The 2011 Hawthorne, Nevada, Earthquake Sequence - Shallow Normal Faulting

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Abstract:

An energetic sequence of shallow earthquakes that began in early March 2011 in western Nevada, near the community of Hawthorne, has slowly decreased in intensity through mid- to late-2011. To date about 1500 reviewed locations have been compiled, we have computed moment tensors for the larger earthquakes and have developed a set of high-precision locations for all reviewed events. The sequence to date has included over 50 ML 3 and larger events with the largest at Mw 4.6. Three 6-channel portable stations configured with broadband sensors and accelerometers were installed by April 20 (on loan from USGS). Data from the portable instruments is telemetered through NSL's microwave backbone to Reno where it is integrated with regional network data for real-time notifications, ShakeMaps, and routine event analysis. The data has been provided in real-time to NEIC, CISN and the IRIS DMC.

The sequence is a remote area about 15-20 km southwest of Hawthorne in the footwall block of the Wassuk Range block. An initial concern was that the sequence might be due to volcanic processes considering to the proximity of late Quaternary volcanic centers; there have been no volcanic signatures observed in near source seismograms. An additional concern, as the sequence has proceeded, was a clear progression northeastward toward the Wassuk Range front fault. The east dipping range bounding fault is capable of M 7+ events, and poses a significant hazard to the community of Hawthorne and local military facilities. The Hawthorne Army Depot is an ordinance storage facility and the nation's storage site for surplus mercury.

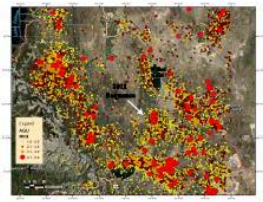
The sequence is within what has been termed the 'Mina Deflection' of the Central Walker Lane Belt. Faulting along the Whiskey Flat section of the Wassuk front fault would be primarily down-to-the-east, with an E-W extension direction; moment tensors for the 2011 earthquake show a range of extension directions from E-W to NW-SE, suggesting a possible dextral component to the Wassuk Range front fault at this latitude.

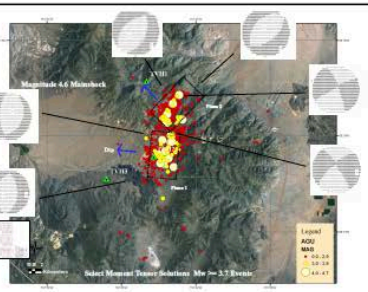
At least two faults are imaged within the sequence; these structures are at shallow depth (3-6 km), strike NNE and NE, and dip ~NW. Prior to temporary station installation event depths were poorly constrained, with the nearest network station 25 km from the source area. Early sequence moment tensor solutions showed shallow depths (2-4 km); locations using the near source stations confirm the shallow depths in the Hawthorne sequence.

Along with the 2011 Hawthorne activity, very shallow depths in Nevada have been observed from near source stations in the 2008 west Reno earthquake sequence (primarily strike-slip faulting; main shock Mw 5.0) and the 1993 Rock Valley sequence in southern NNSS (strike-slip faulting; main shock Mw 4.0). These shallow sequences tend to include high rates of low magnitude earthquakes continuing over several months duration.

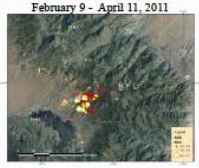
This work was supported by the USGS/ANSS Western Great Basin Network Operations Contract and the State of Nevada.

ANSS Catalog 1955-2011

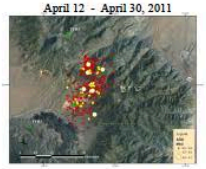




February 9 - April 11, 2011



April 12 - April 30, 2011

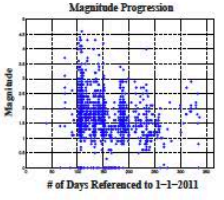


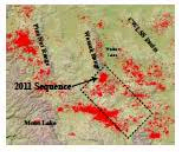
May 1 - November 30, 2011

27 Events >= Magnitude 3.5

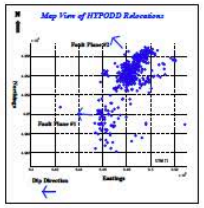
Mag	Yr	Mo	Dy	Hr	Mn
4.6	2011	04	17	00	45
4.3	2011	04	13	22	15
4.3	2011	05	12	16	39
4.2	2011	04	27	13	18
4.2	2011	04	27	13	18
4.2	2011	08	19	22	15
4.2	2011	04	17	01	45
4.2	2011	04	11	00	22
4.1	2011	04	17	00	55
4.1	2011	04	15	17	06
4.1	2011	04	15	22	15
4.0	2011	08	17	21	04
4.0	2011	05	09	09	46
4.0	2011	04	15	17	24
4.0	2011	04	11	00	21
3.9	2011	04	17	00	19
3.9	2011	04	27	13	23
3.8	2011	08	23	08	22
3.7	2011	08	28	09	49
3.7	2011	04	15	14	14
3.6	2011	04	27	13	20
3.6	2011	04	11	00	20
3.6	2011	04	10	22	06
3.5	2011	05	28	14	21
3.5	2011	05	19	19	18
3.5	2011	04	24	02	30
3.5	2011	04	17	00	57

Magnitude Progression



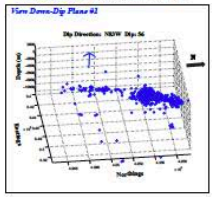


Map View of HYPODD Relocations

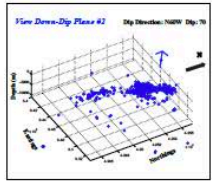


Perspective Views - Imaged Normal Fault Dips

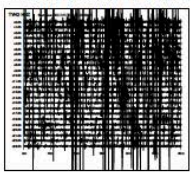
View Down-Dip Plane #1



View Down-Dip Plane #2

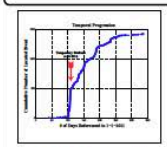


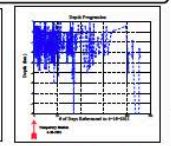
Example 24-Hour Plot - TVH2 - 5/13/2011 JDay 133



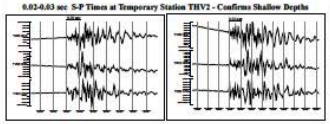
Conclusions:

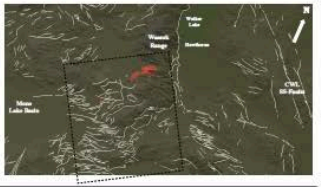
The 2011 Hawthorne, Nevada sequence occurred in the footwall of the west-tilted Wassuk Range normal fault block at the south end of the range. Northeast directed slip on normal faults in the 2011 sequence is interpreted to represent break up of the southern Wassuk Range block and a northwestward evolution of NE striking normal faulting within the Mina Deflection to the SE. The sequence evolved northeastward from a conspicuous ENE oriented zone of Quaternary volcanism, orientation of the Aurora Craters volcanic center also suggests NW directed extension. Fault Plane #1 may represent slip on a previously unrecognized basin bounding structure below the Quaternary volcanic flow. Fault Plane #2 is oriented more northeastward than fault Plane #2, and is directly within the higher elevation range block. A strike-slip fault appears to separate these two normal faulting structures. The Wassuk range front fault is capable of M 7+ earthquakes and has been a concern throughout the sequence. Most of sequence is associated with two shallow normal faults (Fault #1: Strike NNE Dip: 56-WNW – Fault #2: Strike NNE Dip: 70-NW). These structures are imaged with high precision locations and their orientations are consistent with variations in the strike of MT fault plane solutions. Three temporary telemetered seismographs, installed in mid-April, were necessary to constrain the shallow source depths and image the structures in detail within the sequence. Nearly all earthquakes in the sequence are shallower than 5 km; this is evidenced by the small S-P times at near source stations. M 3.5+ strike-slip events appear to represent shallow faulting along a NW striking feature that separates the two normal faults. Also, strike-slip events are observed in the NE part of the sequence.





