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# TELESEISMIC P WAVE AMPLITUDES AND SPECTRA AT NTS AND THE SHOAL SITE AS COMPARED TO THOSE OBSERVED IN EASTERN NORTH AMERICA PRELIMINARY REPORT

Z.A. DER, M.S. DAWKINS, T.W. McELFRESH, J.H. GONCZ, C.E. GRAY & M.D. GILLISPIE

Teledyne Geotech, 314 Montgomery Street, Alexandria, Virginia 22314

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AS COMPARED TO THOSE OBSERVED IN EASTERN NORTH AMERICA  
PRELIMINARY REPORT

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#### ABSTRACT

Three SDCS stations were deployed at NTS to measure magnitude residuals and spectral differences relative to two Eastern United States (EUS) stations in order to determine the degree of anelastic attenuation under NTS. At the NTS station located on the Climax stock (OB2NV), the average teleseismic body-wave magnitude is .13 magnitude units (m.u.) lower than at HNME and .19 m.u. lower than at RKON. The magnitudes at the two Pahute Mesa sites average .25 m.u. higher than at OB2NV, but calculations show that most of the difference can be attributed to site amplification by low velocity volcanics under Pahute Mesa. At all NTS sites the high frequency content of P-waves is less than at RKON; the difference is statistically significant for two of the three NTS stations, and marginally significant at the third. Measurements at the site of the SHOAL explosion yield similar figures, showing lower high frequency content and lower magnitudes of P-waves relative to EUS. The above results are indicative of anelastic losses of body-waves traversing the mantle under both test sites.

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## INTRODUCTION

This report summarizes the most important results of the NTS experiment and some associated work at the SHOAL site relating to anelastic attenuation in the mantle below the Basin and Range. The work is continuing, and some results are subject to changes as more data becomes available. This report was prepared to make the main results accessible to the seismological community before the publication of the detailed final report. The results agree with the interpretation of the Western United States (WUS) magnitude anomaly in terms of anelastic attenuation in the upper mantle.

The magnitude anomaly for short-period teleseismic P arrivals was discovered in the early sixties, and its existence has since been confirmed by many studies (Guyton 1964, Evernden and Clark 1970, Booth, Marshall and Young 1974, Der, Massé and Gurski 1975, North 1976). The anomaly manifests itself as a regional reduction of teleseismic magnitude measurements at the WUS receiving stations relative to those located in the eastern United States (EUS). A similar anomaly seems to exist for short period S waves, (Der, Massé and Gurski 1975). In addition to this, spectral differences exist between short period body-waves which cross the upper mantle under the WUS and those which cross the mantle under shields or stable platforms (Der and McElfresh 1977).

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Guyton, J. W. (1964). Systematic deviations of magnitude from body-waves at seismograph stations in the United States. Proceedings of VESIAC Conference on Seismic Event Magnitude Determination, University of Michigan, 4410-71-X.

Evernden, J., and D. M. Clark (1970). Study of teleseismic P. II. Amplitude data, Phys. Earth. Planet. Int. 4, p. 24-31.

Booth, D. C., P. D. Marshall, and J. B. Young (1974). Long- and short-period amplitudes from earthquakes in the range  $0^{\circ}$ - $114^{\circ}$ , Geophys. J. R. Astr. Soc., 39, p. 523-538.

Der, Z. A., R. P. Massé, and J. P. Gurski (1975). Regional attenuation of short-period P and S waves in the United States, Geophys. J. R. Astr. Soc., 40, p. 85-106.

North, R. G. (1976). Station biases in body-wave magnitude (abstract), Transactions, American Geophysical Union (EOS), 57, 955.

Der, Z. A., and T. W. McElfresh (1977). The relationship between anelastic attenuation and regional amplitude anomalies of short period P waves in North America. (Submitted to Bull. Seism. Soc. Am.).

The regional magnitude anomaly and spectral differences are attributed to anelastice attenuation in the mantle under the WUS by most seismologists. This view is supported by other types of geophysical anomalies in the WUS which indicate partial melting in the mantle under the WUS. Partial melting of rocks must lead to the increase of anelastic attenuation according to experimental and theoretical studies. The spectral differences of P wave arrivals in the WUS vs. the EUS are such that the size of the magnitude anomaly is roughly consistent with the spectral differences assuming a single exponential attenuation factor of the form  $\exp(-\pi f \Delta t^*)$  where  $\Delta t^*$  is derived from slopes of spectral ratios, and  $f$  is frequency.

Anelastic attenuation implies reciprocity, and thus the world-wide validity of the empirical magnitude-yield relationship based on NTS data becomes questionable.

Although the sizes of the average EUS-WUS regional magnitude bias and spectral differences are fairly well established ( $(\Delta m_b \sim .25, \Delta t^* \sim .2)$  Booth et al., (1974), Der and McElfresh, (1977)), this cannot be said for individual receiving stations in the WUS. Both the  $\Delta m_b$  and  $\Delta t^*$  can differ from the regional average at individual sites. To estimate the amount of anelastic attenuation under each individual station, a detailed study of both  $\Delta m_b$  and  $\Delta t^*$  should be made using many teleseismic events. Since both quantities can also be affected by the crustal structure, efforts must be made to estimate and correct for the crustal effects using the best estimate of the local crustal structure. Our past work on simulating the crustal effect indicates that  $\Delta m_b$  is influenced more by crustal structure than is  $\Delta t^*$ .

In order to investigate the question of high anelastic attenuation under NTS, three Special Data Collection System (SDCS) seismic stations were redeployed to that area. The station OB2NV (or OB2) was placed on the Climax stock, a Cretaceous granitic intrusive body, the medium of the Hardhat and

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Booth, D. C., P. D. Marshall, and J. B. Young (1974). Long- and short- period amplitudes from earthquakes in the range  $0^\circ$ - $114^\circ$ , Geophys. J. R. Astr., 39, p. 523-538.

Der, Z. A., and T. W. McElfresh (1977). The relationship between anelastic attenuation and regional amplitde anomalies of short-period P waves in North America. (Submitted to Bull. Seism. Soc. Am.)

Piledriver nuclear explosions. Two other stations, NTNV (or NT) and NT2NV (or NT2) were placed on the Pahute Mesa. This topographic feature is underlain by a deep volcanic caldera (Silent Canyon Volcanic Center) which is filled with low-velocity (3.6 km/sec average) tertiary volcanic tuffs and rhyolites to a depth of at least 4 km. Spence (1974) predicts thicknesses of about 5 km based on gravity data. Two other SDCS stations remained at their previous locations: Red Lake Ontario (RKON) and Houlton, Maine (HNME). The key station at NTS seems to be OB2NV which, like RKON, is located on granite, the test medium of interest. NT2NV and NTNV are, of course, less diagnostic since they are located above the thick low-velocity caldera fill. The locations of the stations used in this study are shown in Figure 1.

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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. R. Astr. Soc., 38, 303-523.

