# Association of the November 30, 2018 M 7.1 Earthquake near Anchorage, Alaska to the Tectonics of Southcentral Alaska

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## ABSTRACT
The November 30, 2018 M 7.1 earthquake near Anchorage, Alaska was caused by a deep normal fault.  It was limited to a Yakutat plate as based on a new proposed tectonic model which reflected the movement of a block of this west-southwest subducting plate into the Cook Inlet subduction zone.  This movement was strongly influenced by a deeper and faster north-northwest subducting Pacific plate.  It is evident that the Cook Inlet subduction zone has two distinct subducting plates in contrast to the Aleutian subduction zone to the immediate southwest which has just one.  Similar normal fault events also exist for the region, but ones comparable to the November 30 size are unknown.  However other deep to shallow M 7± earthquakes associated with large strike-slip faults in the Yakutat plate have been common and are called slice faults.  In addition, varying types of megathrust earthquakes occur.  The great 1964 Alaska earthquake reflected a sudden megathrust slip principally between the Pacific and the Yakutat plates for the offshore region of southcentral Alaska.  Based on paleoseismic data a similar oceanic megathrust is expected in about 800 years.  Paleoseismic evidence and the mechanics of the November 30 event indicate more continental megathrust earthquakes also occur along the bottom and top of the Yakutat plate with the Pacific and the North American plates, respectively.  In fact, based on this paleoseismic data and on present crustal folding for the Cook Inlet region, a more continental megathrust earthquake is expected in about 230± years which would be due to west-southwest thrusting between the Yakutat and the North American plates.  The November 30, 2018 earthquake would be small compared with such a predicted megathrust, but it is a very important precursor to it.  The November 30 event also helps to confirm the existence of a Redoubt slice fault within the Yakutat plate by defining its boundaries and nature.  Collectively these elements verify the existence of a west-southwest subducting Yakutat plate with its regional strike-slip slice faults which helps to explain the seismicity and some of the complex geology of southcentral Alaska.

**Keywords:**  megathrust earthquake, new tectonic model, paleoseismic data, precursor earthquake, recurrence earthquake, slice fault, Yakutat plate

# 1. INTRODUCTION

## 1.1. Tectonic model used

Alaska geology and plate tectonics have not been well understood due to an unacknowledged active Yakutat plate (YAK&yak) that consists of YAK and yak (Fig. 1; Reeder, 2016). The yak is the Yakutat terrane (also called Yakutat microplate). YAK is likely the remains of an ancient Kula plate (Atwater, 1989) and in its eastern part probably consists of numerous thrusted layers of Kula and/or other ancient plates such as the Resurrection, Farallon or even older plates (Bradley et al., 1993; Page et al., 1986). It is positioned throughout most of southcentral Alaska beneath the North American plate (NA) and above the less rigid and less seismic north-northwest subducting Pacific plate (PAC). In opposition to the PAC, the YAK part of the Yakutat plate is subducting more slowly to the west-southwest. This subduction increased when the yak attached/joined the YAK in the Prince William Sound region from the southeast about 5 million years ago (Arkle et al., 2013; Cox and Engebretson, 1985; Reeder, 2016).

The southern part of YAK has moved to the west-southwest from the east faster than its northern part, forming a crustal gap resulting in the large Copper Valley (Fig. 1) which has been partially filled by Wrangell volcanic deposits in its southeast region. This moving YAK has pronounced offsets caused by differential movements of large west-southwest elongated blocks named slices that are bound by long strike-slip fault zones, called slice faults (Reeder, 2016). They extend west-southwest through the YAK into the Cook Inlet subduction zone and are associated with its volcanoes (Fig. 1 & 2). To a degree these slice faults also extend up through the overlying North American plate. Exposures have not been well documented but numerous southwest and west-southwest striking faults have been described within the 10+km wide Montana Creek slice fault (MC) zone (Glen, 2004; McGee, 1978; Werdon et al., 2002).

These regional slice faults are not transforms because they lack plate tectonic boundaries, nor slivers (Jarrard, 1986) since they lie perpendicular to the motion of the PAC and strike along the YAK motion. They are likely caused by the oblique collision of yak and even earlier terranes with YAK (Fig. 1). Because the yak and any older Paleocene through Miocene colliding terranes would have been driven by PAC and NA, these slices could be considered a hybrid type of sliver.
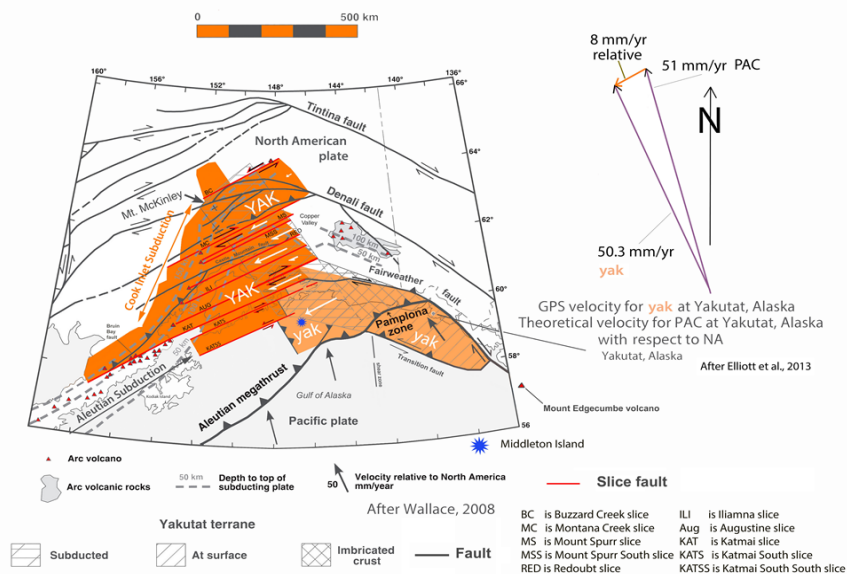


