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Quarry Blast Sources and Earthquake Prediction: The Parkfield, California, Earthquake of June 28, 1966

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Summary – Quarry blasts provide an excellent source of waves with which to study temporal variations of seismic travel times. Using sources from several active quarries we found no time changes at Gold Hill (GHC), California from 7 months before the 1966 Parkfield mainshock to at least 13 months following the event. GHC is within 0.5 km of the zone of ground breakage associated with the earthquake. This event was one of the largest to occur in central California since 1906. The negative result of our experiment does not rule out the existence of an anomaly prior to the event, rather it emphasizes the difficulty of detecting such anomalies without a fortuitous combination of sources and stations. The routine monitoring of temporal changes in seismic velocity along the San Andreas fault may require not only dense networks of high quality seismic stations, but also sources whose spatial location and origin time can be controlled.

1. Introduction

Quarries which detonate large explosions at regular intervals provide a reliable source of waves with which to probe for systematic changes in seismic velocities; uncertainties due to focal depth and epicentral location are not important and sources can be outside the zone of seismic activity. In central California a number of quarries are available. In a previous study (MCEVILLY and JOHNSON [1]), blasts from the Natividad quarry (Fig. 1) were used. Although the scatter in the data was quite small (less than ±0.1 sec), no anomalous velocity behavior was found, leading the authors to suggest a maximum dimension of 10 km for the volume experiencing premonitory velocity changes. During the same time period, however, an anomaly of 0.3–0.4 sec was observed for an earthquake of magnitude 5.1 (BRK) in the Bear Valley region of the San Andreas fault, using local earthquakes, 20–60 km distant, recorded at a station in Bear Valley (ROBINSON *et al.* [2]). The apparent inconsistency between the study using regional earthquakes and that using quarry blasts is easily explained by lack of blast–receiver travel paths in the small anomalous region and by the absence of a blast during the anomalous time period. The two studies, along with that of CRAMER and KOVACH ([3]), emphasize the difficulty in observing travel time variations along the San Andreas fault; a fortuitous combination of sources and receivers is required.

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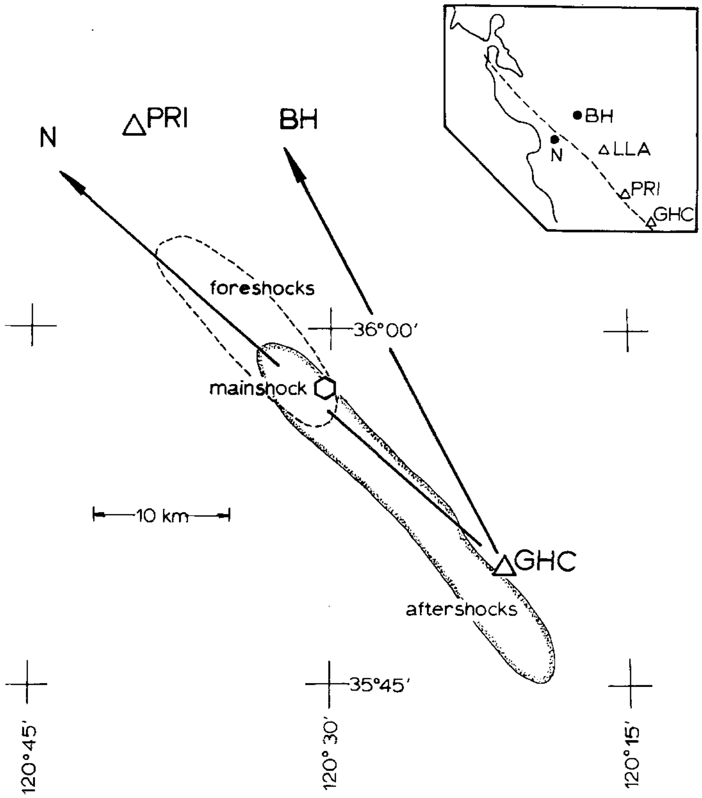

Figure 1
Location map showing the stations Gold Hill (GHC) and Priest (PRI), with arrows pointing to the Basalt Hill (BH) and Natividad (N) quarries. Regions of fore- and aftershock activity are shown schematically. Inset: location of stations and sources

2. Data

In this study blasts at the Basalt Hill (BH) and Natividad (N) quarries (Fig. 1) were used to search for variations in seismic velocity in the vicinity of the June 28, 1966, earthquake near Parkfield. The Parkfield earthquake ($M_L = 5.5$, $m_b = 5.8$, $M_s = 6.4$) is one of the most significant central California earthquakes since the great 1906 San Francisco earthquake. We expected that the source–receiver geometry and the frequency of blasts would provide an almost ideal experiment. Basalt Hill quarry blasts occurred almost weekly in early 1966, and a high quality, short period seismic station was installed at Gold Hill (GHC) 8 months prior to the earthquake. As seen in Fig. 1, GHC is near the southern end of the aftershock area. The arrival times at GHC were compared with those from PRI and LLA. Discussions of the stations can be found in Eaton *et al.* ([4]) and McEvilly and Johnson ([1]). The timed arrival corresponded to a uniquely identifiable phase within 1 second of the initial P-wave

