UK UNLIMITED

AWRE O 17/86

AWRE O 17/86

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

AWRE REPORT No. O 17/86

Body Wave Magnitudes and Locations of
Soviet Underground Explosions at the
Novaya Zemlya Test Site

R C Lilwall
P D Marshall

Available from H.M. Stationery Office
PRICE £4.00 NET

AWRE,
MOD(PE),
Aldermaston, Berks.

UK UNLIMITED

December 1986

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

AWRE REPORT NO. 017/86

Body Wave Magnitudes and Locations of Soviet Underground Explosions at the Novaya Zemlya Test Site

R C Lilwall
P D Marshall

Recommended for issue by

A Douglas, Superintendent

Approved by

B L Elphick, Head of Division

ISBN 0 85518177 x

CONTENTS

SUMMARY

At their underground nuclear test site at Novaya Zemlya the USSR detonates explosions in two areas, here designated the north and south Novaya Zemlya test sites. A least squares joint epicentre estimate of origin time and epicentre together with a maximum-likelihood estimate of magnitude are presented for explosions in each of these test sites. These are based on data taken from the bulletins of the International Seismological Centre.

1. INTRODUCTION

Basic source information (location, origin time, depth, yield, etc) about underground nuclear explosions is important to seismologists interested in studying the structure of the earth, as well as those interested in discrimination between earthquake and explosion generated seismic signals. Numerous scientists have appealed for the release of epicentral details of explosions to aid research programmes (Bullen, Griggs and Press, Teller, (1-3)). In response, Springer and Kinnaman (4,5) published the basic epicentre details for all announced underground nuclear explosions detonated in the USA from 1961 to 1973. Numerous yield estimates were also included. The origin times and precise epicentres of French underground nuclear explosions in the Sahara between 1961 and 1966 have been published by Duclaux and Michaud (6). No comparable data are available for underground explosions in the USSR.

Several international data centres collect seismic wave arrival times from all over the world and compute estimates of the origin time, epicentre, depth and size for seismic disturbances including underground explosions. Bulletins containing these data are published by the US National Earthquake Information Centre (NEIC) in Colorado, USA, and the International Seismological Centre (ISC) in Newbury, UK. A similar service is provided by the Institute of Physics of the Earth in Moscow, but the Soviet bulletin does not usually report data on any nuclear explosions.

From the ISC and NEIS bulletins it is possible to extract either estimates of source parameters of underground explosions or officially announced details for most nuclear tests at the US Nevada Test Site (NTS). Official announcements are particularly useful for seismological researchers interested in solving some of the outstanding problems of verifying compliance with nuclear test ban treaties since they provide researchers with a list of explosion sources upon which to develop techniques for the identification of explosion generated signals. The release, by the US Government, of epicentral details of their nuclear tests and the value of this information to the seismological community should be applauded.

The ISC bulletin includes an estimate of the mean magnitude for most large underground explosions. However the magnitude reported is determined only to one decimal place and takes no account of station magnitude corrections for the seismic stations used. In effect the network used to determine m_b is different for every explosion. A useful

addition to the officially released data would be reliable estimates of the seismic magnitude m_b of the explosion. To provide this additional information the P-wave amplitude and period data provided by stations reporting to the ISC have been analysed using a maximum-likelihood analysis procedure to provide estimates of the magnitude m_b for explosions at the Novaya Zemlya test sites. P wave travel times reported in the ISC bulletin have been used to relocate the epicentres using the Joint Epicentre Determination (JED) developed by Douglas (7).

Estimates of the epicentral parameters and magnitudes of explosions at the Soviet test site near Semipalatinsk (Marshall et al (8)), French nuclear tests at Mururoa (Marshall et al (9)) and for US explosions at the NTS (Marshall et al (10)) have already been published. It is proposed to publish a similar report on Soviet explosions in the North Caspian Sea region.

2. DETERMINATION OF MAXIMUM LIKELIHOOD ESTIMATES OF MAGNITUDE

The size of a seismic source is measured by its magnitude. For short period (SP) seismic P wave data the Gutenberg and Richter definition (11) is used:-

$$m_b = \mathrm{Log}_{10}A/T + B(\Delta) \qquad ....(1)$$

where A is the amplitude of the P wave in nm, T its predominant period in seconds, $B(\Delta)$ a distance normalising term.

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

$$m_{ij} = b_i + s_j + \epsilon_{ij}, \qquad ....(2)$$

where b_i depends on the seismic size of the explosion, s_j is a station correction and ϵ_{ij} is an error term. Least squares can be used to estimate b_i and s_j using the method described by Douglas (12) if it is assumed that

$$\sum_{j=1}^{j=q} s_j = 0 \qquad ....(3)$$

Least squares estimates are unbiased if the observed m_{ij} are sampled randomly from a normal population. The latter cannot be assumed however if station amplitude measurement thresholds result in "censoring" of many lower values of m_{ij}. To allow for threshold effects the following "maximum likelihood" estimation technique has been used.

Following Christoffersson et al (13) the distribution of observed station magnitudes m_{ij} can be written as:

$$P\left[{}^{m_{ij}}_{obs} \middle| b_i, s_j, \sigma \ldots\right] = \Phi\left[\frac{m_{ij}-G_j}{\gamma_j}\right] \theta \left[\frac{m_{ij}-s_j-b_i}{\sigma}\right] \Bigg/ \Phi\left[\frac{s_j+b_i-G_j}{\sqrt{(\sigma^2+\gamma_j^2)}}\right] \quad \ldots.(4)$$

where $G_j = g_j + B(\Delta_j)$ ....(5)

θ is the normal density function of variance σ^2 representing the distribution of "uncensored" values of m_{ij}; Φ the cumulative normal distribution; g_j the mean (50 %) amplitude measurement threshold in terms of Log^A/T for station j; γ_j^2 the variance of the threshold assumed normally distributed about g_j. If the sources are close together equation 5 enables the mean Log^A/T thresholds g_j to be expressed in terms of magnitude thresholds G_j using equation 5.

Estimates of b_i, S_j and σ can be determined by maximising the likelihood function resulting from the product over the observed values of m_{ij} of terms given by equation 4

$$L(b_i, S_j, \sigma) = \prod_{\substack{\text{observed} \\ m_{ij}}} P(m_{ij}|b_i, S_j \ldots.) \quad \ldots.(6)$$

Maximisation being subject to the constraint equation 3.

When using least squares, the effect of large errors, which deviate from normal law, can be reduced by the application of weighting as in Jeffreys' (14) method of uniform reduction. This method assumes that the random variable ϵ_{ij} is essentially normal but modified by the addition of a low amplitude uniform distribution. In the maximum likelihood estimation described above this is introduced by adding a constant term to the probability density function given by equation 4. Examination of observed distributions away from the mode suggested a value 0.01 times the maximum is appropriate for this term. Its introduction progressively reduces the contribution of observations beyond two to three standard deviations from the mode.

