LABORATORY MEASUREMENTS OF ELECTRICAL PROPERTIES OF COMPOSITE MINE DUMP SAMPLES FROM COLORADO AND NEW MEXICO

By Anita L. Anderson[1], David L. Campbell[2], and Shay Beanland[3]

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[1] now at US Geological Survey, Baltimore MD 21237
[2] Denver, CO
[3] now at Department of Geological Science, Ohio State University, Columbus OH 43210-1394

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Abstract

Individual mine waste samples were collected and combined to form one composite sample at each of eight mine dump sites in Colorado and New Mexico. The samples were air-dried and sieved to determine the geochemical composition of their <2mm size fraction. Splits of the samples were then rehydrated and their electrical properties were measured in the US Geological Survey Petrophysical Laboratory, Denver, Colorado (PetLab). The PetLab measurements were done twice: in 1999, using convenient amounts of rehydration water ranging from 5% to 8%; and in 2000, using carefully controlled rehydrations to 5% and 10% water. This report gives geochemical analyses of the <2mm size fraction of the composite samples (Appendix A), PetLab graphs of the 1999 measurements (Appendix B), Petlab graphs of the 2000 measurements (Appendix C), and Cole-Cole models of the PetLab data from the 2000 measurements (Appendix D).

Introduction

As part of a project to characterize mine waste materials, our USGS group made geological, geochemical, and geophysical studies of eight mine dumps on abandoned mine lands in Colorado and New Mexico (Table 1). All eight dumps were associated with polymetallic sulfide deposits. Four of the dumps had nearby carbonate-bearing country rocks, a possible factor in buffering of acid mine drainage. Composite samples of the dumps were collected using the protocol described by Smith and others (2000), and Hageman and Briggs (2000) describe the chemistry of their leachate waters. The mineralogy of the composite samples was found using X-ray diffraction (XRD). The samples contained high percentages of amorphous minerals (Stephen J. Sutley, written commun.). Mineralogical characteristics of the composite samples from May Day, Yukon, Sunday #2 and Venir also were investigated using a sequential extractions method, reported by Leinz and others (2000). This present report describes the electrical properties of the composite samples, measured in the USGS Petrophysical Laboratory, Denver, Colorado (PetLab). The

PetLab measurements were made in order to look for possible correlations between geochemical characteristics of mine waste materials and electrical properties of them which might be measurable in the field.

Locations and Geology

The Mayday and Yukon mines are located in San Juan County in southwestern Colorado, along Cement Creek just north of the town of Silverton (Fig. 1). The minerals mined at the Mayday and Yukon sites were emplaced during Tertiary time by hydrothermal processes related to the formation of the Silverton caldera (see Burbank and Luedke, 1968, for a general description of this mining area).

The Leadville Mining District is on the western slope of the Mosquito Range in the Central Colorado Rocky Mountains in Lake County, east of the town of Leadville. This district covers about 8 square miles. Waste rock and tailings, rich in pyrite and other sulfides, now cover approximately 30 km^2 including part of the town of Leadville. The ore deposits are found in pre-Pennsylvanian Paleozoic rocks that lie on Precambrian granite and are overlain by a thick sequence of Pennsylvanian rocks. Tertiary and Quaternary porphyries, occurring usually as dikes and plugs, have intruded the sedimentary rocks. These rocks have also been broken by a series of north trending faults, usually up thrown to the east. These faults cause the sedimentary strata to rise to the east in a series of steps making access to the productive zones easier. These faults were created during the Laramide uplift, during the Late Cretaceous to early Tertiary periods (above information from Tweto, 1968). The Tucson and Main Iron Incline mines are two waste piles from different parts of the same mining complex on Iron Hill just east of the town of Leadville (Fig.2). The Venir and Sunday #2 mines are both located on or near Ball Mountain, further east of Leadville and west of the Mosquito Range (Fig. 2).

The Carlisle mine is located in the Steeple Rock District northwest of Lordsburg in the northwest corner of Hidalgo County, New Mexico. This district is contains andesite, basaltic andesite, and dacitic lavas inter-bedded with sandstones, volcanic breccias, and rhyolite ignimbrites that are Oligocene to Miocene in age. This sequence has Tertiary age intrusions of plugs, dikes, and domes. Some of these features are associated with epithermal vein formation, brecciation, and faulting. Ore taken from the andesite host rock were predominantly galena and sphalerite (McLemore, 2000; Hageman, Briggs, and others, 2000).

The Petroglyh mine is located east of Silver City in south-central Sierra County, New Mexico. This area is known as the Hillsboro District. Sulfides found in the hydrothermal veins of this district include pyrite, sphalerite, and galena. These hydrothermal veins may be related to a Cretaceous age quartz monzonite intrusive nearby that lies between two beds of unnamed limestone Ordovician and Mississippian in age (Hageman, Briggs, and others, 2000).

Geochemistry

Composite mine waste samples were collected using the protocol of Smith and others (2000) by mixing together at least 30 subsamples taken from each mine waste pile. Splits of the composite samples were leached using the Synthetic Precipitation Leaching Procedure (SPLP; Hageman, Briggs, and others, 2000), and the samples were ordered according to the acidity of their leachate waters (Hageman and Briggs, 2000; Table 1). Appendix A gives results of geochemical analysis of the <2mm fraction of the solid composite samples, together with graphs comparing compositions of selected chemical species. Samples were analyzed by inductively coupled plasma atomic emission spectroscopy (ICP-AES).

Graph A1 (Appendix A) shows that the composite samples with highest leachate pH (Table 1) have highest total carbon, and, in particular, that this carbon occurs dominantly as carbonate (CO_3) for samples TUC, MII, and PET, whose leachate water is neutral or slightly alkaline. Graph A3 shows that Ca and Mg content, like carbonate carbon, generally increases through the series with increasing leachate pH (Table 1). These results confirm what we expect, that carbonate minerals (typically high in $CaCO_3$ and $MgCO_3$), when present, may act to neutralize possible acid mine drainage (AMD). High amounts of Pb, Zn, Cu (graph A4), Fe (graph A2) and S (graph A3), reflect the sulfide minerals, such as galena, sphalerite, chalcopyrite, and pyrite, that were present, at least originally, in these deposits. We notice that PET was low in sulfur, CAR was high in Cu, and the carbonate dump samples (TUC, MII, and PET) were high in As (graph A5). Graph A2 indicates that relatively little of the Fe is present as FeO, arguing that a large portion of the sulfide minerals may have changed to sulfates and oxides.

Laboratory Procedure

Electrical properties were measured in PetLab of 300-500 gm splits of the original composite mine-dump samples. The splits arrived in a dried-out condition, too resistive to make “as received” measurements. Therefore, the splits were re-hydrated with laboratory grade de-ionized water before they were measured. For the initial (1999) data runs, we simply added a convenient amount of water to available sample splits and made the measurements. These results are shown in Appendix B. In Appendix B the samples denoted “060” stand for “BLM 60”, an alternate name for the May Day Mine, whereas those denoted “FEHILL” stand for “Iron Hill”, the geographic location of the Main Iron Incline Mine. Because the splits we started with may not have been completely dry, the calculated water amounts given in Appendix B are approximate. For subsequent (2000) data runs, new splits of the composite samples were procured and thoroughly dried before adding carefully controlled amounts of water to them. First, an amount of de-ionized water equal to 5% of the weight of the dry sample was added. This mixture of soil and water was then stirred thoroughly and part of it was tamped into the sample holder for one measurement. The remaining material was then weighed, and additional de-ionized water was added to bring the total weight percent of de-ionized water up to 10%. The sample was again stirred thoroughly and tamped into another sample holder for the second measurement. These results are shown in Appendix C. All measurements used a driving voltage of 0.5 volts. PetLab procedures and apparatus are described by Olhoeft (1979), Jones (1997), and Campbell and Horton (2000).

The graphs showing the resulting measurements (Appendices B and C) consist of three panels that plot various quantities versus a common frequency abscissa. On the upper panel, resistivity (left legend, linear scale) is plotted as triangular symbols and phase (right legend, logarithmic scale) as circle or diamond symbols. If the phase is negative (the usual situation), its value is plotted as a circle. If the phase is positive—much less usual, but possible—its sign is changed and the value is plotted as a diamond. A vertical whisker through each symbol indicates percent error. The lower two panels give other indicators of possible errors in the measurements. These are percent Hilbert distortion in the resistivity measurement (%RHD, small triangle symbols in middle panel), Hilbert distortion in the phase measurement in milliradians (PHD/mR, small circle symbol in middle panel), percent total harmonic distortion (%THD, asterisk symbol in lower panel), and spontaneous potential in millivolts (SP/mV, small circle symbol in lower panel). The solid lines in the upper panel are Hilbert fit lines. At frequencies where these lines fail to fit the observed points, the Hilbert distortion values in the middle panel are also in error, and can be discounted. All of the samples reported here have some bad data points that throw off the Hilbert calculations. Furthermore, the RHD and PHD scales for most of the samples are dominated by one or two extreme values, which are probably meaningless but which may obscure smaller, possibly significant, variations in other frequency ranges where there is better data. These quantities are described more thoroughly by Campbell and Horton (2000).

It should be noted that our laboratory measurements were made on small samples that had been disturbed, dried out and re-hydrated with de-ionized water. We hoped that the salts left behind when the original sample was dried would go back into solution, so that the re-hydration water would resemble the original pore water. We do not know how closely these PetLab samples resemble in-situ materials, however.

Simple IP Indices and Cole-Cole Models

Some of the parameters used to characterize induced polarization (IP) response can be directly read or calculated from petrophysical curves. These simple IP indices are described in more detail by Campbell and Horton (2000):

Low Res (*low resistivity*) = R(0.2 Hz)

PRE (*percent resistivity effect*) = 100 x [R(0.1 Hz)-R(1.0 Hz)]/R(1.0 Hz)

Low Phz (*low phase*) = -P(0.1 Hz)

PPE (*percent phase effect*) = -100 x [P(0.1 Hz)-P(1.0 Hz)]/P(1.0 Hz)

R = Resistivity
P = Phase

The indices for composite mine dump samples measured in 2000 are listed in table 2. These indices are useful for making comparisons between petrophysical curves, and for correlating these curves with field data. However, they gloss over details of the curves, particularly the phase curves, which can reflect grain size and textural properties, mineralogical compositions, and geochemical reactions that may be taking place. The latter may reflect interactions between grains and pore waters, and so can be of particular interest in acid mine drainage studies. In order to more fully describe the details of the resistivity and phase curves measured in the PetLab, they need to be fit numerically using the Cole-Cole formula (Cole and Cole, 1941) as described by Campbell and Horton (2000). Appendix D shows Cole-Cole fits to the observed data for the 5% and 10% rehydrated composite samples.

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Tables

Sample sources

Table 1. Mine dumps whose composite samples are measured for this report, ordered by increasing pH of leachate waters, measured using Synthetic Precipitation Leaching Procedure (SPLP; Hageman and Briggs, 2000). Abbreviations given here are used in this report.

Mine Dump Name	Abbrev.	Nearby Town	Carbonate rocks nearby?	Leachate pH
Venir	VEN	Leadville CO	No	2.75
Sunday #2	SUN	Leadville CO	No	2.83
Yukon	YUK	Silverton CO	No	3.10
May Day	MAY	Silverton CO	No	3.47
Carlisle	CAR	Lordsburg NM	Yes	5.45
Tucson	TUC	Leadville CO	Yes	6.99
Main Iron Incline	MII	Leadville CO	Yes	8.55
Petroglyph	PET	Hillsboro NM	Yes	8.84

Simple IP Indices

Table 2. Simple IP indices of bulk composite samples from study mine dumps (table 1). The samples are ranked in order of increasing pH of their leachate waters, as reported by Hageman and Briggs (2000).

Sample	PH	5% water				10% water			
		Low Res	PRE	Low Phz	PPE	Low Res	PRE	Low Phz	PPE
VEN	2.75	250.40	0.97	3.70	72.12	72.64	12.27	82.38	-25.77
SUN	2.83	109.69	11.61	76.43	-13.50	18.84	8.40	70.35	-50.29
YUK	3.10	180.17	5.15	34.30	1.04	78.81	16.24	111.11	-37.02
MAY	3.47	1929.2	1.31	50.47	50.81	363.53	5.11	22.85	63.03
CAR	5.45	480.78	1.14	6.70	56.27	268.21	18.49	76.90	53.64
TUC	6.99	324.36	0.55	2.52	68.34	125.28	5.48	28.07	55.52
MII	8.55	361.01	2.84	12.23	66.58	103.52	2.71	15.86	51.91
PET	8.84	199.46	1.79	5.48	67.71	145.77	4.73	22.88	59.17

Figures

Silverton area

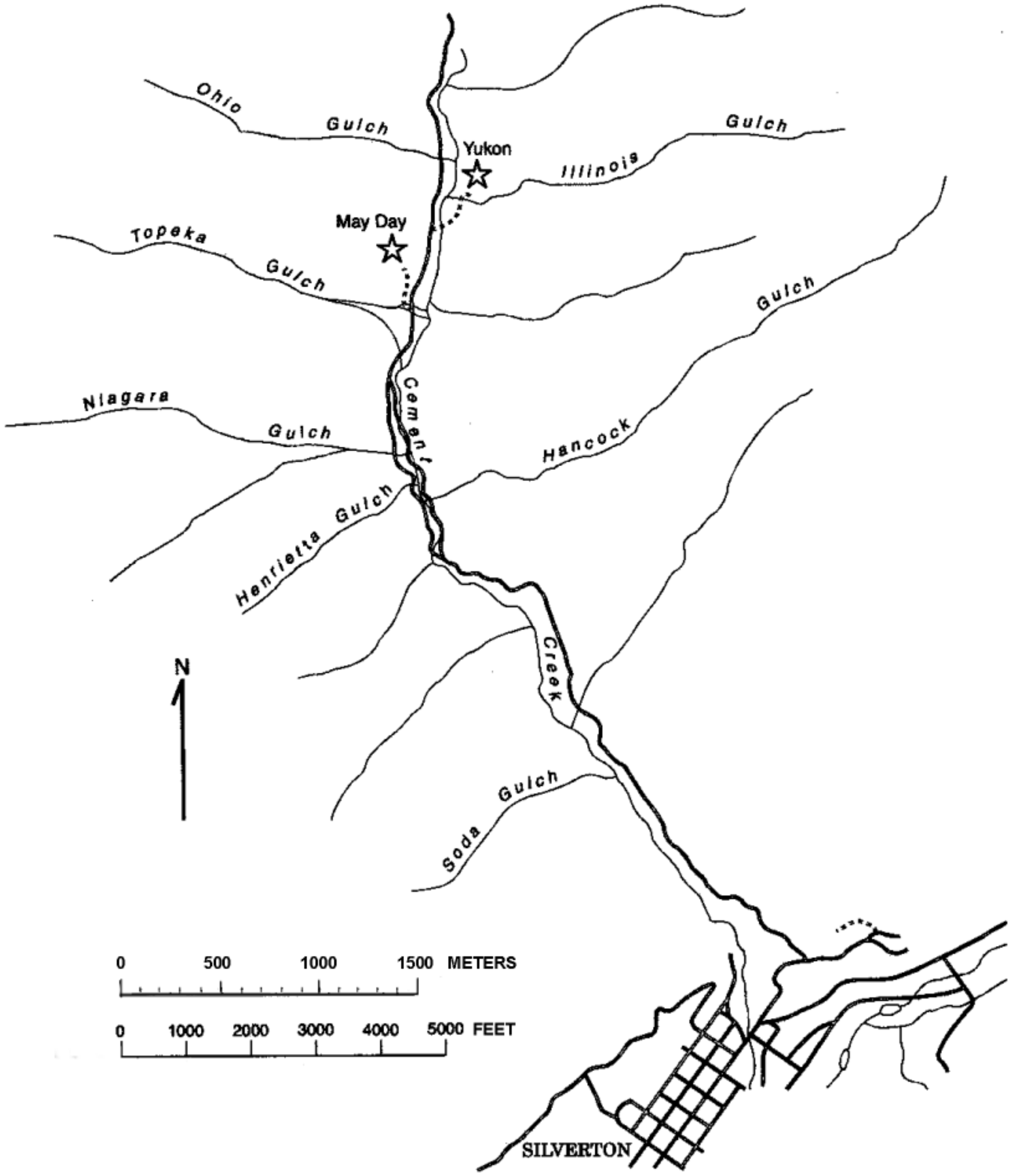


Figure 1. Silverton area, showing location of May Day and Yukon Mines (from Hein and Fitterman, 1998).

Leadville area

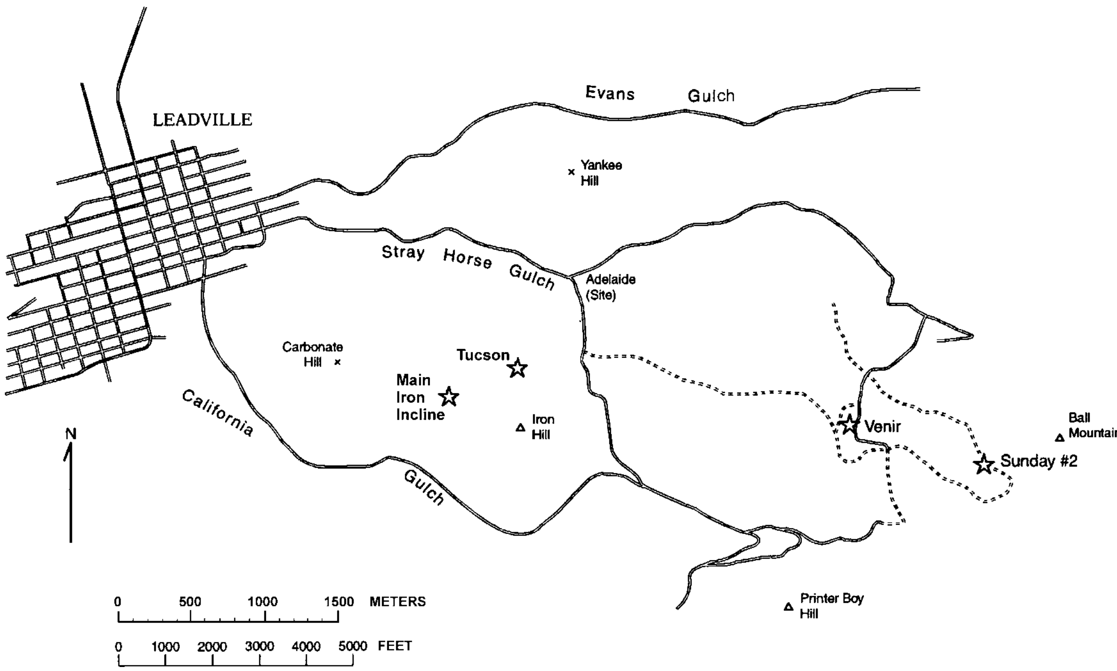


Figure 2. Map of the Leadville area, showing locations of Tucson, Main Iron Incline, Venir, and Sunday#2 mine dumps (from Hein and Fitterman, 1998).

Appendix A – Geochemical analyses

All samples are <2mm fraction of surficial dump material.
Duplicate analyses were made of May Day and Carlisle composite samples.

