Plate kinematics and mechanisms: A perspective on the 20 April 2006 M7.6 Koryakia, Russia earthquake

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Academic Affiliation, Fall 2007: Humboldt State University

RESESS Summer 2007

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ABSTRACT

The occurrence of a Koryakia, Russia magnitude 7.6 earthquake during April 2006 was a mysterious and unusual event. Although the study area is geographically located near two major plates boundaries, the main event and those that followed may support evidence for existence of a microplate. This earthquake and its aftershocks were analyzed using historical seismicity, magnitude, depth, latitude, longitude, and focal mechanisms to determine seismic trends and kinematics. Harvard Centroid Moment Tensors (CMT) and P-axes were produced from the data collected during the events. Building upon existing knowledge of the local plate mechanisms, moment tensor data were analyzed and deformation patterns noted. The results showed trends in significant event epicenters and deformation patterns were used to identify two possible faults that were previously unknown. Data analysis from the events related to the 20 April 2006 shock is intended to add to the body of seismic knowledge for eastern Russia and provide a basis for future research that attempts to clarify microplate plate boundaries and Koryakia's kinematics.

This work was performed through the National Earthquake Information Center (NEIC), Golden, CO and under the auspices of the Research Experience in Solid Earth Science for Students (RESESS) program. RESESS is managed by UNAVCO, with funding from the National Science Foundation and UNAVCO. RESESS partners include the Significant Opportunities in Atmospheric Research and Science Program, the Incorporated Research Institutions for Seismology, the United States Geological Survey, and Highline Community College.

1. Introduction

At 23:25:02 Coordinated Universal Time (UTC) on 20 April 2006, a magnitude 7.6 earthquake occurred in Koryakia, Russia. With epicenter located at 61.075°N latitude and 167.085°W longitude and hypocenter at 22 km this event was situated north of the isthmus of Kamchatka *(figure 1)* [NEIC, 2006].

In an attempt to gain a perspective on the Koryakia earthquake the seismic history of the region was examined and a comparison made between this and other events in the region. The earthquake was unusual in magnitude, but typical in depth. The largest earthquake on record was a shallow M6.6, while the average magnitude for all prior earthquakes (1973-2005) was 4.7. In 1991, 58 seismic events occurred, including a M6.6 event which, until 2006, was the region's largest earthquake on record. Aside from this, only 53 events are recorded in the 32 year time span between the time data collection began and April 2006. Furthermore, between 1991 and 2006 only 29 seismic events are recorded. Contrasting this to the period following the 20 April 2006 earthquake, 312 events occurred within a 15 month span; more than three times the number recorded previously [NEIC, 2007].

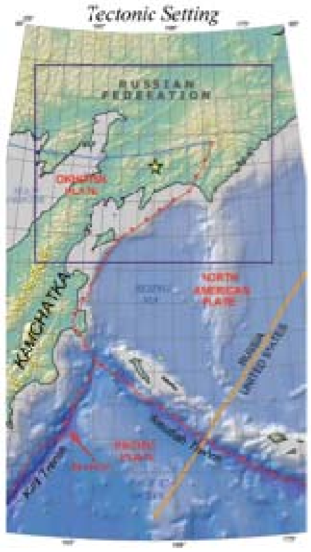

Figure 1. Location of 20 April 2006 earthquake. (Source: USGS)