As well as the observations m_{ij} the method requires values for the threshold parameters g_j and γ_j. These are estimated from the overall distribution of Log^A/T submitted to the ISC by each station using the method of Kelly and Lacoss (15). Table 3 gives the threshold values used in the analysis and are based on those published by Lilwall (16-17) with some small modifications and additions.

The basic input data are taken from the ISC bulletins in the form of Log^A/T readings from stations located in the distance range Δ = 7 to 90 degrees. Resulting magnitude estimates are given in table 1 and the station corrections in table 2. Two separate analyses were made for the north and south test sites. For the northern site 1655 amplitude readings were used to estimate 26 magnitudes and 212 station terms. A value of 0.14 was obtained for the standard deviation σ. For the southern

site 229 readings were used to estimate 4 magnitudes and 104 station terms. In this case an a priori value of σ equal to that for the northern site was used.

In general, differences between the maximum likelihood estimates of magnitude and those obtained using a least squares analysis of variance method (Douglas (12)) are small (< 0.2 units) and are negligible above m_b5.5. These small differences result from the low value of σ obtained for closely grouped explosion sources (Lilwall (17)).

3. JOINT EPICENTRE RELOCATIONS

The Joint Epicentre Determination (JED) method described by Douglas (7) was employed to relocate the epicentres using P and PKP arrival time data taken from International Seismological Centre (ISC) bulletins. JED is most effective when all the epicentres are from a limited spatial region, since deviations from the assumed travel time curve can be corrected by a single term for each station. Accordingly the north and south Novaya Zemlya sites are here treated separately. The method requires that at least one of the epicentres in each group be restrained to predetermined values. Since no published true locations are available the restrained epicentres must be fixed using other evidence. The constrained epicentre for the northern site was for the explosion of 29 September 1976 (event 14, table 1). It is well recorded and centrally placed within the group, but adoption of the ISC location (73.41N 54.50E) results in the epicentres straddling Matochkin Shar Strait (see figure 1). Figure 1 indicates that the region is mountainous and it is reasonable to assume that the devices were emplaced using adits beneath the mountains. The co-ordinates of restrained epicentre were therefore chosen to locate the overall epicentre pattern beneath two mountain groups south of the strait. The relocations are on average some nine kilometres east of those obtained by the ISC. There is no topographic control on the location of the southern group and these were relocated using the same restrained epicentre in a second analysis.

Arrival time readings were weighted to remove gross errors and where possible to allow for variations in the quality of measurements between stations. Gross errors were removed by the method of uniform reduction (Jeffreys (14)). For the northern group there is sufficient data to enable estimates of the standard deviation of the time residuals for many of the stations and the readings were also weighted for variations in this.

Table 1 gives the relocated epicentres and origin times. These are plotted in figures 1 and 2. The weighted standard deviation of the arrival time residuals (0.25s) and the large number of readings result in very small 95% confidence regions (table 1) for the majority of the epicentres. Relative locations will reflect this but absolute locations are tied to the choice of co-ordinates for the restrained epicentre.

4. MULTIPLE EXPLOSIONS

An examination of the seismograms from the underground explosion at the south Novaya Zemlya test site on the 18 October 1975 led Hurley (18) to the conclusion that two explosions, separated by a few kilometres were detonated virtually simultaneously. Hurley's analysis of both P and Rayleigh waves is convincing evidence that two explosions were

indeed detonated. An examination of short period P wave recordings for the explosion at the north Novaya Zemlya test site on 11 October 1980 suggests that this explosion was not a single explosion. More research is being conducted on this particular explosion and will be the subject of a research note to be published later.

5. ACKNOWLEDGMENTS

The authors would like to express their thanks to Miss J Farthing for her help in the preparation of this report. Thanks are also due to the seismogram analysts around the world who so conscientiously report onset times and amplitudes to the ISC and NEIC without whose contribution this publication would not have been prepared.

REFERENCES

1. K E Bullen: "Seismology in our Atomic Age". Compt Rond XIc Assembly Gen UGGI, 29-34 (1958)

2. D T Griggs, F Press: "Probing the Earth with Nuclear Explosions". J Geophys Res, 66, 237 (1961)

3. E Teller: "Plowshare". Nucl News, 6, 1-13 (1963)

4. D L Springer, R L Kinnaman: "Seismic Source Summary for US Underground Nuclear Explosions 1961-1970". Bull Seism Soc Am, 61, 1073-1098 (1971)

5. D L Springer, R L Kinnaman: "Seismic Source Summary for US Underground Nuclear Explosions 1971-1973". Bull Seism Soc Am, 65, 343-349 (1975)

6. F Duclaux, L Michaud: "Conditions Experimentales des Tirs Nucleaires Souterrains Francais au Sahara, 1961-1966". C R Acad Sc Paris, t270, Serie B, 189-192 (1970)

7. A Douglas: "Joint Epicentre Determination". Nature, 215, 47-48 (1967)

8. P D Marshall, T C Bache, R C Lilwall: "Body Wave Magnitudes and Locations of Soviet Underground Explosions at the Semipalatinsk Test Site". AWRE Report No. 016/84 (Re-issue). HMSO London (1985)

9. P D Marshall, R C Lilwall, P Warburton: "Body Wave Magnitudes and Locations of French Underground Explosions at the Mururoa Test Site". AWRE Report No. 012/85, HMSO London (1985)

10. P D Marshall, R C Lilwall, Jean Farthing: "Body Wave Magnitudes and Locations of Underground Nuclear Explosions at the Nevada Test Site". AWRE Report No. 021/86, HMSO London (1986)

11. B Gutenberg, C F Richter: "Magnitude and Energy of Earthquakes". Annali Geofis., 9, 1-15 (1956)

12. A Douglas: "A Special Purpose Least Squares Programme". AWRE Report No. 054/66, HMSO London (1966)

13. L A Christoffersson, R T Lacoss, M A Chinnery: "Statistical Models for Magnitude Estimation". Lincoln Lab SATS, TR-75-335, 2-5 (1975)

14. H Jeffreys: "The Theory of Probability". 3rd Ed Oxford University Press (1961)

15. E J Kelly, R T Lacoss: "Estimation of Seismicity and Network Detection Capability". MIT Lincoln Lab, Tech Note 41 (1969)

16. R C Lilwall: "Redetermination of Body-Wave Magnitudes (m_b) for the Period 1964-81 using ISC Bulletin Data". AWRE Report No. 021/85, HMSO, London (1985)

17. R C Lilwall: "Some Simulation Studies of Seismic Magnitude Estimators". AWRE Report No. 022/86, HMSO, London (1986)

18. R W Hurley: "Anomalous Seismic Signals from Novaya Zemlya". AWRE Report No. 021/77, HMSO, London (1977)

NOTES ON TABLES AND FIGURES

TABLES

Table 1 List of explosion dates, origin times, calculated epicentres and magnitudes for explosions at Novaya Zemlya.

Table 2 Station magnitude terms, followed by standard confidence limits and number of observations.

