A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

1

LA-UR -84-1558

CONF

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--84-1558

DE84 012636

TITLE: SUMMARY OF THE OIL SHALE FRAGMENTATION PROGRAM AT ANVIL POINTS MINE, COLORADO

AUTHOR(S): Richard D. Dick, Los Alamos National Laboratory
Chapman Young, Sunburst Recovery, Inc.
William L. Fourney, University of Maryland

SUBMITTED TO: 17th Oil Shale Symposium
Colorado School of Mines, Golden, Colorado
April 16-18, 1984

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO. 836 R4
ST. NO. 2629 5/81

SUMMARY OF THE OIL SHALE FRAGMENTATION PROGRAM AT ANVIL POINTS MINE, COLORADO

Richard D. Dick
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Chapman Young
Sunburst Recovery, Inc.
Steamboat Springs, Colorado 80477

William L. Fourney
Department of Mechanical Engineering
University of Maryland
College Park, MD 20742

ABSTRACT

During 1981 and 1982, an extensive oil shale fragmentation research program was conducted at the Anvil Points Mine near Rifle, Colorado. The primary goals were to investigate factors involved for adequate fragmentation of oil shale and to evaluate the feasibility of using the modified in situ retort (MIS) method for recovery of oil from oil shale.

The test program included single-deck, single-borehole tests to obtain basic fragmentation data; multiple-borehole, multiple-deck explosive tests to evaluate practical aspects for developing an in situ retort; and the development of a variety of instrumentation techniques to diagnose the blasting event.

This paper will present an outline of the field program, the type of instrumentation used, some typical results from the instrumentation, and a discussion of explosive engineering problems encountered over the course of the program.

INTRODUCTION

The fragmentation program was sponsored by a Consortium of oil companies composed of Cities Service Co., Getty Oil Co., Mobile Research and Development Co., Phillips Petroleum Corp., Sohio Shale Co., and Sunoco Energy Development Co. Science Applications, Inc. (SAI) managed the program and provided technical direction. In a cooperative effort with SAI and the Consortium, Los Alamos National Laboratory participated and shared in the fragmentation research. Sandia National Laboratory also participated in some of the testing which occurred late in the program. Since this program was part of the overall rock fragmentation research sponsored by the Department of Energy (DOE), the Anvil Points Research Mine was chosen as the site for the field tests.

The primary goals of the research program were to establish methods that would allow economic recovery of oil from oil shale by means of the modified in situ retort process and to develop a predictive capability for oil shale fragmentation. Only the field program will be discussed in this paper. The testing was done to provide data concerning stress wave propagation in shale, to determine oil shale characteristics and explosive properties that control fracture and fragmentation, and to identify geometric effects that influence fracture and fragmentation. This information was then to be used to design an in situ retort. The stress wave propagation data came from laboratory tests (which are not discussed in this paper) and from instrumented field tests. Oil shale characteristics affecting fragmentation were obtained from single borehole tests and from a study of the geologic features such as joint spacing and shale grade. Some explosive characteristics which effect fragmentation and fracture such as the detonation pressure and explosive gas generation were obtained by employing different explosive types in simple and complex field test arrangements. Some influences of timing delays and shothole spacing were studied by correlating the particle size distribution and the degree of rubblization in tests in which the horizontal and vertical spacing and timing of the explosive charges were varied.

FIELD TEST PLAN

The tests conducted at the Anvil Points Mine consisted of five sets of experiments. These were designated the A, B, C and D Series and the Special Series. In all, 45 full-scale tests and 12 small scale tests were performed. Ideally, each succeeding series was to build on the results from the previous series, starting with the small scale testing, moving to the full scale single-borehole, single-deck shots and ending with multiple-borehole with decked explosive charges to form an in situ retort. An outline of the test plan for the series of shots is provided in Table 1. The Special Series tests were added to the original plan because specific problems were encountered as the project matured. Some of these were performance problems with the detonator, booster, and explosives (deadpressing and cap delay time changes); identifying an explosive adequate for fragmenting the rich shale beds that were contained within the column to be rubbled; investigating stemming performance problems that were inherent in complex blast patterns; and lack of crater formation data for choosing the proper time delays in a retort design. The individual special tests were performed over the course of the project as the need arose. The small scaled tests were conducted to study presplitting, fracture control blasting, and charge timing effects.

Figure 1 is a map of the Anvil Points Mine showing the location of the 45 large-scale tests conducted in the program. The shale grade variation in the test bed is shown in Figure 2.

INSTRUMENTATION

Instrumentation was an important aspect of the program. The object was to measure stress wave propagation velocities, crater formation times and rates, explosive and stem performance, rock mass motion at the free face and at depth, and to accurately determine the initiation times of the explosive columns; especially when using time delayed caps. Instrumentation included piezoelectric and piezoresistive accelerometer gauges, electromagnetic velocity gauges, CORRTEX (Continuous Reflectometry for Radius vs Time Experiments) time domain reflectometry (Virchow et al., 1980) cable shortening techniques, low framing rate video coverage, as well as other instrumentation types that will not be discussed in this paper.

Data Acquisition Systems

The electronic systems, including the firing electronic devices used throughout the project, were housed in mobile trailers parked inside the mine and located approximately 330 m from the experimental sites. Initiation of the explosive in some tests was accomplished using an FS-10 EBW (Exploding Bridgewire) portable firing system and RP-83 EBW detonators, both manufactured by Reynolds Industries, Inc. This method was used for the simple tests--the A and B Series, some of the C Series, and many of the special tests. For the complex tests of the C, D, and Special Series, an Energy Research of Ohio (ERO) sequential blasting machine was used to initiate the electric caps.

One of the electronic systems was composed of a computer-controlled timing and firing (T/F) system and a signal acquisition system. A DEC (Digital Equipment Corporation) LSI-11/2 minicomputer communicated with external electronic devices through ports (32 ports were available) to provide sequenced closures to trigger power supplies for firing the shot, to activate signal recording equipment, and to trigger the CORRTEX electronic units. Figure 3 is a block diagram of the major components of the main system. The peripheral equipment for the computer included dual floppy disk drives, a monitor screen, and a hard copy device to produce plots and code information. For each test, the T/F information was programmed into the computer to provide trigger pulses to the blasting box, recording electronics, and CORRTEX.

The signal acquisition system consisted of 10 LeCroy multichannel waveform digitizers (Model 2264H manufactured by LeCroy Research Systems, Palo Alto, California), 14 single-channel Ectron signal conditioners (Model 776B, manufactured by Ectron Corp, San Diego, California), for the piezoresistive transducers, a 12-channel PCB (manufactured by PCB Piezotronics, Buffalo, N.Y.) power supply (amplifier unit for the piezoelectric transducers) and 3 magnetic tape units and associated amplifiers for recording the signals in analog form. The memory of each digitizer was 32K words. Sampling rates of 0.04 to 4 MHz were available depending on the number of channels activated on each digitizer. For recording and storing the gauge signal, each digitizer received a stop trigger originating from the computer at a user specified time in the T/F sequence.

As a complement to the main instrumentation system twelve channels of eight-bit transient-digital recording by means of Biomation model 2805 recorders were provided. Each Biomation unit was capable of recording two eight-bit 2,048 work channels, three model 2805M master units provided time base control for themselves and for any 2805S slave units attached to them. As up to three slave units could be given time base control from one master unit, it was common to utilize one master unit with two or three slaves and the other master units with one or no slaves. The Biomation units were rea[illegible] through a sixteen-bit parallel interface into a Hewlett Packard 9835 desktop computer. These data were permanently saved on the cassette recording system which was part of the HP 9835. The HP 9835 was also utilized to reduce the data and to provide plots on a Hewlett Packard 9872 plotter. The Biomation transient digital recorders, the HP 9835 computer and the supporting amplifiers, filters and power supplies were also housed in the trailer.

The CORRTEX electronics were part of the system even though the equipment was self-contained. As many as 17 CORRTEX units were used on a single test to monitor initiation times, explosive performance, and stem behavior.

A variety of signal lines and control wires connected the recording trailers to the remote experimental sites. The transducer signals were carried by RG-223 coaxial cables as well as twisted and shielded wire pairs. CORRTEX signals were transmitted by RG-223 and RG-214 coaxial cables.

Accelerometer Gauges

Two types of transducers were used to measure acceleration, the Endevco piezoresistive 2264A miniature shock accelerometer (manufactured by Endevco, San Juan Capistrano, California) with ratings up to 20,000 g and the PCB piezoelectric 305A high-shock accelerometer with ratings to 50,000 g. A gauge package with as many as three transducers consisted of encapsulating the Endevco and PCB gauges in a canister molded from an epoxy material approximating the impedance of the oil shale. Within a canister, the gauges were oriented to monitor acceleration in one or two, and sometimes three, coordinate directions. Each gauge package was then positioned at a known location in an instrument hole, oriented relative to the charge column and coupled to the shale with a rock matching grout. For rock mass motion at various depths, the usual gauge package consisted of two transducers oriented to measure the vertical and radial components of acceleration relative to the explosive. Occasionally, a third transducer was added to the canister to monitor acceleration in the tangential direction. Surface rock motion was monitored by mounting a single transducer in a canister oriented to measure only the vertical component of acceleration.

The Endevco transducers were connected to Ectron signal conditioning units that contained the bridge completion and balancing circuits, an excitation voltage for the gauge, and an amplifier section. Each Ectron output was connected to one channel to a digitizer recorder. The PCB quartz sensors were connected to a PCB power unit to power the transducer with a built-in amplifier for operation in the voltage mode. The outputs from the power unit were connected to appropriate channels of the digitizer recorders.

Velocity Gauge

As both types of accelerometers were subject to high frequency noise and/or significant baseline shift in the adverse environment in which they were employed, efforts were also directed towards developing an electromagnetic velocity gauge technique suitable for measuring rock mass motion and stem performance in the immediate vicinity of detonating explosive charges.

The type of electromagnetic velocity gauge found to be most effective is depicted in Figure 4 and described in detail by (Young, et al., 1983). This gauge functions simply by the motion of a bar magnet through a helically wound pick up coil. As indicated in the figure, the bar magnet which is free to slide within the tube wrapped with the pick up coil, is positioned prior to the explosive event at a location such that the expected rock mass or stem motion will cause the pick up coil to move past the magnet. The magnets were typically held in place by their magnetic adherence to a small bolt positioned in the tube assembly as illustrated. The arrival of any explosive induced shock or motion would dislodge the magnet from this supporting bolt and during the few milliseconds of valid recording the magnet would remain essentially stationary in space by nature of its inertia while the pick up coil tube assembly moved past it. By performing a variety of drop test calibrations on the electromagnetic velocity gauge assembly, it was possible to calibrate each gauge for the voltage generated as a function of tube velocity past the magnet. The gauge outputs were typically accurate to within five percent over the eight to ten centimeter travel built into the gauges. As each gauge had a known travel or displacement limit, it was possible to verify the gauge calibration factors during an explosive test by comparing the gauge displacement obtained by integrating the velocity record with the mechanically defined displacement limit.

The electromagnetic velocity gauges had the disadvantages that they had a greater impedance mismatch with the oil shale and the grout in which they were embedded than did the piezoelectric and piezoresistive accelerometers and that special precautions had to be taken during gauge installation to ensure that the magnet was not dislodged prior to execution of the explosive test. The electromagnetic gauges had the advantages that they provided a large amplitude, noise free voltage output which was directly proportional to gauge velocity and that they could provide long (up to 30 ms) records of ground or stem motion.

CORRTEX

CORRTEX instrumentation (Schmitt, 1983) was used primarily to monitor the performance of a detonating column of explosive in simple and complex blast designs used in the Consortium field test program. Because the performance of commercial explosives is dependent on geometry, confinement, and external factors such as preshocking, it is important to measure the performance under field conditions to evaluate the blast results. CORRTEX is an application of time-domain-reflectometry (TDR) to interrogate a coaxial sensor cable that changes length with time due to an advancing pressure front. CORRTEX is a portable electronics system which emits electronic pulses at timed intervals that travel to the end of a 50-ohm coaxial sensing cable, reflect, and then return to the receiver. The microprocessor-controlled electronics unit counts, digitizes, and stores the travel time of the pulses. Figure 5 is a schematic of the principles of operation. For measuring explosive performance, the sensor cable runs through the charge column and is crushed at the same rate as the explosive detonation. With this technique, shock/detonation wave position as a function of time was obtained with centimeter resolution. Pulse rates were variable over a 10 to 90 μs range, and 2000 data points could be stored. RG-174, FSJ1-50, RG-223, and RG-214 50-ohm sensing cables were used in the field tests covering the range of crush pressures from 5 MPa to 2.5 GPa. At shot time, the CORRTEX electronics was activated by a trigger pulse originating from the computer-controlled T/F system shown in Figure 3. For the simple borehole tests, usually two sensor cables of different crush strengths such as RG-174 or RG-223 and FSJ1-50 cables were placed in the explosive borehole to measure the detonation velocity. CORRTEX was used to monitor detonation times and detonation velocity by judicious placement of the sensor cables in a blast geometry containing several levels of explosive. CORRTEX was also used to obtain data on times of free surface formation within the resulting craters.