**Fig. 1.** The Yakutat plate (YAK&yak) in southcentral Alaska after Reeder, 2016. YAK (dark orange) is the remains of the ancient Kula and/or other possible ancient plates. The yak (light orange) is the Yakutat terrane (also named Yakutat microplate) that is being presently added to the YAK.
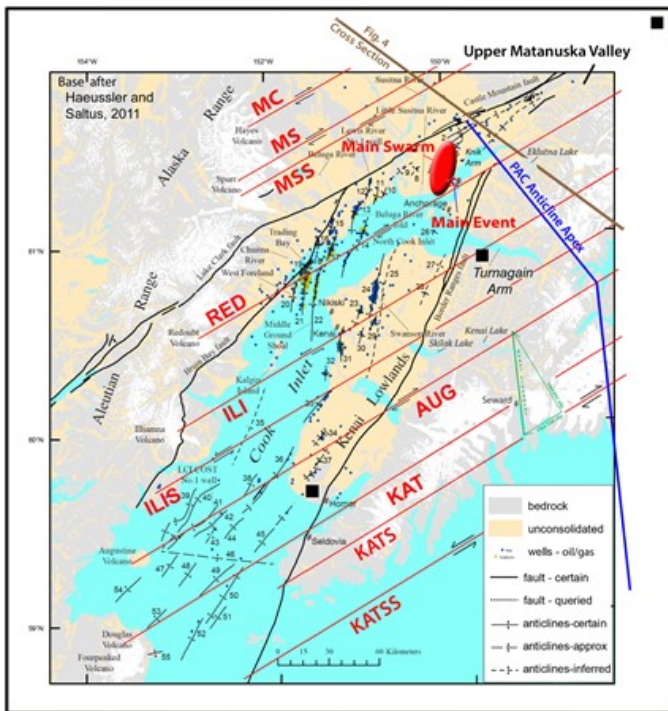
**Fig. 2.** Generalized Tertiary geology of the Cook Inlet basin, Alaska (after Haeussler and Saltus, 2011). The general locations of the strikeslip slice faults are the red lines. The November 30, 2018 earthquake epicenter (star) and resulting earthquake swarm region (red ellipse) are indicated. The location of the earthquake cross-section of Fig. 4 is the brown line. The approximate PAC (Pacific plate) anticlinal apex is the dark blue line. The Kenai lineament is the green line with the 1964 relative slip components of PAC (Pacific plate) and YAK (Yakutat plate) indicated. The three peaks of the presently forming southwest oriented crustal-uplift wave are solid black squares (Freymueller et al., 2008).

### 1.2. Tectonics of the great 1964 Alaska earthquake

The main but not initial megathrust in the eastern part of the great 1964 Alaska M 9.2+ earthquake was actually the yak thrusting west-southwest onto the Pacific plate (Reeder, 2016; Stauder and Bollinger, 1966; Wyss and Brune, 1967). This deep thrust had a strike azimuth of 344° with a dip of 26° to the NE (Berg, 1965) and is represented by the large thrust fault at the western boundary of yak with the Pacific plate as shown on Fig. 1. Furthermore, about half of the recognized aftershocks occurred in the yak with most of the rest occurring in the YAK and shallower

North American plate (Doser et al., 1999)! The epicenter of this great Alaska event and most of the aftershocks actually occurred at/near slice faults. The initial megathrust for the eastern part of this great event was indeed the Pacific plate thrusting northwest (Plafker, 1969) under the Yakutat plate (YAK&yak). This more regional thrusting continued to the immediate west-southwest under the North American plate as part of the Aleutian subduction zone and extended just beyond offshore Kodiak Island (Stauder and Bollinger, 1966). The great 1964 Alaska earthquake was indeed a multiple megathrust event which involved thrust motions between three different plates! It released more than 3,000 times the energy of the recent November 30 event. For clarity, any large and sudden thrust movement between two tectonic plates is a megathrust earthquake.

### 1.3. Tectonics of the Castle Mountain fault

The Castle Mountain fault, oriented N65°E (Fig. 2), is a significant fault of the region and is considered an ancient right-lateral slice fault similar to two presently active nearby slice faults: the Mount Spurr South fault (MSS) just to the north and the Redoubt fault (RED) just to the south. The Castle Mountain fault is Late Paleocene in age (Fuchs, 1980) but it has significant reactivated fault uplifts, principally reverse, on its northern side. The most recent uplifts are reflected by impressive Holocene scarps at and to the immediate west of a deep Pacific plate (PAC) anticlinal apex (Fig. 2). These scarps are suspected to be directly related to this apex which extends south to the deep thrust fault where yak (Yakutat terrane or microplate) is thrusting onto the PAC (Fig. 1).

