U.S. DEPARTMENT OF THE INTERIOR

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Sample analysis and modeling to determine GPR capability for mapping fluvial mine tailings in the Coeur d'Alene River channel

by

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INTRODUCTION

Geoelectrical properties were measured on 11 core samples of sediments taken from the lower Coeur d'Alene River channel to determine if ground penetrating radar (GPR) could be used to map the thickness and distribution of mine tailings in the area. Laboratory measurements of the samples' electrical properties were input into a USGS GPR modeling program to examine how radar waves would propagate through the water-tailings-sediment section. Following this report, Appendix A contains the results of the laboratory measurements.

The 11 samples used for analysis were received from Steve Box of the USGS in Spokane, WA. Seven of the eleven samples were from the upper, tailings-contaminated section. A portion of this core was lost and is not characterized here. The remaining four samples were deposited before mining began in 1885. Table I lists the samples' ID, core depth, and lithology. Previous analyses also note that the mine tailings contain a higher lead content and possibly less clay as reflected in a lower bulk aluminum content. (Written communication, Steve Box, USGS, Spokane, WA).

We expect the tailings section to contain two sub-intervals; a lower interval with relatively high metal content deposited during early mining days in the district, and an upper interval with much lower metal content deposited after better extraction technologies had been introduced. Only sample 95 PCK-1,E is thought to represent the lower interval.

ELECTRICAL PROPERTY MEASUREMENTS

We first measured the electrical properties of the 11 samples. The samples were measured at the Colorado School of Mines in Golden, CO. using an HP 8753D two port network analyzer system, an HP 9000 computer, and a modified version of the program used by Kutrubes, 1986.

Before samples were measured, the network analyzer system was calibrated using the HP 8503 s-parameter test set. The calibration allows the analyzer to make corrections for any directivity or mismatch errors and any electrical length added by internal circuitry and external fixtures. A General Radio 5cm GR 900-LZ3 sample holder was used. With a resonance frequency of 1500 MHz this sample holder provides relatively error free measurements in the 10-1300 MHz range (Kutrubes, 1986).

All samples were measured in a fully saturated state so they would be representative of a submerged sediment environment. When packing the samples into the sample holder, several of the samples lost small amounts of water (a few drops) due to compaction. Other samples however, were undersaturated and water was added in order to obtain a saturated state before analysis.

Appendix A contains the network analyzer output generated by the computer program for each of the eleven samples. The computer output for each sample measurement provides three measured parameters necessary for GPR modeling, relative dielectric permittivity, resistivity, and magnetic permeability. The measured values are found in the columns marked K'meas, Res/ohm-m and Permeability respectively. These values were taken from the output at approximately 80 MHz- the antenna frequency which we will use at Coeur d'Alene. Although exact data at 80MHz is not given in the output, estimates were made from the given values at 53 and 94 MHz. Before entering these parameters into the GPR modeling program the resistivity measurements ρ in ohm-meters (Ω-m) were converted to conductivity values σ milliSiemens per meter (mS/m) using the conversion:

$$\sigma \text{ (mS/m)} = \rho(\Omega\text{-m})/1000$$

COMPUTER MODELING

A modified version of the USGS GPRMODV2 program was used to model the information obtained using the network analyzer. The program was developed by Michael H. Powers and Gary R. Olhoeft of the USGS and is capable of one-dimensional full waveform forward modeling of dispersive ground penetrating radar data (Powers & Olhoeft, 1995). The GPR modeling program uses the following input parameters:

ϵrl = low frequency real relative dielectric permittivity
ϵr∞ = high frequency real relative dielectric permittivity
μrl = low frequency real magnetic permeability
μr∞ = high frequency real magnetic permeability
σ = mS/m (electrical conductivity)

Since we are modeling at a single frequency (80 MHz) and not over a range of frequencies, ϵrl and ϵr∞ correspond to the same K' value for a particular core sample. Likewise the values of μrl and μr∞ correspond to the permeability value for a given core sample. σ corresponds to the conductivity of a core sample.

Table II lists the values of ϵrl, ϵr∞, μrl, μr∞, and σ for each of the 11 core samples and the overlying water as well as the thickness of the layers. The section of missing core is considered to be part of core sample 95PCK-1,A and to have electrical properties similar to the layers around it.

DISCUSSION

Analysis of GPR models help to determine whether a distinct radar reflection occurs at the contact between the tailings and the pre-mining sediments. A reflection would suggest that GPR would be an adequate method for mapping the thickness and distribution of the mine tailings. The models are shown in figures 1 through 14.

Multiple combinations of data were used to produce the models. Two 12-layer models were made using the data for each of the 11 cores and water. For comparison, both models were made at a water depth of 15m. The electrical conductivity of water (σ) measured during Spring runoff was 4.8 mS/m, whereas during the Fall the conductivity rose to 12.9 mS/m (USGS Water Data Report ID-94-2). The two models show how the increasing conductivity of water from May through September affects the GPR propagation. Figure 1 is the Fall model and Figure 6 is the Spring model. Other than an increase in gain with the increase in conductivity, differences between the two models are not noticeable. The shape of the waveform is the same, the reflection at the water/tailings (W/T) interface occurs at the same time (~900 ns), and the reflection at the tailings/pre-mining sediment (T/P) interface occurs at the same time (~1015 ns).

Next, four more 12-layer models were made to demonstrate the effects of water depth on the radar propagation. Since we plan to use GPR in Coeur d'Alene during the Fall we used assumed σ_{H2O} = 12.9 mS/m. Figures 1-5 are the same models with 3m variations in depth from 15m down to 3m. The general shape of these waveforms is the same but the gain and travel time tend to decrease with a decrease in water depth. The gain, for example, gradually decreases from 90 dB at 15m to 80 dB at 3m. The two-way travel time meanwhile decreases at the W/T interface from ~915 ns at 15m to ~185 ns at 3m and at the T/P interface from ~1015 ns at 15m to ~290 ns at 3m.

Four 10-layer models were made next. Core samples 95PCUD-2,A and B were taken from a site approximately 5 miles upstream from 95PCK-1. We modeled the two sites separately rather than as one unit, eliminating two core samples from the 12-layer models. In these models we account for the effect of coupling on the radar system as well. When the radar antennas are placed in water the antenna and the water tend to couple. Hence, the 80 Mhz signal that the antenna would emit in the air may actually have a center frequency of about 40 MHz when it broadcasts a signal into water. To account for the likely 50% decrease in frequency the coupling ratio will be increased by a factor of two and the parameters used in the modeling program will be at 40 MHz. Table III contains the electrical properties of the 11 core samples at 40 MHz.

In the 10-layer models we first assumed the tailings section to be uniform and the pre-mining section to be that of 95PCK-1 core samples F and G from the downstream site. The 10-layer models were created with σ_{H2O}= 12.9 and the coupling ratio = 1 at 80 MHz and 2 at 40 MHz. These models are shown in Figures 13 and 14 of Appendix B and have a more prominent signal at the tailings-sediment (T/P) interface than previously observed in the 12-layer models.

Next we assumed the tailings section to be uniform and the pre-mining section to be that of core samples 95PCUD-2, A and B from the upstream site. Core samples 95PCK-1,F and G were removed from the pre-mining section and 10-layer models were created also with σ_{H2O}= 12.9 and the coupling ratio equal to 1 at 80MHz and 2 at 40 MHz. These models are shown in figures 11 and 12 of Appendix B and show an even more prominent signal at the tailings-sediment (T/P) interface.

Next, four 3-layer models were produced using combinations of the high and low values of permittivity, permeability, and conductivity for the water-tailings-sediment section to determine the best and worst case scenarios. Here the seven cores from the tailings were considered to be one unit and the four pre-mining cores considered another. For comparison purposes the models were once again made with a water depth of 15m and σ_{H2O} = 12.9 mS/m. The high and low values for the water, tailings and sediment sections are listed in Table IV.

Figures 7 and 8 are 3-layer models for the downstream site where the pre-mining sediments have high parameter values. Figure 7 shows a situation where the tailings have a low-metal content and Figure 8 a situation where the tailings have a high-metal content. Both share a major reflection at the W/T interface at ~900 ns. The two models also show a definitive reflection at the T/P interface. In the situation where the tailings have a lower-metal content (Fig.7) the two-way travel time for this reflection is less than in the high-metal contestation situation (Fig.8). This observation tells us two things: 1. that there will be a reflection at the T/P interface in either case, and 2. that the higher the metal content the greater the travel time to the T/P interface.

Figure 9 and 10 are 3-layer models for the upstream site where the pre-mining sediments have low parameter values. Figure 9 shows the situation where the tailings have a high metal content and Figure 10 the situation where the tailings have a low metal content. Both share a major reflection at the W/T interface at ~900 ns. The travel times at the T/P interfaces in Figures 9 and 10 vary with metal content like those in Figures 7 and 8. The major difference between the two sites is the amplitude of the reflection at the T/P interface. This reflection at the upstream site has greater amplitude than at the downstream site. Therefore the models at the upstream site represent the best case scenario for locating the T/P interface using GPR. This is observable when comparing the 10-layer models at the two sites as well.

SUMMARY

By analyzing 3-layer model data (Figures 7-10) it is obvious that any combination of high and low values for the tailings and sediments at the upstream and downstream sites will produce a noticeable reflection at the tailings/pre-mining interface. However, analysis of 12-layer models (Figures 1-6) show that the exact T/P interface may be difficult to identify due to the interference produced by reflections from the surrounding layers .

By modeling the upstream and downstream sites separately and accounting for the coupling factor, the 10-layer models (Figures 11-14) show that the reflection at the T/P interface are more distinguishable from the reflections from the surrounding layers.

The GPRMODV2 program does not account for the ambient noise that interferes with the clarity of the waveforms in an actual scan. Addition of ambient noise from frequencies present in nature may add to the difficulty of identifying the reflections at the T/P interface. Therefore our conclusions are made assuming a noise-free environment.

From the various models created, we feel ground penetrating radar is capable of providing the information necessary to map the thickness and distribution of mine tailings in the area of the Coeur d'Alene River channel. The core samples received have the necessary variation in electrical properties to make a GPR survey a success. It is unknown, however, what effect ambient noise and the missing portion of the upper 95PCK-1 core may have on the radar results.

ACKNOWLEDGEMENTS

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Kutrubes, Doria Lee, 1986, Dielectric permittivity measurements of soils saturated with hazardous fluids: Unpublished masters thesis, Colorado School of Mines.

Powers, M.H. and Olhoeft, G.R., 1995, GPRMODV2: One-Dimensional Full Waveform Forward Modeling of Dispersive Ground Penetrating Radar Data Version 2.0: US Geological Survey Open-file report 95-58.

Box, Steve, 1996, Written communication: US Geological Survey, Spokane, WA.

USGS Water Data Report ID-94-2, 1995.

Table I

Coeur D'Alene Core Samples

Core ID	Depth Below Bottom	Lithology
Tailings section		
95PCD-1	0-33 cm	medium-coarse sand
KA 95	40-45 cm	medium sand
95PCK-1,A	168-193 cm	fine sand
95PCK-1,B	249-250 cm	silty mud
95PCK-1,C	260-262 cm	silty mud
95PCK-1,D	262-297 cm	fine sand
95PCK-1,E	297-326 cm	silt & silty mud
Pre-mining section		
95PCK-1,F	326-343 cm	fine sand & silt interlayers
95PCK-1,G	407-411 cm	silty clay with organic debris
95PCUD-2,A	165-170 cm	thinly laminated very fine sand, silt and mud
95PCUD-2,B	222-227 cm	very fine sand

Table II

GPR Modeling Parameters- 80 MHz

Core ID	$\epsilon r l$, $\epsilon r \infty$	$\mu r l$, $\mu r \infty$	σ (mS/m)	Thickness (m)
Water	80.0	1.00	4.8-12.9	0-15
Tailings section				
95PCD-1	20.8	1.05	64.1	.33
KA 95	22.7	1.04	67.6	.12
95PCK-1,A	14.8	1.01	51.8	1.48
95PCK-1,B	20.1	1.04	64.5	.57
95PCK-1,C	23.4	1.04	84.7	.12
95PCK-1,D	23.0	1.06	73.0	.35
95PCK-1,E	28.4	1.05	63.3	.29
Pre-mining				
95PCK-1,F	27.8	1.03	67.6	.17
95PCK-1,G	31.8	1.03	58.5	.68
95PCUD-2,A	20.7	1.04	15.0	.05
95PCUD-2,B	23.3	1.02	21.7	infinite

Table III

GPR Modeling Parameters- 40 MHz

Core ID	ϵrl, $\epsilon r\infty$	μrl, $\mu r\infty$	σ (mS/m)
95PCD-1	21.3	1.03	16.3
KA 95	23.2	1.02	15.4
95PCK-1,A	15.5	1.00	20.3
95PCK-1,B	20.9	1.02	16.3
95PCK-1,C	24.2	1.02	12.2
95PCK-1,D	23.9	1.04	14.4
95PCK-1,E	29.4	1.03	17.1
95PCK-1,F	29.2	1.01	16.0
95PCK-1,G	32.7	1.01	18.6
95PCUD-2,A	21.2	1.03	77.1
95PCUD-2,B	24.0	1.00	53.3

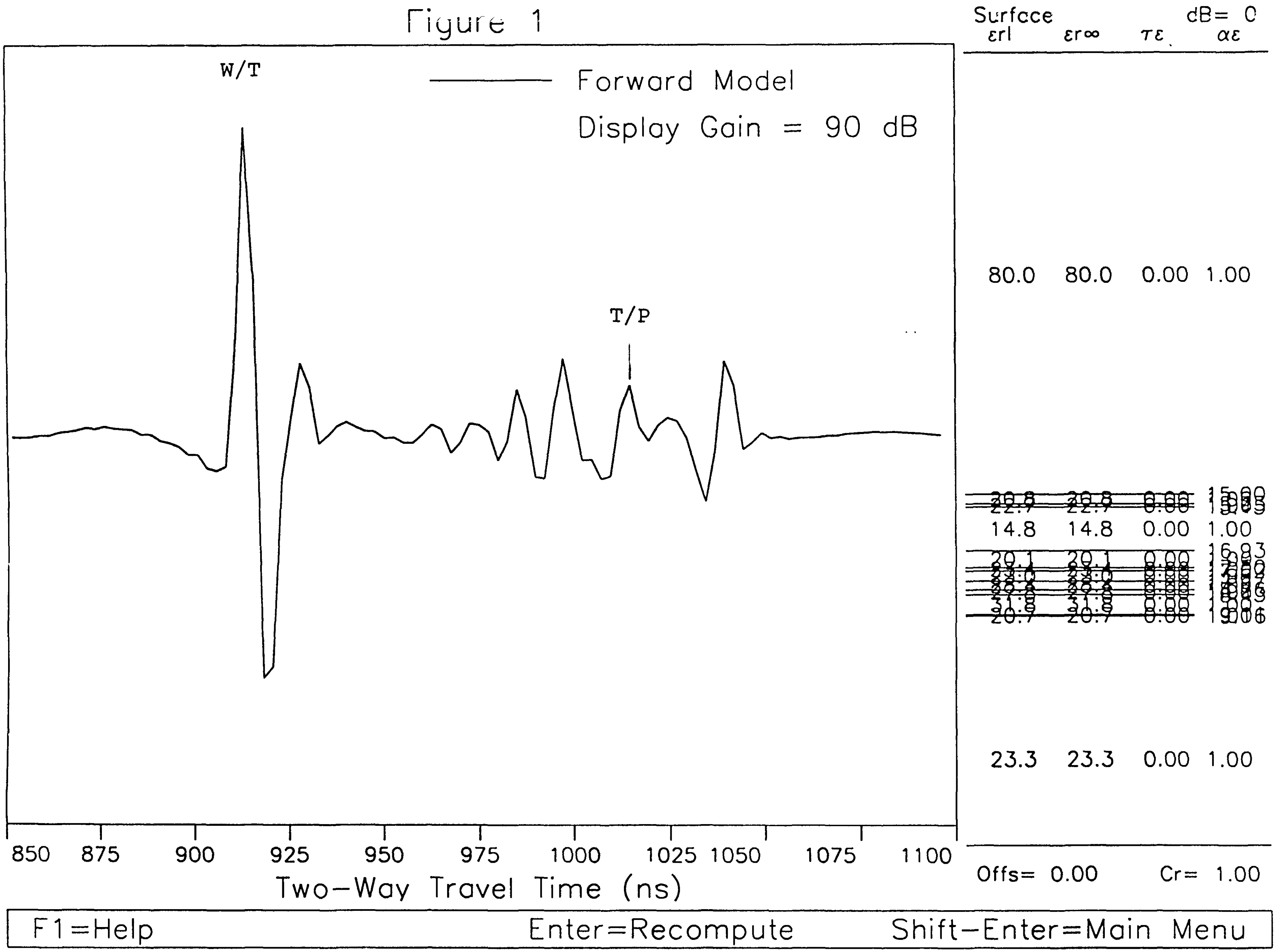
Table IV

3-Layer Model Parameters

Core type	ϵrl, $\epsilon r\infty$	μrl, $\mu r\infty$	σ (mS/m)
Water	80.0	1.00	4.8-12.9
Tailings section			
hi	28.4	1.06	84.7
low	14.8	1.01	51.8
Pre-mining			
hi	31.8	1.04	67.6
low	20.7	1.02	15.0