RESULTS

Rock mass motion measurements were conducted for single- and multiple-borehole arrangements. A representative single-borehole fragmentation test is shown in Figure 6 which illustrates the accelerometer gauge placement for measuring rock motion.

An acceleration record from an Endevco gauge oriented to measure the vertical component placed at a depth of 1.20 m and at a radial distance of 2.66 m for the TNT charge is shown in Figure 7. The record has been integrated to obtain velocity and displacement and these are also shown in the figure. A surface acceleration record from a PCB gauge located 2.0 m radial distance from the charge is shown in Figure 8. A semilogarithmic plot of acceleration of surface mounted gauges from several tests is shown in Figure 9. The data are scattered, but the points have been approximated with a linear line segment. This suggests that acceleration decreases exponentially with radial distance from the explosive column. Figure 10 is a semilogrithmic plot of peak vertical acceleration vs radius for gauges embedded at two depths. The data have less scatter than from surface gauges and the data once again has been fitted with a straight line. Thus surface acceleration and acceleration at depth decreases exponentially with radial distance from the charge for oil shale.

Surface acceleration measurements from a test in which pelletized TNT was used in a 0.15-m-diameter borehole in lean shale were integrated to obtain velocity vs time for the various gauge locations. These peak values for acceleration and velocity are plotted in Figure 11, along with the predicted values from a computer simulation (Adams et al., 1983) from the test. The agreement is very good between the calculated and measured values in the

1.0- to 5.0-m range, especially the peak velocity vs distance plot.

Average stress wave propagation speeds were determined for lean (10 gal/ton) and intermediate (25 gal/ton) grades of oil shale using the time of arrival for the wave of surface mounted and embedded accelerometer gauges. The data from several tests indicate a wave speed of 3.43 km/s in lean shale and 3.25 km/s for intermediate grade shale.

The data from accelerometer gauges at the surface and from those buried in the shale to a depth near the top of the charge show that the velocity of the rock mass decreases with depth during a blast event (as might be expected). This trend was independent of the complexity of the test and the explosive type used. Surface motion was 10-20 m/s while motion at a depth of 2.5 m was 5 m/s or less.

The accelerometer gauge signals were used also to evaluate the overall performance of a complicated test, such as the D Series tests, by comparing the observed signal times (corrected for wave travel times) with the intended delay times of the explosive columns. In this way, the time sequence could be approximately verified for the blast event. The vertical component obtained from a multi-directional accelerometer canister placed near the last and largest of a multi-hole multi-charge mini retort fragmentation test is shown in Figure 12. Also shown in the figure is the expected arrival times for seismic energy generated by the various explosive charges. These arrival times were based upon the actual detonation times of the charges as measured by the CORRTEX and calculated for an average shale wave speed of 3168 m/s. While there is some agreement between the arrivals of large amplitude seismic energy and the detonation of charges, the very complex nature of these records attest to the complex wave propagation occurring in the layered oil shale formation.

Rock Mass Motion from Velocity Gauges

Records from two of the six electromagnetic velocity gauges fielded in the final multi-hole multi-charge fragmentation test are shown in Figure 13. Gauges 1 and 5 shown in Figure 13 were placed directly one above another in a single hole drilled intermediately between the two central upper level explosive holes designed to detonate at zero time. Gauge 1 was placed 2.44 m below the upper level room floor while gauge 5 was placed 1.22 m below the floor. Both gauges show the near simultaneous arrival associated with the detonation of the first charge at 2.0 ms. The deeper gauge does not begin any significant motion until 2 to 3 ms later and then only shows a relatively low velocity of 2 to 4 m/s. At the time of gauge failure (probably due to cable clipping) at 26.6 ms, this gauge has undergone a total displacement of only 4.6 cm. The shallower gauge, located midway between the two zero time shot holes, attains a significant velocity immediately after the first shot and has somewhat higher velocities than the underlying gauge. This gauge reaches the limit of its travel of 6 cm at 14.0 ms. The peak velocity of 7.5 m/s realized by the shallower gauge is still much lower than had been expected.

Stemming Behavior from Accelerometers and Velocity Gauges

In a decked single borehole test, a 50,000 g PCB piezoelectric accelerometer, was placed in the intermediate grout plug and an Endevco 20,000 g piezoresistive accelerometer was placed on the interface between the upper portion of the gravel stem and the upper explosive charge (see Figure 14). These two accelerometers were designed to measure the shock transmission characteristics of the stem and to establish if the stem successfully bridged so as to protect the upper (delayed) charge. The output from the piezoelectric and piezoresistive accelerometers utilized in this test are illustrated in Figure 15. The record for the PCB accelerometer located in the intermediate grout plug shows the distinctive two shock response characteristic of a majority of the stem performance measurements. An initial shock at a time of 700 microseconds corresponds to the arrival of the initial shock wave information through the rock surrounding the wellbore. The larger amplitude arrival at 3 ms corresponds to the shock transmitted through the granular stemming material between the lower charge and the intermediate grout plug. As noted in Figure 15a, the velocity obtained by integrating the acceleration record and the displacement obtained by integrating the velocity record both indicate that the intermediate grout plug was not subjected to a continual acceleration and velocity increase and that this stem most certainly bridged or held. That the stem held is further attested by the record obtained from the piezoresistive accelerometer obtained at the interface between the upper gravel stem and the upper explosive charge. This accelerometer record also shown in Figure 15b shows a much reduced acceleration peak and only a very small 2.0 meter per second velocity for the interface.

An additional special test demonstrating some of the instrumentation capabilities employed at Anvil Points is shown schematically in Figure 16. This test employed two 15.8 cm diameter explosively loaded boreholes located 3.3 m from each other. Two smaller 10.8 cm diameter instrumentation holes were drilled between the two explosive holes with one of the smaller instrumentation holes being only 0.3 m from an explosive hole. In this experiment, electromagnetic velocity gauges were embedded in the grout plug capping each of the explosively loaded holes and at three different levels in the instrumentation hole intermediate between the two explosive holes as illustrated in the figure.

Data from one of the electromagnetic velocity gauges embedded in the grout plug of an explosive hole is illustrated in Figure 17. This figure shows the characteristic rock shock response at 1.3 milliseconds followed by the much larger stem shock at 6.8 ms. The very rapid drop in gauge output occurring just after 8 ms is due to the gauge meeting the mechanical limit of its travel. The 11.0 cm displacement obtained by integrating the velocity record up to the sharp velocity drop served to confirm the gauge calibration factor. The large 12 m/s velocity of the stem prior to the gauge meeting its displacement limit indicates that this stem is probably undergoing failure and in the process of being rifled from the borehole.

CORRTEX Data and Results

CORRTEX proved very valuable in determining the performance of simple and complex blast patterns through the measurement of the detonation times and velocity. In addition, the CORRTEX records provided information on the performance of various stem materials and stemming designs by monitoring the change in cable length as the shock wave propagated through the stemming column. On several of the single-borehole and two-borehole tests, CORRTEX sensor cables were installed in satellite holes in an attempt to measure rock fracture and crater formation during the fragmentation tests.

The detonation velocities of several explosives were measured in simple and complicated geometries in placements similar to that illustrated in Figure 18. This figure shows the cable routing used to measure the detonation times and velocities of several explosive columns with different delay times from a single sensor cable. The average detonation velocities measured for several explosives were 5.10 km/s for pelletized TNT, 3.90 km/s for pelletized ANFO, and 4.83 km/s for the IRECO 1205C ANFO slurry used for some of the C-series, for the D-series, and several of the Special-series tests. A typical CORRTEX record from a sensor cable through the stem and explosive is shown in Figure 19. The record starts at 204.3 ms as designed, a fast rise to the one meter mark (one meter of sensor cable was wrapped around the detonator booster assembly), a straight section with a slope of 4.77 km/s representing the burn velocity of the 1204C slurry, and then at the explosive-stem interface the slope changes to 0.48 km/s describing the shock wave speed in the crushed gravel stemming material. From many CORRTEX records, the average shock wave travels at 0.5 km/s through the first one-half meter of crushed gravel about the charge.

CORRTEX sensor cables were also grouted in satellite instrument holes near explosive boreholes to monitor crater formation. Figure 20 is the CORRTEX record from a cable in the central hole for the test shown in Figure 16 and Figure 21 is a plot of cable crush versus time from test satellite holes in two separate tests used to measure crater formation. The time-distance plot in Figure 21 shows two lines with slopes of 0.36 and 0.37 km/s. These values represent the rate at which the crater forms, or the rock fracturing rate. The fragmentation process seems to proceed slower than previously thought.

The extensive instrumentation employed on the Anvil Points oil shale fragmentation tests has provided an unusually large volume of data on the details of the explosive fragmentation process in oil shale. While the data was initially utilized to verify shot performance and to address specific problem areas, such as stem performance, the contributions of the data to the understanding of the explosive rock fragmentation process in general could be significant. Work is continuing to reduce and interpret the data collected.

Some general conclusions from the program are: geologic influences such as joints do not appear to control the fragmentation process in multiple-borehole, multiple-level designs, but shale grade may have second order effect; explosive engineering problems influence the fragmentation process more than previously imagined; stemming performance is a very important factor in the success or failure in creating a large retort; the role of explosive gas pressure in retort blasting appears to affect rock motion, charge timing, and borehole spacing; and decked charges in a multiple-borehole blast design cause problems in explosive deadpressing, unwanted stem motion, and premature venting of explosive gases.

REFERENCES

Virchow, C.F., G. E. Conrad, and D.M. Holt, 1980, "Microprocessor-Controlled Time Domain Reflectometer for Dynamic Shock Position Measurements", Rev. Sci. Instrum., 51, 642.

Young, C., W.L. Fourney, B.C. Trent and N.C. Patti, 1983, "Electromagnetic Velocity Gauge Measurement of Rock Mass Motion in Explosive Fragmentation Tests" Proceedings, First International Symposium on Rock Fragmentation by Blasting, Lulea, Sweden, August, 1983.

Schmitt, G.G., 1983, "CORRTEX Data for Oil shale Consortium Experiments at Anvil Points Mine 1981-1982", Los Alamos National Laboratory internal report.

Adams, T.F., R.B. Demuth, L.C. Margohn and B.D. Nichols, 1983, "Simulation of Rock Blasting with SHALE Code", Proceedings, First International Symposium on Rock Fragmentation by Blasting", Lulea, Sweden, August, 1983.

TABLE 1 Major Objectives of the Individual Test Series

A Series: Single Hole (6 Tests)

- Compare the effects of TNT and ANFO prills on fragmentation.
- Establish particle size distribution, crater dimensions, and depth of pull.
- Observe the effects of joint spacing and distribution, shale grade, and limited free face on fragmentation and crater dimensions and shape.
- Provide an estimate of the borehole spacing for the B Series tests.
- Replicate Shot 79-10 conducted at Colony Mine to compare cratering and fragmentation characterization for the two oil shale mines.
- Rock motion and displacement data at the surface and at depth by means of accelerometer and velocity gauges.

B Series: 5 Borehole, Single-Deck Pattern (4 Tests)

- Evaluate horizontal spacing and timing on crater formation and fragmentation using TNT prills.
- Measure particle size distribution, crater dimensions, and depth of pull in a multiple-borehole geometry.
- Evaluate changes in depth-of-burial and charge weight on particle size distribution and crater formation.
- Measure rock mass motion using accelerometer and velocity gauges mounted on the free face and embedded in the rock.
- Establish horizontal spacing for 8- and 16-borehole tests in the C and D Series tests.

C Series: Vertical Multilevel in a Multiple-Borehole Arrangement (15 Tests)

- Study and confirm the explosive and stem performance prior to conducting the C Series multiple-hole fragmentation tests.
- Obtain data on effects of horizontal spacing and timing, vertical spacing and timing, staggered decking, and charge overlapping prior to conducting the D Series tests.
- Evaluate multilevel interaction effects from 8, 16 and 24 charges.
- Investigate explosive deadpressing and sympathetic detonation for several explosive types.
- Evaluate electric blasting cap performance in decked charge geometry.
- Fragmentation results from multiple-borehole, multilevel charge placement in a decked pattern.
- Measurement of rock mass motion from accelerometer and velocity gauges and framing camera coverage.

