Bulletin of the Seismological Society of America, Vol. 68, No. 3, pp. 859–862, June 1978

THE EFFECT OF NEVADA TEST SITE GEOLOGY ON ABSOLUTE TRAVEL-TIME RESIDUALS AT MATSUSHIRO, JAPAN, AND COLLEGE, ALASKA

BY CHRIS H. CRAMER* AND DAVID M. BOORE

The suitability of Nevada Test Site (NTS) nuclear shots as a seismic source in searching for temporal changes in *P* velocity has been demonstrated by Utsu (1973) and Boore *et al.* (1975). The precise knowledge of locations and origin times makes the NTS shots a highly desirable source. However, Boore *et al.* (1975) point out the effect of complex geology at NTS on absolute travel-time residuals for a central California station. The purpose of this brief note is to show that at teleseismic distances, source geology at NTS also affects abolute travel-time residuals. In particular, we have applied a geological correction to the teleseismic data of Utsu (1973) for the Matsushiro, Japan station and to data collected by us for the WWSSN station at College (COL), Alaska. This geological correction reduces the observed scatter in both Utsu's original Matsushiro, Japan data and our College, Alaska data. In combination with the uneven distribution of shot locations with respect to time, our results support Engdahl *et al.*'s (1977) suggestion that observed temporal variations at MAT are source dependent and not indicative of *P*-velocity variations beneath the receiving station.

The basic approach used is to start from the travel-time residuals, correct for the gelogical structure under each shot, and then correct to sea level. As briefly described in Boore *et al.* (1975), the geological correction was made by subtracting the travel time from the shot depth to the depth-to-top of the highest velocity in the appropriate crustal model. Table 1 shows the crustal models used for Yucca Flat shots and for Pahute-Rainier Mesa shots, as taken from the Appendix of Boore *et al.* (1975). Surface elevations, shot depths, depths-to-water table, and depths-to-Paleozoic rocks were all taken from Springer and Kinnaman (1971, 1975). As in Boore *et al.*, a mantle velocity of 7.9 km/sec was assumed beneath NTS. Mantle angle of incidence at the source was determined from Pho and Behe (1972). The correction to sea level was made by calculating the travel time through a layer having a velocity equivalent to the highest crustal velocity and a thickness equal to the difference between sea level and the depth-to-top of the highest crustal velocity. This travel time is then added to the residual when sea level is above the top of the fastest crustal layer, otherwise it is subtracted.

Figure 1 shows the results for station MAT of correcting for geological structure and reducing the shots to their equivalent sea level sources. Figure 1a shows the original travel-time residuals (observed minus calculated travel times) for station MAT (Utsu, written communication). This data does not contain the shot elevation correction used by Utsu (1973). As demonstrated by the histograms at the end of Figure 1a, the Pahute Mesa shots have systematically larger residuals than the Yucca Flat shots. Figure 1b shows the same data after applying the source corrections. Clearly the data scatter has been reduced and the Pahute Mesa data points (circles) have merged with the Yucca Flat data points (diamonds).

Figure 2 shows a similar presentation of our data for station COL. The COL travel-time residuals show systematically larger Pahute Mesa residuals than Yucca

* Presently with California Division of Mines and Geology, 2815 O Street, Sacramento, California 95816.

Flat residuals as demonstrated in Figure 2a. Figure 2b shows the College data after supplying the source corrections. Again the data scatter has been reduced and the Pahute Mesa data points have merged with the Yucca Flat data points. Clearly,

TABLE 1
CRUSTAL VELOCITY MODELS
(All depths from surface elevation)

Model	Velocity (km/sec)	Depth to Top of Layer (km)
Yucca Flat (variable)	1.6	0.0
	2.5	Depth of static water table*
	6.0	Depth of Paleozoic rock*
Pahute and Rainier Mesas	2.7	0.00
	3.4	0.94
	3.8	1.33
	4.4	2.14
	5.1	2.50
	6.1	5.00

* Taken from Springer and Kinnaman (1971, 1975).

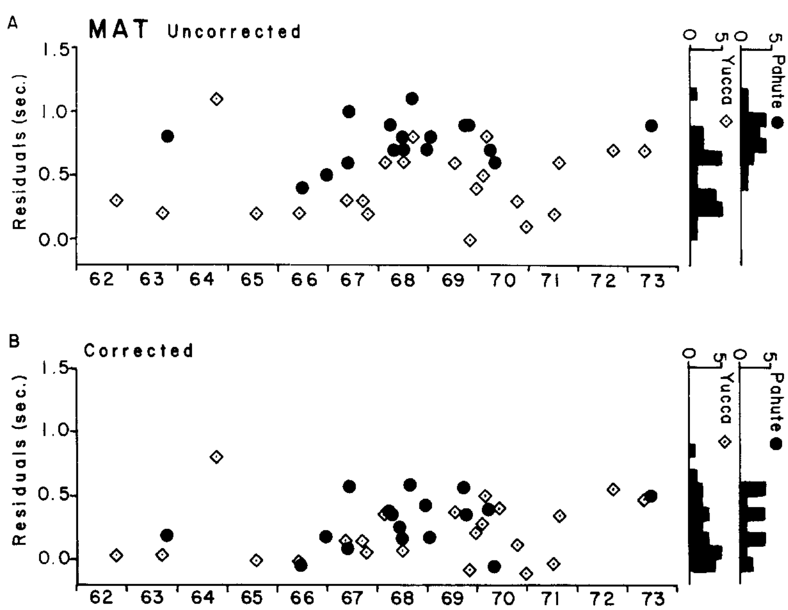

FIG. 1. Data for Matsushiro, Japan. (A) Travel-time residuals versus time: Yucca Flat residuals are shown as diamonds and Pahute Mesa residuals as circles. Histograms at end show the number of shots falling in a given 0.1-sec interval for Yucca Flat and Pahute Mesa. (B) Source corrected travel-time residuals versus time: symbols as above.

even at teleseismic distances, the geology at the source can affect absolute travel-time residuals even for a relatively small source region such as NTS.