### 1.4. The Pacific plate anticlinal apex

The Pacific plate (PAC) anticlinal fold probably formed from the initial thrusting of yak onto the PAC in the very eastern Gulf of Alaska in the Late Miocene (Fig. 1& 2; Reeder, 2016). This yak loading caused the PAC to subside with an anticlinal fold forming in the PAC immediately to the west. Initially, before the yak started to move west-southwest, the resulting PAC anticlinal apex would have been aligned north-northwest with the same orientation as the direction of PAC, which is nearly N 30º W (Elliot

et al. 2013). This alignment still exists beginning at the Augustine slice fault (AUG) and continues beneath the YAK of the Yakutat plate in an approximate north-northwest direction to just beyond the Holocene scarps of the Castle Mountain fault (Fig. 2). This anticlinal apex is positioned just northeast of the November 30, 2018 earthquake. It is recognized on two seismic profiles, one at the very eastern part of the Turnagain Arm (Li et al., 2013) and the other at the Castle Mountain fault (Veilleux and Doser, 2007; Fig. 4).

But back at and beyond the Augustine slice fault (AUG) the PAC anticlinal apex orientation is due south. This directional change was due to the initial west-southwest movement of the Yakutat microplate or terrane (yak) when it collided/locked with the YAK about 5 million years ago (Reeder, 2016). At that time, the yak thrusted west-southwest onto PAC at less rate than the north-northwest movement of the PAC. The result is a shift of the PAC anticlinal apex

to a roughly north/south orientation that trends south into the very western Prince William Sound, just west of high-angle southwest-oriented faults that had reverse movements due to the great 1964 Alaska earthquake (Plafker, 1967). In fact, these were the only surface fault movements observed during this great 1964 earthquake. They appear to reflect deep underthrust movements of the PAC to the north-northwest along with shallower Yakutat plate movements to the west-southwest. Both faults curve at their ends as an echelon's faults (Haeussler et al., 2015) with ends roughly parallel to the deeper Katmai South slice fault (KATS) and the Katmai South South slice fault (KATSS) zones (Fig. 1) which are themselves exhibiting increased seismic activity (Doser et al., 2008). The present PAC fold apex bend at AUG, near the epicenter of the 1964 Alaska earthquake, is just southeast of a 1964 earthquake maximum subsidence axis bend (Plafker, 1969; Fig. 6). This PAC anticlinal apex bend is also suspected to be associated with the Augustine slice fault.
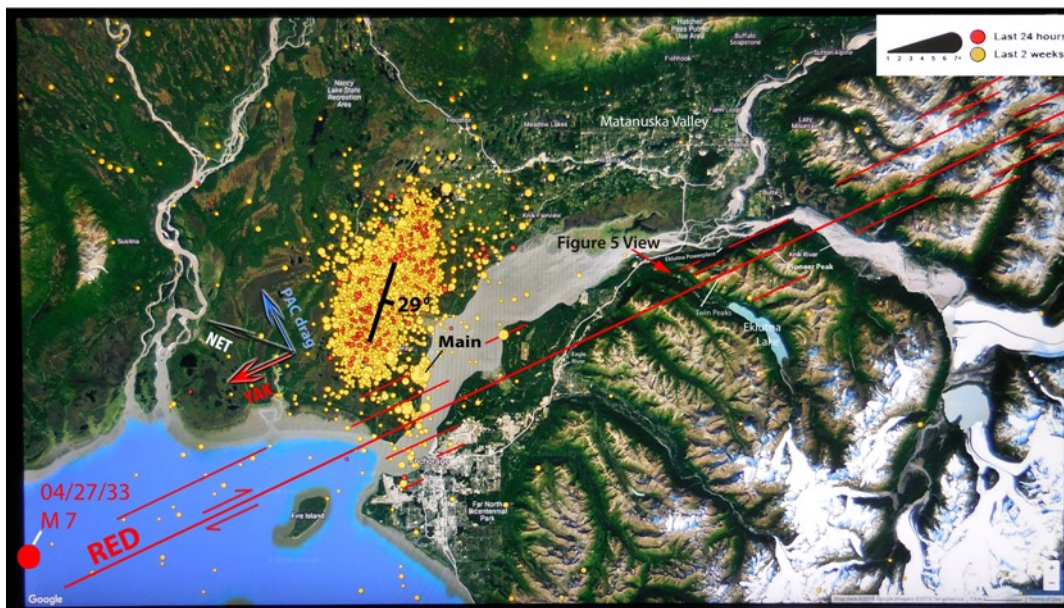


**Fig. 3.** The November 30, 2018 M 7.1 earthquake epicenter near Anchorage (2018-11-30 17:29:30 UT) and resulting earthquake aftershock swarm up to 2018-12-11 23:59:59 UT (data from the National Center Earthquake Information and the Alaska Earthquake Center). The strike and dip of the November 30 earthquake fault are indicated along with estimated relative PAC (Pacific plate) drag and YAK (Yakutat plate) movement. The approximate epicenter location of the 04/27/33 M 7 earthquake is also indicated (Doser and Brown, 2001). The earthquake focal mechanism for 04/27/33 is N 55º E ±18º (Reeder, 2016). The main Redoubt slice fault (RED) is the continuous red line. Discontinuous red lines indicate linear earthquake epicenters/clusters or topographic linear features suspected to be associated with the RED fault zone.
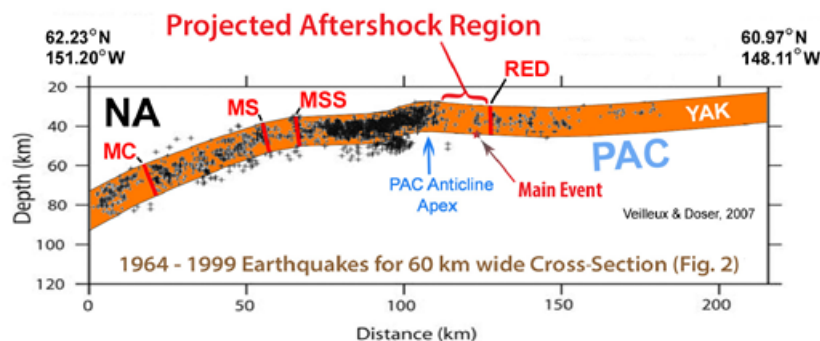
**Fig. 4.** Earthquake vertical profile located on Fig. 2 for the period 1964 through 1999 (Veilleux and Doser, 2007). The North American plate (NA), Yakutat plate (YAK; orange region), Pacific plate (PAC) and the PAC anticlinal apex are indicated. The November 30, 2018 northeast projected hypocenter and the northeast projected earthquake swarm region are indicated.

