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COMMENTS ON THE APPLICABILITY OF ROOM-TEMPERATURE ASTATIC GRAVITY METERS TO SECULAR GRAVITY MONITORING.

by

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ABSTRACT

Drift characteristics, pressure dependence, temperature effects, and vibration effects were observed for three astatic room-temperature gravity meters. The results suggest that none of these meters are suitable for long term registration of non-tidal gravity but may be useful as earth-tide meters for determining tidal constituents.

INTRODUCTION AND BACKGROUND

In 1983 the Earth Physics Branch commenced a program to modify its existing North American and some LaCoste and Romberg gravity meters to fed-back recording instruments. The electrostatic method was chosen to implement the feedback. This work led to two papers: one describing the natural limitation to the dynamic range, approximately 3 mGal, (Hugill and Valliant, JGR, in Press) and one describing a new approach to electrostatic feedback using pulse-width-modulation (PWM) (Valliant, et al., in prep.) instead of amplitude modulation. Extensive testing directed towards establishing the linearity and stability of the PWM system was undertaken as part of this program. Ancillary information was also derived from these tests relating to the short and medium term stability of the gravity meters themselves. The purpose of this report is to summarize these ancillary data and to discuss the potential of these meters for secular gravity monitoring and the need for additional testing. Two gravity meters, G-444 and NA-137 were tested. ET-12, an unmodified LaCoste and Romberg earth-tide meter, provided control data for the tests. The testing spanned the three year interval from 1983 to 1985. All three meters were operated concurrently on the pier in room 8, building number 3 of the Earth Physics Branch. Early tests during 1983 were concerned with developing the PWM system and testing modifications to NA-137. Testing of G-444 was begun in 1985 after it was established that the PWM system functioned properly with NA-137. Sufficient testing of the electronics was carried out to be confident that the effects reported below are not electronic in nature.

METHODOLOGY

The study was done by fitting 10 to 14 day segments of the observations to theoretical earth-tide values by least-squares according to the following model:

$$e = k_0 + k_1 S + k_2 P + k_3 t - g_t$$

where:

g_t = theoretical gravity (Longman, 1959)
S = output signal (duty-cycle)
P = atmospheric pressure
t = time
e = residual error to be minimized

and

k_n = coefficients to be determined (n = 0 to 3).

SCALE FACTOR STABILITY

Valliant et al. (in prep) show that the standard deviations of the scale factor (K_1) determinations were 0.7%, 0.8%, and 2.0% of the mean value for G-444, ET-12, and NA-137 respectively. The conclusion was that there was little difference between G-444 and ET-12, but that NA-137 exhibited poor behaviour despite having to relocated the force rebalance plate to improve the internal geometry of the instrument. It was suggested that much of the scatter for NA-137 was due to its non-linear drift characteristics, to be discussed later, which contravened the above mathematical model.

Repeated calibrations of G-444 against its dial lead to a standard deviation of only .25% of the mean value. We therefore believe that this figure is representative of the stability of the G meter system and that 0.8% represents a base value for the accuracy of the least-squares approach. We therefore ascribe any excess over 0.8% to deficiencies in the instrument itself. This suggests that the stability of NA-137 is much less than for the LaCoste and Romberg meters.

PRESSURE DEPENDENCE

Table 1 lists the values of K_2 for all the tests. The changing mass of the atmosphere with pressure changes has a known effect on gravity which is nominally -0.31 µGal/mbar (IAG resolution, 1983). Note that the correction to observed gravity K_2 will have the opposite sign. Although these results are scattered, there is a tendency for the pressure coefficient to be near the correct value for G-444 and ET-12. This is not apparent for NA-137 however which only rarely has even the correct sign. We recognize that, especially for shorter segments, pressure and earth-tides and pressure and gravity meter drift may accidently correlate leading to erroneous results. Also lack of structure in the pressure variation during a test would produce erroneous results. Such factors can cause the observed scatter. Nevertheless we are led to believe that G-444 and ET-12 exhibit small if not negligible instrumental pressure effects whereas NA-137 has a pressure dependency which would probably render it unsuitable for studying non-tidal secular gravity effects.

Longer segments of the data from ET-12 could be analyzed because this meter was not deliberately reset to different portions of its operating range. The data were sub-sampled at an hourly rate and analyzed in three segments of 36, 44, and 23 days. The results, tabulated in Tables 1 and

2 as segments A, B, and C respectively, show that A and C exhibited very small values of k_2 whereas B produced nearly the correct value. It appears that even with these longer samples cross-correlated effects, probably the meter drift and pressure change, still interfere with the solutions for pressure.

An attempt was made to monitor the internal pressure in NA-137 by connecting a Bell and Howell digital barometer to the interior of the gravity meter case. The results indicated that the amplitude of internal and external pressure variations were the same but that the internal pressure change lagged the external by approximately 200 min. As weather data from the Ottawa Airport were used for external pressure the 6 km separation between the airport and the meter could readily account for the time lag. As the pressure variations were superimposed on a steady state pressure differential, we conclude that the gravity meter case was not leaking, and that the pressure transfer was due to distortion of the case, probably the plastic cover. One deficiency of this test was that a flexible, albeit thick walled, rubber hose was used to connect the barometer to the case. There is a slight possibility that the observed pressure variations were due to compression of the hose.

The results of these data indicate that none of these meters should be applied to monitoring non-tidal secular gravity variations without a thorough and well designed study of instrumental pressure effects.
A study should at least be carried out in conjunction with establishing ET-12 at the Canadian Absolute Gravity Site (CAGS). Such a study would at best be tedious and time consuming and may in the end be inconclusive because other large instrumental errors, such as drift, may tend to mask the pressure effects. Direct testing by deliberately modulating ambient pressure could determine, however, if the instrument had serious pressure related errors.