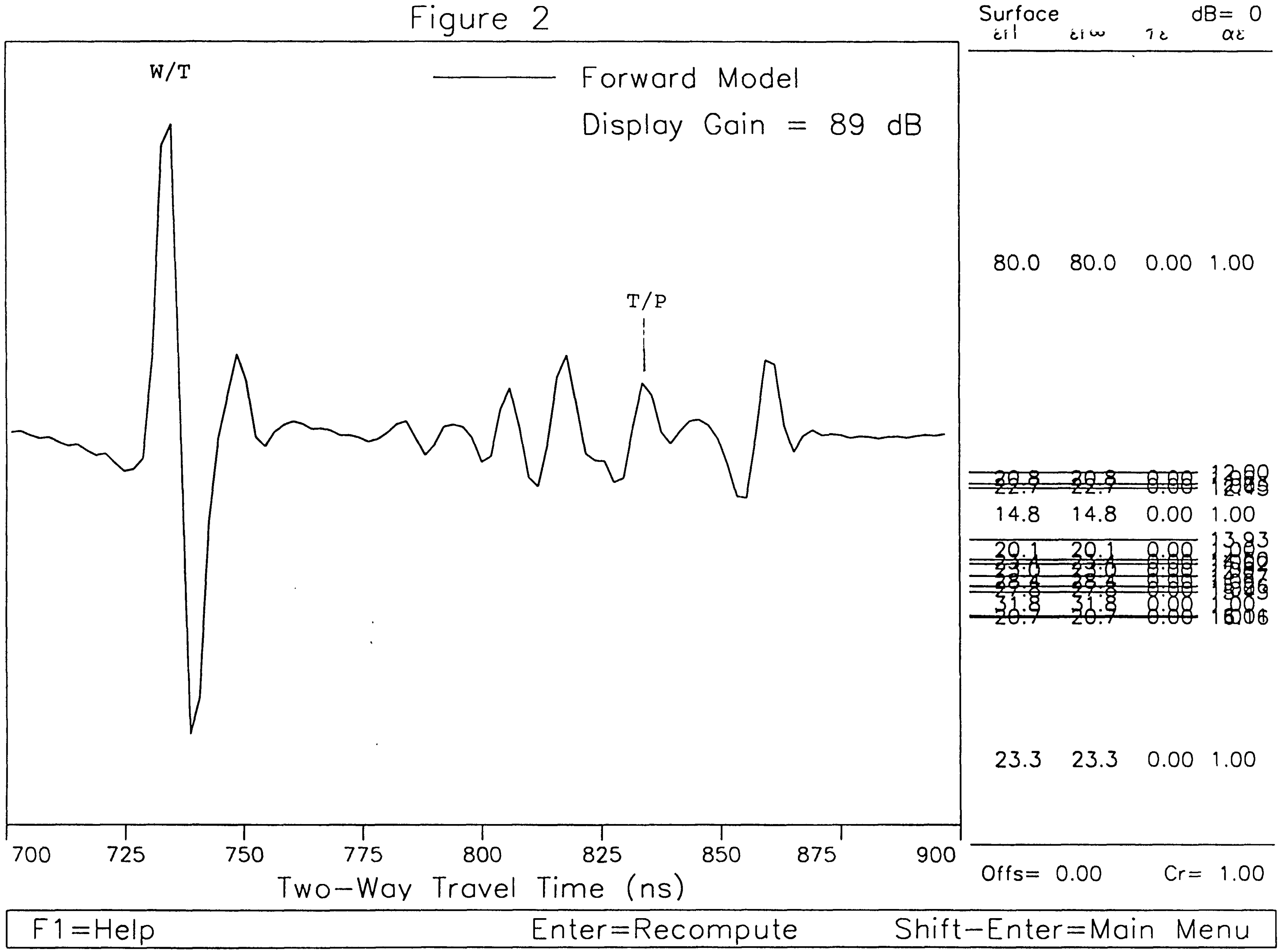
12-layer model, H_2O depth = 15m, σ_{H2O} = 12.9 mS/m

Figure 1



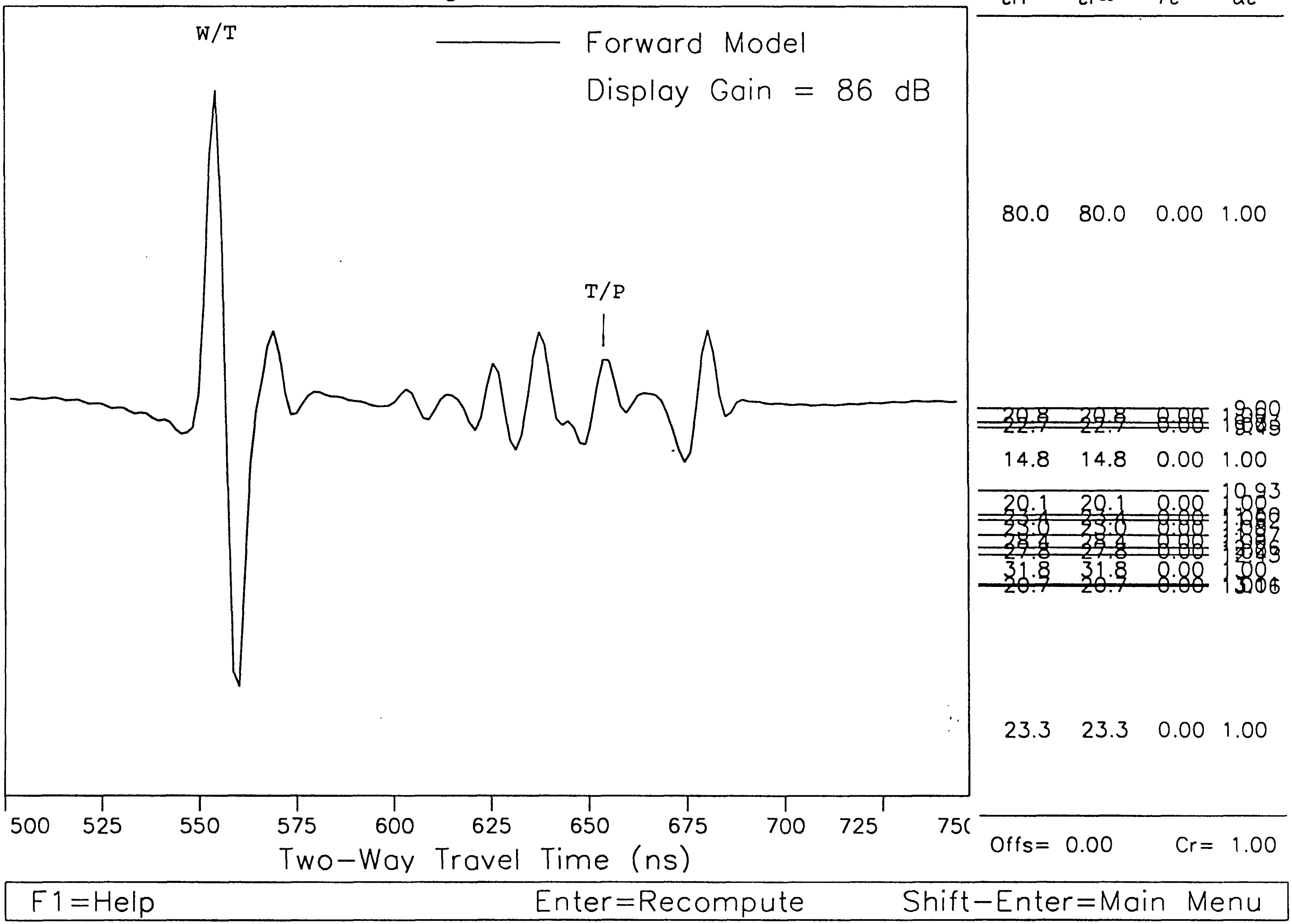
12-layer model, H_2O depth = 12m, σ_{H2O} = 12.9 mS/m

Figure 2



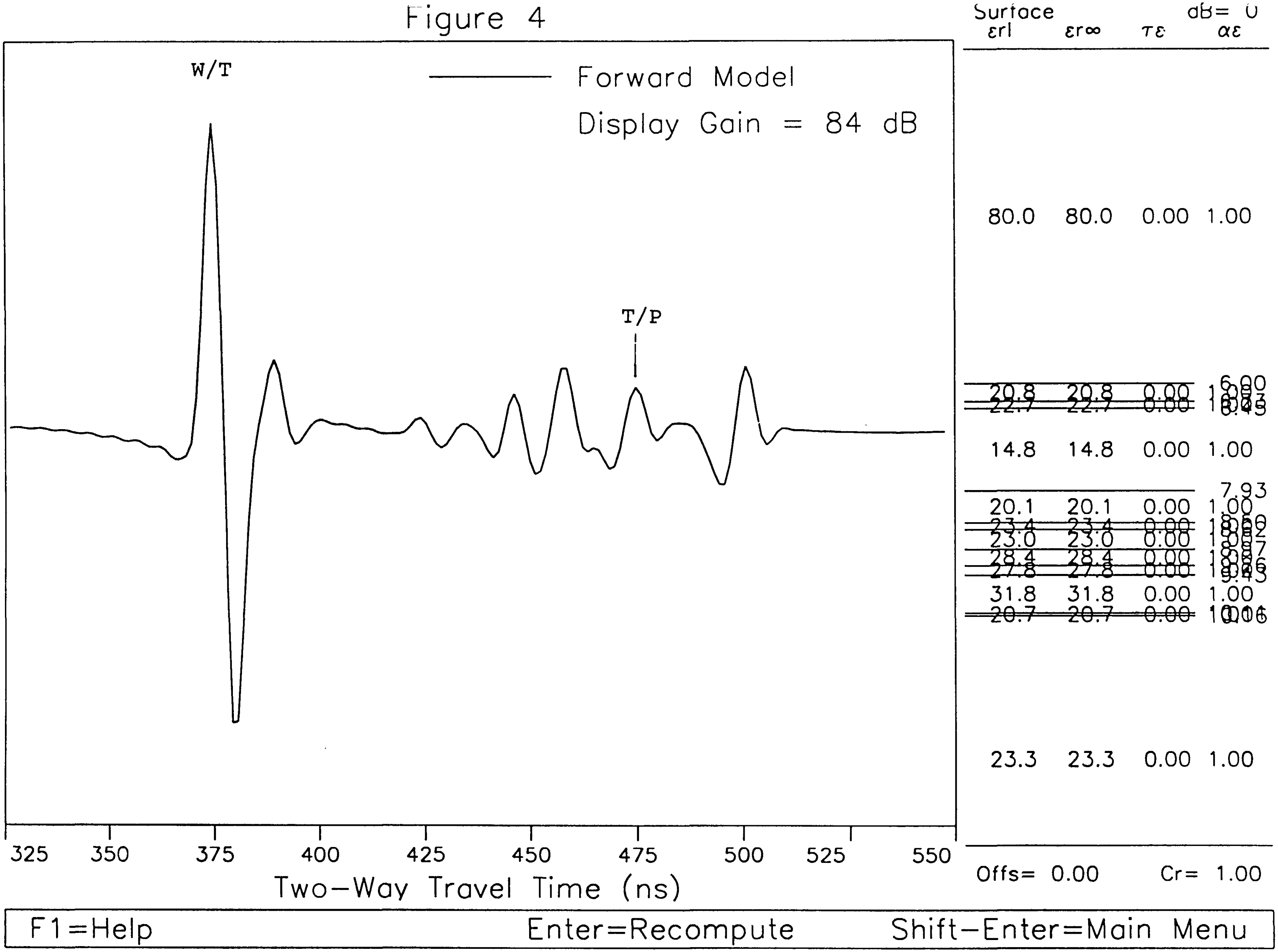
12-layer model, H_2O depth = 9m, σ_{H2O} = 12.9 mS/m

Figure 3



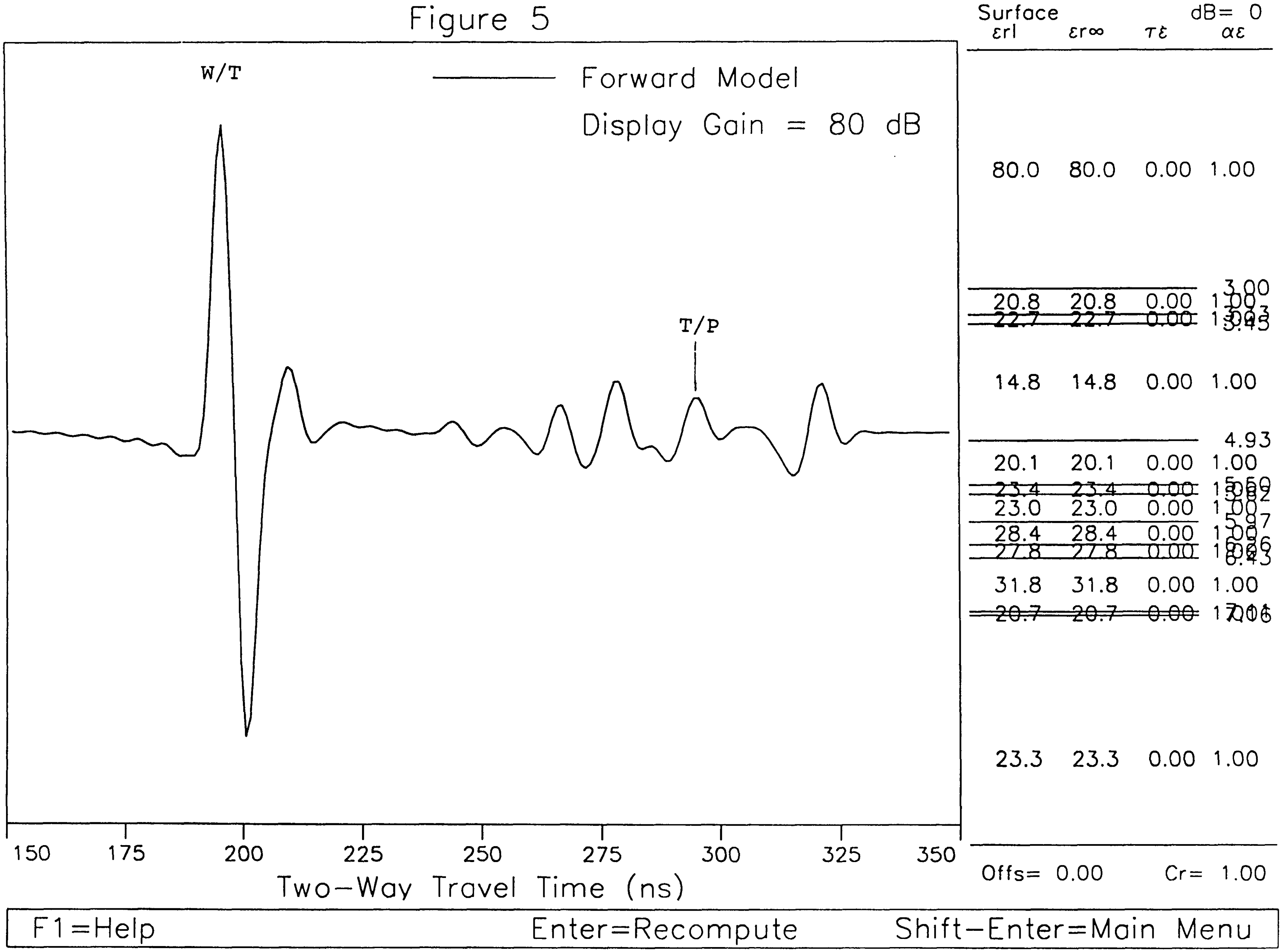
12-layer model, H_2O depth = 6m, σ_{H2O} = 12.9 mS/m

