

IMPACT LOADING AND UNLOADING RESPONSE OF MANGANIN FOILS  
UP TO 100 KBARS

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Introduction

The objective of the present work was to understand the response of the manganin foil gauges,<sup>1</sup> oriented parallel and perpendicular to the wave front in shock wave experiments. We carried out experiments in which the gauges were subjected to well characterized stress waves up to 100 kbars. In this report we have summarized the experimental results and compiled the resistance change profiles of all the gauges in each experiment.

Experimental Techniques

The experimental technique was similar to that described in our earlier paper.<sup>2</sup> The gauges were cut into four terminal configurations from approximately 33 micron thick manganin sheets<sup>3</sup> supplied by Hamilton Tech., Lancaster, PA. These foils have been well characterized in quasi-static experiments.<sup>4</sup> The gauges were about 1 mm wide (Fig. 1) and had about 8 mm long active elements. Their initial resistance was about 110 m $\Omega$ .

The gauges were embedded in the polycrystalline aluminum oxide (Vistal<sup>5</sup>) matrix. The Vistal matrix has been examined in the impact conditions and it remained elastic up to 90 kbars.<sup>6</sup> This feature conforms to the requirements of the existing theoretical model.<sup>7,8</sup> In some of the experiments the gauges were emplaced in the polymethylmethacrylate (PMMA) matrix.

The gauges were embedded in the matrix in the ingroove configuration. In this configuration a gauge sized groove is machined in the surface of one piece of the matrix. The gauge is glued into this groove using hysol adhesive, lapped flush with the matrix surface, and then bonded to the other

matrix piece onto this surface. In this configuration the thickness of epoxy around the gauge may be about 1-2 micron thick so that the gauge can essentially be considered as an inclusion in the matrix. As shown in Fig. 2 the gauges were embedded in two orientations: one with the major surface parallel to the shock wave front (longitudinal gauge) and the other with the major surface perpendicular to the shock front (lateral gauge).

Eighteen experiments were performed using 63.5 mm gas gun at our laboratory. The thickness of the flyer was chosen to obtain complete unloading of the stress in the target. Although most of the experiments were done with symmetric impact condition, some experiments at lower stresses used fused silica flyers.<sup>9</sup> The projectile velocity was measured using standard technique.

The gauge signal recording system was similar to that used by Keough<sup>10</sup> and it is shown in Fig. 3. The resistance change profile of the gauge was measured by sending a constant current pulse through the outer leads of the gauge using a pulse power source (Pulser model 301), and recording the voltage developed across the two inner gauge-leads using fast oscilloscopes.

## Results

A representative resistance change profile is shown in Fig. 4. This figure defines the peak and the residual resistance changes. The measured resistance change profiles for all the gauges in each experiment are given in Appendix A. These profiles were used to determine the peak resistance change and the residual resistance change.

The peak and the residual resistance change data for all the experiments are summarized in Table I. The stress values for the experiments listed in this table were determined from the knowledge of the Hugoniot of Vistal,<sup>6</sup> PMMA,<sup>9</sup> and fused silica,<sup>9</sup> and the measured projectile velocity.

In Fig. 5, we plot the peak resistance change versus the peak longitudinal stress in the matrix for both orientations. The resistance change for both the orientations increases smoothly and, as expected, the difference between the resistance changes of the longitudinal gauge and the lateral gauge increase with increasing peak longitudinal stress. The two experiments performed with different matrices (Vistal and PMMA) shocked to the same longitudinal matrix stress (24.5 kbar) show that the longitudinal gauge response is very close in the two cases.

Figure 6 shows the residual resistance change versus the peak longitudinal stress. For both orientations the residual resistance change increases smoothly up to 50 kbar and becomes almost constant above this stress. Our analysis shows that even if the hysteresis effects are ignored in the plate impact experiments, the stress measured using manganin gauges may be over-estimated by at most 5 kbar.

In Fig. 7 we have compared the present data on the manganin gauges with the already existing data.<sup>11-14</sup>

#### Acknowledgment

We thank Martin Williams and Jerry Thompson for their technical assistance in building the targets and in performing the experiments.

References

1. The term "gauge" here refers to the piezoresistance foil only and two are used synonymously.
2. Satish C. Gupta and Y. M. Gupta, J. Appl. Phys. 57, 2464 (1985).
3. These sheets were obtained through D. D. Keough of SRI International.
4. D. Y. Chen, Y. M. Gupta, and M. H. Miles, J. Appl. Phys. 55, 3984 (1984).
5. Vistal is the trademark of Coors for polycrystalline  $Al_2O_3$  and is a replacement for Lucalox manufactured by G.E.
6. Y. M. Gupta, J. Geophys. Res. 88, 4304 (1983).
7. Y. M. Gupta, J. Appl. Phys. 54, 6256 (1983).
8. Satish C. Gupta and Y. M. Gupta (unpublished).
9. L. M. Barker and R. E. Hollenbach, J. Appl. Phys. 41, 4208 (1970).
10. D. D. Keough, Stanford Research Institute Report, AD 839983 (1968).
11. D. D. Keough and J. Y. Wong, J. Appl. Phys. 41, 3508 (1970).
12. E. Barsis, E. Williams, and C. Skoog, J. Appl. Phys. 41, 5155 (1970).
13. L. M. Lee, J. Appl. Phys. 44, 4017 (1973).
14. J. A. Charest, "Development of a Strain-Compensated Shock Pressure Gauge," Report submitted by Dynasen, Inc., to Los Alamos Scientific Laboratory, Goleta, California, 1979 (unpublished).

Table I. Summary of the Experimental Results<sup>a</sup>

Experiment Number	Projectile Velocity (mm/ $\mu$ s)	Peak Long. Stress (kb)	Longitudinal Gauge		Lateral Gauge	
			$\Delta R/R_o  _{peak}$	$\Delta R/R_o  _{res.}$	$\Delta R/R_o  _{peak}$	$\Delta R/R_o  _{res.}$
84535	0.109 <sup>b</sup>	10.3	0.029	0.005	0.0067	0.002
84534	0.210 <sup>b</sup>	19.9	0.051	0.009	0.014	0.003
84502	0.675 <sup>c</sup>	24.6	0.068	...	...	...
84529	0.153	32.6	0.084	0.012	0.021	0.007
84503	0.185	39.6	0.125	0.018	0.034	0.005
84533	0.190	40.7	0.110	0.014	0.027	0.009
84528	0.199	42.6	0.122	0.018	0.038	0.010
84521	0.257	54.9	0.142	0.017	...	...
84527	0.258	55.2	0.148	0.015	0.045	0.014
84548	0.321	68.7	0.181	...	0.063	...
83536	0.322	68.9	0.168	...	0.053	...
84522	0.379	81.1	0.202	0.018	0.082	0.010
84547	0.463	90.7	0.245	...	0.106	...
83525 <sup>d</sup>	0.398 <sup>c</sup>	7.4	0.021	0.008	0.013	0.006
83510 <sup>d</sup>	0.450 <sup>c</sup>	8.4	0.027	0.011	0.019	0.003
83522 <sup>d</sup>	0.788 <sup>c</sup>	15.1	0.037	0.006	0.035	0.016
83526 <sup>d</sup>	0.605 <sup>b</sup>	18.4	0.047	...	0.028	...
84501 <sup>d</sup>	0.665	24.4	0.065	...	...	...

- a. Experiments used VISTAL matrix and flyer.
- b. Fused silica flyer.
- c. PMMA flyer.
- d. Matrix was PMMA.

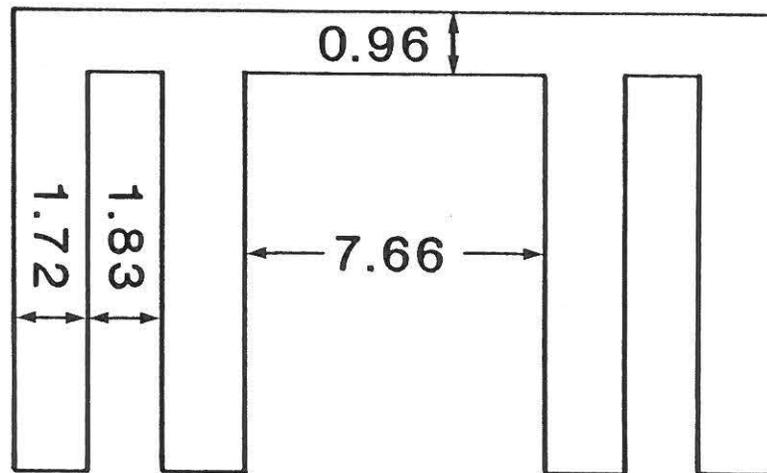


Fig. 1. The manganin gauge used in the experiments. All dimensions are in millimeters. Thickness of the gauge was about 33 micron.

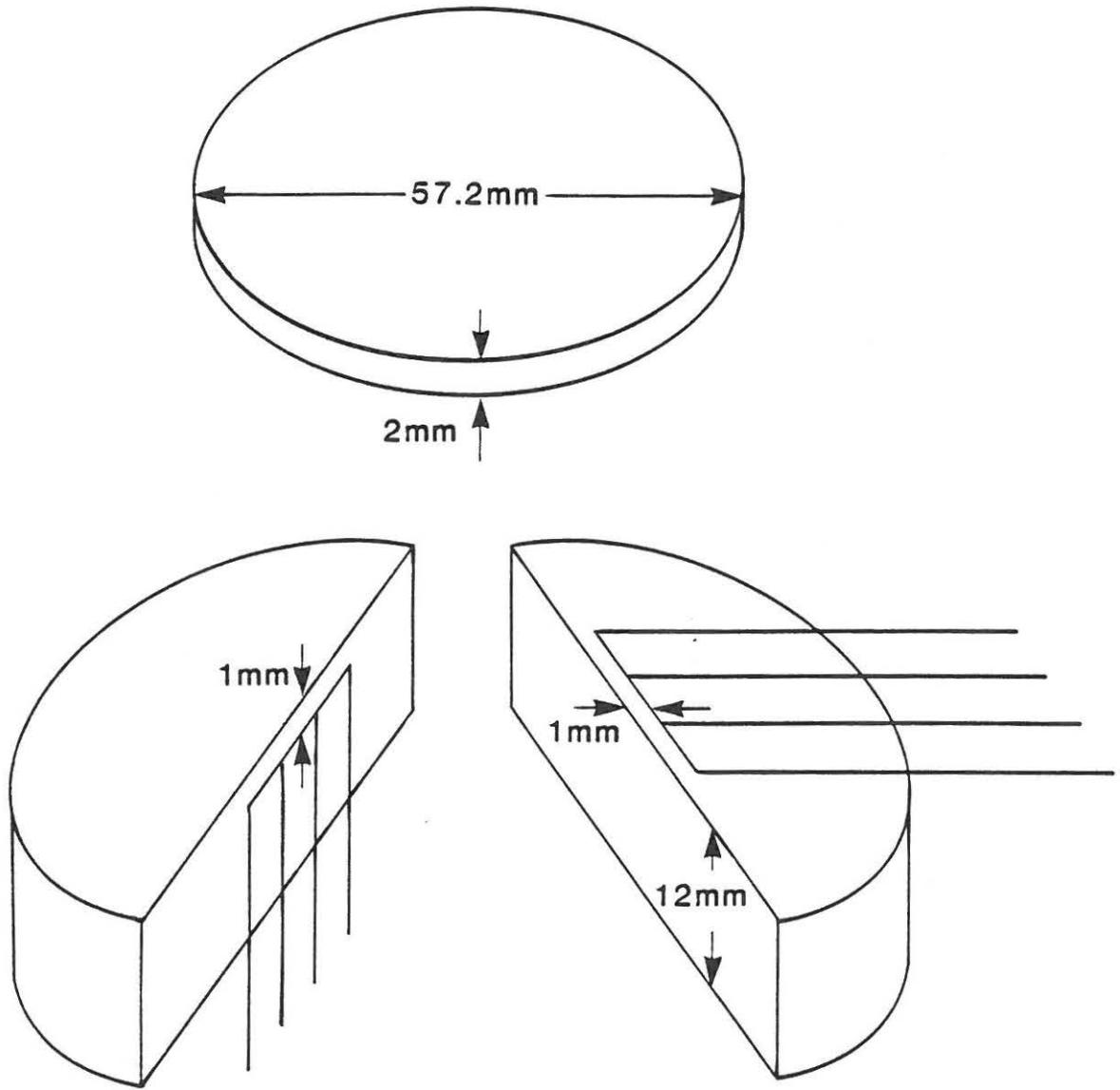


Fig. 2. The target assembly and the layout of the gauges.

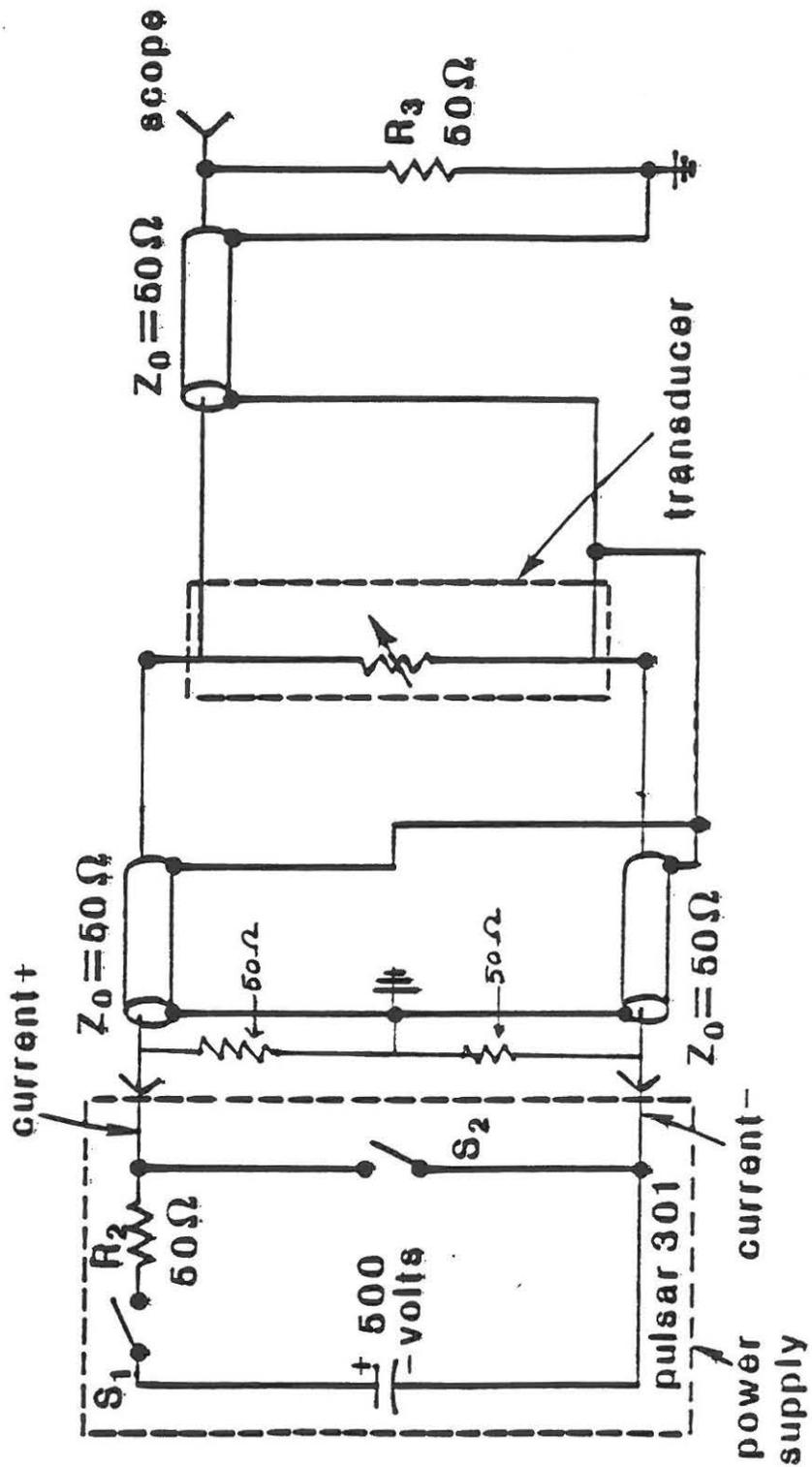


Fig. 3. The gauge signal recording system.

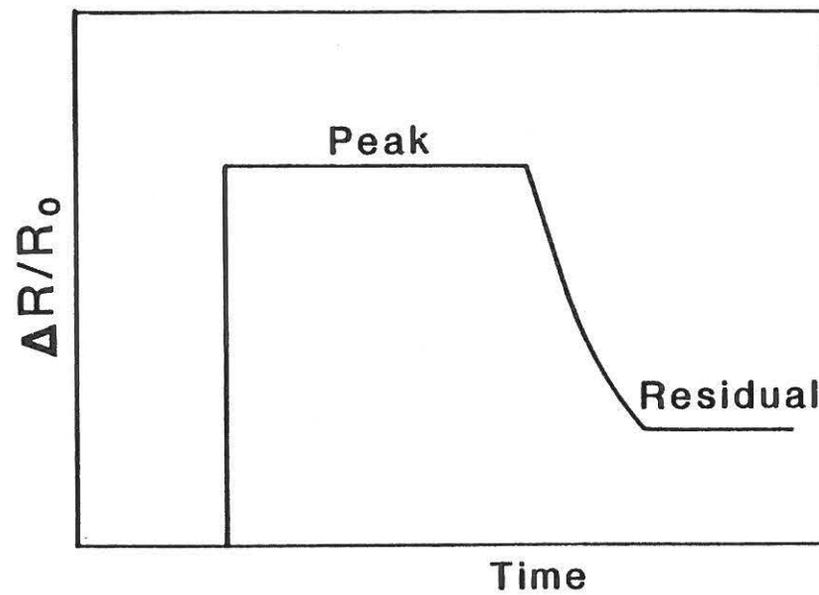


Fig. 4. A representative resistance change profile.

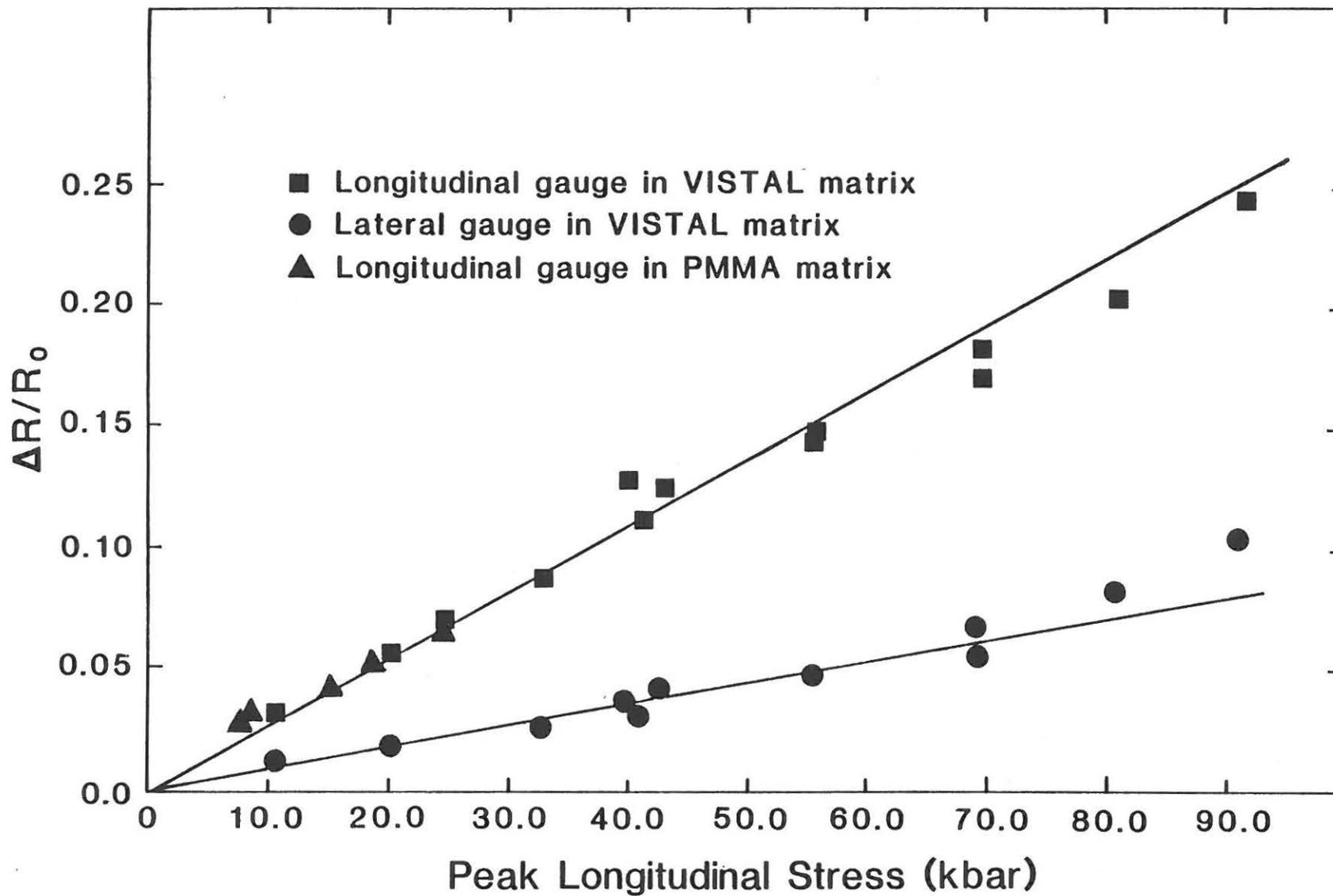


Fig. 5. The peak fractional resistance change for the two orientations as a function of peak longitudinal matrix stress.

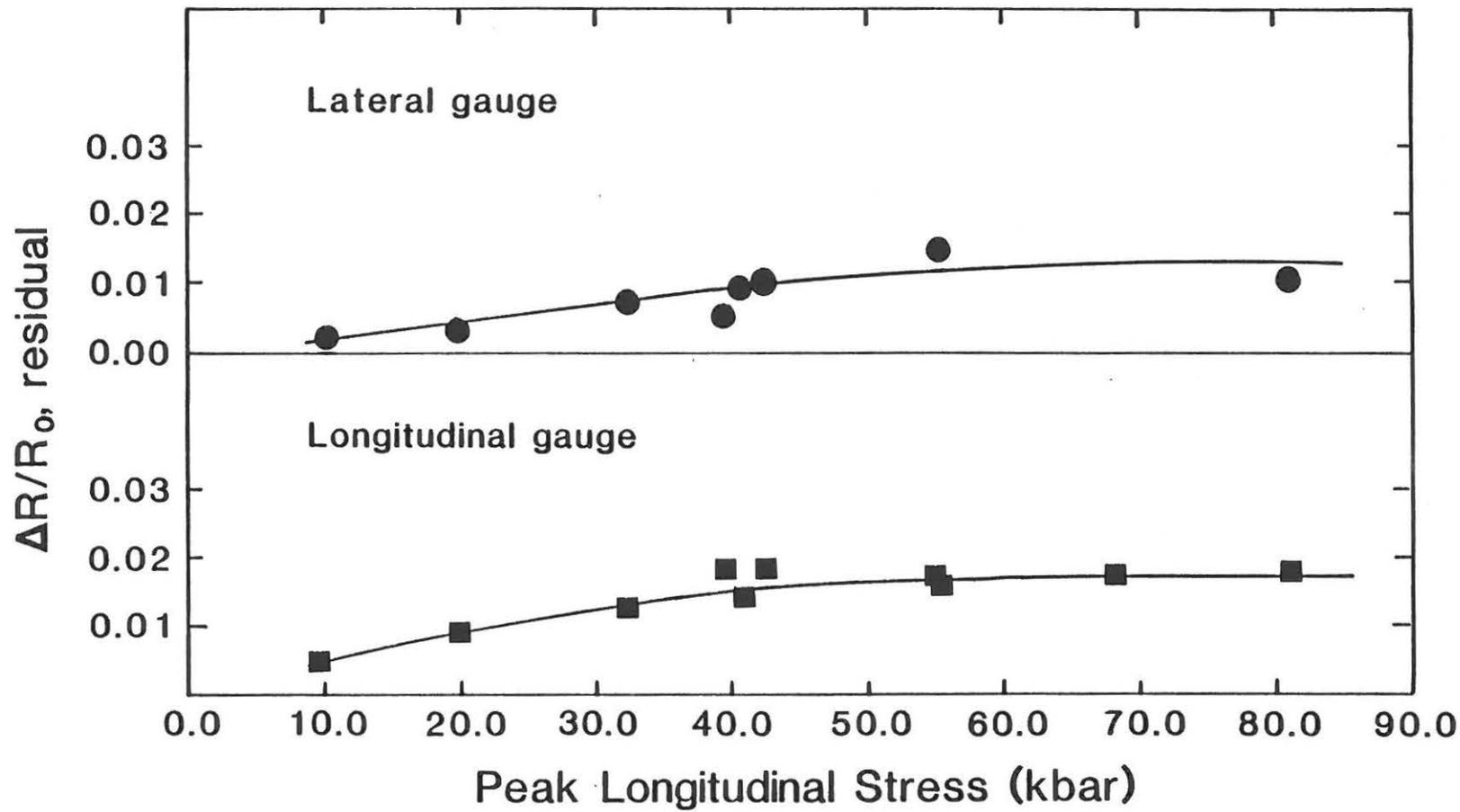


Fig. 6. The residual fractional resistance change for the two orientations.

