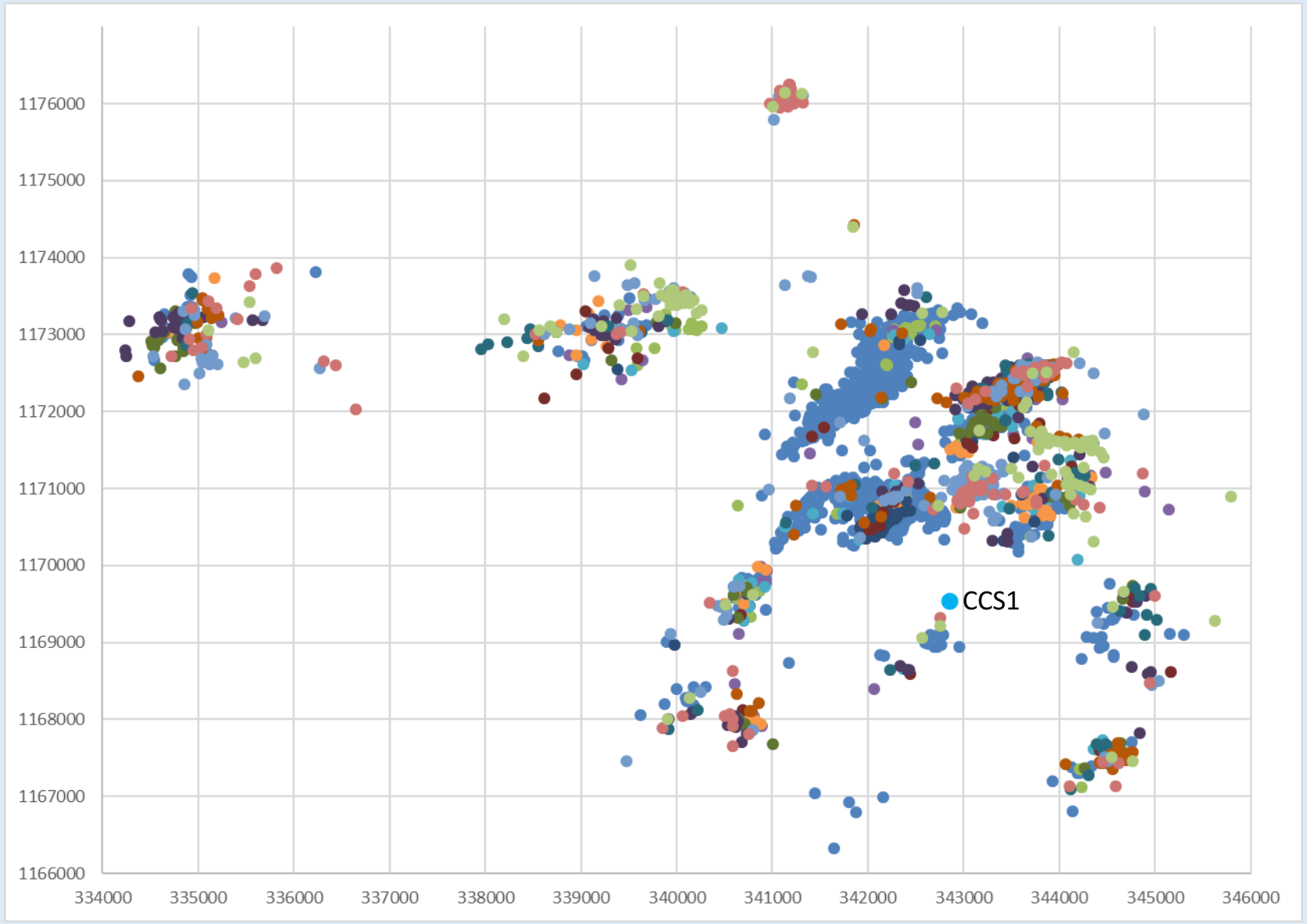
CCS1

Mar 2014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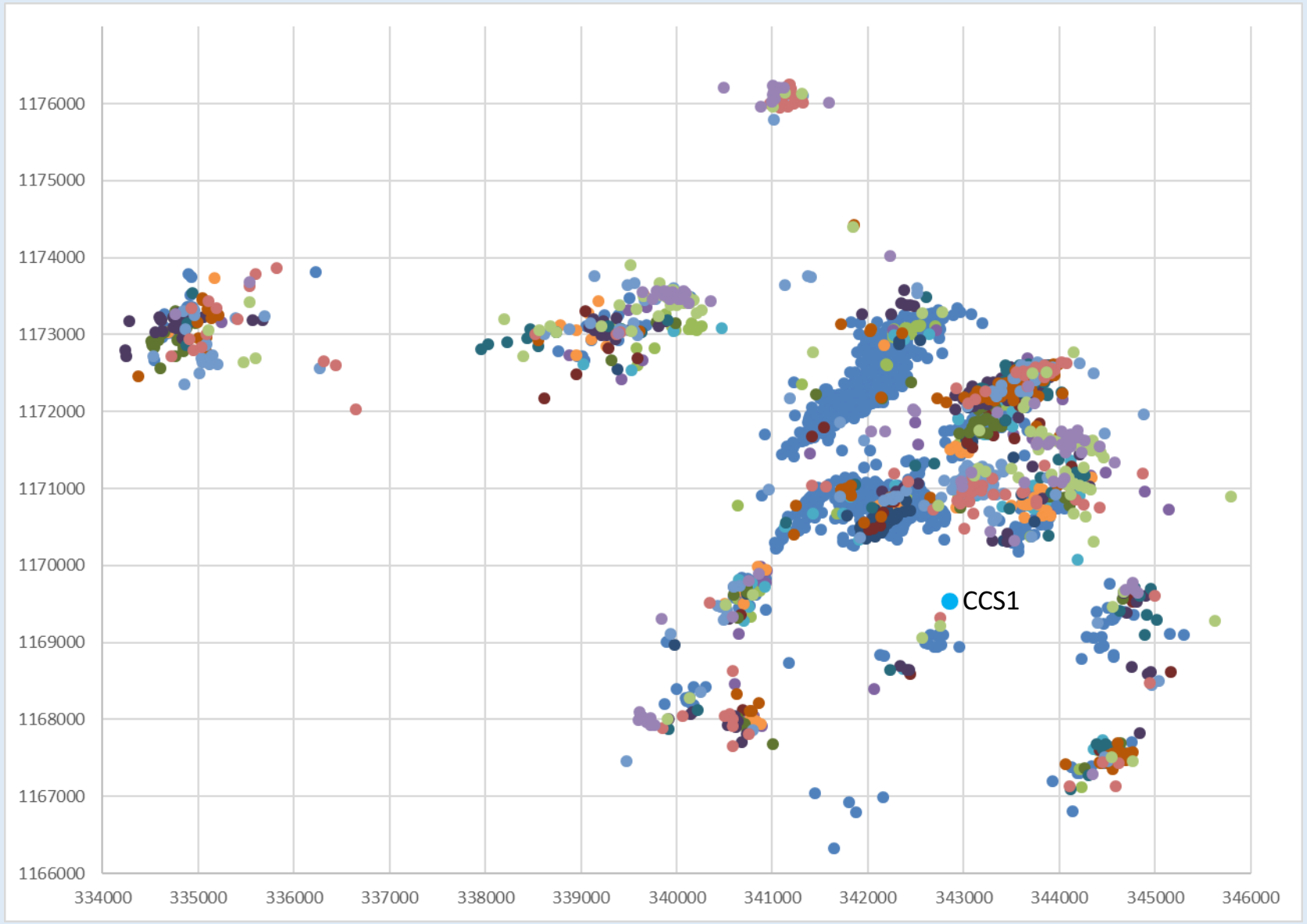
Apr 2014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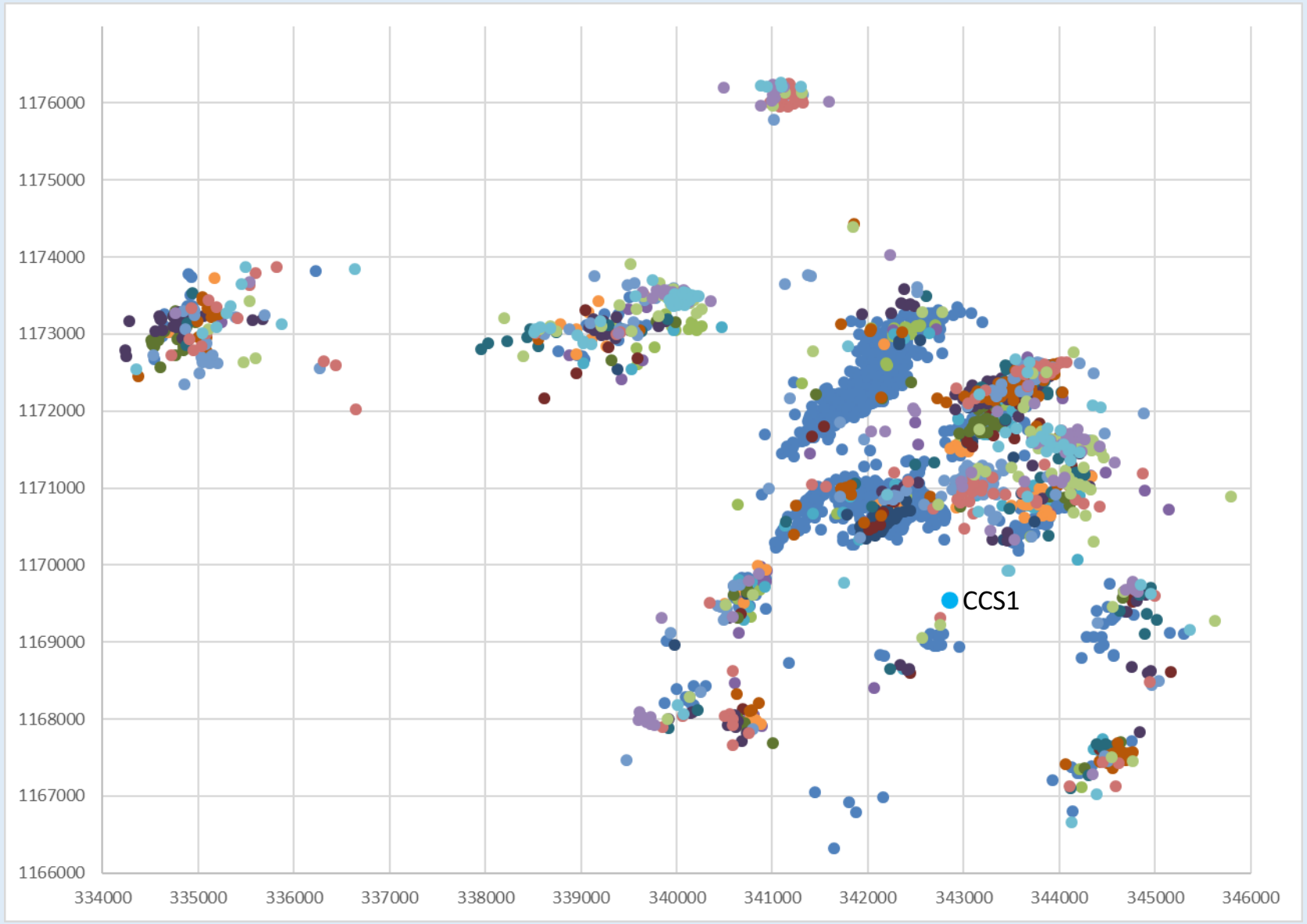
CCS1

May 2014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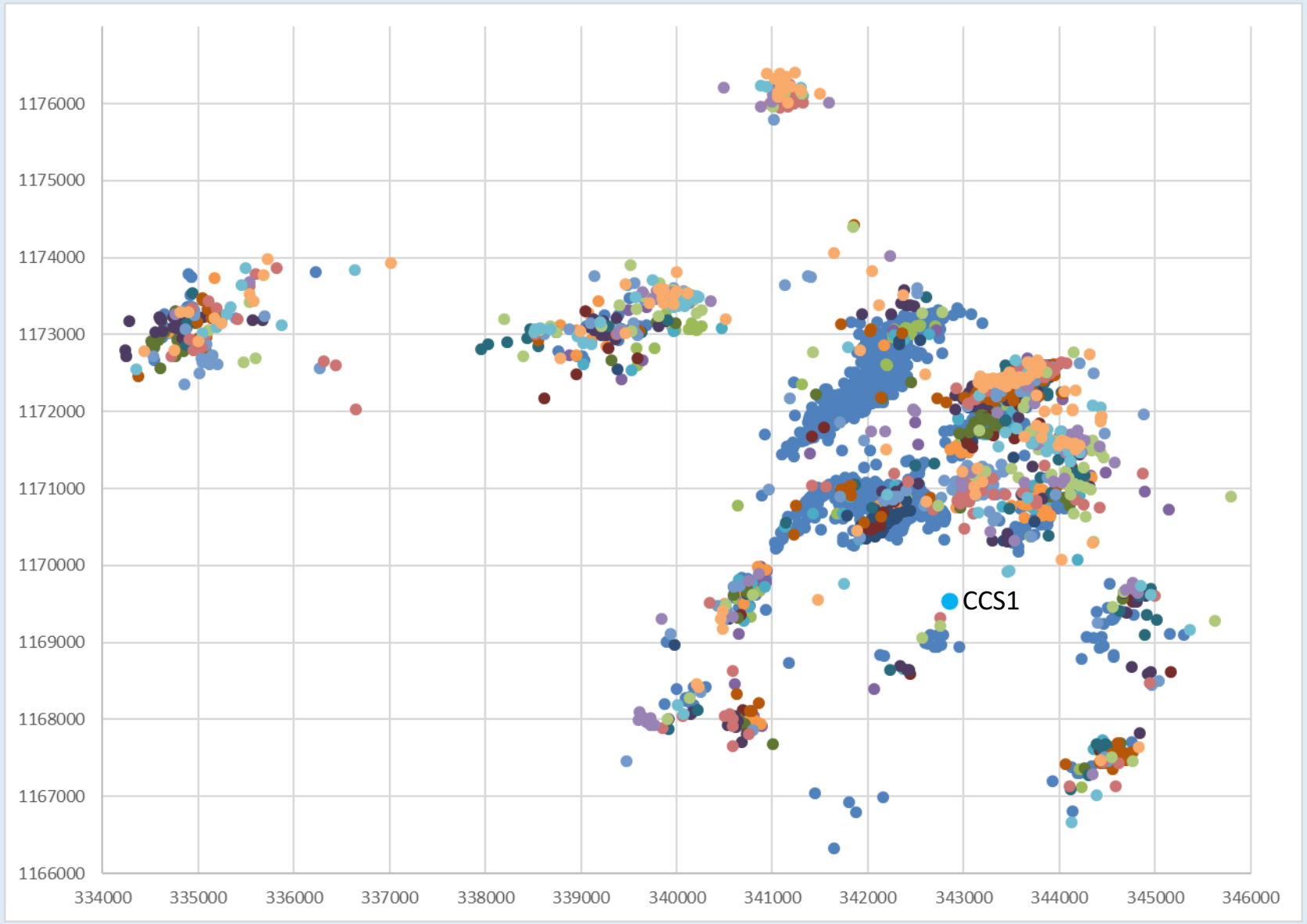
CCS1

June 2014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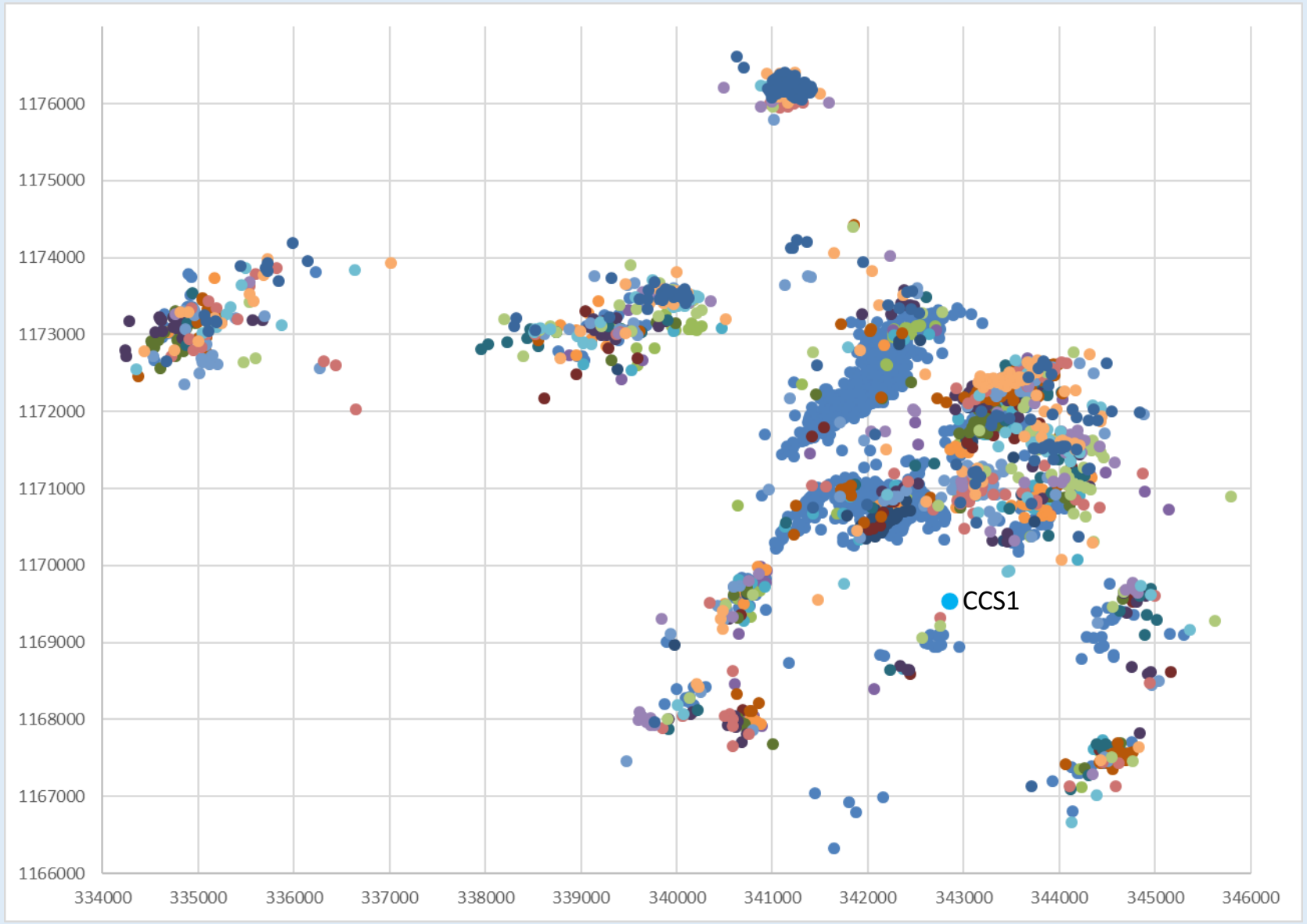
CCS1

July 2014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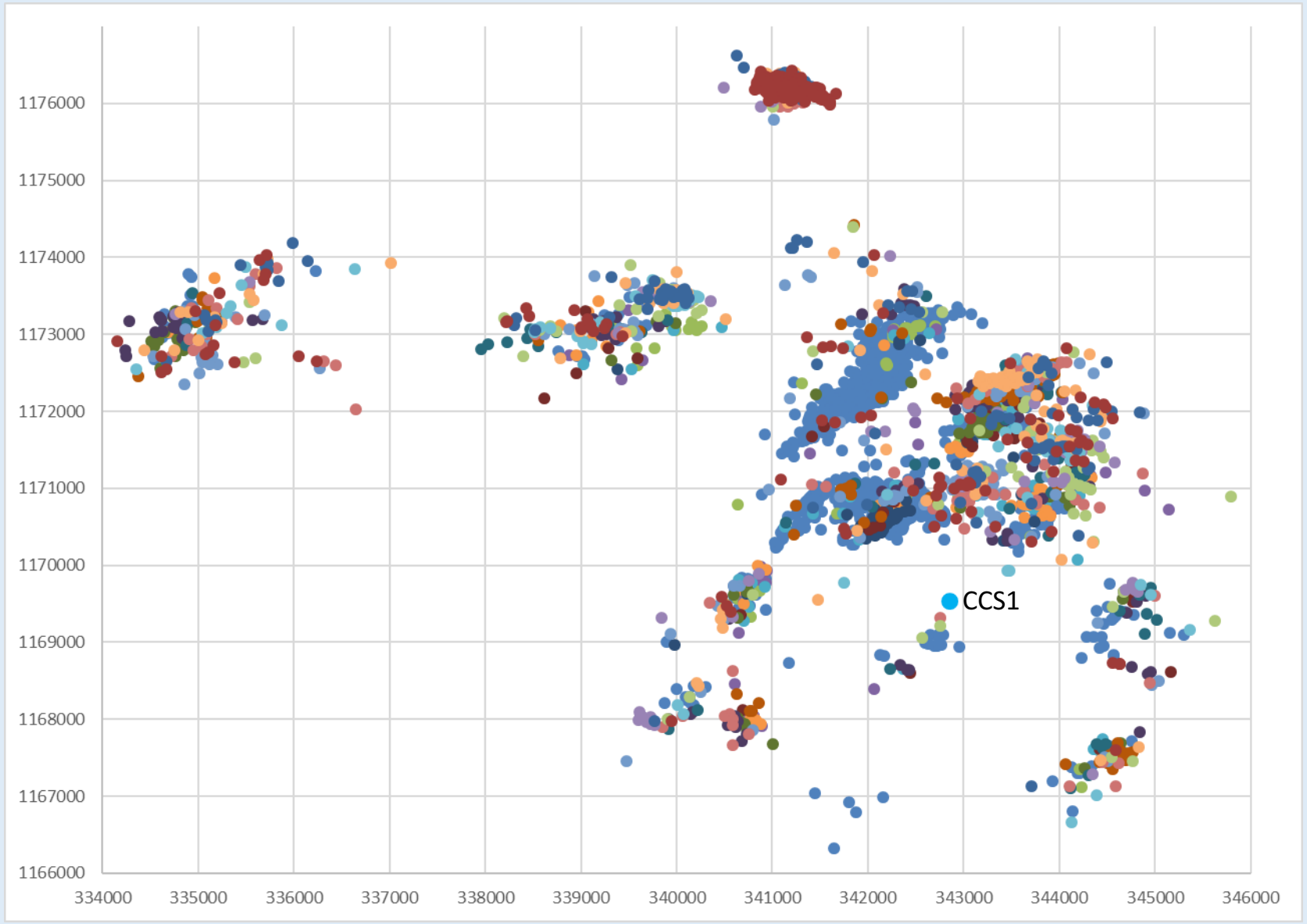
Aug 2014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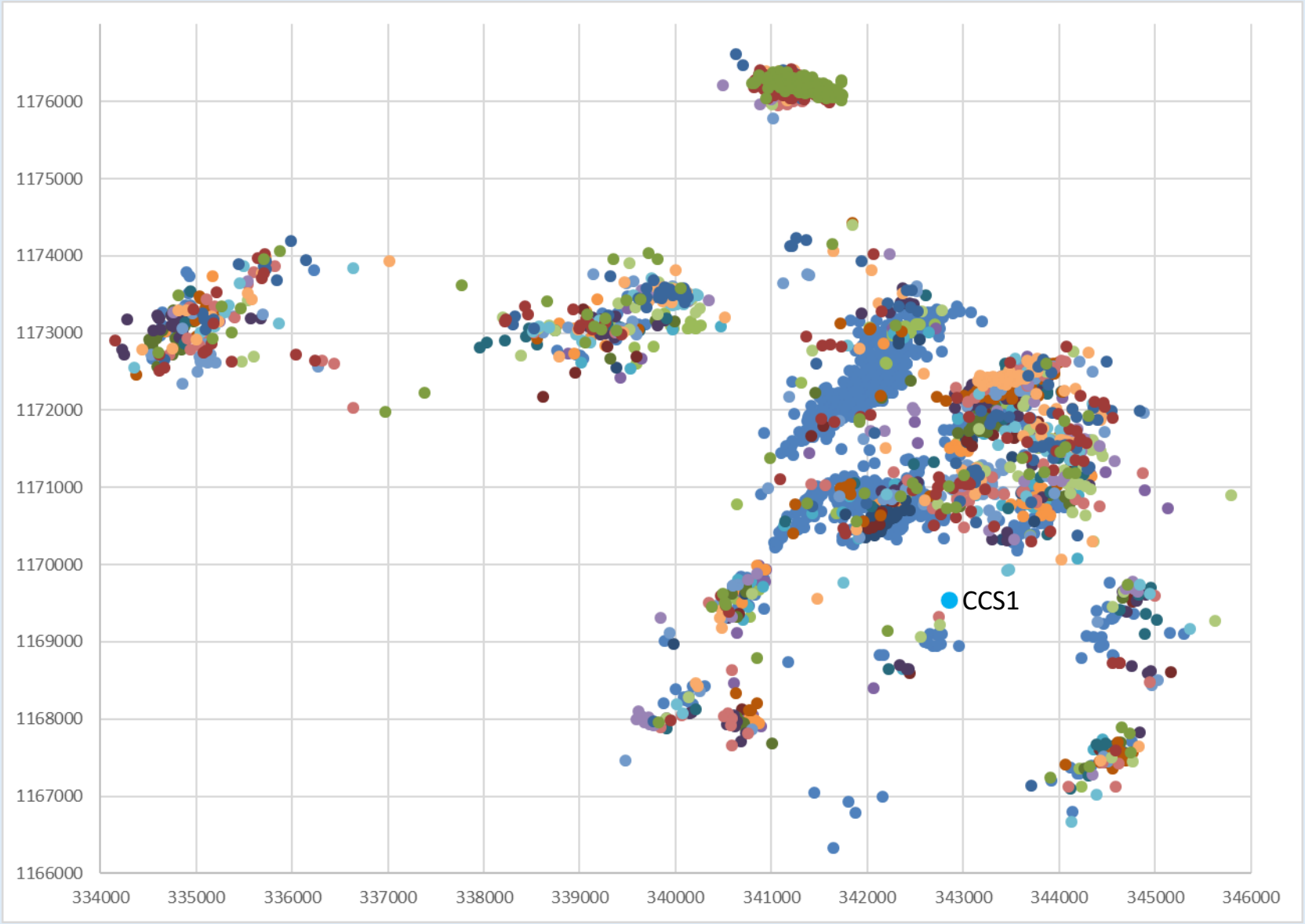
CCS1

Sept 2014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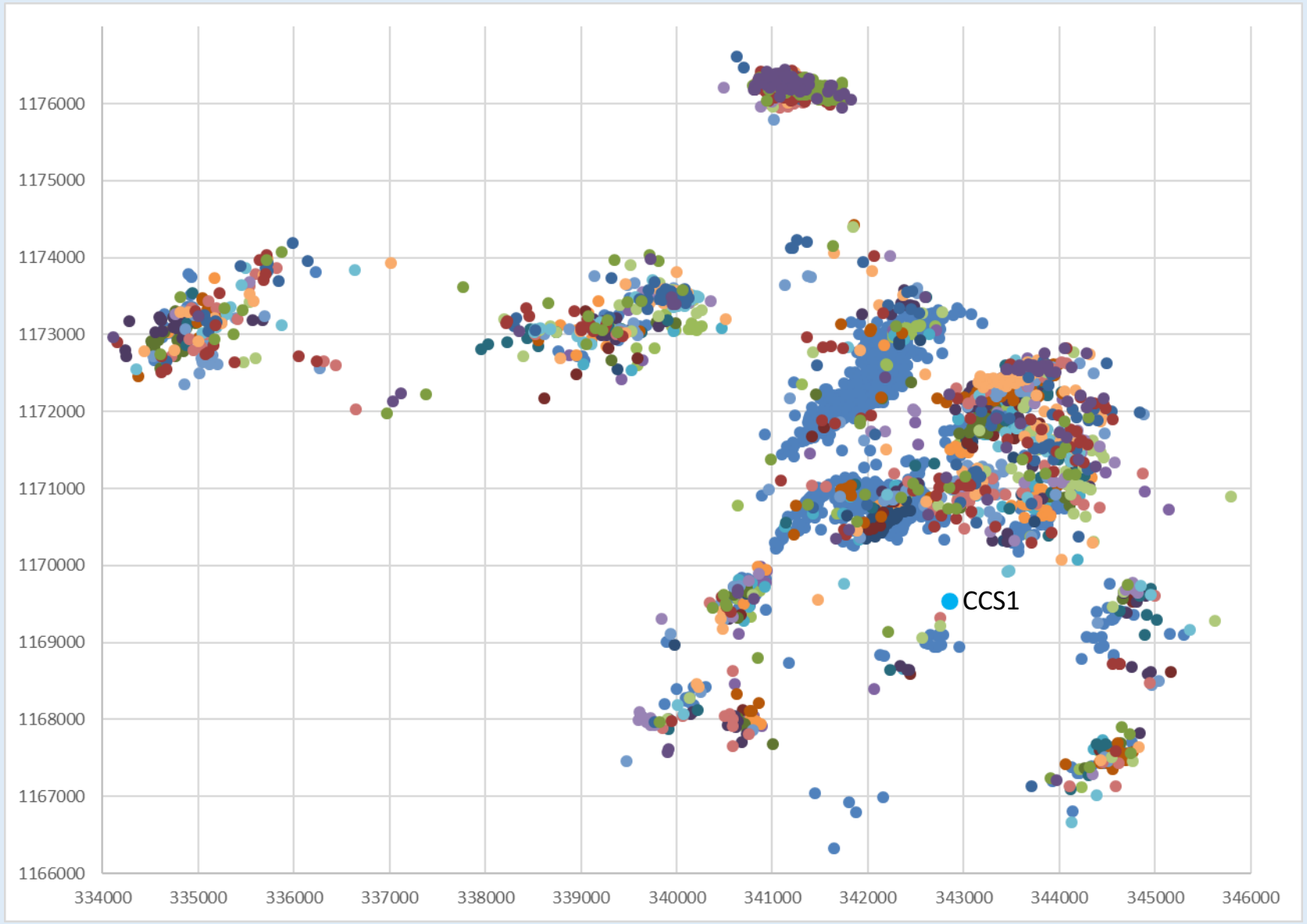
CCS1

Oct 2014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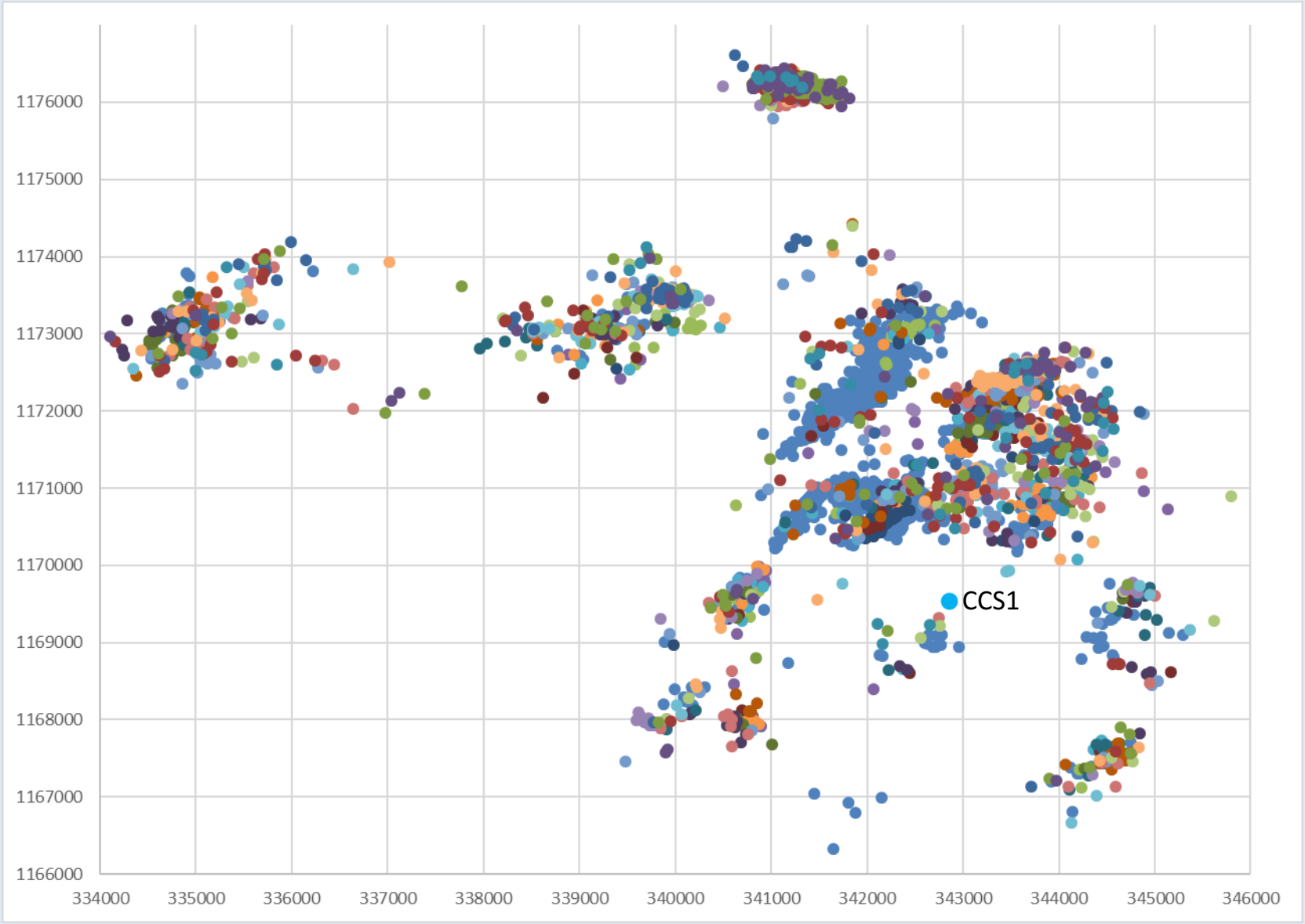
CCS1

