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CONF-770650--1

"DICE THROW - OFF-SITE BLAST PREDICTIONS AND MEASUREMENTS"*

Final Report on Experiment No. 122

MASTER

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ABSTRACT

Predictions and measurements of distant propagations were made of airblasts from Project DICE THROW, including two Pre-DICE THROW events. The purpose was to identify, control, and document the off-site environmental impact from these large explosions. A weather-watch was maintained, using special meteorological observations, to assure that atmospheric acoustic refraction would not cause significant nuisance damage or hazard to surrounding communities. Weak propagation conditions prevailed during the two Pre-DICE THROW events. A moderately strong propagation directed toward the southeast from DICE THROW caused some disturbance in Tularosa and Alamogordo but no damage claims were submitted.

*This work was jointly supported by the Energy Research and Development Administration and the Department of Defense Nuclear Agency.

DISCLAIMER

INTRODUCTION

At the request of the Defense Nuclear Agency Field Command, Sandia Laboratories evaluated the potential for Project DICE THROW airblasts to hazard, damage, or irritate communities surrounding White Sands Missile Range (WSMR). Preliminary evaluations showed that under particular weather conditions, the nuisance damage threshold, often assumed to be near 400-Pa peak-to-peak pressure amplitude, could extend 80 km from the two Pre-DICE THROW calibration shots and over 135 km from the final DICE THROW event. Considering the exposed populations, it appeared that windows could be broken as far away as Albuquerque.

A weather-watch was instituted to determine what propagations could be expected at shot time and provide for delays in case such extreme conditions were encountered. Microbarograph pressure measurements were made in various communities to document the actual wave passage, for use in verification of predictions as well as validation or rejection of any damage claims that resulted.

As it turned out there were no atmospheric propagation problems associated with either calibration event, and only a moderately focused wave was ducted toward Tularosa and Alamogordo from DICE THROW. There may have been some minor damages from this final blast, but no serious claims were made.

Several smaller tasks were also performed for this project. A draft Environmental Impact Assessment [1] was reviewed and corrected. Safe separation distances and altitudes were estimated for project facilities and participating aircraft. Finally, consultant service was provided for evaluating several damage claims that resulted from an associated experiment with 1200 pounds (540 kg) of high-explosives (HE) at Kirtland AFB on March 25, 1975.

SHOT DESCRIPTIONS

Pre-DICE THROW I was a 100-ton (91 Mg) TNT sphere, on and tangent to the ground surface, fired at 1100 MDT (1700Z), August 12, 1975. This explosion ground zero (GZ) was located about 2 km south of the WSMR "Queen 15" Station and 46 km NW of Tularosa, NM.

Pre-DICE THROW II was a 120-ton (109 Mg) ANFO (ammonium nitrate and fuel oil slurry) surface tangent sphere, fired at 1200 MDT (1800Z), September 22, 1975, at a point just east from the previous calibration shot. It was tested to verify that 120-ton ANFO was indeed the equivalent blast generator to 100-ton TNT.

DICE THROW was a 600-ton (544 Mg) ANFO surface tangent sphere, fired at 0800 MDT (1400Z), October 6, 1976. The GZ was located about 5 km west of Trinity Site, thus 56 km SE from Socorro, NM. Various measurements [2] showed that it well simulated the intermediate and distant blast wave phenomena expected from a source of 1-kt NE (nuclear explosion, 4.2TJ) surface burst, or 2-kt NE free-air burst.

DISTANT AIRBLAST PREDICTIONS

Sound or blast waves may be distorted by atmospheric temperature and wind strata. Sound rays are bent away from (toward) ground while passing through layers where sound velocity decreases (increases) with altitude. Sound velocity, a vector, is made up of isotropic sound speed, dependent on temperature, plus a directed wind component. In general, if a directed sound velocity at altitude is greater than at ground level, there will be acoustic ducting or trapping that may considerably amplify airblast overpressures or acoustic amplitudes, above the levels expected from purely spherical (or hemispherical) wave expansion. On the other hand, with a strong gradient of sound velocity with height, much reduced pressures are observed along the ground. More details are available from many sources, a recent one being a Sandia report for Project MIXED COMPANY [3], and will not be repeated here.

Various studies have led to a statistical estimator for window damage as a function of airblast overpressure [4]. Simply stated, $\Delta p(50) = 7.5 \times (2.5)^{\pm 1}$ kPa, or 50 percent of typical window panes are broken by an incident overpressure, Δp, of 7.5 kPa, with a lognormal distribution of failure occurrences and a geometric standard deviation factor of 2.5. Also assumed in damage estimation was an average of 19 window panes per person in a community [5]. Standard explosion overpressure versus distance relations [6] were scaled to yields of calibration shots and DICE THROW as shown in Figure 1 and 2, respectively. Test results have been included for later discussion. Magnifications of 3X for atmospheric boundary layer inversion propagations and 5X for atmospheric focusing were assumed, along with an increased amplitude decay with distance for gradient conditions, for estimating possible window damages to neighboring communities shown in Table I.

Predictions for calibration shots showed that damage levels from airblast focusing on several communities ought to be avoided, lest neighborhood opposition be generated against the much larger final event. The necessary weather restriction was slight, because such focusing at 50-km to 100-km ranges is associated with jet stream winds aloft that are relatively infrequent at this latitude, even in mid-winter.

DICE THROW predictions caused more concern in that low level inversion or down-wind propagations could cause numerous complaints and claims from both Socorro and Albuquerque. Lower pressures at the longer range to Albuquerque than to Socorro were counteracted in this damage estimate by the much larger exposed population in Albuquerque. Climatic weather patterns, with south and southwest winds, made delays for weather quite likely, even with mid-day firing and near maximum surface temperatures. Late in field test preparations it was found that at mid-day, very low frequency (VLF) radio noise caused great difficulty with electrical grounding of various experiment recording systems, and an 0800 MDT shot time was established. That made a strong surface temperature inversion likely, with enhanced airblast propagation. As it turned out, this project was very lucky and no delays were needed.

OPERATING PLAN

A blast prediction service was chartered, as Experiment Number 122, which used special WSMR weather observations to establish whether enhanced airblast propagation conditions were occurring toward any of the surrounding communities. Results were relayed to the Test Group Director for consideration in making final firing decisions.

Airblast measurements were made in vulnerable communities to verify predictions and provide bases for validating or rejecting any damage claims that arose. Calibration shots were monitored by pressure gages at Oscuro, Carrizozo, Tularosa, and Alamogordo, connected by radio-telemetry (TM) link to a recording van at D-7 Site, near the test control center. There were problems with line-of-sight TM communications for the DICE THROW plan, so it was monitored by manned microbarograph (MB) units located at Stallion Site, Socorro, Carrizozo, Tularosa, and Alamogordo. These mobile MB units could be moved to more vulnerable locations if warranted by D-1 day weather forecasts.

Meteorological observations were provided by AVCO, a WSMR contractor. A mobile rawinsonde weather balloon facility was operated at SW.70 Site, 5 km southwest of Queen-15, for pre-DICE THROW events. A permanent rawinsonde station at Stallion Site was used for DICE THROW, 19 km north of the test but with a clear view of it over flat terrain, so that representative weather data were assured. A regular balloon ascension is made at WSMR, near the Small Missile Range, daily at 1200Z (0600 MDT) on the international synoptic schedule, and results were made available for early morning planning. For calibration shots, special ascensions from SW.70 were made at H-2.5, H-1, and H hours. Special DICE THROW ascensions from Stallion Site were scheduled for H-4, H-2, H-1 and H hours.

AIRCRAFT SAFE SEPARATION

Explosion wave scaling laws, including the shock strength dependence on ambient pressure at altitude, were used to derive isobar cross-sections in Figure 3 for the two yields. Light aircraft and helicopters are safe from 0.2 psi (1.4 kPa) incident overpressures, although an added safety factor of 2 is often employed for aircraft positioning in association with explosion tests [7]. More substantial jet transports and bombers are safe from 0.5 psi (3.5 kPa), while fighters are safe from 2 psi (14 kPa).

RESULTS

Pre-DICE THROW I:

Distant propagations were expected and verified to be quite weak, so that no disturbance was created among the WSMR neighbors. Rawinsonde measurements, for blast prediction calculations, are listed in Table II for both 8/11/75 (dry run) and 8/12/75 (live run). On Monday (8/11) there was a layer of northerly winds at 2.7-3.6 km MSL (above mean sea level) that would have ducted, and possibly focused, relatively strong airblasts toward Tularosa and Alamogordo.

On test day (8/12) there was never any indication of blast ducting toward either NE or SE directions of concern, after the night-time temperature inversion had been destroyed by solar heating. Sound velocity versus height functions from pre-test (H-2.5, H-1 hours) and shot time (1100 MDT) soundings are shown toward NE in Figure 4 and toward SE in Figure 5. The strong gradient of sound velocity toward NE was expected to give relatively weak propagations in that direction. Toward SE, less upward blast refraction was expected because of an inversion at 2.1-2.6 km MSL, but no strong blast would be refracted into the surface high velocity layer.

Recorder traces from the TM gage network are reproduced in Figure 6, with numerical results shown in Table III. The microbarograph at Carrizozo disagreed with the TM amplitude, but both weak signals were difficult to distinguish from ambient noise. This discrepancy was not significant. Peak amplitudes were shown in Figure 1 for comparison with various prediction curves. Propagations toward NE, to Oscuro and Carrizozo, were indeed as expected from the strong gradient shown in Figure 4. Stronger SE propagations toward Tularosa and Alamogordo, resulted from the weaker overall gradient of Figure 5, as could well be expected.

In summary, predictions, measurements, and off-site protection from nuisance airblasts were all successful.

Pre-DICE THROW II:

Distant propagations were again expected and verified to be relatively weak, so that no significant disturbance was created among the WSMR neighbors.

Meteorological observations of rawinsonde ascensions are listed in Table IV, as used in blast prediction calculations. During the final dry run on 9/21/75 a layer of moderate westerly winds at 3.7-4.9 km MSL would have ducted, and possibly focused, relatively strong airblasts toward Oscuro and Carrizozo.

On the test date there was no indication of blast ducting toward either NE or SE directions of concern, after the sun had destroyed a night-time surface temperature inversion. Sound velocities versus height at 1200 MDT are shown in Figures 7 and 8, for dry run and event days, respectively. On shot day a strong sound velocity gradient in both directions was expected to give relatively weak propagations at all off-site airblast measurement sites.

Recorded wave data are listed in Table V. Figure 9 shows the weak waves recorded at Oscuro, with an indication of background wind noise levels. In general, amplitudes over about 10 Pa can be heard, but more than 100 Pa is usually required to get people's attention and start them to complaining. At 400 Pa window breakage becomes likely.

