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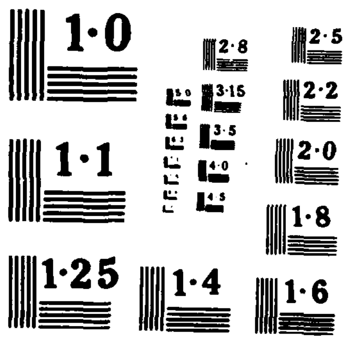
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THE DIRECT COURSE-TRINITY SEISMIC EXPERIMENT

R.E. Reinke

June 1986

Final Report

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AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117-6008

AFWL-TN-84-55

This final report was prepared by the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, under Job Order 88091384. Dr. Robert E. Reinke (NTES) was the Laboratory Project Officer-in-Charge.

This technical report has been reviewed and is approved for publication.

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REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFWL-TN-84-55	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Air Force Weapons Laboratory	6b. OFFICE SYMBOL (If applicable) NTESG
7a. NAME OF MONITORING ORGANIZATION	
6c. ADDRESS (City, State and ZIP Code) Kirtland Air Force Base, NM 87117	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (If applicable)
9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8c. ADDRESS (City, State and ZIP Code)	

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
62601F	8809	13	84

11. TITLE (Include Security Classification)
THE DIRECT COURSE-TRINITY SEISMIC EXPERIMENT

12. PERSONAL AUTHOR(S)
Reinke, R. E.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Final Report	FROM Jul 83 TO Jul 84	1986 June	28

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB. GR.
08	11	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Seismic Signals, High-Explosive Tests, Surface Waves, Body Waves, Source Functions, Modeling, Waveforms

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The proximity of the DIRECT COURSE test site to the TRINITY site where the first atomic bomb was detonated in July 1946 offered a unique opportunity to compare the unusual appearing seismic waves recorded on the TRINITY event with those excited by DIRECT COURSE. Two of the Leet Seismographs used to record the 1945 TRINITY event were obtained and fielded on DIRECT COURSE alongside modern digital instrumentation in an effort to verify the TRINITY seismograms. Good records were obtained from one of the Leet instruments and from most of the digital instrumentation. Comparison between the Leet records and the digital seismograms indicates that the Hydrodynamic wave, first observed at TRINITY, is real and not an instrument phenomenon.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Dr. Reinke	22b. TELEPHONE NUMBER (Include Area Code) (505) 844-0484
22c. OFFICE SYMBOL NTESG	

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I. INTRODUCTION

The DIRECT COURSE event was sited in the eastern margin of the Jornada del Muerto Valley, approximately 6 km south of the TRINITY site, where the first atomic bomb was detonated in 1945 (Fig. 1). Several measurements were made of the strong seismic motions excited by the TRINITY shot. Five Leet three-component strong motion mechanical seismographs recorded the TRINITY motions at five different ranges and azimuths (Ref. 1). The seismogram from one of these stations (8.2 km north of TRINITY) was discussed in a 1946 paper (Ref. 2) and has been the subject of some controversy since the name Hydrodynamic wave was given to one unusual appearing section of the seismogram because the particle motion was prograde and elliptical, resembling that of a water wave (Fig. 2). In a 1962 paper (Ref. 3), it was suggested that the Hydrodynamic or H wave emanated only from explosions and might be useful in discriminating between the seismic waves produced by nuclear explosions and those resulting from naturally occurring earthquakes.

The DICE THROW event, detonated a few kilometers west of TRINITY in 1976, was recorded by a fairly extensive array of close-in seismic stations utilizing modern analog and digital instrumentation. Some of the seismograms recorded from this array closely resembled the 1945 TRINITY record (Refs. 4 and 5). Reference 4 attempted to explain the Hydrodynamic wave and the similar appearing waves observed on the DICE THROW event as higher mode Rayleigh surface waves.

The MILL RACE event, another high explosive event, was donated in 1981 about 300 m to the west of the DIRECT COURSE GZ. A limited seismic array was fielded on MILL RACE (Ref. 6). This effort included an unsuccessful attempt at fielding two of the original seismographs used on TRINITY. The availability again of the original instruments for the DIRECT COURSE event afforded a unique opportunity to once again record the Hydrodynamic wave on the original TRINITY instrumentation. By placing modern digital instrumentation alongside these seismographs, it was hoped that the TRINITY seismograms could be verified.

II. DESIGN OF THE EXPERIMENT

1. THE LEET SEISMOGRAPHS

These instruments were designed and constructed primarily for the registration of vibrations from dynamite blasts, traffic, machinery, and general industrial sources. The instruments have roughly a magnification factor of 25 for frequencies above 3 Hz. The seismograph is optical and mechanical in operation in that mirrors are attached to each of the three inertia elements. Light from a single filament galvanometer lamp is reflected from the mirror and onto a moving strip of photographic paper after being reflected several more times in order to lengthen the optical path and, hence, increase the magnification (Fig. 3, Ref. 7).

A total of five three-component strong motion seismographs were set out to record the strong seismic waves resulting from the TRINITY test. In addition to the one at 8.2 km north, they were also placed in the neighboring towns of San Antonio, Carrizozo and Tularosa and at Elephant Butte Lake (Ref. 1). Two of these original instruments were found to be in the archives of the Los Alamos National Laboratory (LANL), Los Alamos, NMex. The LANL archive personnel granted permission to field these instruments on the DIRECT COURSE event as they had in 1981 for the MILL RACE experiment.

These instruments were found to be in fairly good condition after 38 years in storage, with the exception of some missing parts. Missing from one instrument were several gears from the camera drive train and the camera itself. The other instrument was complete and in operating condition. Using the complete instrument as a model, LANL technicians were able to fabricate the camera and drive train sections missing from the second instrument.

The instruments were then bench tested; whereupon, it was discovered that the film moved past the camera slit at a speed of only about 2 in/min, rather than the average speed of about 4 in/s mentioned in Ref. 7 and roughly the apparent film speed of the instrument which produced the record from TRINITY (Refs. 1 and 2). Apparently, the two archive instruments were used at the more distant ranges on TRINITY where a longer recording time was needed, and resolution of the higher frequencies was not so important. To remedy the problem, the LANL Geophysics Division procured two higher RPM motors which were installed by technicians from the Air Force Weapons Laboratory, Site Characterization and Seismology Section (AFWL/NTESC), bringing the average film speed to near 4 in/s.

Several additional problems were encountered during the fielding of the instruments. The seismographs were designed to operate on 110 V, 60 Hz A.C. power which was not available at the desired station location. This necessitated the use of two 24-V D.C. to 110-V A.C. inverters to provide the required power. When the instruments were fielded on the MILL RACE experiment, safety requirements prohibited the manning of the Leet seismic station. To turn on the instruments remotely, AFWL/NTESC modified a radio-controlled firing system normally used for firing explosive charges while conducting seismic refraction surveys. The system was modified so that, rather than detonating a charge, 24-V power was switched on to the inverters, which in-turn supplied 110-V A.C. power to the instruments. This system was retained for the DIRECT COURSE experiment to simplify logistic problems. These instruments, which were placed at Station 3, were turned on remotely for the DIRECT COURSE shot from Miller's Watch (Fig. 1).