Nov 2014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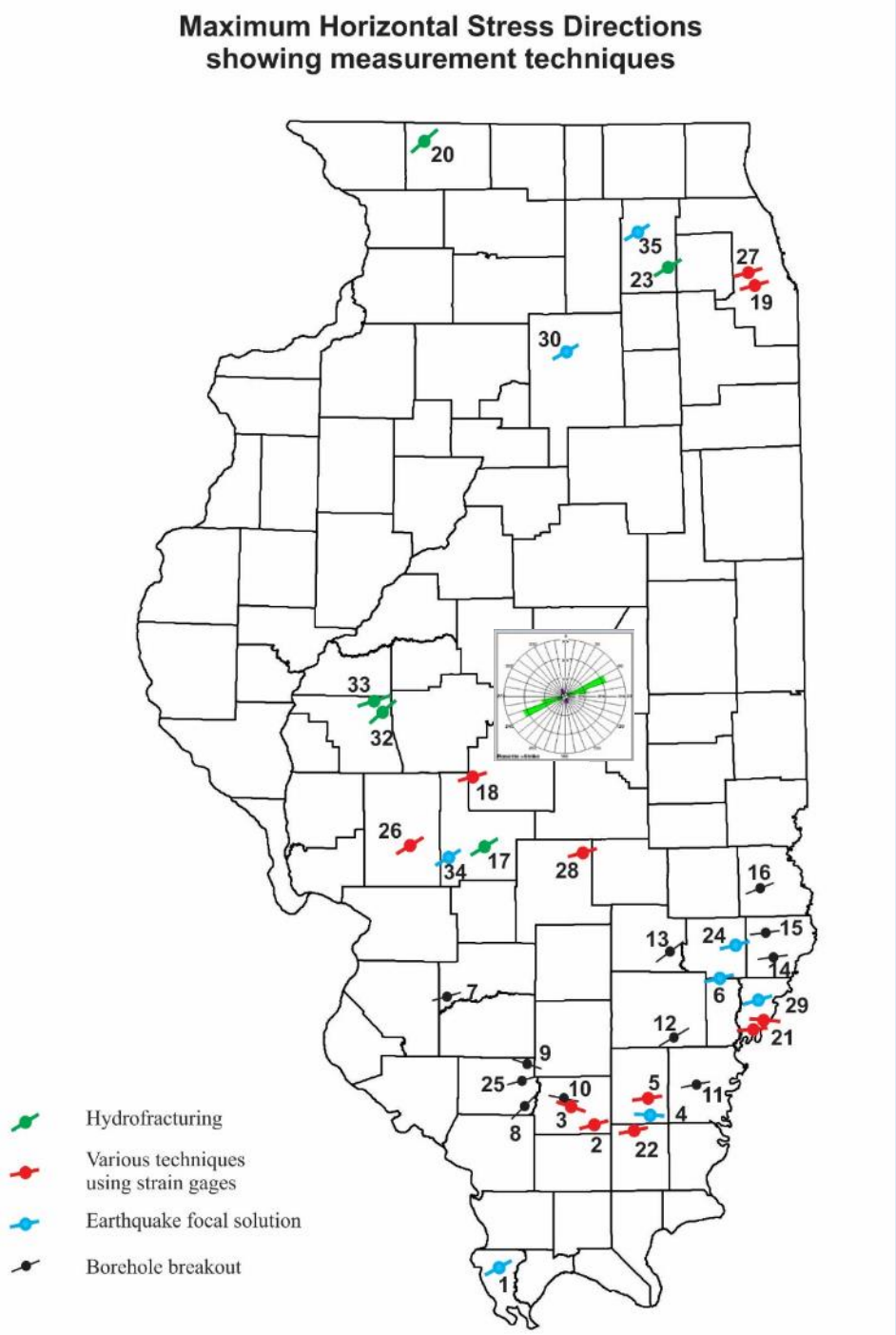
CCS1

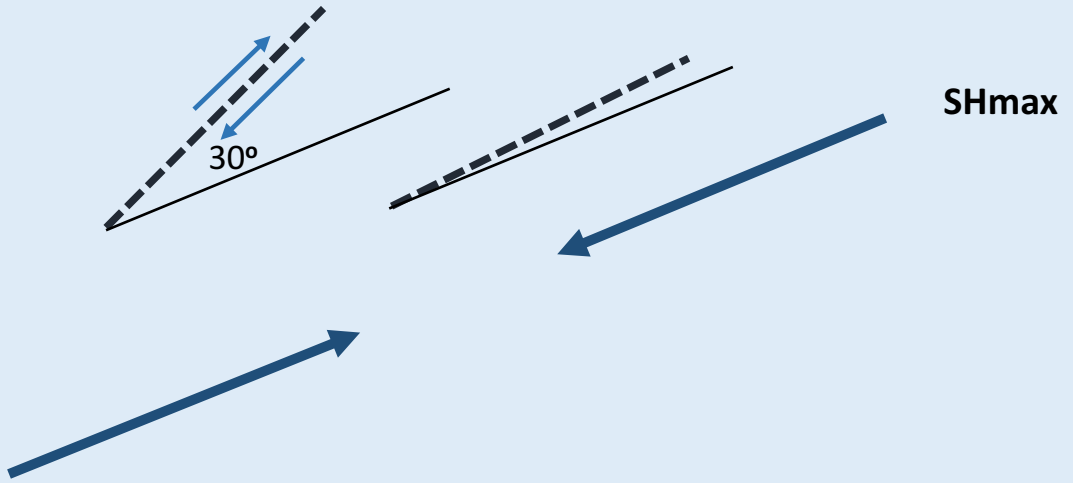
Cluster 1 formed first at about 1,800 feet (550 m) from CCS1 before Cluster 2 at an average of 1,160 feet (350 m) from CCS1.

Estimates are that Cluster 1 Δ pressures were about 50 psi (3.5 bars) or 0.35 MPa at the time of first formation.

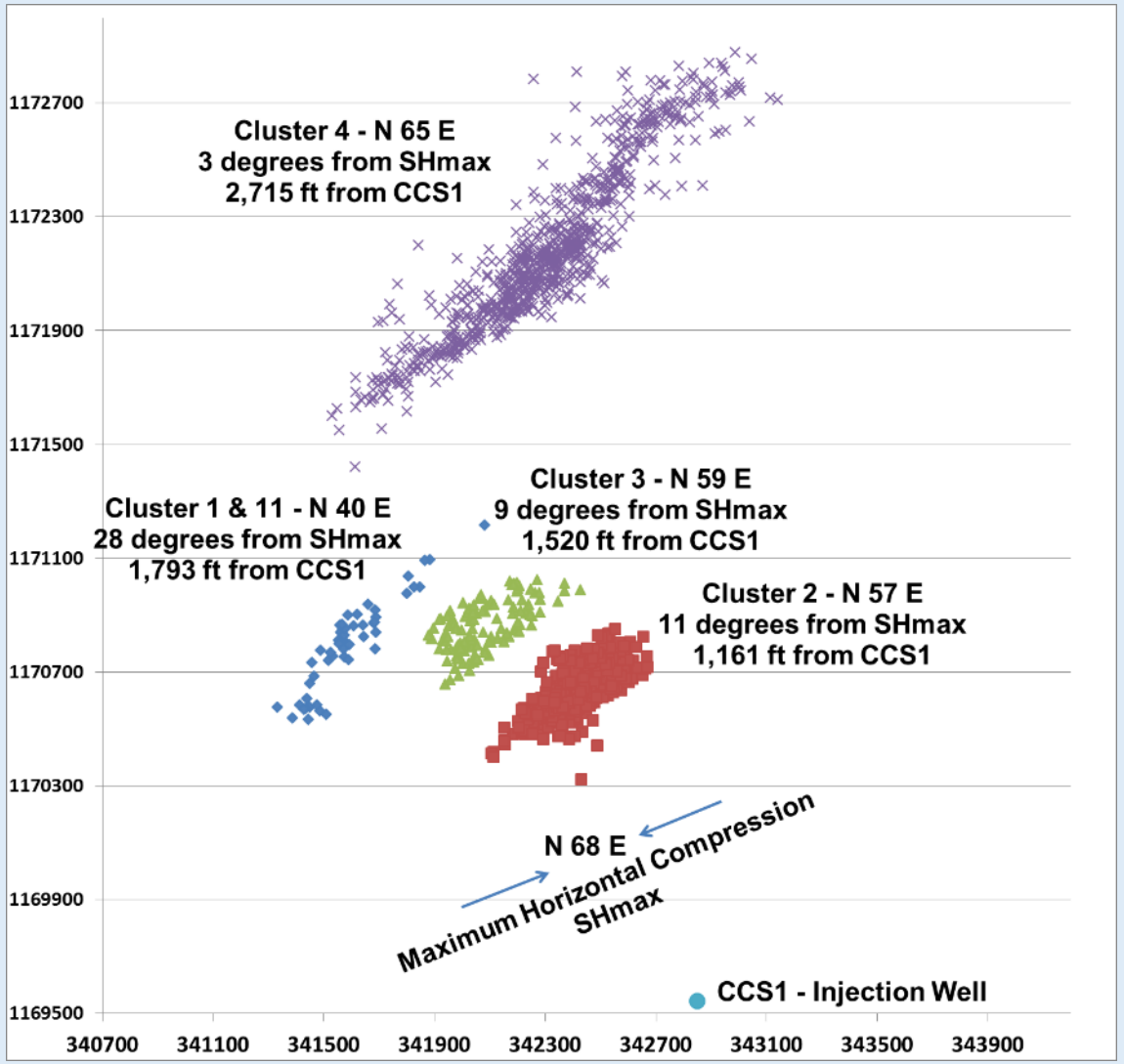
Pre-existing fractures close to 30 degrees from the maximum horizontal stress direction are optimally oriented in the direction expected for strike-slip movements.



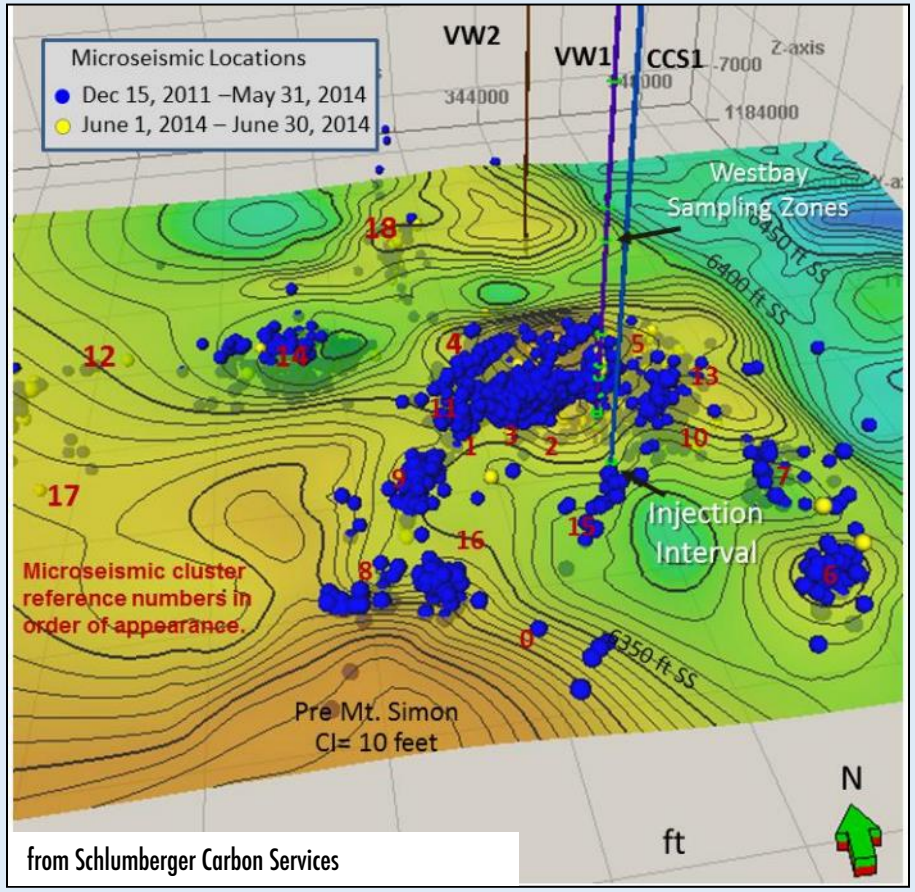
Optimally oriented to slip: strike-slip

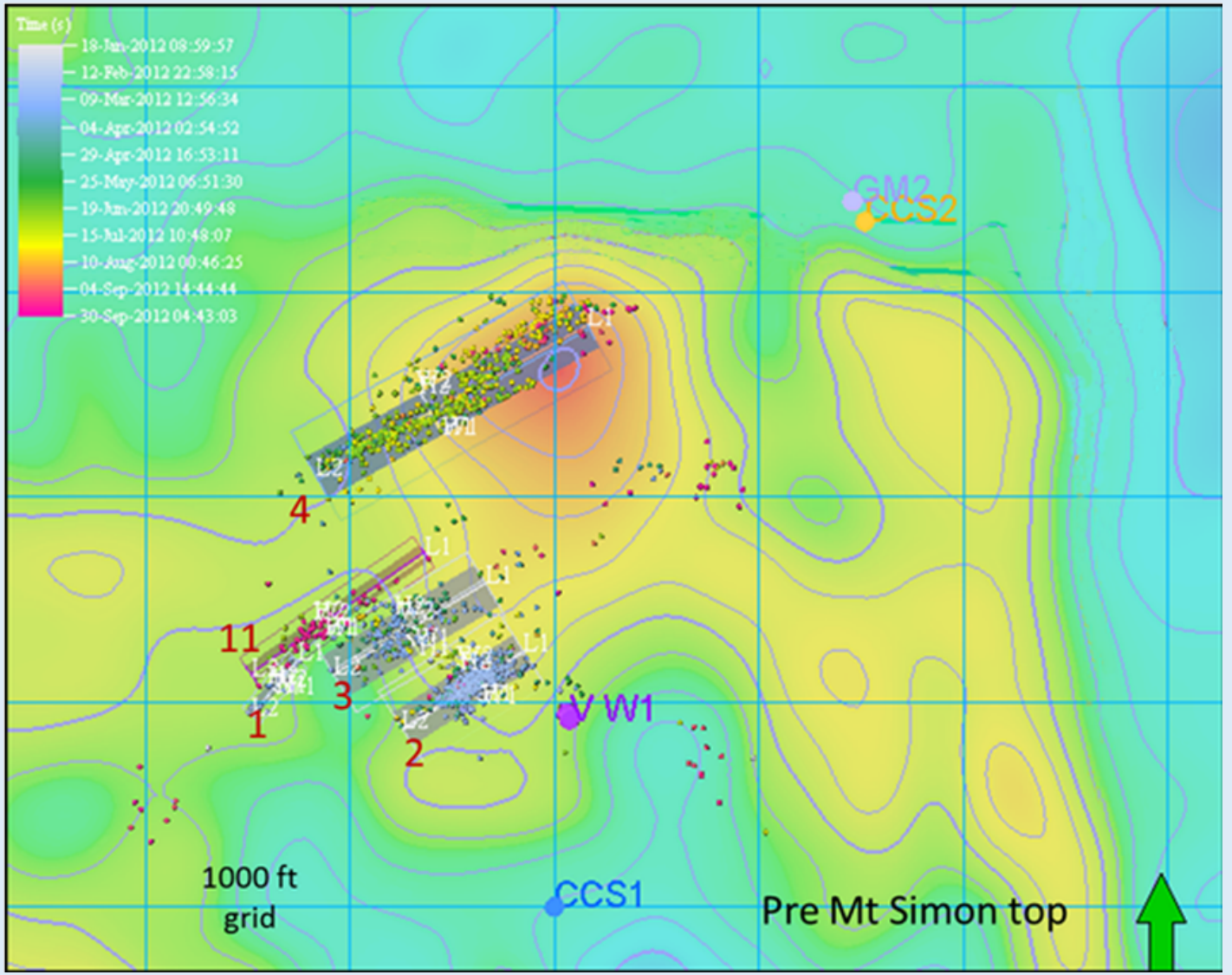


Each Division in X & Y
= 400 Feet or
≈ 120 m

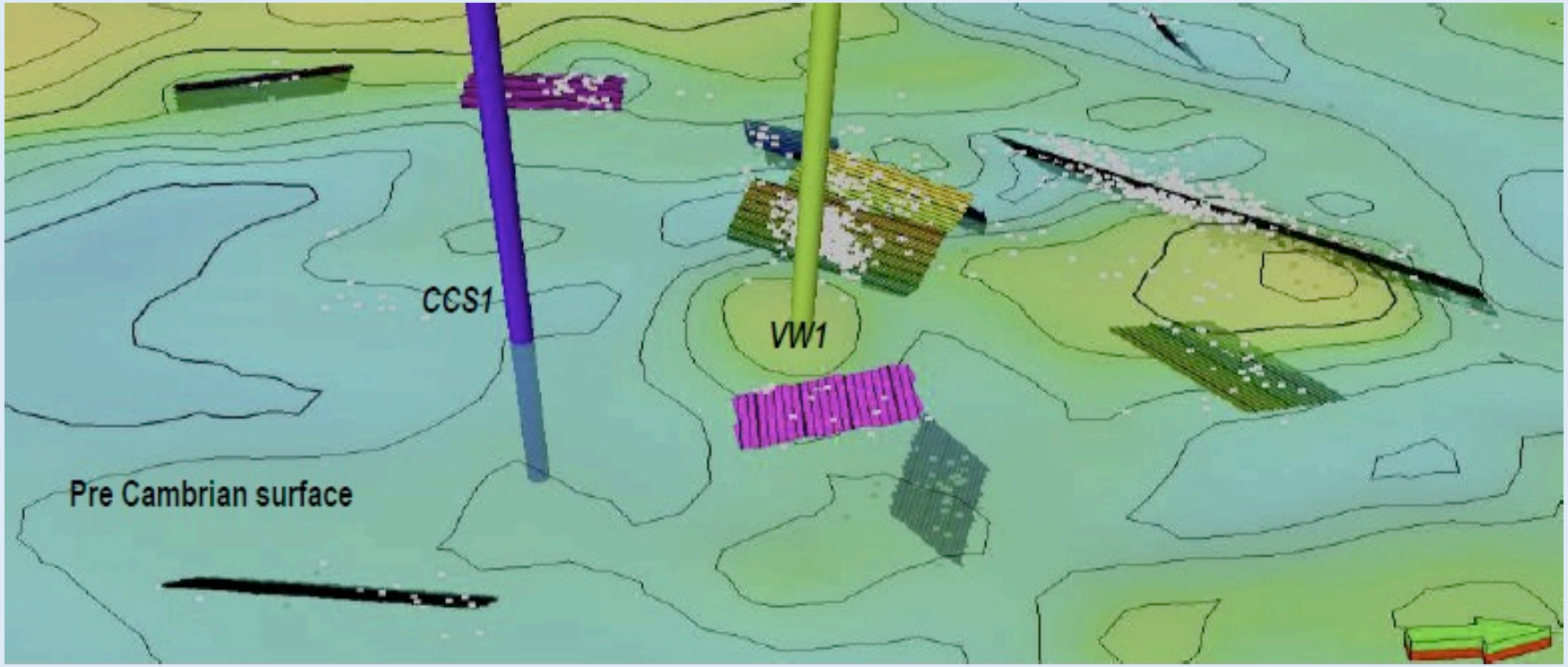


Microseismic Cluster Activity: Relationship to Pre-Mt. Simon Structure




Time (s)
18-Jan-2012 08:59:57
12-Feb-2012 22:58:15
09-Mar-2012 12:56:34
04-Apr-2012 02:54:52
29-Apr-2012 16:53:11
25-May-2012 06:51:30
19-Jun-2012 20:49:48
15-Jul-2012 10:48:07
10-Aug-2012 00:46:25
04-Sep-2012 14:44:44
30-Sep-2012 04:43:03
GM2
CCS2
4
11
3
1
2
V W1
CCS1
1000 ft
grid
Pre Mt Simon top

V. Smith - SLB

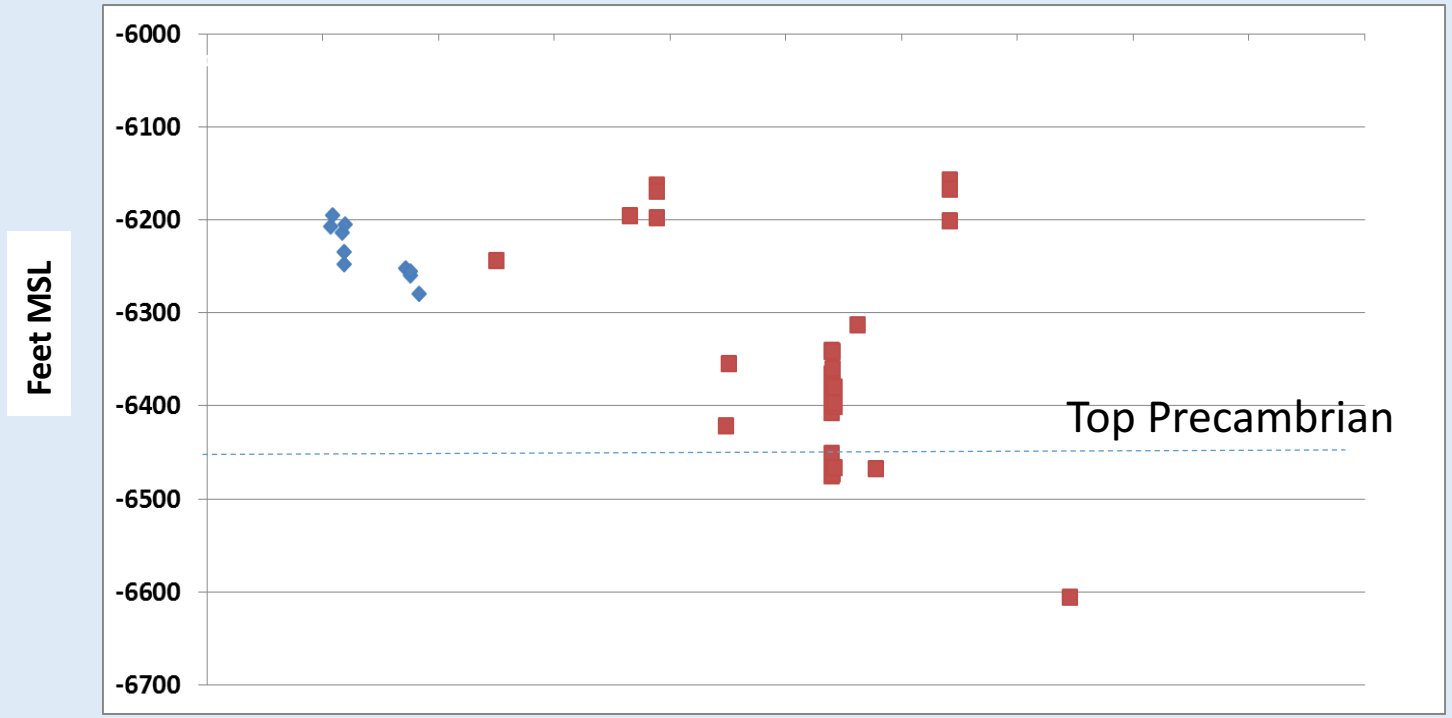


from Schlumberger Carbon Services

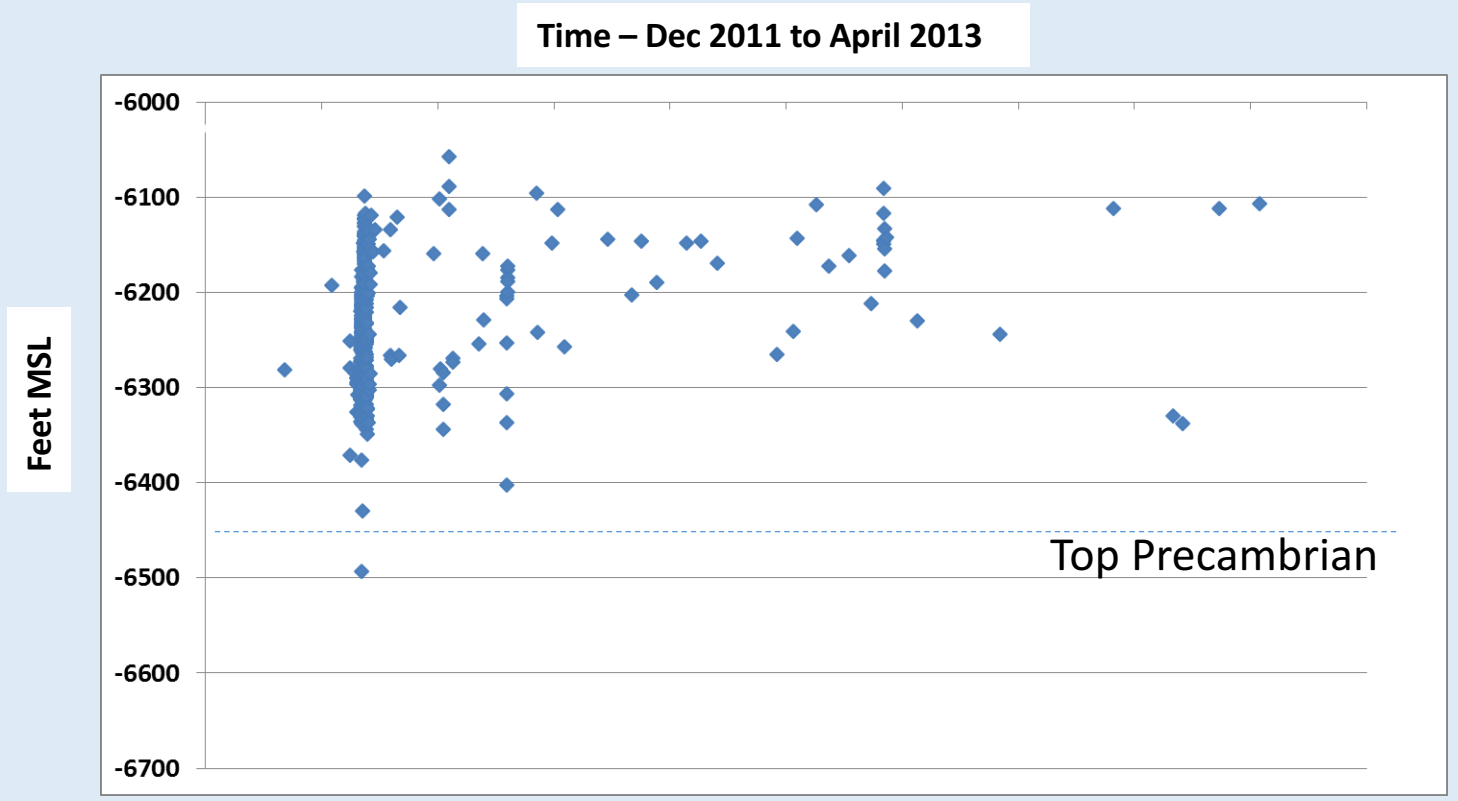
Cluster development in relation to stratigraphy