Table 3 Mean 50% amplitude reporting thresholds (g) followed by standard deviation (γ) for amplitude data submitted to the ISC. Time periods (year followed by month) are intended to bracket overall intervals during which the thresholds are thought appropriate and are not intended to indicate station operation periods.

FIGURES

Figure 1 Location of epicentres of explosions at the north Novaya Zemlya test site, Matochkin Shar Strait. (Admiralty Chart No. 3035).

Figure 2 Location of epicentres of explosions at the south Novaya Zemlya test site, Kostin Shar Strait. (Admiralty Chart No. 3035).

TABLE 1

Estimated Location, Origin Time and Magnitude of Underground Explosions at the Novaya Zemlya Test Site

NOVAYA ZEMLYA (NORTH)

No	Date	JED Computed			Confidence Ellipse sq kms	m_b	σ	n(m)
		Origin Time	Latitude °N	Longitude °E				
1	18 Sep 64	07 59 57.8	73.336	55.391	32.8	4.20	0.08	5
2	25 Oct 64	07 59 58.1	73.386	54.997	4.7	4.82	0.08	6
3	27 Oct 66	05 57 58.1	73.388	54.845	1.9	6.47	0.03	38
4	21 Oct 67	04 59 58.5	73.385	54.826	2.1	5.99	0.03	45
5	7 Nov 68	10 02 05.5	73.388	54.873	1.8	6.11	0.02	54
6	14 Oct 69	07 00 06.6	73.389	54.796	1.9	6.18	0.03	51
7	14 Oct 70	05 59 57.6	73.301	55.044	1.6	6.77	0.03	49
8	27 Sep 71	05 59 55.8	73.393	54.923	1.7	6.63	0.02	54
9	28 Aug 72	05 59 56.9	73.386	54.859	1.7	6.46	0.02	62
10	12 Sep 73	06 59 54.8	73.316	55.059	1.5	6.96	0.03	38
11	29 Aug 74	09 59 56.2	73.395	54.920	1.6	6.54	0.02	55
12	23 Aug 75	08 59 58.3	73.332	54.694	1.6	6.55	0.02	69
13	21 Oct 75	11 59 58.0	73.308	55.012	1.5	6.59	0.02	65
14	29 Sep 76	02 59 57.7	73.360	54.880	Restrained	5.77	0.02	84
15	20 Oct 76	07 59 58.1	73.399	54.835	2.6	4.89	0.03	42
16	1 Sep 77	02 59 58.0	73.339	54.626	1.6	5.71	0.02	84
17	9 Oct 77	10 59 58.1	73.414	54.935	4.9	4.51	0.03	30
18	10 Aug 78	07 59 58.0	73.293	54.885	1.6	6.04	0.02	87
19	27 Sep 78	02 04 58.6	73.350	54.677	1.7	5.68	0.02	85
20	24 Sep 79	03 29 58.8	73.346	54.679	1.6	5.80	0.02	100
21	18 Oct 79	07 09 58.8	73.318	54.821	1.8	5.85	0.02	91
22*	11 Oct 80	07 09 57.5	73.335	54.938	1.7	5.80	0.02	80
23	1 Oct 81	12 14 57.3	73.308	54.817	1.8	5.91	0.02	97
24	11 Oct 82	07 14 58.7	73.348	54.601	2.1	5.52	0.02	89
25	18 Aug 83	16 09 58.9	73.358	55.974	2.0	5.84	0.02	91
26	25 Sep 83	13 09 58.2	73.326	54.564	2.0	5.71	0.02	104

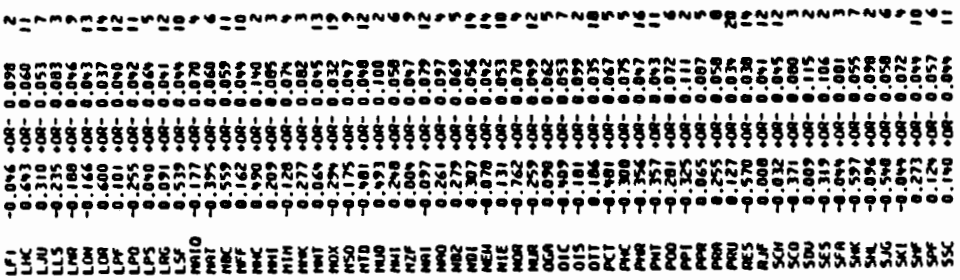
NOVAYA ZEMLYA (SOUTH)

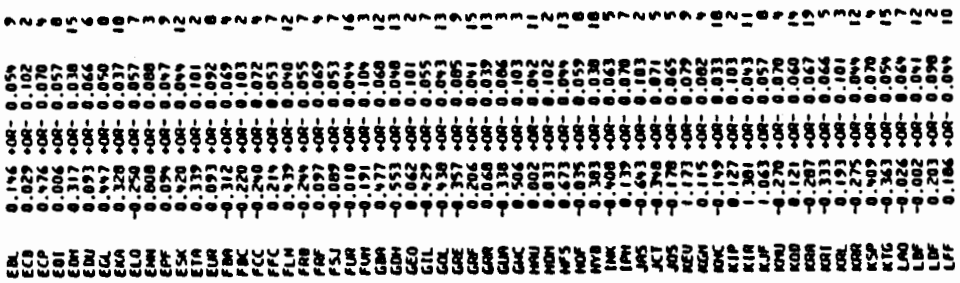
27	27 Sep 73	06 59 58.5	70.756	53.746	1.9	5.83	0.03	56
28	27 Oct 73	06 59 58.0	70.801	53.958	1.7	6.90	0.03	46
29	2 Nov 74	04 59 57.4	70.833	53.825	1.7	6.75	0.02	65
30*	18 Oct 75	08 59 56.8	70.838	53.673	1.6	6.70	0.02	62

* Double Explosions

TABLE 2(a)

Station Correction Terms, North Test Site





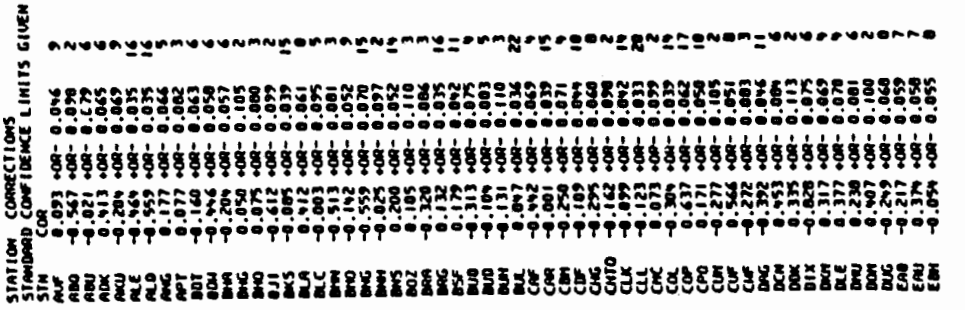


TABLE 2(b)