2. MODERN INSTRUMENTATION USED AND INSTRUMENT LOCATIONS

Six station locations were selected for the DIRECT COURSE event (Fig. 1). Two of these were the same as those on MILL RACE (Ref. 6). On MILL RACE, the Leet instruments had been fielded alongside modern digital instrumentation at Station 1. Although the Leet instruments did not record successfully on MILL RACE, a good record was obtained from part of the digital instrumentation at Station 1 and at Station 4. Since neither of these records bore much resemblance to the original TRINITY record, it was decided to field the instruments at Station 3 for DIRECT COURSE. Station 3 is a short distance to the southeast of the DICE THROW ground zero. The old DICE THROW roads provided easy access to the site. The range from DIRECT COURSE to Station 3 is approximately 7.3 km. It was hoped that the geologic structure along the travel path between DIRECT COURSE and Station 3 would be more favorable for reproducing the H wave than that for Stations 1 or 4.

Station 2 was positioned at a range of approximately 4.9 km along the same radial as Station 3. It was hoped that the data from Station 2 would provide additional information regarding the H wave behavior at closer ranges.

The locations of Stations 5 and 6 were selected to provide information regarding azimuthal variations of the seismic waveforms.

Two modern digital event recorders were placed alongside the instruments at Station 3 for comparison purposes. These instruments record digital data directly onto magnetic tape cassettes. They are equipped with event triggers so that recording will occur when the amplifiers see a signal--if a rough definition of what constitutes a signal has been correctly set by the user. A three-component 1 Hz natural frequency seismometer was connected to one of the digital recorders. Three 1 Hz vertical seismometers supplied the input for the other three-channel digital recorder. These three vertical seismometers were set out in a linear array with 100-m spacing--i.e., the three seismometers were set out on a single radial in increasing distance away from the DIRECT COURSE ground zero. The purpose of this array was to obtain closely-spaced waveforms so that phase velocities could be measured for the Hydrodynamic wave and other portions of the wave train.

The instrumentation at all other stations consisted of three-component 2-Hz natural frequency seismometers coupled to three-channel digital event recorders.

III. RESULTS

Out of a total of 21 digital channels, 18 recorded successfully. The recorder at Station 1 failed to record any data on tape; although it did trigger. The trouble was later traced to a loose analog to digital converter card. All of the other digital systems operated satisfactorily. One of the Leet seismographs successfully recorded all three traces; on the other instrument, the vertical component had drifted off scale. One of the other components on this instrument did not respond for an unknown reason, while one trace recorded successfully.

Figure 4 contains the Leet seismogram from DIRECT COURSE. The traces have been arranged so that the time scales are roughly equal to those on Leet's TRINITY record shown in Fig. 2. The numbers and vertical lines in Figs. 2 and 4 are second marks. The beginning or 0 point on both records is approximately the time of the first P wave arrival. While a direct cycle for cycle comparison cannot be made, the records are qualitatively similar in that there are wave packets of similar frequency arriving at similar time on both records. The Hydrodynamic wave phase beginning at about the 8 s mark is similar in appearance on both records.

Records from the digital instruments are shown in Figs. 5 through 10. Amplitude scales are shown on each record. These are only approximate and are valid only for frequencies above the natural frequency of the instrument. (In the case of the 1 Hz instruments at Station 3, the value given is approximately correct for the 2- to 4-Hz region.) It is evident that there is considerable variation in the character of the waveforms with azimuth. This is likely due to the variation in geologic structure from point to point in the valley. Keeping in mind that these digital records are velocity traces, while the Leet records are displacement traces, a loose comparison can be made between the digital and Leet records at Station 3 (Figs. 4 and 5). It can be seen that there is evidence, in that there are waves of similar frequency, of a Hydrodynamic wave at about the same time on the digital records.

A more quantitative comparison of the phenomenology present in the TRINITY records, the DIRECT COURSE records and the digital DIRECT COURSE records can be made by looking at particle motion diagrams or hodographs in the radial and vertical planes. Such a comparison for the Hydrodynamic wave is shown in Fig. 11. The TRINITY diagram was copied from Ref. 2, the Leet DIRECT COURSE diagram from points digitized from the actual record and the digital diagram from an integrated version of the digital record so that a direct comparison may be made between all three except for absolute amplitudes. All three diagrams are similar in overall character suggesting the phenomenon present is the same for the three cases. The particle motion is, of course, prograde (particle rotation in the same direction as propagation) for all three diagrams. Similar diagrams for the Rayleigh wave phase are shown in Fig. 12. The similarity between the three records for this phase is not as strong as for the Hydrodynamic wave. All three diagrams do, however, show retrograde surface wave motion which is characteristic of classical Rayleigh wave propagation.

A preliminary attempt at modeling the observed waveforms has been made using the reflectivity method (Ref. 8). An example of the output is shown in Fig. 13. This figure presents vertical records for distances from 0.5 to 8 km. The geological model used was one originally constructed for the DICE THROW site. This calculation does not match the data very well; so additional work involving adjustments to the structural model needs to be done. We also plan to compute theoretical dispersion curves and ellipticity curves for the fundamental and higher mode Rayleigh waves for comparison with the data to determine if the Hydrodynamic wave can be explained as a higher mode Rayleigh wave.

IV. CONCLUSIONS

This experiment was successful in that a high rate of data return was obtained from the digital instrumentation, while one of the Leet instruments yielded good data. Comparisons between the Leet records for TRINITY and DIRECT COURSE and the digital records indicate that the Hydrodynamic wave is real and not an instrument phenomenon. A preliminary attempt at modeling the observations has been accomplished with limited success; some additional work must be performed before the Hydrodynamic wave can be satisfactorily explained. At the present time, it is not known if the H wave can be excited by nonexplosive sources. If it is a higher mode Rayleigh wave, its excitation may depend quite strongly on the source depth rather than other details of the source function.