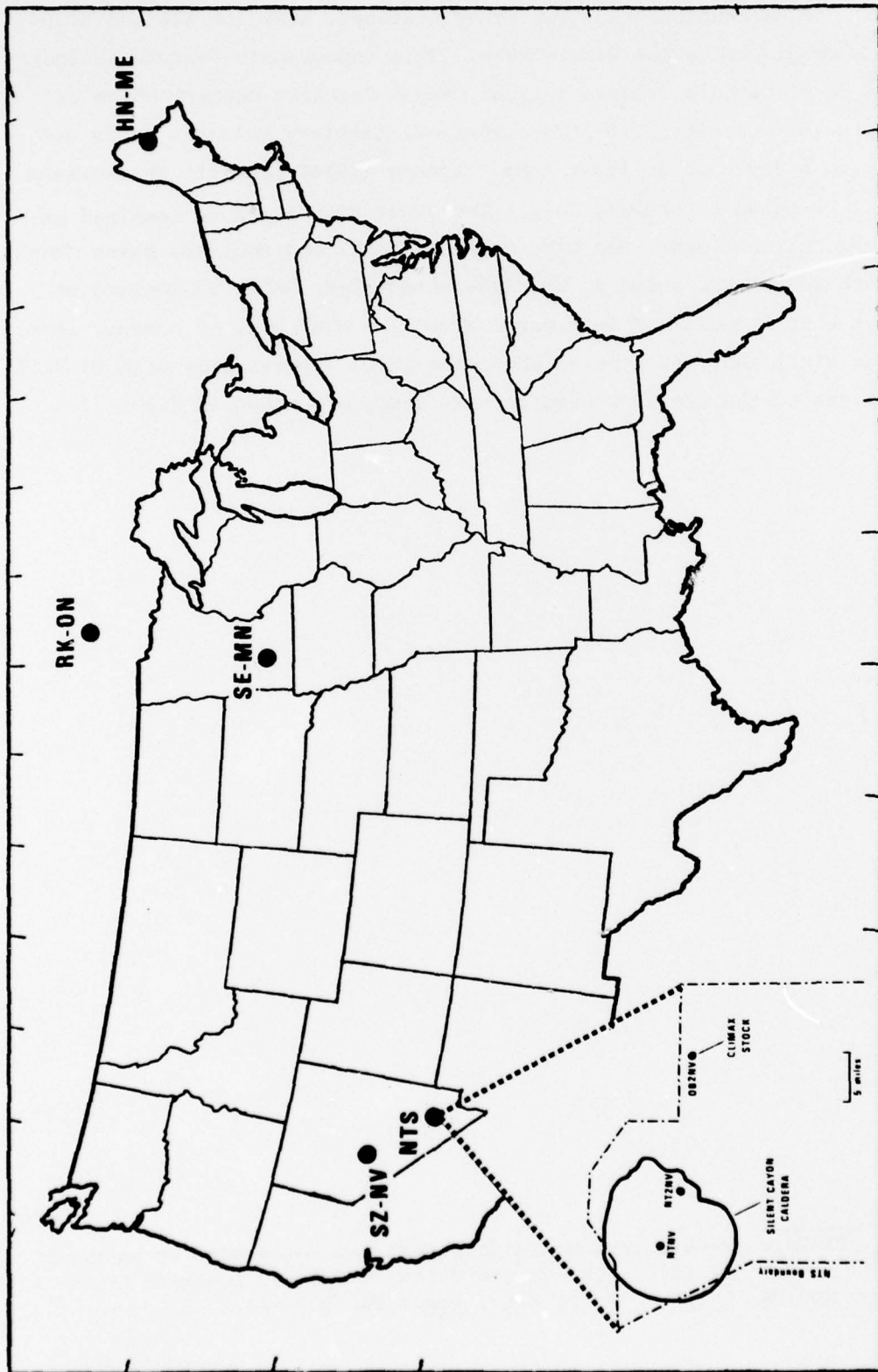


Fig. 1 Location of the recording sites studied.

## DATA ANALYSIS

### Body-Wave Magnitudes

Short-period data were recorded on digital tape at 20 samples/sec at all SDCS sites. Amplitudes, dominant periods, and arrival times of teleseismic P-waves were read for a set of 120 events during the period 1 September 1976 to 31 March 1977. Magnitudes  $m_b$  were computed with the formula

$$m_b = \log_{10} \left( \frac{A}{T} \right) + B(\Delta) \quad (1)$$

where A is the maximum peak to peak amplitude, in  $\mu\mu$ , within the first three seconds of the P-wave, (corrected for period) and T is the dominant period of the signal.  $B(\Delta)$  are the distance correction factors of Gutenberg and Richter (1956) for a surface source. We also computed magnitudes without the division by T which we shall call  $m'_a$  in this report. This quantity is not the same as the  $m_a$  proposed by Masse (personal communication) who measured the amplitude of the first cycle of P-waves.

The results of the study are displayed in a set of histograms of magnitude differentials, dominant period differentials, and  $\Delta t^*$  at pairs of individual stations. In each histogram we calculate the standard deviation ( $\sigma$ ), the mean value, and its approximate 95% confidence limits ( $\pm 2\sigma_{\text{mean}}$ ) where  $\sigma_{\text{mean}} = \sigma/\sqrt{N}$  (assuming normality). For small samples ( $n < 30$ ) we give confidence limits based on the "Student's t" distribution. We also show on each histogram the total number of data points used. The dominant periods at HNME cannot be compared to periods at other stations since the instrument response at this station was different from that of the rest of the stations.

We start the discussion with the RKON-OB2NV station pair (Figures 2 and 3). We consider this pair to be the most diagnostic of possible attenuation since both stations are on granite, and the crustal modification of the signals is expected to be minimal. The figures show that the average magnitude at OB2NV is significantly lower (at the 95% confidence level) than at RKON. Furthermore, P waves at OB2NV have significantly larger dominant periods than at RKON. This is consistent with the assumption of greater attenuation under OB2NV.

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Gutenberg, P., and C. F. Richter (1956). Magnitude and energy of earthquakes. Ann. Geof. (Rome), v. 9, p. 1-15.

There is a considerable difference, however, between OB2NV and the two Pahute Mesa stations (NTNV and NT2NV). The amplitudes are higher and the dominant periods are shorter at Pahute Mesa than on the Climax stock. The magnitudes (and amplitudes) are at the same level or possibly are higher at Pahute than at RKON, and the dominant periods are intermediate between RKON and OB2NV (Figures 4 and 7).



