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Fluid Processes and Waste Management Group

TECHNICAL REPORT WE/97/44

Summary of field activities: Year 1, INCO-DC Project 950176, Electrokinetic Sounding

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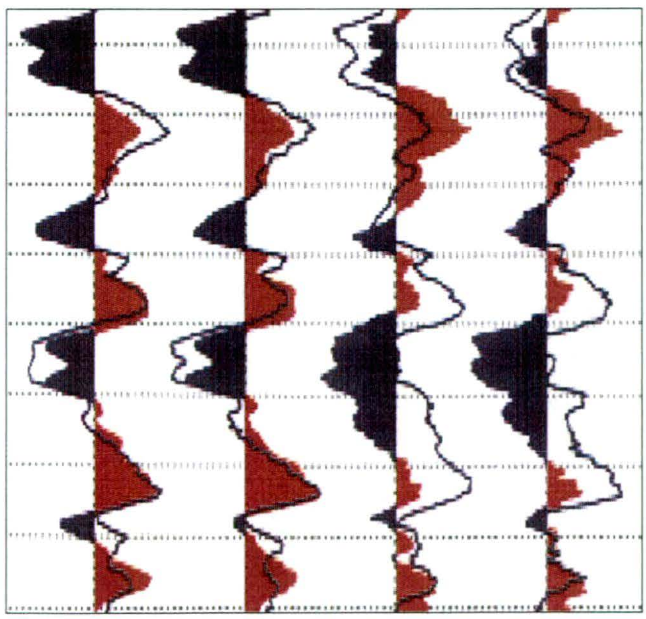

Detail from 8-channel EK sounding, Cyprus 97

British Geological Survey, Keyworth, Nottingham, 1997

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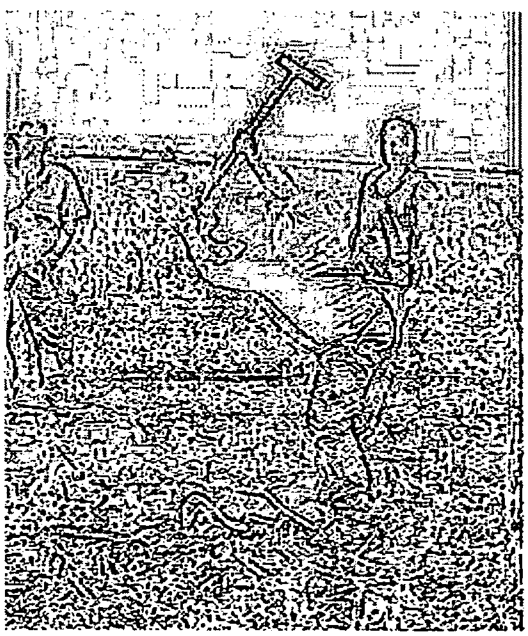


1) Introduction

This report summarises work undertaken for the EEC INCO-DC project: A new integrated geophysical approach for the rational management and exploration of groundwater resources. The programme Project Number is 950176 under Contract Number ERBIC 18 CT 960122.

EU member participants are:

The Netherlands:	RGD: (NITG-TNO), Haarlem James Baker (Project Coordinator)	
France:	BRGM, Orleans Alain Beauce	
U.K.:	BGS, Nottingham D. Beamish and Jon Busby	

Non-EU partners are:

Cyprus:	GSD, Nicosia Sortiris Kramvis	GEOINVEST, Nicosia Andreas Shiathas
Israel:	GII, Holon Mark Goldman	

This report is a summary of the field activities of the Electrokinetic Sounding (EKS) technique which took place on Cyprus during June 1997. Geophysical surveys on Cyprus are designated as Task 3 and the EKS technique designated as sub-task 3.5. EKS fieldwork took place in the Astromeritis-Kokkinotrimithia area of the western Mesaoria. The geology/hydrogeology of the project area on Cyprus has been summarised in an unpublished project document by GSD.

2) Cyprus Field Work

EKS data collection took place between June 03 and June 13 1997 and data were collected along three main profiles designated :

1) Potami
2) Astromeritis
3) Meniko

Profile coordinates of the EK soundings and other information are given in Table 1. Figures 2.1 to 2.3 show the sounding coordinates in map form of the three profiles. Other geophysical surveys conducted along the profiles during 1997 included PMR (BRGM), TDEM (GII), AMT (BRGM) and VLF (GSD). The geophysical techniques are Proton Magnetic Resonance (PMR), Time Domain Electromagnetic Sounding (TDEM), Audiomagnetotelluric sounding (AMT) and Very Low Frequency electromagnetics (VLF).

A single day was used acquiring test data on the Troodos Pillow Lavas (northern fringe of the Troodos Ophiolite) in the Klirou area. A detailed profile of measurements (5 m intervals) was obtained across the location of an Azimuthal Resistivity Sounding (BGS).

Thirteen main EK soundings were obtained along the predominantly NW-SE Potami profile (Fig. 2.1). Site codes are sequential from the first sounding (01, at a profile distance of 200 m) through to 13 (profile distance of 1800 m). Twelve main soundings were obtained along the predominantly E-W Astromeritis profile (Fig.2.2). Site codes are sequential from the first sounding (14, at a profile distance of 70 m) through to 25 (profile distance of 1640 m). Nine main soundings were completed along the NW-SE Meniko profile (Fig. 2.3). Site numbers (0 to 1210) refer to distance along the profile.

Field operations were carried out by BGS (D. Beamish) and staff from the GSD. Typically the field crew comprised four or five members. Views of field operations along the three profiles are shown in Figure 2.4 (Potami), Figure 2.5 (Astromeritis) and Figure 2.6 (Meniko). Operations in the Klirou area are shown in Figure 2.7.

EK data were not acquired in a totally routine manner since the technique remains experimental. A large number of sub-experiments were needed to attempt to improve the methodological procedures for the survey conditions in the western Mesaoria. This requirement was particularly acute due to the very low EK signal amplitudes experienced. Dipole voltages were a factor of 10 below levels associated with typical sandstone environments.

Views of the BGS TEKA recording system during field operations are shown in Figure 2.8. The system provides recording of 8 channels of sensor information. The sensors can be either electric dipoles or conventional seismic geophones. Typically a 2 m dipole length is used and 4 dipoles are operated on either side (symmetrical and co-linear) of the shot point. A standard EK moveout sounding comprises the two main inner electrodes located at 0.5 m from the shot point. Using 2 m dipoles provides inner dipoles centred at an offset of +/- 1.5 m. These act as the most 'sensitive' sounding locations. Additional dipoles at increasing offsets (e.g. 2 m dipoles with centres of +/- 2.5, 3.5 and 4.5 m) are recorded simultaneously.

If additional offset data is required, further 8-channel recordings are subsequently obtained. Finally, at certain locations, near-surface acoustic velocities can also be obtained by replacing the dipoles with acoustic geophones. The geophones used were single component (vertical) with a resonance frequency of 8-10 Hz.

3) Acoustic sources

The main acoustic source used during the survey was the hammer/metal plate combination. For reasons of energy transfer, a metal plate of the same mass as the hammer was preferred. Trials were conducted using a large weight-drop (gravity) source designed by GSD. Various weights of up to 24 kg were available for the winch system which was truck mounted. Views of the source in operation are shown in Figure 3.1.

Difficulties experienced with the weight-drop source included:

- Double (or multiple) strikes leading to several 'impacts' during the 400 ms recording period.
- Failure to trigger the system (an inertia switch)
- Alignment difficulties of the weight suspension cable leading to non-central impact
- Long shot repeat time due to the winch.

The first, main problem was never fully solved despite repeated experimentation. The only consistent and reliable data were obtained using the hammer/plate combination.

4) Data Quality

The voltage amplitudes obtained during the survey are illustrated using two sets of soundings made along the Potami profile on the first two days of field-work.