## 2. THE NOVEMBER 30, 2018 EARTHQUAKE

### 2.1. The recent earthquake(s)

The November 30, 2018 M 7.1 earthquake near Anchorage, Alaska had a hypocenter depth of 47 km (Alaska Earthquake Center; National Earthquake Information Center). It was caused by the sudden movement in the Pacific plate on a deep N 16º E striking normal fault dipping 29º ESE (Fig. 3), which they interpreted to be due to tensional bending of the upper zone of the Pacific plate as it increased its subduction into the Aleutian subduction zone. But based on the model used here, its hypocenter was actually in the deepest part of the Yakutat plate (YAK&yak). A clear double seismic zone marks the Yakutat plate and more aseismic Pacific plate (Fig. 4). The fault occurred in the southern part of the Redoubt and Mount Spurr South slice block (RED/MSS; slice block between RED and MSS faults) of the YAK; the Redoubt slice fault (RED) marked the southern limit for the resulting aftershock swarm (Fig. 2 & 3). The fault propagated within the YAK from its bottom (47 km) to its top (35 km) as well as from the RED slice fault-zone to its north. This normal fault resulted from the tensional pulling by the YAK and the deeper PAC from the YAK's eastern part as they both increased their subduction into the Cook Inlet subduction zone. This event and resulting aftershock swarm occurred just west-southwest of the pronounced Pacific plate anticlinal fold (Fig. 2) and was also just southwest of an aseismic zone within the YAK (Veilleux and Doser, 2007). This aseismic zone exists within the YAK from about 35 to 47 km depth in

the MSS/RED slice block and is indicated on the vertical earthquake profile of Fig. 4. It suggests that this part of YAK is locking, i.e. a slower flat plate exhibits reduced internal seismic activity and increased locking at its upper and lower boundaries.

### 2.2. Tectonic cause of the November 30 event

At the November 30 earthquake and to its east some locking would be expected between the Yakutat and North American fault boundary (YAK/NA) because of its shallow depth but not between PAC/YAK because of its great 47 km depth. Extensive shallow slow slip is indeed occurring as recognized by a large slow slip event (Ohta et al., 2006) which indicates some locking. However, at greater depths, locking could still occur in the disturbance zone due to the PAC anticlinal apex (Reeder, 2016). This would help explain the aseismic zone in the profile of Fig. 4.

Such locking between the PAC/YAK fault boundary is actually evidenced by the November 30 event itself. The YAK is moving west-southwest as the faster north-northwest moving PAC is underneath. But as YAK moves over the PAC anticlinal apex it actually pulls away faster as it starts to subduct more steeply into the Cook Inlet subduction zone. As it does it detaches from the above NA more westward from the PAC anticlinal apex than it does from the PAC. A tensional normal fault, with an east-northeast dip, would be expected to form just west of the PAC apex and would propagate upward to the west where the YAK/NA detached. The result would be a normal

fault striking north-northwest with a gentle dip to the east. However, the November 30 fault was actually oriented north-northeast which would be due to locking at/near the PAC anticlinal apex between PAC and YAK. The PAC dragged YAK north-northwest by roughly the same distance that YAK had moved west-southwest (Fig. 3). The result is the normal fault striking N 16º E with a 29º dip to the east-southeast through the entire thickness of YAK, nearly 10 km as based on the seismic data itself.

### 2.3. Potential for more November 30 types of earthquakes

The aftershock swarm for this earthquake, if projected northeast to the earthquake profile of Fig 4, would completely cover the aseismic zone (suspected lock zone) in the YAK up to the RED fault zone. But this aseismic zone continues southeast along the seismic profile from the Redoubt fault (RED) up to the Iliamna fault (ILM) and even beyond. For this region of the RED/ILM slice a similar November 30 type earthquake is possible just southwest of the PAC apex. For the region of the November 30 event itself, similar large fault events would not be expected in the deeper PAC nor in the shallower NA because the YAK is a separate tectonic plate with its own motion and stresses. Other normal fault earthquakes of this size are unknown for the northern Cook Inlet region.

### 2.4. The numerous slice fault earthquakes similar in size to the November 30 event

Large active and deep strike-slip fault zones (slice faults), oriented west-southwest, are recognized in the Yakutat plate (YAK&yak) that in part penetrate the above NA (Reeder, 2016). These result in fairly common right-lateral and left-lateral strike-slip earthquakes of up to M 7± (Doser and Brown, 2001). For example, a right-lateral M 7.0 occurred near Anchorage on April 27, 1933 at 9 km NA hypocenter depth on the RED (Fig. 3); a right-lateral November 03, 1943 M 7.0 at 27 km depth occurred on the MSS; a left-lateral October 03, 1954 M 6.8 at 60 km depth occurred on the ILI just SW of Anchorage; a more recent steeply-dipping left-lateral January 24, 2016 M 7.1 at 129 km depth occurred on the ILIS near the Iniskin Peninsula; and a right-lateral M 6.4 at 30 km

depth on the AUG near the epicenter of the great 1964 Alaska earthquake. In addition, a left-lateral M 6.5+occurred April 3, 1964 at 56 km depth on the ILI about 150 km east of Anchorage and was one of the largest 1964 Alaska earthquake aftershocks (Doser et al., 1991).