Figures 10 and 11 show recordings at Carrizozo, by microbarograph and the telemetered blast gages, respectively. Wind noise was better filtered by the microbarograph, which has only 30-Hz high frequency response capability, while blast gages respond to about 2 kHz. A discrepancy in timing and general wave appearance cannot be explained; the two sensors were co-located, side-by-side, so there should have been better agreement. The TM timing was from the IRIG standard, while the MB set used a radio receiver on WWVB, world time transmitted from Boulder, Colorado.

There also was trouble with the Alamogordo TM record. A paper record made on-site at blast time showed only an extremely weak, possible signal from Alamogordo, but the channel did appear to have been energized. There was no indication of the easily audible signal that was reported by our technician at the gage site. There was a mix-up in tape channel identifications that we have not been able to correct ~~and~~ to allow further playbacks.

On the other hand, ray path calculations have been made from shot time meteorological data that showed arrival times that were consistent within about 1 second for the Oscuro, Tularosa, and Carrizozo MB signals, as reported herein. Ray calculations for Pre-DICE THROW I had also confirmed arrivals from that event where Carrizozo TM and MB records were in disagreement, but the MB operation was suspect in that case. Previous comparison tests between TM and MB systems had not found such troubles.

The Tularosa record is shown in Figure 12, although this was made from a digitized playback of the Alamogordo-labelled tape track. In consequence, because of the uncertainty about which gage calibration was appropriate, reported amplitudes for Tularosa may be low by a factor of two. This would extrapolate from 26 Pa at Tularosa to about 13 Pa at the distance of Alamogordo, and explain the reported easy audibility, where half that amplitude probably would not.

Amplitude and distance data were shown in Figure 1, in comparison with prediction curves for various atmospheric propagation conditions. Clearly, these records show correct magnitudes for gradient propagations, as determined by meteorological input. That plot also showed that the Carrizozo MB amplitude was in better agreement (pressure-distance decay rate) with the Oscuro amplitude, on nearly the same azimuth, than was the Carrizozo TM recording. Greater propagation strength toward the SE direction may be qualitatively explained by the presence of an upper sound velocity inversion at 3.7-4.3 km MSL for the 140° azimuth in Figure 8.

Most of these details are of little practical importance to test operations, as they deal with problems of working in a low signal-to-noise environment. The important conclusion, is, of course, that recorded signals were weak, as predicted from the weather-watch. If this event had been fired just 24 hours earlier, without weather and blast prediction services, amplitudes at Oscuro and Carrizozo could have been as much as 50 to 100 times greater and caused some window breaking and public relations problems.

DICE THROW:

The schedule for weather balloon observing and blast prediction calculation was exercised during the FPFF (full power, full frequency) dry run on 10/4/76. On shot day, 10/6/76, balloon observations were made on schedule with all results shown in Table VI. There was indeed a 2.0-2.5 K surface temperature inversion, that remained from night-time cooling. Predictions on D-2 days for a southeasterly low level (2-3 km) atmospheric circulation did not materialize, because a low pressure wave had developed on an approaching polar front in Colorado. Instead, general northwesterly circulation persisted throughout the entire period from D-3 days. In result, Tularosa and Alamogordo were threatened with relatively strong blast waves, rather than Socorro and Albuquerque.

Figure 13 shows the sound velocity versus height structures at shot time toward the 095° azimuth of Carrizozo and 140°, between Tularosa and Alamogordo. There were only minor variations from the H-4 hour sounding and predictions relayed to the Test Group Director during the count-down. The Carrizozo curve showed a strong inversion ducting layer to 2.1 km MSL, but it did not extend above the Oscuro Peaks (2.4-2.7 km MSL), so they provided some protection. The high sound velocity at 5.2 km MSL apparently helped propagate a moderate strength wave into Carrizozo.

Tularosa and Alamogordo were nearly downwind from GZ, and on the 140° azimuth sound velocities increased to a maximum at 5.2 km MSL. There was a strong surface inversion to carry a wave southeast through Mockingbird Gap, as well as a complex ducting structure between 2.7 km and 4.3 km MSL that could cause distant blast focusing. Detailed acoustic ray calculations showed a caustic ring about 10 km short of the distance to Tularosa. Experience has shown that this focal range can only be predicted within several kilometers. Therefore, predictions were made that a few windows could be broken in both Tularosa and Alamogordo, but the probability of dozens being broken was quite small, depending on just where the focus or caustic wave might strike.

Propagation toward Truth or Consequences, NM, shown by Figure 14, was slightly ducted below 2.4 km MSL, but little energy could be trapped by the 0.15 m/s excess sound velocity at that height. This was not of sufficient concern to warrant moving a microbarograph to that community.

Propagation toward 320° azimuth, toward Stallion Site and Socorro, was minimized by a strong gradient of sound velocity with height. The averaged sound velocity gradient from 1.8 km MSL was $-7.6 \times 10^{-3}\ s^{-1}$, compared to the calm standard atmosphere gradient of -4×10^{-3} s^{-1} (0.0065 K/m). Thus, minimized propagation was expected for that direction.

Surface weather conditions at Stallion Weather Station (1506 m MSL) were not the same as at DICE THROW GZ (1442 m MSL). This elevation difference was used to estimate GZ ambient air pressure from the Stallion barometer reading given in Table VI.

Reproductions of MB recordings at the five measurement locations are shown in Figures 15-17. Numerical data are listed in Table VII. Each recorder was operated with two pens with set ranges that differed by a factor of four, as shown by Figure 16 and 17. If a signal was weaker than expected it could still be accurately measured from the "High Sensitivity A-Pen". If the signal exceeded expectations it was contained by the scale of the "Low Sensitivity B-Pen". Timing marks were made by a side-marking pen connected to a radio receiver on WWVB.

The Stallion signal consisted of a severely damped explosion waveform, from gradient propagation, followed by two sinusoidal cycles of similar frequency. There were several later cycles of much weaker echo waves that were not reproduced for this report. The 8-Hz oscillations which were superimposed on the fundamental waves probably resulted from weak temperature inversion ducting in the boundary layer which was almost, but not quite, overcome by wind effects, as was shown in Figure 14.

The Socorro record posed a problem with the late arrival time. The first indication of noise came at 159 s, in rough accord with the wave speed determined en route at Stallion. The largest amplitude wave came 50 s later but there was no possible acoustic ray path for this propagation. Ray path analysis has shown this wave probably was a collection of scattered compressions from the proper acoustic wave passing above 9 km MSL.

At Carrizozo the record showed two cycles of damped sinusoidal oscillation much as could be expected. Oscuro Peaks blocked any strong inversion propagation indicated by the weather data, but diffraction over Oscuro Peak appears to have been facilitated by high sound velocities up to 5.2 km MSL. Other experience has shown that mountain shielding may attenuate blast amplitudes by about a factor of two at long ranges.

Strong propagations, predicted for Tularosa and Alamogordo, were verified by recordings shown in Figures 16 and 17, respectively. The Tularosa wave went off-scale on the sensitive A-Pen but was contained by the less sensitive B-Pen recording. There does not appear to be any sign of strong magnification with a pressure spike, caused by the complex upper level ducting layer. Thus there probably was no focus or caustic that struck any part of that small town. The recorded signal with 370-Pa amplitude was noisy, easily heard, and approached the 400-Pa rule-of-thumb threshold for window-breaking waves. According to our station operator this blast wave set off a burglar alarm in a building near our sensor. Also, one resident informed him that the blast had caused a crack in his plastered wall, but he probably would not take any claims action.

The Alamogordo recording was also driven off-scale on the sensitive A-Pen, but a complete record was made by the B-Pen. The amplitude of 390 Pa was slightly higher than that recorded at Tularosa. This blast was loud at the station but our operator reported no sounds of breaking glass. A personal report from a Holloman Air Weather Service contact also reported that considerable house rattling was heard indoors but there was no damage, and little disturbance noted by children playing outdoors. This recorded wave amplitude could indeed be expected to break a few windows in so large a population (24,000 people, estimated 460,000 window panes), but no claims reports were received. Also, in the 5-km extent of that community there could have been wave focusing that was not detected by our single microbarograph sensor. This may provide a useful data point near the "threshold" for annoying cosmetic architectural damages. One previous incident in Las Vegas, Nevada, and two incidents in St. George, Utah, from atmospheric nuclear tests in the 1950's, each resulted in one window damage claim from just over 400 Pa recorded amplitudes, but the so-called "threshold" interpretation cannot be taken as well-established from such meager data.

Pressure-time signatures of waves recorded at both Tularosa and Alamogordo indicate that these large amplitudes were probably propagated by an upper level duct between 4.3 km and 5.2 km MSL.

There was a problem with arrival timing and blast wave velocity at Socorro, as shown by results in Table VII. It appeared that waves traveled faster upwind toward Socorro than downwind toward Alamogordo. Explanation may lie in erroneous mapping. If the map distance from GZ to Stallion were reduced by 508 m (2 1/2%), the recorded arrival time would be consistent with the 339 m/s surface velocity of Figure 14. This incremental distance, added to the Alamogordo map distance, would give 342 m/s wave velocity, consistent with maximum propagation speed under the inversion in Figure 13. With such sensitivity to location, surveyed station sites, detailed ray path time calculations, and time correction for strong shock source conditions would be required to reach full internal consistency in results.

Pressure amplitudes shown by the microbarograph records were entered on the pressure-distance graph of Figure 2 for comparison with planning predictions. Amplitudes along the 320° azimuth to Socorro were much below even an average gradient curve. The actual sound velocity gradient toward 320° was indeed stronger than the average gradient encountered in other ducting test environments. The isolated point representing the wave scattered from high altitude down to Socorro also fell well below the gradient curve. Amplitudes from the two MB sets operated at Carrizozo fell almost exactly on the Standard curve, but that is a coincidence of little significance. Lacking the mountain barrier of Oscuro Peaks, appreciably larger amplitudes would have been expected at that station. Both Tularosa and Alamogordo amplitudes were near the upper limit of expectations for inversion propagations but below likely caustic or focus amplitudes. Focus factors at those two stations were about 2.5X and 3.5X above the Standard, and entirely reasonable for the strong propagations indicated by weather data. Both points fell below the window-breaking threshold but with no significant margin of safety. Some windows may have been broken under these conditions. There should not, however, have been any hazard from flying glass, because the breaks would not likely have been more than cracks, with little likelihood of even falling glass.

CONCLUSIONS

The Project DICE THROW explosion airblast wave could have broken windows and cracked interior wall plaster to more than 100-km ranges under weather conditions that caused refractive blast focusing. Weather observations showed that there should have been relatively strong propagations toward the southeast and weak propagations toward the northwest. Microbarograph recordings verified these propagation conditions and that wave amplitudes in Tularosa and Alamogordo were large enough to rattle houses, possibly causing some damage. No audible wave was propagated in the opposite direction to the shorter distance of Socorro. Weather observations, blast predictions, and off-site measurements were all performed successfully by, or in support of, this project.