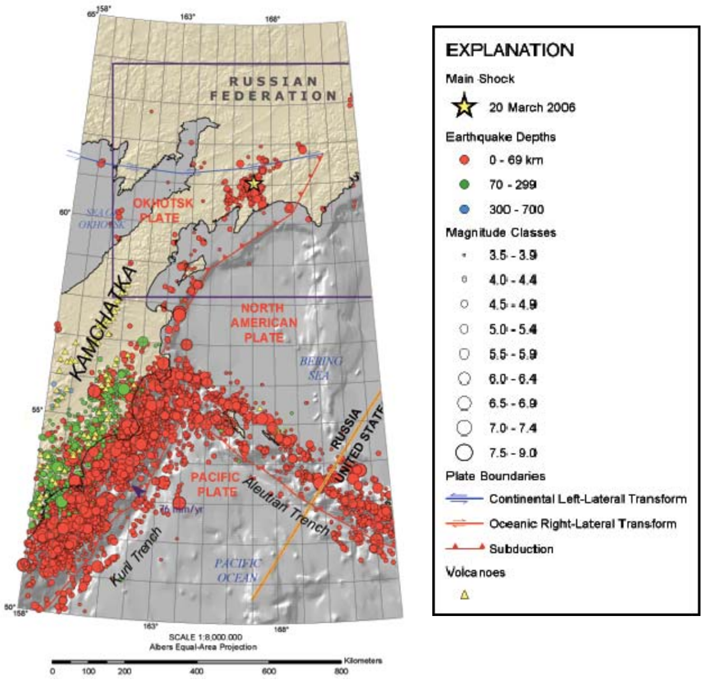

Figure 2. This map shows seismic activity along the boundaries of the North America and Pacific Plates. The frequency, magnitude, and depth of earthquakes along the two boundaries are indicated by dot size and color. (Source: USGS)

Off the eastern coast of the Kamchatka Peninsula is the Kuril Trench, a subduction zone characterized by active volcanoes and frequent earthquakes. This is considered to be the western boundary of the Pacific plate. The Pacfic plate's northern boundary is distinguished by another subduction zone: the Aleutian Trench. Here the plate slips in a roughly horizontal direction along the North America plate. Typical of both boundaries is a high level of continuous seismic activity (*figure 2*). As Pacific plate subduction progresses westward beneath the Kamchatka peninsula, there is a gradual deepening of earthquakes. Along the eastern seaboard of the Kamchatka Peninsula, earthquakes occur at a depth of up to 35 km. Yet, to the west of Kamchatka beneath the Sea of Okhotsk, earthquakes have been recorded up to a depth of 680 km. Thus, over a distance of 450 km the plate boundary slopes gently into the Earth’s interior. This gradual subduction is indicative of an old tectonic plate [Bird, 2003].

The location of the 20 April 2006 Koryakia event occurred 1035 km north of the Kuril - Aleutian Trench intersection. In Koryakia, frequency and depth of earthquakes differ greatly from the subduction zones to the south. In this region the deepest earthquake on record was 33 km. This suggests much different rtectonic processes exist in the Koryakia region.

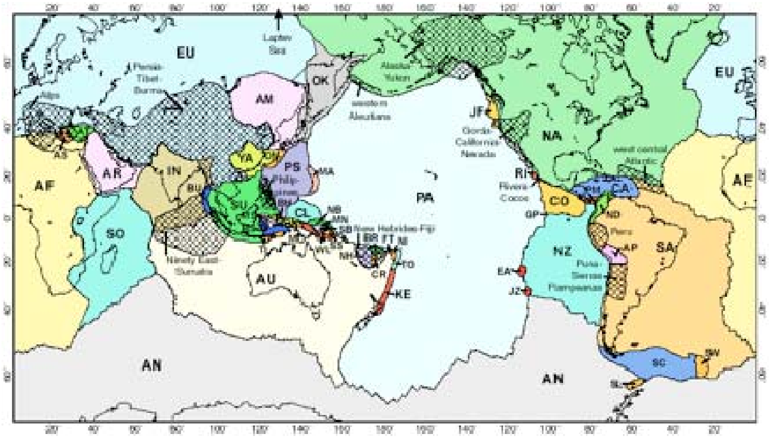

Figure 3. Showing the Bird model for major tectonic plates worldwide. (Source: Bird, 2003)

While there is general agreement between seismologists regarding northeast Asia's major plates *(figure 3)*, microplates are the subject of debate. Bird (2003) accepts the existence of an Okhotsk plate and rebuts the proposed Bering microplate based on Euler pole calculations. Chapman and Solomon (1976) also rebut the existence of a Bering microplate based on revised slip vector data. Lander (1996), on the other hand, gives a convincing argument for a Bering plate based on the relationship between kinematics recent tectonics, and adjusted Euler pole calculations. There are many speculative arrangements of microplates and the debate is destined to continue into the foreseeable future because the historical seismology for this part of the Earth is scant. The lack of seismic recording stations, inaccessibility of terrain, and global politics act as roadblocks to improved data collection that could provide a greater understanding of this area's plate tectonics. Additionally, the seismicity of the area is complex, so well-defined plate boundaries are dependent upon a lengthy and complete seismic catalog [Engdahl and Villaseñor, 2002]. For the purposes of this paper, the existence of the Okhotsk and Amur microplates are assumed, while the existence of the Bering microplate is considered disputed.