Figure 4

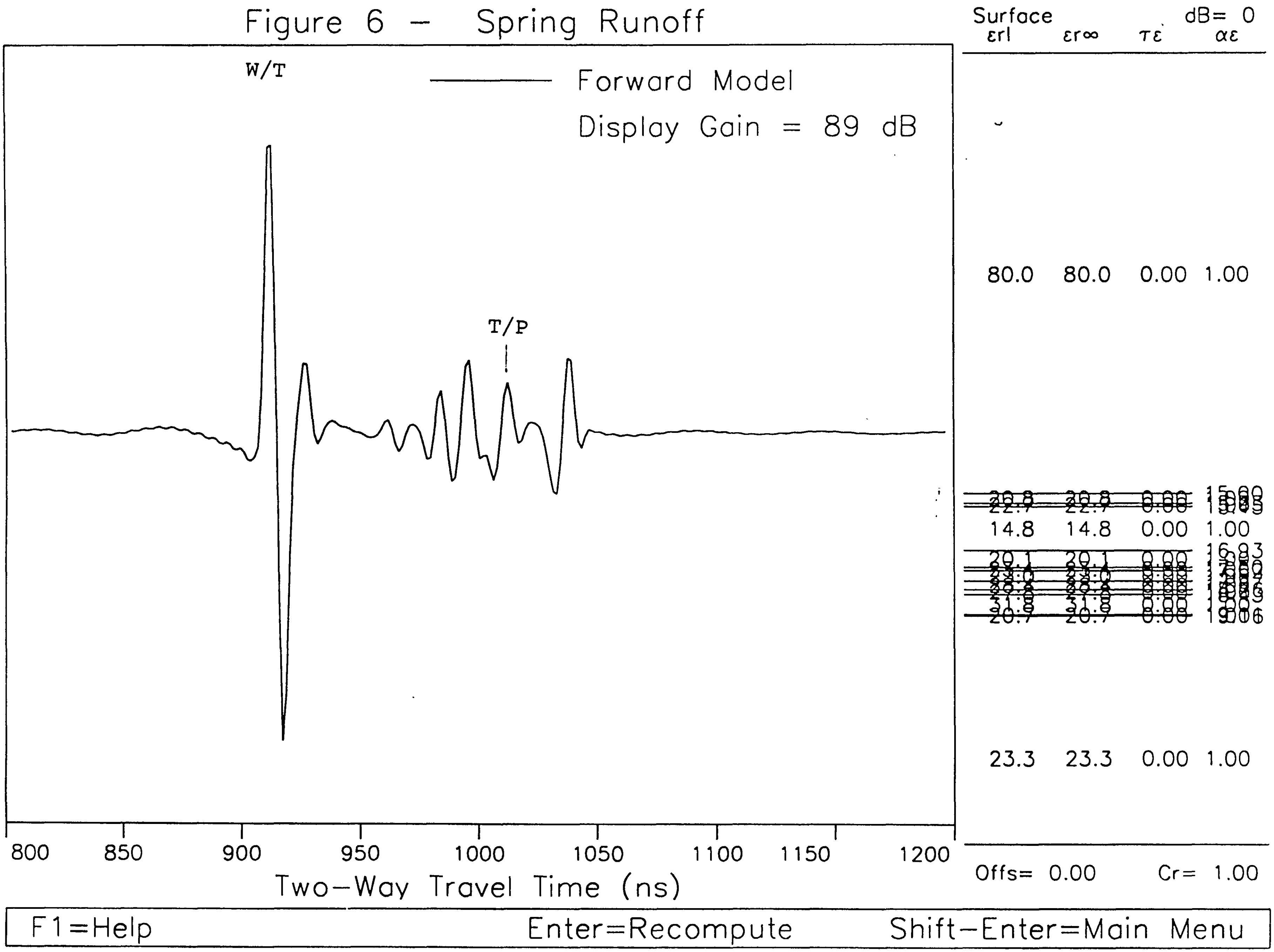


12-layer model, H_2O depth = 3m, σ_{H2O} = 12.9 mS/m

Figure 5

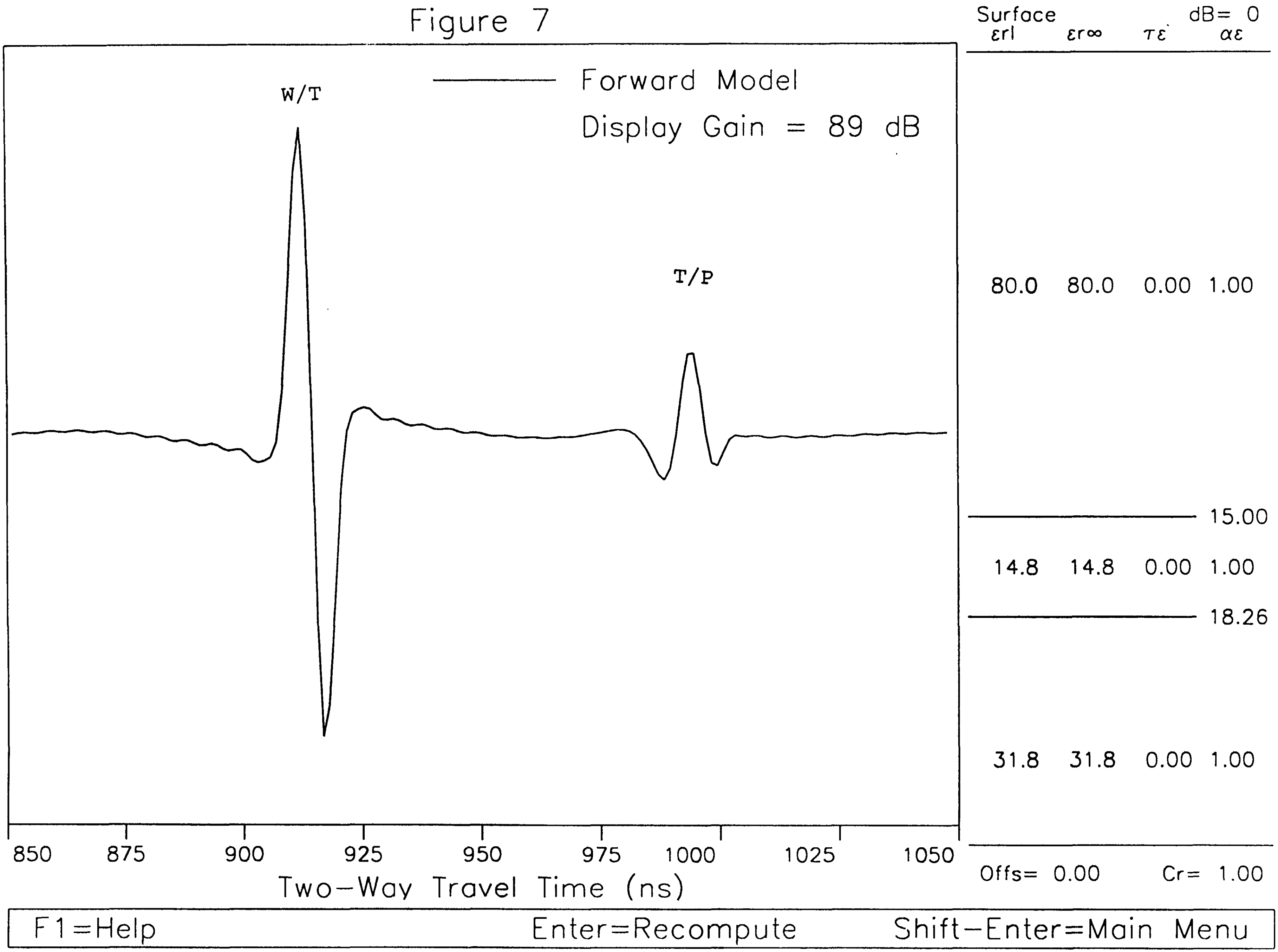


12-layer model, H_2O depth = 15m, σ_{H2O} = 4.8 mS/m



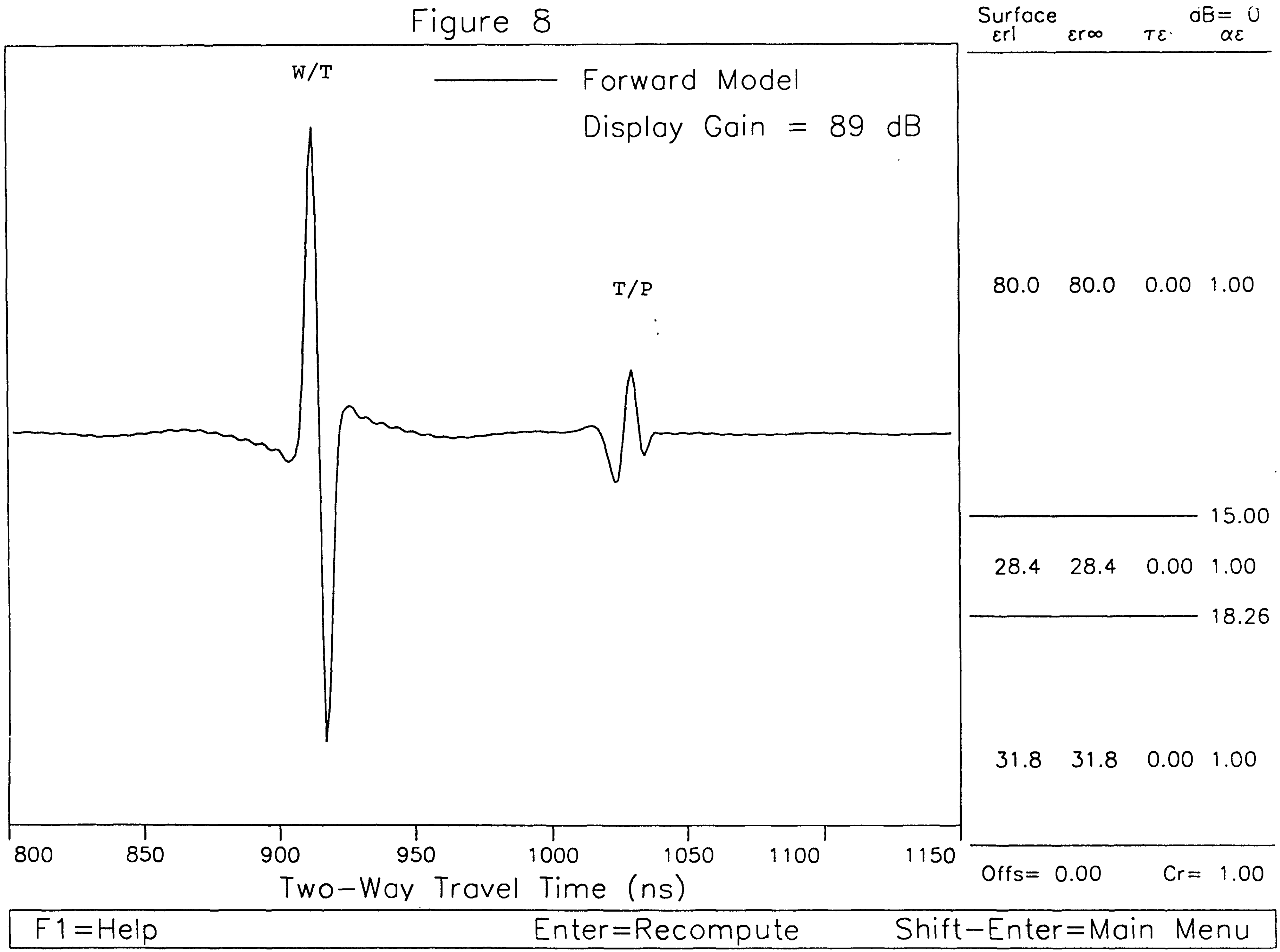
Downstream Site
H_2O depth = 15m, σ_{H2O} = 12.9 mS/m
3-Layer model: Water, low metal content tailings, downstream pre-mining sediments

Figure 7



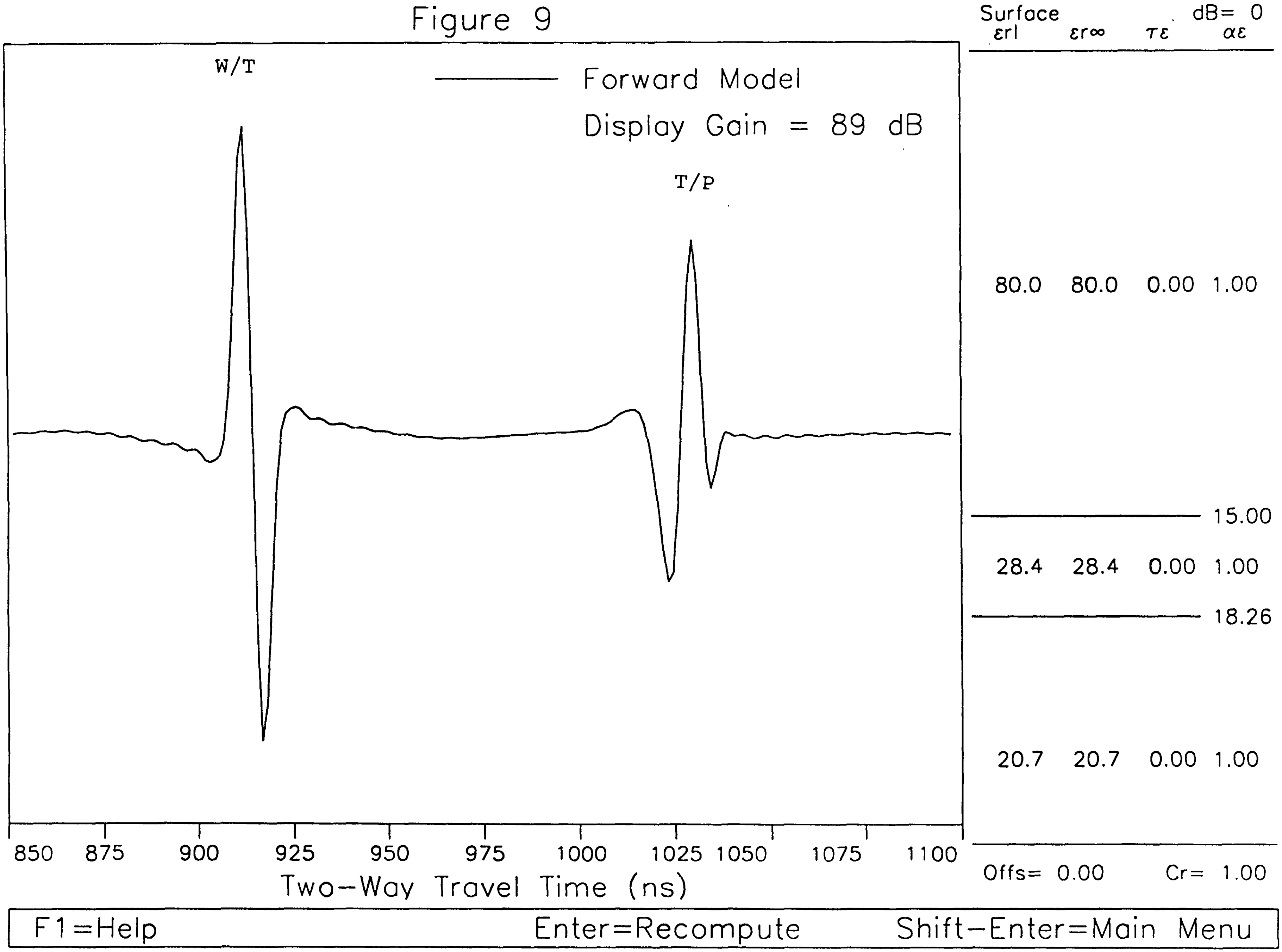
Downstream Site
H_2O depth = 15m, σ_{H2O} = 12.9 mS/m
3-layer model: Water, high metal content tailings, downstream pre-mining sediments

