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ATTACHMENT 8: SEISMIC NETWORK 2014 ANNUAL SEISMICITY REPORT

SUSITNA-WATANA HYDRO

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Technical Memorandum
14-32-REP
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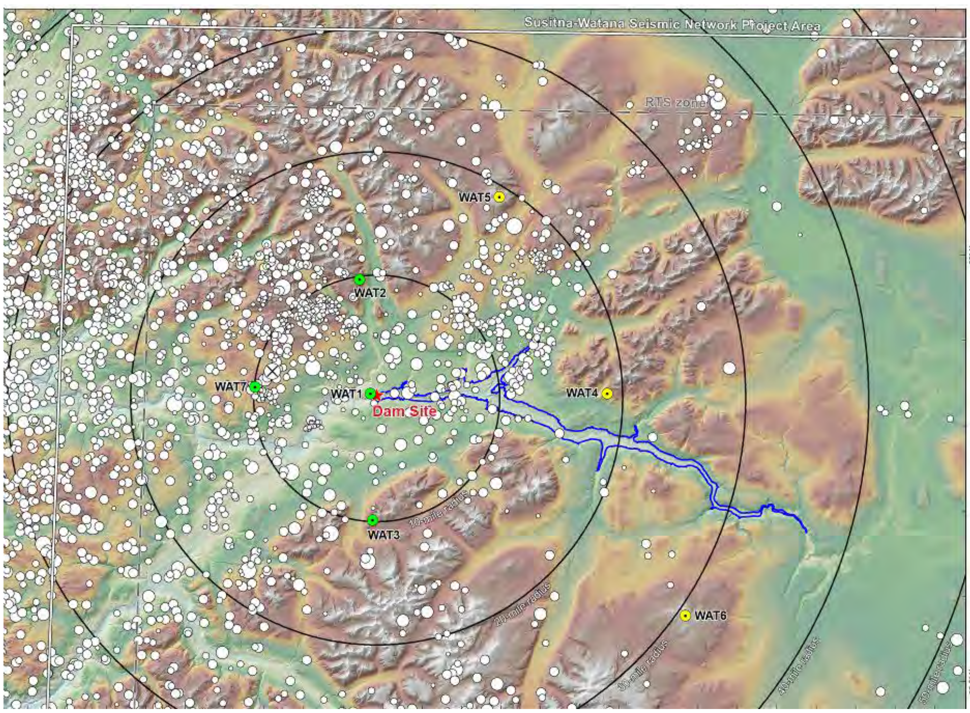
Susitna-Watana Hydroelectric Project
Seismic Network 2014 Annual Seismicity Report

AEA11-022



Prepared for:
Alaska Energy Authority
813 West Northern Lights Blvd.
Anchorage, AK 99503

Prepared by:
Fugro Consultants, Inc. for MWH
1777 Botelho Drive, Suite 262
Walnut Creek, CA 94596

March 31, 2015

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The following individuals have been directly responsible for the preparation, review and approval of this Report.

Prepared by: Roland LaForge

Reviewed by: Justin Pearce, Doug Ott, Carolyn Randolph-Loar, and Mike Bruen

Approved by: ______________________________

Michael Bruen, Geology, Geotechnical, Seismic Lead

Approved by: ______________________________

Brian Sadden, Project Manager

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Explanation of Abbreviations

AEA	Alaska Energy Authority
AEC	Alaska Earthquake Center (formerly known as the Alaska Earthquake Information Center; AEIC)
FCL	Fugro Consultants, Inc.
GPS	Global positioning system
km	Kilometer(s)
M	Moment Magnitude
M_L	Local Magnitude, as calculated by AEC
mi	Miles
MMI	Modified Mercalli Intensity
MWH	MWH Americas, Inc.
RTS	Reservoir-triggered seismicity
SAB	Southern Alaska Block
SWSN	Susitna-Watana Seismic Network
USGS	U.S. Geological Survey

EXECUTIVE SUMMARY

The proposed Susitna-Watana Dam is a hydroelectric power development project planned for the upper Susitna River under the auspices of the Alaska Energy Authority (AEA). Under subcontract to MWH Americas (MWH), Fugro Consultants, Inc. (FCL) is investigating and evaluating the seismic hazard in support of engineering feasibility and the licensing effort for the Susitna-Watana Hydroelectric Project. As part of the evaluation of seismic hazard in the Susitna-Watana project area, a project-specific long-term earthquake monitoring system (Susitna-Watana Seismic Network) was established in August-September 2012 to monitor seismic activity in the vicinity of the planned Susitna-Watana dam site and reservoir area. This report summarizes seismic activity recorded by the Susitna-Watana Seismic Network during calendar year 2014, and also since network initiation on November 16, 2012 through December 31, 2014.

The installation of the Susitna-Watana Seismic Network has increased the station density in the region, leading to greater magnitude and detection capabilities, a decrease in magnitude of completeness, and greater location accuracy. The increase in recorded events has led to a better picture of shallow crustal seismicity and intraslab seismicity associated with the subducting Pacific Plate below the proposed dam site.

In 2014 1,387 earthquakes occurred within the Susitna-Watana Seismic Network Project Area (defined as 62.3-63.25^{o}N and 146.6-149.35^{o}W for this report, and area of approximately 5,700 mi^2 (14,700 km^2)). Since initiation of the Susitna-Watana Seismic Network on November 16, 2012 through December 2014 a total of 2,523 earthquakes have been recorded. In 2014 a daily average of 3.8 events was recorded (1.8 crustal events per day and 2.0 intraslab events per day). The largest event in 2014, M_L 4.6, occurred on November 29, 2014 at a depth of 37.9 mi (62.1 km), with an epicenter 24.5 mi (40 km) southeast of the proposed Susitna-Watana dam site.

The spatial pattern of both crustal and intraslab seismicity is variable over the Project Area, but much more dense in the western half of the Project Area. There is a notable lack of seismicity to the east and southeast of the dam site from both crustal and intraslab sources.

Focal mechanisms calculated by the Alaska Earthquake Center (AEC) in the Susitna-Watana Network indicate that the shallow crust in the area around the proposed dam site is undergoing north-northwest south-southeast compression, consistent with the relative Pacific-North America plate motion, with the maximum horizontal stress rotating progressively in a counterclockwise direction from east to west in the project area. For the intraslab events, the majority of focal mechanisms indicate strike-parallel horizontal compression within the downgoing Pacific Plate (which also show the same counterclockwise rotation of horizontal maximum stress axes seen in the crustal mechanisms), and three focal mechanisms indicate normal faulting with inconsistently oriented stress axes.

Based on recurrence calculations for the period of December 1, 2012 through December 31, 2014 (from combined crustal and intraslab events), about two M_L 4 events per year would be anticipated within the Project Area, a M_L 5 event would be anticipated about every three years, and a M_L 6 event about every 20 years. Due to the low fraction of crustal earthquakes compared to the total, and low upper magnitudes of the crustal seismicity, the intraslab seismicity forms the preponderance of events contributing to these recurrence statistics and thus drives the results.

This current rate of activity appears somewhat above the long-term rate of larger events based on the relative lack of M_L 6 events in the historical record for the project area, as well as the broader geographic region. Caution is advised in extrapolating the rates of these larger events based on the relatively short period of record used in the calculations.

1. INTRODUCTION

A project-specific long-term earthquake monitoring system (Susitna-Watana Seismic Network) was established in August-September 2012 to monitor seismic activity in the vicinity of the Susitna-Watana region. Data recorded by the Susitna-Watana Seismic Network (SWSN) is processed by the Alaska Earthquake Center (AEC)[1] which distributes a monthly list of recorded seismic events and prepares quarterly reports on seismicity within the SWSN area for the Alaska Energy Authority (AEA). The AEC reporting area, referred to herein as the SWSN Area, is defined as 62.3^{o} – 63.6^{o}N and 150^{o} – 147^{o} W.

This report summarizes the seismic activity that has been recorded by the Susitna-Watana Seismic Network in 2014, and also since network inception on November 16, 2012 through 2014, within the Project Area (defined as 62.3-63.25^{o}N and 146.6-149.35^{o}W for this report), an area of approximately 5,700 mi^2 (14,700 km^2)).

The Project Area is an outgrowth of MWH (2013), which examined the potential for Reservoir Triggered Seismicity (RTS). RTS was judged capable of occurring within 30 km of the "operation point", defined as the reservoir outline in map view (Figure 1). This "RTS Zone" is also shown as the dotted line in Figures 4 and 7. A 10 km buffer was added (seen as the solid white boundary in Figures 4 and 7) so that seismicity patterns lying on or just outside the RTS boundary would be discernable and included in the analyses. The Project Area comprises the RTS zone plus the 10 km buffer. An important reason for focusing on this area is to establish a baseline for post-impoundment seismicity analyses.

Analysis and discussion of noted patterns in seismicity are made, along with a calculation of earthquake recurrence for the Project Area. A review of local tectonics in the Susitna-Watana project area is presented, as well as focal mechanisms produced by the AEC (AEIC, 2013a, b, c, d; 2014a, b; AEC, 2014 a, b; AEC, 2015), with discussion of how the seismicity in the Susitna-Watana project area relates to regional tectonics of the Susitna-Watana project area. Because AEC provides focal mechanism data in their quarterly reports, the focal mechanism analysis (section 3.2) is performed for the larger SWSN Area.

Magnitudes report by AEC are in M_L units. Magnitudes for other earthquakes discussed are in units of moment magnitude (M).

[1] Formerly referred to as the Alaska Earthquake Information Center or, AEIC.

1.1 Overview of the Susitna-Watana Seismic Network

A project-specific earthquake monitoring system (Susitna-Watana Seismic Network, or SWSN) was established in August-September 2012 to monitor seismic activity in the vicinity of the Susitna-Watana project area. The first group of stations consisted of four seismograph stations within 20 mi (~32 km) of the proposed Susitna-Watana dam site, with station spacing on the order of 10 mi (~16 km); one broadband station with a co-located strong motion sensor at the proposed dam site (WAT1), and three broadband stations (WAT2, WAT3, and WAT4). In August 2013, three additional seismograph stations were installed (WAT5, WAT6, and WAT7). The additional seismograph stations extended the network to cover the area within 32 mi (~51 km) of the proposed dam site. In the current network configuration, all seven seismograph stations have three-component broadband seismic sensors and four of the stations have co-located three-component strong motion sensors. In addition, a GPS station has been co-located with the seismograph at the proposed dam site (WAT1) (AEC, 2014a).

Figure 1 shows the current SWSN configuration within the Project Area and the overall pattern of seismicity recorded in the Project Area from November 16, 2012 through December 31, 2014. Data recorded by the seismic network is processed by the AEC, who monitors seismic activity from ~400 seismograph stations located throughout Alaska and the neighboring regions (AEC, 2014a). Data are currently recorded continuously in real time, at a sample rate of 50 Hz. AEC picks arrival times, and calculates locations and magnitudes for all events recorded on four or more stations. First-motion focal mechanisms are computed for events $M_L \geq 3.5$, and regional moment tensors are generated for events $M_L \geq 4$ (AEC, 2014a).

Prior to the network installation, the magnitude of completeness in the area was between 1.2 and 1.4 (AEC, 2014a). After the first four seismograph stations were installed, the magnitude of completeness decreased to between 1.0 and 1.2. As of December 2014, the magnitude of completeness was estimated at 1.0 (AEC, 2015). Figure 2 (from AEC, 2015) shows a plot of magnitude vs. time, for the last quarter of 2014. This is very similar to AEC plots for the other three quarters (AEC, 2014a,b,c). During 2014, earthquakes with magnitudes as low as -0.5 have been located. Magnitude of completeness as estimated by AEIC (2014a, b) and AEC (2014a, b; 2015) is for the SWSN Area, is but likely equivalent for the smaller area seen on Figures 4 and 7.

The addition of the SWSN has increased the detection capabilities in the project area, decreased the magnitude of completeness, and improved hypocentral location precision. This has provided a clearer picture of seismicity within the Project Area. Figure 3 shows the distribution of seismicity at depth in the Project Area prior to installation of the Network, that is, from 2010 through November 15, 2012. The location of the Figure 3 cross section is near the cross-section line shown on Figure 4, which is the basis for the cross sections in Figures 5, 6, 8 and 9 (which show seismicity in the Project Area after network installation). Comparison of the seismicity recorded prior to network installation (Figure 3) and subsequent to installation (Figures 5, 6, 8 and 9), illustrates that the limits of shallow crustal and intraslab seismicity as well as the outline of the downgoing slab are now more clearly defined by because of the SWSN.

2. RECORDED SEISMICITY: JANUARY 1, 2014 - DECEMBER 31, 2014

Below is a summary of the events that have been located within the Project Area from January 1, 2014 through December 31, 2014.

2.1 Summary of Recorded Events

A total of 1,387 earthquakes were located within the area of Figure 4 from January 1, 2014 through December 31, 2014. 643 events were located in the crust at depths of less than 18.6 mi (30 km), and 744 events were located deeper, within the subducting North American Plate (intraslab seismicity). The crustal events ranged in magnitude from -0.5 to 3.0; the intraslab events from 0.1 to 4.6. The higher detection threshold for the slab seismicity is undoubtedly due to its greater distance to the stations. Figure 2 shows magnitude vs time for the 3rd quarter of 2014 (AEC, 2015), for the SWSN Area. The plot shows that earthquakes below magnitude zero are being recorded, although not completely.

Table 2-1 summarizes the number of crustal and intraslab events recorded each month of 2014. The month with the greatest amount of recorded events was April (153 events total) and the month with the least amount of recorded events (91 total) was June.

Table 2-1. Summary of Project Area Events by Month

Month	Total # of Events	# of Crustal Events	# of Intraslab Events	Magnitude Range of Crustal Events	Magnitude Range of Intraslab Events
Jan 2014	94	33	61	0.1 – 2.9	0.4 – 3.7
Feb 2014	121	52	69	-0.2 – 1.9	0.4 – 2.6
Mar 2014	123	54	69	-0.1 – 1.7	0.3 – 2.7
Apr 2014	153	70	83	-0.4 – 1.6	0.3 – 2.3
May 2014	146	62	84	-0.2 – 2.2	0.1 – 3.3
June 2014	91	52	39	-0.1 – 2.7	0.3 – 4.4
July 2014	98	50	48	-0.2 – 2.8	0.3 – 3.7
Aug 2014	101	37	64	-0.2 – 1.6	0.2 – 2.9
Sep 2014	134	72	62	-0.5 – 3.0	0.4 – 2.4
Oct 2014	100	44	56	-0.2 – 1.6	0.4 – 3.9
Nov 2014	120	58	62	-0.1 – 2.5	0.7 – 4.6
Dec 2014	106	59	47	0.1 – 1.5	0.6 – 3.0
Average	**116**	**54**	**62**		

Figure 4 shows a map of 2014 seismicity. Red symbols signify crustal events (depth < 18.6 mi (30 km)) and blue symbols signify intraslab events (depths ≥ 18.6 mi (30 km)).

Figure 5 shows a cross section of the seismicity shown in Figure 4. The azimuth of the section line was determined by a least squares fit to intraslab seismicity (FCL, 2014b), and represents the perpendicular to the strike of the downgoing slab. Figure 6 shows a cross section of the seismicity on Figure 4 occurring within a 12.4 mi (20-km) buffer on either side of the cross-section line. The 20-km buffer restriction for Figures 6 and 9 was designed to present a more precise view of seismicity near the site, and minimize the effect of plate geometry variations away from the site.

Table 2-2 summarizes the largest crustal (depth < 18.6 mi (30 km)) and intraslab (depths ≥ 18.6 (30 km)) events that were recorded in the Project Area in 2014. Two crustal events had magnitudes of 3.0. The largest crustal event since network initiation was a M_L 3.8 event on July 24, 2013 (FCL, 2014a).

The M_L 4.6 event on November 29, 2014 is the largest intraslab earthquake in the Project Area since network initiation. It was widely felt in south-central Alaska, as depicted by the USGS ShakeMap (Figure 11).