These deep slice faults in the Yakutat plate (YAK&yak) that penetrate the above North American plate represent very wide fault zones. A few aftershocks of the main November 30 event actually clustered along the RED over at least a 10 km wide zone as indicated by the short parallel red lines on Fig. 3 near the main event. In fact, even the hypocenter of the main November 30 event occurred on the northern edge of the RED fault zone very similar to the April 27, 1933 event; both being 5 km north of the main RED (Fig. 3). The main aftershock earthquake swarm clearly terminates at this northern RED fault zone and reflects the southern limit of the November 30 normal fault movement. But the aftershocks within the RED fault zone also suggest that movements occurred along the RED strike-slip fault zone itself as part of this main event. The Fig. 5 view represents the most extensive debris avalanches of Pleistocene glacial drift which was observed during the U. S. Geological Survey aerial reconnaissance just after the main November 30 event (Robert C. Witter, email communication). Amazingly, this view is from the northern edge of the RED fault zone looking east-southeast directly over the fault zone with Eklutna Lake in the far distance (Fig. 3) and the Eklutna River in the foreground. Near surface RED fault movements are suspected during or shortly after the November 30 event. This could help explain the above-average damage in the nearby community of Eagle River which is also within the RED fault zone. More regional long-term linear west-southwest topographic features exist parallel to the RED within a 10 +km wide zone (Fig. 3; red discontinuous lines). Even the south and north summits of Pioneer Peak (Fig. 3) appear to have had right-lateral west-southwest Quaternary offsets of over 100 m. The total horizontal right-lateral displacement along the RED fault zone in the northern Cook Inlet Tertiary sediments (Haeussler and Saltus, 2011) is about 7 km

over a 10 km wide zone (Fig. 2). Based on the Vp 7.8 km/s isovelocity depth contour at 70 km depth, a right-lateral offset of the RED fault of at least 25 km is indicated (Eberhart-Phillips et al., 2006; Reeder, 2016). Apparently not all of the deep slice fault displacements in the YAK made it to the surface!



**Fig. 5.** Debris avalanches of Pleistocene glacial drift (moraines, glacioalluvial, and glaciolacustrine deposits) at Eklutna River within the Redoubt slice fault zone (RED; photograph taken shortly after November 30, 2018 by Robert C. Witter, U. S. Geological Survey, Anchorage, Alaska). The view is looking east-southeast with the Eklutna Lake in the far distance. The view location and direction are indicated in Fig. 3.

# 3. TYPES AND SIGNIFICANCE OF REGIONAL MEGATHRUST EARTHQUAKES

## 3.1. Continental megathrust between Pacific and Yakutat plates (PAC/YAK)

For the November 30 earthquake region, any megathrust earthquake due to movement along a deep PAC and YAK boundary would most likely be confined along the PAC anticlinal apex. It could possibly extend from the AUG slice fault to the north just beyond the Castle Mountain fault where the PAC plunges into the subduction zone. Paleoseismic radiocarbon ages from buried organic subsidence horizons in the Cook Inlet (Bartsch-Winkler and Schmoll, 1992) and disturbed/buried organic horizons at the Castle Mountain fault (Haeussler et al., 2002) indicate such possible deep PAC/YAK megathrust earthquakes occurred about 200, 1100, 1930, and 2750 years before present (Fig. 6). Such a deeper more continental PAC/YAK megathrust earthquake would be smaller and would help to explain many of the Holocene reverse uplift scarps on the Castle

Mountain fault zone. The associated locking of the PAC/YAK boundary along the PAC anticlinal apex also explains the deep origin of the November 30 event itself. The PAC drag of YAK to the north-northwest as evident in the November 30 event (Fig. 3) needs to eventually rebound back to the south-southeast. A deep PAC/YAK megathrust would represent such a south-southeast rebound. This is why the 30 November 2018 event should be considered a precursor to a developing deep megathrust event. Most likely the rebound would not be complete and would possibly result in uplifts on the Castle Mountain fault and minor YAK net deformation to the north-northwest.

## 3.2. Continental megathrust between Yakutat and North American plates (YAK/NA)

A west-southwest moving megathrust earthquake between the shallower YAK/NA boundary east of the 30 November event would be much more regional and therefore larger. The crust of southcentral Alaska in this region is actively folding (Freymueller et al., 2008) in such a way that the NA appears to be detaching from the YAK. The wavelength of 250 to 475 km in the 1964 Alaska earthquake vertically folding crust (Plafker, 1969) was the result of decoupling between PAC and a united YAK & NA (Reeder, 2016). A wavelength of 200 km or less would be required for decoupling of NA from YAK to get a YAK/NA type of megathrust. Of interest, crustal vertical movements in the southeastern and east-northeastern part of the Cook Inlet have formed a 160 km crustal wave since 1964 (Freymueller et al., 2008) with three recognizable peaks marked by solid black squares in Fig. 2. Both of the two outer peaks reflect regions of recent slow slip events (Li et al., 2016). These crustal vertical movements suggest that the southeastern, east central and very far east-northeastern Cook Inlet regions are starting to decouple between YAK and NA. The eventual YAK/NA megathrust would include all of the Kenai lowlands up through the upper Matanuska Valley (Fig. 2) and would have a M 8±.