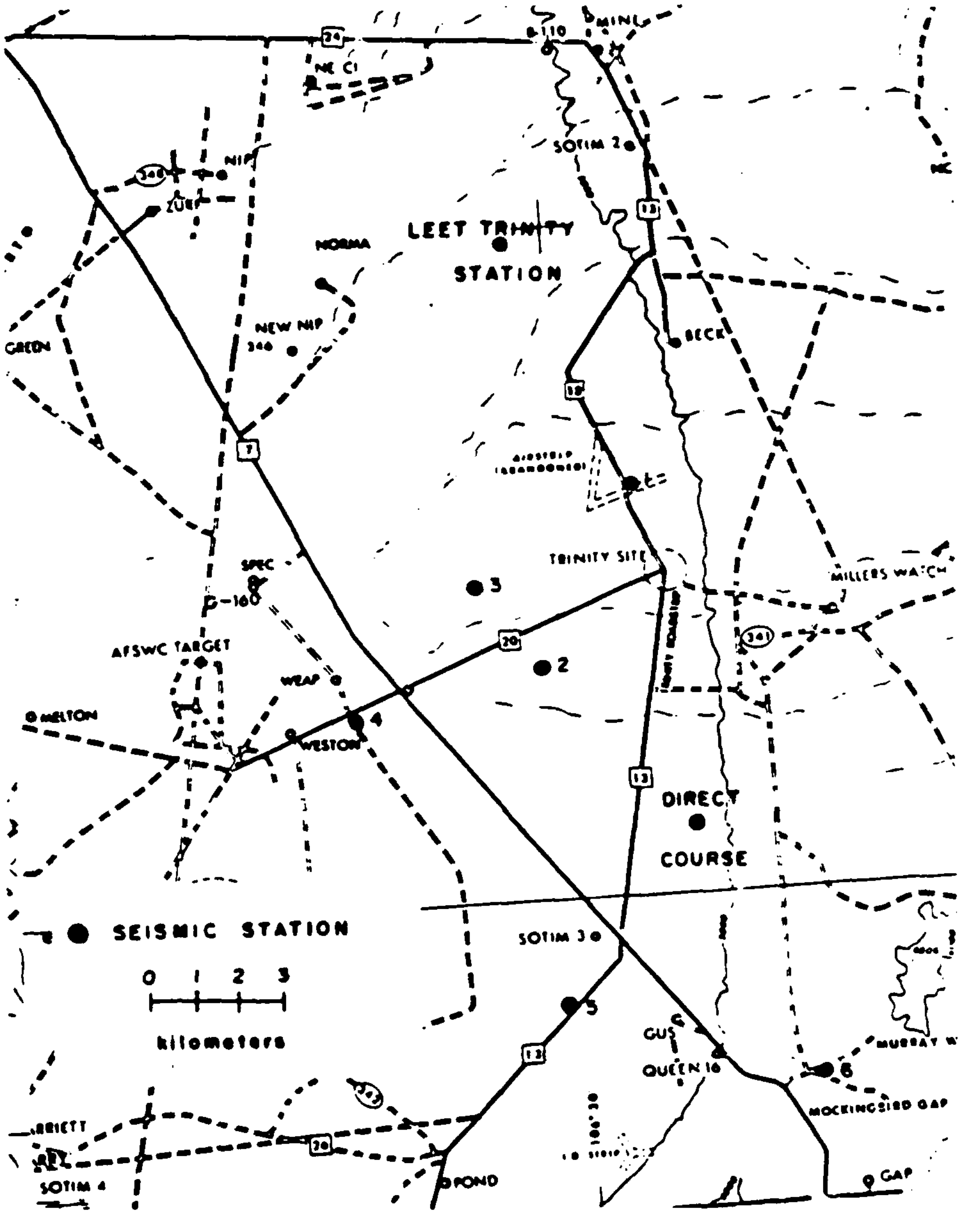


Figure 1. Seismic station map for DIRECT COURSE.

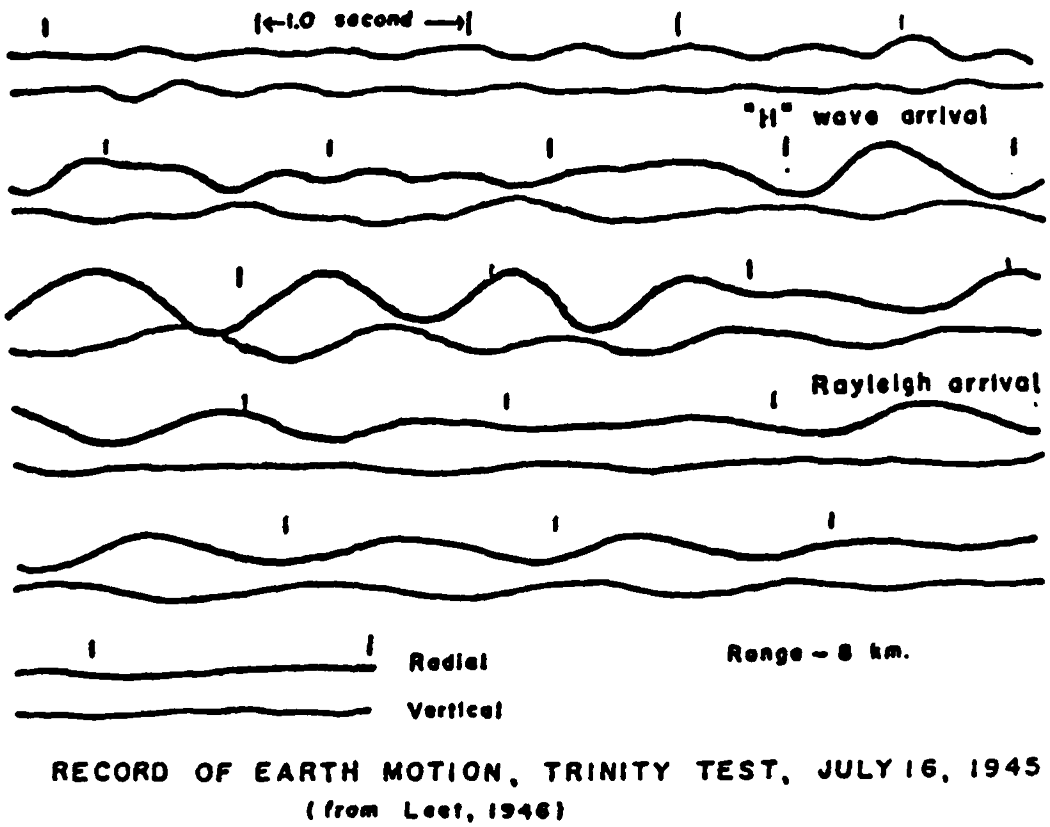
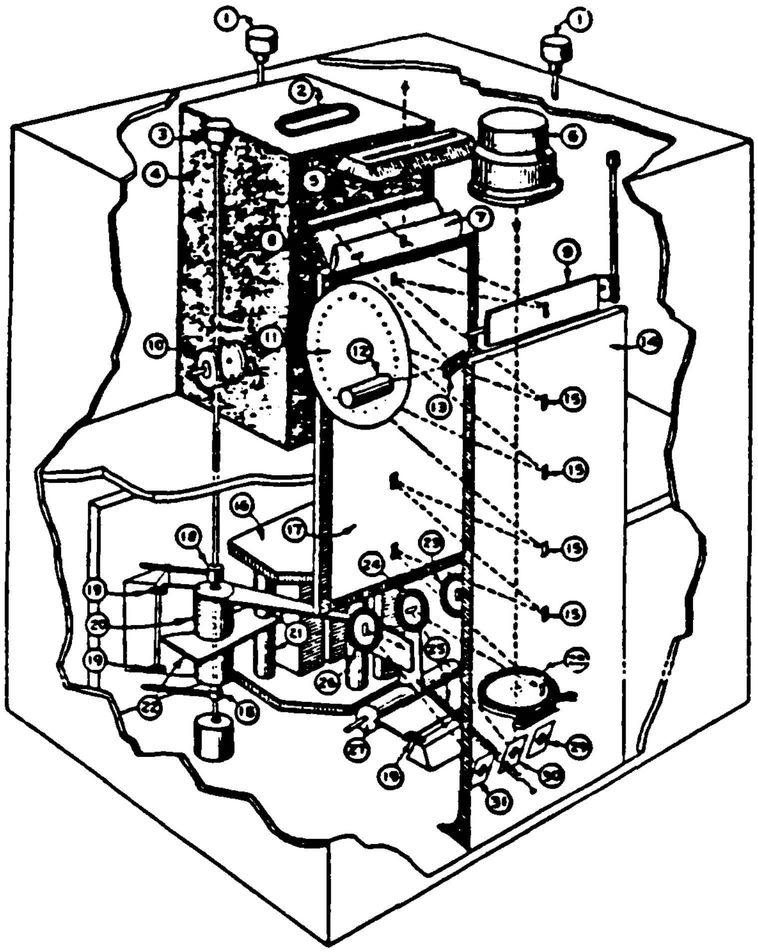


Figure 2. Leet's TRINITY seismogram.



Leet three-component portable seismograph. (1) Knobs controlling leveling feet; (2) camera handle; (3) knob for locking inertia member; (4) camera; (5) viewing slit; (6) light-source housing; (7) cylindrical lens; (8) half-silvered mirror; (9) adjustable mirror; (10) camera-drive clutch; (11) timing-line shutter; (12) timing-line light housing; (13) timing-line mirror; (14) and (17) plane mirrors; (15) point of reflection; (16) permanent magnet; (18) locking nut; (19) spring; (20) and (27) inertia members; (21) magnet poles; (22) damping vane; (23), (24) and (26) inertia member mirrors; (25) stabilizing spring; (28) condensing lens; (29), (30), and (31) fixed mirrors.