Figure 8



Upstream Site
H_2O depth = 15m, σ_{H2O} = 12.9 mS/m
3-layer model: Water, high metal content tailings, upstream pre-mining sediments

Figure 9

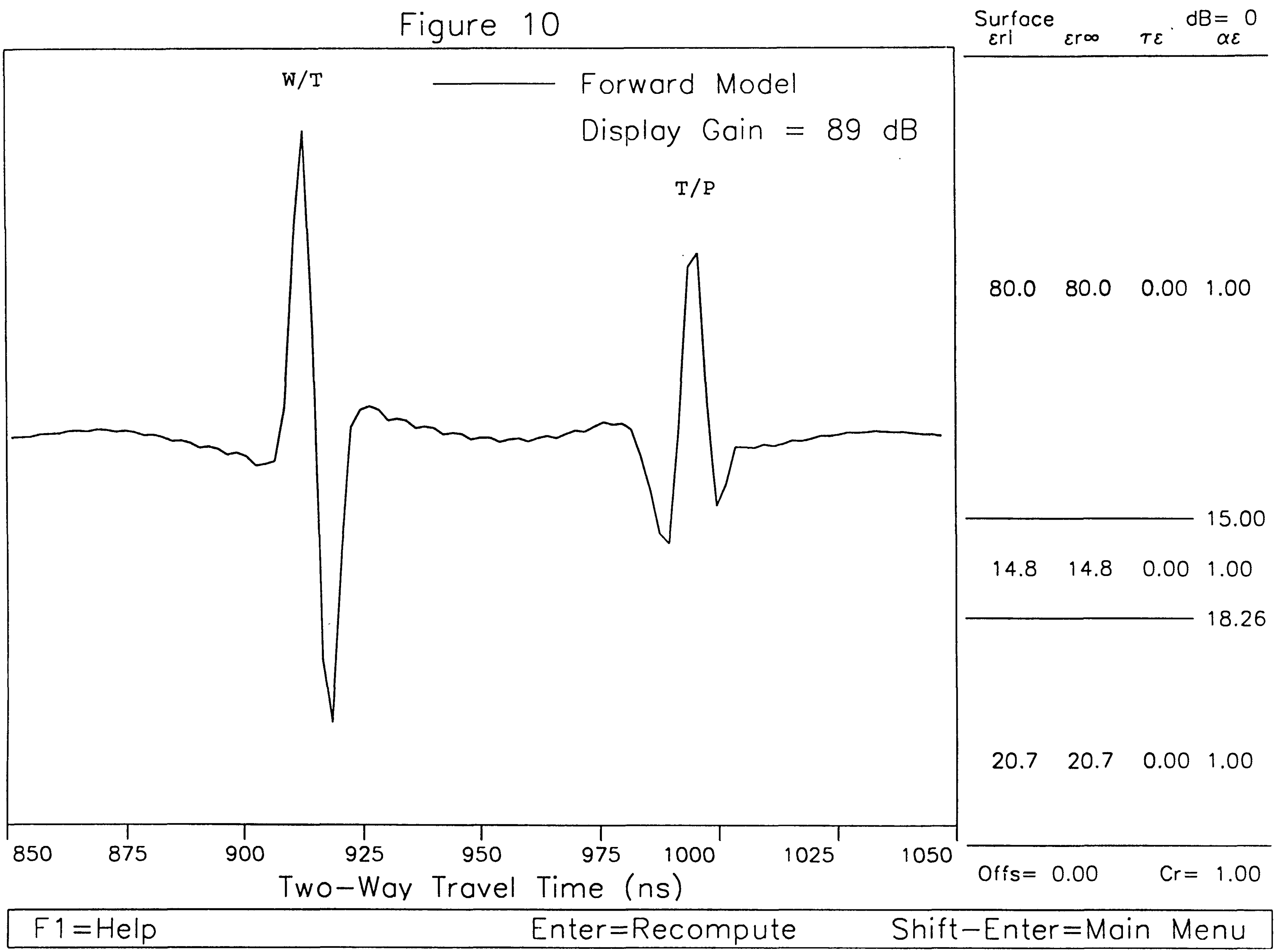


Upstream Site

H_2O depth = 15m, σ_{H2O} = 12.9 mS/m

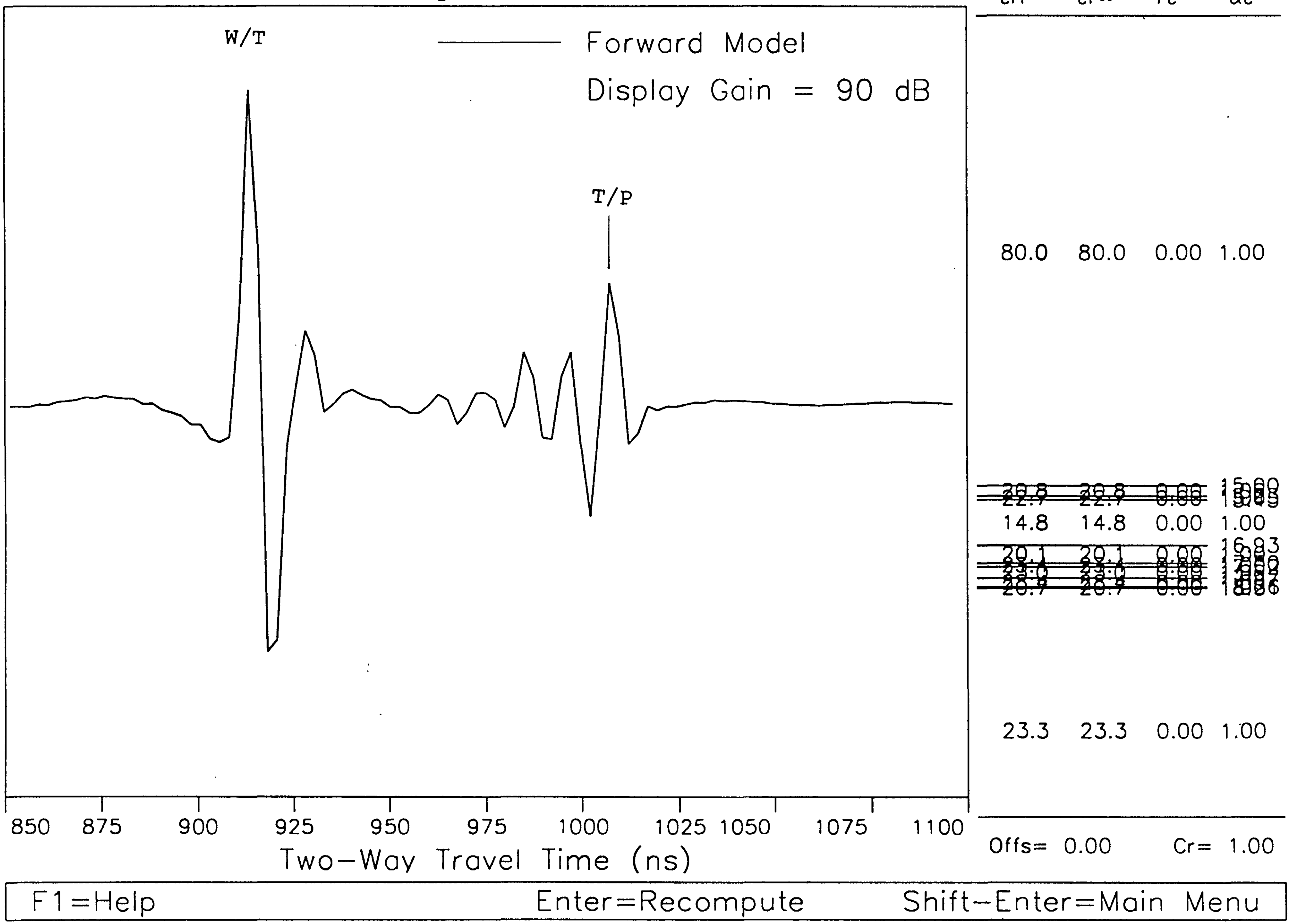
3-layer model: Water, low metal content tailings, upstream pre-mining sediments

Figure 10



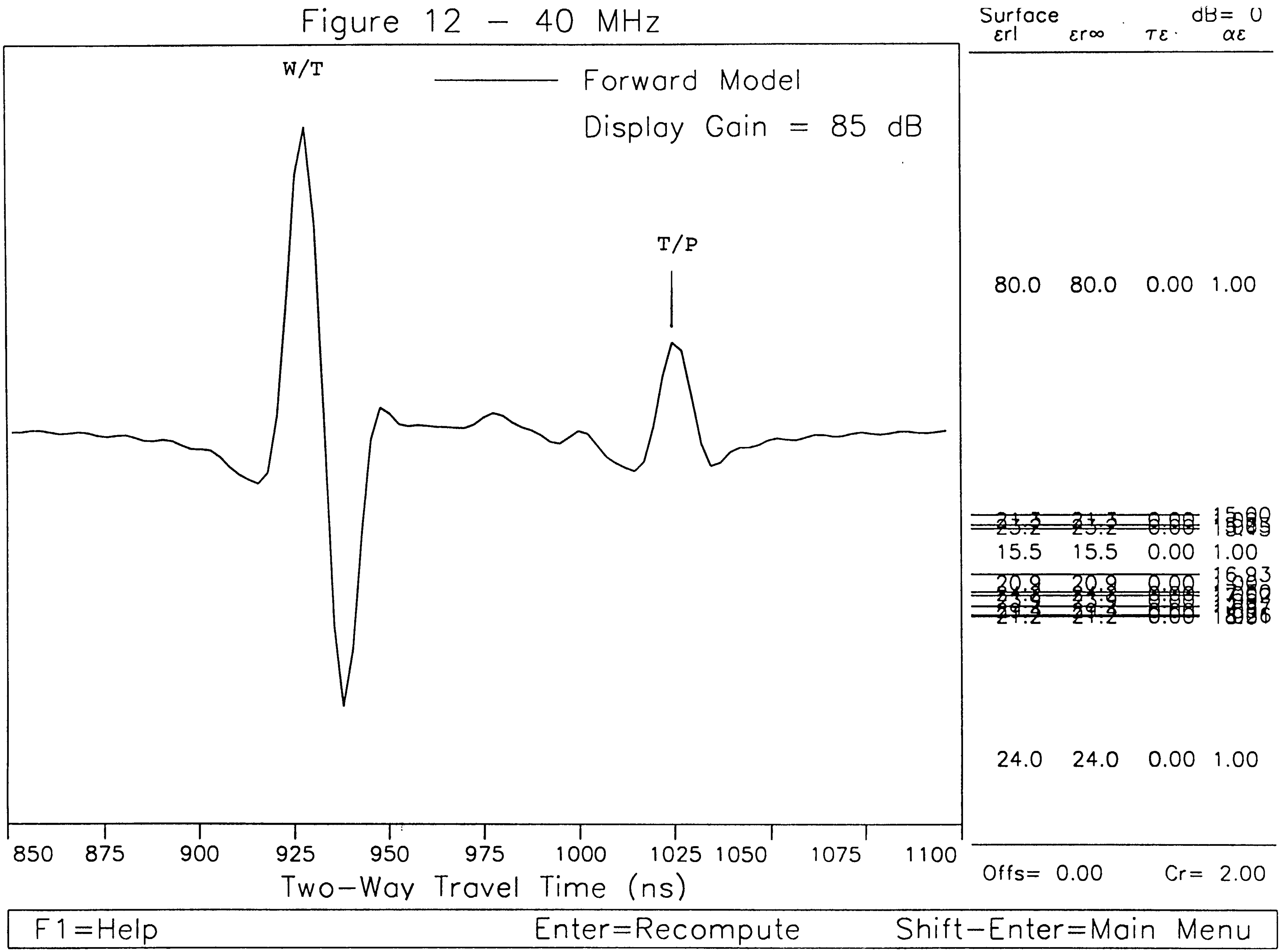
Upstream Site
10-layer model, H_2O depth = 15m, σ_{H2O} = 12.9 mS/m, Cr = 1.00

Figure 11



Upstream Site

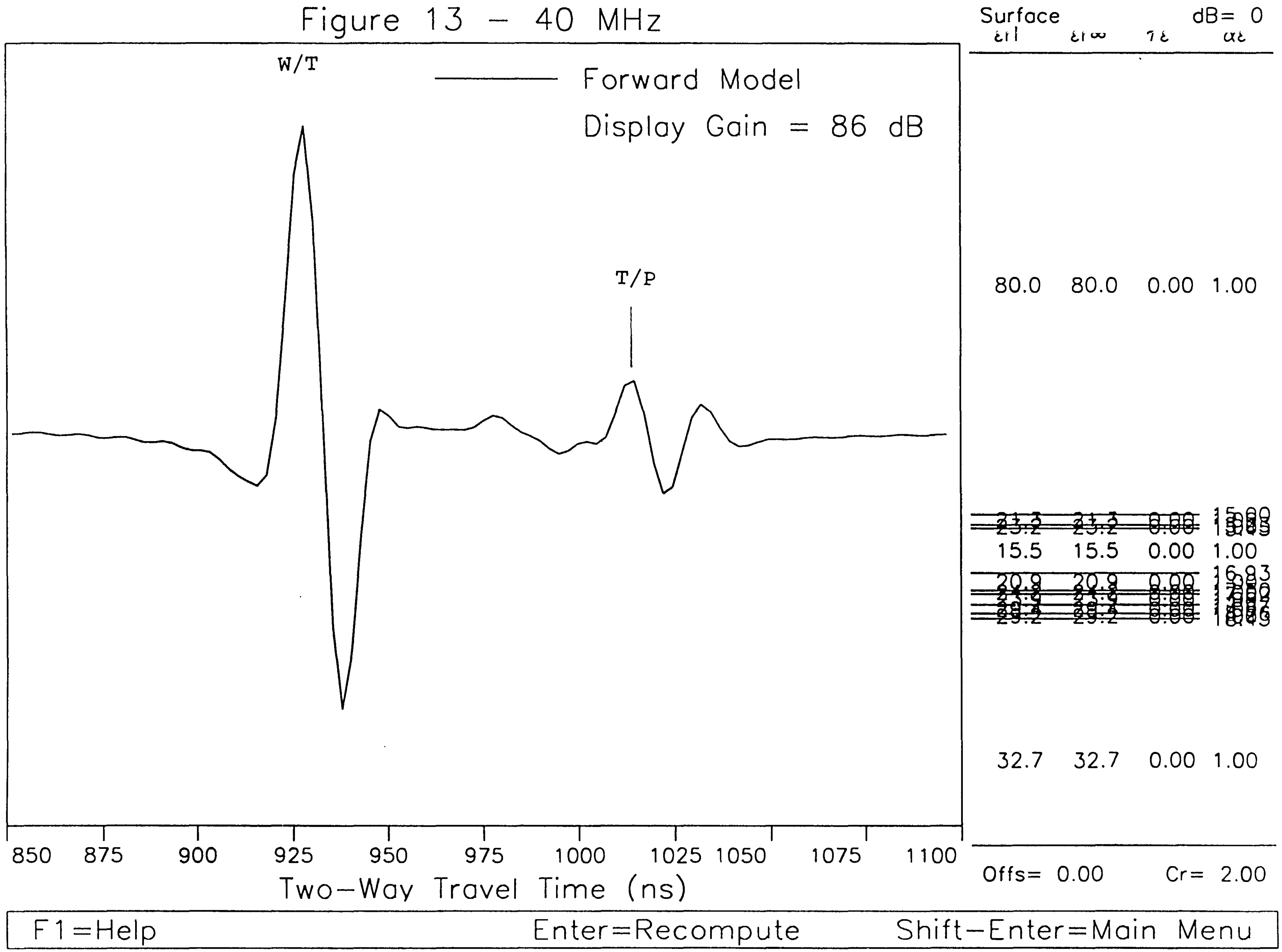
10-layer model, H_2O depth = 15m, σ_{H2O} = 12.9 mS/m, Cr = 2.00



