# A TELESEISMIC P WAVE ANALYSIS OF THE 30 JUNE 1975 EARTHQUAKE AT YELLOWSTONE NATIONAL PARK, WYOMING

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At 18:54:13 Universal Time on 30 June 1975 an earthquake of magnitude 6.1 ($M_L$) occurred in Yellowstone National Park, Wyoming. This earthquake was part of a sequence consisting of 5 foreshocks, 1 main shock, and 91 aftershocks occurring through 19 July 1975. An analysis of this earthquake sequence was done by Pitt et al. (1979) utilizing mainly local seismic recordings and a few teleseismic recordings. However, Pitt et al. (1979) never fully constrained the main shock. Therefore, the purpose of this study was to reexamine the teleseismic P wave recordings in order to constrain the main shock of this earthquake sequence.

## GEOLOGIC SETTING

Yellowstone National Park, spanning 9,000 square kilometers, is located on the Yellowstone Plateau in the northwestern portion of the state of Wyoming and parts of Idaho and Montana. The plateau, formed at the intersection of three Late Cenozoic tectonic trends, is located directly above a mantle diapir or hot spot. During the Pleistocene, this hot spot caused a period of volcanism to begin within the plateau. This volcanism, lasting two thousand years, consisted of three major cycles each climaxing in a violent pyroclastic caldera-forming eruption of rhyolites and ash flow tuffs. The last eruption resulted in the formation of a large collapsed caldera 75 kilometers by 45 kilometers in size. Because of this hot spot Yellowstone lies within one of the most seismically active regions of the Rocky Mountains. The vast majority of the earthquakes in this area result from regional tectonic movement and/or activity within the magma chamber underneath Yellowstone. It is believed that another period of volcanism is developing within Yellowstone (Towell, 1980; Smith and Christiansen, 1980).

## LOCATION

The epicenter of the main shock was centered near Norris Junction on the north-central boundary of the Yellowstone caldera (Fig. 1). Located just north of the epicenter is an exposure of a slump surface that dips southward into the caldera. At some lateral distance and depth, this slump surface intersects more steeply dipping ring-fracture zones which were the principal outlets of the last major pyroclastic eruption 600,000 years ago. No visible faults are present in the vicinity of the epicenter, however, numerous north-to-northwest trending normal faults exist north of the epicenter (Pitt et al., 1979).

## PREVIOUS ANALYSIS

Pitt et al. (1979) determined that most of the focal mechanisms for this sequence indicated normal faulting striking north-northwest. Some focal mechanisms, however, did show a strike-slip component. Pitt et al. (1979) believes that the 30 June earthquake sequence combined with the trends of previous activity south of Norris Junction indicates that two buried subparallel fault zones exist underneath the north-central boundary of the caldera. In addition, Pitt et al. (1979) believes that this earthquake sequence demonstrates that seismicity within the northern part of the Yellowstone caldera relates to a regional stress system and that the caldera is capable of supporting major block tectonics, a feature common throughout the region. Pitt et al. (1979), however, does not believe that the 30 June earthquake sequence reflected any current activity within the magma chamber underneath Yellowstone.

## DATA ANALYSIS

Eight Canadian and twenty-eight WWSSN long period vertical and horizontal seismograms recording this earthquake were obtained from the National Earthquake Information Center in Denver, Colorado. Additional data were also obtained from the International Seismological Center (ISC) Bulletin (1975).

A first motion analysis was attempted of the Canadian and WWSSN seismograms in order to determine a double couple mechanism for this earthquake. However, because most of the recordings had low amplitudes it was extremely difficult to determine the first motion polarity of the P waves. Consequently, a double couple mechanism could not be determined from this data. First motion data from the ISC were then analyzed to augment the Canadian and WWSSN data. Because the ISC data were inconsistent both internally and with the Canadian and WWSSN data, it was unable to augment the Canadian and WWSSN data. Thus, from first motion analysis it seemed that this earthquake did not result from a double couple source as previously determined by Pitt et al. (1979).

rado. Seismograms for the 1958, Huslia, Alaska earthquake were obtained directly from seismic observatories in the U.S. and Europe, and one Russian record was obtained from the Historical Seismogram Filming Project, administered by the NEIC. All of the microfilm and microfiche seismograms were examined on viewers, the P and SH wave arrivals identified, and the useful parts of the records were printed. All of the paper records and prints were then digitized on a digitizing table, smoothed, and sampled to produce digital records. The resulting seismograms were then modeled and the focal parameters of the earthquakes estimated.