Figure 3. Drawing of Leet seismograph (Ref. 7).

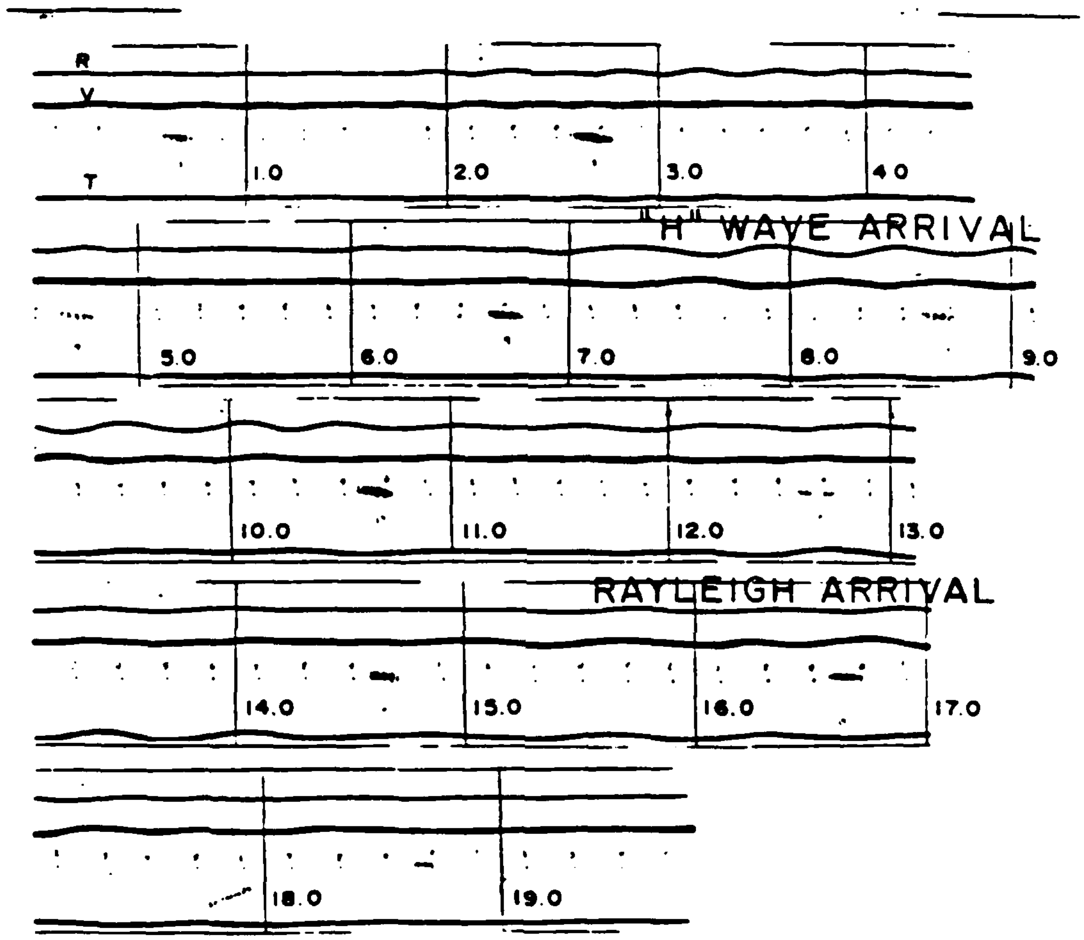


Figure 4. Leet DIRECT COURSE seismogram.

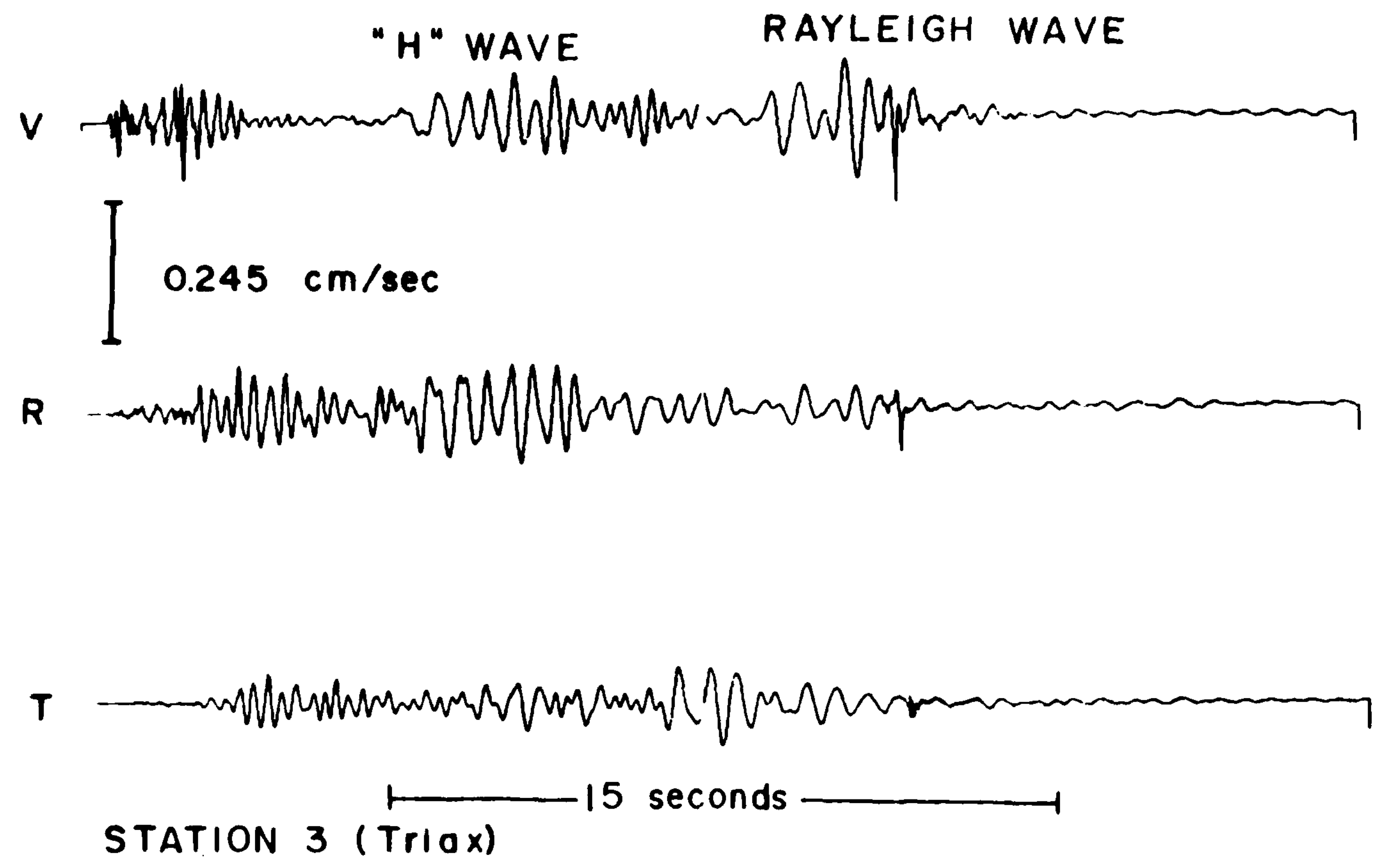


Figure 5. Triaxial digital record from Station 3.

