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Estimates of the Teleseismic Magnitudes of Some Early Nevada Test Site Explosions

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SUMMARY

Estimates of the magnitude (m_b) of 45 explosions at the Nevada Test Site (NTS) during the period 1961-1963 are presented. The data used to determine the magnitudes are taken from the bulletins published as part of the Long Range Seismic Measurements (LRSM) and the World-Wide Standard Station (WWSS) measurements programme conducted under the auspices of the US Vela Uniform programme. Eight explosions which occurred after 1963 but for which little or no teleseismic data are available are included. A relationship between magnitude and yield for explosions detonated above the water table at NTS is found to be

$$m_b = (0.91 \pm 0.18 \log_{10}Y + (3.45 \pm 0.23).$$

1. INTRODUCTION

In the early years of research in forensic seismology much effort was made to improve methods of detecting, locating and identifying seismic source using seismological methods. The specific objective was to identify underground explosions against a background of naturally occurring earthquakes. In recent times more attention has been given to the estimation of the yield of the explosion once the source has been identified as such. One of the ways to do this is to relate the seismic magnitude determined from either body or surface waves to the yield of the explosion via calibration curves for each medium and each test site. A major difficulty of establishing magnitude-yield calibration curves is the lack of yield data to define the relationship. An additional difficulty is to determine a magnitude which is free of the recording network bias. The network of seismograph stations for which data are readily available is continually changing with new stations opening up and older ones closing down thus the network of stations reporting data for explosions in the early 1960's is quite different from that repotting explosions at the present time.

In an attempt to minimise the difficutties encountered by a changing network of stations Lilwall (1) developed a joint maximum-likelihood method of estimating magnitude using P wave amplitude and period data reported in the ISC bulletins. The magnitudes determined using this method minimises the network bias and can be regarded as a reasonable indicator of the size of the source. Unfortunately ISC amplitude data are not available for explosions fired before 1964. During the period 1961-1963 many explosions were detonated at the Nevada Test Site (NTS) for which the yield was announced and data from these would be useful for determining the magnitude-yield relationship of explosions above the water table. Most of these explosions were of relatively low yield (<20 kton) and detonated above the water table with the result that very few of them were recorded at teleseismic distances so it is difficult if not impossible to estimate a teleseismic magnitude.

However during the period 1961-1968 as part of the Vela Uniform (2) programme the Long Range Seismic Measurements (LRSM) experiments and the US Coast and Geodetic World-Wide Standard Station (WWSS) Seismic Measurement programmes were being conducted and a great deal of high quality data from explosions of low yield were recorded at distances of up to about 2500 km. For many of the explosions detected by the WWSS and LRSM stations Shot Reports (3,4) were published which tabulated the basic Pn, Pg and Lg amplitude and period data, These data can be used to determine the local magnitude but there remains the problem of relating local magnitudes to teleseismic magnitudes.

The LRSM and WWSS programmes continued into the middle sixties and by this time much larger explosions were being detonated which were detected by stations located at teleseismic distances from the shot point and which reported amplitude and period data to the ISC for publication in their bulletin. It should be possible to use LRSM and WWSS regional data to determine equivalent teleseismic magnitudes using the larger explosions data. To do this the explosions for which LRSM and WWSS data are available, and for which teleseismic magnitudes have been determined, are used to normalise regional observations to teleseismic magnitudes of large explosions recorded at teleseismic distances. The LRSM and WWSS amplitude and period data for large explosions recorded at teleseismic distances are restrained to the same base-line as the teleseismic m_b values, in this way Pn, Pg and Lg magnitudes are equated to the teleseismic m_b value. The remainder of the LRSM and WWSS data for the small explosions are then used to determine least squares estimates of magnitudes relative to the restrained baseline. In this way the magnitude determined, whether from Pn, Pg or Lg is an estimate of the equivalent teleseismic magnitude m_b.

The yields of some of the explosions used in this report have been announced (5). The magnitudes determined here together with other explosions for which the yield is known and teleseismic magnitudes are available are used to determine the nature of the relationship between magnitude and yield for explosions detonated above the water table at the NTS.

2. DATA

The amplitude and period data of each of the seismic waves Pn, Pg and Lg are taken from LRSM and WWSS shot reports. Examples of how the data are presented in the shot-reports are given in figures 1 and 2. The announced yields for the explosions used to determine the magnitude-yield relationship for explosions above the water table are taken from a US Department of Energy report (5). To determine whether the explosion was above or below the water table use was made of the data on NTS explosions published by Springer and Kinnaman (6)(7).

3. METHOD OF ANALYSIS

Consider n explosions recorded at some or all of q stations. Then if m_{ij} is the magnitude of the ith explosion measured at station j we can write

$$m_{ij} = b_i + s_j + \varepsilon_{ij} \qquad \text{(a)}$$

where b_i depends on the seismic size of the explosion, s_j is a station term and ε_{ij} an error term. Given a set of observations m_{ij}, estimates of the b_i and s_j can be found by least squares (Douglas (8)) or by a joint maximum likelihood technique if station detection thresholds need to be taken into account (Lilwall (1)). With either method some constraints must be applied to the equations of condition (a) to obtain a solution. The constraint essentially provides a baseline for the results and can be applied to one or more of the station or source terms, eg,

$$\Sigma s_j = \text{constant}$$

$$\text{or} \qquad \Sigma b_i = \text{constant} \qquad \text{(b)}$$

where the summations can be over one or more of the terms up to q and n respectively.