Figures 4.1 and 4.2 show 10 repeated shots made at EP01 (200 m). Dipole lengths are 1 m and 2 shot-symmetric channels are displayed in each case. Thin lines are individual shot records and the stacked averages are shown by a thick line. The four plots represent soundings with dipole centre offsets of (a) 1 m, (b) 2 m (Fig. 4.1) and (a) 5 m and (b) 6 m (Fig. 4.2) from the shot point. The first 80 ms of data are shown in each case and it should be noted that the amplitude scales (in mV/m) decrease with increasing offset. In Figure 4.1 (near offsets) some evidence of in-phase behaviour is observed with voltage excursions restricted to about 0.2 mV/m at an offset of 2 m. At offsets of 5 and 6 m (Fig. 4.2) amplitudes have reduced considerably. Although there are some indications of in-phase behaviour at an offset of 5 m, by 6 m the voltage excursions throughout the 80 ms record approach 10 microvolts and appear 'lost' in the stacking residuals (noise).

The 'standard' EK dipole arrangement proved to be unsuited to the low signal amplitudes encountered, particularly the rapid spatial fall-off in signal strength with offset. In an attempt to improve the S/N of the survey data, various modifications were introduced. The two sets of inner dipoles (2 m dipoles with offsets of +/- 1.5 and 2.5 m) were retained and different arrangements of the outer two dipoles were investigated. The arrangements included increasing the dipole length to 4 m and/or placing inner electrodes at 0.25 or 0.5 m from the shot point.

A similar set of recordings obtained at EP05 (900 m) along the Potami profile are shown in Figures 4.3 and 4.4. In this case 3 of the dipole lengths are 2 m and the fourth was increased to 4 m. Dipole centre offsets are 1.5 m and 2.5 m (Fig. 4.3) and 3.0 and 3.0 m (Fig. 4.4); in the latter case the dipole length is 4 m (inner electrodes at +/-1 m). It is the position of the **inner electrode** that has **increased the voltage signal levels** (in-phase behaviour) of this recording. The increased *dipole length* is responsible for the *increased residual voltage levels* (out-of-phase noise).

The final stacked sounding data (70 shot records) of the 1.5 m offset (2 m dipole) and 3.0 m offset (4 m dipole) recordings are compared in Figure 4.5. Here the data are shown as true amplitudes in mV (actual voltage output from the dipoles). The difference in location of the inner electrodes (0.5 m) is responsible for a factor of 2 difference in signal amplitudes. In addition, the same difference is responsible of a small, but significant, moveout behaviour identified in Figure 4.5 by the dashed lines.

Eventually, following extensive trials, the higher sensitivity of the two inner dipole sets led to the routine deployment of an 8-channel azimuthal array. Four 2 m in-line dipoles were arranged at centre offsets of +/- 1.5 and 2.5 m along the survey profile and this configuration was repeated along a line perpendicular to the survey profile. The azimuthal sounding sites, which were performed during the latter half of the survey, are identified in Table 1.

5) Acquisition Parameters

Standard data acquisition involved 8-channels of data recorded at a sampling interval of 10 kHz. The record length was 4000 data points (400 ms). Due to the low signal amplitudes a large number of repeat shots was required to complete a sounding. The total number of shots varied between 40 and 100, with 70 shots being typical.

Initial processing of each shot record allows for:

- three methods of 50 Hz and mains harmonic rejection
- low-pass data smoothing (frequency < 500 Hz)

Each shot record is graphically displayed to allow for acceptance/rejection in a stacking procedure. Automation of this procedure is difficult due to both obvious (e.g. large amplitude sferics) and more subtle (e.g. hammer bounce) sources of noise. Graphical inspection of the data remains the only reliable method of maintaining quality control of the stacking procedure. The requirements of graphical inspection multiply when signal amplitudes are small and the data must be examined at a variety of scales.

6) Electrodics

A specific requirement of EK sounding is that the stainless steel electrodes be hammered into the ground until 'rigidity' is achieved. If rigidity is not achieved then an individual electrode will shake rather than respond electrically. During the survey recently ploughed fields were avoided as sounding locations because adequate electrode rigidity could not readily be achieved.

Hard, dry top soil conditions were often encountered leading to difficulties in both electrode emplacement and high contact resistances. Contact resistances were routinely monitored and electrodes were always watered. Following watering, typical contact resistances were less than 2000 ohm. Examples of the ground conditions are shown in Figure 6.1.

7) Summary

Thirty four main electrokinetic soundings were conducted along the three main project profiles in the western Mesaoria. Other data acquired included detailed (5 m) local EK (2-channel) profiles together with some detailed and very shallow seismic refraction data. A further day was spent on a test profile on the Troodos Pillow Lavas in the Klirou area. The data from this latter area displayed 'shot/time-dependent' behaviour suggesting that the EK technique cannot be applied successfully in this environment.

The EK data along the three main profiles displayed very low amplitudes which were typically a factor of 10 below those associated with aquifer environments in sandstones. The low S/N led to tests of various sensor configurations and the use of large numbers of repeat shots. The data obtained, however, remain difficult to interpret especially at later times. In order to extract reliable information at later times for the study of signal originating at depths from 90 to 200 m, it has been necessary to improve the basic processing and display of the data. This work is currently underway.

8) Acknowledgements

It is a pleasure to acknowledge the major contribution made by the GSD, Nicosia during the field work. Manpower, ancillary equipment and vehicles were made available and their contributions led to a professional and successful field programme. Many staff members were involved and I thank Sortiris Kramvis for his organisational and logistic skills together with his reassuring ability to solve problems as they arose.