Cluster 1 & 11 development

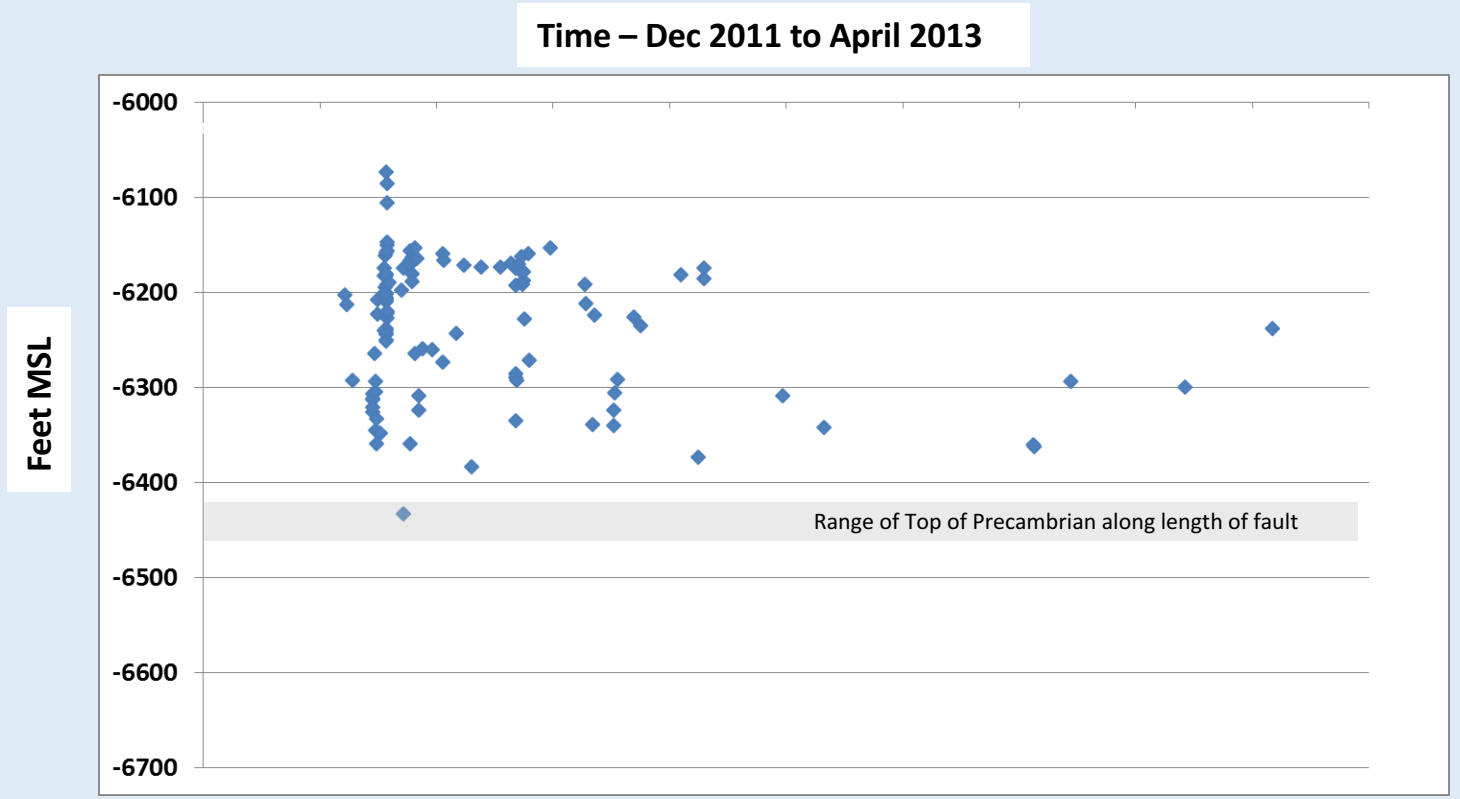
Time – Dec 2011 to April 2013



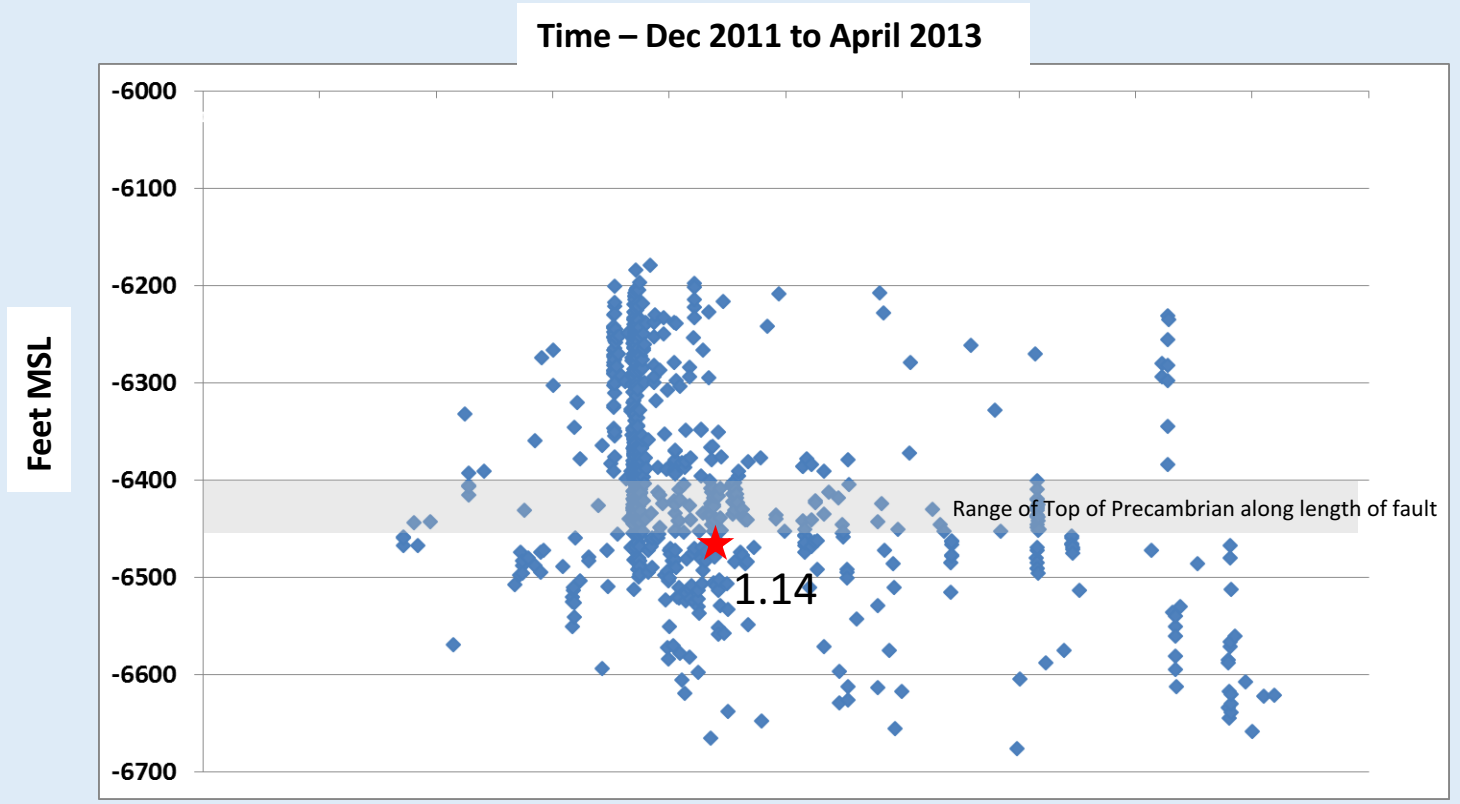
Cluster 2 development



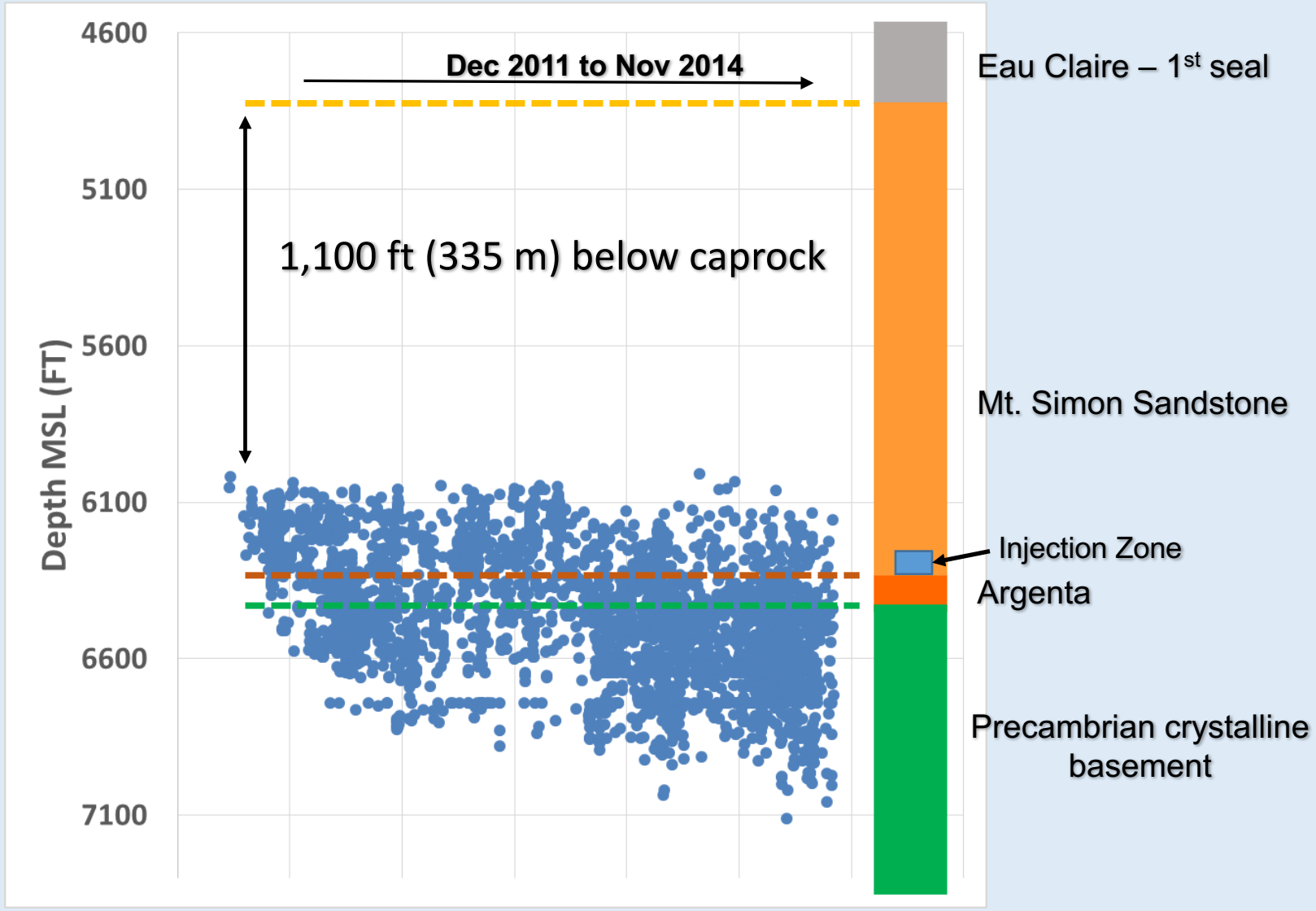
Cluster 3 development

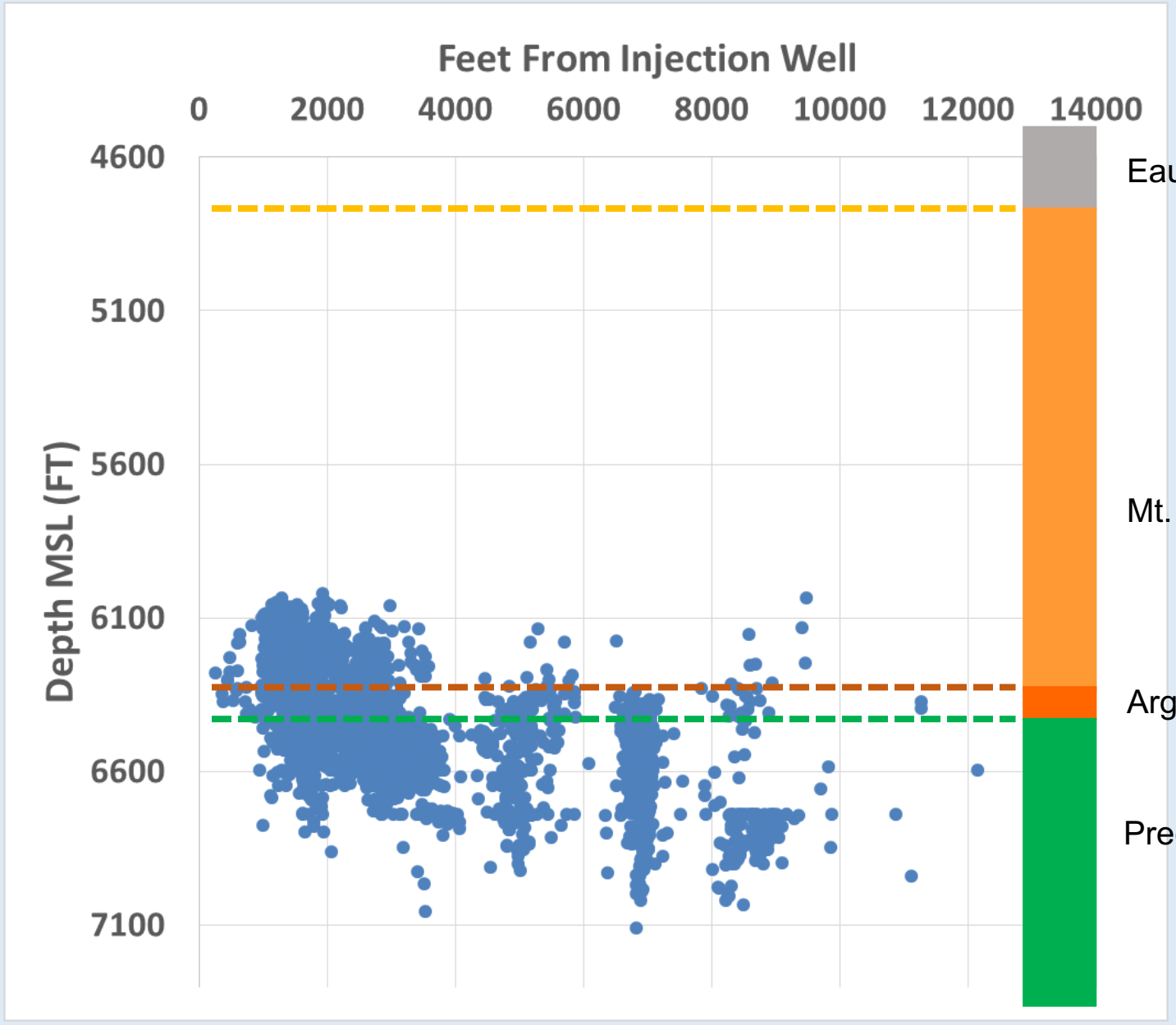


Cluster 4 development

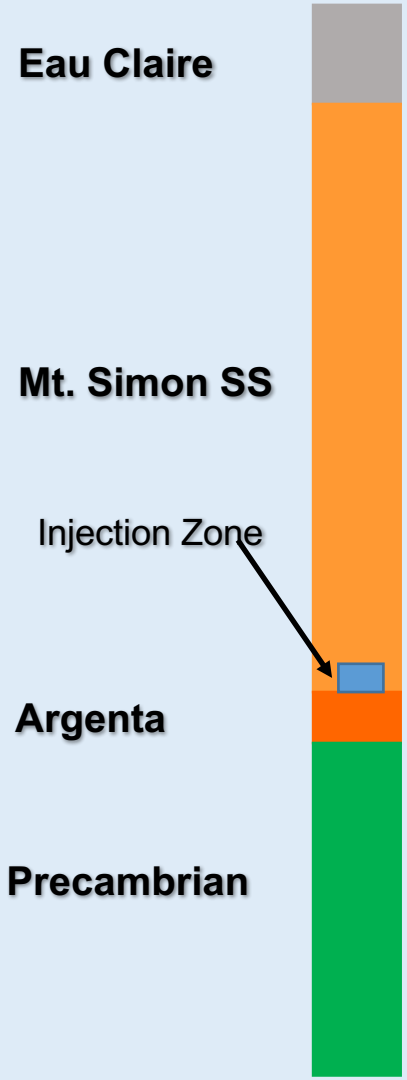


Depth thru Time

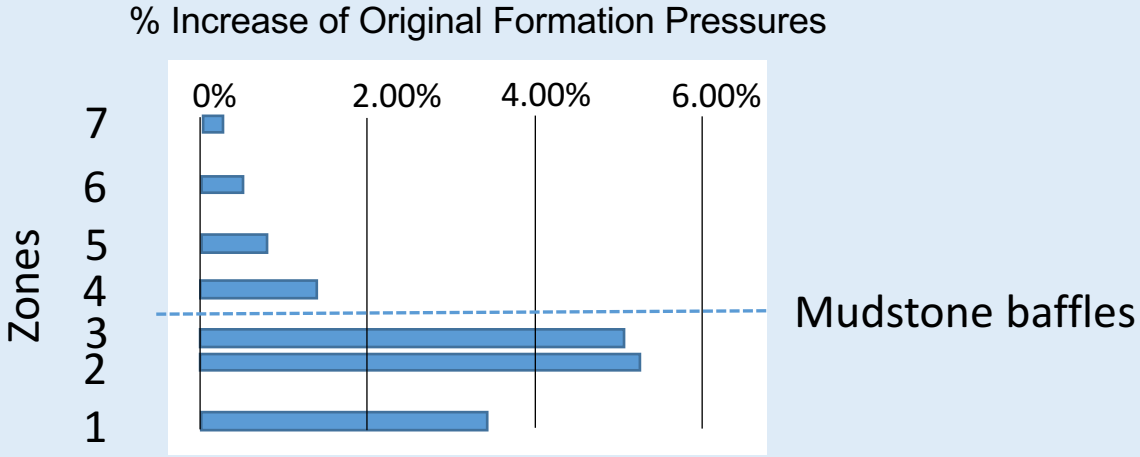



Feet From Injection Well
0
2000
4000
6000
8000
10000
12000
14000
Depth MSL (FT)
4600
5100
5600
6100
6600
7100
Eau Claire
Mt. Simon Sandstone
Argenta
Precambrian crystalline basement

Permanent Shut In Started 26 Nov 2014



VW1 Formation pressure readings 900 feet from Injection borehole

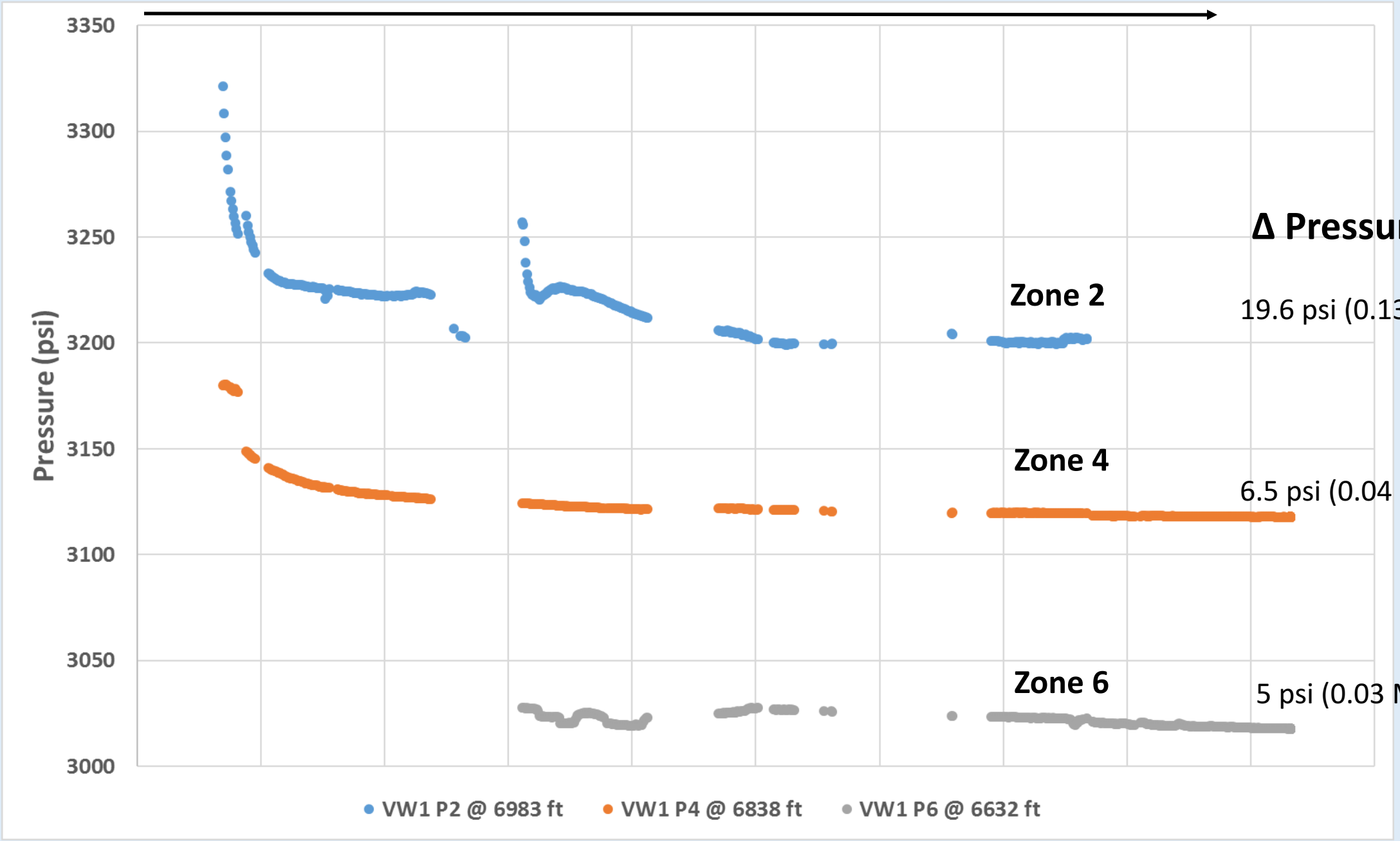


Down hole Injection pressure @ CCS1 14% increase over original formation pressure

Shut In

27 Nov 2014 - 7 April 2017

CCS2 Start

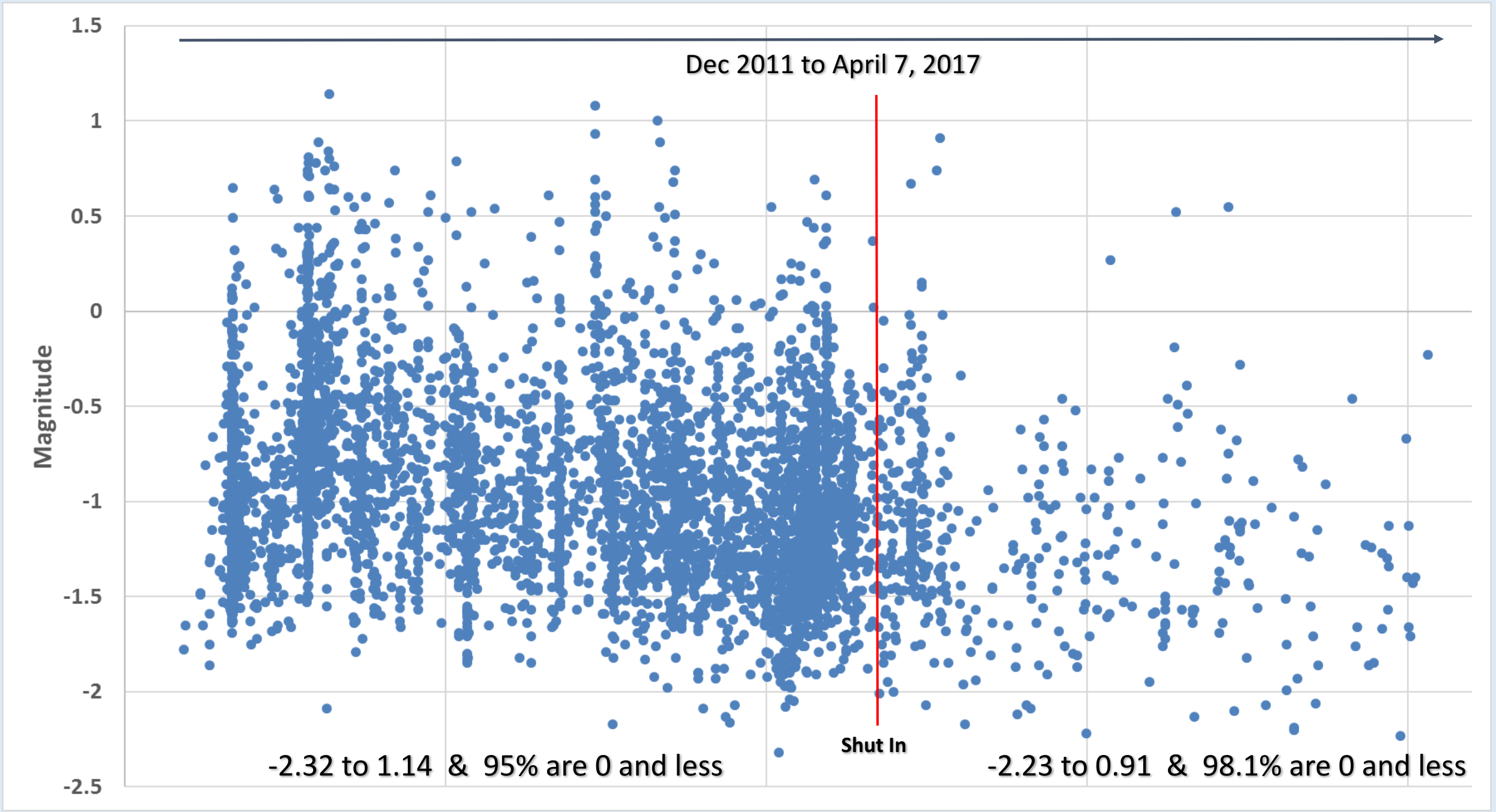


Δ Pressure

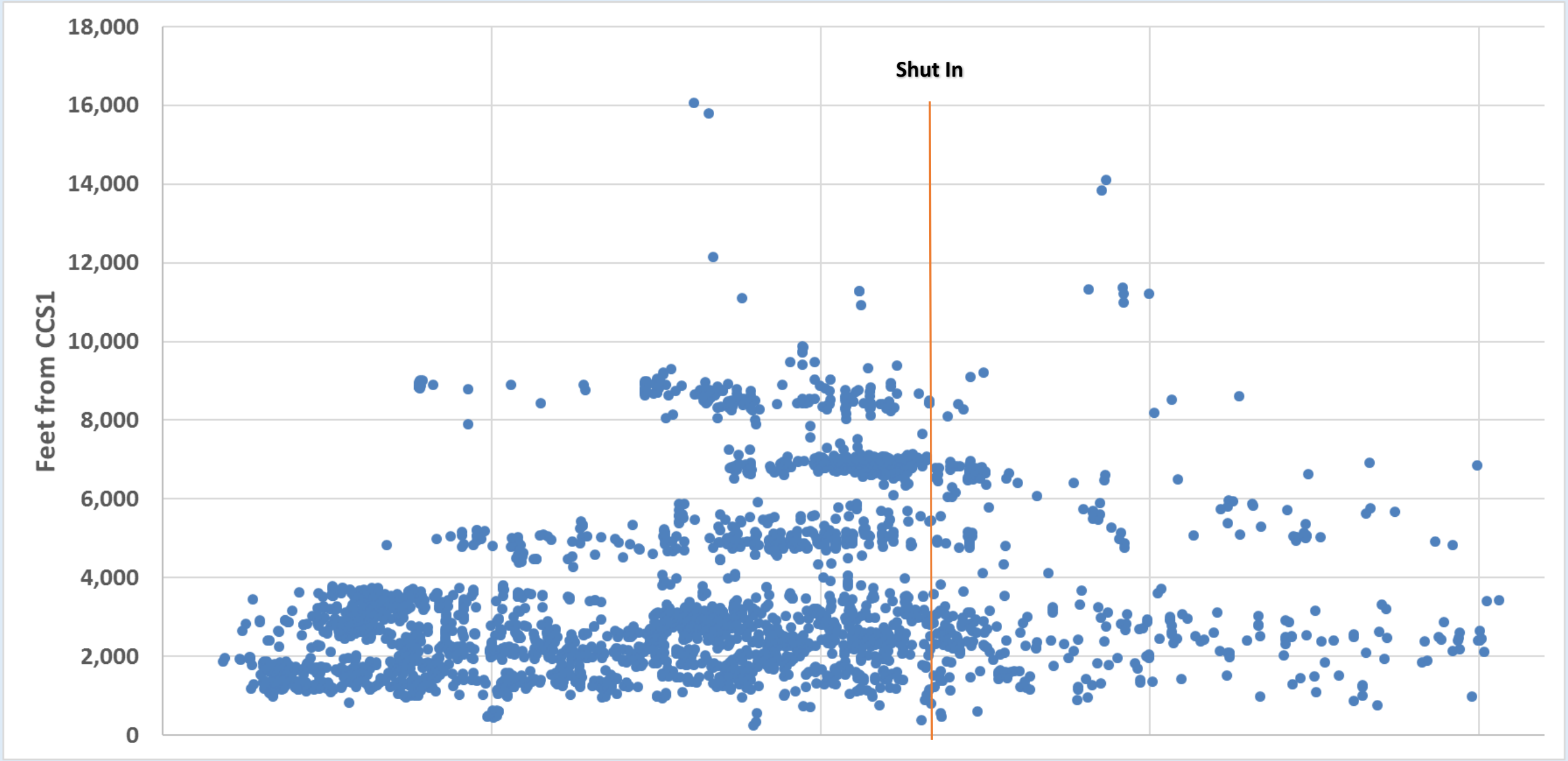
19.6 psi (0.13 MPa)

6.5 psi (0.04 MPa)

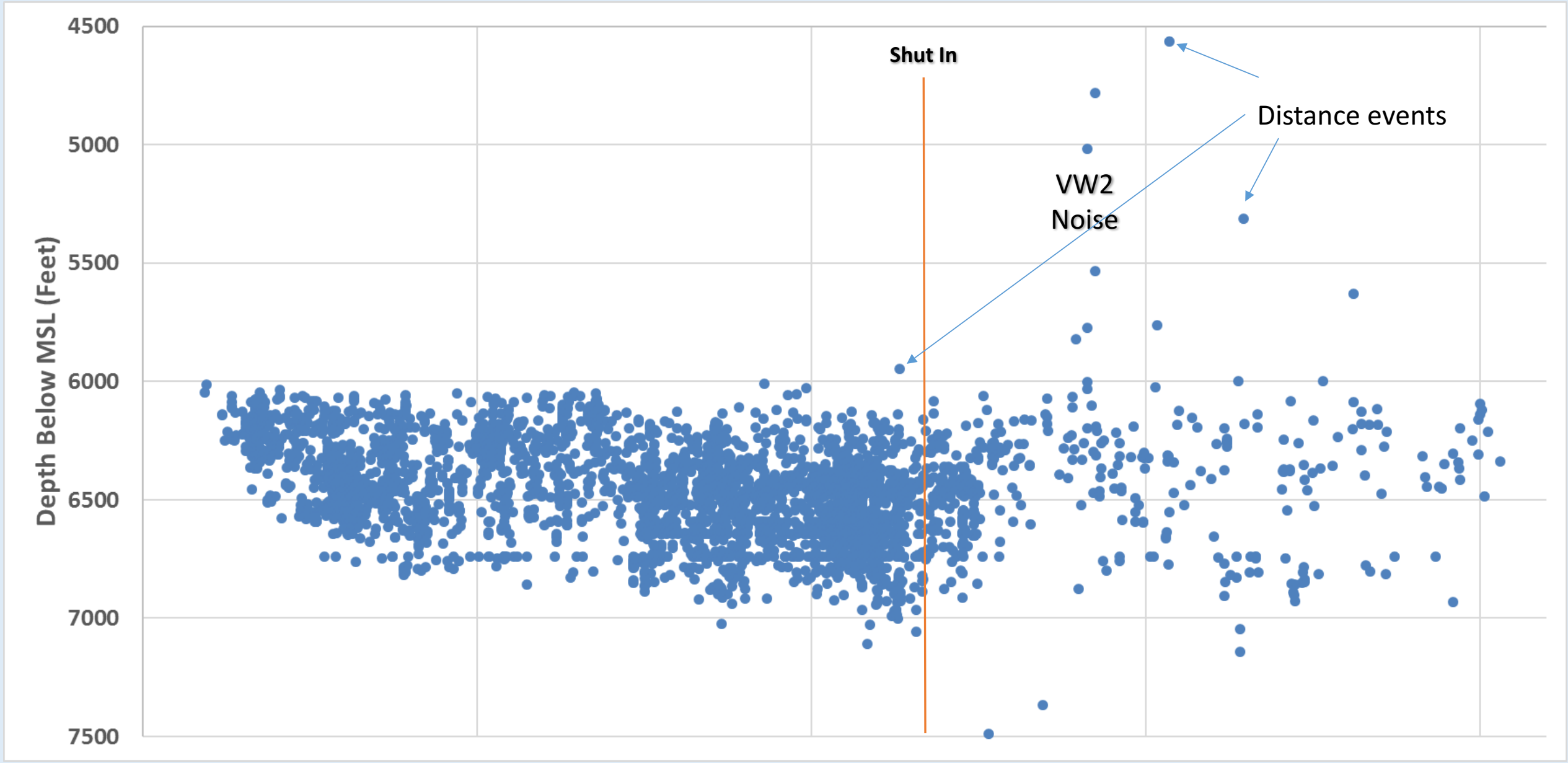
5 psi (0.03 MPa)


Dec 2011 to April 7, 2017
Magnitude
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
Shut In
-2.32 to 1.14 & 95% are 0 and less
-2.23 to 0.91 & 98.1% are 0 and less

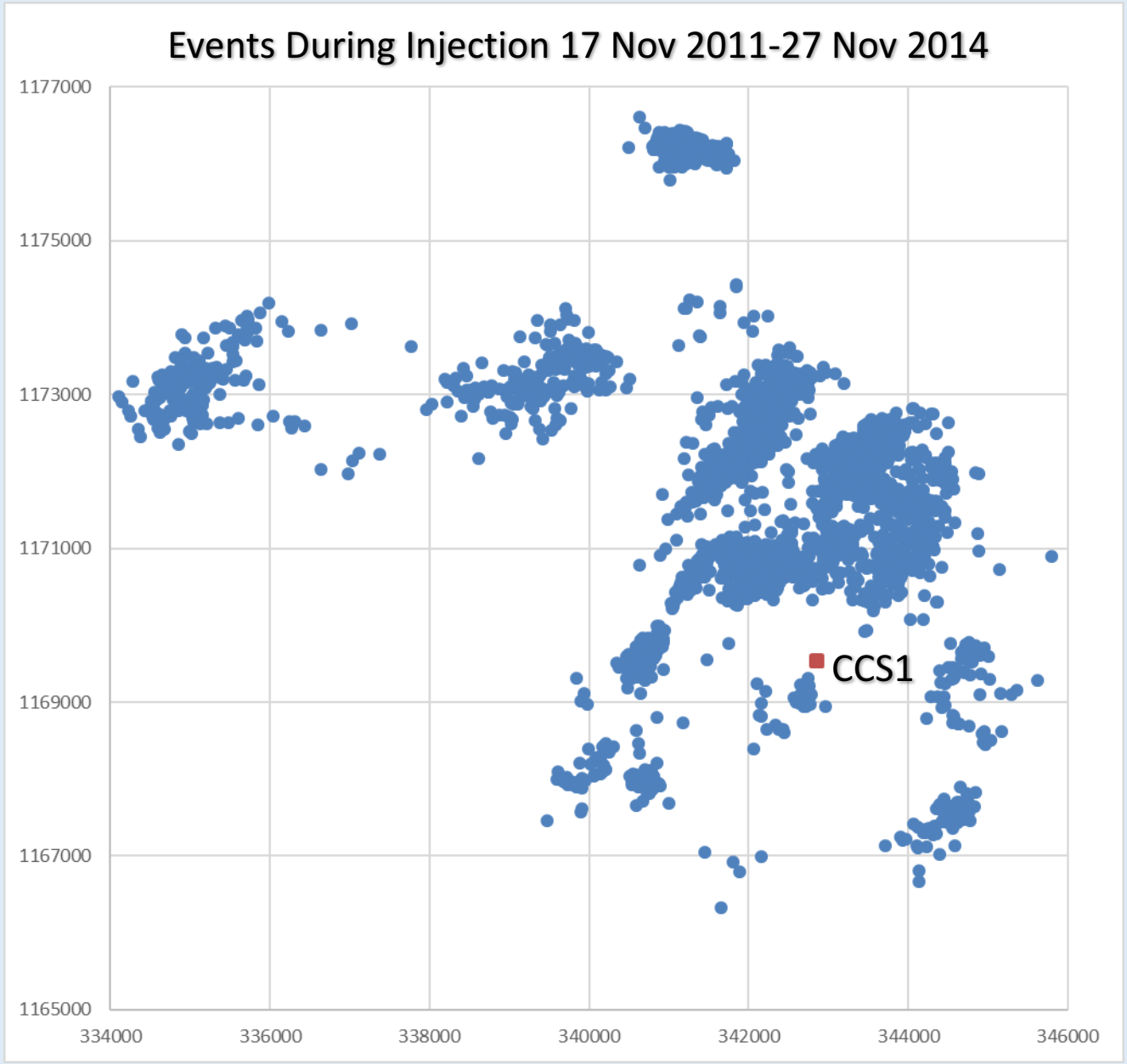
Distance from Injection Well from Dec 2011 to April 7, 2017