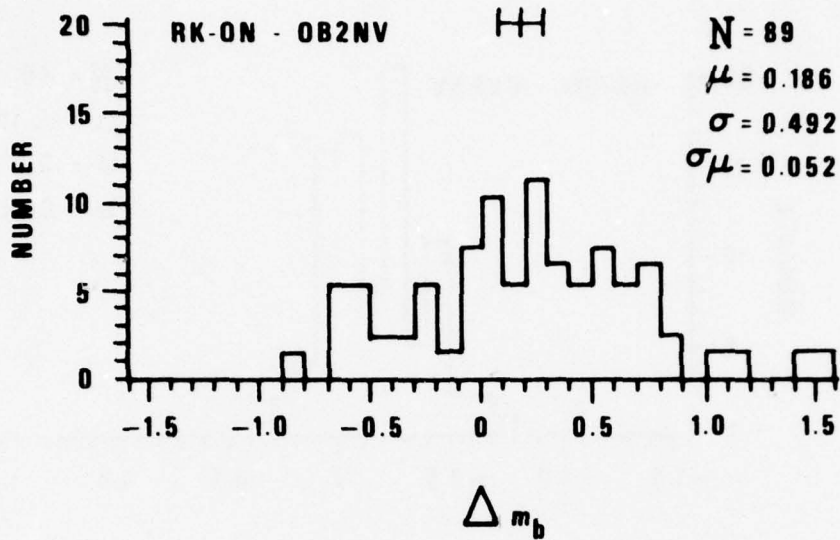


Fig. 2

Histogram of body-wave magnitude differentials for the station pair RKON-OB2NV.  $N$  = number of points,  $\mu$  = mean,  $\sigma$  = standard deviation,  $\sigma_{\mu}$  = standard deviation of mean. Mean and 95% confidence limits of the mean ( $\pm 2\sigma_{\mu}$ ) are indicated by connected vertical bars on the top of the figure.

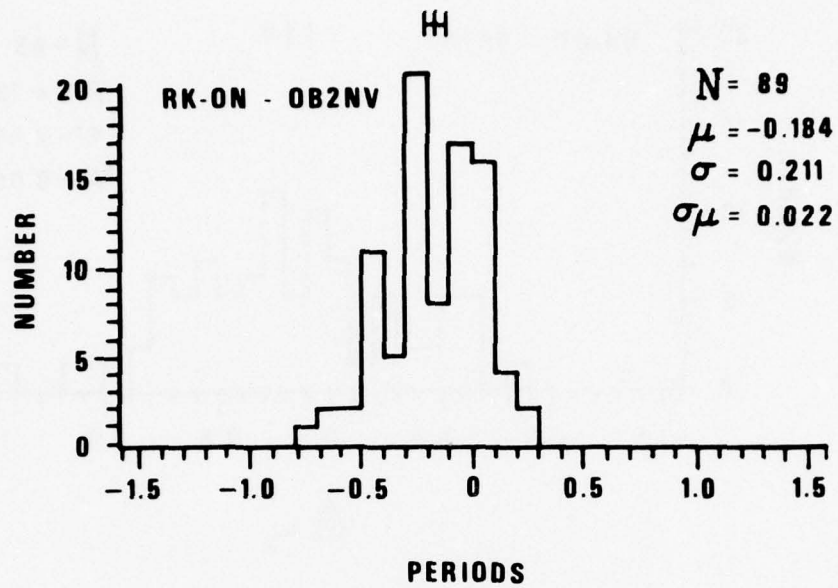


Fig. 3 Histogram of dominant period differentials for station pair RKON-OB2NV. Symbols are explained under Fig. 2.

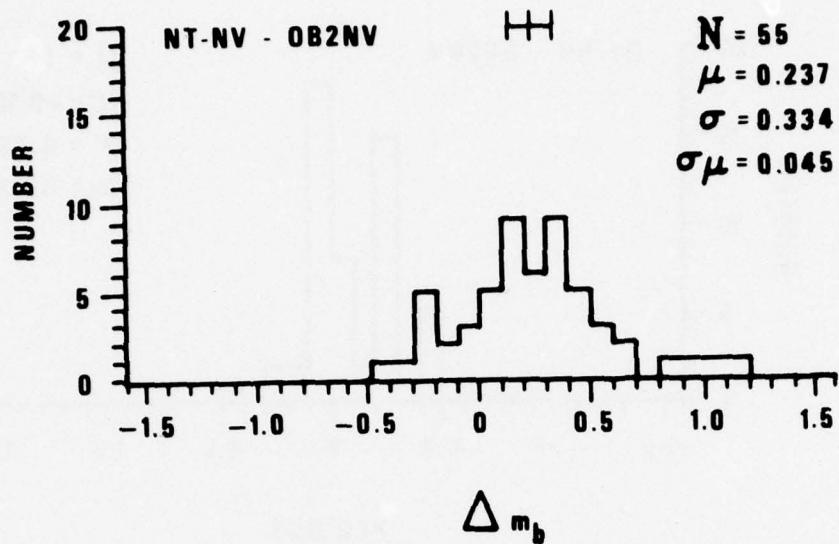


Fig. 4 Histogram of body-wave magnitude differentials for the station pair NTNV-OB2NV. Symbols are explained under Fig. 2.

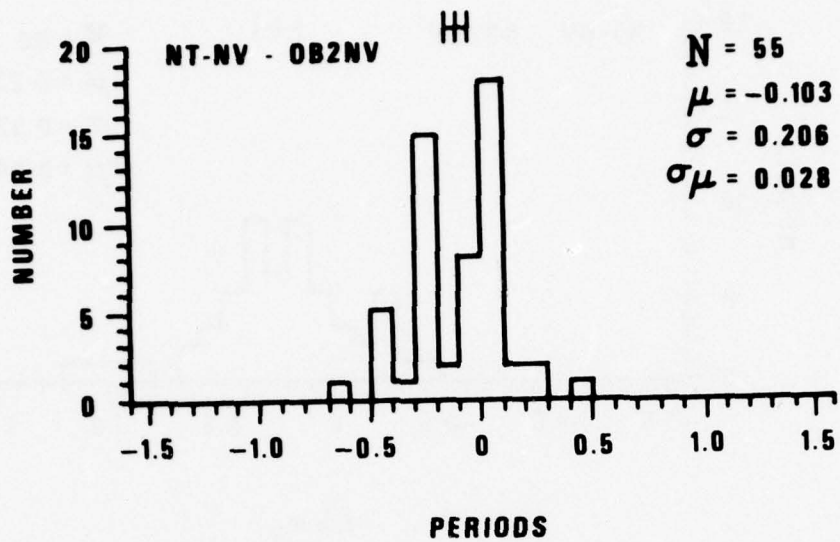


Fig. 5

Histogram of dominant period differentials for the station pair NTV-OB2NV. Symbols are explained under Fig. 2.

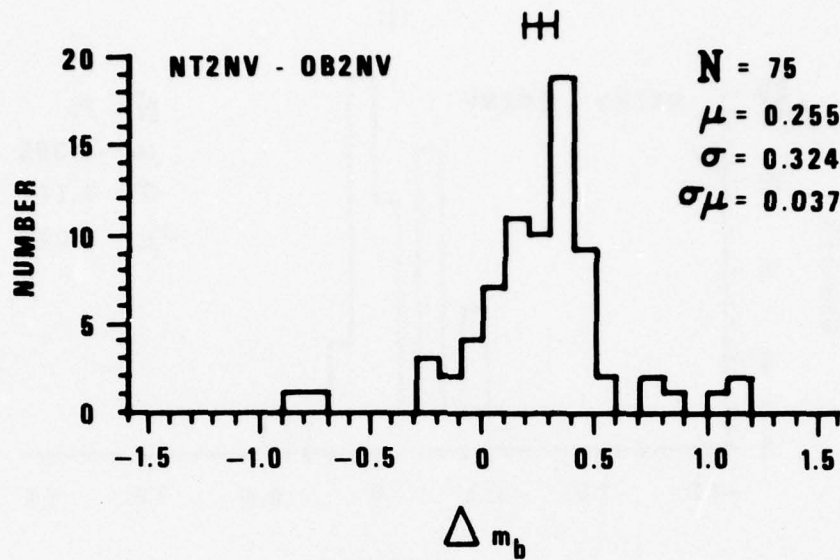


Fig. 6

Histogram of body-wave magnitude differentials for the station pair NT2NV-OB2NV. Symbols are explained under Fig. 2.