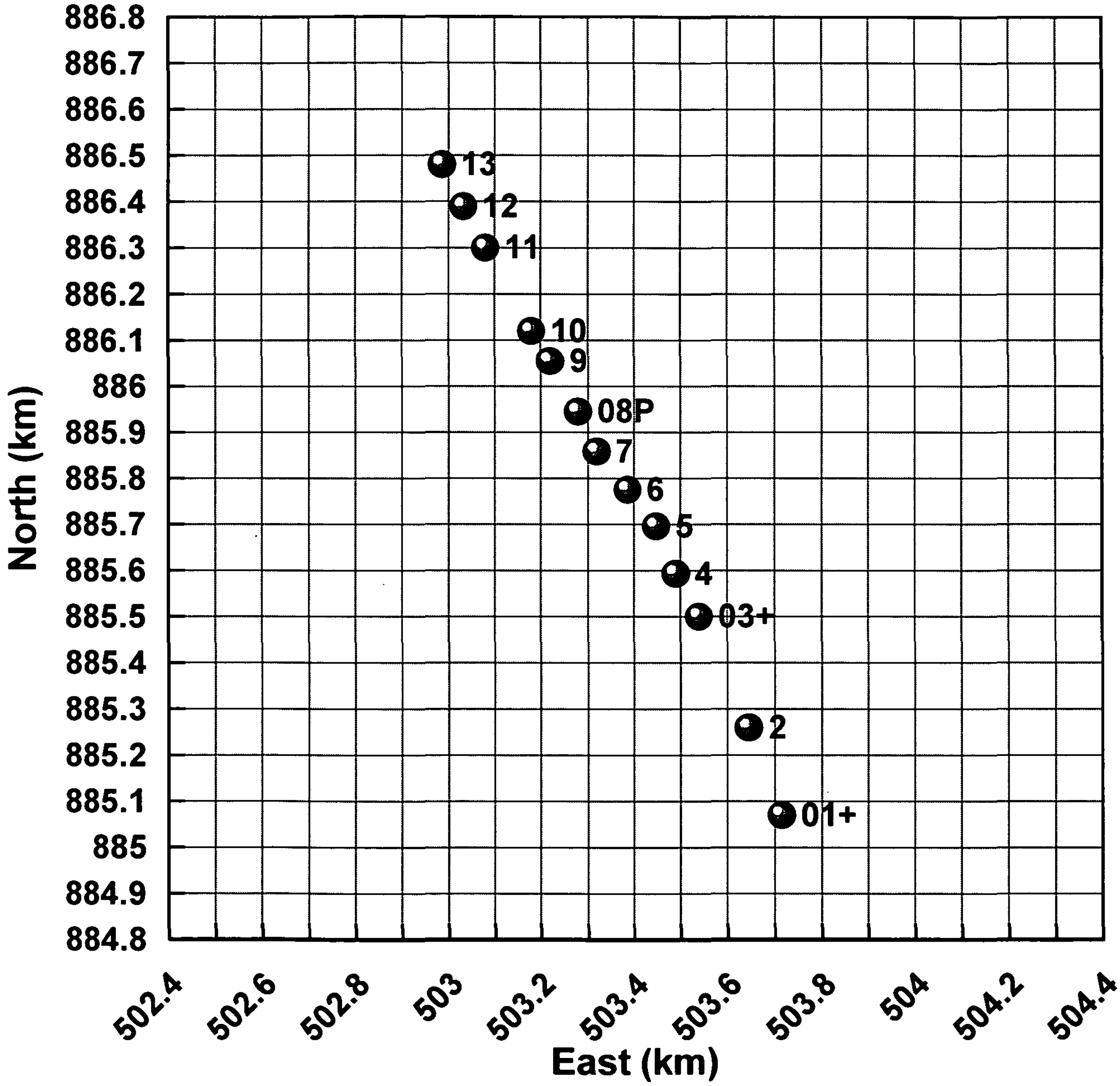
Table 1		**Cyprus-97**		
Electrokinetic Soundings			**Coordinates**	
3 Main profiles				
POTAMI				
	East (m)	North (m)	Distance (m	Type
01+	503.715	885.070	200	Linear
02	503.645	885.259	500	Linear
03+	503.540	885.500	700	Linear
04	503.490	885.593	800	Linear
05	503.448	885.696	900	Linear
06	503.386	885.775	1000	Linear
07	503.319	885.858	1100	Linear
08P	503.279	885.945	1200	Linear
09	503.220	886.055	1295	Linear
10	503.180	886.120	1560	Linear
11	503.080	886.300	1600	Linear
12	503.032	886.389	1700	Linear
13	502.986	886.480	1800	Linear
ASTROMERITIS				
	East (m)	North (m)	Distance (m	Type
14	504.140	889.775	70	Linear
15	504.250	889.795	180	Linear
16+	504.380	889.843	325	Linear
17+	504.515	889.838	480	Linear
18+	504.650	889.868	620	Linear
19P	504.813	889.870	780	Linear
20	505.005	889.898	960	Linear
21	505.112	889.905	1070	Linear
22+P	505.220	890.035	1216	Azimuthal
23	505.403	889.990	1396	Azimuthal
24	505.475	890.045	1490	Azimuthal
25	505.628	890.042	1640	Linear
MENIKO				
	East (m)	North (m)	Distance (m	Type
0	514.957	883.425	0	Azimuthal
162	515.094	883.266	162	Azimuthal
312	515.200	883.165	312	Azimuthal
600	515.405	882.952	600	Azimuthal
814	515.546	882.800	814	Azimuthal
909	515.620	882.713	909	Azimuthal
1000	515.670	882.644	1000	Azimuthal
1110	515.748	882.566	1110	Azimuthal
1210	515.827	882.485	1210	Azimuthal

Site codes ending in + have acoustic data
Site codes ending in P have local EK profiles

Fig. 2.1

Cyprus-97 Electrokinetic Soundings

Potami Profile



Site codes ending in + have acoustic data

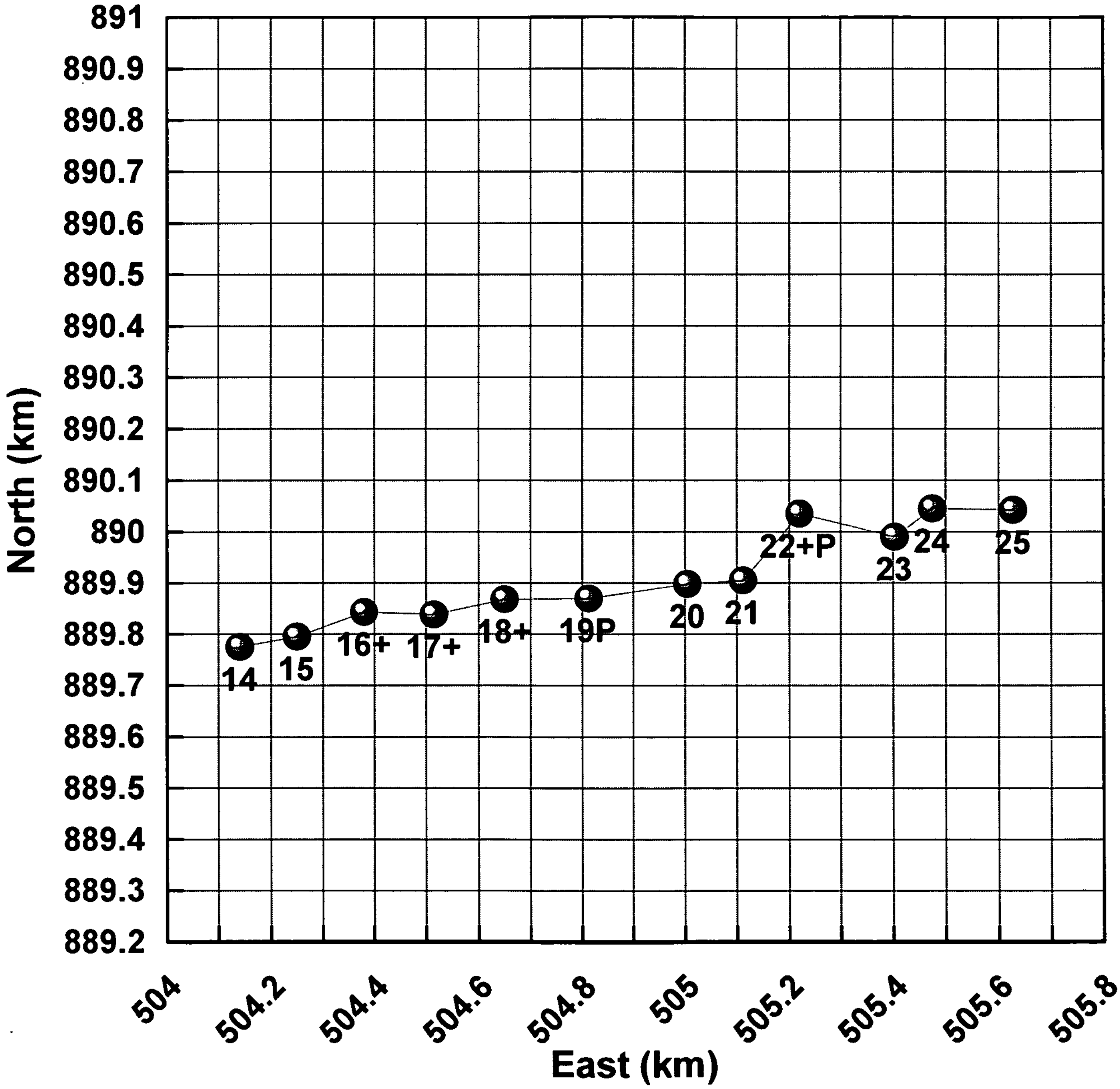
Site codes ending in P have local EK profiles

Figure 2.1 Main soundings along Potami profile.