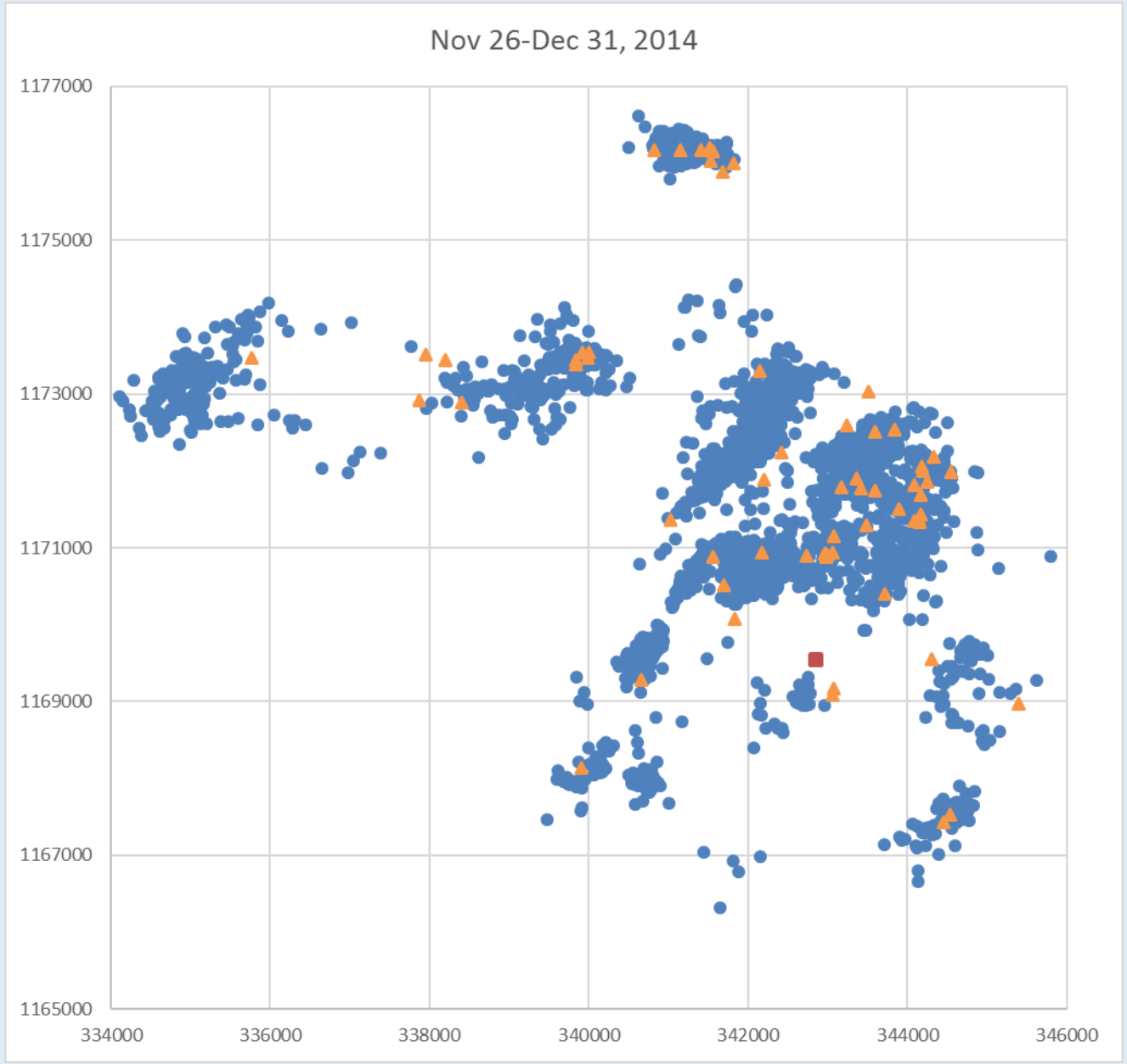


Depth Through Time from Dec 2011 to April 7, 2017



Each square =
2,000 ft / 610 m




Nov 26-Dec 31, 2014
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1165000
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336000
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340000
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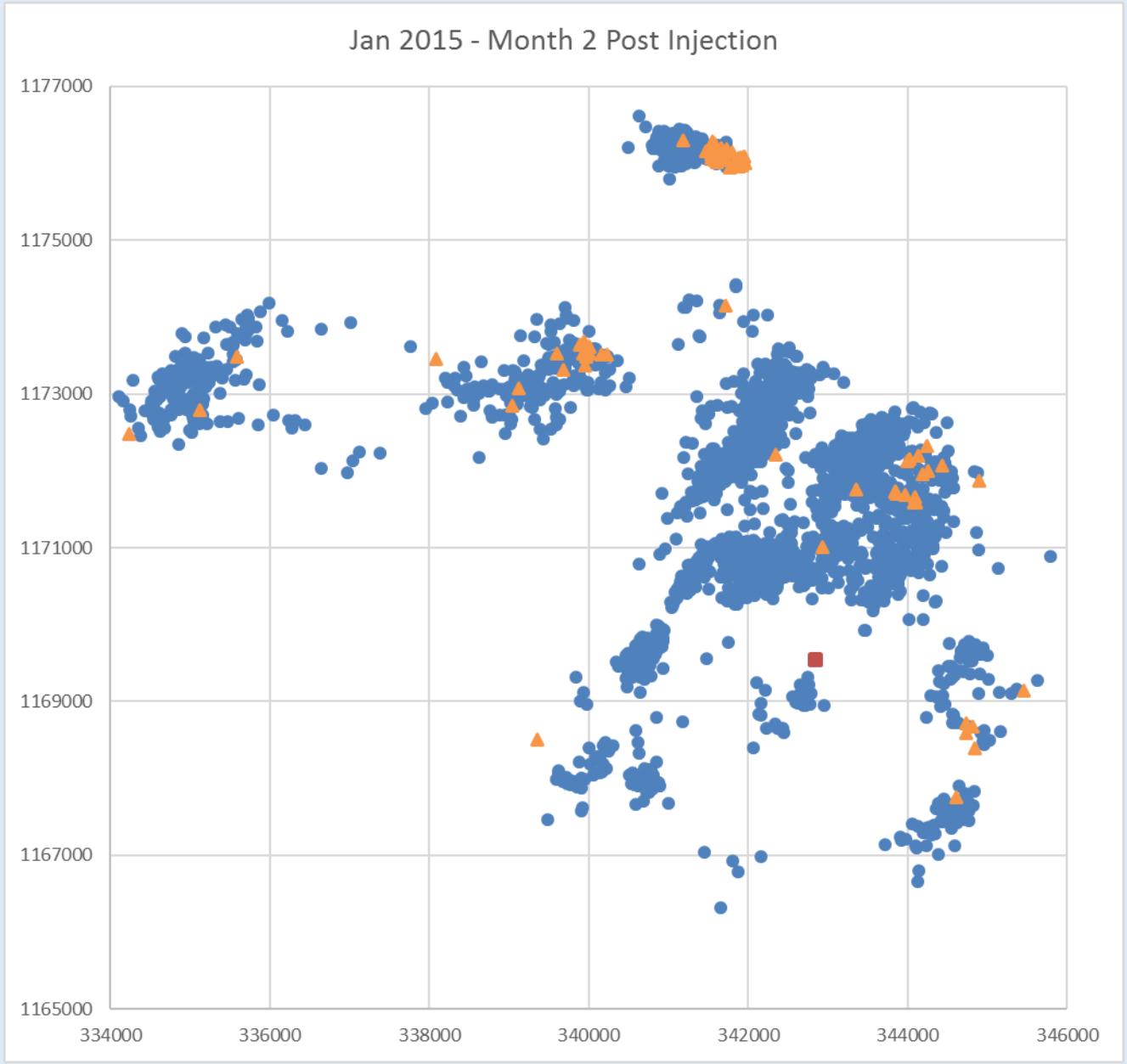
344000
346000


Jan 2015 - Month 2 Post Injection
1177000
1175000
1173000
1171000
1169000
1167000
1165000
334000
336000
338000
340000
342000
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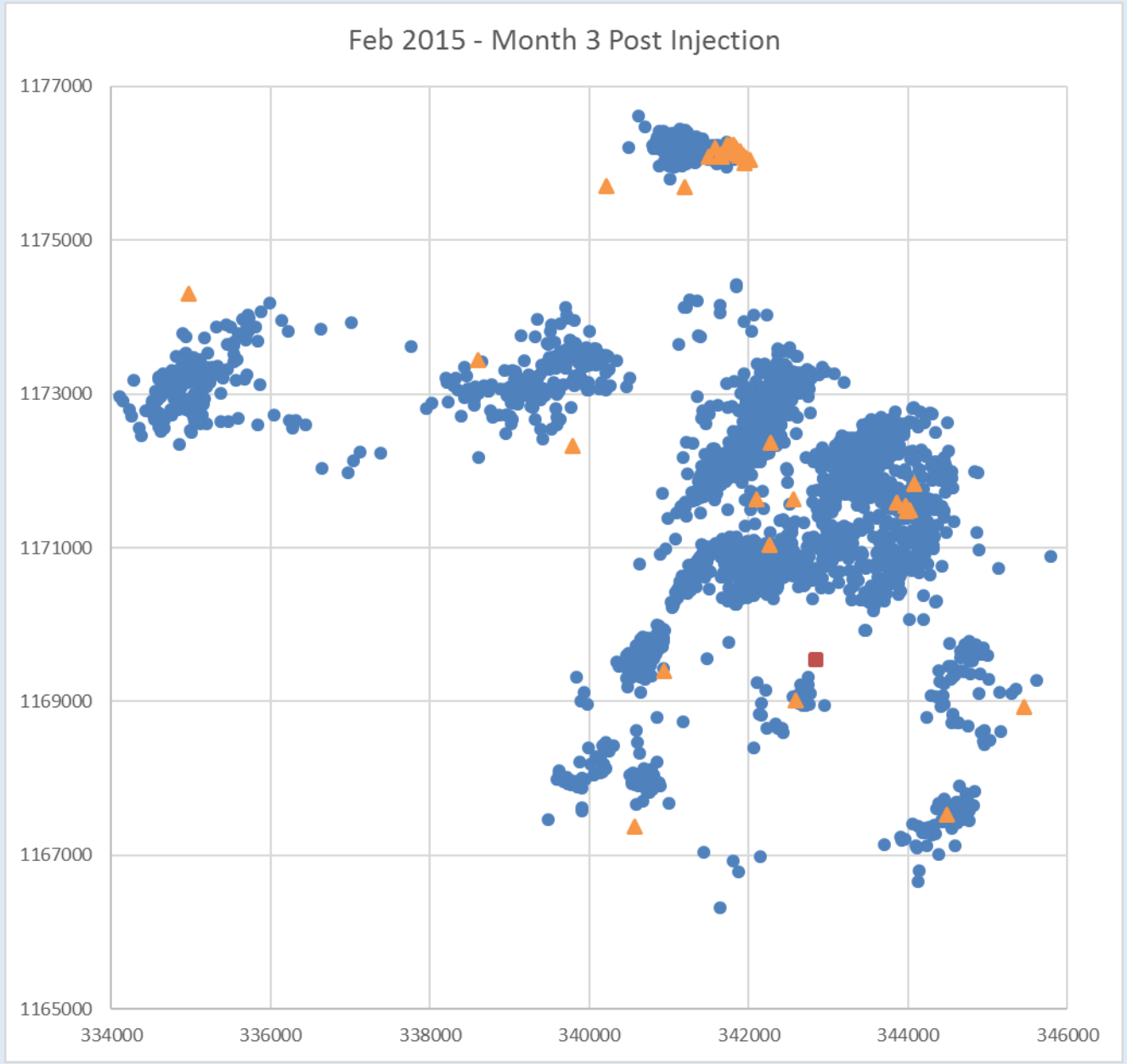
Feb 2015 - Month 3 Post Injection
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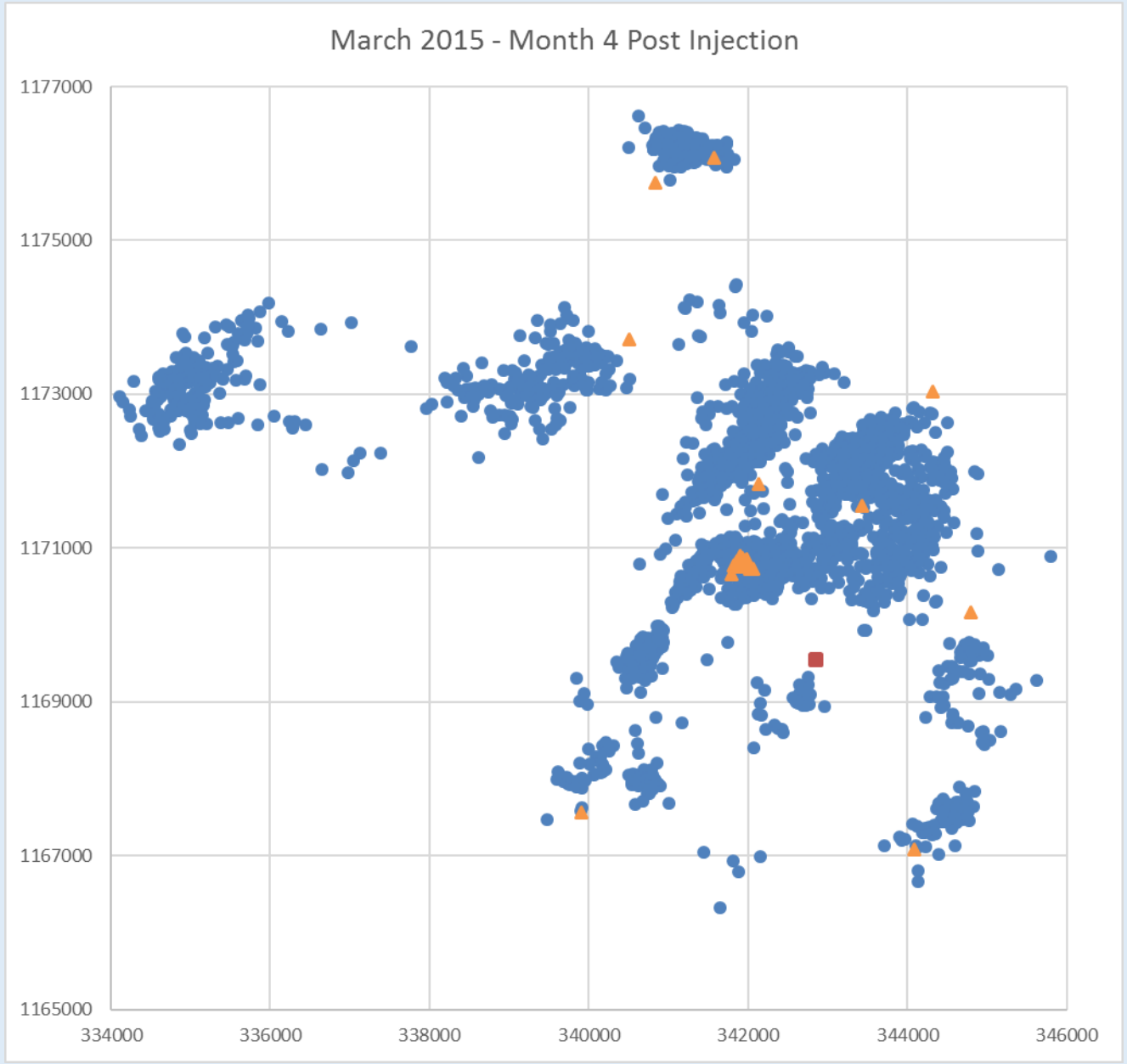
March 2015 - Month 4 Post Injection
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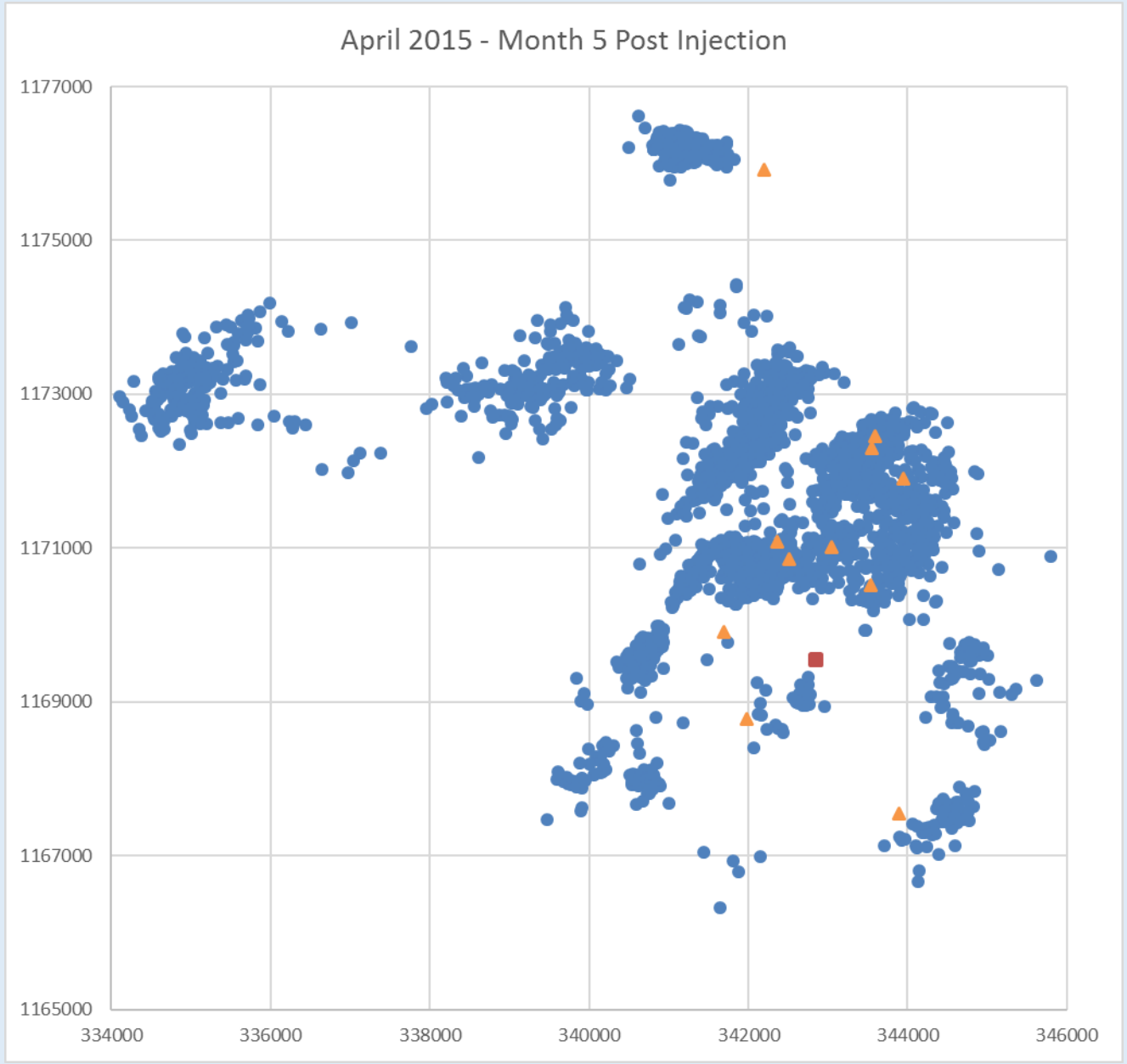
April 2015 - Month 5 Post Injection
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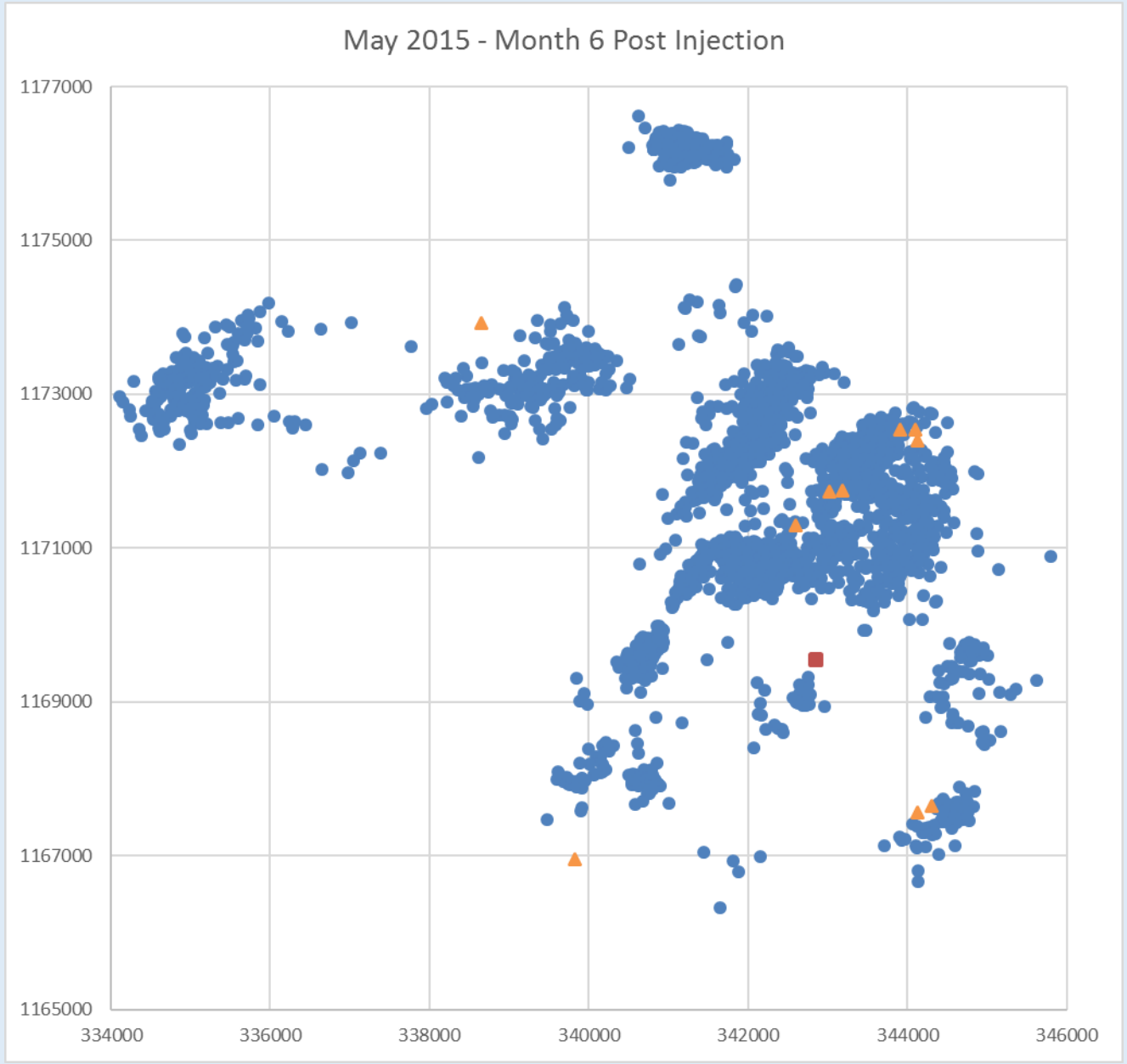
May 2015 - Month 6 Post Injection
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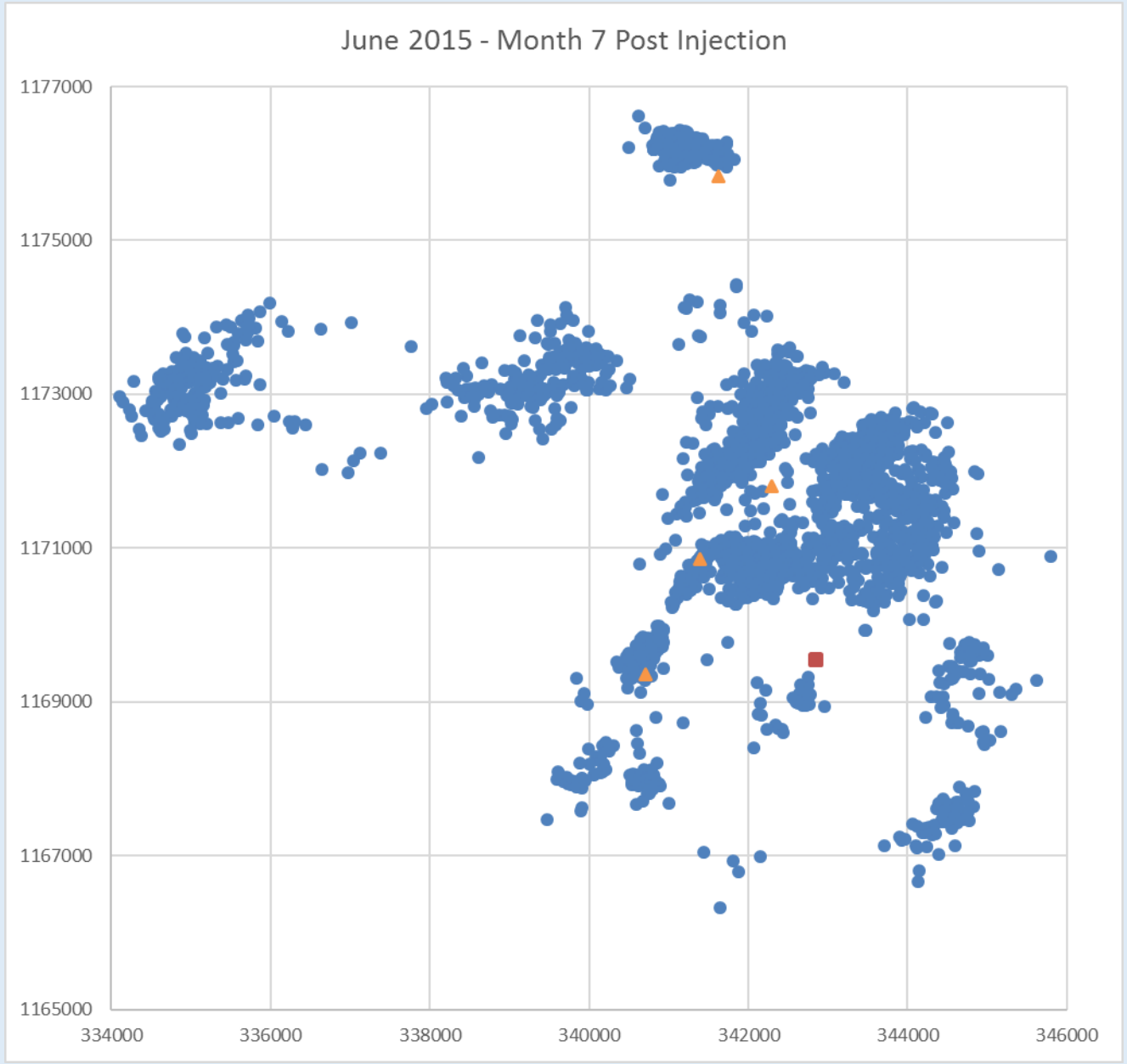
June 2015 - Month 7 Post Injection
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336000
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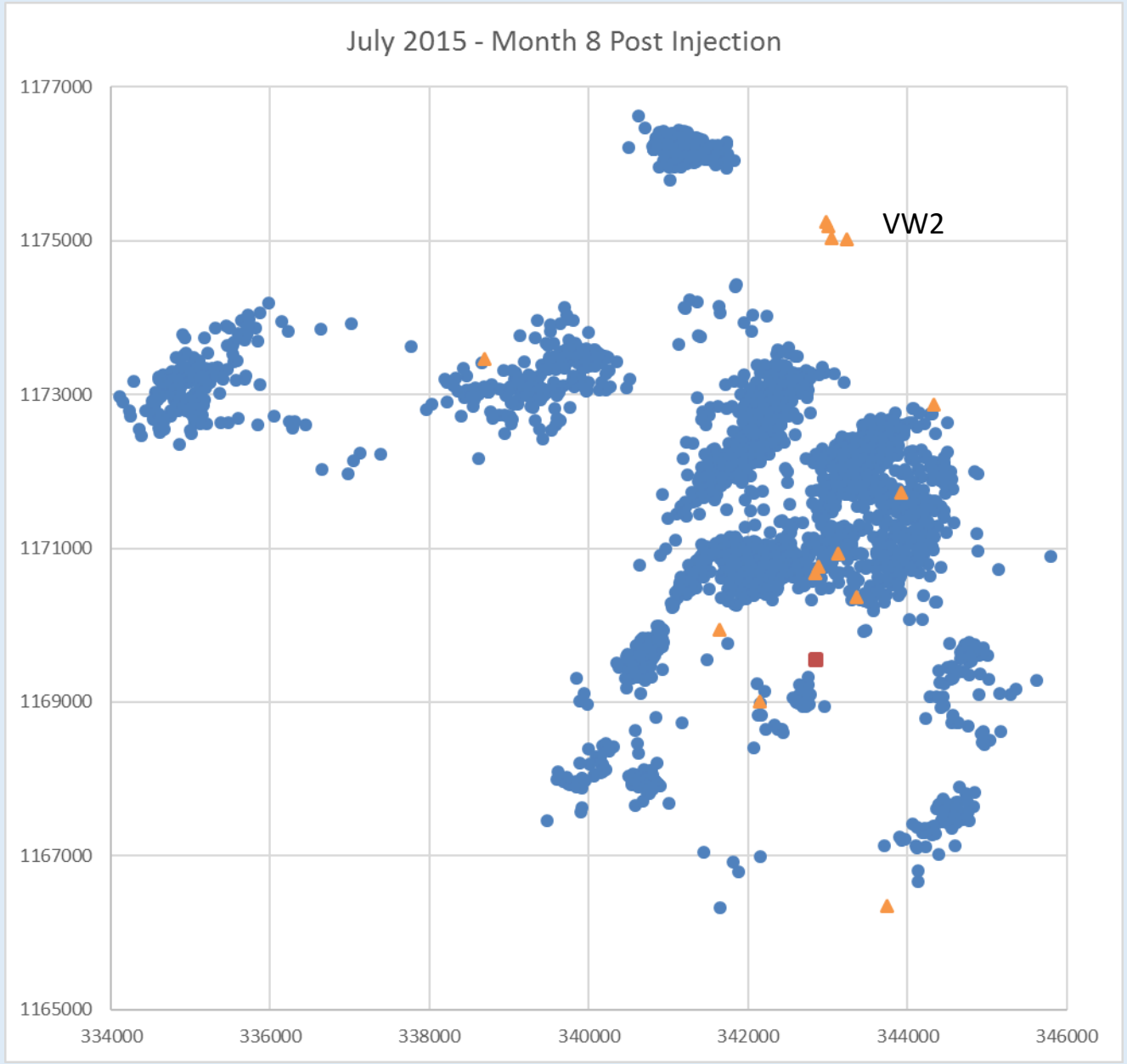
July 2015 - Month 8 Post Injection
1177000
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1169000
1167000
1165000
334000
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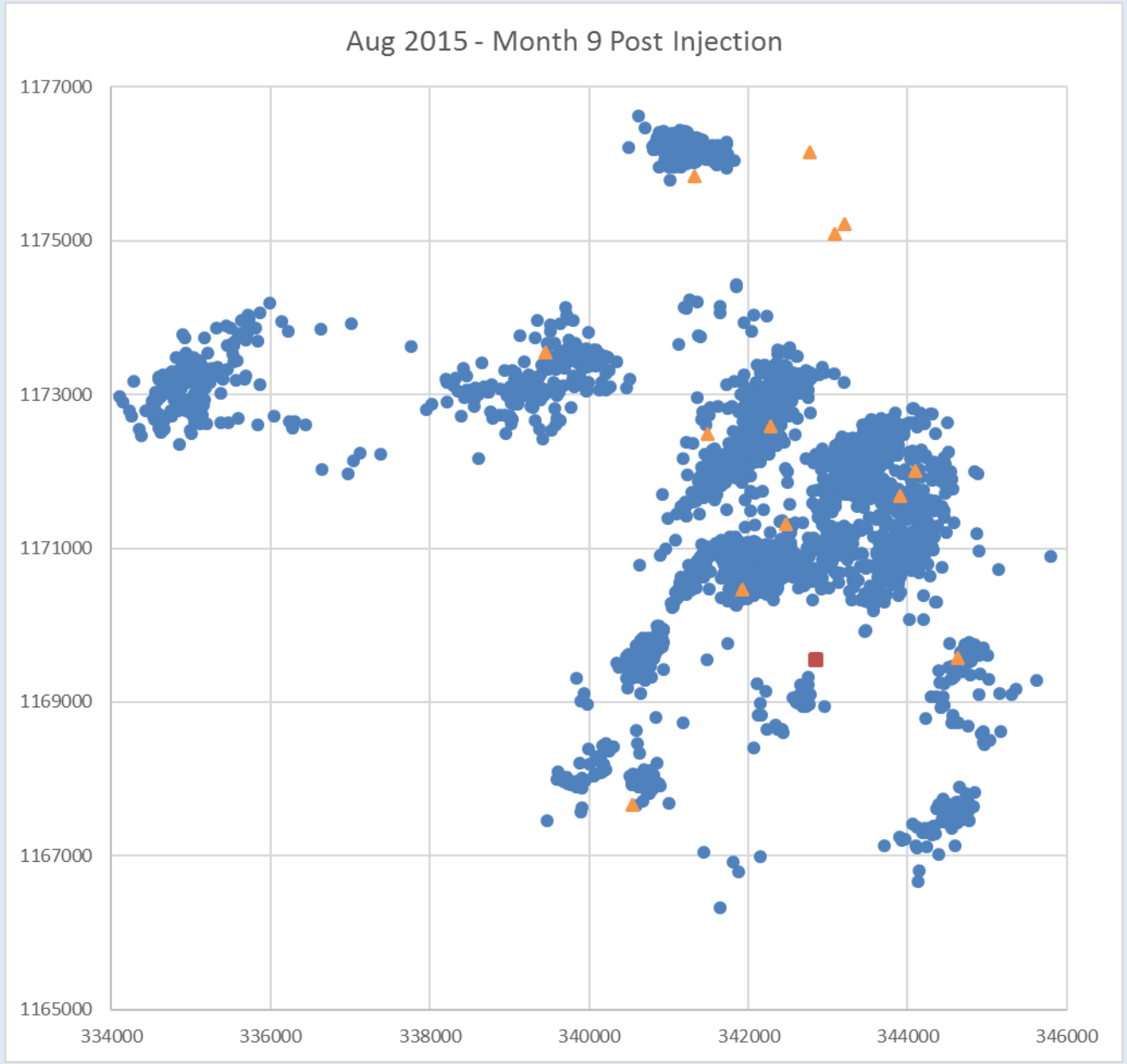
344000
346000
VW2