Given the framework of this discussion, seismologists were afforded an opportune moment in Earth history on 20 April 2006 to study kinematics and plate tectonics in this curious, controversial and little-understood region of eastern Russia.

2. Methods

To gain a perspective of events in the Koryakia region, an understanding of the area's existing earthquake history is necessary. Beginning in 1973, events are recorded in the USGS earthquake catalog (http://neic.usgs.gov/neis/epic/). A search of this database from latitude 59° to 63° N and longitudes 160° to 173° E produced 110 earthquakes prior to the 20 April 2006 event. These range in magnitude from 3.4 to 6.6, and in depth from 9 to 33 km. The largest earthquake on record prior to April 2006, occurred on 8 March 1991. A total of 57 lesser-magnitude shocks occurred beginning 17 February 1991 and tapering off until 22 June 1991 when the aftershocks subsided *(figure 4)* [NEIC, 2007].

By comparison, 311 aftershocks followed the April 2006 Koryakia earthquake over period of fifteen months, ranging in magnitude from 3.5 and 6.7 and occurring up to a depth of 44 km. Since the last recorded earthquake occurred on 06 June 2007, it is assumed the chain of events motivated by the April 2006 event has run its course [NEIC, 2007].

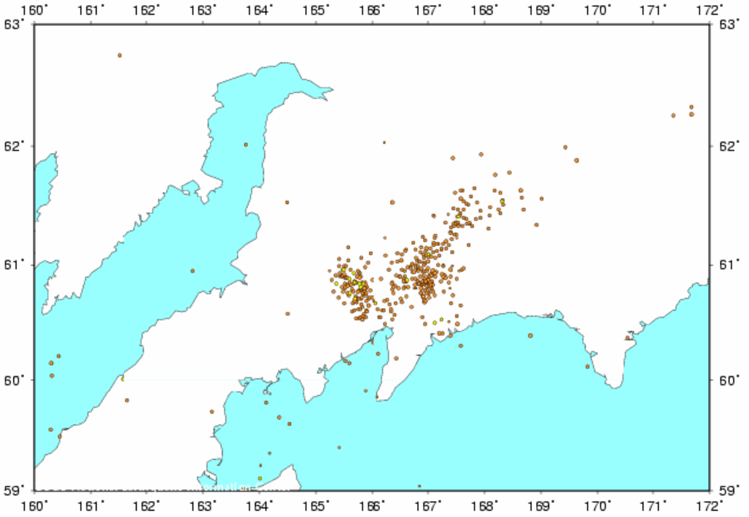

Figure 4. Map shows location of 2006 - 2007 seismic events (Source: NEIC, 2007)

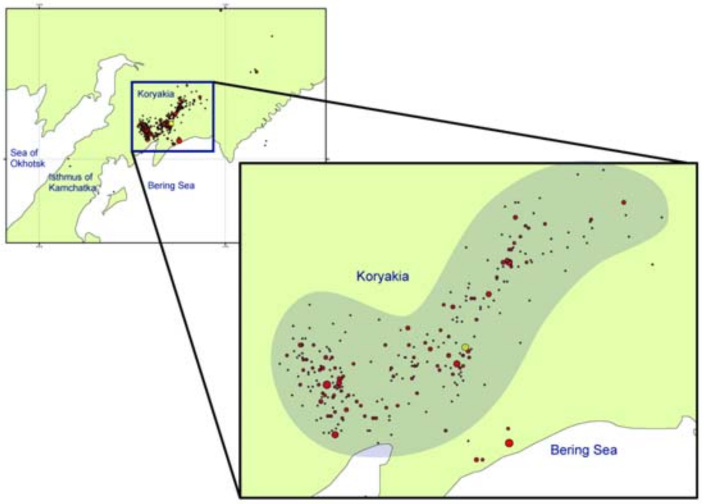

Figure 5. Map shows reverse L-shaped activity area. (Source: NEIC, 2007)