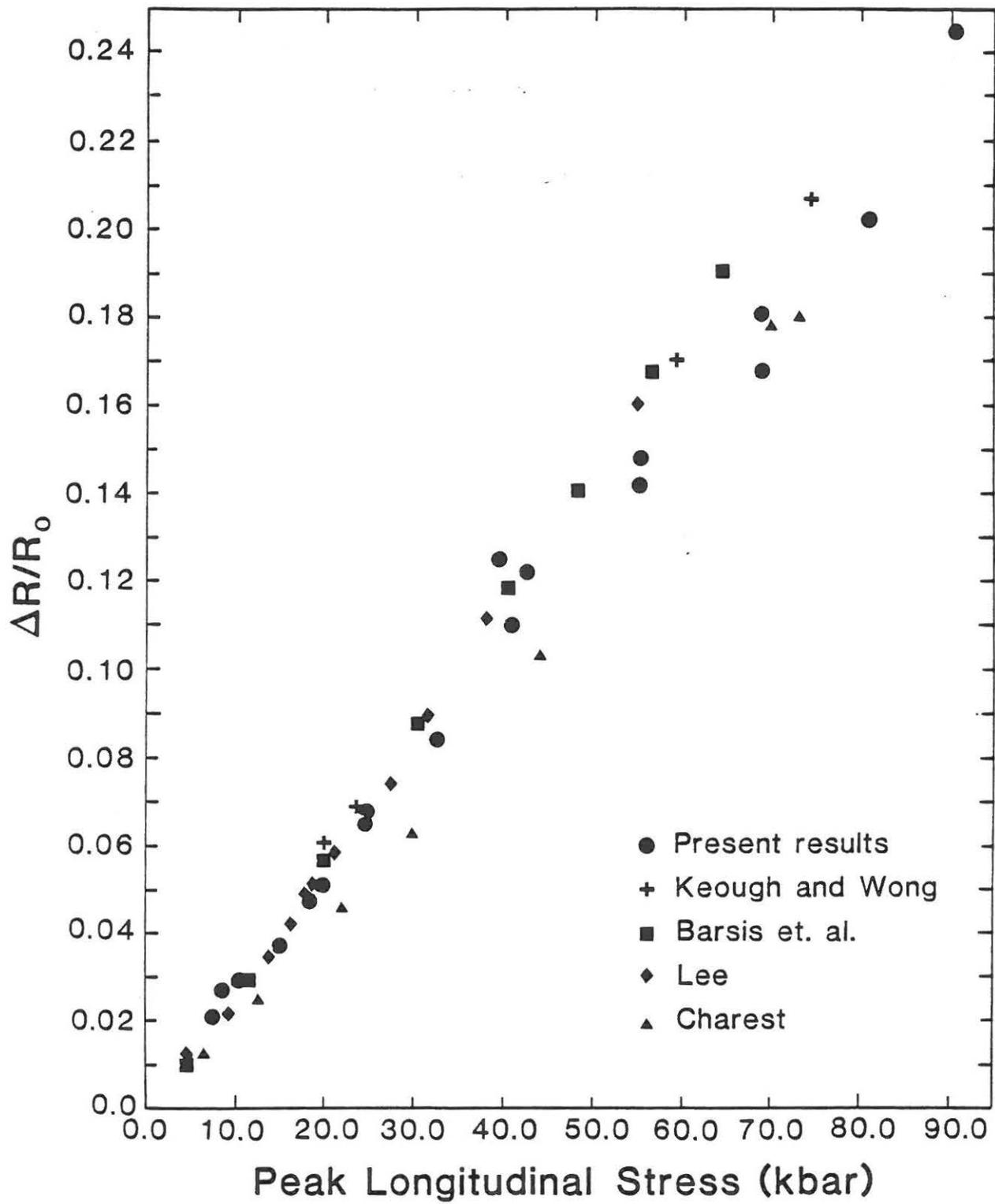


Fig. 7. Comparison of the present data with the existing data on manganese gauge response.

## APPENDIX A

In this appendix we give the details of each experiment and the experimentally measured profiles.

For each experiment we have given a table listing the important experimental parameters. Following the table are given the plots of measured resistance change profiles for every gauge. In these plots the term "longitudinal gauge" refers to the gauge oriented parallel to the shock front and the term "lateral gauge" refers to the gauge oriented perpendicular to the shock front.

Shot Number: 84501

Projectile Velocity: 0.665 mm/ $\mu$ s

Shock Stress: 24.4 kbar

Impactor Material: Vista1

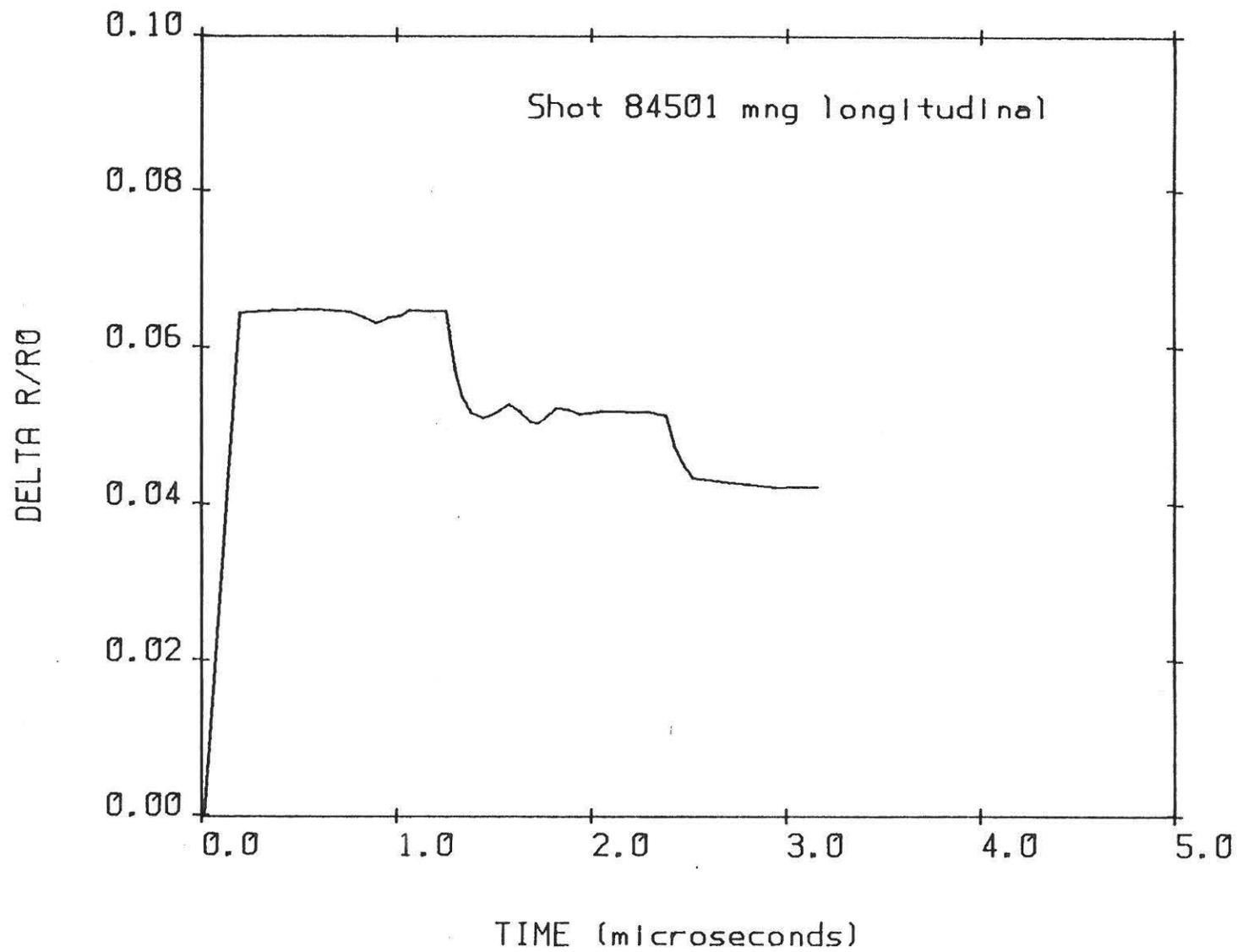
Impactor Thickness: 6.1 mm

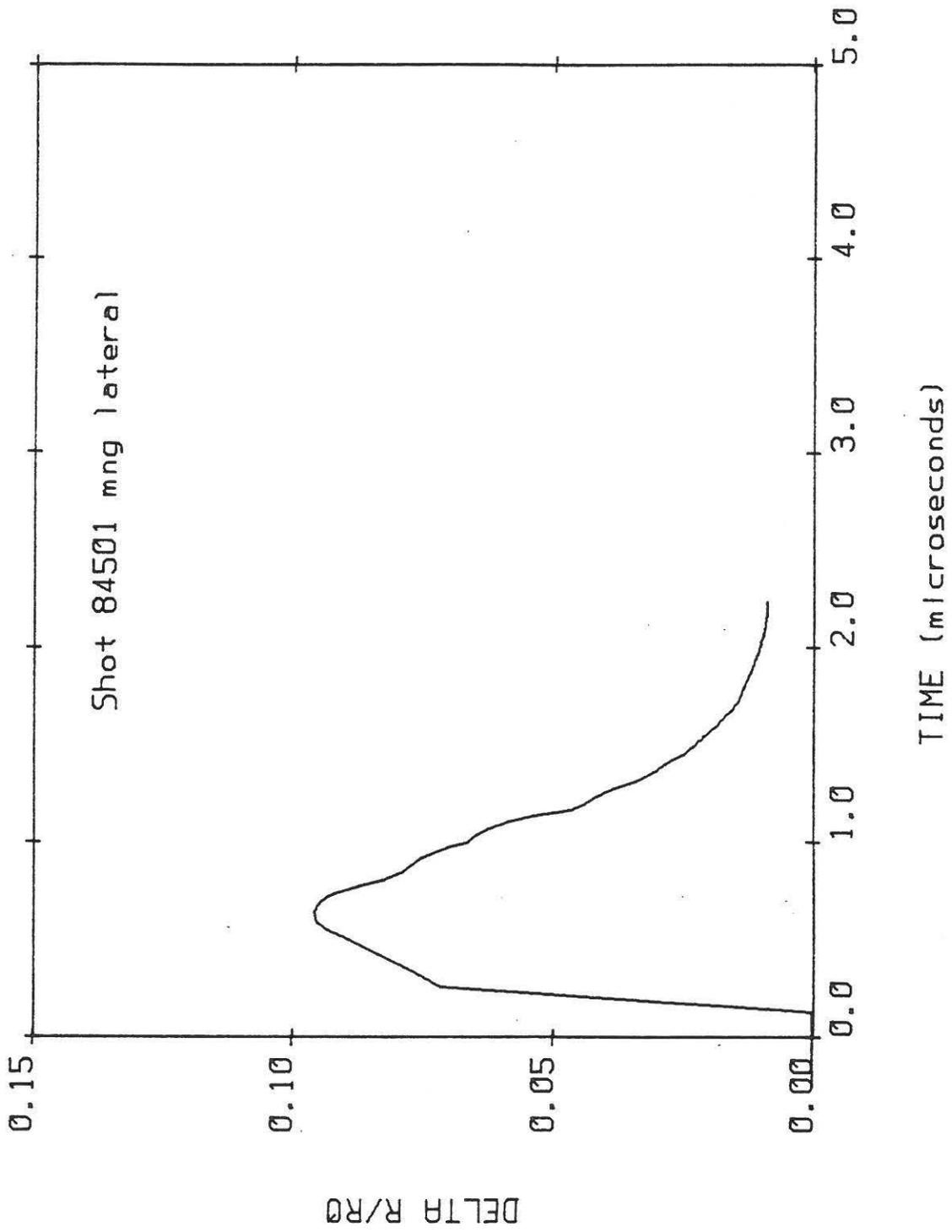
Matrix Material: PMMA

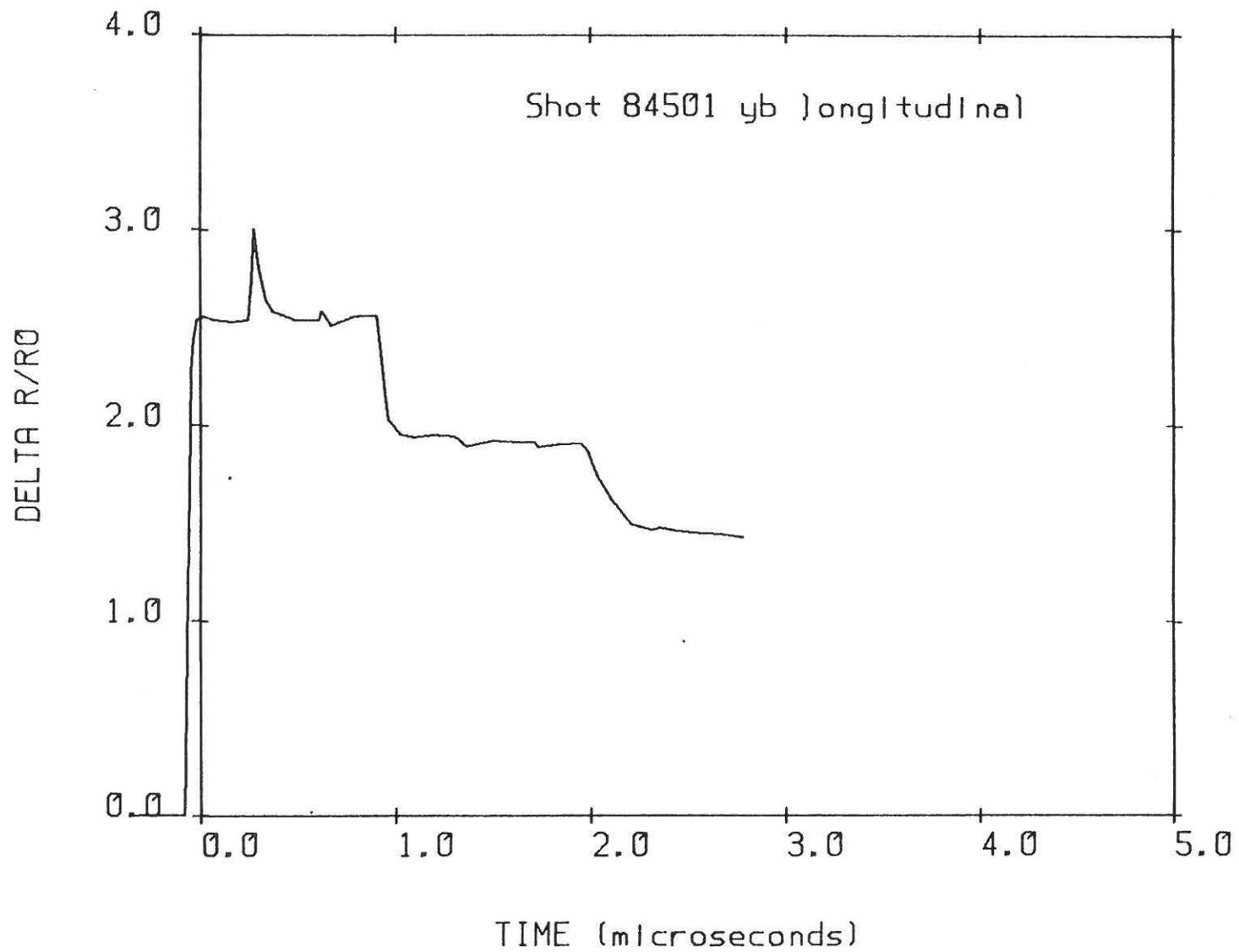
Longitudinal Gauge Depth in Matrix: 1 mm

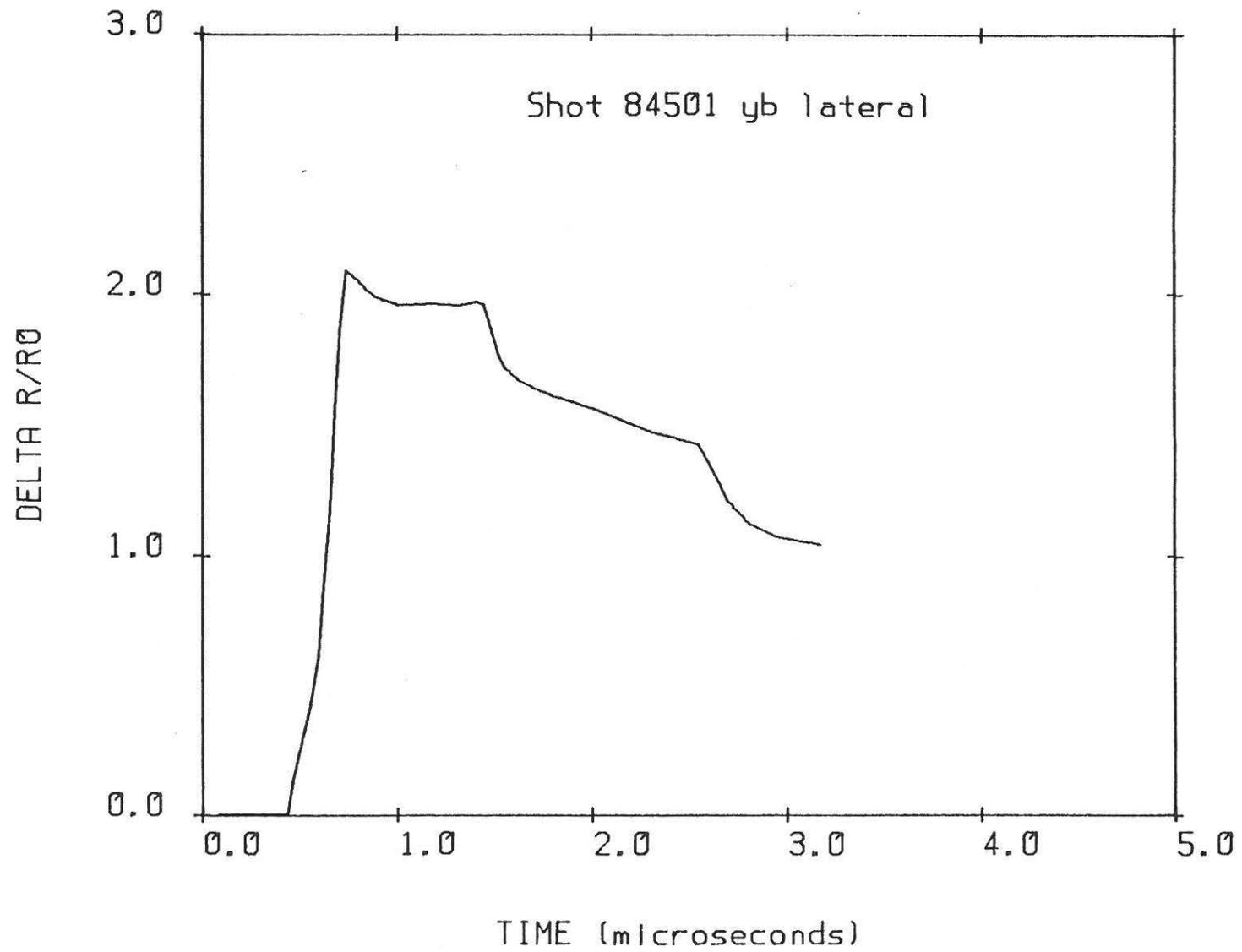
Gauges Embedded in Matrix: One in-groove longitudinal ytterbium and one in-groove longitudinal manganin.

Remarks: Shots 84501 and 84502 are performed to examine the effect of matrix properties on the response of ytterbium and manganin gauges.