An example of this method is provided in Lilwall, Marshall & Rivers (9) who describe the estimation of magnitudes of 71 NTS explosions. The station magnitude measurements used in their study are amplitudes and periods read from the records of WWSSN stations augmented with amplitude data taken from the bulletins of the ISC and NEIS. The constraint:

$$\sum_{j=1}^{j=q} s_j = 0.0 \qquad \text{(c)}$$

was used to baseline the data. Not all stations with amplitude data were used, in an attempt to achieve as even distribution of stations as possible, given the limits imposed by the uneven distribution actually in existence. Station detection thresholds were taken into account in the analysis but the effect on the estimated event terms of allowing for these is small (<0.03 m_b units). This is expected with spatially close explosions where variation in source radiation pattern to a given station is relatively small (eg, Lilwall (1)). The NTS magnitudes determined by Lilwall et al (9) were used to baseline the magnitudes described in this report using the procedure described below.

Station magnitudes m_{ij} were computed from the LRSM and WWSS amplitude and period data described in the previous section. The station magnitudes were computed using the formula:

$$m_{ij} = \log(A/T) + Q(\Delta) \qquad (d)$$

where A and T are the amplitude and period of the phase considered, ie, Pn, Pg or Lg. The distance factor $Q(\Delta)$ needs only to approximate the amplitude variation for the small range of distances to each station, overall errors being taken up in the station term s_j. For Pn the Gutenburg and Richter (10) distance factors were used, modified to assume an inverse cube decay at distances less than 4°. For Pg and Lg inverse cube and square decay laws were assumed respectively.

Station and event terms were estimated from these magnitudes using the same maximum-likelihood technique used in Lilwall et al (9). Station detection thresholds are not known for this data set but since their effect on the estimated source terms b_i is expected to be small they were all set to low values. The method then is equivalent to the least squares as described by Douglas (8). A baseline to the results is provided through 11 explosions which were recorded by both the regional WWSS and LRSM networks and also at teleseismic distances. Magnitudes for these 11 explosions were obtained by extending the analysis described by Lilwall et al (9) for the 71 NTS explosions to include a much larger suite of 198 explosions from 1964-85. The sum of the magnitudes of the 71 explosions was held fixed to that determined in the original study (9). Magnitudes determined for the 11 explosions mentioned above are given in table 1 and were likewise used to baseline the estimates for the 1961-63 period. The resulting magnitudes for Pn, Pg and Lg given in table 2 are therefore baselined to the teleseismic m_b estimates described in Lilwall et al (9). Station terms for the Pn readings are in table 3.

4. RESULTS

The magnitudes determined by the method described in this report are given in table 2 together with the standard error and the number of observations. The yield of 21 of the explosions listed are given in a US DOE report (5), 11 of them being detonated in dry material above the water table. The magnitude, taken from the extended analysis referred to in the previous section and yield of 9 other explosions (5) detonated in similar conditions are also known. By using these explosions (table 4) a relationship between magnitude and yield for explosions detonated above the water table is found to be:

$$m_b = (0.91 \pm 0.18)\log_{10}Y + (3.45 \pm 0.23) \quad n=20$$

where Y is the yield in kilotons. The error terms are 95% confidence limits. The data points are illustrated in figure 3.

The coefficients are similar to those determined by Patton (11) who used the amplitude of Lg from Nevada explosions to determine a magnitude defined as $m_b(Lg)$. Patton's relationship (11) is given as

$$m_b(Lg) = (0.95 \pm 0.03)\log_{10}Y + (3.52 \pm 0.04) \quad n=120.$$

The agreement between the two relationships is very good given that in this report only 20 explosions were used compared with 120 used by Patton. The 20 explosions used here are all announced yields (5). The agreement between the two studies suggests that the ratio of Lg and Pn amplitudes is approximately constant with yield for explosions detonated above the water table. Insufficient data are available in this study to define a relationship between $m_b(Pg)$, $m_b(Lg)$ and yield.

The $m_b(Pg)$ and $m_b(Lg)$ computed for the explosions used in this study have been superpositioned on figure 3 to illustrate the scatter compared to $m_b(Pn)$. $m_b(Pg)$ and $m_b(Lg)$ are not available for the remainder of the explosions used to prepare figure 3.