For the 2006-2007 events data analysis was conducted using ArcGIS to view the events by magnitude, epicenter, hypocenter, and physical location in relation to the main shock. Spatial distribution of the shocks appeared to be clustered in a reverse L-formation and generally located on both sides of the mail event in a northeast and northwest direction, with a few outliers to the southeast *(figure 5)*. Depth for all events greater than M5.0 was mapped using two methods: GMT and 3D Viewer. Both visualizations confirmed these were no deeper than 35 km, falling within expected range for shallow earthquakes *(figure 6)*. When epicenters of the 1991 M6.6 and 2007 M7.6 earthquakes were compared, it was discovered that both earthquakes were extremely close geographically. The 8 March 1991 earthquake was located at 60.9°N latitude and 167.02°W longitude. The 20 April 2006 earthquake was located at 60.95°N latitude and 167.09°W longitude *(figure 7)*. The epicenters of these two events were located in the same place.

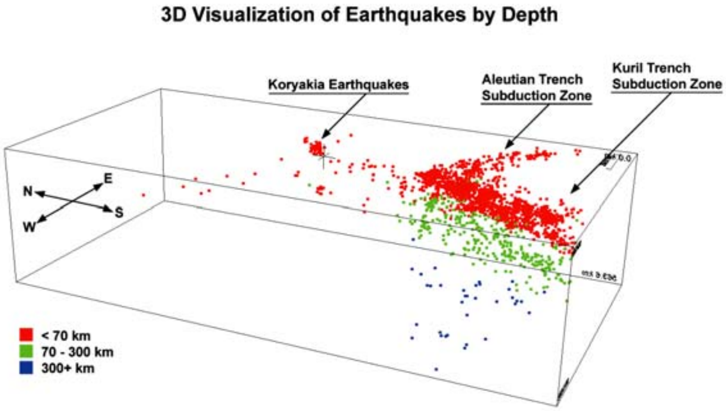

Figure 6. Depth of Koryakia events in comparison to Pacific Plate seismic activity. (Source: Angster, NEIC, 2007)

NEIC: Earthquake Search Results

Year	Month	Day	Time (hhmmss.mm) UTC	Latitude	Longitude	Magnitude	Depth
1991	3	8	113628.43	**60.9**	**167.02**	6.6	13
2006	4	20	232502.15	**60.95**	**167.09**	7.6	22

Figure 7. Comparison of 1991 and 2006 significant events by latitiude and longitude. (Source: NEIC, 2007)

Faulting was classified by three basic types: thrust, normal, and strike-slip. A fourth mechanism, representing events that were less than 75% any single mechanism type was also used. These "hybrid" type mechanisms are considered unusual. Using azimuth, dip-angle and wave data collected at the time of the events, Harvard Centroid Moment Tensors (CMT) were produced using Global Mapping Tools (GMT) to determine types and direction of faulting for events of M5.0 and greater *(figure 8)*. The result showed thrust and strike-slip types predominated. Of the 38 shocks that were analyzed the majority were thrust-type that appeared linearly on a southwest-to-northeast direction and strike-slip type on a linear northwest to southeast direction. There were a several hybrid mechanisms, mostly located to the east of the main group of shocks. There was only one normal fault mechanism. *Figure 9* shows the distribution of fault mechanisms by depth (size) and type (color).

It was observed that four gaps in mechanisms exist. The reason for this may be that shocks less than M5.0 released enough pressure to prevent greater magnitude events from occurring. There was also one area where strike-slip and thrust-type events overlapped. In this location both types of activity were consistent in their deformation toward the northeast *(figure 10)*. Data were also processed as P-axis events, which indicate the direction of maximum compression. P-axes were consistent with tensor mechanisms, showing a distinct faulting pattern in southeast-to-northwest directions located at roughly a 90° angle to each other *(figure 11)*.