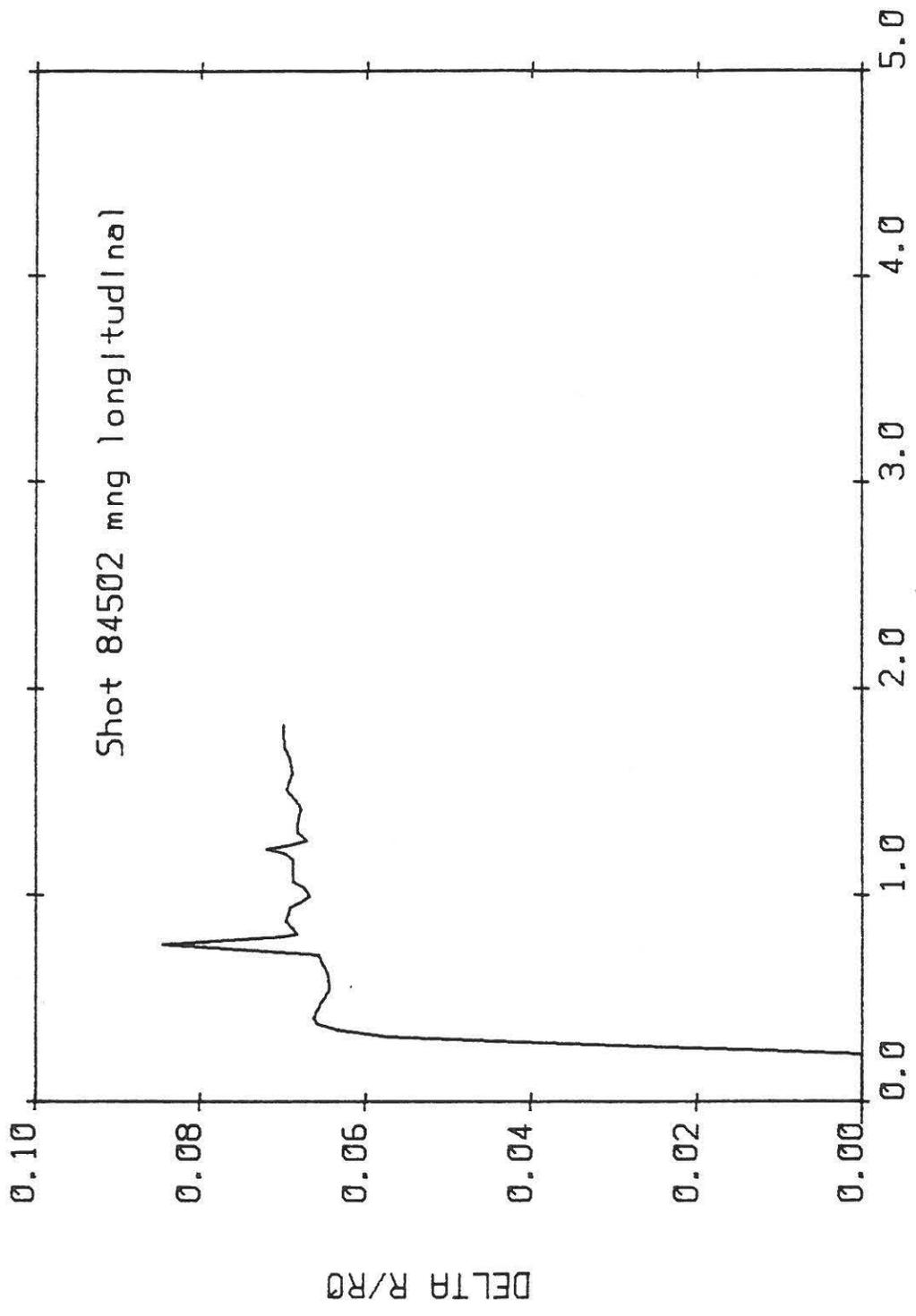




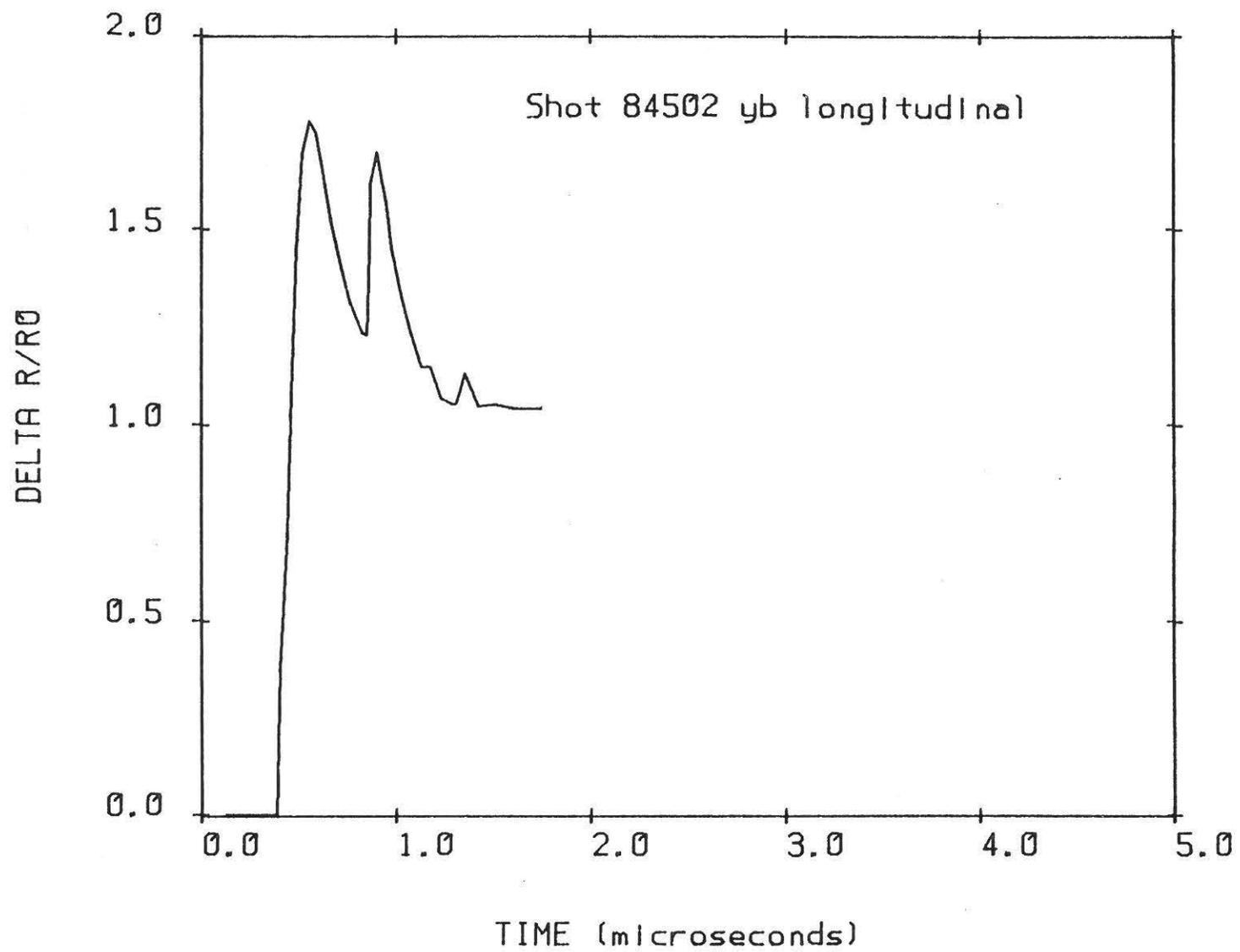
Shot Number: 84502  
Projectile Velocity: 0.675 mm/ $\mu$ s  
Shock Stress: 24.6 kbar  
Impactor Material: PMMA  
Impactor Thickness: 6 mm  
Matrix Material: VVstal

Longitudinal Gauge Depth in Matrix: 2.59 mm  
Gauges Embedded in Matrix: One in-groove longitudinal ytterbium and one in-groove longitudinal manganin.

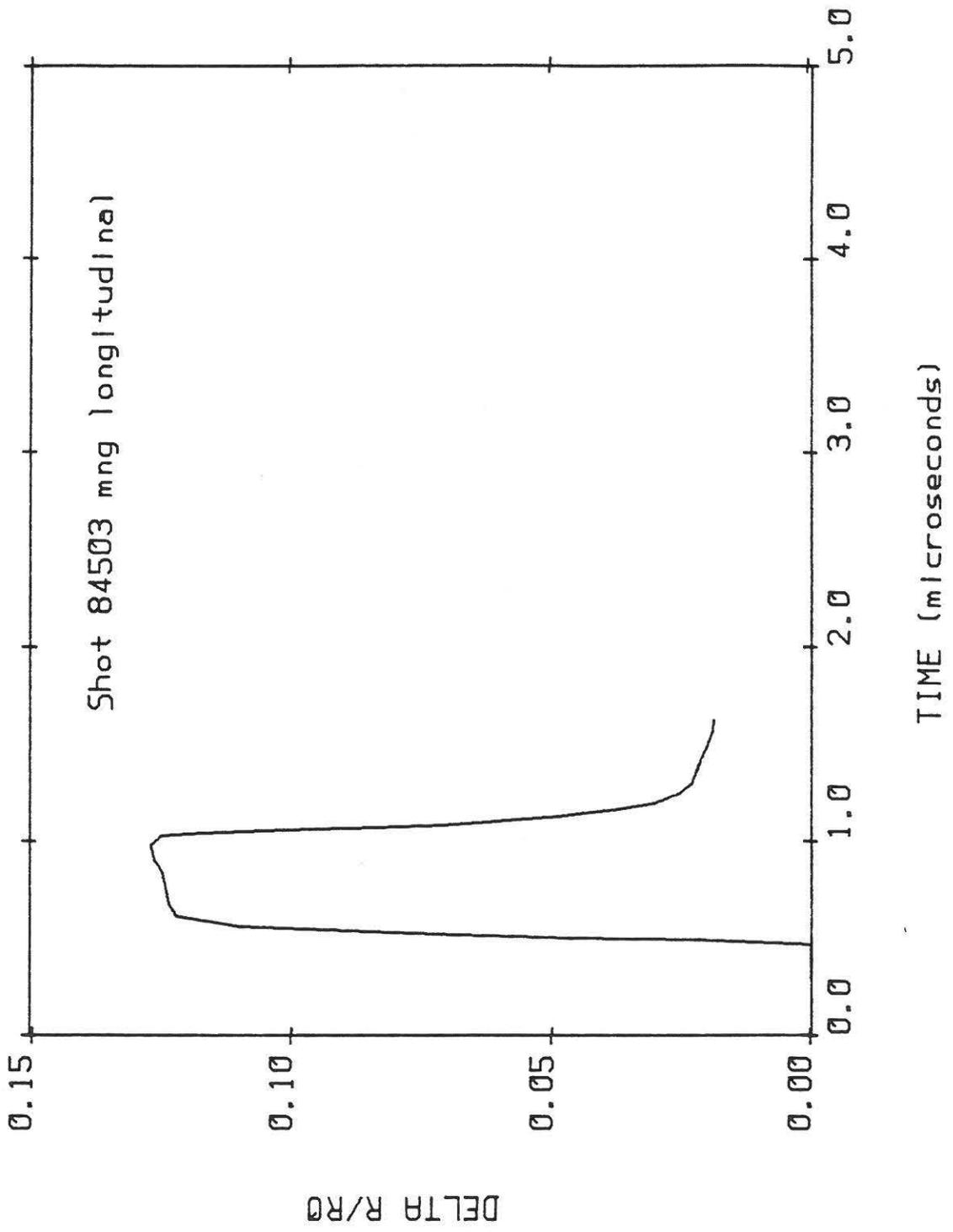
Remarks: (i) Shots 84501 and 84502 were performed to examine the effect of matrix properties on the response of ytterbium and manganin gauges.  
(ii) The two gauges were 2 mm apart.

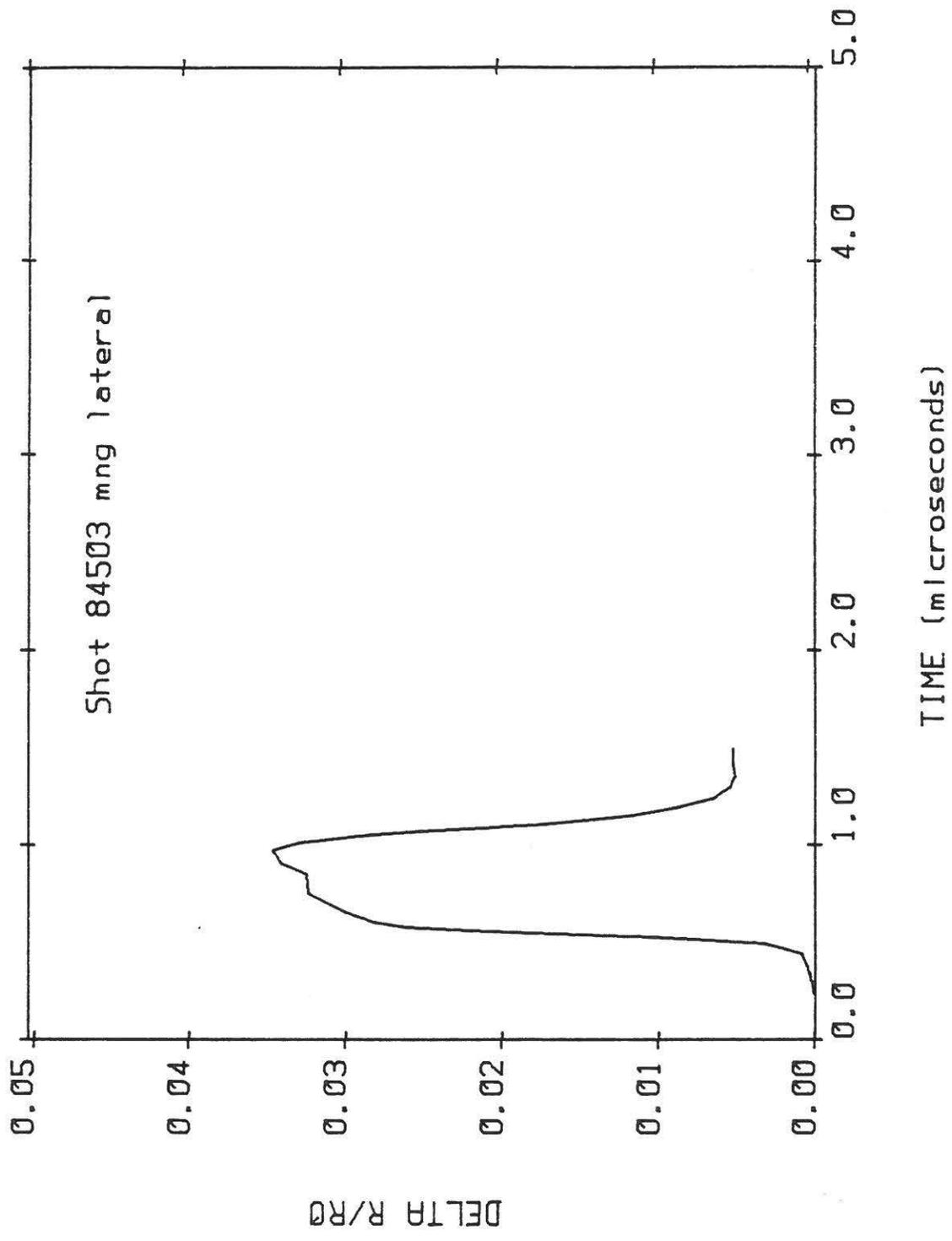


TIME (microseconds)



Shot Number:	84503
Projectile Velocity:	0.185 mm/ $\mu$ s
Shock Stress:	39.6 kbar
Impactor Material:	Vistal
Impactor Thickness:	3.07 mm
Matrix Material:	Vistal
Longitudinal Gauge Depth in Matrix:	2.59 mm
Lateral Gauge Depth in Matrix:	3.59 mm
Gauges Embedded in Matrix:	One in-groove longitudinal and one in-groove lateral.





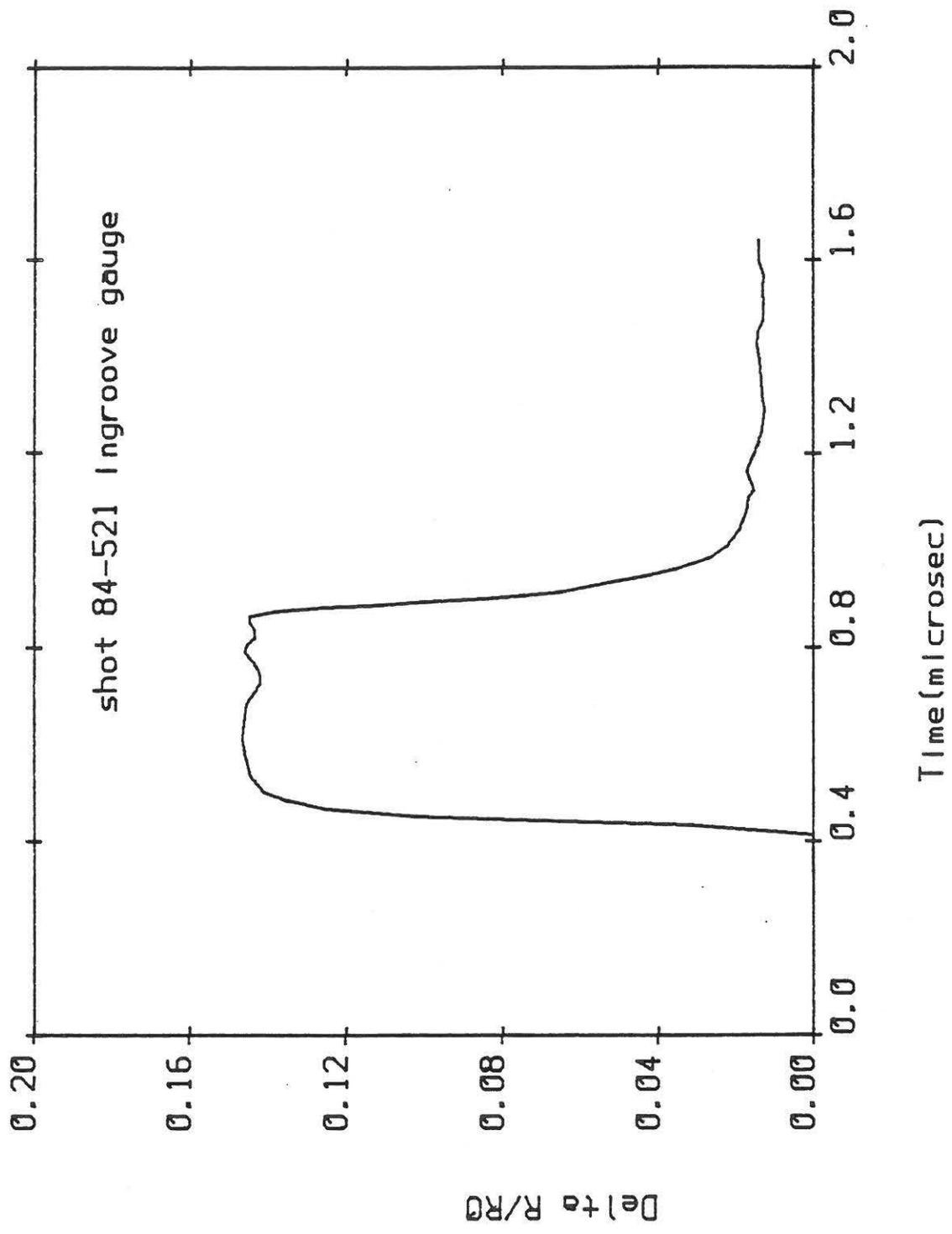
Shot Number: 84521  
Projectile Velocity: 0.257 mm/ $\mu$ s  
Shock Stress: 54.9 kbar  
Impactor Material: Vistal  
Impactor Thickness: 2.54 mm  
Matrix Material: Vistal

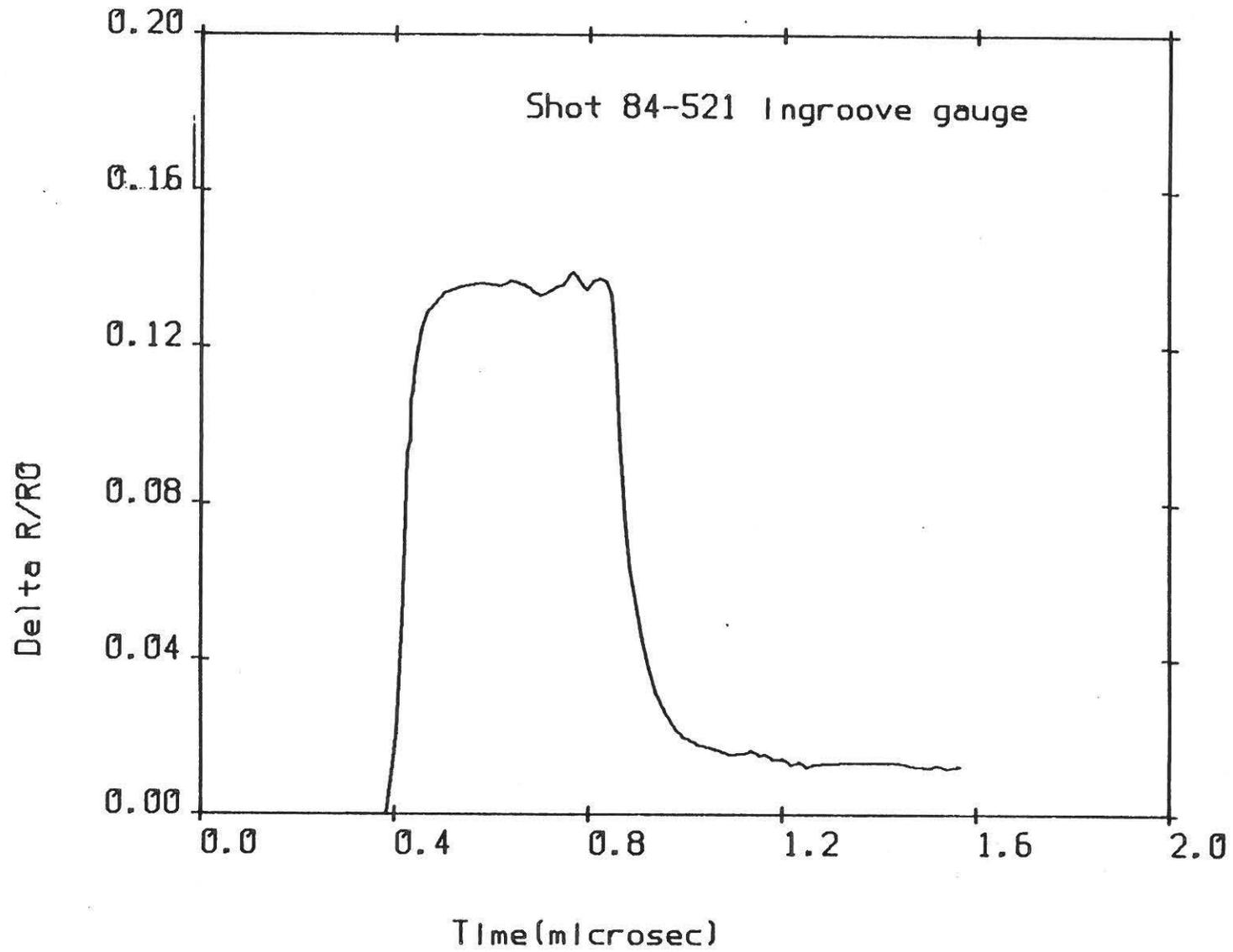
Longitudinal Gauge Depth in Matrix: 2 mm

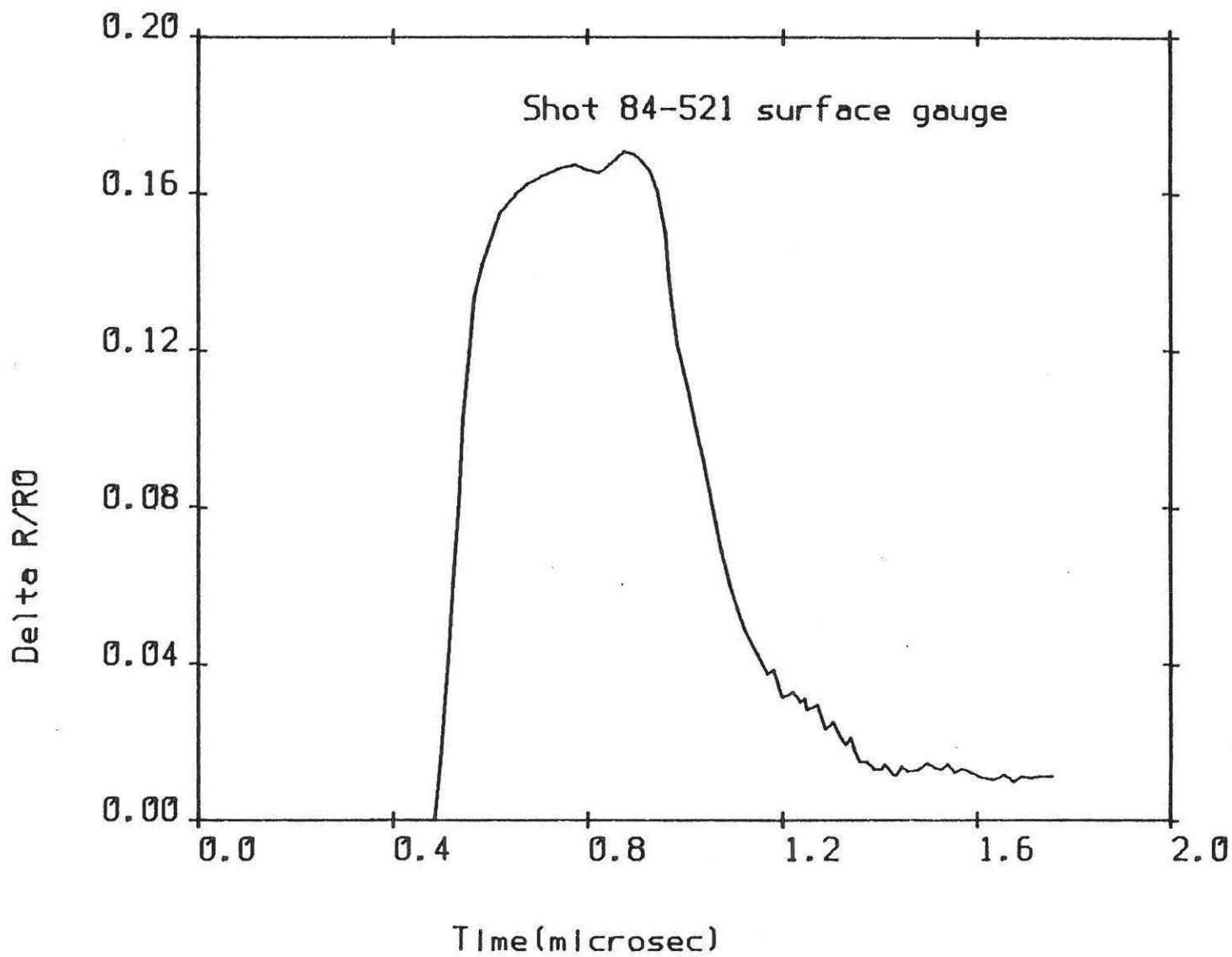
Gauges Embedded in Matrix: One in-groove longitudinal and  
one surface longitudinal.