5. ACKNOWLEDGEMENTS

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TABLE 1

Maanitudes of 11 NTS Explosions used to Normalise the Maanitude Estimates aiven in table 2 computed usina LRSM Pn, Pa and Lg Data

	Explosion	Date	Magnitude
1	Bourbon	20 Jan 1967	5.10
2	Buff	16 Dec 1965	5.22
3	Chartreuse	6 May 1966	5.27
4	Wagtail	3 Mar 1965	5.50
5	Knicker-Bocker	26 May 1967	5.31
6	Corduroy	3 Dec 1965	5.58
7	Piledriver	2 Jun 1966	5.59
8	Scotch	23 May 1967	5.60
9	Tan	3 Jun 1966	5.64
10	Dumont	19 May 1966	5.78
11	Commodore	20 May 1967	5.83

TABLE 2

Magnitudes Equivalent to Teleseismic m_b determined from Pn, Pg and Lg data for Explosions at the Nevada Test Site

				MAG (Pn)	+or-	NST	MAG (Pg)	+or-	NST	MAG (Lg)	+or-	NST
1.	610915		Antler	4.54	0.11	4	4.02	0.12	2	4.46	0.18	1
2.	611203		Fisher	4.21	0.05	20	4.34	0.04	17	4.38	0.05	13
3.	611213		Mad	3.38	0.13	5	3.05	0.06	9	3.24	0.07	9
4.	611217		Ringtail	4.61	0.10	6	3.601	0.10	3			
5.	620109		Stoat	4.14	0.06	16	3.98	0.05	11	3.95	0.07	8
6.	620118		Agouti	4.16	0.06	20	4.10	0.04	22	4.18	0.06	14
7.	620130		Dormouse	4.53	0.09	7	4.47	0.10	3			
8.	620208		Stillwater	4.13	0.06	20	3.93	0.04	26	4.14	0.04	22
9.	620209		Armadillo	4.36	0.05	28	4.10	0.04	27	4.33	0.06	17
10.	620215		Hardhat	4.83	0.06	37	4.80	0.03	28	4.55	0.04	28
11.	620219	1	Chinchilla I	3.97	0.11	4	4.41	0.20	2			
12.	620219	2	Codsaw	4.00	0.13	3	3.95	0.10	4	3.96	0.11	3
13.	620223		Cimarron	4.59	0.06	29	4.27	0.04	25	4.48	0.04	27
14.	620301		Pampas	4.36	0.09	8	4.69	0.12	2			
15.	620305		Danny Boy	4.45	0.16	2	3.40	0.16	2			
16.	620331		Chinchilla II	3.71	0.15	2	3.64	0.11	2	3.76	0.19	1
17.	620405		Dormouse Prime	4.38	0.10	7	4.28	0.10	5	4.63	0.14	2
18.	620406		Passaic	4.31	0.08	8	4.47	0.07	6			
19.	620414		Platte	4.09	0.12	4	3.66	0.08	4	4.31	0.13	2
20.	620512		Aardvark	5.12	0.05	26	5.07	0.05	13	5.08	0.05	19
21.	620606		Packrat	4.34	0.08	9	4.46	0.08	5	4.59	0.10	4
22.	620613		Des Moines	4.24	0.11	7	3.80	0.10	6	4.10	0.12	3
23.	620627		Haymaker	4.97	0.04	36	5.01	0.04	18	5.11	0.04	22
24.	620628		Marshmallow	4.64	0.07	10	4.25	0.11	2	4.60	0.12	4
25.	620630		Sacramento	3.91	0.09	7	4.04	0.07	7	4.11	0.10	4
26.	620706		Sedan	4.65	0.05	23	4.58	0.05	15	4.95	0.05	17
27.	620713		Merrimac	4.40	0.05	19	4.51	0.04	18	4.64	0.05	16
28.	620727		Wichita	4.03	0.16	2	4.01	0.10	4	4.21	0.11	4
29.	620824	1	York	4.34	0.04	33	4.33	0.04	17	4.51	0.04	22
30.	620824	2	Bobac	4.05	0.06	19	3.79	0.05	13	4.06	0.05	17
31.	620914		Hyrax	4.13	0.05	22	4.11	0.04	17	4.43	0.04	22
32.	620920		Peba	4.38	0.08	9	4.32	0.09	4			
33.	620929		Allegheny	3.60	0.12	3	3.40	0.08	4	3.77	0.11	3
34.	621012		Roanoke	3.49	0.16	3	3.54	0.09	3			
35.	621019		Bandicoot	4.35	0.10	7	3.99	0.07	7	4.17	0.19	1
36.	621127		Anacostia	3.69	0.11	6						
37.	621207		Tendrac	4.44	0.09	8	3.60	0.10	6	4.64	0.14	2
38.	621212		Madison	4.04	0.08	9	4.31	0.07	7	4.42	0.09	6
39.	630208	1	Casselman	4.21	0.13	5	3.95	0.11	3	4.88	0.15	2
40.	630208	2	Acushi	4.33	0.08	8	4.18	0.08	5	4.51	0.12	3
41.	630221		Kaweah	4.15	0.15	2	3.80	0.09	5	3.94	0.10	5
42.	630522		Stones	4.90	0.05	26	4.80	0.04	17	4.89	0.05	19
43.	630605		Yuba	4.24	0.05	20	3.94	0.04	18	4.12	0.05	20
44.	630913		Bilby	5.71	0.05	24	5.79	0.06	9	5.72	0.06	10
45.	631016		Clearwater	5.24	0.06	24	5.09	0.05	13	5.27	0.05	19