The age of a 5 km long buried continuous peat horizon in an ENSTAR (a natural gas company) 1984

trench across the Knik Arm tidal flats (Fig. 6 & 7) along with the ages of Anchorage landslides (Reeder, 2014) indicates that a major YAK/NA megathrust earthquake occurred about 570 y.b.p. (years before 1950). The 1964 Alaska earthquake has left one of the best stratigraphic markers in Holocene deposits in the Cook Inlet, therefore it is the preferred time reference; it indicates that a major YAK/NA megathrust earthquake occurred about 584 years before 1964. The amazing stratigraphy of this Knik Arm section is not in question. However, many of the auger and well cores taken throughout the Cook Inlet and Prince William Sound regions (Carver and Plafker, 2008; Combellick, 1991; Shennan et al. 2014) have in part resulted in a significant number of heterogeneous paleopeat ages. The problem is that well core and auger organic samples may not be from actual in place stratigraphic sections, especially considering the dynamic environments involved. In addition, auger samples have an extremely high risk of contamination during sampling. Bartsch-Winkler and Schmoll (1992) sought large and well exposed stratigraphic sections at low tides in the Cook Inlet for their direct paleo-organic sampling. They not only identified this 584± years before 1964 subsidence event, but also similar Cook Inlet subsidence events of 1,360 and 2,280 years before 1964. Assuming a consistent recurrence interval, the next YAK/NA megathrust earthquake would be expected in 230± years (Reeder, 2016). The duration of such an event would be long enough to cause land sliding in Anchorage similar but smaller to what happened in 1964 (Reeder, 1974 and 2014). It could also cause movement on/near the Castle Mountain fault similar to that shown by paleoseismic data (Fig. 6; Haeussler et al., 2002). The present westward extent of the YAK/NA locking, compared to the less westward extent of the PAC/YAK locking, explains the more westward location of the upper reach of the November 30 normal fault. This also indicates that locking of boundaries between the plates exists to the east-northeast. Therefore, the 30 November event is indeed a precursor to this presently building YAK/NA megathrust earthquake and the eventual PAC/YAK megathrust earthquake.

### 3.3. An oceanic 1964 type megathrust between the Pacific and Yakutat plates

Also based on Cook Inlet subsidence paleopeat age dates, a previous 1964 type of megathrust earthquake occurred about 850 years before present (Bartsch-Winkler and Schmoll, 1992; Carver and Plafker, 2008; Combellick, 1993; Reeder, 2016). It will be a long time before another great 1964 type PAC/(YAK&yak) megathrust earthquake occurs (in about 810 years; Reeder, 2016) or even for the occurrence of a smaller and deeper PAC/YAK continental megathrust earthquake (in about 610 years; Reeder, 2016).

### 3.4. Megathrust paleoseismic data

Based on the recognized subsidence events for the upper Cook Inlet region and on liquefaction/fault-movement events on the Castle Mountain fault (Fig. 6), past megathrust earthquakes appear to occur in a cyclic sequence of about 864 years for each type of megathrust. If such a recurrent earthquake cycle is considered, it would result in the "theoretical age in years before 1964" for each historical PAC/YAK, YAK/NA and PAC/(YAK&yak) megathrust type as listed in Fig. 6. Unfortunately, due to the complexity of faults, such constant cyclic behaviour does not normally occur (Thatcher, 1984; Schwartz and Coppersmith, 1984; Shennan et al., 2009). Nevertheless, there is still an amazing visual correlation between the theoretical and the actual paleoseismic data!

This cyclic recurrence of large megathrust earthquakes in southcentral Alaska is somewhat supported by a recent paleoseismic study of Eklutna, Skilak and Kenai lakes (Praet et al., 2017). In this study, the Eklutna proximal basin, Eklutna distal basin, Kenai and Skilak lakes (Fig. 2) had seismic events on the average of every 250, 450, 450 and 900 years, respectively. The proximal basin of Eklutna Lake was found to have possibly recorded PAC/YAK, YAK/NA and PAC/(YAK&yak) megathrust earthquakes going back roughly 3,000 years with 14 earthquake landslide events. Fig. 6 indicates there are just 11 such theoretical megathrust events. The distal basin of Eklutna Lake and the Kenai Lake appear to have recorded the YAK/NA and the PAC/(YAK&yak)

megathrust events going back 3500 years with 8 events and going back 3000 years with 7 events, respectively.  Interestingly, 9 and 7 of these megathrust events, respectively, were theoretically predicted.  Skilak Lake appears to have only recorded the large PAC/ (YAK&yak) megathrust earthquakes going back about 5000 years with 7 events.  Based on interpolation of the theoretical recurrence up to 5200 years ago (Fig. 6), 7 theoretical PAK/(YAK&yak) megathrust events were predicted.  Given the northern location of Eklutna Lake it is not surprising that it documented all three types of megathrust earthquakes common to the northern Cook Inlet.  However, it recorded two extra events that suggest more megathrust earthquakes are occurring (Shennan et al., 2014) and/or other local earthquakes are triggering landslides.  Another likely explanation would be that the recurrence interval for the megathrust earthquakes actually vary (Thatcher, 1984).  Nevertheless, good agreement exists between the paleoseismic lake data and the theoretical data which supports the possible existence of multiple types of megathrust events such as PAC/(YAK&yak), PAC/YAK and YAK/NA.

ence events for the upper Cook  Inlet region and resulting radiocarbon age data from Bartsch-Winkler and Schmoll (1992); locations of trenches (green) associated with the Castle Mountain fault and resulting radiocarbon age data from Haeussler et al. (2002); and the location of the over 5 km long EN-STAR trench across the Knik Arm tidal flats (solid red line) and theoretical megathrust earthquake ages from Reeder (2016).

