Attachment A-4
Stratigraphics Cone Penetrometer Test Report

**PIEZOMETRIC CONE PENETRATION TESTING WITH
SEISMIC SHEAR WAVE VELOCITY SURVEY
CPS-EPS FIELD EXPLORATION
AMERGEN NUCLEAR POWER PLANT
CLINTON, ILLINOIS**

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1.0 INTRODUCTION

STRATIGRAPHICS, The Geotechnical Data Acquisition Corporation, performed cone penetrometer exploration at the AMERGEN Nuclear Power Plant CPS-EPS site in Clinton, Illinois. We performed Piezometric Cone Penetration Test with seismic shear wave velocity measurement (CPTU-S) and CPTU soundings to provide data on geotechnical properties of site soils for evaluation by CH2M Hill.

The work was performed on July 23 and 24, 2002 for a total of about 1.5 days of testing. Two CPTU-S and two CPTU soundings were completed to depths ranging from 54.0 to 78.1 ft, for a total of 264.7 ft of sounding. Four pore water pressure dissipation tests were performed. A total of thirty six seismic shear wave velocity measurements were taken at 1 meter intervals in the two CPTU-S soundings, and interval velocities were calculated. Open hole was pressure grouted at the completion of subsurface activities.

This report includes CPTU-S and CPTU sounding logs and tabulations of recorded data and correlated geotechnical parameters. The soundings are summarized on Table 1 while seismic data are summarized in Tables 2. Dissipation tests are summarized in Table 3. Interval seismic shear wave velocities are also plotted on CPTU-S sounding logs. Digital data summaries are presented for each sounding on the attached data disk, along with JPEG images of the logs. Details of penetrometer exploration techniques are included in the main body of the report.

2.0 PENETROMETER EQUIPMENT AND DATA ACQUISITION

2.1 Procedure The Cone Penetration Test (CPT) consists of smoothly and continuously pushing a small diameter, instrumented probe (penetrometer) deep into the ground while a PC data acquisition system displays and records the soil response to penetration (Figure 1). In geotechnical terms, the CPT penetrometer models a foundation pile under plunging failure load conditions. CPT data are used to develop continuous, high resolution profiles of in situ soil conditions rapidly, accurately and economically.

The soil resistance to penetration, acting on the tip and along the sides of the penetrometer, is measured during CPT. CPT soil resistance measurements are accurate and highly repeatable. The measurements can be used for the evaluation of stratigraphy and various geotechnical parameters. Performance of CPT is specified by ASTM Standard D3441.

A pressure transducer is added to the CPT penetrometer to acquire hydrogeologic data (Saines and others, 1989) and is called a Piezometric Cone Penetration Test (CPTU). A soil electrical conductivity sensor is added to the penetrometer (CPTU-EC) to acquire qualitative moisture information in vadose zone soils, and general groundwater quality data (Strutynsky and others, 1991, 1998). Penetrometer groundwater, soil, and soil gas samplers are used for direct sampling (Strutynsky and Sainey, 1990, Strutynsky and others, 1998). Recent advances in penetrometer instrumentation include a natural gamma sensor, induced UV fluorescence for detection of hydrocarbons and other compounds, and shear wave velocity and stress controlled testing for low and high strain soil deformation evaluation.

The penetrometer is mounted at the tip of a string of sounding rods. A hydraulic ram is used to push the rod string into the ground at a constant rate of 4 ft per minute. Electronic signals from downhole sensors are transmitted by a cable, strung through the sounding rods, to an uphole PC data acquisition system. Measurements are displayed and recorded for definition of subsurface conditions. Downhole equipment can be steam cleaned during retrieval.. Open hole can be grouted using bentonite grout.

Large 3 or 4 axle trucks are used to carry the 2 penetrometer systems used by STRATIGRAPHICS. Truck weight and ballast serve to counteract the thrust of the hydraulic ram. Enclosed rig work areas allow all-weather operations. Computers, samplers, electrical power, lighting, compressed air, steam cleaner, grout pump, and water tank are all included on each rig, providing for self-contained operations. Other portable systems or systems for mounting on drill rigs can be used in areas with poor access or for overseas projects.

Lightning detection systems are mounted on the rigs to monitor dangerous weather conditions that can effect safety and productivity. Differential, carrier phase, post processed Global Positioning Systems (GPS) are also mounted on the rigs to allow surveying exploration locations.

No borehole is required during exploration because penetrometers are directly thrust into the soil from the ground surface. Pressures of over 3 million pounds per square foot can be applied to the tip of the penetrometer for penetration of most soils finer than medium gravel. Asphalt pavements up to 6 inches thick can usually be penetrated by penetrometer methods without pre drilling. Site disturbance is reduced since no borehole cuttings or drilling fluids are generated during penetrometer operations. Personnel exposure to contaminated soil is less than exposures during drilling and sampling operations. CPT equipment can be easily decontaminated during retrieval.

Four to thirteen hundred feet of CPT (with no time dependent piezometric or shear wave measurements) can be performed in a day, depending on site access. Depths of more than 200 ft can be achieved, depending on stratigraphy. Where soils are exceptionally dense or gravelly, an uninstrumented prepunch tool can be used for probing. Information obtained using the prepunch tool can be similar to mechanical (Dutch) cone data especially where friction on the rod string is minimal. Dynamic driving can be used in gravelly soils.

2.1.1 Signal Conditioning and Recording CPT data are acquired using a 16 bit (resolution of 1 part in 32,768) analog to digital data logger and PC computer. Sounding logs are graphically displayed and printed for immediate evaluation of subsurface conditions. Data are recorded on disk for data processing and archiving.

2.2 Soil Shear Resistance Measurements The soil penetration resistance is measured on the tip and along the sides of the CPT penetrometer using strain gage loadcells (Figure 1, Strutynsky and others, 1985). The conical tip of the penetrometer has a projected cross-sectional area of 15 square centimeters (2.3 sq. in., and a diameter of 1.7 inches. The cone tip resistance reflects the deep bearing capacity of a soil. Soil friction is measured along a cylindrical sleeve mounted behind the cone tip. The friction sleeve has a surface area of 200 square centimeters (31.0 sq. in.), a length of 5.8 inches, and a diameter slightly larger than the cone tip. The tip measurement has a layer resolution of about 2 to 4 inches, while the friction resolution is about 6 inches.

2.3 Piezometric Measurements A pressure transducer is used to measure the soil pore water pressure response to penetration. The advance of the penetrometer causes volumetric distortion of surrounding soils, which generates a local pore water pressure field. These generated pressures dissipate almost instantaneously in soils of high permeability, so equilibrium water pressures are measured during CPTU in coarse sand and gravel. In medium or low permeability soils, the generated pore water pressure field is sustained for a lengthy period of time (Saines and others, 1989). The dissipation of generated pressures can be recorded during pauses in penetration. The rate of dissipation is used to estimate soil hydraulic conductivity and consolidation characteristics. If the pauses are long enough for all generated water pressures to dissipate, potentiometric surface measurements can be obtained at multiple depths in a single CPTU sounding. The CPTU piezometric measurement has a layer resolution of about 1 inch.

2.3.1 Piezometer Saturation The CPTU piezometer filter is saturated with an incompressible liquid so that instantaneous response (zero lag time) can be achieved during testing. High filter saturation levels are indicated by sharp responses at interfaces and immediate regeneration of water pressure after pauses in penetration. Low filter saturation levels leading to poor measurements can be caused by inadequate filter preparation, soil suction, or filter damage on coarse soil particles. Clogging of piezometric filters can also lead to poor results. Loss of filter saturation or clogged filters are beyond the control of the operator. Thus, CPTU piezometric measurements can be less repeatable than CPT tip and friction sleeve resistance measurements.

2.4 Electrical Conductivity and Thermal Measurements A CPTU-EC penetrometer including tip, sleeve, piezometric, temperature, and electrical conductivity (EC) sensors can be used to simultaneously acquire geotechnical, hydrogeological and qualitative geochemical information. Soil EC is measured using a two electrode array, energized with a 3 kHz signal, mounted on the penetrometer tip. The EC measurement has a resolution of about 1 inch. The CPT thermal sensor is used to acquire soil thermal properties.

2.5 Natural Gamma Measurements A CPTU-EC-G penetrometer incorporating cone, friction, piezometric, soil electrical conductivity and natural gamma (G) sensors can be used to simultaneously acquire geotechnical, hydrogeological, qualitative geochemical and radiological information. Gamma measurements can be used to detect radionuclide contamination and to enhance lithologic evaluation.

2.6 UV Fluorescence A CPTU-EC-UVF penetrometer incorporating cone, friction, piezometric, soil electrical conductivity, and Ultraviolet Fluorescence (UVF) sensors can be used to simultaneously acquire geotechnical, hydrogeological, and qualitative geochemical information. The UVF system consists of a sapphire window in the penetrometer, a UV excitation light source, and photodiode light detectors. UV light is transmitted through the window into the adjacent soil. If the soil contains compounds such as petroleum hydrocarbons that fluoresce, the photodiodes are used to detect the resulting light. The UV light source is bandpass filtered to provide an excitation wavelength of 254 nm. The photodiode sensors are longpass filtered to monitor resulting fluorescent light emissions above 290 nm.

2.7 CPT Seismic Wave Velocity Measurements A geophone module is attached to the penetrometer to acquire P (compression) and S (shear) wave velocity data. CPT geophones have superior coupling to the soil, resulting in better definition of wave arrival, as compared to borehole deployed geophones. The CPT seismic system consists of three downhole geophones, an uphole wave source with timing trigger, signal conditioning, signal acquisition software, and the PC data acquisition computer. The test procedure is as follows: 1) the CPT penetrometer and geophone module is pushed to a test depth; 2) signal acquisition is initialized; 3) a hammer with timing trigger is used as a wave source; and 4) geophone output is recorded as a function of time. The procedure is repeated at multiple depths to allow calculation of interval wave velocities between adjacent tests.

A source rich in S-wave generation is used for S-wave tests. A sledge hammer is swung to horizontally strike the main leveling jack pad of the CPT rig. The 8-ft long steel jack pad, coupled to the ground surface by the weight of the CPT rig, transmits strong S-waves through the soil into a pair of horizontally opposed downhole geophones. The geophones are aligned with the jack pad to maximize the amplitude of the received signals.

A series of hammer blows is typically used for each test using signal stacking techniques. Signal stacking enhances data evaluation, as random noise rarely reinforces itself, while the repeated shear waves stack onto each other, increasing signal to noise ratios. The stacked output of the geophones typically results in obvious, high amplitude waves 180 degrees out of phase with each other at the instant of S-wave arrival.

After completion of a S-wave test, a P-wave test can be performed at the same depth. The sledge hammer is swung to vertically strike a steel plate placed on the ground next to the CPT rig. A series of blows is also used for each P-wave test. P-wave arrivals are recorded using the vertical CPT geophone.

P-wave arrivals are often much less obvious than S-wave as the amplitude of the P-wave is typically lower, the travel times are much shorter, and P-waves can easily be transmitted through the steel rod string connecting the penetrometer to the surface. The very fast P-wave transmission through the rod string at about 15,000 ft/sec, can set downhole geophones vibrating, thus masking the arrival of the slower soil P-wave. Occasionally, the S-wave geophones can also indicate P-wave arrival, differentiated from S-wave arrival by the fact that each geophone will vibrate in phase, rather than 180 degrees out of phase, as during S-wave arrival.

P-waves typically travel 2 to 4 times faster than S-waves. In saturated soils, the P-wave travels at about the speed of sound in water, about 5000 ft/sec. After arrival of the P-wave, the three downhole geophones will also pick up the arrival of the S-wave. This S-wave arrival during P-wave testing can be used to check S-wave arrivals measured during the first series of S-wave tests.

2.8 CPT-EMOD measurements The standard CPT procedure is conducted as a constant rate of strain test, resulting in a continuous measurement of soil ultimate bearing and frictional strength. By conducting CPT under monotonically increasing stress conditions, soil deformation properties can be evaluated. The CPT-EMOD test is conducted during short pauses in the continuous push process. Load/settlement data are analyzed using elastic theory, as might be done for a plate load test, for evaluation of Young's Modulus at various stress levels. 2.9 Penetrometer Geometry The CPT penetrometer external geometry is specified by ASTM standards. Differences in penetrometer internal design can lead to some variability in response between penetrometers of different manufacture, especially in very soft clays. STRATIGRAPHICS uses a cone with a 20 sq cm tip and a 235 sq cm sleeve. The CPTU measurement of generated water pressure depends on external filter geometry. Measurements of equilibrium water pressures after pauses in the penetration process are not sensitive to geometry, and reflect undisturbed conditions.

CPTU piezometric filters are typically mounted on either the cone tip (U1 position) or just ahead of the friction sleeve (U2 position). Each position has advantages and disadvantages. Measurements taken with the cone tip U1 filter are at a maximum and show high resolution of thin soil seams. The cone tip U1 filter is prone to damage on coarse soil particles. Negative pressures are often measured in dense, silty or clayey sands and hard clays when using the U2 friction sleeve filter. These low pressures are probably caused by soil elastic rebound (expansion) as the soil moves from the intensely loaded region beneath the cone tip to the less loaded region next to the friction sleeve. Soil expansion can induce large suction forces on the U2 friction sleeve filter, which can result in decreased filter saturation levels.

Site characteristics and data usage determine which piezometric filter geometry is appropriate. The piezometric filter is placed at the U2 friction sleeve position on the STRATIGRAPHICS CPTU-EC penetrometer. The filter housing is internal to the cone tip. Generally good results can be obtained using this geometry when proper filter preparation techniques are followed.

2.10 Equipment Decontamination and Grouting The rod string is retrieved through a rodwasher mounted on the hydraulic ram assembly. High pressure hot water is sprayed from internal nozzles to clean the rod string. Wash water (about ½ gallon per 10 ft of rod) can be captured for disposal.

The STRATIGRAPHICS grouting system can be used to seal open hole. As penetrometers are being advanced, bentonite grout (about ¾ gallon per 10 ft of open hole) is pumped into the annular space formed between the smaller diameter sounding rods and the larger diameter penetrometer. A bypass is opened and additional grout is pumped to seal the hole during rod string retrieval. Pressure grouting during sounding advance can control cross-contamination between different strata. The grout decreases the contact of downhole equipment with contaminated soil. The grout also can decrease rod friction which may allow deeper penetration. Grout levels are checked after sounding completion, and more grout is added to account for penetration of grout into permeable strata.

3.0 PENETROMETER SAMPLING EQUIPMENT

Groundwater, soil gas, and soil samplers are deployed in the same manner as CPT penetrometers. Good sample isolation is achieved because no open hole exists during penetrometer operations.

3.1 Groundwater Sampler The STRATIGRAPHICS groundwater sampler is a shielded wellpoint sampler of heavy construction. The shield prevents sampler contamination while penetrating soils above the sampling depth. After shield retraction, groundwater flows under in situ pressure conditions, through a 20 inch long screen, into the 350 ml sample barrel. The sampler is retrieved to pour off the sample and for decontamination. Small diameter pumps can be used with the sampler to acquire large volumes of sample. This sampler can be deployed in any soil capable of being penetrated by the CPTU-EC penetrometer (Strutynsky and others, 1998).

A pressure transducer can be placed inside the sampler barrel. This allows the measurement of sample inflow rate. Analysis of inflow data using rising head slug test methods can provide a means of estimating soil hydraulic conductivities. If equilibrium conditions are reached, a measurement of the static water pressure head is obtained during groundwater sampling.

3.2 Soil Gas Sampler The STRATIGRAPHICS soil gas sampler is a shielded screen sampler, similar to the groundwater sampler. The shield is opened by pulling back the rod string during sampling, and soil gases are then extracted. The shield can be closed, and the rod string advanced to another depth, allowing multiple samples during a single rod trip. Soil gasses are extracted from the rod string. A vacuum box can be used to inflate Tedlar bags for off site analysis. Portable analytical equipment can be used to allow immediate soil gas profiling. The sampler, rod string and any sample tubing are purged before sampling using a vacuum pump.

3.3 Soil Samplers Fixed piston samplers can be used to obtain soil samples during penetrometer exploration. The STRATIGRAPHICS and MOSTAP 2-meter samplers are deployed similarly to a penetrometer. A piston, locked into the tip of the barrel to prevent soil from entering the sampler prematurely, is released at the top of the sampling interval, and the barrel is then advanced. Soil enters the barrel and is retained by a core catcher. The sampler is retrieved to remove the sample and for sampler decontamination.

The MOSTAP Sampler is used to obtain 1 inch diameter samples as long as 2 meters (78 inches). This sampler incorporates a PVC liner and a nylon stocking to allow retrieval of such a long sample. As the sample enters the sampler, it is encased in the nylon stocking. The stocking lessens soil friction around on the sample as it enters the PVC liner. At the end of the 2 meter run, the sampler is rotated to twist the stocking, helping retain the sample. This sampler can only be used in softer soils.

4.0 PIEZOMETER INSTALLATION TECHNIQUES

Penetrometer methods can be used to install piezometers for water level measurements, slug testing, groundwater sampling, and for remediation activities, such as sparging and soil vapor extraction (SVE). Various installation techniques are available (Saines and others, 1989). Proprietary, low volume change piezometers also can be installed using penetrometer equipment. These piezometers are often used for long term water pressure measurements during geotechnical projects. PVC piezometers are installed using a steel casing pushed to depth. The casing is sealed with an expendable tip which prevents soil from entering the casing during deployment. The PVC screen and risers are lowered into the casing, the casing is then withdrawn, leaving the PVC in place.

5.0 DATA REDUCTION

Test data are monitored as the soundings are performed. Data are recorded on hard disk and may consist of: depth, time, tip and sleeve resistance, generated water pressure, EC, UVF, temperature and natural gamma. Data are processed in-house and undergo quality control review prior to final reporting.

Several parameters can be computed to enhance data correlation:

friction ratio, FR (in %):

FR = fs/qc * 100 (Eq. 1); and

pore pressure ratio, Bq (dimensionless):

Bq = (U-Ue)/(qc-Sv) (Eq. 2);

where: *fs* is the measured friction sleeve resistance, in TSF;
qc is the measured cone end bearing resistance, in TSF;
U is the measured generated pore water pressure, in TSF;
Ue is the measured or estimated equilibrium pore water pressure, in TSF; and
Sv is the total soil overburden pressure, in TSF.

Measured data, computed and correlated parameters are presented in a graphical sounding log format for each sounding; numerical data are typically tabulated at 0.5 ft intervals. Digital data are also included on disk.

CPTU dissipation test data are recorded as a function of time during pauses in the penetration process. Dissipation data are normalized using the following equation:

normalized dissipation level, U* (dimensionless):

(Ut - Ue) / (U0 - Ue) (Eq. 3);

where: *Ut* is the excess pore water pressure at time t, in TSF;

Ue is the measured or estimated equilibrium, undisturbed pore water pressure (in situ pore water pressure before penetrometer insertion), in TSF; and

U0 is the excess pore water pressure at time equal to zero, at the start of the dissipation test, in TSF

The normalized dissipation level is plotted versus log time. In uniform soils, the plot takes the shape of a reverse S-curve, beginning at one at zero time (at the instant the penetration process is stopped) and falling to zero when equilibrium pressures are achieved. Boundary effects in interbedded deposits can cause deviation from this ideal.

An estimate of the horizontal coefficient of soil consolidation can be calculated (Baligh and Levadoux, 1980) using: Ch (in cm**2/sec) = (r**2*T)/t (Eq. 4a).

Estimates of soil hydraulic conductivity in the horizontal direction can be calculated using:

kh (in cm/s) = ((r**2*T)/t)*RR*(Gw/(2.3*Sv')) (Eq. 4b);

where: *r* is the penetrometer radial dimension at the plane of the piezometric filter, equal to 2.2 cm for the U2 friction sleeve filter and 1.9 cm for the U1 cone tip filter;

T is a dimensionless time factor at the 50% normalized dissipation level, equal to 5.5 for the U2 friction sleeve filter and 3.8 for the U1 cone tip filter;

t is the measured time, in seconds, at which the normalized dissipation level is 50%;

RR is a dimensionless soil compressibility parameter;

Gw is the unit weight of water, in kg/cm***3; and

Sv' is the effective soil vertical overburden pressure, in kg/cm**2.

Dissipation test data can be presented in graphical plots and are summarized in tabular form.

6.0 GENERAL DATA EVALUATION

6.1 Sounding Log The CPT sounding logs provide high resolution information on subsurface conditions. Soil layering is often highly apparent. Soil relative strength and saturation levels can also be evaluated. Zones of anomalous soil electrical conductivity can be identified. Apparent lateral continuity of conditions can be evaluated by comparing adjacent soundings. Digital CPT data files can be used in two and three dimensional data visualization, CAD or GIS software programs.

6.2 Soil Type Classification Correlations between penetrometer data and soil classification have been developed from geotechnical bearing capacity theory and a relational database on adjacent CPT soundings and drilled boreholes (Douglas and Olsen, 1981). A CPT soil type chart based on cone tip resistance and friction ratio is presented in Appendix A.

The CPT tip resistance increases exponentially with soil grain size. For example, tip resistance in dense sands ranges from about 100 to 400 tons per square foot (TSF), while tip resistance in a stiff clay ranges from about 5 to 15 TSF. The friction ratio (Section 5.0) is also used for indication of soil type. The friction ratio increases with the fines content and compressibility of a soil. The friction ratio is less than about 1% in a sand and greater than about 3% in a clay. CPT soil types reflect the soil shear resistance to penetration. Soil shear resistance is not entirely controlled by grain size distribution. However, CPT soil types generally agree with classifications based on grain size distribution methods, such as the Unified Soil Classification System (USCS).

The generated pore water pressure measurement is also useful for evaluation of saturated soils. Penetration of coarse sand and gravel occurs under drained loading conditions, and thus equilibrium pressures are measured during CPTU. The pore pressure ratio (Section 5.0) is zero in high permeability soils. For saturated soils of permeability less than about 1*10E-2 cm/sec, undrained loading with significant excess water pressure generation occurs during CPTU. Positive excess water pressures are generally measured during penetration of silt or clay soils when using either the U1 cone tip or U2 friction sleeve filter penetrometer (Section 2.7). Pore pressure ratios of fine grained soils typically range from about 0.4 to 1.0.

Positive excess water pressures are also usually measured in dense, silty or clayey sands when using the U1 filter penetrometer, with pore pressure ratios from about 0 to 0.3. Due to geometric effects (Section 2.7), negative pressures are usually measured in dense, silty or clayey sands, sandy silts, or hard sandy clays with the U2 filter penetrometer. Thus, it is important to note the type of piezometer filter in use. The CPTU-EC penetrometer uses a U2 friction sleeve piezometric filter.

6.3 Potentiometric Surfaces Equilibrium water pressures are measured during penetrometer advance in saturated, coarse sand and gravel. Measurements of equilibrium water pressures can be obtained during CPTU in lower permeability soils by pausing during penetration and allowing generated water pressures to dissipate.

6.4 Soil Saturation Soil saturation often can be evaluated using the CPTU sounding log. Atmospheric (zero) pressure is measured during CPTU in unsaturated soils. Hydrostatic pressures are measured in saturated, high permeability soils. Significant water pressures are generated in saturated, low permeability soils due to penetrometer advance. Decreased levels of water pressure generation can be indicative of partially saturated soils. Decreased water pressure generation also may occur in organic soils due to the high compressibility of organic soil particles and the presence of biogenic gases, such as methane and hydrogen sulfide.

6.5 Soil Hydraulic Conductivity Excess water pressures are generated by penetrometer advance in saturated soils with permeability of less than about 1*10E-2 cm/sec. These generated pressures can be allowed to dissipate during pauses in the penetration process. The CPTU dissipation test is similar to a slug test and can be used to estimate soil hydraulic conductivity in the horizontal direction. Very high water pressures are typically generated in low permeability soils by penetrometer advance, so soil compressibility (storage) effects must be included in analyses. The CPTU tip resistance provides an index of soil compressibility for these computations.

6.6 Soil Electrical Conductivity Behavior Soil electrical conductivity (EC) is controlled by the conductance of both the soil particles and soil pore fluids. The ratio between pore fluid and soil-pore fluid electrical conductivity is termed the formation factor (Archie, 1942). Clays can be electrically conductive due to adsorbed water and ionic electrical charges on the clay platelets. Thus, clay EC depends on mineralogy, porosity and pore fluid characteristics. Sand grains are typically non-conductive, so granular soil conductance is primarily dependent on the conductance of pore fluids and the sand's porosity.

Pore fluids play a major role in sand EC. A dry sand has low EC since both the sand grains and the air in the pore space have very low conductance. Sands saturated with conductive liquids, such as brine or landfill leachates, have high EC. Hydrocarbons typically decrease EC because of their low conductance. **Soil saturation** has a pronounced effect on sand EC, as conductance increases with water saturation. Low saturation is typically associated with low EC. The low **porosity** of a dense sand results in less pore fluid available for electrical conductance and thus lower EC; the high porosity of a loose sand is often associated with higher EC. Formation factors vary as an inverse function of porosity, from about 3 at high porosity to about 4.5 at low porosity. The addition of as little as 5% clay to a sand can increase soil EC (Windle, 1977).

The high resolution of the STRATIGRAPHICS CPTU-EC electrode array makes measurements sensitive to gravel content. Two behaviors can occur when penetrating gravelly soils. One can occur when a large particle is crushed against an electrode, masking it from the pore fluids, which results in low EC values. An opposite behavior is observed in gravel deposits which contain few fine grained intersticial soils. The high resolution EC measurement can result in electrical conductance paths within the soil pore space. In this situation, high EC measurements more closely reflect pore fluid EC, rather than soil EC.

6.7 EC Evaluation EC data are evaluated in conjunction with CPTU-EC piezometric data and soil types for qualitative geochemical characteristics. Anomalous zones possibly indicative of contaminants can be directly sampled for quantitative chemical analysis.

Vadose Zone Low or zero EC values are typically measured in dry sandy soils. Increased EC in vadose zone sands may indicate moisture infiltration. Low EC data in vadose zone silty or clayey soils can be anomalous as fine grained soils often retain significant amounts of moisture within their pore spaces due to capillarity. Elevated EC values in the vadose zone may be associated with road deicing salts, buried metals and rusted metal objects, flyash and cinders, among others.