D Series: Small-Scale Retorts (3 Tests)

- Evaluate fragmentation from a 16-borehole staggered pattern of 24 and 32 charges in 3- and 4-level configurations.
- Reproducibility of mini retort designs.
- Reverse pull fragmentation study.
- Evaluate performance of stem designs, electric blasting caps, and IRECO 1205C ANFO slurry.
- Effects of geologic features on fragmentation in a complex geometry.
- Rock mass motion measurements within the 16-borehole array and outside the blast location.

Special Series: Single and Multiple Borehole (17 Tests)

- Study special problem areas that affect fragmentation of oil shale such as stem performance, crater formation mechanism, improved breakage at crater the reverse pull plane, fragmentation of rich oil shale beds using different explosive slurries, deadpressing in single borehole, and decked arrangements.

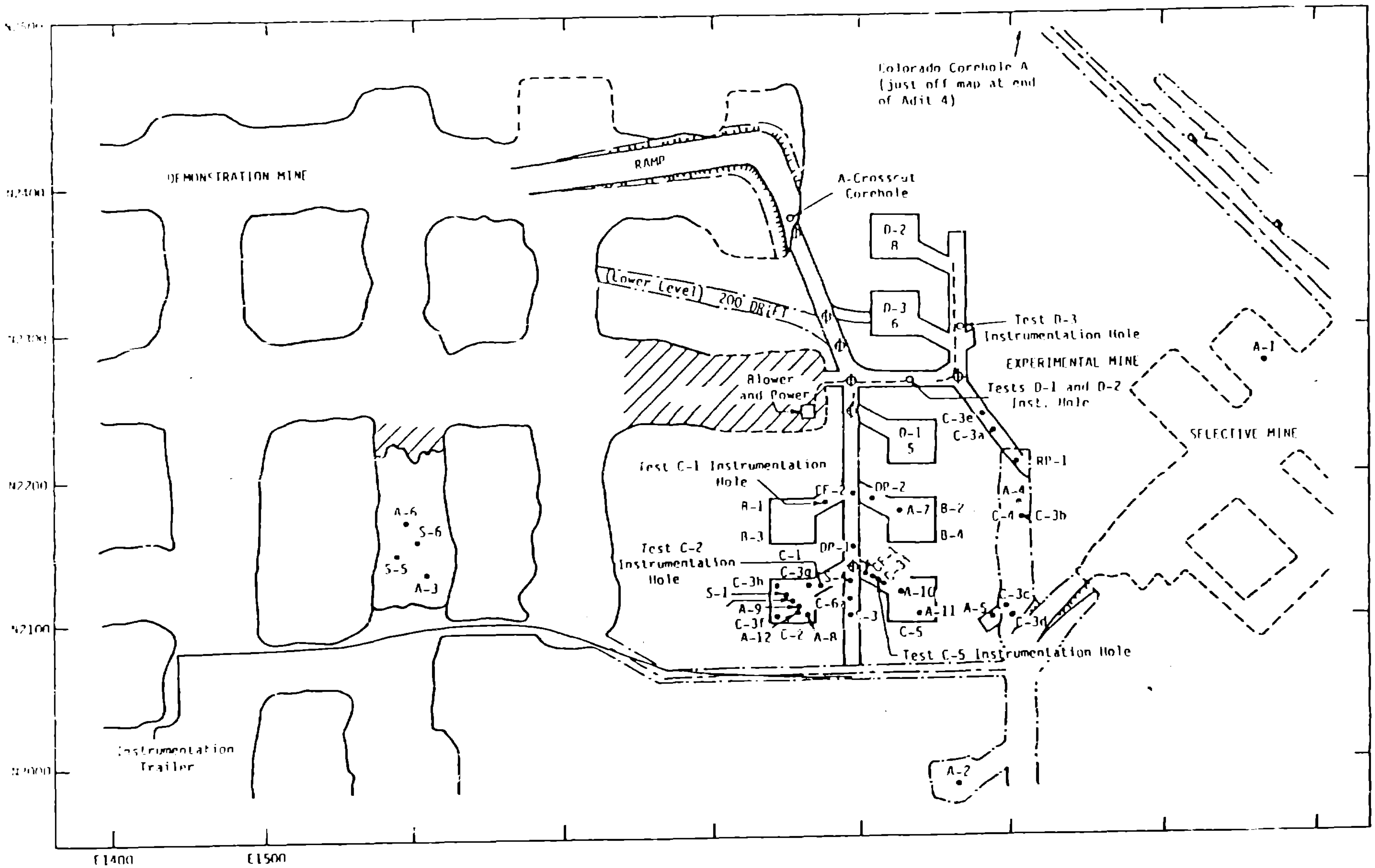


Fig. 1. Map of Anvil Points Mine showing the location of the fragmentation tests conducted.

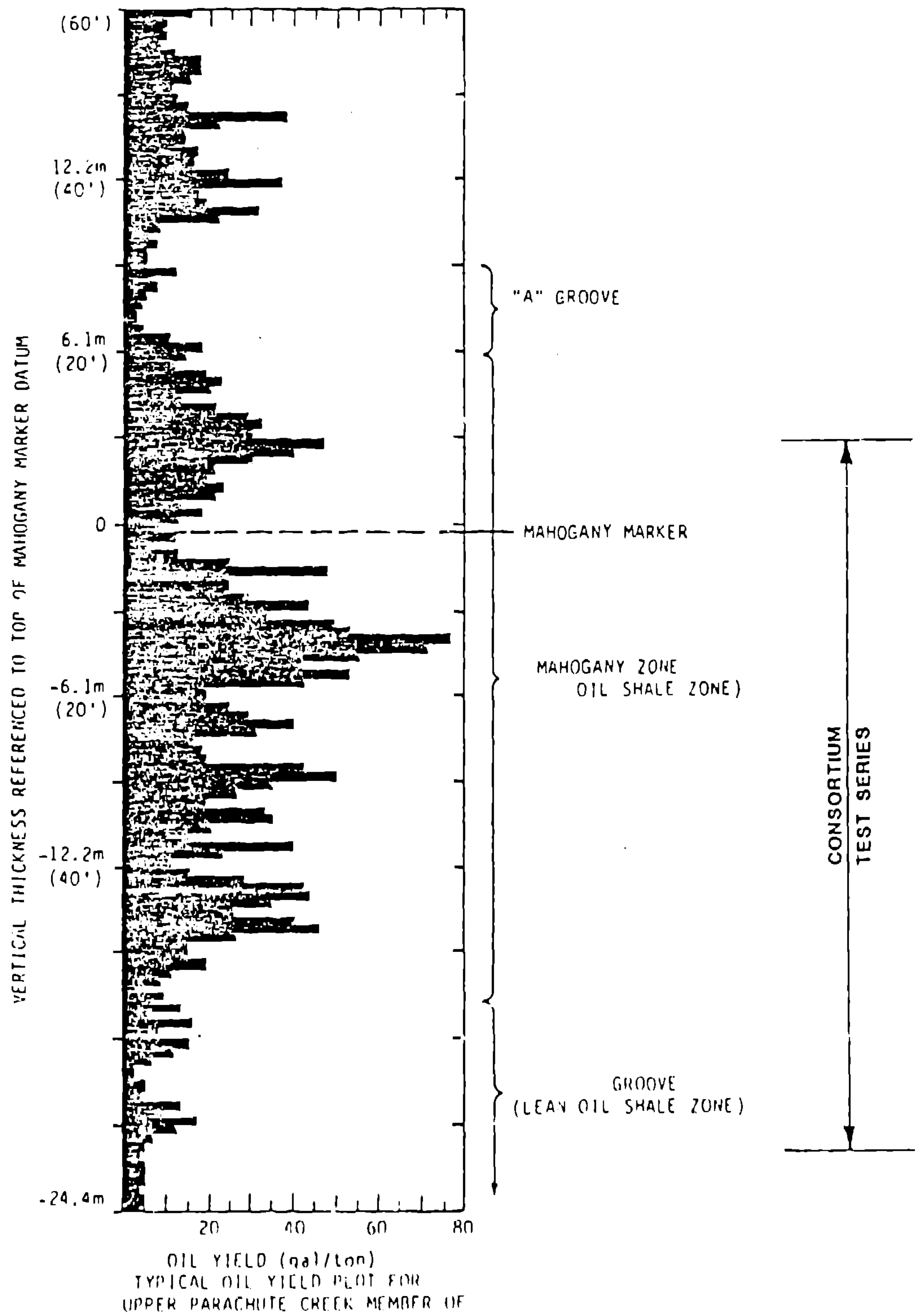


Fig. 2. Shale grade versus thickness for consortium tests.

DATA ACQUISITION SYSTEM AT ANVIL POINTS

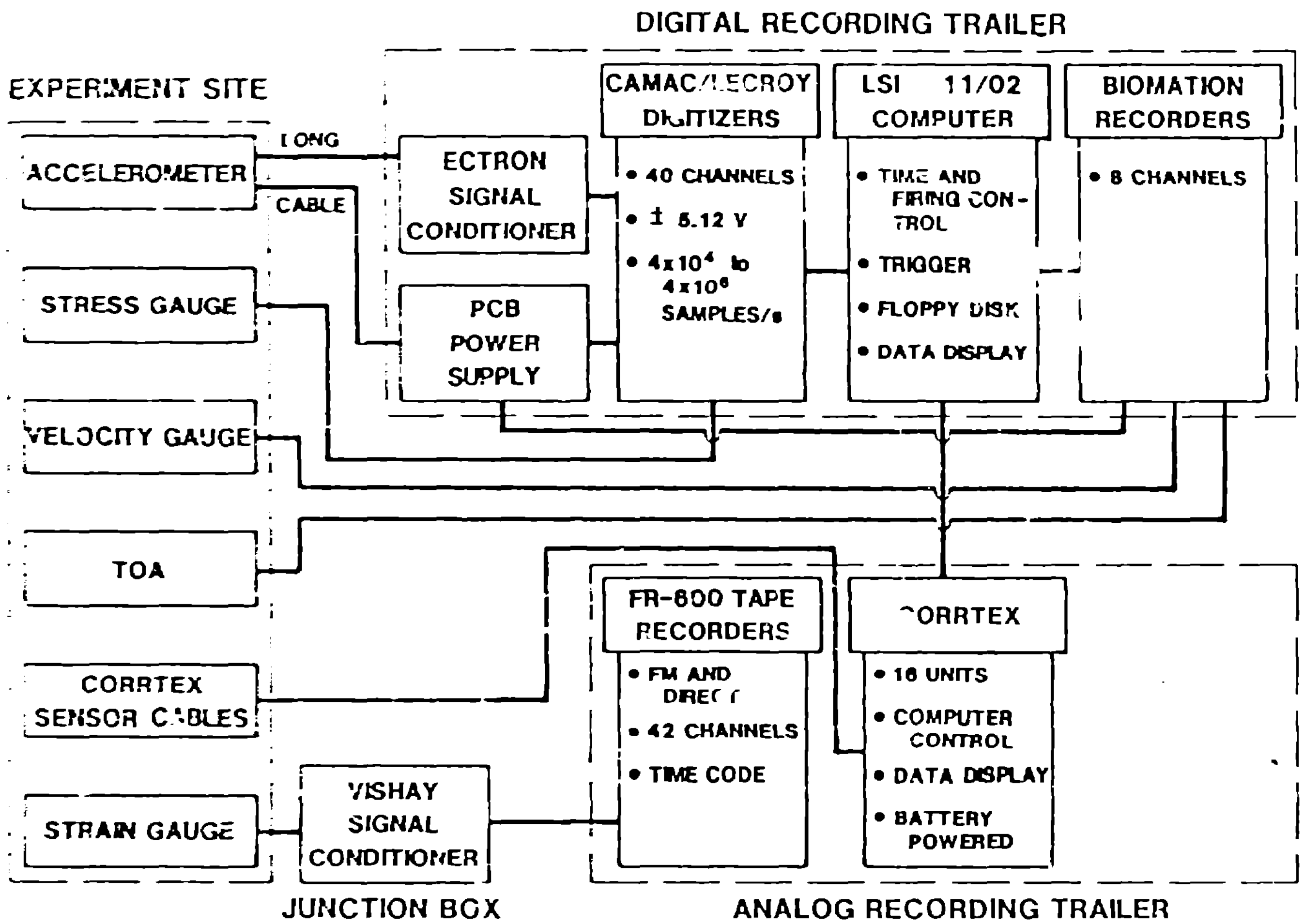


Fig. 3. Block diagram of the data acquisition system used at the Anvil Points Mine.