3. Discussion

The most unique feature of the 20 April 2006 event is its correspondence to the M6.6 earthquake on 8 March 1991. It is worth noting latitude and longitude show a close correspondence. This could indicate a weak point where pressure is most easily released. This location may be the epicenter of future significant events.

A time span of 34 years is but a the briefest moment in geological time; at least 100 years of consistent data need to be available to paint an accurate picture of seismic trends [Engdahl and Villaseñor, 2002]. Based upon the 34-year record available through the NEIC seismic catalog, Koryakia experiences periods of limited earthquake activity in which pressure builds up and culminates in significant pressure release through a high magnitude event. Thus, while on average two low-magnitude events may occur per year, occasionally there will be significant high-magnitude earthquakes followed by a cluster of shallow aftershocks.

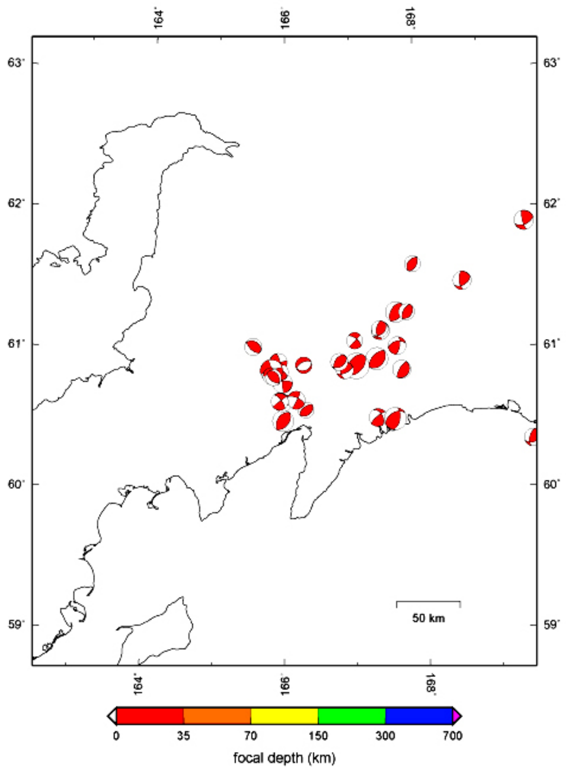

Figure 8. Tensor mechanisms by depth. (Source: Villaseñor, NEIC, 2007)

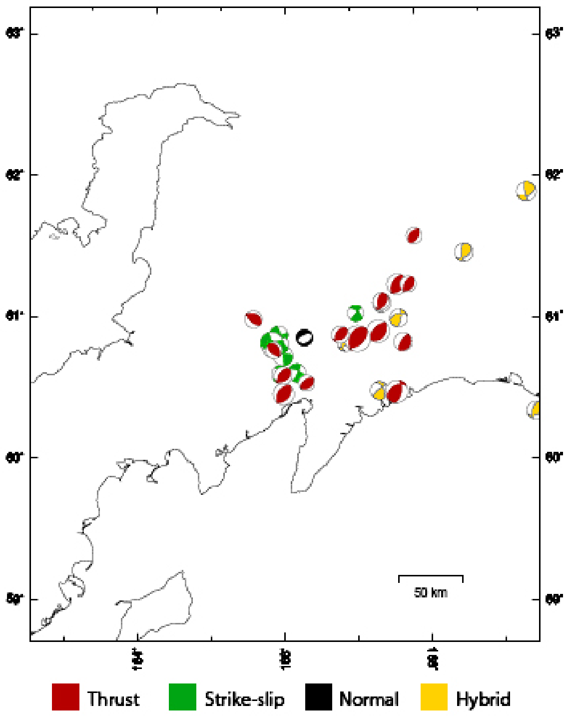

Figure 9. Tensor mechanisms by type. (Source: Villaseñor, NEIC, 2007)