Saturated Soils Low EC values in saturated soils can be indicative of anomalous geochemistry. In particular, depressed EC zones immediately at the water table may be associated with floating (LNAPL) compounds. Very low EC zones at interfaces between aquifers and aquitards may be associated with either LNAPL or DNAPL compounds. Gravel interference must be considered when evaluating depressed EC zones in saturated soils.

Elevated EC values in saturated soils can be due to increased soil clay content or to increased dissolved salts in the ground water. Increased clay contents are evaluated based on the CPTU-EC piezometric data and soil type information. Zones of elevated EC immediately above an aquiclude may be associated with brines or landfill leachates (Strutynsky and others, 1998).

6.8 UV Fluorescence Behavior Fluorimetry (measurement of fluorescence) has been used for many years for the detection and identification of various compounds and minerals. An excitation light of short wavelength is used to expose the specimen. If fluorescent compounds or minerals are present, light of longer wavelength, as compared to the excitation wavelength, will be emitted from the specimen. This resulting light can be monitored for intensity and spectral distribution.

Compounds that fluoresce include a wide range of hydrocarbon and other organic compounds. Heavy hydrocarbons (e.g. fuel oil and coal tars) fluoresce at relatively long wavelength excitation. As excitation wavelength decreases below about 300 nm, fluorescence from lighter hydrocarbons (e.g. jet fuel and gasoline) is observed. In addition to hydrocarbons, other compounds and minerals, such as fluorites and other carbonates, also exhibit fluorescence. Compounds that fluoresce include dyes and optical brighteners, used in paints, detergents, antifreeze compounds, some food additives and cosmetics, among others. UVF response will be affected by the presence of any such compounds.

6.9 CPT-SPT Correlation Since most geoscientists are familiar with drilling and split spoon sampling, CPT data have been correlated with SPT blowcount N-values. The SPT N-value is defined by ASTM to be the number of blows of a 140 lb hammer, dropped 30 inches, required to drive a 2 inch outside diameter sampler 12 inches into the bottom of the borehole, after an initial seating drive of 6 inches. Correlations of CPT to the crude SPT have been based on numerical modeling of the two penetration processes and on side by side comparisons (Douglas and others, 1981). Additional details on CPT-SPT correlations are included in Appendix A.

7.0 GEOTECHNICAL DATA CORRELATION

CPT data have been correlated with soil type, drained friction angle, undrained shear strength, relative density and SPT blowcounts, among others. A correlation scheme including tip resistance and friction ratio has generally proved most useful for evaluating CPT data. Correlation of CPT data with other parameters has been developed using: 1) comparisons between CPT data and results of other in situ and laboratory tests in adjacent boreholes; 2) CPT testing on large scale soil samples of known composition; and 3) geotechnical bearing capacity and cavity expansion theory. Site specific information can be used to fine tune correlations. Additional information on correlation techniques, including overburden pressure normalization, test drainage conditions and recommended practices, is presented in Appendix A.

8.0 PROGRAM RESULTS

Acquired data are presented following the report text and consist of: 1) sounding logs with lithologic evaluation; 2) data presentation sounding logs; and 3) tabulations of correlated geotechnical parameters, including soil classifications. Digital data are presented on the attached disk, and include statistical summaries of evaluated strata for each sounding, among other data presentations. It should be noted that the computerized evaluations of soil types and other geotechnical properties were generated using a global rather than site specific data base. Use of site specific data was beyond the scope of this study.

9.0 STATEMENT OF LIMITATIONS

Subsurface information was gathered only at the sounding locations. Extrapolation of sounding data to develop stratigraphic continuity is conjectural. Actual site conditions between sounding locations may differ. Evaluation of soil saturation and potentiometric surfaces is only representative of conditions encountered during the field program. Seasonal variation must be expected.

Correlation of penetrometer data with other parameters was performed using generalized, global charts rather than on site specific information. Site specific correlation work based on results of detailed, complementary laboratory testing was beyond the scope of this study.

Data gathering for this study was attempted to be performed in general accordance with accepted procedures and practices. Correlation of penetrometer data with other parameters is empirical and should not be considered as the exact equivalent of laboratory testing. STRATIGRAPHICS shall not be responsible for another's interpretation of the information obtained for this study.

10.0 REFERENCES

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TABLE 1
SUMMARY OF CPTU-EC SOUNDINGS
CPS-ESP FIELD EXPLORATION
CLINTON, ILLINOIS

SOUNDING NUMBER	DATE PERFORMED	SOUNDING TYPE	SOUNDING DEPTH (feet)	COMMENTS
CPT-01	07/24/2002	CPTU-EC	78.1	
CPT-02	07/24/2002	CPTU-EC-S	55.7	
CPT-03	07/24/2002	CPTU-EC	54.0	
CPT-04	07/23/2002	CPTU-EC-S	76.9	

STRATIGRAPHICS

Table 2a

Seismic Shear Wave Velocity Computation

Project Name: CPS-EPS Field Exploration

Project No: 02-120-110

Sounding No: CPT-02

S -Source offset:: 4.3 ft
S-Receiver offset: 1.1 ft
Depth correction factor: 1.002

Recorded CPT Tip Depth (ft)	Corrected CPT Tip Depth (ft)	**Seismic Receiver Depth (ft)**	S-source Slant Distance (ft)	Shear Wave Arrival (sec)	Shear Wave Velocity (ft/sec)	**Interval Shear Wave Velocity (ft/sec)**
7.2	6.9	**5.8**	7.21	0.0080	902	**902**
10.4	10.2	**9.1**	10.03	0.0120	835	**703**
13.7	13.4	**12.3**	13.06	0.0152	859	**948**
17.1	16.8	**15.7**	16.28	0.0180	904	**1148**
20.3	20.0	**18.9**	19.38	0.0208	932	**1107**
23.5	23.3	**22.2**	22.58	0.0240	941	**1002**
26.9	26.6	**25.5**	25.88	0.0264	980	**1162**
30.1	29.8	**28.7**	29.07	0.0294	989	**1062**
33.4	33.1	**32.0**	32.33	0.0324	998	**1088**
36.7	36.4	**35.3**	35.58	0.0348	1022	**1354**
40.0	39.7	**38.6**	38.87	0.0380	1023	**1029**
43.2	43.0	**41.9**	42.13	0.0416	1013	**905**
46.5	46.3	**45.2**	45.40	0.0448	1013	**1022**
49.6	49.4	**48.3**	48.48	0.0476	1018	**1101**
52.9	52.7	**51.6**	51.76	0.0504	1027	**1173**
55.86	55.6	**54.5**	54.72	0.0528	1036	**1231**

STRATIGRAPHICS

Table 2b

Seismic Shear Wave Velocity Computation

Project Name: CPS-EPS Field Exploration

Project No: 02-120-110

Sounding No: CPT-04

S -Source offset:: 4.3 ft
S-Receiver offset: 1.1 ft
Depth correction factor: 1.004

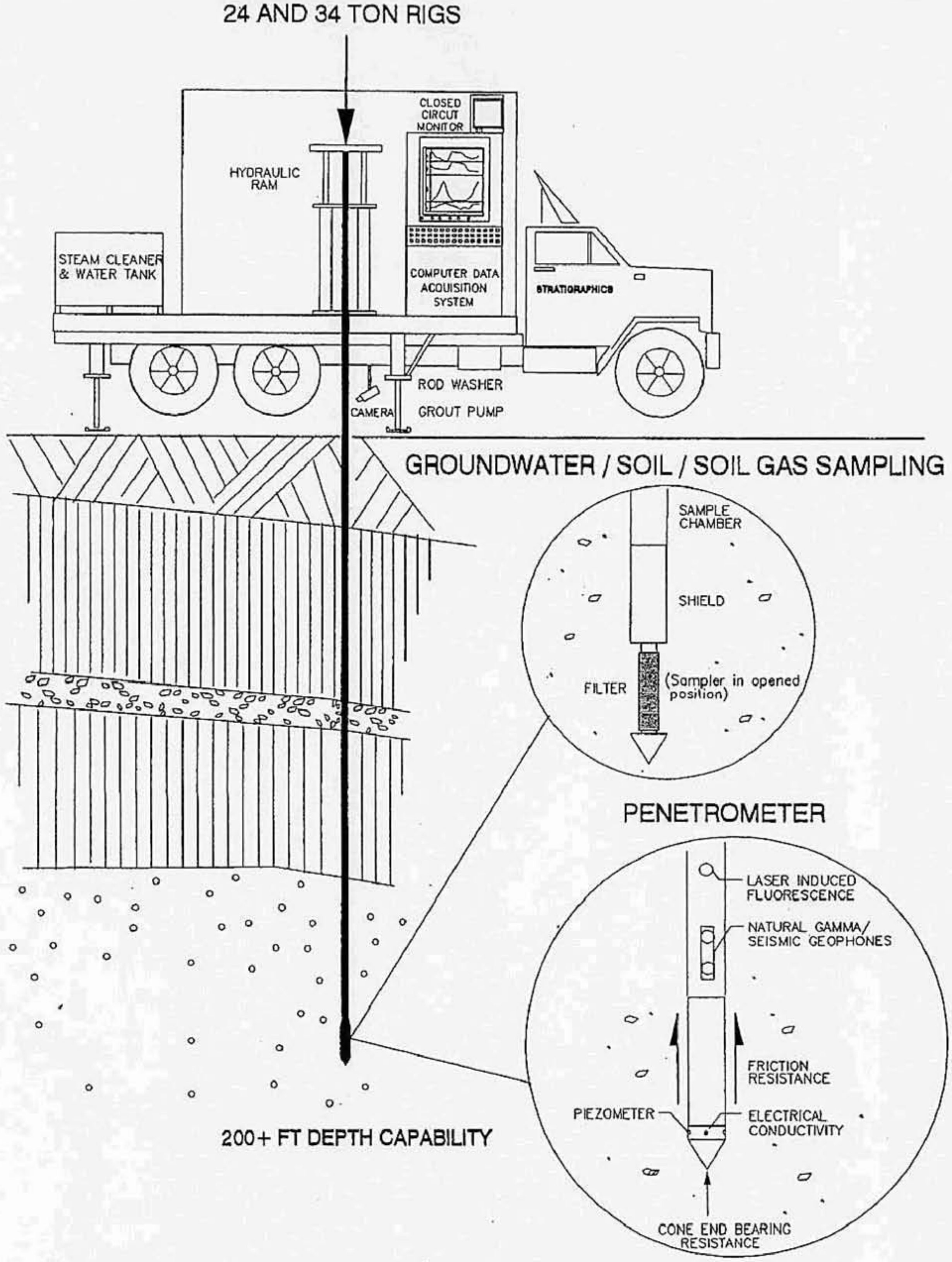
Recorded CPT Tip Depth (ft)	Corrected CPT Tip Depth (ft)	**Seismic Receiver Depth (ft)**	S-source Slant Distance (ft)	Shear Wave Arrival (sec)	Shear Wave Velocity (ft/sec)	**Interval Shear Wave Velocity (ft/sec)**
7.2	6.9	**5.8**	7.23	0.0100	723	**723**
10.4	10.2	**9.1**	10.05	0.0144	698	**641**
13.7	13.5	**12.4**	13.09	0.0188	696	**692**
17.0	16.7	**15.6**	16.22	0.0224	724	**869**
20.3	20.0	**18.9**	19.42	0.0260	747	**890**
26.8	26.6	**25.5**	25.87	0.0336	770	**848**
30.5	30.3	**29.2**	29.53	0.0372	794	**1017**
33.3	33.1	**32.0**	32.32	0.0408	792	**776**
36.7	36.5	**35.4**	35.67	0.0440	811	**1046**
39.9	39.8	**38.7**	38.90	0.0470	828	**1077**
43.1	43.0	**41.9**	42.11	0.0520	810	**643**
46.4	46.3	**45.2**	45.38	0.0548	828	**1167**
49.6	49.5	**48.4**	48.60	0.0580	838	**1006**
52.9	52.8	**51.7**	51.89	0.0608	853	**1175**
56.09	56.0	**54.9**	55.08	0.0632	872	**1330**
59.29	59.2	**58.1**	58.29	0.0652	894	**1602**
62.69	62.6	**61.5**	61.69	0.0680	907	**1216**
65.89	65.9	**64.8**	64.90	0.0708	917	**1145**
69.09	69.1	**68.0**	68.10	0.0728	935	**1603**
72.33	72.3	**71.2**	71.35	0.0756	944	**1160**
75.73	75.7	**74.6**	74.76	0.0776	963	**1704**
76.86	76.9	**75.8**	75.89	0.0780	973	**2832**

TABLE 3
SUMMARY OF CPTU-EC DISSIPATION TEST DATA
CPS-EPS FIELD EXPLORATION
CLINTON, ILLINOIS

SOUNDING NUMBER	DEPTH (ft)	SOIL TYPE AT DISSIPATION DEPTH	t50 (sec)	ESTIMATED SOIL HORIZONTAL HYDRAULIC CONDUCTIVITY kh (cm/sec)	ESTIMATED HORIZONTAL COEFFICIENT OF CONSOLIDATION IN OVERCONSOLIDATED RANGE* Ch(oc) (cm**2/sec)
CPT-02	42.8	Clayey silt	37.5	2E-006	7E-001
	46.0	Silty clay	300	2E-007	8E-002
CPT-04	49.3	Clayey silt	120	5E-007	2E-001
	50.5	Silty sand	10	1E-005	3E+000

NOTE: All dissipation tests must be performed in lower hydraulic conductivity (less than about 1E-2 cm/s) soil layers and strata, as CPTU-EC generated soil pore water pressures in more conductive soils dissipate faster than the response time of the sensors and data acqusition system. As such, this summary of test results is necessarily biased towards lower conductivity layers at the Site, and must not be considered as representative of the entire soil profile. Inspection of the continuous CPTU-EC sounding logs will indicate the relative frequency of lower and higher hydraulic conductivity soil layers at the Site.

*1. Estimates of the vertical coefficient of consolidation, in the normally consolidated range, can be estimated using:
Cv(nc)= RR(probe)/CR *(kv/kh)*Ch(oc) from Baligh and Levadoux, 1980 (see Appendix B of this report)



PENETROMETER EXPLORATION SYSTEM

STRATIGRAPHICS

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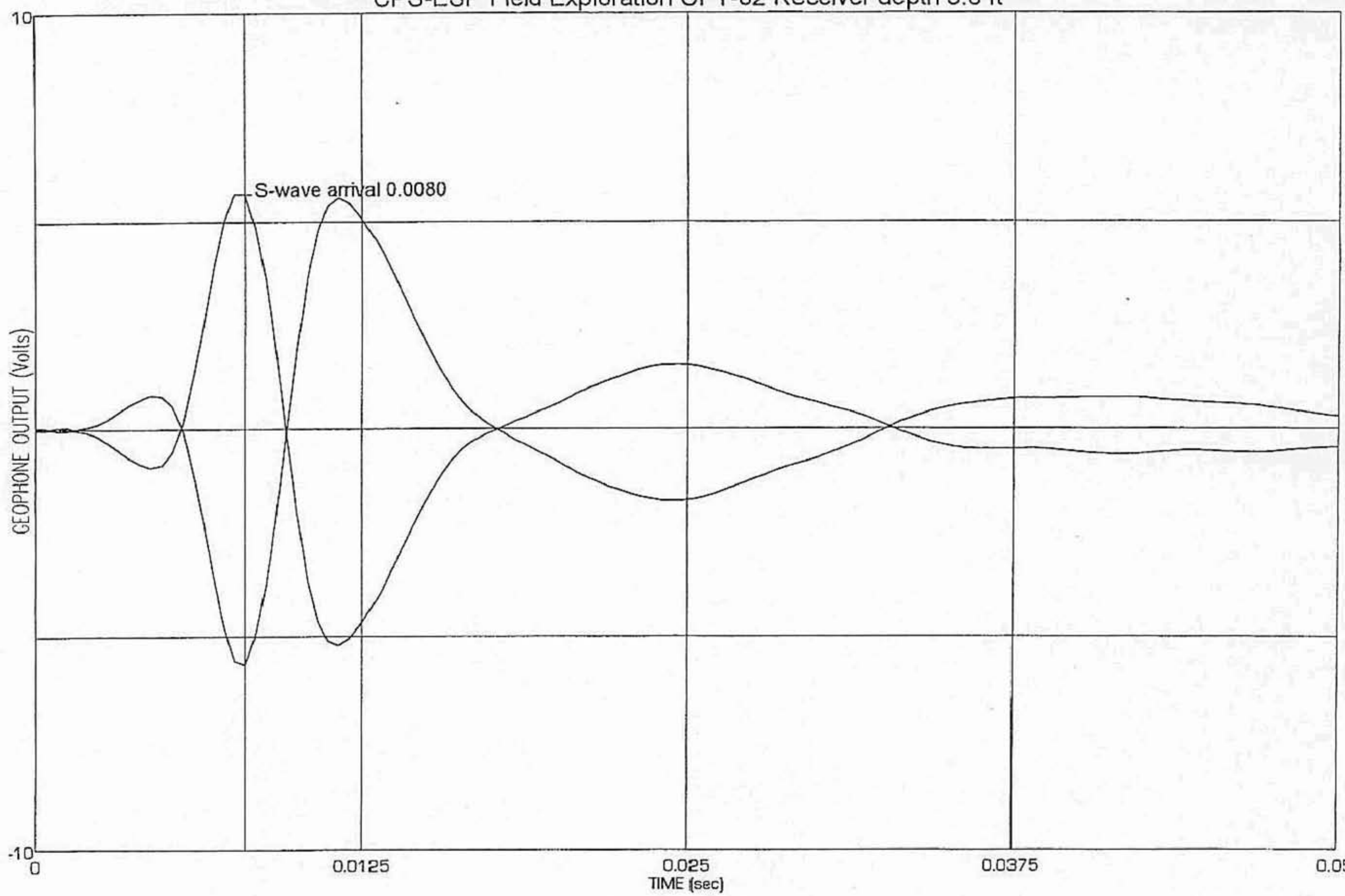
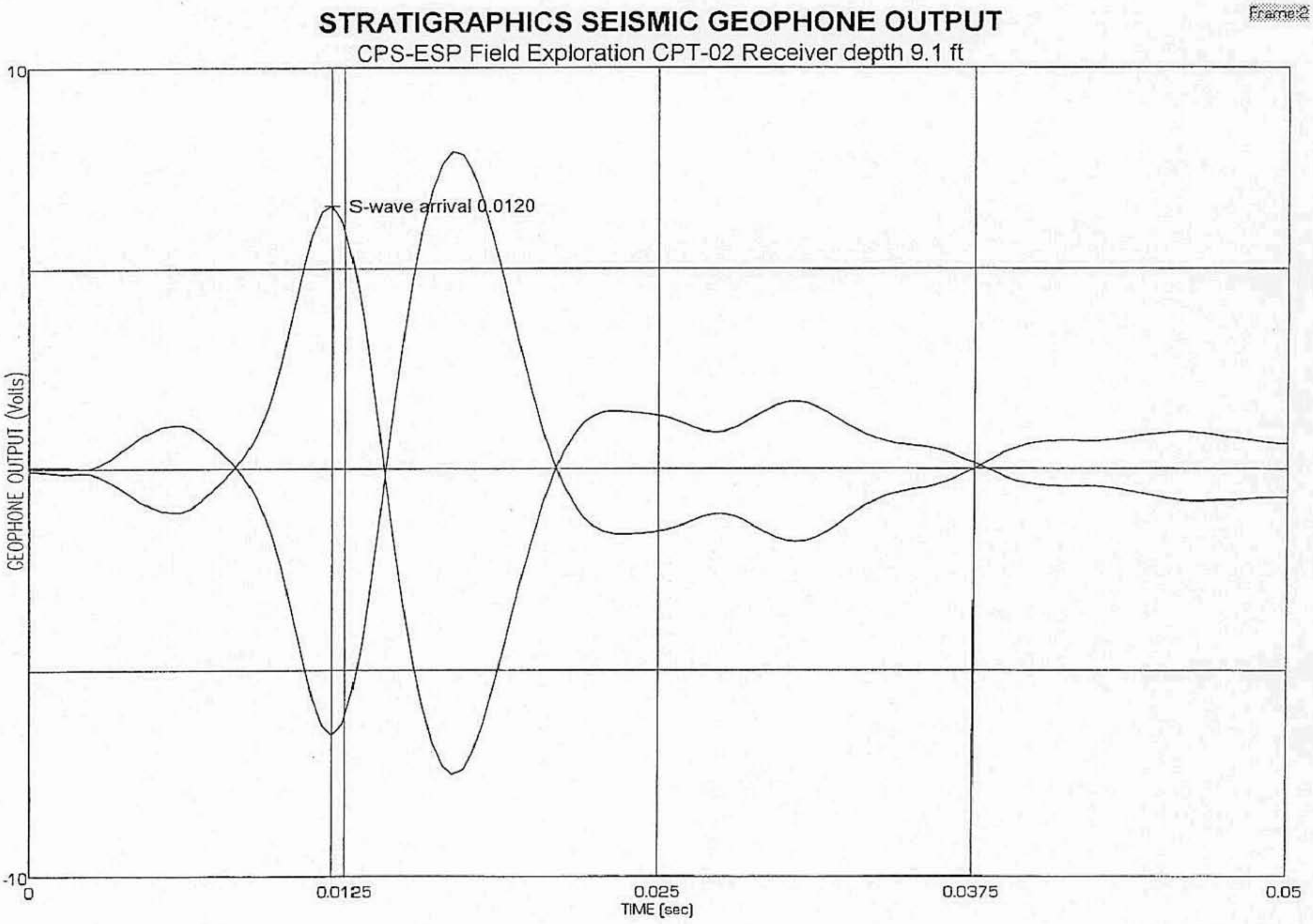
REV 2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

CPS-ESP Field Exploration CPT-02 Receiver depth 5.8 ft

Frame:2



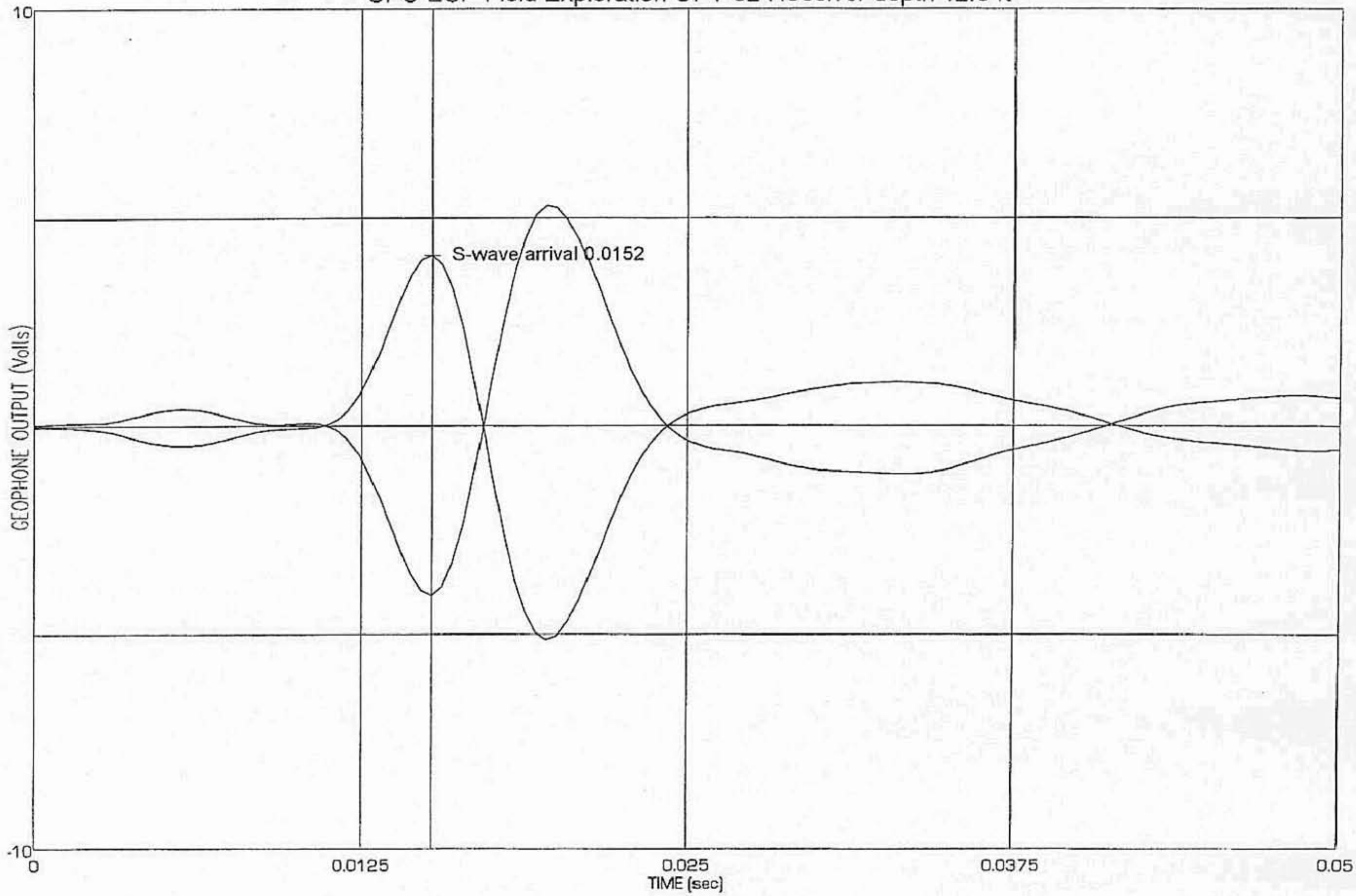

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT
CPS-ESP Field Exploration CPT-02 Receiver depth 9.1 ft
Frame:2
S-wave arrival 0.0120
GEOPHONE OUTPUT (Volts)
10
-10
0
0.0125
0.025
0.0375
0.05
TIME (sec)