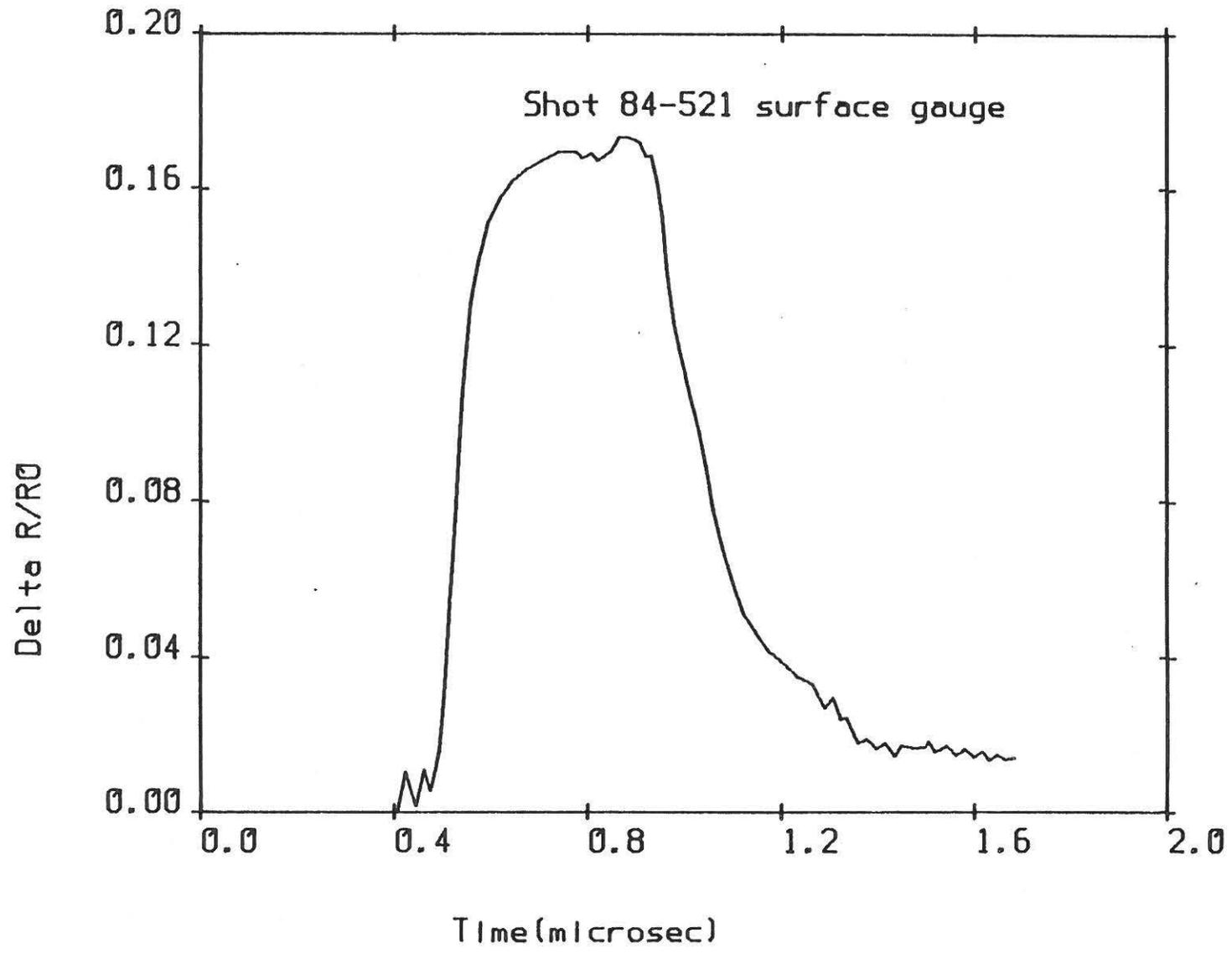
Remarks: The experiment was performed to study the difference between the response of the in-groove gauge and that of the surface gauge. The peak resistance change for the surface gauge was 17% higher than that of the in-groove gauge.

*The gauge signal was recorded on two scopes for each gauge. Therefore there are two resistance change profiles for each gauge.*







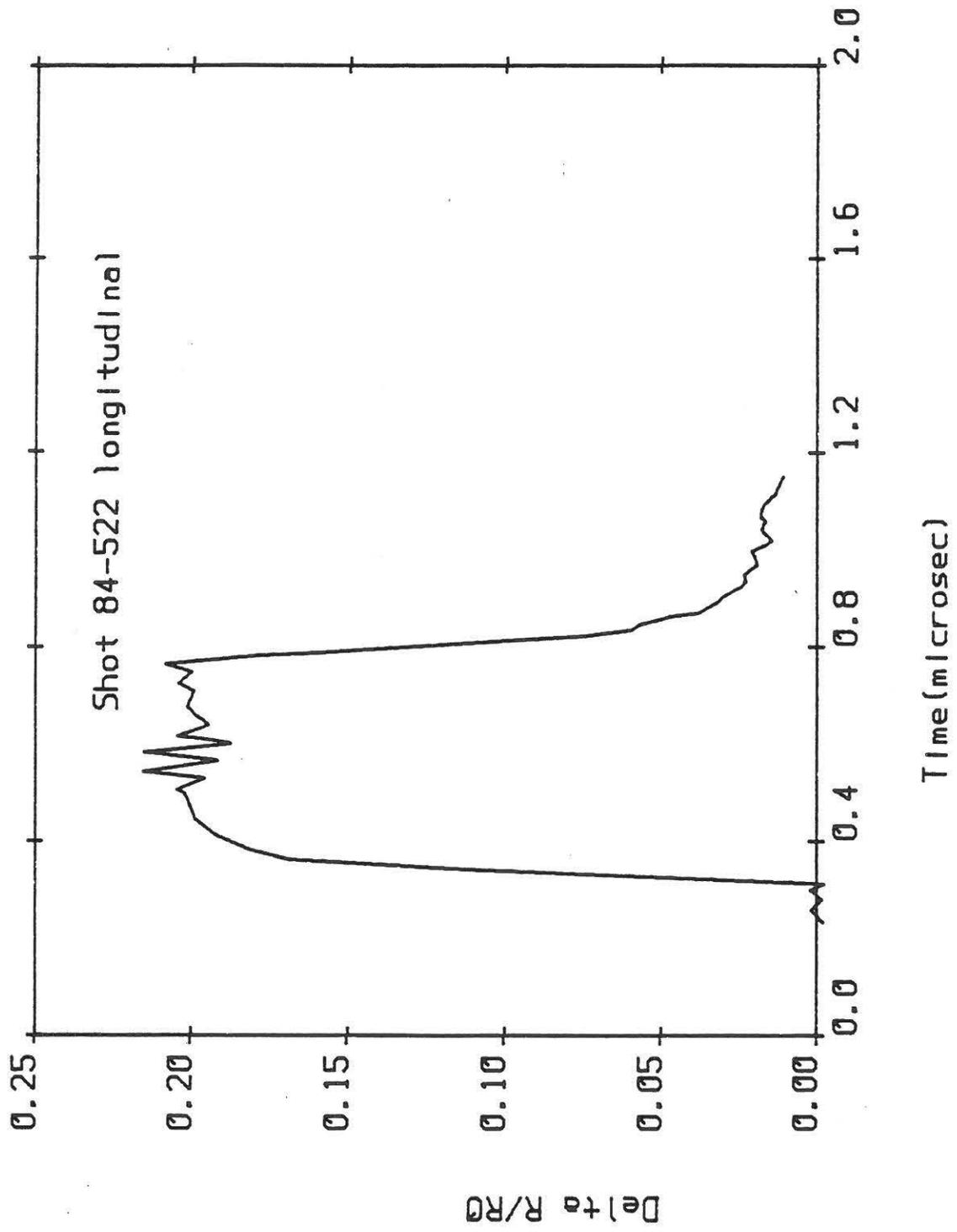


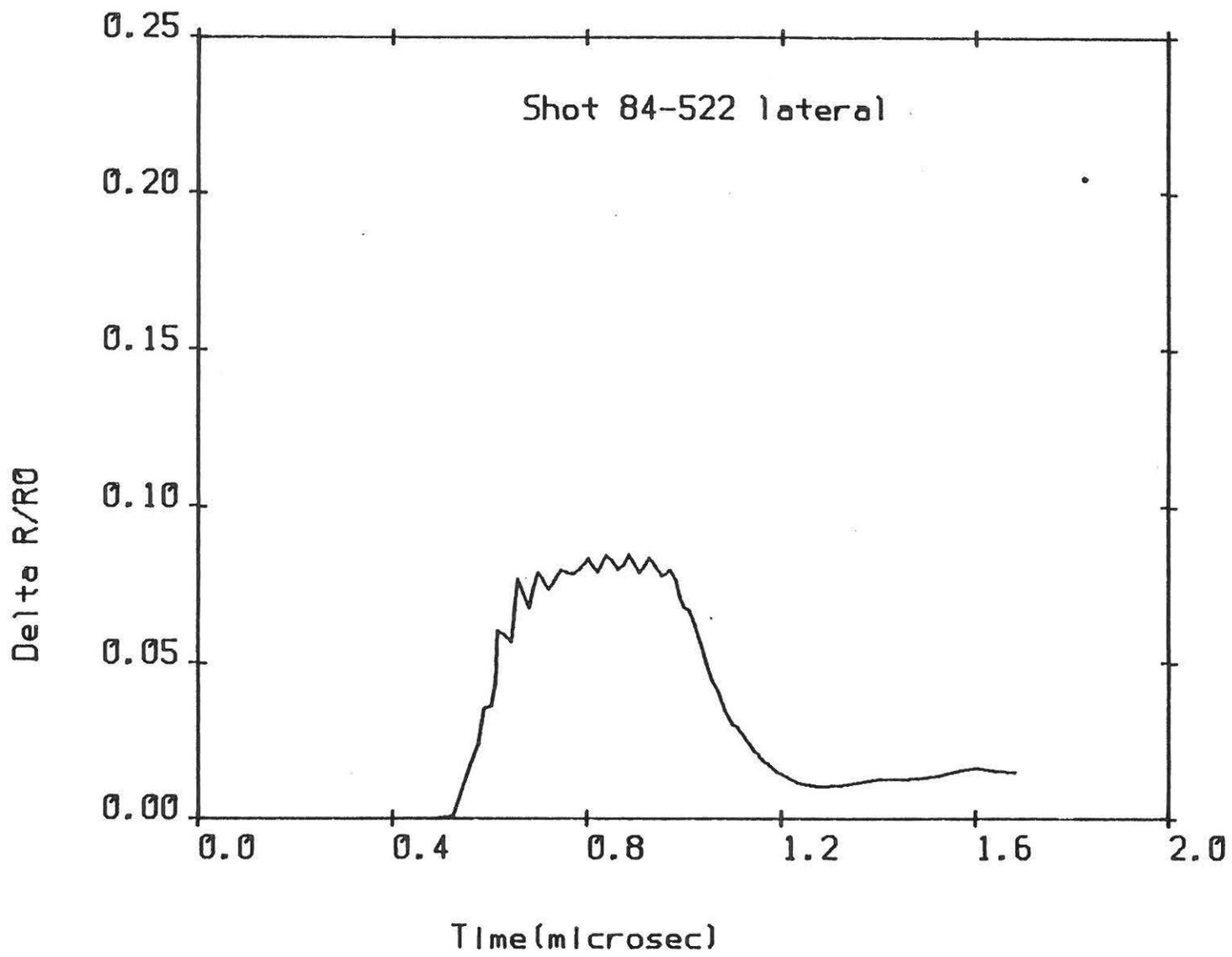
Shot Number: 84522  
Projectile Velocity: 0.379 mm/ $\mu$ s  
Shock Stress: 81.1 kbar  
Impactor Material: Vistal  
Impactor Thickness: 2.54 mm  
Matrix Material: Vistal

Longitudinal Gauge Depth in Matrix: 2 mm

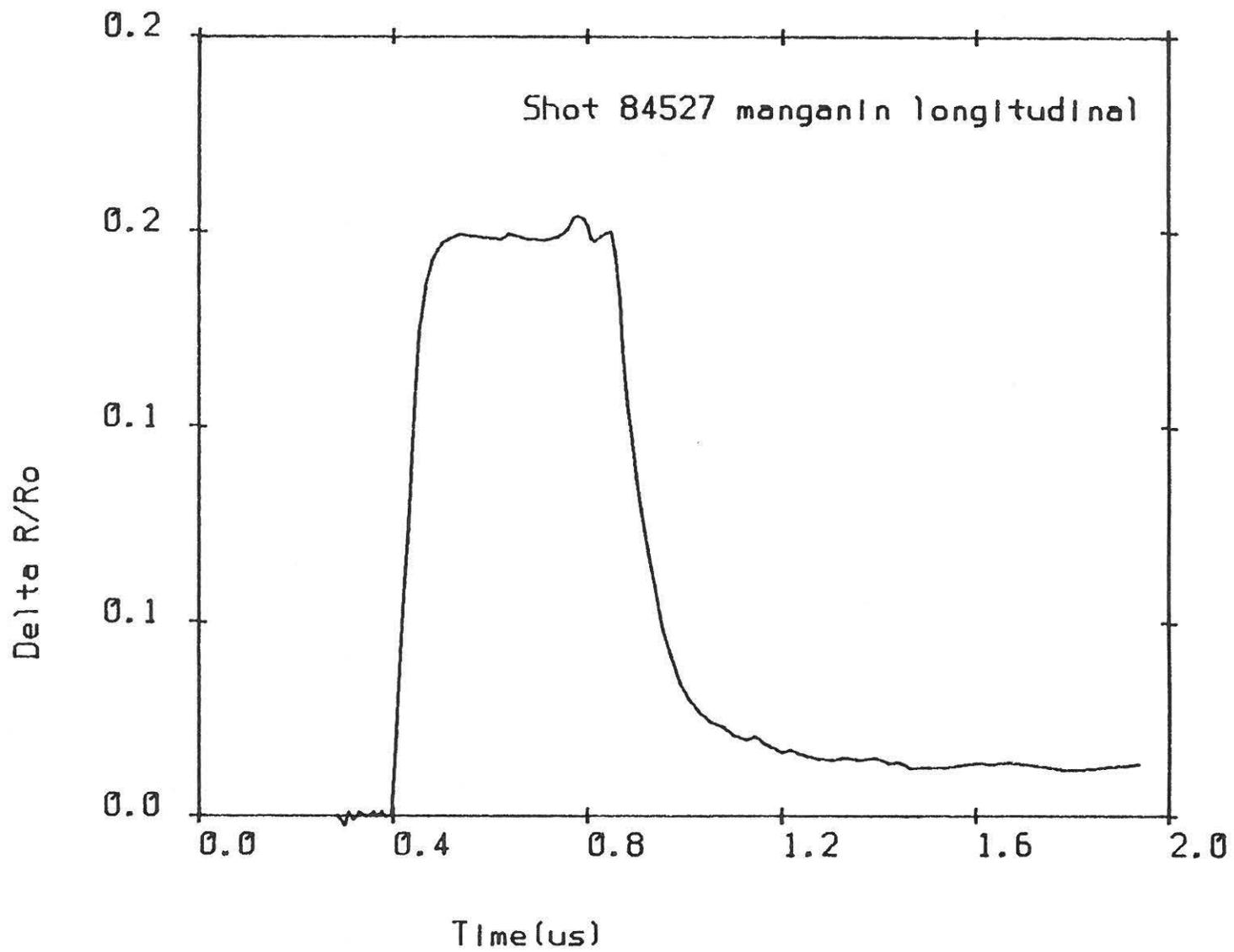
Lateral Gauge Depth in Matrix: 3 mm

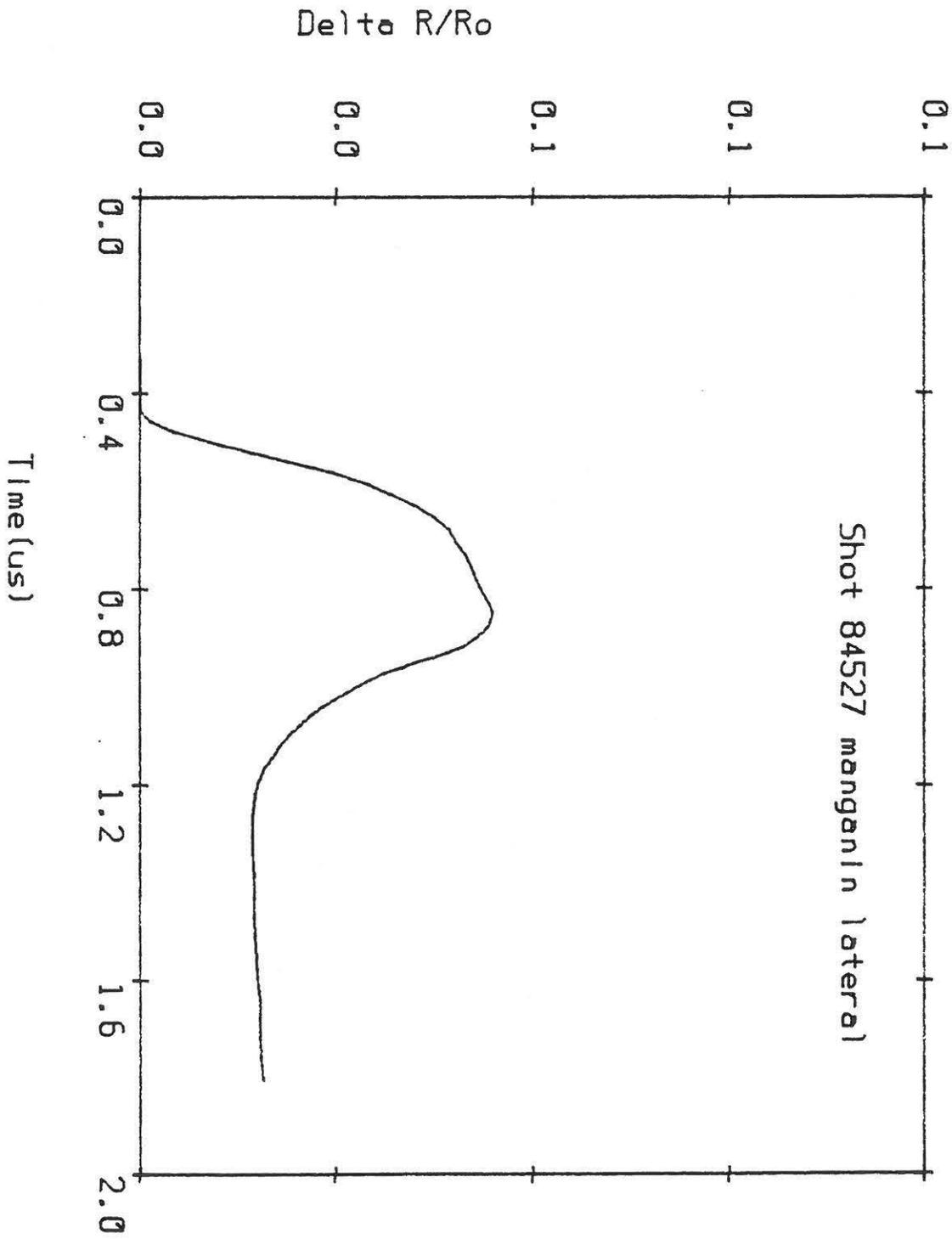
Gauges Embedded in Matrix: One in-groove longitudinal and  
one in groove lateral.



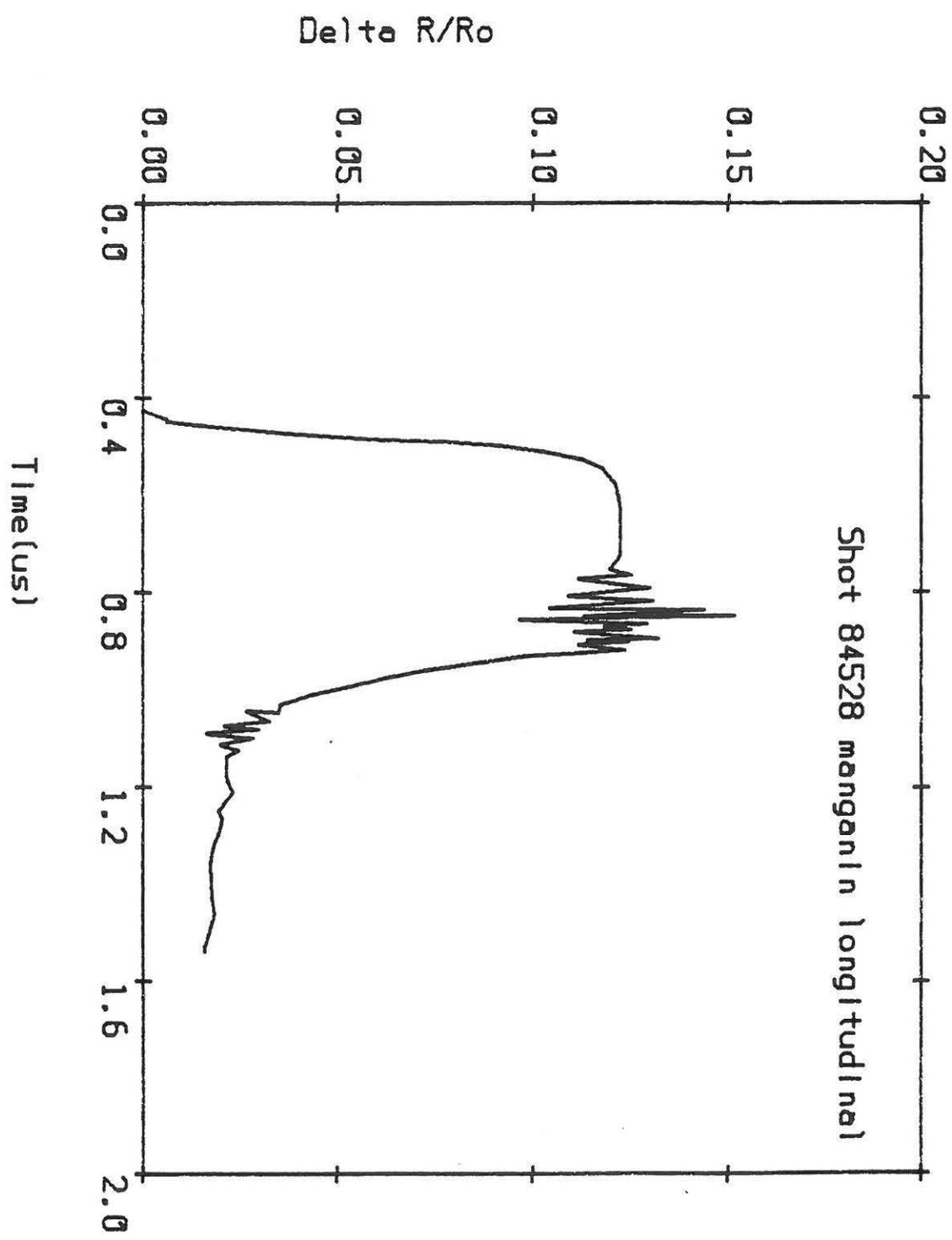


Shot Number:	84527
Projectile Velocity:	0.258 mm/ $\mu$ s
Shock Stress:	55.2 kbar
Impactor Material:	Vistal
Impactor Thickness:	2.54 mm
Matrix Material:	Vistal
Longitudinal Gauge Depth in Matrix:	2 mm
Lateral Gauge Depth in Matrix:	3 mm
Gauges Embedded in Matrix:	One in-groove longitudinal and one in-groove lateral.