Table 2-2. Largest 2014 Crustal and Intraslab Events

Largest Crustal Events										
Year	Month	Day	Hour	Min	Lat (N)	Lon (W)	Depth	Mag (M_L)	Epicentral Distance to Site	Hypocentral Distance to Site
2014	9	27	15	58	63.178	147.665	3.9 mi (6.2 km)	3.0	36.7 mi (59.1 km)	36.9 mi (59.4 km)
2014	12	1	3	33	62.349	147.626	26.1 mi (42.0 km)	3.0	43.7 mi (70.3 km)	50.9 mi (81.9 km)
Largest Intraslab Event										
Year	Month	Day	Hour	Min	Lat (N)	Lon (W)	Depth	Mag (M_L)	Epicentral Distance to Site (km)	Hypocentral Distance to Site (km)
2014	11	29	21	06	62.544	148.058	37.9 mi (62.1 km)	4.6	24.5 mi (39.5 km)	45.7 mi (73.6 km)

2.2 Notable Seismicity Patterns and Events

A number of patterns may be apparent in the seismicity recorded in the Project Area since network initiation. Below is a summary of some of the more notable and prominent patterns.

1. The spatial pattern of both crustal and intraslab seismicity is variable over the project area, but much more dense in the western half of the project area. There is a lack of seismicity to the east and southeast of the dam site (see Figures 4 and 7) in both crustal and intraslab seismicity.
2. Crustal seismicity seen in cross section on Figures 5, 6, 8 and 9 appears to have a well-defined lower bound at a depth of about 13.7 mi (22 km), which is now better defined than prior to the installation of the Susitna-Watana Seismic Network stations (compare to Figure 3).
3. Clusters of crustal seismicity near WAT2 and WAT7 (Figure 7) that were intermittently active in 2013 continued to be active in 2014, with the exception of cluster 1A.
4. There is a cluster of persistent small-magnitude seismicity located at shallow depths in the southwest corner of Figure 7 that may or may not indicate a potential seismotectonic feature, but

has not been examined in detail. This cluster has been consistently active since network initiation.

5. Intraslab seismicity dips about 25° to the northwest, beginning at a depth of about 18.6 mi (30 km) and extending to ~56 mi (~90 km) in the network area. Comparison of Figures 5, 6, 8 and 9 to Figure 3 shows the improved resolution of epicenters in the area due to installation of the network. Similar to the crustal seismicity pattern, intraslab seismicity is very sparse east and southeast of the site. The cluster of activity seen at ~25-31 mi (~40-50 km) depths on Figures 5, 6, 8 and 9 can be attributed almost exclusively to seismicity south of latitude 62.5°N.
6. There appears to be a gap in the intraslab seismicity at about 31.1 mi (50 km) depth (more prominent on Figures 6 and 9). Intraslab seismicity in the ~19-31 mi (~30-50 km) depth range occurs about 24.9 mi (40 km) south of the dam site, and is absent east of the site (see Figure 7), particularly within the 12.4 mi (20 km) buffer zone.
7. The 11/29/2014 M_L 4.6 intraslab earthquake was located about 25 miles (40 km) southeast of the dam site) at a depth of 38 mi (62 km). This was the largest recorded event within the project area since network initiation. A USGS ShakeMap for this earthquake is shown in Figure 11. A ShakeMap for a M_L 5.1 instraslab event that occurred on April 16, 2014 is shown in Figure 10. This earthquake occurred outside the Project Area but within the SWSN Area. Both earthquakes produced Modified Mercalli Intensity (MMI) III – IV shaking at the site.

2.3 Daily Rates of Crustal and Intraslab Events

Figures 12 and 13 shows average daily rates for crustal, intraslab, and total seismicity for November 16, 2012 through 2013, and calendar year 2014, respectively. The algorithm uses a moving time window scheme, where each daily rate point is the average of a 5-day window centered on the midpoint of the window.

Similar to observations for the 2012-2013 seismicity data (FCL, 2014a) rate correlations between the crustal and intraslab seismicity appear to be intermittent and occasional in 2014. In 2014 it is most clear in mid-late May, early October, and late September. For the most part, however, activity in the crust and slab appears to be uncorrelated. The spike in late September 2014 seen on Figure 13 is anomalous. It does not appear to be due to a mainshock-aftershock sequence or increased activity in a particular cluster, but rather to a relatively large number of small magnitude (< 1.0) earthquakes.

Some of the patterns seen on Figures 12 and 13 are influenced by outages of one or more stations due to technical malfunction. These are transcribed below (from N. Ruppert, AEC, pers. comm., 2015) and noted on the figures.

1) In May 2013 sites WAT1, 3 and 4 were latent (running hours behind), with some data gaps around mid-May and minor gaps throughout the month.

2) 8/30/2013-9/10/2013 - outage affected entire network

3) 1/1/2014-1/31/2014 - WAT3 and WAT5 outage

4) 7/4-7/8/2014 - WAT1 and WAT2 outage, these two sites were intermittent in June-July 2014, but the data mostly backfilled with some minor gaps.

3. SEISMOTECTONIC INTERPRETATION

3.1 Seismotectonic Setting

The Project Area is located in south-central Alaska (Figure 14), which experiences tectonic deformation from the movement of the Pacific Plate as it converges with the North American Plate in a northwesterly direction. Southeast of the Susitna-Watana project area, convergent movement occurs as the Pacific Plate is subducted under the North American Plate almost perpendicular to the strike of the Alaska-Aleutian megathrust, while right-lateral transform faulting occurs along the Queen Charlotte and Fairweather fault zones to the southeast (outside figure boundary of Figure 14). Closer to the Project Area, transpressional deformation is occurring on the right-lateral Denali fault to the north and the Castle Mountain fault to the south (FCL, 2012).

The Susitna-Watana proposed dam site is located within the Talkeetna block, which encompasses the north-central portion of the Southern Alaska Block (SAB) of Haeussler (2008) (Figure 14). The Talkeetna block is bounded by the Denali fault system to the north, the Wrangell Mountains to the east, the Castle Mountain fault to the south, and the Tordrillo Mountains volcanic ranges to the west. Strain release occurs on the northern and southern block boundaries of this crustal block (i.e., Quaternary Denali and Castle Mountain faults), but strain mechanisms are less well defined to the east and west (FCL, 2012). There is a lack of mapped faults within the Talkeetna block that have Quaternary displacement (FCL, 2012, 2015; Koehler, 2013). There is also a relative absence of large historic earthquakes within the Talkeetna block, although large events have occurred along the northern boundary on the Denali fault (M 7.9; 58 mi (94 km) from the site) and to the south on the Alaska-Aleutian plate interface megathrust (M 9.2) (FCL, 2012).

Earthquakes within the region generally occur within three seismotectonic sources. These are: (1) the subducting slab (intraslab events; depths $\geq$ 18.6 mi (30 km)), (2) the crust (depths < 18.6 mi (30 km)), and, (3) along the interface of the Pacific and North American plates at depths of ~19-25 mi (~30-40 km), about 31 mi (50 km) southeast of the proposed dam site in map view. Seismicity associated with the plate interface is too far from the site to be seen on the seismicity map figures and cross-sections. Within the Project Area, there has been a fairly high rate of low magnitude seismicity (crustal and intraslab events) since network installation, as evidenced by Figure 7.

3.2 AEC Focal Mechanisms and Regional Stresses

The AEC quarterly reports summarize seismicity within the SWSN Area (AEIC, 2014a, 2014b; AEC 2014c, 2015). Figures 15 and 16 show focal mechanisms produced by the AEC for events within the SWSN Area for the four quarters of 2014. Tables 3-1 and 3-2 summarize the location and focal mechanism parameters for each event. The tables include mechanisms since network initiation in 2012, within the SWSN Area shown on Figures 15 and 16. This area is larger than the Project Area shown on Figures 4 and 7, in that it extends about 90 mi (150 km) further to the west.

For crustal mechanisms within the SWSN Area, faulting types are exclusively strike-slip or reverse, with P-axes restricted to northwest-trending azimuths (All P-axis azimuths have been restricted to the western hemisphere). This is shown on Figure 17a. The long arrow is the mean azimuth. Figure 17b shows that this azimuth has a positive correlation with longitude, which shows counterclockwise rotation of principal compressive stress from east to west. A least-squares fit to the data is shown.

Intraslab mechanisms are predominantly strike-slip/reverse or normal, as defined by a T-axis plunge of less than 45 degrees. By this criterion, there are 11 strike-slip/reverse and 3 normal mechanisms. The 1/20/2014 event is the lone reverse faulting event (Figure 15a, western-most slab mechanism) of this group. For the purposes of further discussion, it is included in the "strike-slip" group.

Figure 18a shows P-axis azimuths of the individual intraslab events, and the mean azimuth for sub-groups, with strike-slip/reverse mechanism azimuths colored blue, and normal mechanism azimuths colored green. The mean azimuths for each group are the long arrows on the figure. For the strike-slip/reverse group the P-axes are restricted to azimuths between 200 and 274 degrees. There appears to be no consistency in the 3 P-axes for mechanisms classified as normal, though this may be due to the small number in the data set.

Figure 18b shows T-axis azimuths for the intraslab events, with the same coloring scheme. With 3 exceptions the T-axes are clustered in a narrow range between 310 and 334 for the strike-slip events. The existence of 3 normal faulting mechanisms out of the total of 12 implies that normal faulting may be a secondary mode of intraslab faulting, at least for these small magnitude earthquakes. For the normal mechanisms there appears to be no consistency in the T-axis orientations.

Figure 18c shows the P and T-axis azimuths as a function of longitude for the strike-slip/reverse group only. The P-axes are black circles, and T-axes red. Least-squares fits to each data set are shown. As for the crustal events, the same counterclockwise rotation of both P and T-axes stress axes from east to west is apparent as for crustal P-axes (Figure 17b)[3]. This suggests that the counterclockwise rotation of P-axes seen in the crust is also occurring within the slab. The slopes of the P-axis least-squares fits on Figures 17a and 18c are remarkably similar, at 28.1 and 29.7, respectively. Comparing Figure 17b to 18c, the mean longitude for each pattern appears to be consistent, roughly 149W. However, the slab P-axis azimuths are about 80 degrees more westerly than the crustal ones.

The greater P and T-axis azimuth consistency of the strike-slip/reverse group, relative to normal group, suggests that for this data set horizontal compressive or transpressional stresses are dominant in the slab.

The cross-section line on Figure 4 and 7 represents a line perpendicular to the Pacific plate interface and orientation of the downgoing plate, at this location (FCL, 2014b). With the azimuth of the cross section line at 335 degrees, the strike azimuth of the plate is 245 degrees (dashed line on Figure 18c). This is roughly consistent with the gross distribution of strike-slip/reverse P-axis azimuths on Figure 18c. Although normal faulting is occurring in the slab, if transtension were dominant, greater consistency in P and T-axis orientations for the normal mechanisms would be expected (Figure 18b)[2].

[2] For the sake of visualization, the strike-slip T-axis plotted at 194 degrees on Figure 18b is rotated (i.e., plotted in the opposite quadrant) to 374 degrees on Figure 18c.

Table 3-1. Focal Mechanisms Produced by the AEC for the SWSN Area, 2012-2014

Event Date	Lat (N)	Lon (W)	Magnitude (M_L)	Depth	Epicentral Distance to Site	Mechanism
Crustal Events						
10/17/12	62.703	-148.780	2.0	1.1 mi (1.7 km)	11.3 mi (18.2 km)	oblique reverse
3/25/13	62.6323	-148.5455	3.3	4.4 mi (7.1 km)	13.2 mi (21.2 km)	strike-slip
7/24/13	62.9221	-148.7133	3.8	6.9 mi (11.1 km)	8.8 mi (14.2 km)	reverse
8/13/13	63.1410	-149.2942	2.6	10.5 mi (16.9 km)	32.4 mi (52.1 km)	oblique normal
9/29/13	62.6319	-149.5092	2.7	9.9 mi (15.9 km)	33.6 mi (53.9 km)	oblique reverse
11/6/13	62.9016	-148.8529	2.8	8.4 mi (13.6 km)	11.4 mi (18.3 km)	reverse
11/8/13	62.908	-148.786	2.5	8.8 mi (14.2 km)	9.8 mi (15.8 km)	reverse
2/26/14	62.353	-149.109	1.9	3.5 mi (5.6 km)	37.2 mi (59.9 km)	strike-slip
2/28/14	62.768	-149.551	1.8	0.8 mi (1.3 km)	32.3 mi (52.0 km)	strike-slip
5/11/14	62.962	-148.993	2.2	10.5 mi (13.6 km)	17.3 mi (27.8 km)	oblique normal
6/21/14	62.372	-149.137	2.2	3.0 mi (4.8 km)	36.5 mi (58.8 km)	oblique reverse
7/25/14	62.622	-149.343	2.8	5.6 mi (9.0 km)	29.1 mi (46.8 km)	reverse
9/27/14	63.178	-147.665	3.0	3.9 mi	36.7 mi (59.1 km)	reverse

				(6.2 km)		
9/29/14	62.842	-148.822	2.8	7.6 mi (12.2 km)	9.1 mi (14.7 km)	reverse
11/25/14	63.1110	-149.166	2.5	7.9 mi (12.7 km)	28.1 mi (45.2 km)	reverse
Intraslab Events						
1/21/13	62.6856	-149.5287	4.0	41.3 mi (66.4 km)	32.8 mi (52.8 km)	strike-slip
3/2/13	62.6181	-148.8506	3.8	36.7 mi (59.1 km)	17.3 mi (27.9 km)	normal
10/23/13	62.8522	-148.8045	4.0	42.0 mi (67.6 km)	8.7 mi (14.0 km)	strike-slip
1/3/14	63.03	-148.19	3.5	40.6 mi (65.4 km)	17.9 mi (28.8 km)	normal
1/13/14	62.81	-149.05	3.7	44.7 mi (71.9 km)	16.3 mi (26.3 km)	strike-slip
1/20/14	62.83	-149.78	3.7	48.0 mi (77.2 km)	39.3 mi (63.2 km)	reverse
3/20/14	62.36	-148.15	2.6	23.1 mi (37.2 km)	34.6 mi (55.7 km)	normal
4/16/14	62.89	-149.91	5.1	51.6 mi (83.0 km)	43.6 mi (70.2 km)	strike-slip
6/5/14	62.85	-149.40	3.8	49.3 mi (79.4 km)	27.4 mi (44.1 km)	strike-slip
6/20/14	63.12	-149.32	4.4	50.6 mi (81.5 km)	32.3 mi (51.9 km)	strike-slip

7/25/14	62.88	-148.26	3.7	37.3 mi (60.0 km)	9.6 mi (15.4 km)	oblique reverse
9/1/14	62.97	-149.93	3.5	53.6 (86.3 km)	45.1 mi (72.6 km)	strike-slip
10/6/14	62.94	-148.33	3.9	40.3 mi (64.9 km)	10.2 mi (16.5 km)	normal
11/8/14	62.74	-148.74	3.6	37.6 mi (60.km)	8.8 mi (14.1 km)	normal
11/29/14	62.54	-148.06	4.6	38.6 mi (62.1 km)	24.5 mi (39.5 km)	oblique reverse

References: AEIC, 2013a-d, AEIC, 2014a-b; AEC, 2014a-b, 2015

Table 3-2. Focal Mechanism Parameters, SWSN Area, 2012-2014

Event Date	Strike1 (deg)	Dip1 (deg)	Rake1 (deg)	Strike2 (deg)	Dip2 (deg)	Rake2 (deg)	T-axis (azimuth) (deg)	T-axis (plunge) (deg)	P-axis (azimuth) (deg)	P-axis (plunge) (deg)
Crustal Events										
10/17/12	281	67	132	35	47	33	238	50	342	12
3/25/13	275	71	171	8	81	19	233	20	140	7
7/24/13	75	41	143	195	67	55	61	54	309	15
8/13/13	348	70	-27	88	65	-158	39	3	307	33
9/29/13	64	40	166	165	81	51	39	41	284	26
11/6/13	69	40	104	231	51	79	92	79	329	6
11/8/13	235	41	99	43	50	82	265	83	139	4
2/26/14	257	78	-174	166	84	-12	121	13	212	4
2/28/14	332	78	-9	64	81	-168	288	15	198	2
5/11/14	10	79	-2	100	88	-169	235	6	326	9
6/21/14	281	76	-154	184	65	-16	51	7	145	28
7/25/14	78	28	122	223	67	74	106	65	324	20
9/27/14	100	49	118	241	48	62	80	69	171	0
9/29/14	237	41	95	50	49	8	285	85	143	4
11/25/14	208	37	81	39	54	97	338	80	124	8

Intraslab Events										
1/21/13	110	81	14	18	76	171	243	3	334	16
3/2/13	118	59	40	5	57	142	241	1	332	49
10/23/13	222	67	-173	129	84	-23	83	21	178	11
1/3/14	223	46	-143	105	64	-50	64	53	168	11
1/13/14	85	85	-169	354	79	-5	310	11	219	4
1/20/14	37	46	132	165	58	55	279	6	20	60
3/20/14	5	32	-137	237	69	-65	181	59	308	20
4/16/14	109	71	31	8	61	158	331	35	237	7
6/5/14	92	81	16	359	74	171	316	18	225	5
6/20/14	10	73	159	106	70	18	328	27	59	2
7/25/14	53	58	177	145	87	32	14	24	274	20
9/1/14	5	88	-175	275	85	-2	140	2	230	5
10/6/14	133	37	-44	261	65	-118	11	16	129	59
11/8/14	98	12	-62	249	79	-96	344	34	152	55
11/29/14	126	60	-1	217	89	-150	347	20	85	21

Strike = azimuth of the horizontal line in a dipping plane or the intersection between a given plane and the horizontal surface
Dip = angle of plane from horizontal, positive downward
Rake = angle between a linear element that lies in a given plane and the strike of that plane
T-axis = tension axis; minimum compressive stress direction
P-axis = pressure axis; maximum compressive stress direction
Plunge = angle of axis from horizontal, positive downward

4. EARTHQUAKE RECURRENCE

4.1 Recurrence Calculations

Recurrence calculations were performed for the period of SWSN operation for 2014, and also for the total period of operation from December 1, 2012, through December 31, 2014. Calculations were done for the total seismicity shown on Figures 4 and 7, respectively (for events within the Project Area), and separately for crustal (depth < 18.6 mi (30 km)) and intraslab (depth ≥ 18.6 mi (30 km)) seismicity.