0.02-0.03 sec S-P Times at Temporary Station THV2 - Confirms Shallow Depths





HYPODD Relocations:

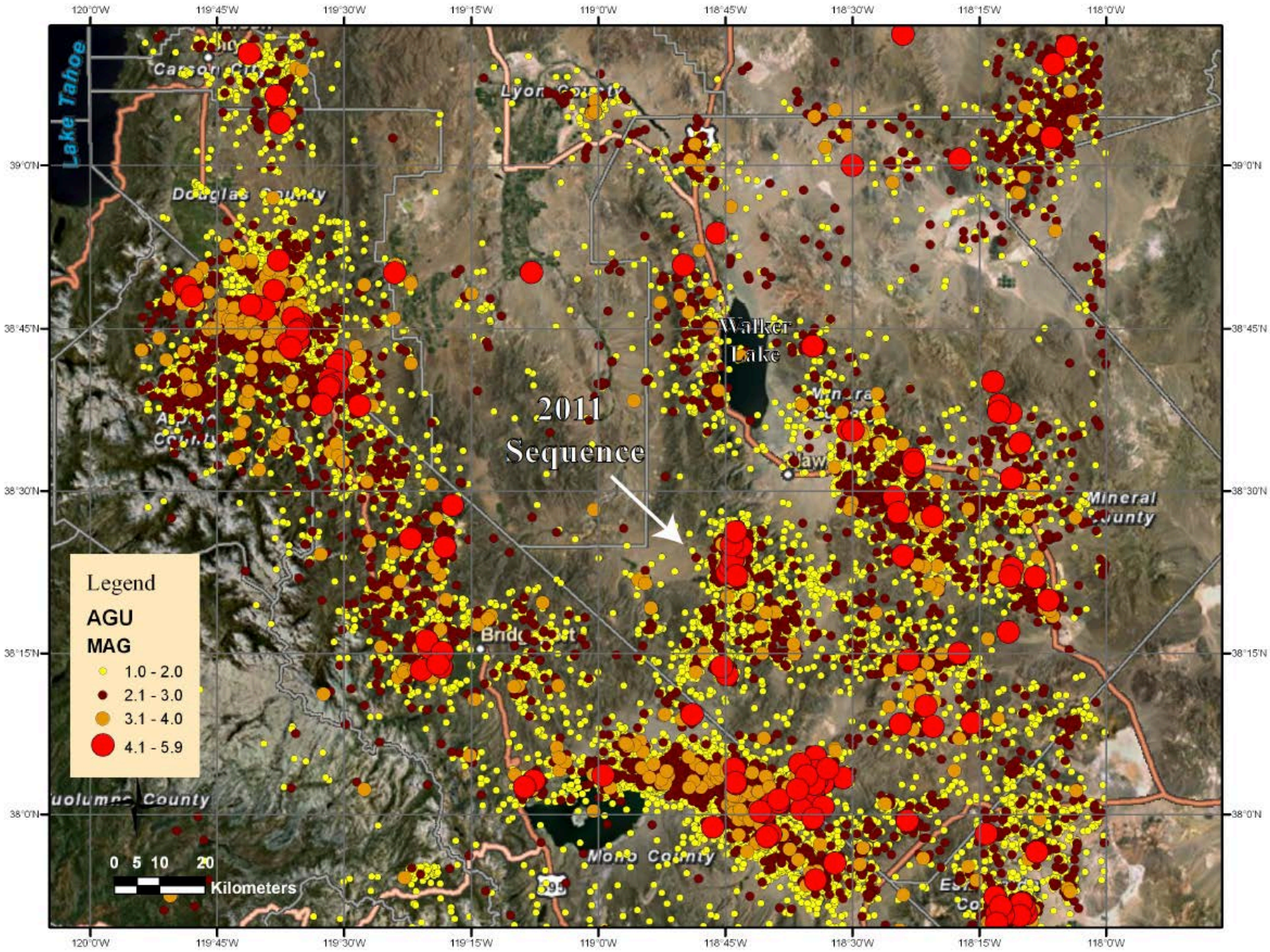
For imaging structures within the Hawthorne sequence, only the period after the temporary installation is applied. Phase and waveform cross-correlations were used in HYPODD. Reasonable modifications to the velocity model did not significantly changes source depths (S-P times confirm shallow sources). An application was developed to quickly receive and reformat phase data in Antelope for HYPODD input to monitor the progress of the sequence regularly. Two issues were of concern: 1) the close proximity to a conspicuous Quaternary volcanic centre and the potential association with volcanism, and 2) the evolution of the sequence NE toward the Wassuk range front fault.

Three telemetered instruments were installed beginning April 18th. Each included a Trillium Compact (on loan USGS) and Episensor accelerometer. Stations were removed in October; a 3-channel strong motion system remains at TVH1. To date, there have been about 1500 reviewed earthquake locations of the many 1000s of Hawthorne events. Depths were not constrained prior to temporary installation; the nearest permanent station is 25 km from the source area.

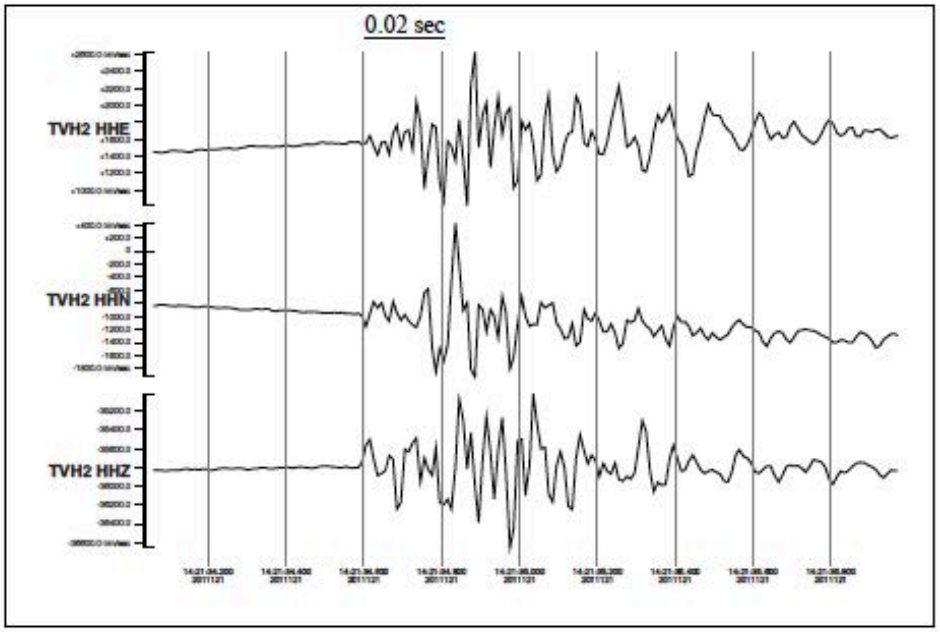
Moment Tensor Solutions:

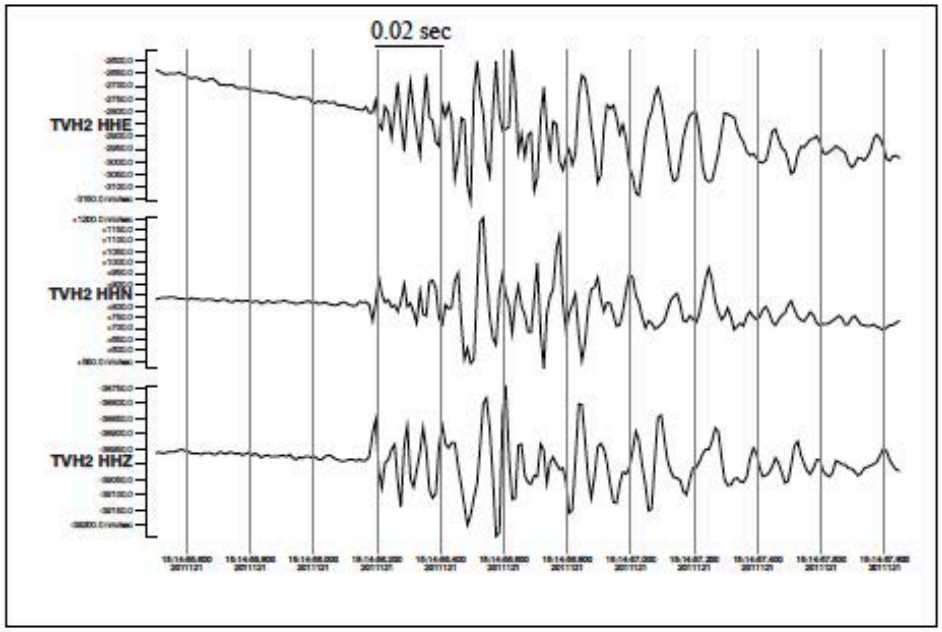
Nevada Seismological Laboratory Moment Tensors have been regularly computed with Gene Ichinose's MT application. A DMS/SCO front end has been developed (by Gabe Plank) to retrieve waveforms and response files from the IRIS and NCEDC. This runs automatically as well as manually following any Nevada M 3.5; all solutions are reviewed prior to posting on the NSL web site and USGS Recent Events page. MT solutions indicated shallow sources in the Hawthorne sequence prior to installation of temporary telemetered near source instruments. MT solutions have improved in the Nevada region with addition of broadband stations installed under ANSS ARRA 2011 upgrades. Nevada region MTs agree well with USGS and CISN solutions.

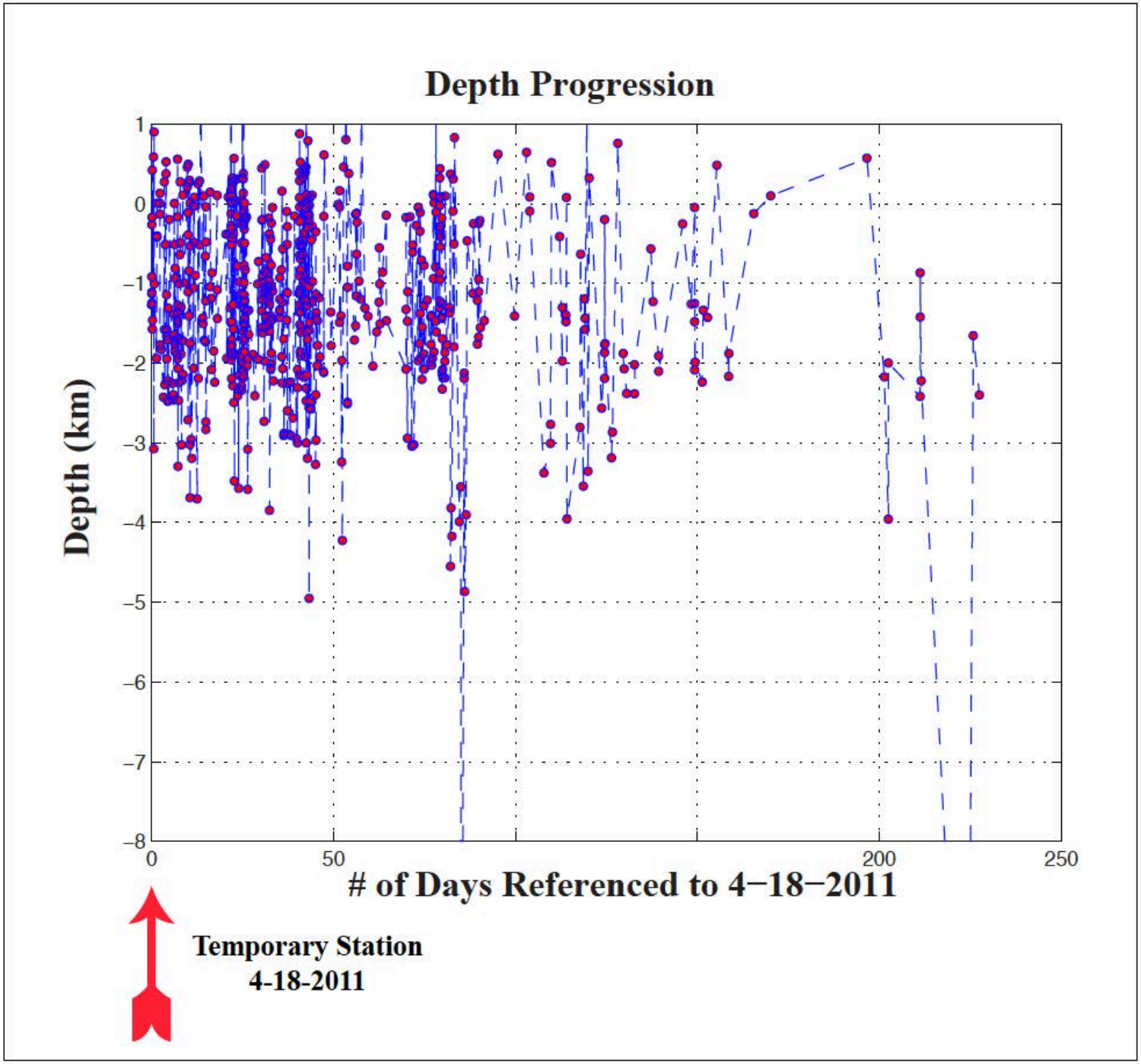
ANSS Catalog 1955-2011



0.02-0.03 sec S-P Times at Temporary Station THV2 - Confirms Shallow Depths






Depth Progression
Depth (km)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
0
50
200
250
# of Days Referenced to 4−18−2011
Temporary Station
4-18-2011