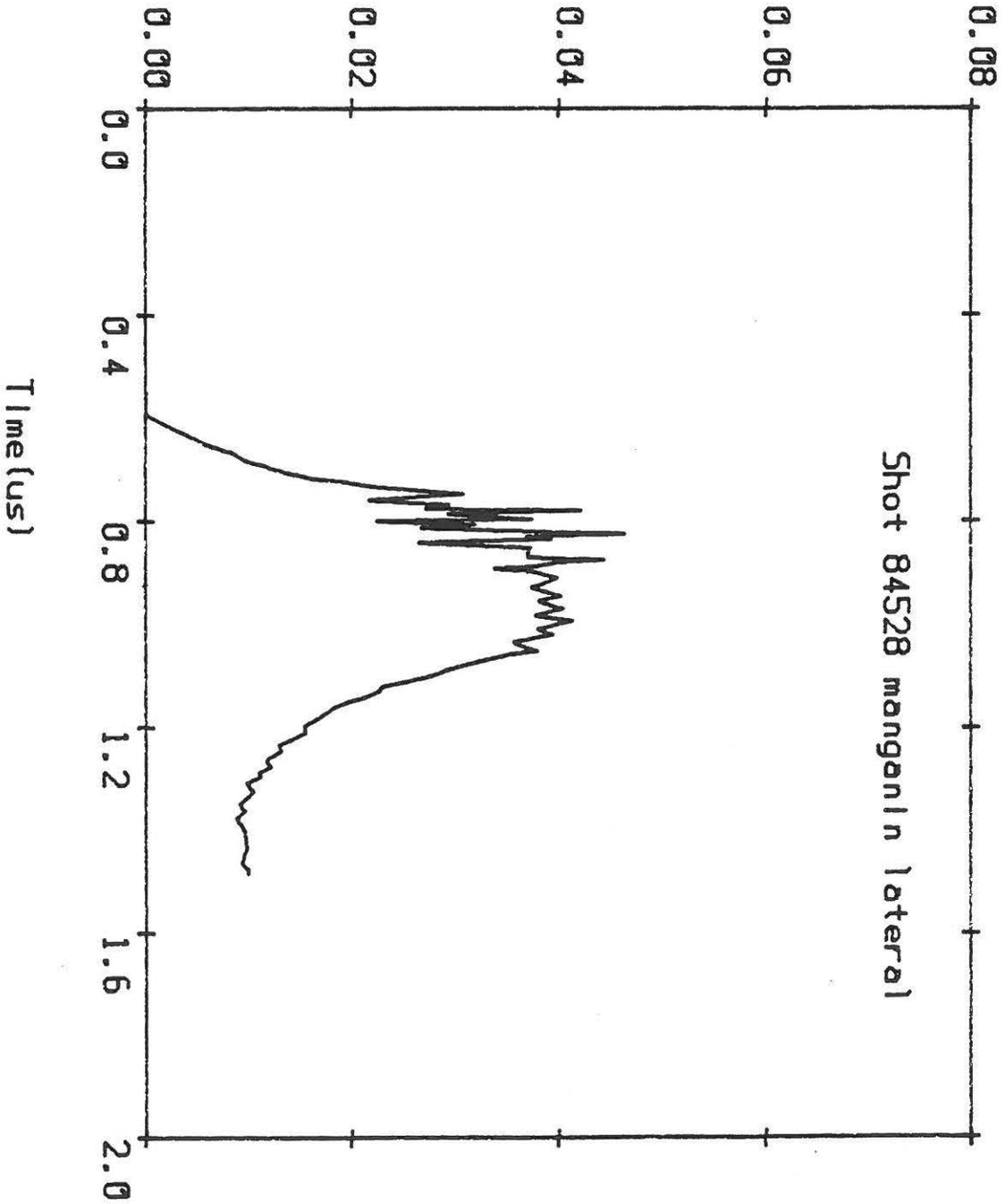




Shot Number:	84528
Projectile Velocity:	0.199 mm/ $\mu$ s
Shock Stress:	42.6 kbar
Impactor Material:	Vistal
Impactor Thickness:	2.54 mm
Matrix Material:	Vistal
Longitudinal Gauge Depth in Matrix:	2 mm
Lateral Gauge Depth in Matrix:	3 mm
Gauges Embedded in Matrix:	One in-groove longitudinal and one in-groove lateral.

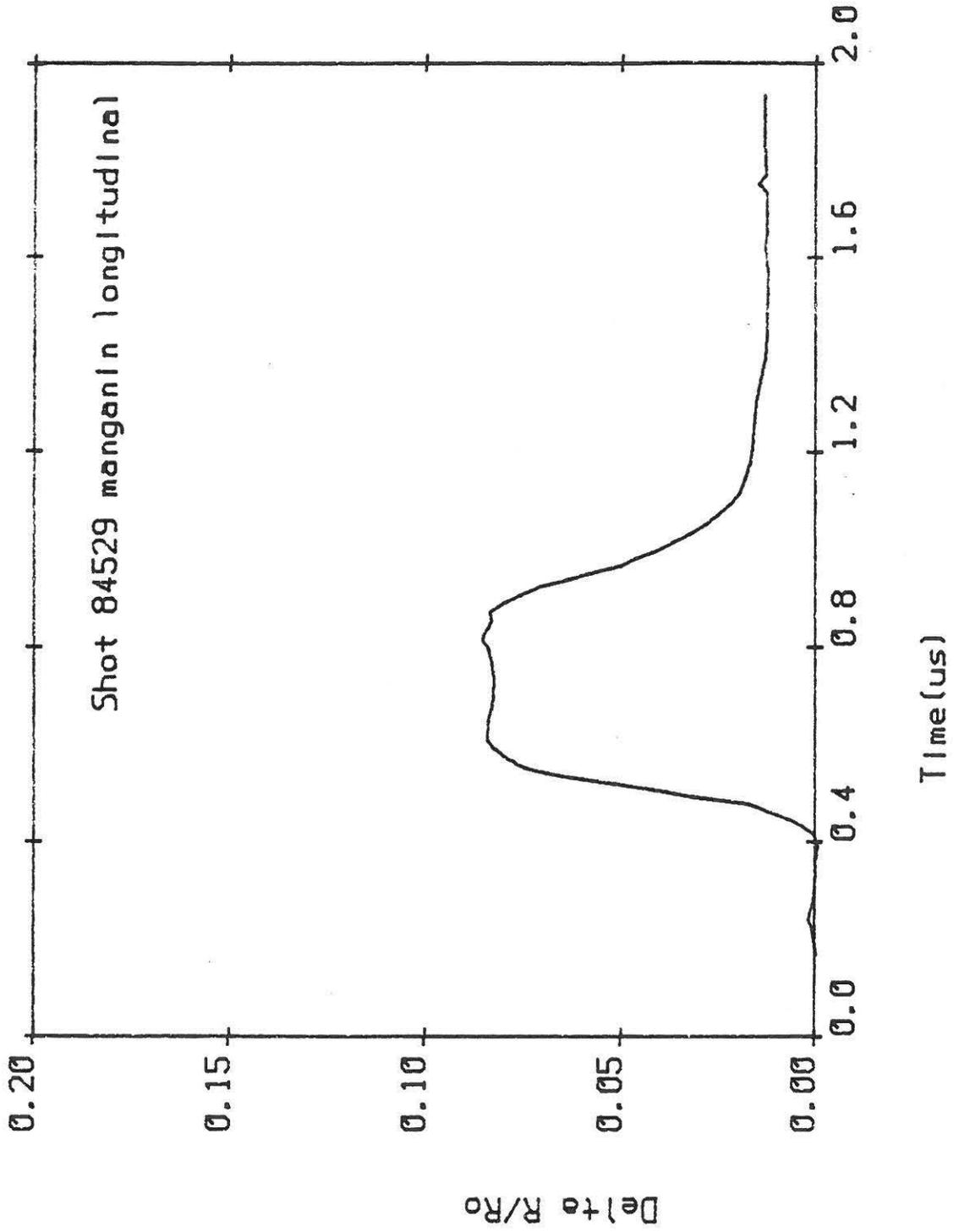


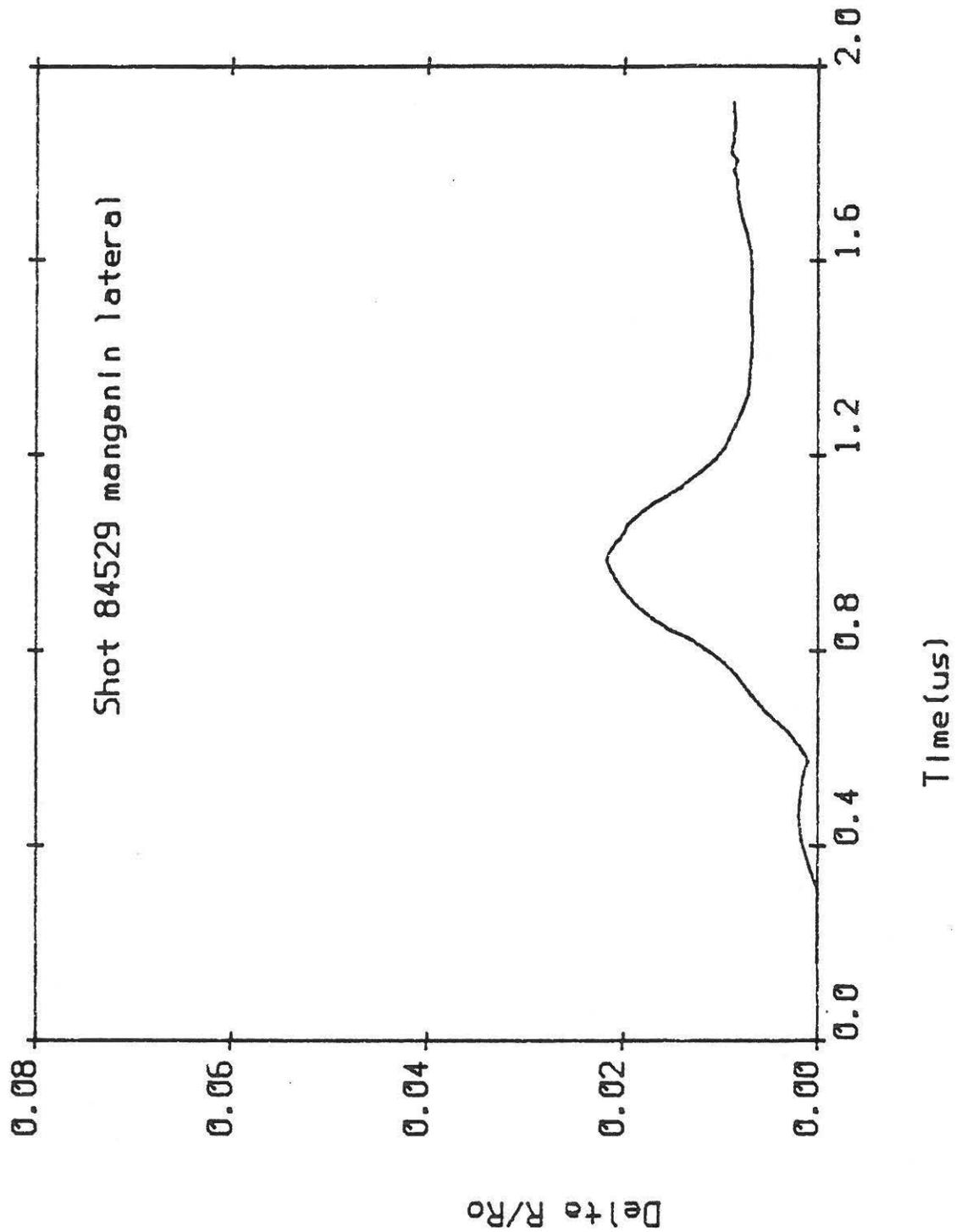
Delta R/Ro



Shot Number: 84529  
Projectile Velocity: 0.153 mm/ $\mu$ s  
Shock Stress: 32.6 kbar  
Impactor Material: Vistal  
Impactor Thickness: 2.54 mm  
Matrix Material: Vistal

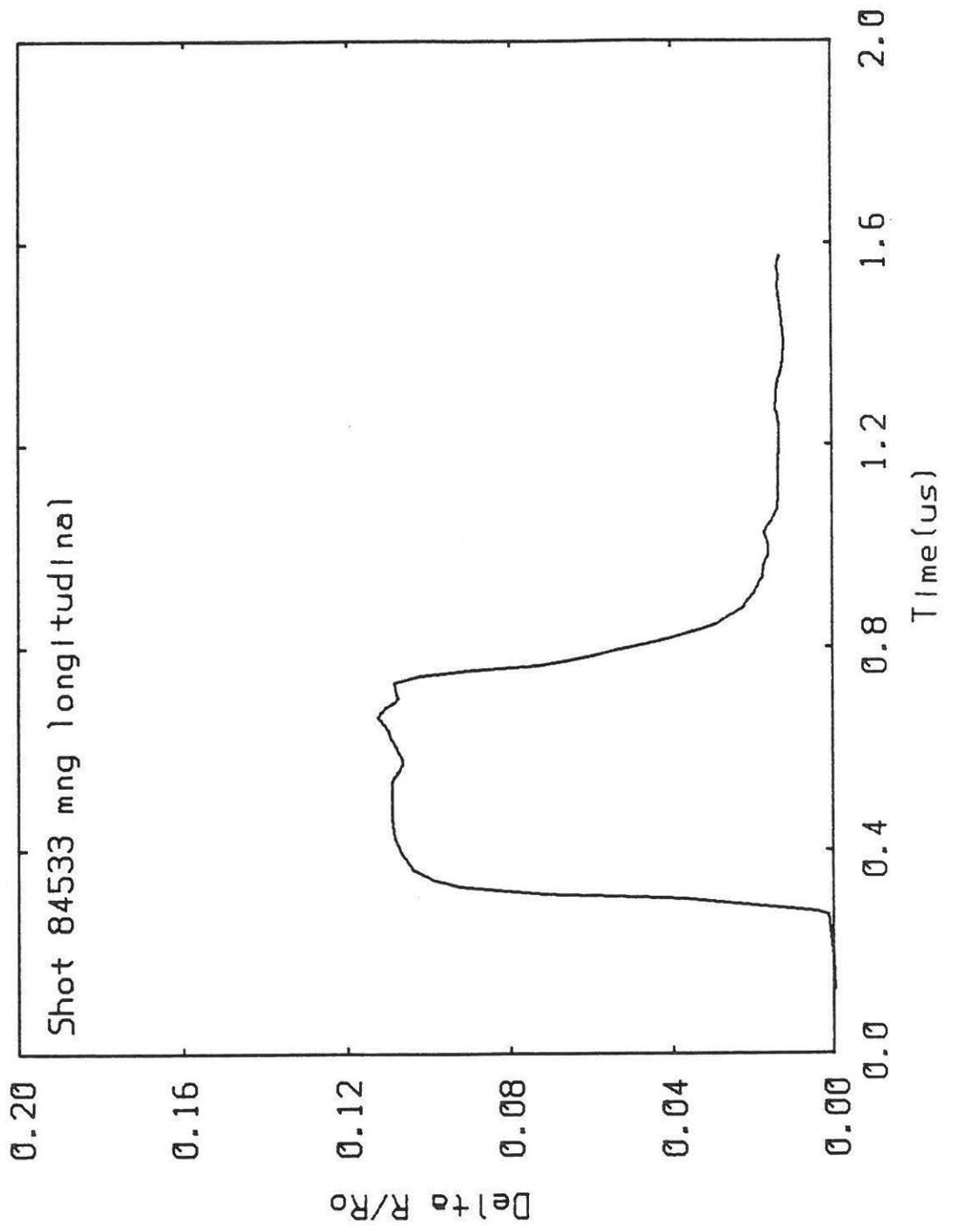
Longitudinal Gauge Depth in Matrix: 2 mm  
Lateral Gauge Depth in Matrix: 3 mm  
Gauges Embedded in Matrix: One in-groove longitudinal and  
one in-groove lateral.

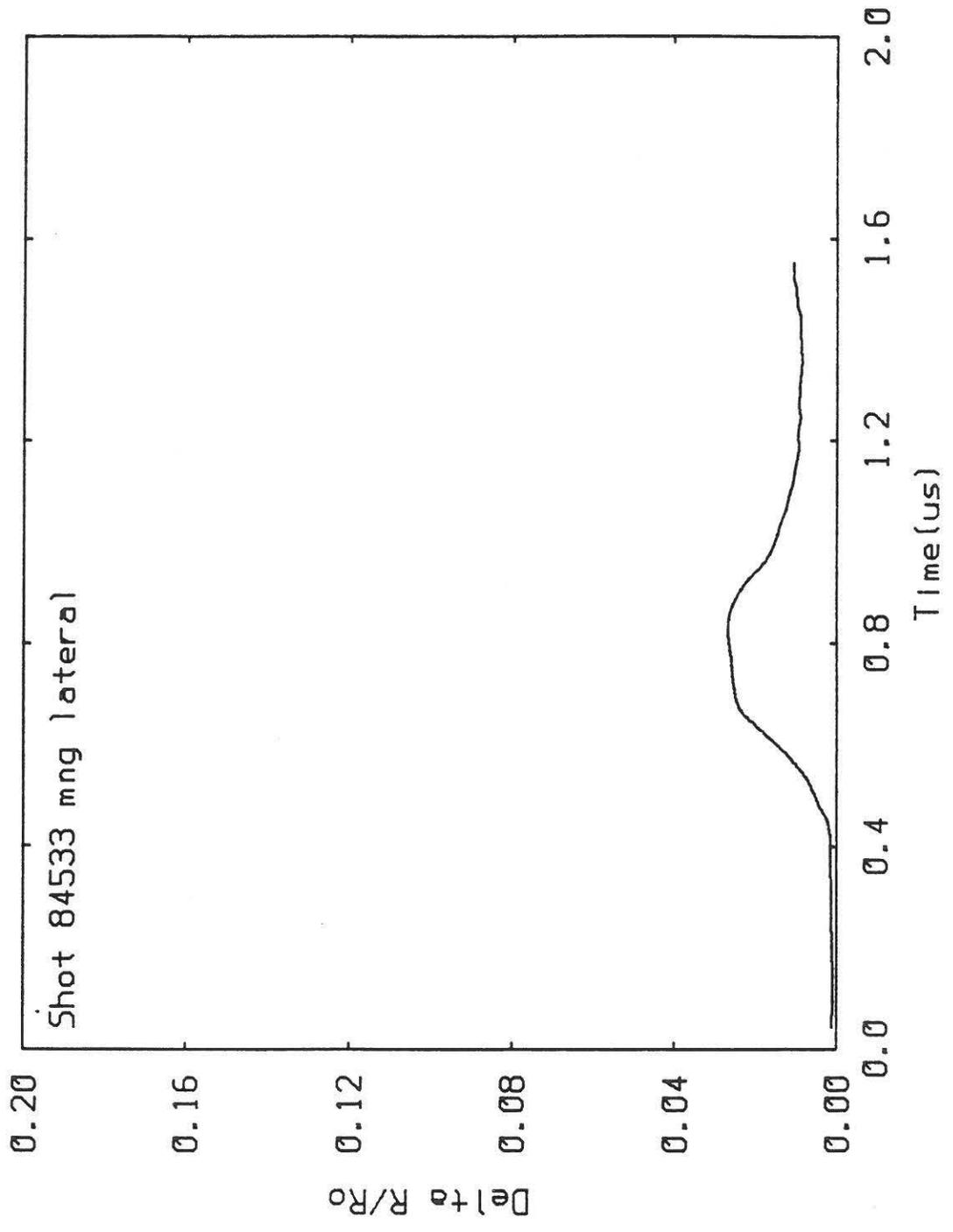




Shot Number: 84533  
Projectile Velocity: 0.19 mm/ $\mu$ s  
Shock Stress: 40.7 kbar  
Impactor Material: Vistal  
Impactor Thickness: 2.54 mm  
Matrix Material: Vistal

Longitudinal Gauge Depth in Matrix: 2 mm  
Lateral Gauge Depth in Matrix: 3 mm  
Gauges Embedded in Matrix: One in-groove longitudinal and  
one in-groove lateral.