The data set was not declustered. Declustering of magnitudes less than 3 (which comprise most of the data set) is problematical, as published declustering techniques rely on assumptions and observations from larger magnitudes only. In any case, aftershocks and swarm events appear to comprise a very small percentage of the total number of events, and the magnitude cutoff of 1.5 will likely eliminate most of such events from the data set. The recurrence calculations presented here thus show recurrence rates without declustering.

Three data sets were considered for each time span: crustal and intraslab seismicity combined, and crustal and intraslab seismicity independently. The seismicity was grouped into 0.5 magnitude unit bins, and the maximum likelihood technique of Weichert (1980) was employed. Tables 4-1 and 4-2 show the number of events in each bin, for the three data sets, for the two time spans. Preliminary calculations using minimum magnitudes (Mmin) of 1.0 and 1.5 showed that Mmin of 1.5 gave more stable results, and better consistency with rates of magnitude 3.0 and above. This appears to confirm the AEC conclusions that magnitudes are not complete at the level of magnitude 1.0 and less. The network outages discussed in section 2.3 are unlikely to have a significant impact on the calculations.

Table 4-1. Event Counts by Source and Magnitude Range, 2014

Magnitude Range	Crustal	Intraslab	Project Area Total
1.50 - 2.00	26	82	108
2.00 - 2.50	5	30	35
2.50 - 3.00	6	10	16
3.00 - 3.50	1	5	6
3.50 - 4.00	0	5	5
4.00 - 4.50	0	1	1
4.50 – 5.00	0	1	1

Table 4-2. Event Counts by Source and Magnitude Range, 12/1/2012 – 12/31/2014

Magnitude Range	Crustal	Intraslab	Project Area Total
1.50 - 2.00	50	159	209
2.00 - 2.50	11	65	76
2.50 - 3.00	9	27	36
3.00 - 3.50	2	12	14
3.50 - 4.00	1	6	7
4.00 - 4.50	0	2	2
4.50 – 5.00	0	1	1

Figures 19a-c and 20a-c show the maximum likelihood incremental fit to the observations for the three sources and the two time spans. In general the intraslab curves show better fits to the observations than for the crustal seismicity, probably due to the larger number of intraslab earthquakes. The fits are best for the combined data, with only one observation point lying outside the 95% model confidence bounds for the 2014 time span, and all lying within these bounds for the 2012-2014 time span.

The computed recurrence parameters are shown in Table 4-3 and 4-4. The parameters Acum and b are equivalent to *a* and *b* in the Gutenberg-Richter relation:

$$Log(N) = a - b(M) \quad (1)$$

Where *N* is the cumulative number of events greater than or equal to *M*. Acum(norm) is the Acum value normalized to square km/year, based on a Project Area area (Figure 4) of approximately 5,700 mi^2 (14,700 km^2). The similarity in parameters for the two time spans shows that seismicity rates calculated for magnitude >= 1.5 earthquakes appear to have been stable in the area over the two year period. This also suggests that the increase in rates associated with the addition of 3 stations in August 2013 (Figure 12) can be attributed to the increase in detection and location of events smaller than magnitude 1.5.

Table 4-3. Recurrence Parameters, 2014

Parameter	Crustal	Intraslab	Project Area Total
b	0. 913	0. 747	0. 780
Na	38.0	134.0	172.0
Acum	2.950	3.249	3.406
Acum(norm)	-1.216	-0.918	-0.760

Table 4-4. Recurrence Parameters, 12/1/2012 – 12/2014

Parameter	Crustal	Intraslab	Project Area Total
b	0.904	0. 747	0.777
Na	35.017	130.473	165.490
Acum	2.901	3.237	3.385
Acum(norm)	-1.265	-0.930	-0.781

Using the parameters in Tables 4-3, cumulative rates for various magnitude ranges can be computed for the network duration to date, using the Cornell and van Marke (1969) relation:

$$N(m) = Na\beta \exp(-\beta(m - m^0))/(1 - \exp(-\beta(m^u - m^0)) \quad (2)$$

Where $N(m)$ is the annual number of events greater than or equal to m, m^0 is minimum magnitude, m^u is maximum magnitude, Na is the number of events greater than or equal to m^0, and β is b x ln(10).

Table 4-5 shows the expected rates and return periods of magnitudes $\geq$3 through 6 based on these calculations, assuming the 25 month time span represents the most reliable estimate to date. The table indicates that about two M_L >= 4 events per year might be expected within the Susitna-Watana project area, one $M_L \geq 5$ would be expected about every three years, and a $M_L \geq 6$ about every 20 years, assuming magnitude 5 and greater events obey equation (1). Note that these rates are based on only 25 months of data, and are provisional and subject to future updates based on a longer data record. Note that given the calculated rate of $M_L \geq 6$ events, within the past 100 years five such events would be expected to exist in the historic record in the Susitna-Watana project area of Figure 4, and none exist in the historic record. In a larger region encompassing the Susitna-Watana project area (FCL, 2012;

Figure 23), four M_L 6 events have been recorded in an area about twice as large as the project area of Figure 4. Therefore, scaling by area, about 10 $M_L \geq 6$ events would be expected in the larger region of Figure 23 of FCL (2012), whereas only 4 have occurred. The recurrence statistics computed here thus appear to overestimate the rate of $M_L \geq 6$ events in the larger region surrounding the project area by about a factor of 2. Therefore it is inadvisable to extrapolate recurrence rates beyond magnitudes observed in the relatively short 25 month time period of this analysis.

It is clear from Table 4-5 and Figure 20 that recurrence statistics are dominated by the intraslab earthquakes: of the total number in the Project Area only 21% are crustal and only 3 of the 24 events of magnitude 3 and greater (13%) are crustal. While return periods for crustal event magnitudes are listed in Table 4-3, a low level of confidence should be assumed for these values.

Table 4-5. Annual Rates and Return Periods for the Project Area, December 1, 2012- December 31, 2014

Magnitude	Crustal		Intraslab		Project Area (Total)	
	Annual Rate	Return Period (yrs)	Annual Rate	Return Period	Annual Rate	Return Period
>= 3	1.545	0.65	9.908	0.10	11.324	0.09
>= 4	0.193	5.19	1.774	0.56	1.892	0.53
>= 5	0.024	41.59	0.318	3.16	0.316	3.16
>= 6	0.003	333.43	0.057	17.58	0.053	18.92

Seismicity plots at many scales, e.g. Figure 1, Figure 4, and plots in FCL (2012), show a marked decrease in the apparent activity rates southeast of the proposed Susitna-Watana dam site. The reason for this is unclear, but may be due to a tear, detachment, or other discontinuity in the Pacific Plate (see FCL 2012, 2014b) In detail, patterns between intraslab and crustal seismicity differ somewhat. For seismic source models, these differences correspond to the eastern margin of the intraslab source and to alternative crustal source zones with different rates of earthquake recurrence (e.g., SAB Central and SAB East in FCL, 2012).

These recurrence calculations produce average rates for the Project Area, and are designed to provide a pre-impoundment baseline for potential reservoir-triggered seismicity. As discussed in Section 2.2 and seen in Figures 4 and 7, the seismicity distribution is very heterogeneous, with the great majority of earthquakes occurring in the northwest and south-central portion of the Project Area. Activity rates in this part of the Project Area will clearly be higher, on a per-area basis, than rates in the eastern part.

5. CONCLUSIONS

With the installation of the SWSN, the seismic station density in the region has increased. This has led to greater magnitude detection capabilities, a decrease in magnitude of completeness, and greater location accuracy. In 2014 SWSN recorded 1,387 low magnitude events, an average of 3.8 events per day (1.8 crustal events per day and 2.0 intraslab events per day). Since its initiation on November 16, 2012 through December 2014, 2,523 earthquakes have been recorded. This represents an average of 3.2 events per day (1.4 crustal events and 1.8 intraslab events per day). The 2014 averages are higher than the 2012-2014 averages, but this is likely due to the addition of three stations in August 2013 which allowed more earthquakes to be located. The increase in number and location quality of local earthquakes since November 2012 has led to a more accurate picture of shallow crustal seismicity and of seismicity associated with the subducting Pacific Plate below the proposed dam site (Figure 8).

Focal mechanisms produced by the AEC in the SWSN Area indicate that the crust around the proposed dam site is undergoing north-northwest south-southeast horizontal compression, consistent with the relative Pacific – North America plate motion, with the maximum horizontal stress rotating in a counterclockwise direction from east to west in the network area. This appears to be consistent with what is known about the seismotectonic regime in the project area (Haeussler et al., 2008) and with other studies in the area (Ratchkovski and Hansen, 2002; Fuis et al., 2008; and Ruppert, 2008).

Stresses within the downgoing Pacific Plate appear to be characterized primarily by strike-parallel horizontal compression. Three mechanisms, however, indicate normal faulting, which implies vertical or downdip slab pull and/or gravity as the causative force. Larger, damaging intraslab earthquakes appear to be of this type (e.g., Ichinose et al, 2006 for the Puget Sound region; Apperson and Frohlich, 1987, globally). Therefore it should not be concluded that the stress observations and faulting types from these small magnitude events can be extrapolated to larger ones. It may be possible that smaller earthquakes in this environment respond to slab strike-parallel stresses, while the larger, more damaging ones respond to downdip, gravity-driven extension.

For intraslab strike-slip/reverse slab mechanisms, both P and T-axes appear to mimic the same counterclockwise rotation from east to west observed in the crustal P-axes, but with the slab P-axes oriented about 80 degrees more westerly than the crustal ones, more consistent with the strike of the slab.

Based on recurrence calculations for the period of December 1, 2012 through December 31, 2014, about two $M_L \geq 4$ events per year can be expected within the Susitna-Watana project area, a $M_L \geq 5$ event can be expected about every three years, and one of $M_L \geq 6$ about every 20 years. These return periods pertain primarily to the intraslab earthquakes, which dominate the recurrence statistics. Due to the relatively small number of crustal earthquakes (and only 3 in the magnitude 3 range) recurrence statistics for crustal seismicity should not be considered reliable. The extrapolated rates for the larger events are somewhat higher than those indicated by longer-term historical and prior network data (e.g., FCL, 2012). However, the current recurrence calculations are based on a limited amount of data and largest event of M_L 4.6, since the Susitna-Watana Seismic Network has only been active for 25 months. It also is important to note that because of the short amount of time in which data has been recorded, these rates should not be extrapolated for larger events.

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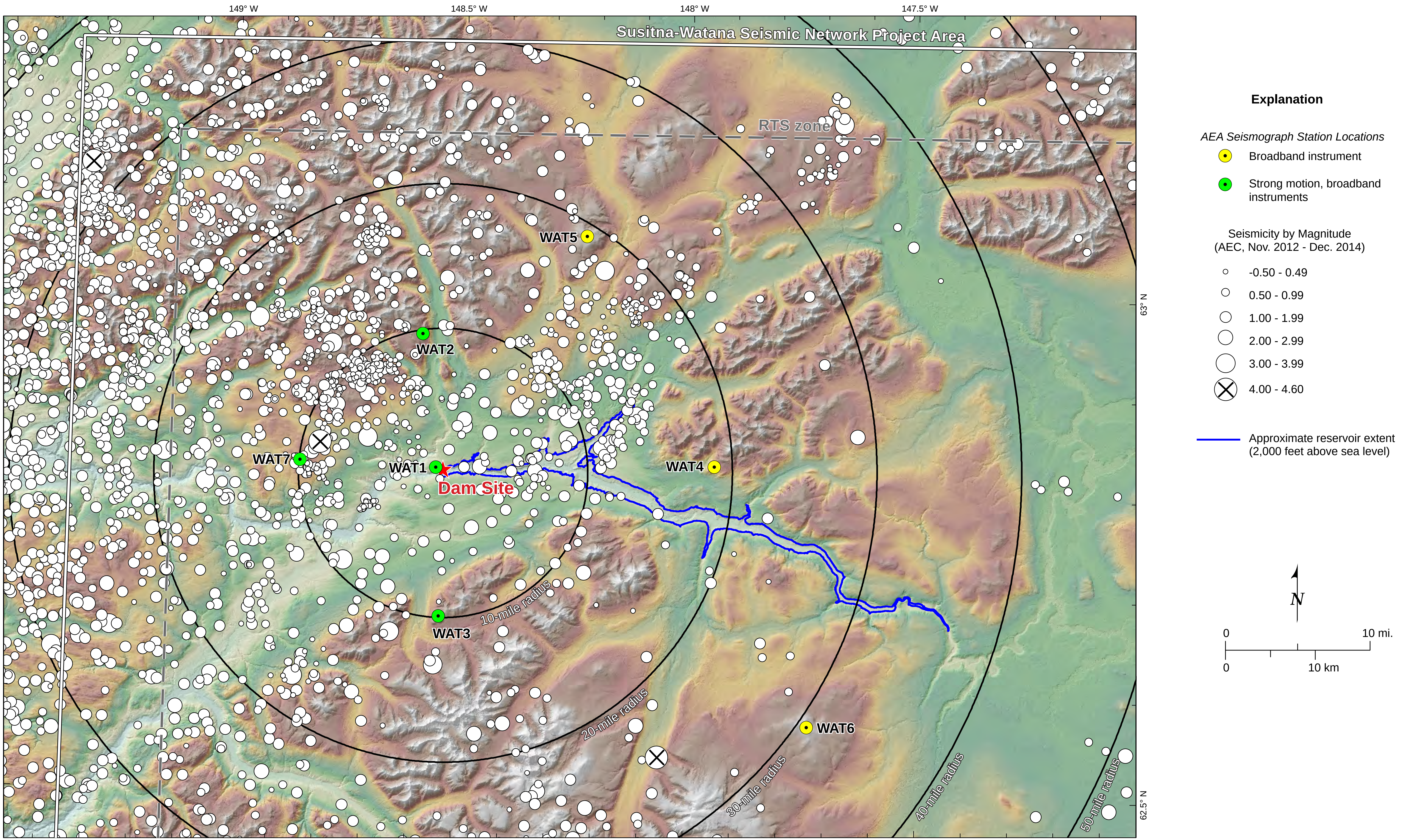
Figures



FUGRO

Date 03/31/15

STATE OF ALASKA
ALASKA ENERGY AUTHORITY
ALASKA ENERGY AUTHORITY

SUSITNA-WATANA HYDROELECTRIC PROJECT
SUSITNA-WATANA SEISMIC NETWORK
LOCATION PLAN AND NOVEMBER 16, 2012
THROUGH DECEMBER 31, 2014 SEISMIC EVENTS