Amy Larson (Smith College), Valerie Scruggs (Smith College), Laura Reiser (Beloit College) and Tim Daughton (Colorado College) worked on a series of aftershocks of the 10 June 1975 Nemuro-Oki tsunami earthquake located on the arcward slope of the Kurile trench. The mainshock produced anomalously large tsunamis for its seismic moment. This enhanced tsunamigenic efficiency has been attributed to a very long rupture which lasted in excess of 40 seconds. This slow rupture may result from rupture occurring in the sediments of the accretionary wedge. Because of the complex rupture of the mainshock it is difficult to model and its depth beneath the seafloor is not well constrained. Determining the depths of the aftershocks is critical to understanding this slow rupture process. In the process of modeling these aftershocks, it was found that they too have anomalously long rupture times for their size. Preliminary results of this modeling were presented at the Fall 1989 American Geophysical Union Meeting. Amy and Valerie have continued to refine these models and present the results in their abstract in this volume.

After the summer session, Laura tackled the analysis of the 7 April 1958 Huslia, Alaska earthquake. This proved to be a great challenge as that available data was scarce and much of it was of poor quality. An additional problem was the lack of standardized instruments in 1958. This earthquake is the largest non-subduction related earthquake ever recorded in Alaska. Some early analysis was carried out in the 1960's, but the techniques and theories applied are now known to be in error. It is therefore critical to use modern techniques to look at the data that still exists from this major event.

Since his return to Colorado College, Tim Daughton has analyzed the 22 November 1969 Kamchatka earthquake. This earthquake turned out to be significantly larger than had previously been determined. It is an important earthquake as it lies at the corner between the Kurile arc and the Aleutian arc. In this location it may represent residual motion on a now inactive subduction zone. Understanding the tectonics of this region is critical to the delineation of the North American-Asia plate boundary. He sought to verify previous work on the focal mechanism and to make the first accurate determination of the depth of this earthquake. Previous estimates of depth were based only on crude locations and qualitative analysis of the seismograms.

During the summer session, Robert Andrews (College of Wooster) and Greg Wimpey (Trinity University) began an analysis of the 30 June 1975 Yellowstone earthquake. This relatively small event ($M_L$= 6.1) event has never been studied using teleseismic records. Reported first motion data were inconsistent and there was some question whether this earthquake represented a double-couple source. The records showed very weak arrivals making this a very difficult event to analyze. Robert has completed a careful study of the P waves in which he shows that this earthquake is indeed a double-couple event and that the effects of a low velocity diapir under Yellowstone must be included in the modeled seismograms. Greg has modeled the SH waves in order to better constrain the strike and slip-angle of the event, two parameters which were relatively poorly constrained by the P waves. Greg continues to work on the surface waves from this event.

During the summer session, Tim Vick and Glenn Kroeger spent the majority of their time removing bugs from software which the students were so kind as to find. I am especially indebted to Tim for his music, his software development, and for managing Sunday breakfasts. Finally, all of the participants in the earthquake seismology project wish to thank the Keck Foundation for the funding that made this experience possible.