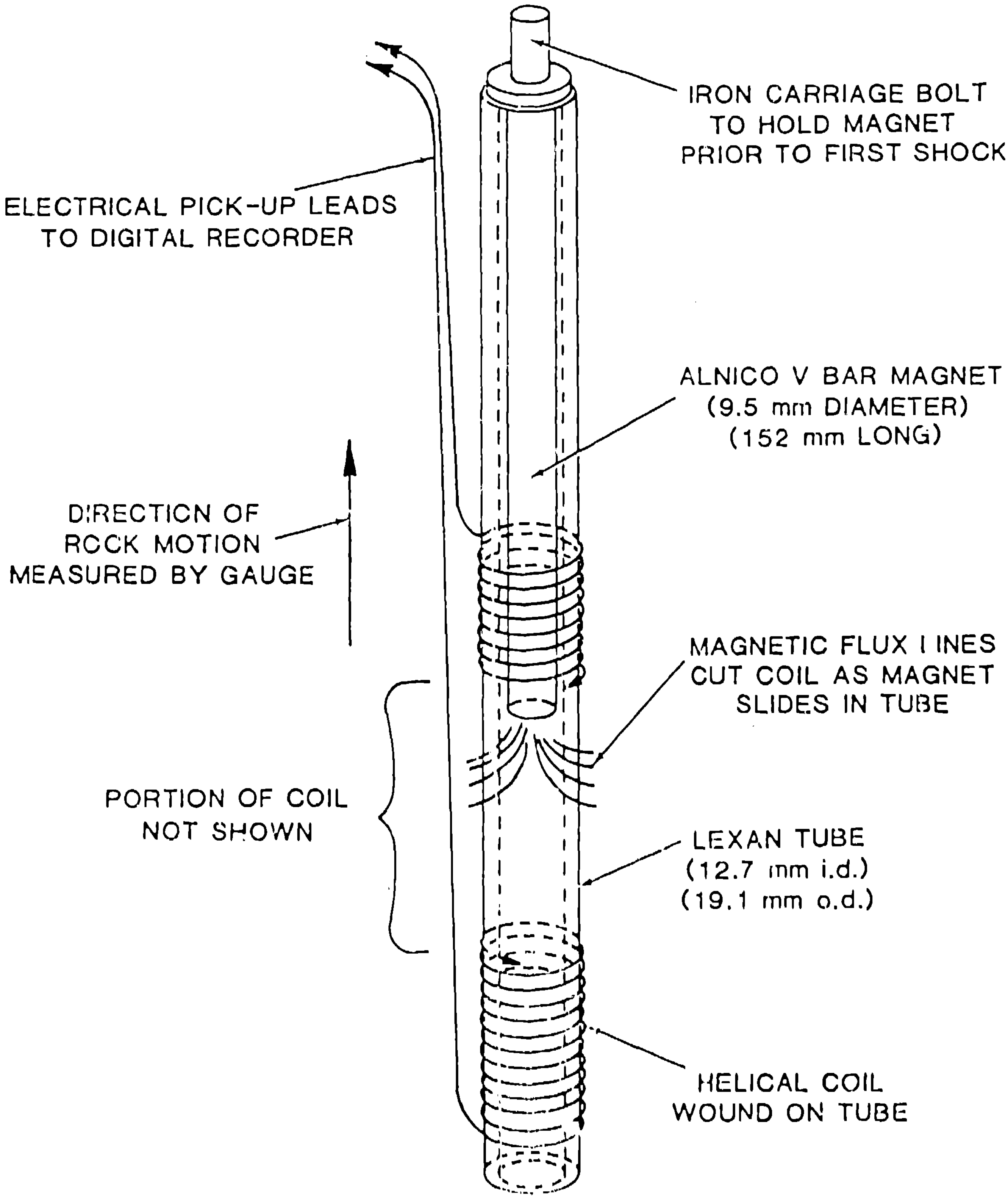


Fig. 4. Schematic view of tube-type velocity gauge used for rock-mass motion and stem performance measurements.

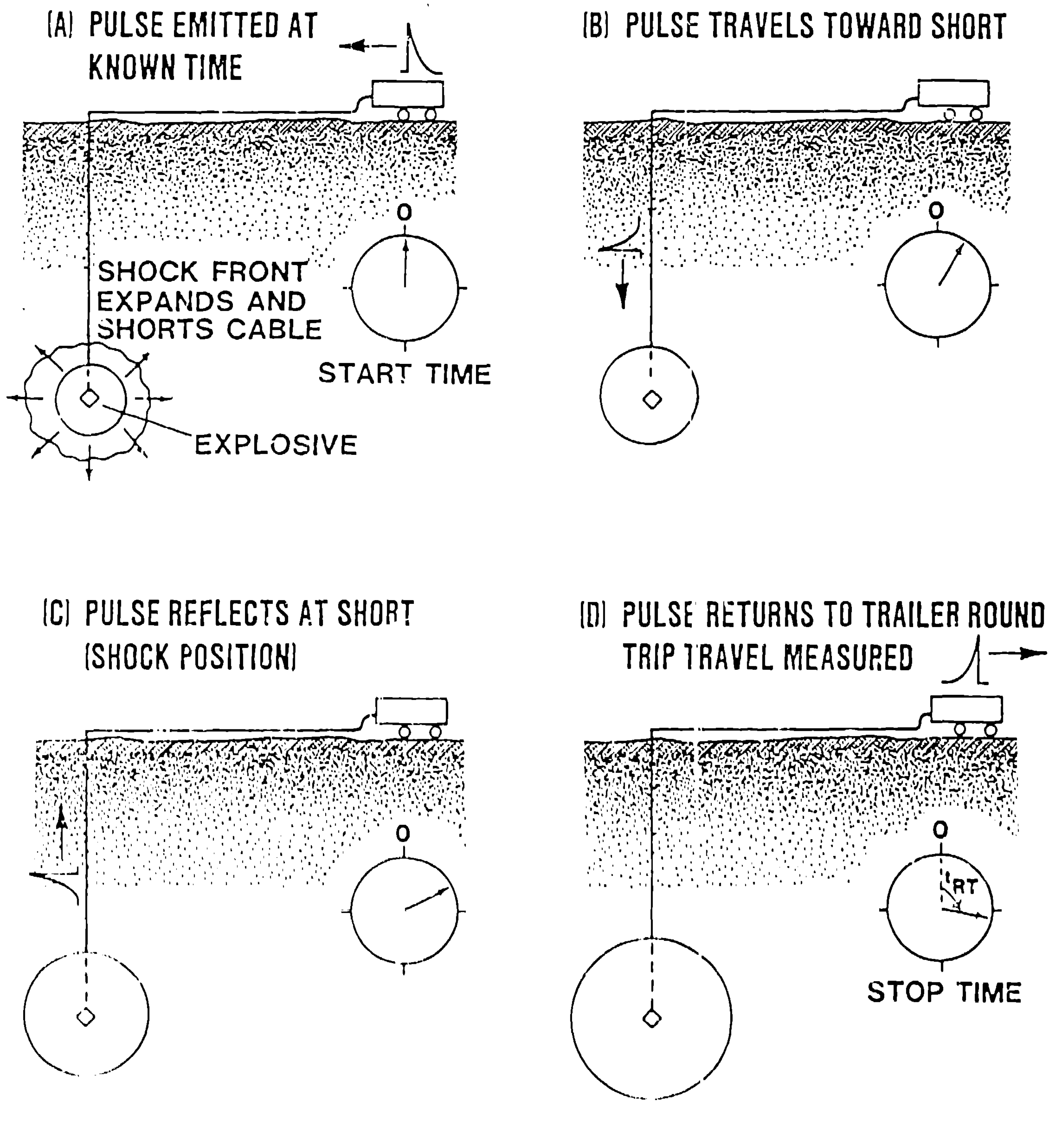
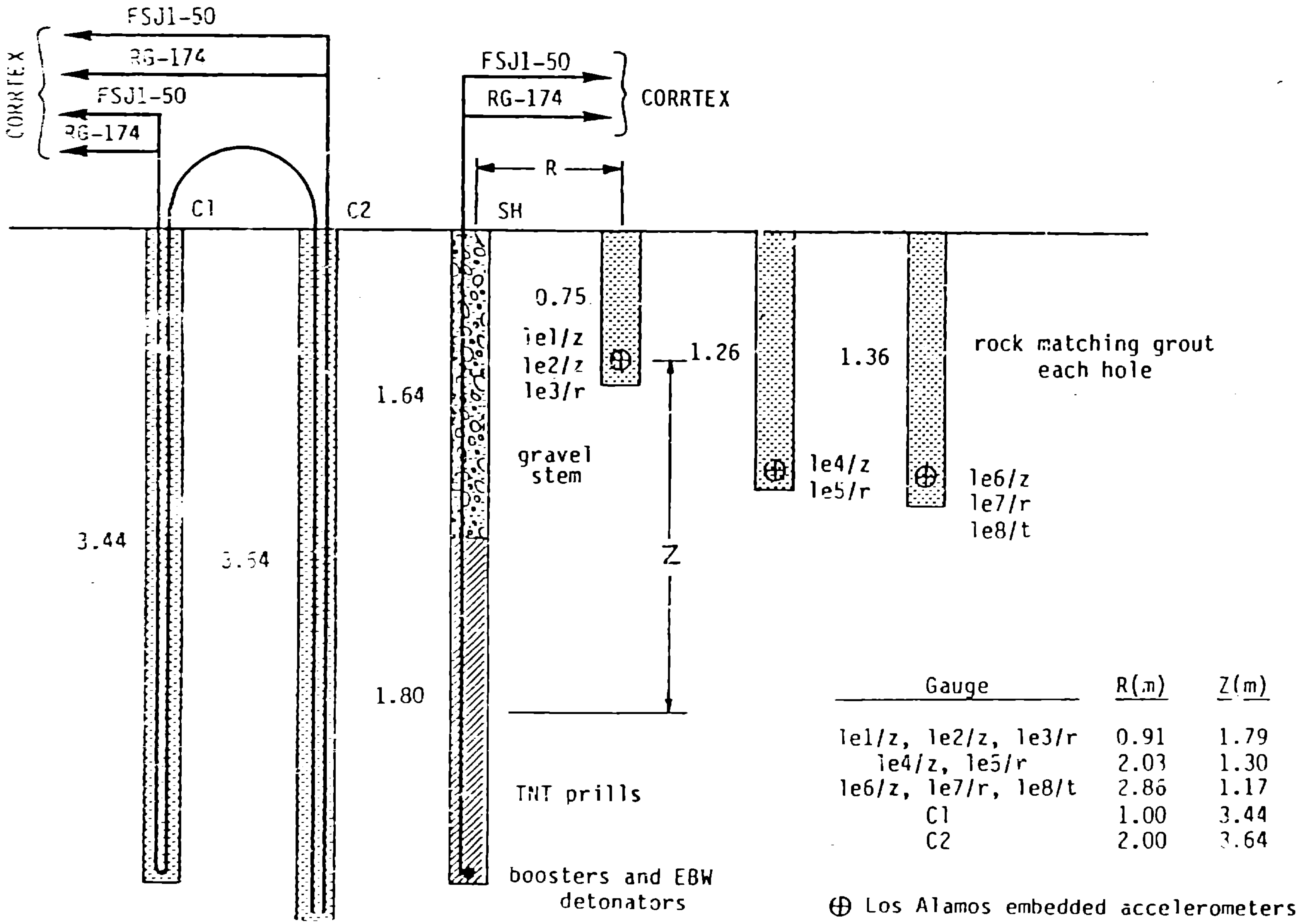


Fig. 5. Principles of time-domain-reflectrometry used by CORRTEX.



Gauge	R(m)	Z(m)
1e1/z, 1e2/z, 1e3/r	0.91	1.79
1e4/z, 1e5/r	2.03	1.30
1e6/z, 1e7/r, 1e8/t	2.86	1.17
C1	1.00	3.44
C2	2.00	3.64

Fig. 6. Placement of accelerometers for rock motion measurements.