FIGURE
1

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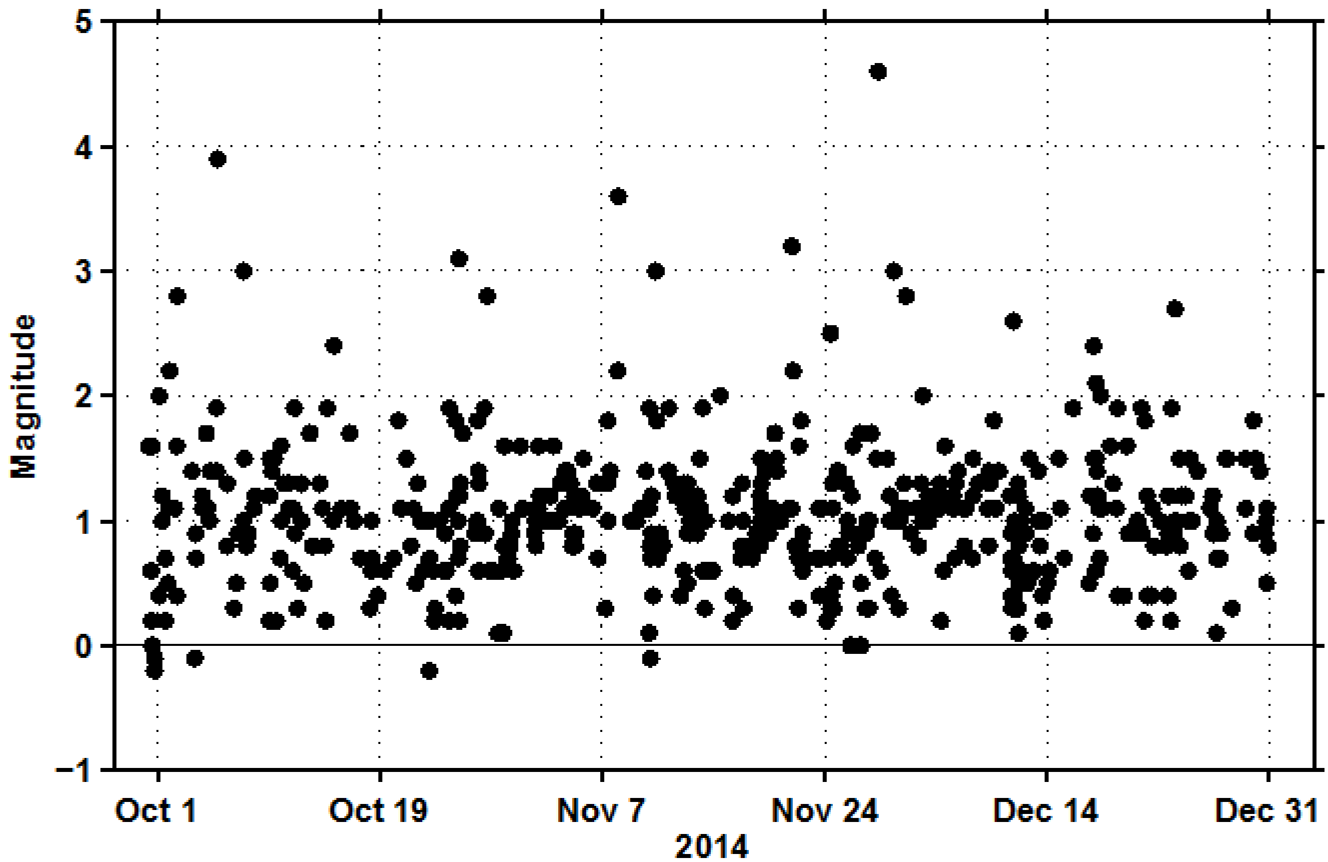

Image from AEC (2015).

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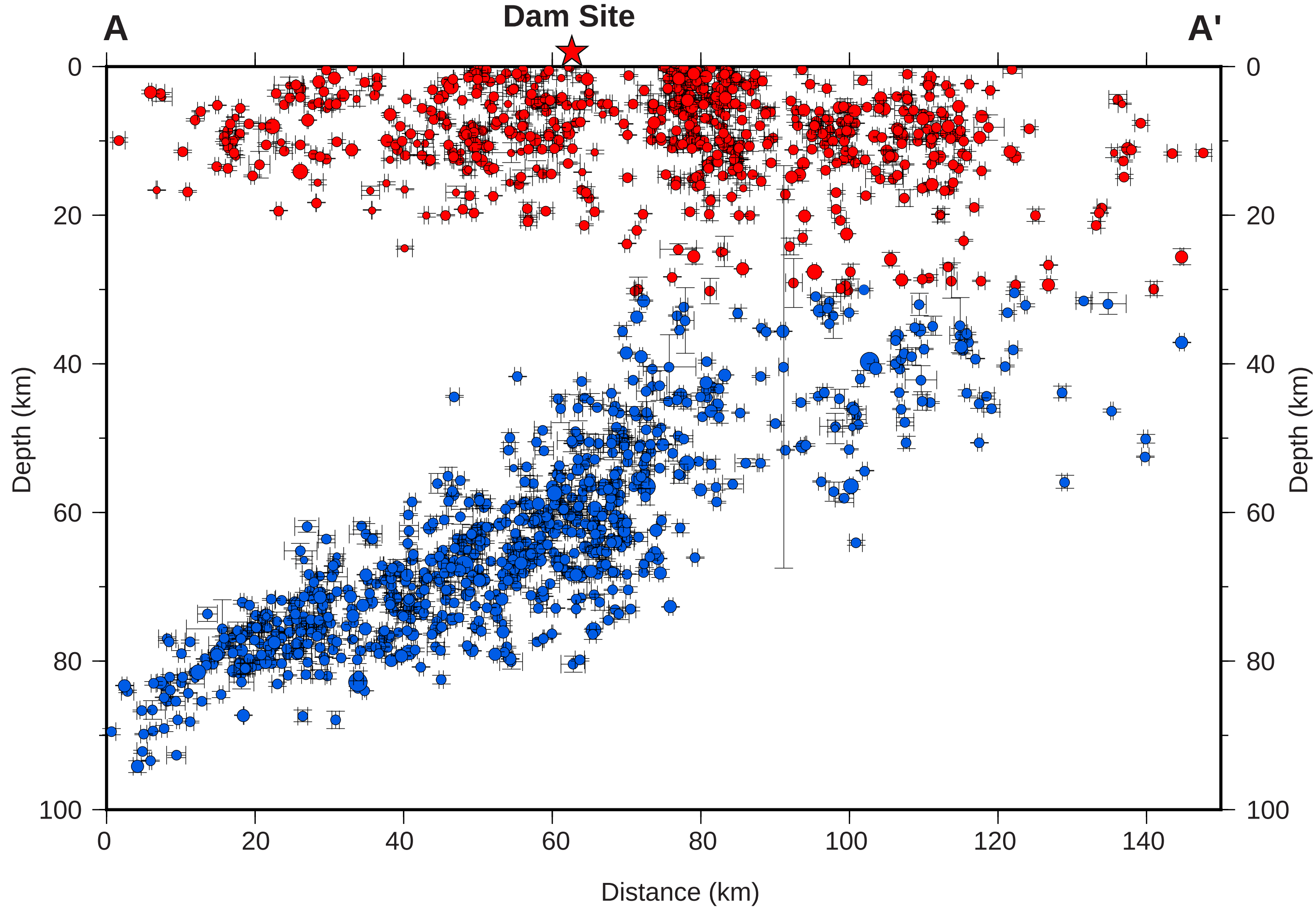
FUGRO Date 03/31/15	STATE OF ALASKA ALASKA ENERGY AUTHORITY ALASKA ENERGY AUTHORITY	SUSITNA-WATANA HYDROELECTRIC PROJECT MAGNITUDE VS TIME, OCTOBER-DECEMBER, 2014	FIGURE 2

2010 - November 15, 2012

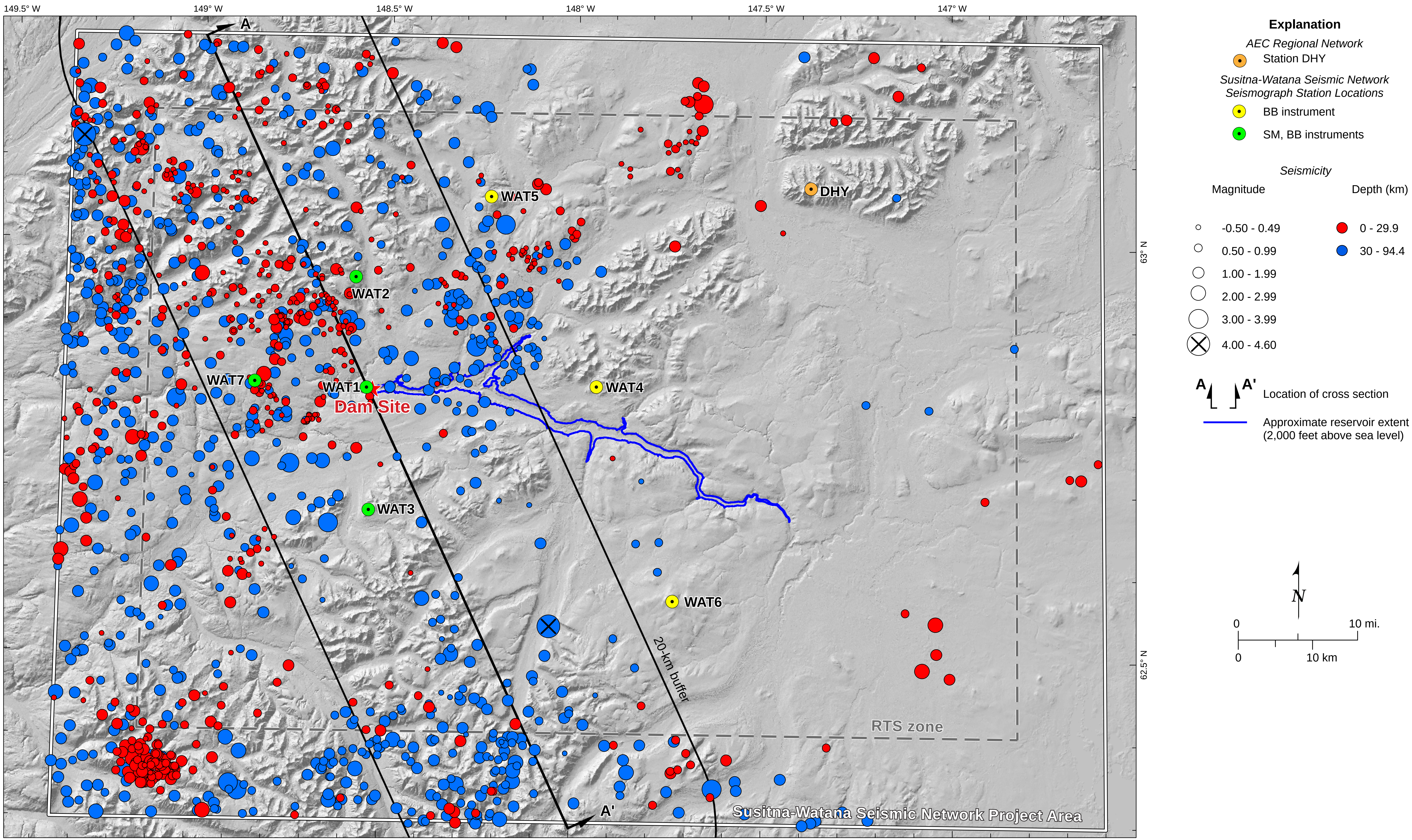


Explanation

- Crustal event (depths <30 km)
- Intraslab event (depths ≥30 km)

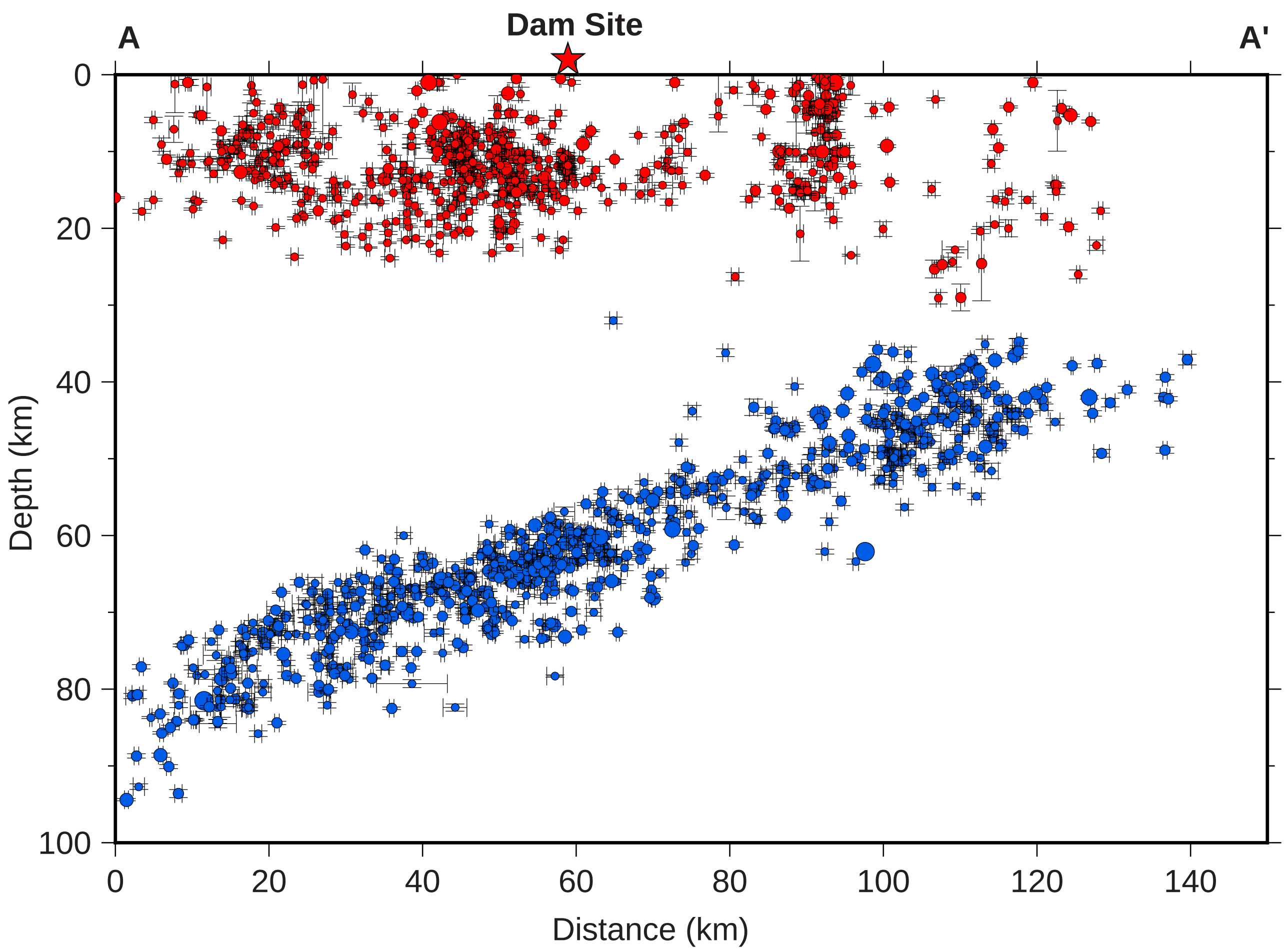
Notes: 1. Vertical and horizontal standard location errors are shown.
2. Location of section is shown on Figure 4.