DRIFT CHARACTERISTICS

Table 2 lists the values of k_3 for all the tests. Here there are a great variety of drift rates and directions probably superimposed on a long-term linear drift which is not evident in the 10 to 14 day samples. These trends are not artifacts of the reduction procedure because they are visually obvious in the data. An extreme case is shown in Fig 1 which is a plot of the long-term drift for meter G-7 which has been operating, without feedback, in Building No 1. since 1978. In this case there appears to be a 1.5 mGal peak-to-peak annual cycle superimposed on a long-term linear drift. At present we have no explanation for the periodic term and testing is currently in progress to isolate the cause of this effect. Although it is expected that this behaviour is related to instrument malfunction, Figure 1 serves to illustrate that very long periods of continuous observations are needed to reveal these type of effects. Such testing is an absolute necessity at least to reject poor performers such as G-7. Indeed G-7 may not be a poorly performing gravity meter as site dependent effects have not yet been ruled out.

Not only are these short term trends very chaotic, but they are not always very linear. Fig 2 is an example of non-liner drift characteristics for both G-444 and NA-137 over approximately 2 week intervals. Even if a long-term trend can be modeled, the amplitude of the chaotic trends is such as to render all of these instruments unsuitable for non-tidal secular gravity measurements.

TEMPERATURE EFFECTS

There are few temperature data available. Initially, room temperature recording was not available, and when it was established it was in conjunction with setting up a room temperature control. Consequently what little room temperature data we have come from an epoch when the room temperature was stable. We measured no temperature related effects but this question is still very much open.

MECHANICAL EFFECTS

The gravity meter beam output also gives some indication of the mechanical behaviour of the gravity meter. For the instruments equipped with the PWM system it is possible to separate and independently record the beam position and the feedback voltage. We note that NA-137 responds to noise (ie. traffic, slamming doors and etc.) with a pulse generally in the same direction whereas G-444's response is much more symmetrical. The reason may lie in the gravity meter's response to vibration. The anomalous behaviour can probably be explained on the basis of transverse vibration of either the main-spring or the ligatures with more noise being coupled to the earth-tide signal in the case of NA-137 than for G-444. Fig 3a shows a sample record from NA-137 illustrating the unidirectional spikes associated with noise. Figs 3b and 3c shows the response of NA-137 and G-444 to the same small seismic events. It is noted that the beam position signal is more uniform and symmetrical for G-444 and the amplitude of the recorded background noise is often seen to correlate with local and distant microseismic activities. The background noise recorded by NA-137 appears more like a random stagger which is not correlated with seismicity. No large earthquakes were successfully recorded with G-444 because the beam would stick to the stops during large excursions and had to be released, when discovered sometime after the event, by tapping the meter. All other considerations being equal it would not be hard to choose from these records which meter one would prefer to employ for earth tide recording.

CONCLUSIONS AND RECOMMENDATIONS

It should be emphasized that these data are a spin-off from a study intended for another purpose and although are suggestive of certain problems they should not be construed as conclusive. They however do suggest areas where additional testing is needed and lead to the following recommendations:

1) It is doubtful if any of the meters tested are satisfactory for non-tidal secular gravity measurements. Certainly much more testing, especially for temperature and pressure effects, needs to be done before even ET-12 could be considered as a useful instrument for this purpose.

2) Both ET-12 and the converted G-444 (and presumably any other ET, G,

or D meter) appear to be adequate to determine tidal constituents for Absolute Gravity sites. Although NA-137 yielded satisfactory gravimetric factors (Valliant et al., in press), its generally poorer performance makes the North American gravity meter a second choice for this application. Remember also that before the North American meters can be used the pressure transfer through its case must be corrected, and a new force rebalance plate installed. Also these meters require a high-voltage feedback system.

3) Either a cryogenic gravity meter and/or the development of a drift-free instrument of some other type should be considered for long term comparisons with the Absolute Gravity Meter at the permanent Absolute Gravity sites to be established in the Ottawa (CAGS) and Yellowknife regions.

REFERENCES

Hugill A. L. and H. D. Valliant, Limitations to the application of electrostatic feedback in gravity meters, JGR, in Press (1985).

Valliant, H. D., C. Gagnon, and J. F. Halpenny, An inherently linear electrostatic feedback method for gravity meters, In Prep (1985).

CAPTIONS

Fig 1. Long term drift for meter G-7.

Fig 2. Example of non-linear drift for meter G-444 and NA-137. Plots of residuals after removal of linear trend by least squares.

Fig 3. Selected portions of analog recordings:

a) An example of a swarm of unidirectional noise pulses recorded by NA-137

b) An example of three types of seismic events recorded on both NA-137 and G-444
(A) Noise recorded by NA-137 but not observed by G-444.
(B) Small microseism clearly defined by G-444 but only marginally detectible in NA-137 trace.
(C) Cluster of large noise spikes recorded on NA-137 resulting in a very large spike in the earth tide trace for NA-137 and a much smaller response from G-444.

c) An example of three small earthquakes recorded on both NA-137 and G-444. Note also the variation in the amplitude of background noise between events recorded on G-444 but not on NA-137

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TABLE 1

PRESSURE DEPENDENCE (K2)

(μGal/mbar)

Yr:dd	Number of 10 minute samples	ET-12	NA-137 Old plate	NA-137 New plate	G-444
83:340	3016	+0.12±.01	-1.5±.00		
84:11	2714	-0.36±.02	+0.8±.01		
84:32	3551		-1.3±.02		
84:33	2410	+0.47±.01	-1.1±.02		
84:272	1593	+0.34±.01	-1.2±.02		
84:285	1287	+0.53±.03	-0.2±.03		
84:293	2895	+0.17±.01	-0.91±.02		
85:08[1]	1815		-0.55±.01		
85:25[2]	2427		-0.44±.02		
85:190	1425	-0.44±.02	-0.12±.02		
85:200	1822	+0.21±.02	-0.05±.02		
85:158	1959	+0.38±.02		+0.07±.03	
85:172	1605	+0.37±.02		+0.30±.06	
85:214	1680	-0.88±.04		-0.01±.02	
85:226	1860			+0.87±.16	
85:239	1860			-0.59±.07	
85:252	1420			+1.04±.03	
85:263	1713			-0.76±.01	
85:294	1428			-0.35±.01	
85:148	1863	+0.08±.01			+0.06±.01
85:161	1977	+0.18±.02			+0.33±.01
85:193	1404	-0.19±.02			+0.35±.01
85:203	2101	-0.04±.02			+0.01±.02
85:218	1985	-0.66±.04			-0.16±.03
85:232	1968				+0.01±.00
85:246	1298				+0.42±.01
85:283	1542				+0.34±.01
85:294	1428				+0.33±.01
SEG A	820 [3]	-0.14±.04			
SEG B	1031[3]	+0.39±.05			
SEG C	575 [3]	+0.06±.08			