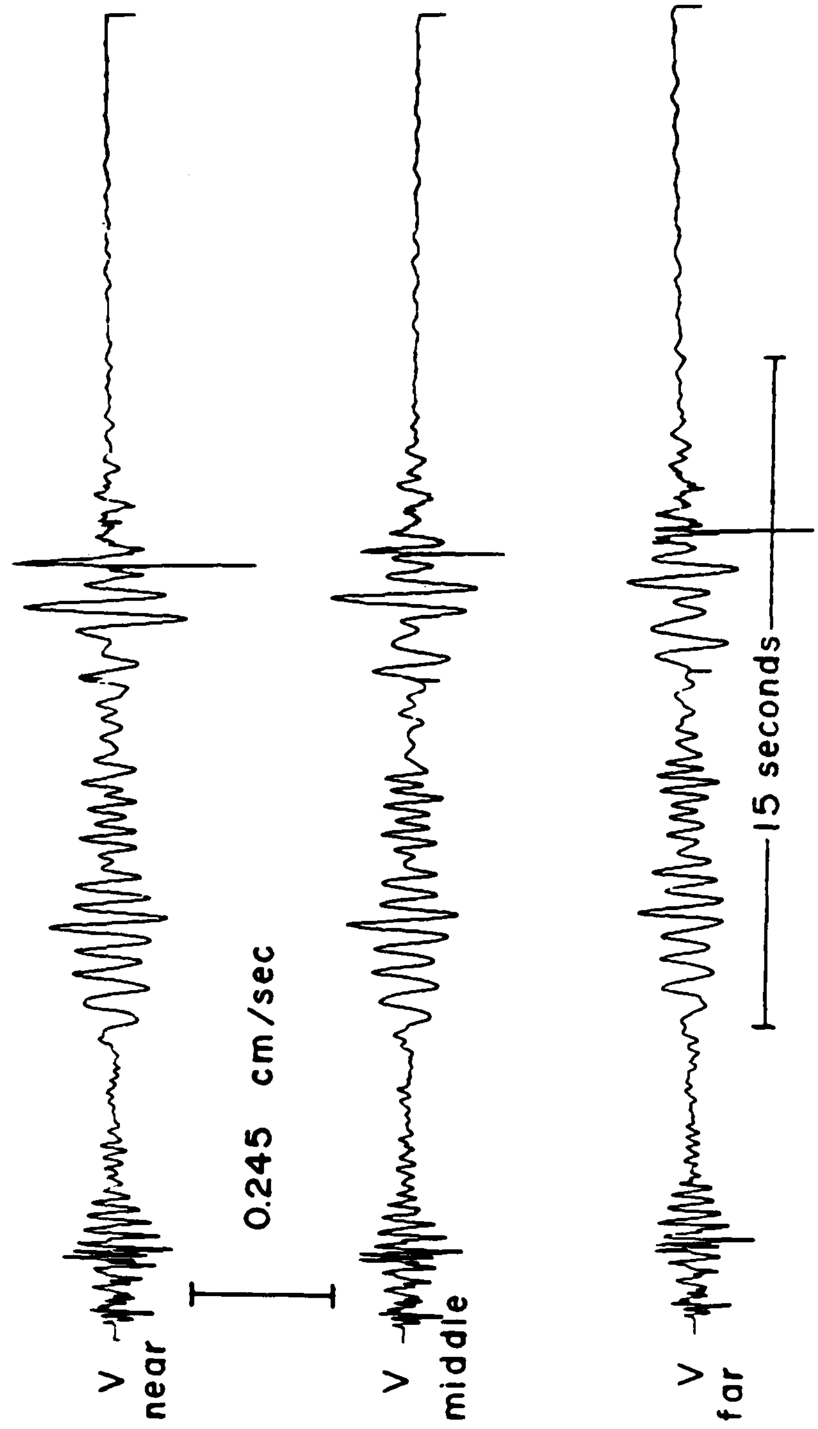


Figure 6. Linear array record from Station 3.

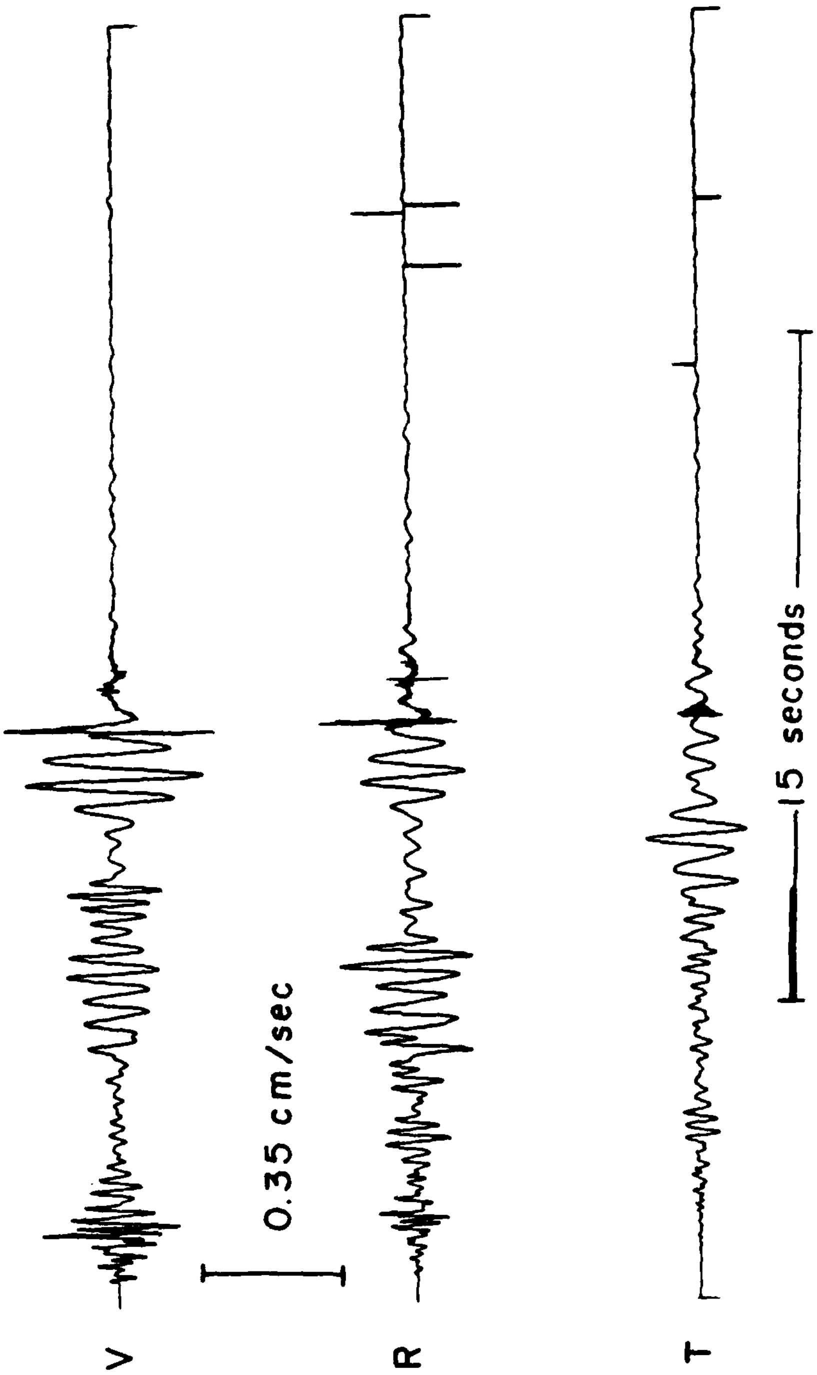


Figure 7. Record from Station 2.