FUGRO	STATE OF ALASKA ALASKA ENERGY AUTHORITY	SUSITNA-WATANA HYDROELECTRIC PROJECT	FIGURE
Date 03/31/15	ALASKA ENERGY AUTHORITY	SEISMICITY IN THE SUSITNA-WATANA PROJECT AREA, PRE-2012 NETWORK – SECTION	3



fwla-wc-file1/project/Projects/79_2000/79_218900_Alaska_Railbelt/05_Graphics/Seismicity Report February 2015

FUGRO Date 03/31/15	STATE OF ALASKA ALASKA ENERGY AUTHORITY ALASKA ENERGY AUTHORITY	SUSITNA-WATANA HYDROELECTRIC PROJECT SEISMICITY FROM JANUARY 1, 2014 THROUGH DECEMBER 31, 2014	FIGURE 4

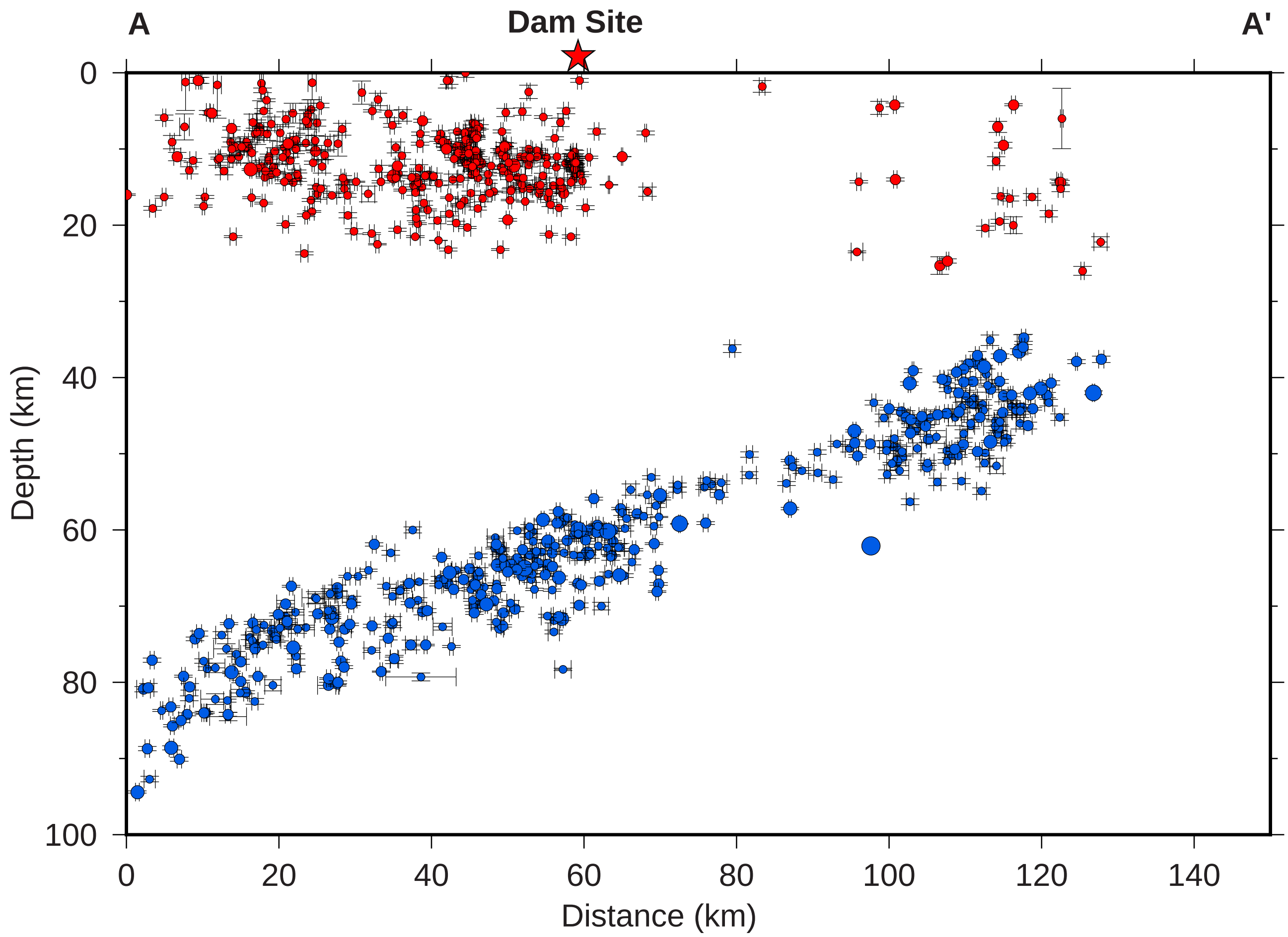


Explanation

- Crustal event (depths <30 km)
- Intraslab event (depths ≥30 km)

Notes: 1. Vertical and horizontal standard location errors are shown.
2. Location of section is shown on Figure 4.

FUGRO Date 03/31/15	STATE OF ALASKA ALASKA ENERGY AUTHORITY ALASKA ENERGY AUTHORITY	SUSITNA-WATANA HYDROELECTRIC PROJECT CROSS SECTION OF JANUARY 1, 2014 THROUGH DECEMBER 31, 2014 SEISMICITY IN FIGURE 4	FIGURE 5



Explanation

- Crustal event (depths <30 km)
- Intraslab event (depths ≥30 km)

Notes: 1. Vertical and horizontal standard location errors are shown.
2. Location of section is shown on Figure 4.

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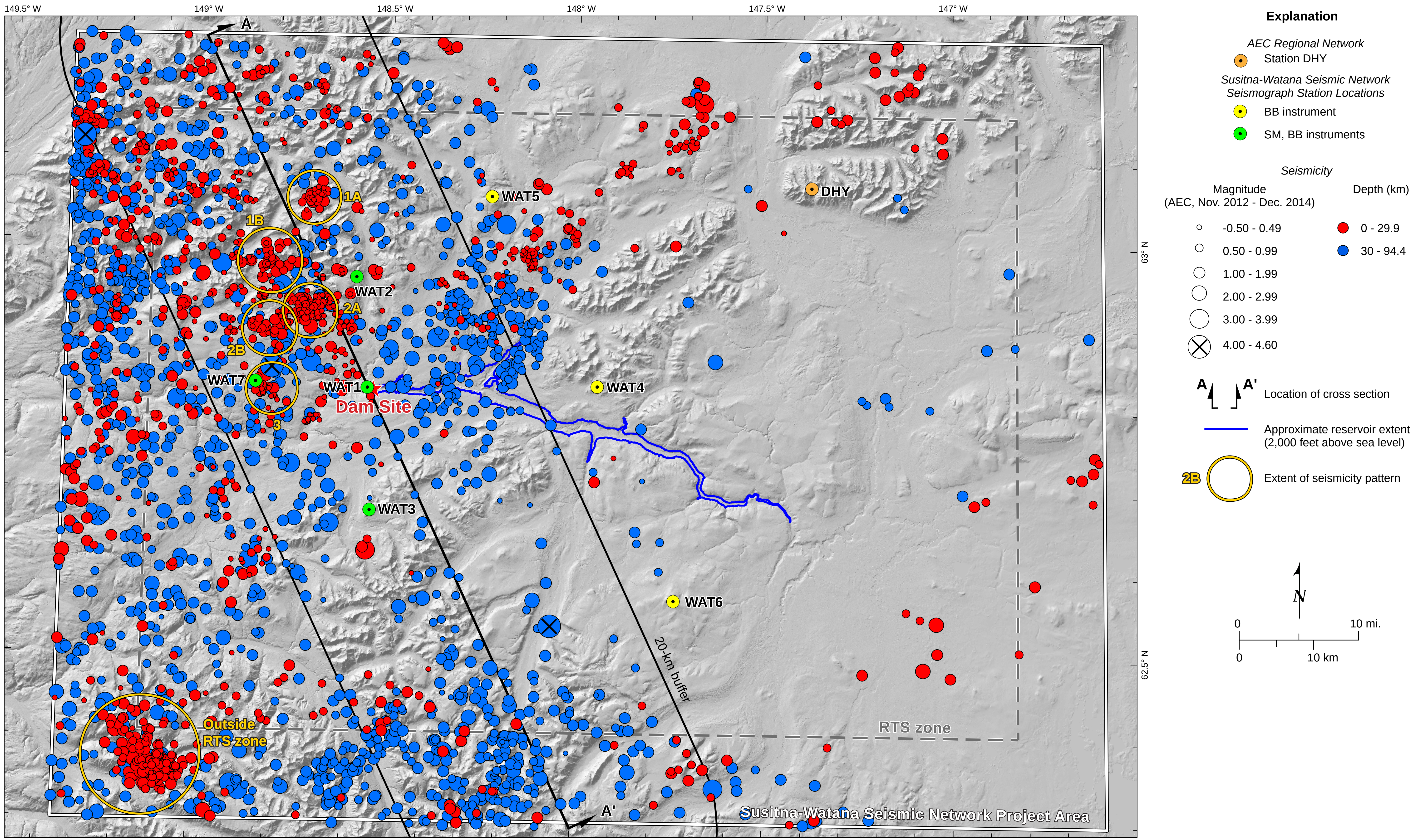
STATE OF ALASKA
ALASKA ENERGY AUTHORITY
ALASKA ENERGY AUTHORITY

SUSITNA-WATANA HYDROELECTRIC PROJECT
CROSS SECTION OF JANUARY 1, 2014
THROUGH DECEMBER 31, 2014
SEISMICITY IN FIGURE 4 WITHIN 20-KM BUFFER

FIGURE
6



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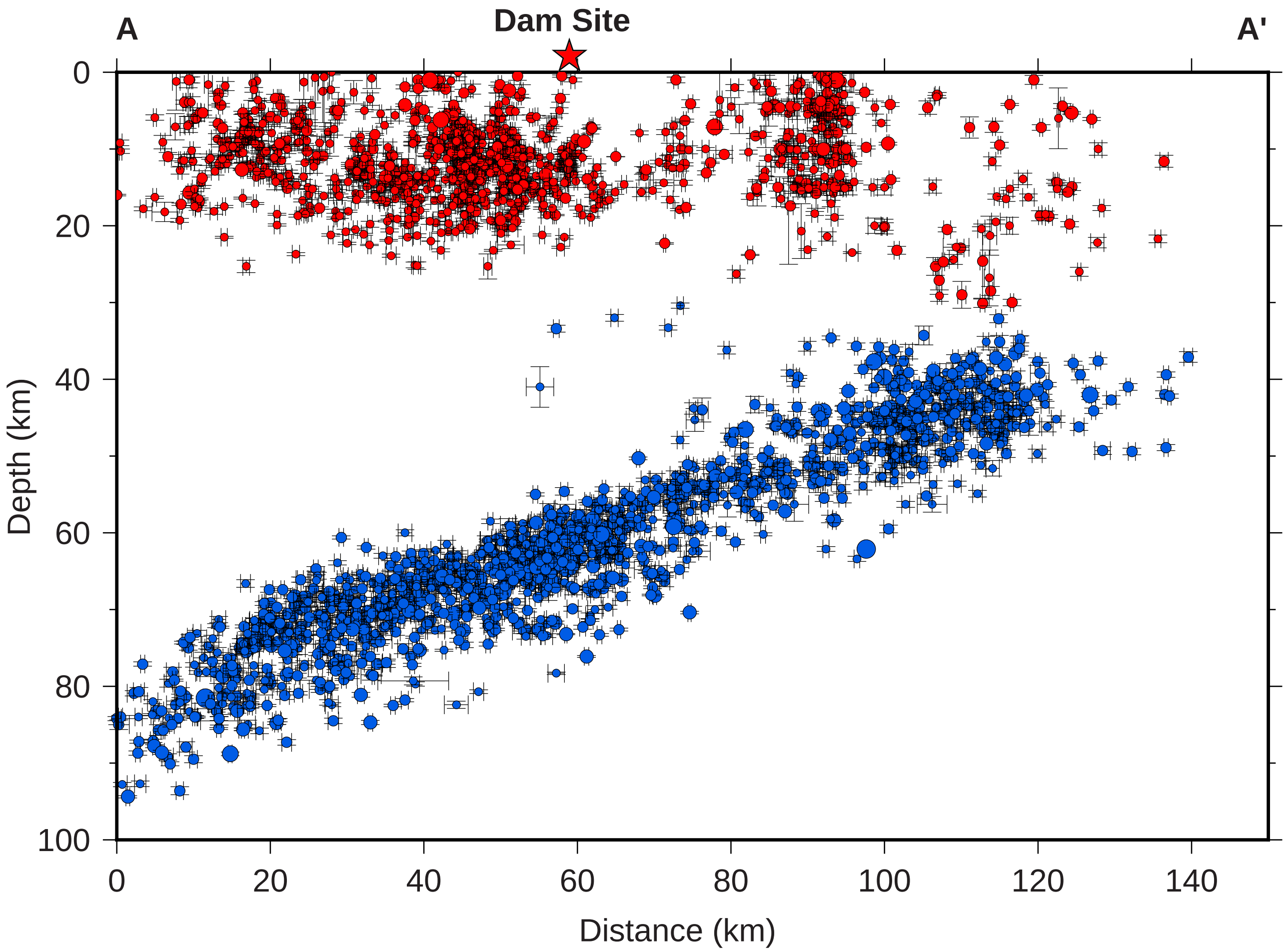
STATE OF ALASKA
ALASKA ENERGY AUTHORITY

SUSITNA-WATANA HYDROELECTRIC PROJECT

SEISMICITY FROM NOVEMBER 16, 2012 THROUGH DECEMBER 31, 2014 WITH NOTABLE SEISMICITY PATTERNS

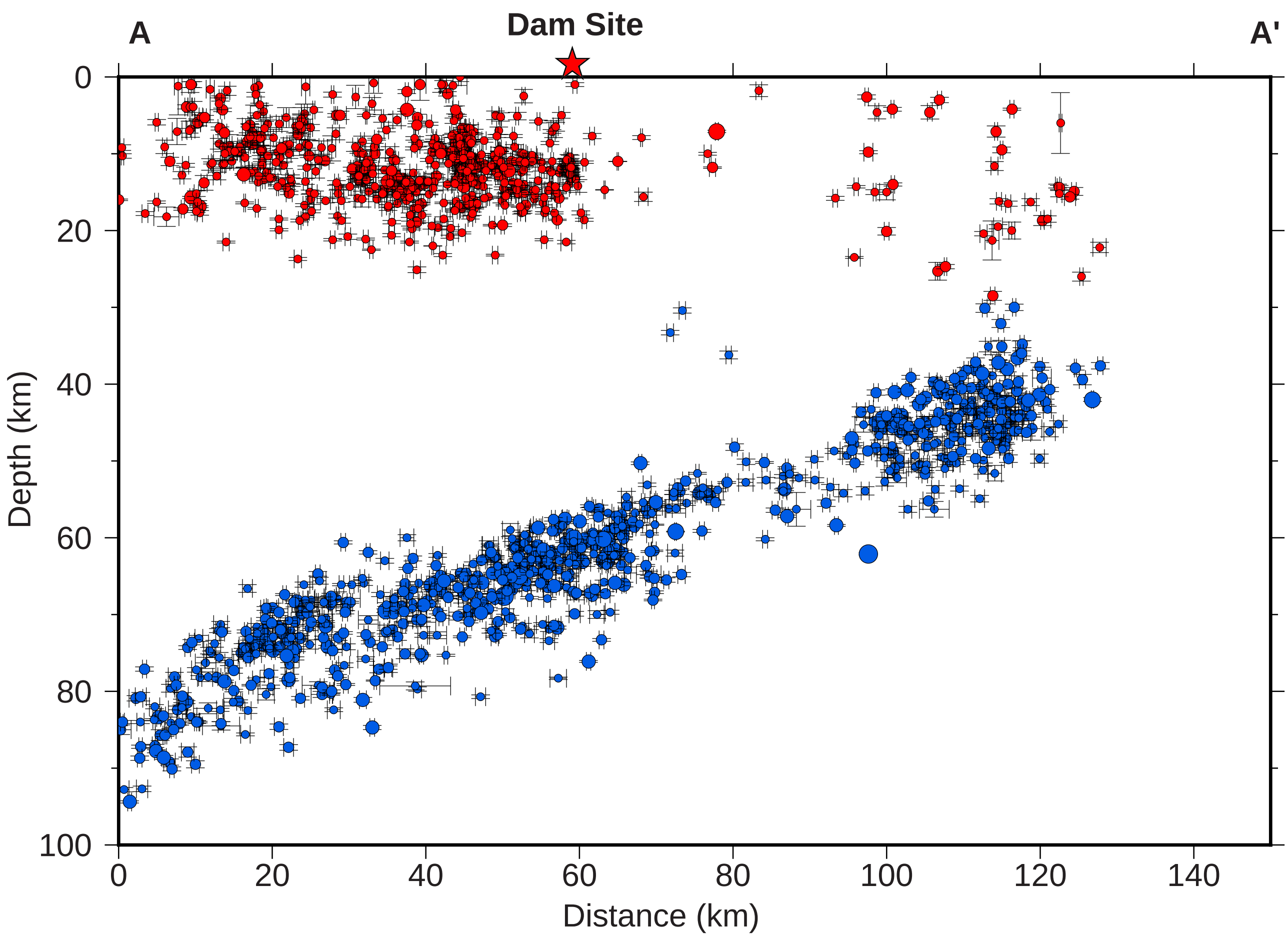
FIGURE 7



Explanation

- Crustal event (depths <30 km)
- Intraslab event (depths ≥30 km)

Notes: 1. Vertical and horizontal standard location errors are shown.
2. Location of section is shown on Figure 7.



Explanation

- Crustal event (depths <30 km)
- Intraslab event (depths ≥30 km)

Notes: 1. Vertical and horizontal standard location errors are shown.
2. Location of section is shown on Figure 7.