1 Located 2rd floor anti-room building #3

2 Located room 118, ground floor, building #3

3 Hourly samples

TABLE 2

LINEAR DRIFT COEFFICIENT (K3)

(μGal/day)

Yr:dd	Number of 10 minute samples	ET-12	NA-137 Old plate	NA-137 New plate	G-444
83:340	3016	+9.1±.27	-2.4±.04		
84:11	2714	-8.1±.04	-1.7±.02		
84:32	3551		+2.1±.01		
84:33	2410	+1.7±.02	-2.7±.04		
84:272	1593	-13.2±.03	-4.8±.05		
84:285	1287	-0.5±.05	+3.3±.05		
84:293	2895	+9.4±.03	-2.6±.03		
84:08[1]	1815		-1.8±.04		
84:25[2]	2427		+3.0±.03		
85:190	1425	-1.3±.04	-3.0±.04		
85:200	1822	-1.2±.04	-0.7±.04		
85:58	1959	-3.5±.02		-0.1±.04	
85:72	1605	-3.1±.03		-2.5±.07	
85:214	1680	-3.9±.04		-0.8±.02	
85:226	1860			-3.6±.11	
85:239	1860			-0.7±.08	
85:252	1420			-4.6±.06	
85:263	1713			+0.7±.02	
85:294	1428			+1.3±.02	
85:148	1863	-1.4±.02			-4.7±.02
85:161	1977	-3.8±.02			-6.0±.01
85:198	1404	-4.3±.04			-3.2±.03
85:203	2101	-0.3±.03			+2.3±.03
85:218	1985	-2.7±.04			-1.0±.02
85:232	1968				+4.7±.04
85:246	1298				+3.4±.02
85:283	1542				+4.2±.03
85:294	1428				+3.2±.02
SEG A	820 [3]	-2.9±.03			
SEG B	1031[3]	-2.0±.02			
SEG C	575 [3]	-1.0±.05			

1 Located 2rd floor anti-room building #3
2 Located room 118, ground floor, building #3
3 Hourly samples

FIGURE 1

LONG TERM DRIFT FOR METER G-7.