Aug 2015 - Month 9 Post Injection
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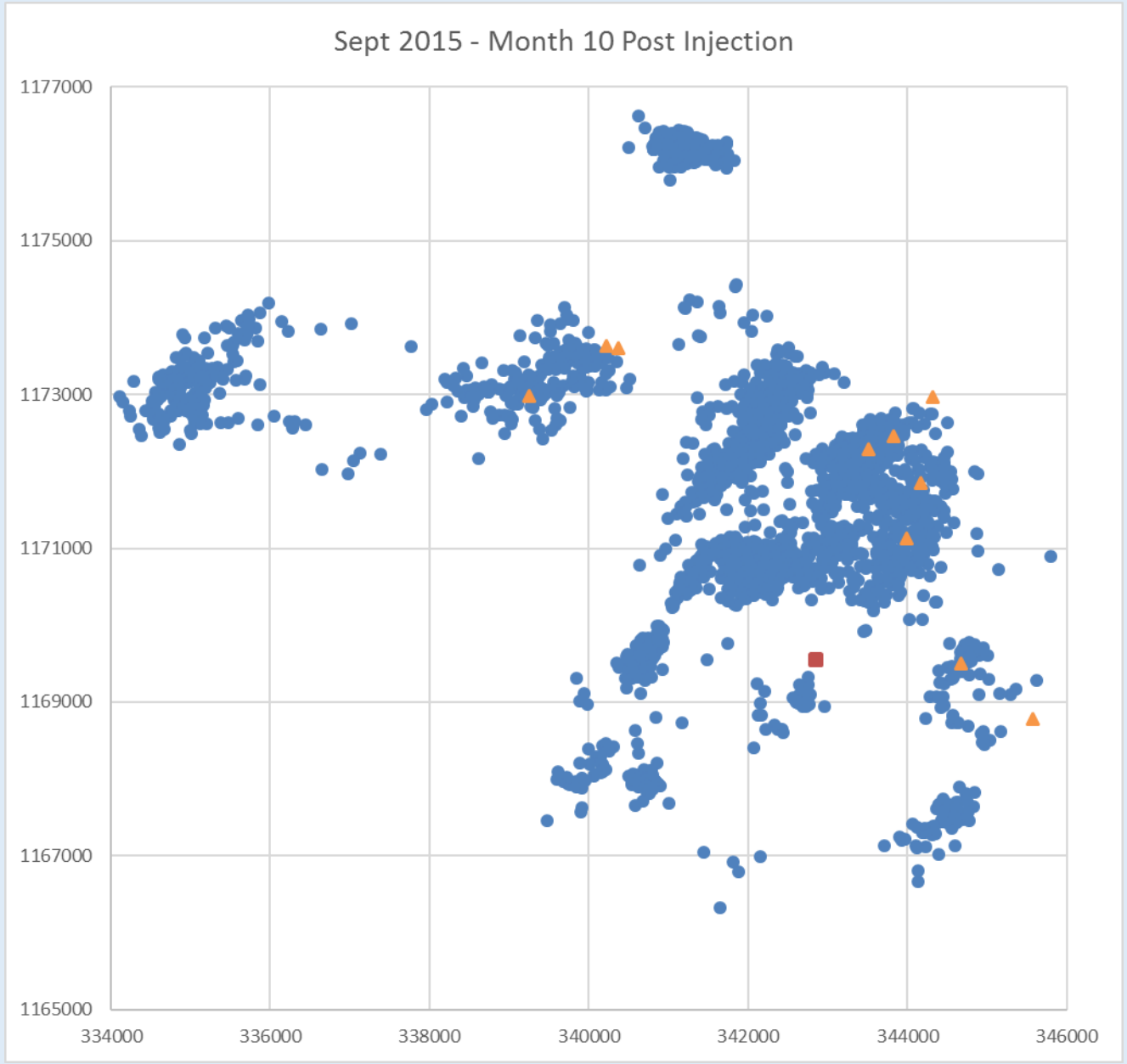
Sept 2015 - Month 10 Post Injection
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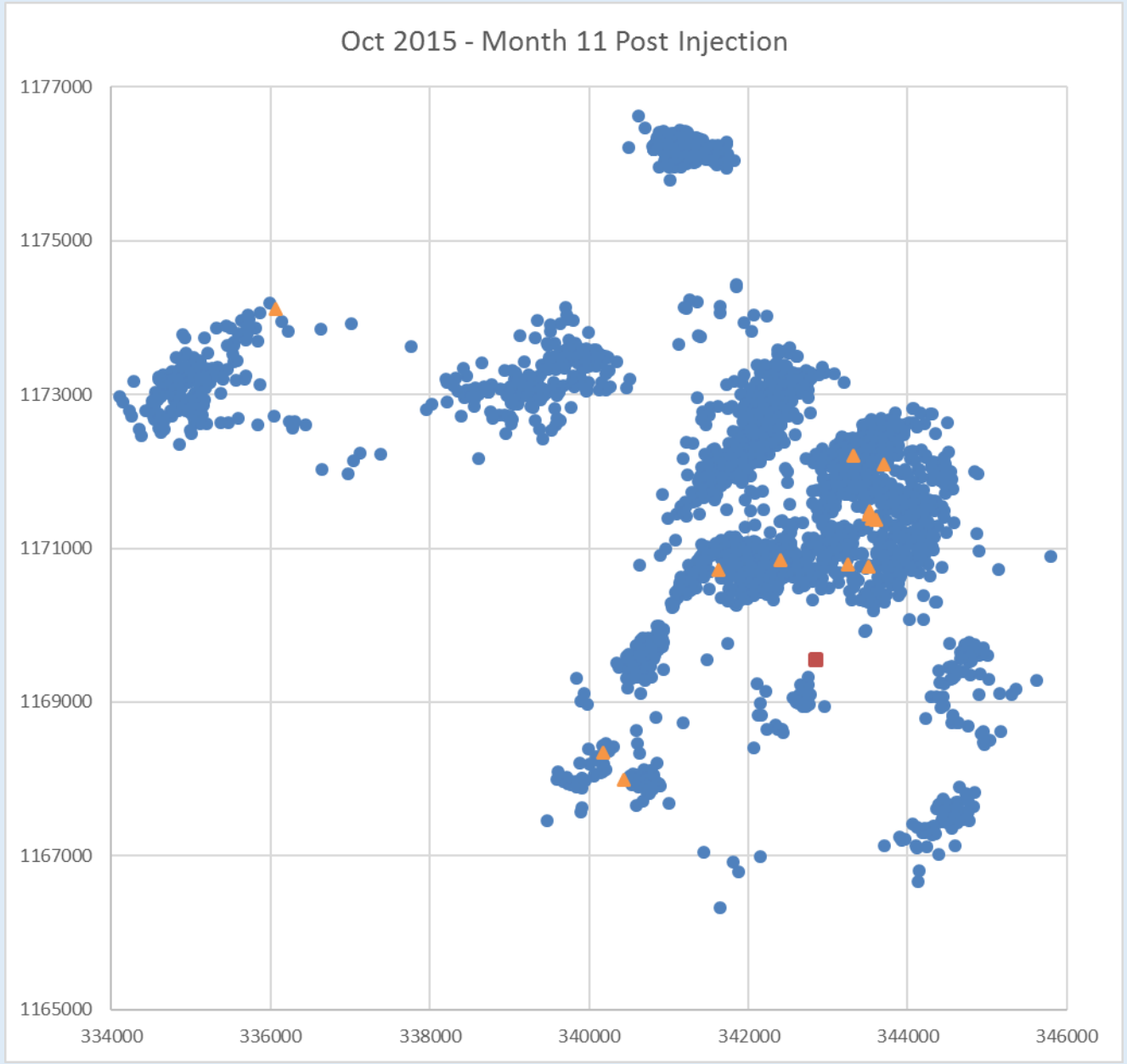
Oct 2015 - Month 11 Post Injection
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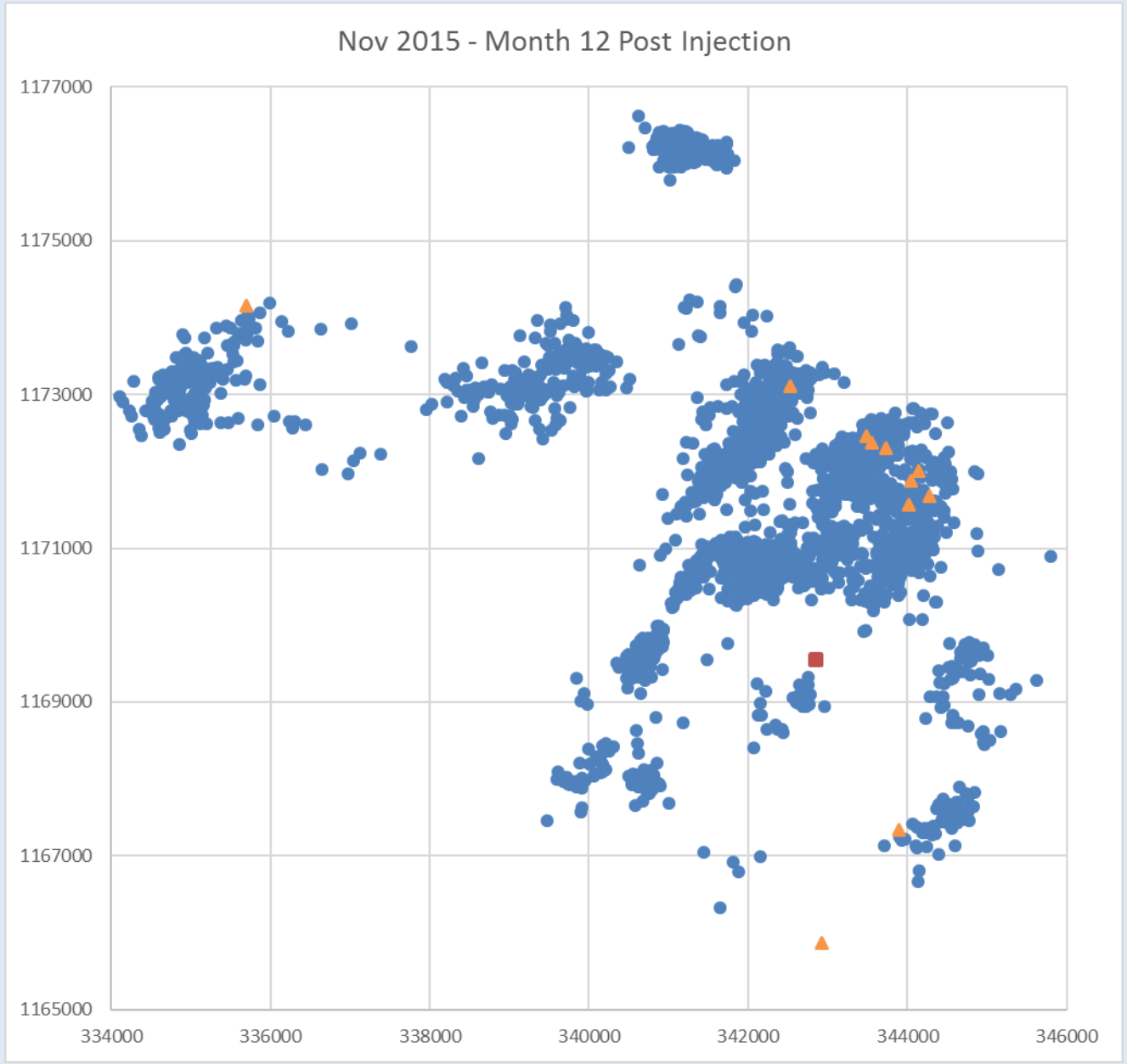
Nov 2015 - Month 12 Post Injection
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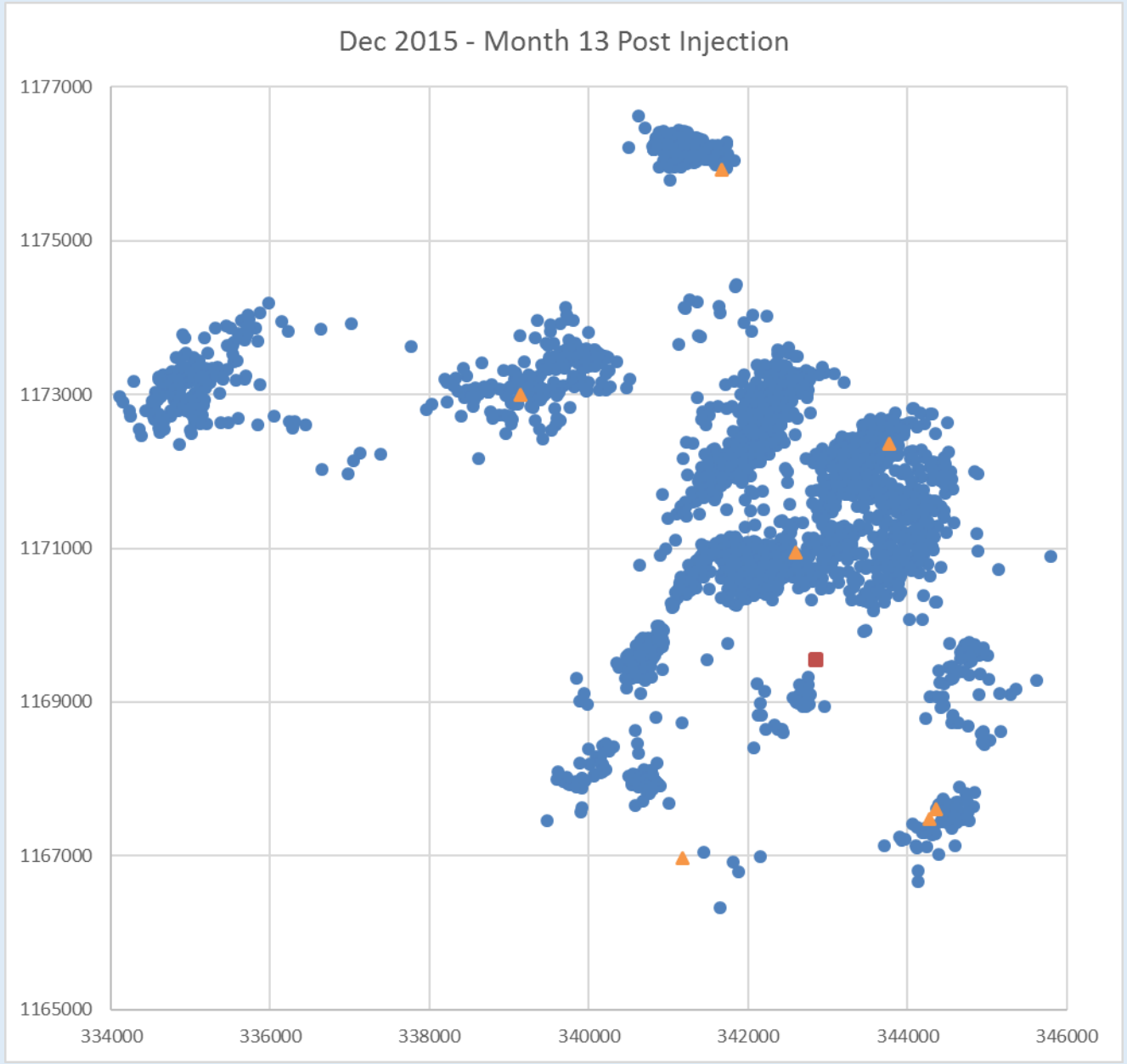
Dec 2015 - Month 13 Post Injection
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336000
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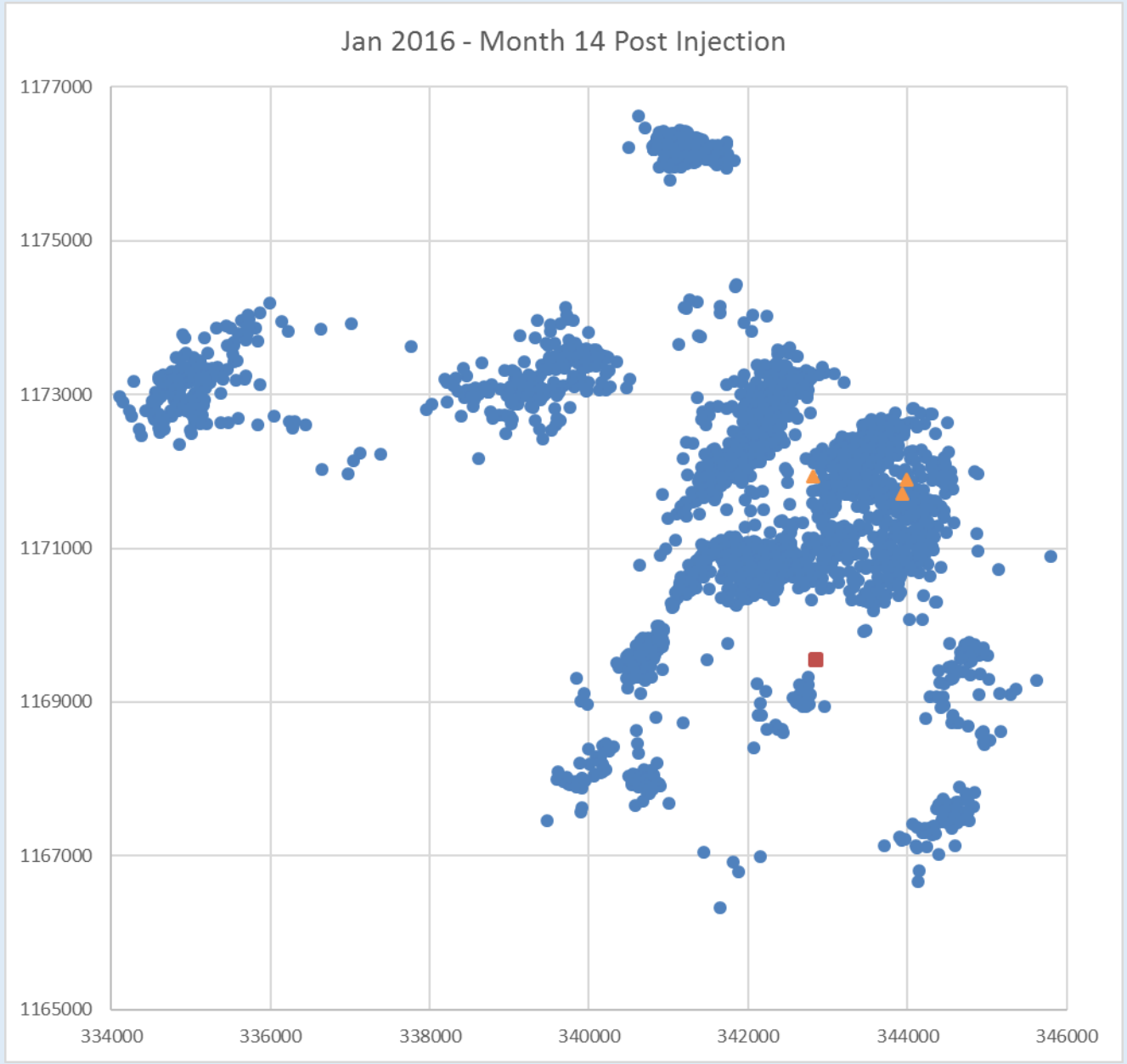
342000
344000
346000


Jan 2016 - Month 14 Post Injection
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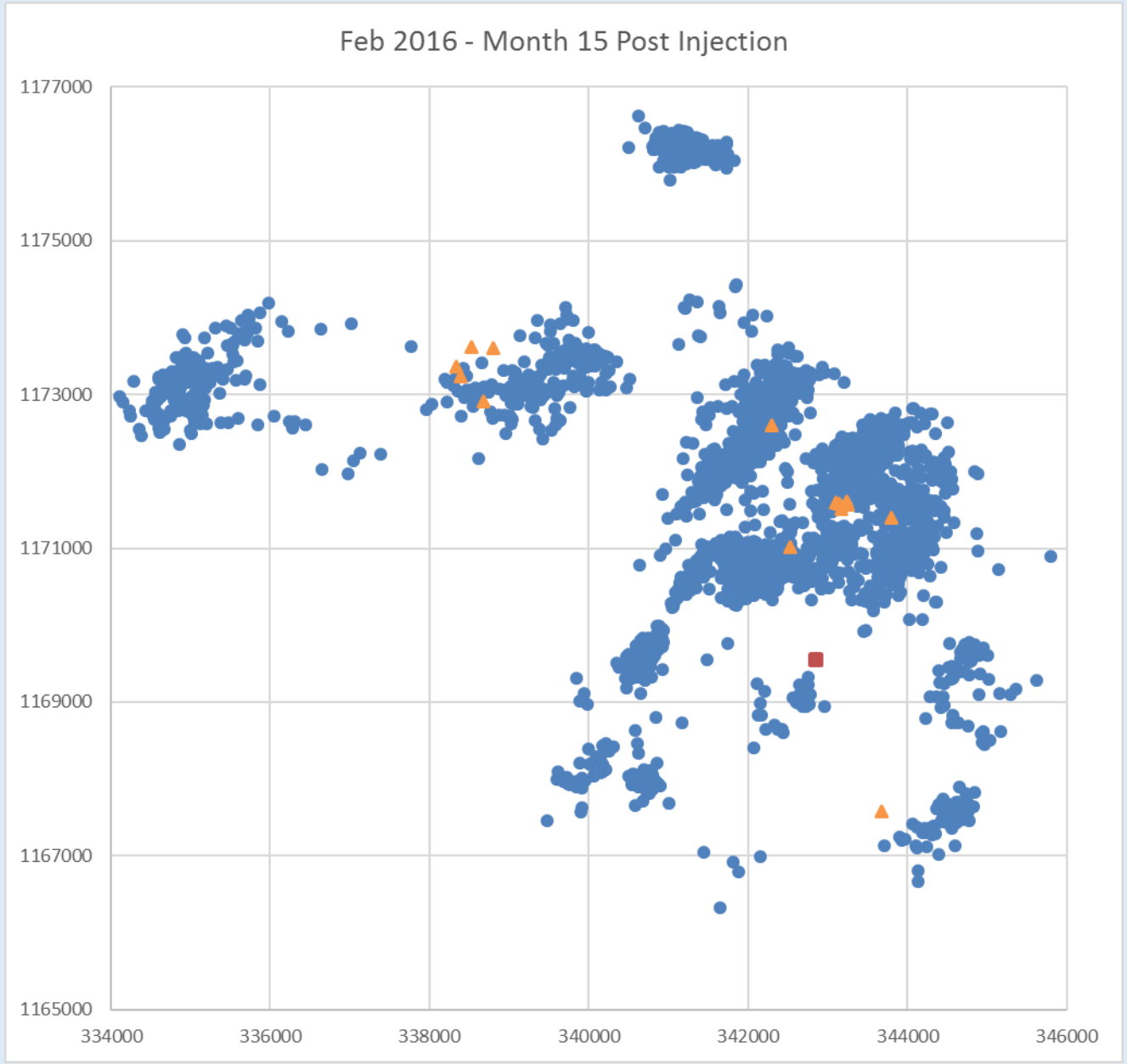
1169000
1167000
1165000
334000
336000
338000
340000
342000
344000
346000


Feb 2016 - Month 15 Post Injection
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1171000
1169000
1167000
1165000
334000
336000
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342000
344000
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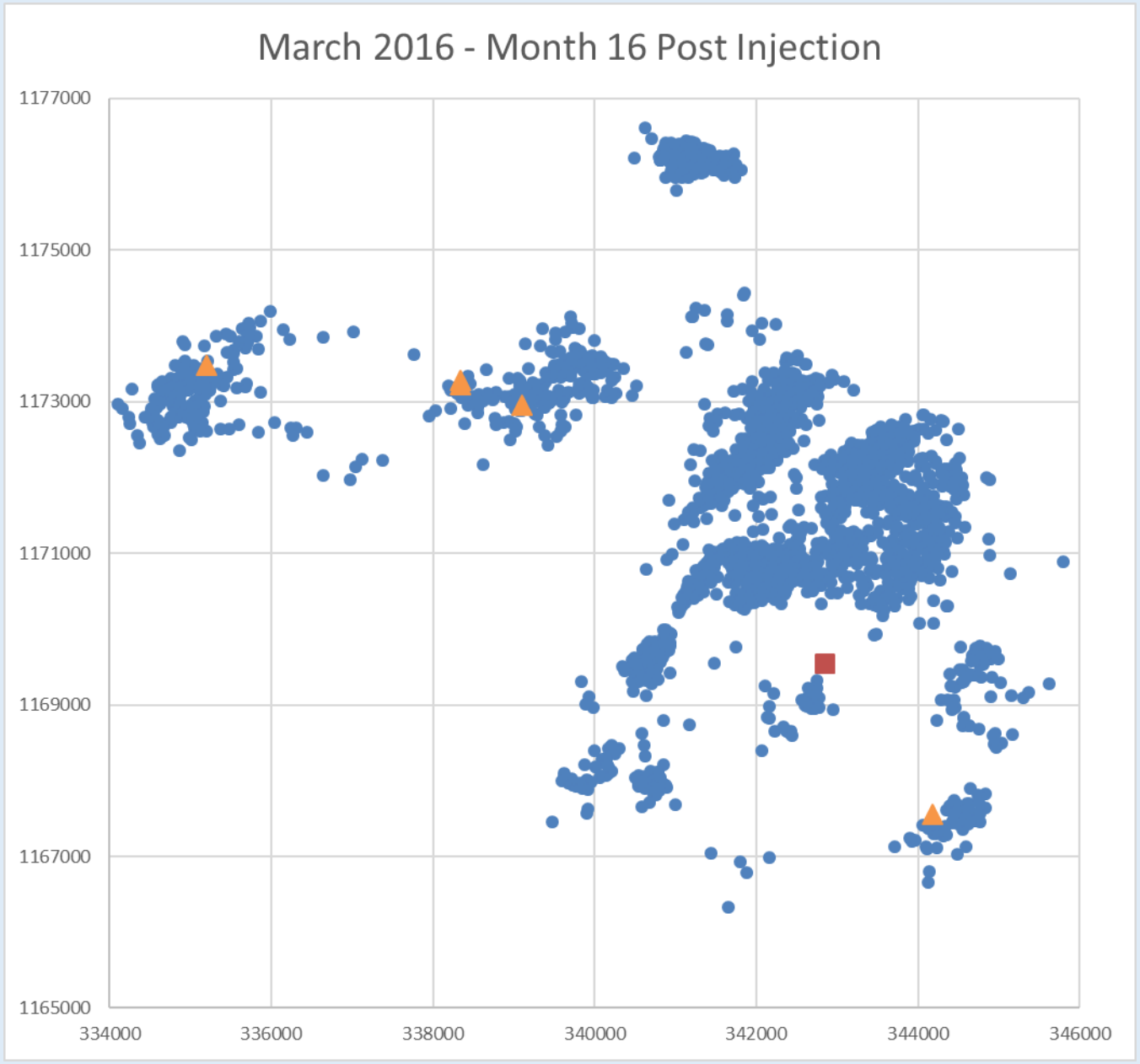
March 2016 - Month 16 Post Injection
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1165000
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338000
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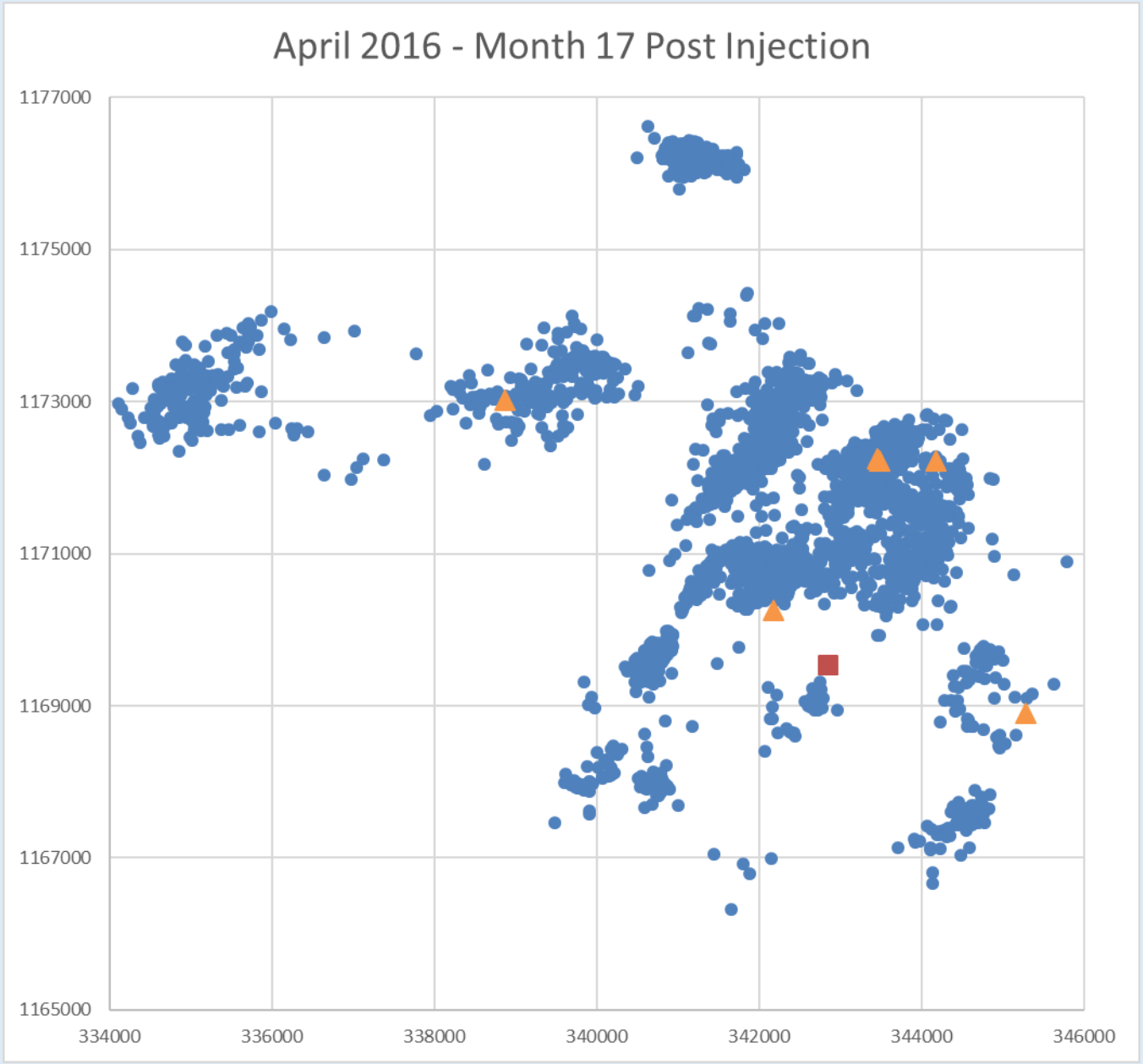
April 2016 - Month 17 Post Injection
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1171000
1169000
1167000
1165000
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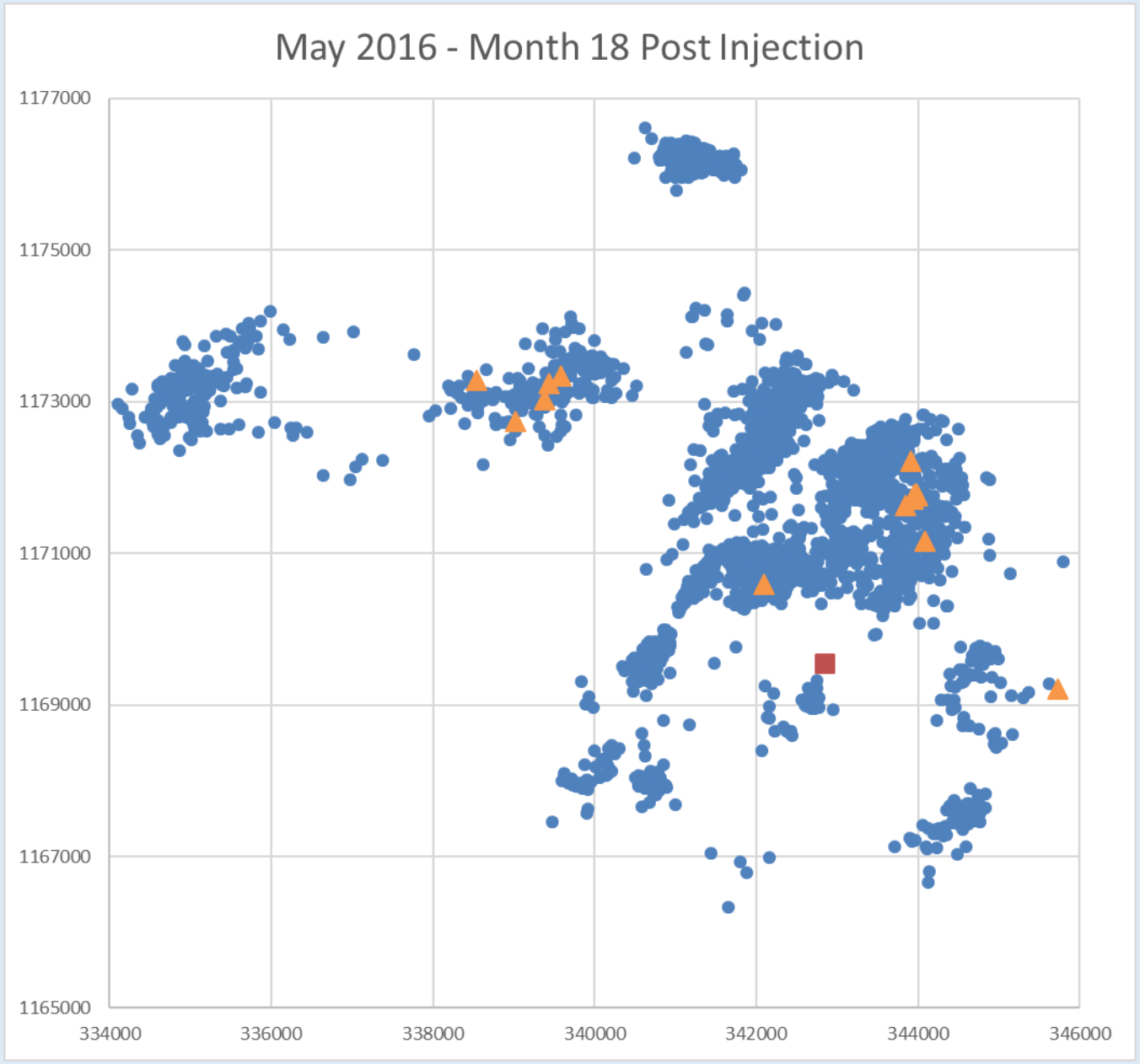
336000
338000
340000
342000
344000
346000