			MAG (Pn)	+or-	NST	MAG (Pg)	+or-	NST	MAG (Lg)	+or-	NST
1.	641002	Auk	4.89	0.04	28	4.88	0.04	17	4.87	0.05	19
2.	641009	Par	4.72	0.04	30	4.64	0.04	21	4.75	0.04	21
3.	641105	Handcar	4.63	0.04	28	4.62	0.04	17	4.75	0.05	20
4.	640414	Palanquin	4.11	0.06	17	4.20	0.06	13	4.25	0.05	15
5.	660224	Rex	4.96	0.06	14	4.94	0.09	3	4.89	0.07	7
6.	660305	Red Hot	3.88	0.08	9	3.62	0.06	8	3.76	0.07	7
7.	660425	Pinstripe	4.55	0.08	12	4.64	0.11	2	4.72	0.08	6
8.	680423	Scroll	4.16	0.07	13	4.20	0.06	11	4.10	0.08	5

TABLE 3

Pn Magnitude Station Terms
(For use as station corrections the sign should be reversed)

STN	TERN	+OR-	DIST	NE
ADIS	0.30	0.105	44.85	4
ALQ	0.13	0.050	8.14	27
ANMA	0.44	0.121	12.27	3
APOK	0.07	0.146	14.70	2
ARWS	-0.20	0.145	22.80	2
ATNV	0.65	0.075	2.46	9
AX2A	0.09	0.082	25.23	7
BEFL	-0.08	0.087	29.97	6
BFCL	0.40	0.168	2.68	8
BKS	0.55	0.149	4.95	2
BLWV	-0.31	0.092	27.80	5
BMO	0.00	0.120	7.83	3
BMSO	0.07	0.058	7.82	15
BPCL	0.25	0.122	2.03	3
BRPA	-0.23	0.119	29.40	3
CKBC	-0.18	0.147	14.40	2
CNWS	-0.27	0.145	20.55	2
COL	0.03	0.059	33.91	22
CPCL	0.34	0.056	4.45	19
CPO	-0.19	0.120	24.83	3
CPSO	-0.22	0.053	24.89	18
CRNB	-0.20	0.096	15.67	6
CTOK	-0.76	0.147	17.35	2
DAL	-0.18	0.148	16.65	2
DHNY	-0.35	0.078	32.21	7
DRCO	0.05	0.055	6.70	19
DUG	-0.25	0.063	4.05	15
DUOK	-0.42	0.149	16.70	2
EKNV	0.31	0.145	2.15	2
ENMO	-0.75	0.121	20.60	3
EPTX	0.40	0.151	9.95	2
EUR	0.49	0.072	2.43	14
EYNV	-0.18	0.150	2.35	2
FGU	0.31	0.064	6.53	27
FXCO	0.82	0.108	9.70	4
FLO	-0.17	0.085	20.53	7
FMUT	-0.04	0.074	3.74	17
FRMA	0.55	0.148	11.65	2
FSAZ	0.37	0.064	4.40	14
GCA	0.01	0.057	3.61	28
GEAZ	0.05	0.086	5.73	6
GIMA	0.21	0.148	13.50	2
GOL	0.41	0.059	8.89	22
GPMN	-0.46	0.145	19.85	2
GR1T	-1.19	0.153	15.55	2
GVTX	-0.65	0.093	16.32	5
HBOK	0.04	0.123	14.13	3
HETX	-0.40	0.148	18.20	2
HKWY	0.77	0.146	10.25	2
HL2I	-0.20	0.087	6.62	6
HLID	-0.09	0.059	6.74	17
HNME	-0.15	0.054	36.99	17
HRAZ	0.14	0.095	4.98	5
HVMA	0.42	0.146	12.35	2
HYMA	0.16	0.145	11.25	2
JELA	-0.09	0.152	20.85	2
JPAT	-0.96	0.092	15.93	7
JRAZ	0.44	0.080	4.11	7
XCMO	-0.55	0.105	17.18	4
KGAZ	0.45	0.106	2.50	4