27 Events >= Magnitude 3.5

Mag	Yr	Mo	Dy	Hr	Mn
4.6	2011	04	17	00	45
4.4	2011	04	13	22	10
4.3	2011	05	12	16	23
4.3	2011	04	27	19	19
4.3	2011	04	15	13	33
4.3	2011	04	13	22	16
4.2	2011	05	27	19	45
4.2	2011	04	11	00	22
4.1	2011	04	17	00	55
4.1	2011	04	15	17	06
4.1	2011	04	13	22	15
4.0	2011	08	17	21	04
4.0	2011	05	09	09	46
4.0	2011	04	15	17	24
4.0	2011	04	11	00	21
3.9	2011	04	17	01	19
3.9	2011	04	15	18	21
3.8	2011	05	20	00	20
3.7	2011	04	28	00	49
3.7	2011	03	15	18	14
3.6	2011	04	27	13	23
3.6	2011	04	11	00	20
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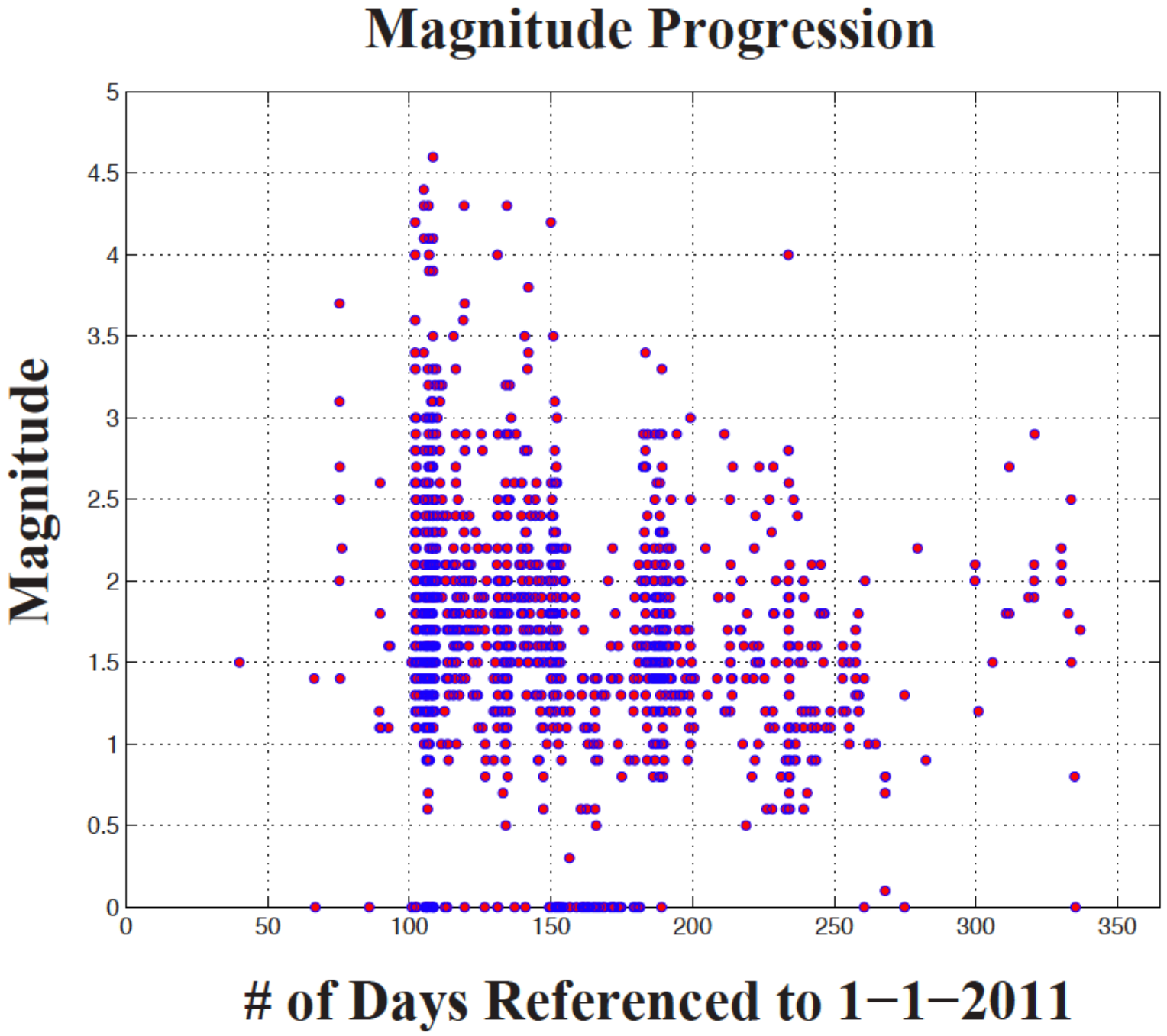
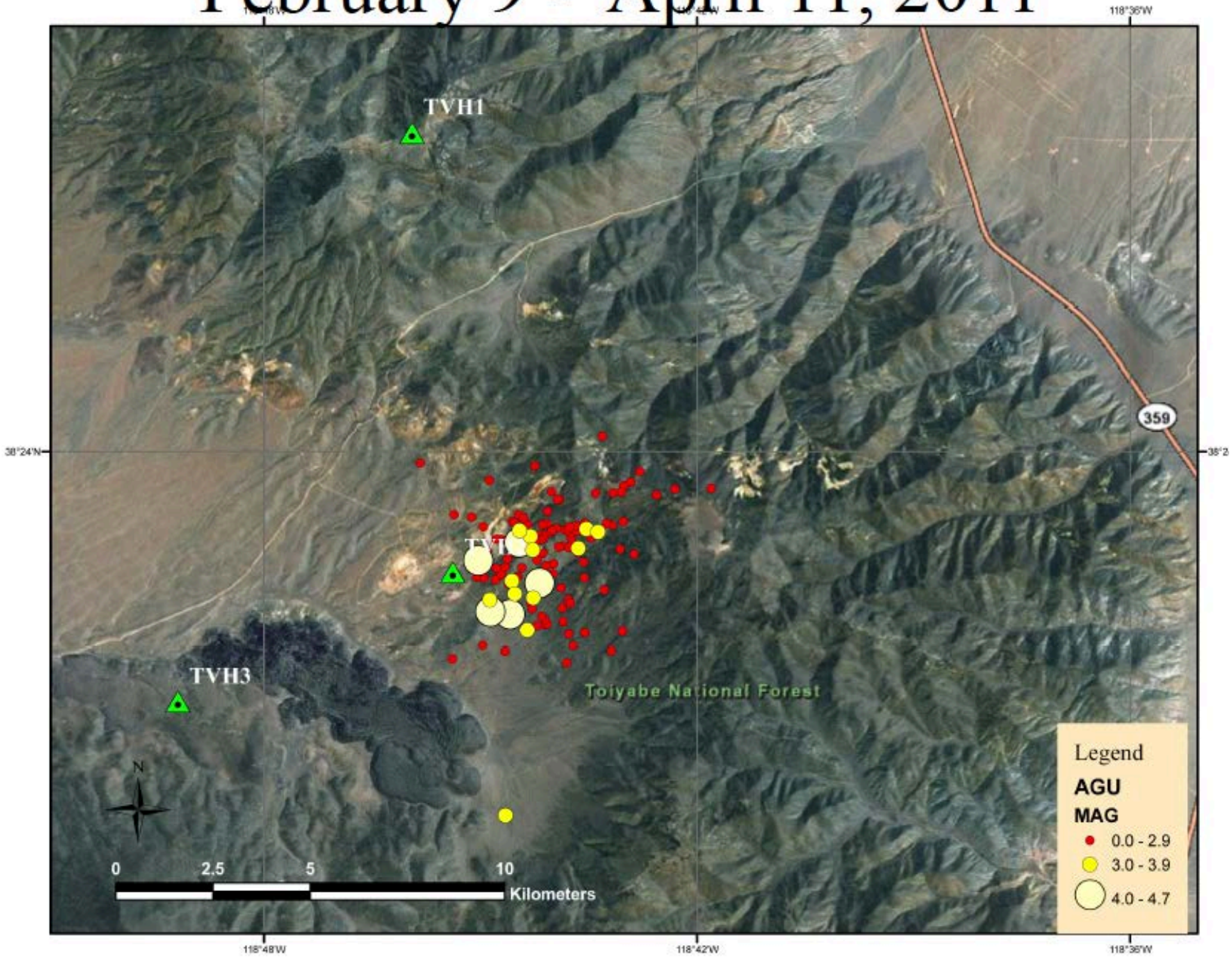
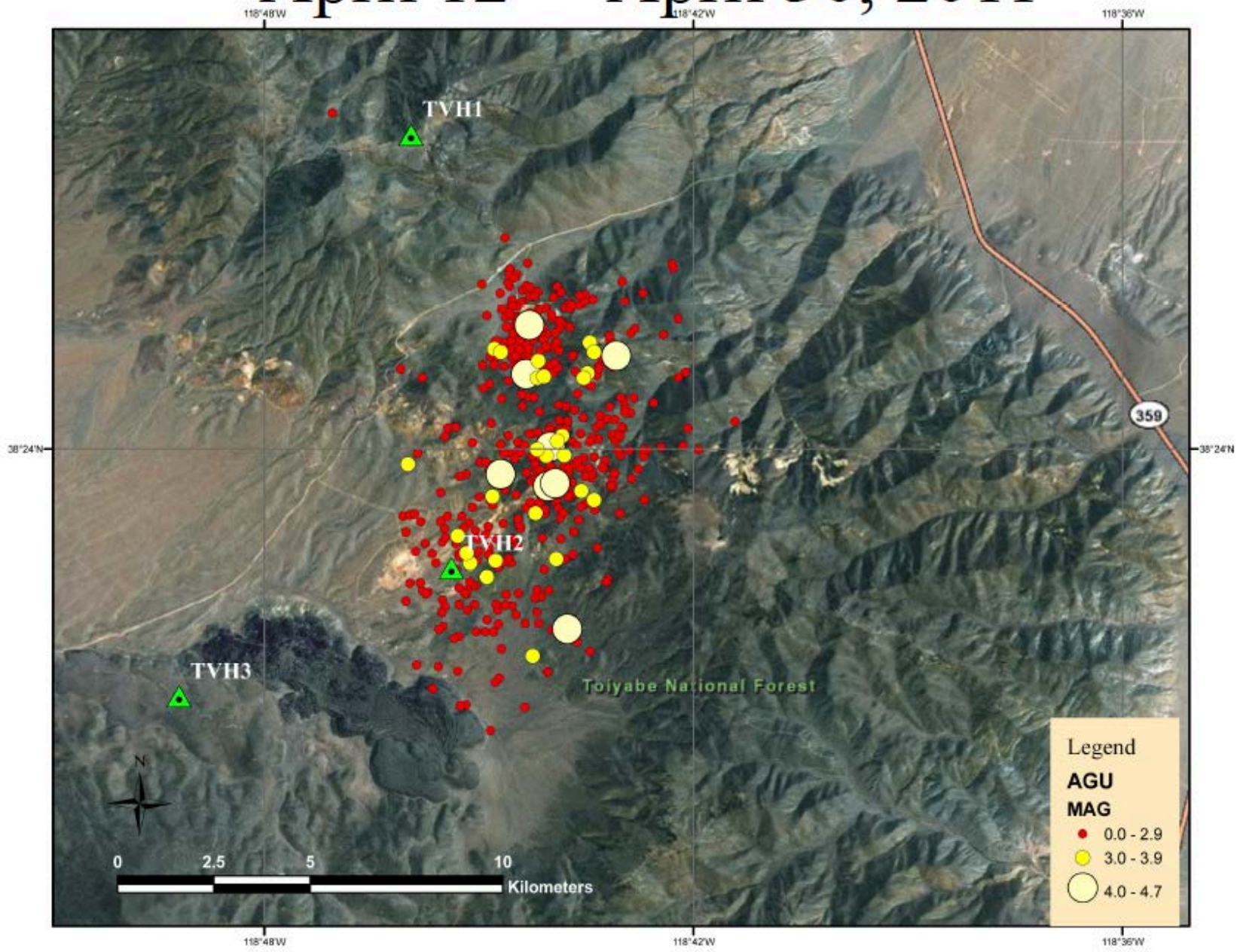
3.5	2011	05	18	19	18
3.5	2011	04	24	02	30
3.5	2011	04	17	00	57