Downstream Site

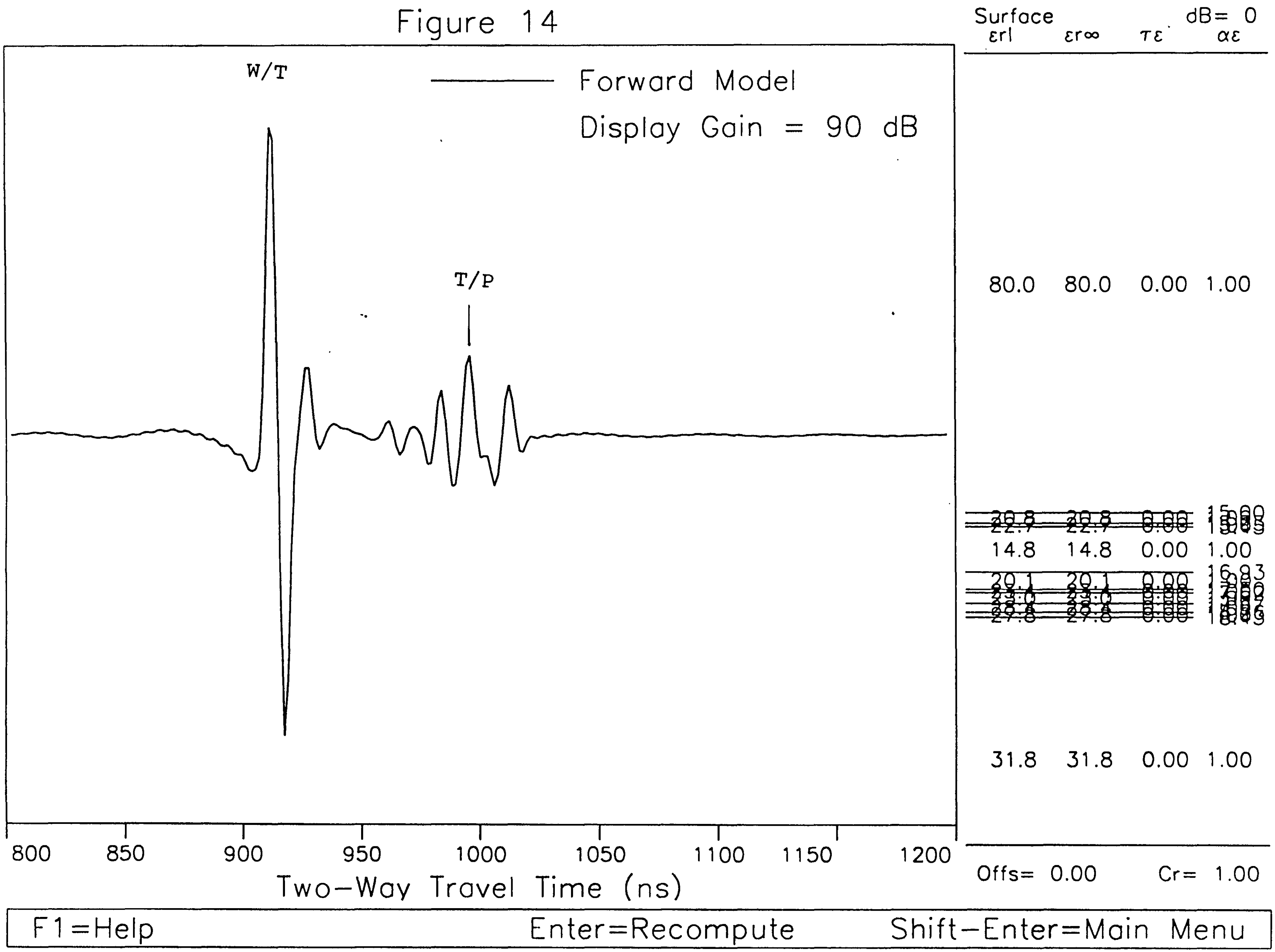
10-layer model, H_2O depth = 15m, σ_{H2O} = 12.9 mS/m, Cr = 2.00

Figure 13 – 40 MHz



Downstream Site
10-layer model, H_2O depth = 15m, σ_{H2O} = 12.9 mS/m, Cr = 1.00

Figure 14



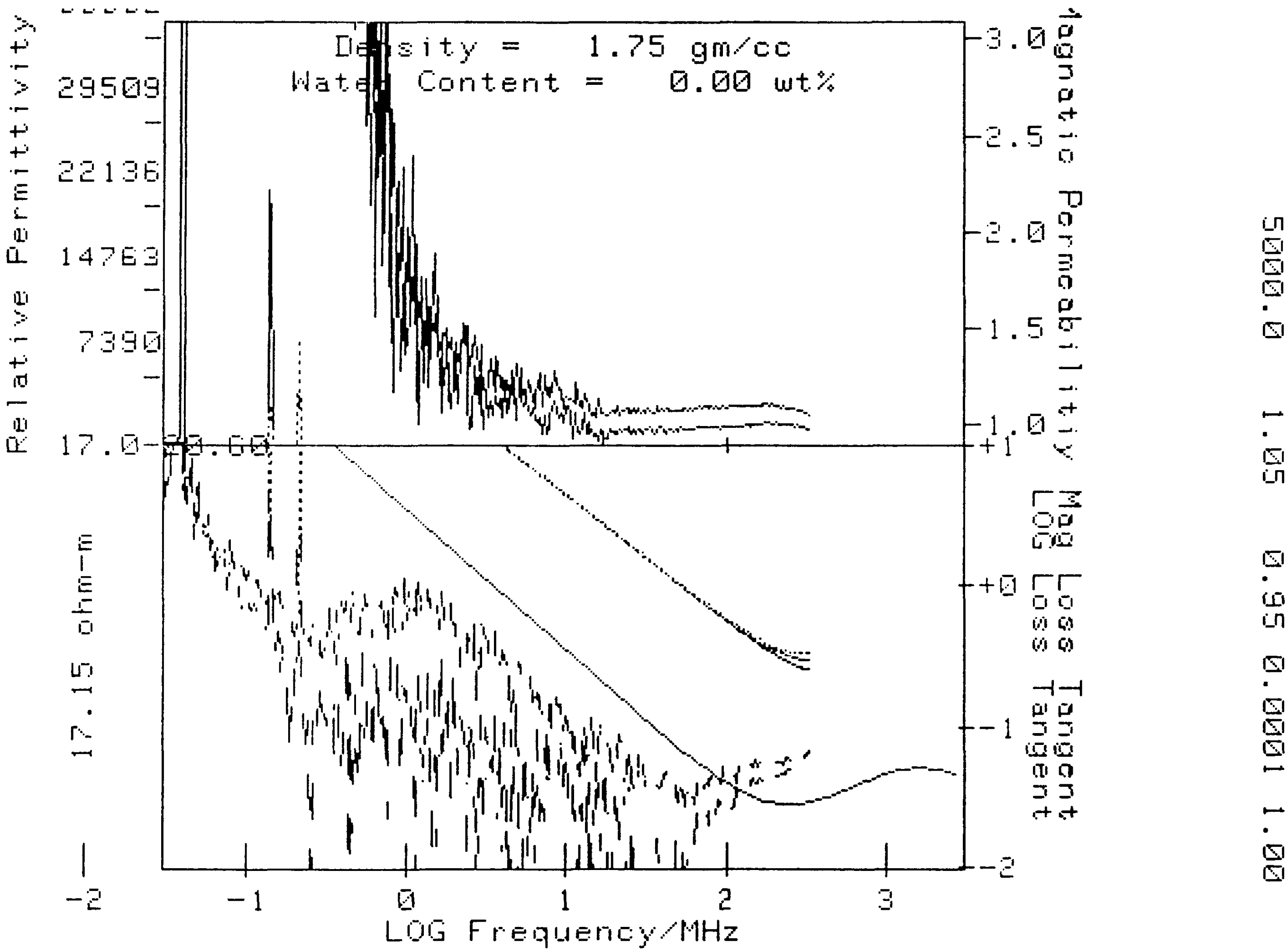
APPENDIX A

Network Analyzer Data

**Analysis of
Coeur d'Alene Core Samples**

WET PCD-1[WT PCD-1]

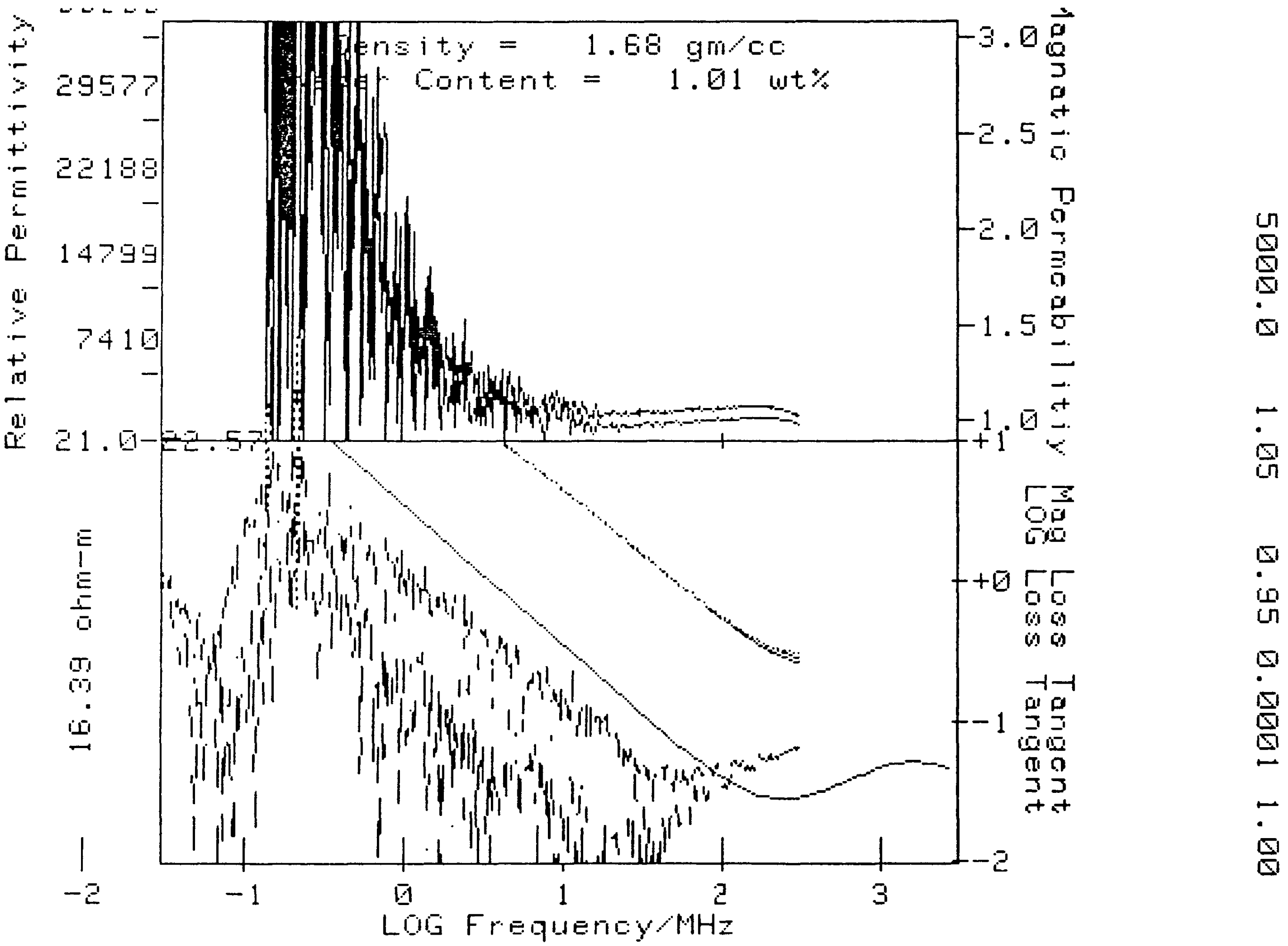
Freq/MHz	K'meas	K'calc	Tandmeas	Tandcalc	Res/ohm-m	Permeability	TanMag
0.030	228.392	228.392	151.887	151.887	17.272	29.653	5.288
0.053	70.203	70.203	279.804	279.804	17.153	39.805	2.521
0.095	35.627	35.627	361.825	361.825	14.698	37.254	1.114
0.169	47.700	47.700	124.013	124.013	18.012	25.664	0.432
0.300	53.929	53.929	61.761	61.761	17.989	8.764	0.251
0.533	44.804	44.804	41.970	41.970	17.918	2.993	0.466
0.949	35.286	35.286	30.132	30.132	17.820	1.413	0.667
1.687	31.496	31.496	19.103	19.103	17.709	1.341	0.370
3.000	27.224	27.224	12.526	12.526	17.571	1.098	0.240
5.335	25.331	25.331	7.611	7.611	17.477	1.150	0.128
9.487	23.674	23.674	4.639	4.639	17.253	1.089	0.066
16.870	22.487	22.487	2.785	2.785	17.017	0.988	0.054
30.000	21.684	21.684	1.659	1.659	16.659	1.025	0.033
53.348	21.038	21.038	0.994	0.994	16.114	1.040	0.022
94.868	20.623	20.623	0.603	0.603	15.236	1.051	0.039
168.702	20.474	20.474	0.387	0.387	13.431	1.064	0.051
300.000	20.844	20.844	0.302	0.302	9.508	1.037	0.063
327.055	21.008	21.008	0.301	0.301	8.681	1.023	0.067



WET PCD-1[WT PCD-1]

WET KA-95[WT_KA95]