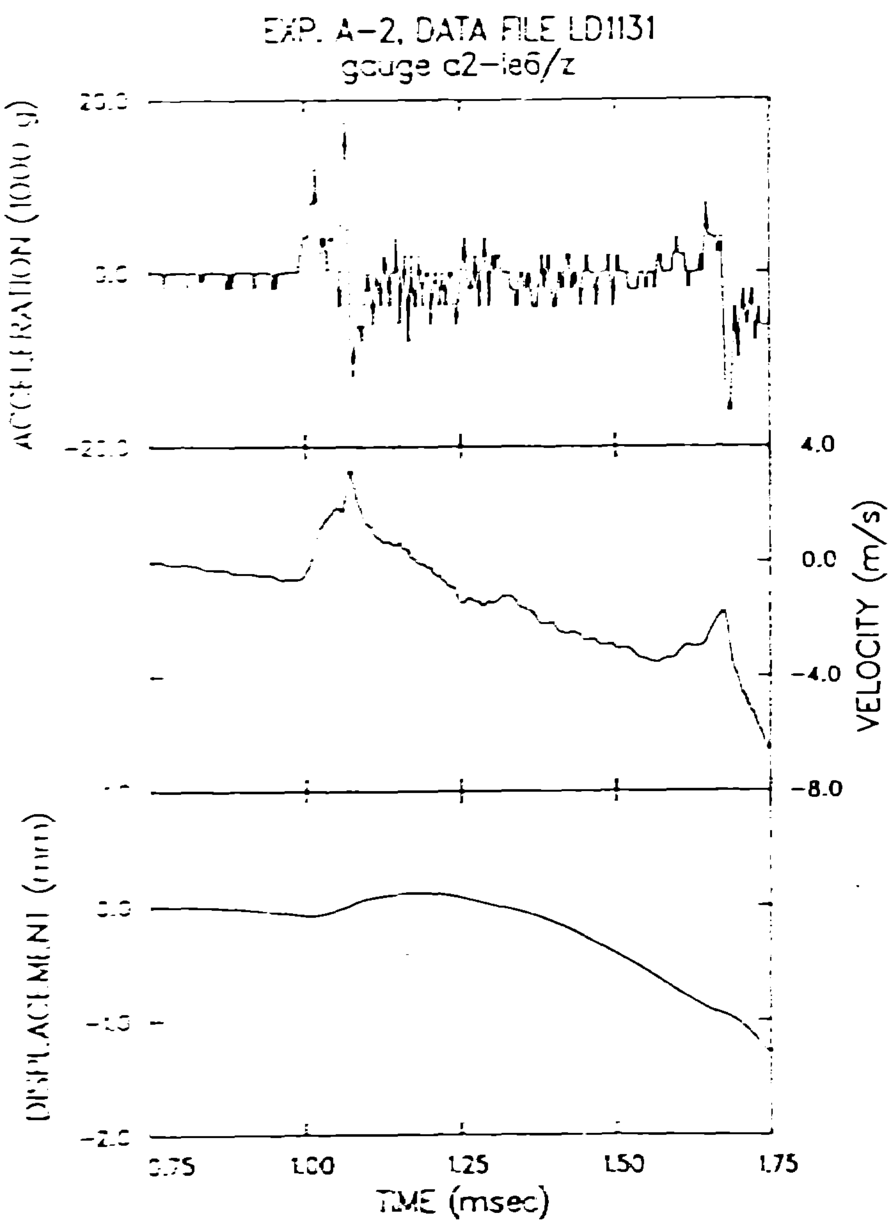


Fig. 7. Results from an accelerometer buried 1.26 m and 2.81 m from the charge - vertical orientation.

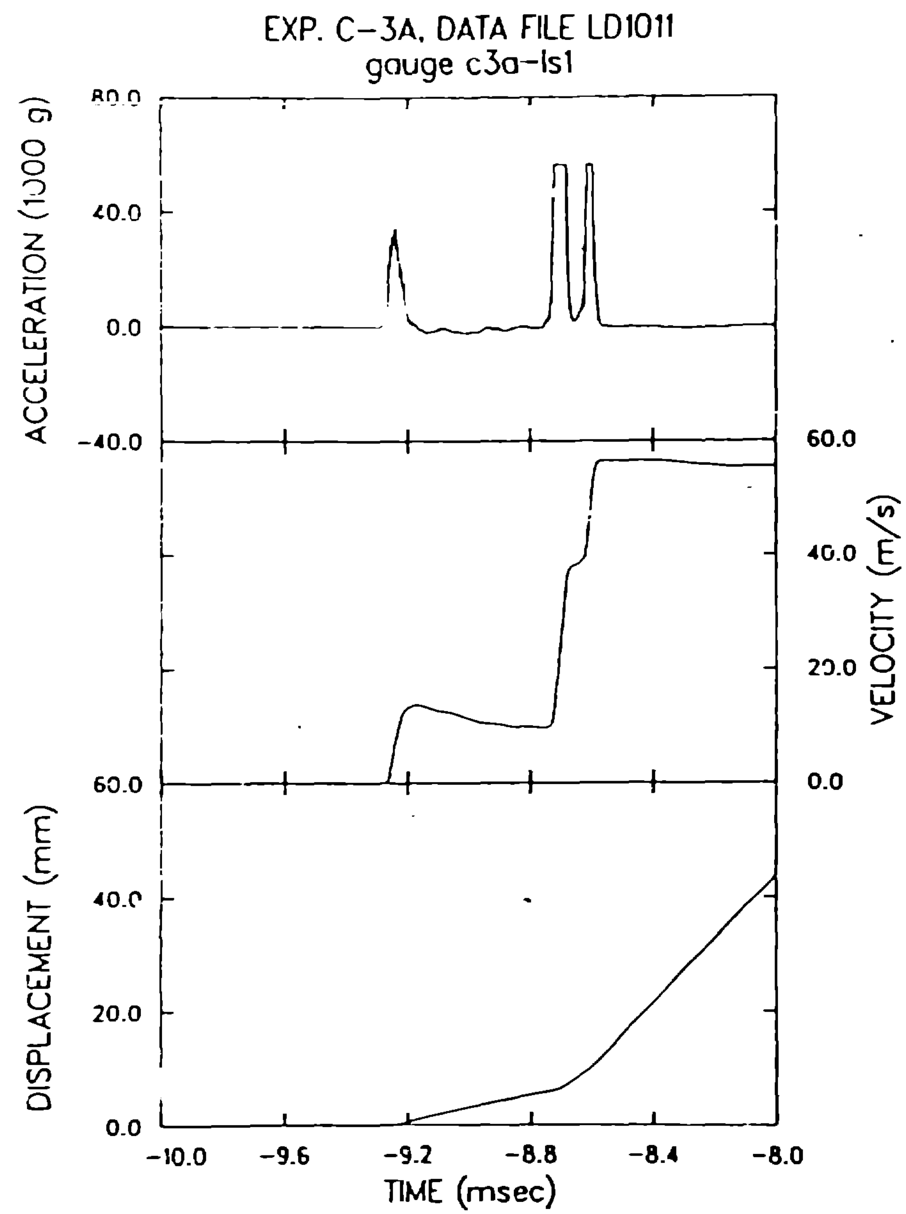


Fig. 8. Surface results for an accelerometer mounted 2 m radially from the charge.

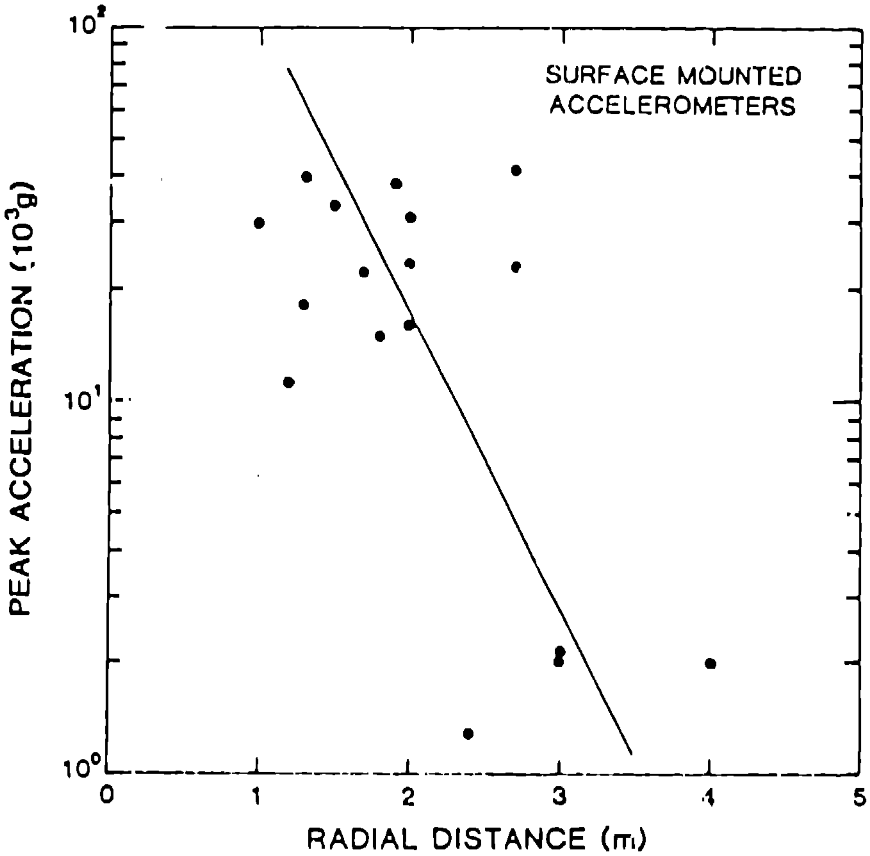


Fig. 9. Peak vertical acceleration versus radius for surface-mounted gauges - results from several tests.

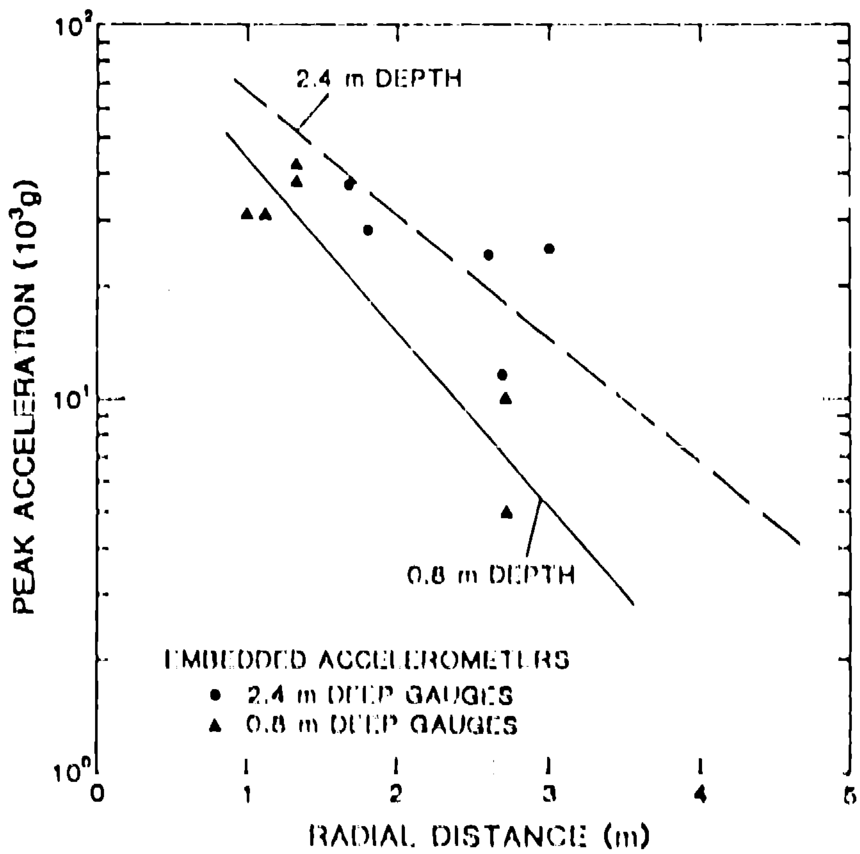
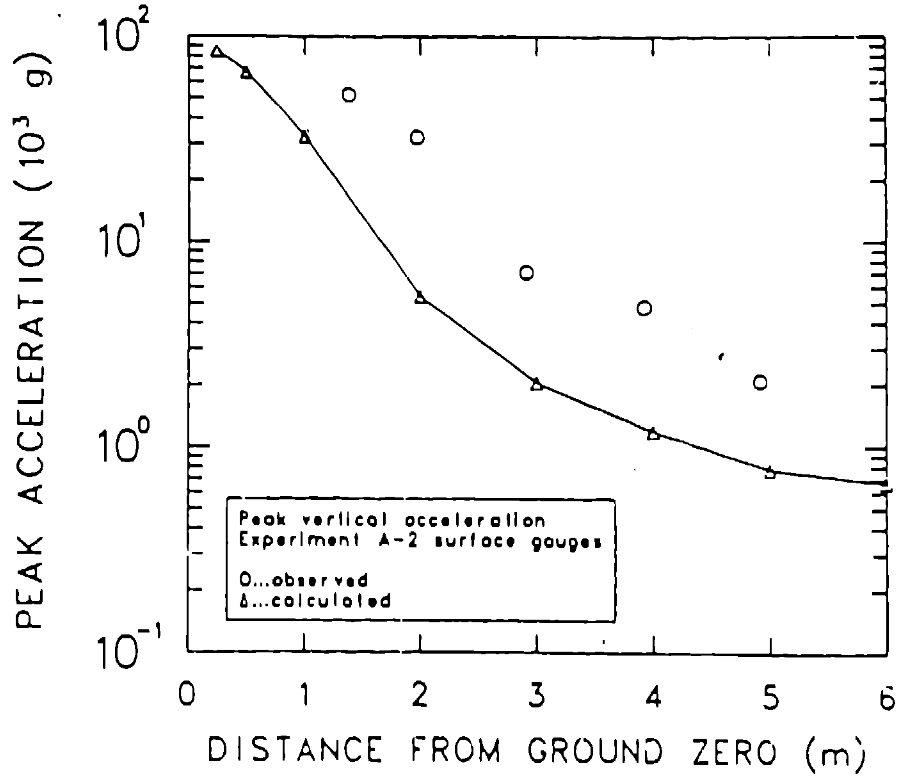


Fig. 10. Peak vertical acceleration versus radius for embedded gauges from several tests.