Station Corrections, Southern Test Site

STATION CORRECTIONS
STANDARD CONFIDENCE LIMITS GIVEN

STN	COR			
ABQ	-0.306	+OR-	0.097	2
ABU	-0.205	+OR-	0.140	2
ADK	0.211	+OR-	0.097	2
ALQ	-0.391	+OR-	0.099	2
ANG	0.435	+OR-	0.137	1
BHA	-0.398	+OR-	0.137	1
BKS	-0.022	+OR-	0.078	4
BLC	0.022	+OR-	0.137	1
BMO	0.365	+OR-	0.107	3
BNG	-0.960	+OR-	0.098	3
BNS	0.285	+OR-	0.093	4
BRA	-0.377	+OR-	0.098	2
BRG	0.338	+OR-	0.097	2
BUB	0.255	+OR-	0.137	1
BUD	-1.144	+OR-	0.100	2
BUL	0.043	+OR-	0.080	4
CAR	-0.147	+OR-	0.081	3
CLK	0.124	+OR-	0.080	3
CLL	0.241	+OR-	0.080	3
COP	0.473	+OR-	0.137	1
CPO	0.215	+OR-	0.079	3
CUM	-0.469	+OR-	0.087	3
DAG	-1.045	+OR-	0.137	1
DUG	0.042	+OR-	0.138	1
EAB	-0.021	+OR-	0.097	2
EAU	0.079	+OR-	0.098	2
EBM	0.029	+OR-	0.097	2
EBL	0.079	+OR-	0.098	2
EDI	0.029	+OR-	0.097	2
EDM	0.223	+OR-	0.079	3
EDU	0.202	+OR-	0.137	1
EGL	-0.021	+OR-	0.097	2
EKA	0.110	+OR-	0.080	3
ELO	0.102	+OR-	0.137	1
ESK	1.202	+OR-	0.137	2
FFC	0.323	+OR-	0.137	1
FSJ	-0.082	+OR-	0.141	1
FUR	-0.322	+OR-	0.099	2
GDH	-0.094	+OR-	0.080	4
GOL	-0.352	+OR-	0.080	3
GRE	-0.107	+OR-	0.085	3
GRF	0.473	+OR-	0.137	1
GRR	-0.138	+OR-	0.137	1
GUA	-0.539	+OR-	0.087	3
HFS	0.073	+OR-	0.137	2
HOF	0.674	+OR-	0.079	3
HYB	-0.274	+OR-	0.098	3
INK	-0.395	+OR-	0.137	1
JOS	-1.343	+OR-	0.154	1
KEV	1.273	+OR-	0.137	1
KHC	-0.192	+OR-	0.070	4
KJF	0.773	+OR-	0.137	1
KMU	-0.065	+OR-	0.098	2
KOD	0.270	+OR-	0.139	1
KRA	-0.300	+OR-	0.098	3
KRR	-0.368	+OR-	0.069	4
KTG	-0.511	+OR-	0.080	4
LAO	0.358	+OR-	0.106	3
LHC	0.192	+OR-	0.137	1
LJU	0.314	+OR-	0.097	2
LON	0.138	+OR-	0.105	2
LOR	0.612	+OR-	0.137	1
LPS	-0.183	+OR-	0.099	2
LRG	0.442	+OR-	0.137	1
MBC	-0.185	+OR-	0.137	1
MMT	0.039	+OR-	0.070	4
MOX	-0.068	+OR-	0.069	4
MSO	0.322	+OR-	0.137	2
MTD	-0.318	+OR-	0.071	4
MWI	0.355	+OR-	0.137	1
NAO	-0.662	+OR-	0.098	2
NDI	-0.777	+OR-	0.122	2
NEW	0.583	+OR-	0.137	2
NIE	-0.598	+OR-	0.137	1
OIC	-0.086	+OR-	0.099	3
OTT	-0.010	+OR-	0.082	4
PHC	0.116	+OR-	0.081	3
PNR	0.209	+OR-	0.084	3
PNT	-0.012	+OR-	0.097	2
POO	-0.083	+OR-	0.138	1
PRA	0.435	+OR-	0.113	2
PRU	-0.027	+OR-	0.137	1
RES	-0.252	+OR-	0.099	2
SCH	0.337	+OR-	0.099	2
SFA	-0.178	+OR-	0.121	2
SHK	-0.160	+OR-	0.097	3
SJG	0.309	+OR-	0.097	2
SKI	0.278	+OR-	0.097	2
SSC	0.012	+OR-	0.137	1
STU	0.442	+OR-	0.080	3
SVT	0.821	+OR-	0.098	3
TOL	0.028	+OR-	0.069	4
TRN	0.371	+OR-	0.069	4
TUC	0.073	+OR-	0.137	1
TUL	0.132	+OR-	0.070	4
UAV	0.204	+OR-	0.138	2
VAL	0.148	+OR-	0.070	4
VIE	-0.172	+OR-	0.104	2
YKC	-0.241	+OR-	0.097	2
BAG	0.463	+OR-	0.141	1
CIR	0.383	+OR-	0.103	3
KON	0.227	+OR-	0.137	1
SOP	-1.158	+OR-	0.142	1
VIC	0.315	+OR-	0.137	1