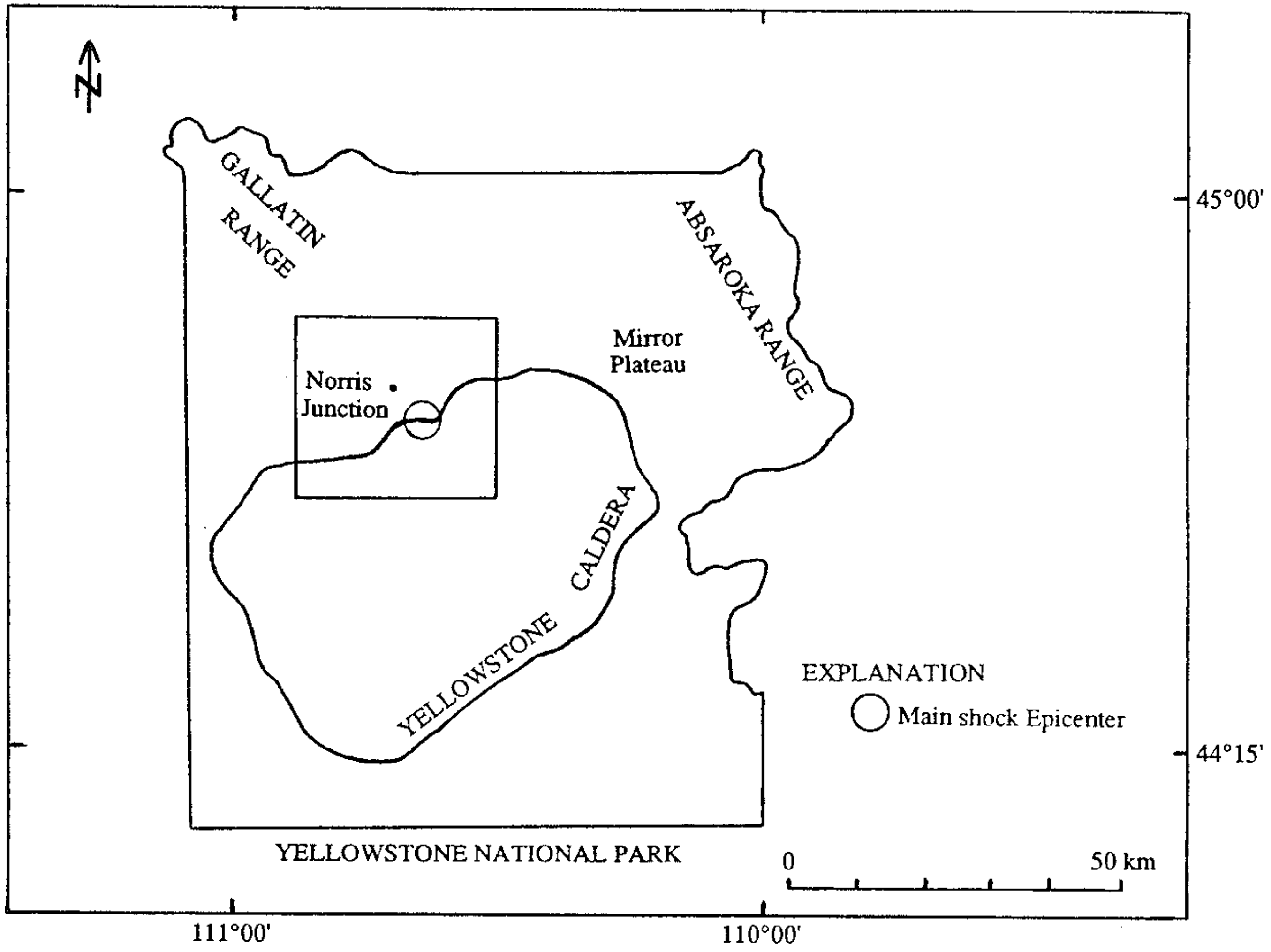

Figure 1: Map showing the location of the 30 June 1975 earthquake on the north-central boundary of the Yellowstone caldera (44°42'N latitude and 110°40'W longitude). (After Pitt et al., 1979)

Body wave modeling was then attempted on those Canadian and WWSSN seismograms which had large amplitudes (13 in all). After much work and the utilization of a crustal structure which best compensated for the geology near the caldera a double couple mechanism was achieved.

## RESULTS

One nodal plane was determined to be trending to the northwest at a strike of 320° and dipping 60° to the northeast. Assuming this plane as the fault plane, based on the local geology, the slip angle was determined to be 285°, implying that this earthquake was the result of a normal fault movement with some strike-slip component. The depth of focus was then determined to be 2.5 kilometers.

Modeling of the body waves also determined an azimuthal variation in the source-time function for this earthquake. Station COL had a total duration of 2.0 seconds (rise = 1.0, flat = 0, fall = 1.0) while stations GEO, BEC, CAR, BOG, and BDF had a total duration of 7.5 seconds (rise = 3.0, flat = 1.5, fall = 3.0). All other stations had a total duration of 5.5 seconds (rise = 3.0, flat = 1.5, fall = 1.0). Based on the above mentioned determinations a best fit for the focal mechanism and the synthetics of all modeled stations is presented in Figure 2.

## DISCUSSION

The findings of this study agree with the local geology, the analysis of epicenters near the caldera by Trimble and Smith (1975), and the previous analysis of this earthquake by Pitt et al. (1979). First, since normal northwest trending faults are present north of the epicenter it was realistic to have a normal fault mechanism trending to the northwest as a solution for this earthquake. Second, Trimble and Smith (1975) determined from 182 epicenters that focal depths near and within the caldera range between one and five kilometers. Since this earthquake was on the north-central boundary of the caldera, it was reasonable from this analysis for the depth of focus to be 2.5 kilometers. Finally, even though more aspects of the this earthquake were constrained with this study than the analysis of Pitt et al. (1979), both analyses agree that this earthquake occurred as a normal fault movement with evidence of a strike-slip component.