Fig. 2.2

Cyprus-97 Electrokinetic Soundings

Astromeritis Profile



Site codes ending in + have acoustic data

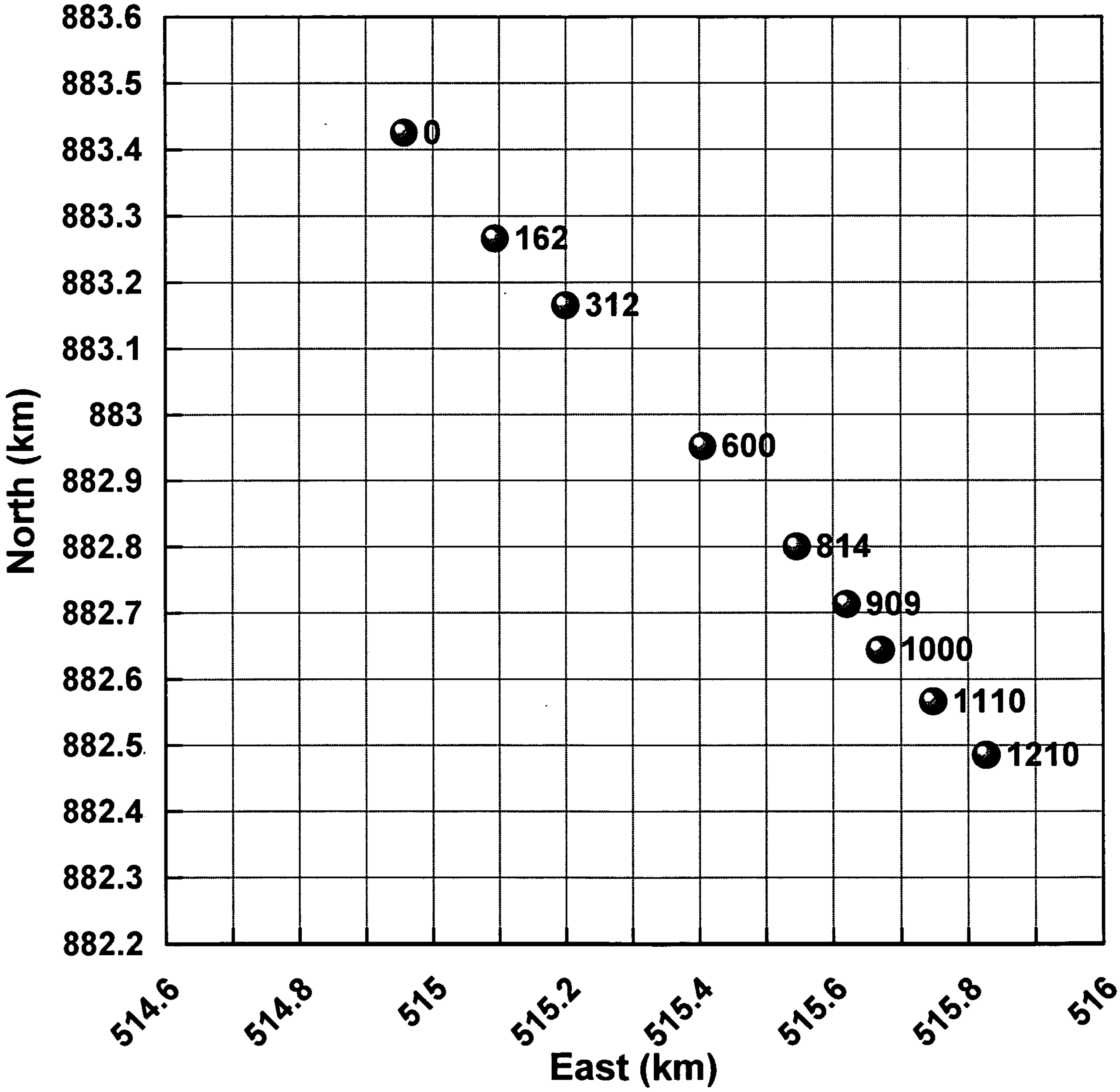
Site codes ending in P have local EK profiles

Figure 2.2 Main soundings along Astromeritis profile

Fig. 2.3

Cyprus-97 Electrokinetic Soundings

MENIKO Profile



Sounding codes are distances along profile.

Figure 2.3 Main soundings along Meniko profile

Fig. 2.4

a)

b)

Figure 2.4 Potami profile. 2 views of EK field operations. (a) Sounding 09 (1295 m) looking south. (b) Sounding 10 (1560 m) looking north.

a)

b)

c)

Figure 2.5 Astromeritis profile. 3 views of EK field operations. (a) Sounding 14 (70 m), (b) Sounding 16 (325 m), (c) Sounding 22 (1216 m).

Fig. 2.6

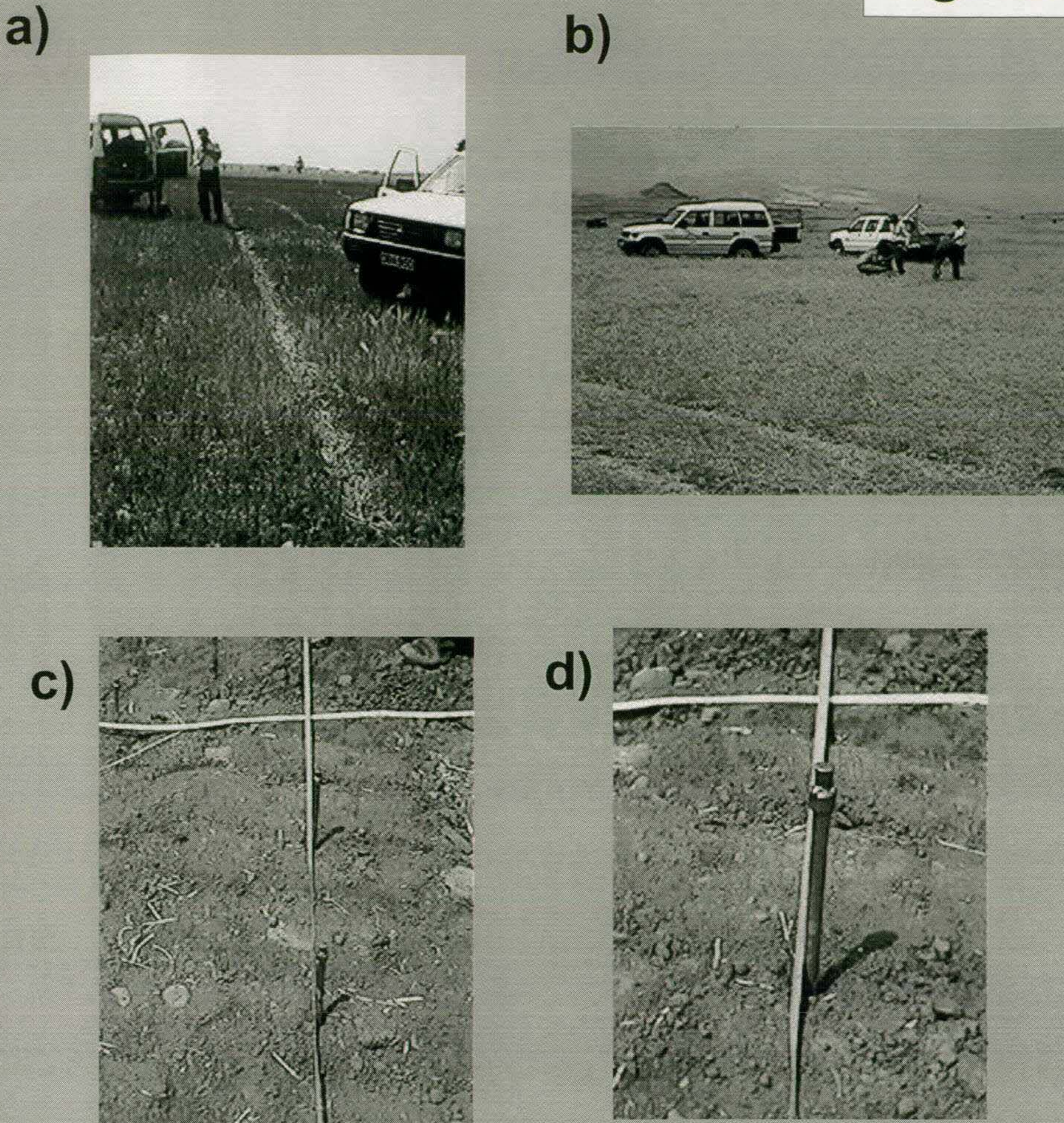
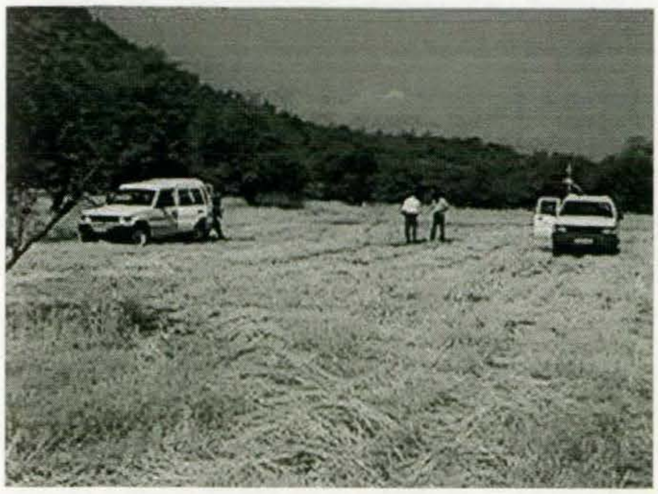


