Aftershock Analysis of the Mw 7.1 November 30, 2018 Anchorage Earthquake with 3D Velocity Model and Regional Moment Tensors

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November 30, 2018 Mw=7.1 earthquake was a normal faulting intraslab event within the subducting Pacific plate.
Intraslab Earthquakes

- Intermediate depth intraslab earthquakes are located between 30-300 km depth.
- The nucleation mechanism is believed to be dehydration-related embrittlement, different from crustal earthquakes.
- Depending on the structure, material properties and temperature regime, the intraslab earthquakes can be located in the crust or mantle of the oceanic plate and can be normal, strike-slip or reverse faulting.

(Figure from Hasegawa and Nakajima, EPS 2017)
Tectonic Setting cont.

- One M≥5 earthquake per year on average
- All previously recorded M≥6 intraslab earthquakes were below 100 km

Background seismicity 1970-2018
- circles: M=5-5.9 and stars: M≥6
- depth - yellow: 0-25 km,
  orange: 25-50 km, and
  dark red: below 50 km
## Southern Alaska Intraslab Earthquakes

<table>
<thead>
<tr>
<th>Source mechanism</th>
<th>1999 Kodiak EQ</th>
<th>2016 Iniskin EQ</th>
<th>2019 Anchorage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strike-slip</td>
<td>strike-slip</td>
<td>strike-slip</td>
<td>normal</td>
</tr>
<tr>
<td>Depth (km)</td>
<td>46</td>
<td>126</td>
<td>47</td>
</tr>
<tr>
<td>Mw</td>
<td>7.0</td>
<td>7.1</td>
<td>7.1</td>
</tr>
<tr>
<td>Largest aftershock (M&gt;=4)</td>
<td>6.4 and 6.5</td>
<td>4.7</td>
<td>5.7</td>
</tr>
<tr>
<td>Mc</td>
<td>1.9</td>
<td>1.8</td>
<td>1.3</td>
</tr>
<tr>
<td>b-value</td>
<td>0.6</td>
<td>1.05</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Aftershock Sequence

- ~10,200 aftershocks through the end of August, 2019
- ~400 with M>=3 – felt;
- ~50 with M>=4 (last on August 28, 2019);
- 7 with M>=5 (last on January 13, 2019);
- Current estimate for duration of the aftershock sequence is 2.5 years (when the aftershock rate returns to the background, pre M7.1, level).
We use double difference relocation algorithm \textit{hypoDD} (Waldhauser and Elsworth, 2000) and regional 3D velocity model (Eberhart-Phillips et al., 2006, 2019) to relocate ~2,000 \(M \geq 2.5\) aftershocks.

- In additional to regional seismic stations, we incorporate picks from the Anchorage strong motion network and temporary USGS aftershock monitoring sites.
- The relocated aftershocks do not align along a single plane but rather form two distinct clusters.
2,038 M>=2.5 relocated aftershocks (black circles). White circles – original catalog locations. Crosses – M>=2.5 background seismicity.

The relocated aftershock depths range between 42 and 69 km, with 95% of events being below 48 km or above 56 km.

The mainshock is located at 55.7 km depth near the deepest and southernmost extent of the aftershock zone.
The aftershocks fall within high Vp/Vs region. It has been interpreted as representing subducted Yakutat crust (Eberhart-Phillips et al., 2006, 2019). Slab structure is comprised of a 3-5-km-thick low-velocity layer underlain by 10-to-15-km-thick Yakutat crust.
Aftershock Relocations

TomoDD relocated aftershock distribution with slip model (Liu et al., 2019), black star indicates the location of the Mw 7.1 mainshock and green circles indicate aftershocks with M>=4.0: view onto longitude x – depth z plane
TomoDD relocated aftershock distribution with slip model (Liu et al., 2019), black star indicates the location of the Mw 7.1 mainshock and green circles indicate aftershocks with M>=4.0: view towards strike from the south.
Aftershock Moment Tensors

- To examine the differences in faulting characteristics between the southern and northern aftershock segments we compute well-constrained regional moment tensors for 18 aftershocks with $M_W=4.1-5.0$.
- We use modified ‘cut-and-paste’ (CAP) method (Silwal and Tape, 2016) and take great care in selecting stations and inversion parameters to ensure best possible waveforms fits.
The resulting focal mechanisms are remarkably similar with no systematic differences between those located within the northern and the southern segments.

The average dip is 63.4° for the first and 31.7° for the second fault planes (Richards, 2019).
Discussion: Single vs multi-fault fault rupture?

Single fault plane:
• Finite fault modeling (NEIC; Liu et al., 2019) indicates that the data can be fit well with a single fault plane with the west-65 degree-dipping plane being preferred.
• Mainshock and aftershock fault plane solutions are remarkably similar with no systematic differences between the northern and southern clusters.

East- or west-dipping fault plane?
• NEIC finite model and Liu et al: West-65 degree-dipping plane is preferred. (Both east and west-dipping planes match main characteristics of the geodetic and seismological observations, and the difference in fitting errors is very small. However, west-dipping plane is found to better explain details of teleseismic data.)
• If assume a single fault plane, what does complexity in the aftershock distribution indicate?

Two fault segments:
• Aftershocks form 2 clusters with different dipping angles: shallower-east-dipping southern cluster and steep west-dipping northern cluster.
• Finite source modeling indicates 2 pulses of energy release 4 sec apart, possibly related to first coming from the southern and second from the northern fault segments.
Conclusions

Kim et al., JGR Solid Earth 2019
Conclusions

- The November 30, 2018 Mw 7.1 mainshock generated a vigorous aftershock sequence with over 10,000 aftershocks with magnitude of completeness of 1.3 reported by the Alaska Earthquake Center within first 8 months. Over 400 aftershocks were felt.

- The aftershocks do not align along a single plane and instead form two clusters: shallower-east-dipping southern cluster and steeply-west-dipping northern cluster.

- Fault plane solutions for the mainshock and aftershocks are remarkably similar and do not indicate systematic differences between the southern and northern clusters.

- Our preferred hypothesis is that the mainshock rupture initiated in the Yakutat lower crust or uppermost mantle and propagated both upwards into the crust to near its top and downwards into the mantle. The aftershocks do not illuminate rupture segment located in the uppermost mantle instead concentrating in the crust on and in the hanging wall of the main west-dipping normal-faulting rupture.