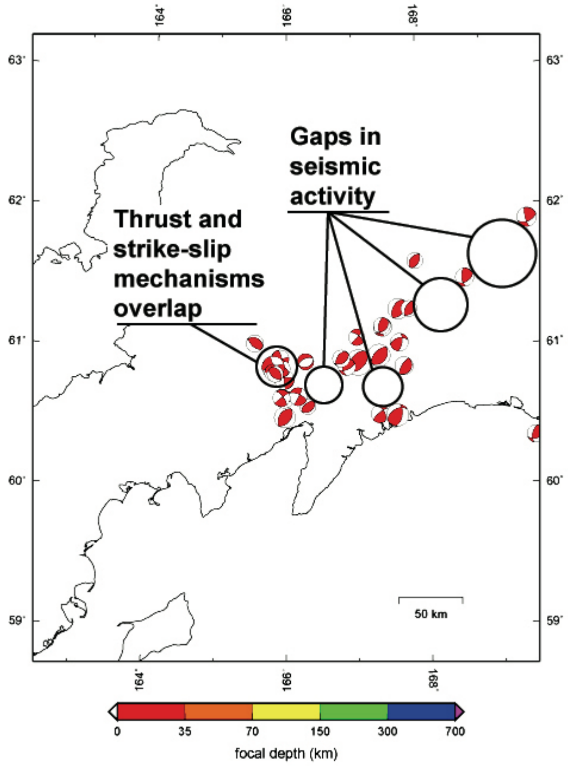

Figure 10. Map shows gaps and overlapping fault mechanisms. (Source: Villaseñor & Boshell, NEIC, 2007)

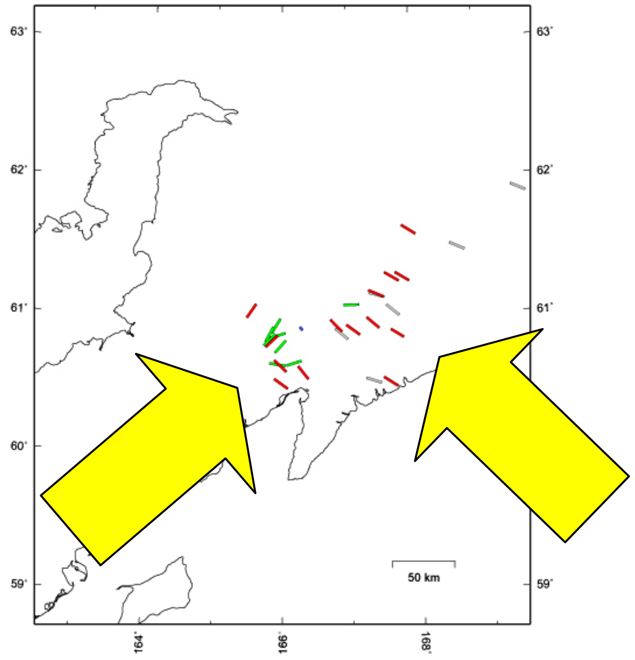

Figure 11. P-axes indicate direction of maximum compression (yellow arrows). (Source: Villaseñor & Boshell, NEIC, 2007)

The 20 April 2006 event holds the record for the region's largest earthquake at M7.6. On average the region's earthquakes have occurred in the M3 to M5 range. While low-to-moderate earthquakes are the norm as are events with shallow hypocenters, evaluation of fault mechanisms indicated two interesting characteristics: faults previously unidentified by the seismic community and the absence of subduction.

Moment tensors show a pattern of thrust-type activity in a southwest to northeast direction and strike-slip activity in a southeast-to-northwest direction. This indicates two separate faults. Given the type of fault mechanisms and where they are located geographically in relation to one another, it appears two faults may be present. The first fault appears to begin at approximately 60.5°, 166° northeastward in a straight line to approximately 61.5°, 168° and possibly further to 61.9°, 169.5° *(figure 12)*. Since this is mainly a thrust-type fault, one possibility is a Bering plate colliding with Eurasia plate. Henceforth this fault will be referred to as the Benz Fault.