REV 2

Frame:2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

CPS-ESP Field Exploration CPT-02 Receiver depth 12.3 ft

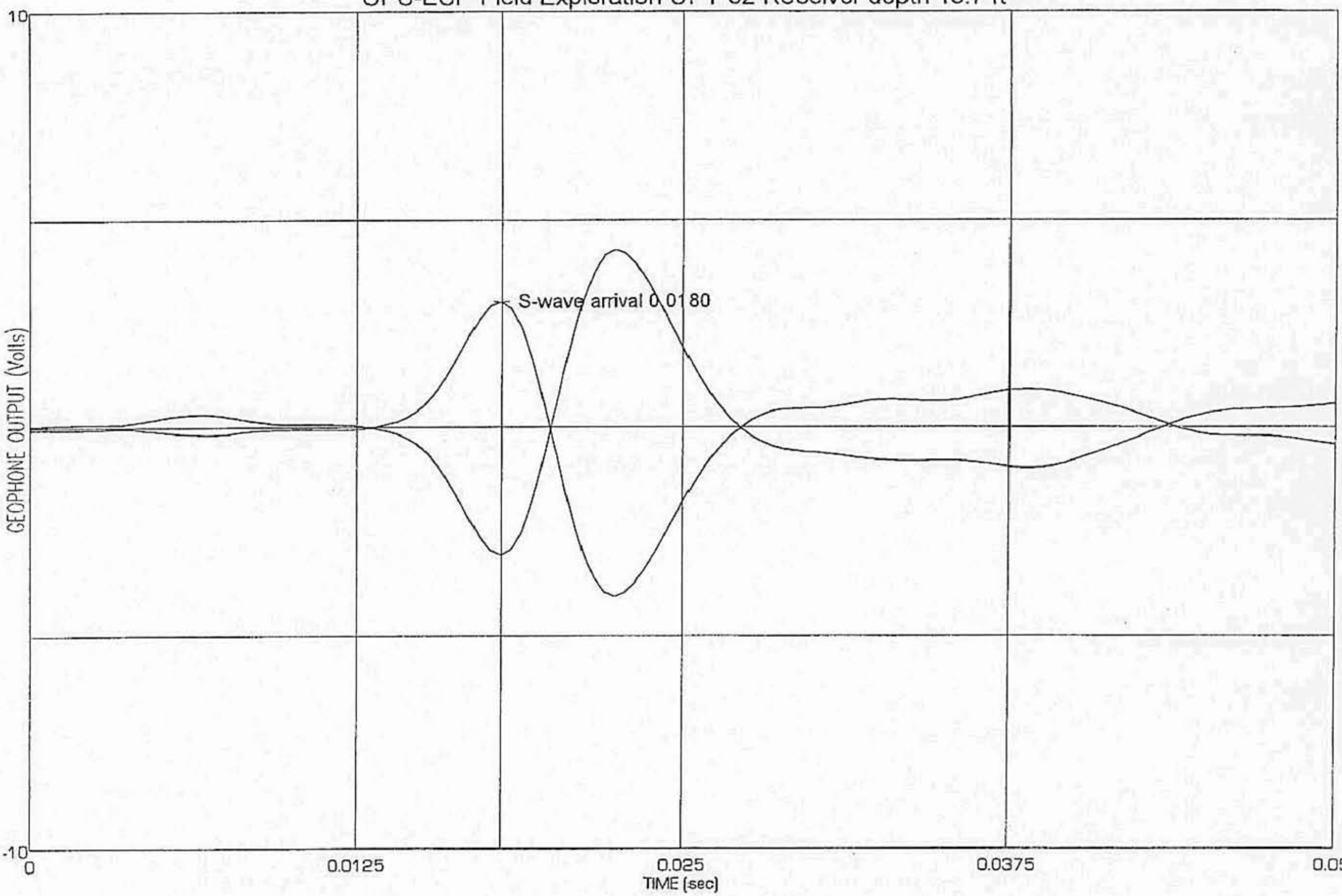


REV 2

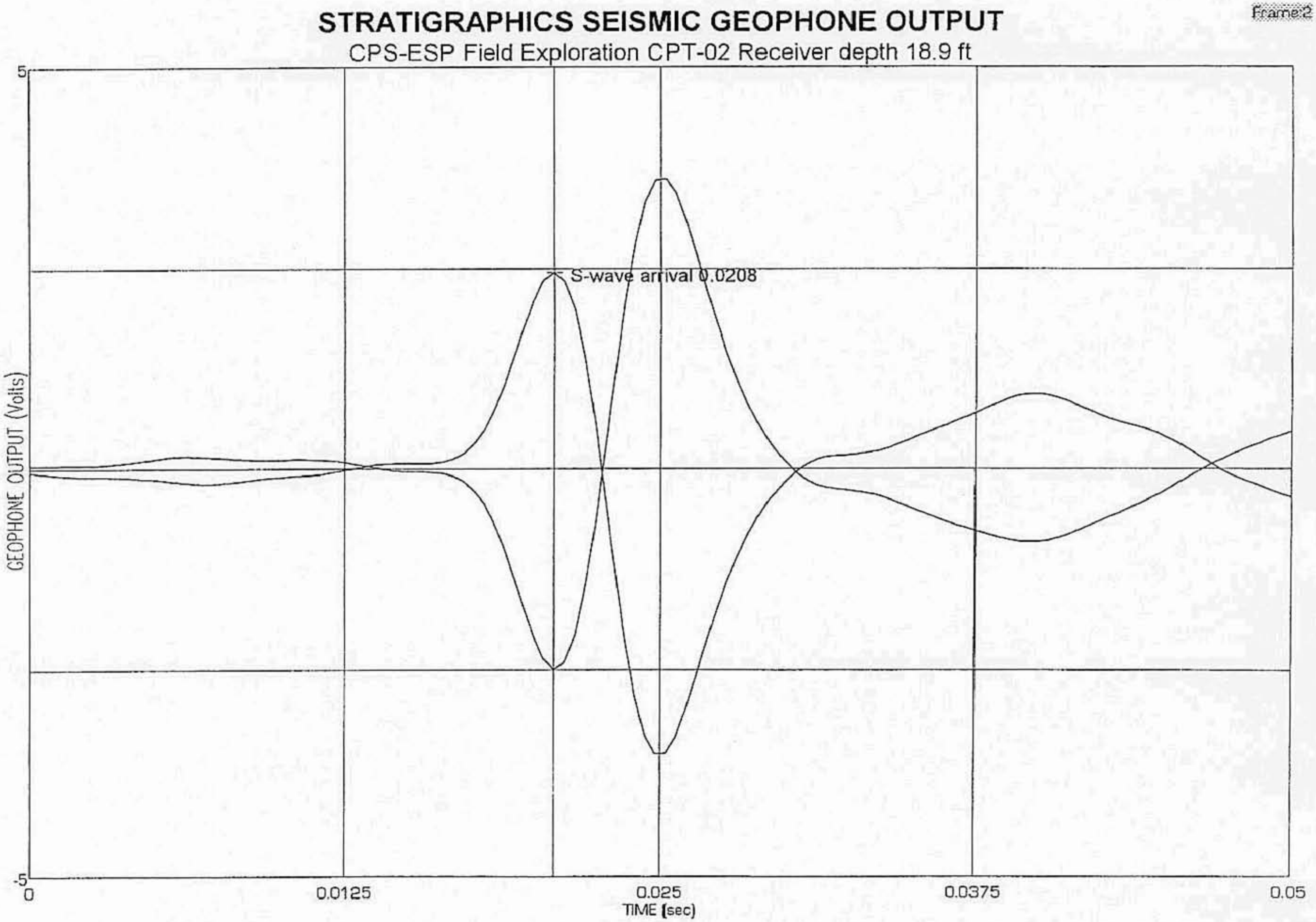
STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

CPS-ESP Field Exploration CPT-02 Receiver depth 15.7 ft

Frame:2

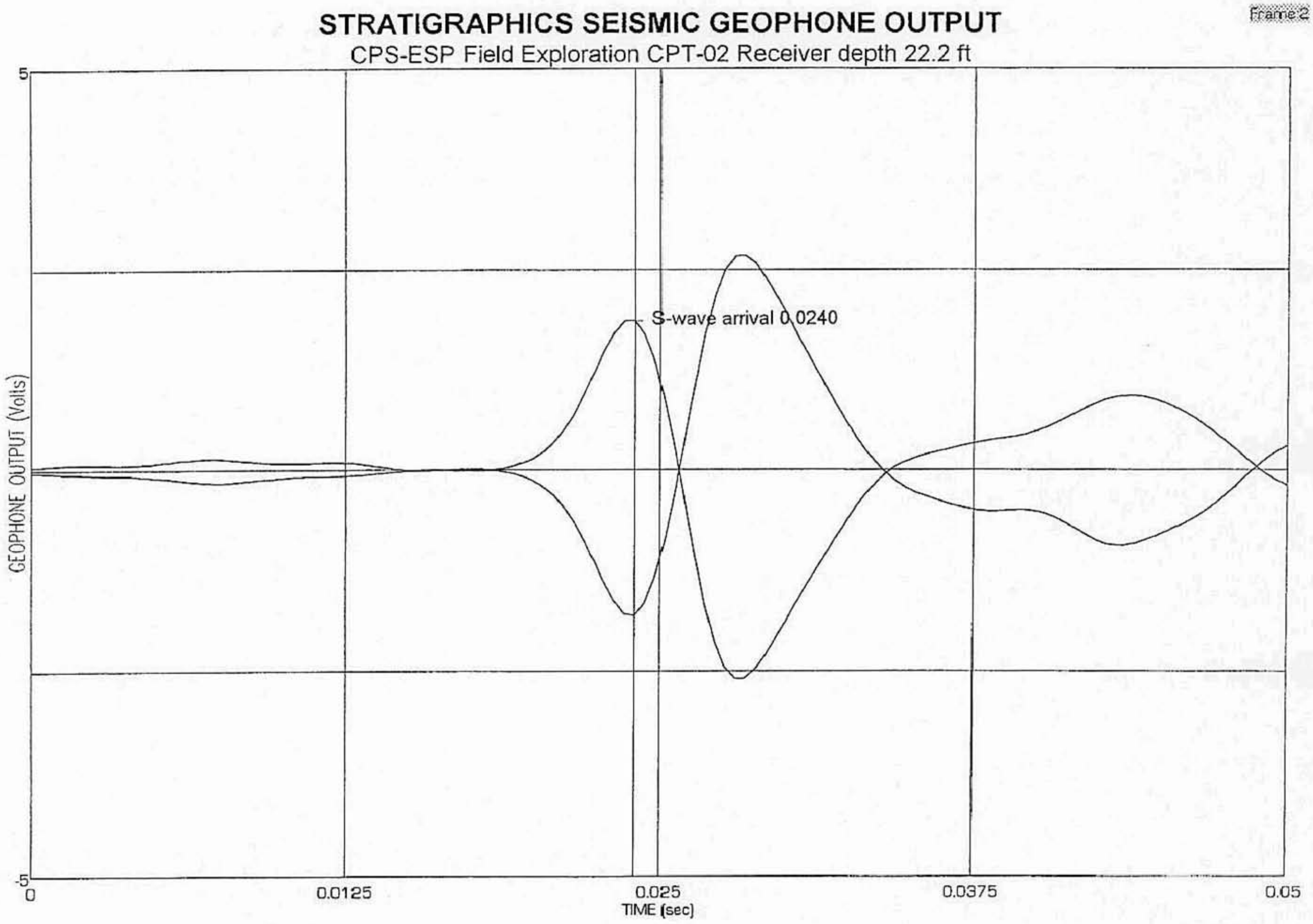


REV 2



STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT
CPS-ESP Field Exploration CPT-02 Receiver depth 18.9 ft
Frame:2
5
-5
S-wave arrival 0.0208
GEOPHONE OUTPUT (Volts)
0
0.0125
0.025
0.0375
0.05
TIME (sec)

REV 2



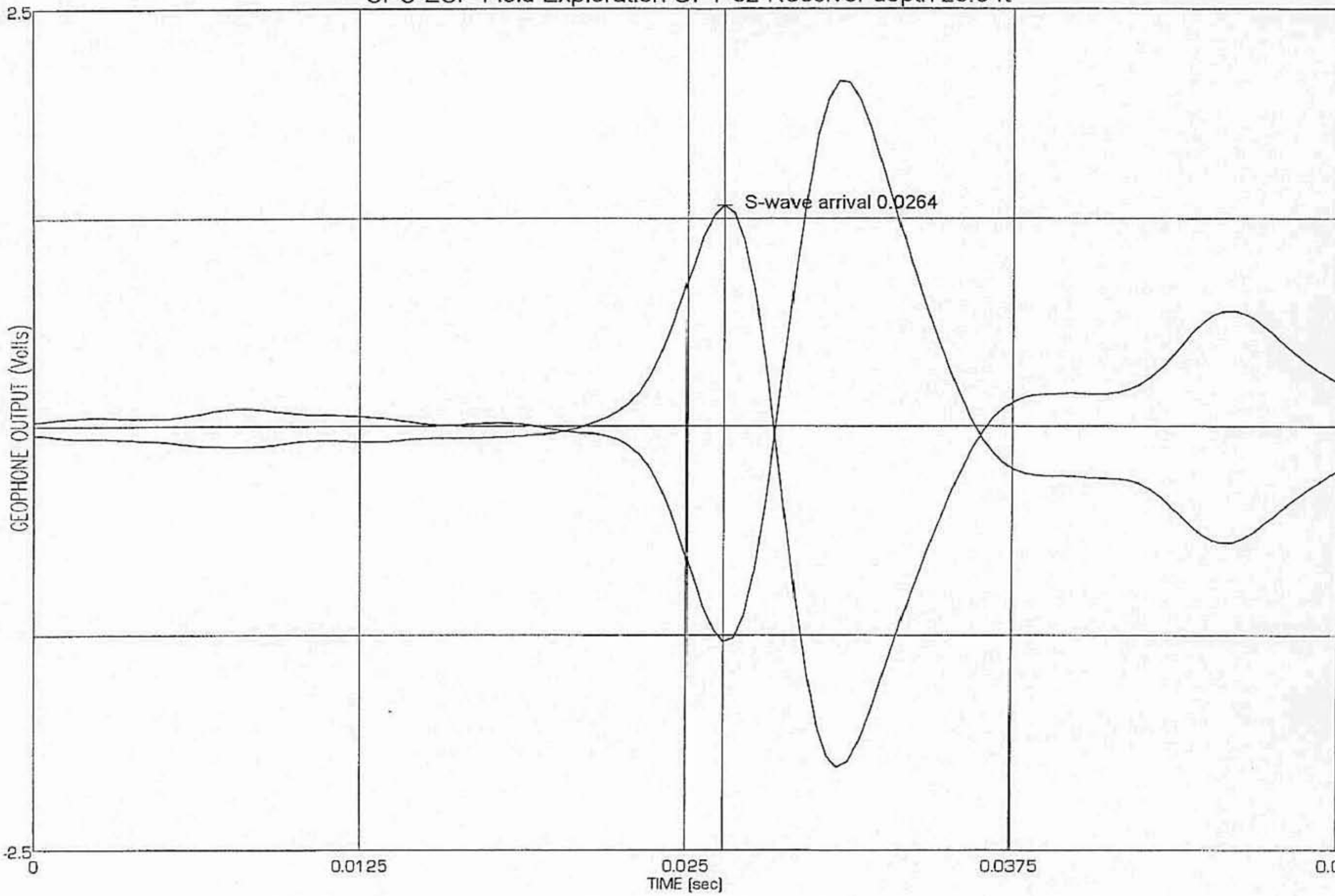
STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT
CPS-ESP Field Exploration CPT-02 Receiver depth 22.2 ft
Frame 2
S-wave arrival 0.0240
GEOPHONE OUTPUT (Volts)
5
-5
0
0.0125
0.025
0.0375
0.05
TIME (sec)

REV 2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

CPS-ESP Field Exploration CPT-02 Receiver depth 25.5 ft

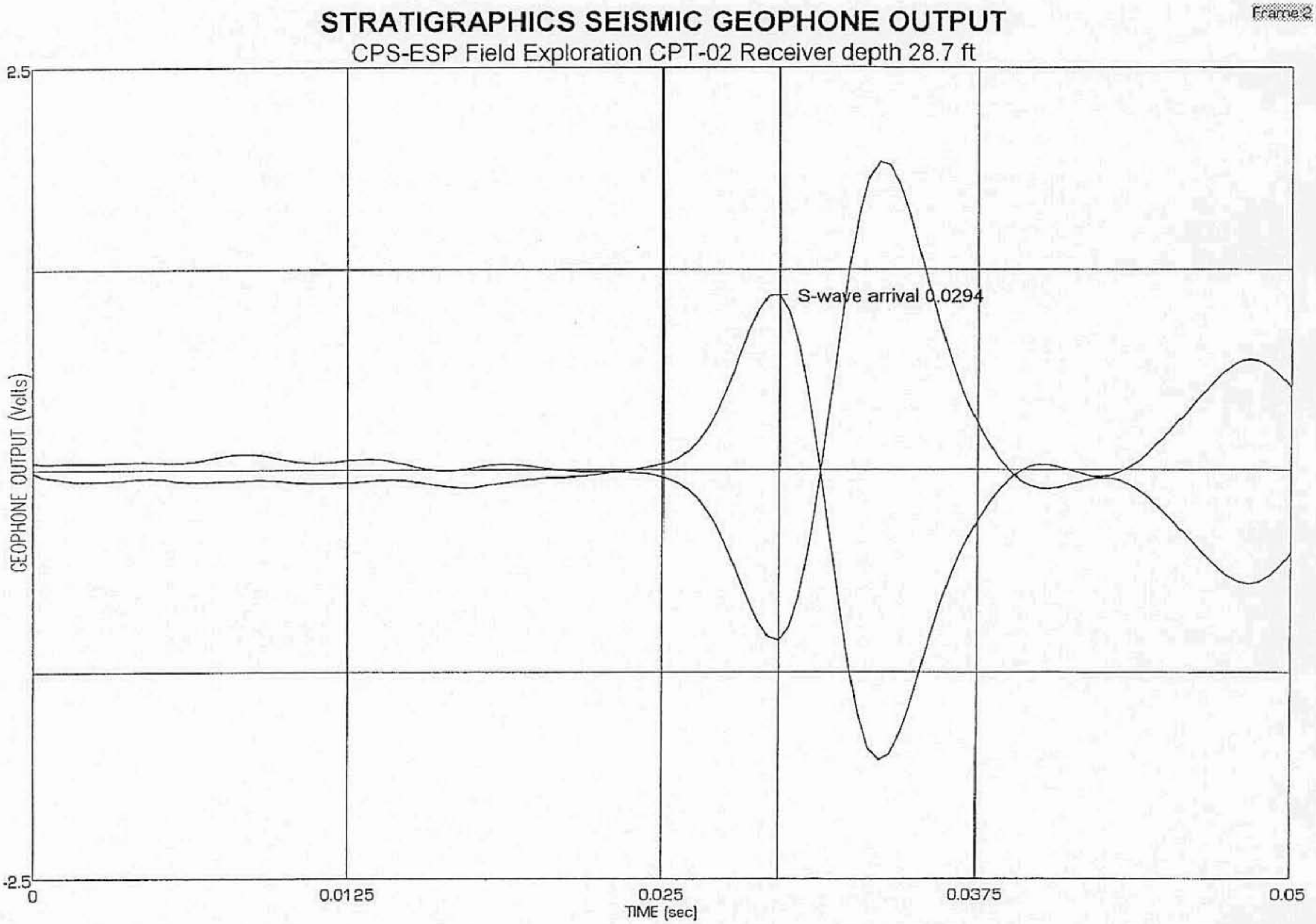
Frame 2



REV 2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

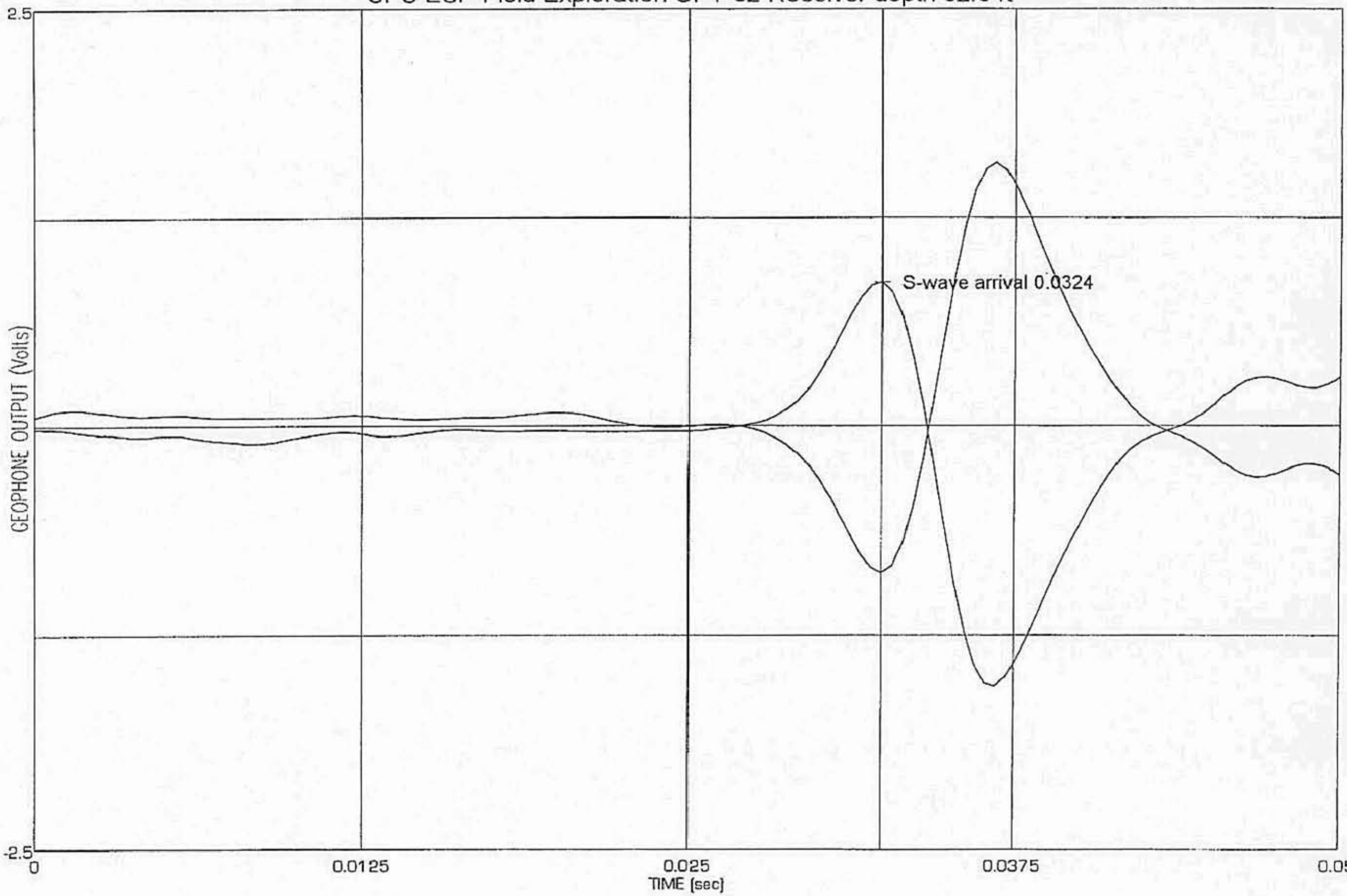
CPS-ESP Field Exploration CPT-02 Receiver depth 28.7 ft