KMCL	-0.01	0.150	2.50	2
KNUT	0.49	0.034	2.67	43
LAO	0.18	0.071	12.20	10
LCNN	-0.08	0.052	9.18	20
LGAZ	0.19	0.080	4.66	7
LPTX	-0.85	0.120	16.00	3
LZBV	-0.30	0.119	70.23	3
MCSD	-0.74	0.145	15.45	2
MDS	-0.19	0.079	21.21	13
NHT	-0.37	0.120	15.68	5
MLNM	-0.21	0.123	7.03	3
MMTN	-0.33	0.104	25.03	4
MNNV	0.28	0.035	2.06	41
MOID	0.25	0.127	5.93	3
MPAR	-0.71	0.074	18.90	8
MVCL	-0.19	0.063	4.70	15
NDCL	-0.20	0.107	2.73	4
NGWS	-0.38	0.095	22.78	5
NL2A	0.46	0.120	5.53	3
NLAZ	0.37	0.119	5.40	3
NPNT	-0.15	0.054	39.63	16
OONW	-0.23	0.129	73.87	3
PGBC	-0.86	0.081	17.54	14
PI2W	0.54	0.120	7.63	3
PLH	0.65	0.056	3.83	26
PMWY	0.43	0.079	9.35	10
PTOR	0.87	0.060	8.83	13
RGSD	0.17	0.091	12.60	9
RKON	0.11	0.053	21.30	25
RTNN	-0.01	0.088	9.50	6
RYND	0.25	0.121	15.48	4
SEMN	-0.59	0.074	17.94	8
SFAZ	0.56	0.105	5.27	6
SGAZ	0.11	0.104	2.83	4
SIBC	-0.70	0.077	19.30	8
SJTX	-0.40	0.104	17.90	4
SKTX	0.58	0.148	13.05	2
SNAZ	0.28	0.080	4.91	7
SSTX	-0.09	0.078	13.55	8
SV2Q	-0.24	0.103	38.08	4
SV3Q	-0.25	0.070	38.12	10
SVAZ	0.17	0.121	6.43	3
SWMA	0.55	0.082	12.30	8
TCNN	0.24	0.109	8.13	4
TDNN	-0.18	0.149	8.10	2
TFCL	-0.15	0.086	3.73	6
TFO	0.31	0.147	4.85	2
TFSO	0.22	0.053	4.99	21
TKWA	0.21	0.148	12.05	2
TNCL	0.26	0.098	2.98	5
TSND	0.05	0.120	13.70	3
TUC	0.27	0.121	6.50	4
TUT	-0.03	0.064	6.55	18
UBO	0.97	0.120	6.07	3
UBSO	0.96	0.047	6.13	23
VNUT	0.66	0.081	6.14	7
VOIO	-0.03	0.121	19.30	3
VTOR	0.48	0.095	6.34	5
WFMN	0.06	0.119	19.40	3
WH2Y	-0.77	0.098	26.60	5
WINV	0.08	0.054	4.43	19
WMAZ	0.12	0.098	3.55	8
WMO	-0.39	0.138	14.55	4
WNSO	-0.23	0.061	14.60	17
WNSD	0.33	0.066	13.75	12
WOAZ	0.11	0.086	5.05	6
WWUT	0.16	0.149	2.50	2

Table 3 (continued)

TABLE 4

Explosions Detonated above the Water Table
in Dry Rock at the Nevada Test Site at Pahute Mesa and Yucca Flats

Explosion	Date	m_b	Ykt
Mad	13 Dec 1961	3.38	0.5
Chinchilla	19 Feb 1962	3.97	1.9
Stillwater	8 Feb 1962	4.13	3.1
Stoat	9 Jan 1962	4.14	5.1
Agouti	18 Jan 1962	4.16	6.4
Armadillo	9 Feb 1962	4.36	7.1
Cyathus	6 Mar 1970	4.04	8.7
Dormouse Prime	5 Apr 1962	4.38	10.6
Cimarron	23 Feb 1962	4.59	11.9
Cyclamen	5 May 1966	4.23	12
Fisher	3 Dec 1961	4.21	13.4
Delphinium	26 Sep 1972	4.03	15
Discus Thrower	27 May 1966	4.77	22
Labis	5 Feb 1970	4.43	25
Par	9 Oct 1964	4.72	38
Haymaker	27 Jun 1962	4.97	67
Duryea	14 Apr 1966	5.18	70
Chartreuse	6 May 1966	5.27	73
Knicker-Bocker	26 May 1967	5.31	76
Flask	26 May 1970	5.53	105