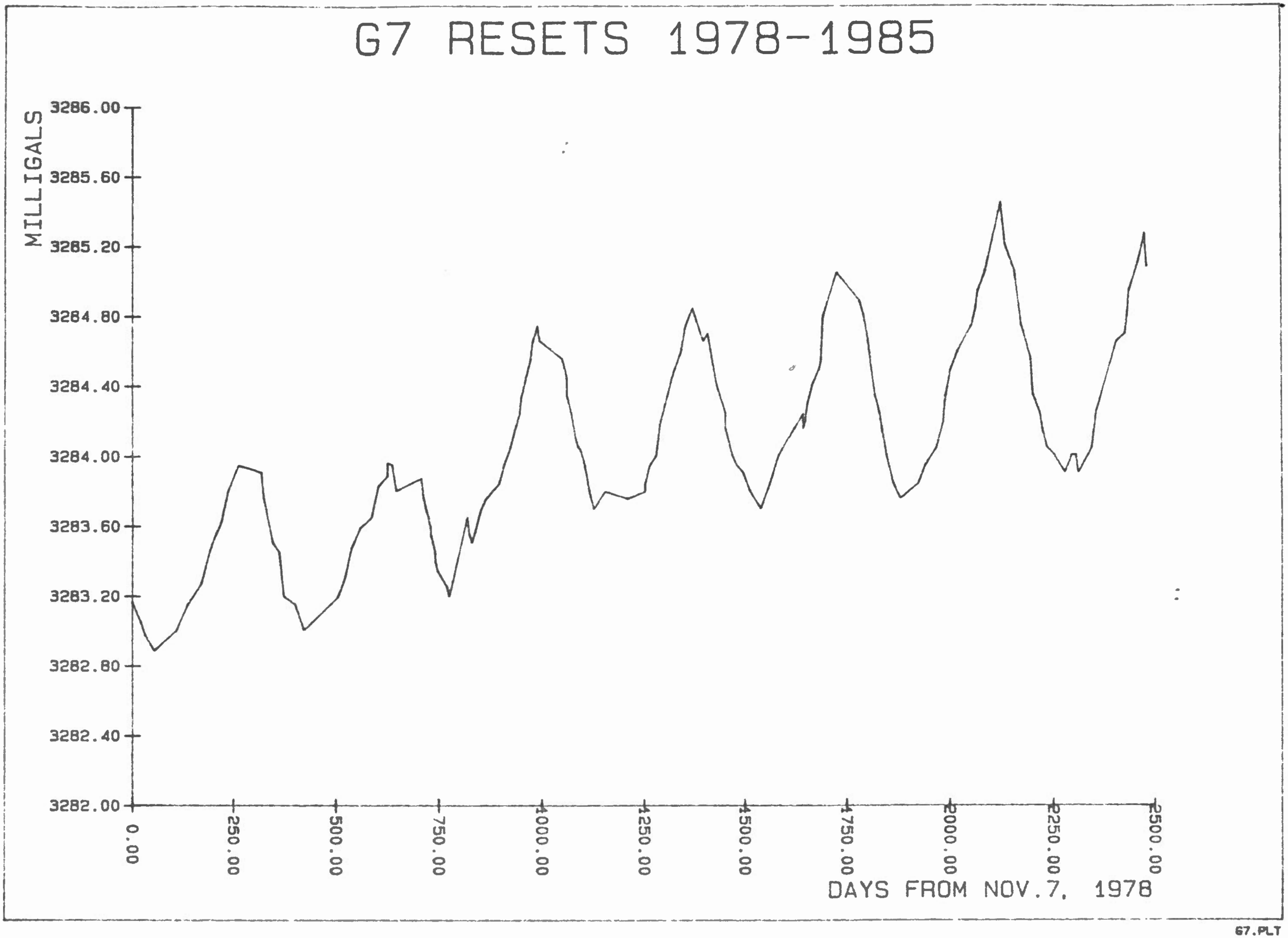
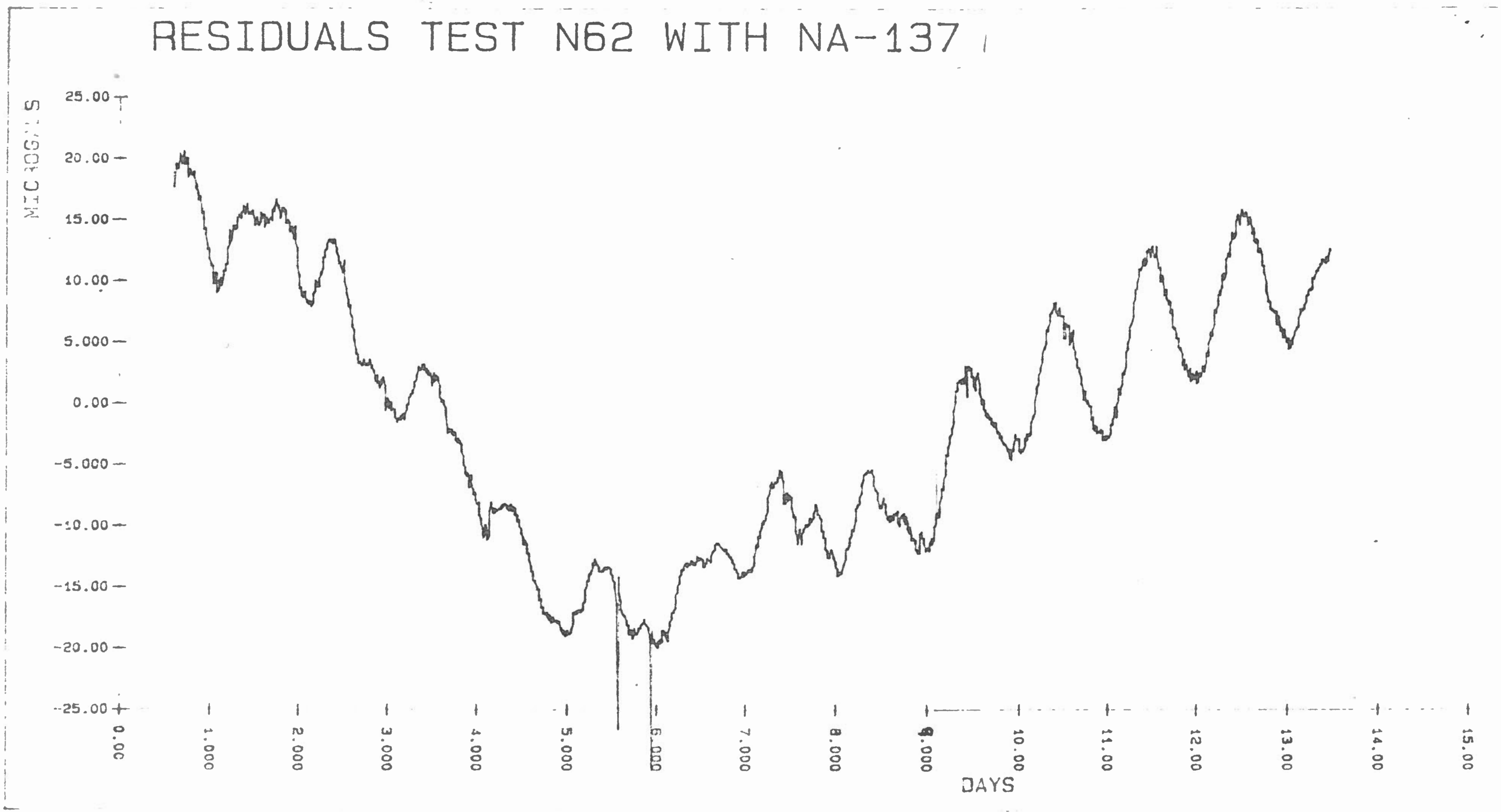

G7 RESETS 1978-1985
MILLIGALS
3286.00
3285.60
3285.20
3284.80
3284.40
3284.00
3283.60
3283.20
3282.80
3282.40
3282.00
0.00
250.00
500.00
750.00
1000.00
1250.00
1500.00
1750.00
2000.00
2250.00
2500.00
DAYS FROM NOV.7, 1978
G7.PLT

FIGURE 2

EXAMPLE OF NON-LINEAR DRIFT FOR METER G-444 AND NA-137. PLOTS OF RESIDUALS AFTER REMOVAL OF LINEAR TREND BY LEAST SQUARES.



RESIDUALS TEST N62 WITH NA-137
MICROGALS
25.00
20.00
15.00
10.00
5.000
0.00
-5.000
-10.00
-15.00
-20.00
-25.00
0.00
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.00
11.00
12.00
13.00
14.00
15.00
DAYS