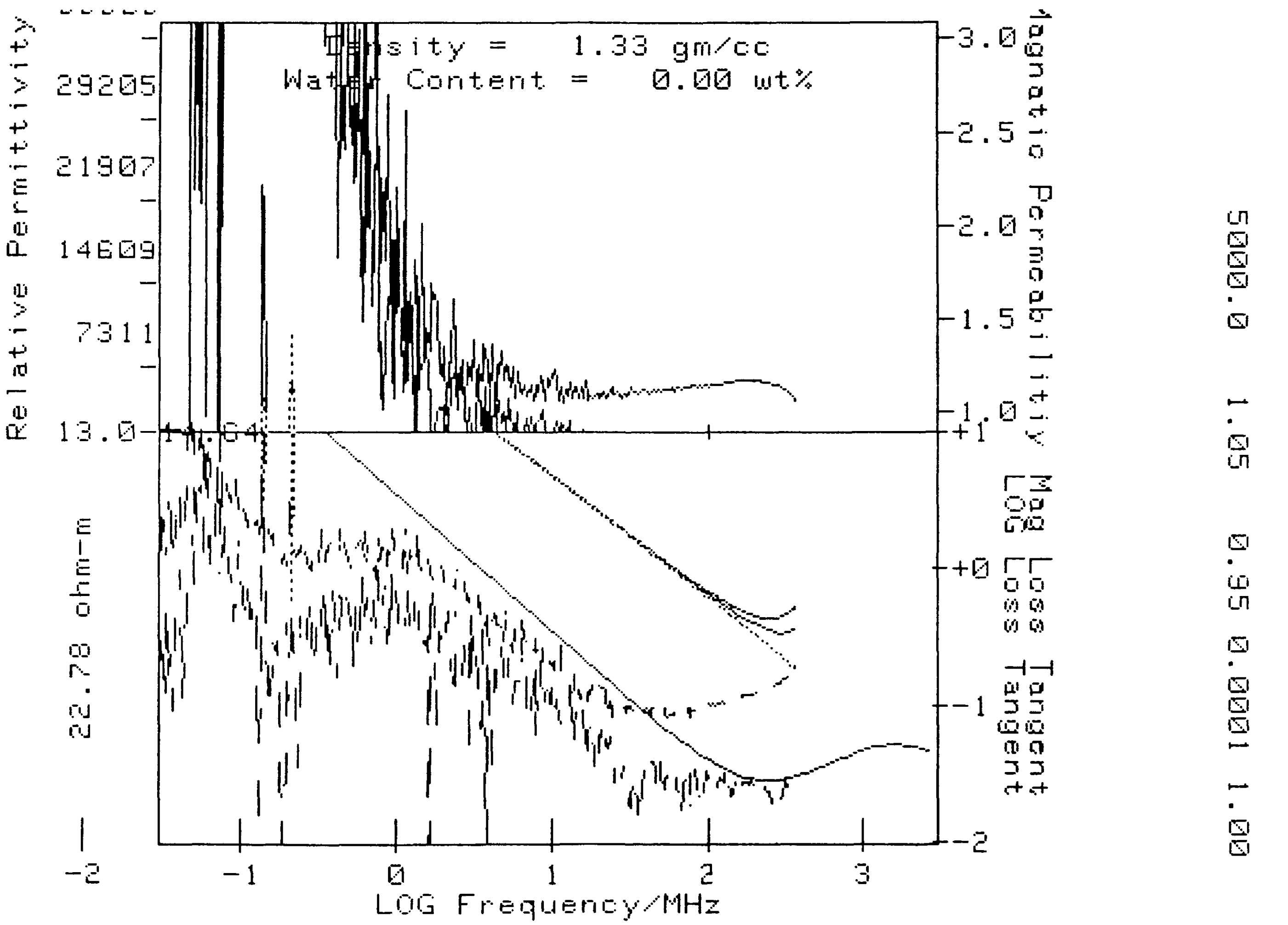
Freq/MHz	K'meas	K'calc	Tandmeas	Tandcalc	Res/ohm-m	Permeability	TanMag
0.030	272.480	272.480	136.658	136.658	16.091	104.280	1.412
0.053	92.494	92.494	222.236	222.236	16.392	60.579	0.232
0.095	68.377	68.377	165.193	165.193	16.775	15.122	0.936
0.169	73.698	73.698	86.663	86.663	16.682	3.864	2.395
0.300	62.295	62.295	57.539	57.539	16.716	3.191	1.310
0.533	47.533	47.533	42.594	42.594	16.642	1.679	0.810
0.949	37.864	37.864	30.225	30.225	16.556	1.072	1.024
1.687	33.323	33.323	19.414	19.414	16.470	1.185	0.348
3.000	29.167	29.167	12.544	12.544	16.376	1.059	0.253
5.335	26.971	26.971	7.677	7.677	16.274	1.088	0.128
9.487	25.440	25.440	4.619	4.619	16.124	1.018	0.119
16.870	24.366	24.366	2.747	2.747	15.921	1.000	0.037
30.000	23.565	23.565	1.629	1.629	15.607	1.007	0.025
53.348	22.961	22.961	0.970	0.970	15.122	1.028	0.032
94.868	22.608	22.608	0.587	0.587	14.278	1.046	0.040
168.702	22.522	22.522	0.377	0.377	12.538	1.055	0.052
300.000	23.269	23.269	0.295	0.295	8.739	1.018	0.072
308.760	23.373	23.373	0.293	0.293	8.487	1.012	0.072



WET KA-95[WT_KA95]

AS RECEIVED PCK-1,A[AR PCK-1A]

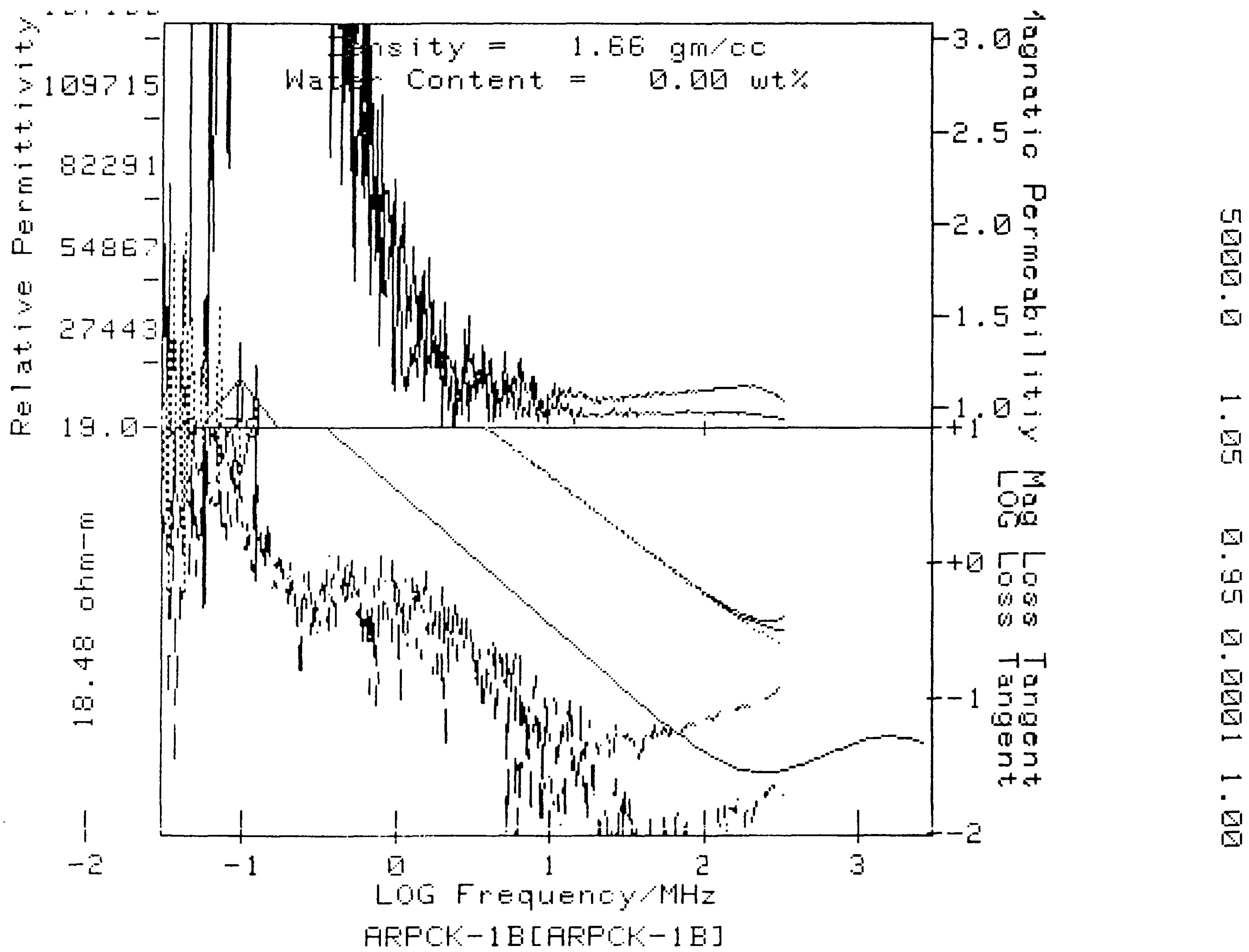
Freq/MHz	K'meas	K'calc	Tandmeas	Tandcalc	Res/ohm-m	Permeability	TanMag
0.030	316.235	316.235	86.159	86.159	21.991	44.855	4.148
0.053	134.940	134.940	109.632	109.632	22.776	2.860	23.656
0.095	79.747	79.747	104.275	104.275	22.785	9.963	2.128
0.169	64.387	64.387	72.768	72.768	22.741	16.489	0.793
0.300	52.909	52.909	49.823	49.823	22.730	5.919	0.885
0.533	38.918	38.918	38.271	38.271	22.622	2.554	0.988
0.949	28.694	28.694	29.362	29.362	22.489	1.374	1.031
1.687	24.665	24.665	19.346	19.346	22.330	1.122	0.839
3.000	21.073	21.073	12.829	12.829	22.162	0.982	0.572
5.335	19.189	19.189	7.987	7.987	21.983	1.083	0.208
9.487	17.691	17.691	4.929	4.929	21.731	1.032	0.147
16.870	16.633	16.633	3.003	3.003	21.334	0.948	0.082
30.000	15.829	15.829	1.822	1.822	20.770	0.987	0.064
53.348	15.131	15.131	1.117	1.117	19.932	1.006	0.057
94.868	14.667	14.667	0.691	0.691	18.693	1.016	0.063
168.702	14.508	14.508	0.446	0.446	16.472	1.020	0.074
300.000	14.937	14.937	0.346	0.346	11.605	0.987	0.088
366.962	15.386	15.386	0.366	0.366	8.710	0.938	0.110



AS RECEIVED PCK-1
A[AR PCK-1A]

ARPCK-1B[ARPCK-1B]

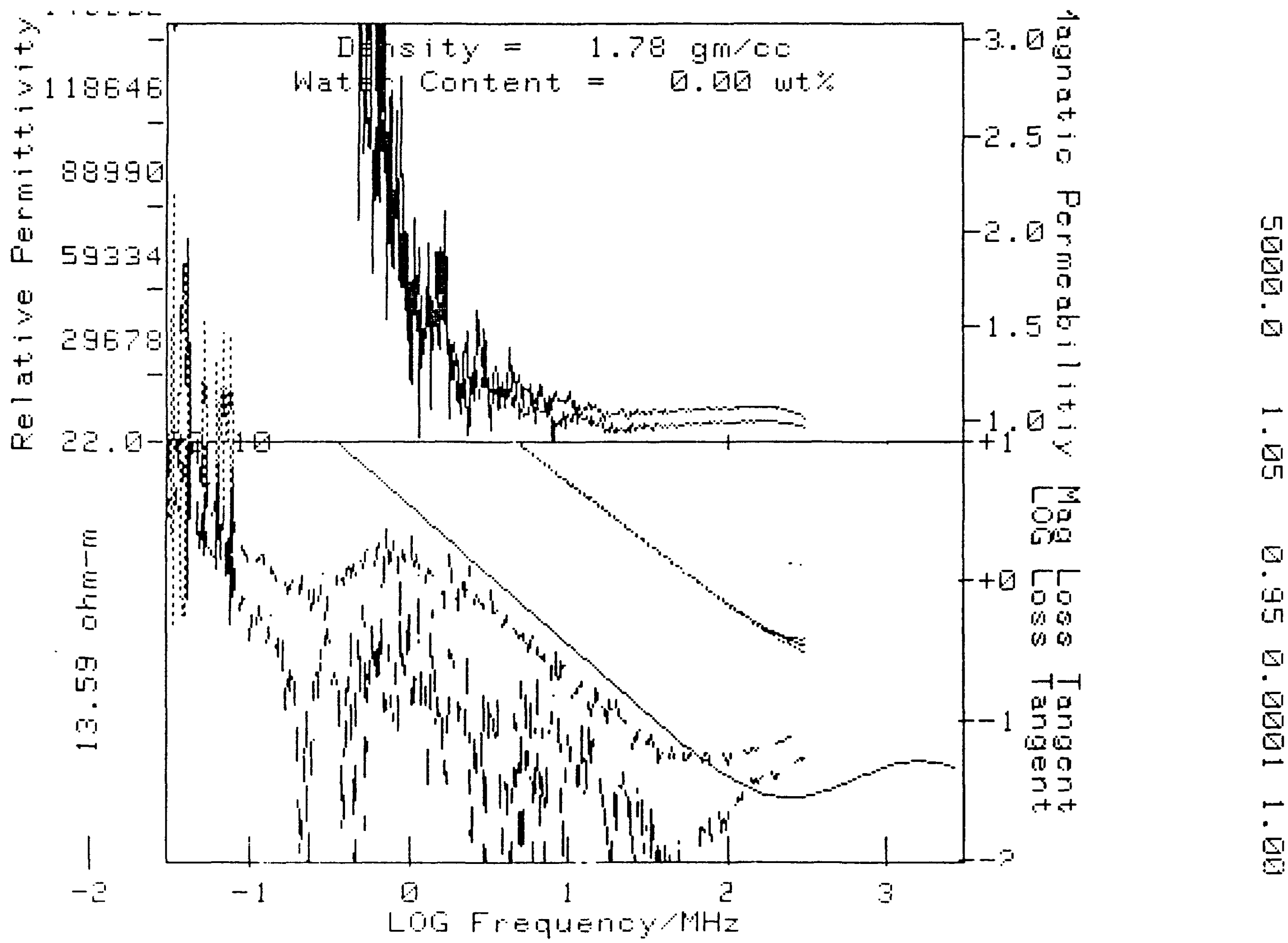
Freq/MHz	K'meas	K'calc	Tandmeas	Tandcalc	Res/ohm-m	Permeability	TanMag
0.030	344.727	344.727	95.399	95.399	18.219	53.126	0.988
0.053	141.552	141.552	128.829	128.829	18.476	14.247	3.977
0.095	16585.476	16585.476	4.268	4.268	2.677	15722.143	4.364
0.169	76.903	76.903	74.992	74.992	18.475	13.820	0.877
0.300	67.451	67.451	48.240	48.240	18.414	6.557	0.333
0.533	51.790	51.790	35.504	35.504	18.324	2.935	0.532
0,949	38.665	38.665	26.903	26.903	18.215	1.678	0.794
1.687	32.104	32.104	18.371	18.371	18.066	1.486	0.231
3.000	28.201	28.201	11.826	11.826	17.966	1.191	0.359
5.335	25.757	25.757	7.356	7.356	17.783	1.071	0.169
9.487	23.786	23.786	4.540	4.540	17.545	1.055	0.098
16.870	22.524	22.524	2.747	2.747	17.218	1.027	0.035
30.000	21.335	21.335	1.682	1.682	16.696	1.005	0.026
53.348	20.423	20.423	1.030	1.030	16.016	1.032	0.031
94.868	19.844	19.844	0.638	0.638	14.964	1.045	0.033
168.702	19.619	19.619	0.416	0.416	13.054	1.055	0.051
300.000	20.322	20.322	0.328	0.328	8.977	1.017	0.069
327.055	20.643	20.643	0.332	0.332	8.008	0.999	0.076



95PCK-1,C

AR PCK-1C[AR PCK-1C]

Freq/MHz	K'meas	K'calc	Tandmeas	Tandcalc	Res/ohm-m	Permeability	TanMag
0.030	599.987	599.987	73.123	73.123	13.657	14.716	23.263
0.053	262.967	262.967	94.311	94.311	13.586	32.628	2.614
0.095	142.460	142.460	97.895	97.895	13.586	35.946	0.949
0.169	102.922	102.922	76.298	76.298	13.568	21.120	0.537
0.300	90.562	90.562	48.986	48.986	13.506	8.110	0.570
0.533	65.388	65.388	38.378	38.378	13.427	2.832	1.015
0.949	46.820	46.820	30.347	30.347	13.336	1.808	0.745
1.687	37.631	37.631	21.331	21.331	13.274	1.668	0.521
3.000	32.500	32.500	13.991	13.991	13.177	1.308	0.316
5.335	29.214	29.214	8.809	8.809	13.093	1.118	0.290
9.487	27.312	27.312	5.354	5.354	12.958	1.074	0.131
16.870	25.768	25.768	3.241	3.241	12.756	0.979	0.099
30.000	24.658	24.658	1.947	1.947	12.480	1.020	0.043
53.348	23.763	23.763	1.177	1.177	12.049	1.030	0.032
94.868	23.147	23.147	0.720	0.720	11.366	1.041	0.039
168.702	[illegible].891	22.891	0.463	0.463	10.063	1.045	0.051
300.000	[illegible]588	23.588	0.354	0.354	7.171	1.008	0.074
308.760	[illegible].736	23.736	0.356	0.356	6.897	1.003	0.077