### 3.5. Yakutat plate west-southwest motion rates

From horizontal crustal surface movements due to the 1964 Alaska earthquake (Parkin, 1966) estimates can be made for YAK and yak movement rates.  The event caused a movement of 9.5 meters to the southwest at Middleton Island in the very northern Gulf of Alaska (Fig. 1).  This would represent a horizontal rebound by yak from the PAC drag of 2.4 m to the south-southeast and a yak vector-component movement of 9.15 m to the west-southwest.  Obviously, a lot of slow north-northwest slip is occurring between yak and PAC since PAC is moving at least 5 cm/year on average.  Assuming an 864 year recurrence interval for a PAC/ (YAK & yak) type of megathrust earthquake, the yak would be moving an average of 1.06 cm/year to the west-southwest as a minimum.

The 1964 crustal movement at Seward of about 13.6 m was directly south along the Kenai lineament (Parkin, 1966).  This lineament reflects the PAC fold apex to the northeast with the NA being well attached to YAK.  In other words, the NA is traveling west-southwest with the YAK with no slow slip nor megathrust occurring between YAK/NA, otherwise the Kenai lineament would not exist.  At the right-lateral AUG slice fault, the Kenai lineament is truncated and does not appear to continue anywhere north of AUG.  This indicates that slip is occurring between NA and YAK north of AUG and that AUG would be the southern limit of any YAK/NA megathrust earthquake!
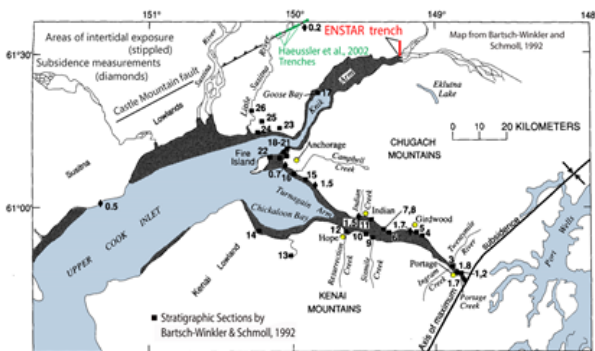


| EVENT | SITE■ | Weighted Mean* C-14 Years B.P. Conventional | 2 sigma Cal. B.P. (yrs. before 1950) Reimer et al., 2004 | Median Age Cal. B.P. | Megathrust Type | Castle Mountain Fault Events* Median Age Cal. B.P. (2 sigma) | Theoretical Age in Years before 1964 | |
|---|---|---|---|---|---|---|---|---|
| 1964 | | | | | PAC/(YAK&yak) | | | |
| I | 2,14,15, 22, 23 & 26 | 227±16 | 0-290 | 145 | PAC/YAK | | 200 | |
| II | 4, 15, 16 & 17 | 674±34 | 545-675 | 610 | YAK/NA | 670 (610-730) | 584 | |
| III | 9 & 15 | 866±51 | 695-900 | 800 | PAC/(YAK&yak) | | 864 | |
| IV | 12 | 1,180±90 | 930-1,275 | 1,102 | PAC/YAK | 1225 (1070-1375) | 1,064 | total ppp |
| V | 14, 15 &17 | 1,490±29 | 1,305-1,410 | 1,360 | YAK/NA | | 1,448 | |
| VI | 5 & 20 | 1,840±41 | 1,640-1,870 | 1,755 | PAC/(YAK&yak) | | 1,728 | |
| | | | | | PAC/YAK | 1914 (1870-2145) | 1,928 | |
| VII | 5 & 21 | 2,301±54 | 2,160-2,400 | 2,280 | YAK/NA | | 2,312 | total ppp |
| VIII | 4,12 & 17 | 2,580±80 | 2,400-2,745 | 2,572 | PAC/(YAK&yak) | | 2,592 | |
| | | | | | PAC/YAK | 2735 (2730-2740) | 2,792 | |
| | | | | | YAK/NA | | 3,176 | total ppp |
| IX | 5, 17 & 20 | 3,256±59 | 3,370-3,625 | 3,500 | PAC/(YAK&yak) | | 3,456 | |
| | | | | | PAC/YAK | | 3,656 | |
| | | | | | YAK/NA | | 4,040 | total ppp |
| | | | | | PAC/(YAK&yak) | | 4,320 | |

■ Stratigraphic sections & resulting conventional C-14 ages before present (1950) by Bartsch-Winkler and Schmoll, 1992
* Ages assigned to events are weighted by inverse square of laboratory quoted error.
* Recognized earthquake events on Castle Mountain fault (Haeussler et al., 2002)