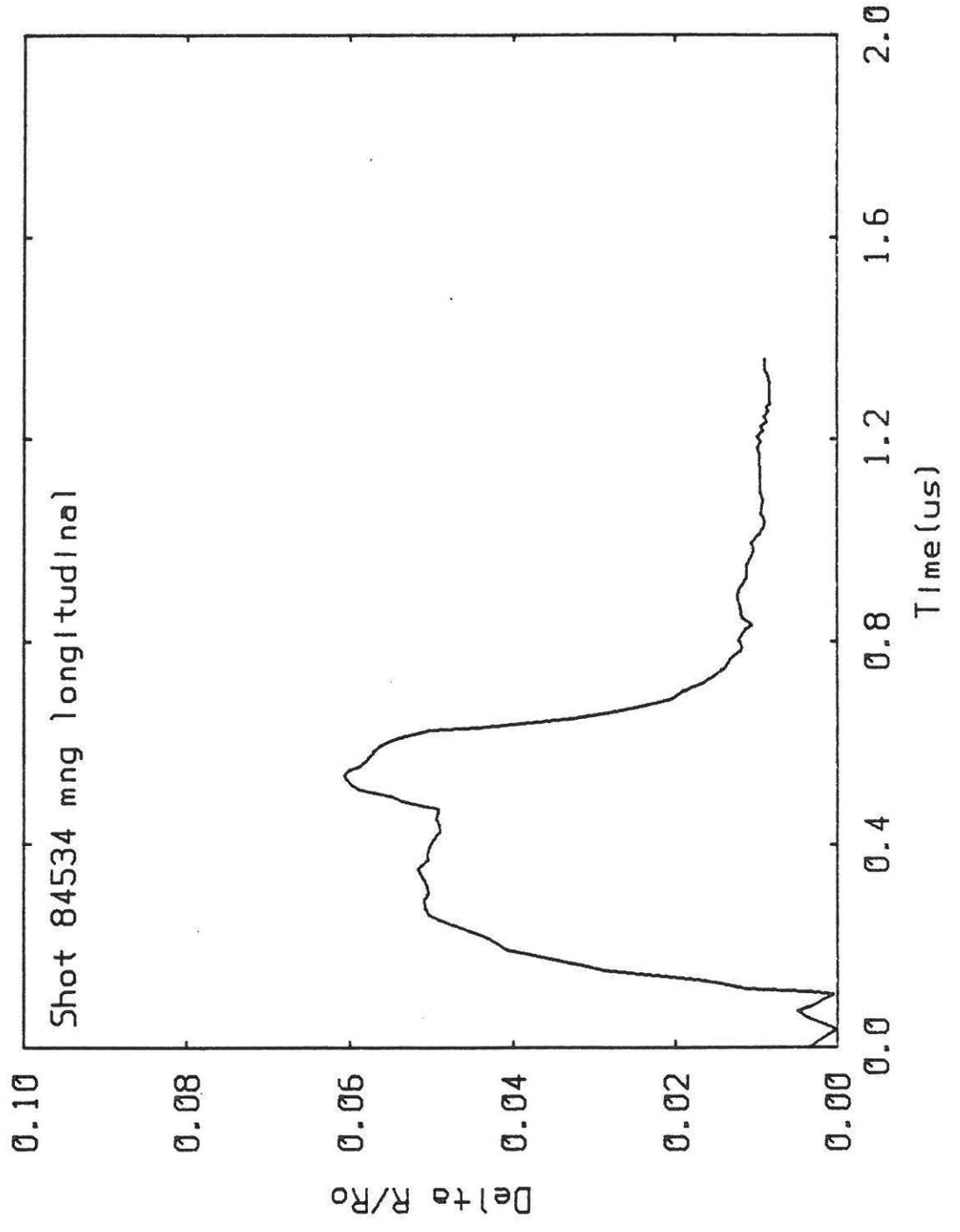


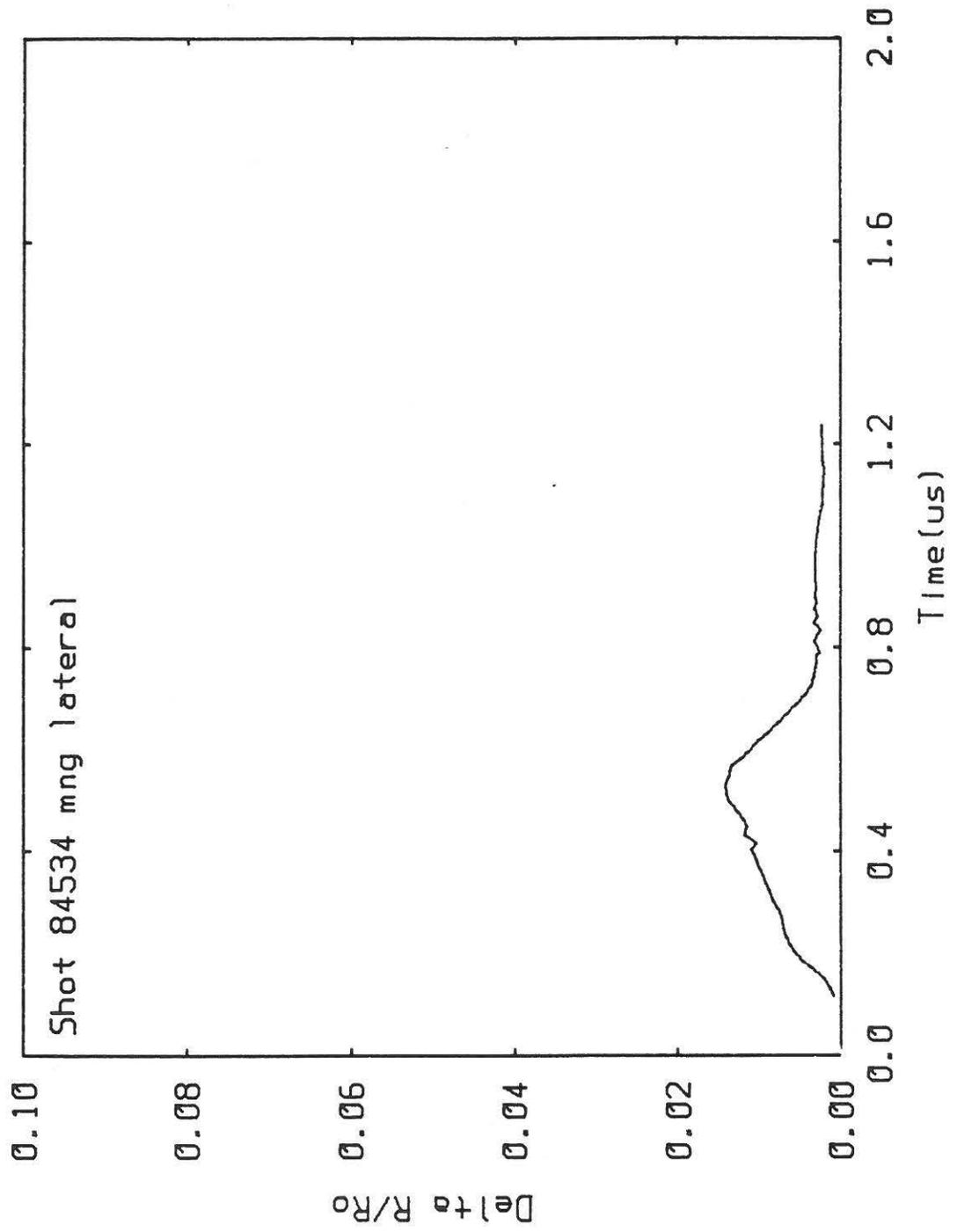
Shot Number: 84534  
Projectile Velocity: 0.21 mm/ $\mu$ s  
Shock Stress: 19.9 kbar  
Impactor Material: Fused silica  
Impactor Thickness: 1.44 mm  
Matrix Material: Vistal

Longitudinal Gauge Depth in Matrix: 2 mm

Lateral Gauge Depth in Matrix: 3 mm

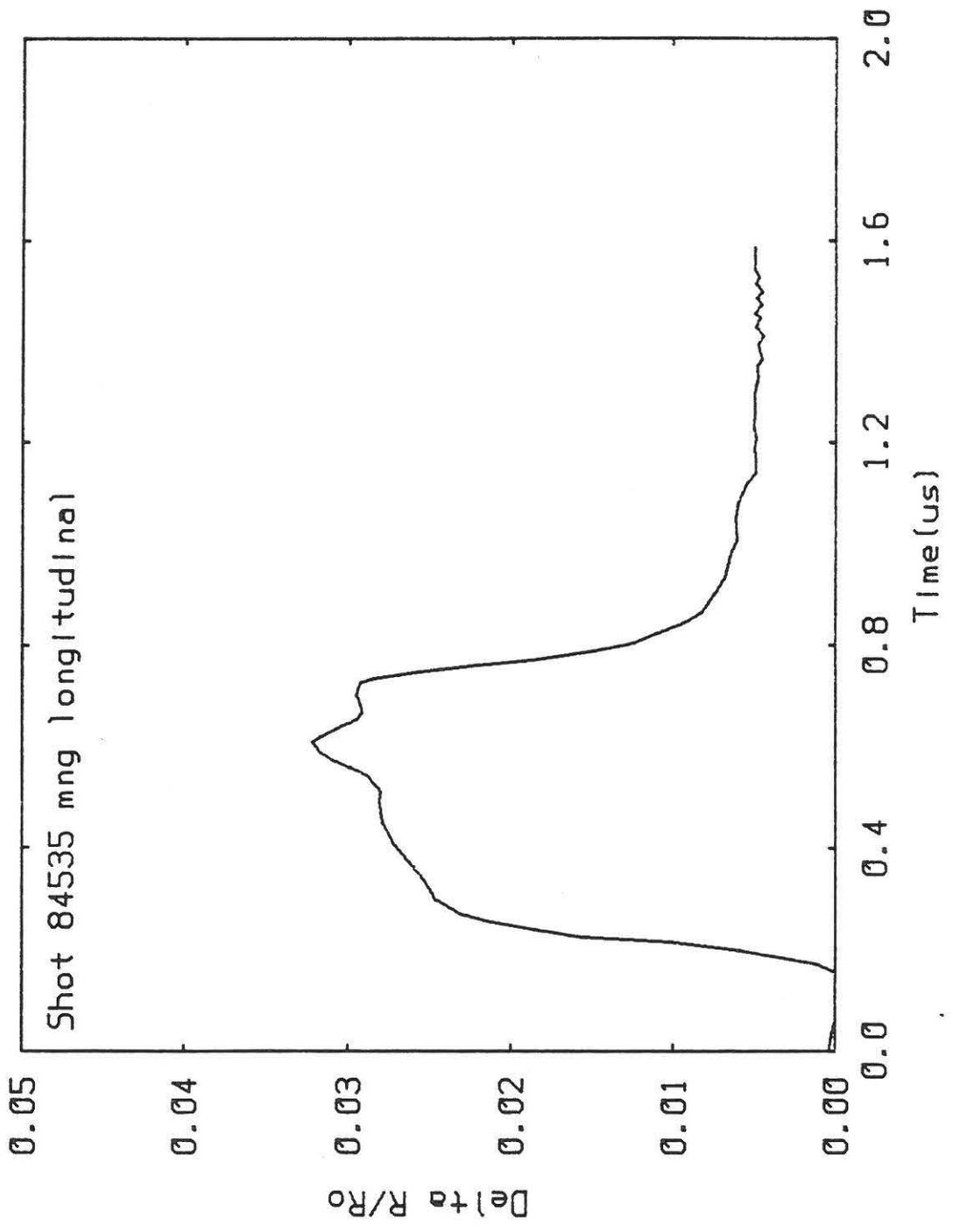
Gauges Embedded in Matrix: One in-groove longitudinal and  
one in-groove lateral.

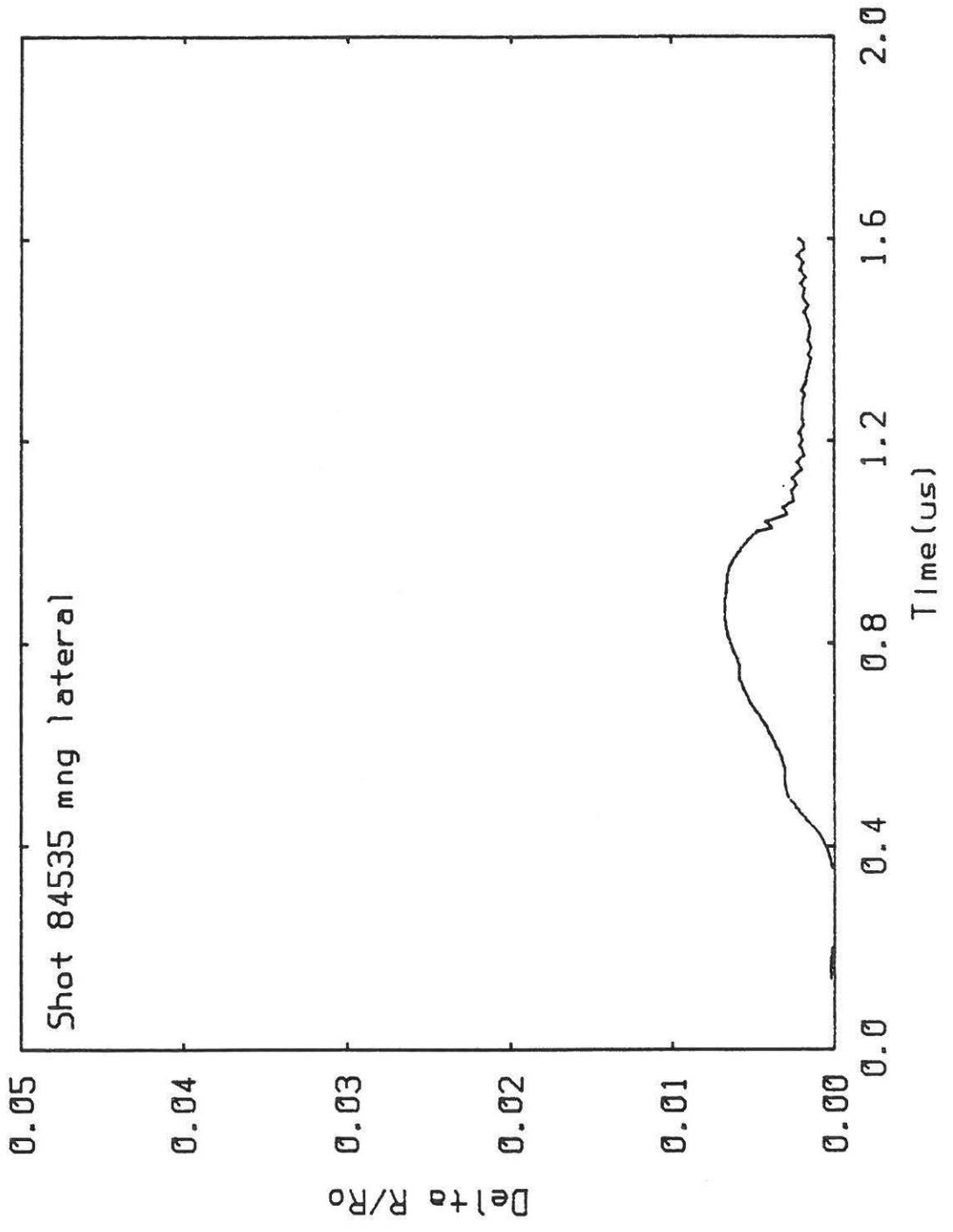




Shot Number: 84535  
Projectile Velocity: 0.109 mm/ $\mu$ s  
Shock Stress: 10.3 kbar  
Impactor Material: Fused Silica  
Impactor Thickness: 1.61 mm  
Matrix Material: Vista1

Longitudinal Gauge Depth in Matrix: 2 mm  
Lateral Gauge Depth in Matrix: 3 mm  
Gauges Embedded in Matrix: One in-groove longitudinal and  
one in-groove lateral.

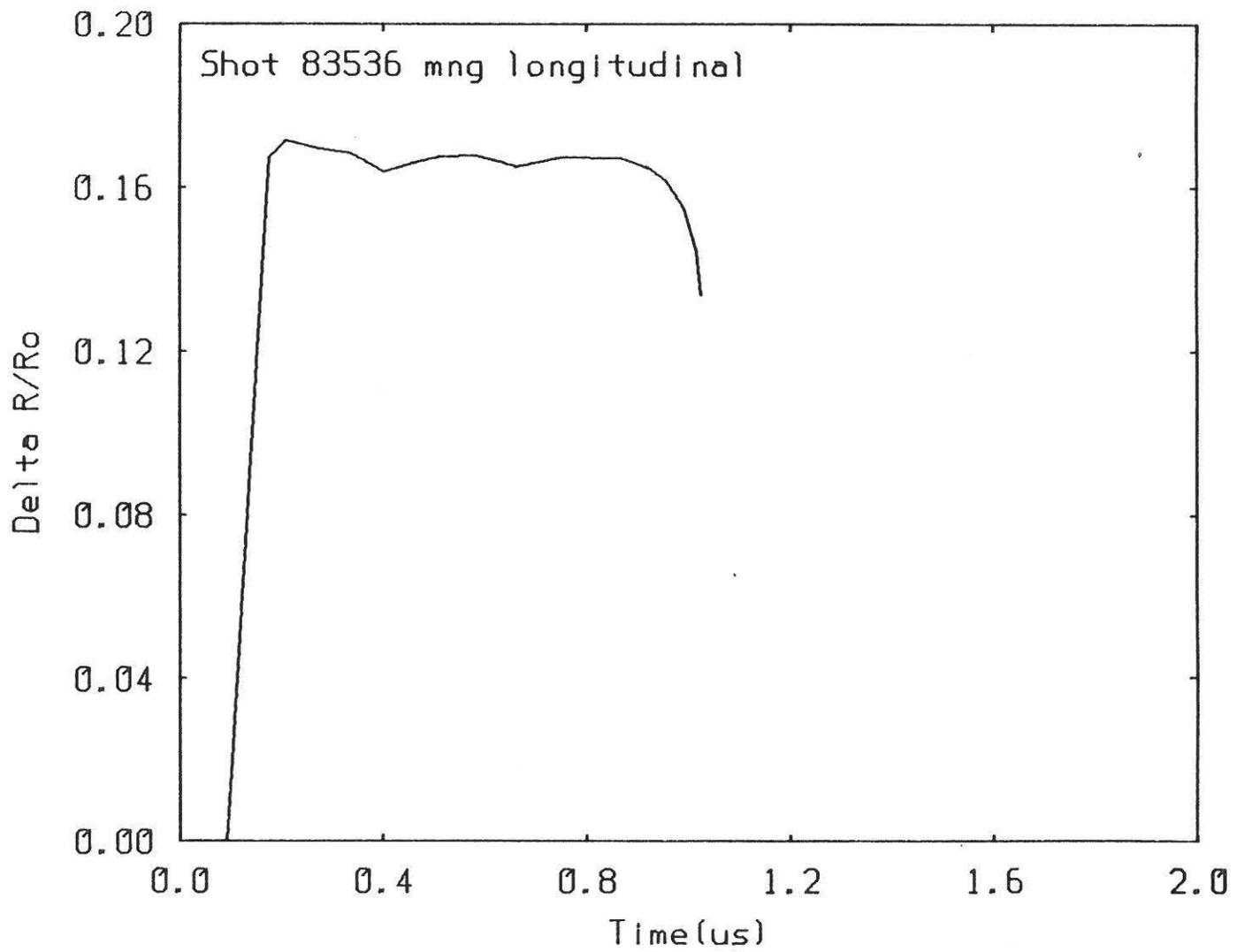


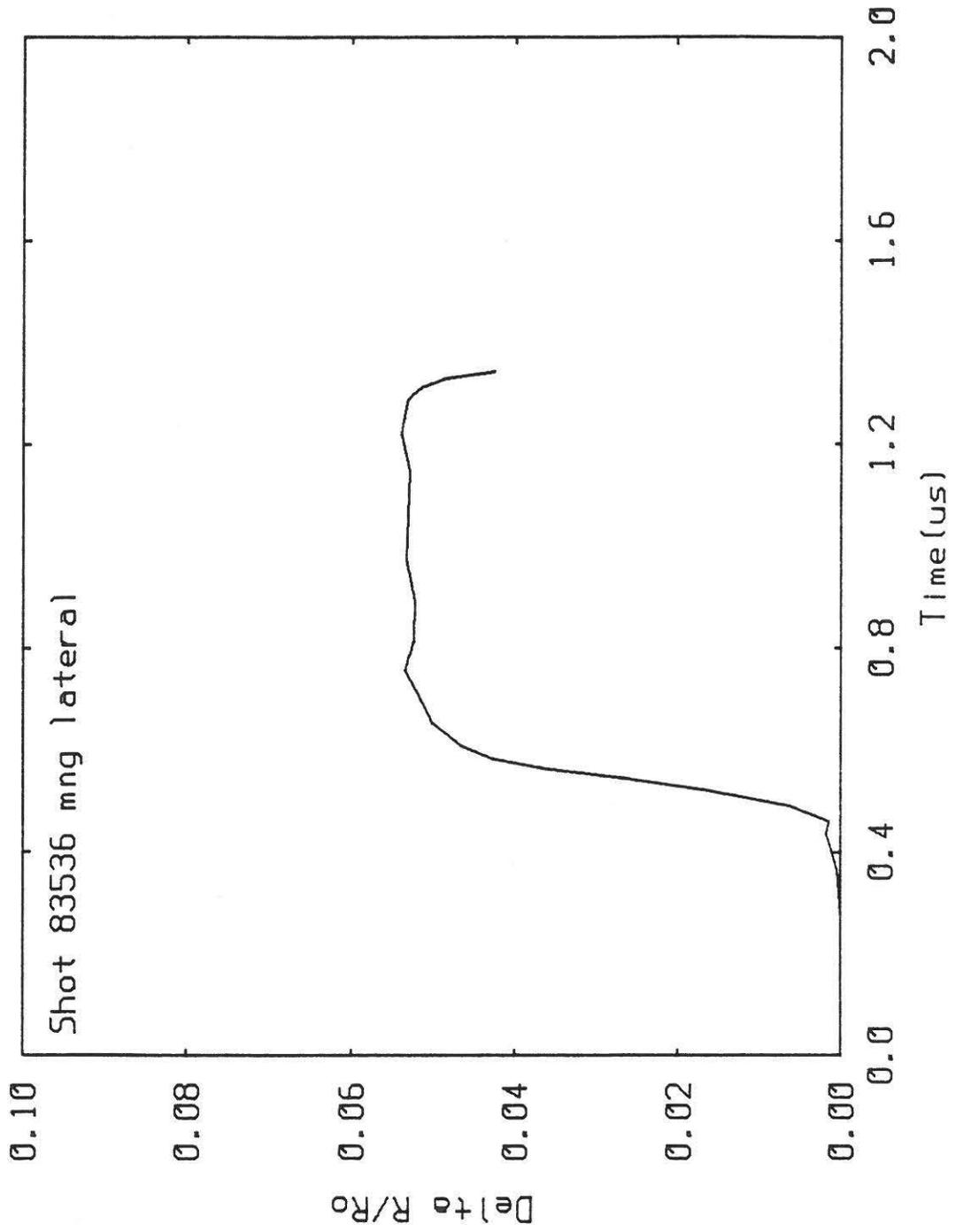


Shot Number: 83536  
Projectile Velocity: 0.322 mm/ $\mu$ s  
Shock Stress: 68.9 kbar  
Impactor Material: Vistal  
Impactor Thickness: 6.1 mm  
Matrix Material: Vistal

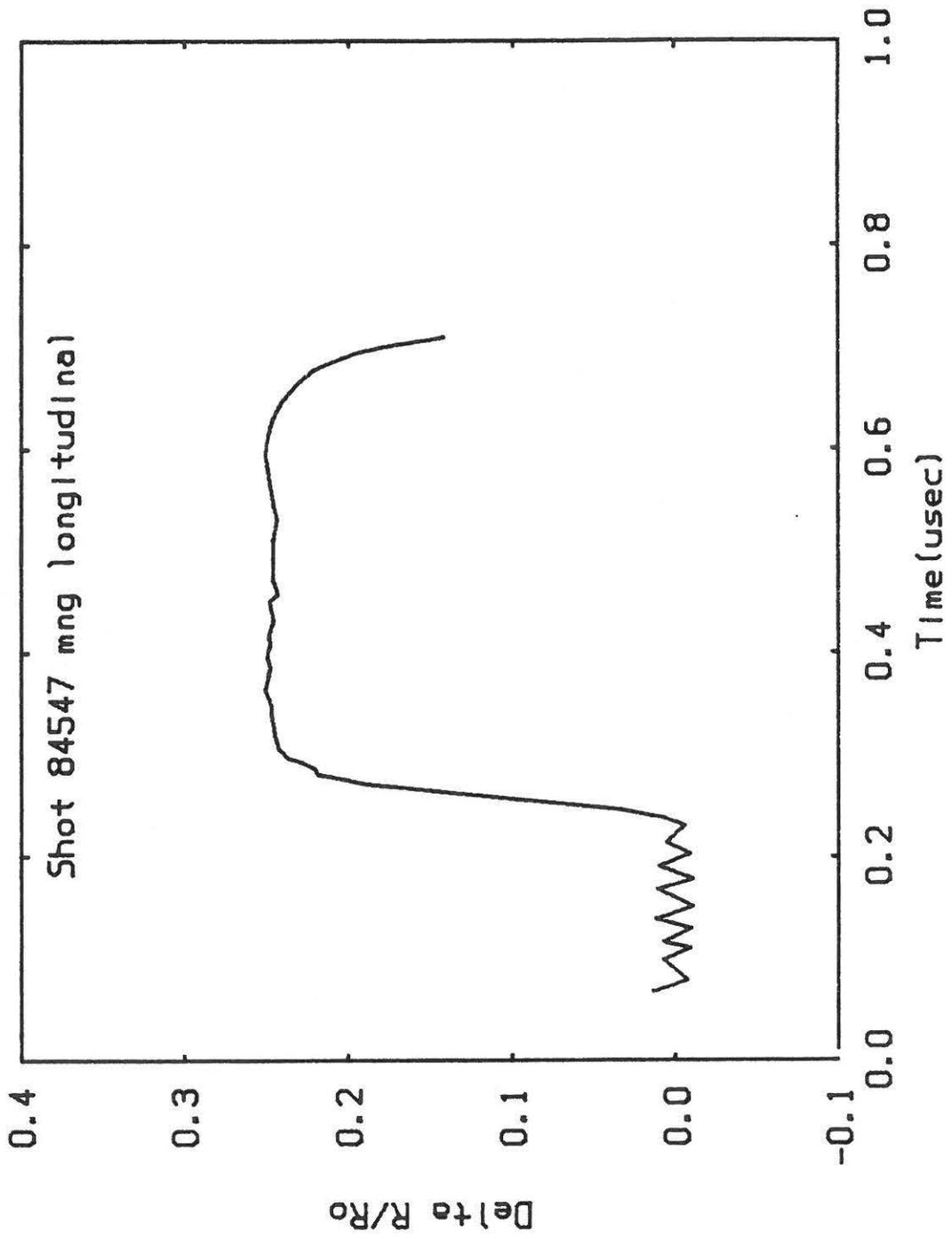
Longitudinal Gauge Depth in Matrix: 2.56 mm  
Lateral Gauge Depth in Matrix: 3.56 mm  
Gauges Embedded in Matrix: One in-groove longitudinal and  
one in-groove lateral.