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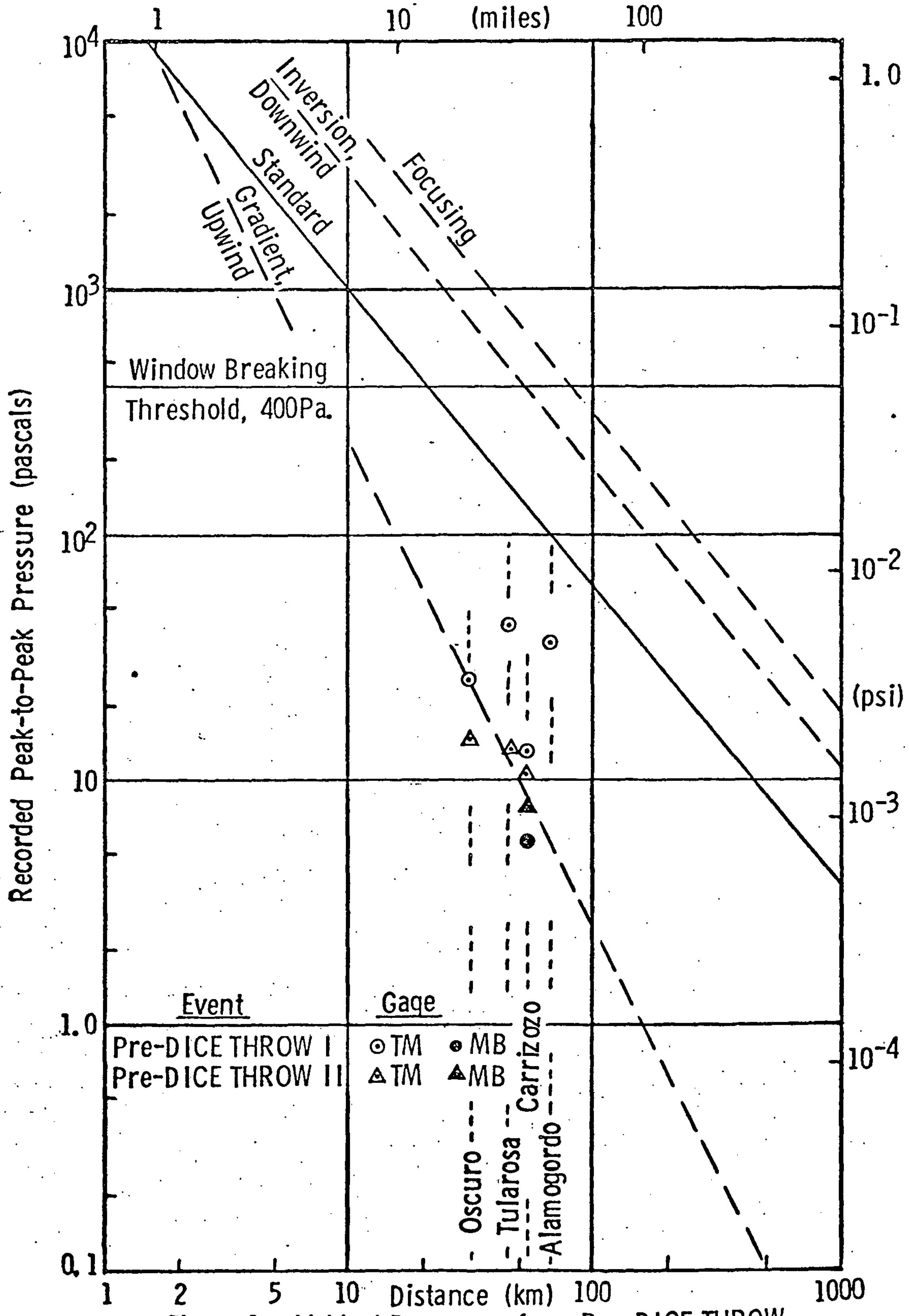


Figure 1. Airblast Pressures from Pre-DICE THROW Events, 100-ton TNT and 120-ton ANFO Surface Bursts.

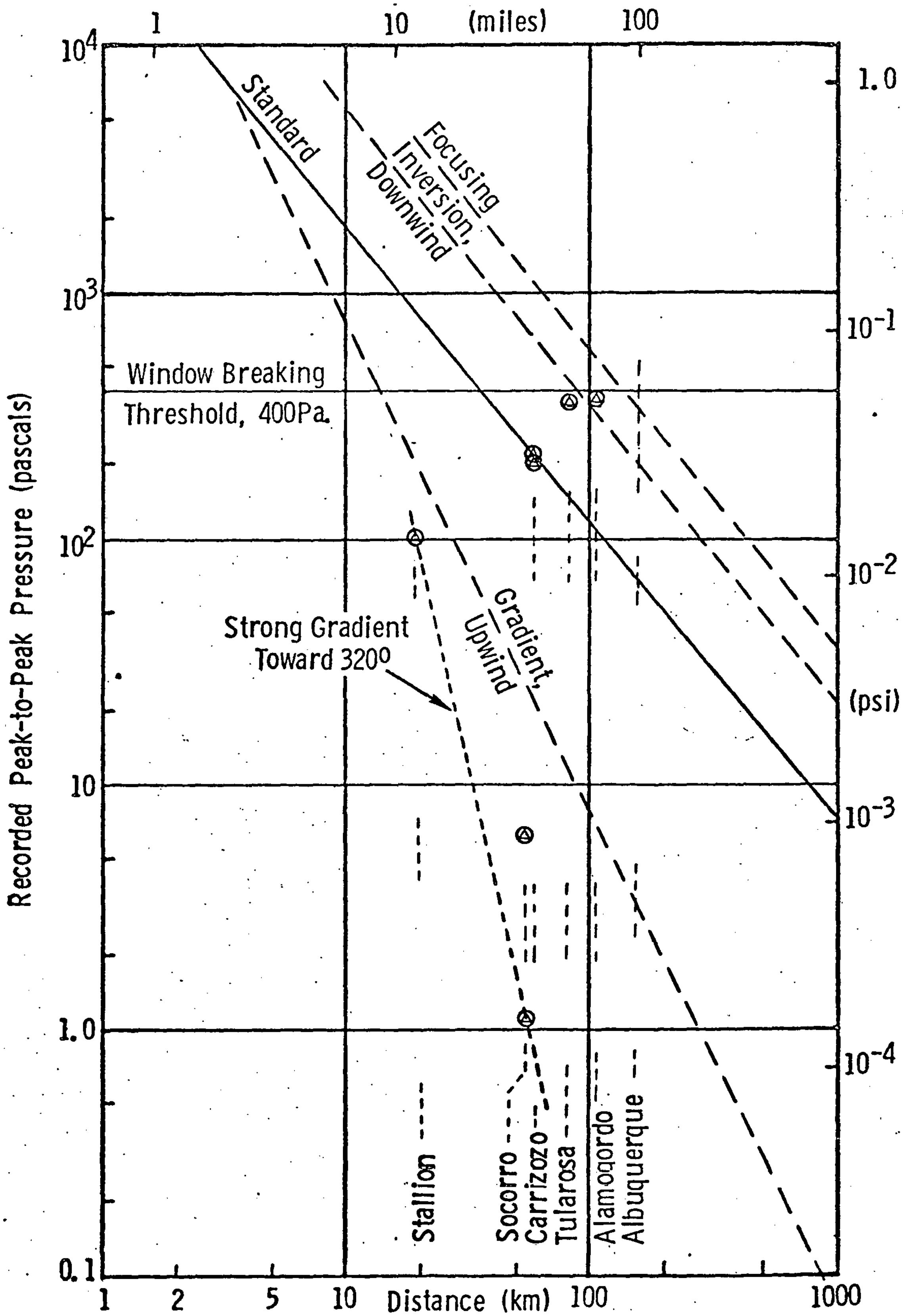


Figure 2. Airblast Pressures from DICE THROW, 600-ton ANFO Surface Burst

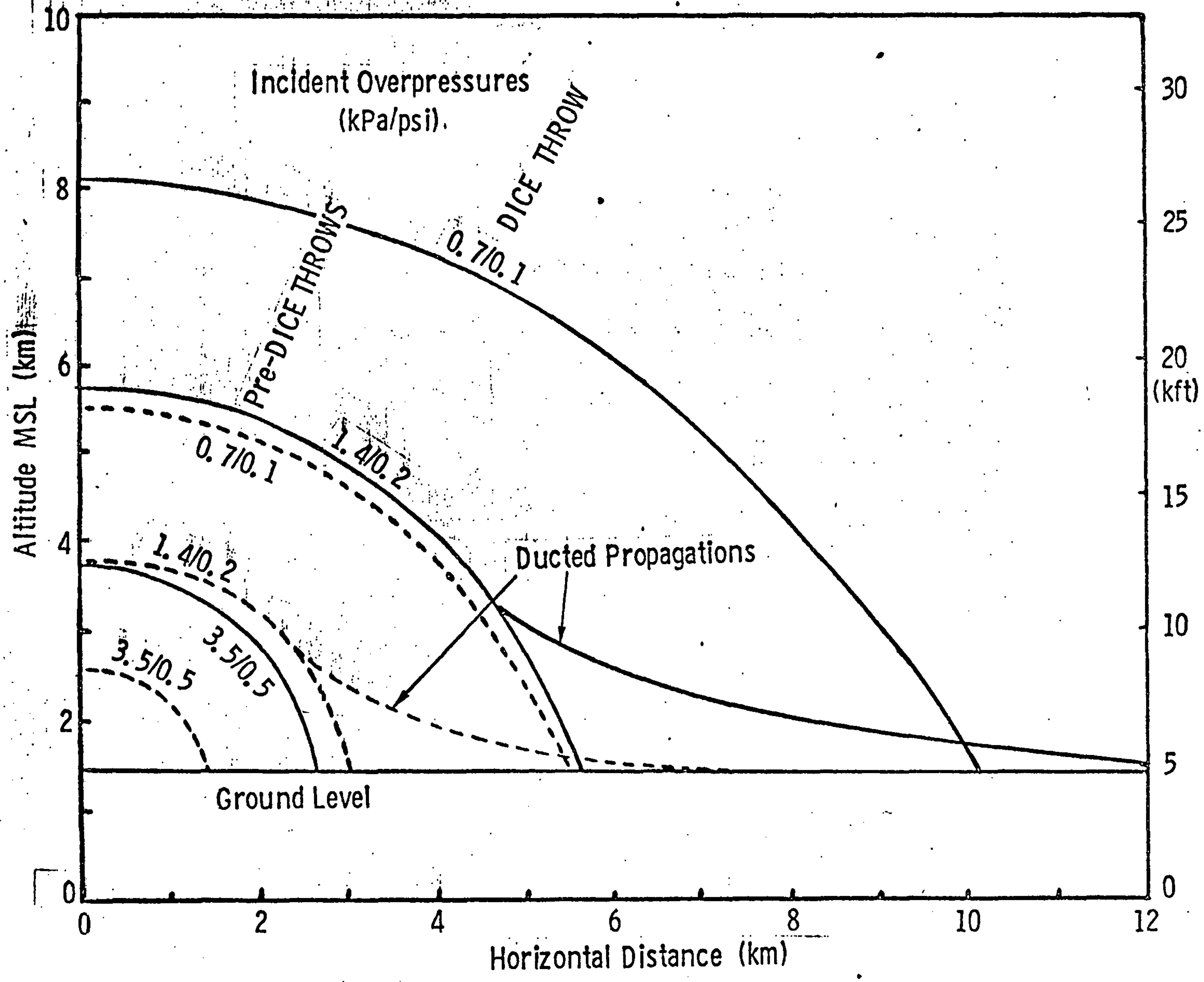


Figure 3. Project DICE THROW Free Air Blast Isobars.