May 2016 - Month 18 Post Injection
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1169000
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1165000
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336000
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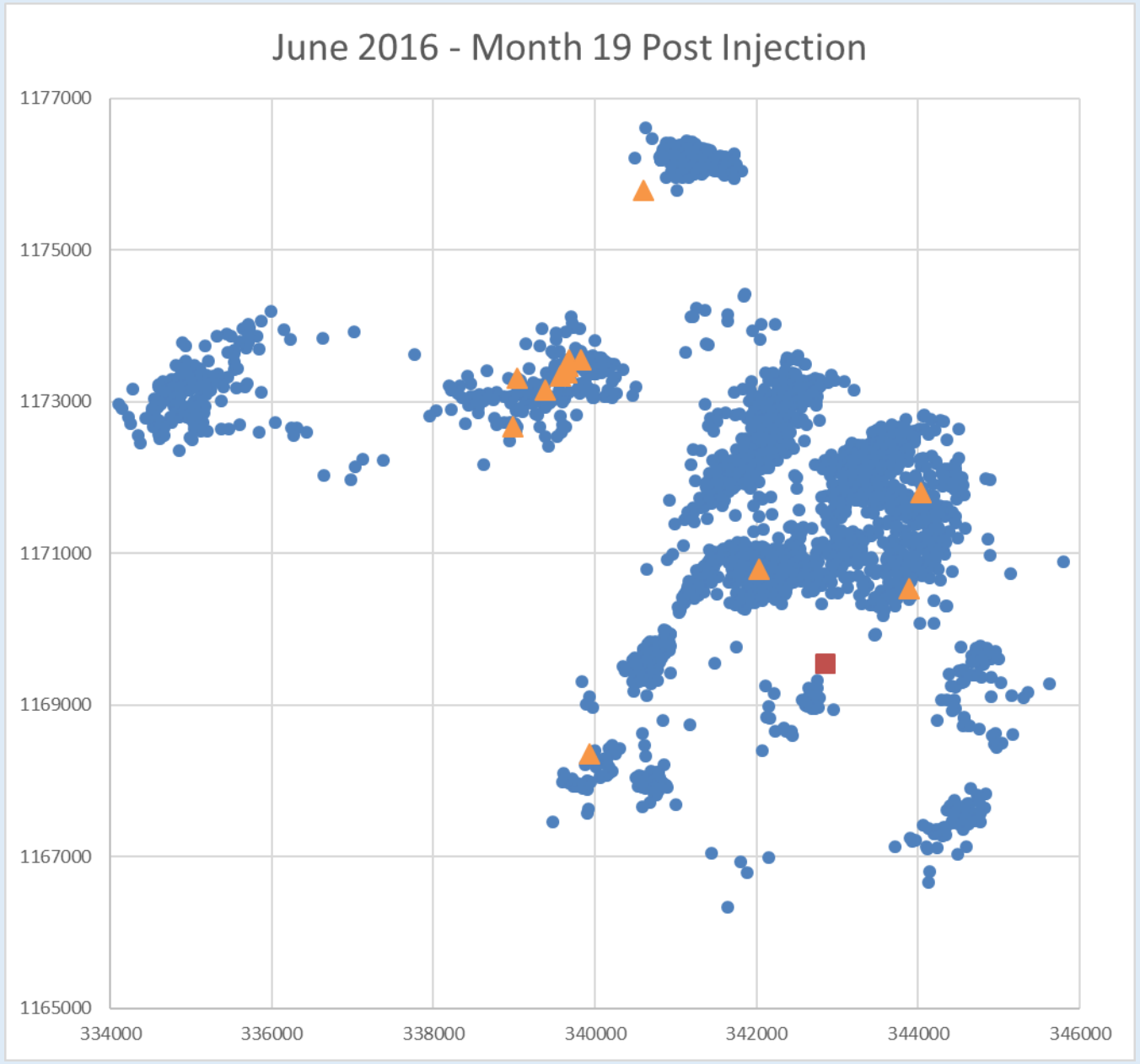
342000
344000
346000


June 2016 - Month 19 Post Injection
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1171000
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1165000
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336000
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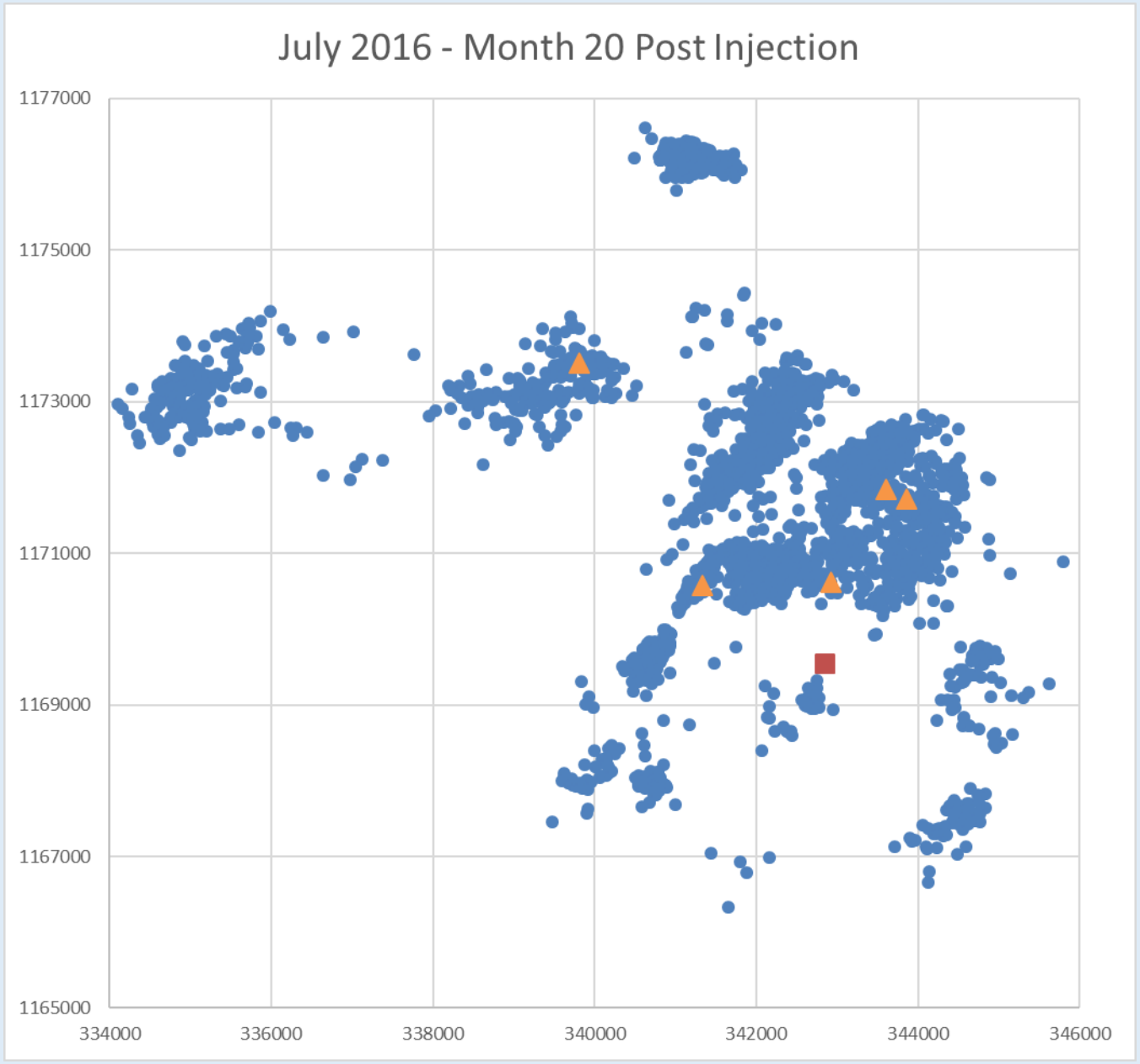
July 2016 - Month 20 Post Injection
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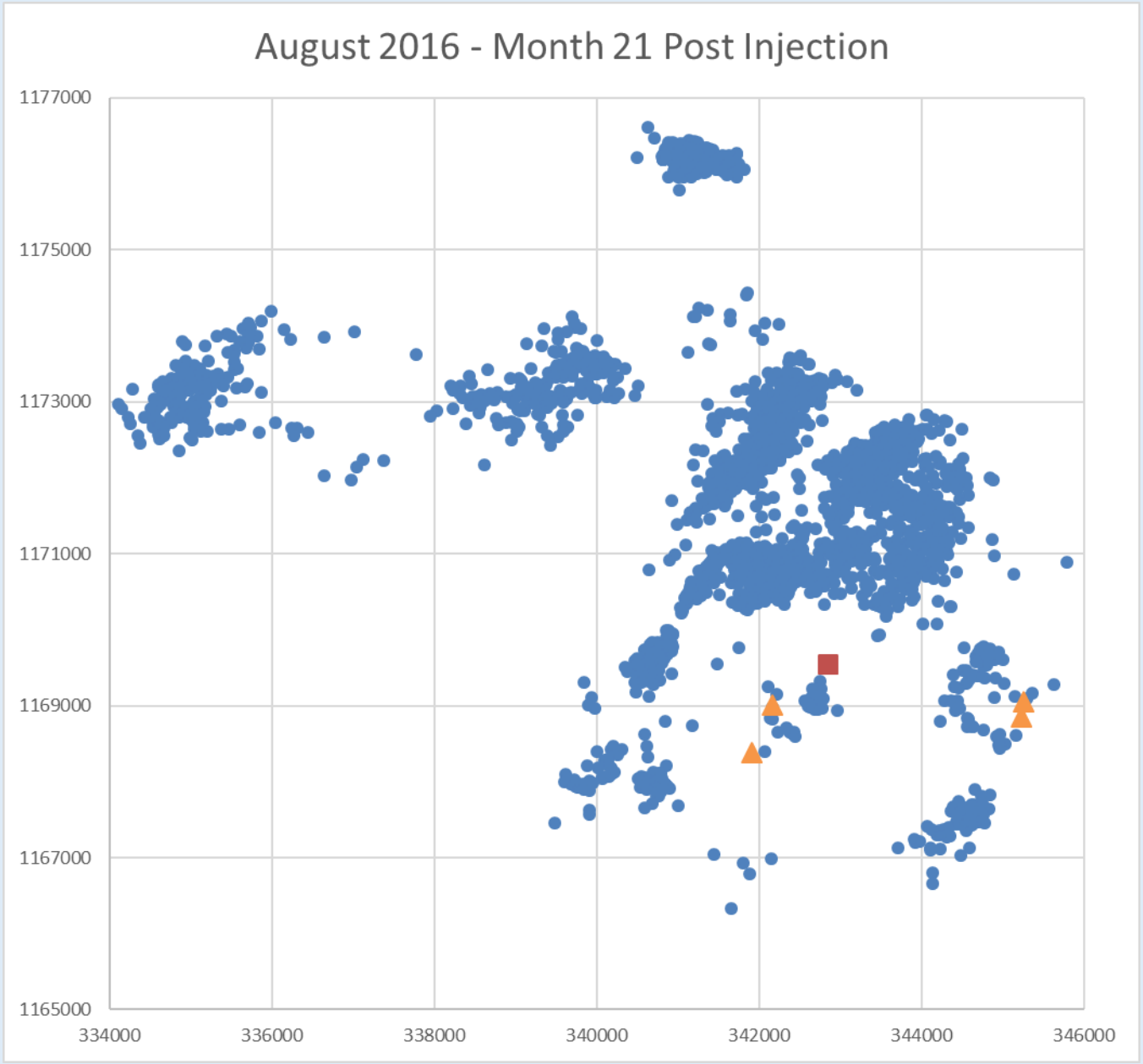
August 2016 - Month 21 Post Injection
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1167000
1165000
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336000
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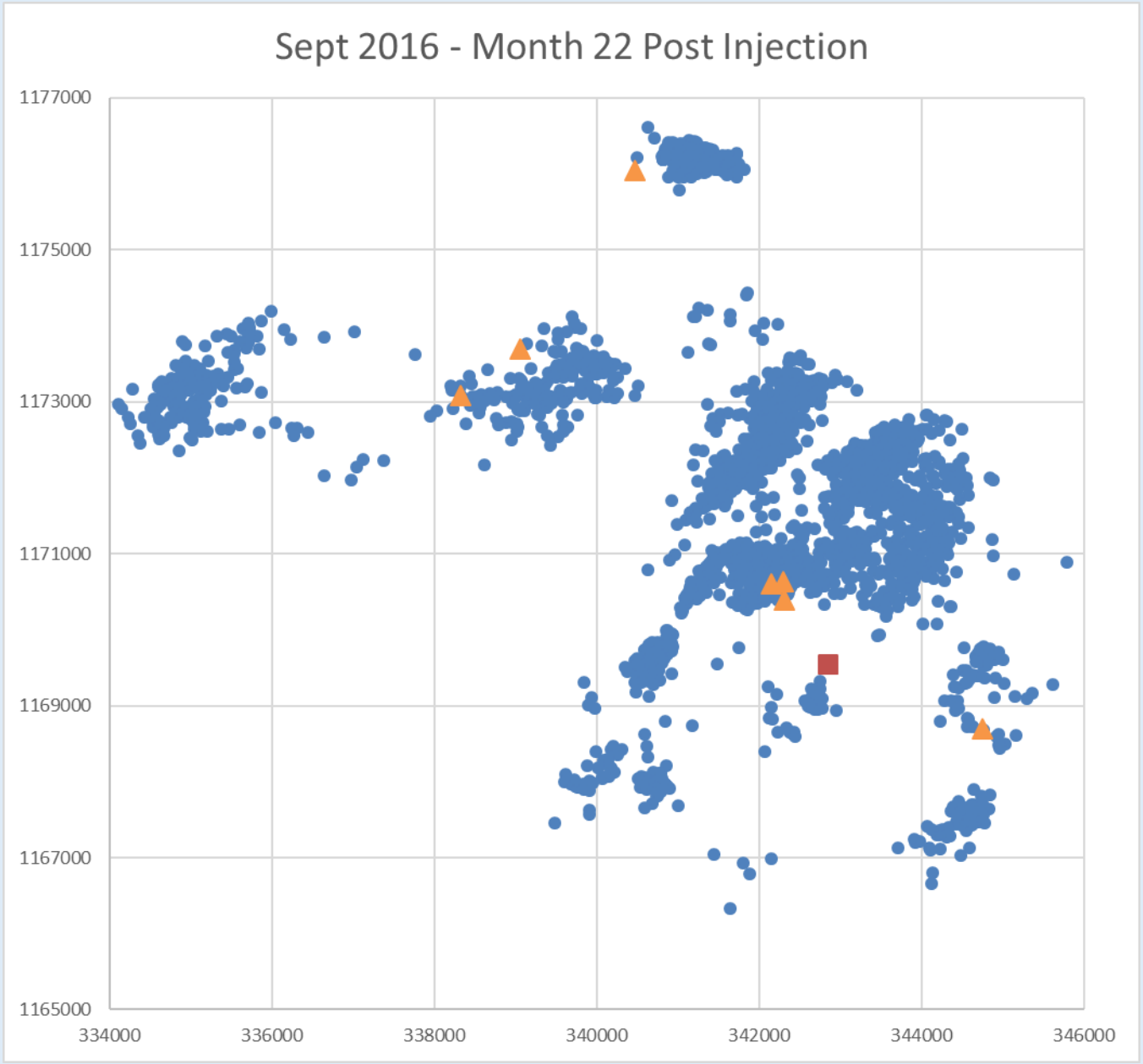
Sept 2016 - Month 22 Post Injection
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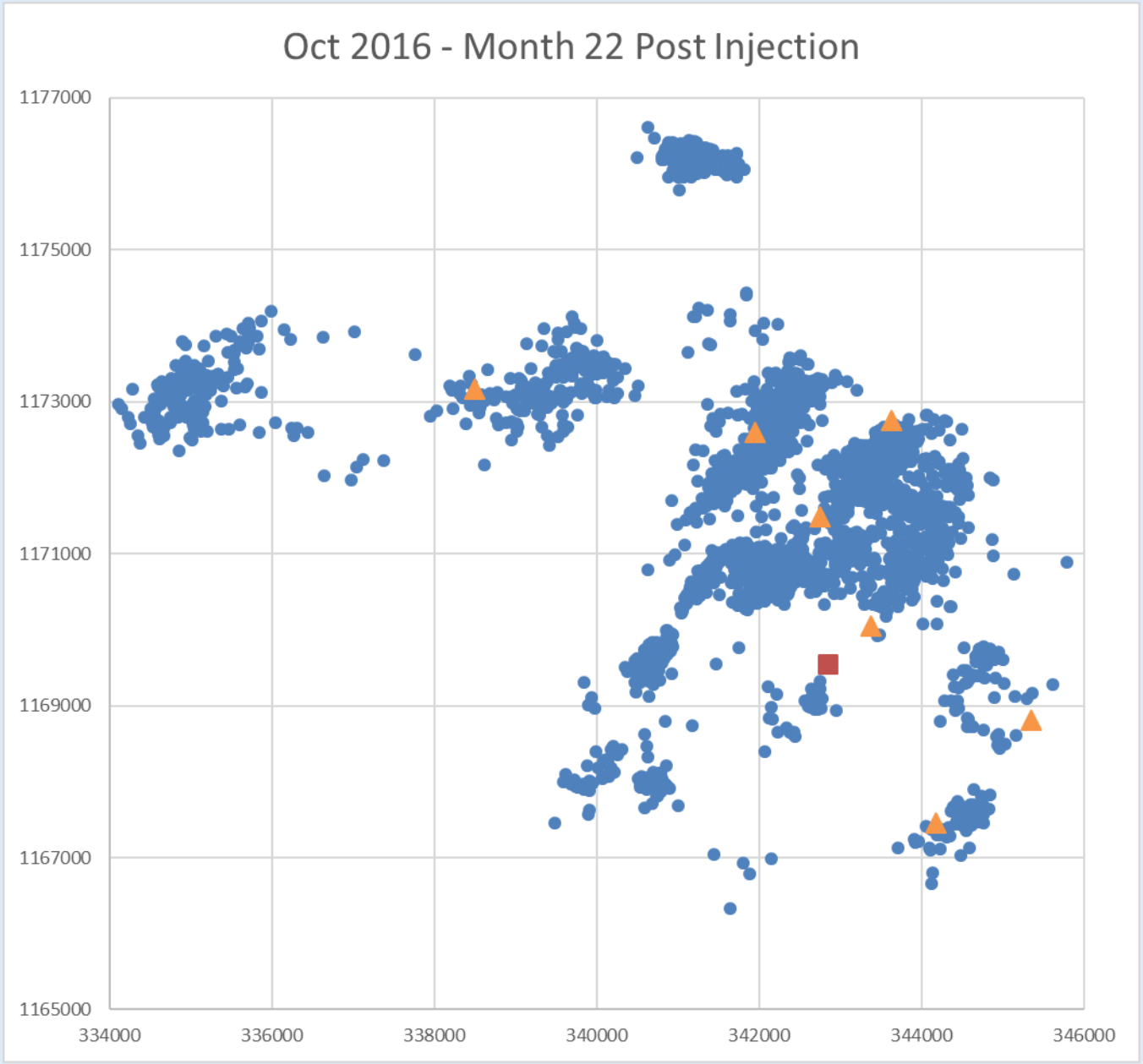
Oct 2016 - Month 22 Post Injection
1177000
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1171000
1169000
1167000
1165000
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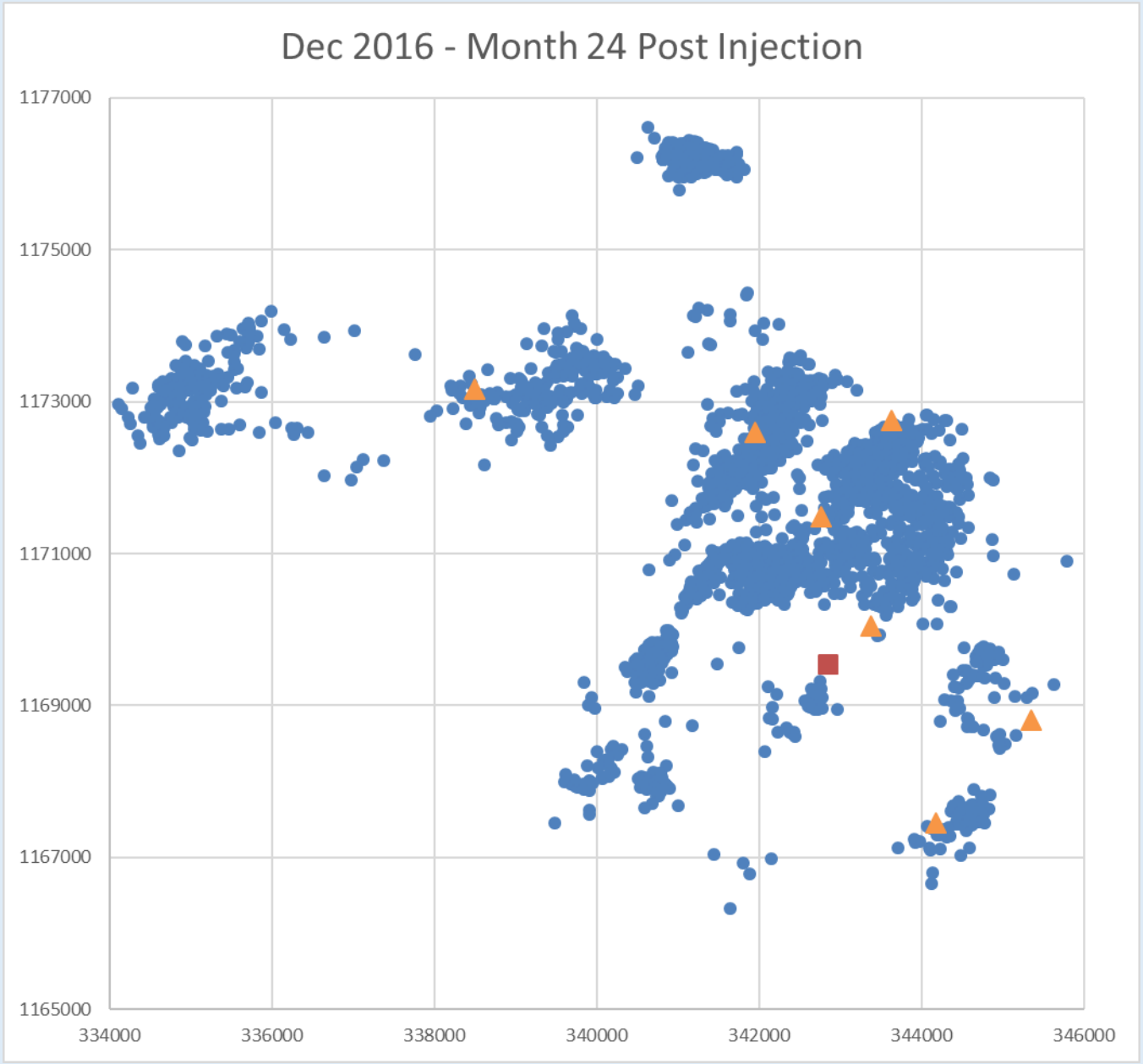
340000
342000
344000
346000

None In Nov 2016


Dec 2016 - Month 24 Post Injection
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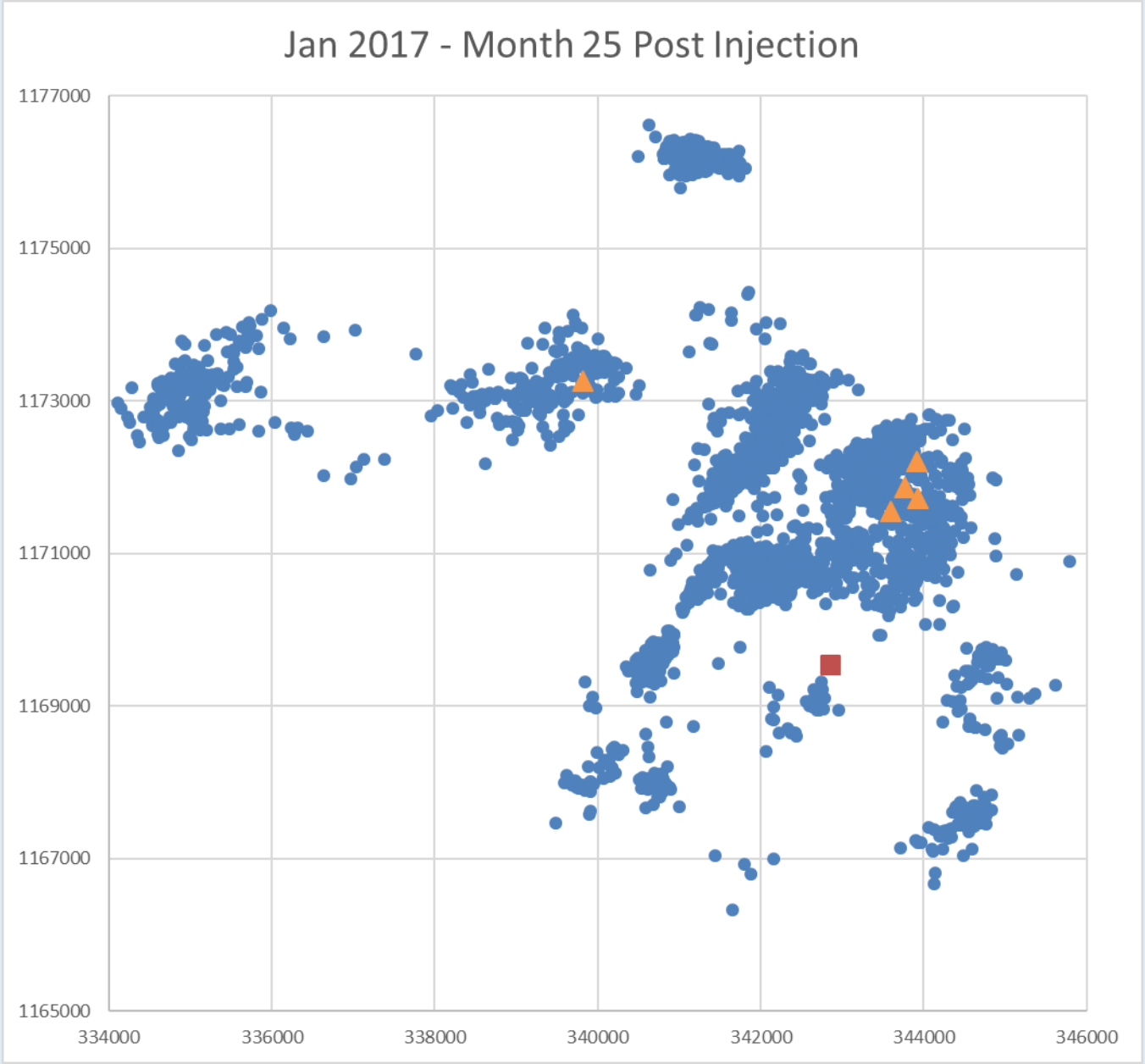
Jan 2017 - Month 25 Post Injection
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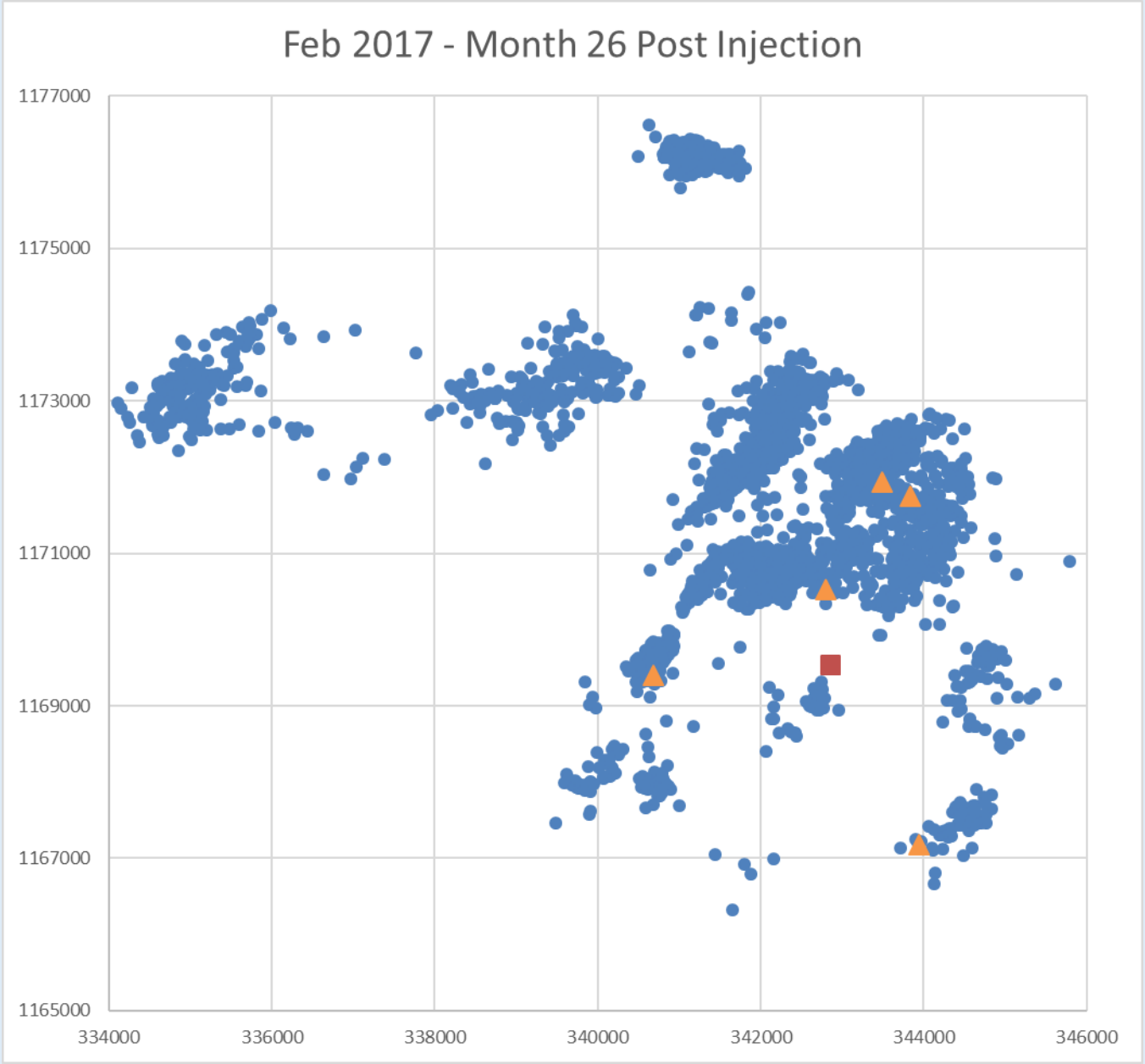
1173000
1171000
1169000
1167000
1165000
334000
336000
338000
340000
342000
344000
346000