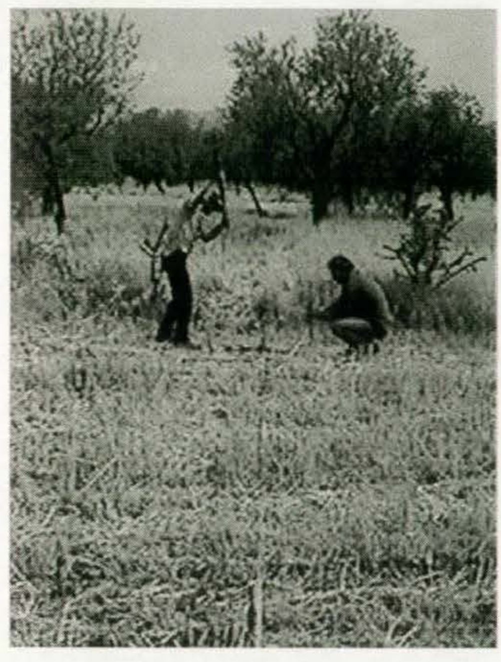
Figure 2.6 Meniko profile. 4 views of EK field operations. (a) Sounding 0 m, (b) Sounding 312 m, (c)&(d) ground conditions at Sounding 1210 m

Fig. 2.7

a)



c)



b)

Figure 2.7 Klirou site in orchards. 3 views of EK field operations. (a) and (b) looking west (c) hammer source looking along profile.

Fig. 2.8

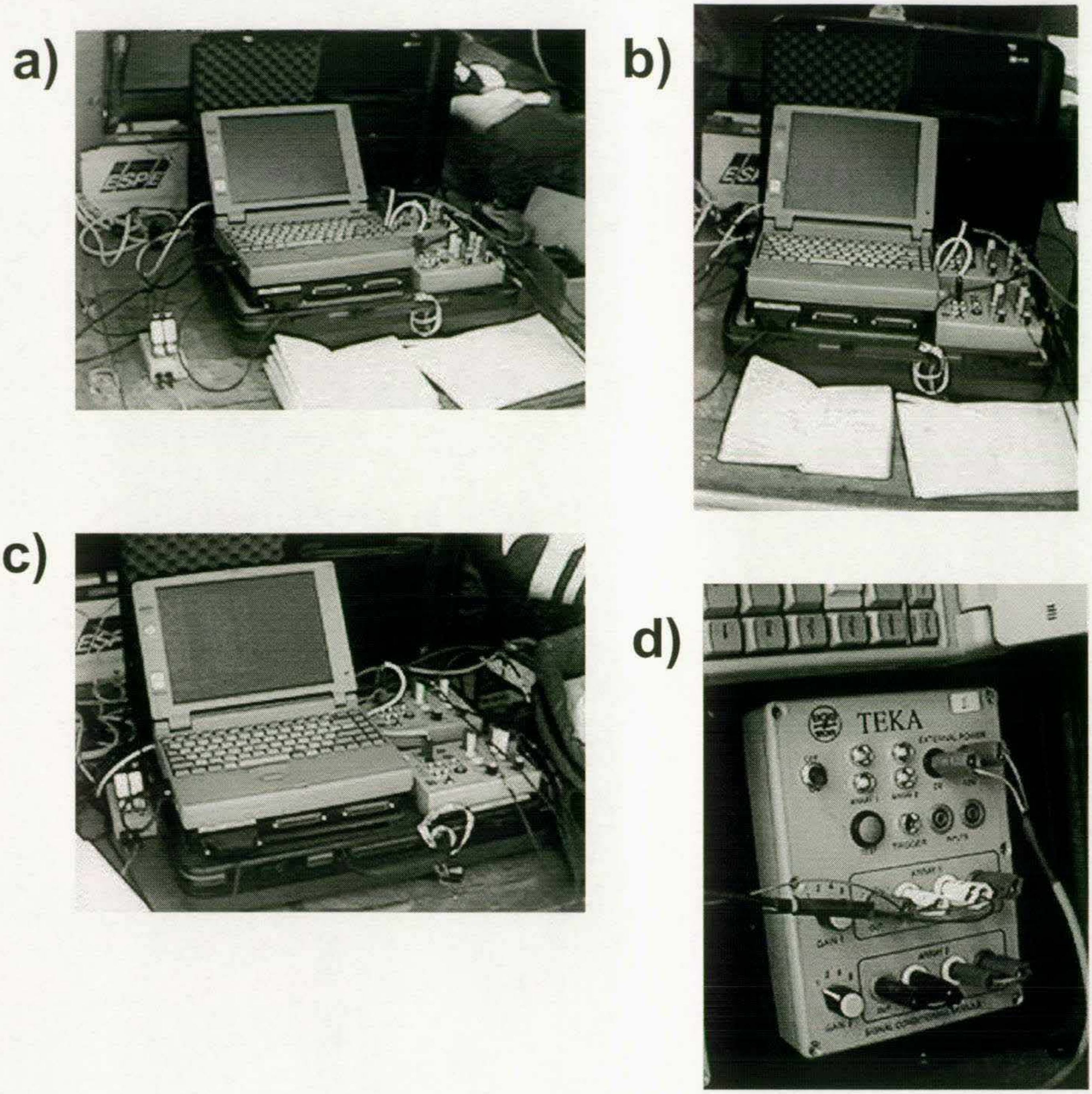


Figure 2.8 Four views of BGS TEKA recording system in use during Cyprus survey. System used in rear of vehicle. (d) shows one of two 4-channel signal conditioning units