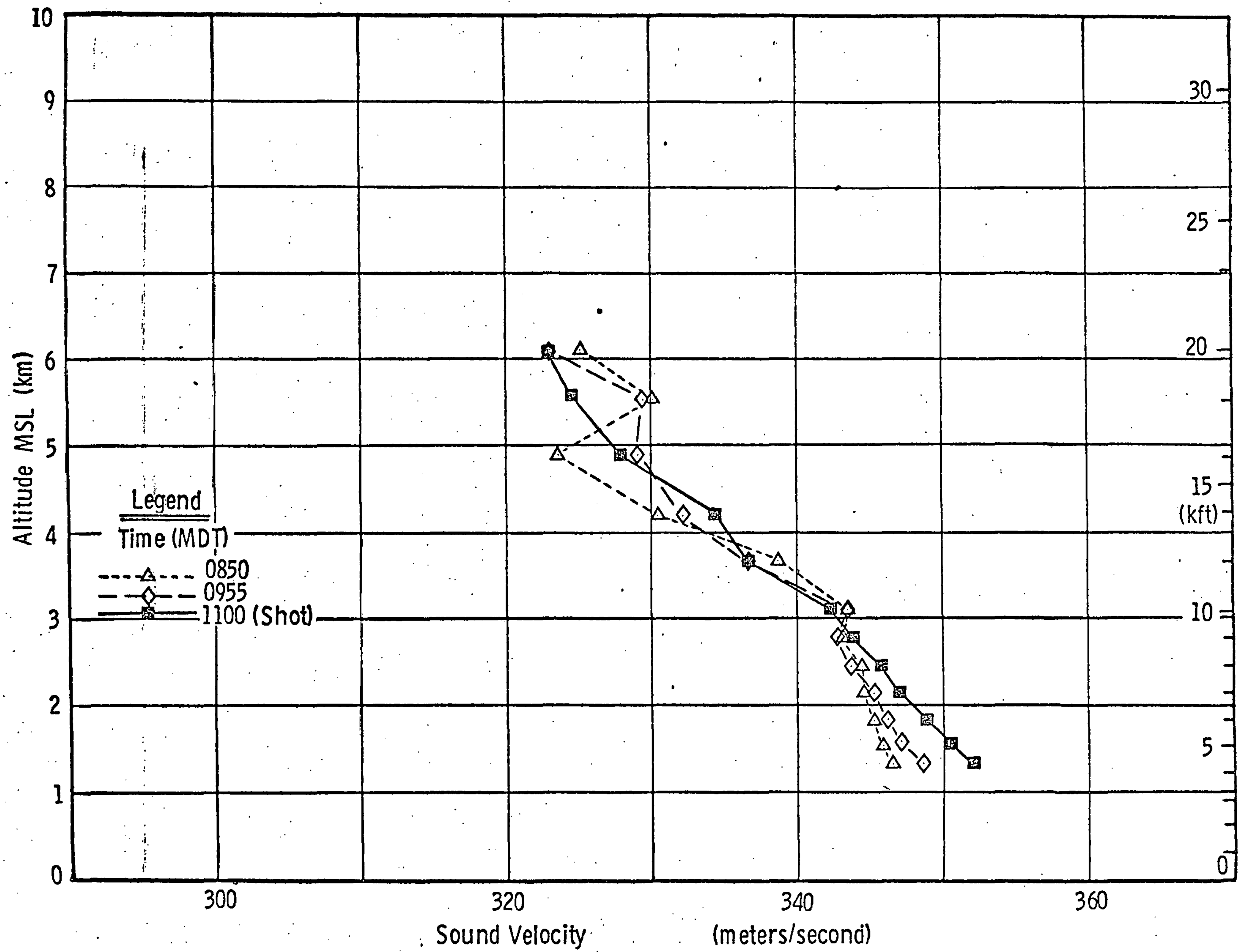


Figure 4. Pre-DICE THROW I Sound Velocities Toward 063° Direction of Oscuro and Carrizozo.

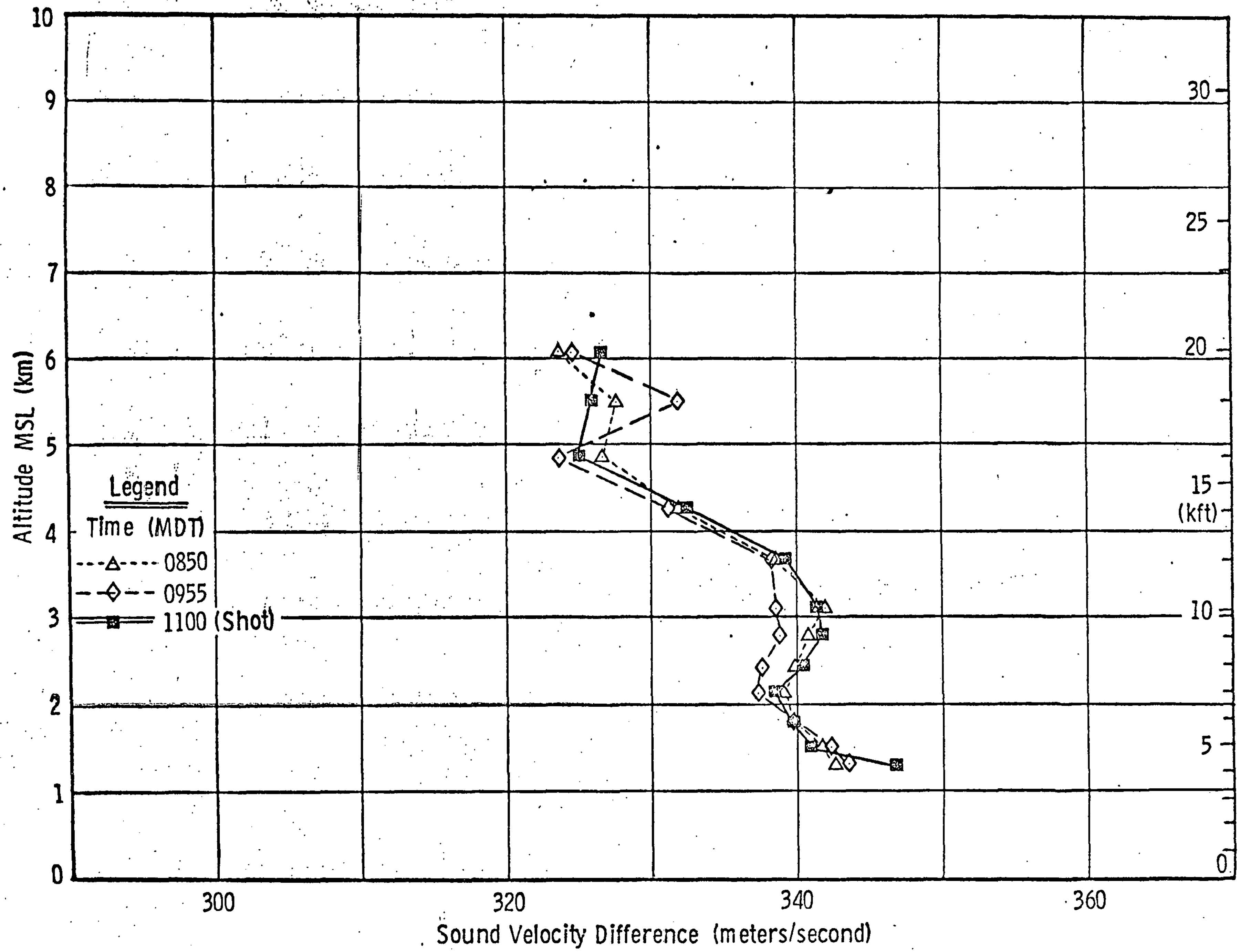


Figure 5. Pre-DICE THROW I Sound Velocities Toward 140° Direction of Tularosa and Alamogordo.