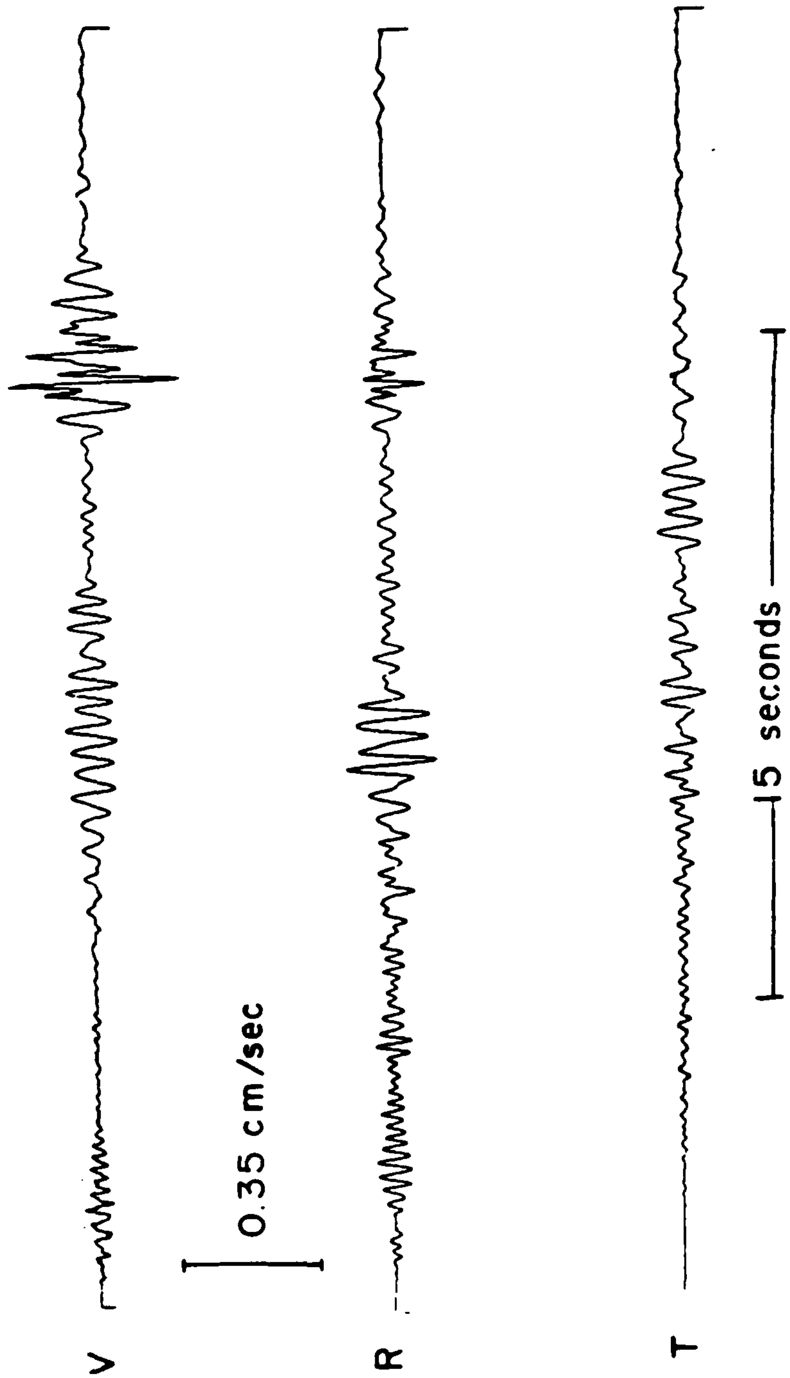


Figure 8. Record from Station 4.

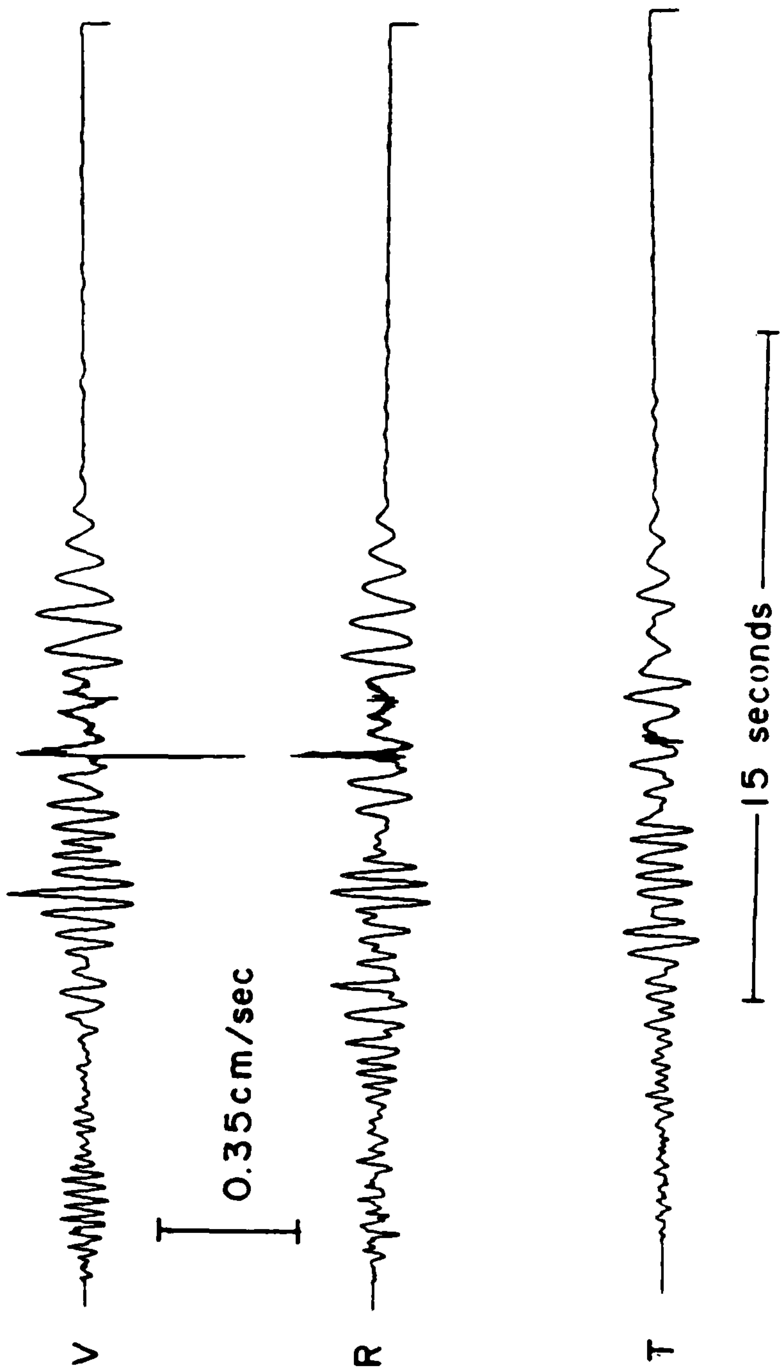


Figure 9. Record from Station 5.