Principal Phases
DURYEA
14 April 1966
14:13:43.12

Code	Station	Distance (km)	Inst.	Magnification (k) Film x 10	Phase	Observed Travel Time (min)	Observed Travel Time (sec)	Period T (sec)	Maximum Amplitude mμ	Magni- (m)	Area (mm²) LPZ
MN-NV	Mina, Nevada	201	[illegible] SPZ SPT [illegible]	2.4* 2.4* 5.9*	Pn Pg Lg LR	0 0	32.5 34.6	0.5 — — 9.0	.679 — — 1142		34.6
KN-UT	Kanab, Utah	321	[illegible] [illegible] SPT LPT [illegible]	0.89* 0.89* 1.60* 11.3* 5.30	[illegible] Lg LR	0 [illegible]	47.7 54.7	0.4 — 0.5 10.0 11.0	2362 — 4417 [illegible] 703	6.02	124.4
TFO	Tonto Forest Observatory, Arizona	570	SPZ-1 SPZ-1 [illegible] SPZ-1 SPW [illegible]	15.0 15.0 15.0 64.0* 15.0 1.0	Pn [illegible] P Pg LR	01 01 01 [illegible]	19.8 22.5 27.7 34.5	0.4 0.4 1.6 1.6 1.6 15.0	168 112 [illegible] 472 1042 330	5.65	147.3
UBO	Uinta Basin Observatory, Utah	667	SPZ-10 SPZ-10 [illegible] LPN [illegible]	9.7 9.1 9.0 22.0 30.0	Pn Pg [illegible] LR	[illegible] 01	[illegible] 11.1	0.6 0.7 1.1 16.0 13.0	289 618 853 63.7 39.5	6.10	25.1
BMSO	Blue Mountains Observatory, Oregon	848	SPZ-3 SPZ-3 SPZ-3 SPZ LPZ LPZ	35.0 35.0 35.0 16.5* 15.0*	[illegible] [illegible] Pg Lg LR	01 [illegible] [illegible]	55.3 06.9 18.2	1.0 0.8 — 16.0 13.0	32.1 [illegible] — 114 11	5.44	66.7
LAO	[illegible]	1344	SPZ SPZ SPZ	350 350 32.5	Pn (PP) [illegible]	[illegible] 03 03	(54.1) 06.7 08.1	1.0 1.0 0.9	24.4 24.3 64.1	5.40	
[illegible]	[illegible]	1352	SPZ SPZ SPZ SPR LPR LPZ	174 174 174 172 23.5 36.3	P PP Pg Lg LR	02 03 03	(58.1) 07.8 47.5	1.1 0.8 1.0 (1.4) 18.0 11.0	47.1 26.4 51.7 (197) 33.7 90.7	5.75	25.0
RG-SD	Redig, [illegible]	1395	[illegible] SPZ SPT LPR LPZ	83.0 83.0 73.9 9.88 10.55	P PP Lg LR	03 03	01.9 13.8	0.8 1.0 (1.1) [illegible] 13.0	17.7 130 (246) (34.9) 49.9	5.30	35.1
WN-SD	Winner, South Dakota	1531	SPZ SPZ SPZ SPZ SPR LPR [illegible]	90.4 90.4 90.4 90.4 88.2 [illegible]	P PP [illegible] Lg LR	03 03 03 03	17.7 28.9 43.5 59.7	0.6 0.8 1.0 0.5 1.2 15.0 13.0	24.6 54.9 [illegible] 177 46.8	5.08	33.6
WMSO	Wichita Mountains Observatory, Oklahoma	1631	SPZ-6 SPZ-6 SPZ-6 SPZ-6 SPW	130 130 130 130 130	P (PP) Pg [illegible] [illegible]	03 03 [illegible] 04	31.2 41.5 35.7 56.2	0.9 1.2 1.1 2.0	47.6 20.8 52.0 44.2 176	5.08	
CR-NB	[illegible]	1735	SPZ SPZ SPZ SPZ SPT LPT LPZ	36.2 36.2 36.2 36.2 18.5 14.50 40.2	P [illegible] [illegible] Pg Lg LR	03 03 [illegible] [illegible]	(42.1) 47.7 [illegible] [illegible]	0.9 0.9 0.8 1.0 (1.0) 14.0 13.0	58.1 134 35.5 51.8 (196) 90.7 164	4.82	58.5
JP-AT	Jasper, Alberta, Canada	1745	[illegible] SPZ SPR LPR LPZ	151 151 145 [illegible] 44.4	P [illegible] Lg LR	03 04	(45.8) 03.7	0.7 0.9 (2.8) 17.0 14.0	15.3 37.6 (78.4) 34.2 80.9	4.20	91.2
KC-MO	Kansas City, Missouri	1913	[illegible] SPZ SPT LPT LPZ	[illegible] 48.1 48.2 29.8 4.03	P (PP) Lg LR	04 04	05.8 13.1	(0.9) (0.7) (1.7) 14.0 14.0	(63.6) (46.6) (208) 74.8 191	(4.72)	87.5
PG-BC	Prince George, British Columbia, Canada	1921	[illegible] SPZ SPZ SPZ [illegible]	155 155 155 115	[illegible] [illegible] [illegible] (PP) [illegible]	04 [illegible] 04 [illegible]	[illegible] 07.0 09.9 19.5	1.1 1.2 1.1 1.0 1.0	37.8 111 73.7 43.2 33.4	4.40	
SI-BC	Smithers, British Columbia, Canada	2113	[illegible] [illegible] SPZ [illegible]	99.6 99.6 [illegible]	[illegible]	04 04 04 04	26.8 28.3 11.1 36.2	1.0 1.0 1.0 0.9	40.9 [illegible] 40.2	4.69	
RK-ON	Red Lake, [illegible]	3353	[illegible] SPZ SPZ [illegible] SPZ [illegible] SPT LPT [illegible]	188 188 188 188 188 188 [illegible] 38.1 47.6	P [illegible] [illegible] PP [illegible] [illegible] Lg LR	04 04 [illegible] 05 05 [illegible]	46.3 49.8 59.7 08.6 14.1 21.9	0.8 1.0 1.1 0.9 0.8 0.9 [illegible] 13.0 12.0	[illegible] 121 [illegible] 43.6 [illegible] 23.5 72.5 16.8 32.9	4.93	11.1
CPSO	Cumberland Plateau Observatory, Tennessee	2762	SPZ-8 SPZ-8 SPW LPW LPZ	40.0 40.0 530* 25.0* (25.0*)	P [illegible] [illegible] LR	[illegible] 05	24.4 47.9	0.1 — — 14.0 13.0	54.1 24.6 67.9 80.1 (257)	5.20	33.0
AX2AL	Alexander City, [illegible]	2790	SPZ SPZ SPZ SPT LPT LPZ	174 174 174 187.5 33.2 32.2	P [illegible] [illegible] Lg LR	05 05 05	28.4 35.3 42.2	1.0 0.9 0.9 (2.0) 18.0 17.0	51.0 19.3 16.9 (46.6) 19.9 29.5	5.19	79.1
BE-FL	Belleview, Florida	3319	LPZ	24.4	LR			16.0	63.7		103.6
HN-ME	Houlton, Maine	4087	SPZ SPZ SPZ LPT LPZ	105 105 105 25.3 26.6	P [illegible] [illegible] [illegible] LR	[illegible] [illegible] 07	09.6 13.2 34.2	1.1* 1.0 1.0 17.0 11.0	64.2 17.9 17.9 28.5 46.7	5.33	22.6
SV3QB	Schefferville, Quebec, Canada	4201	SPZ SPZ SPZ LPT LPZ	101 101 101 60.9 31.0	[illegible] (LR)	07 07 07	(16.9) 24.2 41.0	0.9 0.8 18.0 11.0	22.9 7.3 7.3 14.0	4.86	6.1