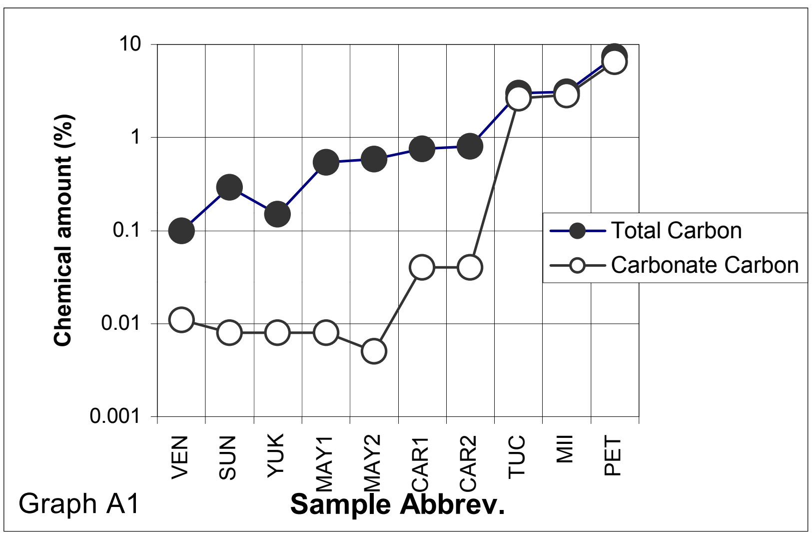
Sample abbreviations:

VEN	Venir composite sample
SUN	Sunday composite sample
YUK	Yukon composite sample
MAY1	May Day composite sample
MAY2	May Day composite sample, duplicate
CAR1	Carlisle composite sample
CAR2	Carlisle composite sample, duplicate
TUC	Tucson composite sample
MII	Main Iron Incline composite sample
PET	Petroglyph composite sample

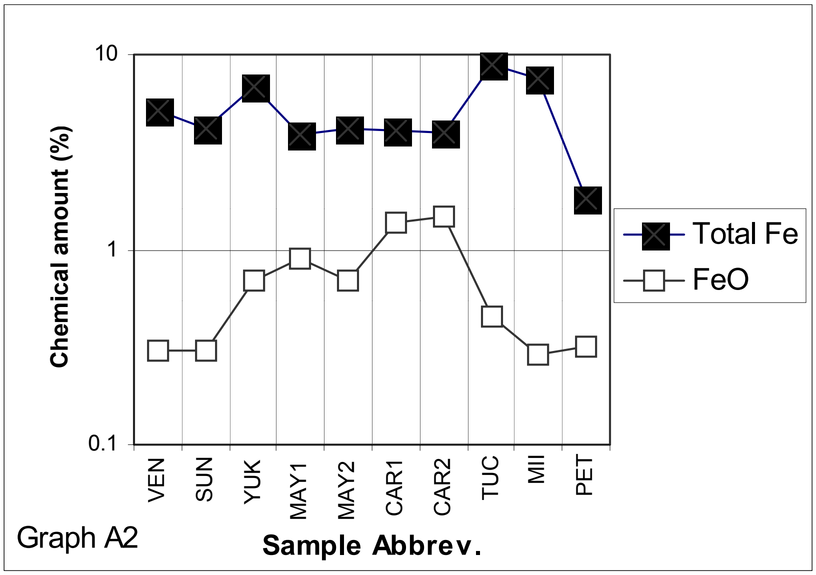
		VEN	SUN	YUK	MAY1	MAY2	CAR1	CAR2	TUC	MII	PET
Organic Carbon	CO2 %	0.089	0.282	0.142	0.532	0.585	0.14	0.14	9.75	10.4	24
Carbonate Carbon	CO3 %	0.011	0.008	0.008	0.008	0.005	0.04	0.04	2.66	2.84	6.55
Total Carbon	C %	0.1	0.29	0.15	0.54	0.59	0.75	0.81	2.98	3.11	7.39
H2O_Minus	%						0.8	0.8	1	0.8	1
H2O_Plus	%						4	3.9	3.9	3.7	2.2
Total_H2O	%						4.8	4.7	4.9	4.5	3.2
FeO	%	0.3	0.3	0.7	0.9	0.7	1.36	1.49	0.45	0.29	0.32
Al	%	6.3	6.3	7.7	10	9	6.99	6.935	4.07	5.055	2.335
Ca	%	0.03	0.03	0.65	0.2	0.21	0.515	0.5	5.088	5.243	17.5
Total Fe	%	5.2	4.2	6.8	3.9	4.2	4.03	3.96	8.92	7.5	1.81
K	%	3.7	2.6	3.5	3.2	3.2	2.88	2.85	1.49	1.84	0.94
Mg	%	0.44	0.33	0.6	0.62	0.54	0.751	0.732	3.031	3.572	4.123
Na	%	0.07	0.05	0.24	0.26	0.29	0.288	0.288	0.072	0.077	0.144
P	%	0.08	0.11	0.07	0.09	0.08	0.072	0.062	0.093	0.067	0.067
Total S	%	3.74	3.01	5.76	0.95	1.13	0.97	0.98	2.6	0.64	0.02
Ti	%	0.16	0.1	0.47	0.71	0.71	0.325	0.294	0.088	0.081	0.138
Ag	ppm	17	27	14	22	26	10	10	36	85	5
As	ppm	21	124	38	68	60	11.1	11.9	264	195	209
Au	ppm	4.71	1.67	1.19	0.048	0.117	0.489	0.579	0.105	0.018	0.018
Ba	ppm	503	157	111	1400	1160	678	695	433	856	877
Be	ppm	2	2	2	2	2	2	2	1	2	<1
Bi	ppm	40	< 10	44	43	39	<50	<50	<50	<50	<50
Cd	ppm	< 2	< 2	< 2	5	4	81	77	150	121	130
Ce	ppm	84	58	45	67	57	56	59	55	41	29
Co	ppm	2	< 2	11	< 2	< 2	9	9	7	9	7
Cr	ppm	14	< 2	10	6	6	64	62	61	66	30
Cu	ppm	222	313	749	315	299	1910	2050	282	66	82
Eu	ppm	< 2	< 2	< 2	< 2	< 2	<2	<2	<2	<2	<2
Ga	ppm	21	16	21	23	17	13	15	9	<4	19
Hg	ppm						1.17	1.14	0.56	0.24	1.88
Ho	ppm	< 4	< 4	< 4	< 4	< 4	<4	<4	<4	<4	<4
La	ppm	48	34	28	41	36	31	29	24	19	11
Li	ppm	9	13	22	18	15	40	38	11	11	20
Mn	ppm	134	88	896	415	374	496	480	8930	20320	3930
Mo	ppm	4	12	48	11	11	15	14	9	9	271

		VEN	SUN	YUK	MAY1	MAY2	CAR1	CAR2	TUC	MII	PET
Nb	ppm	10	6	11	17	13	10	9	<4	<4	<4
Nd	ppm	39	33	23	32	28	22	23	14	14	<9
Ni	ppm	8	4	9	< 3	< 3	14	14	<3	8	10
Pb	ppm	1430	8150	1650	5130	5250	5470	5410	19050	10760	24160
Sc	ppm	6	5	16	24	21	12	11	2	4	3
Sn	ppm	< 5	< 5	32	80	78	<50	<50	<50	<50	<50
Sr	ppm	101	121	134	314	284	114	115	47	66	187
Ta	ppm	< 40	< 40	< 40	< 40	< 40	<40	<40	<40	<40	<40
Te	ppm	10.8	0.7	7.4	4.9	5.6	1.7	2.3	23.3	11.2	16
Th	ppm	10	< 6	< 6	8	6	6	8	11	10	<6
Tl	ppm	3.3	4.5	4.7	5.4	5.6	1.3	1.3	1.9	1.3	1.3
U	ppm	< 100	< 100	< 100	< 100	< 100	<100	<100	<100	<100	<100
V	ppm	53	41	186	292	260	104	101	83	98	549
Y	ppm	8	9	6	6	5	13	12	7	9	11
Yb	ppm	1	< 1	< 1	< 1	< 1	2	2	<1	<1	1
Zn	ppm	183	600	885	2540	2200	6560	6210	23870	18010	32670

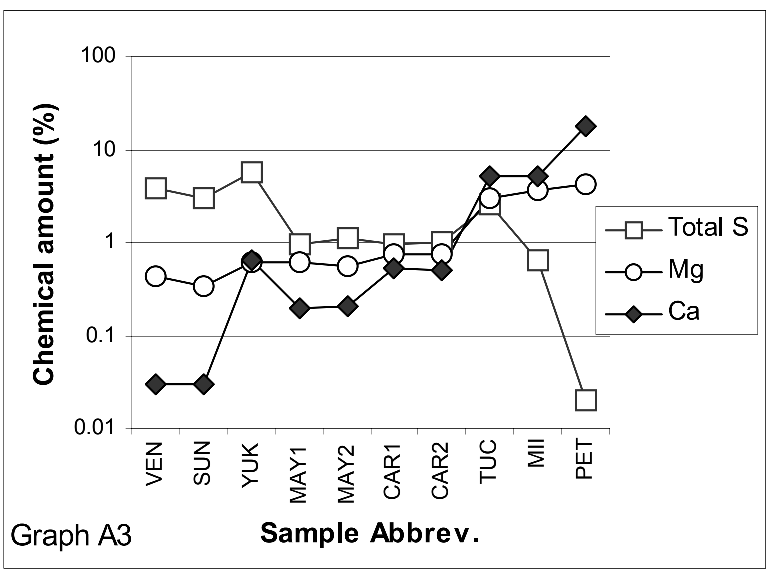
Graph A1



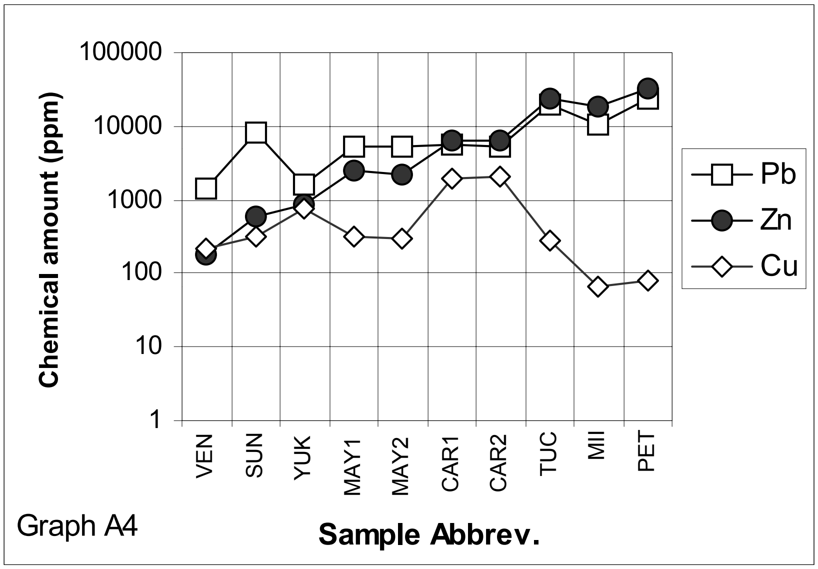
Graph A2



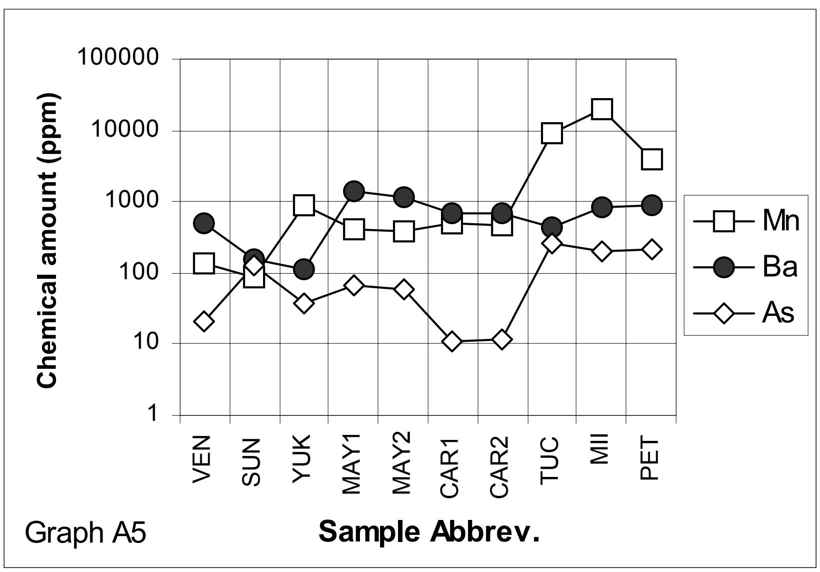
Graph A3



Graph A4

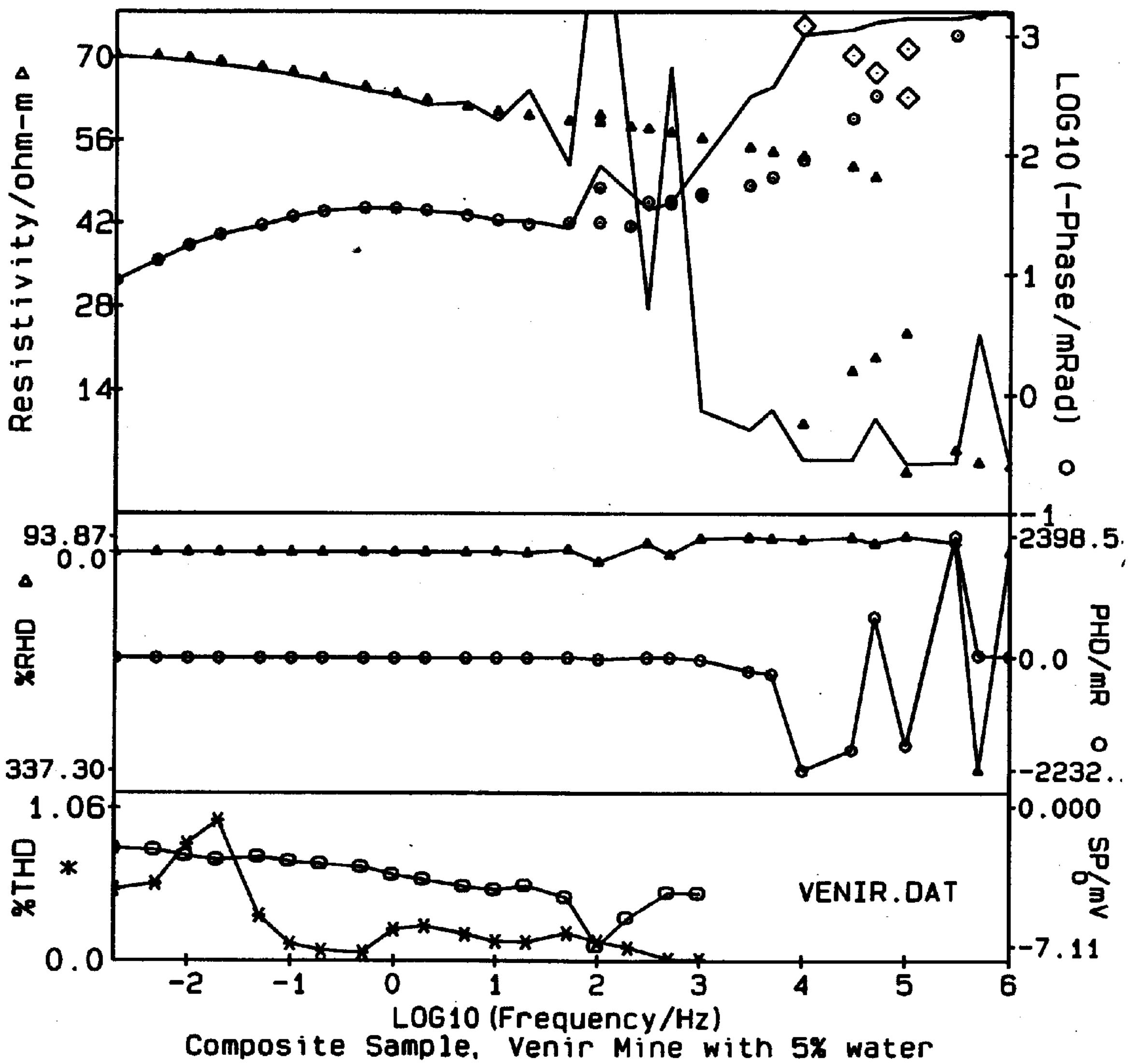


Graph A5

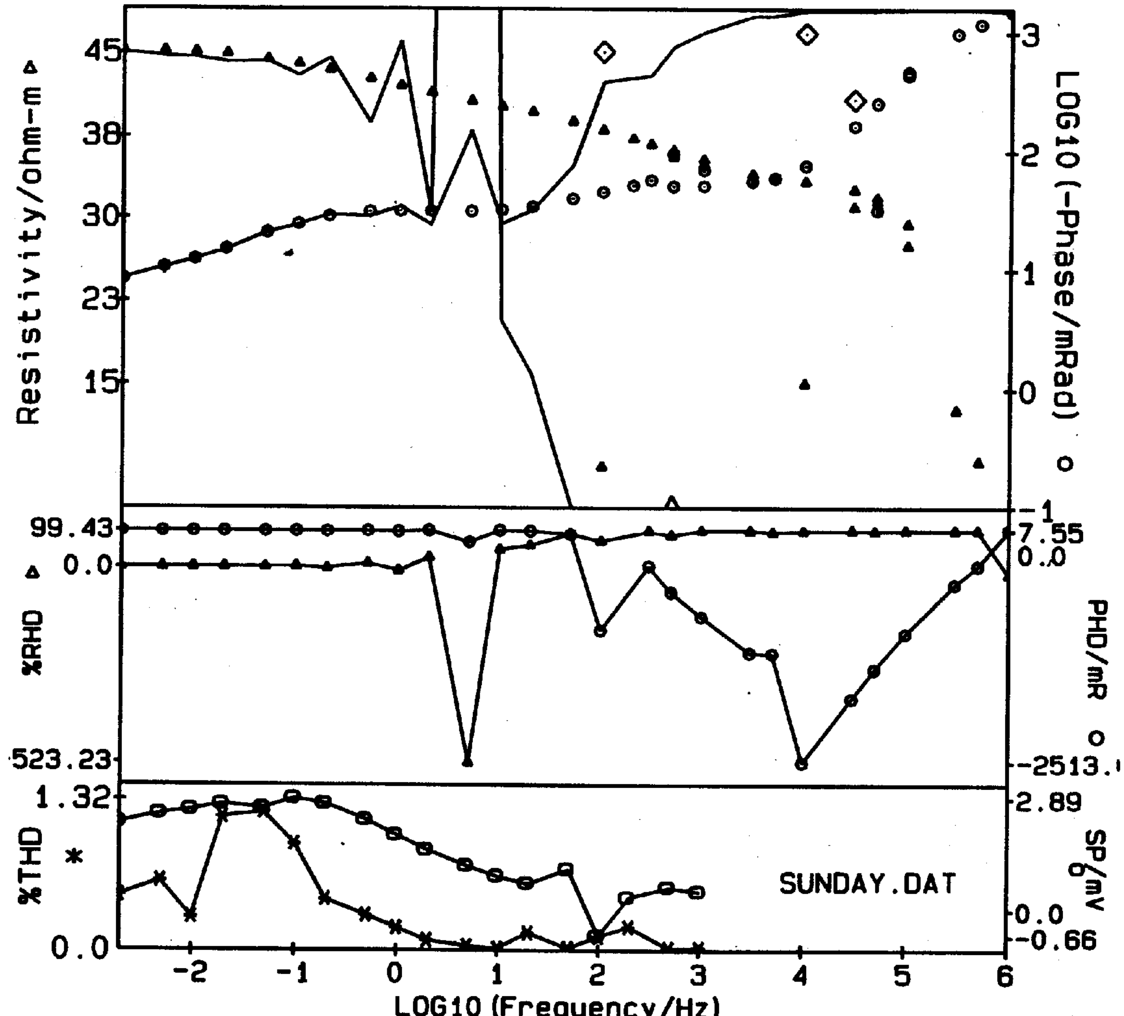


Appendix B – PetLab data from 1999 runs.