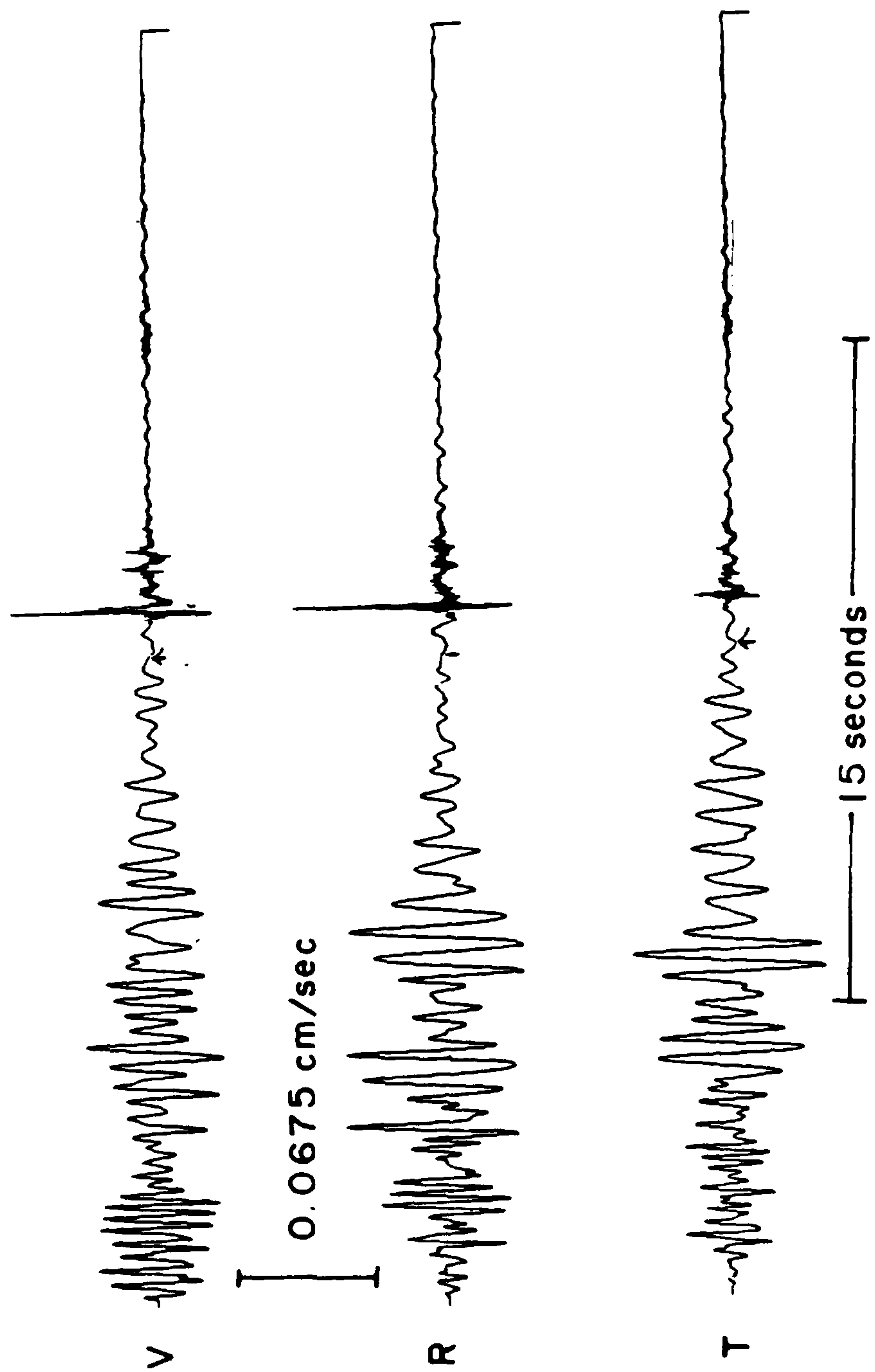


Figure 10. Record from Station 6.

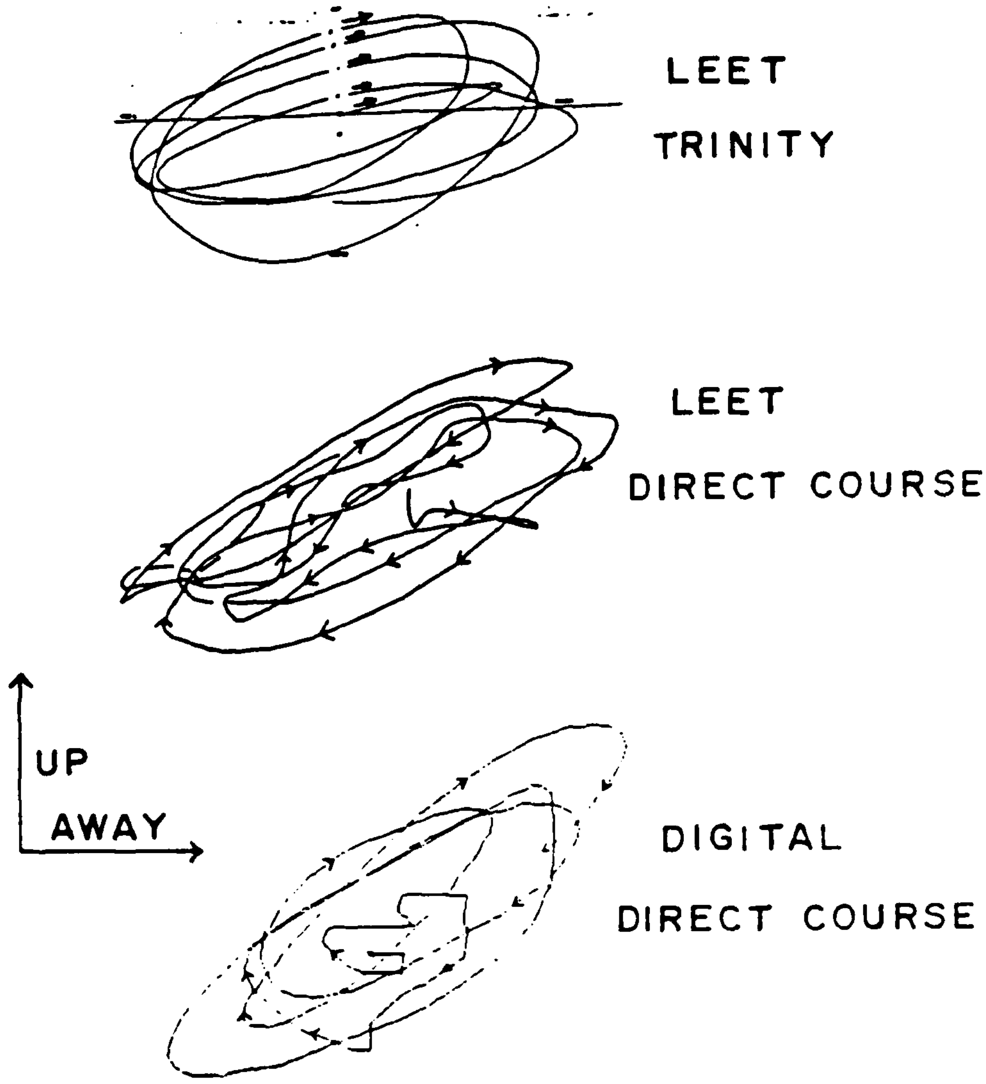


Figure 11. Hydrodynamic wave particle motions.