Magnitude Progression
Magnitude
# of Days Referenced to 1−1−2011
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
50
100
150
200
250
300
350

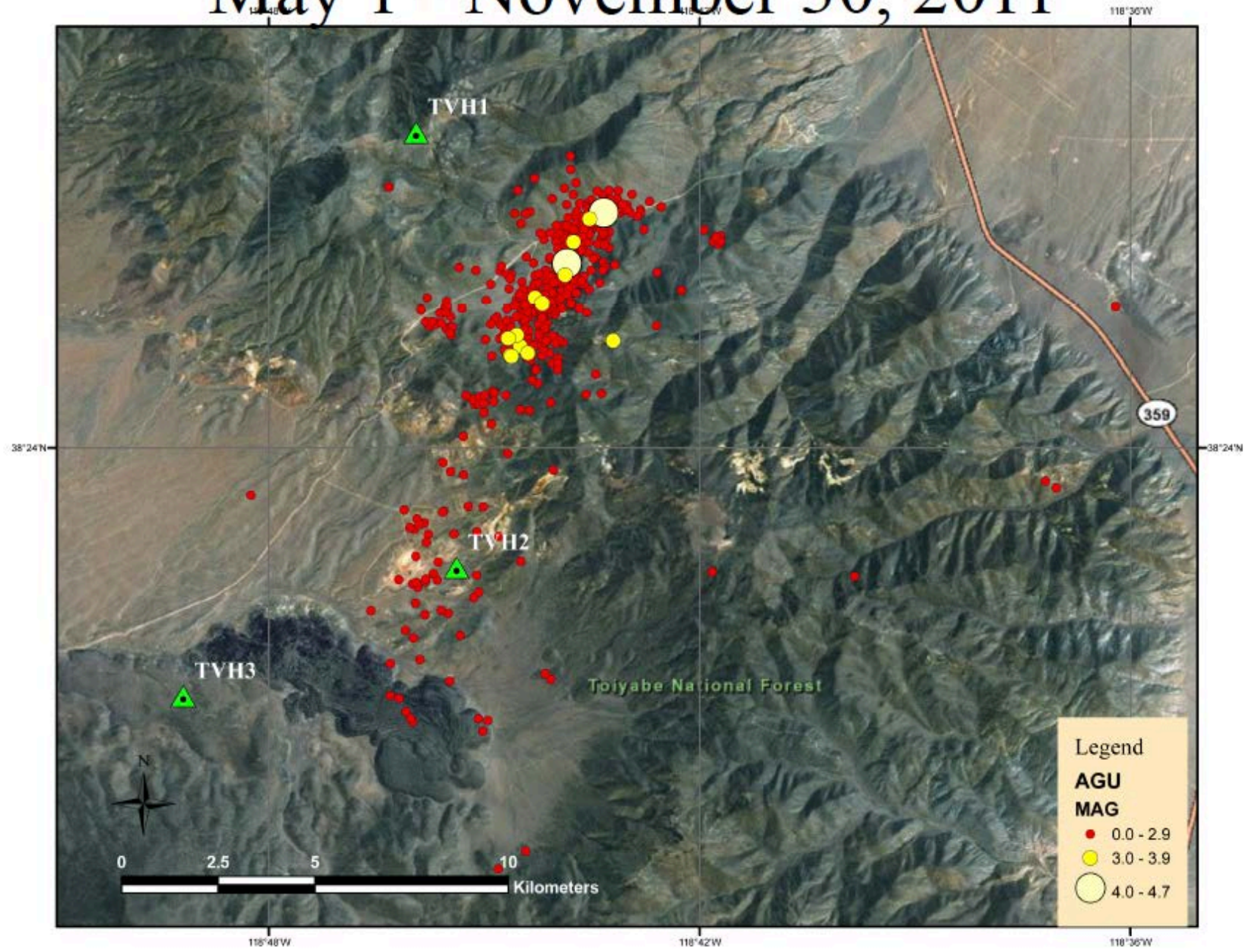
February 9 - April 11, 2011



April 12 - April 30, 2011



May 1 - November 30, 2011

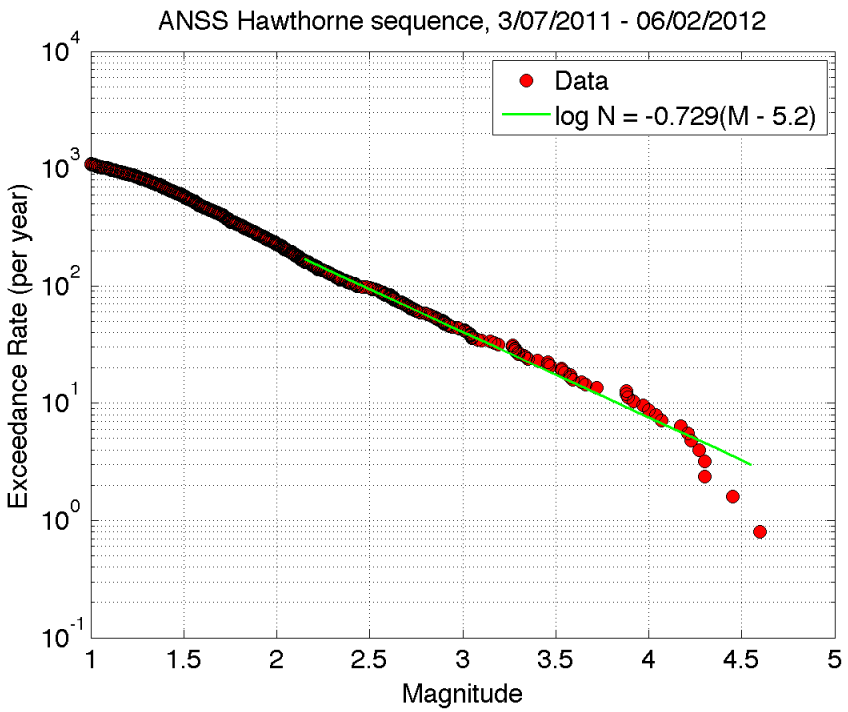


John Anderson – thought # 1

- Active fault structure is not in the USGS Quaternary fault and fold database.
  - Reinforces the point that a background seismicity zone is essential for USGS hazard maps.

John Anderson – thought # 2

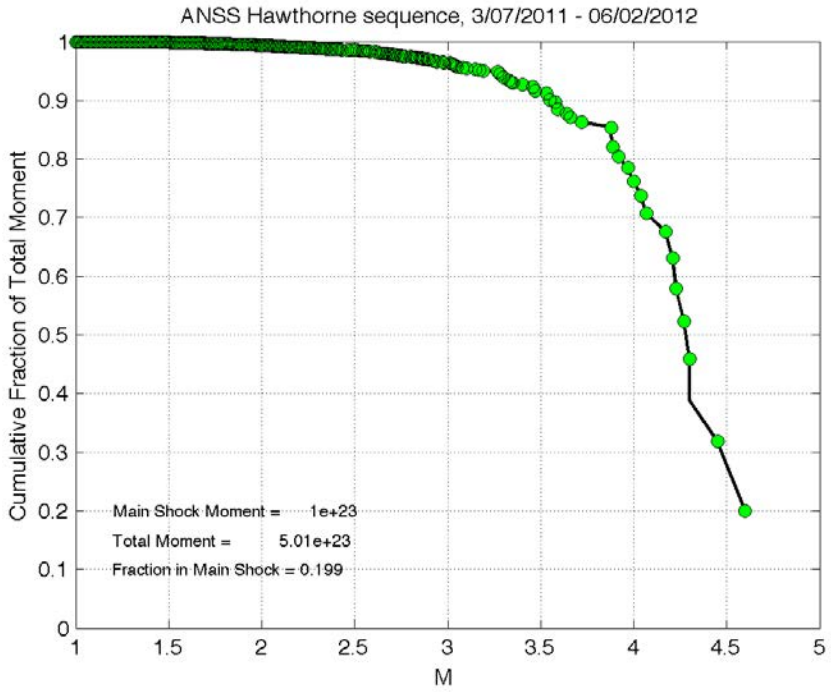
- Declustering:
  - Chuck Mueller wrote that only one M=4.6 earthquake survives the declustering process.



This sequence has several events with M close to 4.6, and a high b-value above M~4.25.