Venir

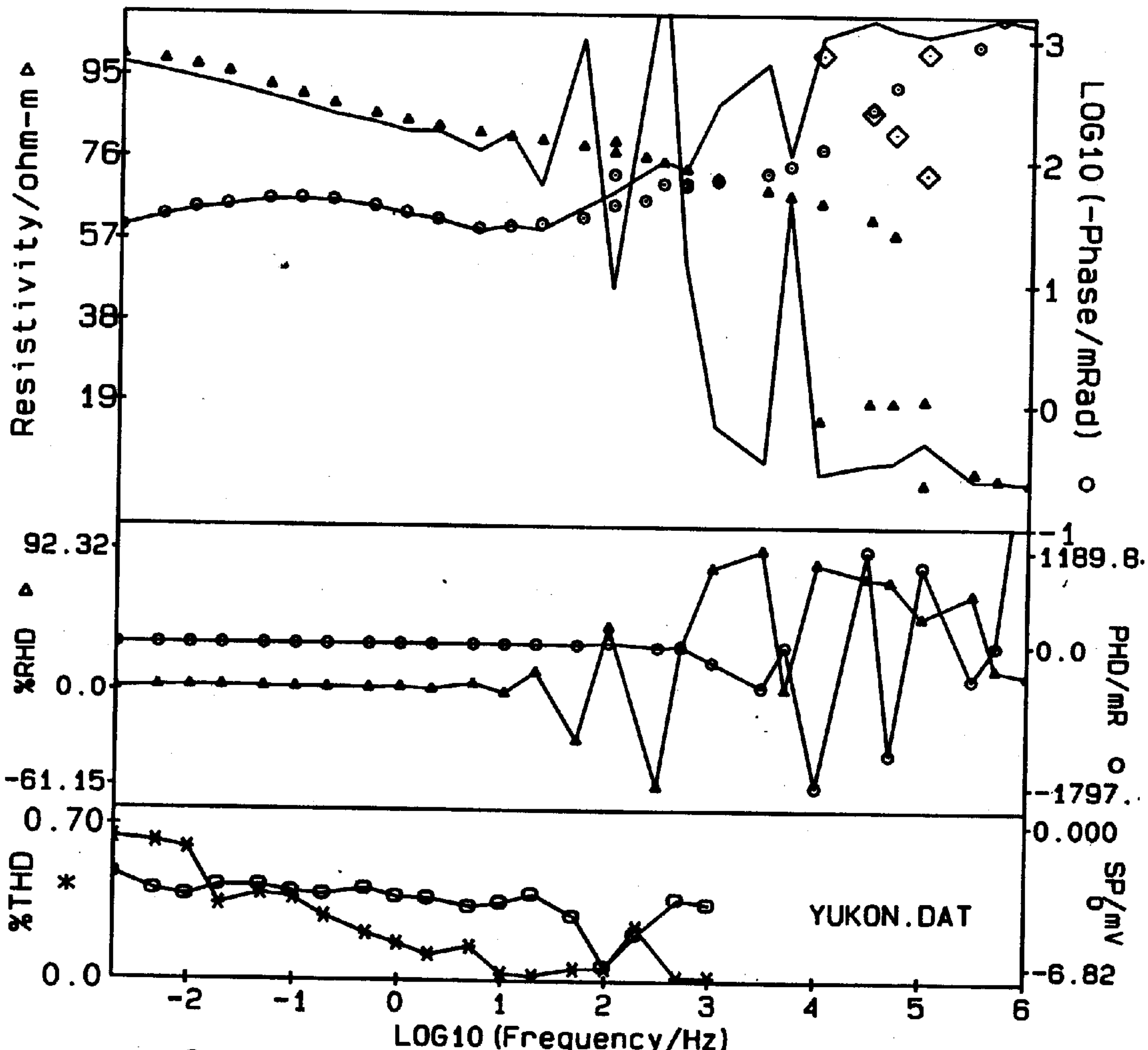


Sunday



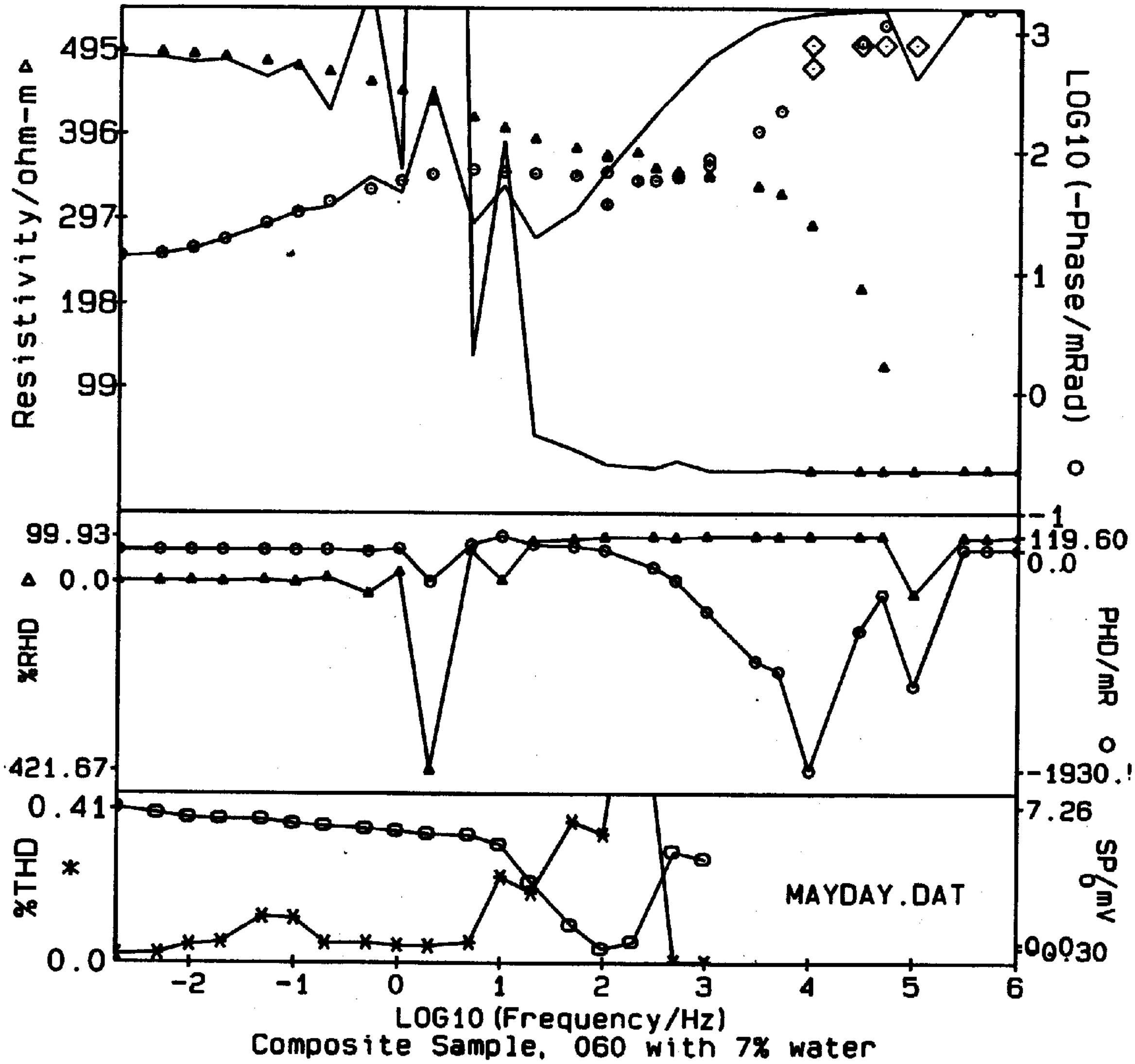
Composite Sample, Sunday #2 with 7% water

Yukon



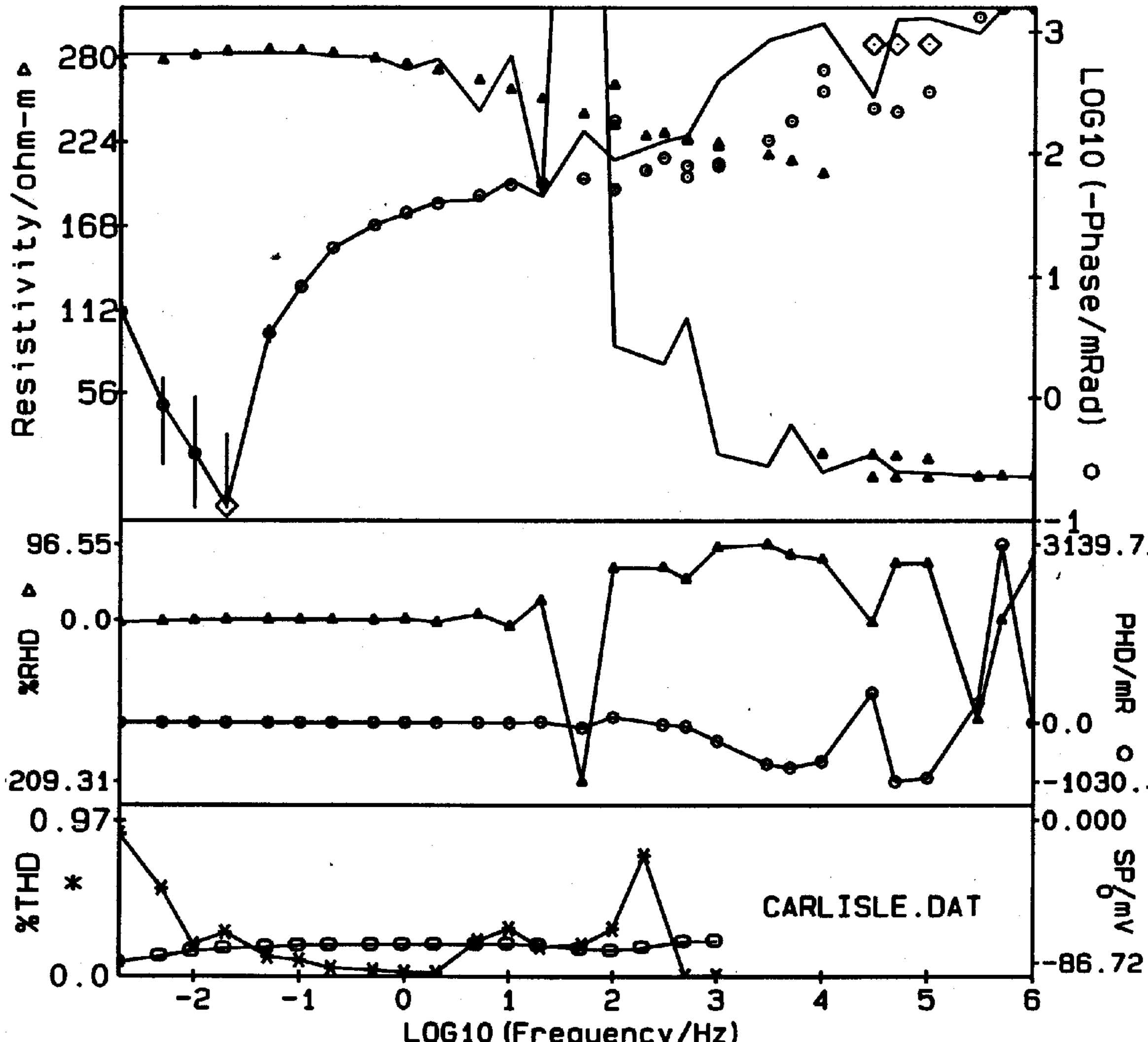
Composite Sample, Yukon Mine with 5% water

May Day



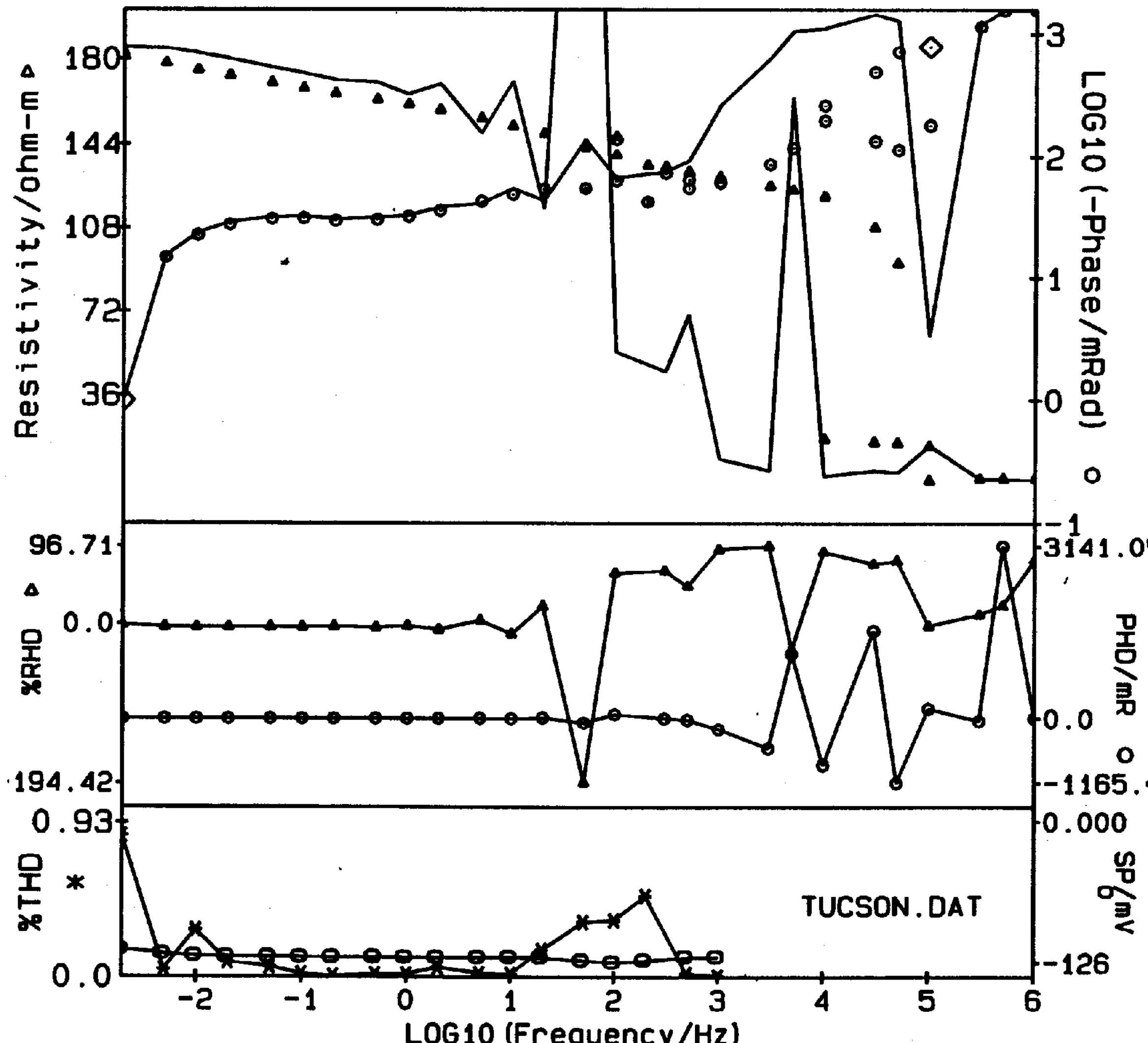
495
396
297
198
99
Resistivity/ohm-m
LOG10 (-Phase/mRad)
3
2
1
0
-1
99.93
0.0
%RHD
-421.67
119.60
0.0
PHD/mR
-1930.
0.41
%THD
0.0
7.26
SP/mV
MAYDAY.DAT
-2
-1
0
1
2
3
4
5
6
LOG10 (Frequency/Hz)
Composite Sample, 060 with 7% water

Carlisle



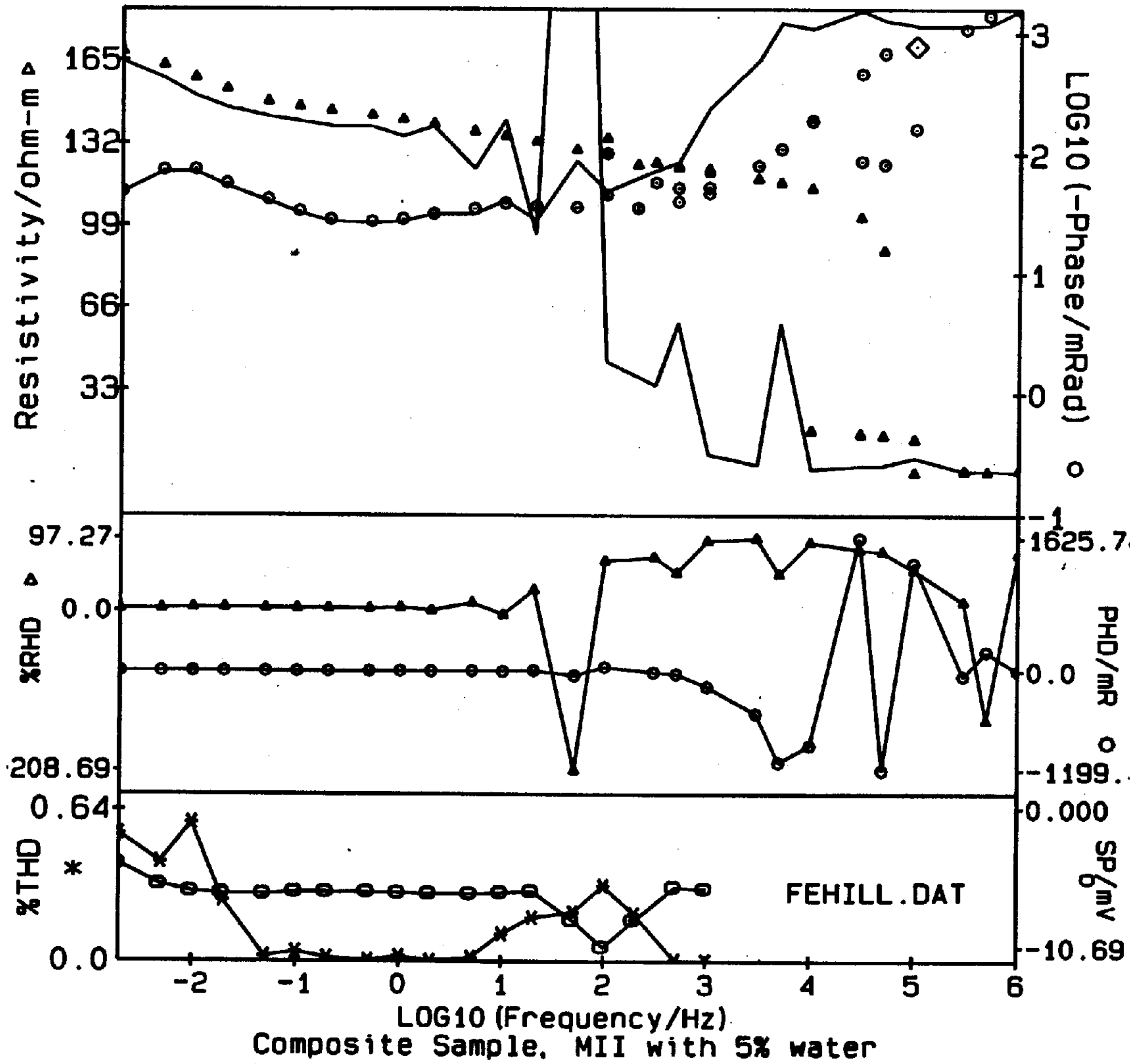
Composite Sample, Carlisle Mine with 5% water