Principal Phases - DURYEA
Table 2

A/T mμ/sec
( ) Doubtful Values of Phases
* Measurements Made From Playouts
— Maximum Amplitude Clipped on Film & Magnetic Tape

Principal Phases - DURYEA

FIGURE ▮ _ AN EXAMPLE OF THE BASIC DATA TAKEN FROM THE LRSM PROGRAMME FOR THE EXPLOSION DURYEA

Table. 5. FISHER

Periods and Amplitudes of P_n and P

Sta.	Dist. (km)	T-T* (sec)	Per. (sec)	Ampl. (mμ)	Ampl./Per. (mμ/sec)	m_b
EUR	267	41.4	--	--	--	--
GCA	400	58.0	0.3	7	23	4.1
PLM	411	61.1	0.6	95	159	5.3
mu	722	97.3	0.4	2	5	4.3
ALQ	889	118.9	0.6	1.6	3	4.3
MHT	1722	226.8	0.8	16	20	4.4
COL	3733	404.2	0.9	5.3	6	4.3

* Observed travel time
-- Signal not measureable because of excessive amplitude

Table 6. FISHER

Periods and Amplitudes of P_g

Sta.	Dist. (km)	T-T* (sec)	Per. (sec)	Ampl. (mμ)	Ampl./Per. (mμ/sec)	Comp.
EUR	267	48.0	--	--	--	
GCA	400	66.1	0.7	120	171	SPZ
FCU	722	111.8	0.7	6.7	10	SPZ
ALQ	889	148.9	0.8	20	25	SPZ

* Observed travel time
-- Amplitude off scale

Table 7. FISHER

Periods and Amplitudes of L_g

Sta.	Dist. (km)	T-T* (sec)	Per. (sec)	Ampl. (mμ)	Ampl./Per. (mμ/sec)	Comp.
CCA	400	110.9	(0.8)	(47)	(59)	SPN
mu	722	193.1	0.9	3	10	SPZ
ALQ	889	250.9	1.0	11	11	SPZ