John Anderson – thought # 2

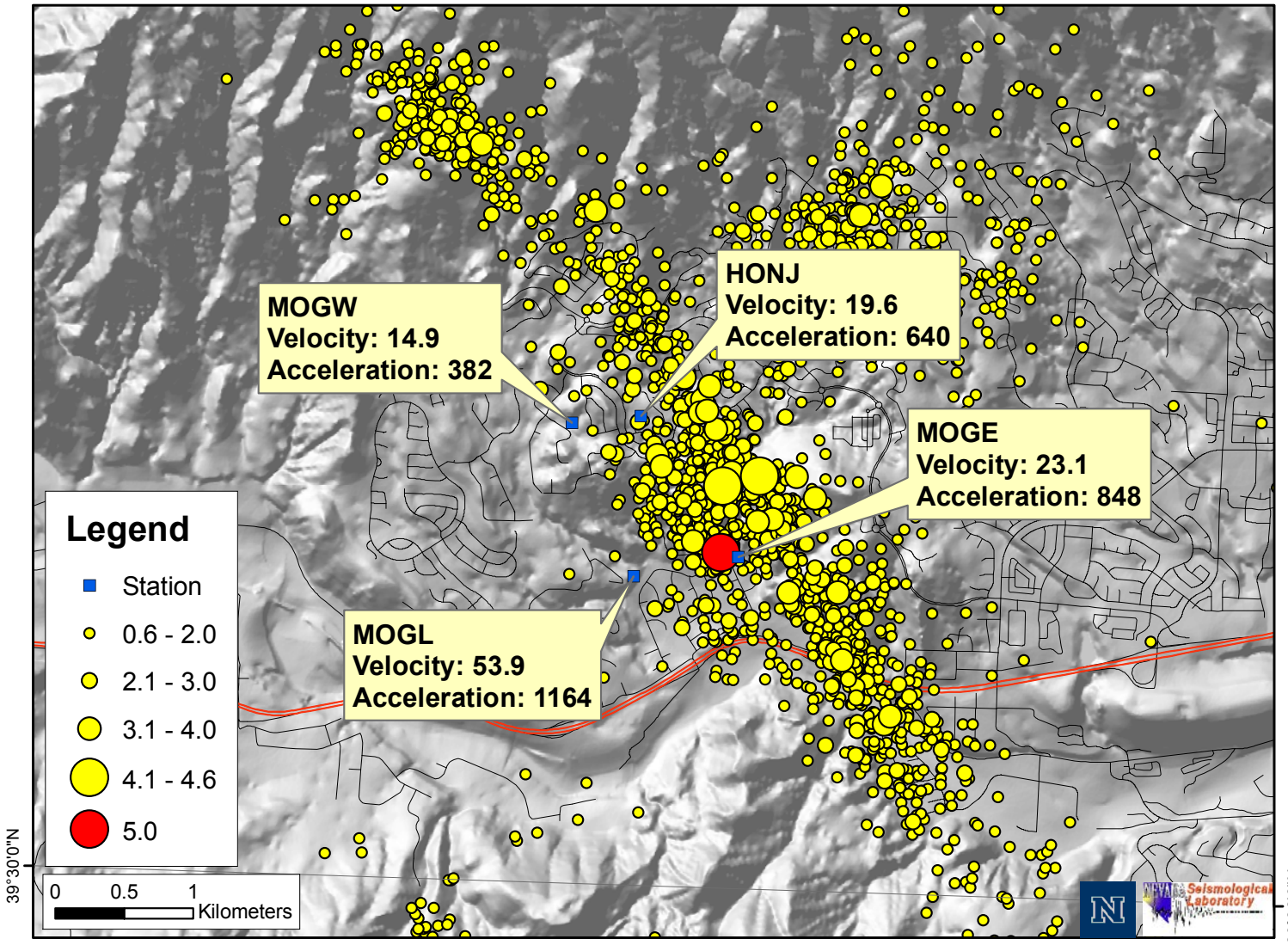
- Cumulative Moment:
  - Only 20% of the total moment is released in the main shock. Usually it is much higher.