Fig. 3.1

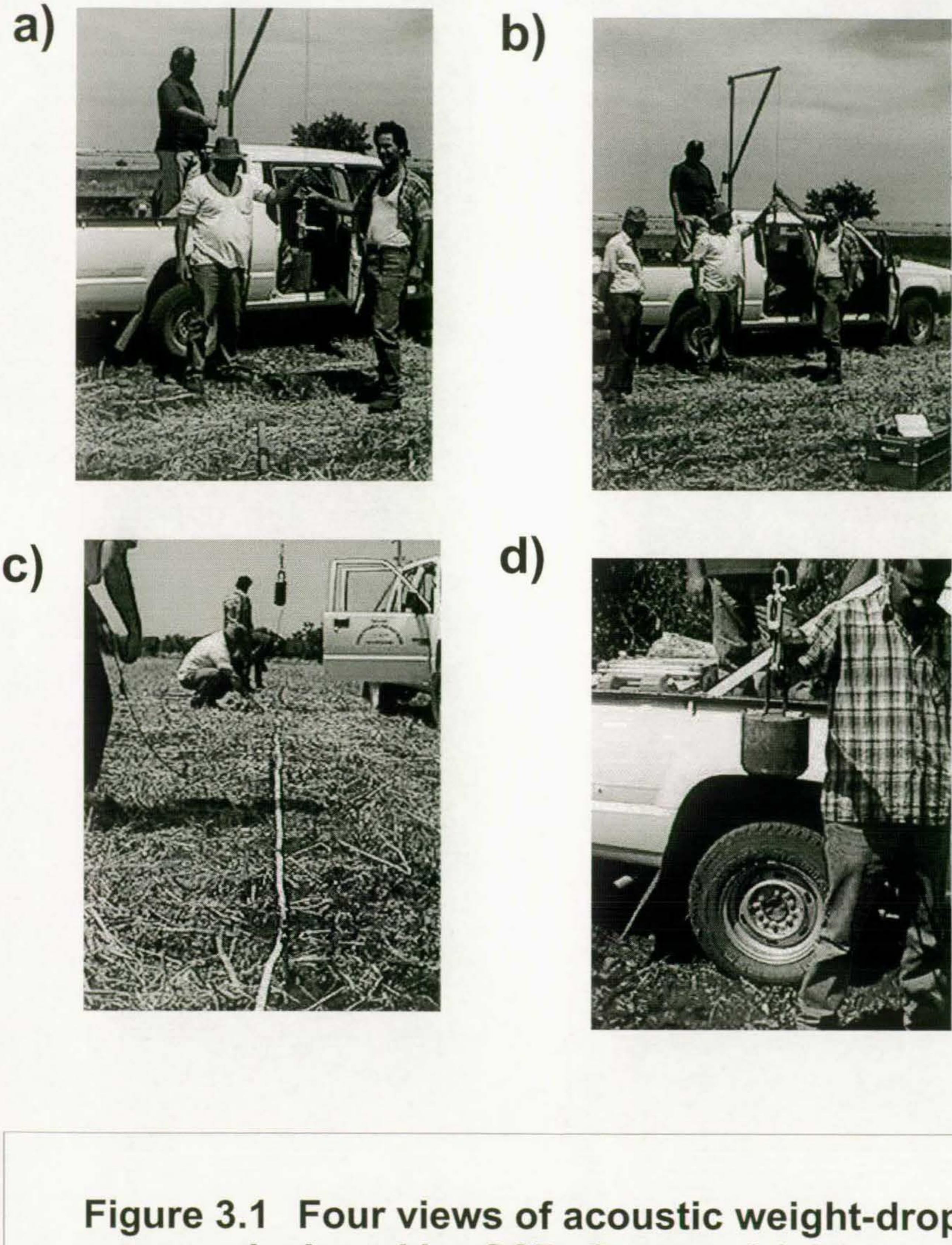
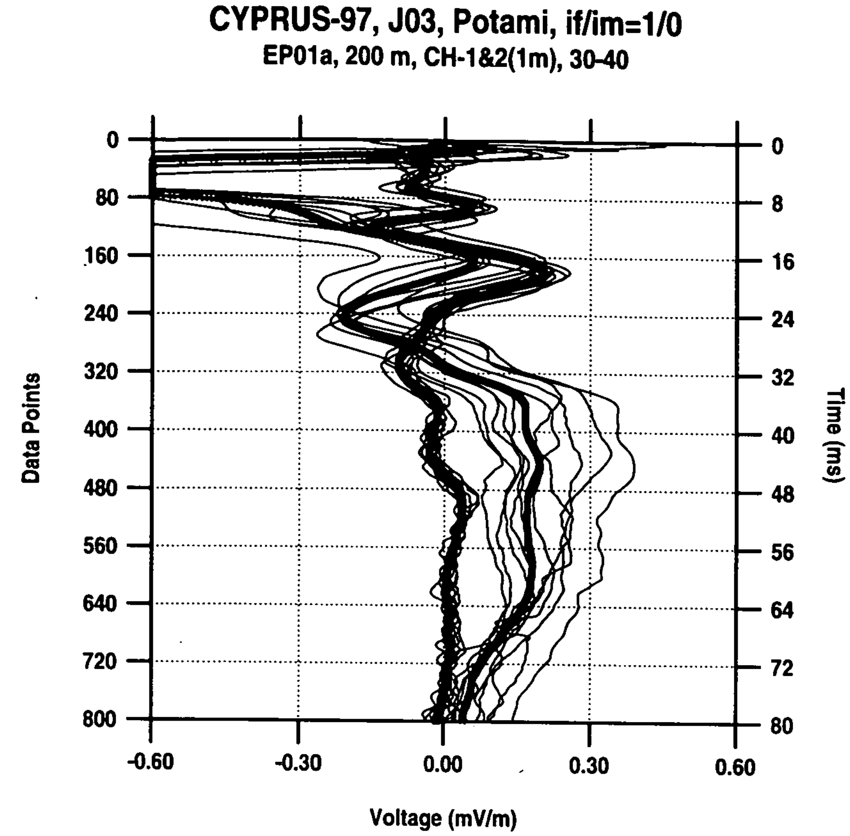


Figure 3.1 Four views of acoustic weight-drop source, designed by GSD, Cyprus. (a)-(c) Potami profile, (d) Astromeritis profile



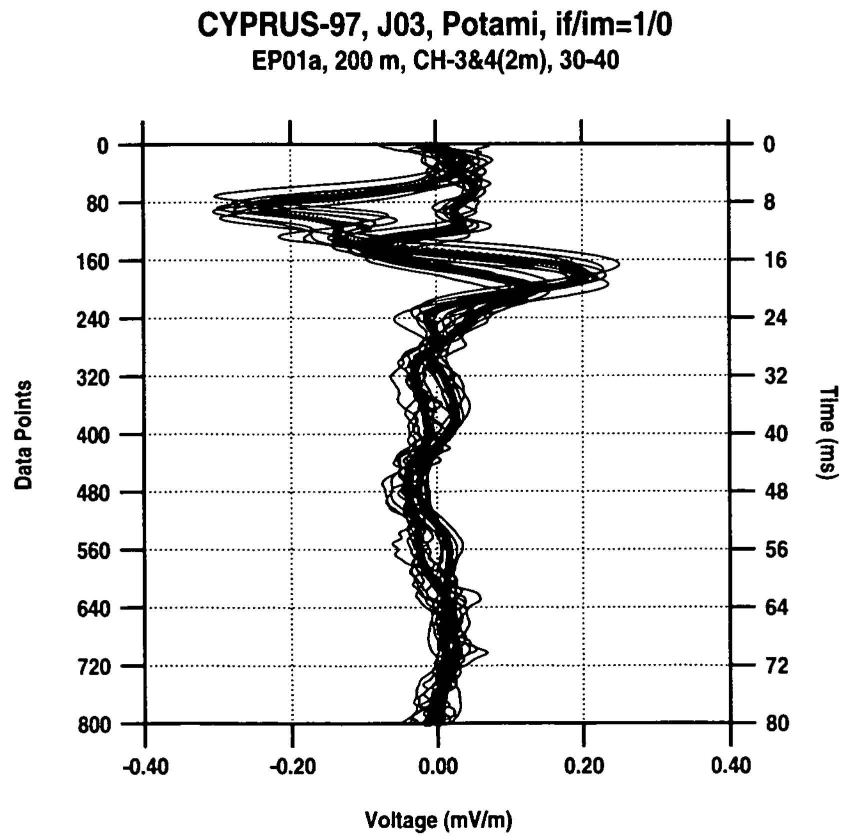


Figure 4.1 Potami profile, sounding 01, 200 m. 10 repeat shots from two symmetric channels (thin lines), with stack averages (thick lines). 1m dipoles. Upper plot (a): dipole centre offsets of +/- 1m. Lower plot (b): dipole centre offsets of +/- 2m.