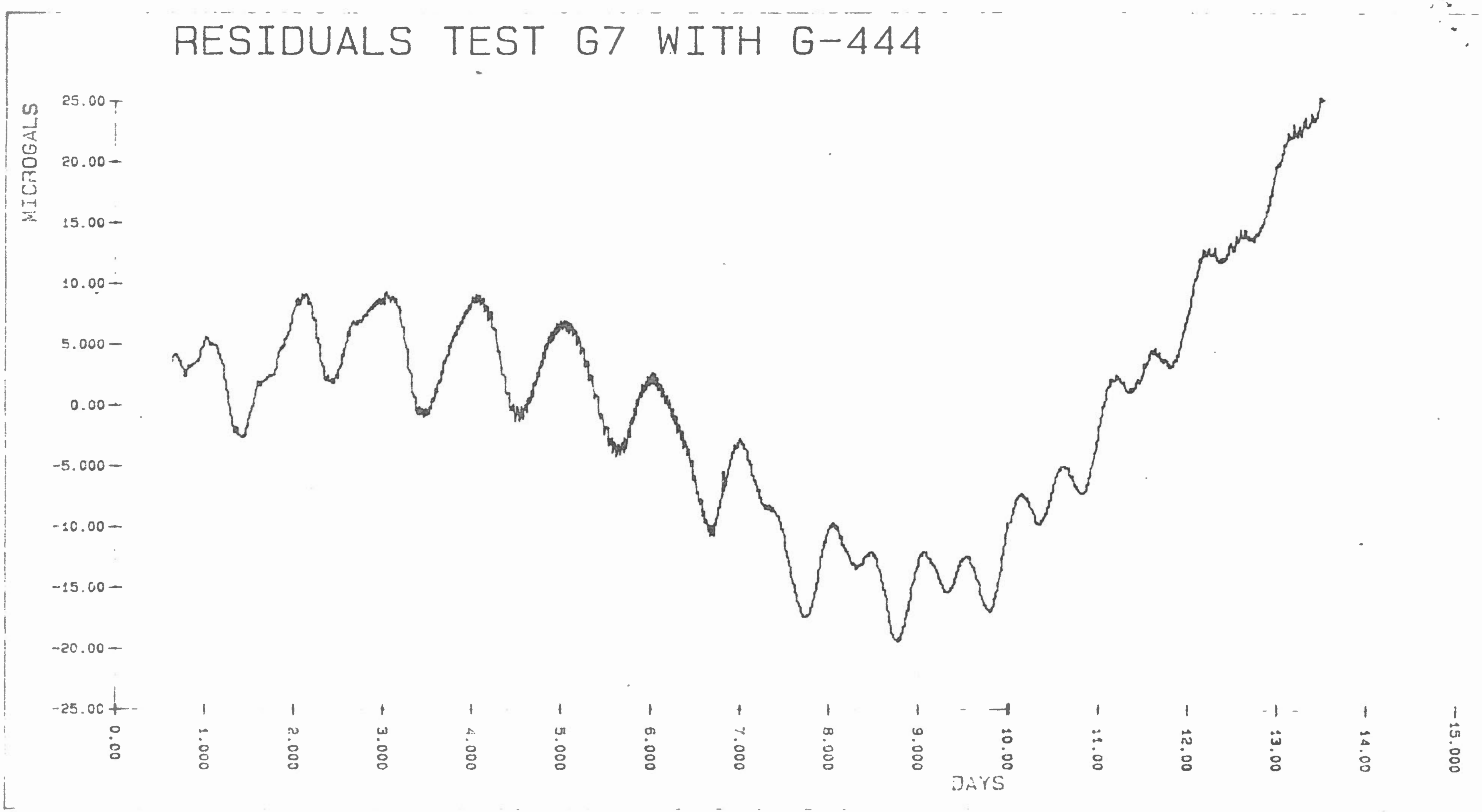

RESIDUALS TEST G7 WITH G-444
MICROGALS
25.00
20.00
15.00
10.00
5.000
0.00
-5.000
-10.00
-15.00
-20.00
-25.00
0.00
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.00
11.00
12.00
13.00
14.00
15.000
DAYS

FIGURE 3a

SELECTED PORTIONS OF ANALOG RECORDINGS:

An example of a swarm of unidirectional noise pulses recorded by NA-137

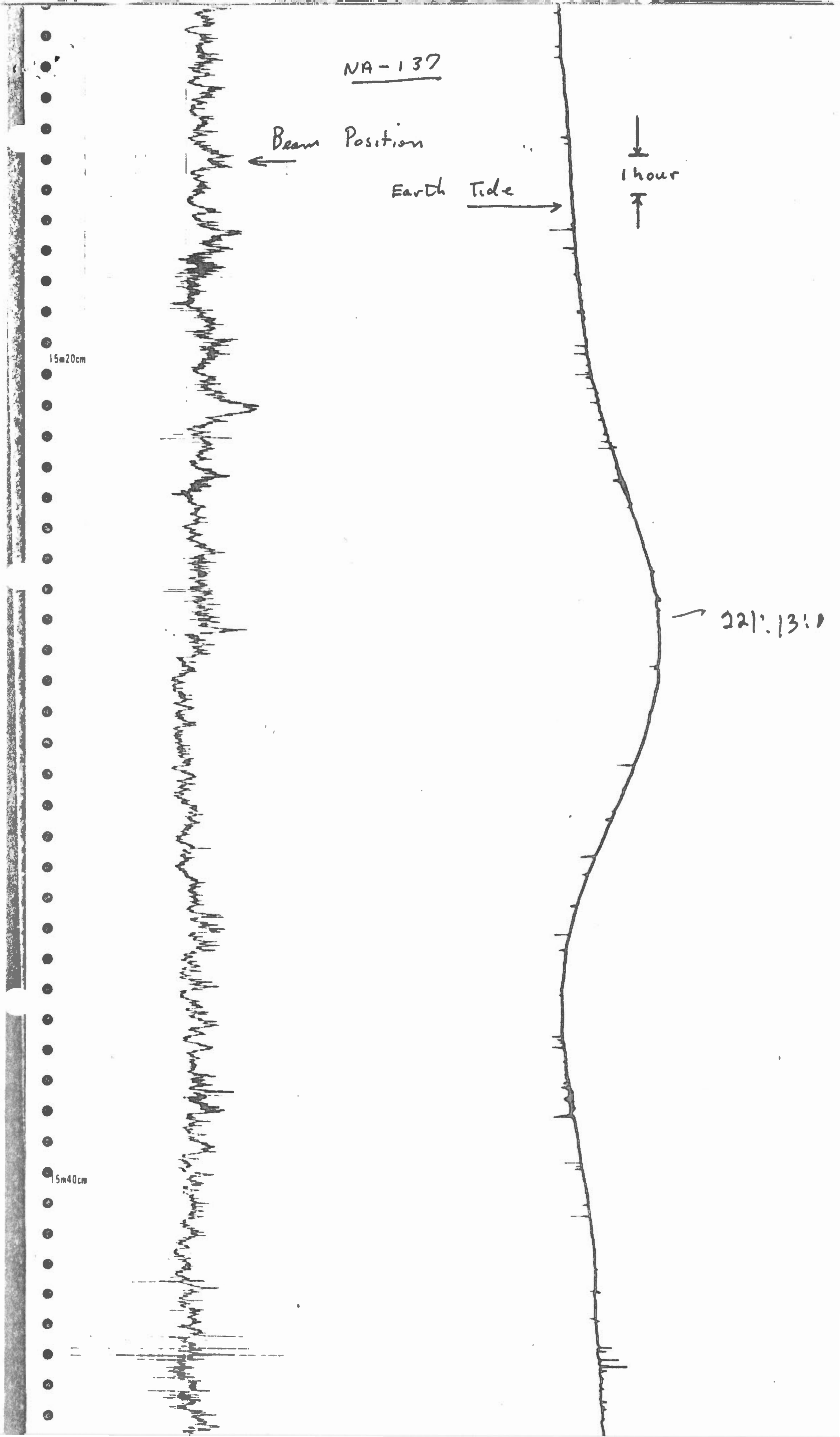

NA-137
Beam Position
Earth Tide
1 hour
221:13:0
15m20cm
15m40cm

FIGURE 3b

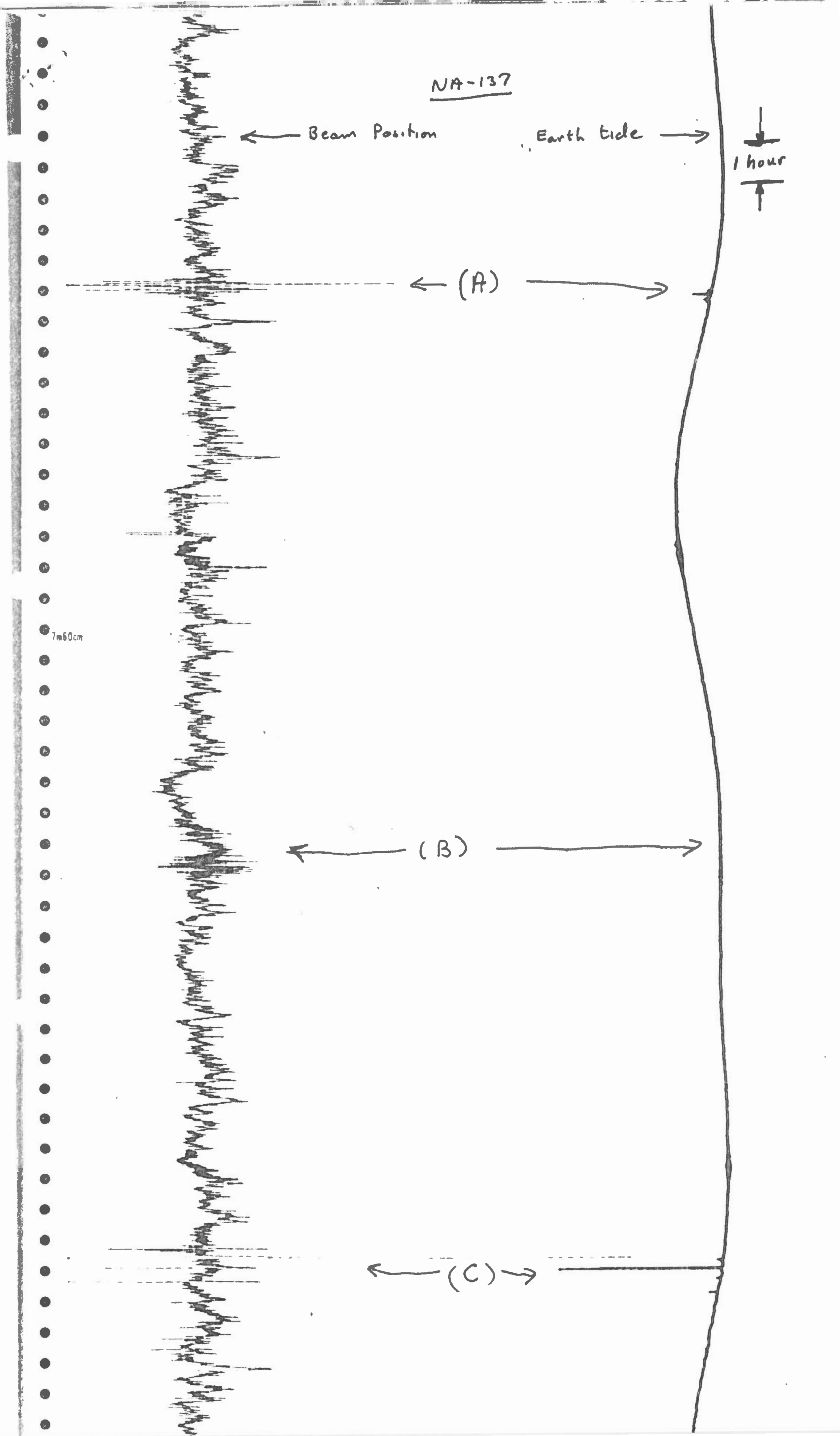
SELECTED PORTIONS OF ANALOG RECORDINGS:

An example of three types of seismic events recorded on both NA-137 and G-444

(A) Noise recorded by NA-137 but not observed by G-444.

(B) Small microseism clearly defined by G-444 but only marginally detectible in NA-137 trace.

(C) Cluster of large noise spikes recorded on NA-137 resulting in a very large spike in the earth tide trace for NA-137 and a much smaller response from G-444.