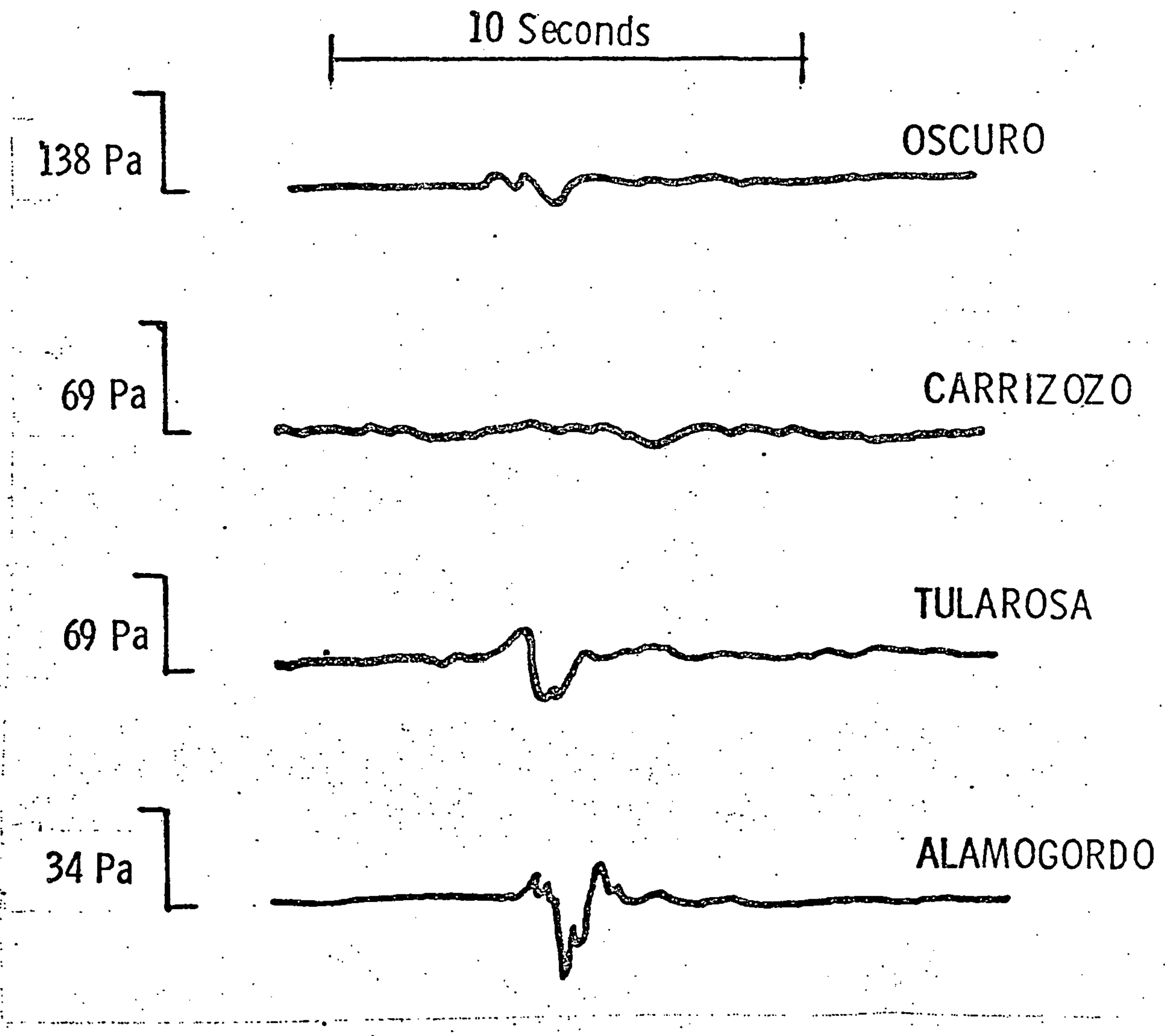


Figure 6. Pre-DICE THROW I Pressure Signatures.

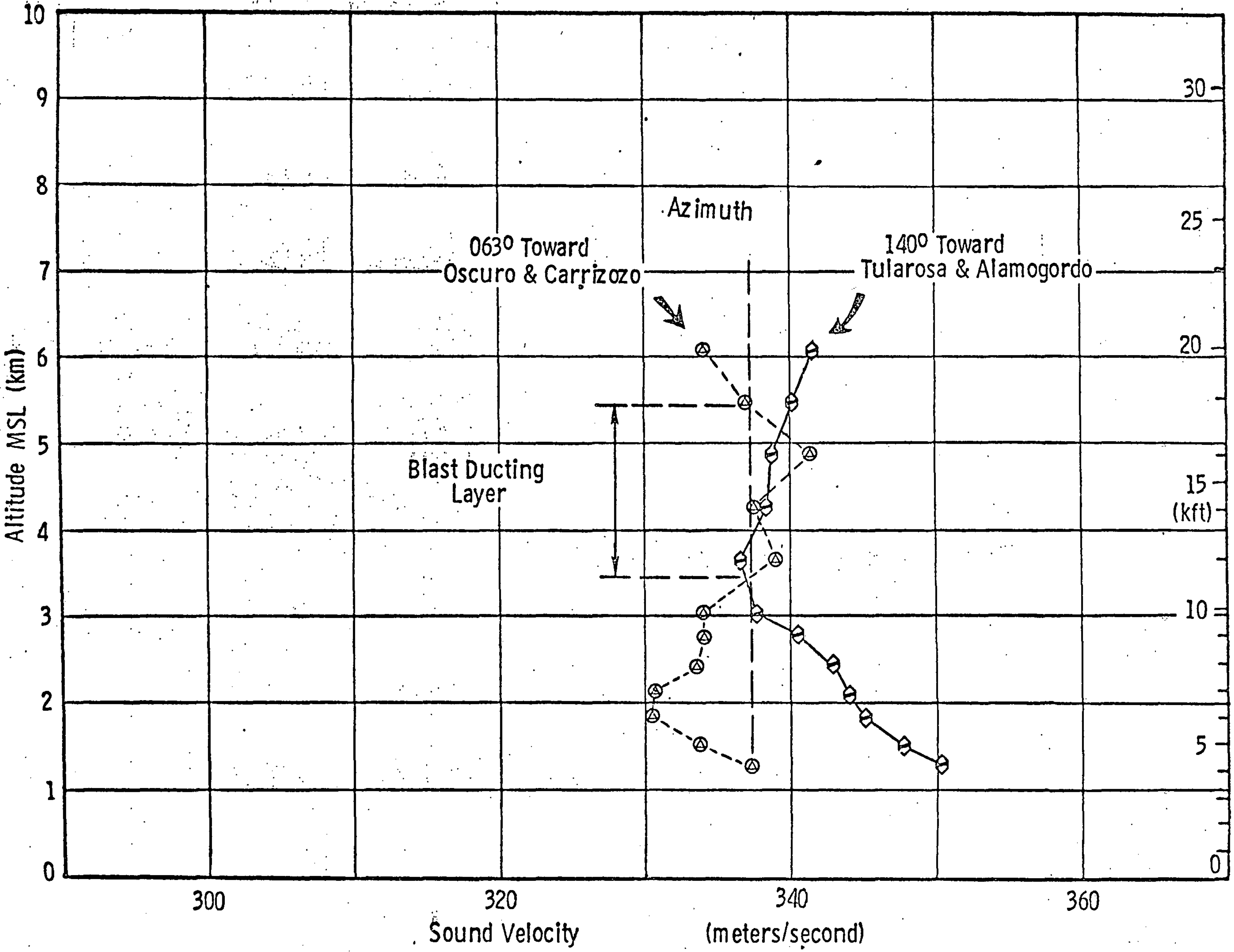


Figure 7. Pre-DICE THROW II Dry Run Sound Velocities at 1200 MDT, 9/21/75.

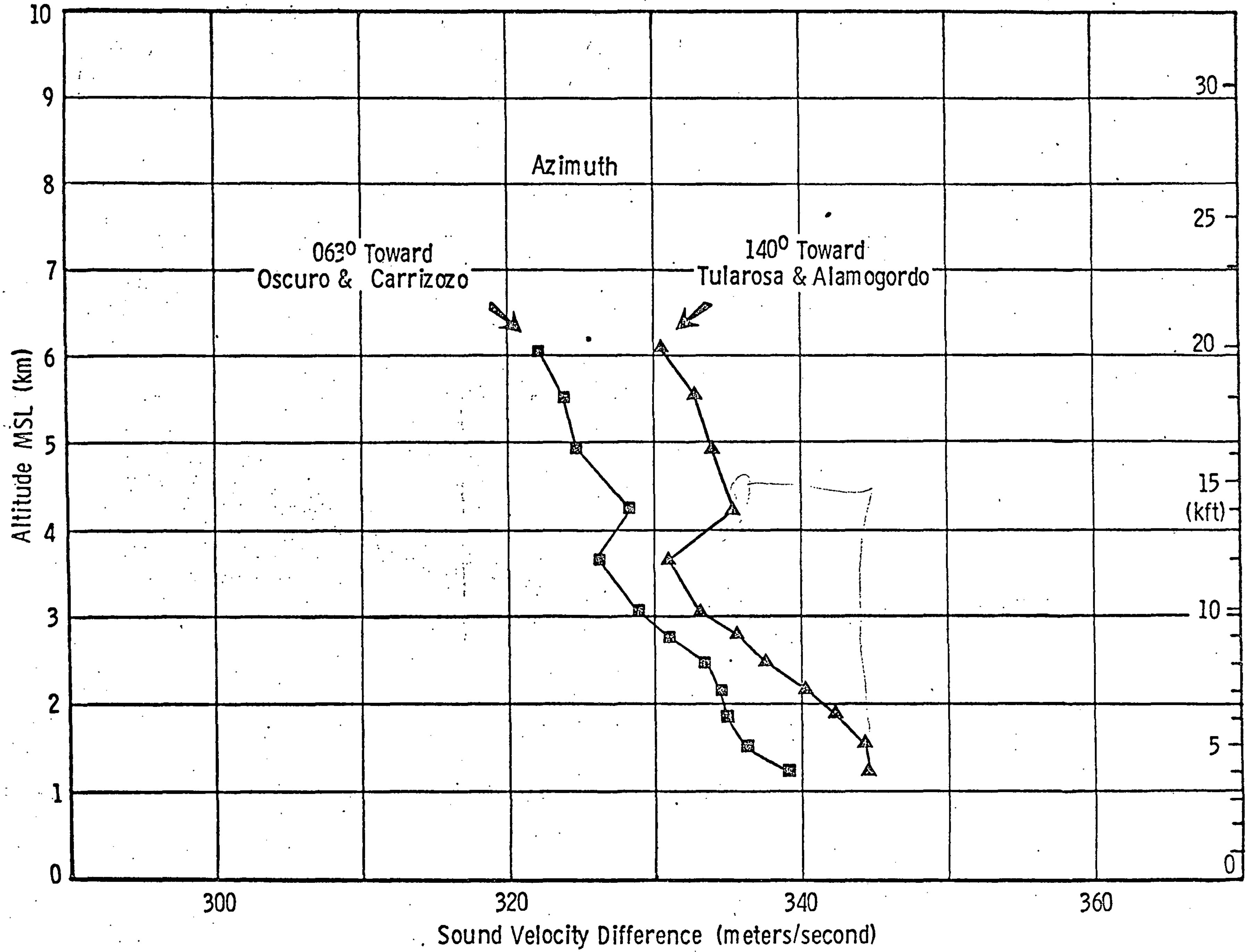


Figure 8. Pre-DICE THROW II Sound Velocities, 1200 MDT, 9/22/75.