Although the crustal structures in Table 1 have accounted for most of the difference in the residuals from the two source areas, it should be noted that Spence (1974) found evidence for lateral variations extending to the upper mantle. These variations most affected waves leaving NTS at directions with an easterly component and were required to explain early arrivals of P waves from Pahute Mesa shots relative to those from Yucca Flat for these azimuths. (Note that this relationship of the residuals is just the opposite of what we found at COL and MAT, where the Pahute Mesa shots gave relatively late arrivals.)

Comparing the corrected data of Figures 1b and 2b, it is particularly striking that both stations have an identically large delay of about 0.8 sec in their 1964 residual. Although the College residual is indicated as questionable due to an emergent arrival, it does suggest that the 1964 Matsushiro residual might be late for reasons other than a *P*-velocity change under that station. (In his paper Utsu indicates that the 1964 arrival is impulsive at MAT.) An alternative explanation might be that the late 1964 residuals are due to a source effect. To maintain objectivity in picking arrival times, the questioned COL data point has not been reread so that it is also possible that the striking similarity might be a coincidence.

Generally, the College residuals seem quite uniform in time with some increased

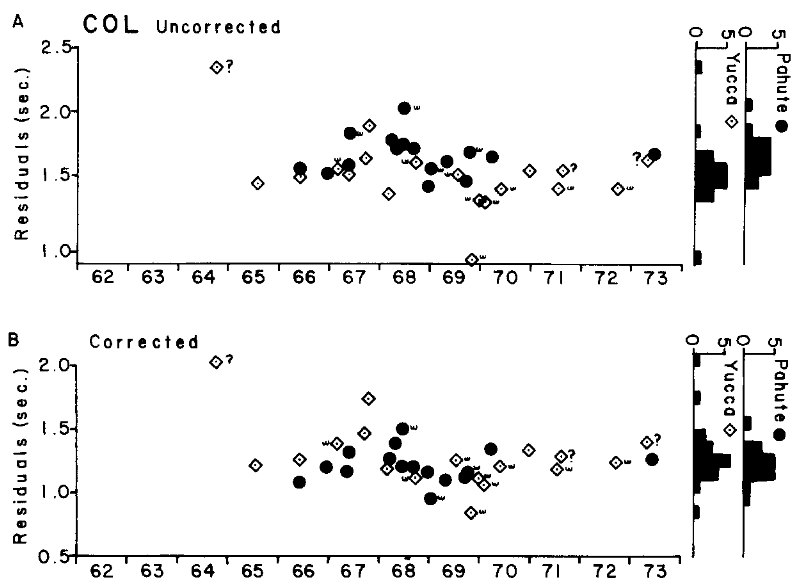

FIG. 2. Data for College, Alaska presented in the same manner as Figure 1. Queried data indicate residuals for questionable arrivals; W near a symbol indicates residuals for weak or emergent arrivals. (A) Travel-time residuals versus time. (B) Source corrected travel-time residuals versus time.

scatter from 1967 through 1969, while the Matsushiro residuals appear to show a small increase with time with a larger scatter from 1967 through 1971. The variations in the MAT residuals might be attributed to temporal variations in velocity. However the long term trend is based on a small number of shots at either end of the time span. Both the long term and the shorter term variations in the MAT residuals may be due to systematic reading errors or may be a random pattern in the background noise. In light of the difficulty in establishing the existence of *P*-velocity related temporal variations elsewhere, the fact that data for COL in 1962 to 1963 is unavailable, and the demonstrated source effects in both data sets, the variations exhibited in Figure 1b should not be interpreted as demonstrating *P*-velocity variations at Matsushiro unless other corroborative evidence can be found.

ACKNOWLEDGMENT

We would like to thank an anonymous reviewer for his valuable suggestions to improve this paper. Partial support for this research was provided by the Division of Earth Sciences, National Science Foundation, Grant EAR75-04291 A02.

References

Boore, D. H., A. G. Lindh, T. V. McEvilly, and W. W. Tolmachoff (1975). A search for travel-time changes associated with the Parkfield, California, earthquake of 1966, *Bull. Seism. Soc. Am.* **65,** 1407-1418.

Engdahl, E. R., J. G. Sindorf, and R. A. Eppley (1977). Interpretation of relative teleseismic P wave residuals. *J. Geophys. Res.* **82,** 5671-5682.

Pho, H.-T. and L. Behe (1972). Extended distances and angles of incidence of P-waves, *Bull. Seism. Soc. Am.* **62,** 885-902.

Spence, W. (1974). P-wave residual differences and inferences on an upper mantle source for the Silent Canyon volcanic centre, Southern Great Basin, Nevada, *Geophys. J.* **38,** 505-523.

Springer, D. L. and R. L. Kinnaman (1971). Seismic source summary for U.S. underground nuclear explosions, 1961-1970, *Bull. Seism. Soc. Am.* **61,** 1073-1098.

Springer, D. L. and R. L. Kinnaman (1975). Seismic source summary for U.S. underground nuclear explosions, 1971-1973, *Bull. Seism. Soc. Am.* **65,** 343-349.

Utsu, T. (1973). Temporal variations in travel time residuals of P waves from Nevada sources, *J. Phys. Earth* **21,** 475-480.

Department of Geophysics
Stanford University
Stanford, California 94305

Manuscript received November 11, 1977