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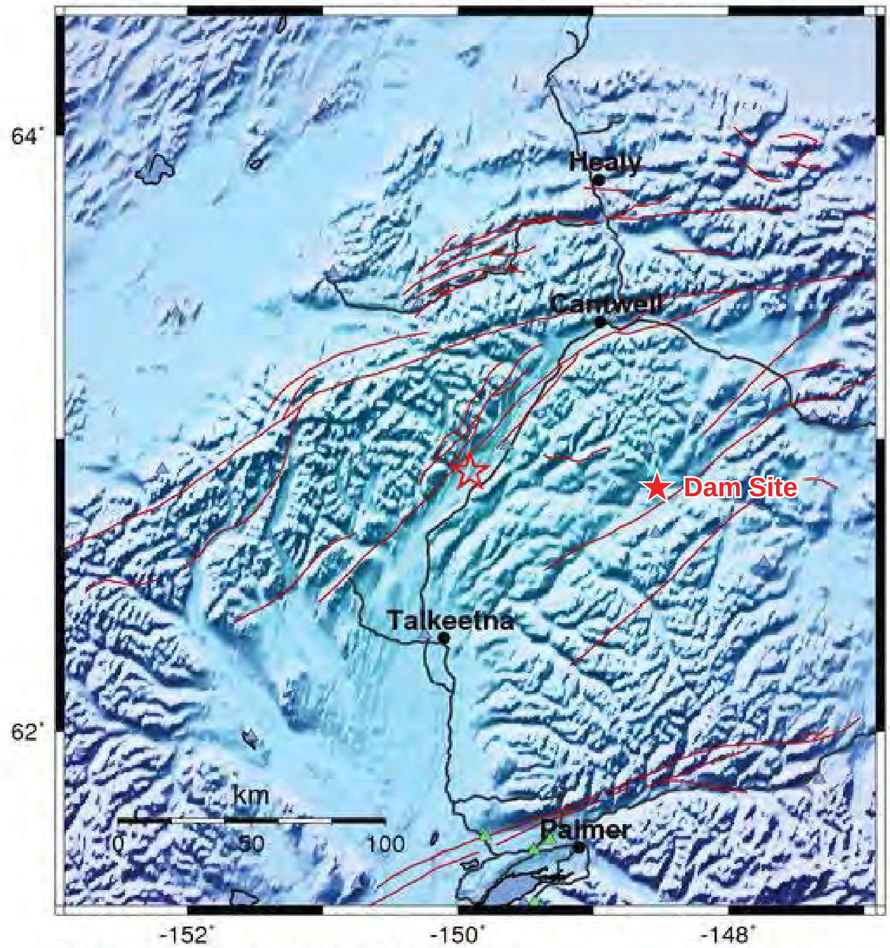
SUSITNA-WATANA HYDROELECTRIC PROJECT

CROSS SECTION OF JANUARY 1, 2014
THROUGH DECEMBER 31, 2014
SEISMICITY IN FIGURE 4 WITHIN 20-KM BUFFER

FIGURE
9

AEIC ShakeMap : 39.6 miles N of Talkeetna

Apr 16, 2014 12:24:23 PM YDT M 5.1 N62.89 W149.91 Depth: 82.9km ID:11230823



Map Version 3 Processed Sun Apr 20, 2014 09:30:46 PM YDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	*<0.02*	*0.1*	*1.4*	*4.7*	*9.6*	*20*	*41*	*86*	*>178*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

fwla-wc-file1/project/Projects/79_2000/79_218900_Alaska_Railbelt/05_Graphics/Seismicity Report February 2015

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STATE OF ALASKA
ALASKA ENERGY AUTHORITY

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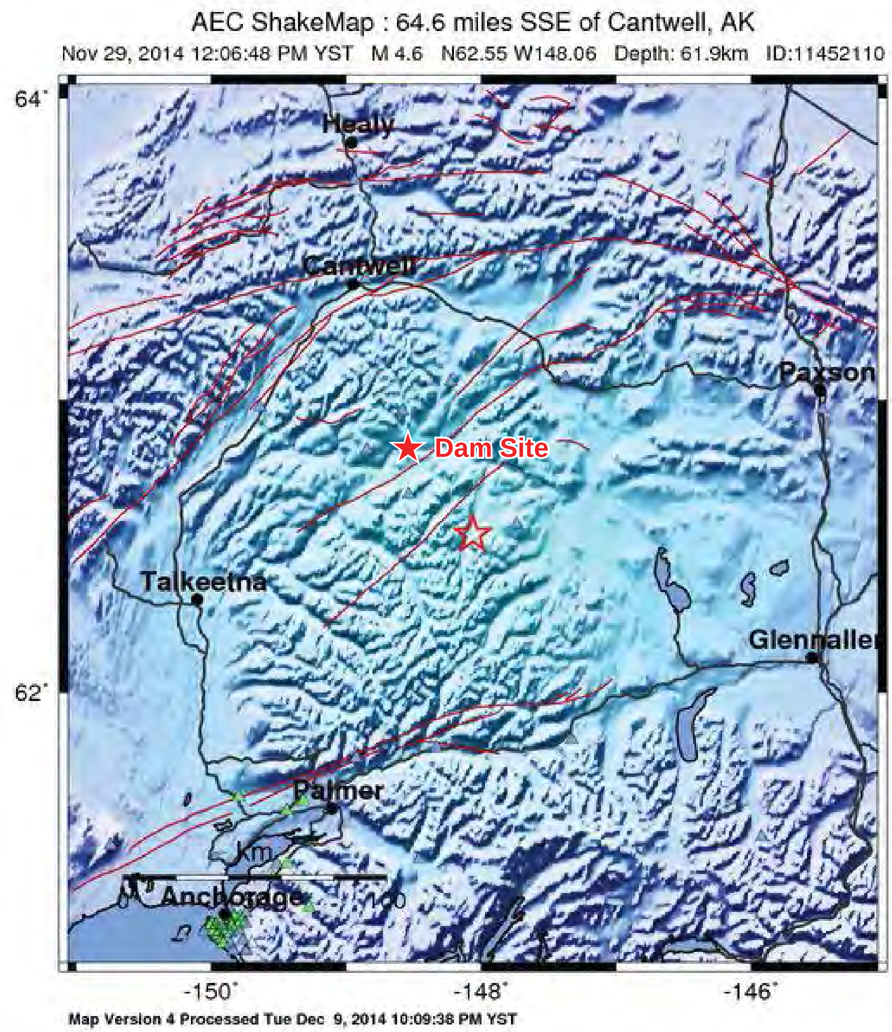
SUSITNA-WATANA HYDROELECTRIC PROJECT

USGS SHAKEMAP OF 4/16/2014 ML 5.1 EVENT

FIGURE 10



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

fwla-wc-file1/project/Projects/79_2000/79_218900_Alaska_Railbelt/05_Graphics/Seismicity Report February 2015

FUGRO

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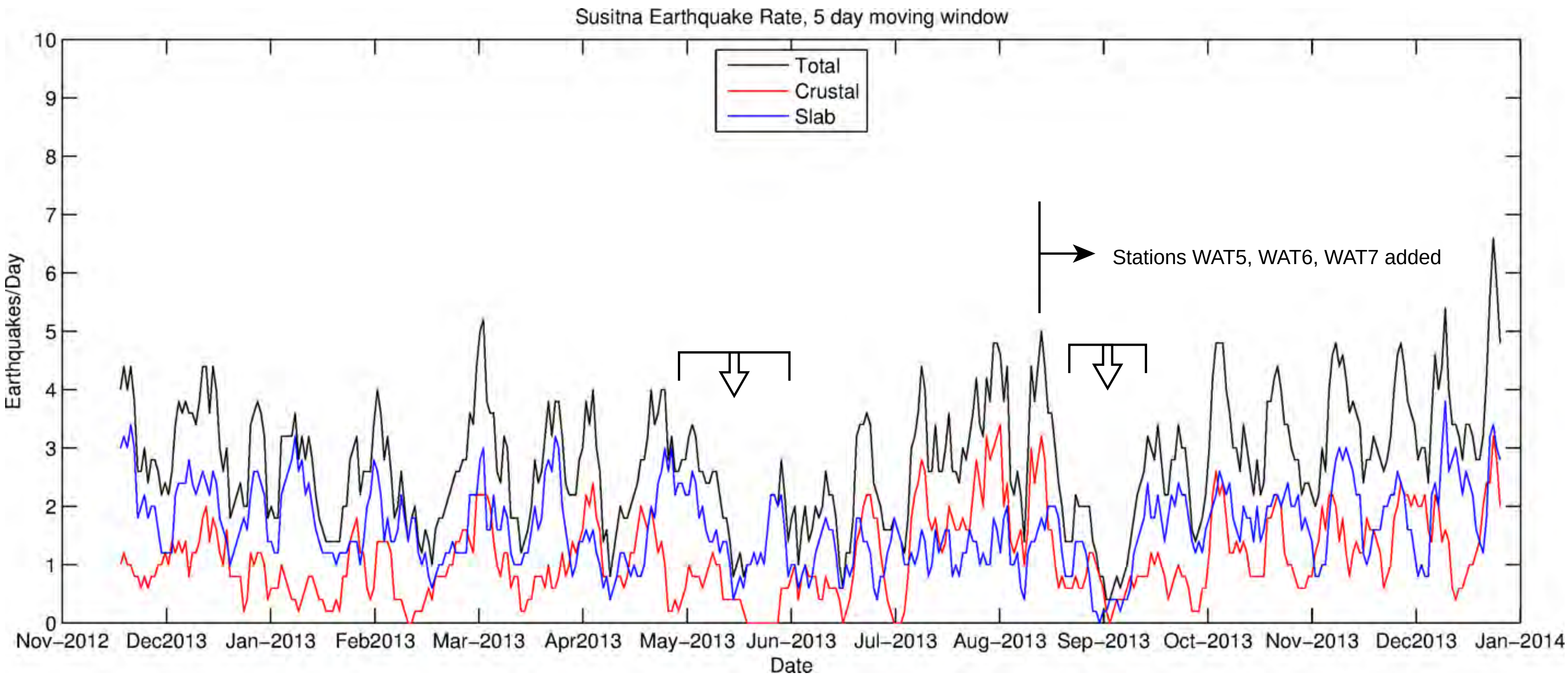
STATE OF ALASKA
ALASKA ENERGY AUTHORITY

ALASKA ENERGY AUTHORITY

SUSITNA-WATANA HYDROELECTRIC PROJECT

USGS SHAKEMAP OF 11/29/2014 ML 4.6 EVENT

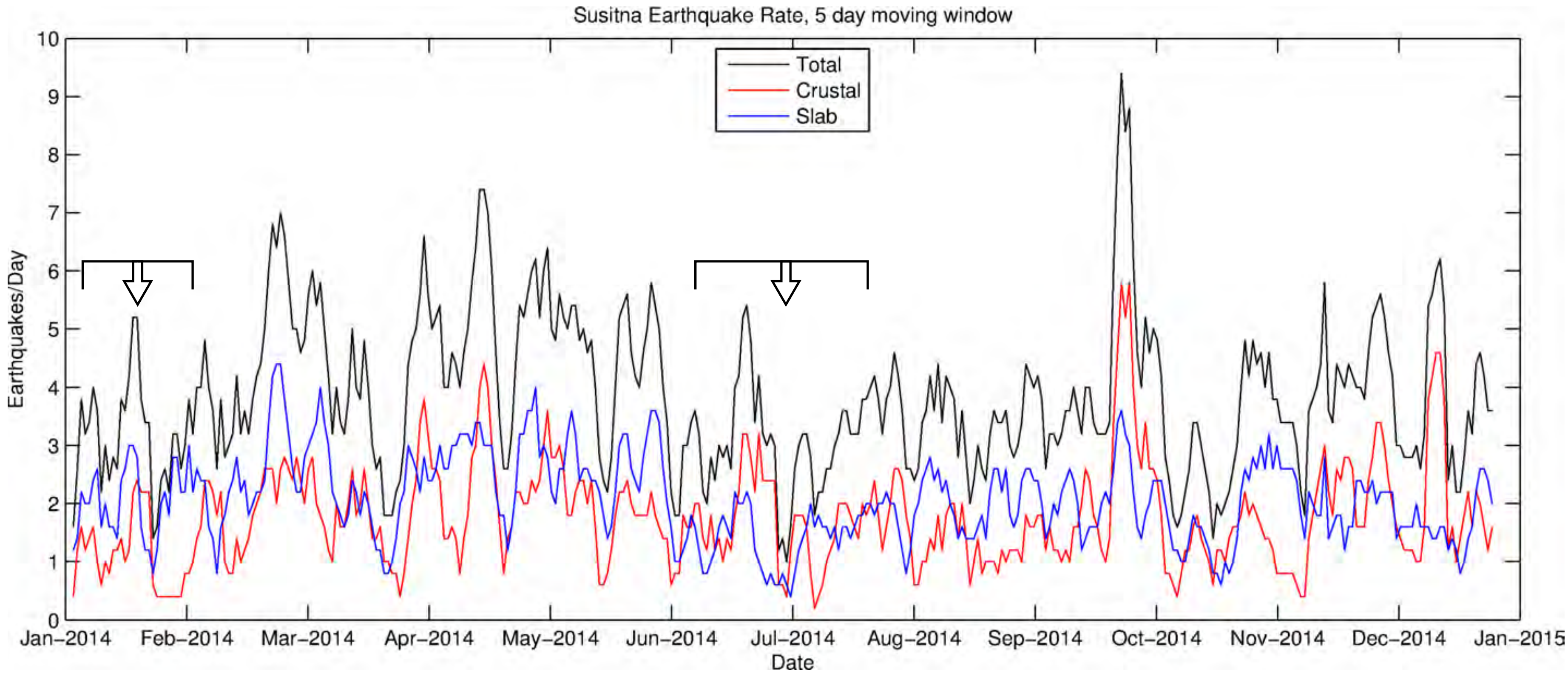
FIGURE
11



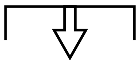
Explanation

Network station dropouts (see text)

FUGRO Date 03/31/15	STATE OF ALASKA ALASKA ENERGY AUTHORITY ALASKA ENERGY AUTHORITY	SUSITNA-WATANA HYDROELECTRIC PROJECT DAILY AVERAGE EARTHQUAKE RATES OF SEISMICITY IN PROJECT AREA, 2013	FIGURE 12

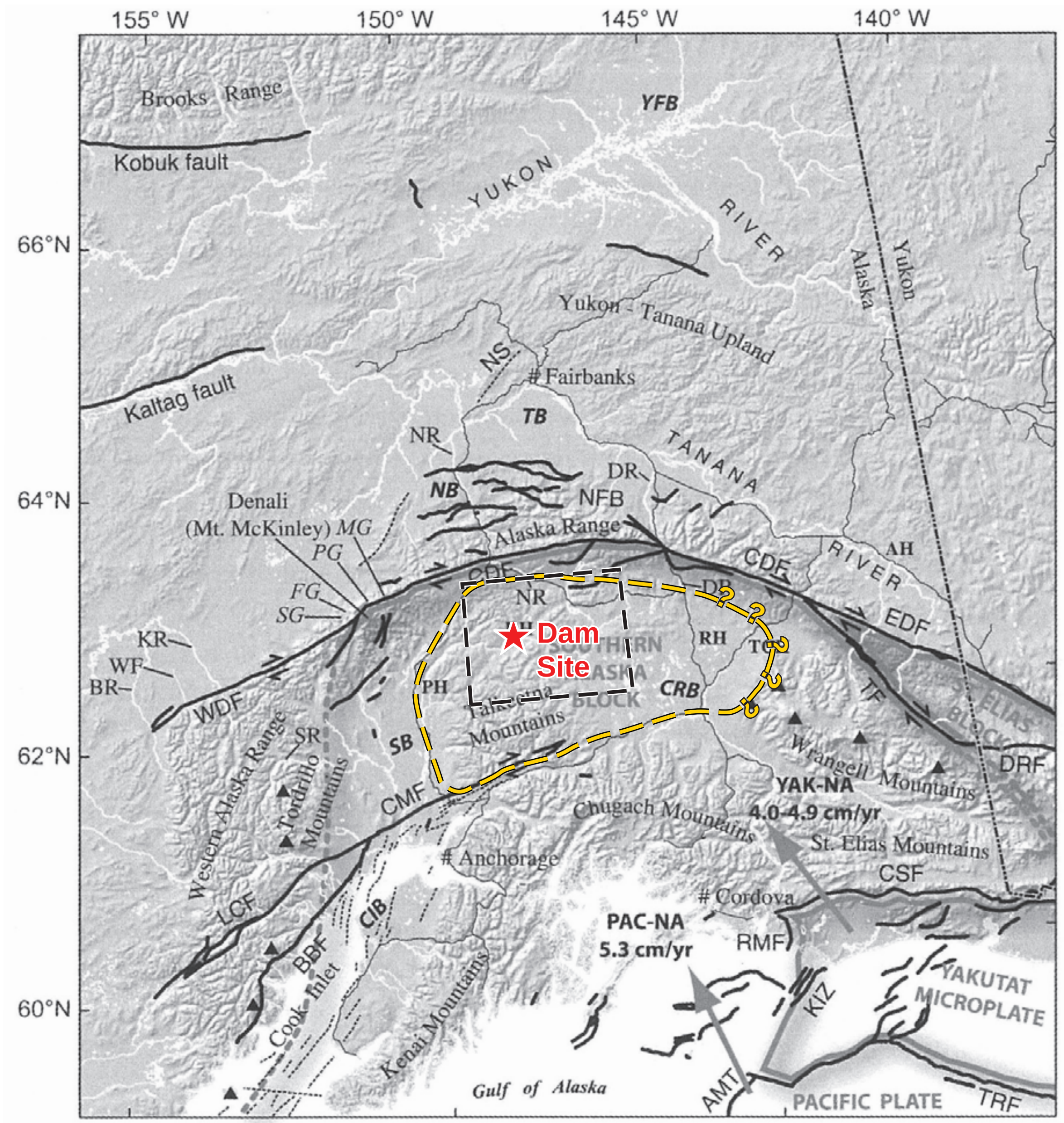


Explanation



Network station dropouts (see text)