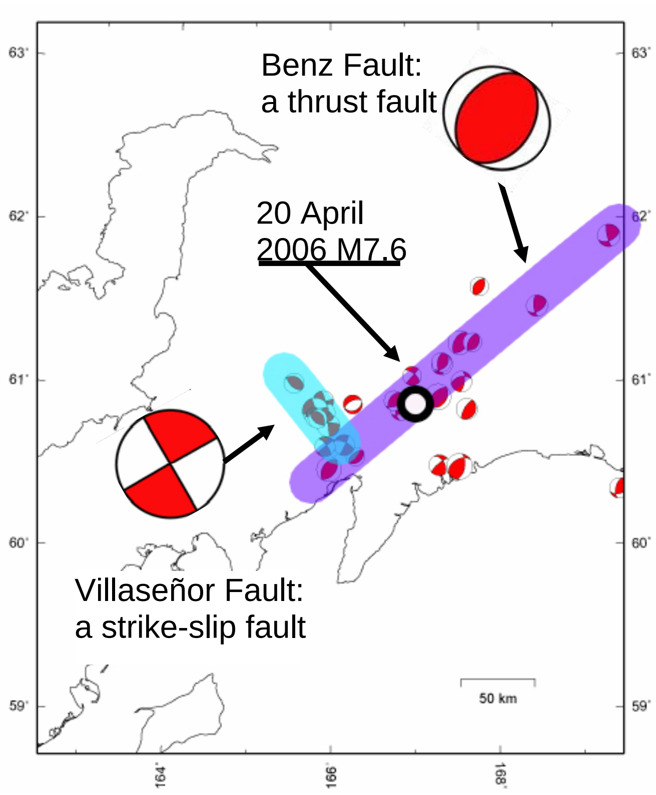

Figure 12. Liines superimposed indicate fault location and direction. The two large mechanisms show expected deformation expected for each fault. (Source: Villaseñor & Boshell, NEIC, 2007)

The second fault appears to be mainly strike-slip type and is a shorter fault, extending from approximately 60.5°, 166.5° in the south to 61.2°, 165.5 in the north, making this a southeast-northwest directional fault. This action is at a 90° angle to the fault action discussed in the previous paragraph. Going forward, this fault will be referenced as the Villaseñor Fault.

These faults are related in that pressure release along the Benz Fault motivates activity along the Villaseñor Fault. However, they are unrelated in deformation type. The direction and type of deformation indicate collision is occurring. The shallow depth indicates subduction is not occurring here [Villaseñor, 2007].

4. Conclusion

This evaluation provides no absolute evidence for or against the existence of a Bering microplate. While the presence of faults in the vicinity of the proposed plate boundary could be used as evidence, the absence of subduction could be used as a rebuttal. One interesting possibility is that the Bering plate is so young that it's colliding with the old Eurasia plate. Monitoring future event hypocenters could provide clues. If hypocenters begin to deepen, then subduction may be occurring.

The co-location of epicenters within a 43 km^2 area of the Benz fault indicates a structural weakness and future significant earthquakes may occur at this point. Additionally, thrust-type activity should be expected to continue along the Benz fault and strike-slip activity should be observed along the Villaseñor fault. Caution would dictate avoidance of these faults when planning construction of any kind, especially in the area of 61°N latitude and 169°W longitude.

This research lays the foundation for broader studies. Analysis of plate rotation could yield interesting clues for Bering plate researchers. Further analysis of tomography and deformation is also recommended since these factors were only briefly addressed. A study of structural geology would be helpful in providing information about the terrain and could yield some excellent clues about the conditions surrounding earthquakes in Koryakia. A physical inspection of the Benz and Villaseñor fault areas could provide some useful information otherwise unobtainable.

A search should be done for records prior to 1973. It is unknown if Russian seismic catalogs exist for eastern Russia before 1973, however, if so it would be interesting to run the historical data through the same analysis as the 2006-2007 sequence. Also, other catalogs may exist. For this study the NEIC earthquake catalog was the sole source. Given the sparse historical data, oral accounts of past memorable seismic events might provide further insights. Koryakia is home to indigenous communities and small villages. Residents whose families have lived here for generations often preserve natural history through storytelling and could prove a valuable source of historical information for researchers.

GPS stations like those used in the EarthScope project could provide the best source of seismic information and would be an enormous step forward in determining microplate boundaries. Future funding might well address this approach.

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