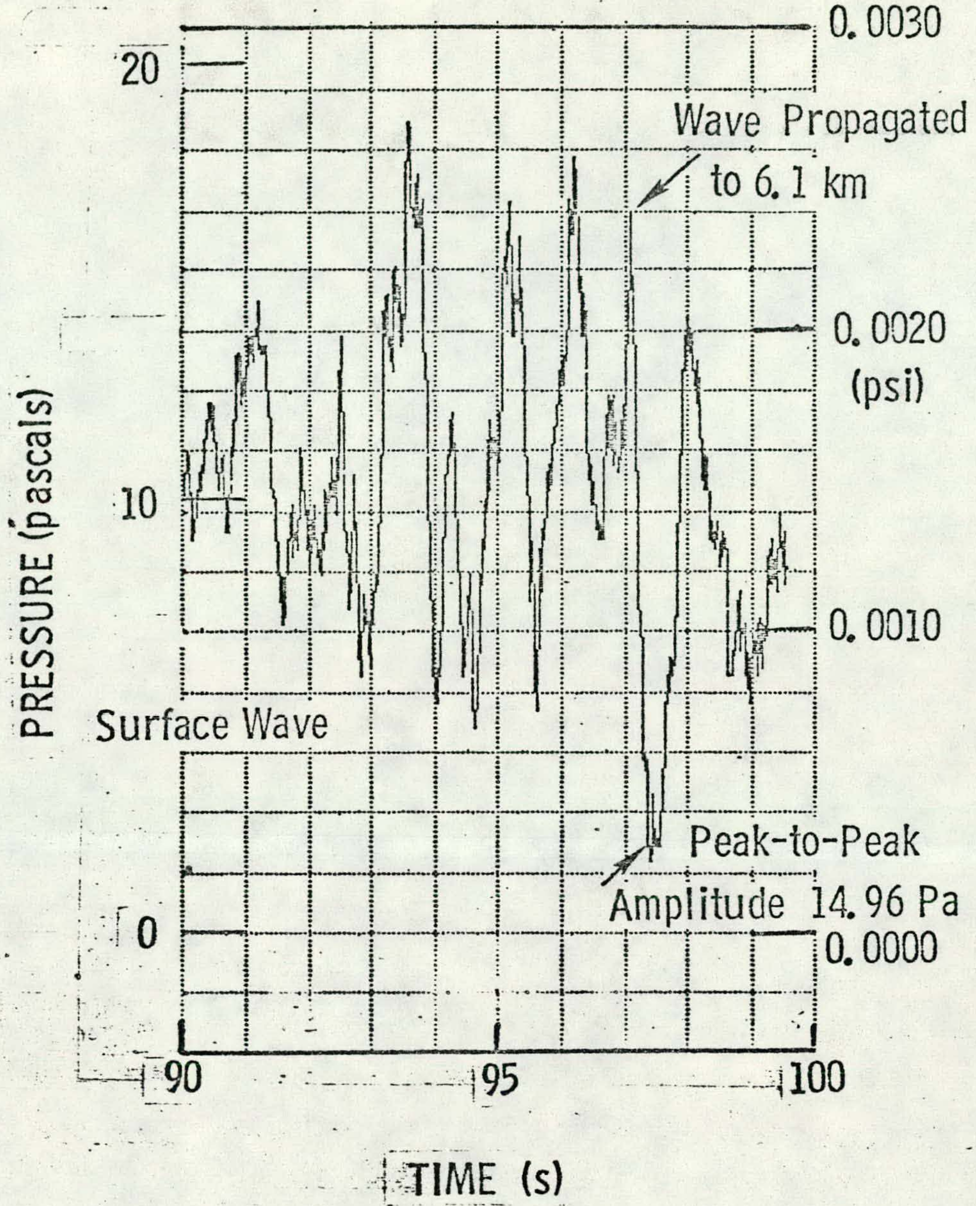


Figure 9. Pressure Gage Record, Pre-DICE THROW II, at Oscuro, New Mexico, 31.1 km Range.

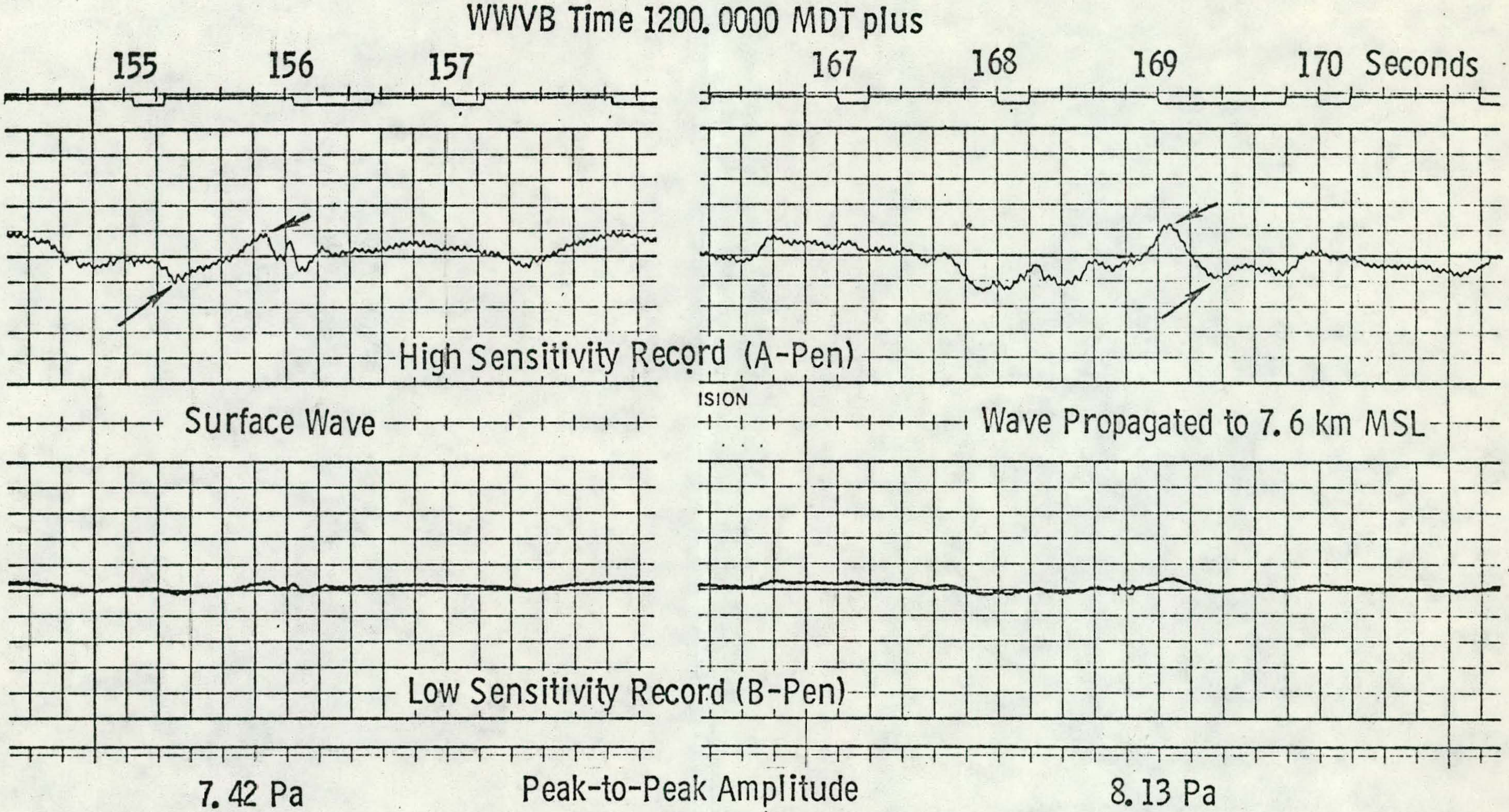


Figure 10. Microbarograph Record, Pre- DICE THROW II at Carrizozo.

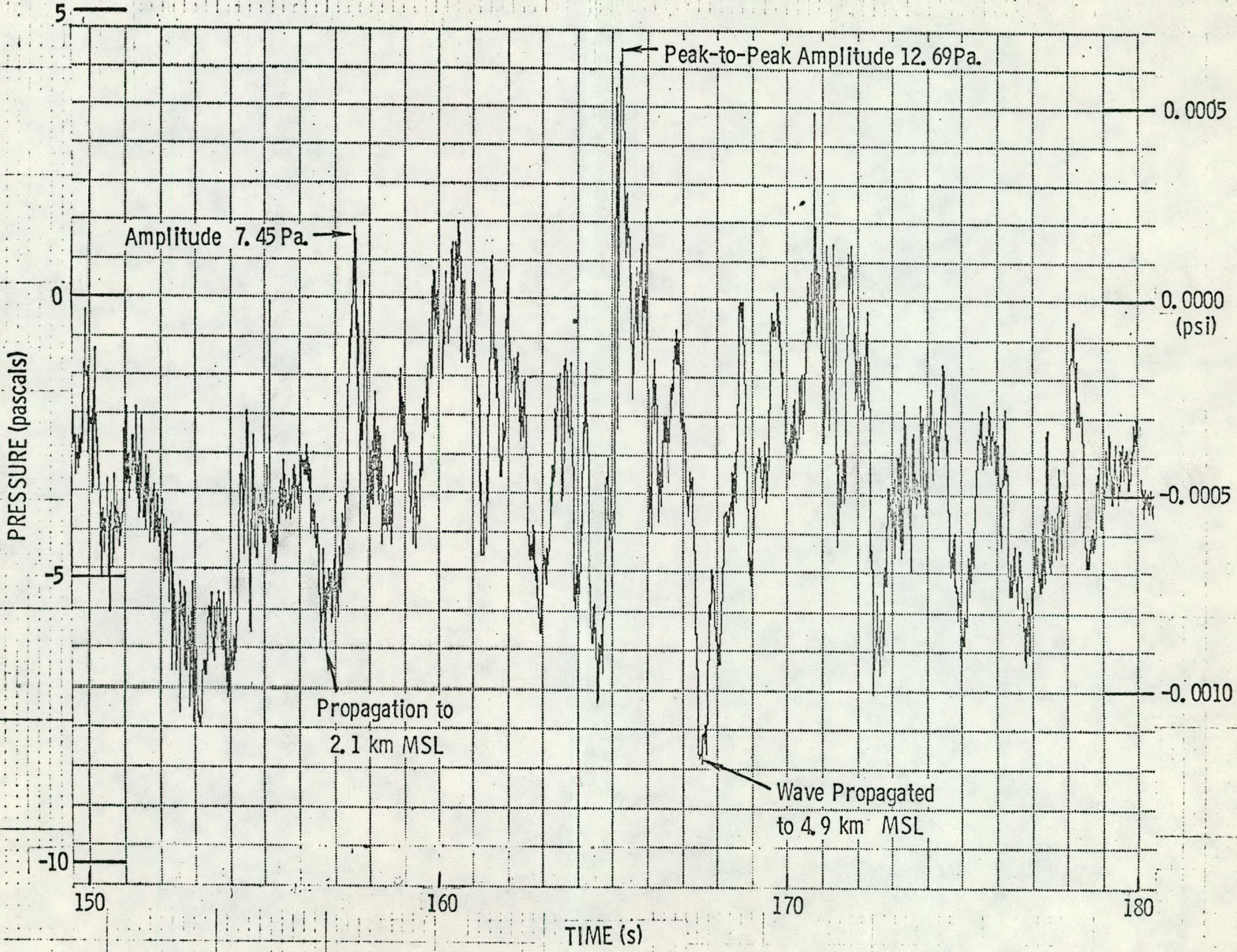


Figure 11. Pressure Gage Record, Pre-DICE THROW II at Carrizozo, New Mexico, 53km Range.