Feb 2017 - Month 26 Post Injection
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1171000
1169000
1167000
1165000
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336000
338000
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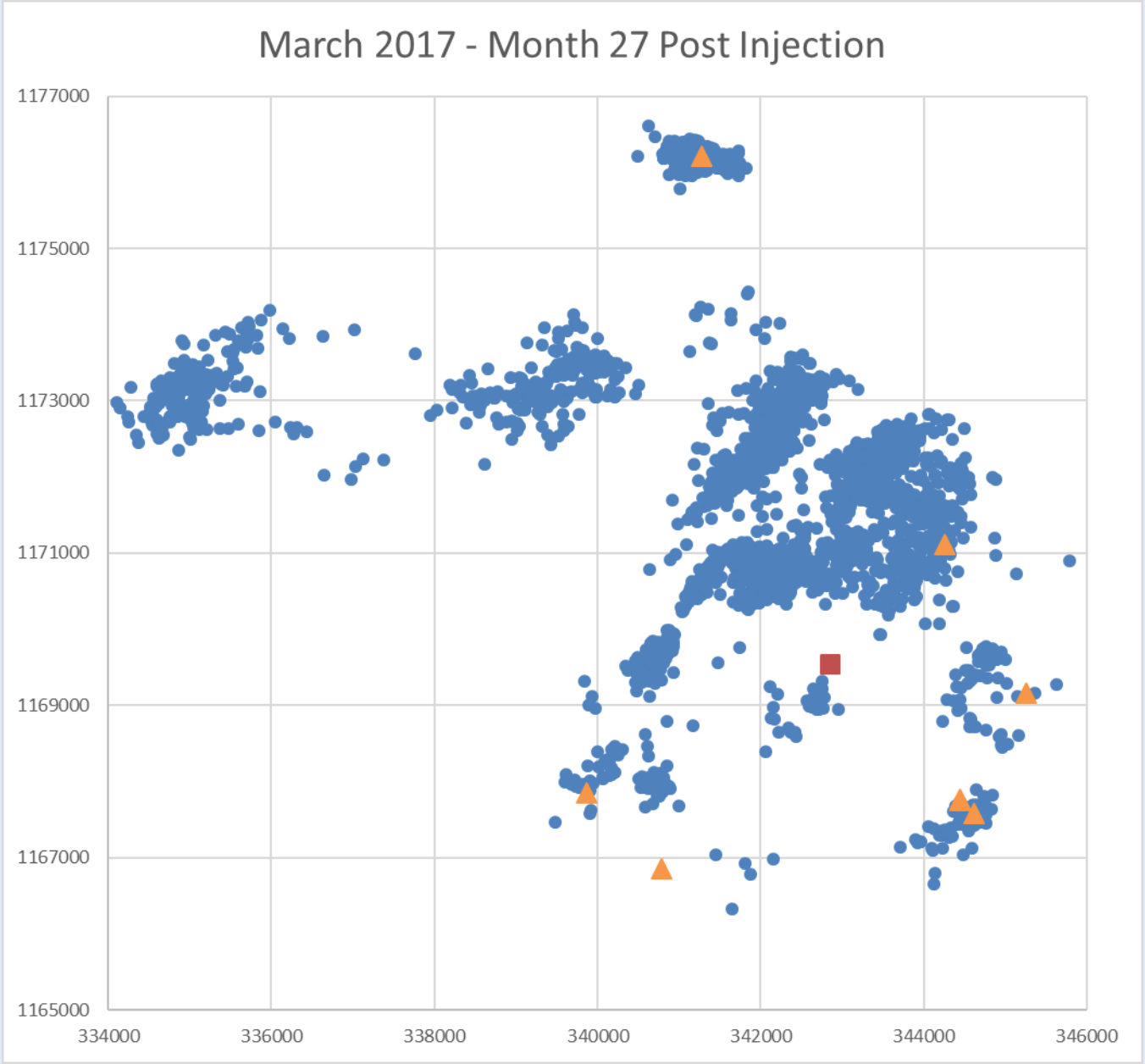
342000
344000
346000


March 2017 - Month 27 Post Injection
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1171000
1169000
1167000
1165000
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336000
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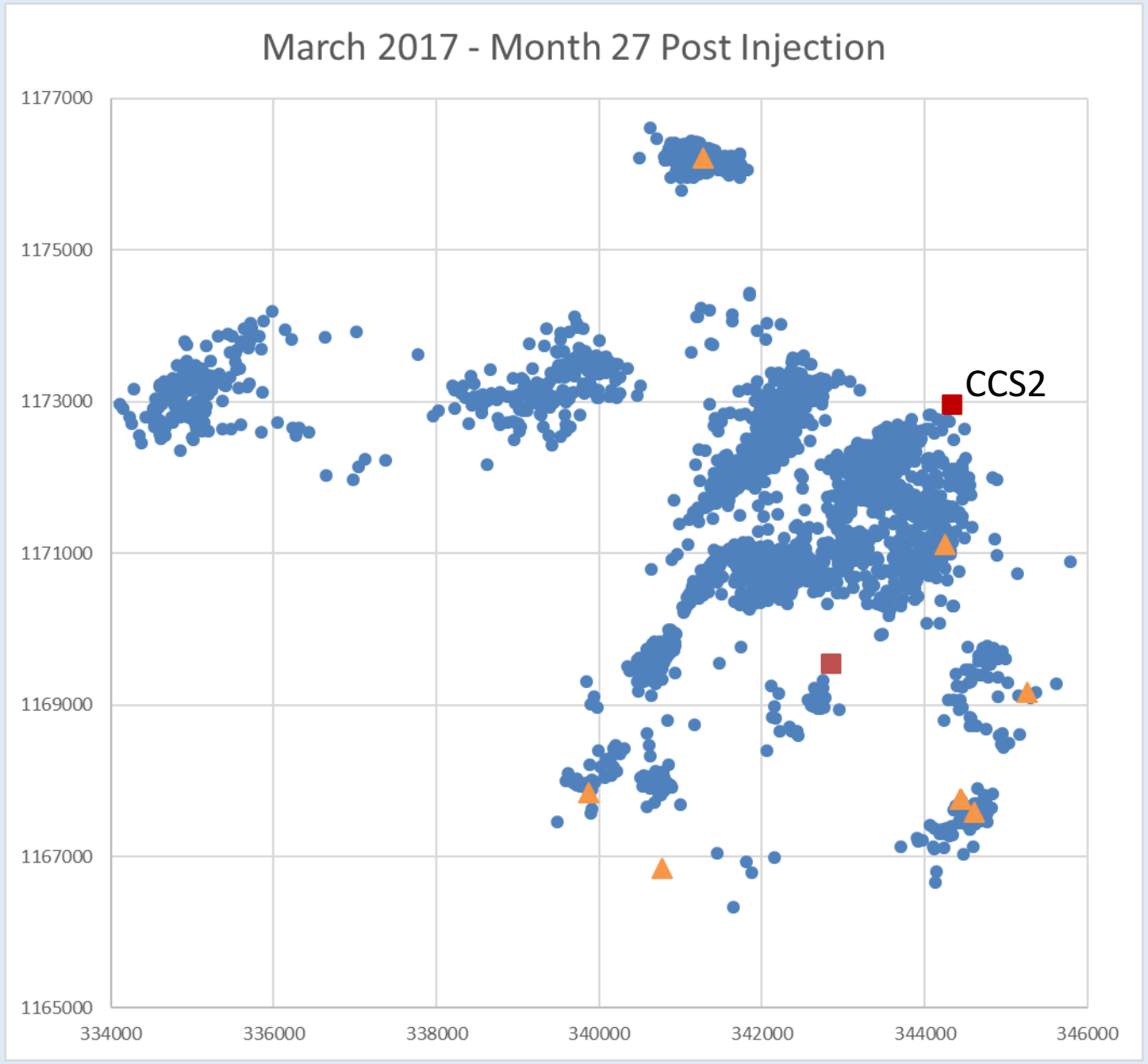
342000
344000
346000

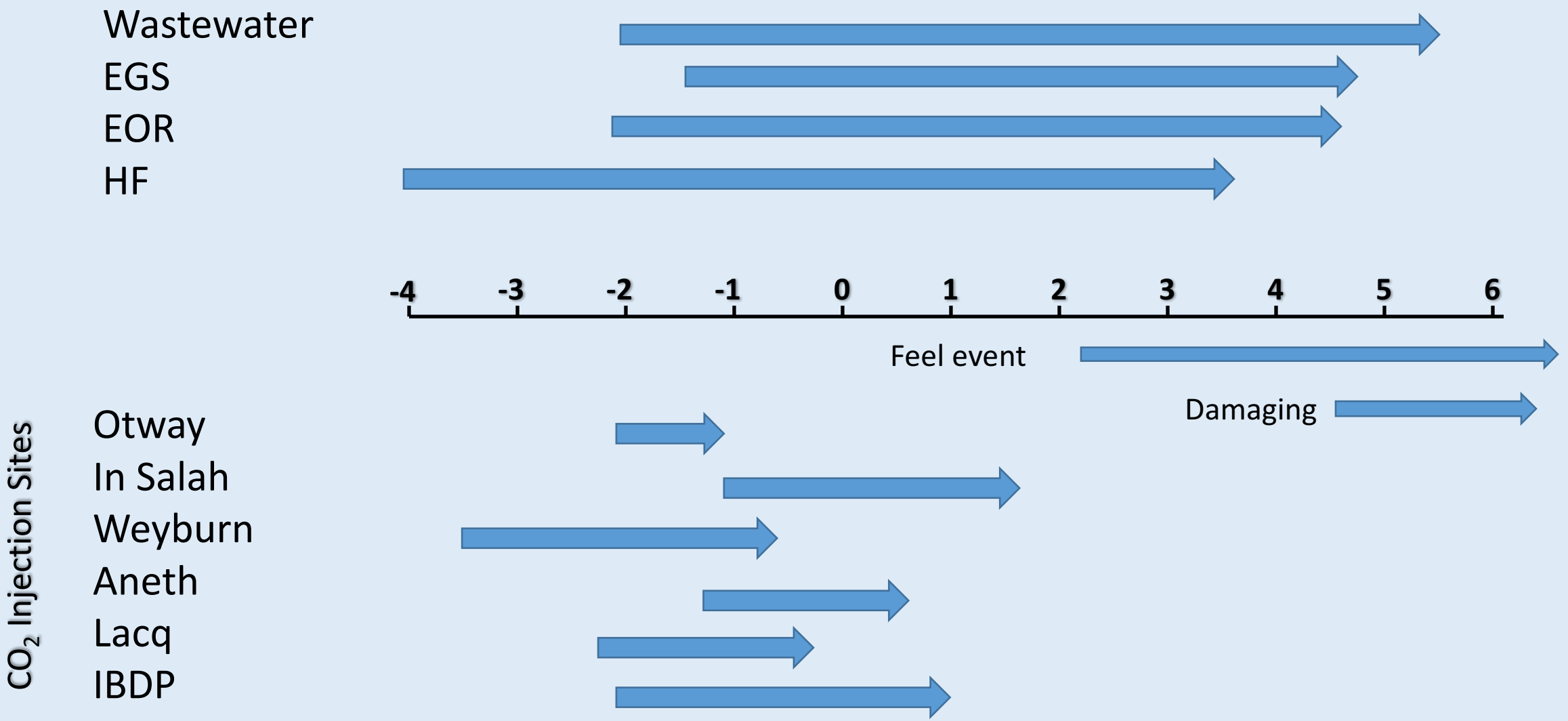

March 2017 - Month 27 Post Injection
1177000
1175000
1173000
1171000
1169000
1167000
1165000
334000
336000
338000
340000
342000
344000
346000
CCS2

How does IBDP microseismicity compare to other sites?

There is limited published data from other CO_2 injection sites!

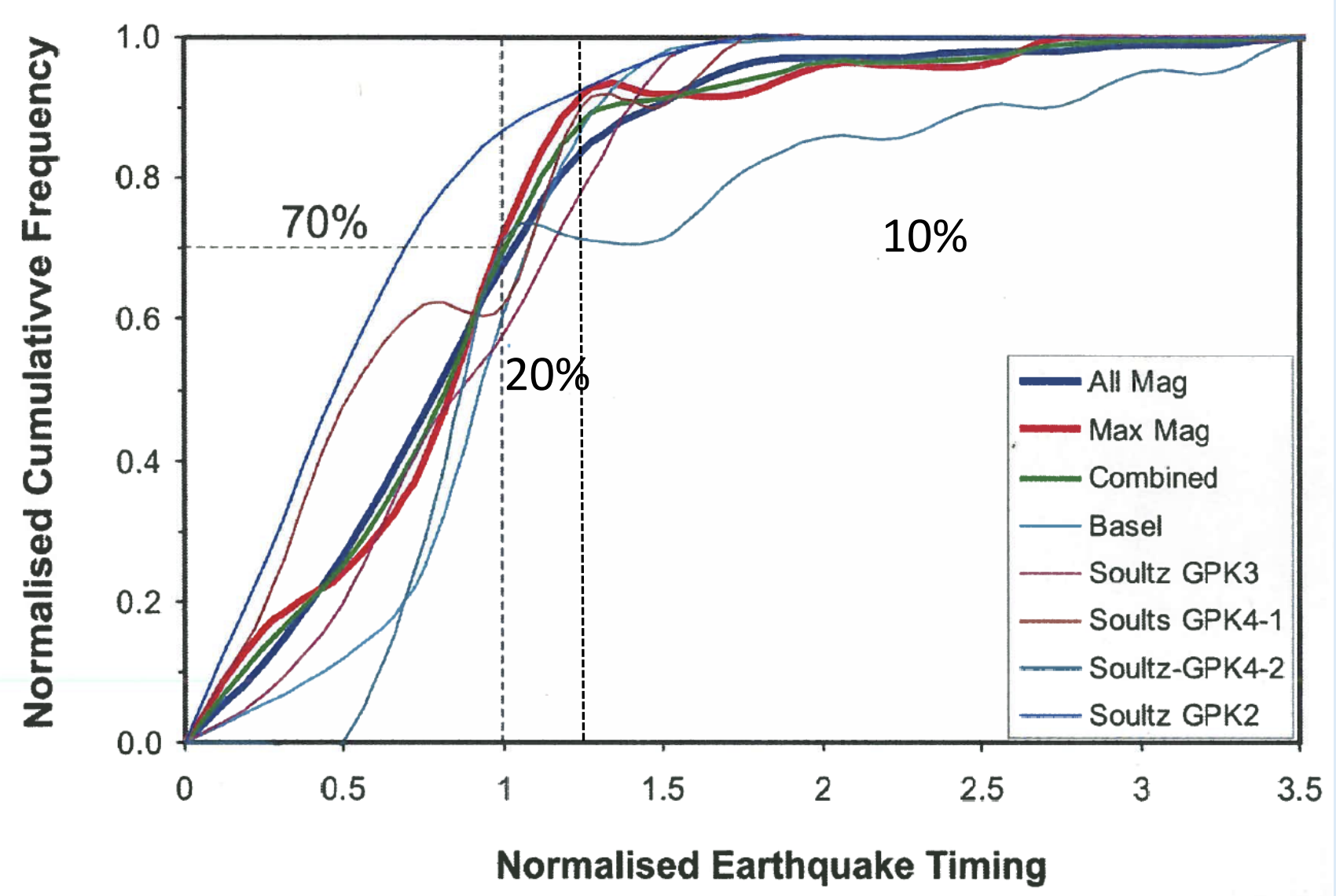
Compare to Wastewater Disposal, Enhanced Geothermal Systems (EGS), Enhanced Oil Recovery (EOR) data.

Magnitudes of Seismic Event per Injection

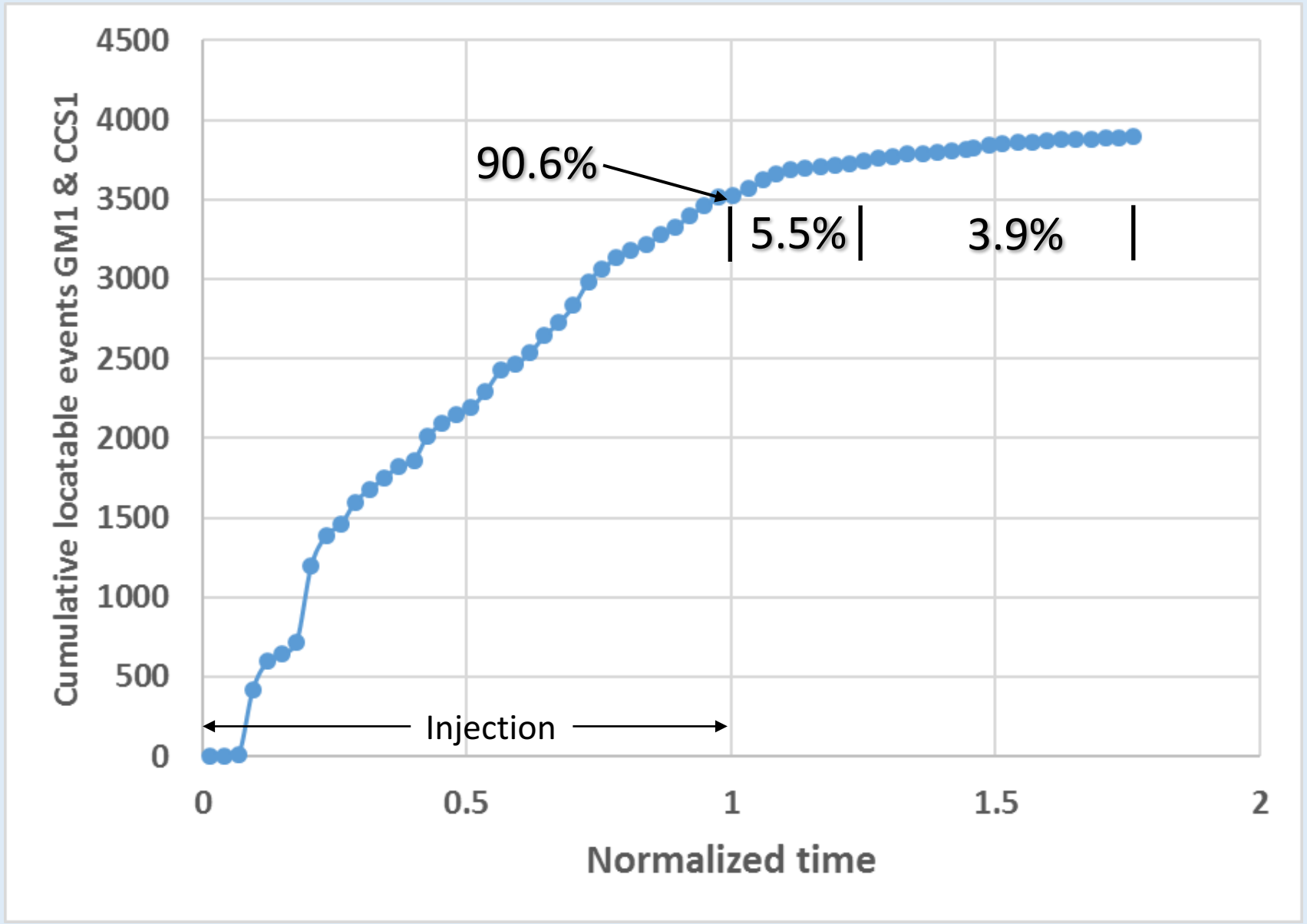


Bauer 2016, IEAGHG 2013, Verdon 2016, White 2016

Wastewater Disposal and Enhanced Geothermal Systems Seismicity



Using 2 IBDP vertical arrays



b-value is a slope of Gutenberg-Richter relationship of magnitude of events vs frequency of the those events

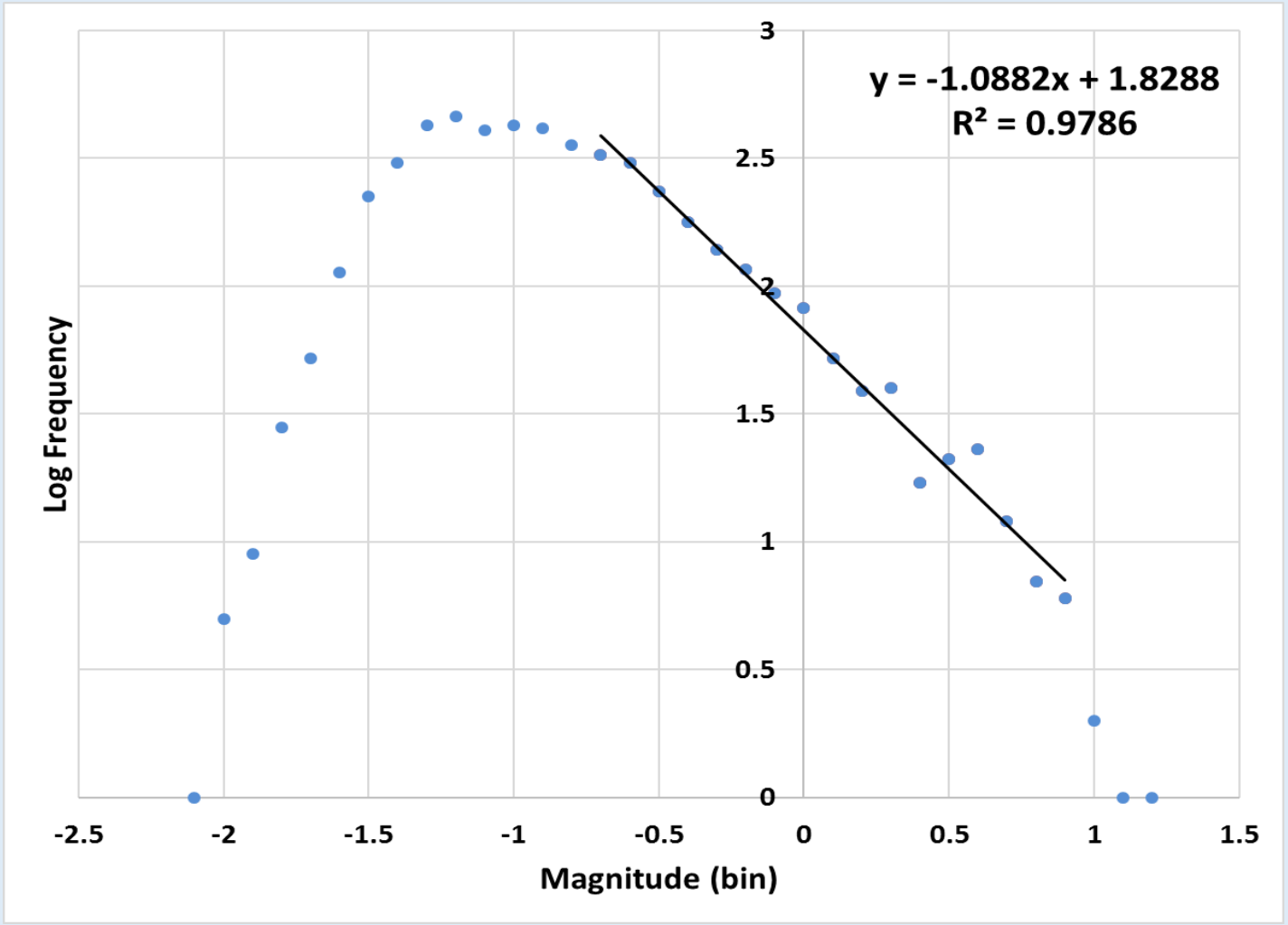
b-value of about 1 indicates a movement on a pre-existing fault/fracture

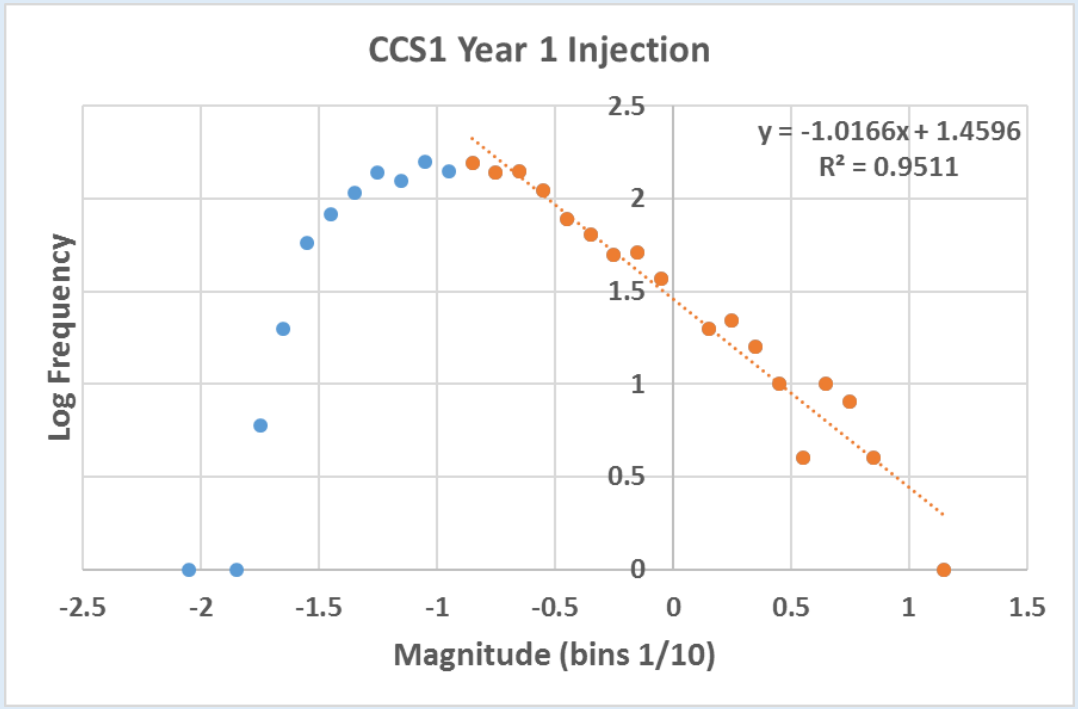
Much higher b-values (2 to 2.5 for HF) indicate fracturing of intact rock

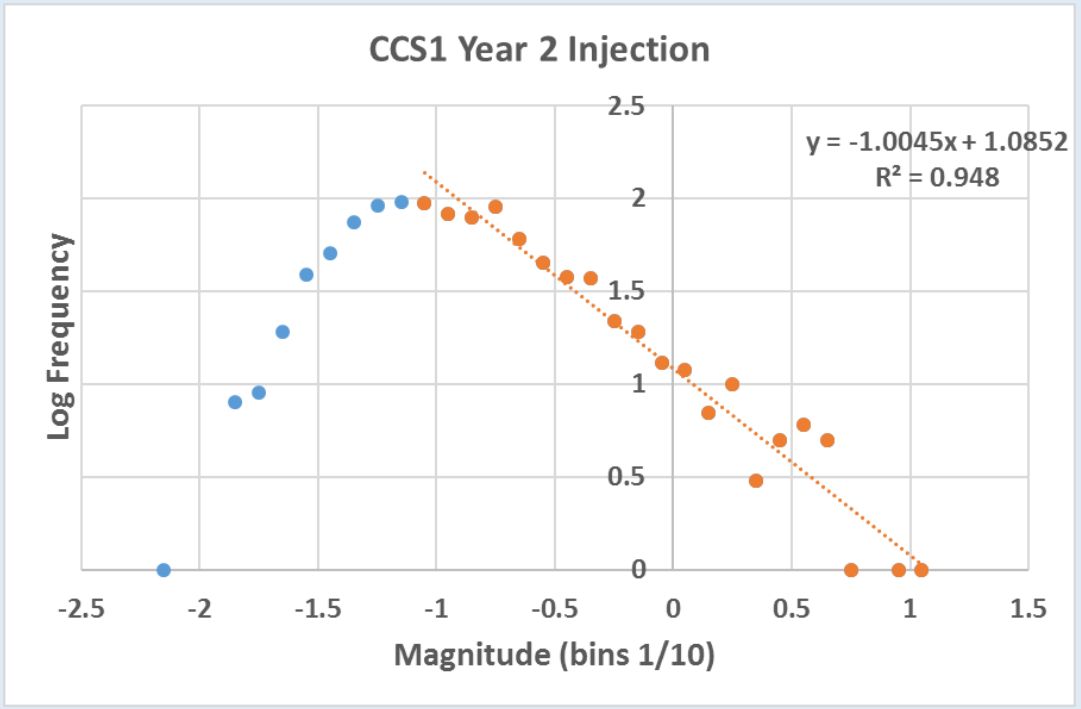
For EGS Bachmann (2010) shows a decrease in b-value following injection – decrease means a proportionally larger magnitude earthquakes compared to the smaller events. Leading to increase probability of large events during shut in.