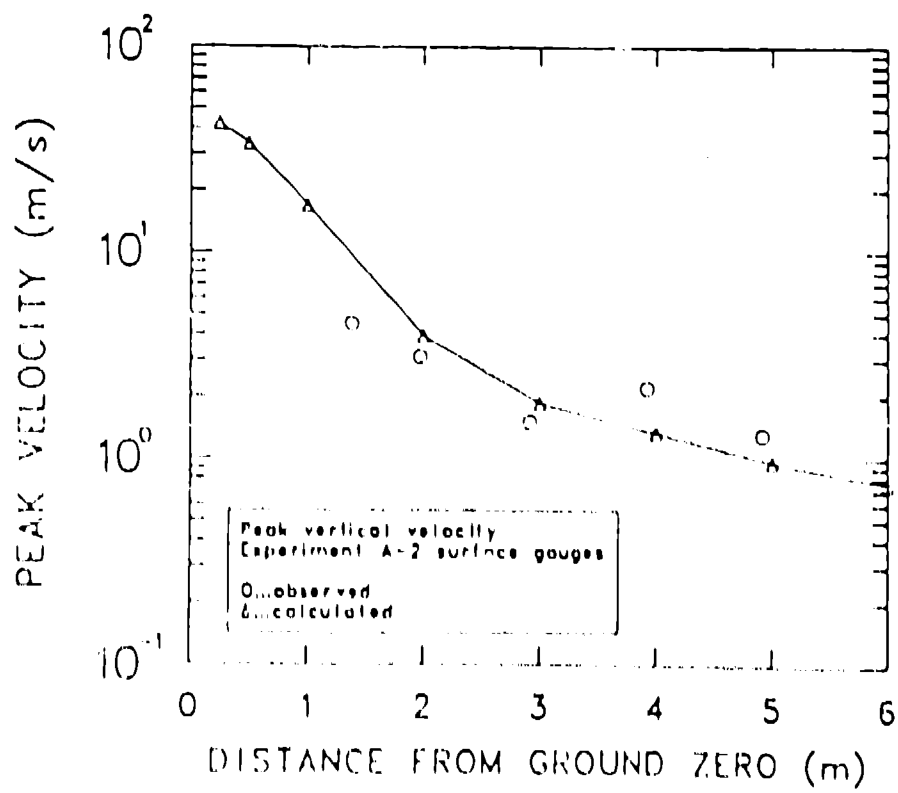


Fig. 11. Comparison of observed and computed peak surface values for acceleration and velocity in a single borehole test.

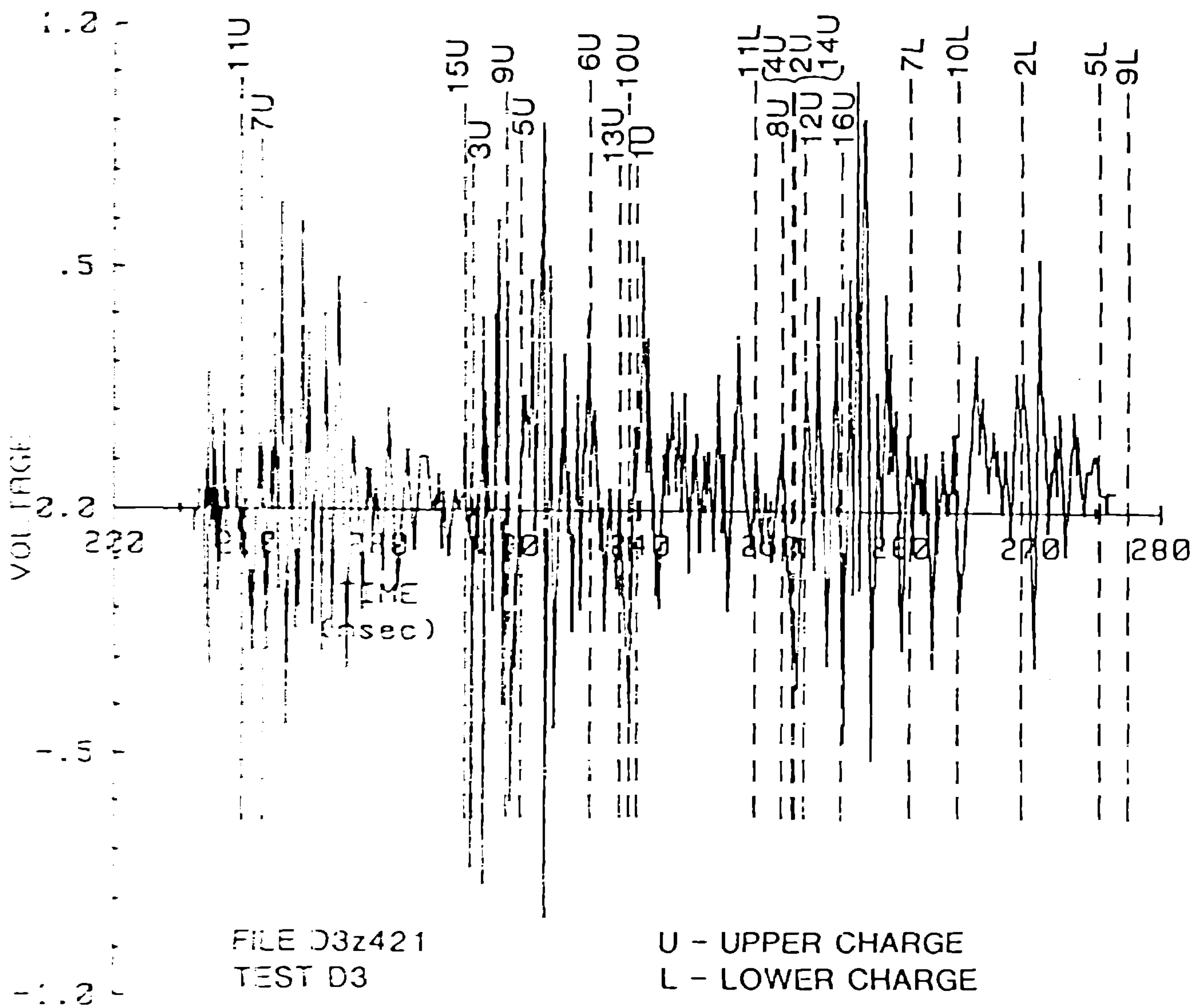


Fig. 12. Expected arrival of shock waves for individual charges in relation to raw accelerometer data from Los Alamos canister 2 (Test D-3).

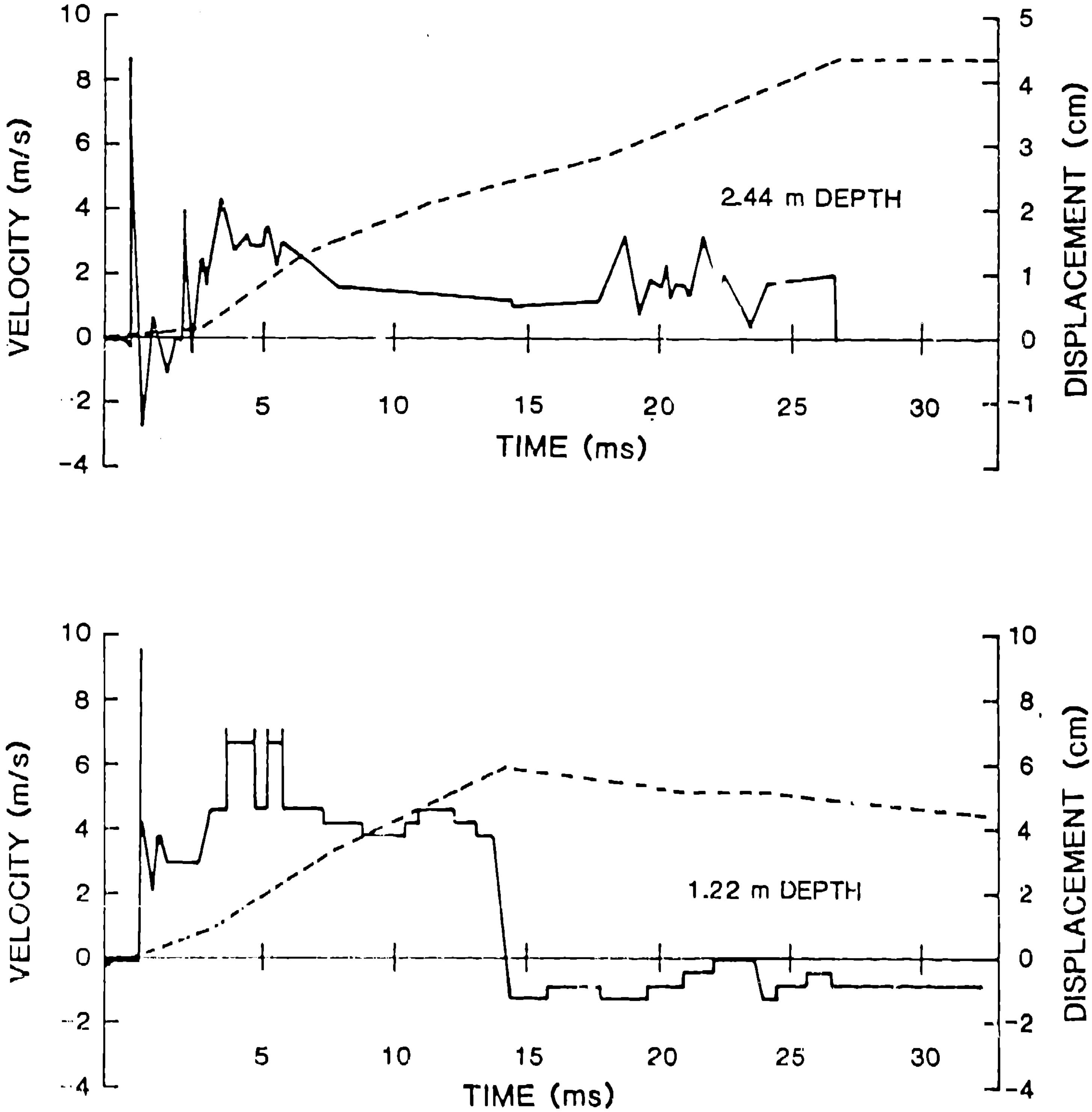


Fig. 13. Velocity gauge records for gauges 1 and 5 (Test D-3).