* Observed travel time
( ) Doubtful values

FIGURE 2. AN EXAMPLE OF THE BASIC DATA TAKEN FROM THE WWSS MEASUREMENTS PROGRAMME FOR THE EXPLOSION FISHER

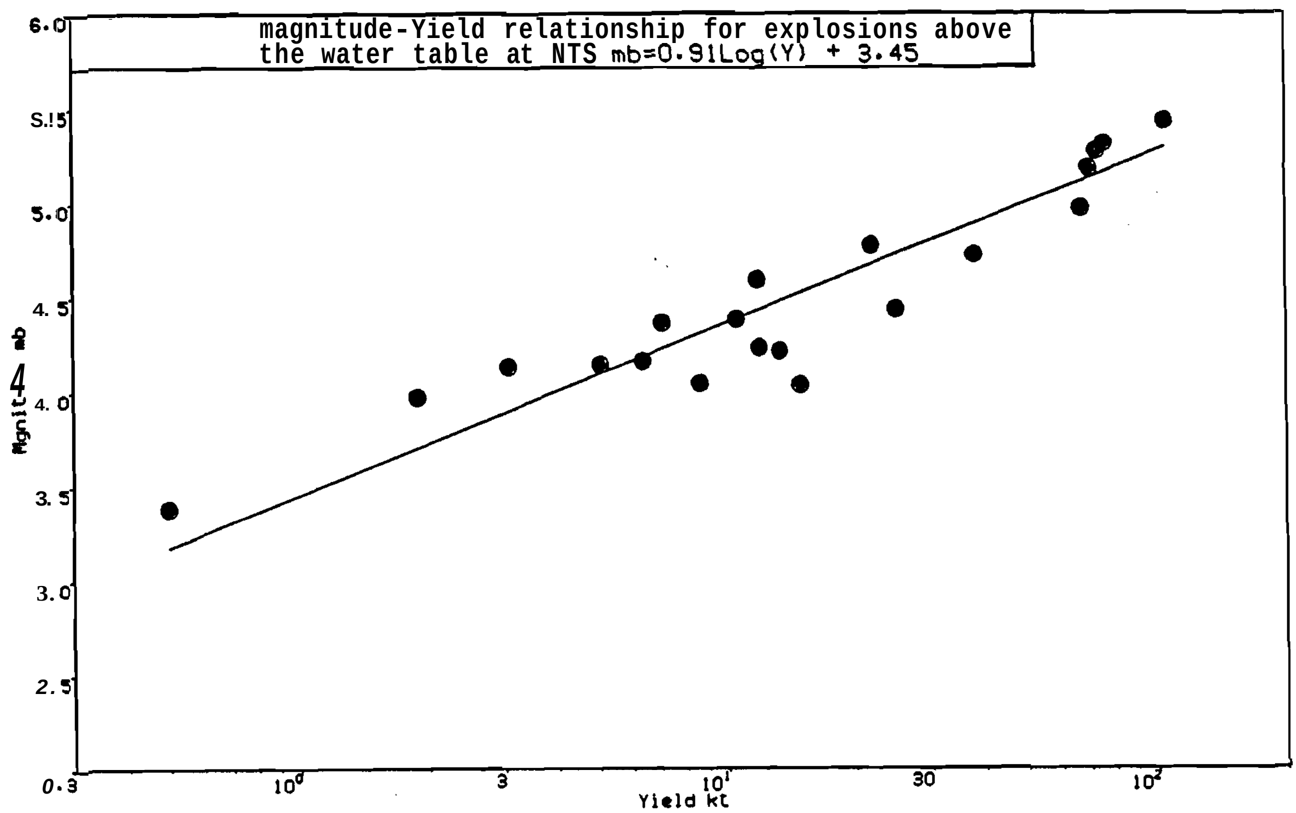

FIGURE 3. MAGNITUDE:YIELD RELATIONSHIP FOR EXPLOSIONS ABOVE THE WATER TABLE AT THE NEVADA TEST SITE

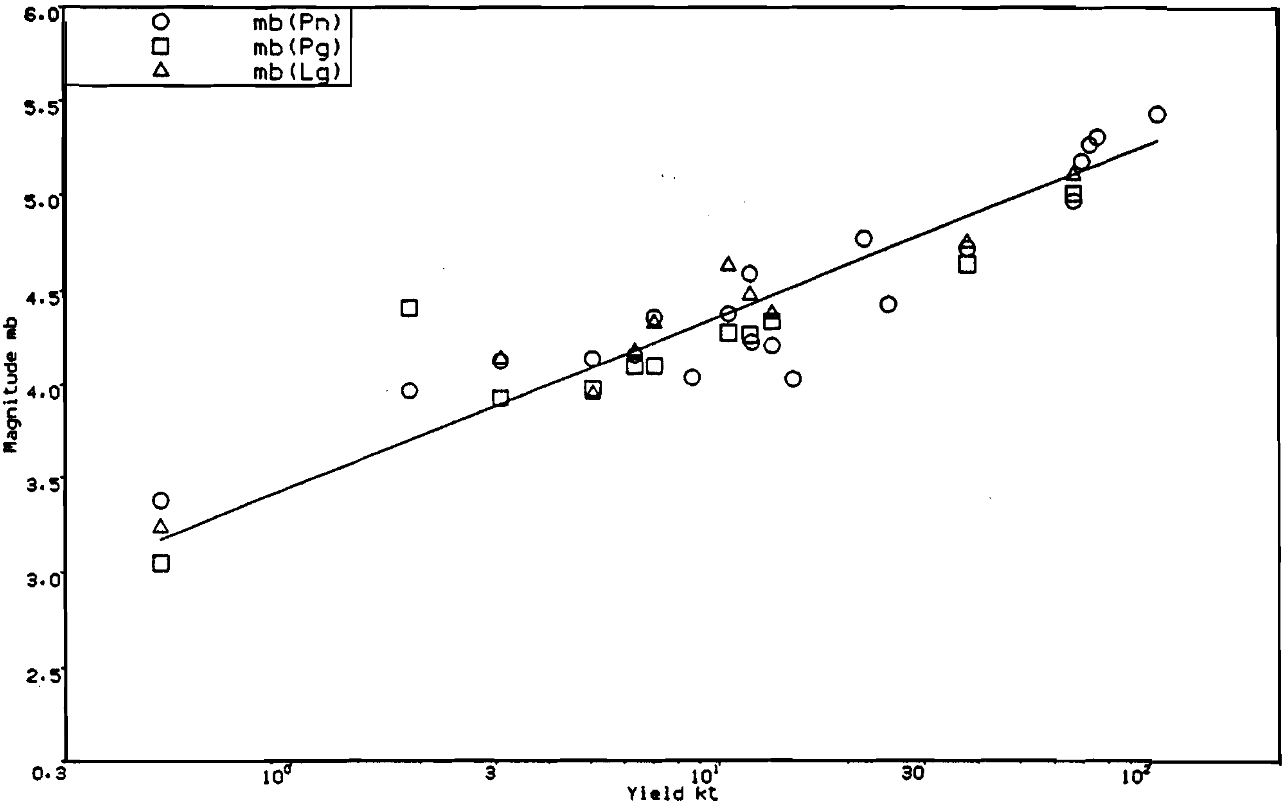

FIGURE 4. m_b(PG) AND m_b(LG) SUPERPOSITIONED ON THE DATA PRESENTED IN FIGURE 3

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