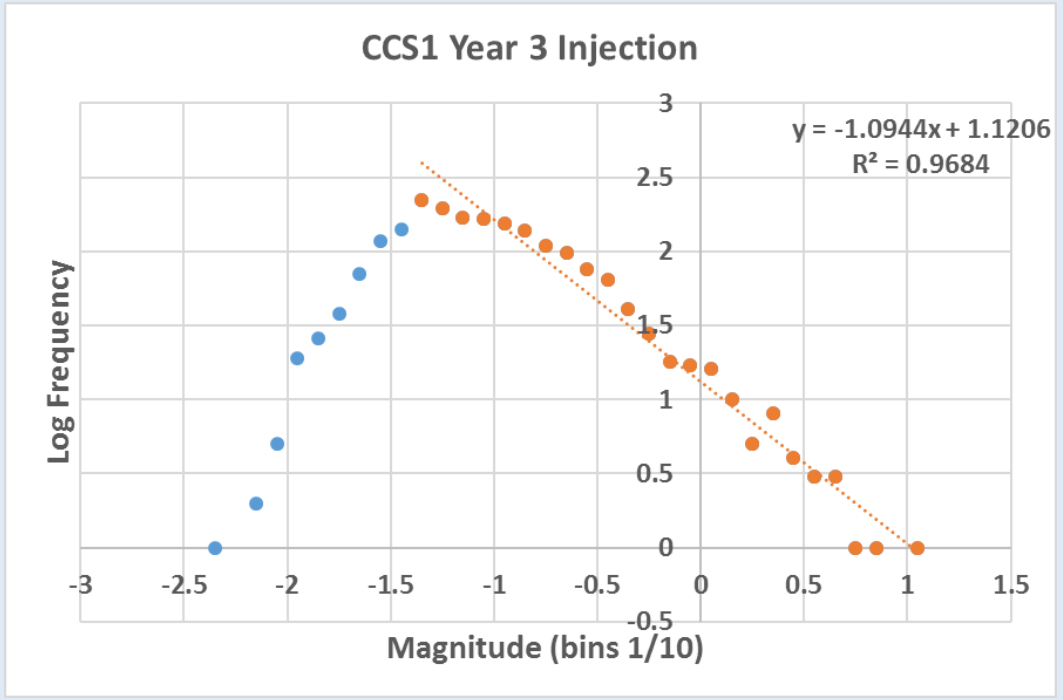
b-values are about the same for IBDP during injection and post-injection.

During Injection with 3 vertical arrays



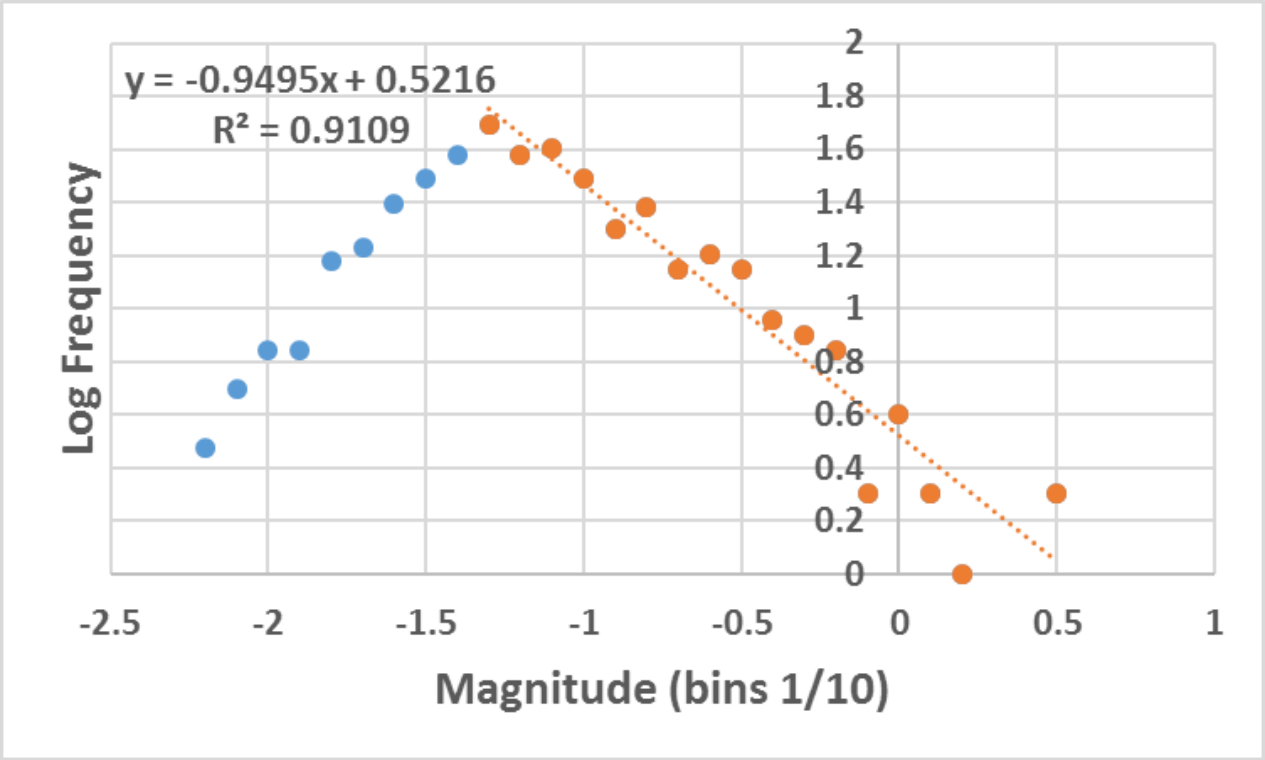

CCS1 Year 1 Injection
y = -1.0166x + 1.4596
R² = 0.9511
Log Frequency
Magnitude (bins 1/10)
2.5
2
1.5
1
0.5
0
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5


CCS1 Year 2 Injection
y = -1.0045x + 1.0852
R² = 0.948
Log Frequency
Magnitude (bins 1/10)
2.5
2
1.5
1
0.5
0
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5

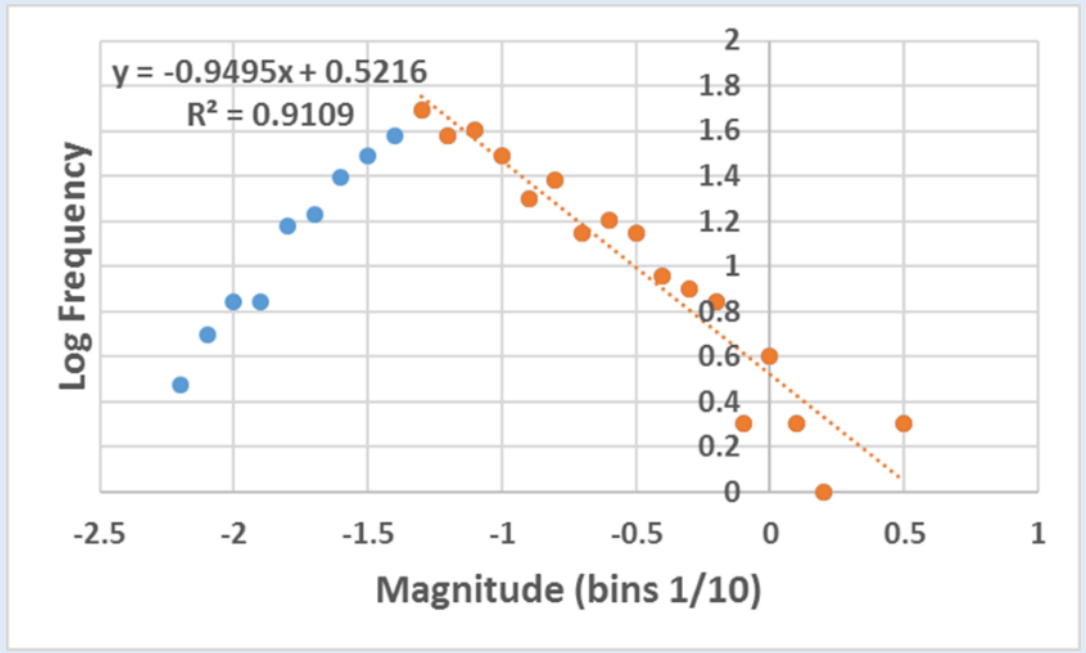

CCS1 Year 3 Injection
y = -1.0944x + 1.1206
R² = 0.9684
Log Frequency
Magnitude (bins 1/10)
3
2.5
2
1.5
1
0.5
0
-0.5
-3
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5

CCS1 Post-Injection 28 Months

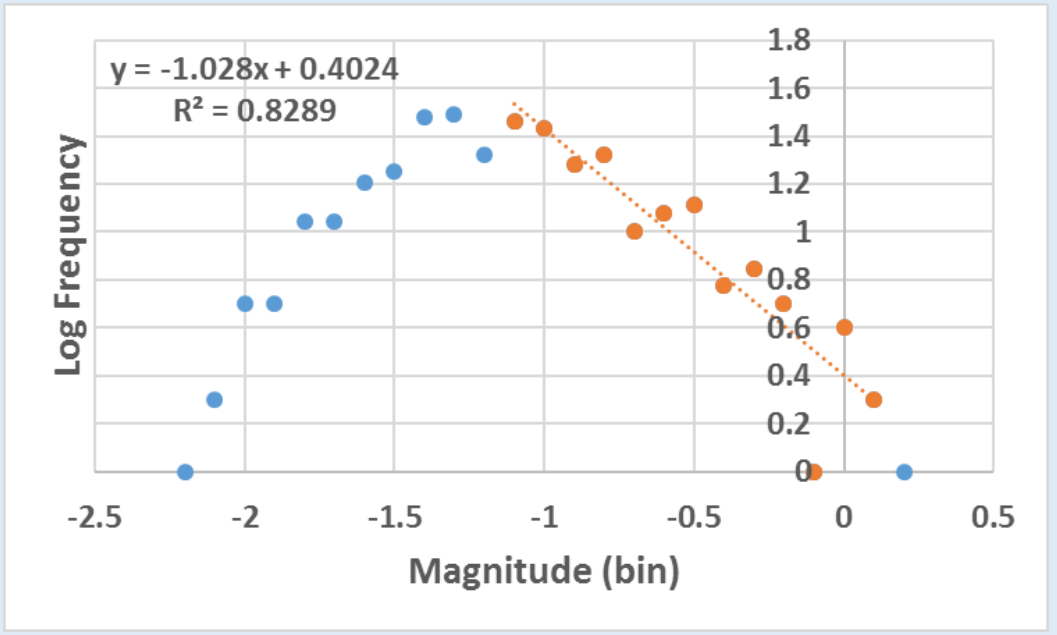
from shut in to CCS2 start



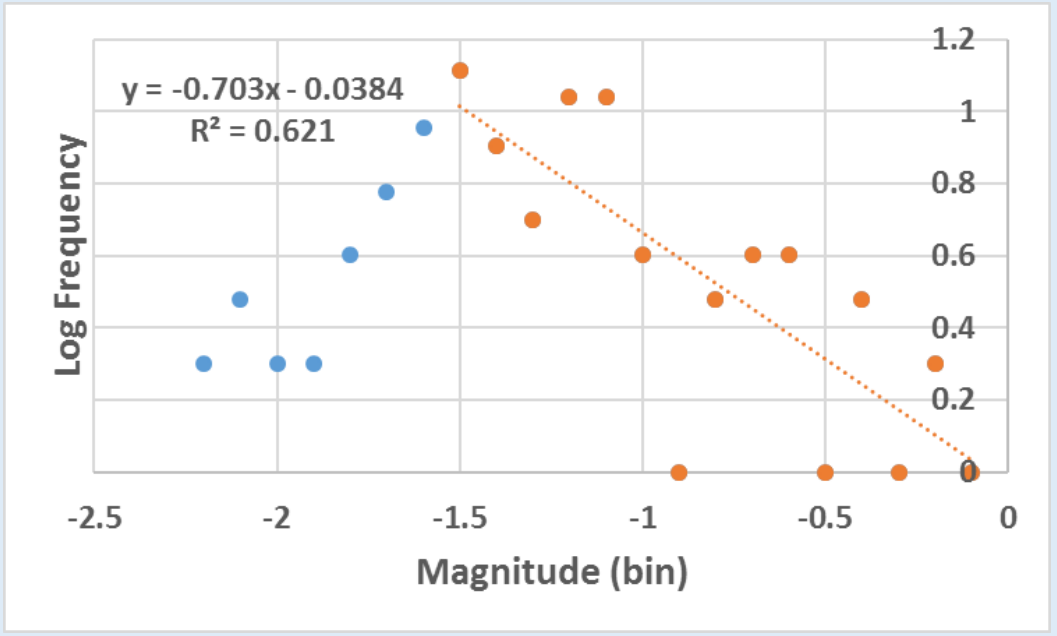
Post-Injection 28 Months

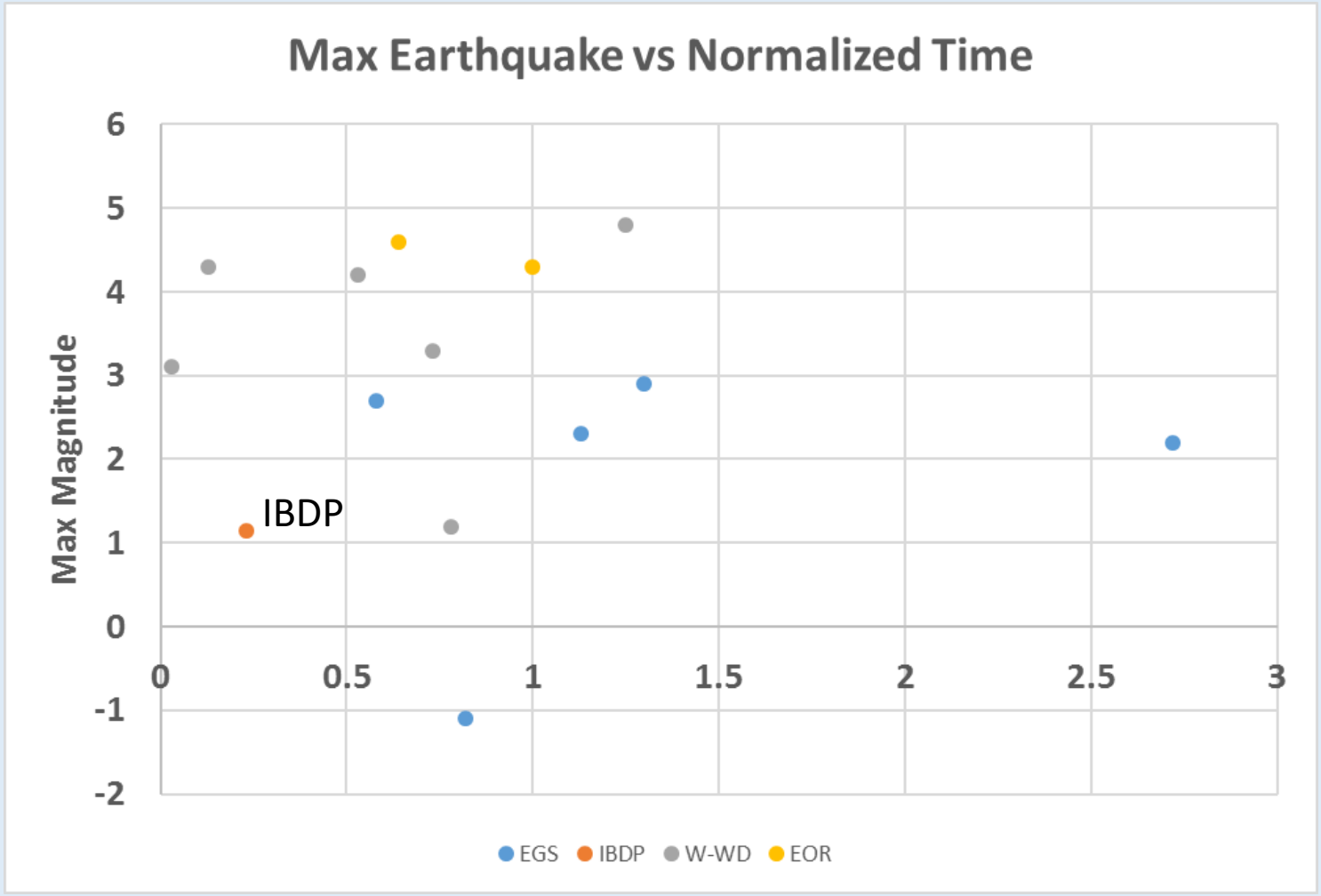


First 14 Months

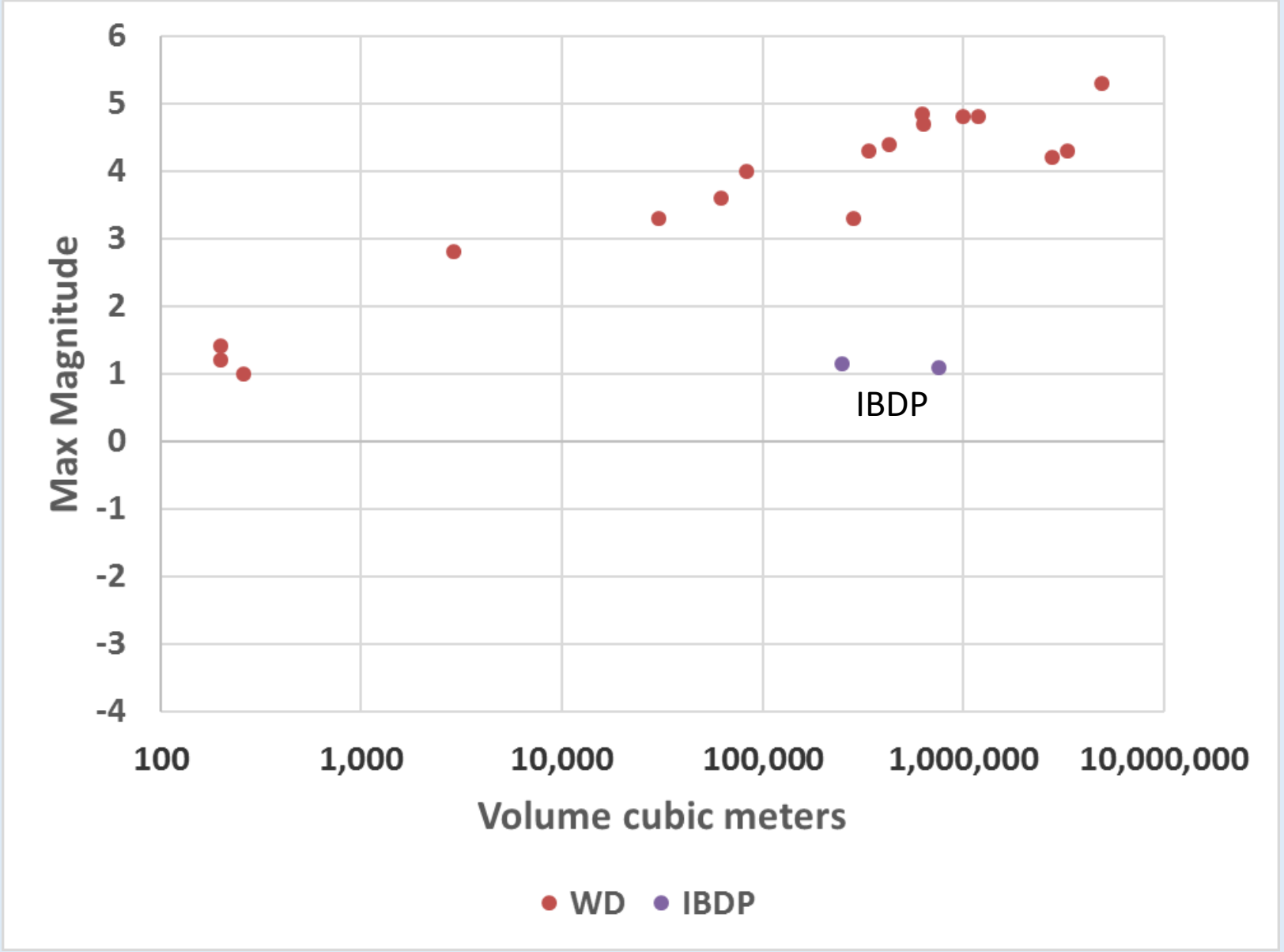


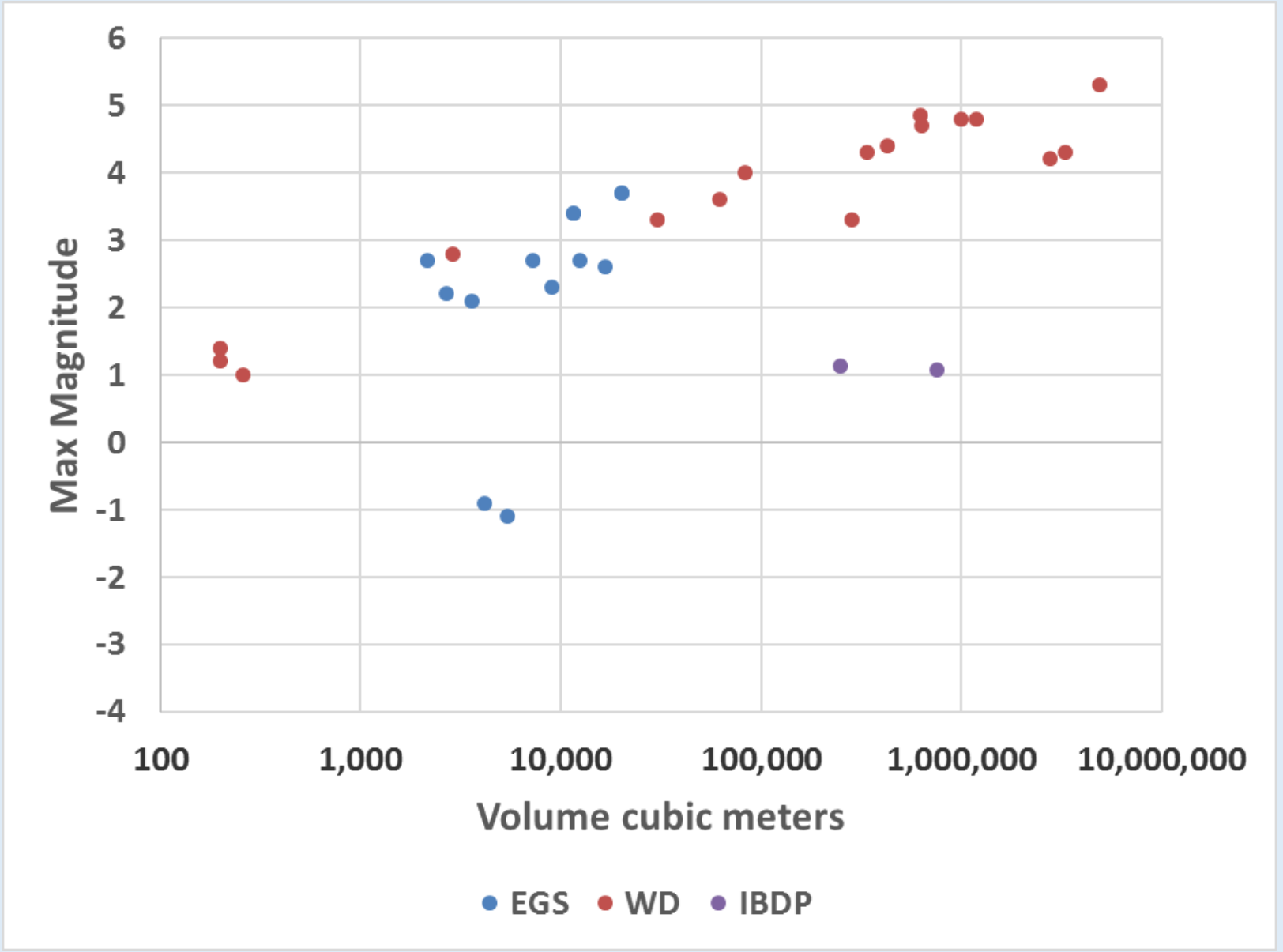
Second 14 Months



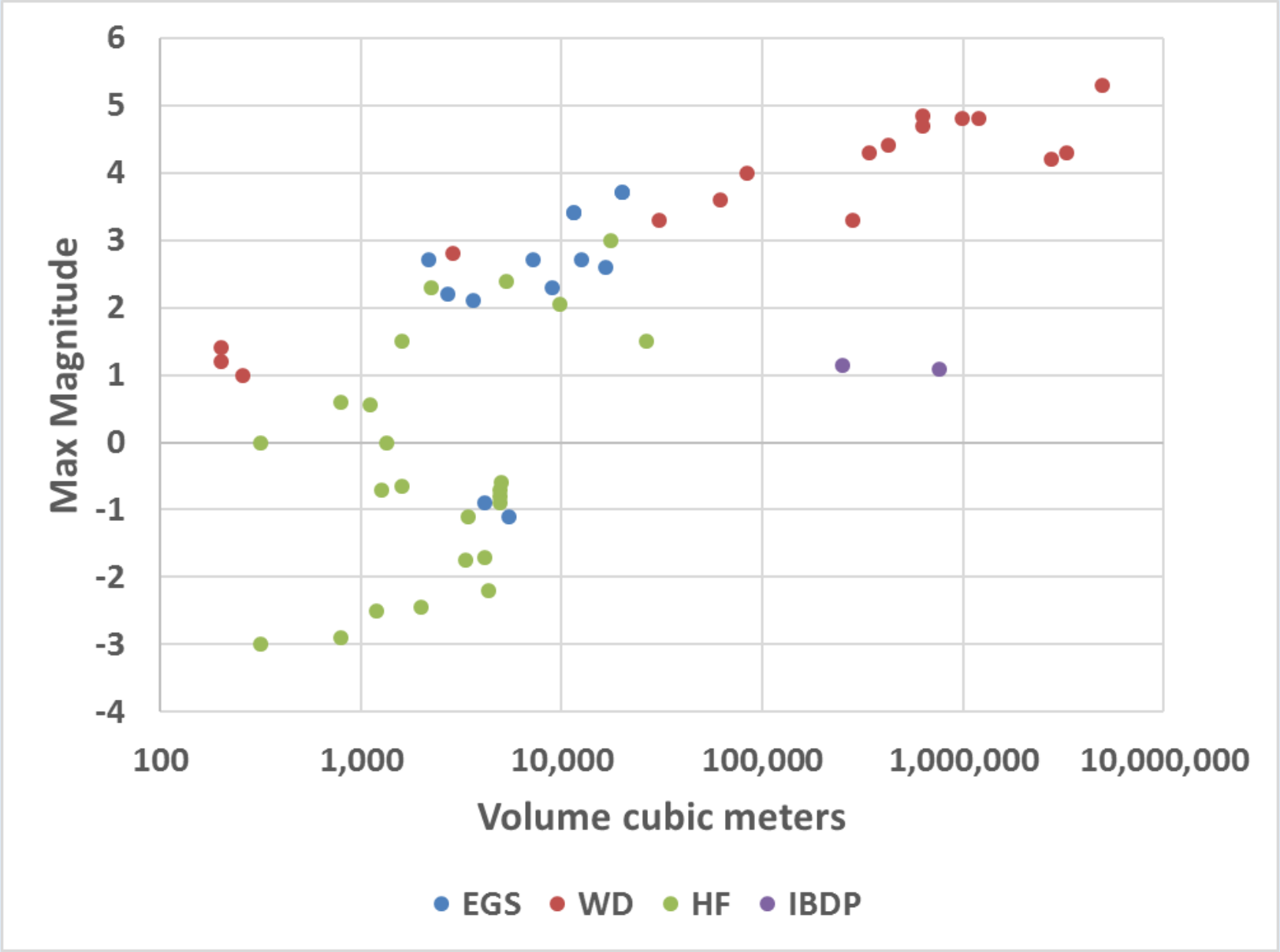

Max Earthquake vs Normalized Time
Max Magnitude
6
5
4
3
2
1
0
-1
-2
0
0.5
1
1.5
2
2.5
3
IBDP
EGS
IBDP
W-WD
EOR

Max Magnitude vs Injection Volume

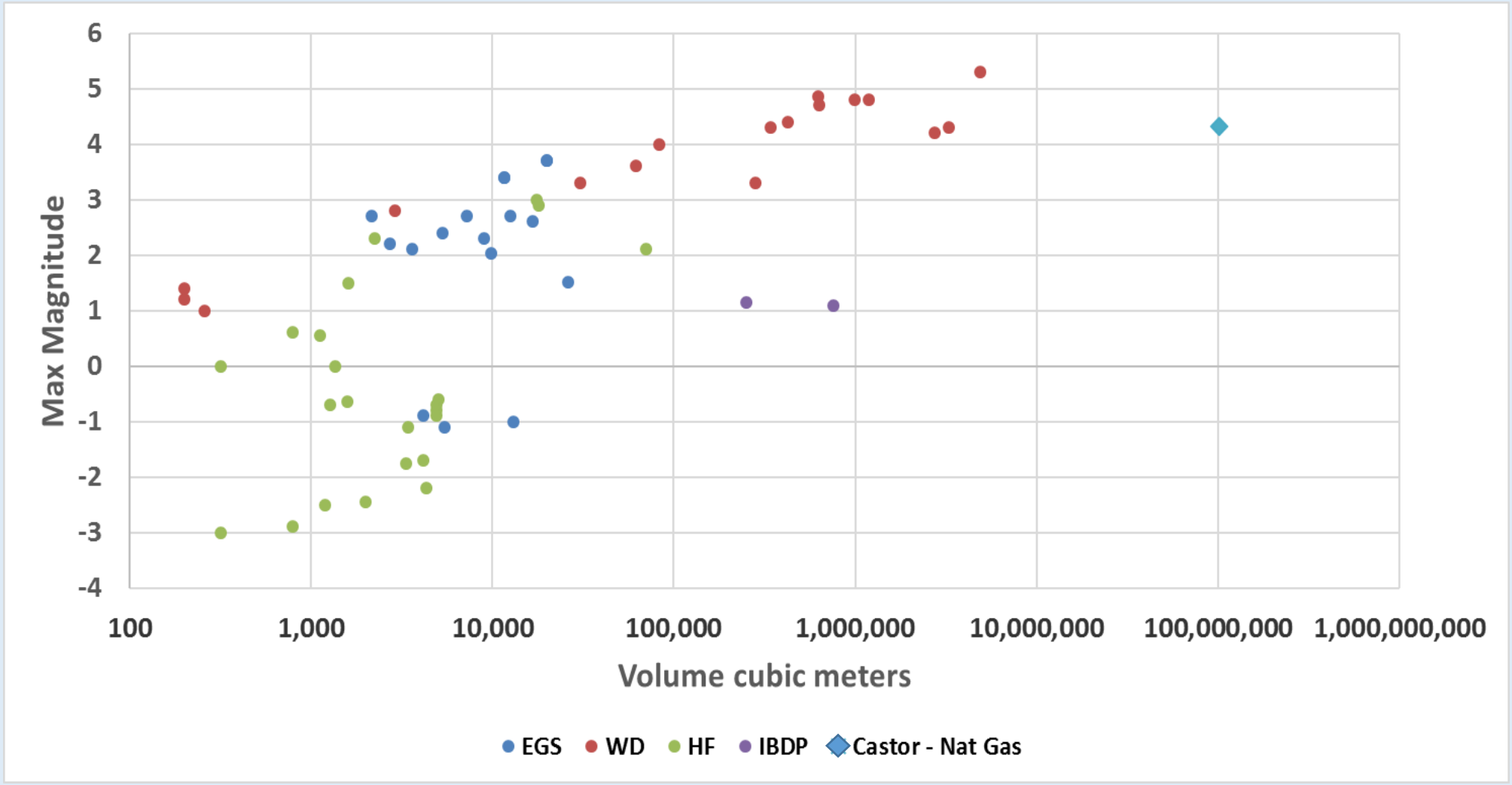




Cladouhos 2013, IEAGHG 2013



Warpinski 2012 (hydraulic fracturing)


Max Magnitude
6
5
4
3
2
1
0
-1
-2
-3
-4
100
1,000
10,000
100,000
1,000,000
10,000,000
100,000,000
1,000,000,000
Volume cubic meters
EGS
WD
HF
IBDP
Castor - Nat Gas

Microseismic Activity: Overview

- Stratified pressures and Max. Δ P of 5.2% increase for one “zone”
- Max CCS1 DHP at 73% of fracture pressures
- Low permeability thin mudstone layers 300 ft above injection, restrict pressure increases upward, restricting microseismic development to 1,100 feet below Eau Claire caprock
- Form distinct clusters along undetected pre-existing faults/fractures
- Distributed between Lower Mt. Simon and Argenta Sandstones, and ~ 50% in Precambrian basement
- Injection magnitudes range from -2.32 to 1.14 & 95% are 0 and less
- Post-injection range from -2.23 to 0.91 & 98.1% are 0 and less
- b values of about 1 during and after injection indicate reactivation of pre-existing features
- Overall project average of microseismic events during injection using same seismic arrays was 3.2 per day

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