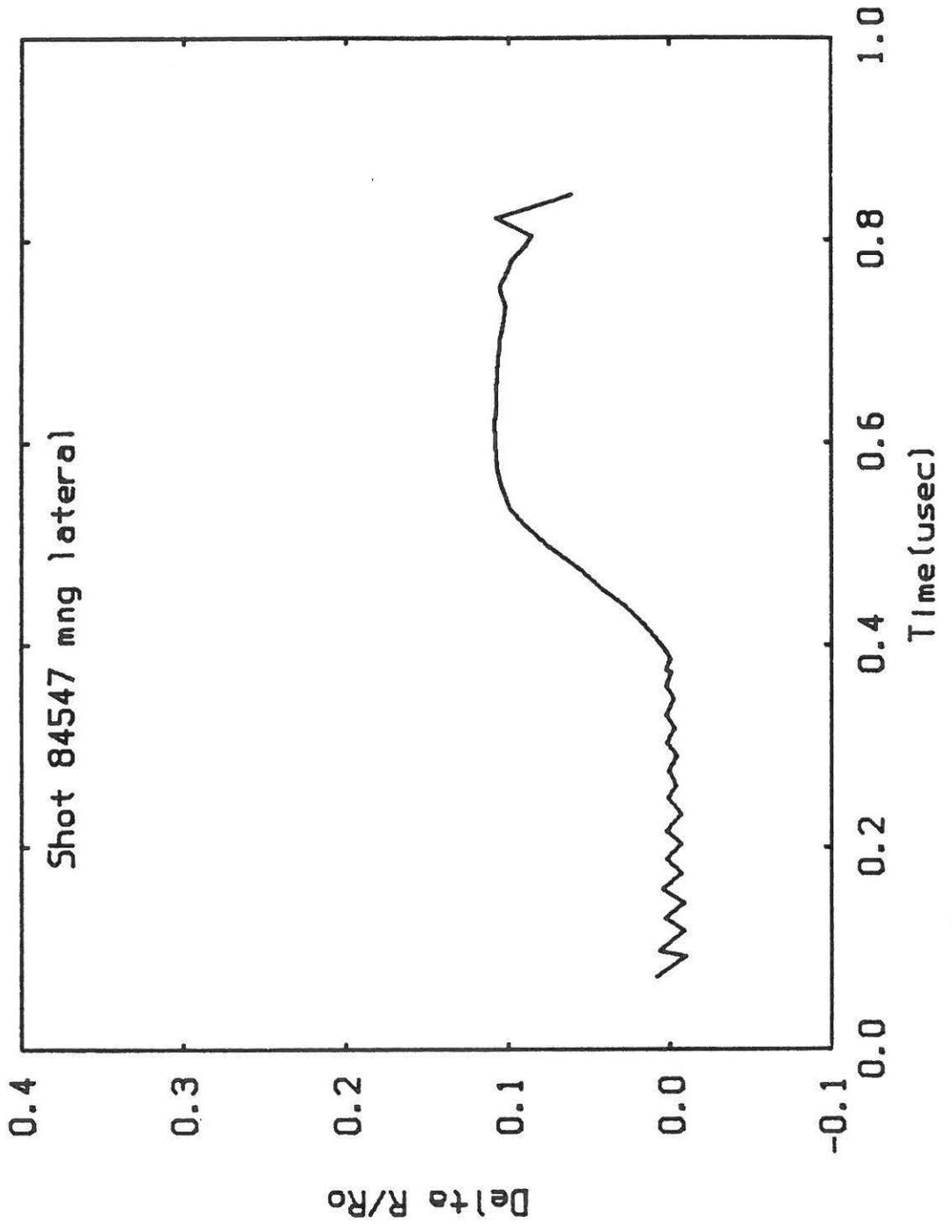
Remarks: This experiment was done to test the  
design of the target.



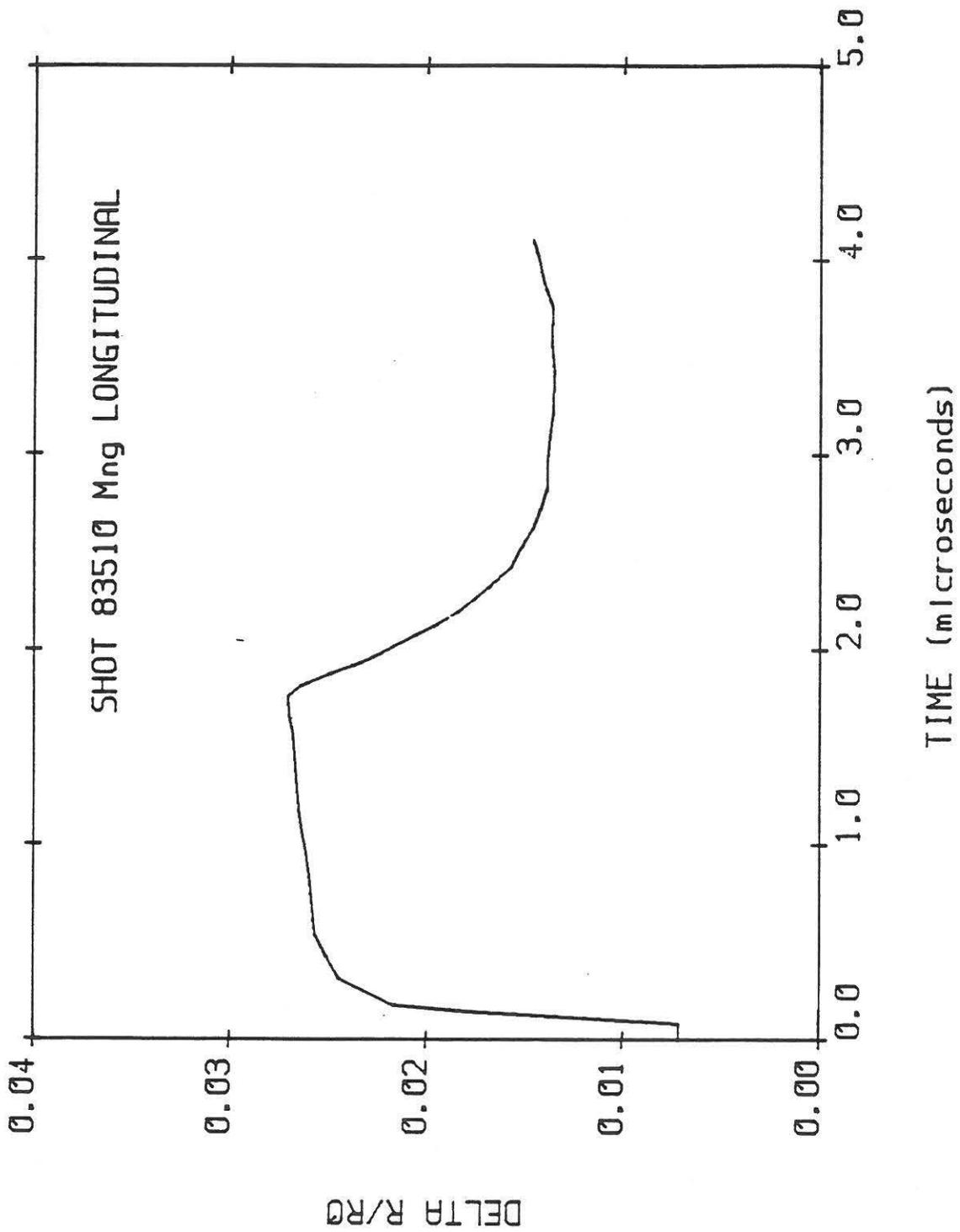


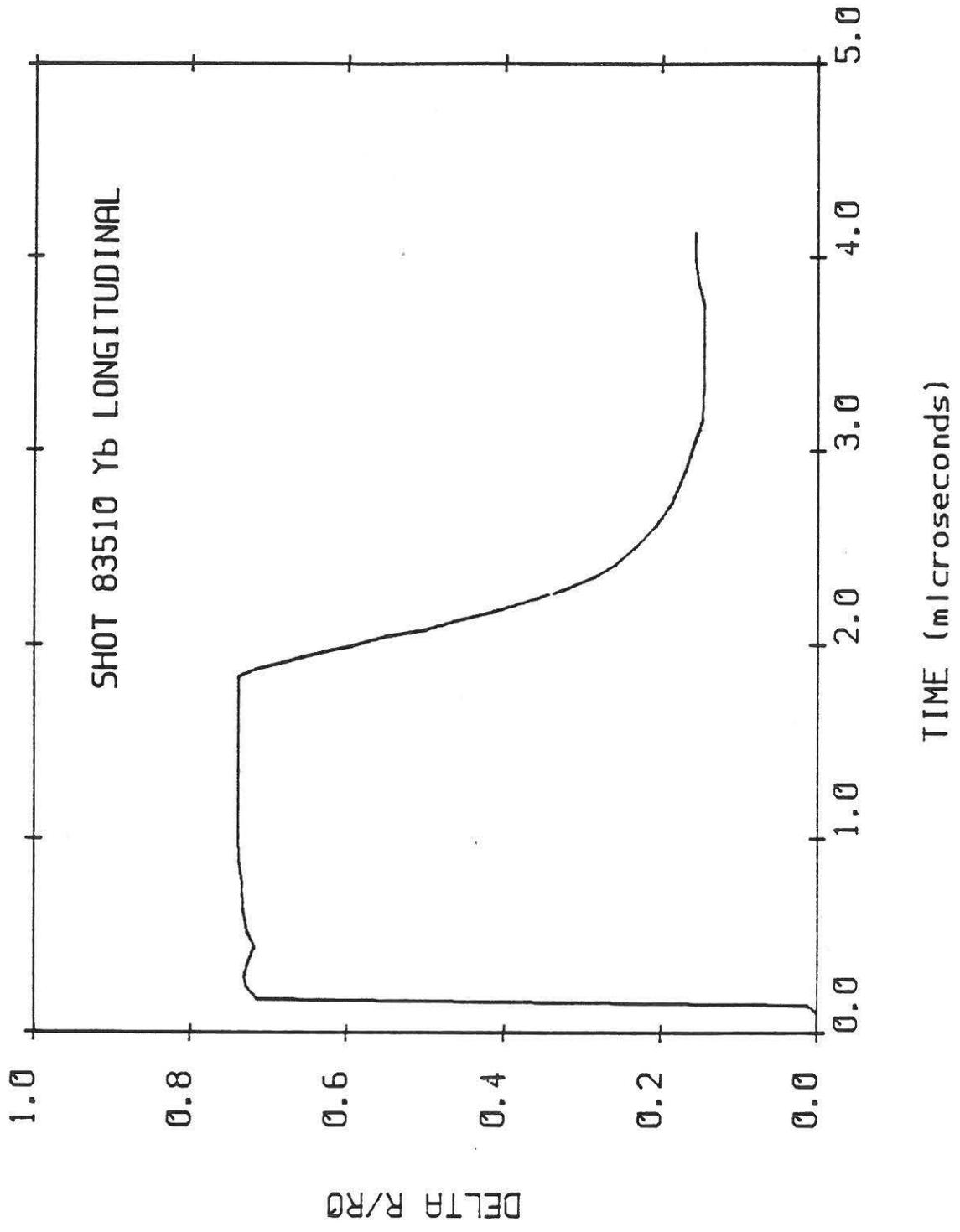
Shot Number:	84547
Projectile Velocity:	0.463 mm/ $\mu$ s
Shock Stress:	90.68 kbar
Impactor Material:	Vista1
Impactor Thickness:	2.54 mm
Matrix Material:	Vista1
Longitudinal Gauge Depth in Matrix:	2 mm
Lateral Gauge Depth in Matrix:	3 mm
Gauges Embedded in Matrix:	One in-groove longitudinal manganin and one in-groove lateral manganin

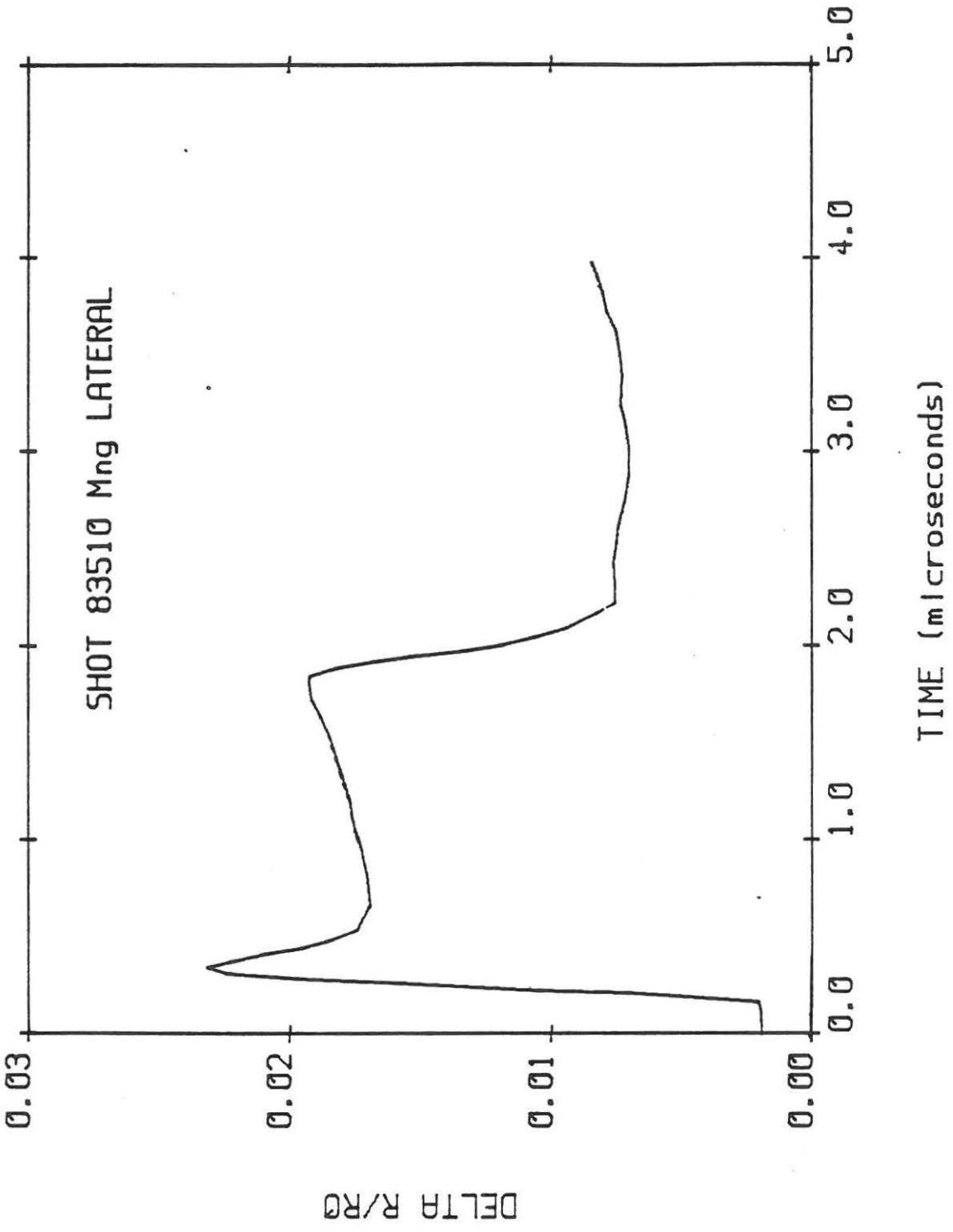




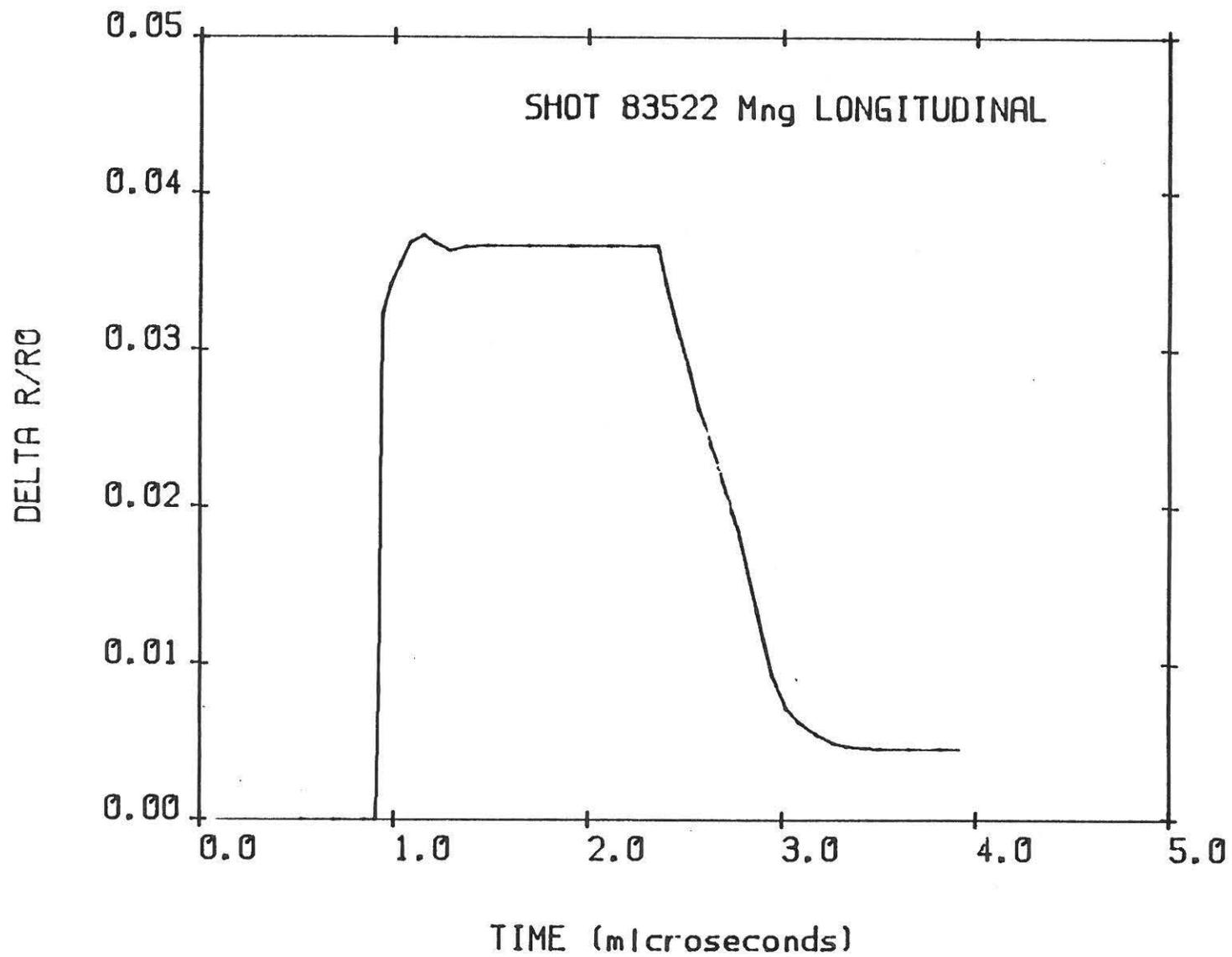
Shot Number: 83-510  
Projectile Velocity: 0.45 mm/ $\mu$ s  
Shock Stress: 8.4 kbar  
Impactor Material: PMMA  
Impactor Thickness: 2.95 mm  
Gauge Depth in PMMA Matrix: 0.96 for longitudinal gauge  
1.0 for lateral gauge.  
Gauges Embedded in PMMA Matrix: 4 gauges  
one longitudinal ytterbium, one  
lateral ytterbium; one longitudinal  
manganin and one lateral manganin.  
Remarks: We did not obtain resistance change  
profiles for lateral Yb gauge because  
power supply did not work.