FUGRO Date 03/31/15	STATE OF ALASKA ALASKA ENERGY AUTHORITY ALASKA ENERGY AUTHORITY	SUSITNA-WATANA HYDROELECTRIC PROJECT DAILY AVERAGE EARTHQUAKE RATES OF SEISMICITY IN PROJECT AREA, 2014	FIGURE 13



Explanation

Approximate boundary of Talkeetna block

Approximate boundary of Figures 4 and 7

N

0 300 km

Black lines are Neogene and active faults, dashed lines are anticlines. Triangles show active volcanoes. Crustal blocks are outlined in gray and are dashed where boundaries are uncertain. Faults: WDF, western Denali fault; CDF, central Denali fault; EDF, eastern Denali fault; NFB, northern foothills fold-and-thrust belt; NS, Nenana structure; TF, Totschunda fault; DRF, Duke River fault; LCF, Lake Clark fault; CMF, Castle Mountain fault; BBF, Bruin Bay fault; CSF, Chugach-St. Elias thrust fault; KIZ, Kayak Island fault zone; RMF, Ragged Mountain fault; AMT, Aleutian megathrust; TRF, Transition fault. Major roads are shown with thin black lines. AH, Alaska highway; PH, Parks highway; DH, Denali highway; RH, Richardson highway; DH, Denali highway; TCH, Tok cutoff highway. Abbreviated river names mentioned in text: NR, Nenana River, Delta River (both rivers flow north); BR, Big River; WF, Windy Fork; KR, Kuskokwim River; SR, Skwentna River. Glaciers: SG, Straightaway Glacier; FG, Foraker Glacier; PG, Peters Glacier; MG, Muldow Glacier. Sedimentary basins: cm, Cook Inlet basin; SB, Susitna basin; CRB, Copper River basin; NB, Nenana basin; TB, Tanana basin; YFB, Yukon Flats basin. Modified from Haeussler, 2008.

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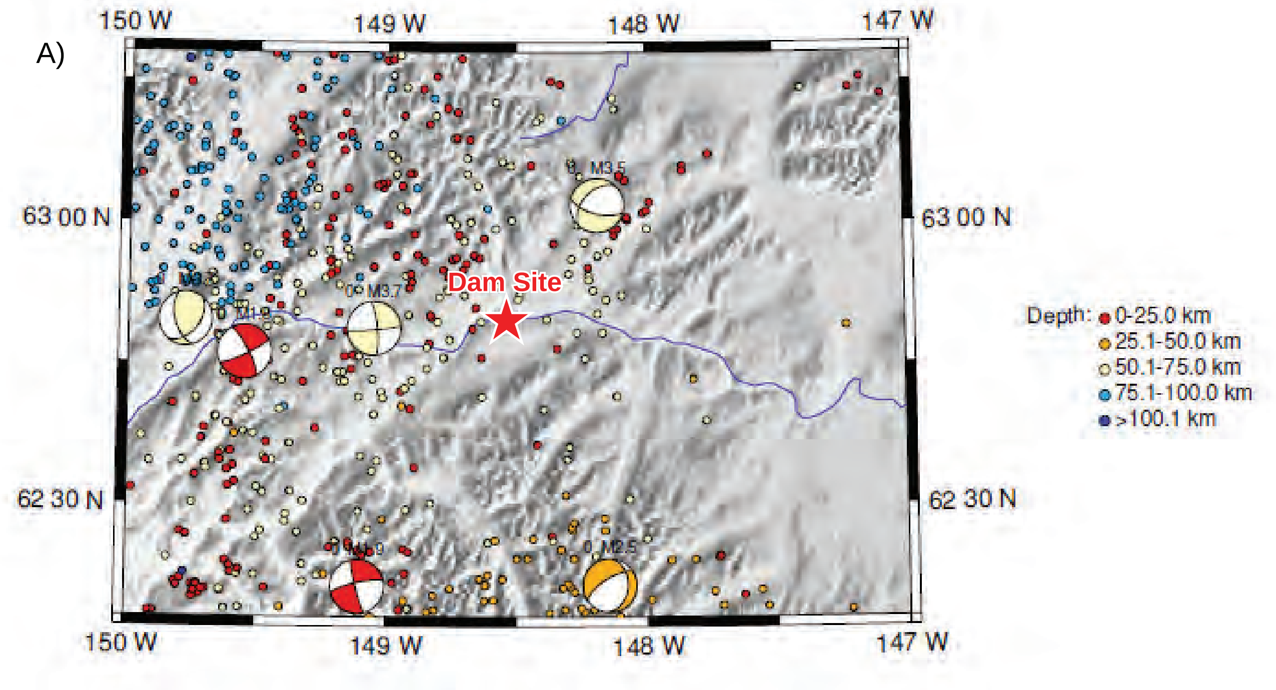
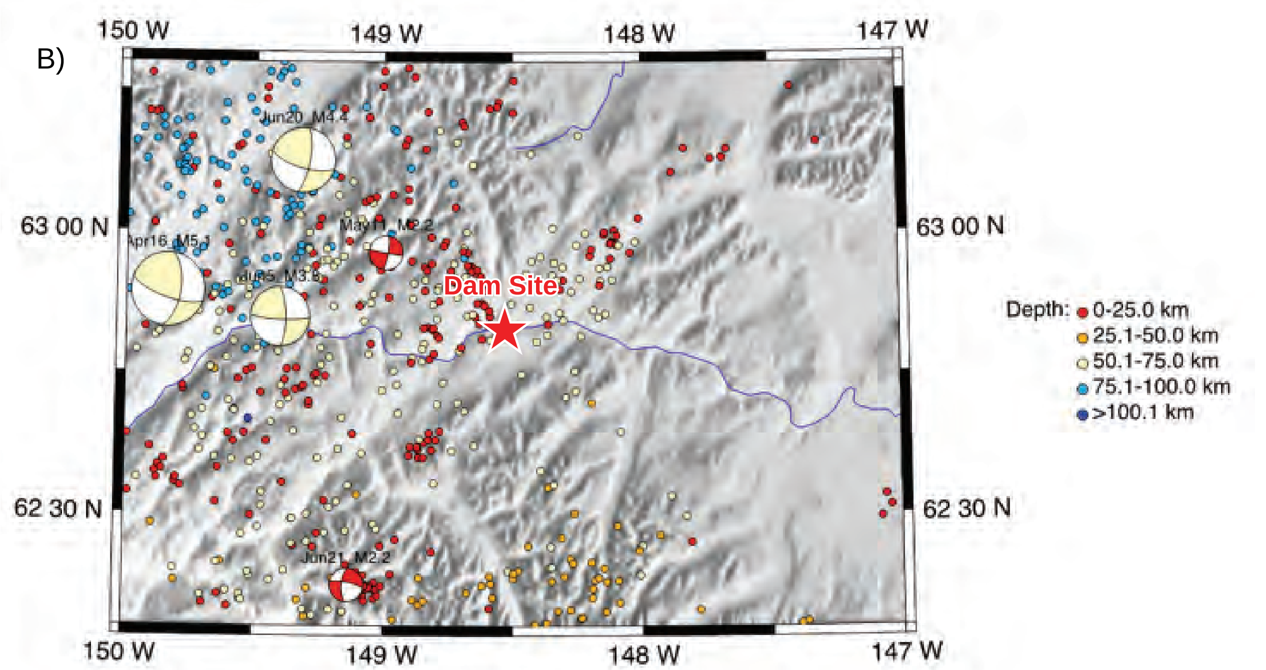
FUGRO Date 03/31/15	STATE OF ALASKA ALASKA ENERGY AUTHORITY ALASKA ENERGY AUTHORITY	SUSITNA-WATANA HYDROELECTRIC PROJECT TECTONIC OVERVIEW OF CENTRAL INTERIOR ALASKA	FIGURE 14

A)



Quarter 1, 2014
(image from AEIC, 2014b)

B)



Quarter 2, 2014
(image from AEC, 2014a)

fwla-wc-file1/project/Projects/79_2000/79_218900_Alaska_Railbelt/05_Graphics/Seismicity Report February 2015

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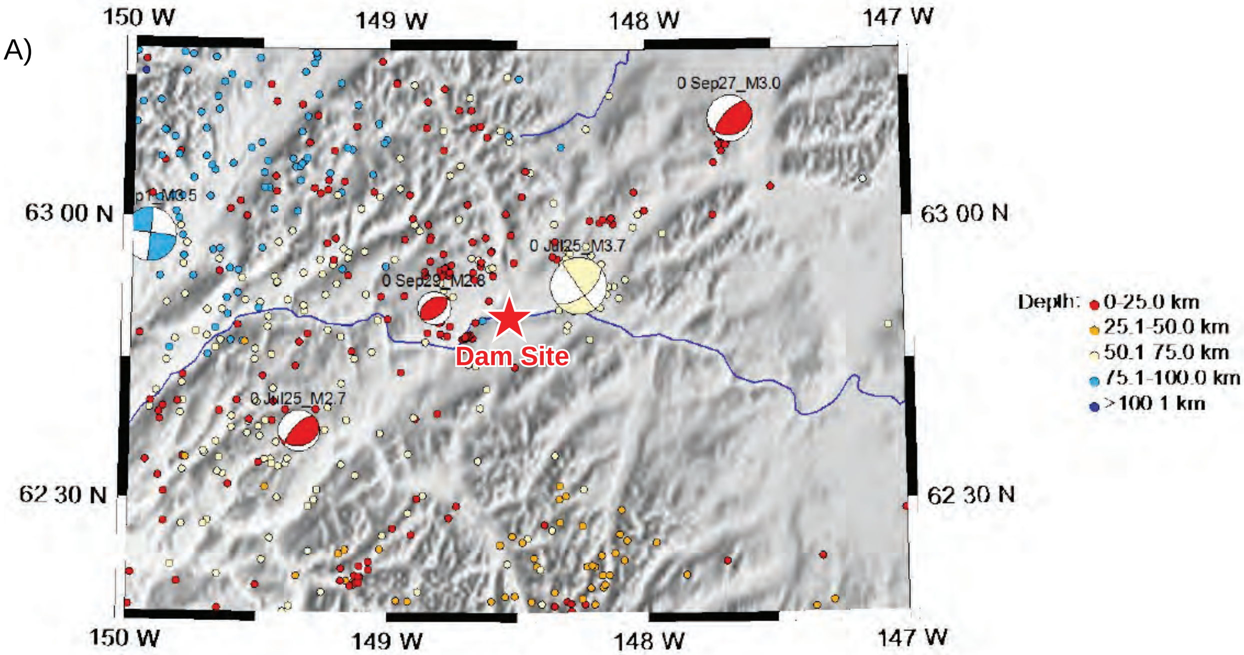
STATE OF ALASKA
ALASKA ENERGY AUTHORITY

SUSITNA-WATANA HYDROELECTRIC PROJECT

FOCAL MECHANISMS IN THE SUSITNA-WATANA PROJECT AREA, 1ST AND 2ND QUARTERS, 2014

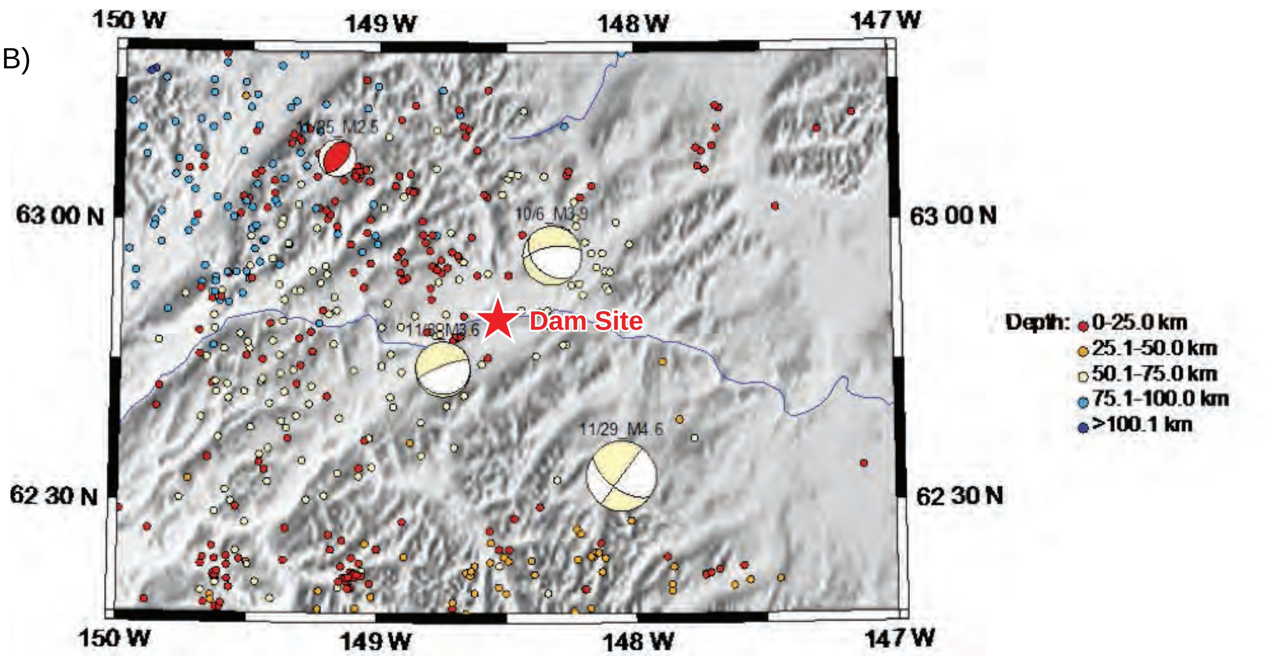
FIGURE 15

A)



Quarter 3, 2014
(image from AEC, 2014b)

B)



Quarter 4, 2014
(image from AEC, 2015)