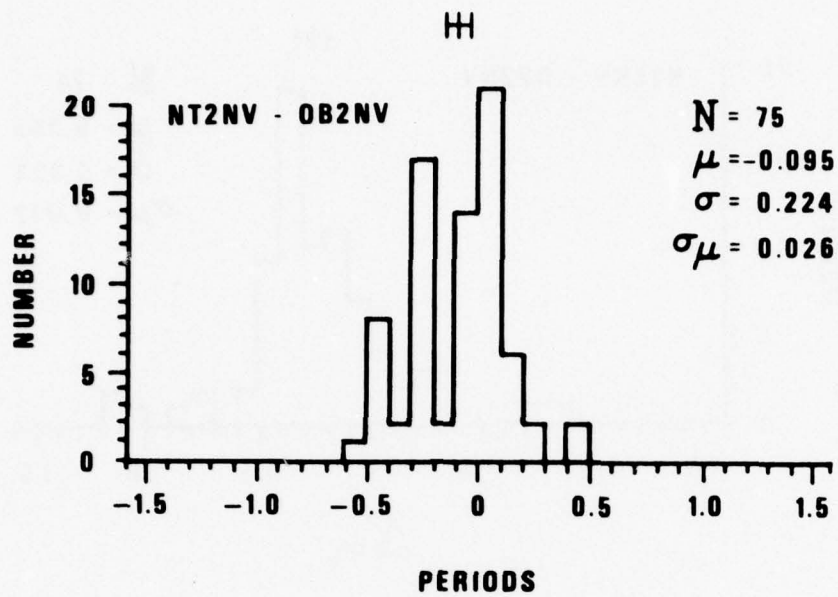


Fig. 7

Histogram of the dominant period differentials for the station pair NT2NV-OB2NV. Symbols are explained under Fig. 2.

Computation of crustal response at Pahute Mesa, modelling the thick low-velocity volcanics present in the Silent Canyon Volcanic Centre using information from well logs close to the stations NTV and NT2NV, yields a crustal amplification factor of .2 m.u. relative to OB2NV. While these crustal models based on well-logs near the SDCS stations at NTS have been successful in explaining the observed amplitude differences, they have only partially explained the observed frequency content difference. It seems therefore that if proper corrections for crustal effects are made, the Pahute sites appear reasonably similar in magnitude characteristics to the site on the Climax stock.

It is interesting to note that the mean of standard deviations of  $m_b$  measurements at the three NTS sites relative to RKON is almost twice the mean standard deviation of the relative  $m_b$  among pairs of NTS stations. This is at least partially due to radiation patterns of the events used, which cause greater variability between azimuths to the RKON-NTS station pairs from the epicenters, while the NTS stations are looking at practically the same point in the radiation patterns.

The last station to discuss is HNME, which is located in a region of high microseismic noise. The high background substantially reduced the number of amplitude and period readings at this station. Furthermore, comparisons of dominant periods involving HNME are invalid, since the instrument response at this station is significantly less peaked at high frequencies than the responses at the other stations. The magnitude comparisons are valid, however, since the instrument response is approximately corrected for. Comparisons of HNME with other stations are inconclusive due to wide confidence limits.

#### Spectral Ratio Studies

In addition to magnitude measurements we also computed relative  $t^*$  values for all combinations of stations pairs for a set of selected events. The procedure begins with the computation of a corrected power spectrum at each station. A time window comprising 9 sec of the signal and 4 sec of the preceding noise is tapered with a Parzen window and Fourier transformed, and the power spectrum is computed by multiplying the Fourier spectrum by its conjugate. This power spectrum is then smoothed by a 12-point running average. The shift of the time window is designed to avoid heavy tapering of the first

arrival. A noise power spectrum ahead of this window is computed using an identical procedure and is subsequently subtracted from the spectrum of the window containing the signal.

The  $\Delta t^*$  estimates are obtained by fitting a straight line to the logarithm of the amplitude spectral ratio between each pair of stations. We use only the portion of spectrum between .5 and 4. Hz, and in fitting straight lines to the spectral ratios we require that the signal power spectrum exceed that of the noise by a factor of three. Portions of spectra not satisfying this criterion are not used in the least squares fit.

The histograms of the  $t^*$  differentials ( $\Delta t^*$ ) between selected station pairs are given in Figures 8-10.

The mean  $\Delta t^*$  for the OB2NV-RKON pair (Figure 8) is 0.169. The difference between NT2NV and NTVN is small and not significant, but both stations are richer in high frequencies than OB2NV (Figure 9 and 10). Both Pahute Mesa stations are, in turn, significantly lower than RKON in the high frequency content of P waves. Summarizing the above results, the spectral analyses give a picture qualitatively consistent with magnitude biases and with visual observations of dominant periods. The results of measurements at NTS are summarized in Table I and Fig. 11. Figure 11 shows the differences of  $m_b$ ,  $m'_a$ , T and  $t^*$  of all stations relative to OB2NV with their confidence limits.

The size of the mean observed magnitude bias is less than one would expect for a monochromatic component of frequency at, say, 1 Hz (.23 m.u.). This apparent discrepancy is an artifact that can be traced to the method of computing  $m_b$ . In making the instrument response correction it is assumed that the signal is monochromatic. Since the dominant periods at OB2NV are about .2 sec longer than at RKON (.9 and .7 seconds respectively), the relative difference in the instrument correction at these two periods reduces the observed raw amplitudes at RKON by a factor of 1.5 relative to OB2NV. Since most of the actual energy of the signals at both sites is at lower frequencies, even allowing for the modification by the instrument, the "corrected amplitude" is unduly reduced at the high Q stations. Thus magnitudes computed without dividing by the dominant periods,  $m'_a$ , (see Table I) seem to be less different



at the two stations than the conventional magnitudes. If one accounts for these effects, the observed magnitude differential agrees with our  $\Delta t^*$  values within the uncertainty of the measurements.