Tucson

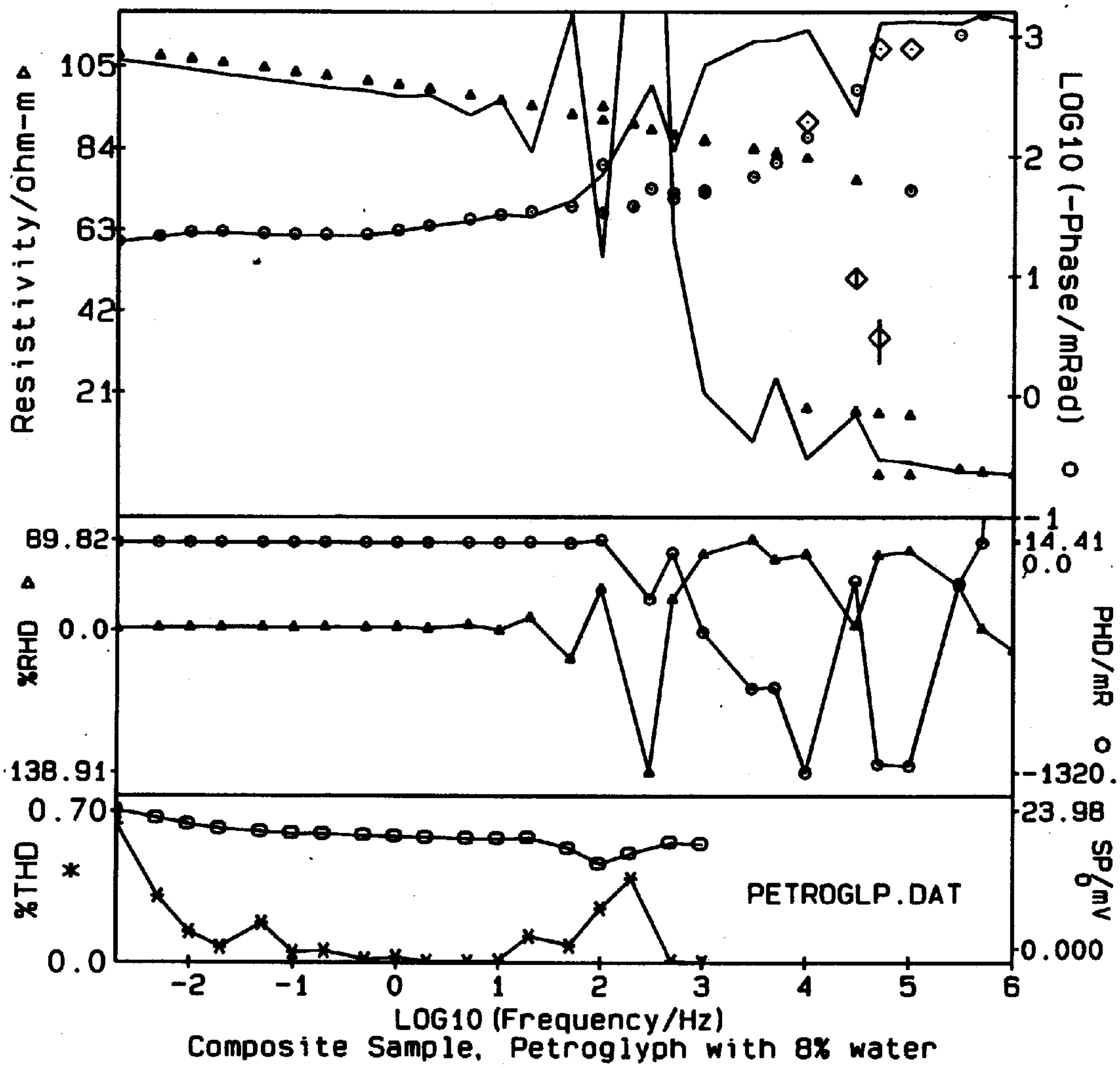


Composite Sample, Tucson with 6% water

Main Iron Incline



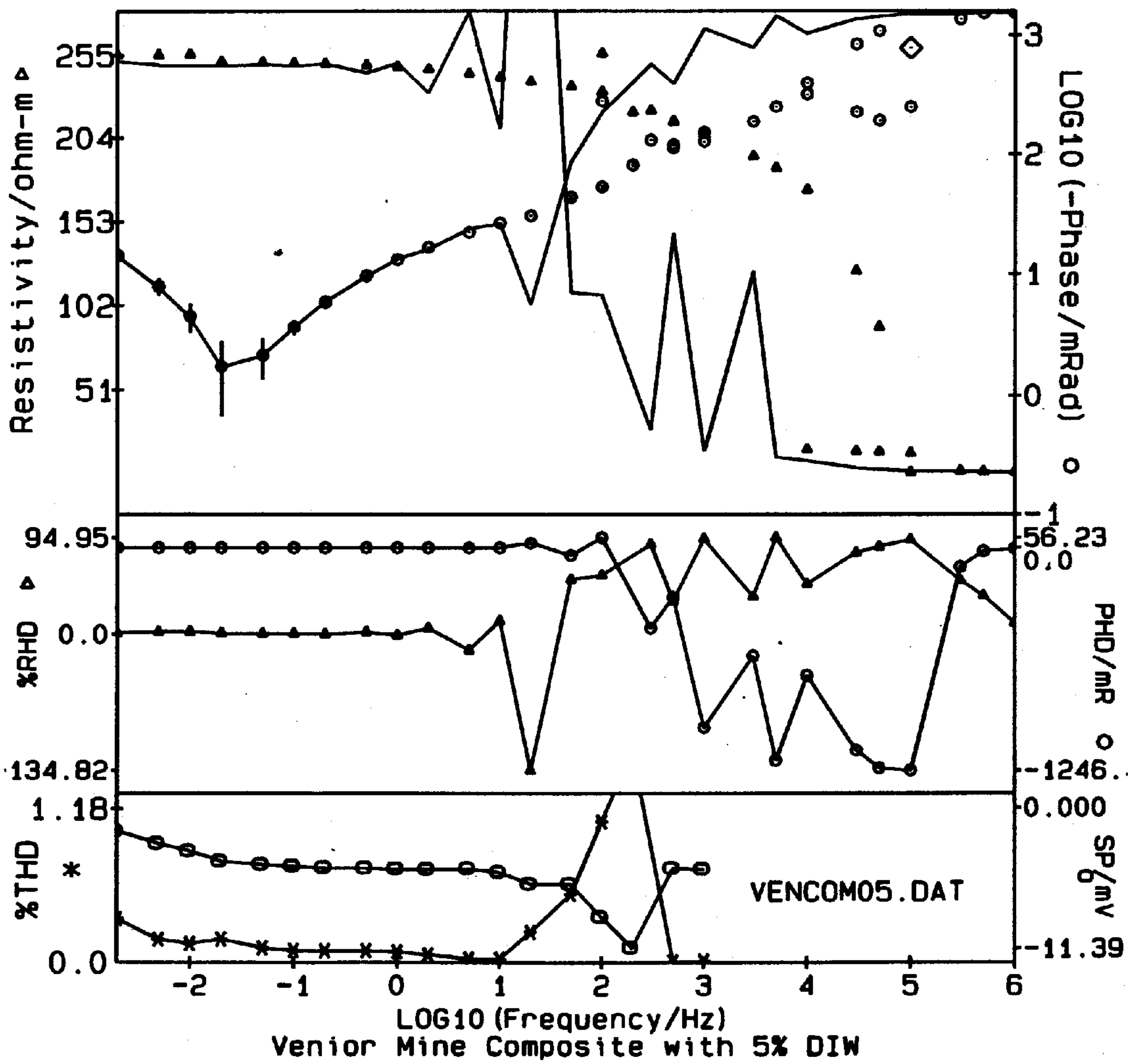
Petroglyph



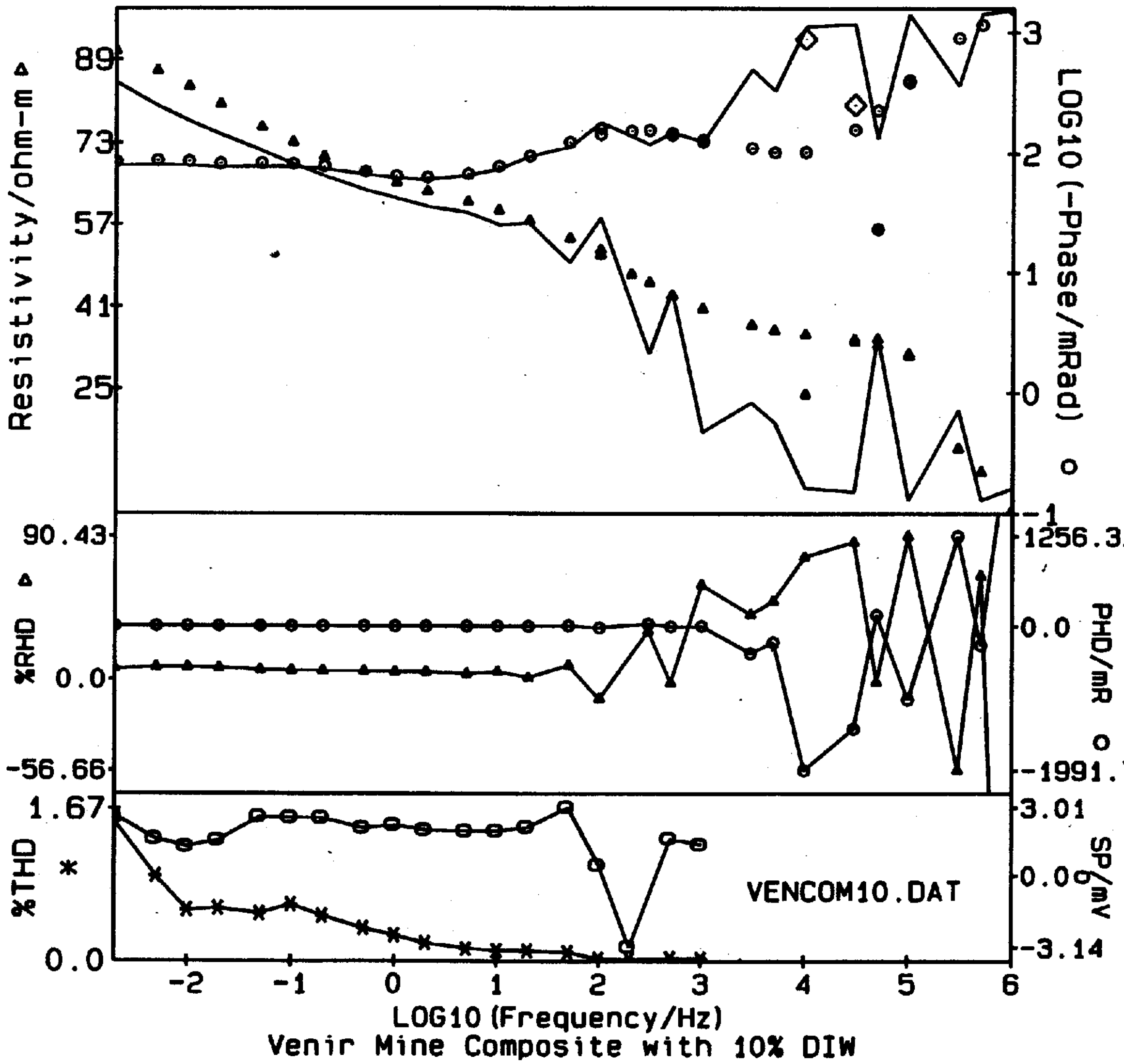
Resistivity/ohm-m
105
84
63
42
21
LOG10(-Phase/mRad)
3
2
1
0
-1
89.82
0.0
-138.91
%RHD
PHD/mR
14.41
0.0
-1320.!
0.70
0.0
%THD
SP/mV
23.98
0.000
PETROGLP.DAT
-2
-1
0
1
2
3
4
5
6
LOG10(Frequency/Hz)
Composite Sample, Petroglyph with 8% water

Appendix C—PetLab data from 2000 runs.