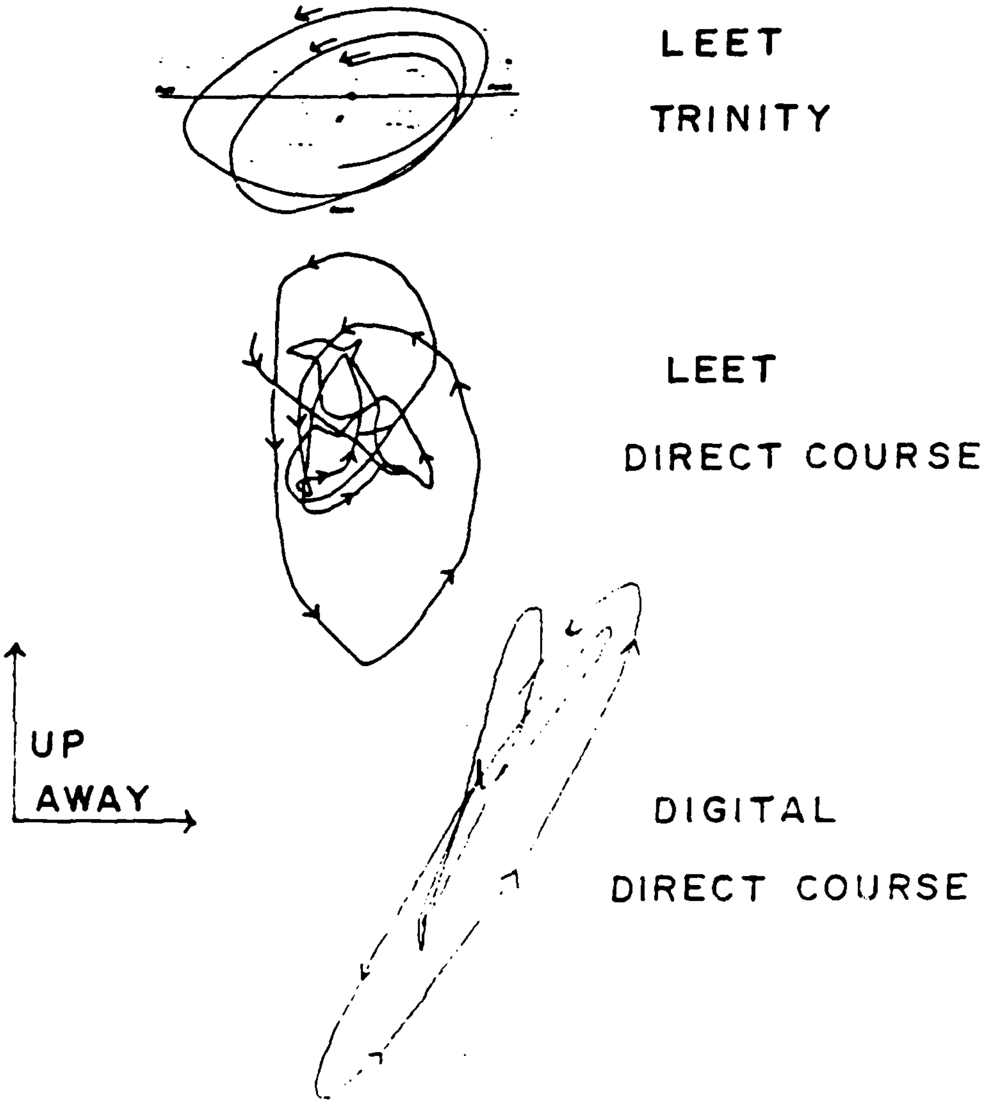


Figure 12. Rayleigh wave particle motions.

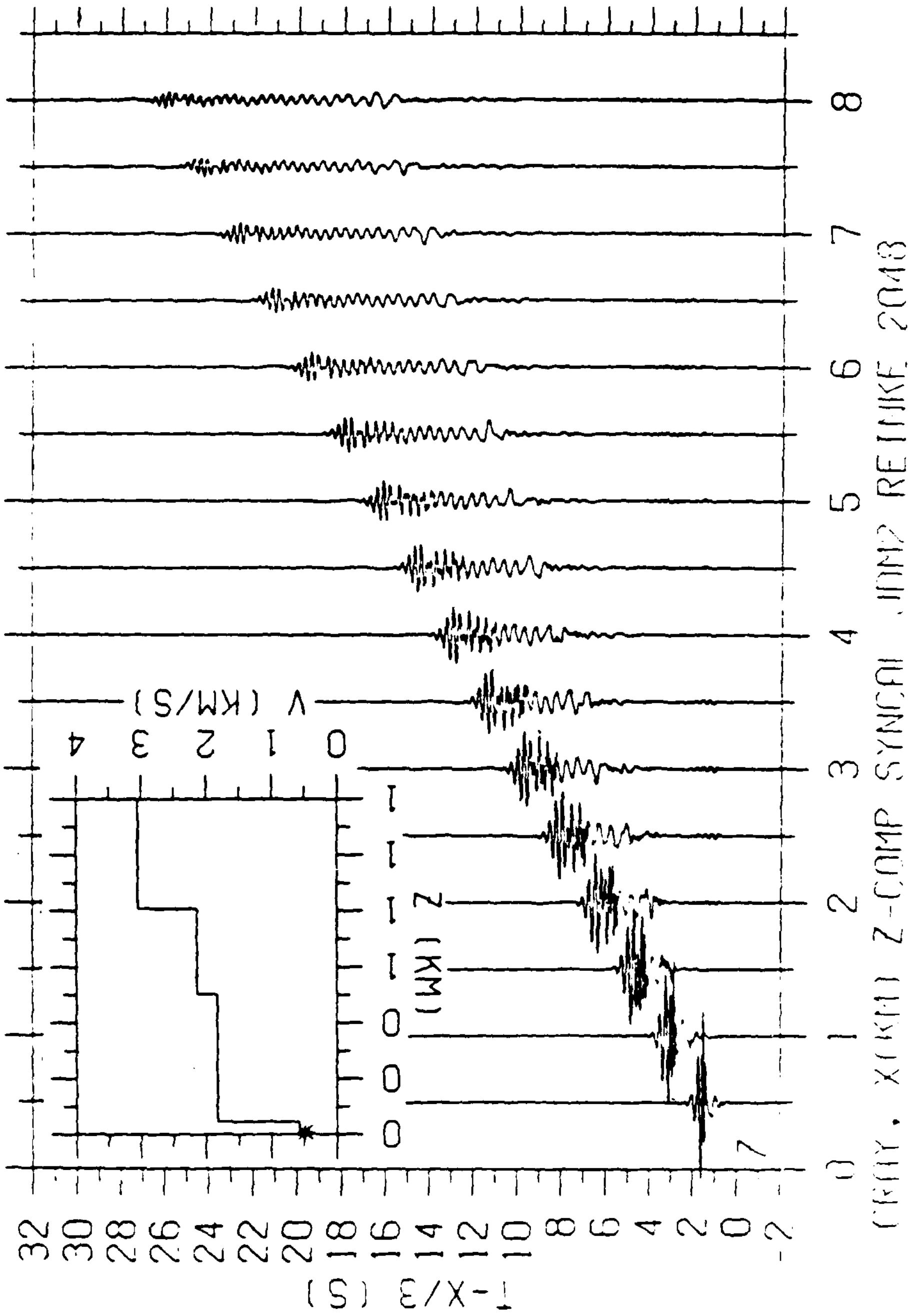


Figure 13. Example of reflectivity calculation.

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