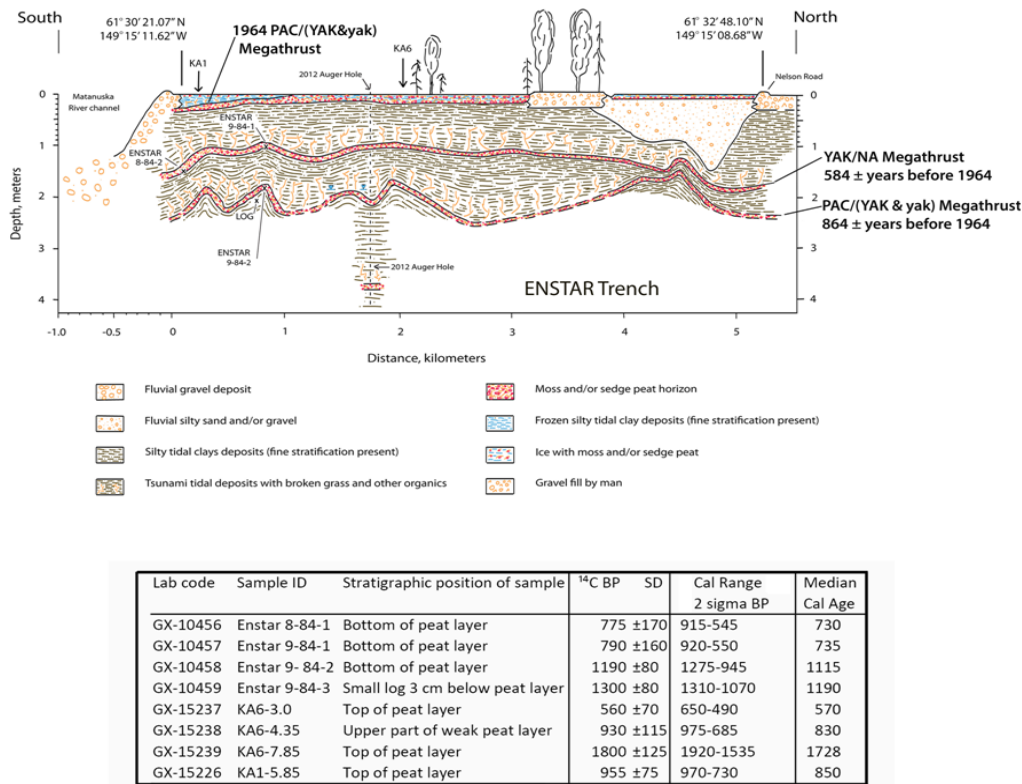**Fig. 6.**  Locations of stratigraphic sections of subsid-

**Fig. 7.** The 5 km geologic cross-section of the ENSTAR trench across the Knik Arm tidal flats (Fig. 6) with corresponding table of radiocarbon age determinations based on Reimer et al. (2004) calibration (Combellick, 1991; Reeder, 2016).

Back at Seward, the YAK component of the 1964 movement as shown in Fig. 2 was a "push" of 5.6 m to the west-southwest. Again, assuming an 864 year recurrence interval for PAC/(YAK&yak) earthquake events, this would equate to a YAK average rate of 0.65 cm/year which is presuming no west-southwest slow slip is occurring between the YAK and PAC.

We know PAC is moving an average of $5+$ cm/year north-northwest but its component of the 1964 rebound at Seward was 12.1 m to the south-southeast. For the assumed 864 year recurrence interval this would equate to only a 1.4 cm/year average PAC drag to the north-northwest. A lot of slow north-northwest slip appears to be occurring beneath Seward.

Obviously, there are too many variables and unknowns to make a creditable estimate for YAK movement at the November 30 earthquake location. But most likely it is moving west-southwest at an average rate less than that estimated at Seward, i.e. less than 0.65 cm/year. GPS surface crustal-motion investigations and related research have fortunately been undertaken for Alaska since the 1990s (Geophysical Institute of the University of Alaska) and are of critical significance. Research on slow slip events under the Cook Inlet predicted global rotational velocities with respect to a stationary theoretical pole. This revealed surface crust net motions of between 4 to 7 mm/yr to the west-southwest for the entire Cook Inlet region (Li et al., 2016). Exotic terranes have been tectonically transported to and/or within Alaska (Plafker and Berg, 1994; Finzel et al., 2015) and these complex terranes in southcentral Alaska, such as the Wrangellia composite terrane, would be presently moving/deforming to the west-southwest.

## 4. RESULTS AND DISCUSSION

A tectonic model can be used to test and define recent earthquakes as is done here with the November 30 earthquake event. This present model, consisting of dual Yakutat and Pacific plates subducting in very different directions, enables a much better understanding of the November 30, 2018 earthquake and shows the model has substance. The recent event and aftershocks helped define the boundaries of the Redoubt slice fault zone of the Yakutat plate and the lower and upper boundaries of the plate itself. The recent event also appears to be a precursor to YAK/NA and PAC/YAK continental megathrust earthquakes. These are all significant aspects of the proposed tectonic model and adds to its credibility.

The scientifically accepted tectonic model for southern Alaska, originally proposed with supporting evidence by Brocher et al. (1994), is for the yak (Yakutat terrane or microplate) to be carried as an attachment by the Pacific plate as it is subducted north-northwest under the North American plate. This model is shown in Fig. 1 by Wallace (2008) as the Yakutat terrane and has been used in numerous scientific publications about Alaska tectonics. However, a thick yak staying attached to a fast moving PAC is physically impossible (Reeder, 2016). It also does not explain the November 30, 2018 earthquake nor the existence of the RED slice fault. The concept of dual subducting plates with distinctly different plate motions in southcentral Alaska is a very real possibility which cannot be ignored by the scientific community.

## CONCLUSION

New ideas about the tectonics of southcentral Alaska have been presented and the mechanics of the November 30, 2018 earthquake have been in general explained. Many assumptions have been made that should be qualified in the future. But in order for geologists and seismologists to better understand the earthquakes of southcentral Alaska, they need to research the possibility that two very different tectonic plates are being subducted in the Cook Inlet subduction zone with each moving in very different directions! The mechanics of the November 30, 2018

event supports such distinct plate motions and additional tectonic evidence has been presented to advance this assertion. Until such a realization is made by the Earth science community the earthquake and even the geologic processes for this region may never be fully understood!

## ACKNOWLEDGMENTS

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