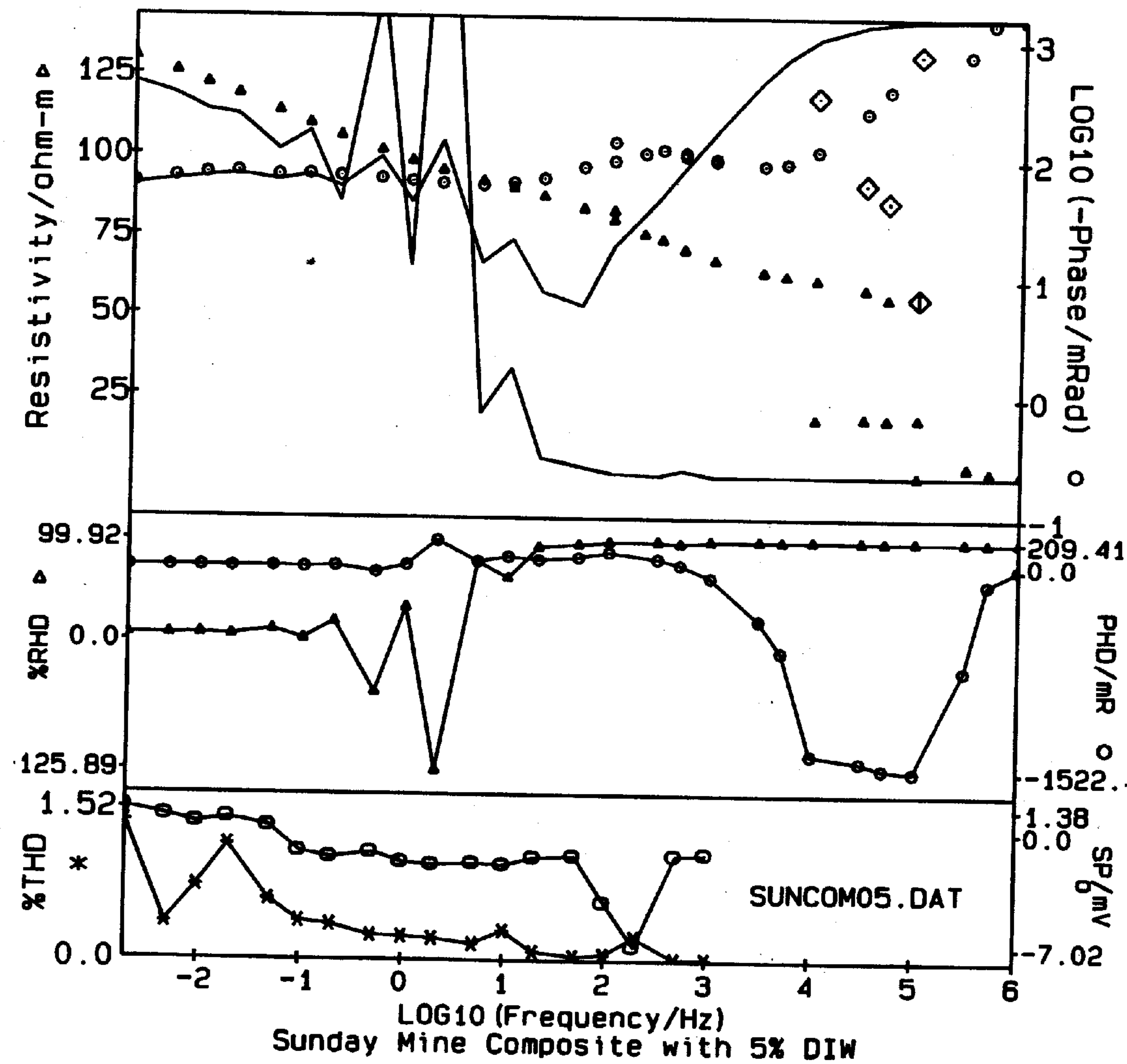
Venir-5% water



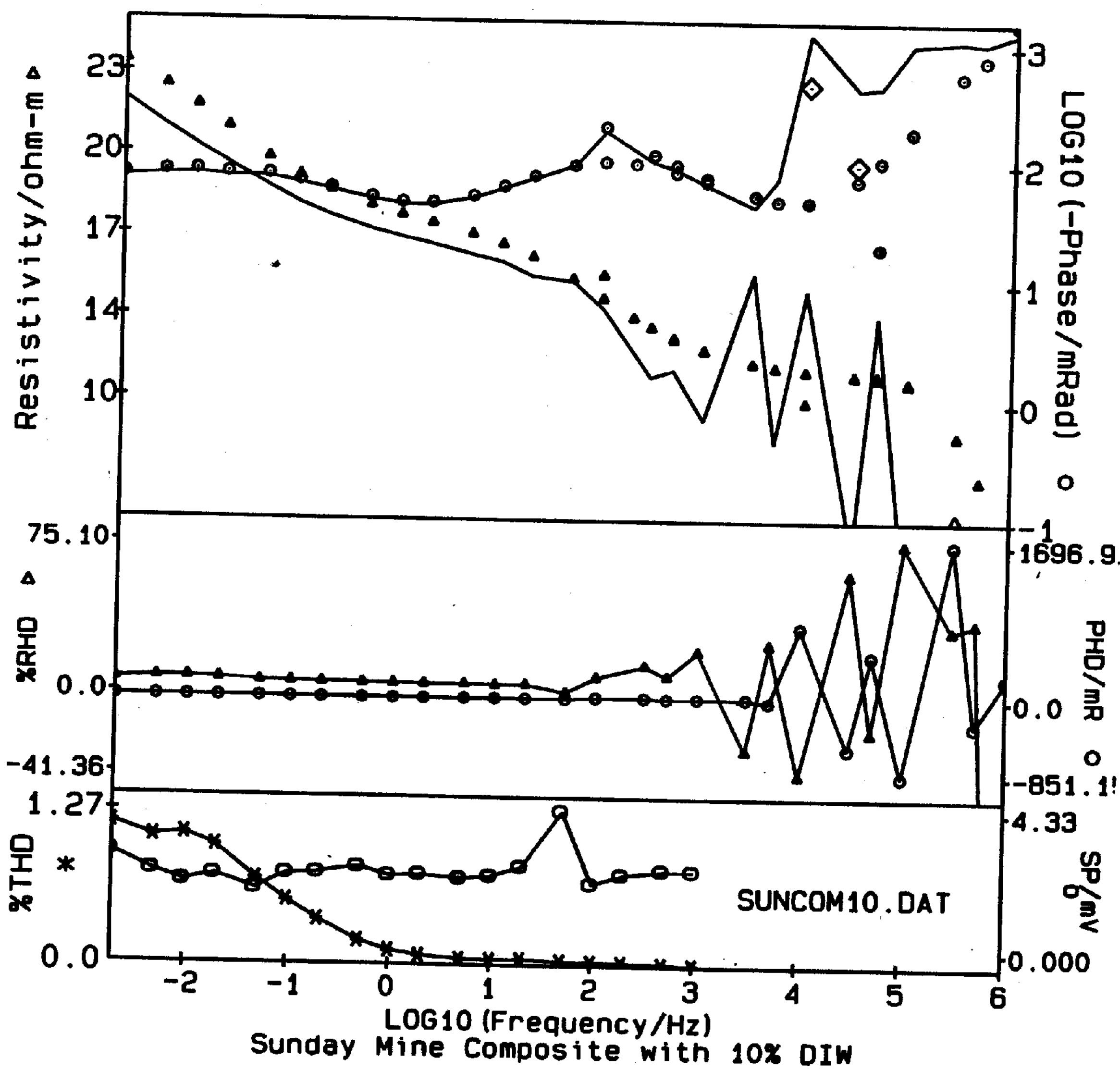
Venir-10% water



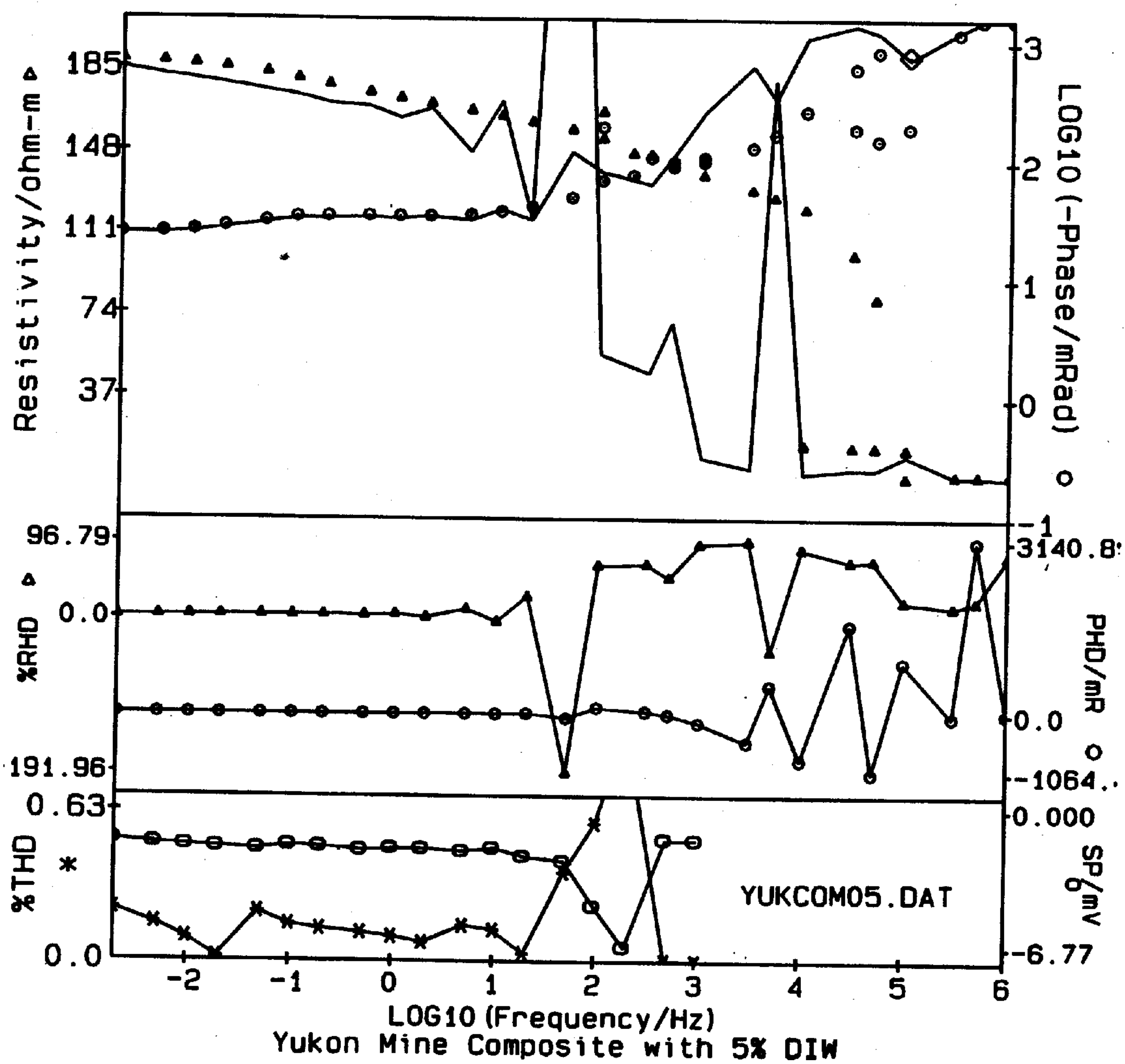
Sunday-5% water



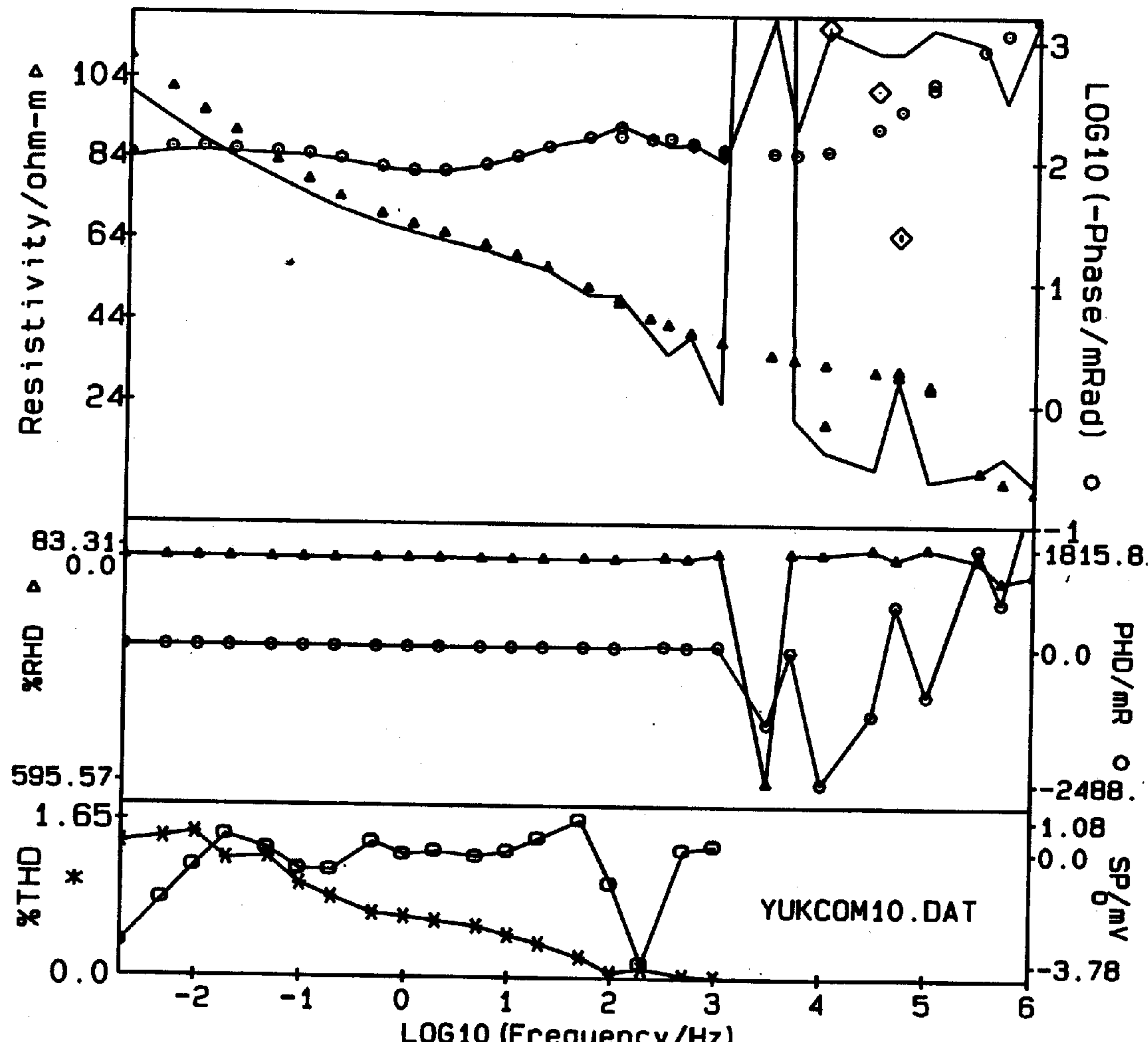
Sunday-10% water



Yukon-5% water

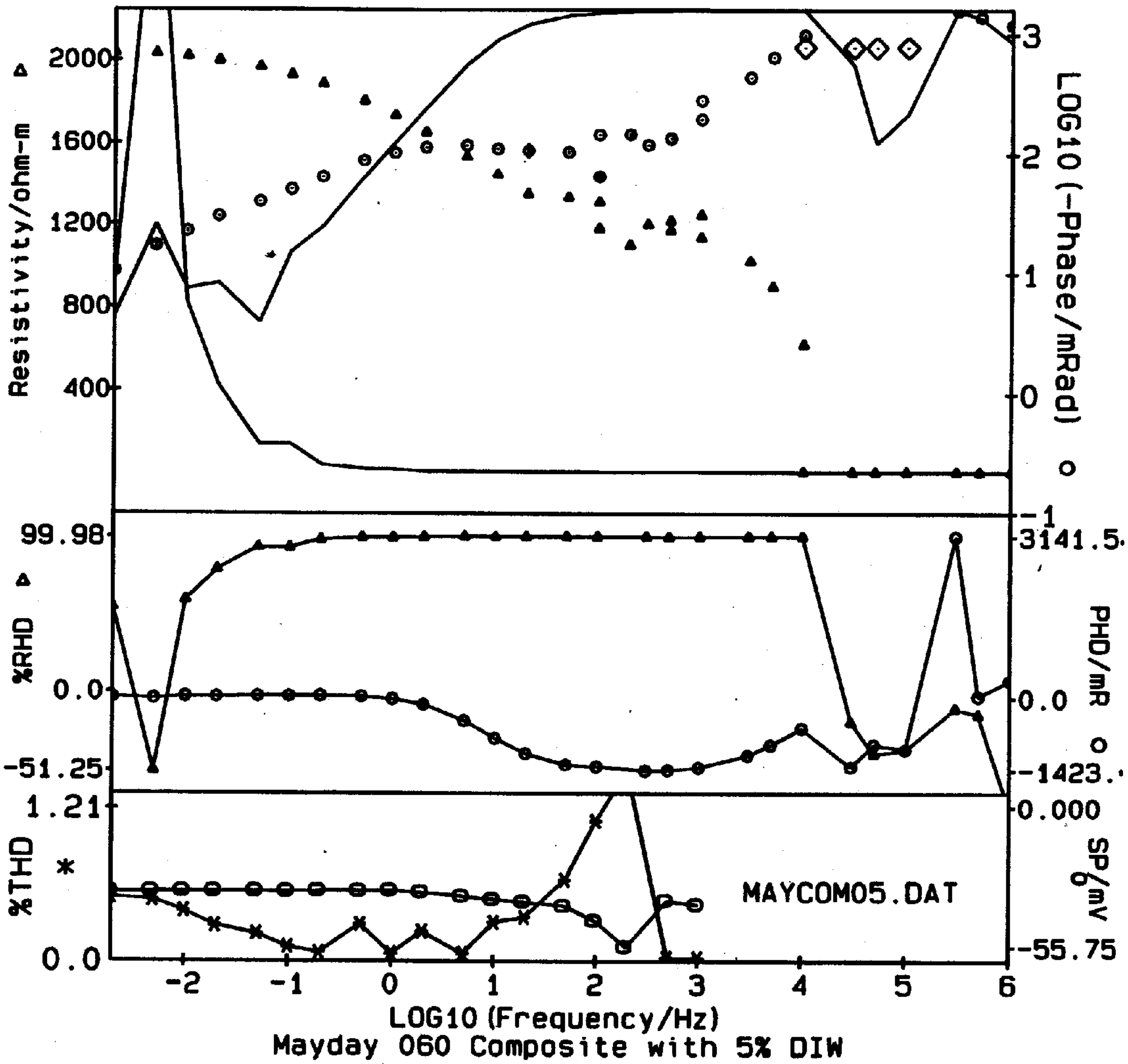


Yukon-10% water

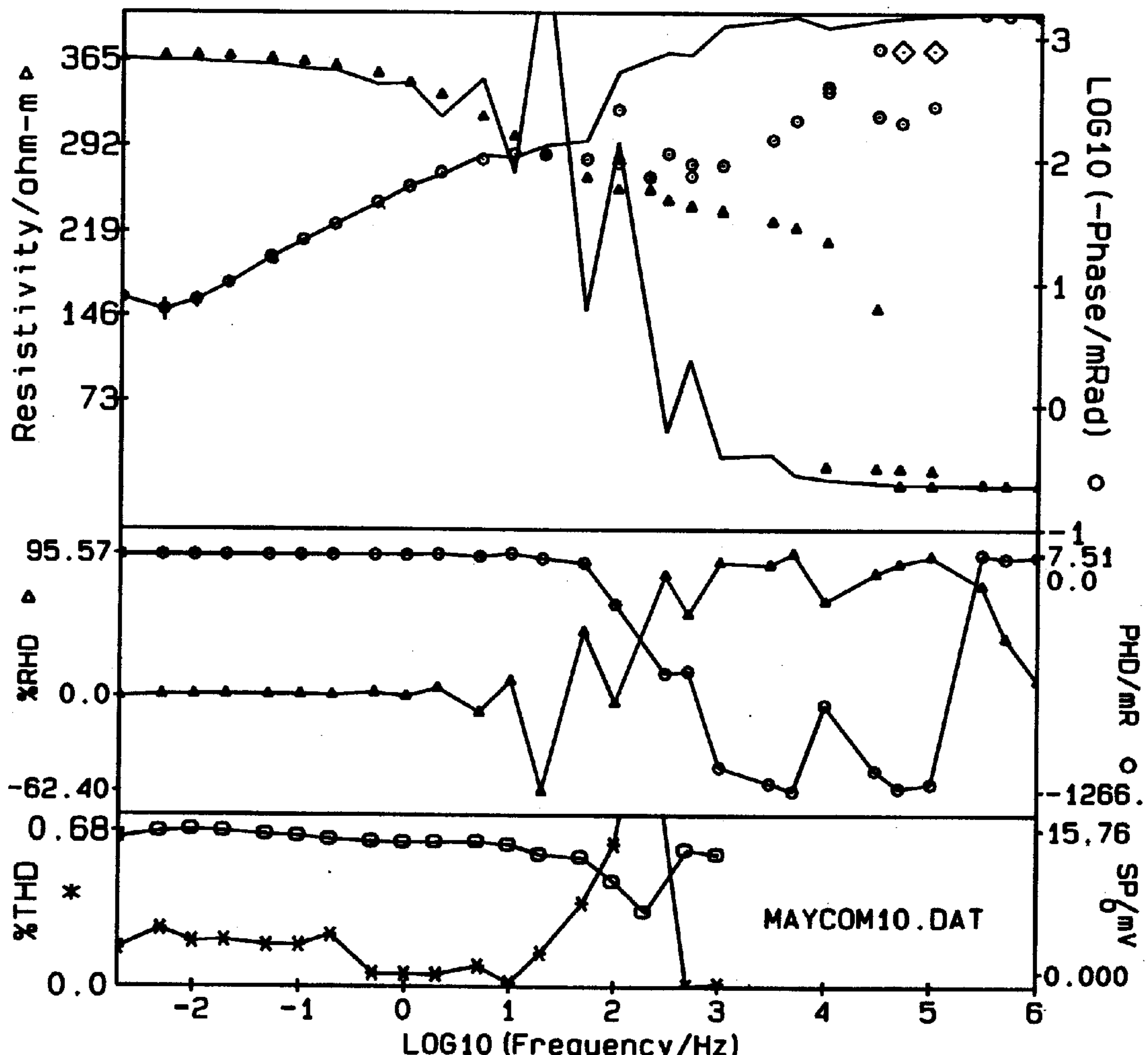


Yukon Mine Composite with 10% DIW

May Day-5% water

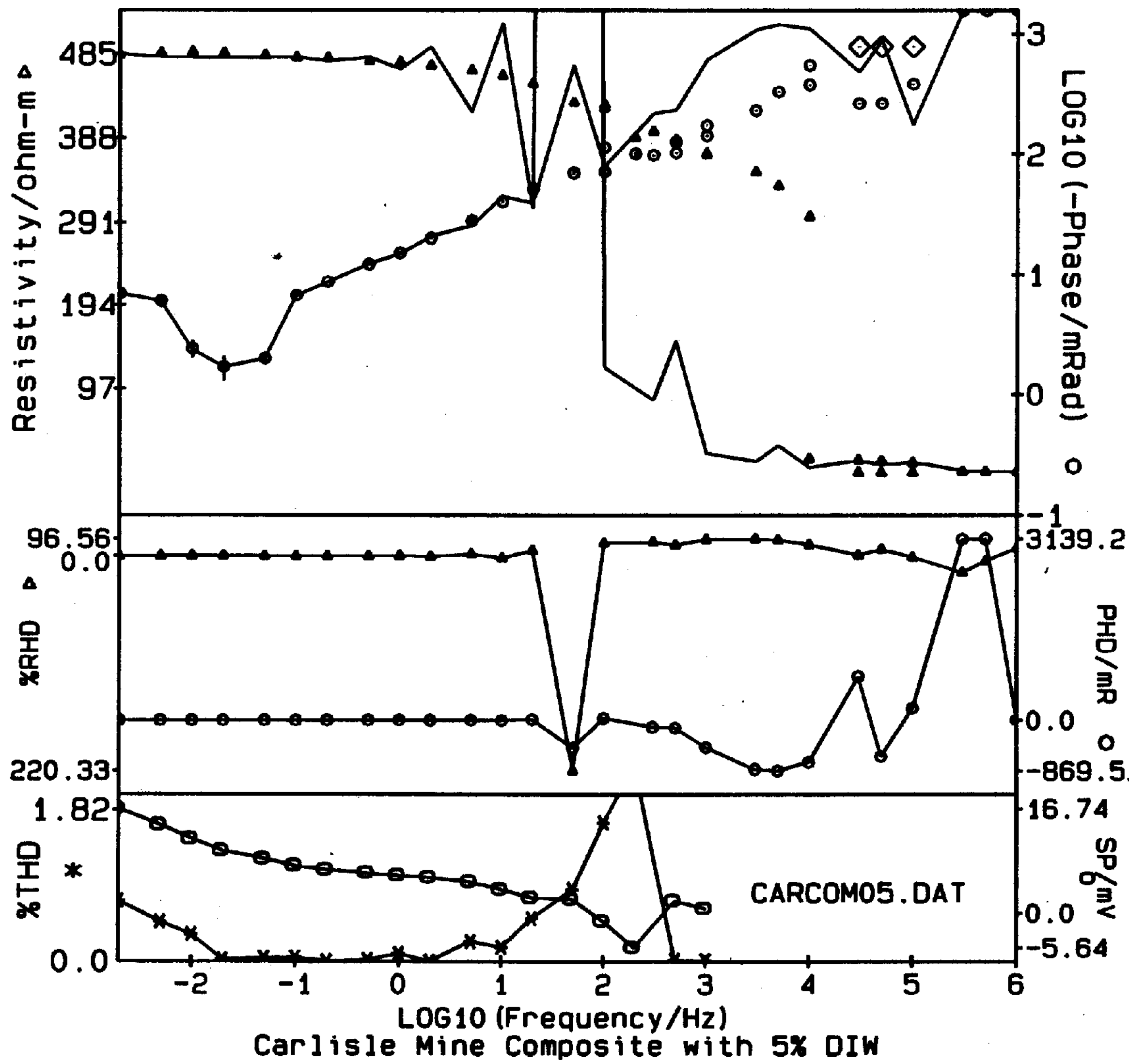


May Day-10% water

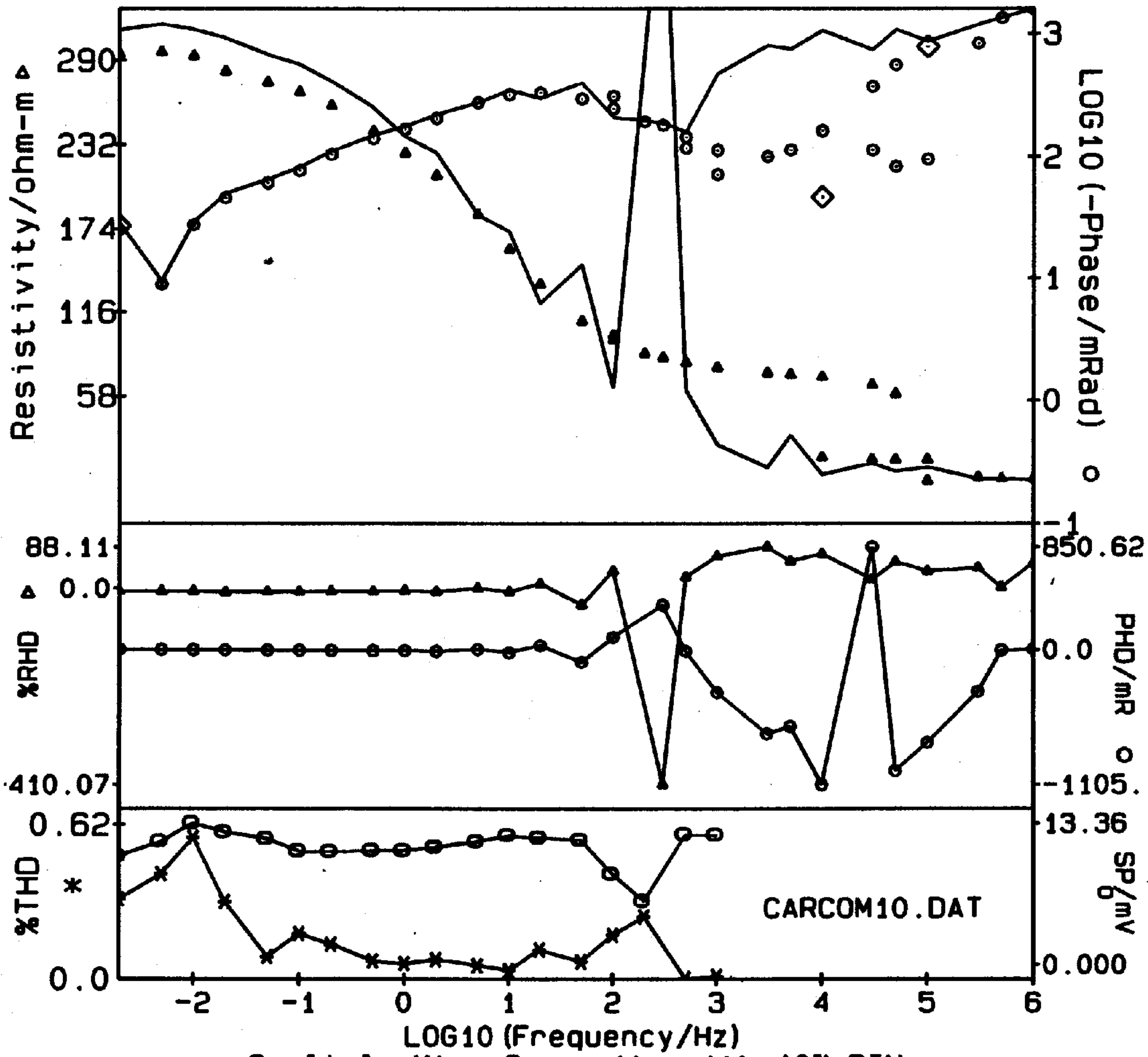


Mayday 060 Composite with 10% DIW

Carlisle-5% water

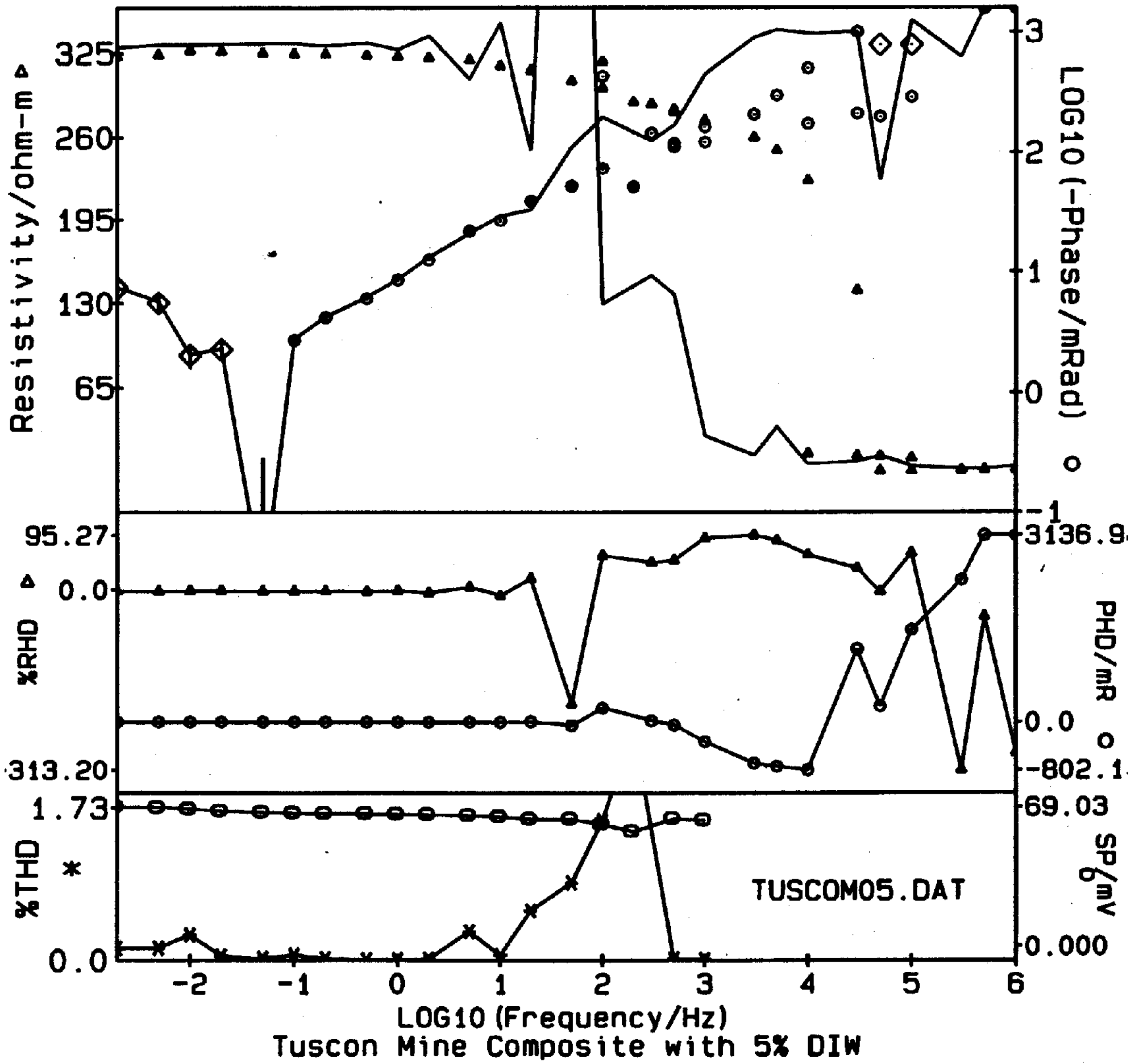