REV 2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

CPS-ESP Field Exploration CPT-02 Receiver depth 32.0 ft

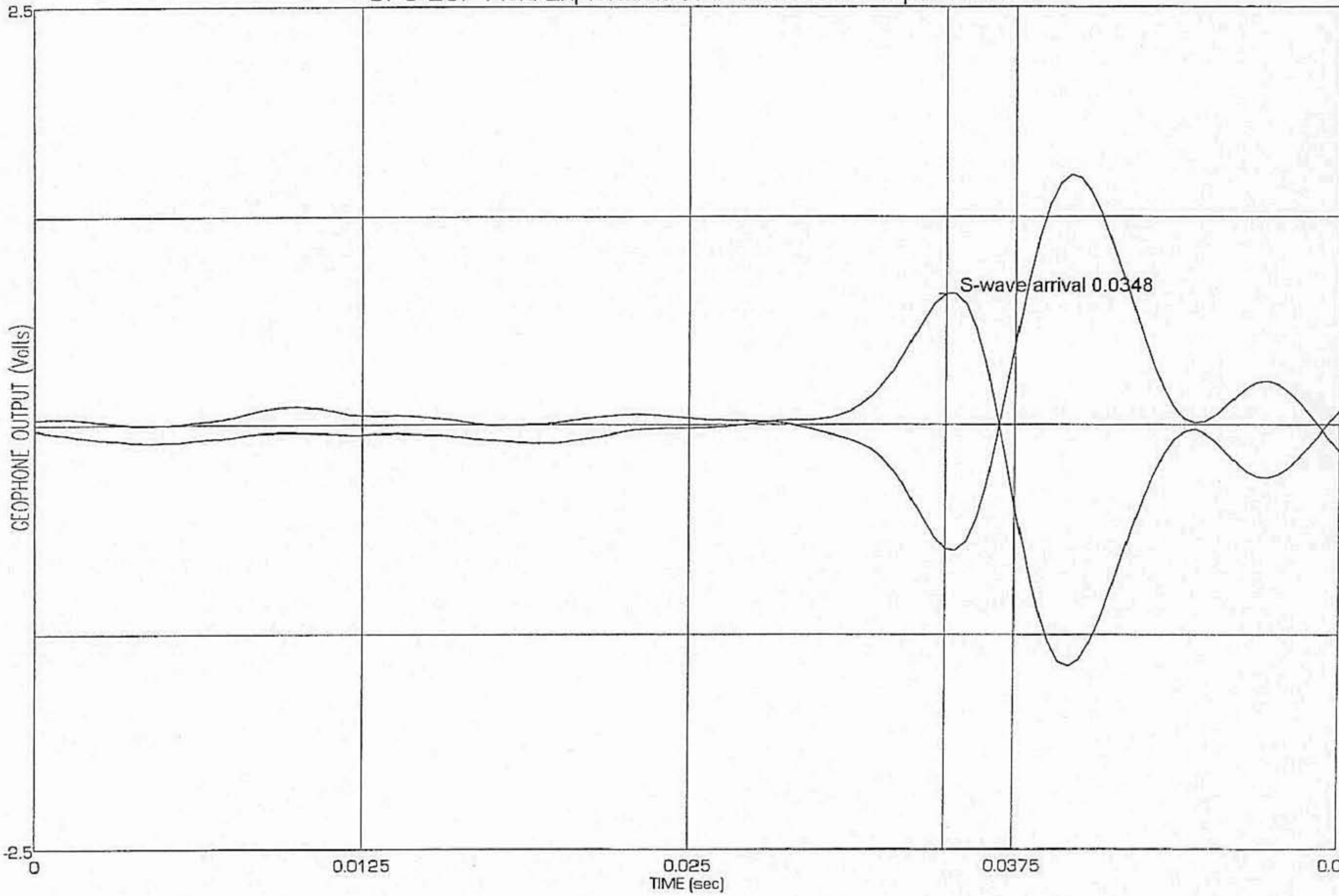


REV 2

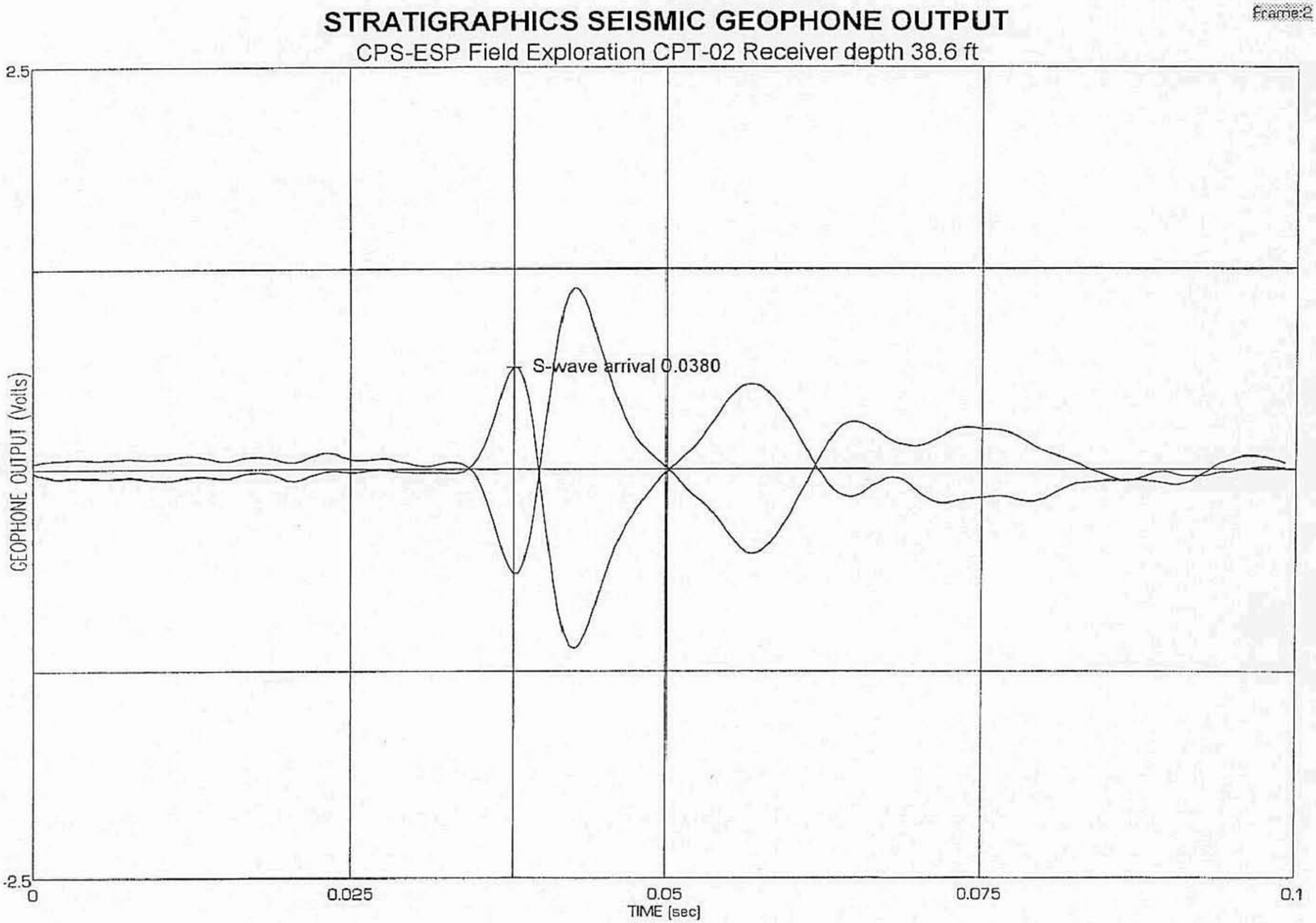
Frame 2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

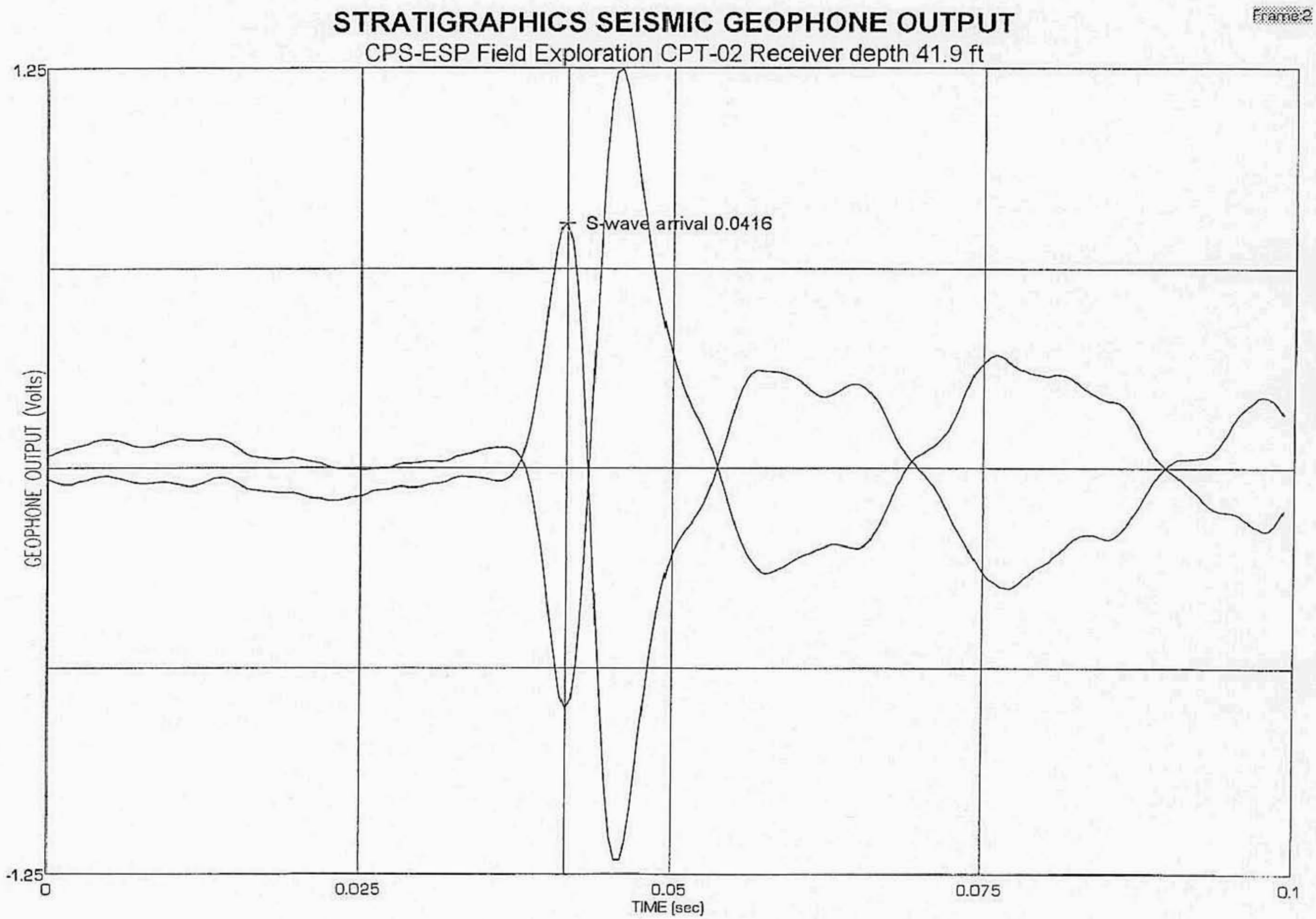
CPS-ESP Field Exploration CPT-02 Receiver depth 35.3 ft



REV 2

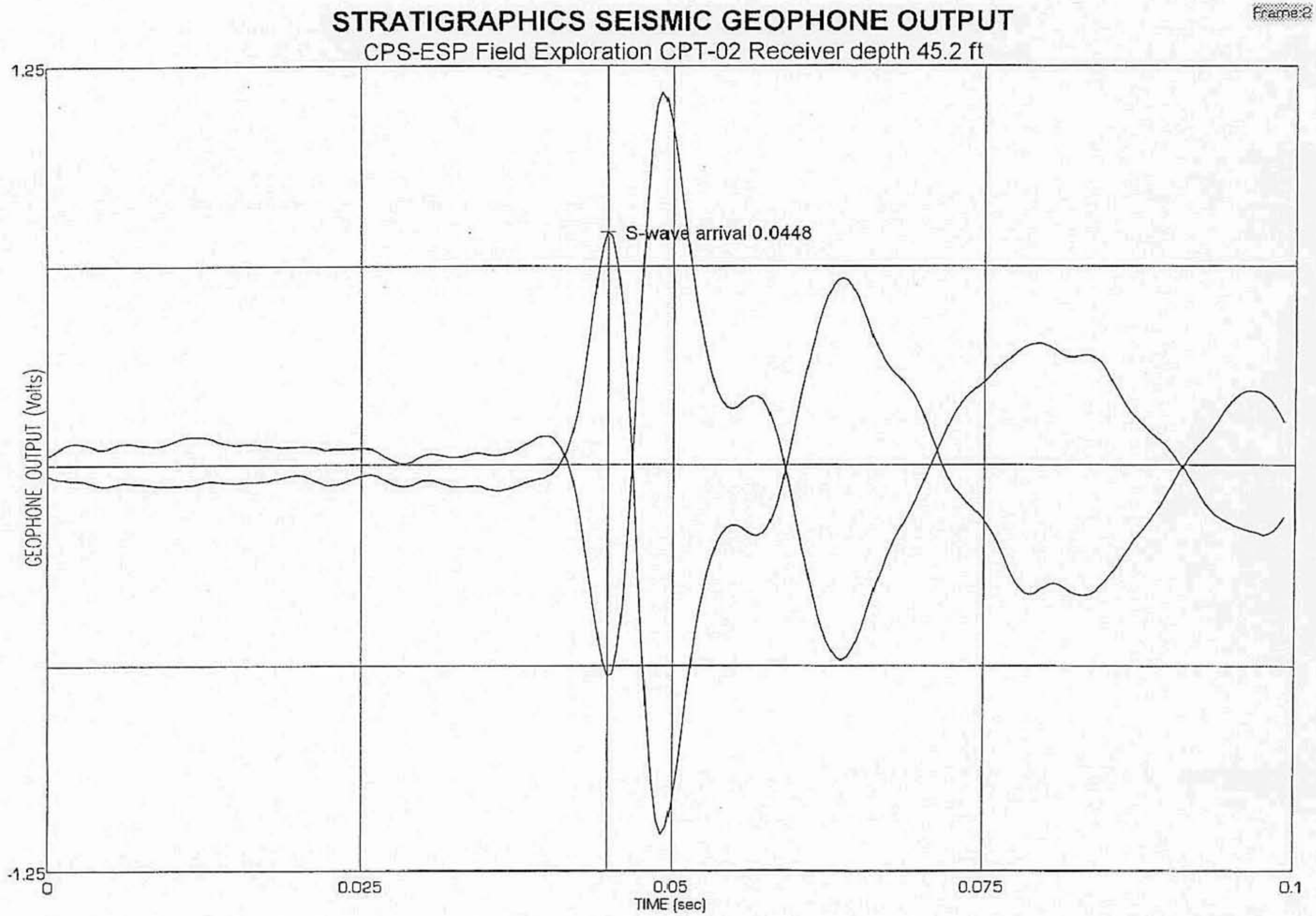

Frame:2
STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT
CPS-ESP Field Exploration CPT-02 Receiver depth 38.6 ft
2.5
-2.5
GEOPHONE OUTPUT (Volts)
S-wave arrival 0.0380
0
0.025
0.05
0.075
0.1
TIME [sec]

REV 2



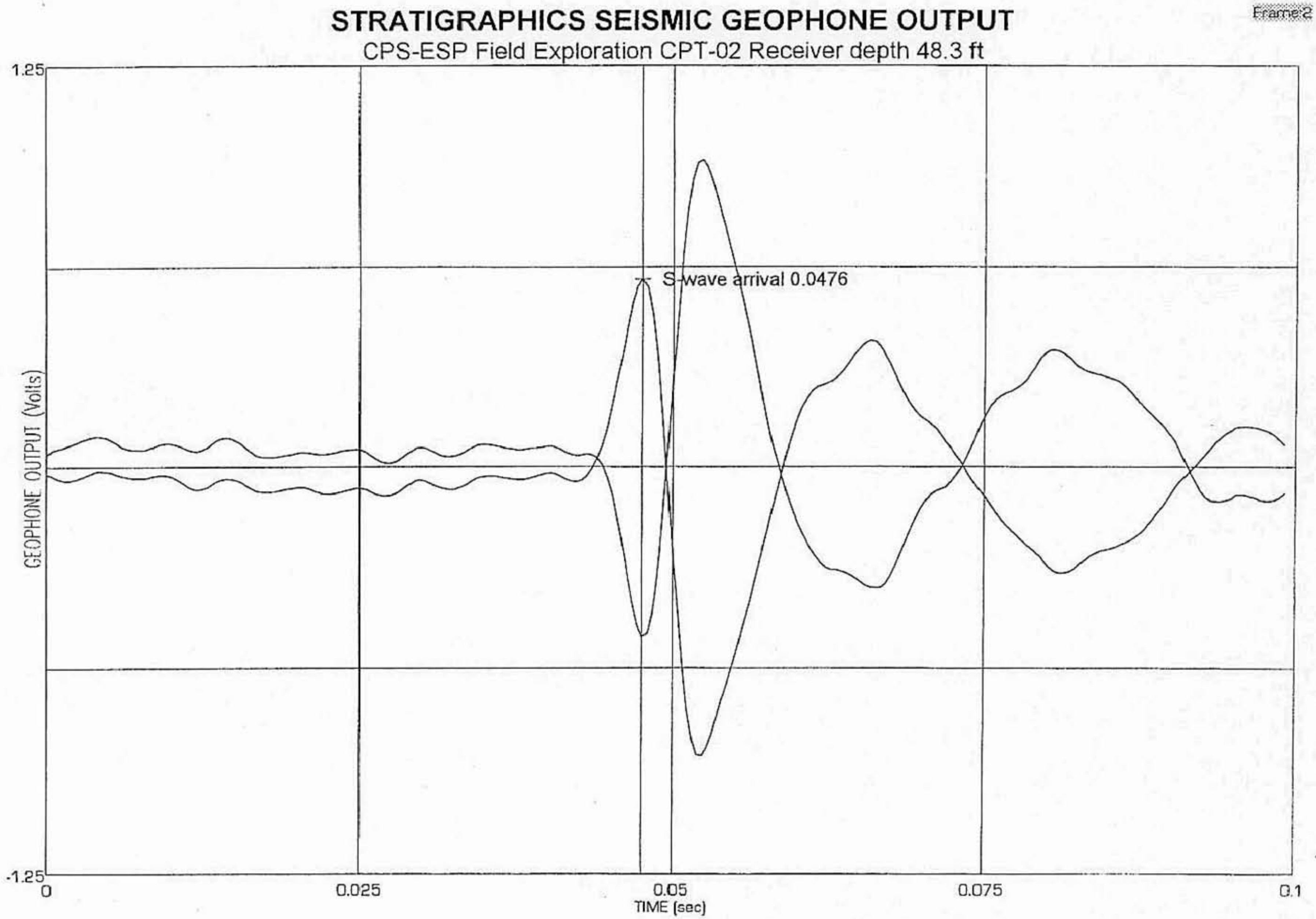
STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT
Frame2
CPS-ESP Field Exploration CPT-02 Receiver depth 41.9 ft
1.25
-1.25
GEOPHONE OUTPUT (Volts)
S-wave arrival 0.0416
0
0.025
0.05
0.075
0.1
TIME (sec)

REV 2

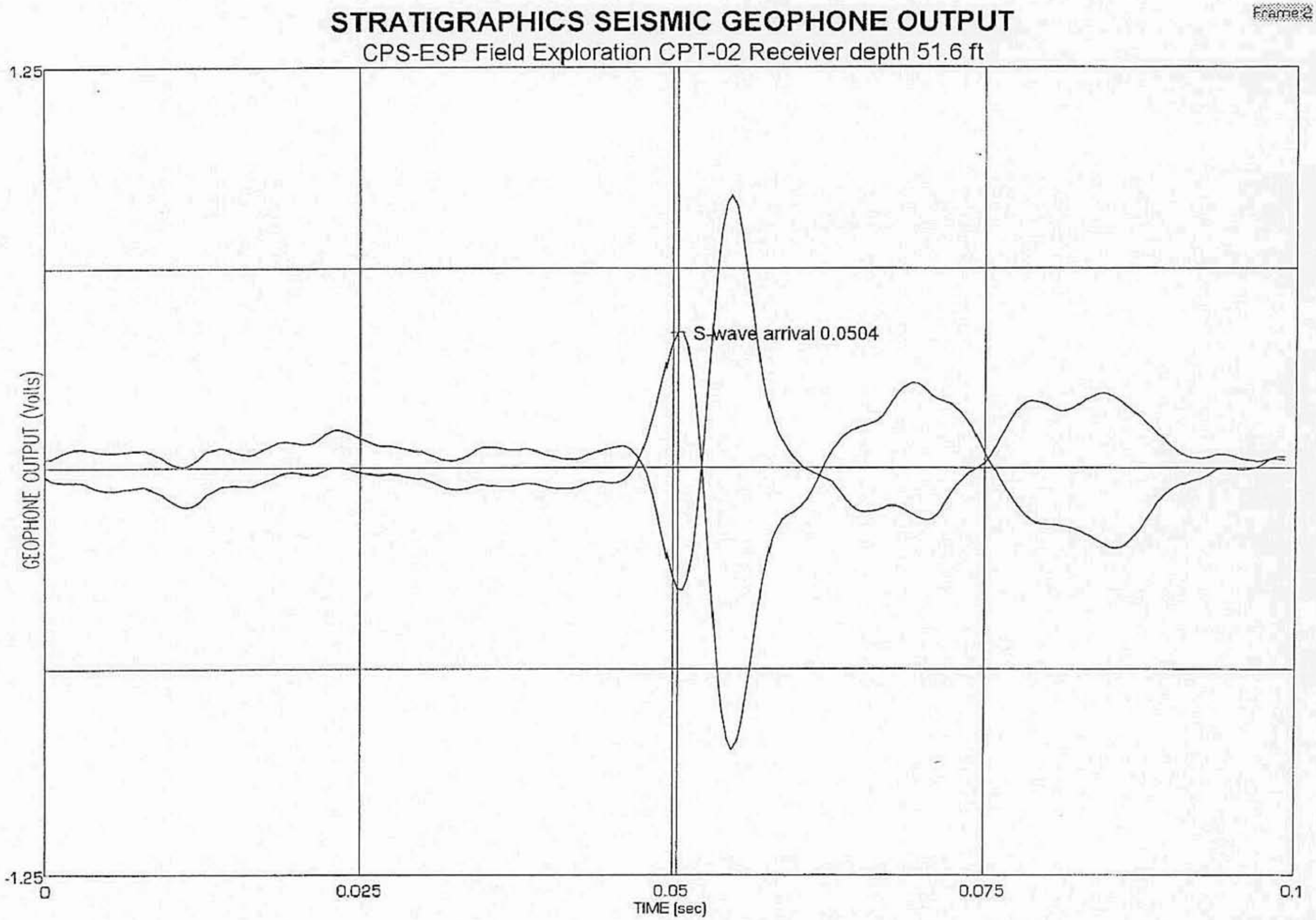


Frame:2
STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT
CPS-ESP Field Exploration CPT-02 Receiver depth 45.2 ft
1.25
-1.25
GEOPHONE OUTPUT (Volts)
S-wave arrival 0.0448
0
0.025
0.05
0.075
0.1
TIME (sec)

REV 2


STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT
CPS-ESP Field Exploration CPT-02 Receiver depth 48.3 ft
Frame:2
1.25
-1.25
GEOPHONE OUTPUT (Volts)
S-wave arrival 0.0476
0
0.025
0.05
0.075
0.1
TIME (sec)

REV 2

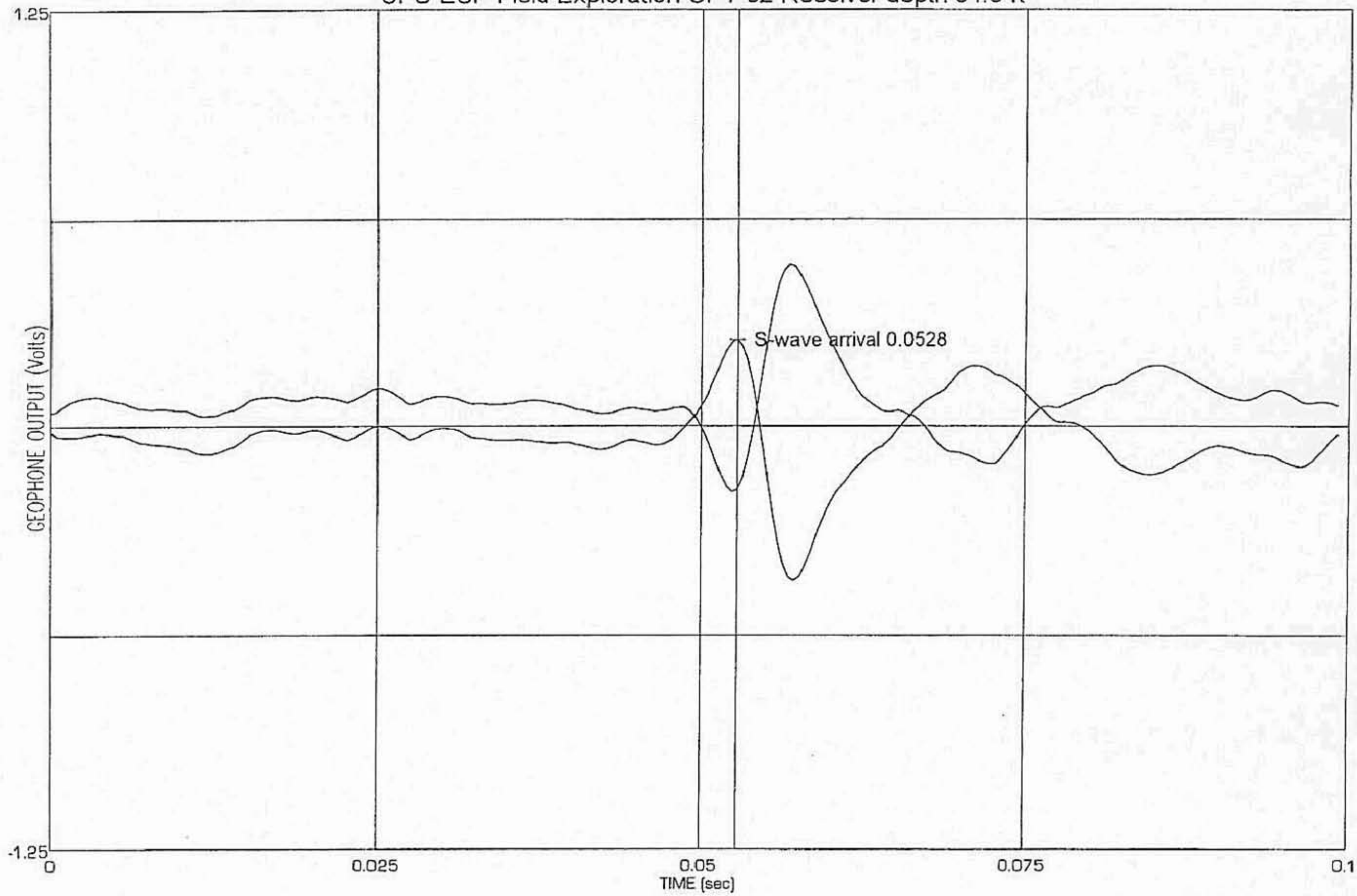

Frame:2
STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT
CPS-ESP Field Exploration CPT-02 Receiver depth 51.6 ft
1.25
-1.25
GEOPHONE OUTPUT (Volts)
S-wave arrival 0.0504
0
0.025
0.05
0.075
0.1
TIME (sec)