TABLE 3

Station Threshold Data as a Function of Time

STATION THRESHOLD DATA AS FUNCTION OF TIME

AVF	7701-7712	0.98	0.21	7801-8312	0.94	0.21						
ABQ	7401-7712	-.05	0.17									
ABU	6401-7712	2.20	0.30	7801-8312	2.24	0.20						
ADK	7001-7712	1.89	0.29									
AKU	7801-8312	1.49	0.19									
ALE	6401-6912	1.53	0.24	7001-7309	1.13	0.14	7310-7712	0.72	0.18	7801-8312	0.81	0.23
ALQ	6401-6912	0.68	0.22	7001-7312	1.02	0.19	7401-7712	0.93	0.23	7801-8312	0.37	0.14
ANG	6401-6912	2.22	0.10	7001-8112	2.41	0.25						
APT	7401-7712	1.50	0.30									
BDT	7801-7904	1.60	0.34	7905-8312	1.58	0.24						
BDW	7801-7902	0.71	0.25	7903-8312	0.65	0.26						
BHA	6401-6912	0.55	0.20	7001-7312	0.61	0.15	7401-7712	0.71	0.05			
BHG	8108-8312	1.88	0.24									
BHO	8105-8312	1.15	0.39									
BJI	7001-8112	1.24	0.19									
BKS	6401-6912	1.92	0.26	7001-7312	1.58	0.19	7401-7712	1.60	0.23	7801-8312	1.61	0.21
BLA	6401-7712	2.00	0.36	7801-8312	1.91	0.29						
BLC	6401-7012	1.90	0.12	7101-7405	2.00	0.26	7406-7706	1.20	0.26			
BMN	7801-8212	0.63	0.26									
BMO	6401-6912	0.04	0.17	7001-7312	0.08	0.17	7401-7712	0.16	0.22			
BNG	6401-7012	0.76	0.33	7001-7312	0.51	0.17	7401-7712	0.62	0.17	7801-8312	0.78	0.13
BNH	7001-8112	1.20	0.26									
BNS	6401-6912	1.62	0.19	7001-7312	1.63	0.25	7401-7712	1.63	0.25			
BOZ	6401-6912	0.93	0.22									
BRA	7001-8112	2.13	0.30									
BRG	7001-7312	0.88	0.13	7401-7712	0.89	0.13	7801-8312	0.94	0.09			
BSF	7401-7712	1.11	0.18	7801-8312	1.14	0.21						
BUB	7001-8112	1.58	0.19									
BUD	7401-7712	1.74	0.32	7801-8312	1.76	0.24						
BUH	6401-7012	1.57	0.26									
BUL	6401-6912	0.68	0.16	7001-7312	0.74	0.11	7401-7712	0.81	0.11	7801-8312	0.67	0.09
CAF	8101-8312	0.90	0.19									
CAR	6401-6912	1.50	0.16	7001-7312	1.54	0.11	7401-7712	1.65	0.16	7801-8312	1.69	0.18
CBM	7401-7712	1.31	0.26	7801-8312	1.26	0.26						
CDF	7401-7712	1.07	0.20	7801-8312	1.00	0.21						
CHG	6401-6712	0.75	0.19	7401-7712	0.69	0.19	7801-8312	1.09	0.17			
CHTO	8201-8312	0.73	0.21									
CLK	6401-6912	0.56	0.16	7001-7312	0.64	0.11	7401-7712	0.78	0.07	7801-8303	0.71	0.06
CLL	6401-6912	1.57	0.23	7001-7312	1.21	0.12	7401-7712	1.16	0.11	7801-8312	1.17	0.13
CMC	6401-6912	1.85	0.19									
COL	6401-6912	0.83	0.21	7001-7312	0.95	0.14	7401-7712	0.97	0.14	7801-8312	0.90	0.12
COP	6401-6912	1.89	0.13	7001-7312	1.81	0.18	7401-7712	1.91	0.18	7801-8312	1.90	0.18
CPO	6401-6912	0.49	0.21	7001-7312	0.75	0.15	7401-7712	0.71	0.16			
CUM	7001-8112	2.12	0.18									
CVF	7401-7712	1.47	0.25	7801-8312	1.43	0.30						
CWF	7001-8112	1.27	0.27									
DAG	7401-7712	0.97	0.20	7801-8312	0.94	0.17						

TABLE 3 (Continued)

Station Threshold Data as a Function of Time

STATION THRESHOLD DATA AS FUNCTION OF TIME

DCN	7801-7903	1.83	0.28	7904-8312	1.84	0.27									
DDK	7001-8006	1.68	0.18	8007-8312	1.71	0.21									
DIX	7401-8112	0.81	0.21												
DKM	7801-8112	1.72	0.21												
DLE	7801-8005	1.77	0.27	8006-8312	1.76	0.24									
DMU	7801-7903	1.78	0.27	7904-8312	1.80	0.28									
DOM	6401-6912	2.15	0.25												
DUG	6401-6810	0.31	0.22	6811-7312	0.98	0.30	7401-7712	1.12	0.26						
EAB	7401-7712	1.55	0.28	7801-8208	1.58	0.26									
EAU	7401-7712	1.55	0.28	7801-8209	1.69	0.27									
EBH	7401-7712	1.51	0.31	7801-8209	1.63	0.26									
EBL	7401-7712	1.38	0.27	7801-8209	1.56	0.28									
ECB	8102-8312	1.88	0.29												
ECP	7801-8005	2.57	0.52	8006-8312	2.06	0.36									
EDI	7401-7712	1.46	0.25	7801-8208	1.59	0.22									
EDM	6401-6912	1.80	0.20	7001-7312	1.59	0.12	7401-7712	1.69	0.15	7801-8312	1.69	0.14			
EDU	7001-8112	1.57	0.30												
EGL	7401-7712	1.42	0.28	7801-8112	1.59	0.27									
EKA	6401-6912	1.05	0.26	7001-7312	1.39	0.22	7401-8001	1.17	0.20	8002-8312	0.91	0.27			
ELO	7401-7712	1.53	0.30	7801-8209	1.58	0.27									
ENN	8201-8312	1.22	0.21												
EPF	7801-8312	1.11	0.25												
ESK	6401-6912	1.53	0.19	7401-7712	2.05	0.30	7801-8312	1.91	0.24						
ETA	8202-8312	2.11	0.36												
EUR	6401-6912	0.54	0.22	7001-7312	0.72	0.36	7401-7712	0.60	0.35	7801-8203	0.71	0.37	8301-8312	0.71	0.37
FBA	7801-7805	1.16	0.29	7806-8312	1.23	0.30									
FBC	6401-6912	1.65	0.11	7001-7312	1.76	0.14									
FCC	6401-6912	1.71	0.10	7001-7312	1.73	0.09	7401-7712	1.81	0.17	7801-8312	1.83	0.28			
FFC	7001-7309	1.60	0.07	7310-7712	0.99	0.26	7801-8312	1.07	0.25						
FLN	7401-7712	1.36	0.24	7801-8312	1.32	0.25									
FRB	7401-7712	1.82	0.19	7801-8312	1.81	0.16									
FRF	8107-8312	1.40	0.29												
FSJ	6401-6912	2.14	0.39	7001-7312	1.55	0.13	7401-8112	1.64	0.28						
FUR	6401-6912	1.52	0.42	7001-7312	1.54	0.31	7401-7908	1.41	0.25	7909-8012	2.10	0.25	8101-8312	1.84	0.24
FVM	7501-7505	1.00	0.20	7805-8112	2.20	0.20	8205-8312	1.29	0.24						
GBA	6401-6912	1.26	0.20	7401-7712	1.18	0.19	7801-7912	0.80	0.30	8001-8312	0.55	0.24			
GDH	6401-6912	1.67	0.25	7001-7312	1.43	0.34	7401-7712	1.49	0.36	7801-8312	1.49	0.27			
GEO	6401-6912	2.14	0.35												
GIL	6401-6912	0.88	0.23	7001-7312	0.89	0.25	7401-8112	1.11	0.28						
GOL	6401-6912	0.56	0.23	7001-7312	0.83	0.27	7401-7712	0.93	0.24	7801-8312	0.94	0.28			
GRE	6401-6912	1.76	0.24	7001-8112	1.95	0.24									
GRF	6901-7312	1.53	0.19	7401-7712	1.47	0.23	7801-8312	1.28	0.26						
GRR	7401-7712	1.33	0.22	7801-8312	1.31	0.24									
GUA	7001-7312	2.30	0.20	7401-7712	2.17	0.22	7801-8312	2.22	0.17						
GWC	6401-6912	1.81	0.11	7001-7312	2.00	0.19									
HAU	7401-7712	1.18	0.18	7801-8312	1.04	0.20									
HDM	7401-7712	1.34	0.27	7801-8112	1.54	0.32									