Carlisle-10% water

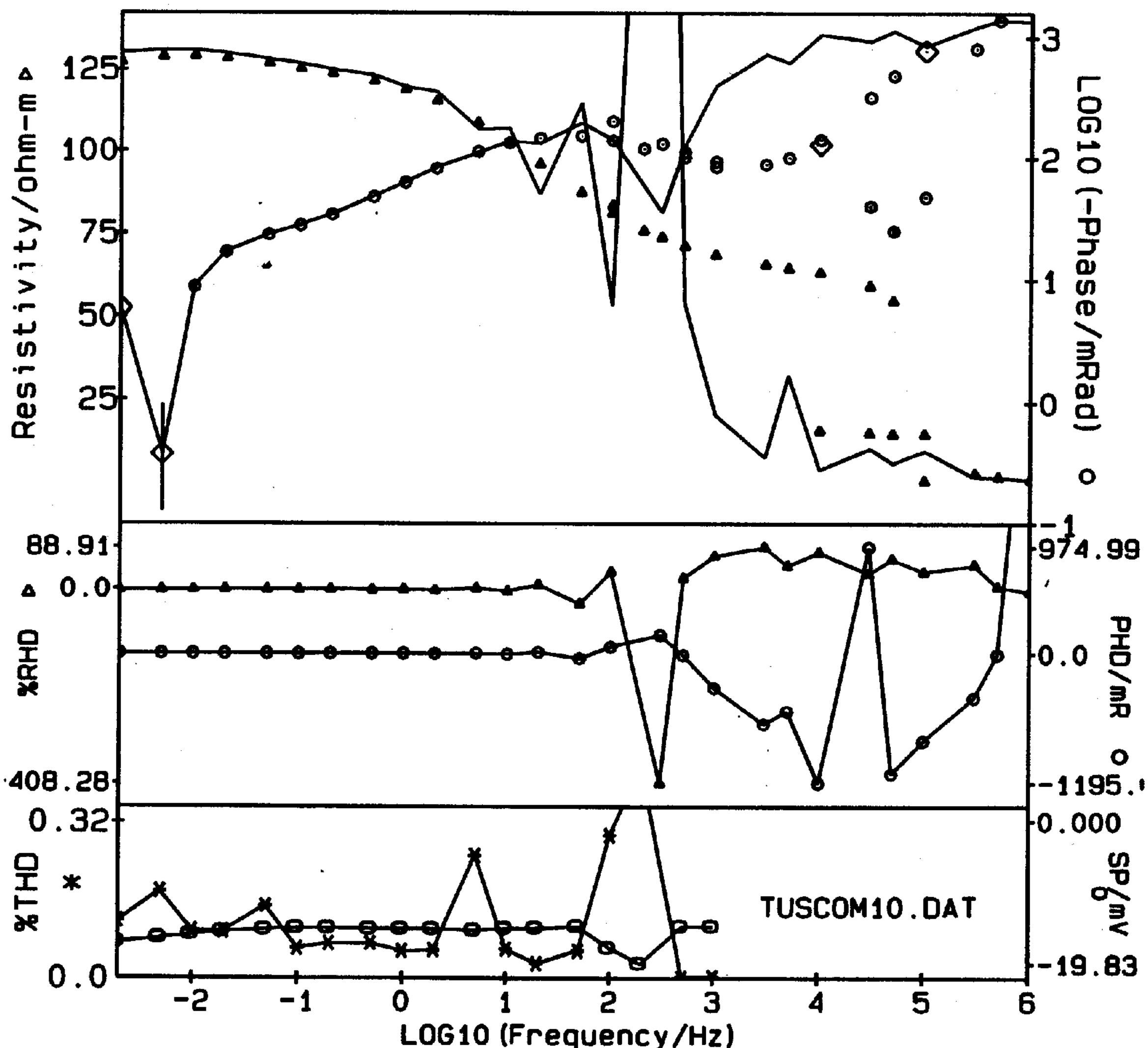


Carlisle Mine Composite with 10% DIW

Tucson-5% water

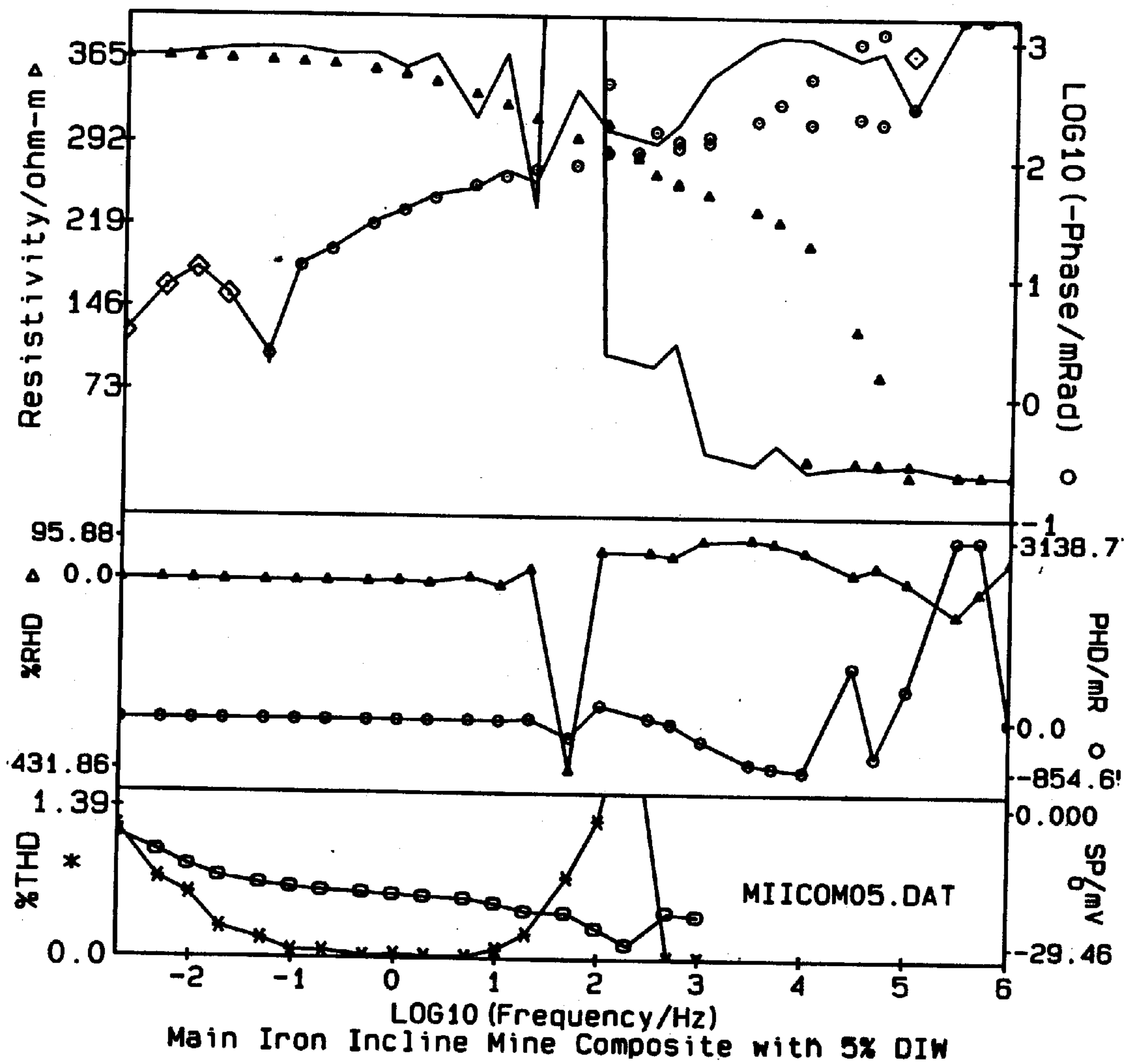


Tucson-10% water

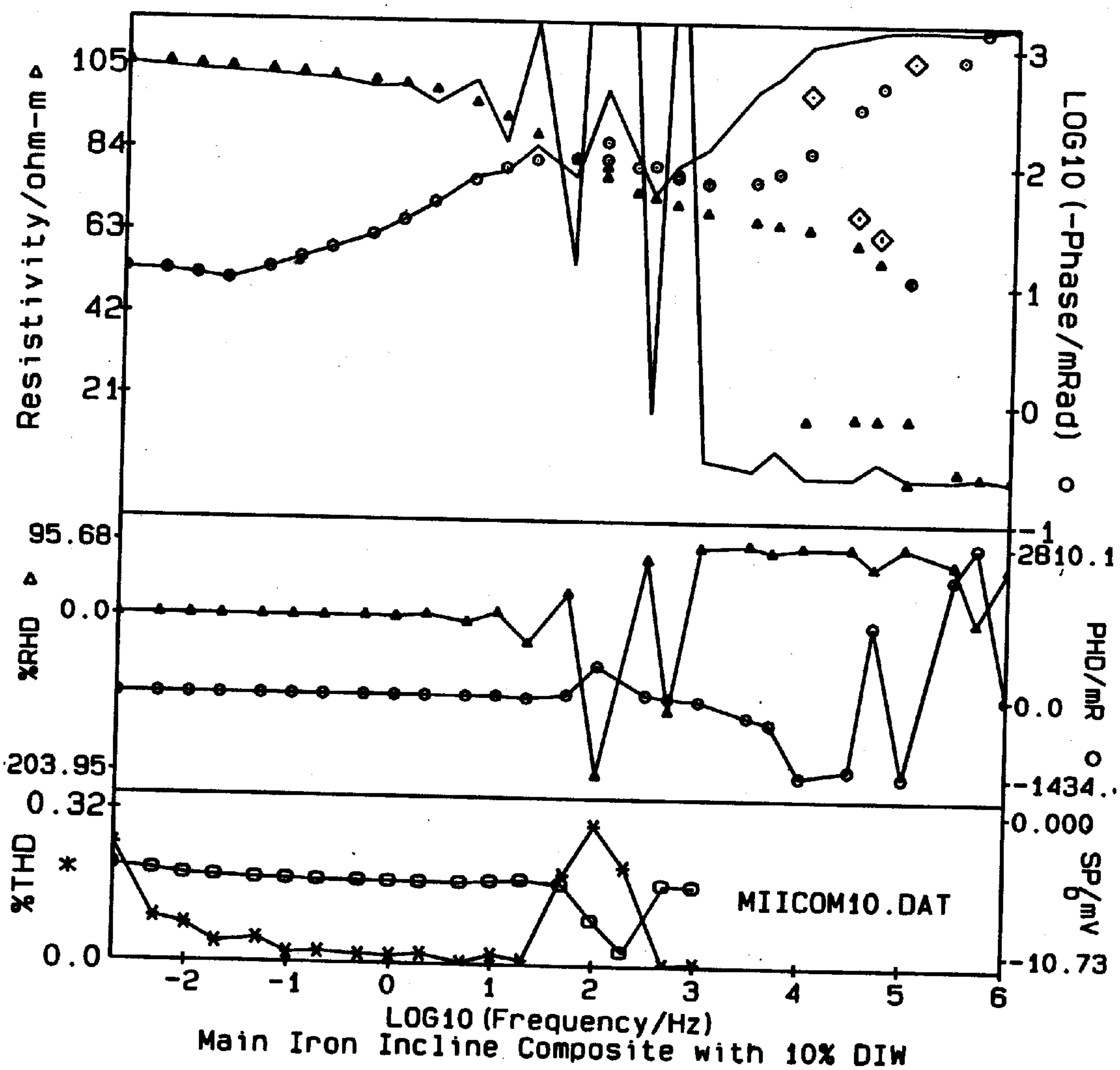


Tuscon Mine Composite with 10% DIW

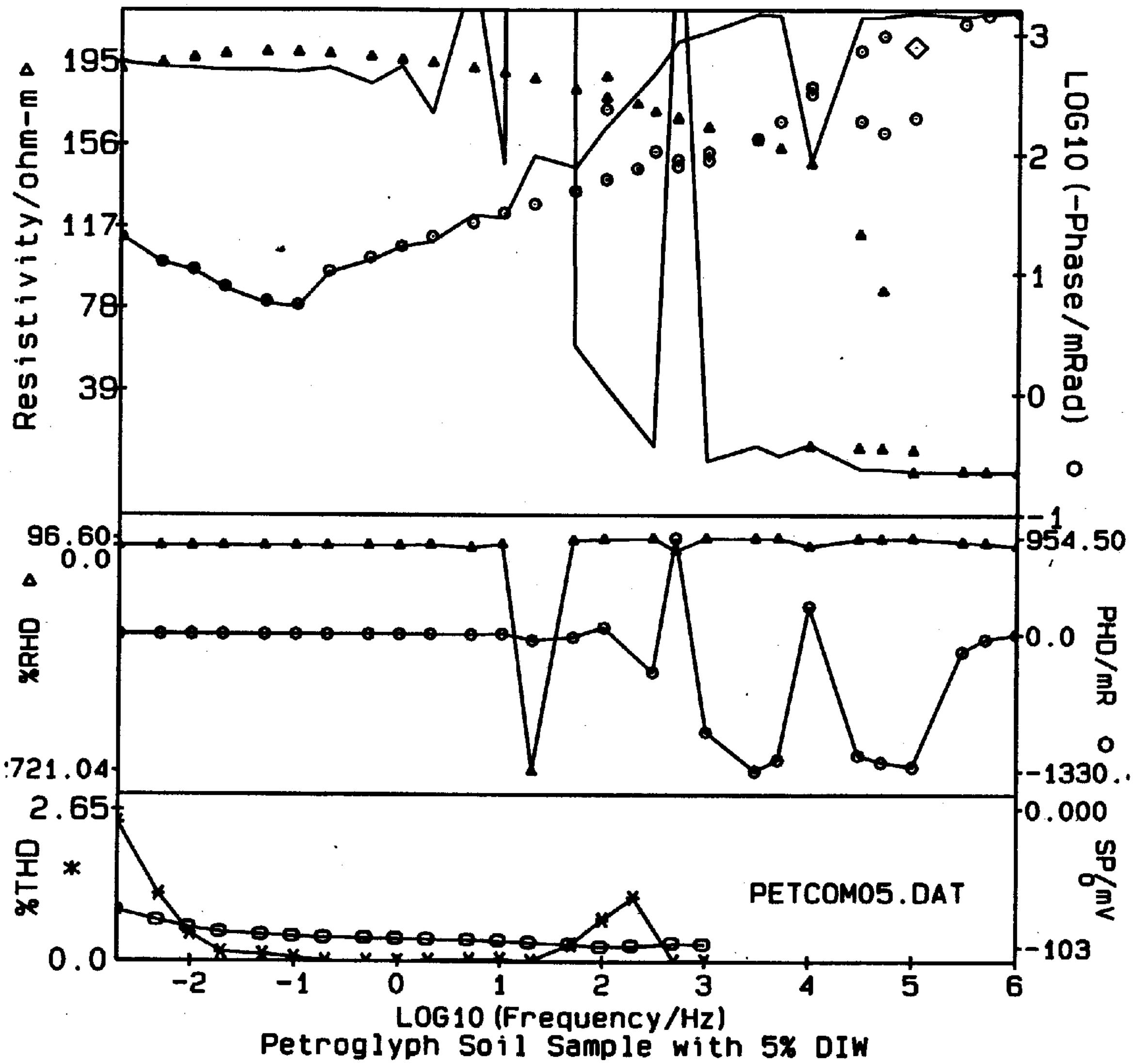
Main Iron Incline-5% water



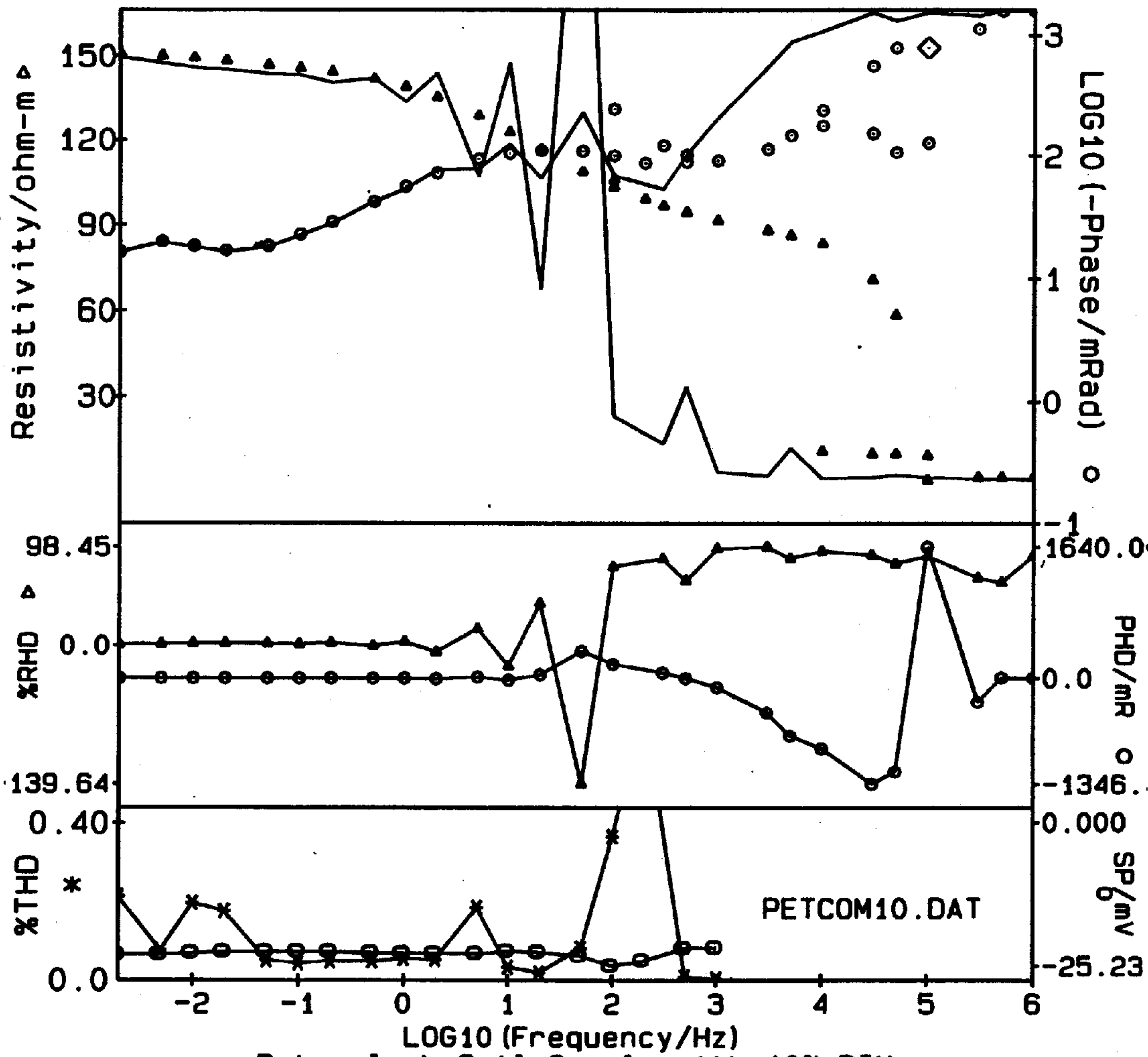
Main Iron Incline-10% water



Petroglyph-5% water



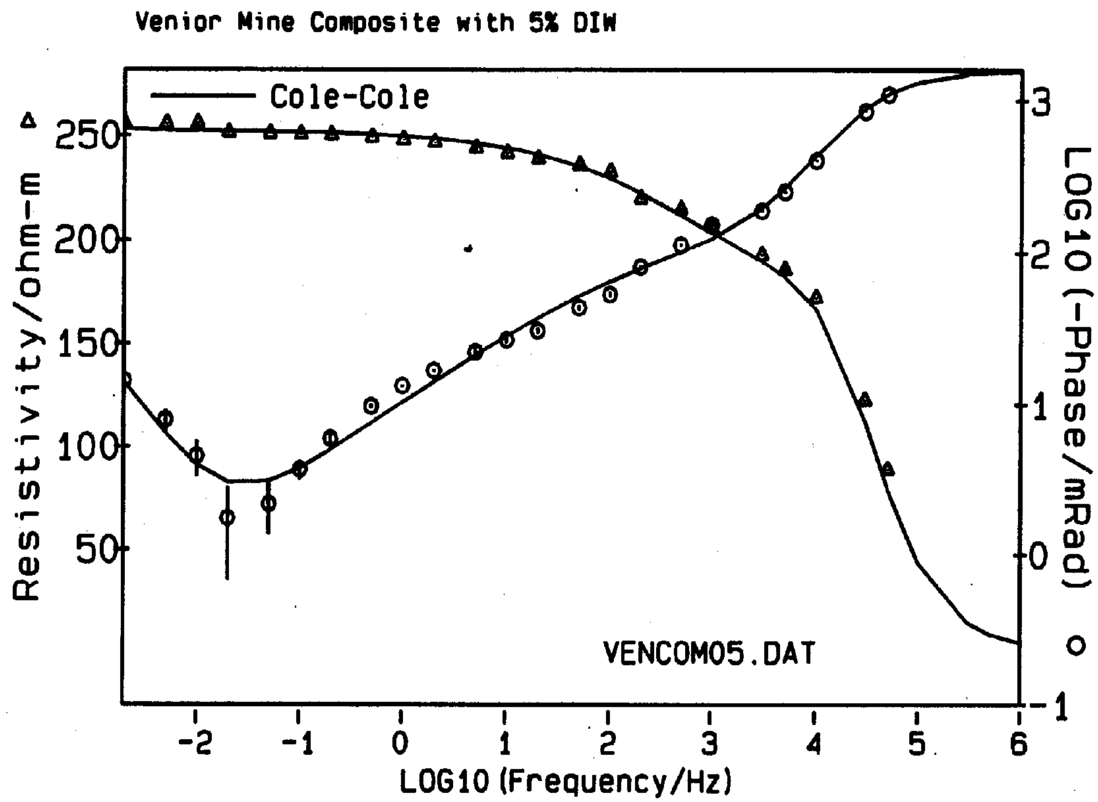
Petroglyph-10% water



Petroglyph Soil Sample with 10% DIW

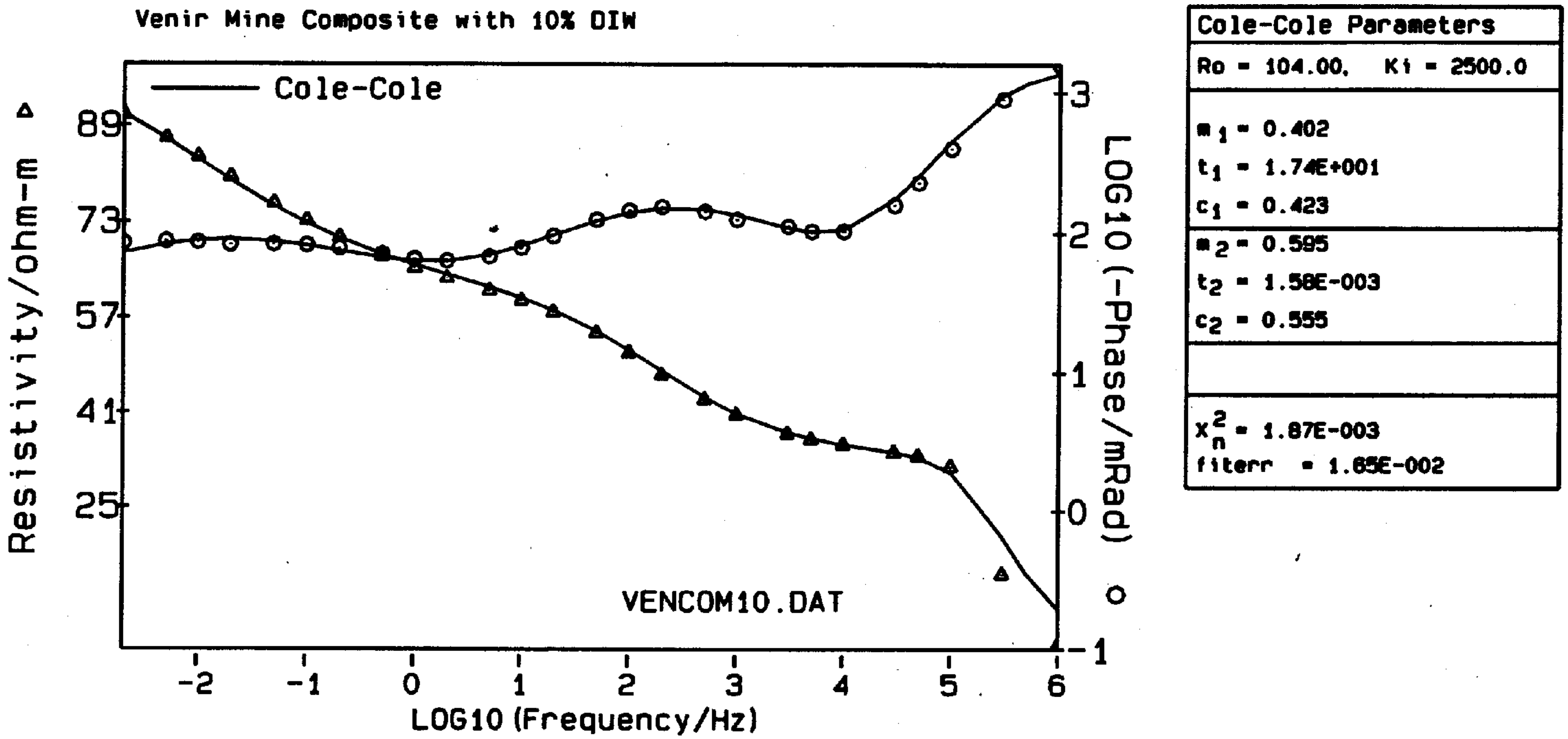
Appendix D – Cole-Cole models for PetLab data from 2000 runs.