The azimuthal variation of the source-time function is explainable by the following. First, for stations east and southeast of the epicenter (Fig. 2) the length of 7.5 seconds probably represents the attenuation of the body waves traveling through the mantle diapir underneath Yellowstone. Second, for station COL (Fig. 2) the length of 2.0 seconds might yield that this earthquake propagated in a northwesterly direction. However, because this length was only observed at one station, it probably does not represent the propagation direction, but instead it's a station that has an unresolvable source-time function. Therefore, based on the previous discussion a best estimate for the duration of this earthquake is about 5.5 seconds.

From this study it can not be confirmed whether this earthquake was related to movement within the magma chamber or to a regional stress system near Yellowstone (Pitt et al., 1979). However, since a double couple mechanism fit as a solution, it can be concluded that this earthquake did not occur within the magma body or did not result from the direct intrusion of magma into a fracture. In addition, because the magma chamber underneath Yellowstone is believed to begin at a depth of 5 kilometers (Lehman et al., 1982) and the depth of focus for this earthquake was determined to be 2.5 kilometers, it can again be concluded that this earthquake did not occur within the magma body.

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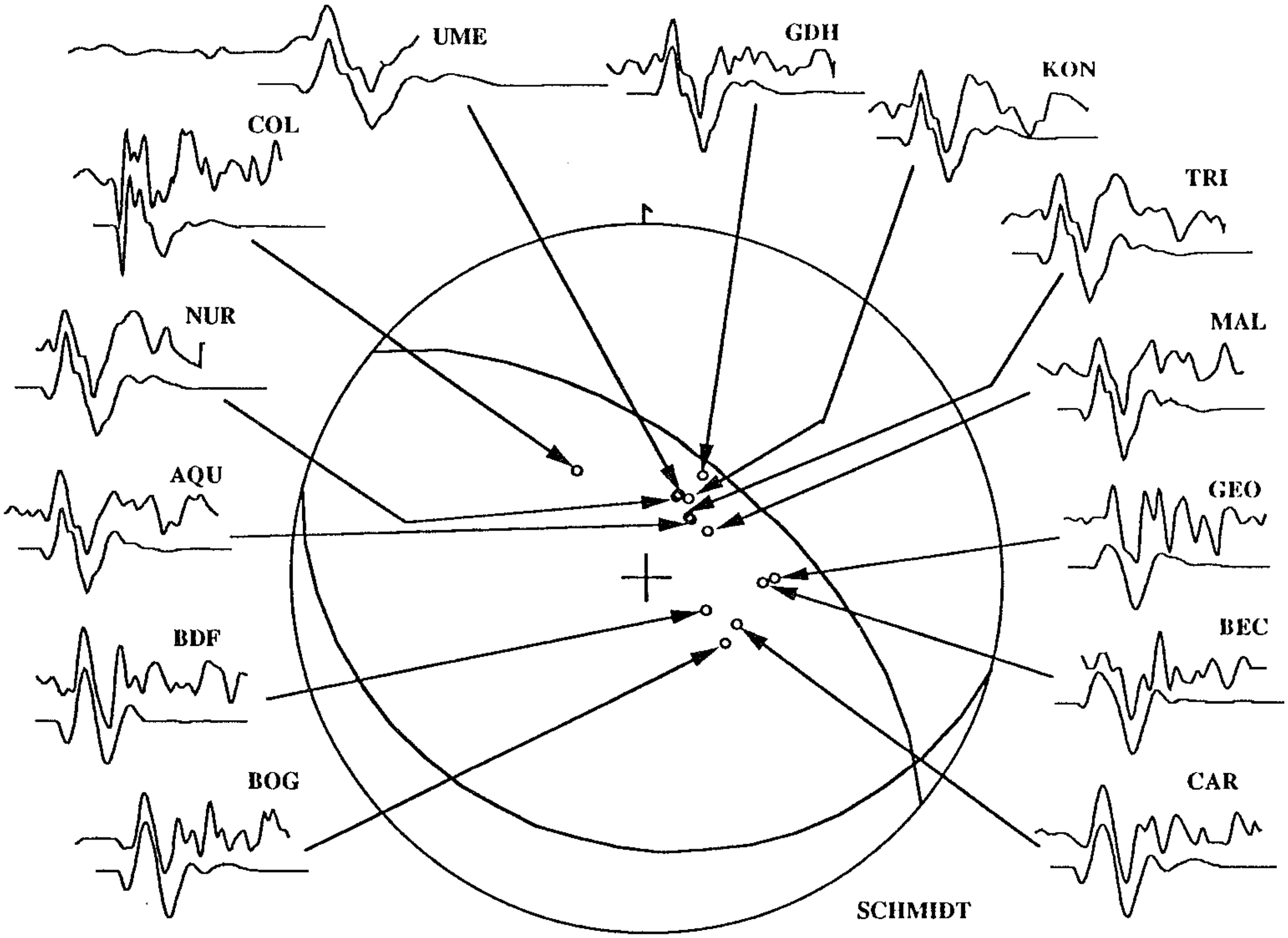