TABLE 3 (Continued)

Station Threshold Data as a Function of Time

STATION THRESHOLD DATA AS FUNCTION OF TIME

HFS	7001-7312	0.58	0.24	7401-7712	0.68	0.22	7801-8312	0.72	0.23			
HOF	7001-8012	2.07	0.30	8101-8312	1.79	0.25						
HYB	6401-6912	1.38	0.15	7001-7312	1.55	0.21	7401-7712	1.54	0.21	7801-8312	1.45	0.18
INK	6901-7312	1.58	0.12	7401-7712	1.53	0.10	7801-8312	1.55	0.12			
IPM	7801-7904	1.55	0.15	7905-8312	1.54	0.15						
JAS	6401-7012	1.70	0.32									
JCT	6401-7312	1.04	0.18	7401-7712	1.17	0.30	7801-8003	0.99	0.20	8004-8312	0.98	0.18
JOS	7001-7712	1.30	0.23	7801-8312	1.28	0.21						
KEV	6401-6912	1.22	0.16	7001-7312	1.26	0.14	7401-7712	1.18	0.13	7801-8312	1.21	0.12
KGM	7801-7904	2.18	0.17	7905-8312	2.20	0.20						
KHC	6401-6912	1.26	0.20	7001-7312	1.15	0.16	7401-7712	1.01	0.16	7801-8312	1.15	0.30
KIP	6401-6912	2.13	0.25									
KIR	7401-7712	1.81	0.11	7801-8312	1.85	0.11						
KJF	7001-7312	1.12	0.14	7401-7712	1.08	0.10	7801-8312	1.21	0.12			
KMU	7001-8112	1.88	0.14									
KOD	6401-6912	1.35	0.21	7001-7312	1.61	0.17	7401-7712	1.56	0.20	7801-8312	1.91	0.22
KRA	6401-6912	1.42	0.16	7001-7312	1.54	0.18	7401-7712	1.49	0.14	7801-3312	1.49	0.09
KRI	7801-7809	0.66	0.05	7810-8312	0.66	0.05						
KRL	6401-6912	2.37	0.22									
KRR	6401-6912	0.55	0.16	7001-7312	0.62	0.14	7401-7712	0.75	0.06			
KSP	8110-8312	1.43	0.11									
KTG	6401-6912	1.56	0.28	7001-7312	1.33	0.35	7401-7712	1.10	0.28	7801-8112	1.21	0.22
LAO	6401-6912	0.40	0.27	7001-7312	0.03	0.24	7401-7712	-.08	0.13			
LBF	7401-7712	0.91	0.19	7801-8312	0.95	0.23						
LDF	8209-8312	1.26	0.23									
LFF	7401-7712	1.27	0.20	7801-8312	1.28	0.23						
LFI	6401-7012	0.14	0.12									
LHC	7401-7712	1.79	0.08	7801-8312	1.96	0.16						
LJU	6401-6912	1.59	0.20	7001-7312	1.68	0.22	7401-8112	1.74	0.19			
LLS	8104-8312	1.55	0.28									
LMR	7401-7712	1.45	0.26	7801-8312	1.26	0.32						
LON	6401-6912	1.16	0.30	7001-7312	1.18	0.23	7401-8112	1.13	0.14			
LOR	7001-7312	1.46	0.40	7401-7712	1.01	0.21	7801-8312	0.92	0.22			
LPF	7401-7712	1.21	0.21	7801-8312	1.29	0.24						
LPO	7401-7712	1.26	0.22	7801-8312	1.18	0.24						
LPS	6401-6912	1.35	0.21	7001-7312	1.21	0.16	7401-7712	1.33	0.19	7801-8312	1.59	0.15
LRG	7401-7712	1.45	0.25	7801-8312	1.55	0.31						
LSF	7401-7712	1.22	0.21	7801-8312	1.13	0.23						
MAIO	7001-7712	1.10	0.17	7801-8011	1.04	0.15						
MAT	7401-7712	1.42	0.31	7801-8312	1.26	0.20						
MBC	6401-6912	1.30	0.18	7001-7309	1.43	0.14	7310-7712	0.70	0.22	7801-8312	0.66	0.25
MFF	7401-7712	1.23	0.19	7801-8312	1.26	0.27						
MHC	6401-6912	2.04	0.28									
MHI	8110-8312	1.89	0.21									
MIM	7401-8112	1.26	0.26									
MMK	8201-8312	1.53	0.25									
MNT	7001-7312	1.81	0.17	7401-7712	1.91	0.21	7801-8312	1.71	0.19			

TABLE 3 (Continued)

Station Threshold Data as a Function of Time

STATION THRESHOLD DATA AS FUNCTION OF TIME

MOX	6401-6912	1.21	0.20	7001-7312	1.03	0.13	7401-7712	1.08	0.13	7801-8312	1.22	0.13			
MSO	7001-8112	1.15	0.32												
MTD	7001-7312	0.71	0.10	7401-7712	0.84	0.09	7801-8312	0.66	0.05						
MUD	8208-8312	1.53	0.3;												
MWI	6401-7612	2.05	0.12												
MZF	7001-7712	0.90	0.25	7801-8312	1.01	0.21									
NAI	6401-6912	1.50	0.25	7001-7312	0.91	0.05	7401-7712	1.43	0.19	7801-8312	1.45	0.18			
NAO	7001-7312	0.16	0.22	7401-7712	0.17	0.28	7801-8312	0.42	0.31						
NB2	7801-8312	0.21	0.26												
NDI	6401-6912	1.65	0.24	7001-7312	1.88	0.28	7401-7712	1.79	0.24	7801-8312	1.83	0.31			
NEW	6401-6912	1.28	0.21	7001-7312	1.17	0.21	7401-7712	1.43	0.31	7801-8312	1.44	0.34			
NIE	6401-6912	1.20	0.19	7001-7312	1.04	0.14	7401-7712	0.97	0.05	7801-8312	1.20	0.10			
NOR	6401-6912	1.02	0.19	7001-7312	0.88	0.16									
NUR	6401-6912	1.19	0.18	7001-7312	1.26	0.15	7401-7712	1.11	0.11	8001-8312	1.18	0.12			
OGA	8010-8312	1.52	0.24												
OIC	7001-7312	1.29	0.24	7401-8112	1.67	0.33									
OIS	6401-6912	1.67	0.34	7001-7312	1.70	0.27									
OTT	6701-7309	2.10	0.16	7310-7712	1.39	0.16	7801-8312	1.46	0.19						
PCT	7801-8312	1.40	0.29												
PHC	7001-8112	2.50	0.32												
PMR	6401-6912	1.04	0.22	7001-7312	1.06	0.26	7401-7712	1.22	0.34	7801-8112	1.15	0.28	8201-8312	1.46	0.33
PNT	7001-7309	1.40	0.12	7310-7712	1.19	0.17	7801-8312	1.21	0.16						
POO	6401-6712	1.33	0.20	6801-7312	1.56	0.20	7401-7712	1.61	0.19	7801-8312	1.63	0.18			
PPI	7801-8312	1.63	0.18												
PPR	7907-8312	1.80	0.20												
PRA	6401-7112	2.36	0.21	7201-7312	1.54	0.12	7401-7712	1.52	0.09	7801-8312	1.57	0.18			
PRU	6401-6912	1.24	0.14	7001-7312	1.27	0.12	7401-7712	1.39	0.21	7801-8312	1.40	0.20			
RES	6401-6912	1.50	0.15	7001-7309	1.54	0.15	7310-7712	0.72	0.18	7801-8112	0.68	0.12			
RJF	7401-7712	1.28	0.24	7801-8312	1.08	0.21									
SCH	7001-7312	1.93	0.17	7401-7712	1.92	0.21	7801-8312	1.61	0.26						
SCO	8208-8312	1.35	0.35												
SDV	7801-8312	1.81	0.16												
SES	6701-7312	1.65	0.16	7401-7712	1.75	0.15	7801-8312	1.82	0.18						
SFA	6701-7312	2.12	0.13	7401-7712	2.09	0.22									
SHK	6401-6912	1.63	0.26	7001-7312	1.78	0.22	7401-7712	1.88	0.17	7801-8112	2.04	0.16			
SHL	6401-6708	1.22	0.23	6709-6912	1.50	0.17	7001-7312	1.75	0.11						
SJG	6401-6912	1.43	0.26	7001-7712	1.56	0.22	7801-8312	1.56	0.21						
SKI	7001-8112	2.27	0.22												
SMF	7401-7712	0.99	0.21	7801-8312	1.02	0.22									
SPF	7401-8112	1.39	0.24												
SSC	7401-7712	1.31	0.25	7801-8312	1.25	0.22									
SSE	7001-7910	1.54	0.27	7911-8312	1.67	0.29									
SSF	7401-7712	0.93	0.18	7801-8312	0.96	0.22									
STJ	7001-8112	2.33	0.24												
STU	6401-6912	1.68	0.28	7001-7312	1.86	0.22	7401-7712	1.82	0.22						
SUD	6401-7012	1.97	0.16												
SUF	8101-8312	0.66	0.15												