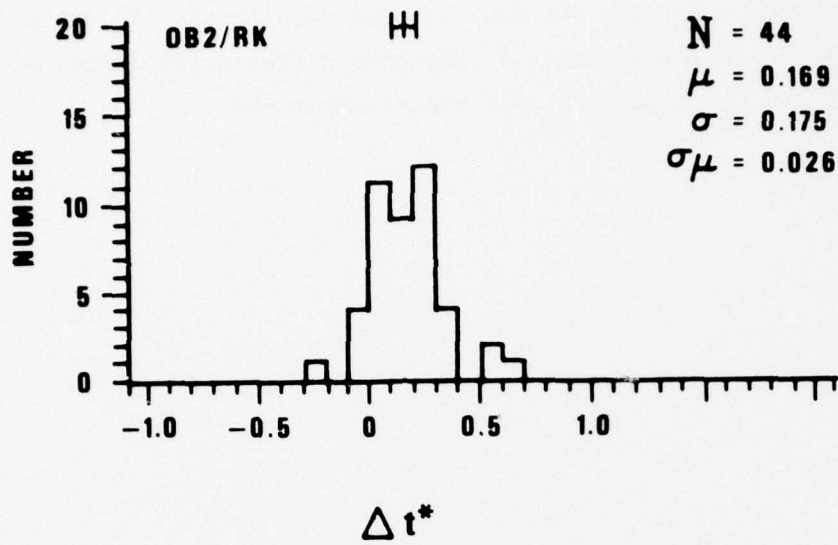


Fig. 8 Histogram of  $t^*$  differentials for the station pair OB2NV-RKON. Symbols are explained under Fig. 2.

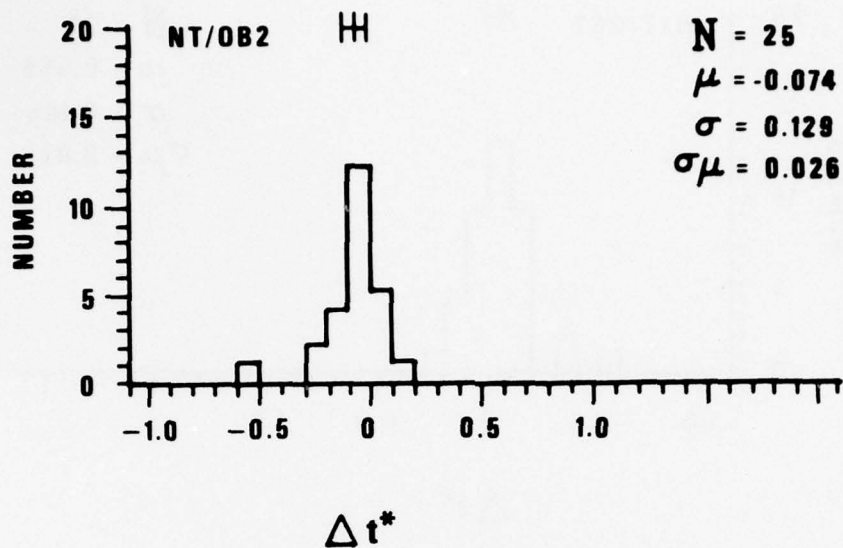


Fig. 9 Histogram of  $t^*$  differentials for the station pair NTNV-OB2NV. Symbols are explained under Fig. 2.

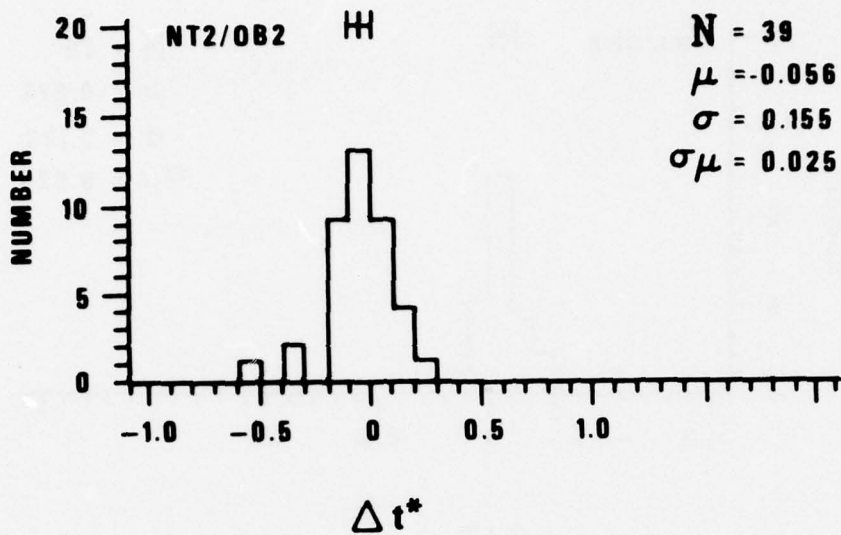


Fig. 10 Histogram of  $t^*$  differentials for the station pair NT2NV-OB2NV. Symbols are explained in Fig. 2.