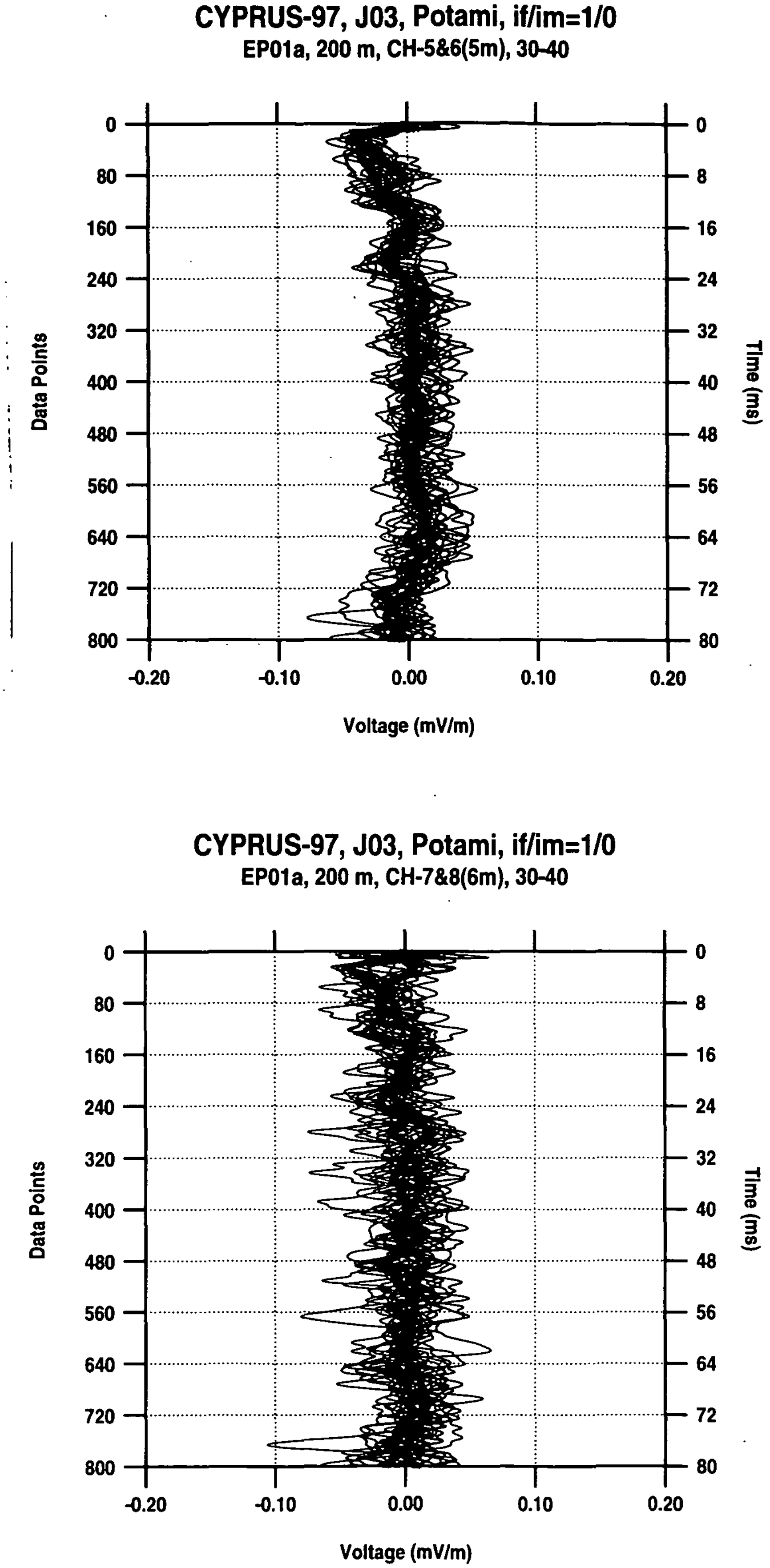


Figure 4.2 Potami profile, sounding 01, 200 m. 10 repeat shots from two symmetric channels (thin lines), with stack averages (thick lines). 1m dipoles. Upper plot (a): dipole centre offsets of +/- 5m. Lower plot (b): dipole centre offsets of +/- 6m.

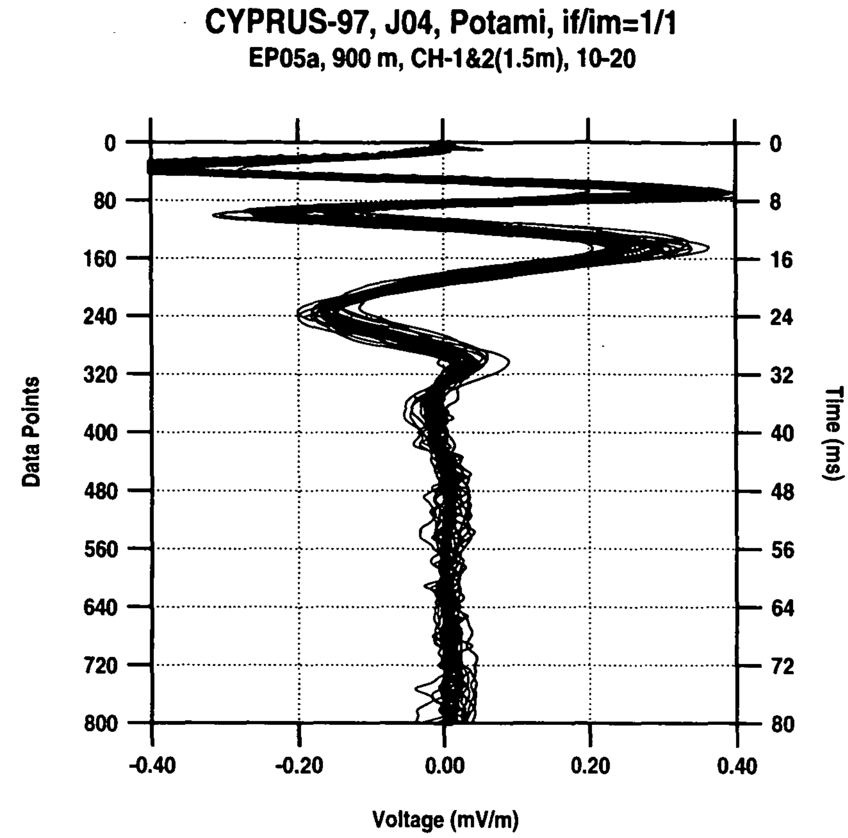
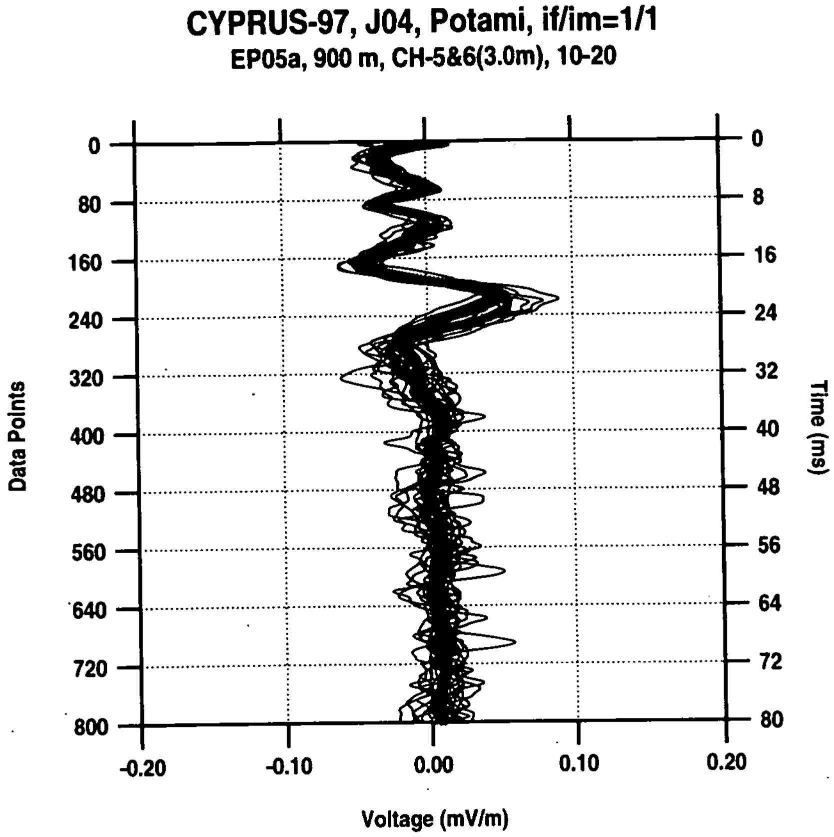