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STATE OF ALASKA
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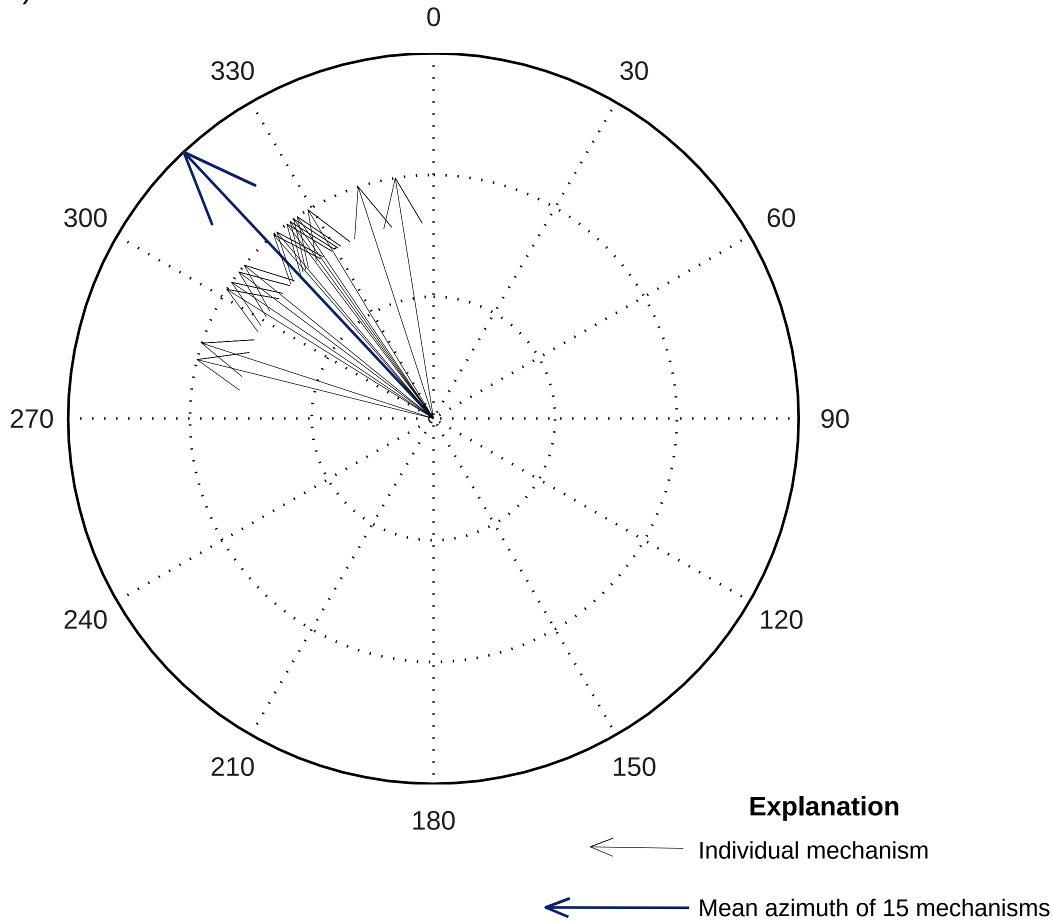
SUSITNA-WATANA HYDROELECTRIC PROJECT

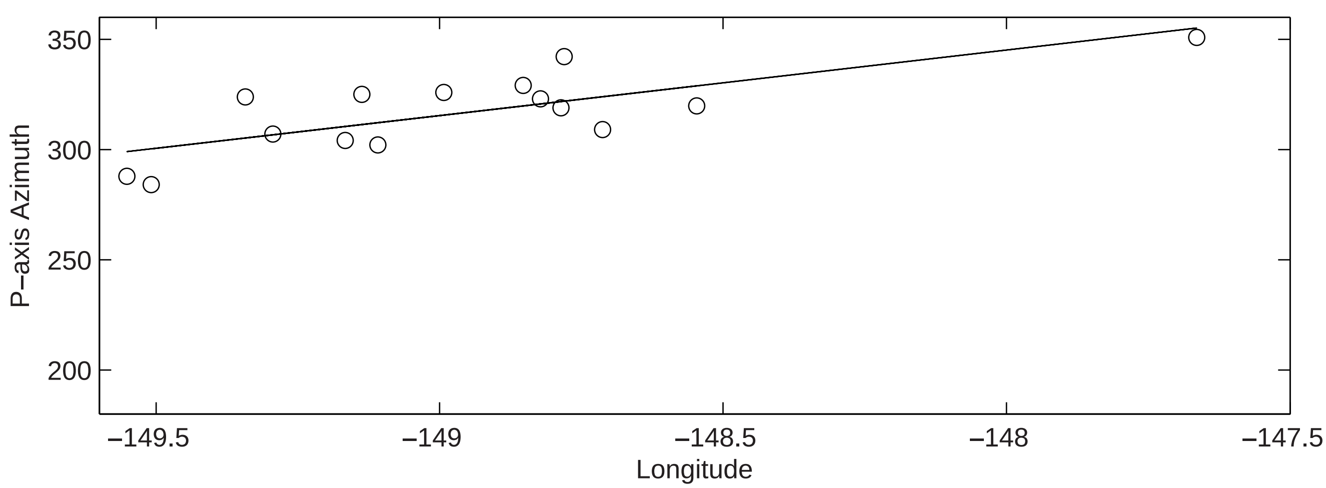
FOCAL MECHANISMS IN THE SUSITNA-WATANA PROJECT AREA, 3RD AND 4TH QUARTERS, 2014

FIGURE
16

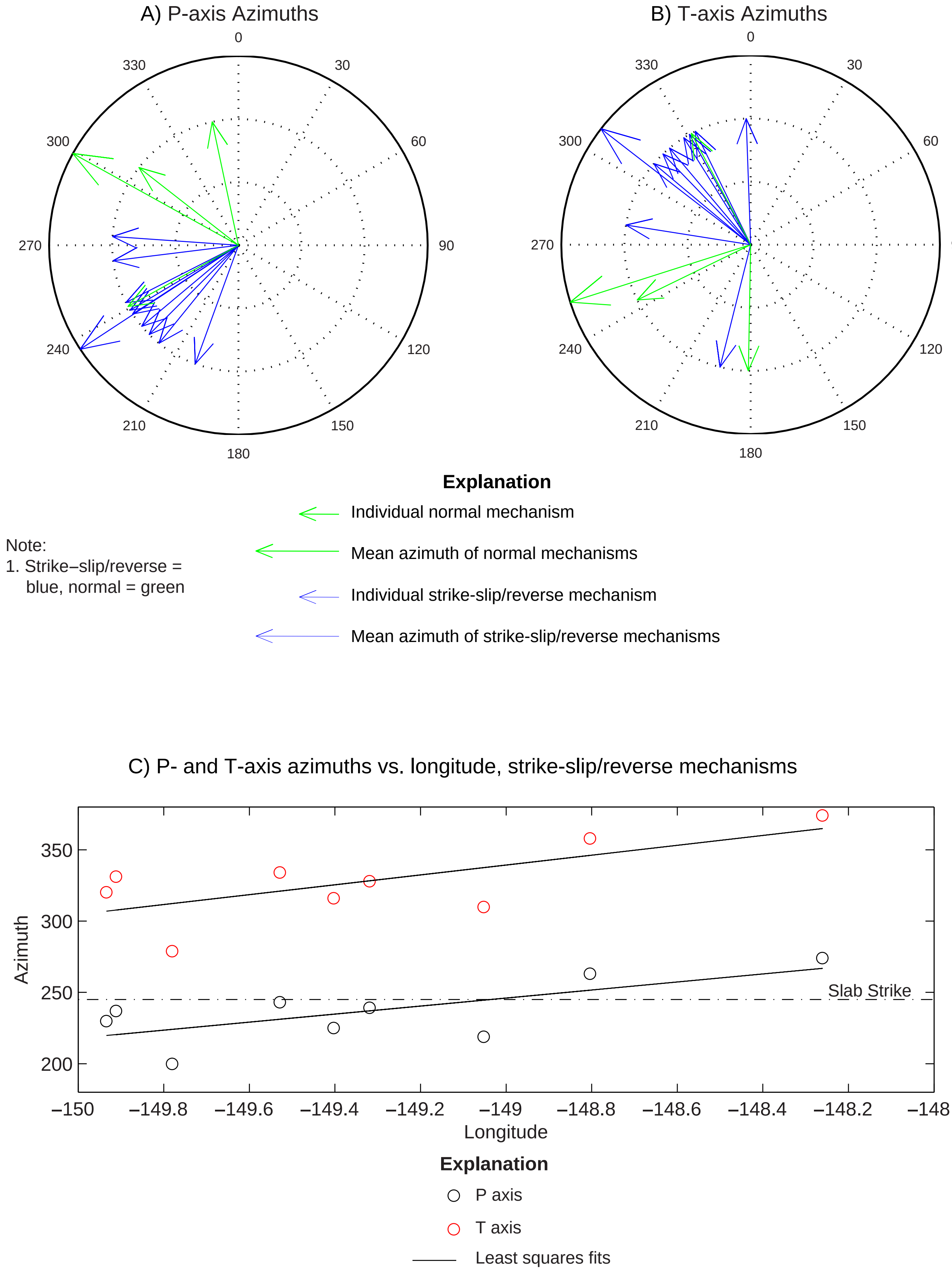
A) P-axis azimuth of crustal focal mechanisms



B) P-axis azimuth vs. longitude



FUGRO Date 03/31/15	STATE OF ALASKA ALASKA ENERGY AUTHORITY ALASKA ENERGY AUTHORITY	SUSITNA-WATANA HYDROELECTRIC PROJECT P-AXIS ANALYSIS FOR CRUSTAL FOCAL MECHANISMS, OCTOBER 2012 – DECEMBER 2014	FIGURE 17



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SUSITNA-WATANA HYDROELECTRIC PROJECT

INTRASLAB FOCAL MECHANISMS,
P AND T AXIS ORIENTATIONS

FIGURE
18

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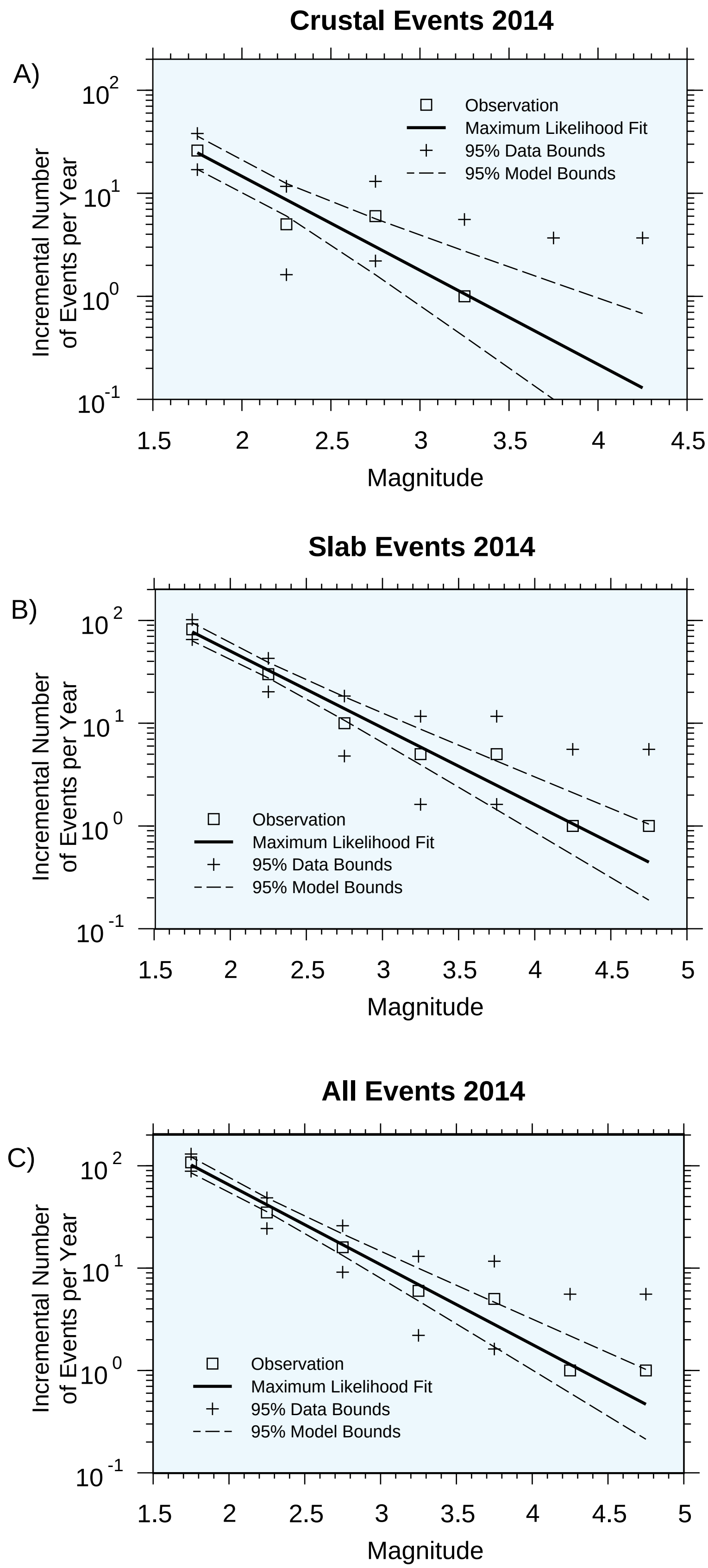

STATE OF ALASKA
ALASKA ENERGY AUTHORITY

SUSITNA-WATANA HYDROELECTRIC PROJECT

INCREMENTAL MAXIMUM LIKELIHOOD FIT, OBSERVATIONS AND 95% CONFIDENCE DATA AND MODEL BOUNDS, JANUARY 1, 2014 THROUGH DECEMBER 31, 2014

FIGURE 19

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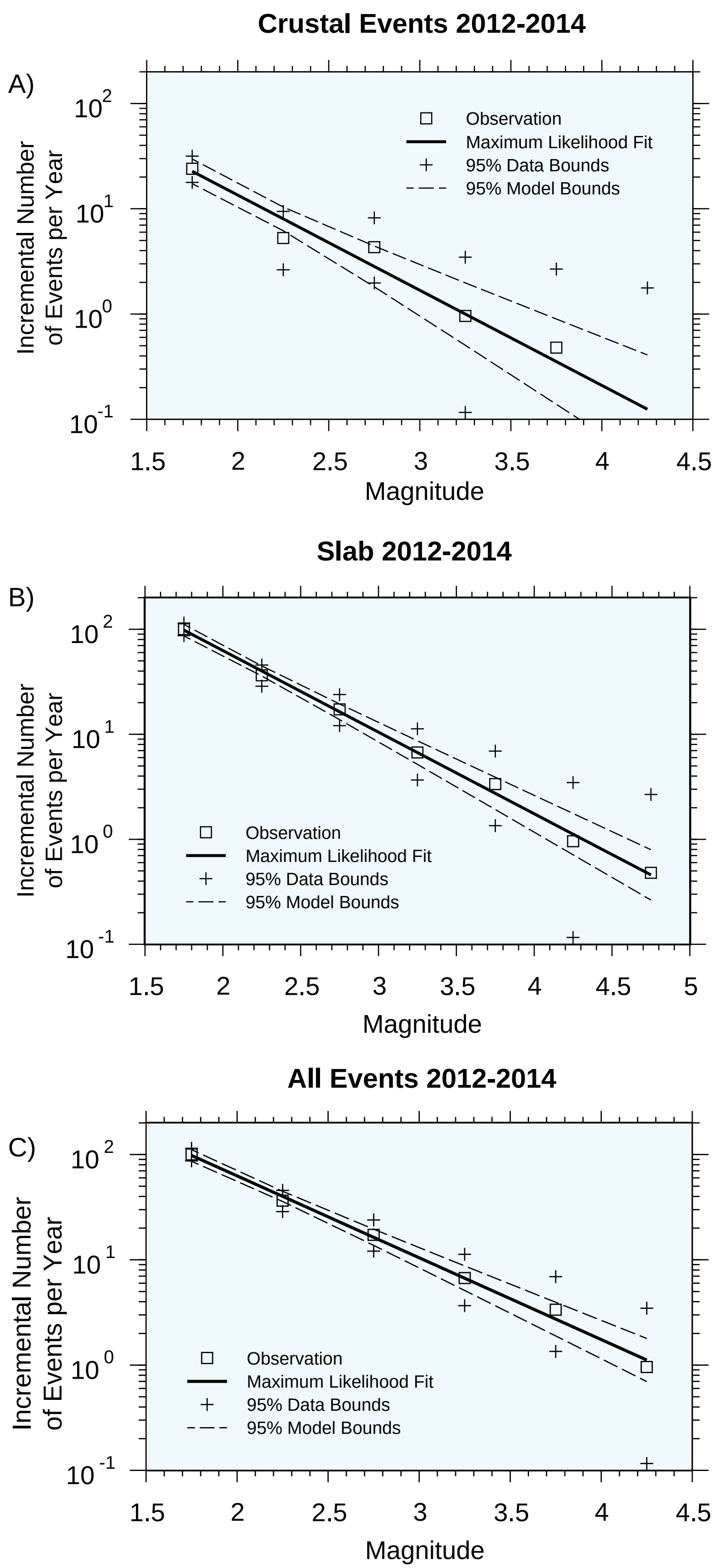

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Date 03/31/15

STATE OF ALASKA
ALASKA ENERGY AUTHORITY

SUSITNA-WATANA HYDROELECTRIC PROJECT

INCREMENTAL MAXIMUM LIKELIHOOD FIT, OBSERVATIONS, AND 95% CONFIDENCE DATA AND MODEL BOUNDS, DECEMBER 1, 2012 THROUGH DECEMBER 31, 2014

FIGURE 20