NA-137
Beam Position
Earth tide
1 hour
(A)
(B)
(C)
7m60cm

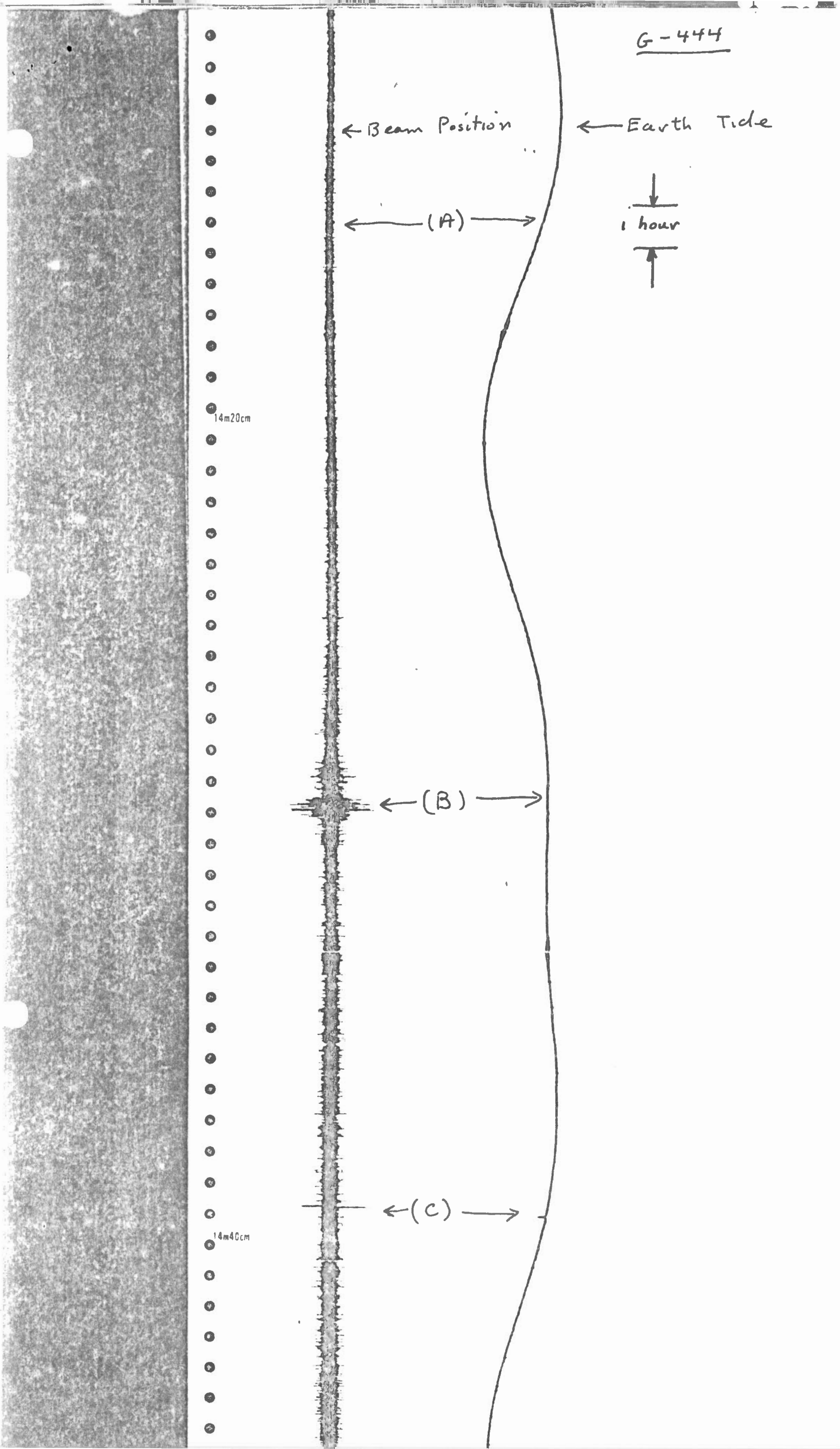
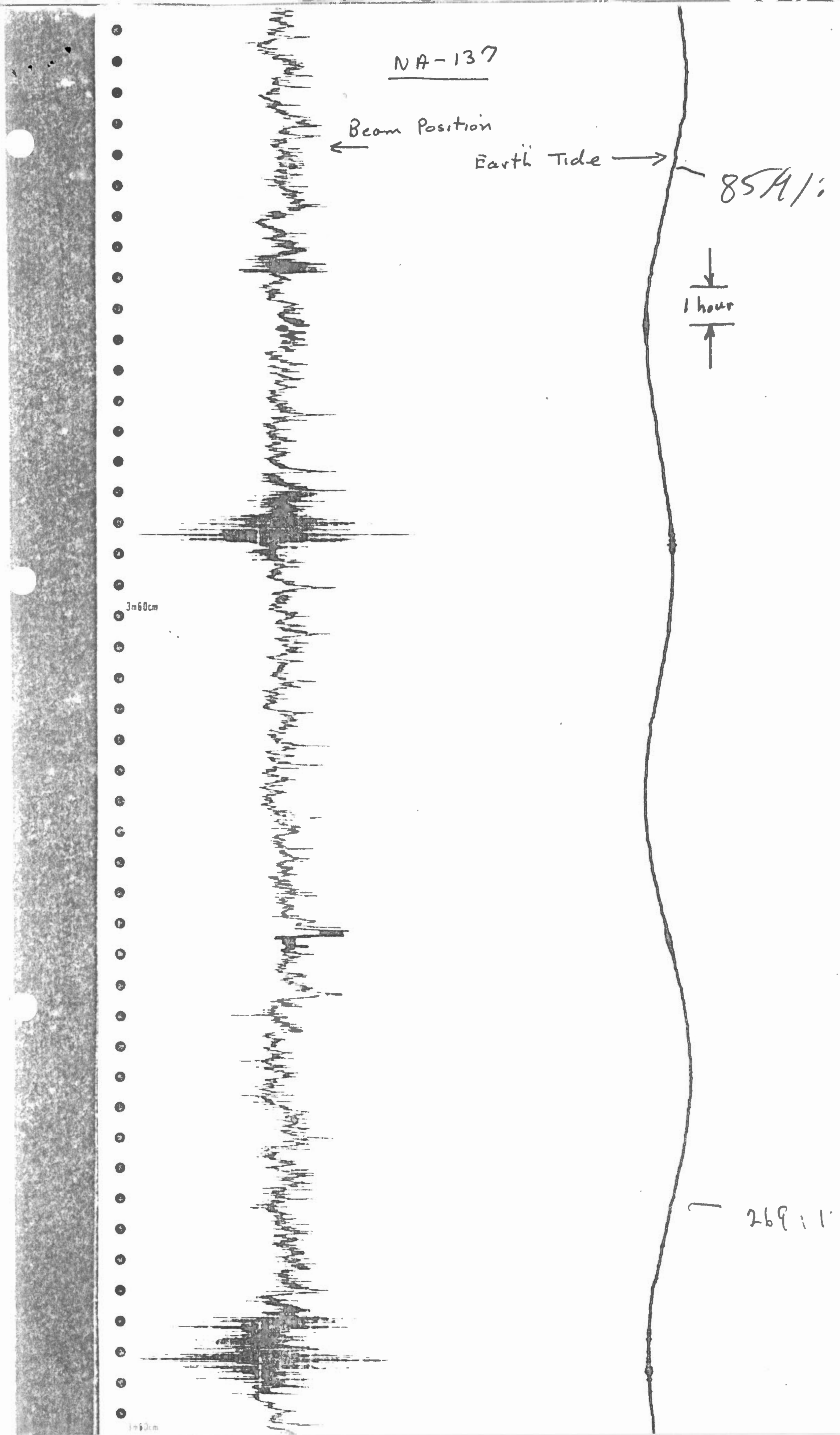