REV 2

Frame 2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

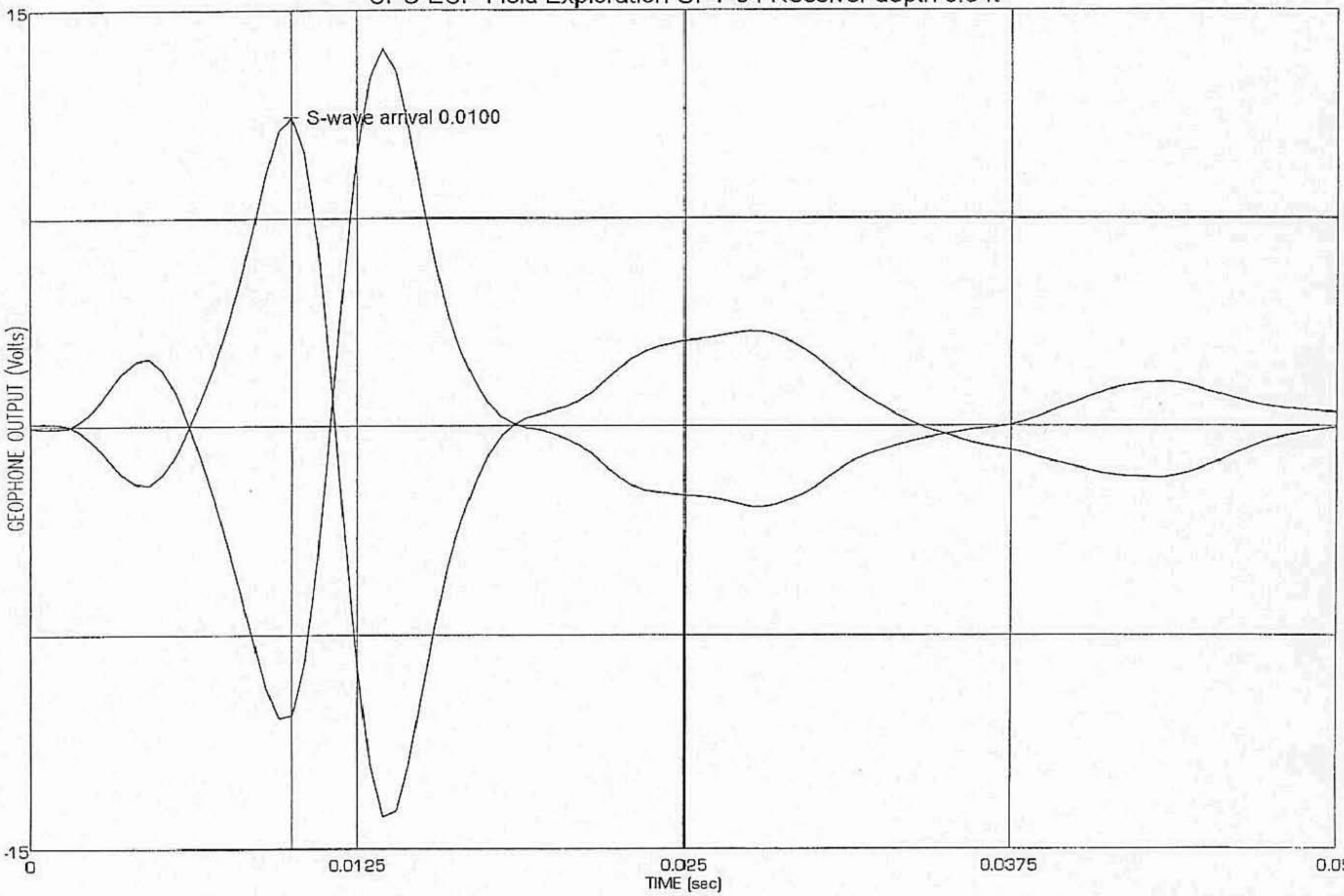
CPS-ESP Field Exploration CPT-02 Receiver depth 54.5 ft



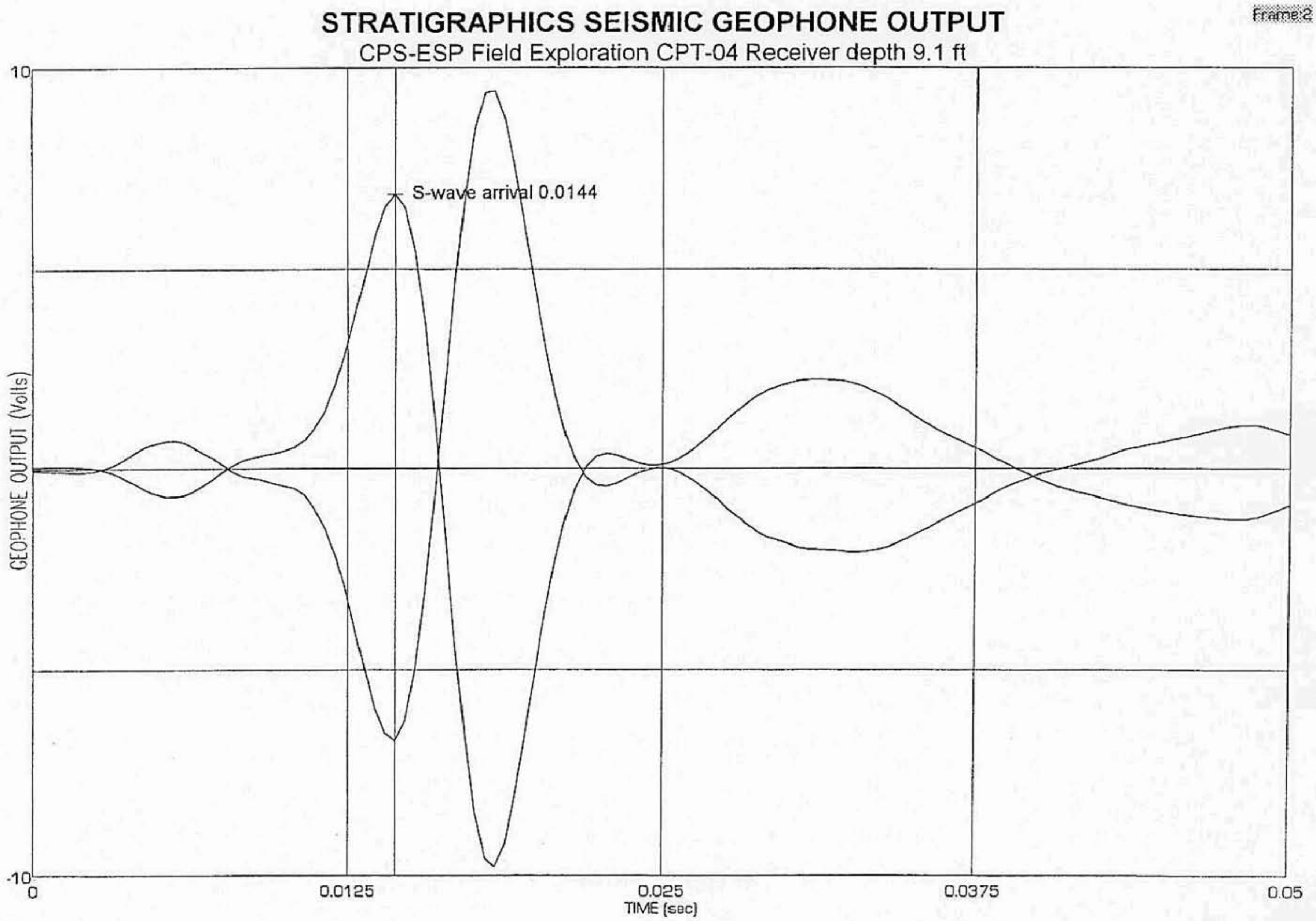
REV 2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

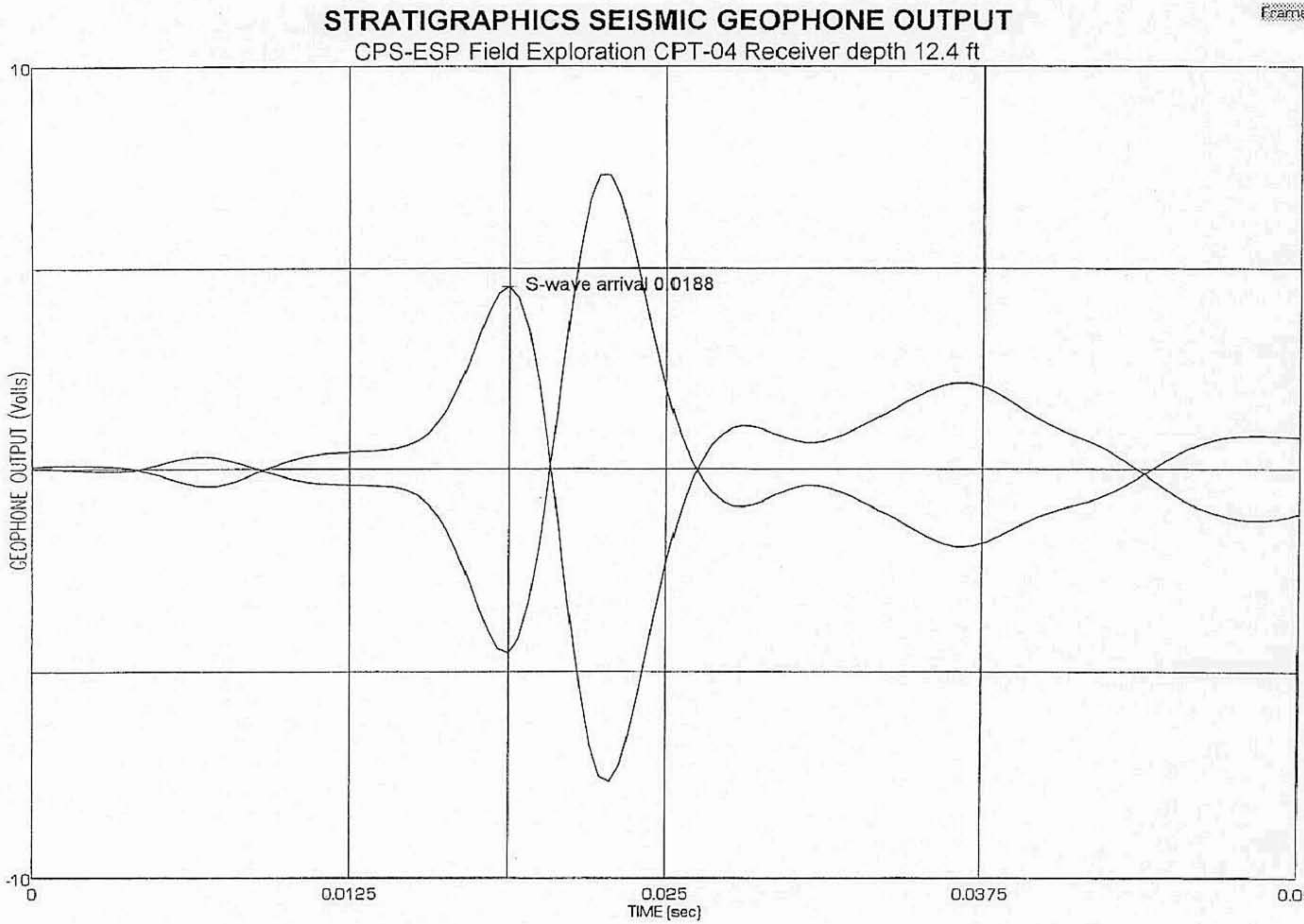
CPS-ESP Field Exploration CPT-04 Receiver depth 5.8 ft



REV 2


STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT
CPS-ESP Field Exploration CPT-04 Receiver depth 9.1 ft
Frame:2
S-wave arrival 0.0144
GEOPHONE OUTPUT (Volts)
10
-10
0
0.0125
0.025
0.0375
0.05
TIME (sec)

REV 2

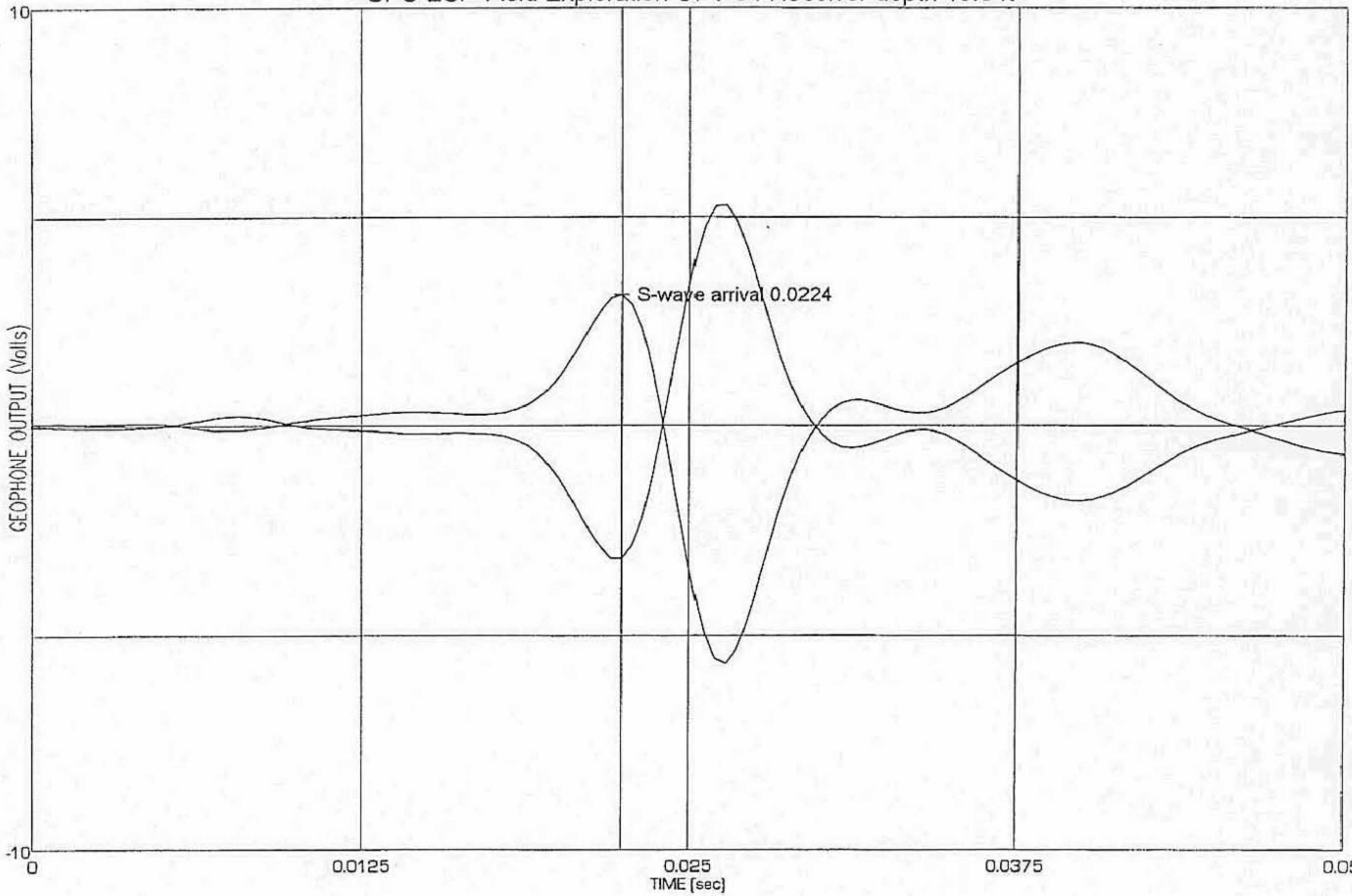

Frame:2
STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT
CPS-ESP Field Exploration CPT-04 Receiver depth 12.4 ft
10
-10
GEOPHONE OUTPUT (Volts)
S-wave arrival 0.0188
0
0.0125
0.025
0.0375
0.05
TIME (sec)

REV 2

Frame:2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

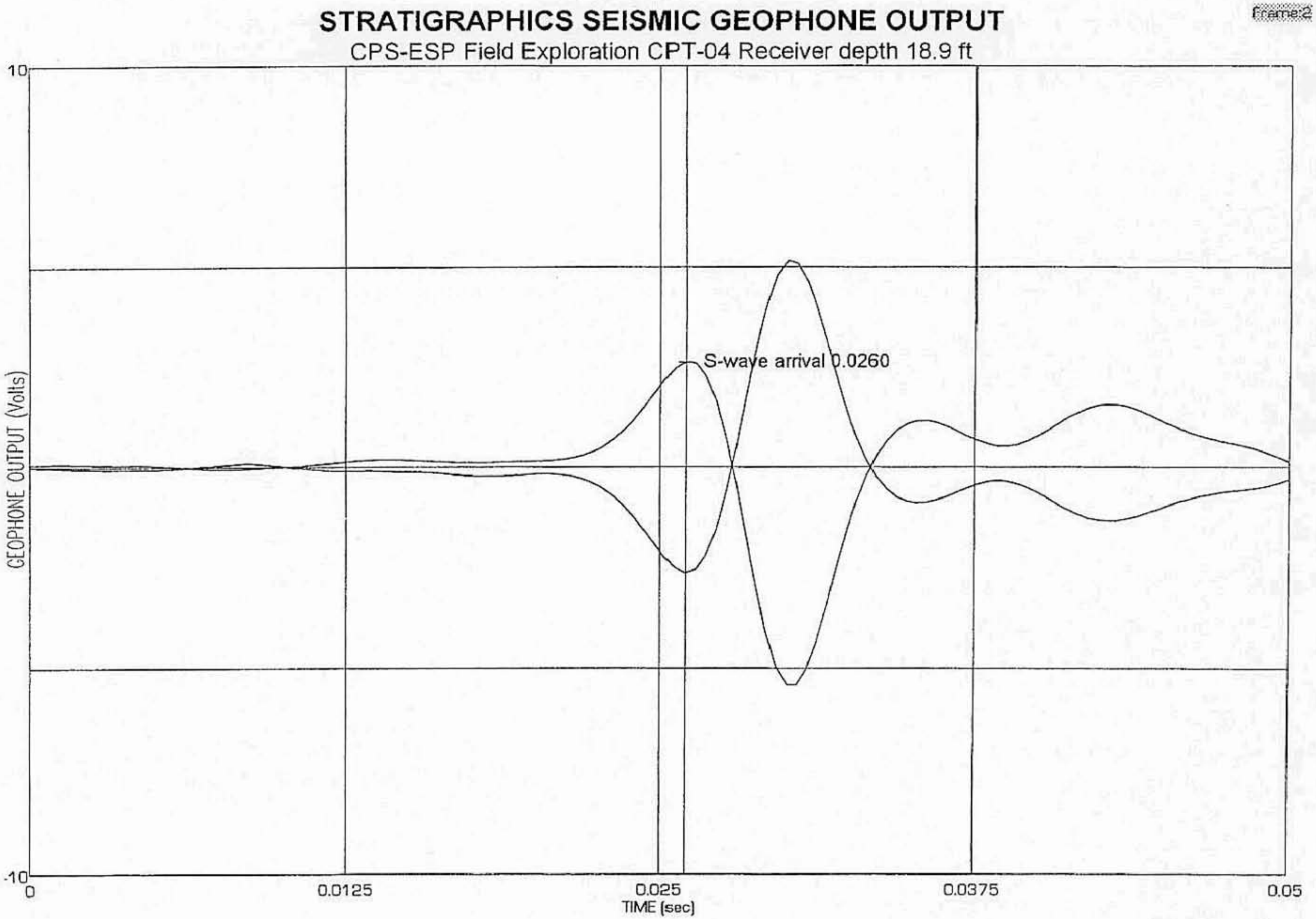
CPS-ESP Field Exploration CPT-04 Receiver depth 15.6 ft



REV 2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

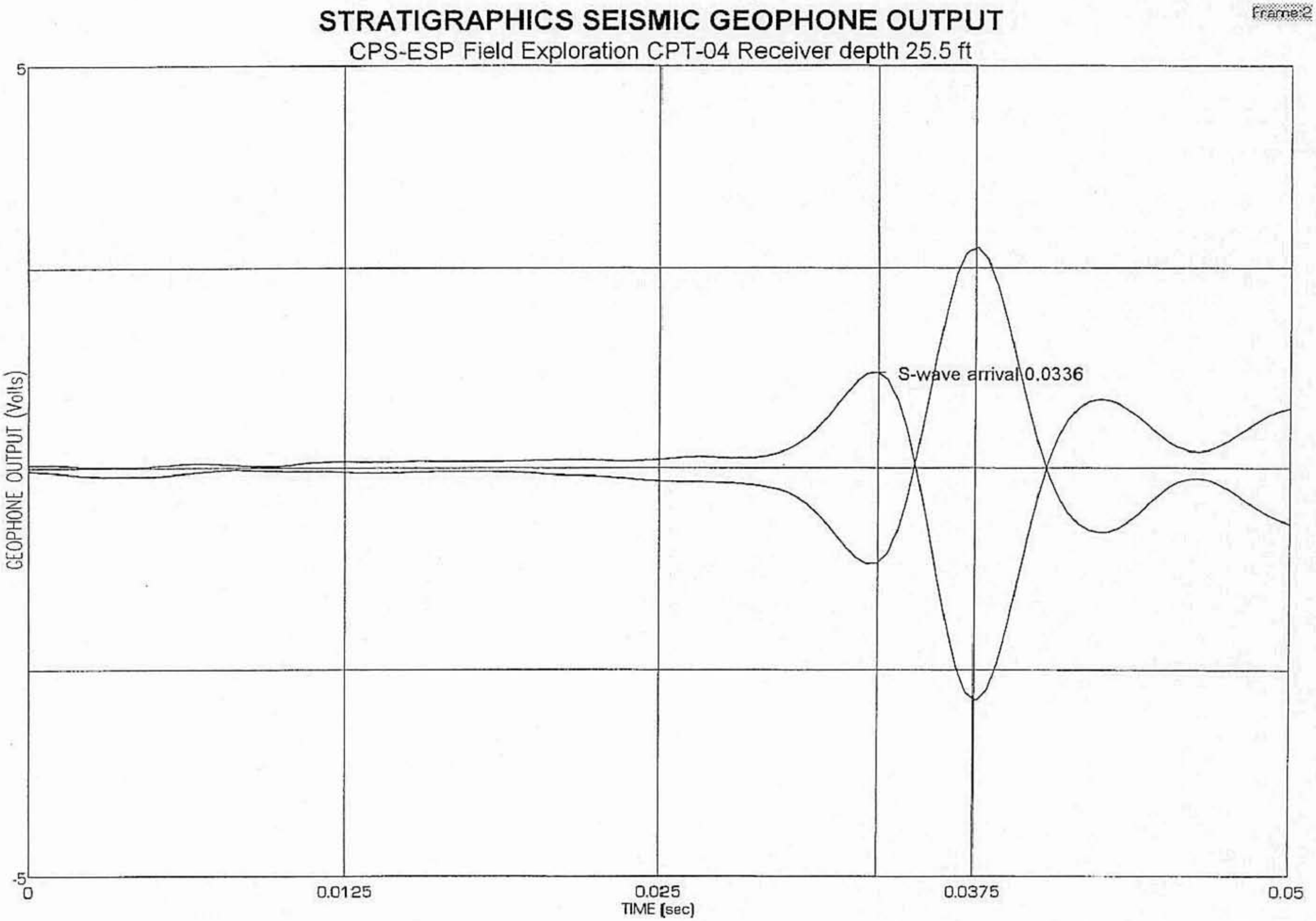
CPS-ESP Field Exploration CPT-04 Receiver depth 18.9 ft



REV 2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

CPS-ESP Field Exploration CPT-04 Receiver depth 25.5 ft

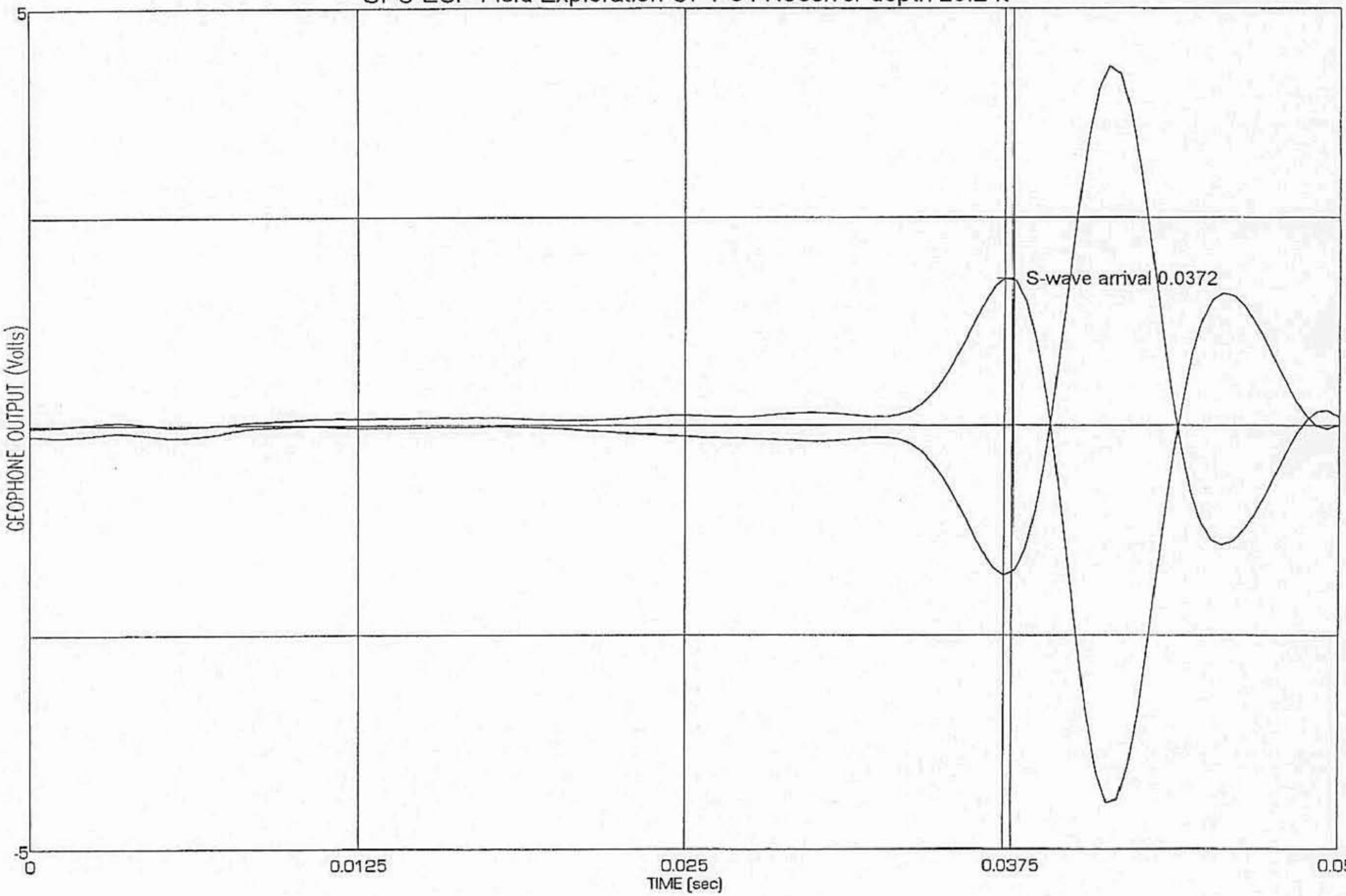


REV 2

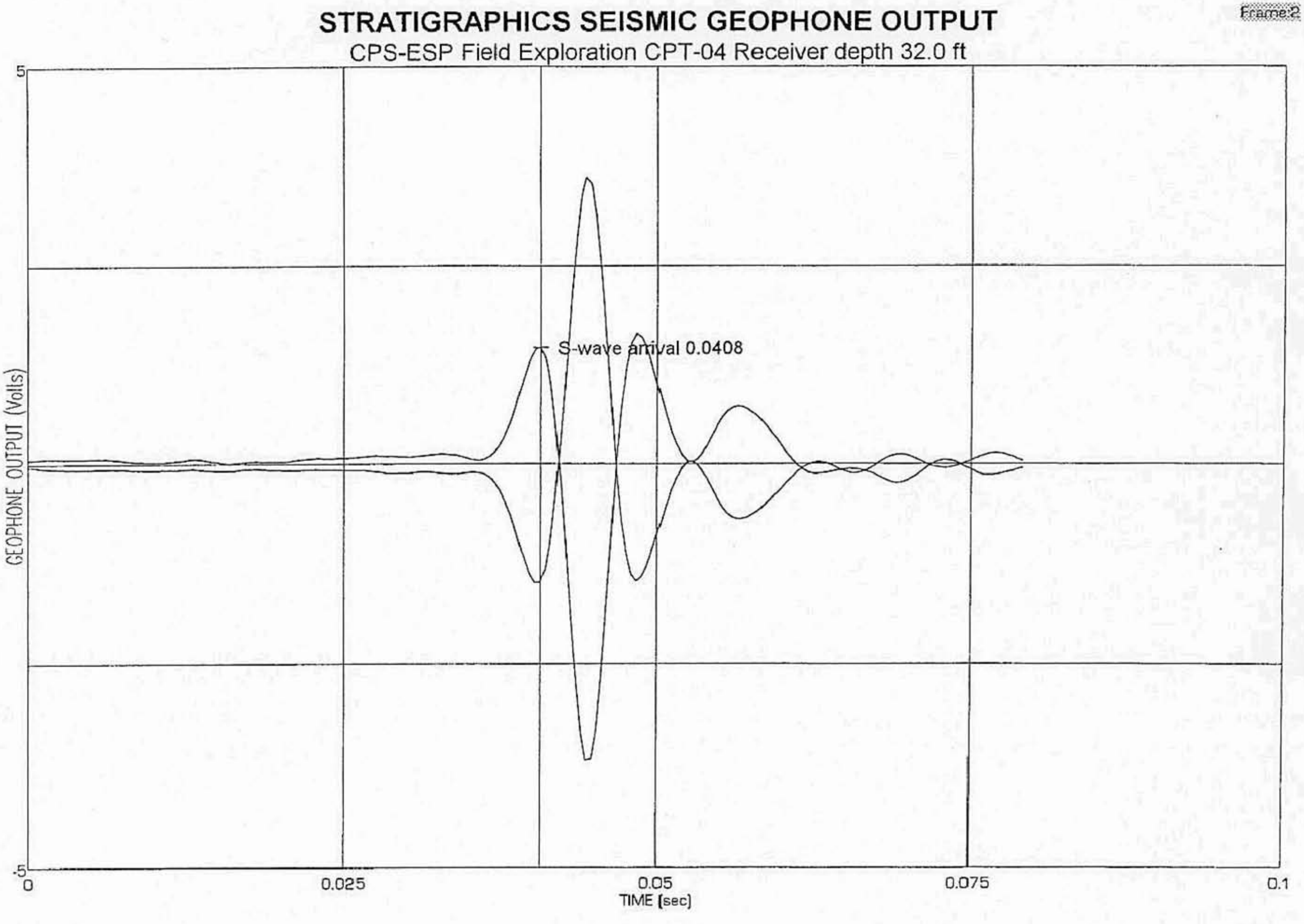
Frame:2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