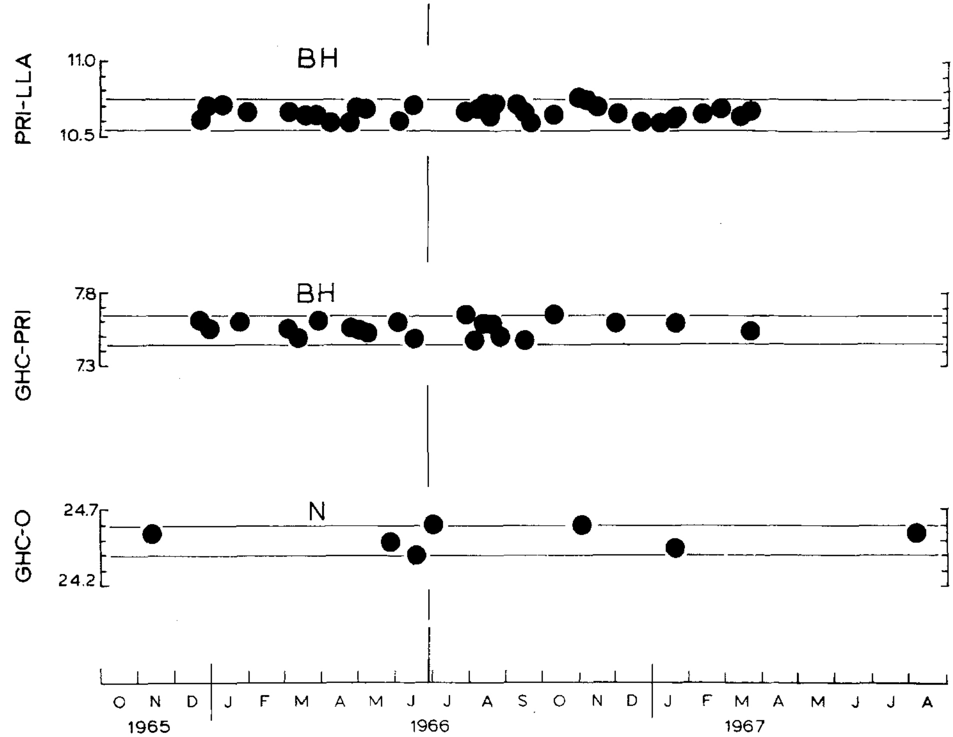

Figure 2
The residuals from BH and N as recorded at LLA, PRI, and GHC. Units of ordinate are seconds; vertical line shows the date of the Parkfield mainshock. The light lines through the data are ± 0.1 sec from the estimated mean and correspond to the approximate uncertainty in our readings

arrival. Transparent overlays were used to aid in the identification of the phase. Uncertainties in the arrival time are about ± 0.1 sec for the GHC data and about ± 0.05 sec for the PRI and LLA data.

The data are shown in Fig. 2. The time differences GHC–PRI and PRI–LLA are shown in the top bands for the Basalt Hill (BH) quarry blasts (148 km from GHC). The data from the Natividad (N) quarry (149 km from GHC), in the third band, are referenced to the origin time of the blast (as given by McEvilly and Johnson [1]). No temporal variations of travel time are apparent within the accuracy of our readings. Data from other, somewhat less accurate, sources are in accord with the stable results shown by the quarry blast observations (Boore *et al.* [5]).

3. *Discussion*

The lack of any variations in travel time can be explained in many ways. If, by analogy with the results of Robinson *et al.* ([2]) for a magnitude 5 earthquake along the fault to the north, we assume that a decrease in seismic velocity was associated with the Parkfield earthquake, then there is an outside chance that the anomaly had returned to zero before the installation of GHC 8 months prior to the earthquake and thus was missed by our measurements. This seems unlikely to us (we estimate a precursor time of 140–500 days based on the results of ROBINSON *et al.* [2] and SCHOLZ *et al.* [6]).

There are several more likely explanations involving the spatial extent of the region of anomalous velocity. If the region were only 5 km in depth and several km in width, velocity changes of 10–15% would be undetected both because of the small effect on the rays traveling through the zone and because of diffraction around the zone. On the other hand, a larger zone of low velocity material would be undetected if it existed in the region of the foreshocks to the north of the main shock epicenter.

Overall, it is disconcerting that, with a sensitivity of ±0.1 sec at a station essentially within the aftershock zone, one of the largest central California earthquakes since 1906 showed no velocity precursor. The implication for earthquake prediction along the San Andreas fault is that dense networks of high quality seismic stations and, ideally, controlled sources are required. Furthermore, it is possible that the zone of anomalous velocity change may not coincide with the full zone of subsequent earthquake rupture.

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