Figure 2: Composite figure representing the best fit of the synthetics to the observed achieved with this study. The circles represent dilatations. The epicenter of the main shock is the center of the stereonet. Observed seismograms are represented with the top line and the synthetics are represent with the bottom line. The source-time function varied with azimuth and the following were held constant: Strike = 320°, Dip = 60°, Slip Angle = 285°, Depth = 2.5 km

# FOCAL MECHANISM OF THE 22 NOVEMBER 1969 KAMCHATKA EARTHQUAKE FROM TELESEISMIC WAVEFORM ANALYSIS

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## Introduction

On November 22, 1969 an earthquake with a magnitude of approximately $M_s$=7.5 occurred off of the eastern coast of the Kamchatka peninsula, USSR. (Figure 1). This large earthquake is located in an extremely complex tectonic setting where the active plate boundary geometry is poorly understood. Thus an understanding of the mechanism of this event is important to the understanding of the plate tectonics of the region.

## Tectonic Setting

The Kamchatka peninsula is a remnant island arc system. During the late Cretaceous, the Kula plate was being subducted under the Eurasian plate forming the Iruneiskaya arc (Savostin *et al.*, 1983). The subduction continued until the Eocene when the Kula-Pacific ridge was subducted under the Aleutian trench (Savostin *et al.*, 1983). At this time, the modern tectonic setting began to form.

Today, the tectonic setting is much more complicated than 150 million years ago. The Pacific plate is being subducted under the southern half of the peninsula in the Kurile trench. Subduction under the peninsula probably ends at the junction of the Kurile and Aleutian trenches near the Kamchatka Cape (Stauder and Maulchin, 1976). The boundary between the Sea of Okhotsk microplate and the North American plate runs northeast from this junction to Karaginskiy Island where it turns northwest, across the peninsula, through the Sea of Okhotsk, and onto the Soviet mainland. The dominant motion along this boundary has been strike-slip (Savostin *et al.*, 1983). The Eurasian plate bounds the Sea of Okhotsk plate microplate on the west. None of these plate boundaries have been accurately defined. This may be due to the relatively young age of the Sea of Okhotsk microplate, probably Holocene (Savostin *et al.*, 1983). This may not have been enough time for surface expressions to form. The 22 November 1969 earthquake was located in the area where the boundary between the North American plate and the Sea of Okhotsk microplate changes from a northeasterly trend to a northwesterly trend.

## Previous Studies

None of the previous studies of this event have involved the use of body waveform analysis. In 1976, Stauder and Maulchin examined this earthquake using first motion analysis and S wave polarization angles. They gave the magnitude of the event as $m_b$=6.3 and gave a depth of 33 km. This depth was based on a location inversion and represents a standard default depth for the method. Their methods were not designed to determine depth or to estimate the rupture time of the earthquake.

The ISC Bulletin gives a depth of 51.1 km for this event. ISC depths are generally considered to be unreliable for earthquakes of less than 100 km depth. The ISC reports a magnitude of 6.3. A more recent study by Seno and Eguchi (1983) report a depth of 38 km and a body wave magnitude of $m_b$=7.0. They estimate that the moment-magnitude, $M_w$ may be as large as 7.8.

## Analysis

A first motion mechanism was determined from picks made on 24 WWSSN long period seismograms. This mechanism is shown in Figure 2. The fault plane is probably the shallow, northwest dipping nodal plane. The strike and dip of this plane, N50°-80°E, 5°-10° NW are approximately coincident with the paleo-subduction zone. The cluster of compressions surrounding the center of the focal sphere clearly indicates a thrust mechanism.

It was clear from the examination of the P wave arrivals that this event was significantly larger than the magnitude 6.3 reported by some of the previous studies. Many of the P records were off scale, and only those records from