TABLE 3 (Continued)

Station Threshold Data as a Function of Time

STATION THRESHOLD DATA AS FUNCTION OF TIME

SVT	*****	6401-6912	1.72	0.14	7001-8112	2.23	0.17						
TAN	*****	6901-7312	2.05	0.19									
TCF	*****	7401-7712	0.97	0.20	7801-8312	1.01	0.24						
TFO	*****	6401-6912	-.01	0.20									
TMA	*****	8206-8312	1.64	0.24									
TMT	*****	7001-8112	1.42	0.26									
TOL	*****	7001-8112	2.00	0.33									
TRN	*****	6401-6912	1.55	0.19	7001-7312	1.56	0.15	7401-7712	1.57	0.15	7801-8112	1.67	0.18
TRT	*****	7801-8312	1.94	0.21									
TSK	*****	6401-6912	1.48	0.35	7001-8112	1.38	0.27						
TUC	*****	6401-6912	1.06	0.20	7001-7312	1.16	0.13	7401-7712	1.11	0.26			
TUL	*****	6907-7312	1.24	0.30	7401-7712	1.09	0.27	7801-8312	1.11	0.26			
UAV	*****	7001-8112	2.08	0.21									
UBO	*****	6401-6912	0.17	0.20	7001-7312	0.31	0.29						
UCT	*****	7401-7712	1.35	0.26	7801-8112	1.42	0.23						
UPP	*****	7604-7712	1.83	0.11	7801-8312	1.82	0.09						
VAL	*****	6401-6912	2.30	0.29	7001-7312	2.17	0.28	7401-7712	2.07	0.23	7801-8312	2.09	0.29
VIE	*****	7001-7312	2.17	0.19	7401-7712	2.09	0.31						
WES	*****	7001-8112	2.54	0.37									
WET	*****	8010-8312	1.45	0.22									
WMO	*****	6401-6912	0.23	0.14									
WOL	*****	7001-8112	1.53	0.17									
WTS	*****	8101-8312	1.31	0.23									
YKC	*****	6901-7309	1.75	0.15	7310-7712	1.15	0.20	7801-8312	1.13	0.19			