Venir-5% water

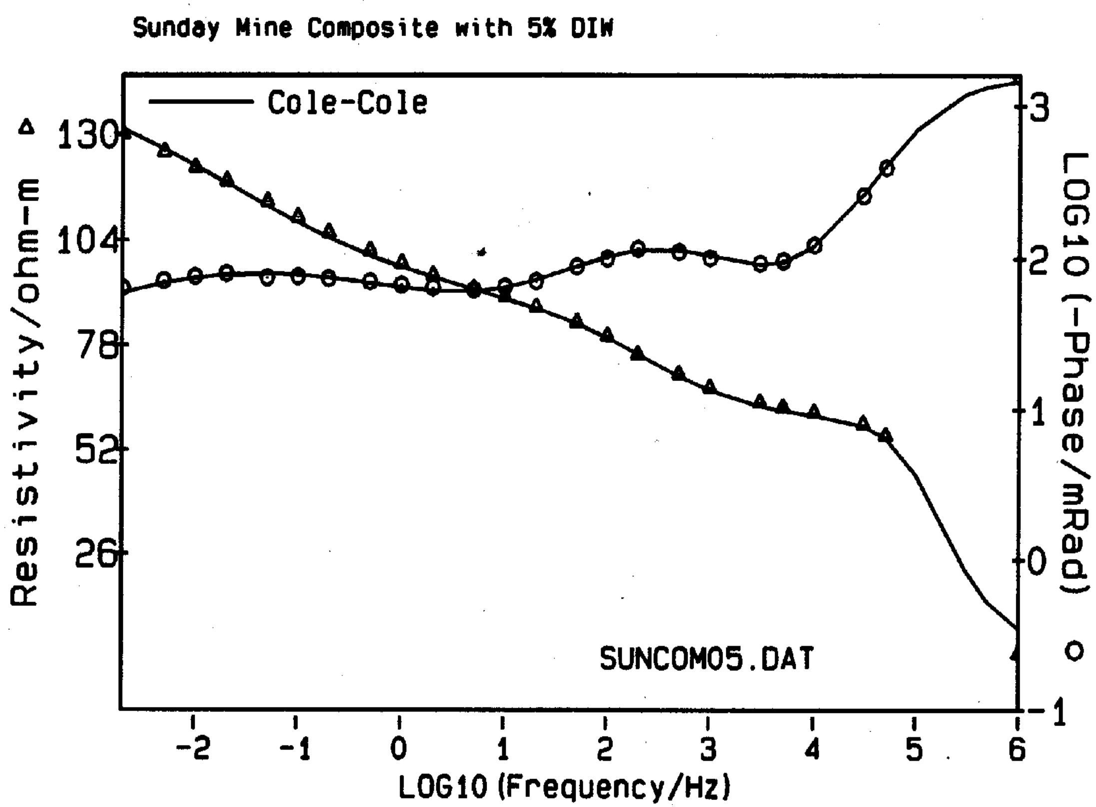


Cole-Cole Parameters
Ro = 270.00, Ki = 4000.0
m_1 = 0.065 t_1 = 3.89E+002 c_1 = 1.000
m_2 = 0.343 t_2 = 3.15E-004 c_2 = 0.484
x_n^2 = 3.12E-003 fiterr = 1.24E+000

Venir-10% water

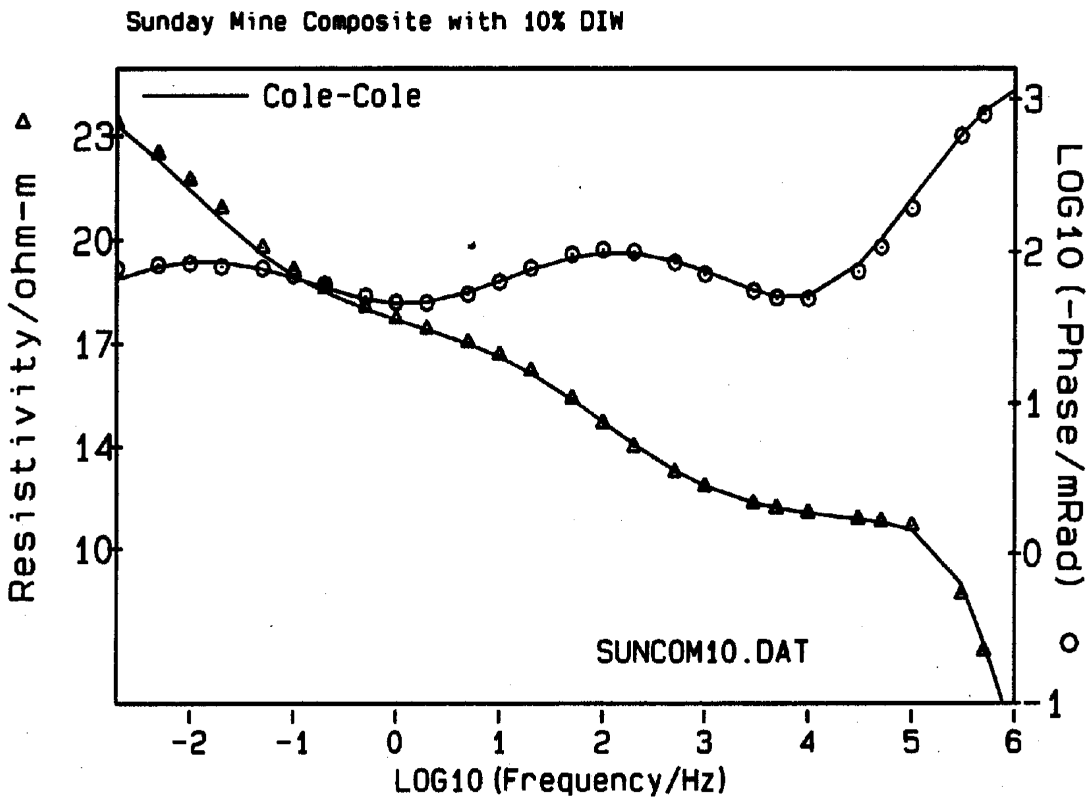


Sunday-5% water



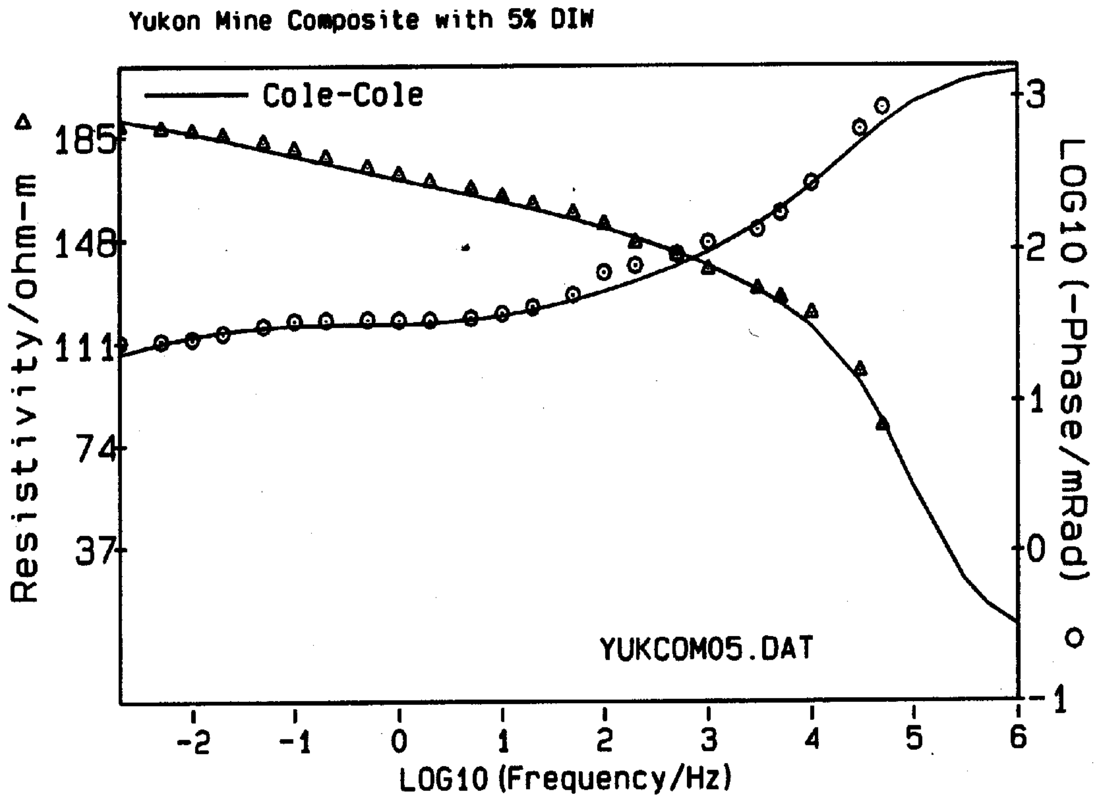
Cole-Cole Parameters
Ro = 150.00, Ki = 2500.0
m_1 = 0.420 t_1 = 9.00E+000 c_1 = 0.360
m_2 = 0.450 t_2 = 9.00E-004 c_2 = 0.620
X_n^2 = 1.67E-002 fiterr = 9.79E-001

Sunday-10% water



Cole-Cole Parameters
Ro = 25.50, Ki = 3500.0
m_1 = 0.324
t_1 = 1.82E+001
c_1 = 0.522
m_2 = 0.445
t_2 = 2.19E-003
c_2 = 0.539
x^2_n = 4.36E-004
fiterr = 9.95E-003

Yukon-5% water



Cole-Cole Parameters

Ro = 200.00, Ki = 2000.0

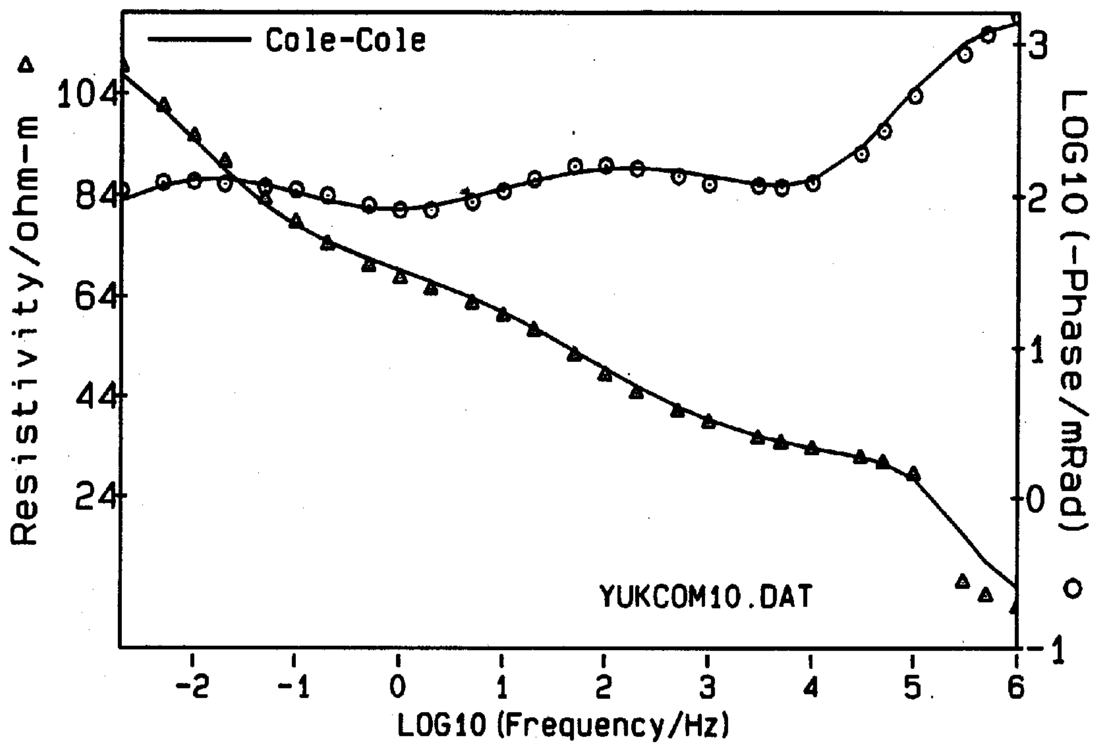
m_1 = 0.143
t_1 = 4.50E+000
c_1 = 0.364

m_2 = 1.546
t_2 = 8.06E-008
c_2 = 0.231

X_n^2 = 1.51E-003
fiterr = 1.19E+000

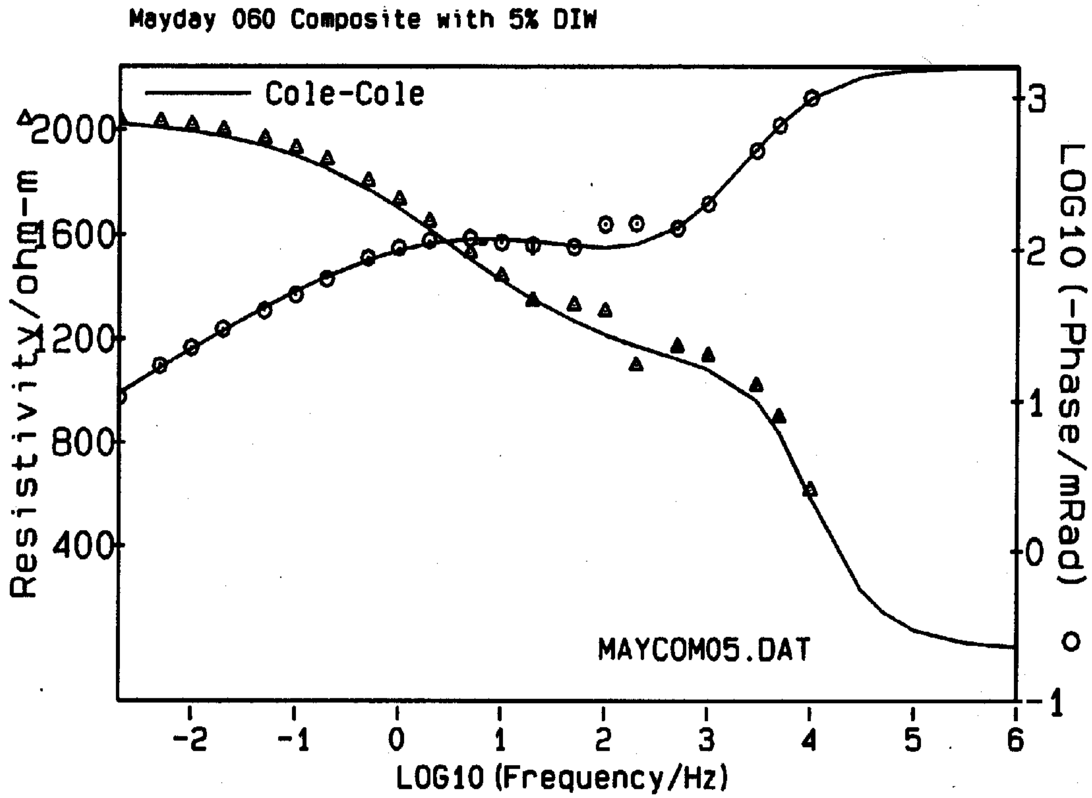
Yukon-10% water

Yukon Mine Composite with 10% DIW



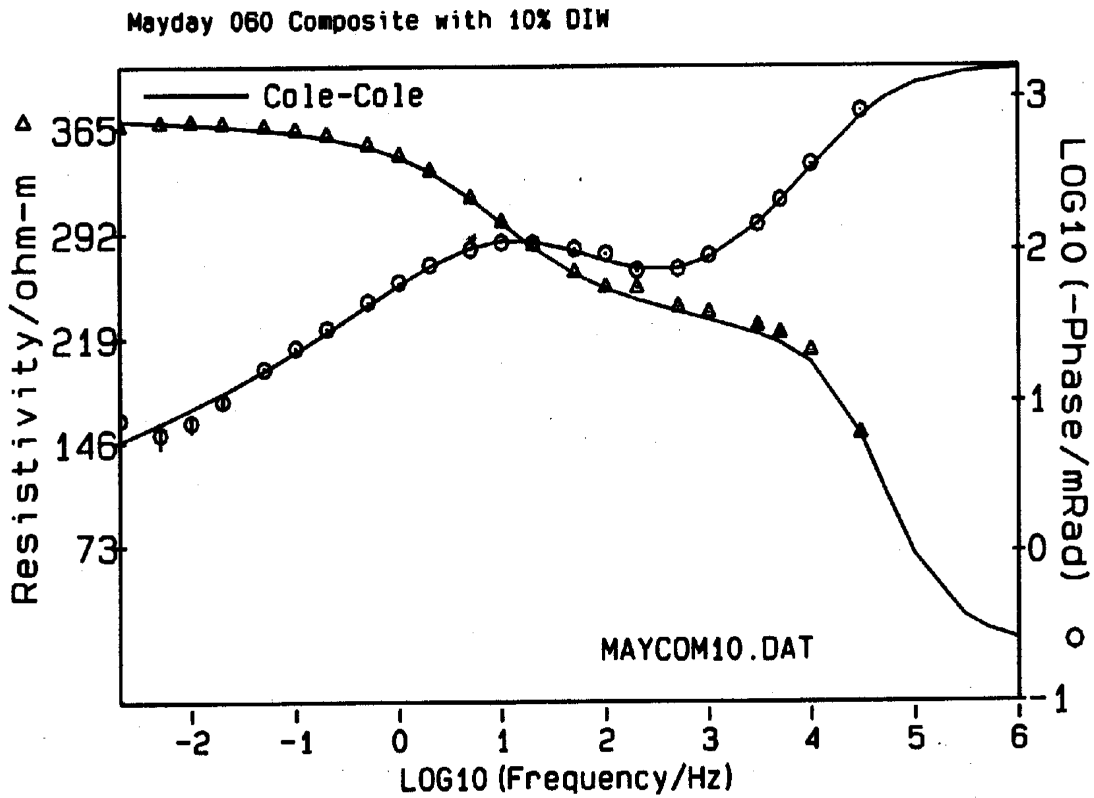
Cole-Cole Parameters
Ro = 122.00, Ki = 3000.0
m_1 = 0.406 t_1 = 1.88E+001 c_1 = 0.558
m_2 = 0.697 t_2 = 5.47E-003 c_2 = 0.436
x_n^2 = 1.24E-002

May Day-5% water



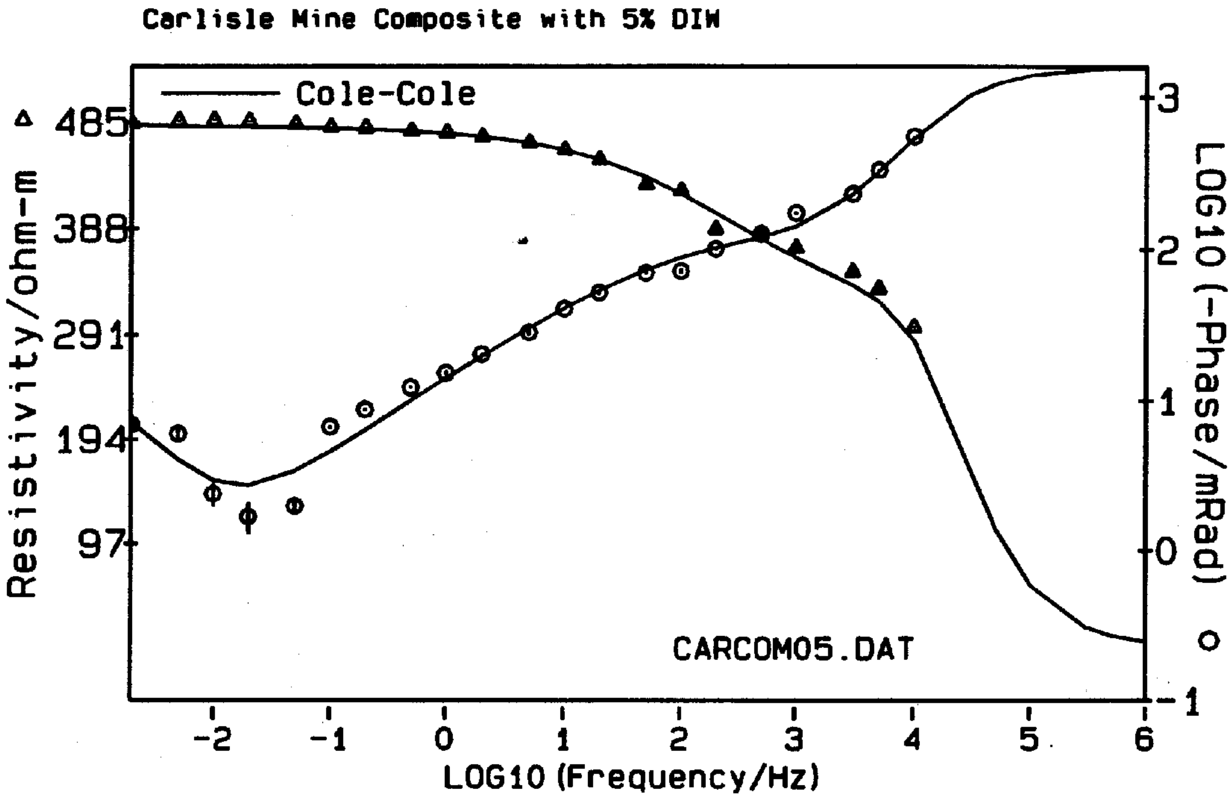
Cole-Cole Parameters
Ro = 2050.00, Ki = 2500.0
m_1 = 0.413
t_1 = 5.87E-002
c_1 = 0.460
m_2 = 0.264
t_2 = 8.38E-004
c_2 = 0.383
x_n^2 = 1.08E-003
fiterr = 3.95E+000