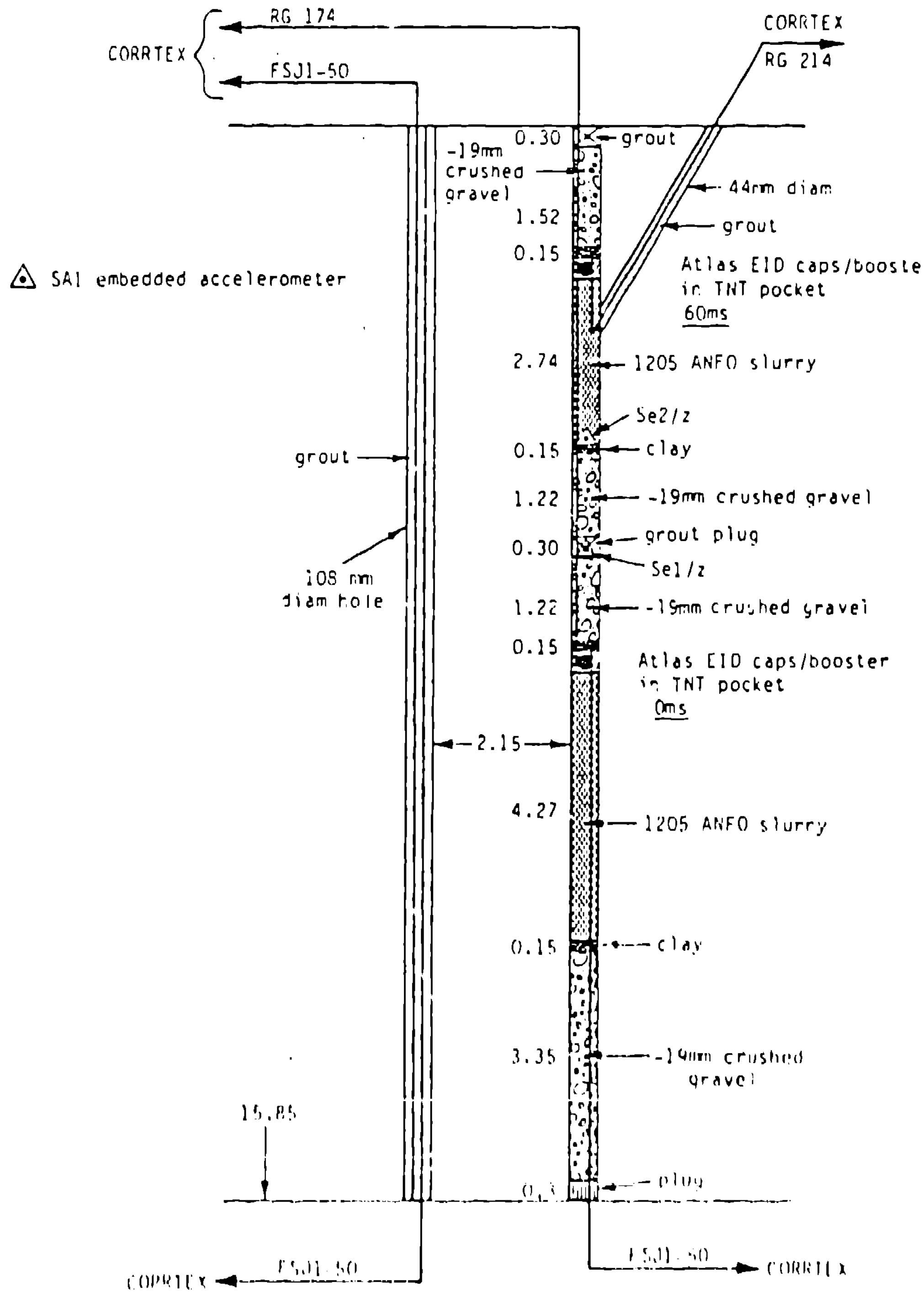


Fig. 14. Vertical cross section of test DP-2.

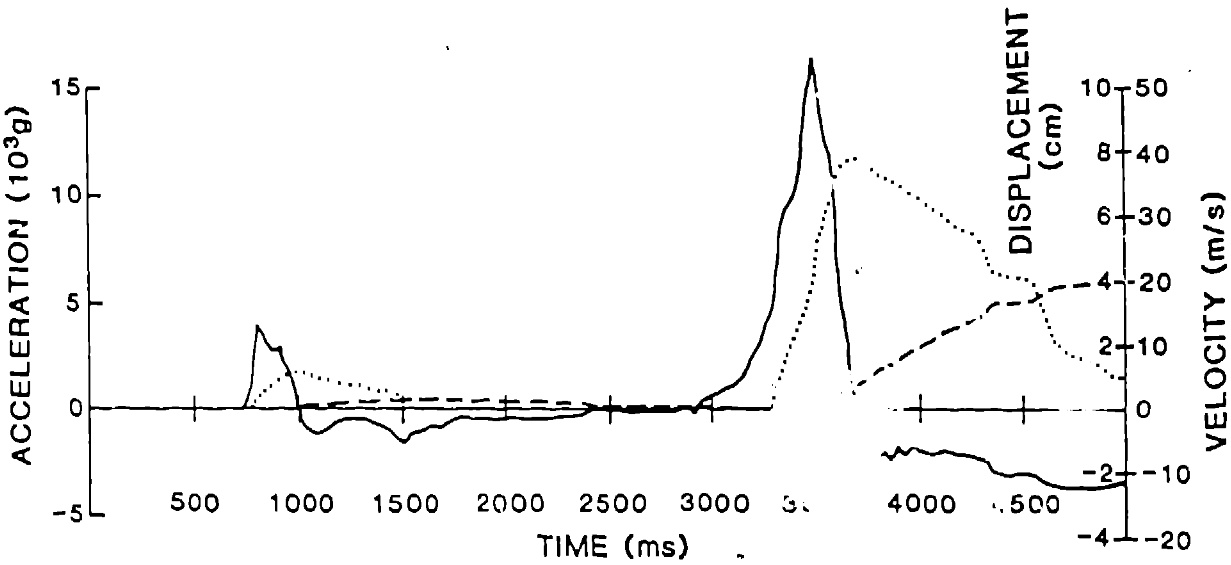


Fig. 15a. PCB at grout plug of intermediate stem.

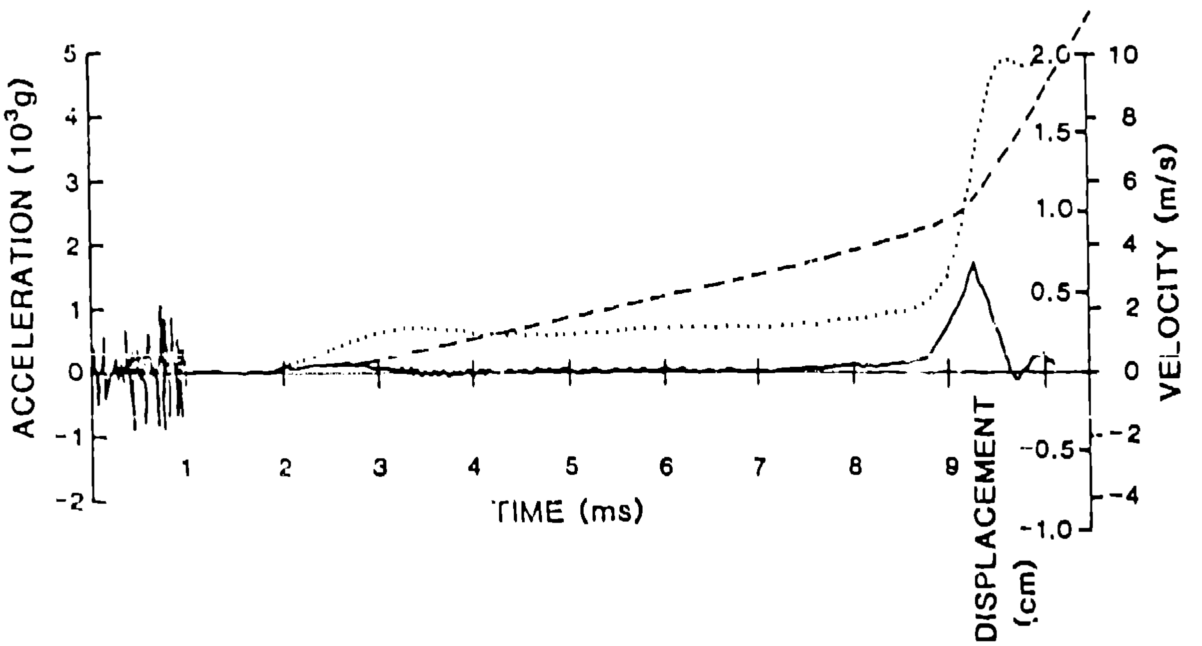


Fig. 15b. Endevco immediately below upper charge.

Fig. 15. Test DP-2 accelermoeter records.

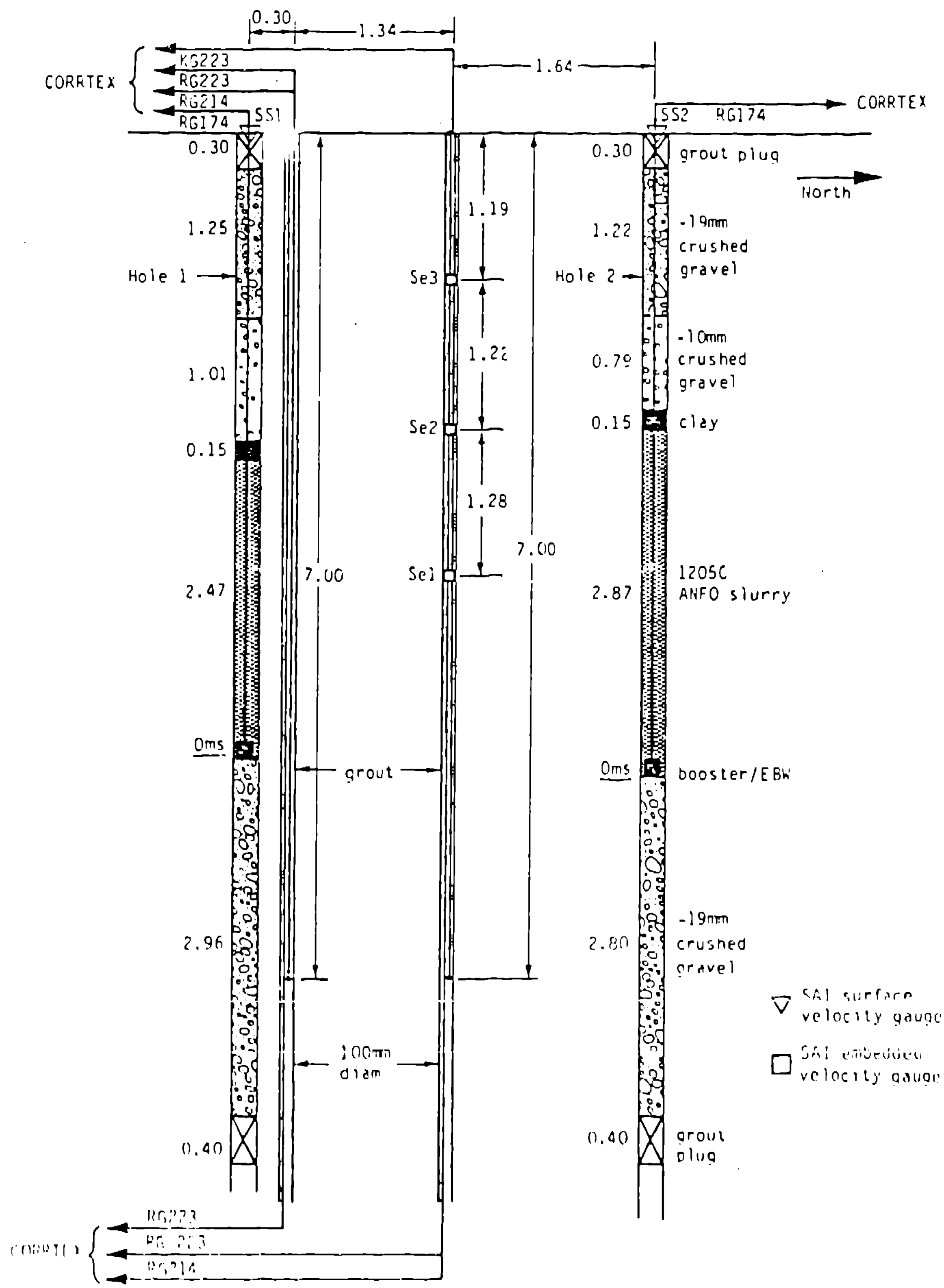


Fig. 16. Vertical cross section of test CF-2.

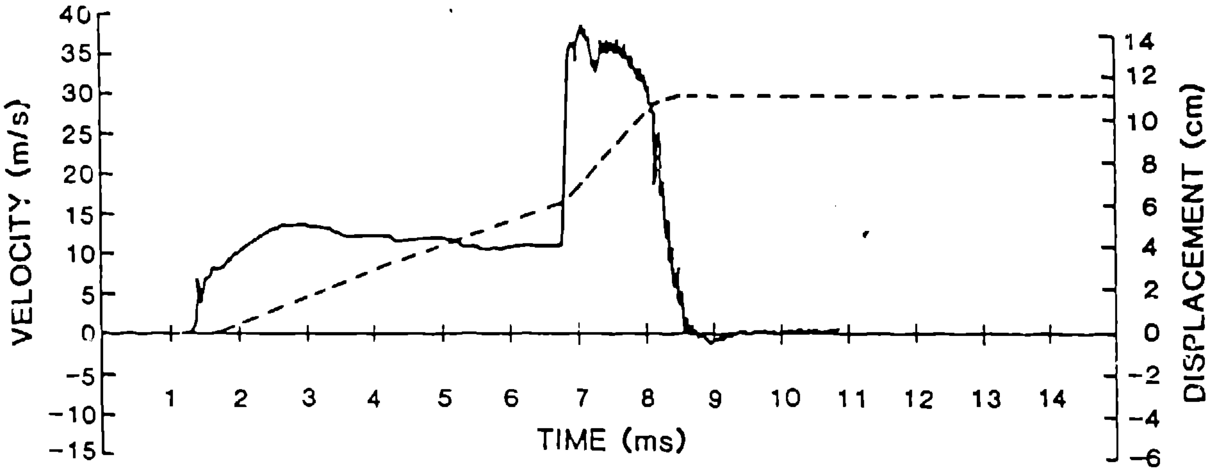


Fig. 17. Velocity gauge record from group plug of shot hole (Test CF-2).