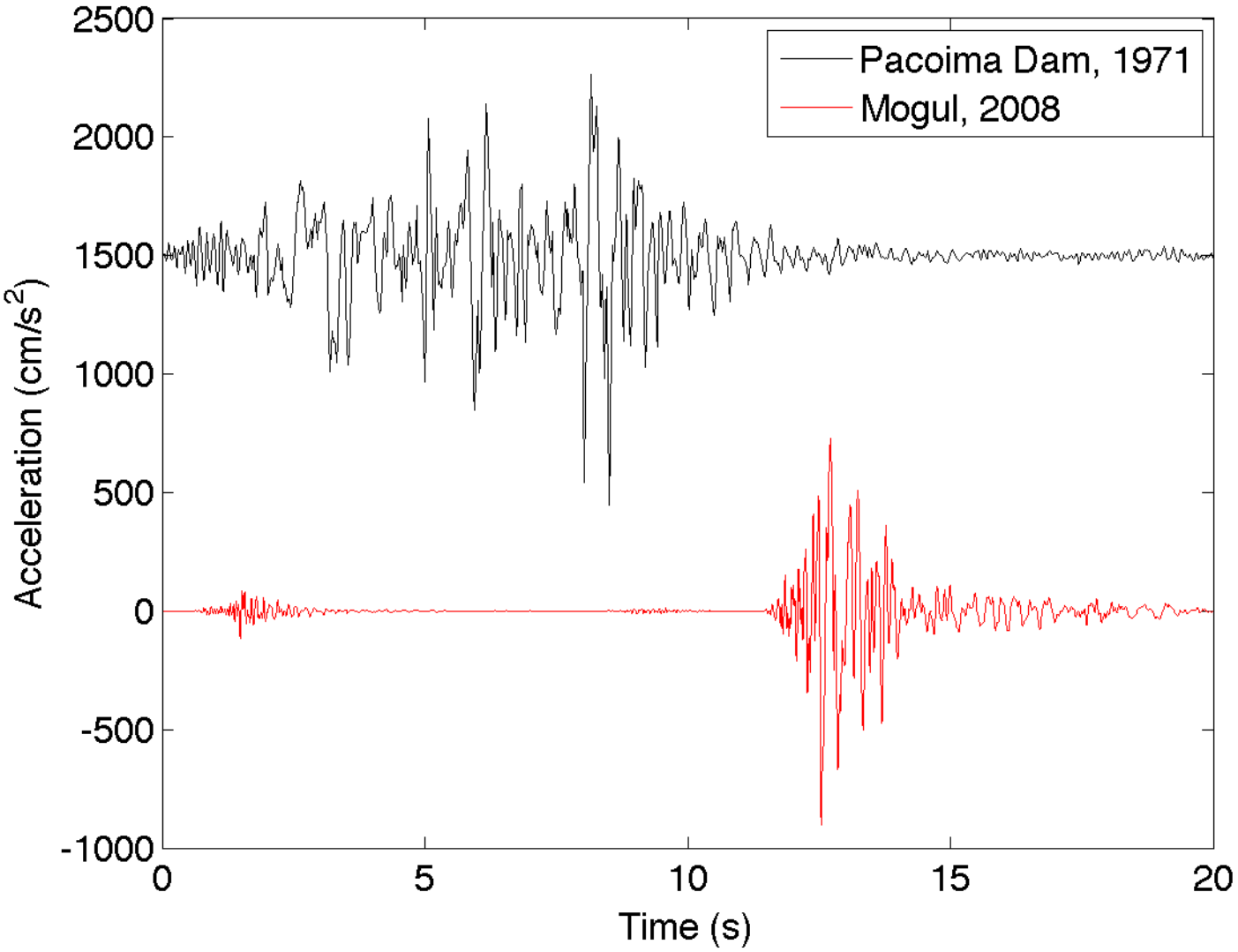


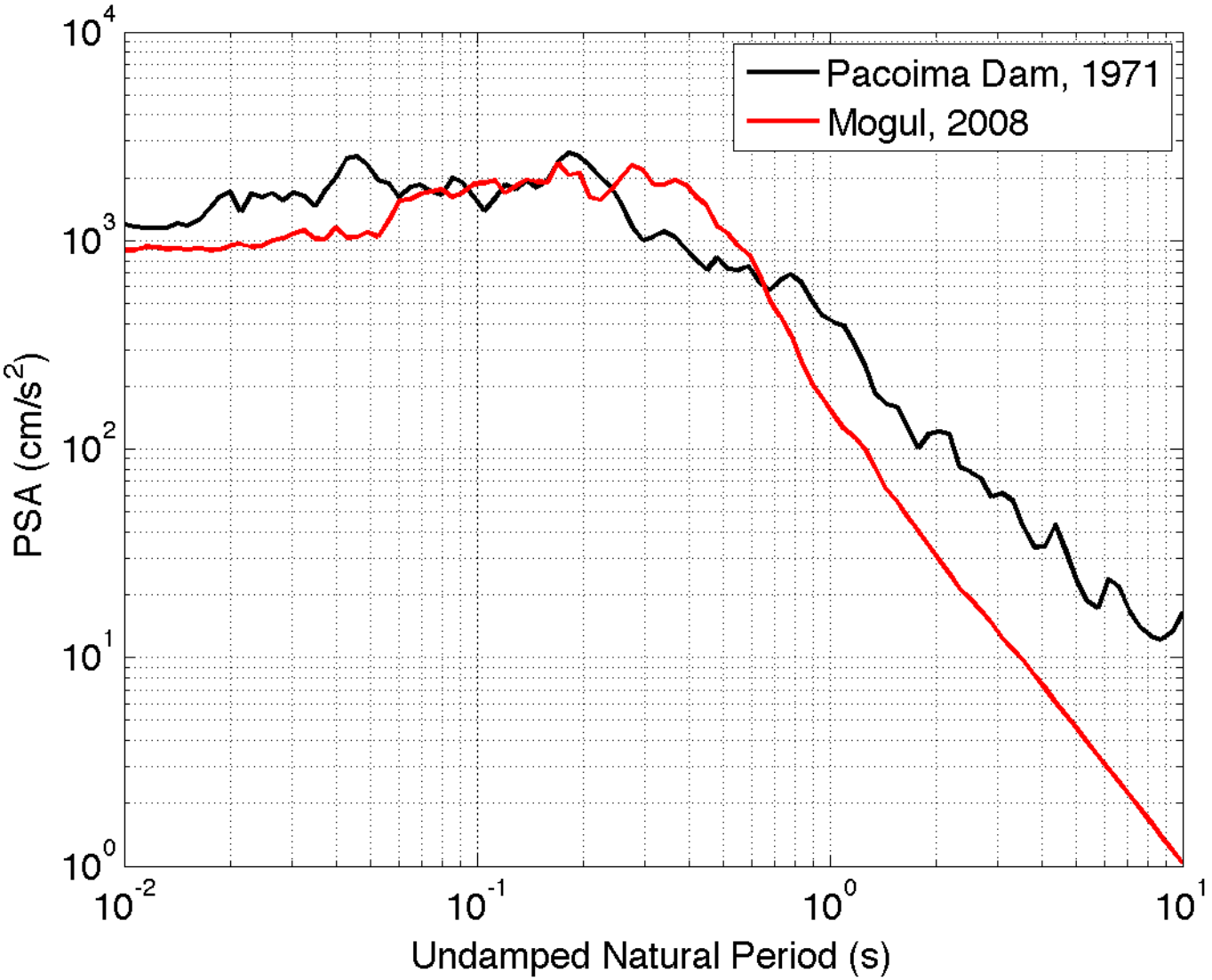
Does this violate any declustering assumptions?

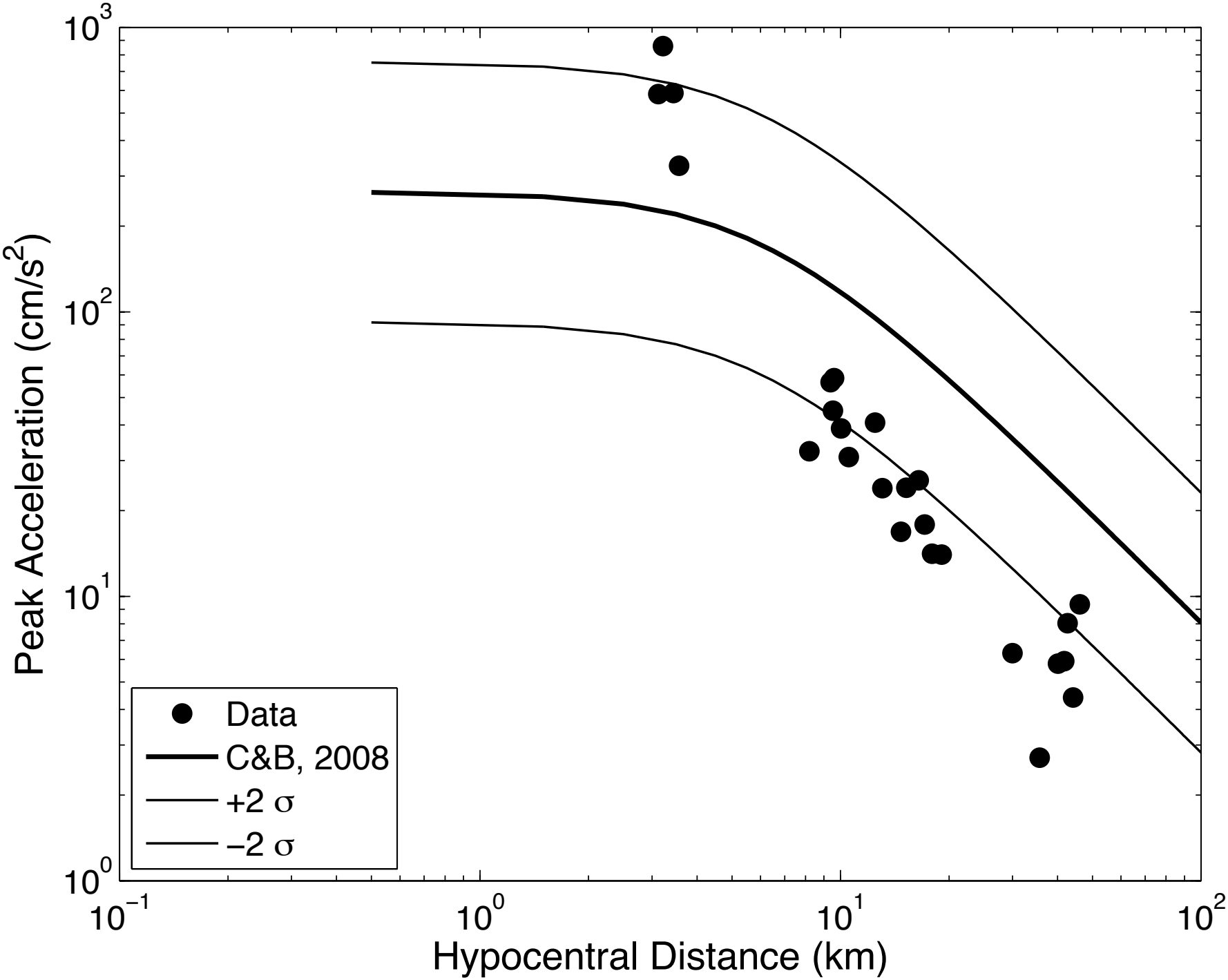
Moment of the entire sequence corresponds to M_W=5.07.

Mogul Earthquake, M_W=5.0




Pacoima Dam, 1971
Mogul, 2008
Acceleration (cm/s^2)
Time (s)
2500
2000
1500
1000
500
0
-500
-1000
0
5
10
15
20


Pacoima Dam, 1971
Mogul, 2008
PSA (cm/s2)
Undamped Natural Period (s)
10^4
10^3
10^2
10^1
10^0
10^-2
10^-1
10^0
10^1


Peak Acceleration (cm/s^2)
Hypocentral Distance (km)
10^3
10^2
10^1
10^0
10^{-1}
10^0
10^1
10^2
Data
C&B, 2008
+2 σ
–2 σ

John Anderson – thought # 3

- Ground Motion:
  - Extrapolating from Mogul, perhaps shallow events may have higher ground motions at short distances, which may have broad implications for the hazard.
  - Without nearby instruments, the Hawthorne events were located much deeper than what we found later (at least according to the NEIC catalog). This could be a common occurrence, although it is hard to tell how common.
- Combining these two points, would the hazard be more reliably estimated if a range of depths were considered in the background zone, and the GMPEs include depth as a prediction parameter for these smaller earthquakes?