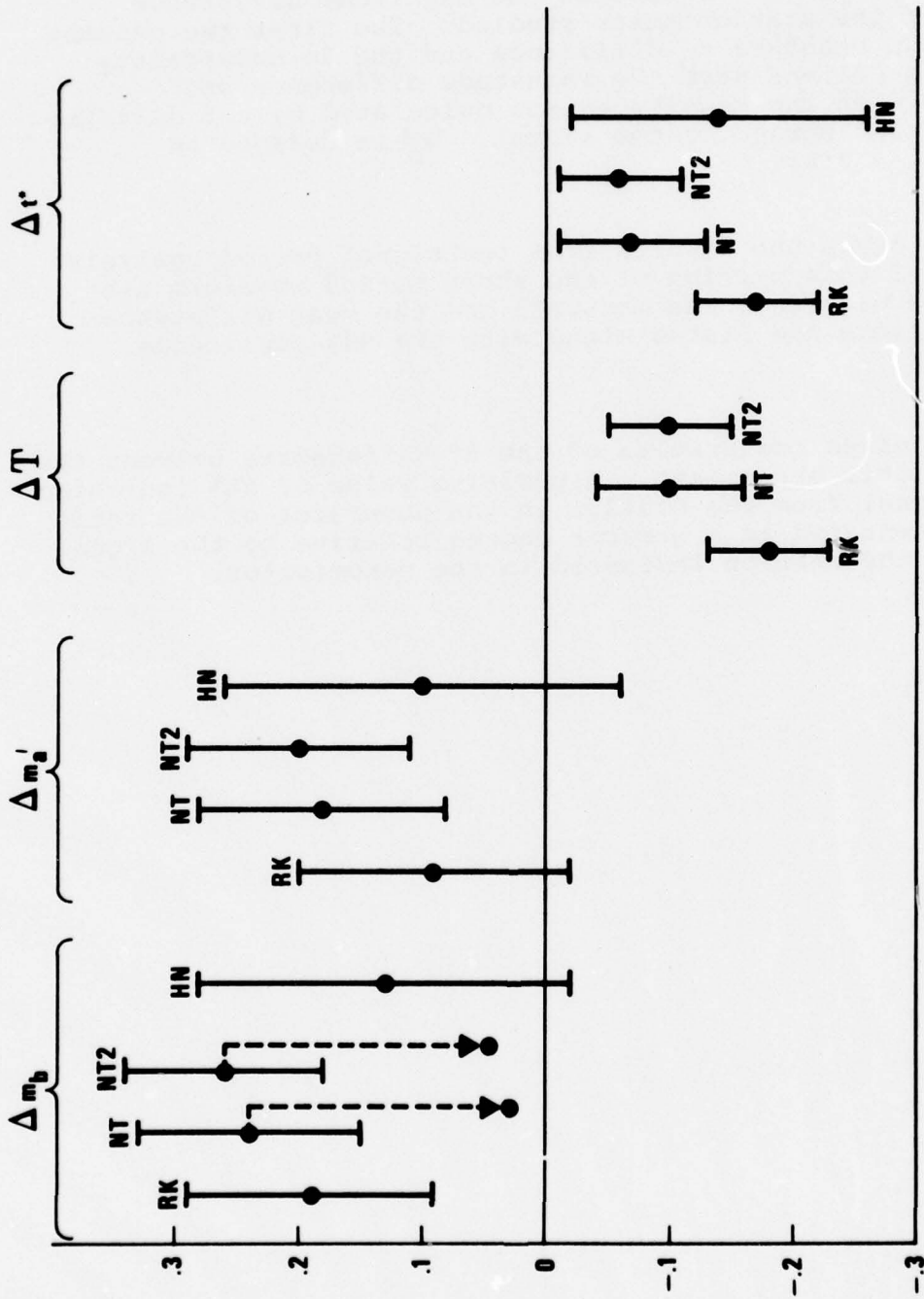


Fig. 11 Summary of  $m_b$ ,  $m_a'$ , T and  $t^*$  differentials relative to OB2NV for all stations studied with their confidence limits. Dashed lines mark the estimated amount of  $m_b$  corrections for crustal amplification under the Pahute Mesa.

### Table 1

Table 1 (a) gives the results of the magnitude difference analysis for the station pairs studied. The first two columns list the mean standard  $m_b$  difference and the  $2\sigma$  uncertainty. The last two columns give the magnitude difference and uncertainty when the magnitudes are calculated by not dividing by the apparent period of the signal.  $m'_a$  is defined as  $m'_a = \log (A) + B(\Delta)$ .

Table 1 (b) gives the results from the signal period analysis. The period of this portion of the short period waveform used to determine magnitude was measured and the mean difference between stations are listed along with the 95% confidence uncertainty.

Table 1 (c) gives the results of the  $t^*$  differences between the stations in this experiment. A positive value of  $\Delta t^*$  indicates that the signal from the station in the numerator of the ratio has been attenuated to a greater degree relative to the signal recorded at the station indicated in the denominator.

Table 1 (a)

	<u>Mean <math>\Delta m_b</math></u>	<u><math>2 \sigma \Delta m_b</math></u>	<u>Mean <math>\Delta m'_a</math></u>	<u><math>2 \sigma \Delta m'_a</math></u>
RKON-OB2NV	0.19	0.10	0.09	0.11
NTNV-RKON	0.08	0.11	0.13	0.12
NT2NV-RKON	0.10	0.10	0.15	0.11
RKON-HNME	0.07	0.10	-0.02	0.12
NTNV-OB2NV	0.24	0.09	0.18	0.10
NT2NV-OB2NV	0.26	0.08	0.20	0.09
HNME-OB2NV	0.13	0.15	0.10	0.16
NTNV-NT2NV	0.00	0.06	-0.01	0.07
NTNV-HNME	0.14	0.16	0.07	0.19
NT2NV-HNME	0.09	0.13	0.07	0.15

Table 1 (b)

	<u>Mean <math>\Delta T</math></u>	<u><math>2\sigma_{\Delta T}</math></u>
OB2NV-RKON	0.18	0.05
NTNV-RKON	0.09	0.06
NT2NV-RKON	0.11	0.05
OB2NV-NTNV	0.10	0.06
OB2NV-NT2NV	0.10	0.05
NT2NV-NTNV	0.02	0.05

Table 1 (c)

	<u>Mean <math>\Delta t^*</math></u>	<u>95% Confidence Limits</u>
OB2NV/RKON	0.17	.12-.23
NTNV/RKON	0.15	.07-.23
NT2NV/RKON	0.11	.05-.17
OB2NV/HNME	0.14	.02-.26
NTNV/HNME	0.02	-.11-.15
HNME/NT2NV	0.03	-.09-.15
OB2NV/NTNV	0.07	.01-.13
OB2NV/NT2NV	0.06	.01-.11
NT2NV/NTNV	0.02	-.02-.06
HNME/RKON	0.09	-.02-.20

### Evaluation of Attenuation Under the SHOAL Site

In addition to the NTS experiment we also studied the attenuation characteristics of the SHOAL test site. The 12.5 kt contained nuclear explosion SHOAL was detonated in a granite body in western Nevada. The LRSM station SZNV was operated from 5 January 1963 to 8 February 1963 only about six hundred feet north of the ground zero of SHOAL, on the same granite body in which the nuclear device was emplaced. The existence of station SZNV offers an opportunity to compute attenuation under this test site by comparing spectra of P waves observed here to those recorded at a station on a stable platform (shield) type structure. The site selected for comparison is Sleepy Eye, Minnesota (SEMN), also on granite.

The histogram of  $\Delta t^*$  values derived from the SZNV/SEMN spectral ratios for 21 teleseismic events is shown in Figure 12. The mean of all the values in the table is  $\Delta t^* = .17 \pm .09$  (95% limits) and is thus significantly different from zero. This value is of the same order as other determinations of the regional WUS-EUS bias in  $t^*$  (Der and McElfresh, 1976a, b; Der, 1976).

Observations of seismic waves from the nuclear explosion SHOAL enables us to solve the reciprocal problem, to compute the attenuation of P waves to various North American stations. The source spectrum used for computing spectral ratios was obtained by scaling up the standard 5 kt granite source

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Der, Z. A., and T. W. McElfresh (1976a). Short-period P wave attenuation along various paths in North America as determined from P wave spectra of the Salmon nuclear explosion, Bull. Seism. Soc. Am., 66, 1609-1622.

Der, Z. A., and T. W. McElfresh (1976b). The effect of attenuation on the spectra of P waves from nuclear explosions in North America, SDAC-TR-76-7, Teledyne Geotech, Alexandria, Virginia 22314.

Der, Z. A. (1976). On the existence, magnitude and causes of broad regional variations in body-wave amplitudes (magnitude bias), SDAC-TR-76-8, Teledyne Geotech, Alexandria, Virginia 22314.



spectrum of von Seggern and Blandford (1972) using cube root scaling. Due to the relatively small difference in yield the spectrum does not change much even if this scaling law is not strictly valid (Der and McElfresh, 1976). The average of all  $t^*$  values thus determined is .42, which is in fairly good agreement with other shield-WUS type paths (Der 1976).

The average .42 for shield-to-SHOAL site paths combined with the SZNV-SEMN differential  $\Delta t^* \sim .17$  yields the absolute average  $t^*$  of .25 for shield-to-shield type paths. This value is again in very good agreement with our past work and with other data from the literature summarized by Der (1976). The magnitude bias at the SHOAL site is within .08 m.u. of that at MNNV (Der and McElfresh, (1975), page 61) which was found to be -.3 m.u. by Booth et al. (1974).