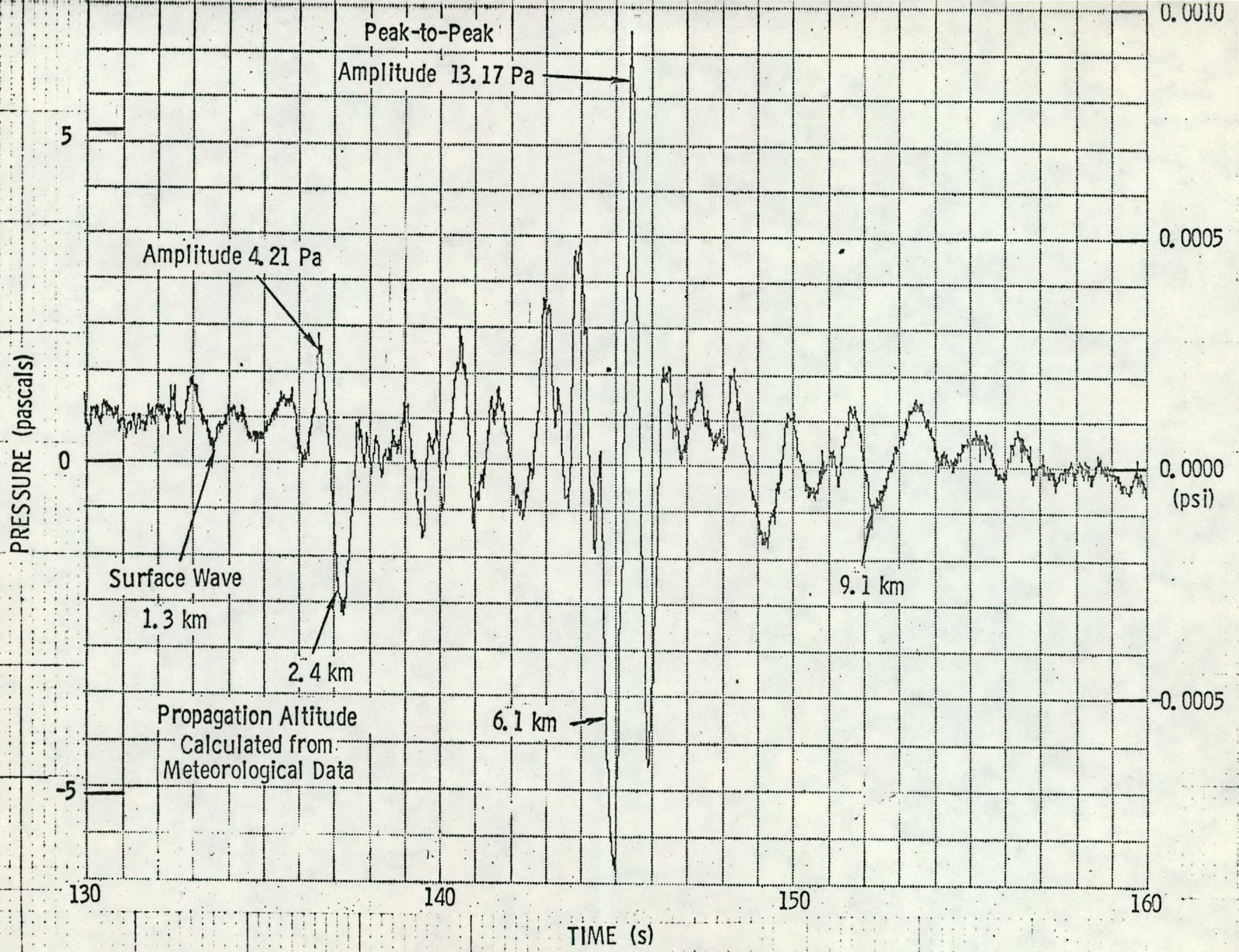


Figure 12. Pressure Gage Record, Pre-DICE THROW II, at Tularosa, New Mexico, 46 km Range.

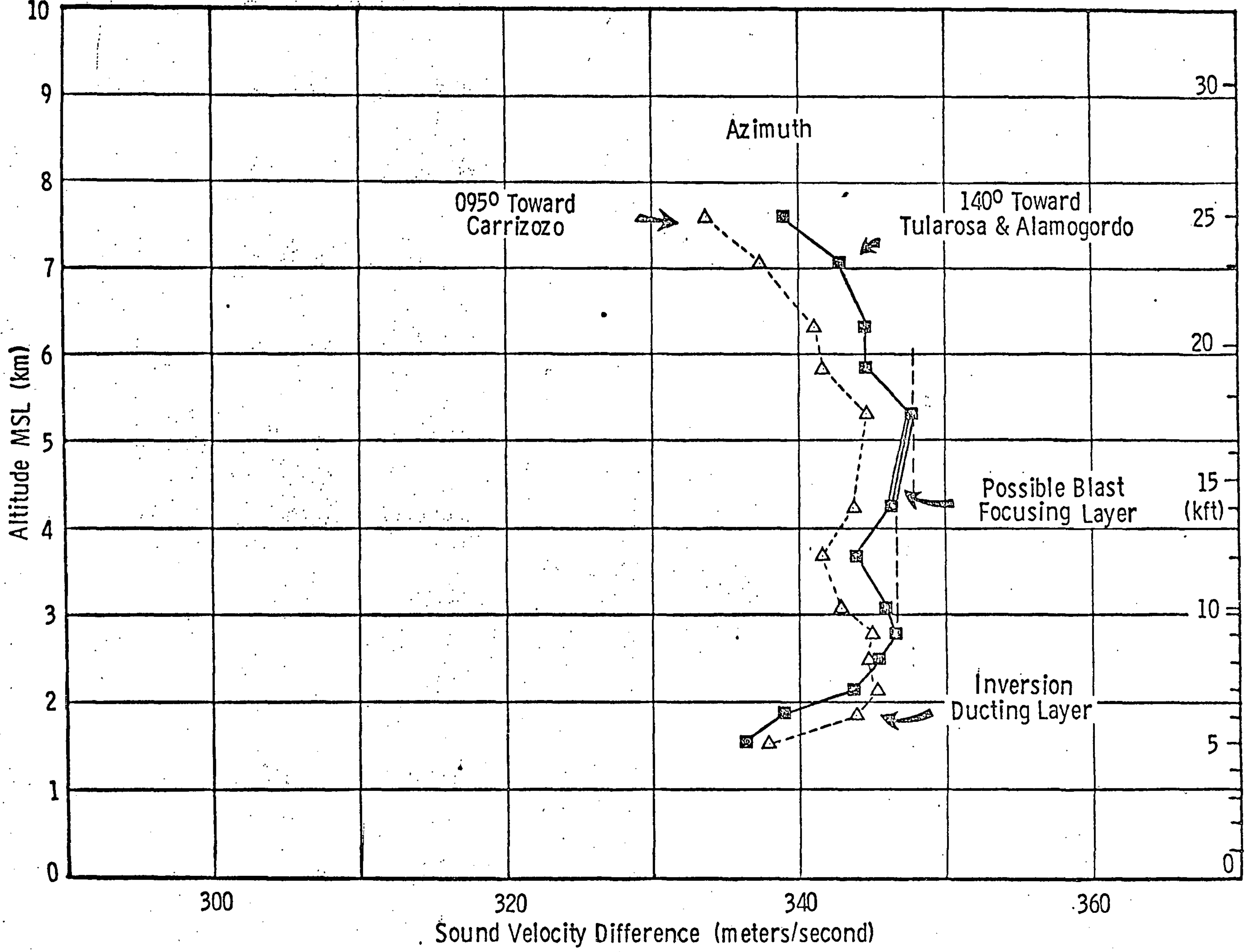


Figure 13. DICE THROW Sound Velocities Toward East Quadrants.