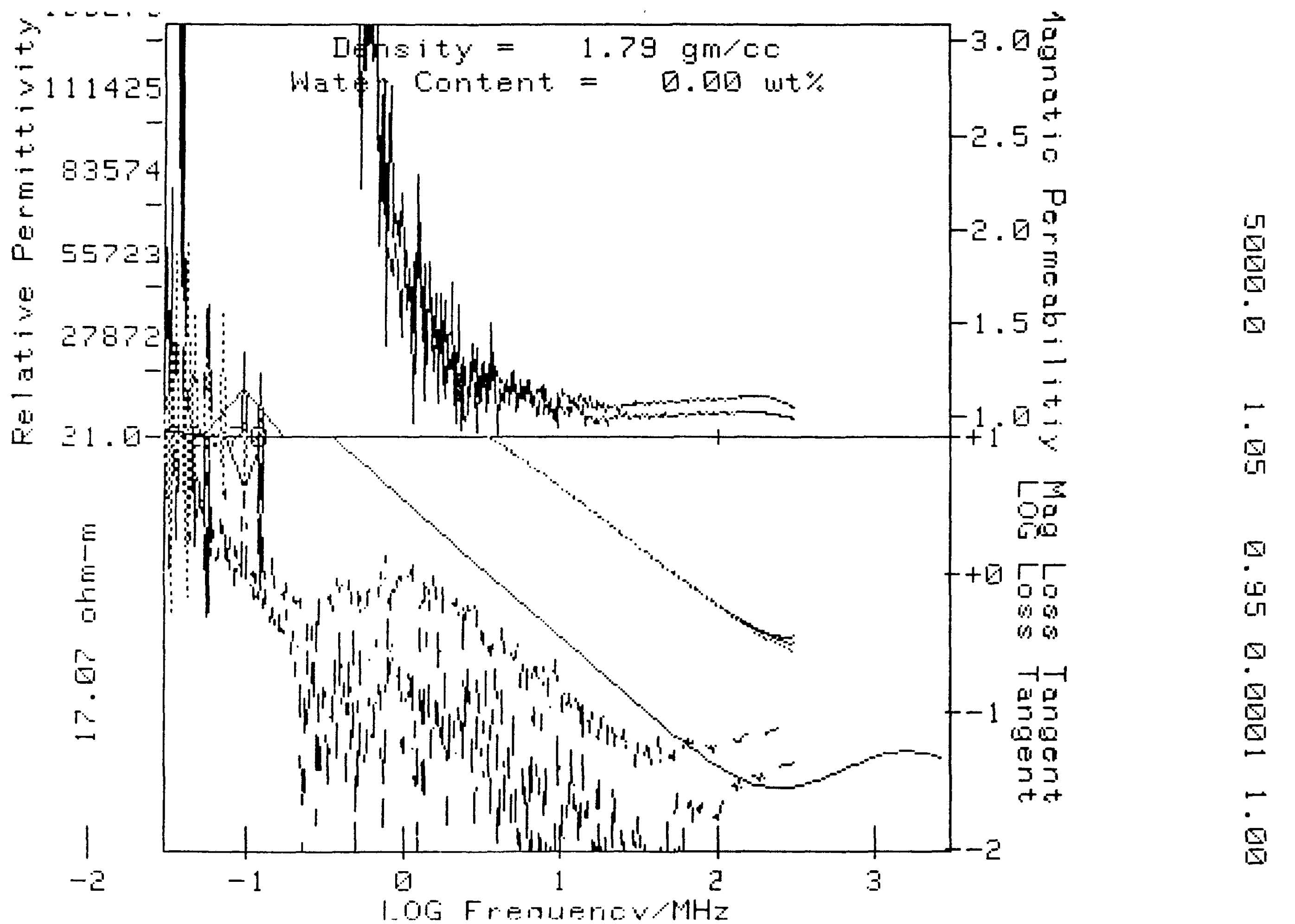


AR PCK-1C[AR PCK-1C]

95PCK-1,D

ARPCK-1D[ARPCK-1D]

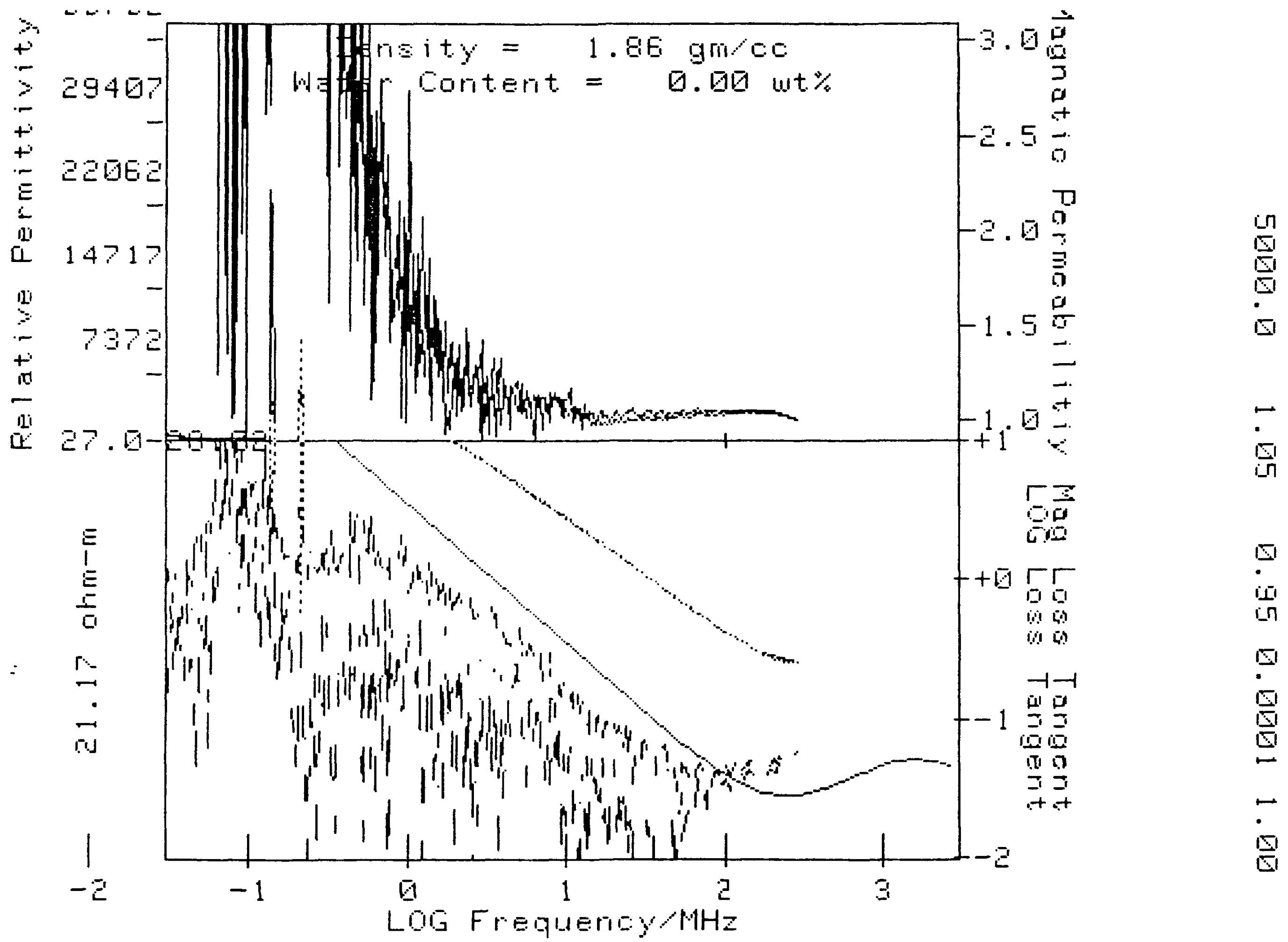
Freq/MHz	K'meas	K'calc	Tandmeas	Tandcalc	Res/ohm-m	Permeability	TanMag
0.030	1541.429	1541.429	22.380	22.380	17.368	15.334	8.559
0.053	794.350	794.350	24.854	24.854	17.066	38.346	2.173
0.095	16518.570	16518.570	4.250	4.250	2.699	15568.539	4.360
0.169	226.400	226.400	28.172	28.172	16.706	19.627	0.483
0.300	140.144	140.144	25.862	25.862	16.531	9.136	0.308
0.533	86.939	86.939	23.718	23.718	16.340	4.455	0.332
0.949	57.206	57.206	20.476	20.476	16.176	1.814	0.491
1.687	42.086	42.086	15.816	15.816	16.007	1.583	0.166
3.000	34.153	34.153	11.053	11.053	15.872	1.163	0.357
5.335	29.951	29.951	7.171	7.171	15.687	1.078	0.169
9.487	27.358	27.358	4.474	4.474	15.478	1.091	0.094
16.870	25.660	25.660	2.733	2.733	15.195	1.044	0.036
30.000	24.366	24.366	1.665	1.665	14.766	1.041	0.023
53.348	23.403	23.403	1.015	1.015	14.182	1.050	0.030
94.868	22.778	22.778	0.627	0.627	13.263	1.066	0.035
168.702	22.498	22.498	0.410	0.410	11.553	1.076	0.051
300.000	23.224	23.224	0.321	0.321	8.034	1.034	0.068
308.760	23.344	23.344	0.322	0.322	7.755	1.030	0.071



ARPCK-1D[ARPCK-1D]

AS RECEIVED PCK-1,E[AR PCK-1E]

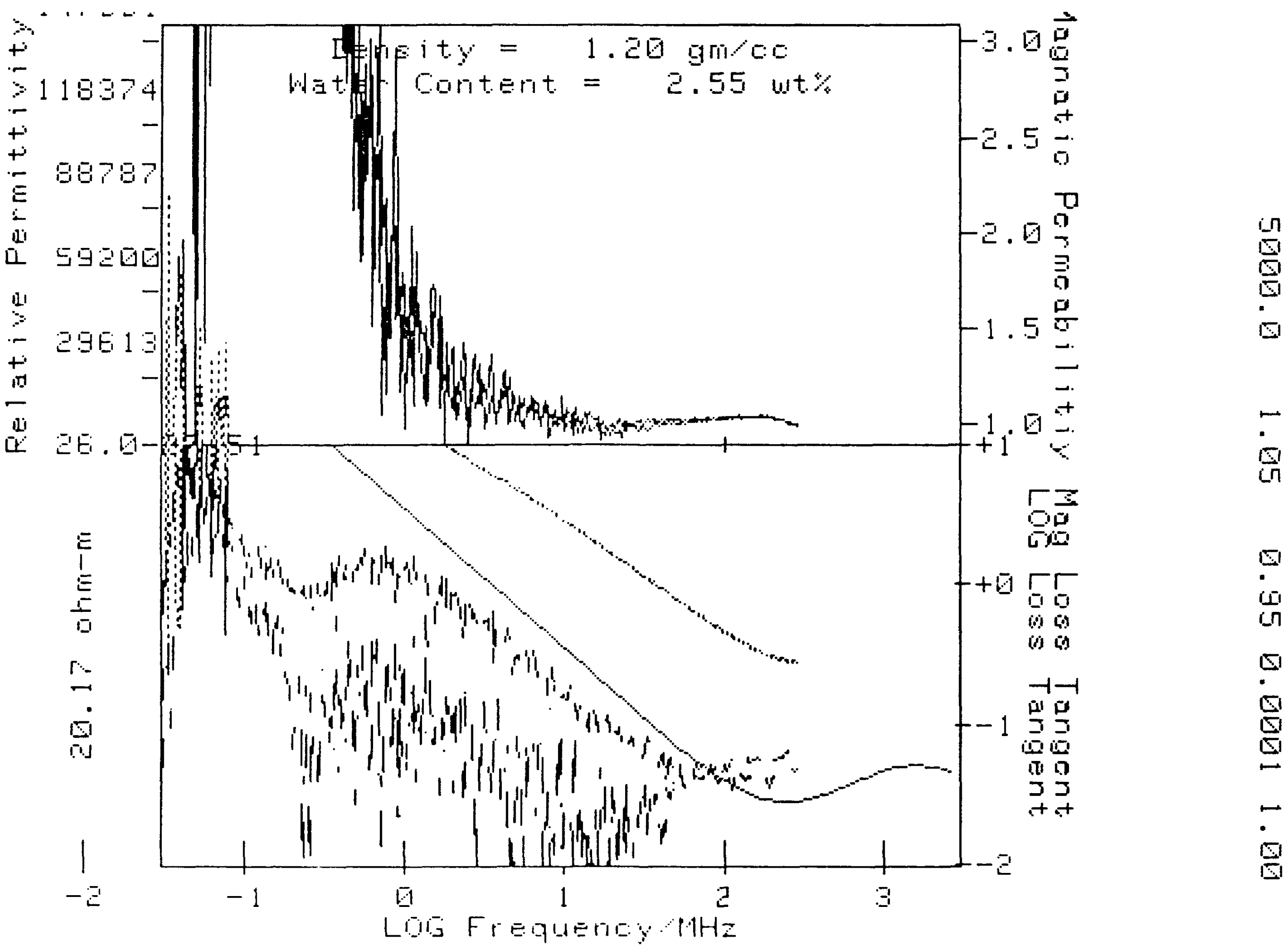
Freq/MHz	K'meas	K'calc	Tandmeas	Tandcalc	Res/ohm-m	Permeability	TanMag
0.030	439.355	439.355	64.193	64.193	21.244	60.079	0.954
0.053	264.685	264.685	60.117	60.117	21.175	18.312	2.298
0.095	184.493	184.493	48.647	48.647	21.111	2.977	7.088
0.169	148.247	148.247	34.209	34.209	21.010	10.243	1.000
0.300	109.983	109.983	26.183	26.183	20.807	3.025	1.327
0.533	81.159	81.159	20.182	20.182	20.571	2.224	1.009
0.949	59.866	59.866	15.561	15.561	20.339	1.121	0.994
1.687	49.677	49.677	10.695	10.695	20.055	1.232	0.565
3.000	42.358	42.358	7.155	7.155	19.769	1.119	0.359
5.335	37.657	37.657	4.609	4.609	19.411	1.092	0.232
9.487	34.281	34.281	2.916	2.916	18.956	1.089	0.099
16.870	31.841	31.841	1.822	1.822	18.367	1.003	0.063
30.000	30.054	30.054	1.132	1.132	17.618	1.012	0.035
53.348	28.836	28.836	0.703	0.703	16.623	1.041	0.028
94.868	28.096	28.096	0.445	0.445	15.156	1.051	0.038
168.702	27.850	27.850	0.302	0.302	12.652	1.057	0.047
283.218	28.911	28.911	0.260	0.260	8.447	1.009	0.065



AS RECEIVED PCK-1
E[AR PCK-1E]

AR PCK-1F[AR PCK-1F]