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von Seggern, D., and R. R. Blandford (1972). Source-time functions and spectra for underground nuclear explosions, Geophys. J. R. Astr. Soc., 31, p. 89-97.

Der, Z. A., and T. W. McElfresh (1976b). The effect of attenuation on the spectra of P-waves from nuclear explosions in North America, SDAC-TR-76-7, Teledyne Geotech, Alexandria 22314.

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Der, Z. A., and T. W. McElfresh (1975). Short period P-wave attenuation along various paths in North America as determined from P-wave spectra of the SALMON nuclear explosion, SDAC-TR-75-16, Teledyne Geotech, Alexandria, Virginia 22314.

Booth, D. C., P. D. Marshall, and J. B. Young (1974). Long- and short-period amplitudes from earthquakes in the range  $0^{\circ}$ - $114^{\circ}$ , Geophys. J. R. Astr. Soc., 39, p. 523-538.

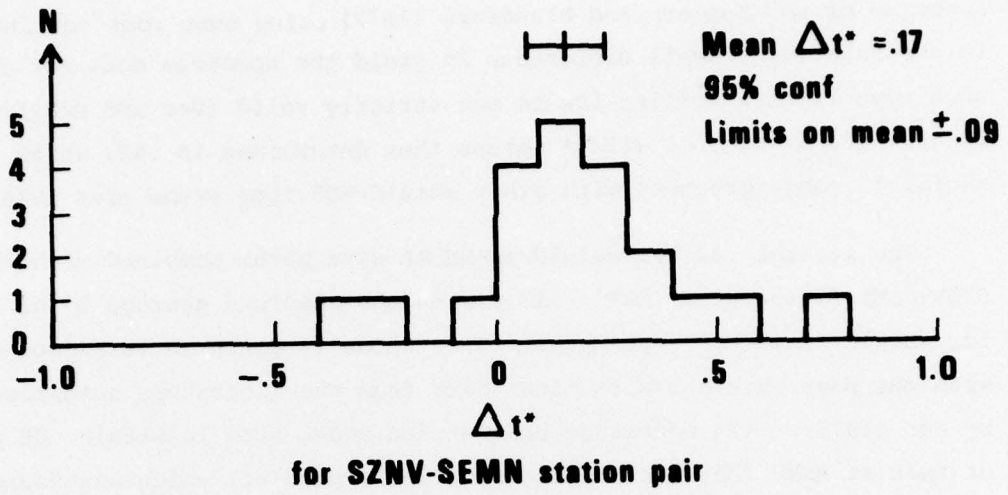


Fig. 12 Histogram of SZNV-SEMN  $t^*$  differentials.

#### SUMMARY

The results of this study show that NTS is significantly different from a typical stable platform in the degree of anelastic attenuation in the underlying upper mantle. We have succeeded only partially in modelling the crustal effects due to thick sections of low-velocity volcanics under Pahute Mesa. Computations for SHOAL site show that it is also characterized by lower observed magnitudes (Der and McElfresh (1975)) and the reduction of high frequency content of both incoming and outgoing P-waves relative to EUS stations. The size of the magnitude and  $t^*$  differentials computed are in good agreement, within the accuracy of such measurements, with those previously found by other investigators.

Fig. 13 shows a summary of absolute  $t^*$  determinations for short period P-waves plotted against epicentral distances. Absolute  $t^*$  values are prone to scatter since the assumed source spectra are somewhat uncertain. Nevertheless, the effect of attenuation is the most significant modification the P-wave spectrum experiences, and the uncertainties in the source spectra are therefore small in comparison. Open symbols in the figure denote  $t^*$  values derived for paths (incoming and outgoing) crossing the upper mantle once under the WUS. The rest of the symbols denote  $t^*$  values derived for paths with both descending and ascending portions crossing the mantle under shields or stable platforms (tectonically inactive regions).

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Der, Z. A., and T. W. McElfresh (1975). Short period P-wave attenuation along various paths in North America as determined from P-wave spectra of the SALMON nuclear explosion, SDAC-TR-75-16, Teledyne Geotech, Alexandria, Virginia 22314.

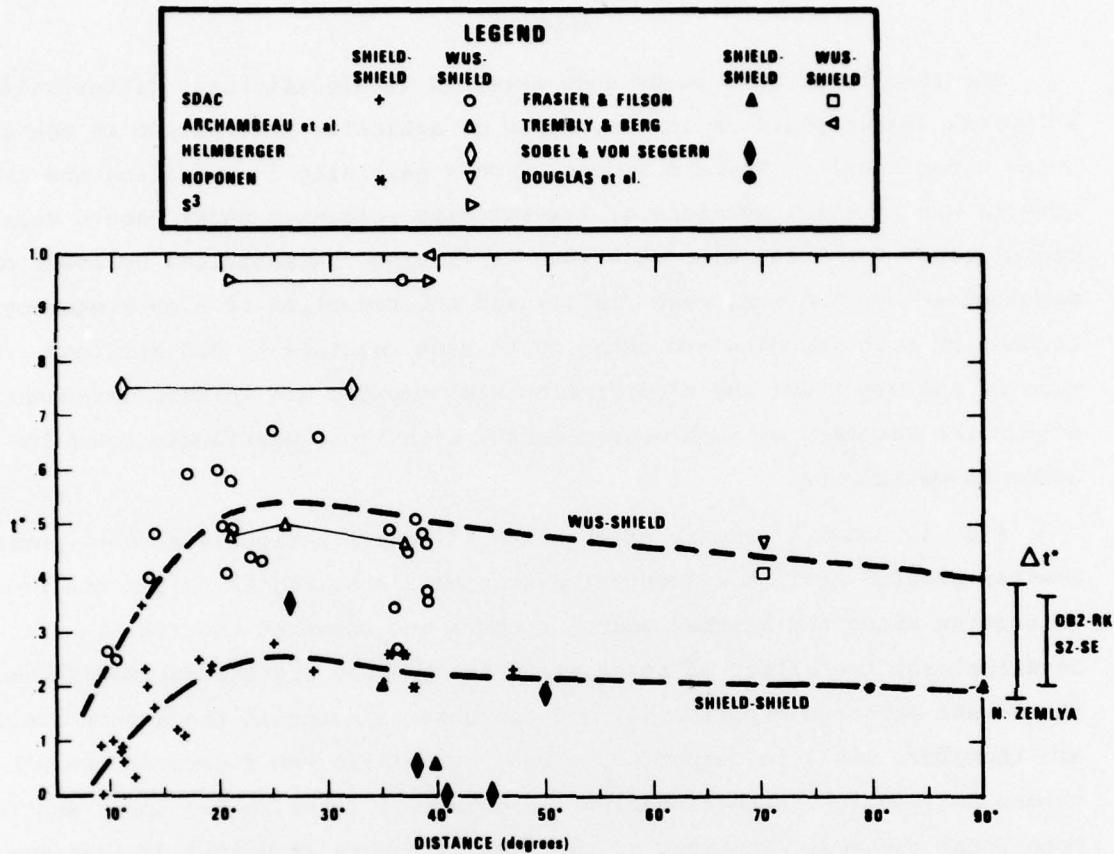


Fig. 13 Summary of absolute and relative  $t^*$  measurements as functions of epicentral distance. Open symbols denote absolute  $t^*$  estimates for WUS-shield type paths, the rest of the symbols are for shield-shield paths. Vertical bars on the right hand side of the figure show the magnitudes of the relative  $t^*$  differentials for the two types of paths. Source references are identified in the legend.