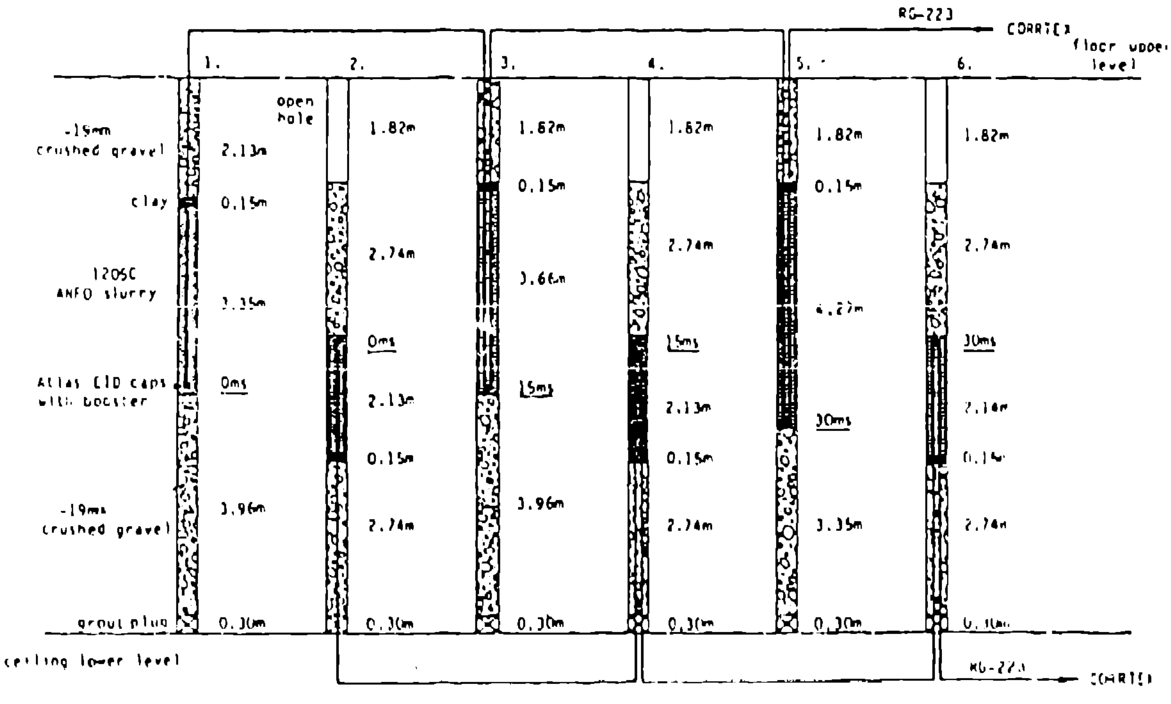


Fig. 18. CORRTEX sensor cable placement from a complex test. Measurement of detonation velocities and initiation times.

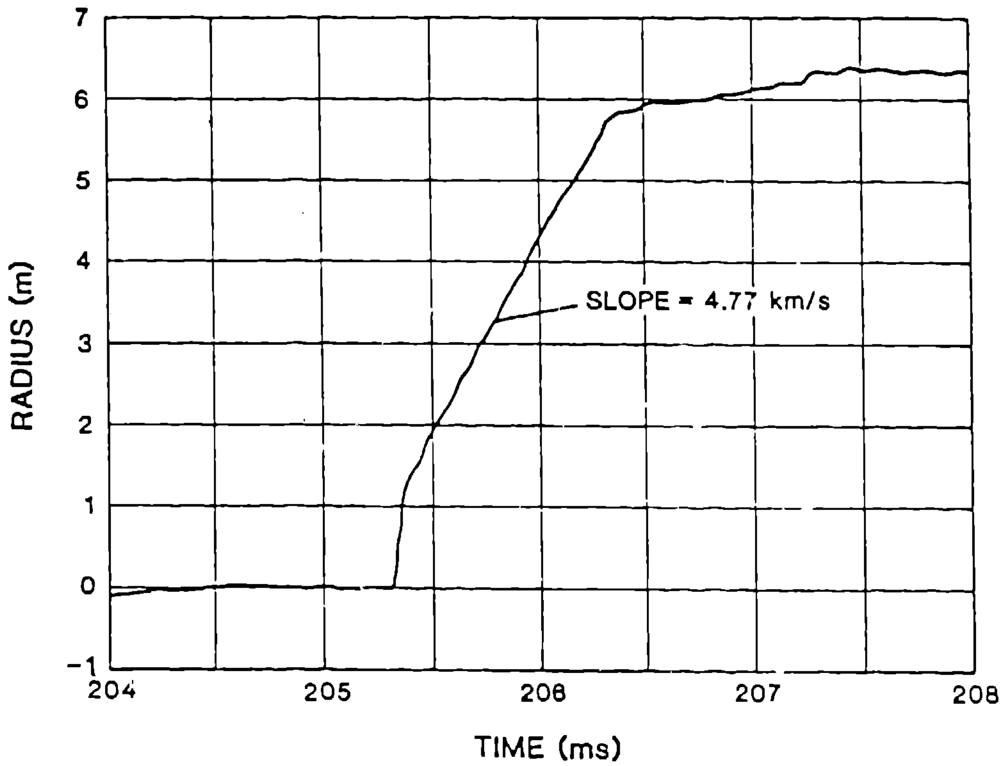


Fig. 19. CORRTEX record from column of IRECO 1205C ANFO slurry.

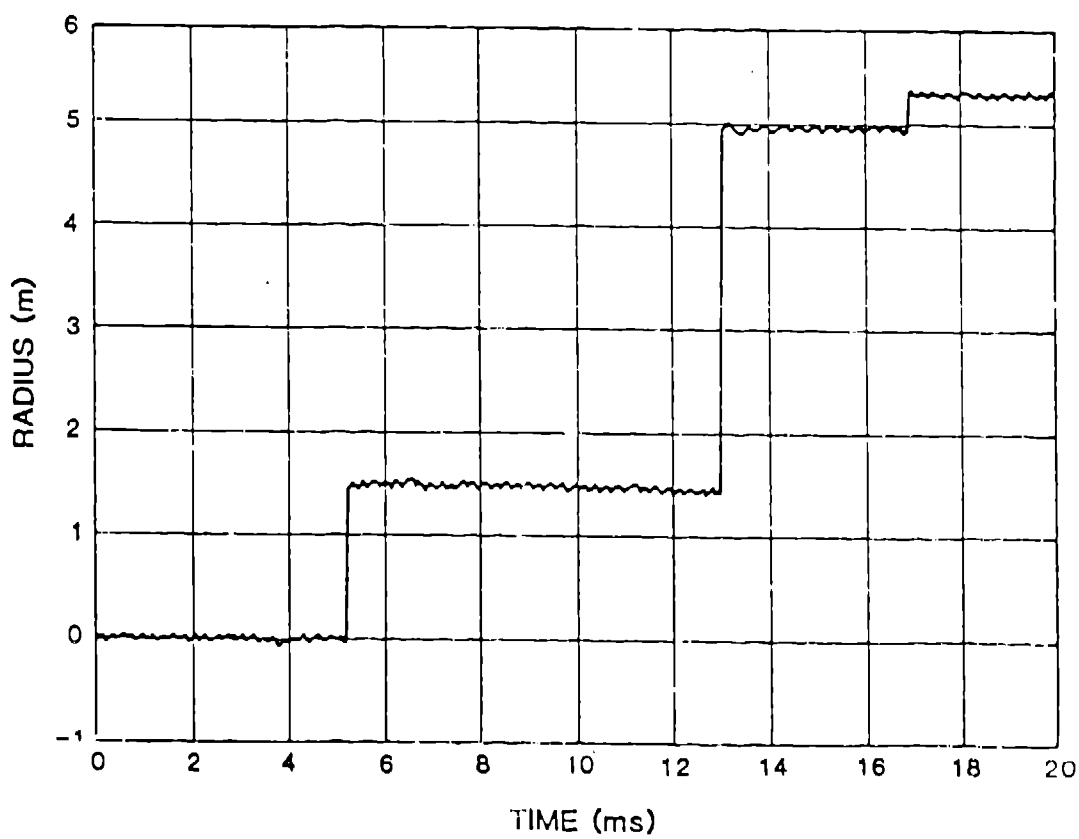


Fig. 20. CORRTEX record from a sensor cable grouted in a satellite instrument hole - measurement of crater formation mechanism.

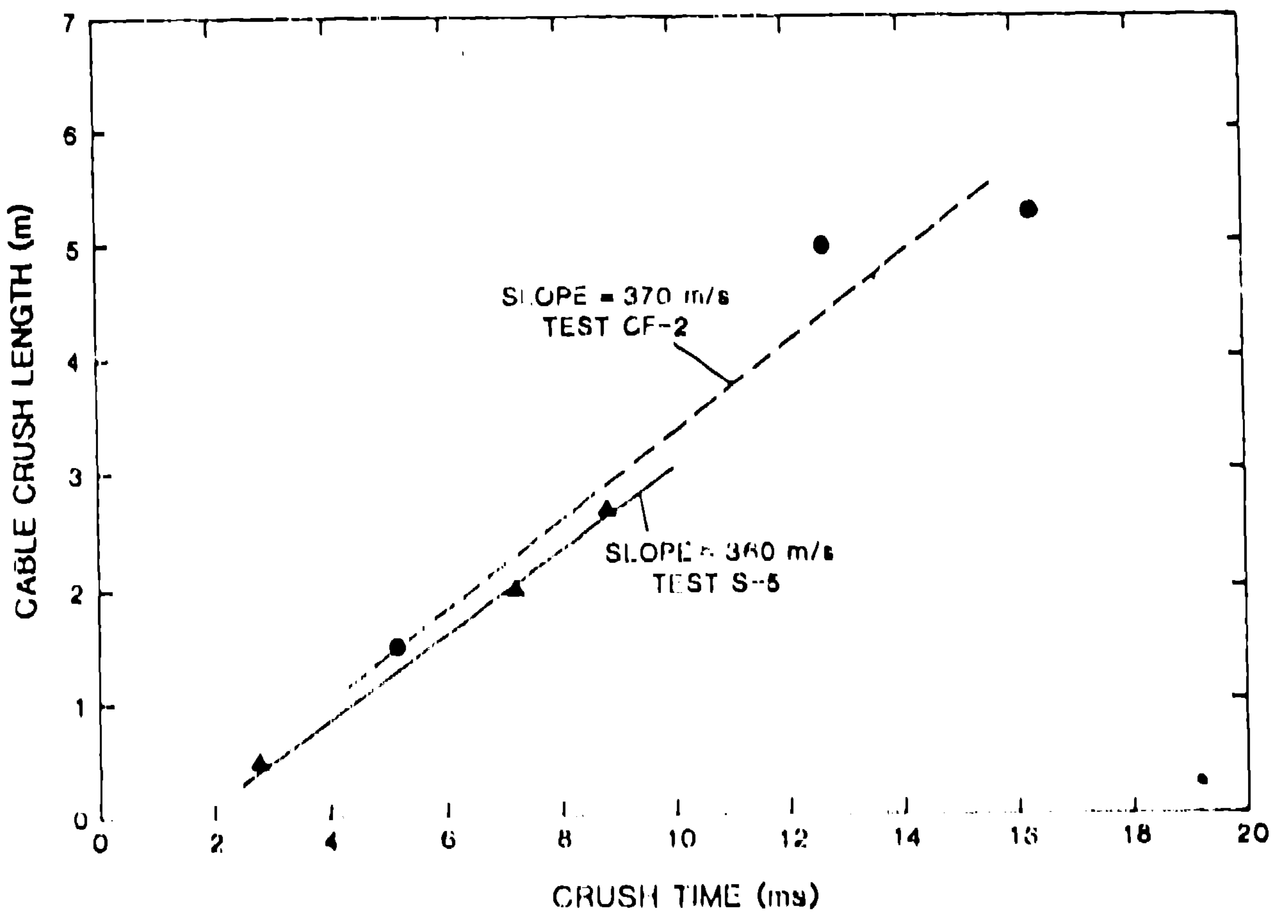


Fig. 21. CORRTEX cable crush length versus time from two tests.