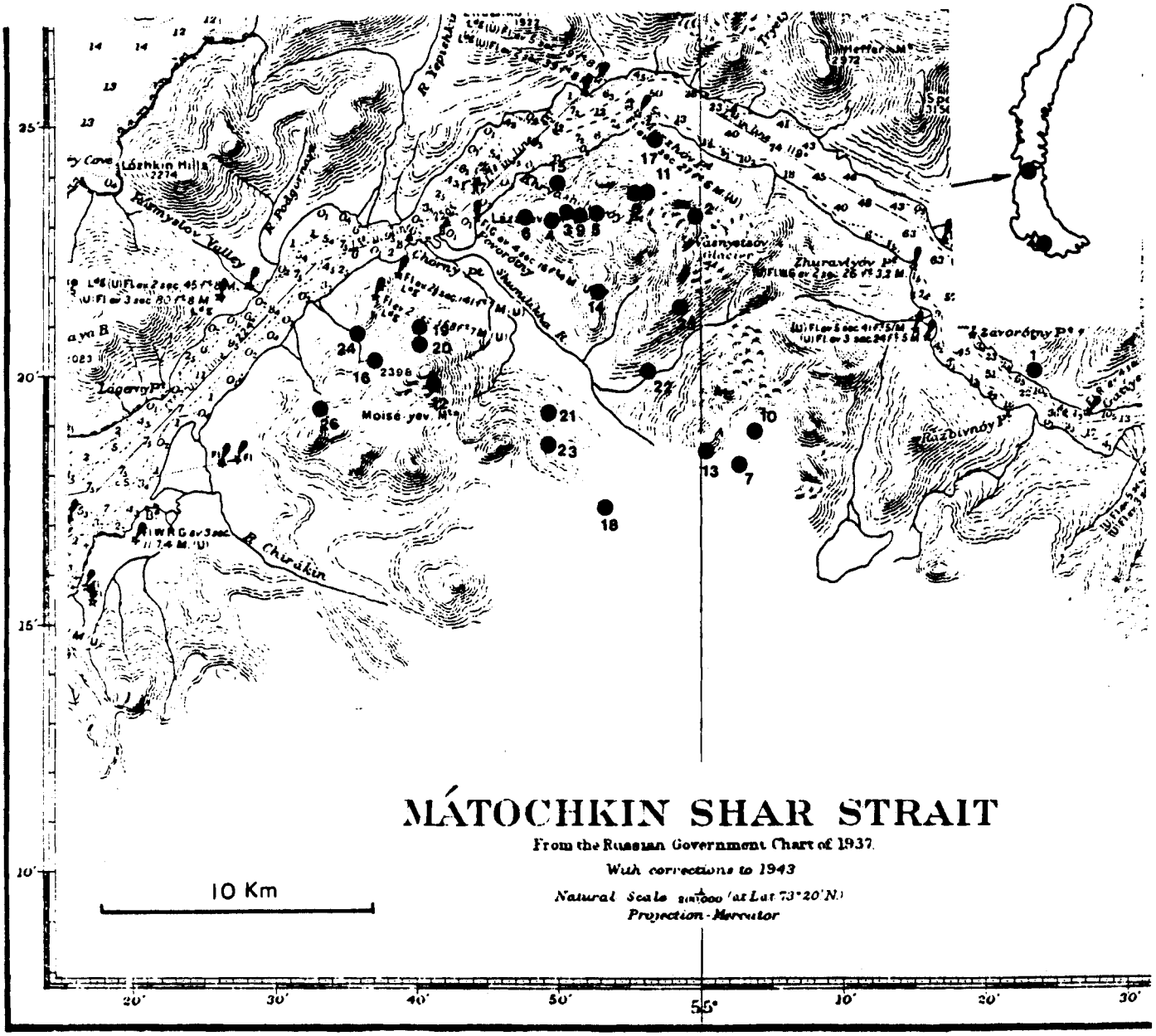


FIGURE 1. EPICENTRE LOCATION AT THE NORTHERN TEST SITE

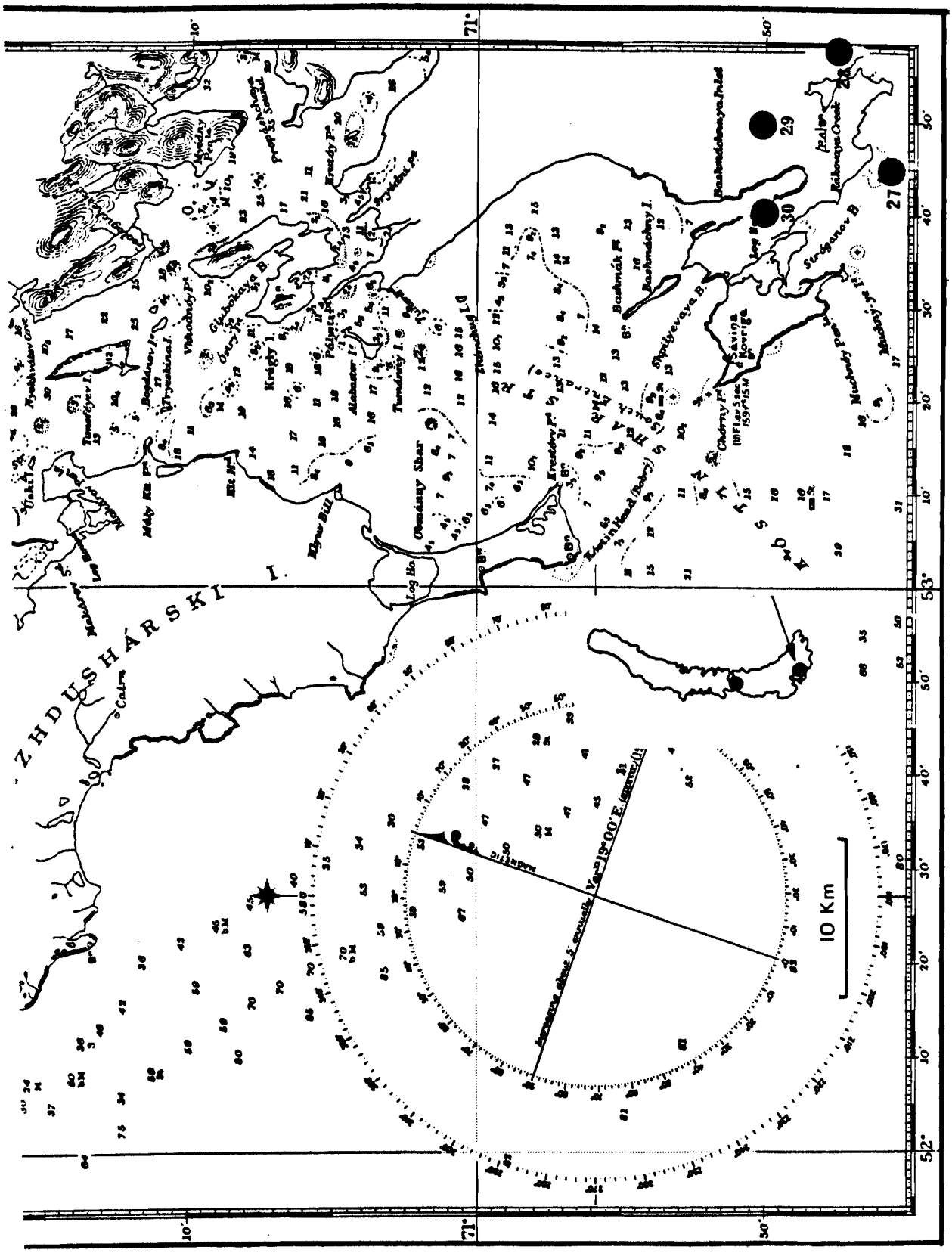


FIGURE 2. EPICENTRE LOCATIONS AT THE SOUTHERN TEST SITE

DOCUMENT CONTROL SHEET

Overall security classification of sheet ..... Unclassified .....

(As far as possible this sheet should contain only unclassified information. If it is necessary to enter classified information, the box concerned must be marked to indicate the classification eg (R), (C) or (S)).

1. DRIC Reference (if known)	2. Originator's Reference	3. Agency Reference	4. Report Security Classification
-	AWRE Report No. 017/86	-	UK UNLIMITED

5. Originator's Code (if known)	6. Originator (Corporate Author) Name and Location
?	Atomic Weapons Research Establishment, Aldermaston

5a. Sponsoring Agency's Code (if known)	6a. Sponsoring Agency (Contract Authority) Name and Location
-	-

7. Title

Body Wave Magnitudes and Locations of Soviet Underground Explosions at the Novaya Zemlya Test Site

7a. Title in Foreign Language (in the case of Translation)

-

7b. Presented at (for Conference Papers). Title, Place and Date of Conference

-

8. Author 1.Surname, Initials	9a. Author 2	9b. Authors 3, 4	10. Date	pp	ref
Lilwall, R C	Marshall, P D	-	November 1986	20	18

11. Contract Number	12. Period	13. Project	14. Other References
-	-	-	-

15. Distribution Statement

See front cover

16. Descriptors (or Keywords) (TEST)

SEISMIC WAVES NUCLEAR EXPLOSIONS
UNDERGROUND EXPLOSIONS

Abstract

At their underground nuclear test site at Novaya Zemlya the USSR detonates explosions in two areas, here designated the north and south Novaya Zemlya test sites. A least squares joint epicentre estimate of origin time and epicentre together with a maximum-likelihood estimate of magnitude are presented for explosions in each of these test sites. These are based on data taken from the bulletins of the International Seismological Centre.