CPS-ESP Field Exploration CPT-04 Receiver depth 29.2 ft



REV 2

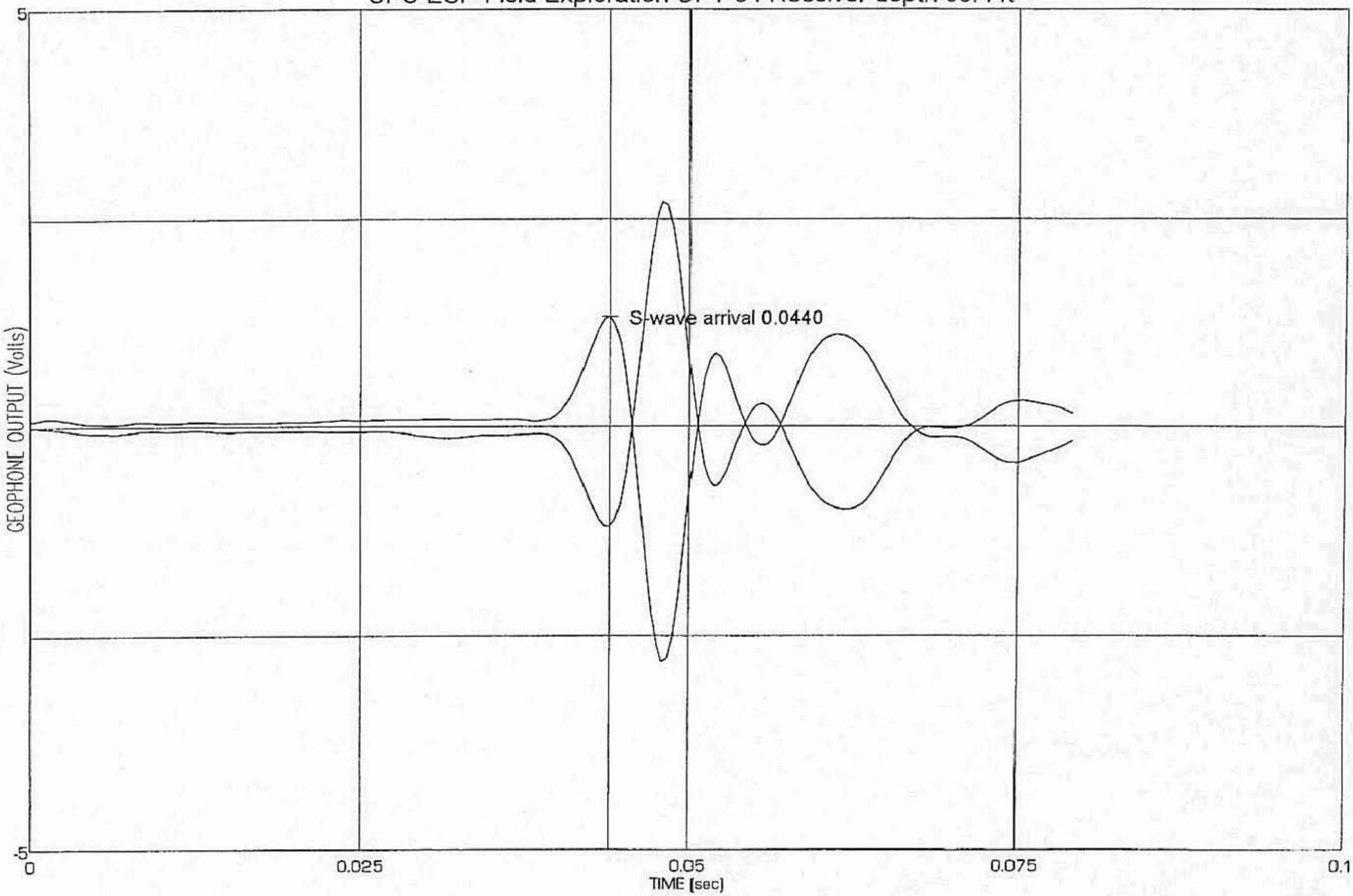

Frame:2
STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT
CPS-ESP Field Exploration CPT-04 Receiver depth 32.0 ft
S-wave arrival 0.0408
GEOPHONE OUTPUT (Volts)
5
-5
0
0.025
0.05
0.075
0.1
TIME (sec)

REV 2

Frame:2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

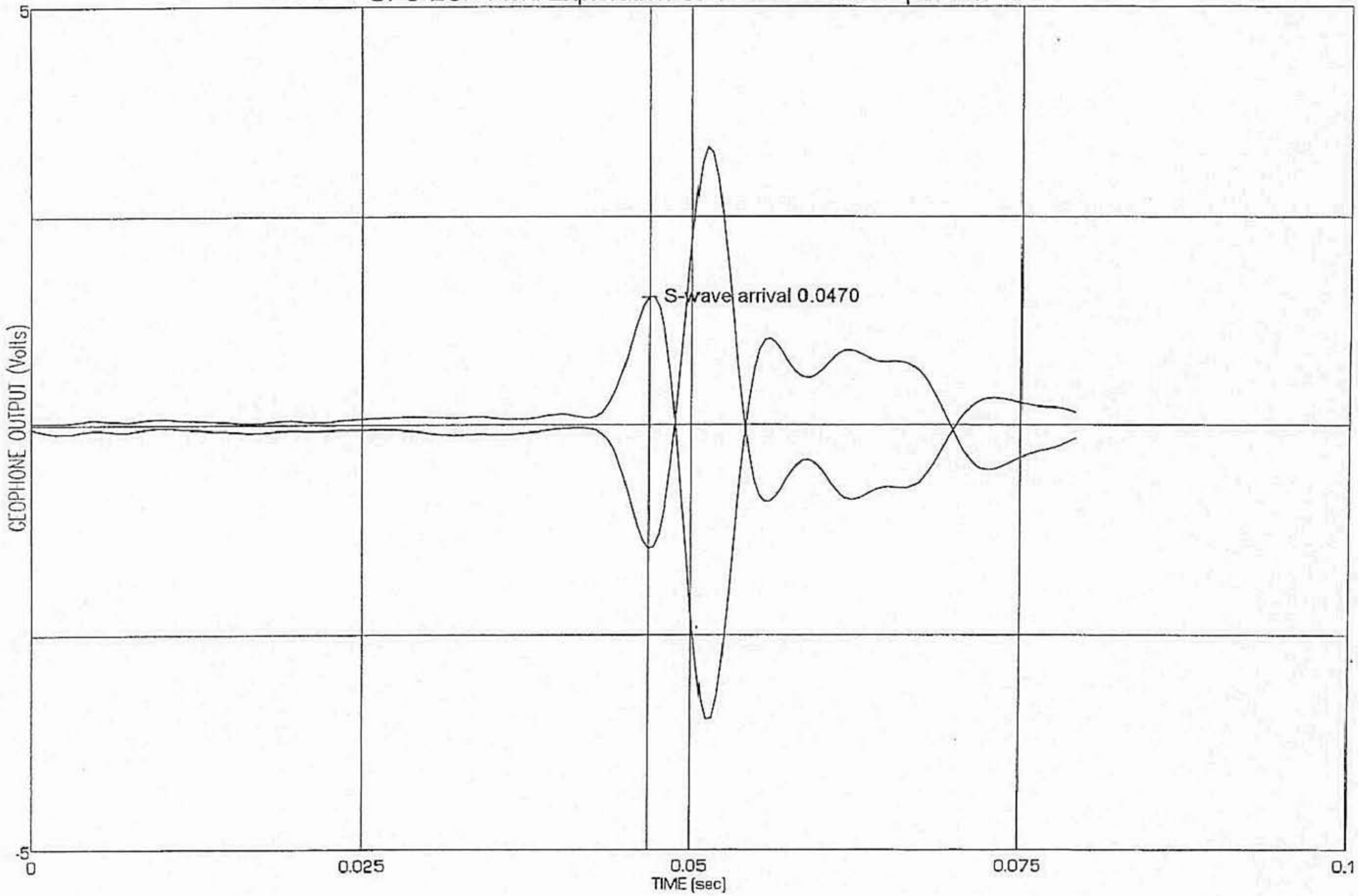
CPS-ESP Field Exploration CPT-04 Receiver depth 35.4 ft



REV 2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

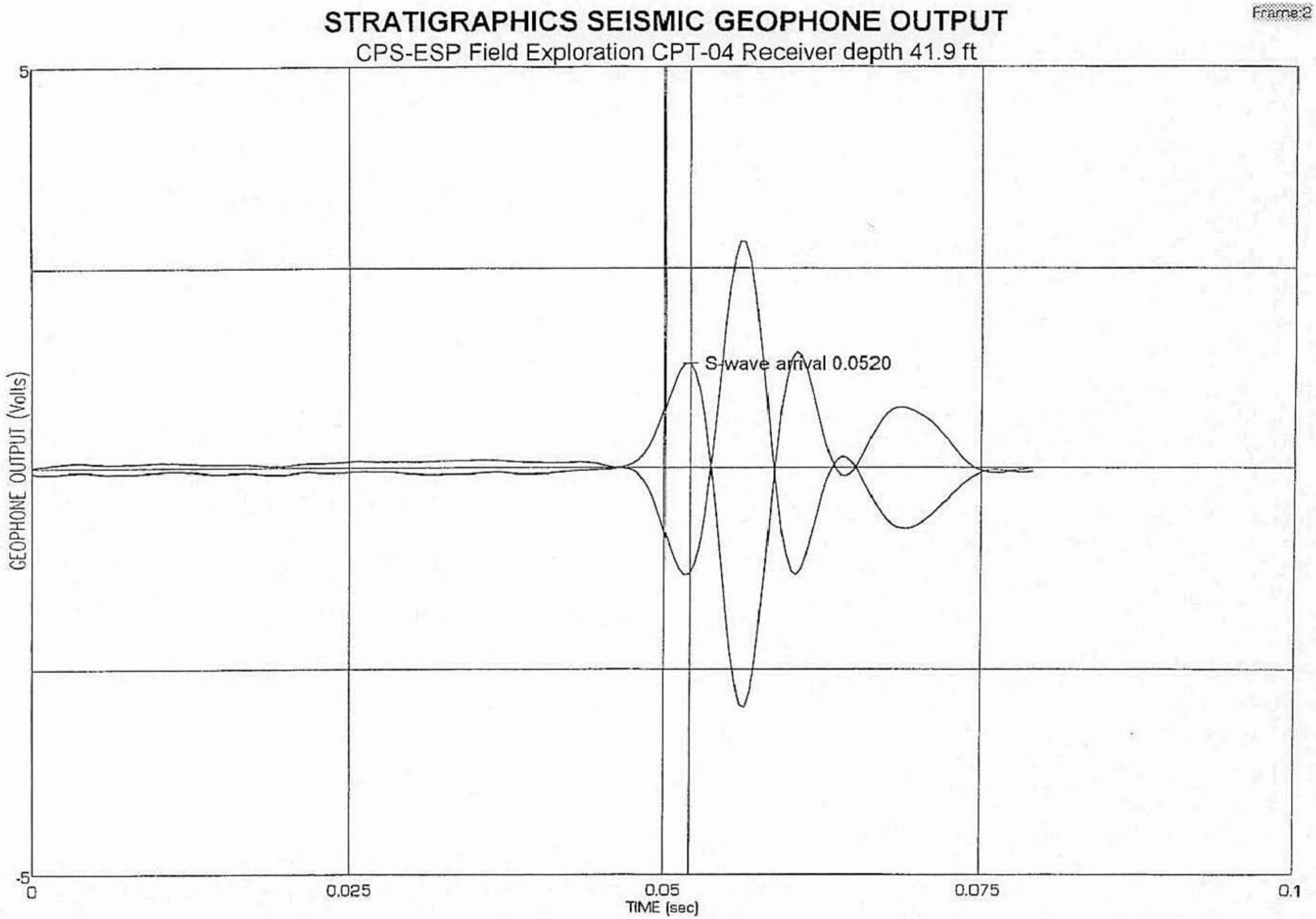
CPS-ESP Field Exploration CPT-04 Receiver depth 38.7 ft



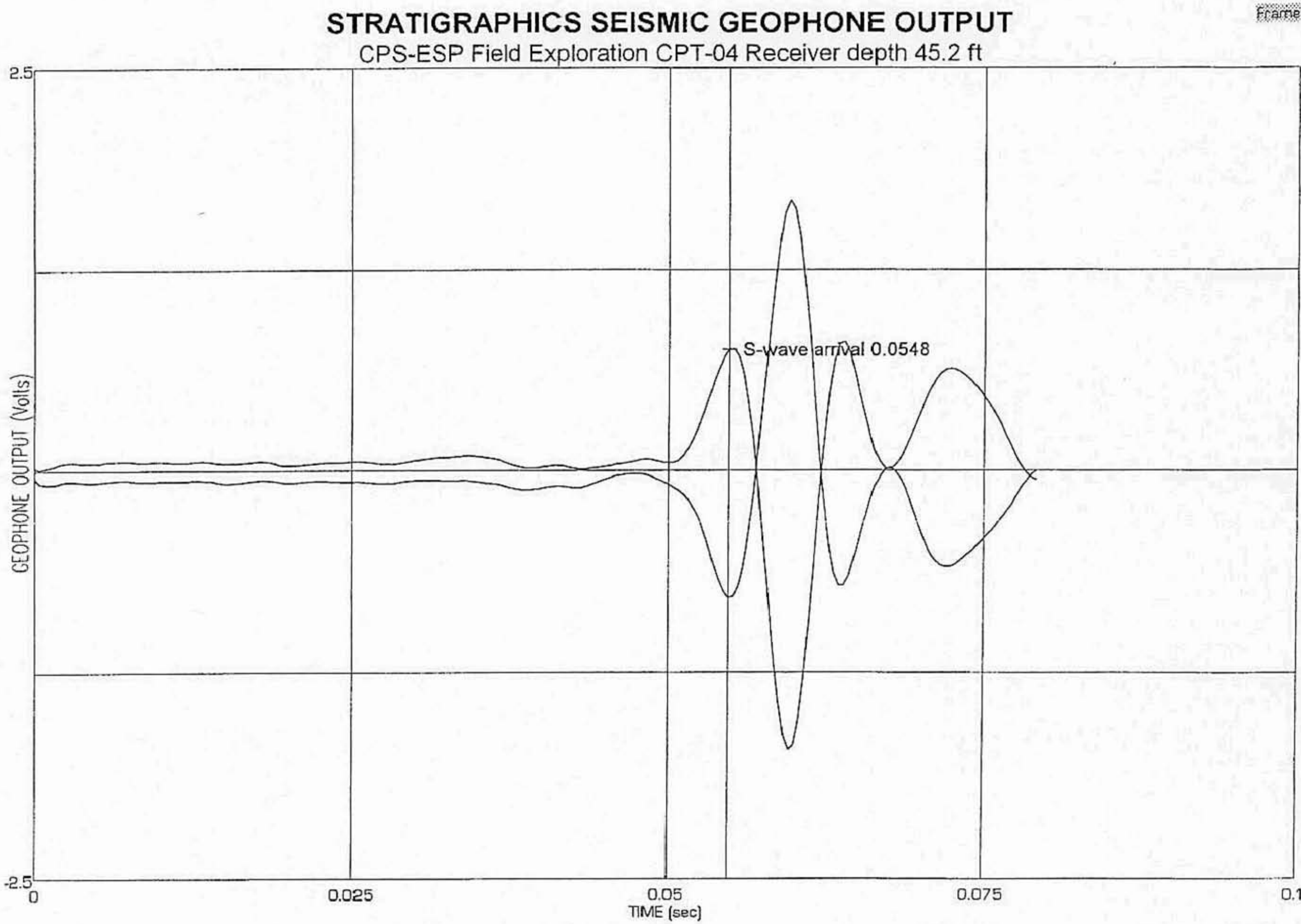
REV 2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

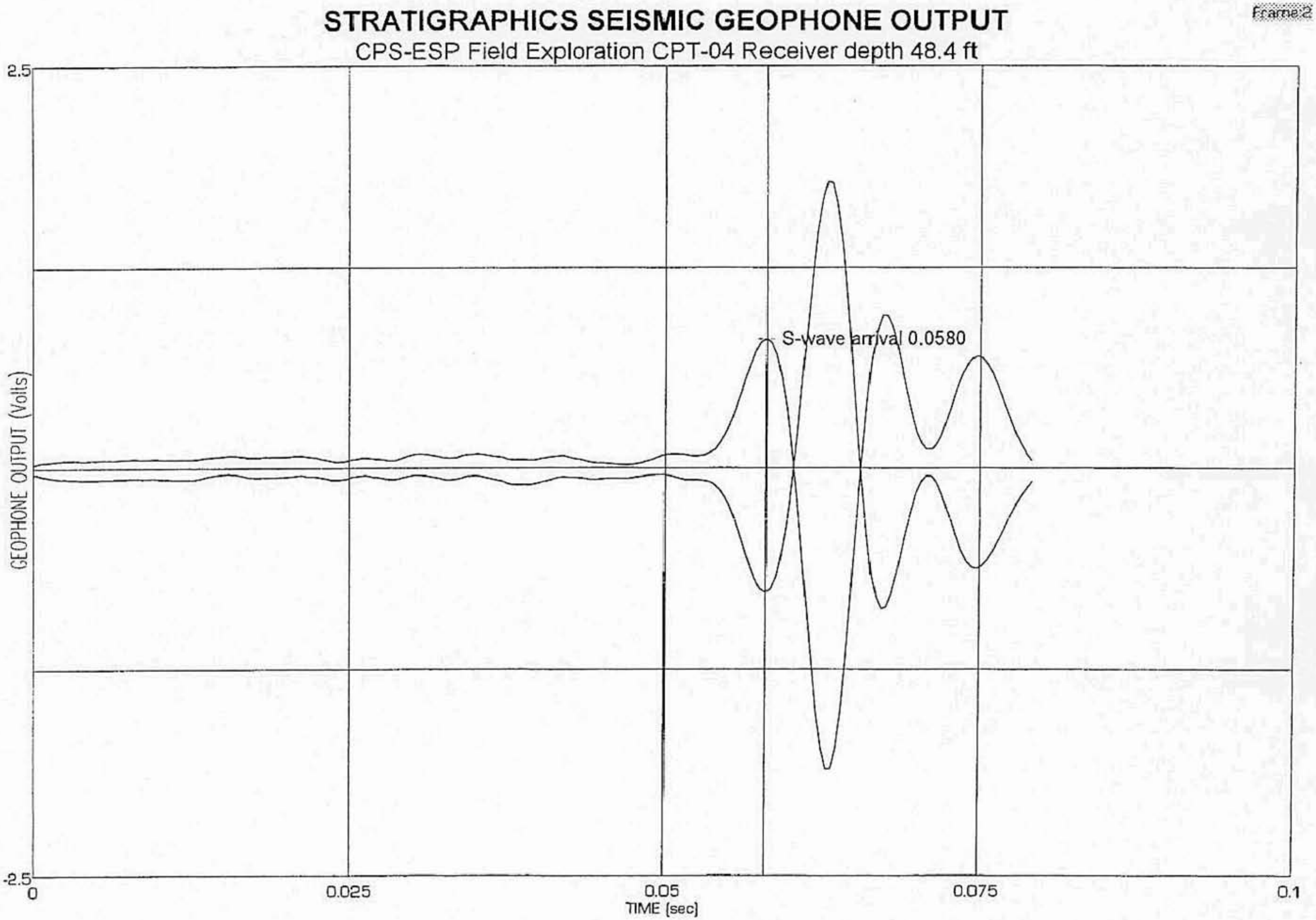
CPS-ESP Field Exploration CPT-04 Receiver depth 41.9 ft



REV 2


Frame:2
STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT
CPS-ESP Field Exploration CPT-04 Receiver depth 45.2 ft
2.5
-2.5
GEOPHONE OUTPUT (Volts)
S-wave arrival 0.0548
0
0.025
0.05
0.075
0.1
TIME (sec)

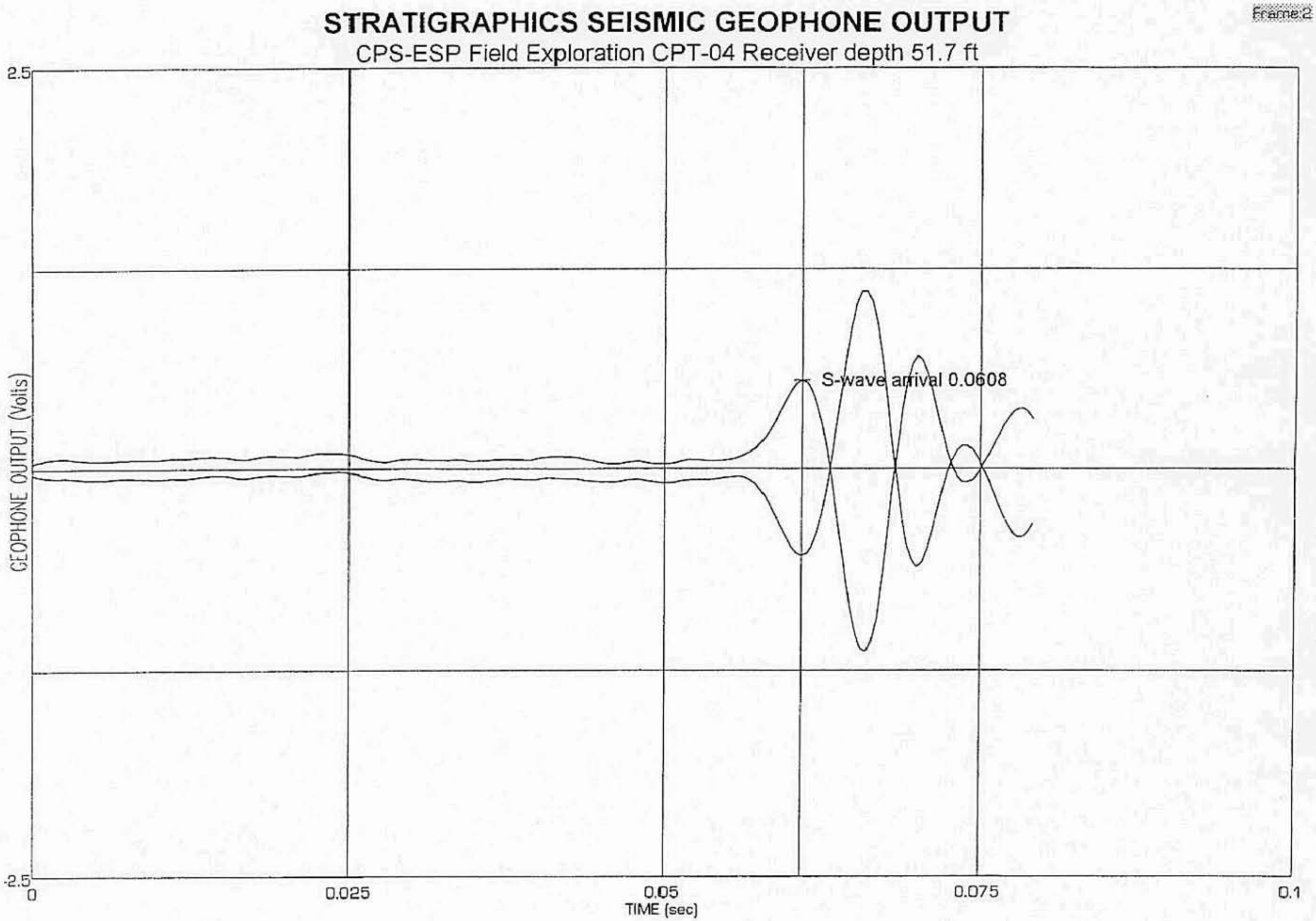
REV 2


Frame:2
STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT
CPS-ESP Field Exploration CPT-04 Receiver depth 48.4 ft
2.5
-2.5
GEOPHONE OUTPUT (Volts)
S-wave arrival 0.0580
0
0.025
0.05
0.075
0.1
TIME (sec)