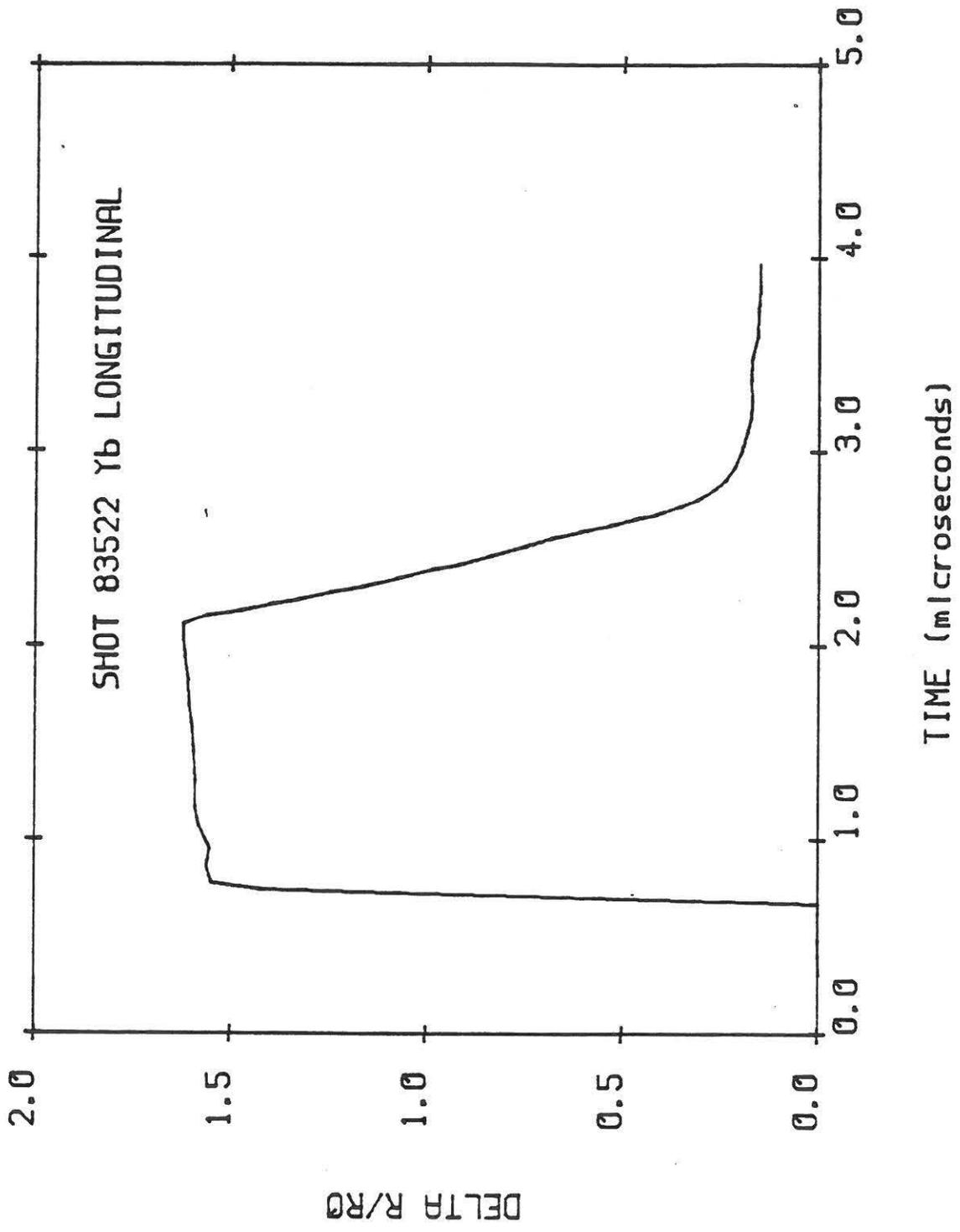


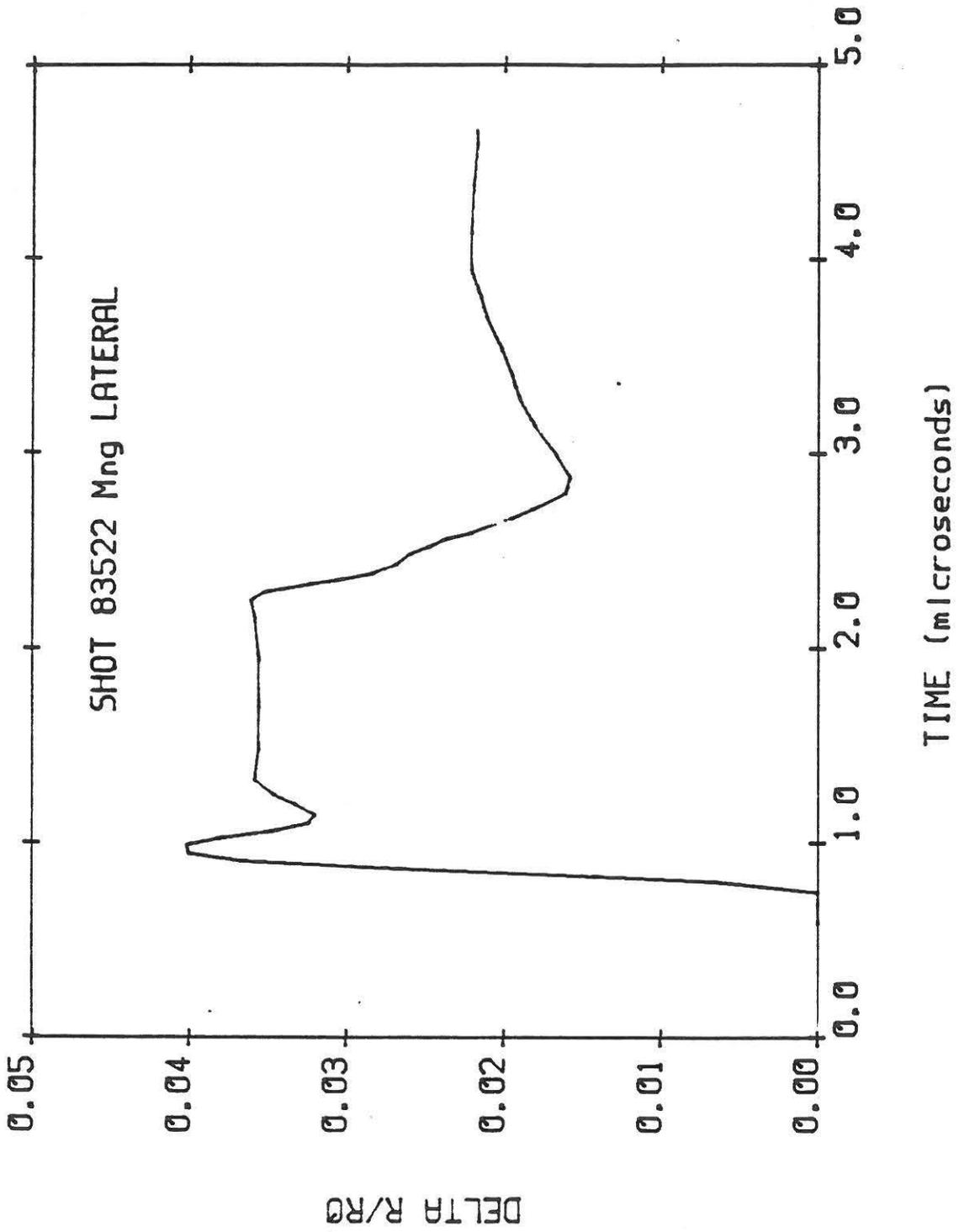


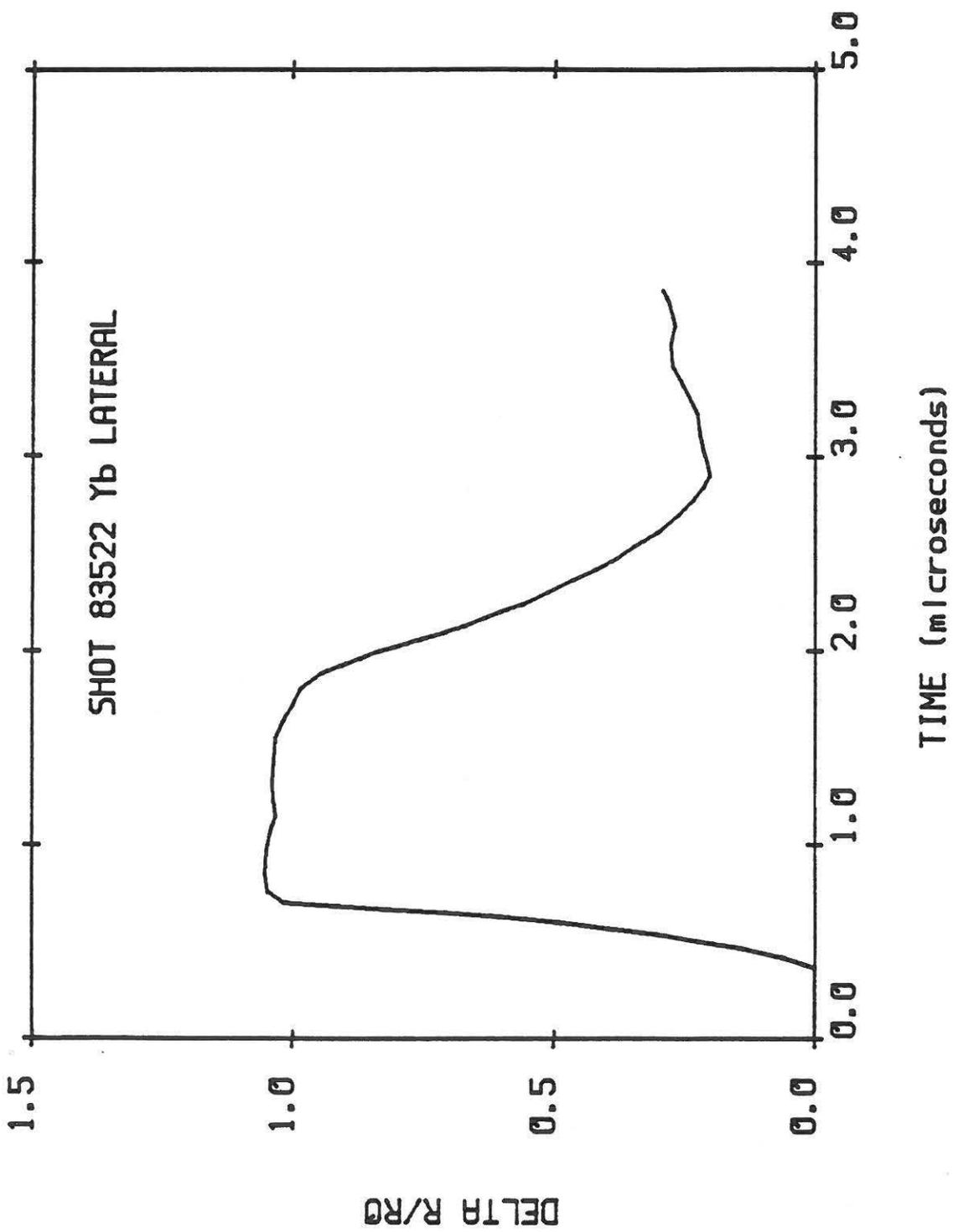


Shot Number: 83-522  
Projectile Velocity: 0.788 mm/ $\mu$ s  
Shock Stress: 15.1 kbar  
Impactor Material: PMMA  
Impactor Thickness: 2.84 mm  
Gauge Depth in PMMA Matrix: 1.01 mm  
Gauges Embedded in PMMA Matrix: 4 gauges  
one longitudinal and one lateral  
ytterbium; one longitudinal and  
one lateral manganin.

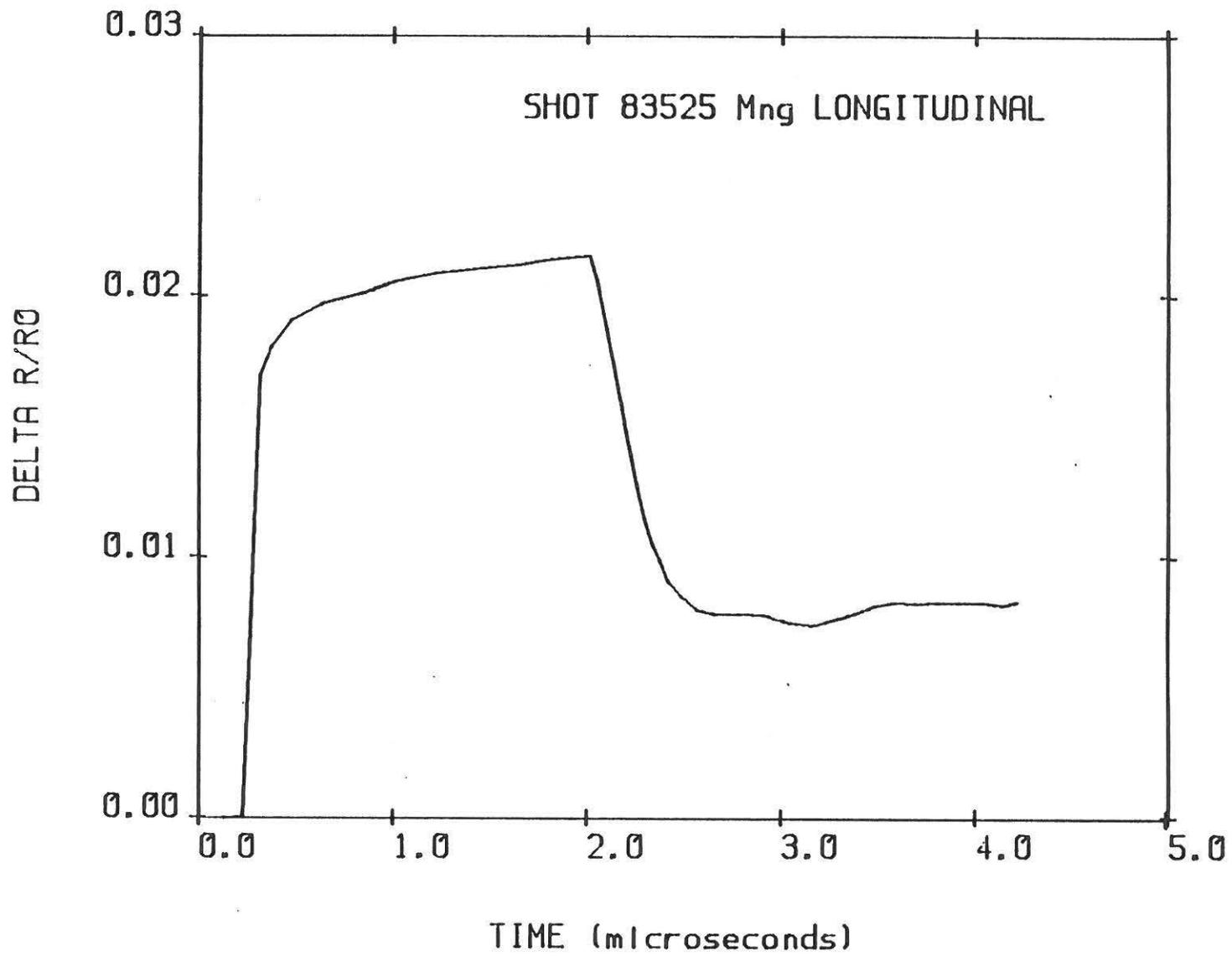


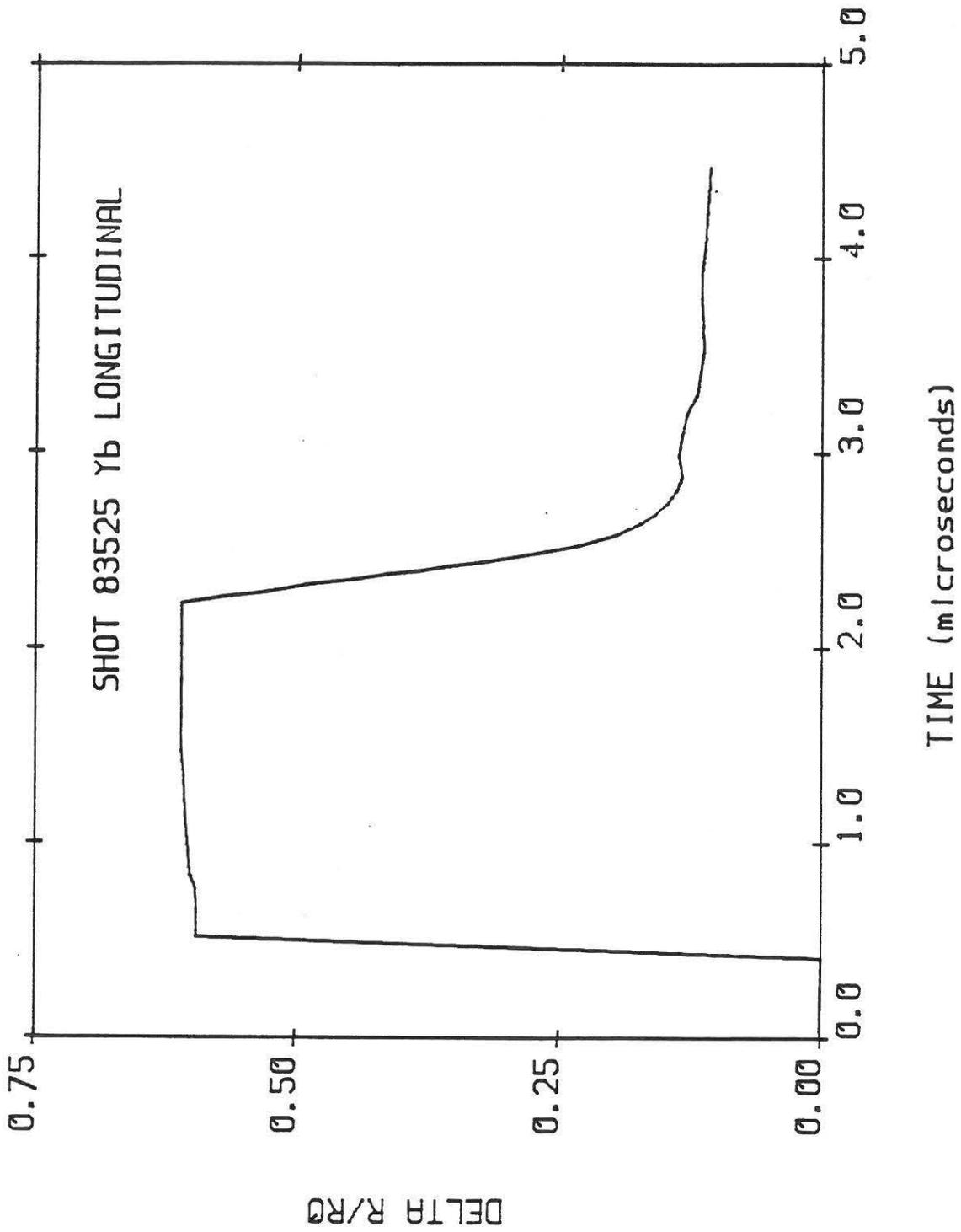


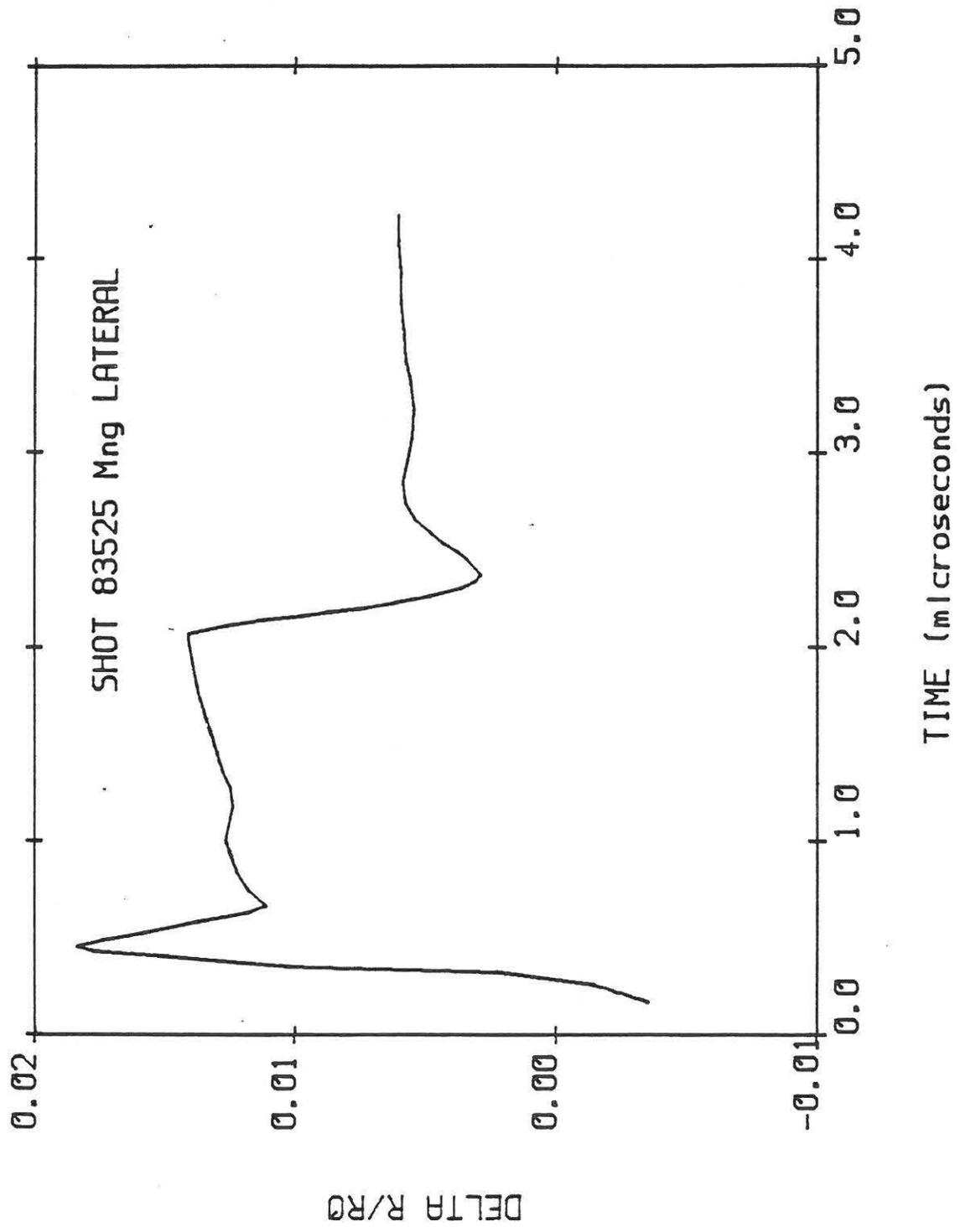


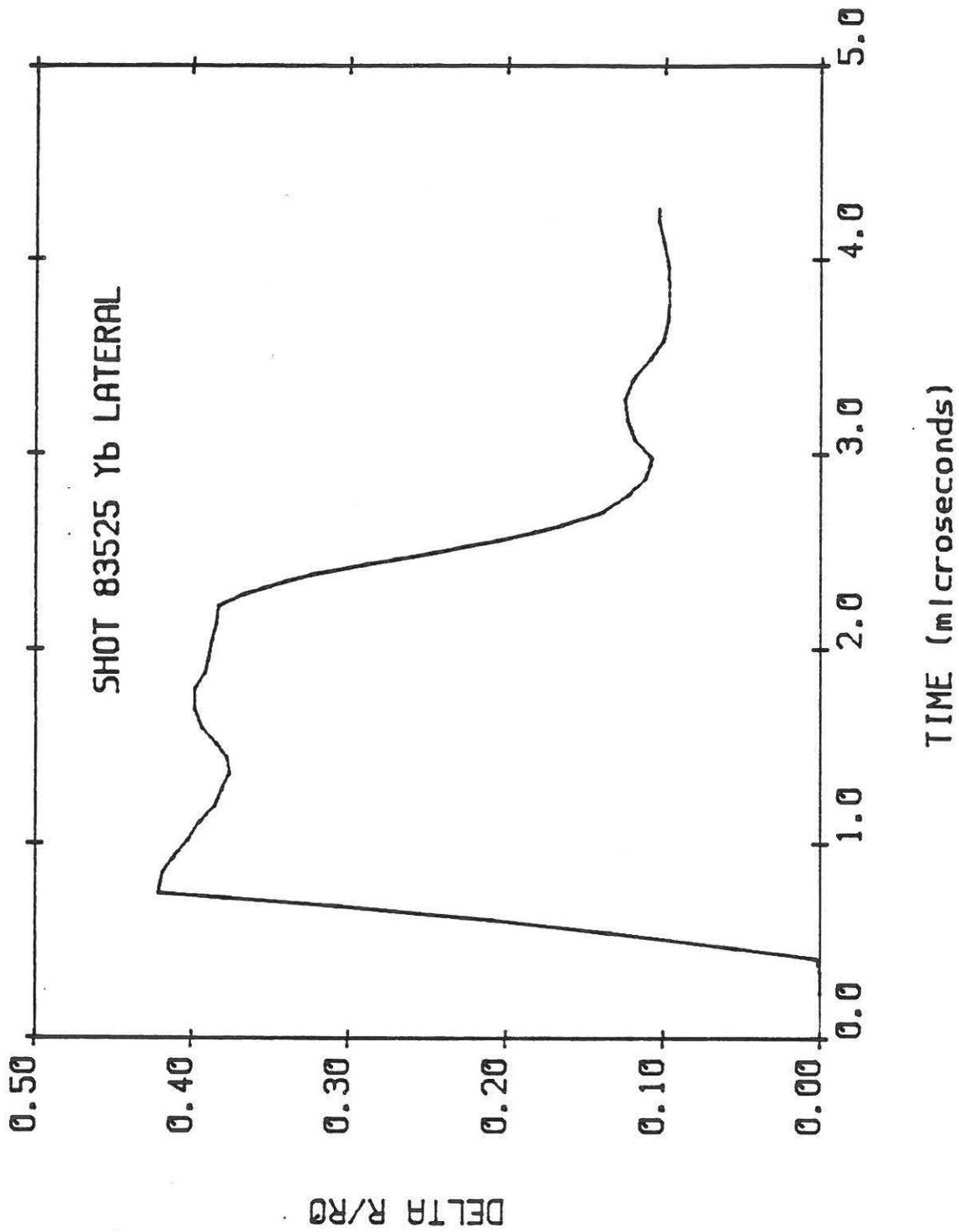


Shot Number: 83-525  
Projectile Velocity: 0.398 mm/ $\mu$ s  
Shock Stress: 7.4 kbar  
Impactor Material: PMMA  
Impactor Thickness: 3.048 mm  
Gauge Depth in PMMA Matrix: 0.955 mm  
Gauges Embedded in PMMA Matrix: 4 gauges  
one longitudinal and one lateral  
ytterbium; one longitudinal and  
one lateral manganin.









Shot Number: 83-526  
Projectile Velocity: 0.605 mm/ $\mu$ s  
Shock Stress: 18.4 kbar  
Impactor Material: Fused silica  
Impactor Thickness: 6.35 mm  
Gauge Depth in PMMA Matrix: 0.96 mm  
Gauges Embedded in PMMA Matrix: 4 gauges  
one longitudinal and one lateral  
ytterbium; one longitudinal and one  
lateral manganin.

Remarks: This experiment was designed to study step unloading response of the gauges. Only one step could be observed before the gauge was broken by rarefaction waves from the edges.