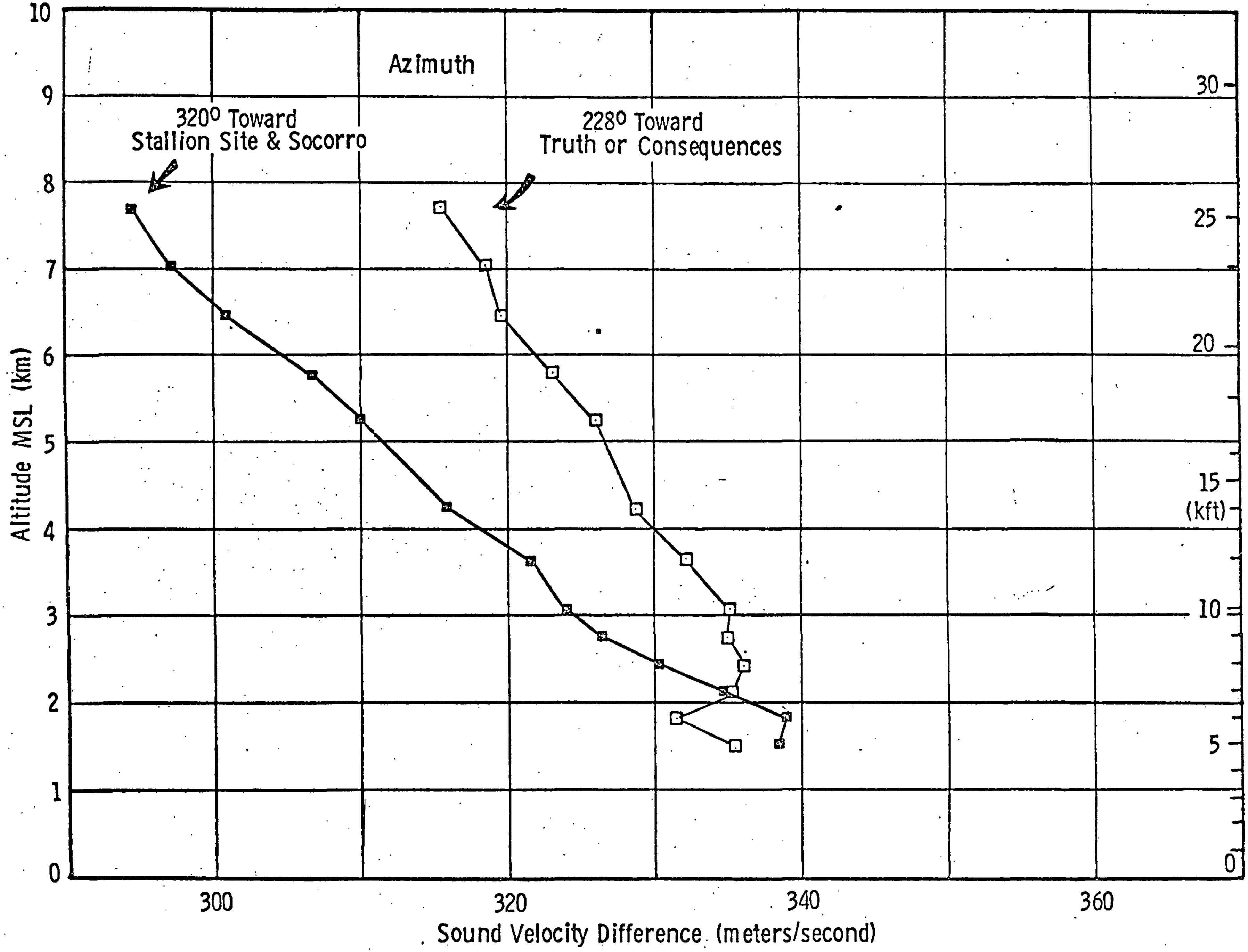
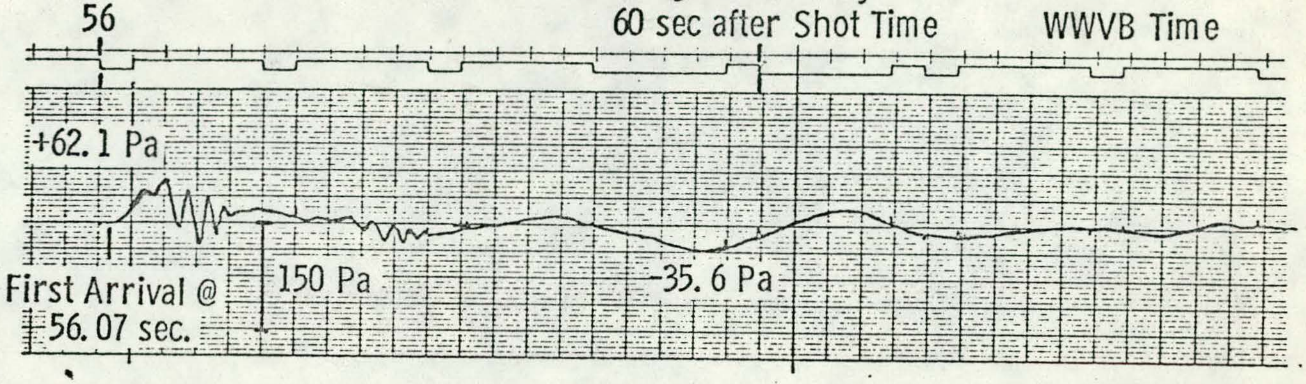


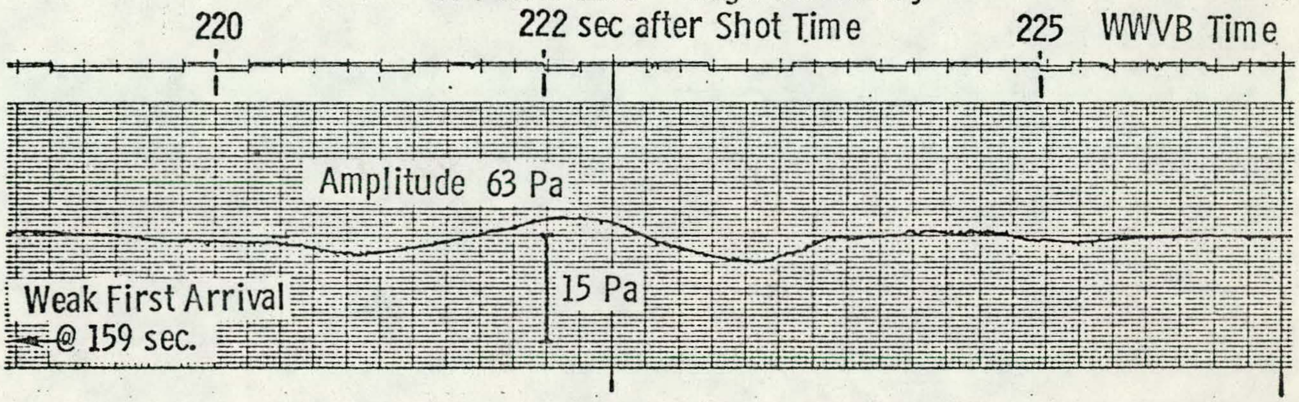
Figure 14. DICE THROW Sound Velocities Toward West Quadrants.

Figure 15.
Project DICE THROW Microbarograph Records
Shot Time 0800MDT 10/4/76

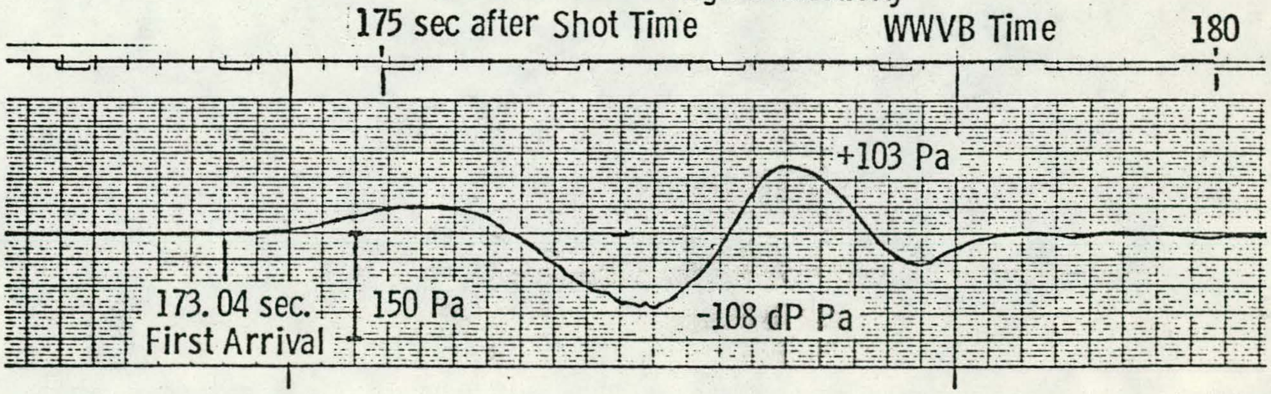
Stallion Range Center (Weather Station)
A-Pen Record High Sensitivity



Socorro, New Mexico (Golden Manor Motel)
A-Pen Record High Sensitivity



Carrizozo, New Mexico (Crossroads Motel)
A-Pen Record High Sensitivity



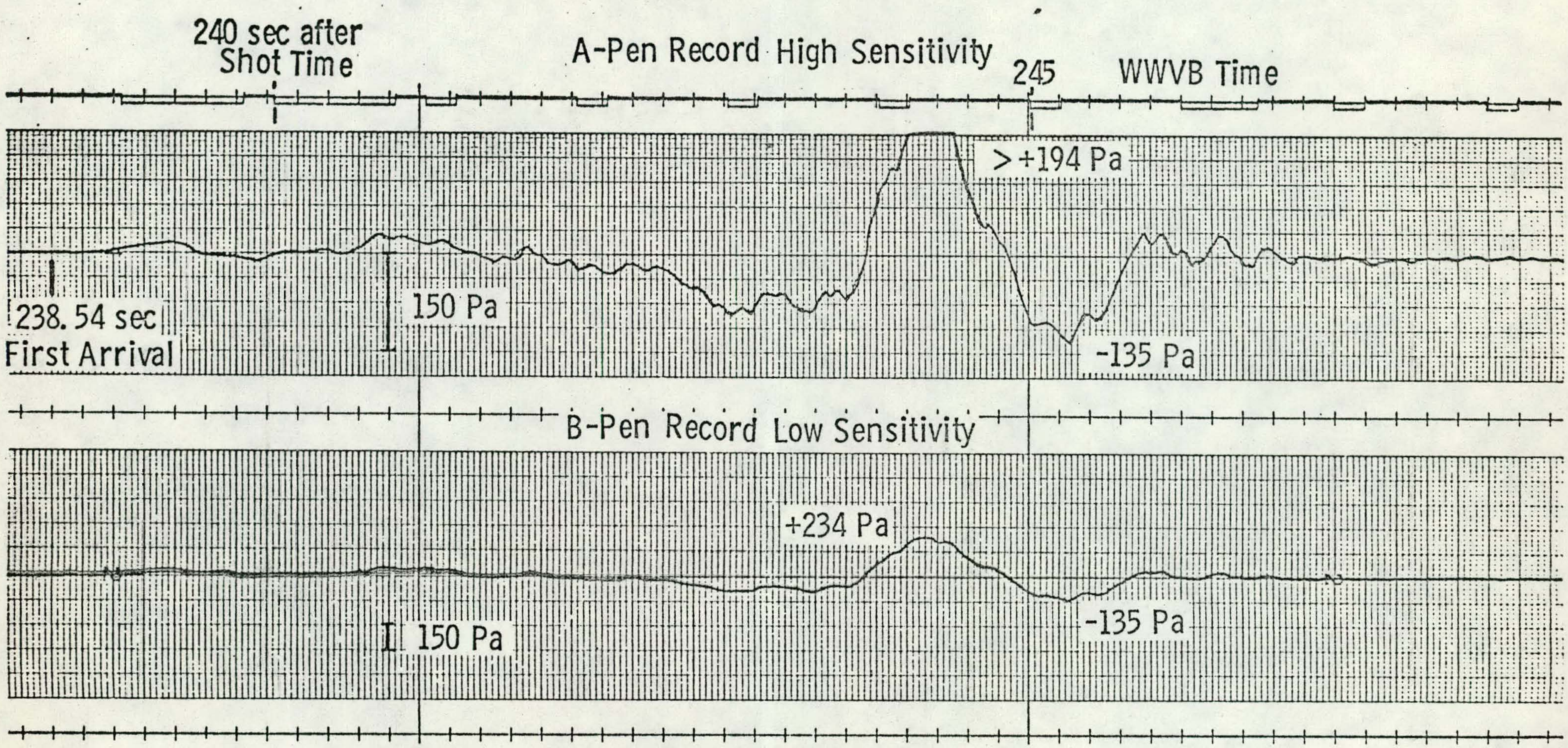
Paper Speed 2.5 cm/sec

Figure 16.

Project DICE THROW Microbarograph Records

Tularosa, New Mexico (J&J Laundromat)

Shot Time 0800MDT 10/4/76



Paper Speed 2.5 cm/sec

Figure 17.
Project DICE THROW Microbarograph Records
Alamogordo, New Mexico (Sands Motel)
Shot Time: 0800MDT, 10/4/76