Figure 4.3 Potami profile, sounding 05, 900 m. 10 repeat shots from two symmetric channels (thin lines), with stack averages (thick lines). 2m dipoles. Upper plot (a): dipole centre offsets of +/- 1.5m. Lower plot (b): dipole centre offsets of +/- 2.5m.



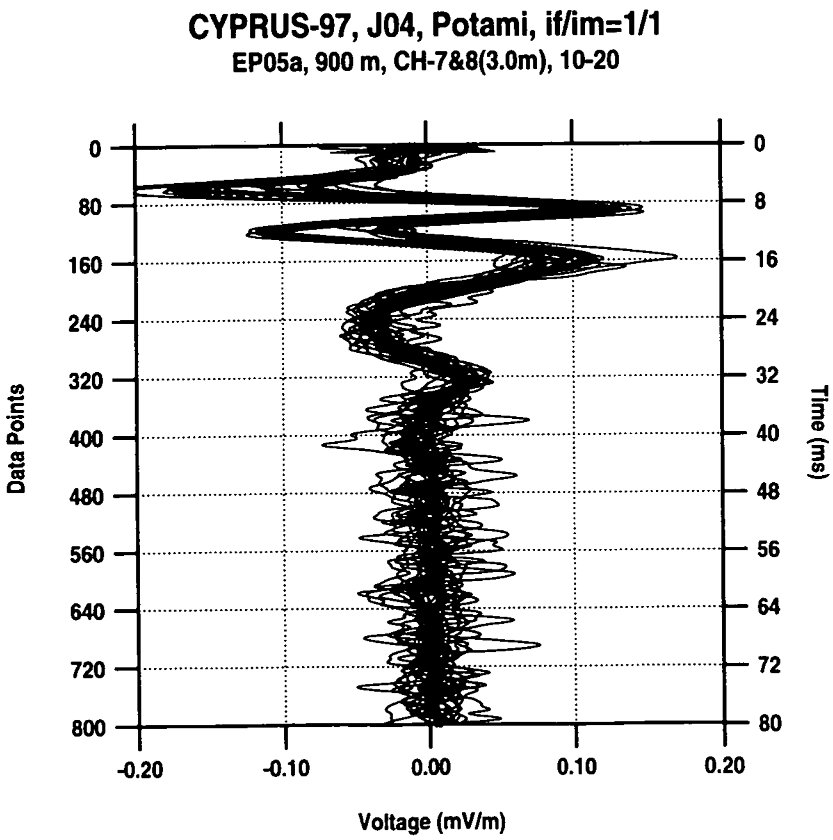


Figure 4.4 Potami profile, sounding 05, 900 m. 10 repeat shots from two symmetric channels (thin lines), with stack averages (thick lines). 2m and 4 m dipoles. Upper plot (a): 2m dipoles with centre offsets of +/- 3.0m. Lower plot (b): 4m dipoles with centre offsets of +/- 3.0m.

Fig. 4.5

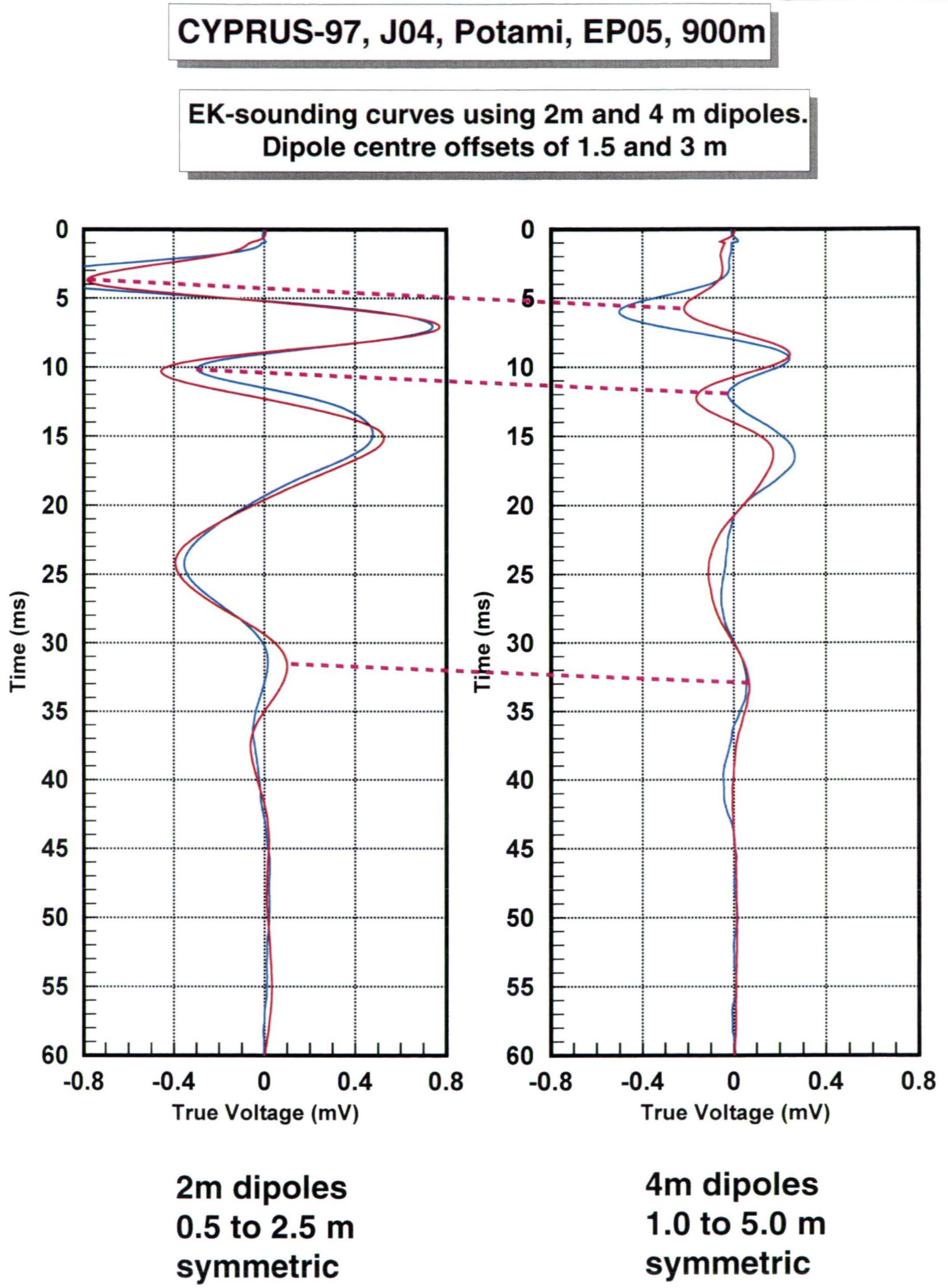


Figure 4.5 EK sounding curves using 2m and 4m dipoles. Sounding 05 (900 m), Potami profile.