Some of the points are from publications of the Seismic Data Analysis Center (SDSC) of Teledyne Geotech (Der and McElfresh (1977)), some are yet unpublished values by us and by our colleagues Phyllis Sobel and David von Seggern at SDAC, and the rest are from the seismological literature (Archambeau et al. (1969); Trembly and Berg, (1968); Frasier and Filson, (1972); Filson and Frasier, (1972); Douglas et al., (1974); Noponen, (1975); Helmberger, (1973); Bache et al., (1974); the latter at Systems Science and Software, S<sup>3</sup> for short). Most of the values were derived using data from nuclear explosions.

The figure shows that in spite of scatter the two groups of t\* values are almost completely separated. The relative t\* differentials which are averages in the epicentral distance range of  $30^{\circ} < \Delta^{\circ} < 90^{\circ}$  are shown in the right hand side of the figure. These include some averaged EUS-WUS t\* differentials for Novaya Zemlya shots (Der and McElfresh (1977)) as well as

Der, Z. A., and T. W. McElfresh (1977). The relationship between anelastic attenuation and regional amplitude anomalies of short period P-waves in North America. (Submitted to Bull. Seism. Soc. Am.).

Archambeau, C. B., E. A. Flinn, and D. H. Lambert (1969a). Fine structure of the upper mantle, J. Geophys. Res., 74, 5825-5865.

Trembly, L. D., and J. W. Berg (1968). Seismic source characteristics from explosion generated P-waves. Bull. Seism. Soc. Am., 60, 819-838.

Frasier, C. W., and J. Filson (1972). A direct measurement of Earth's short-period attenuation along a teleseismic ray path, J. Geophys. Res., 77, 3782-3787.

Filson, J., and C. W. Frasier (1972). Multisite estimation of explosive source parameters, J. Geophys. Res., 77, 2045-2061.

Douglas, A., J. A. Hudson, P. D. Marshall, and J. B. Young (1974). Earthquakes that look like explosions, Geophys. J. R. Astr. Soc., 36, 227-233.

Noponen, I. (1975). Compressional wave power spectrum from seismic sources, Institute of Seismology, University of Helsinki, ISNB-951-45-0538, Contract AFOSR-72, 2377, Final Report.

Helmberger, D. V. (1973). On the structure of the low-velocity zone, Geophys. J. R. Astr. Soc., 34, 251-263.

Bache, T. C., T. G. Barker, N. Rimer, and J. M. Savino (1976). Comparison of theoretical and observed body and surface waves for Kasserli, an explosion at NTS, Systems, Science and Software, SSS-R-76-2937.

the  $t^*$  averages of the station pairs OB2NV-RKON and SZNV-SEMN described in this report. Dashed lines are free hand sketches of the trends of values for both populations. The differentials shown at the right of the figures are of the the same order of magnitude as the mean difference of the two absolute  $t^*$  populations.

The idea of high anelastic attenuation under the WUS is supported by a great body of other types of geophysical evidence which indicates the existence of partial melting of the rocks in the mantle under the WUS. Partial melting causes attenuation of seismic waves due to viscous losses in the melt phase.

Recent reviews of the evidence for partial melting were given by Solomon (1972) and Herrin (1972). Partial melting manifests itself in the reduction of body-wave velocities in the upper mantle under the WUS, resulting in a low-velocity layer for P and S waves (Archambeau, Flinn and Lambert, 1969; Massé et. al, 1972; Johnson, 1967; Biswas and Knopoff, 1974; and many others),

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Solomon, S. C. (1972). Seismic-wave attenuation and partial melting in the upper mantle of North America, J. Geophys. Res., 77, 1483-1502.

Herrin, E. (1972). A comparative study of upper mantle models, Canadian Shield and Basin and Range provinces, *The Nature of the Solid Earth* (E. C. Robertson, Editor), McGraw-Hill International Series in the Earth and Planetary Sciences.

Archambeau, C. B, E. A. Flinn, and D. H. Lambert (1969a). Fine structure of the upper mantle, J. Geophys. Res., 74, 5825-5865.

Massé, R. P., Landisman, M., and J. B. Jenkins (1972). An investigation of the upper mantle compressional velocity distribution beneath the Basin and Range Province, Geophys. J. R. Astr. Soc., 30, 19-36.

Biswas, N. N., and L. Knopoff (1974). The structure of the upper mantle under the United States for dispersion of Rayleigh waves, Geophys. J. R. Astr. Soc., 36, 515-540.

teleseismic travel time delays (Hales and Doyle, 1967; Hales et. al., 1968; Hales and Roberts, 1970; Julian and Sengupta 1973), and low  $P_n$  velocities (Herrin and Taggart, 1962). Marshall and Springer (1976) point out that a direct relationship seems to exist between station magnitude residuals and local  $P_n$  velocity. Other types of evidence for elevated temperatures under the WUS are high heat flow (Sass et al., 1971; Roy et al., 1972) and high upper mantle conductivity (Gough, 1973).

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Hales, A. L. and H. A. Doyle (1967). P and S travel-time anomalies and their interpretation, Geophys. J. R. Astr. Soc., 13, 403-415.

Hales, A. L., J. R. Cleary, H. A. Doyle, R. Green, and J. Roberts (1968). P-wave station anomalies and the structure of the upper mantle, J. Geophys. Res., 73, 3885-3986.

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Julian, B. R. and M. Sengupta (1973). Travel-time anomalies for the global station network, Semiannual Technical Summary Seismic Discrimination, EDS-TR-7 -348, Lincoln Laboratories, MIT, Lexington, Massachusetts.

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Sass, J. H., Lachenbruch, R. J. Munroe, G. W. Greene, and T. H. Moses, Jr. (1971). Heat flow in the Western United States, J. Geophys. Res., 76, 6376-6413.

Roy, R. F., D. D. Blackwell, and E. R. Decker (1972). Continental heat flow. The Nature of the Solid Earth (E. C. Robertson, Editor) McGraw-Hill International Series of the Earth and Planetary Sciences.

Gough, D. I. (1973). The geophysical significance of geomagnetic variation anomalies, Phys. Earth. Planet Int., 7, 379-388.

The NTS experiment is continuing. New data will enable us to narrow the confidence limits on both  $\Delta m_p$  and  $\Delta t^*$ . Field work presently being conducted at NTS will allow us to refine the crustal models and thus increase the precision of our estimates of the crustal effect on spectra and amplitudes. The study of short period S waves recorded during the project is presently underway. Preliminary results show that S waves undergo a loss of high frequencies similar to that observed for P waves at NTS.



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