REV 2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

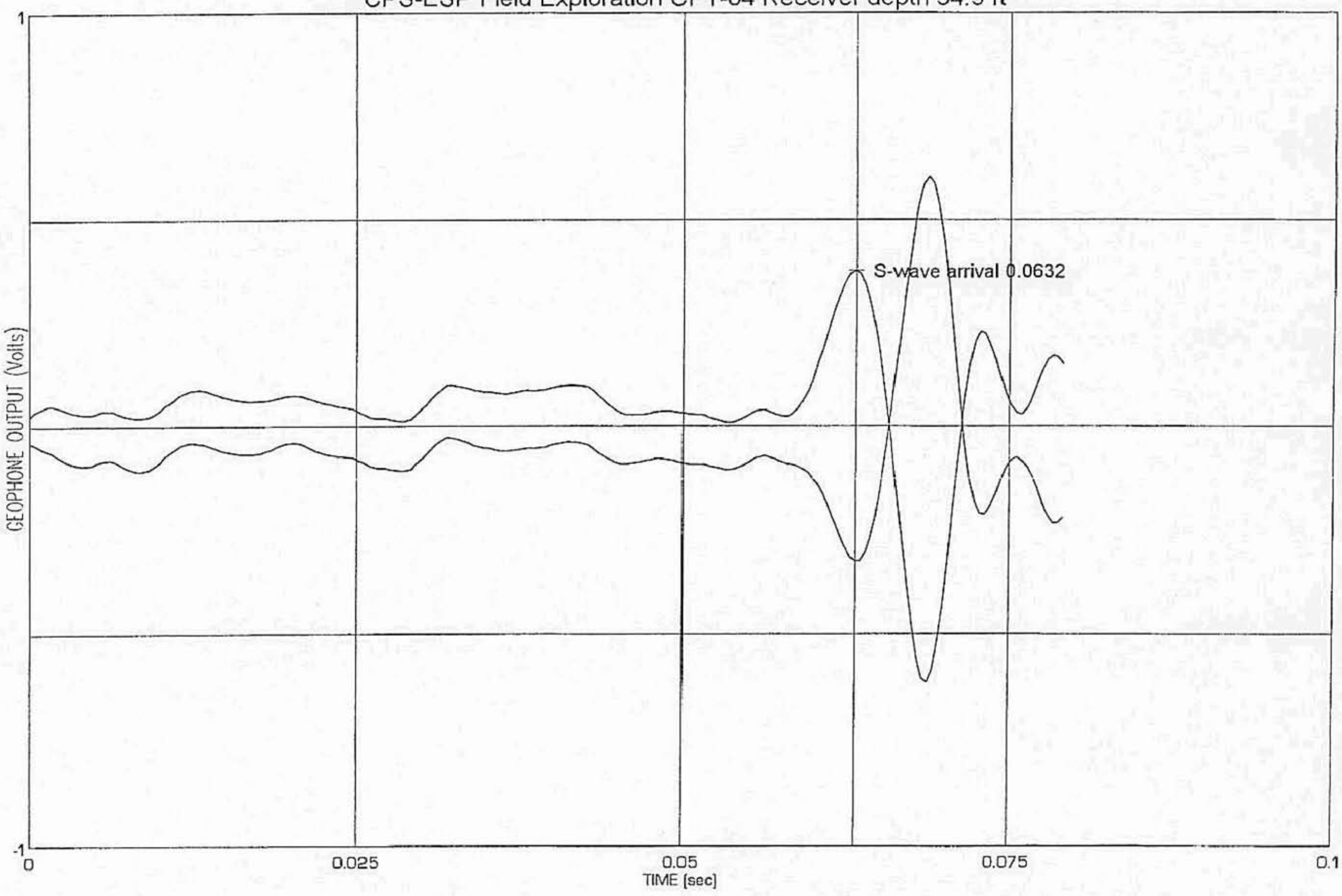
CPS-ESP Field Exploration CPT-04 Receiver depth 51.7 ft



REV 2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

CPS-ESP Field Exploration CPT-04 Receiver depth 54.9 ft

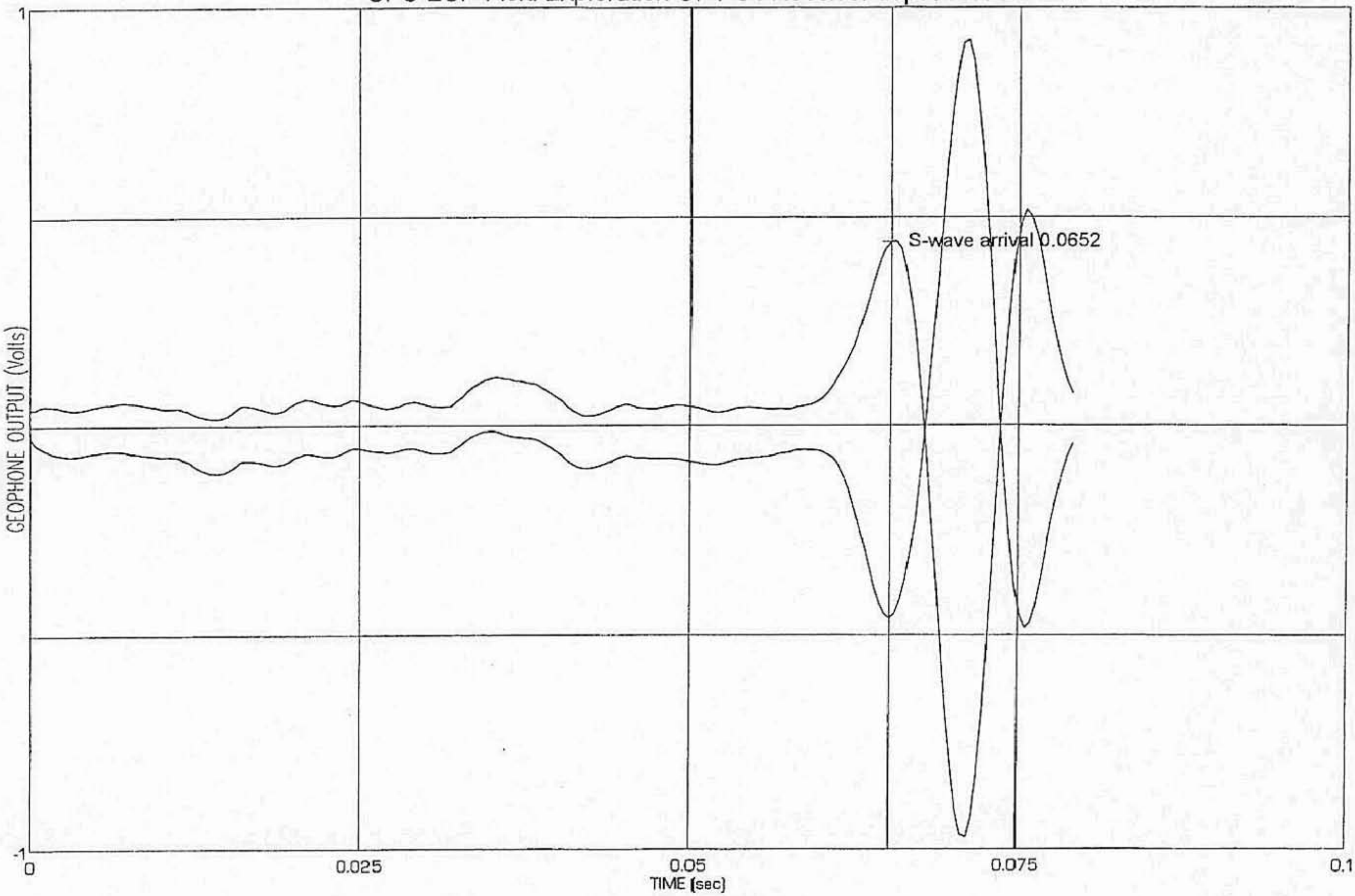


REV 2

Frame:2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

CPS-ESP Field Exploration CPT-04 Receiver depth 58.1 ft

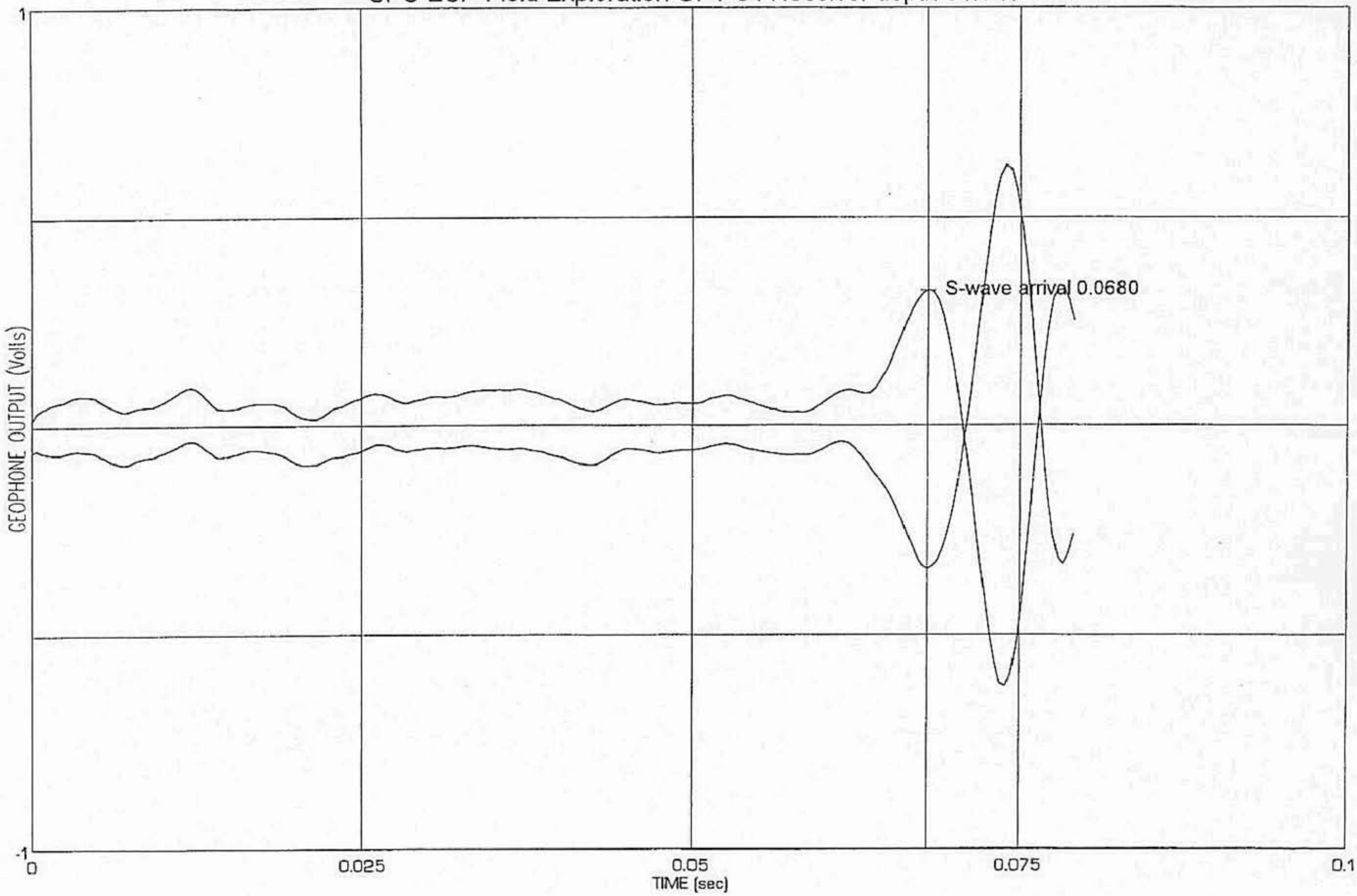


REV 2

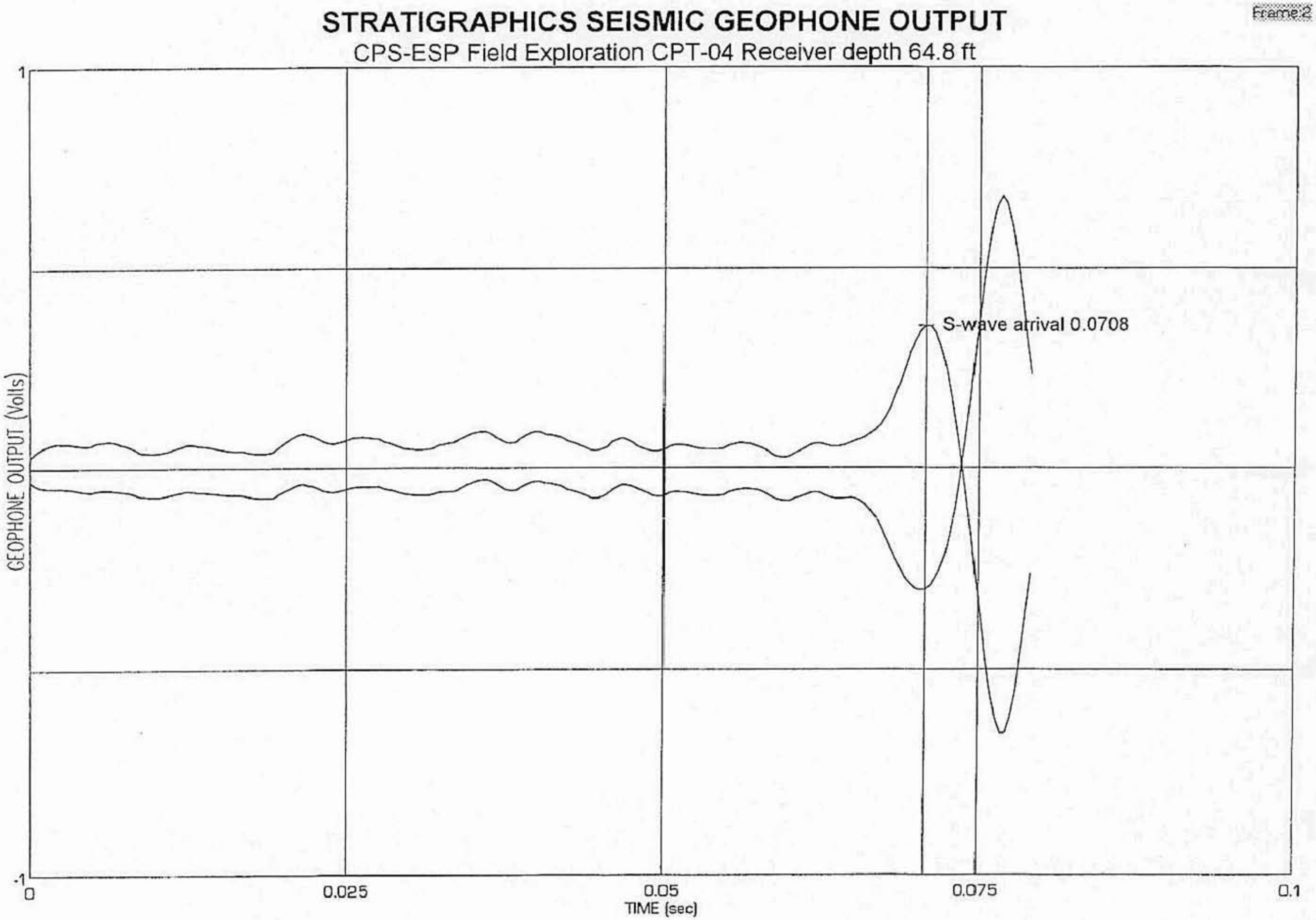
Frame:2

STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

CPS-ESP Field Exploration CPT-04 Receiver depth 61.5 ft



REV 2

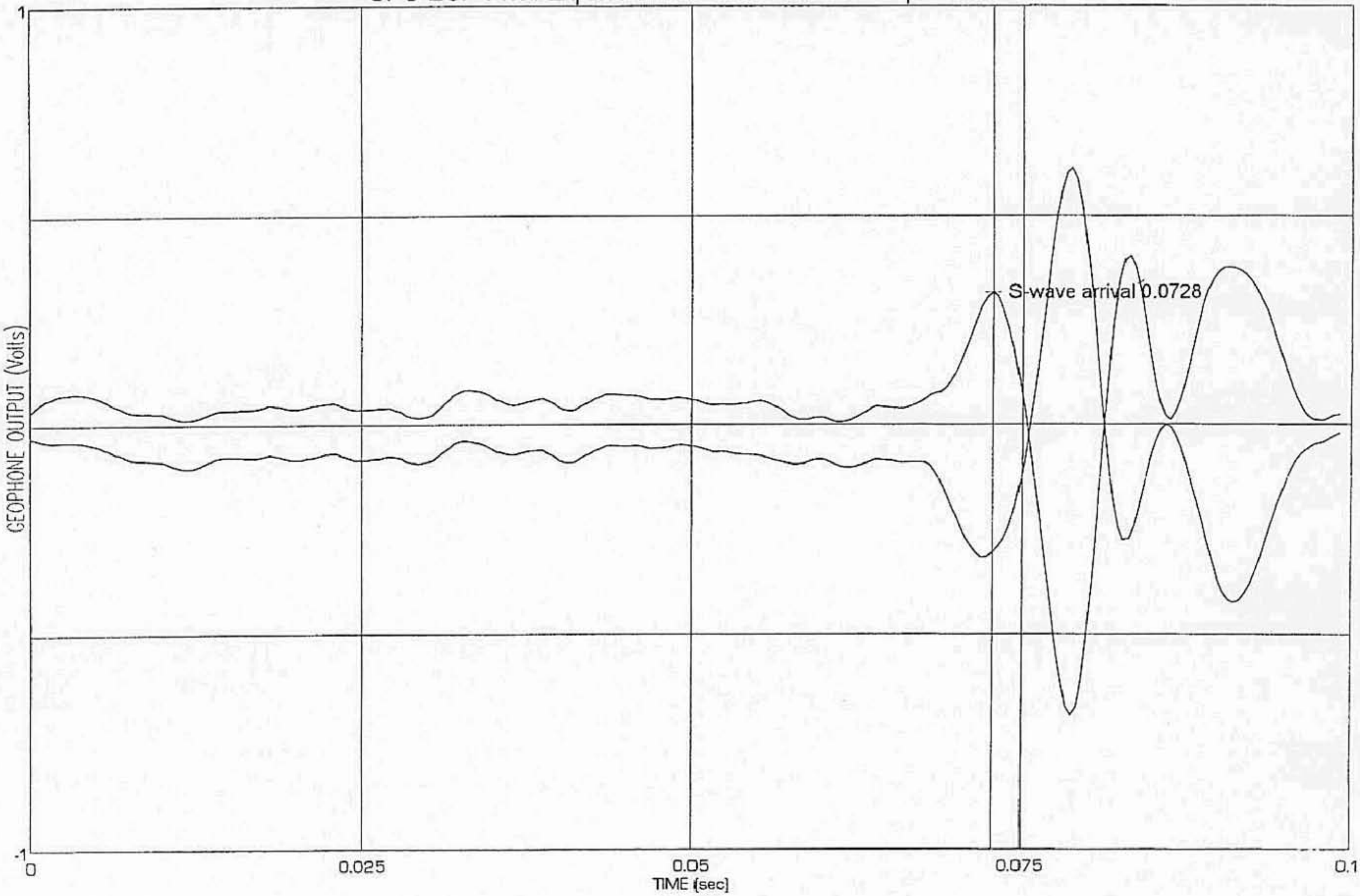

Frame:2
STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT
CPS-ESP Field Exploration CPT-04 Receiver depth 64.8 ft
1
-1
GEOPHONE OUTPUT (Volts)
S-wave arrival 0.0708
0
0.025
0.05
0.075
0.1
TIME (sec)

REV 2

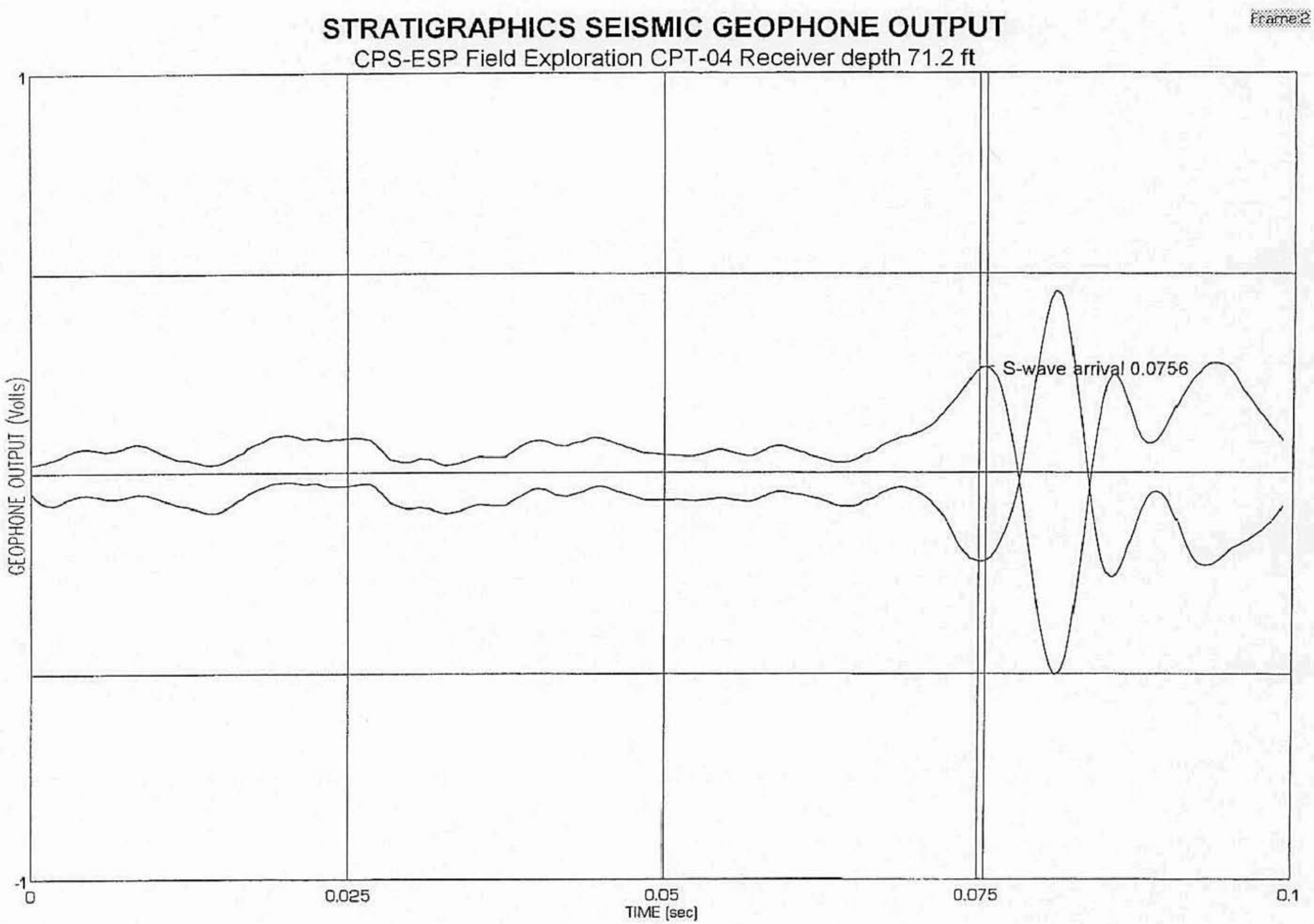
STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