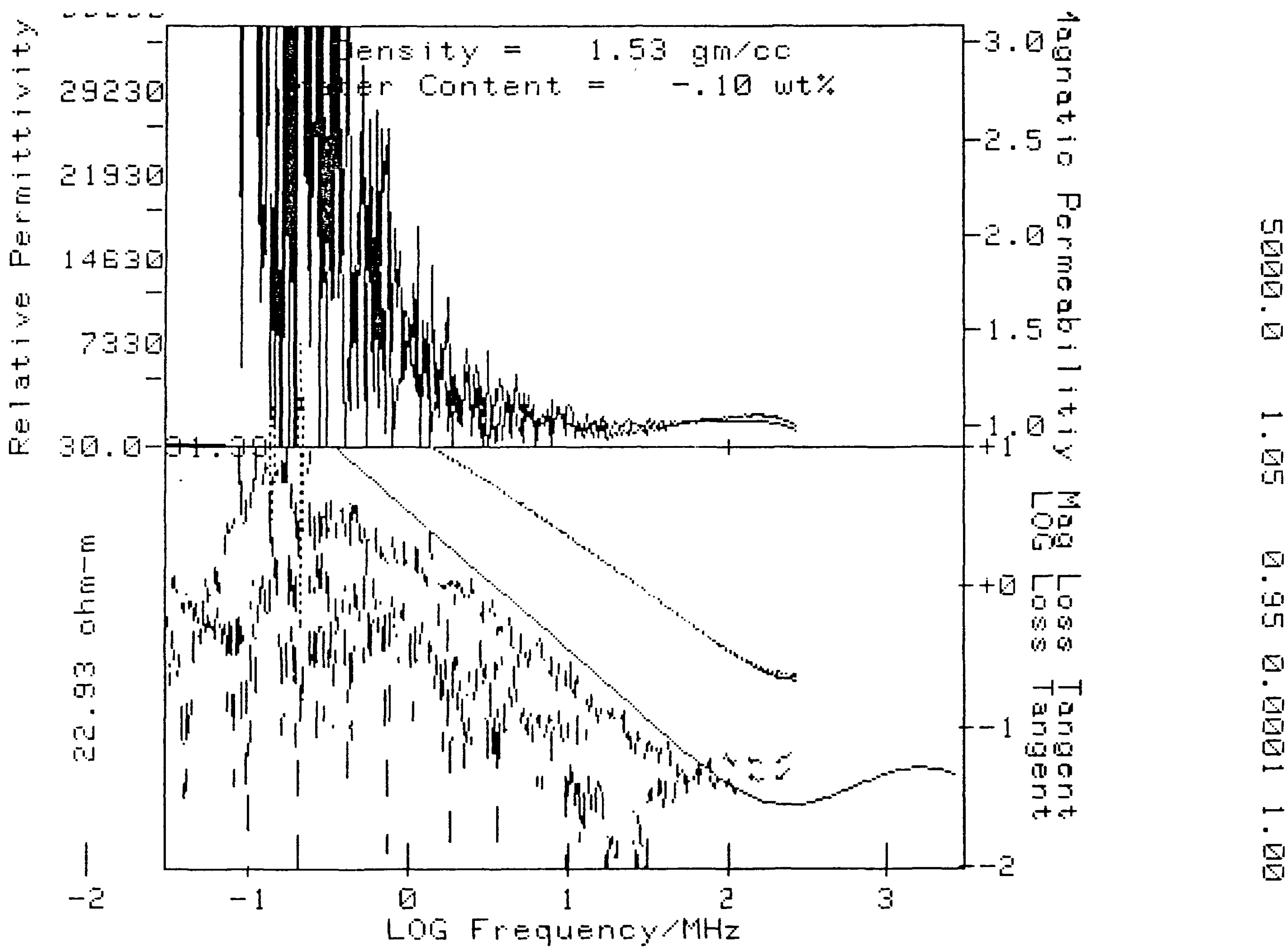
Freq/MHz	K'meas	K'calc	Tandmeas	Tandcalc	Res/ohm-m	Permeability	TanMag
0.030	321.475	321.475	91.657	91.657	20.335	37.419	1.826
0.053	159.006	159.006	105.067	105.067	20.168	7.336	9.461
0.095	127.085	127.085	73.262	73.262	20.351	15.867	1.713
0.169	115.925	115.925	45.187	45.187	20.341	13.863	0.764
0.300	108.647	108.647	27.347	27.347	20.166	6.245	0.591
0.533	86.564	86.564	19.501	19.501	19.960	2.300	0.868
0.949	67.772	67.772	14.179	14.179	19.717	1.691	0.685
1.687	55.273	55.273	9.932	9.932	19.409	1.386	0.512
3.000	46.000	46.000	6.846	6.846	19.026	1.233	0.358
5.335	39.719	39.719	4.566	4.566	18.577	1.053	0.162
9.487	35.555	35.555	2.954	2.954	18.041	1.109	0.122
16.870	32.211	32.211	1.904	1.904	17.370	0.967	0.068
30.000	30.039	30.039	1.202	1.202	16.598	1.008	0.050
53.348	28.517	28.517	0.759	0.759	15.576	1.028	0.048
94.868	27.561	27.561	0.486	0.486	14.139	1.039	0.046
168.702	27.163	27.163	0.333	0.333	11.785	1.049	0.049
283.218	27.953	27.953	0.286	0.286	7.934	1.004	0.061



AR PCK-1F[AR PCK-1F]

AS RECEIVED PCK-1,G [AR PCK-1G]

Freq/MHz	K'meas	K'calc	Tandmeas	Tandcalc	Res/ohm-m	Permeability	TanMag
0.030	238.845	238.845	108.888	108.888	23.038	104.402	1.108
0.053	165.268	165.268	88.903	88.903	22.932	42.181	0.849
0.095	136.197	136.197	59.204	59.204	23.498	9.762	1.978
0.169	120.579	120.579	37.751	37.751	23.407	4.630	2.197
0.300	100.421	100.421	25.646	25.646	23.265	1.084	5.378
0.533	81.135	81.135	18.047	18.047	23.011	1.274	3.185
0.949	65.740	65.740	12.695	12.695	22.703	1.451	1.073
1.687	55.238	55.238	8.630	8.630	22.351	1.326	0.642
3.000	47.052	47.052	5.814	5.814	21.904	0.925	0.568
5.335	41.898	41.898	3.756	3.756	21.411	1.079	0.238
9.487	37.920	37.920	2.403	2.403	20.793	1.046	0.131
16.870	35.164	35.164	1.510	1.510	20.066	0.956	0.063
30.000	33.330	33.330	0.937	0.937	19.189	0.994	0.034
53.348	32.148	32.148	0.581	0.581	18.029	1.022	0.048
94.868	31.447	31.447	0.371	0.371	16.252	1.046	0.050
168.702	31.399	31.398	0.257	0.257	13.217	1.050	0.051
267.375	32.684	32.684	0.230	0.230	8.945	1.001	0.063

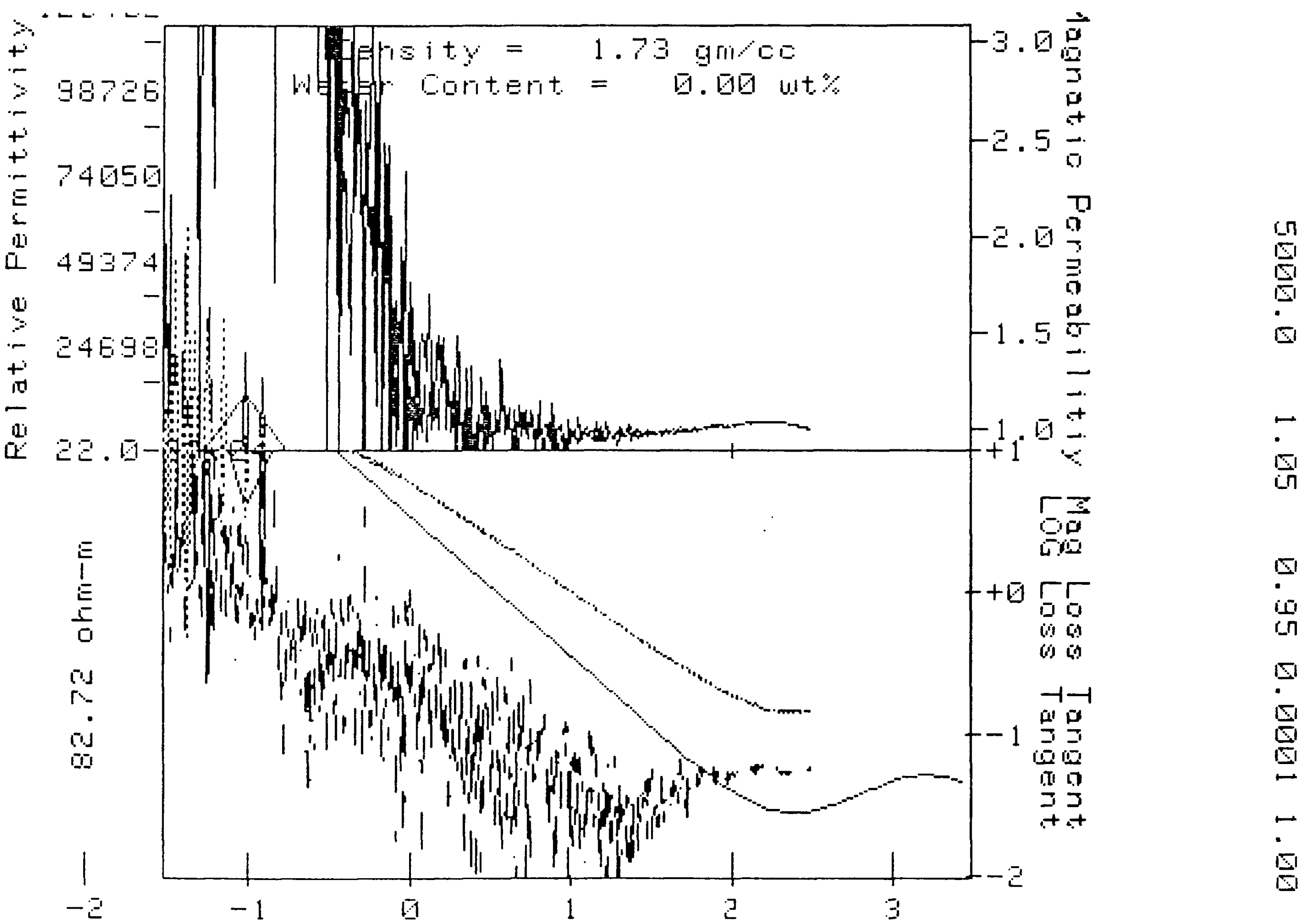


AS RECEIVED PCK-1
G [AR PCK-1G]

95PCUD-2,B

AR..UD-2B[ARPCUD-2B]

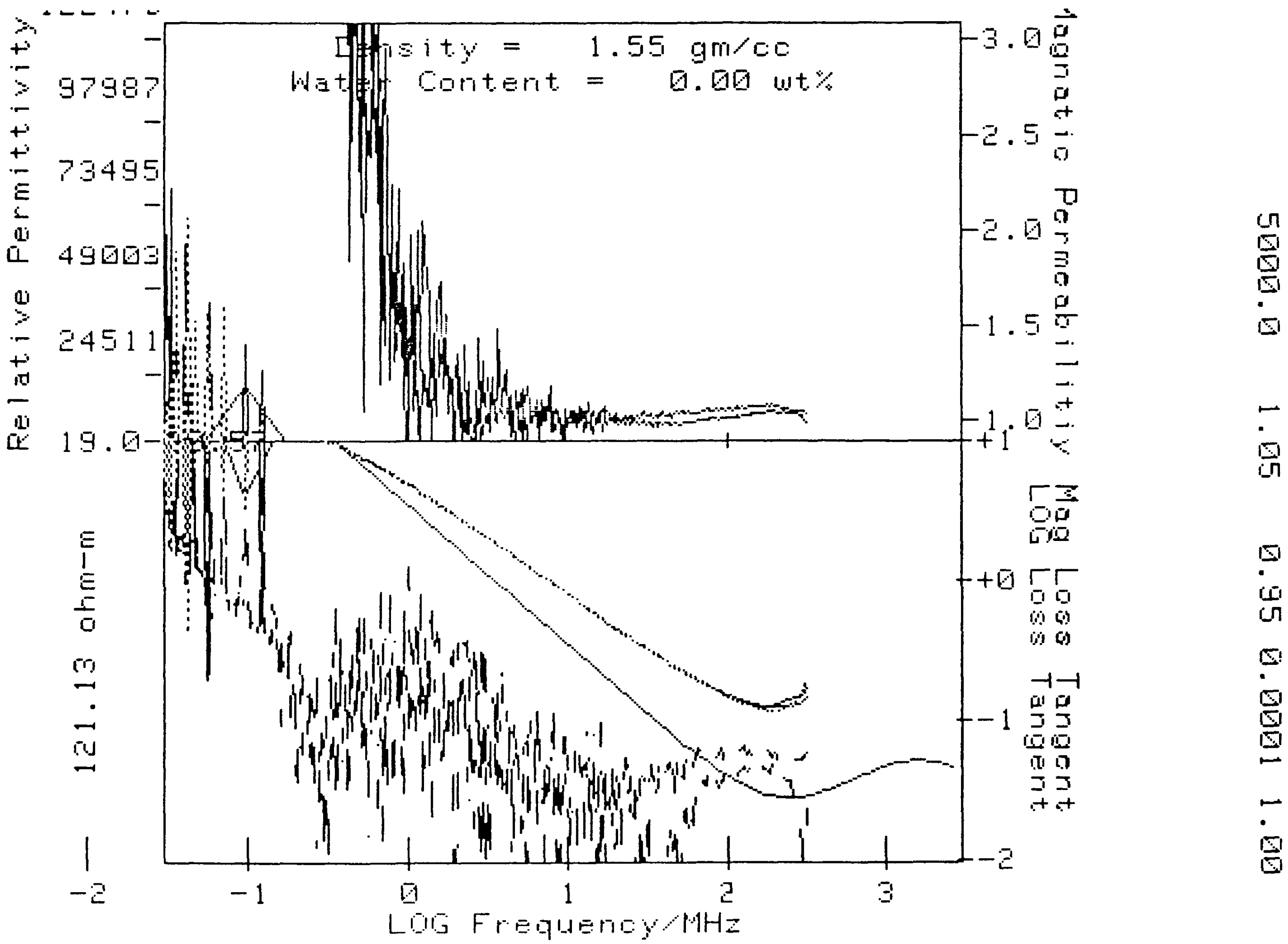
Freq/MHz	K'meas	K'calc	Tandmeas	Tandcalc	Res/ohm-m	Permeability	TanMag
0.030	142.587	142.587	56.605	56.605	74.236	21.795	2.953
0.053	134.046	134.046	30.386	30.386	82.722	26.467	3.260
0.095	16352.648	16352.648	4.066	4.066	2.850	15915.073	4.118
0.169	74.272	74.272	17.596	17.596	81.529	9.958	0.602
0.300	59.122	59.122	12.619	12.619	80.309	2.682	0.280
0.533	48.504	48.504	8.776	8.776	79.150	2.430	0.354
0.949	39.659	39.659	6.162	6.162	77.527	1.035	0.552
1.687	34.659	34.659	4.073	4.073	75.470	1.257	0.027
3.000	31.565	31.565	2.593	2.593	73.193	1.037	0.216
5.335	28.859	28.859	1.664	1.664	70.151	0.974	0.053
9.487	26.964	26.964	1.054	1.054	66.693	1.015	0.058
16.870	25.549	25.549	0.670	0.670	62.291	1.014	0.029
30.000	24.462	24.462	0.432	0.432	56.698	0.988	0.023
53.348	23.617	23.617	0.285	0.285	50.137	1.004	0.044
94.868	23.086	23.086	0.196	0.196	41.915	1.032	0.050
168.702	22.920	22.920	0.150	0.150	31.005	1.049	0.059
300.000	23.860	23.860	0.147	0.147	17.104	1.013	0.058
308.760	24.011	24.011	0.147	0.147	16.513	1.008	0.059



ARPCUD-2B[ARPCUD-2B]

ARPCUD-2A[ARPCUD-2A]

Freq/MHz	K'meas	K'calc	Tandmeas	Tandcalc	Res/ohm-m	Permeability	TanMag
0.030	173.543	173.543	29.113	29.113	118.593	91.924	2.471
0.053	128.822	128.822	21.593	21.593	121.127	87.954	1.189
0.095	16326.931	16326.931	4.048	4.048	2.867	15924.173	4.097
0.169	59.232	59.232	14.882	14.882	120.872	22.221	0.316
0.300	47.936	47.936	10.476	10.476	119.319	6.661	0.061
0.533	39.087	39.087	7.358	7.358	117.157	3.086	0.137
0.949	32.889	32.889	5.020	5.020	114.770	1.159	0.624
1.687	29.216	29.216	3.279	3.279	111.217	1.483	0.129
3.000	26.619	26.619	2.094	2.094	107.496	1.058	0.138
5.335	24.740	24.740	1.323	1.323	102.977	1.068	0.036
9.487	23.260	23.260	0.838	0.838	97.218	0.992	0.073
16.870	22.312	22.312	0.526	0.526	90.738	1.049	0.020
30.000	21.512	21.512	0.339	0.339	82.273	1.027	0.023
53.348	20.932	20.932	0.223	0.223	72.086	1.025	0.031
94.868	20.608	20.608	0.155	0.155	59.345	1.045	0.046
168.702	20.605	20.605	0.124	0.124	41.742	1.068	0.055
300.000	21.887	21.887	0.152	0.152	17.986	1.041	0.029
317.776	22.019	22.019	0.170	0.170	15.148	1.023	0.041



ARPCUD-2A[ARPCUD-2A]