G-444
Beam Position
Earth Tide
1 hour
(A)
14m20cm
(B)
(C)
14m40cm

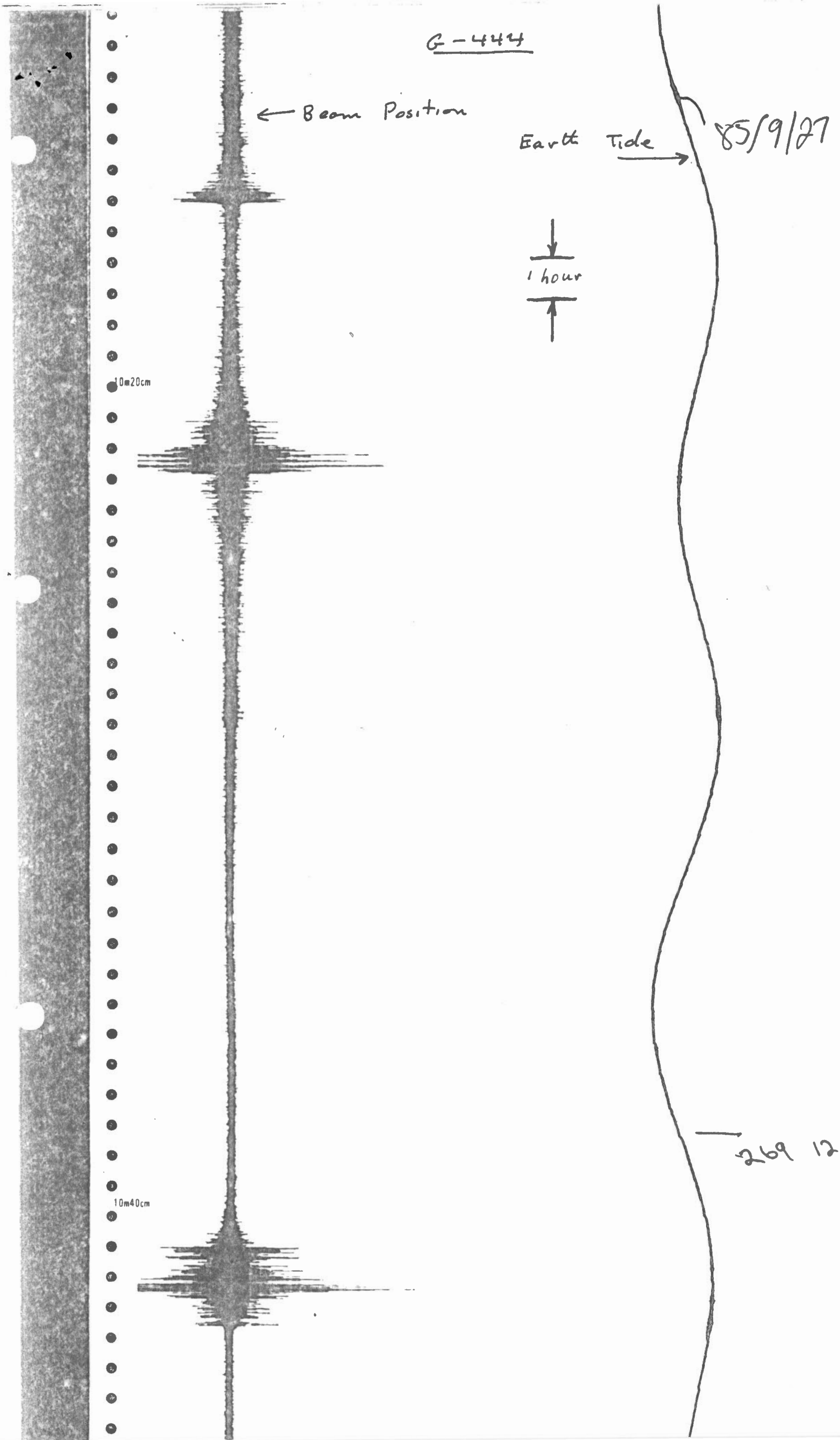
FIGURE 3c

SELECTED PORTIONS OF ANALOG RECORDINGS:

An example of three small earthquakes recorded on both NA-137 and G-444. Note also the variation in the amplitude of background noise between events recorded on G-444 but not on NA-137.



NA-137
Beam Position
Earth Tide
85A/:
1 hour
3m60cm
269:1


G-444
← Beam Position
Earth Tide
85/9/27
1 hour
10m20cm
10m40cm
269 12