CPS-ESP Field Exploration CPT-04 Receiver depth 68.0 ft

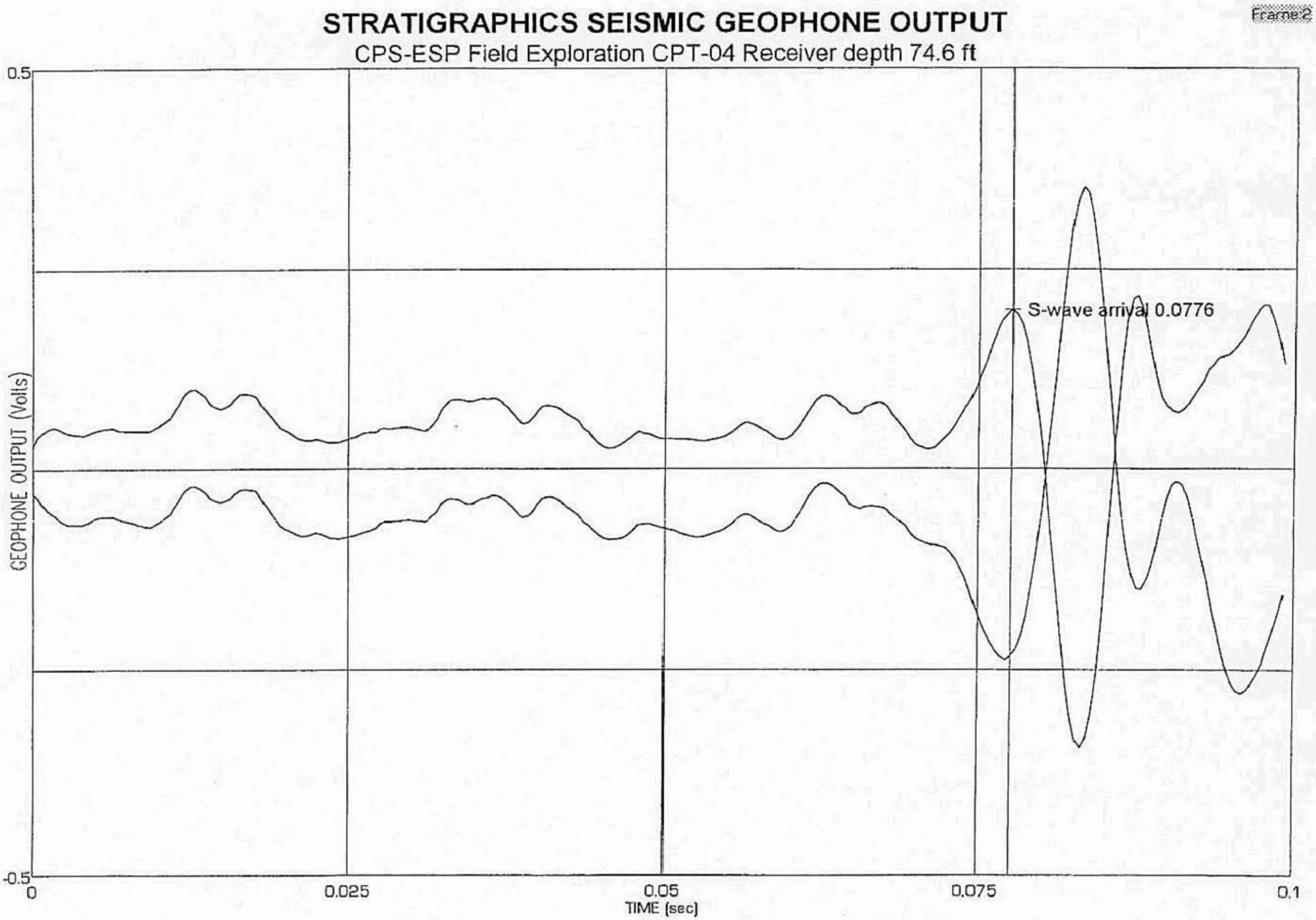
Frame:2



REV 2


STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT
CPS-ESP Field Exploration CPT-04 Receiver depth 71.2 ft
Frame:2
1
-1
GEOPHONE OUTPUT (Volts)
S-wave arrival 0.0756
0
0.025
0.05
0.075
0.1
TIME (sec)

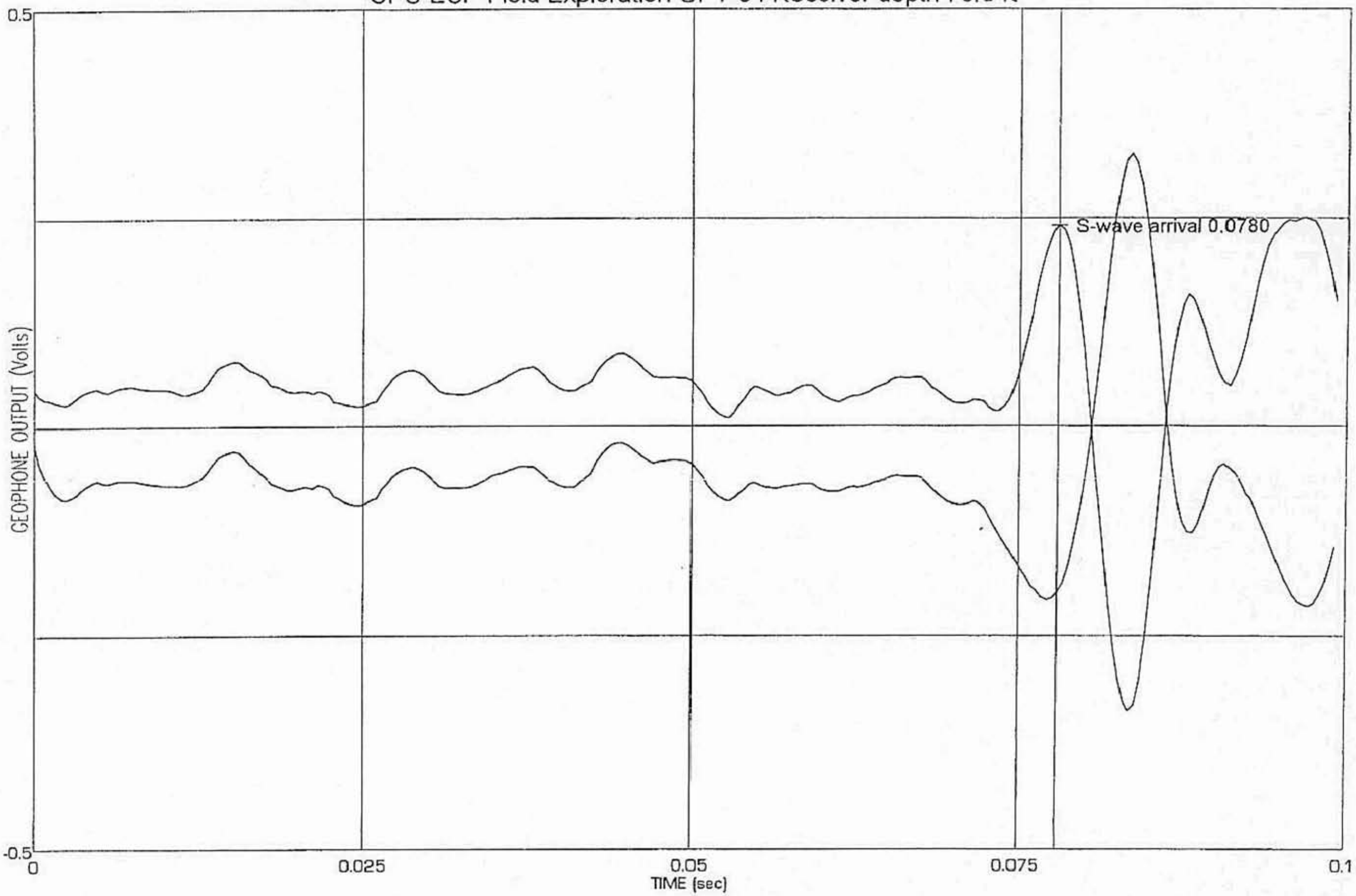
REV 2


STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT
CPS-ESP Field Exploration CPT-04 Receiver depth 74.6 ft
Frame:2
0.5
-0.5
GEOPHONE OUTPUT (Volts)
S-wave arrival 0.0776
0
0.025
0.05
0.075
0.1
TIME (sec)

REV 2

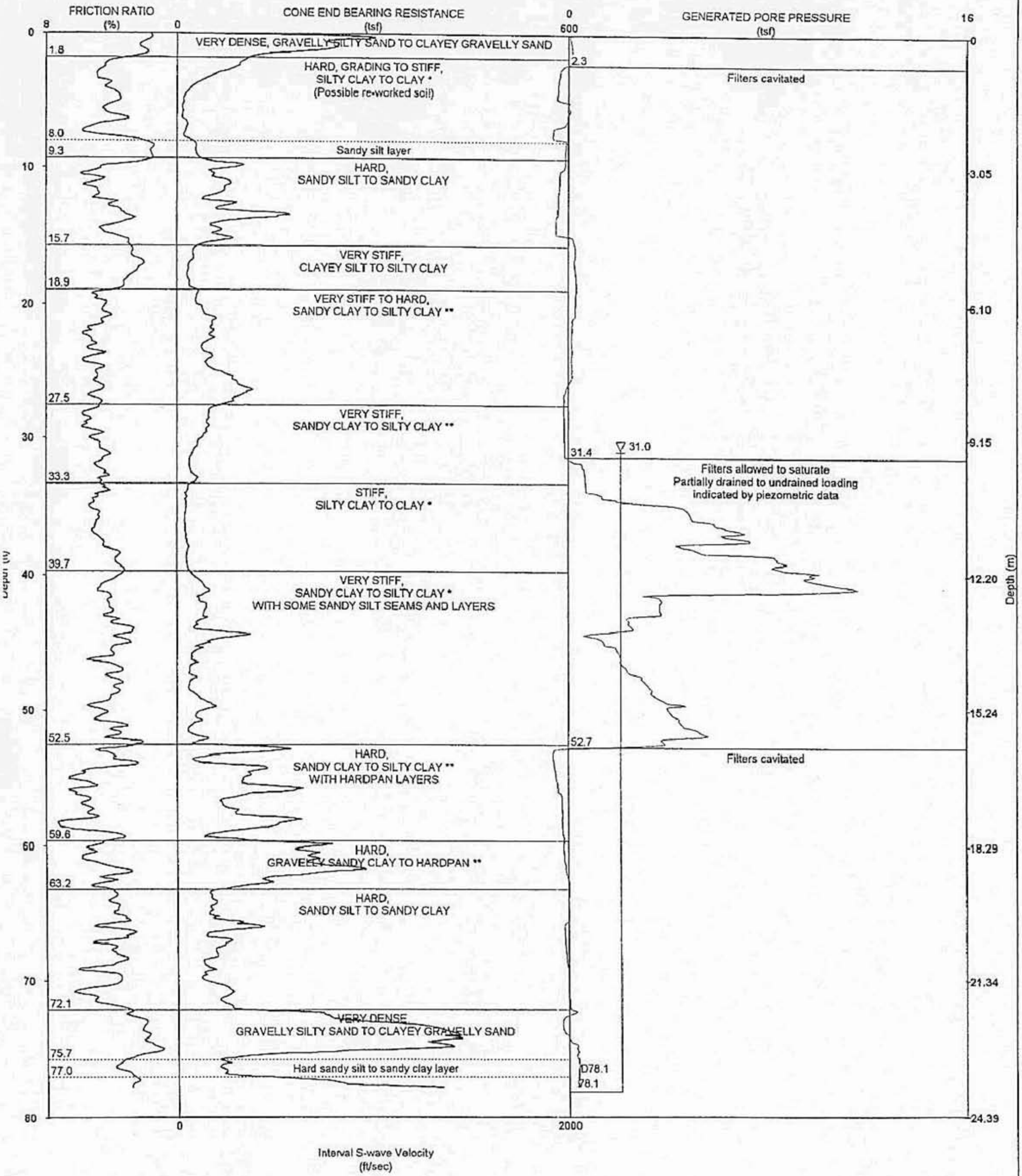
STRATIGRAPHICS SEISMIC GEOPHONE OUTPUT

CPS-ESP Field Exploration CPT-04 Receiver depth 75.8 ft



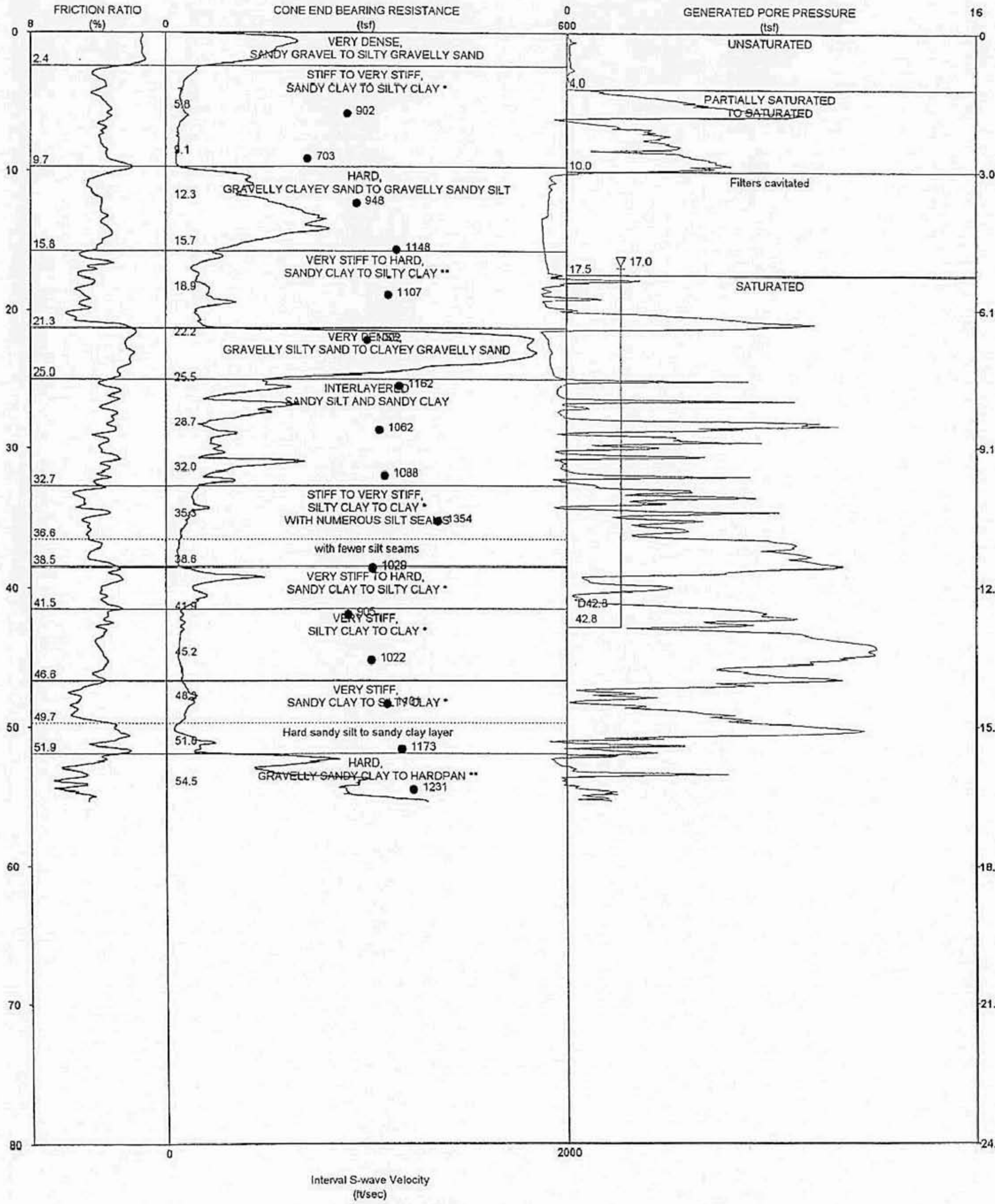
REV 2

CPTU-S LOG WITH LITHOLOGIC EVALUATION

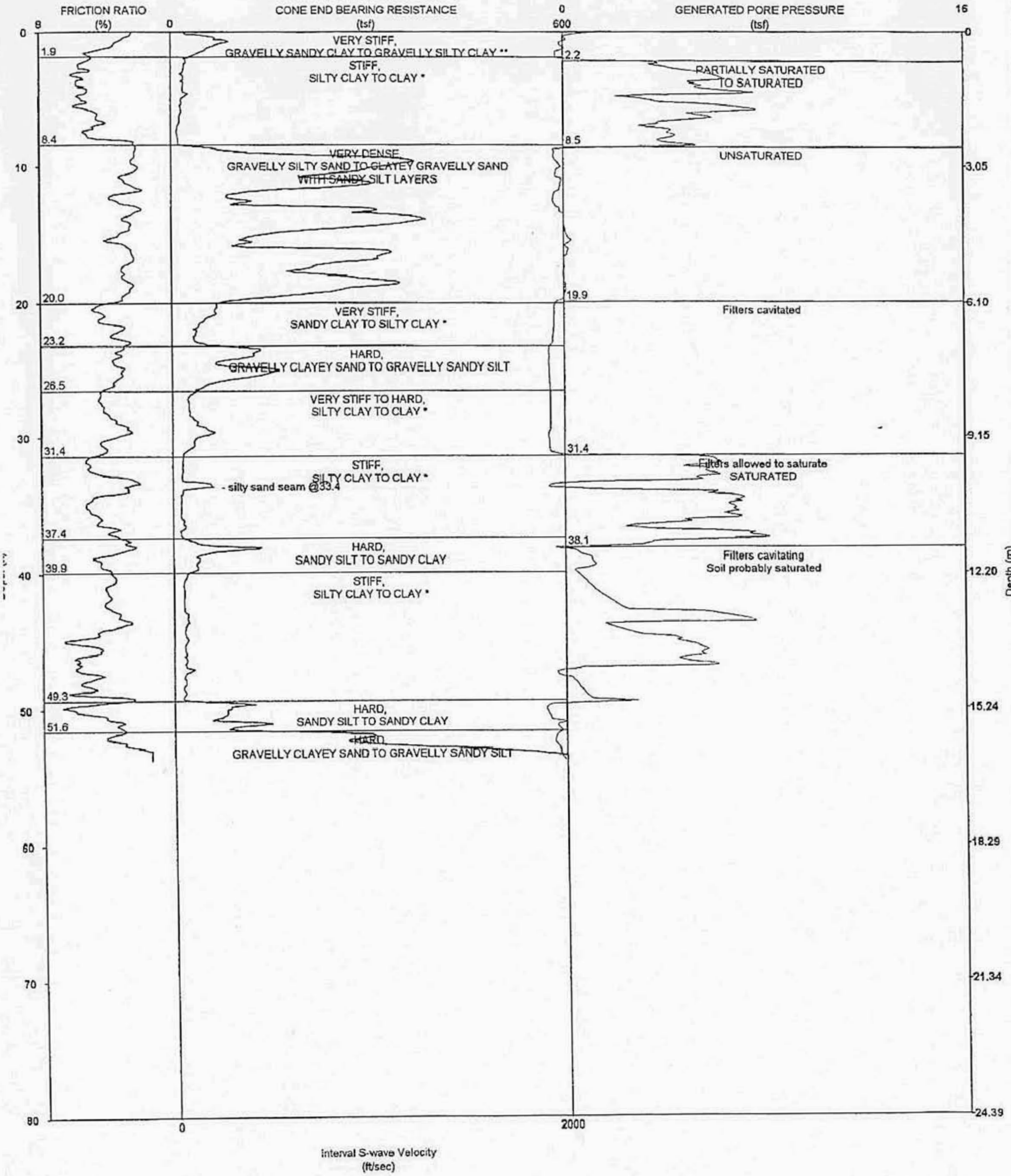


REV 2

CPTU-S LOG WITH LITHOLOGIC EVALUATION

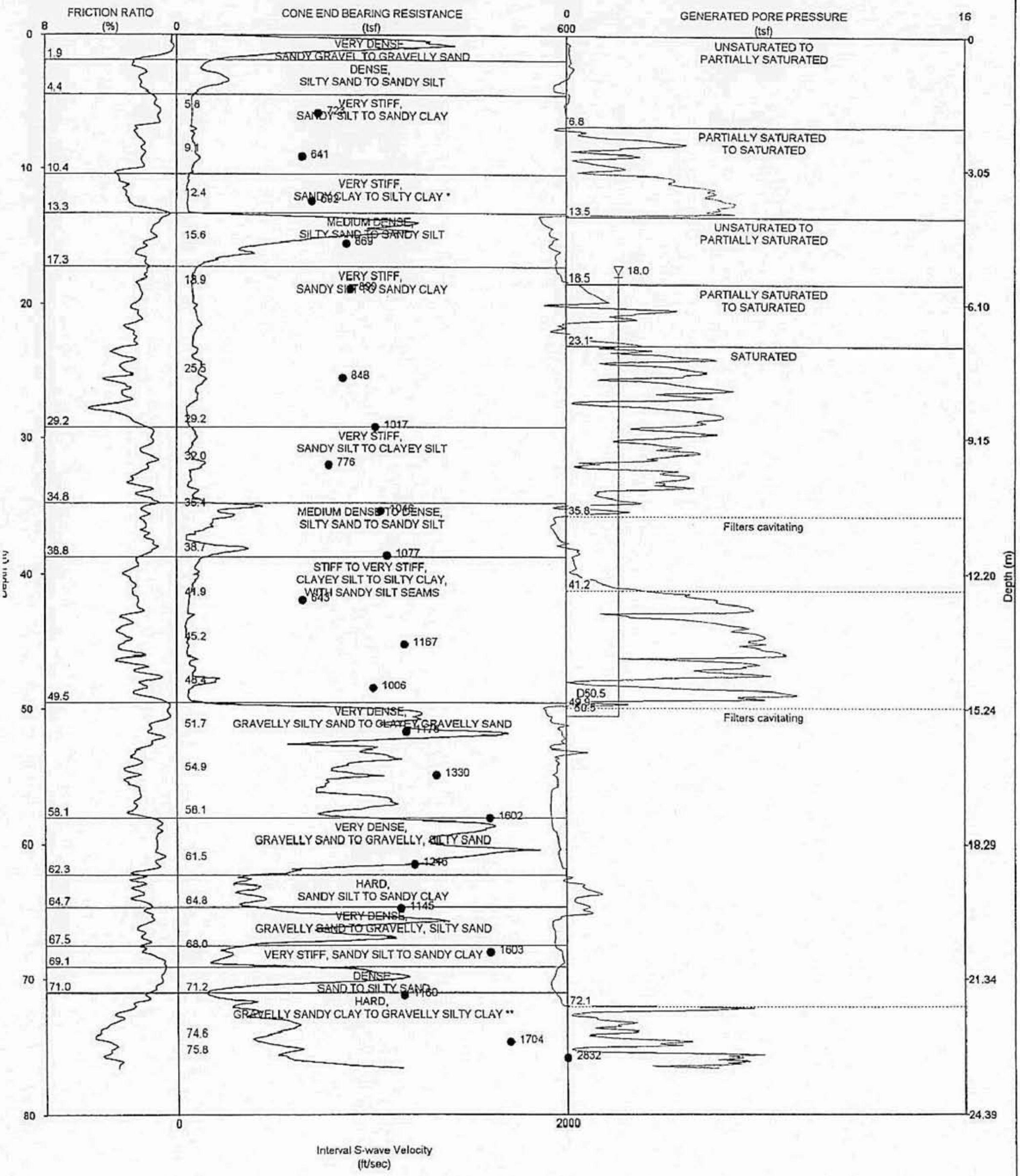


CPTU-S LOG WITH LITHOLOGIC EVALUATION



REV 2

CPTU-S LOG WITH LITHOLOGIC EVALUATION



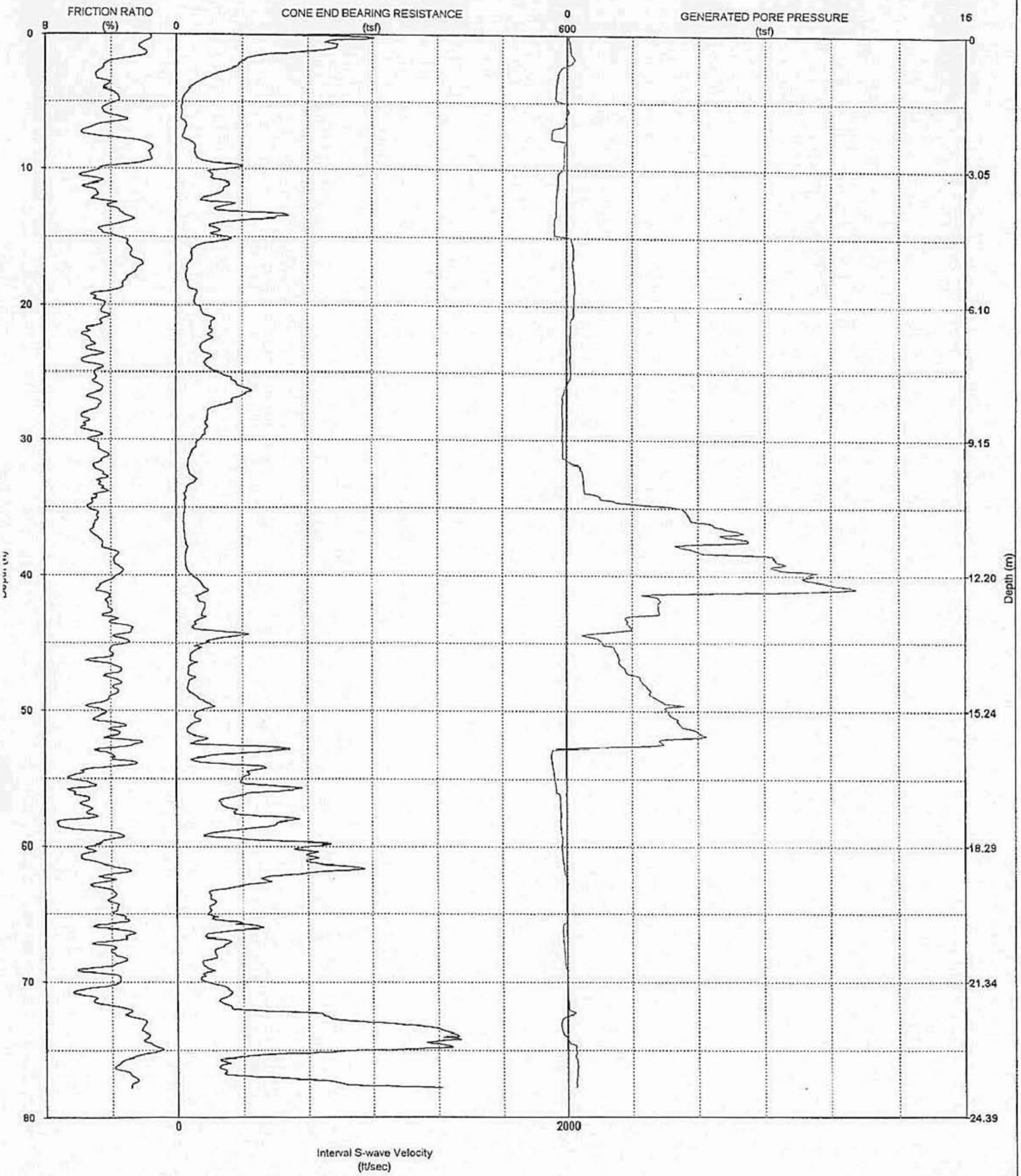
REV 2

PROJECT NAME:CPS-EPS Field Exploration
PROJECT NUMBER:02-120-110

STRATIGRAPHICS

R2DATE: 7-23-2002 TIME:17:32:39.15
SOUNDING NUMBER:CPT-04

CPTU-S LOG



REV 2

PROJECT NAME:CPS-EPS Field Exploration
PROJECT NUMBER:02-120-110

STRATIGRAPHICS

R2DATE: 7-24-2002 TIME:14:53:33.48
SOUNDING NUMBER:CPT-01