May Day-10% water



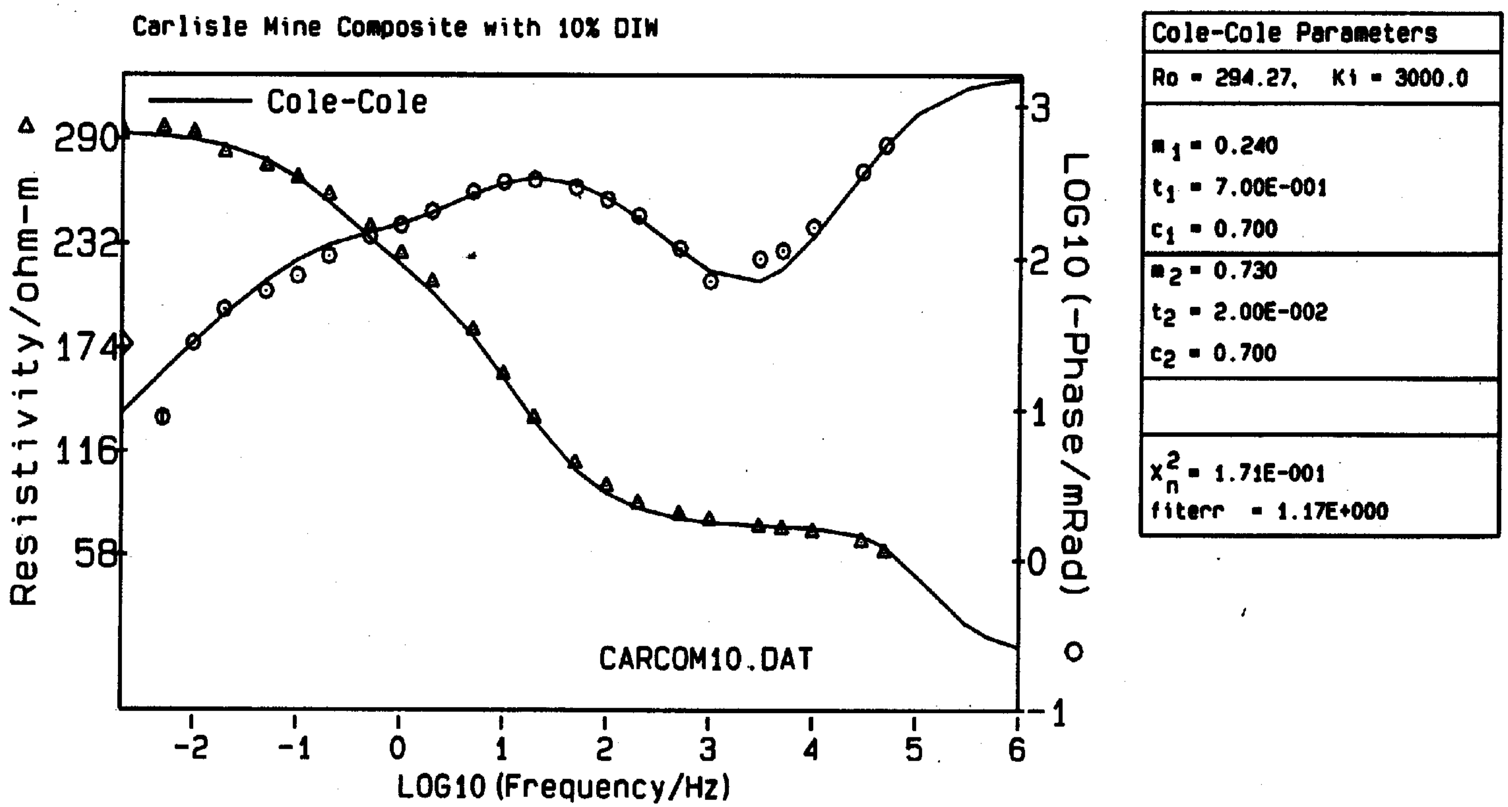
Cole-Cole Parameters
Ro = 375.00, Ki = 2500.0
m_1 = 0.283 t_1 = 1.68E-002 c_1 = 0.679
m_2 = 0.590 t_2 = 6.88E-006 c_2 = 0.232
x_n^2 = 9.33E-004 fiterr = 2.47E+000

Carlisle-5% water

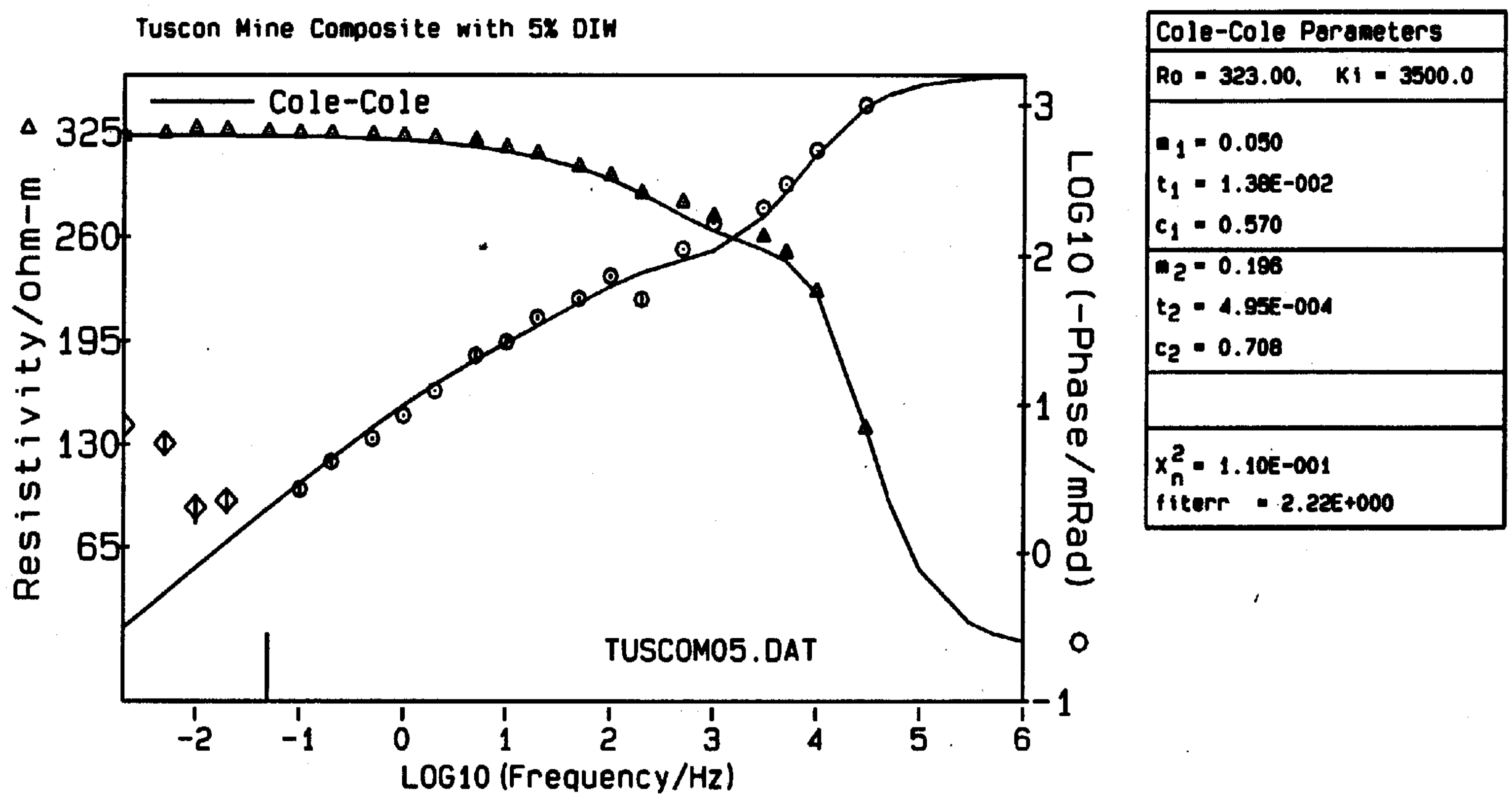


Cole-Cole Parameters
Ro = 490.00, Ki = 3000.0
m_1 = 0.017 t_1 = 1.69E+002 c_1 = 1.000
m_2 = 0.345 t_2 = 7.51E-004 c_2 = 0.524
χ^2_n = 3.92E-003 fiterr = 3.50E+000

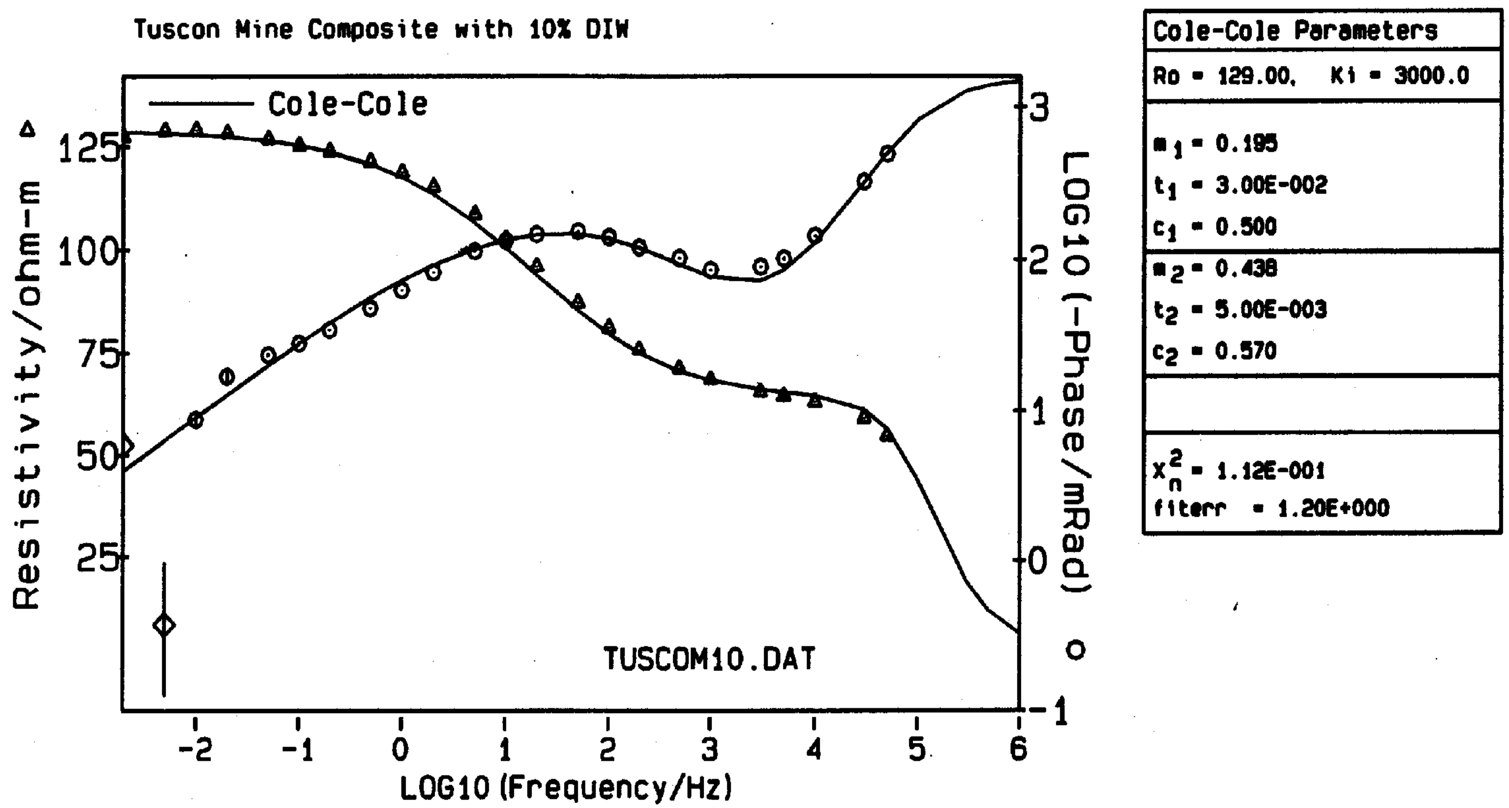
Carlisle-10% water



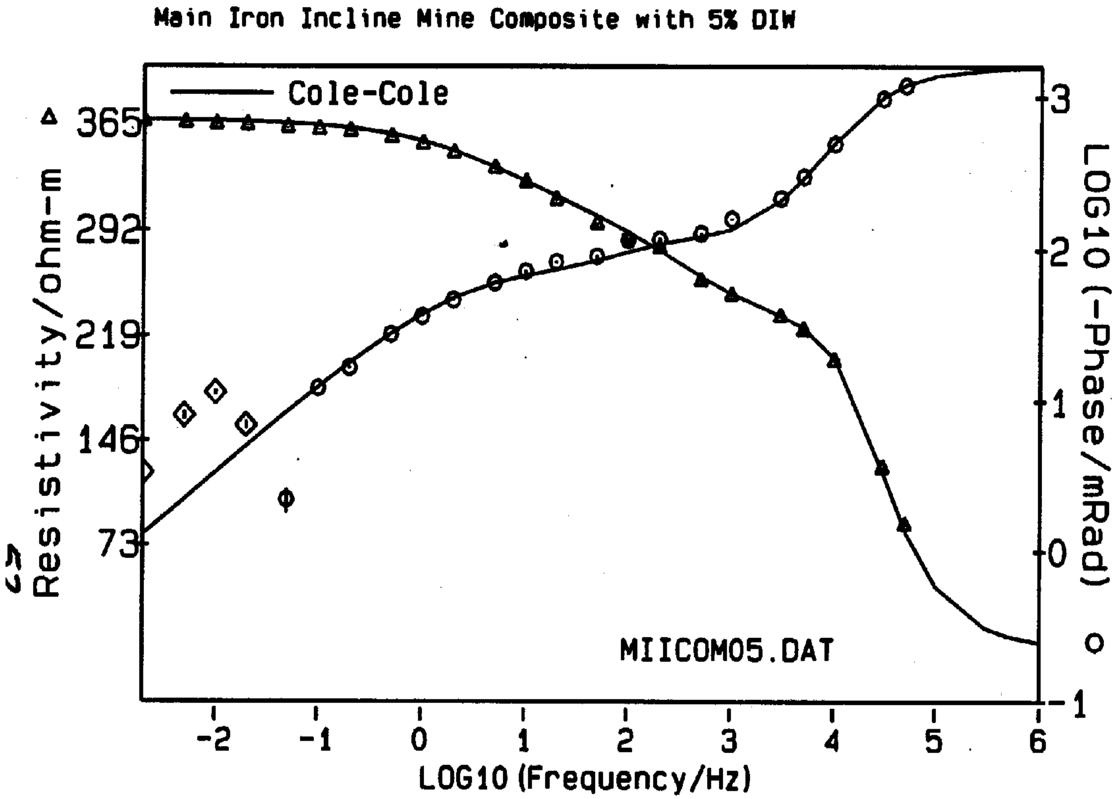
Tucson-5% water



Tucson-10% water

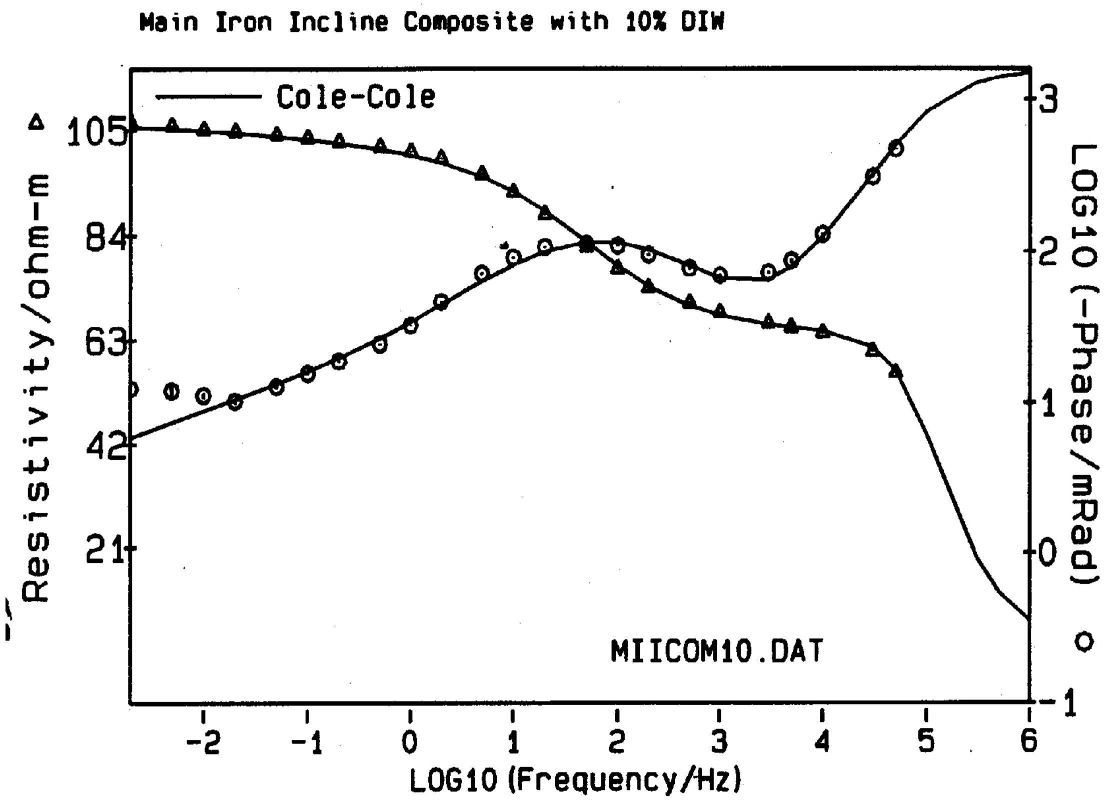


Main Iron Incline-5% water



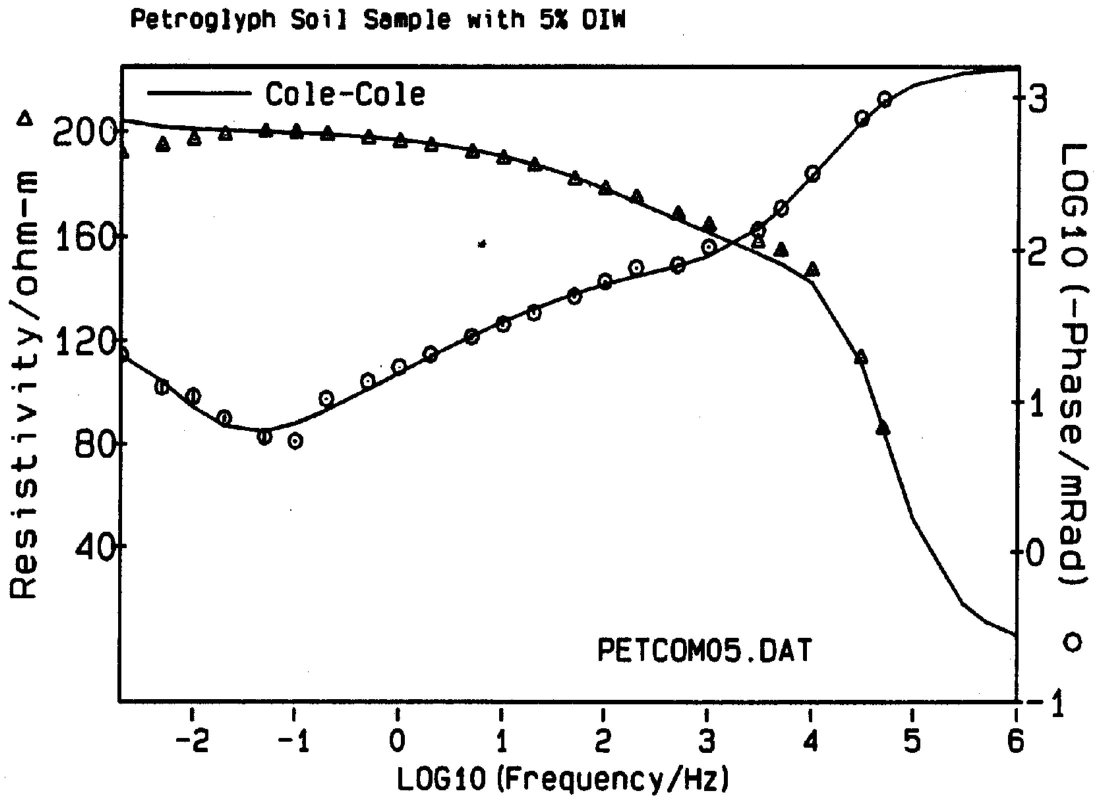
Cole-Cole Parameters
Ro = 368.00, Ki = 4000.0
m_1 = 0.160 t_1 = 3.00E-002 c_1 = 0.598
m_2 = 0.303 t_2 = 5.93E-004 c_2 = 0.645
X_n^2 = 2.78E-001 fiterr = 1.33E+000

Main Iron Incline-10% water



Cole-Cole Parameters
Ro = 107.00, Ki = 3000.0
m_1 = 0.090 t_1 = 2.30E-001 c_1 = 0.300
m_2 = 0.360 t_2 = 3.30E-003 c_2 = 0.620
X_n^2 = 3.30E-003 fiterr = 9.93E-001

Petroglyph-5% water



Cole-Cole Parameters

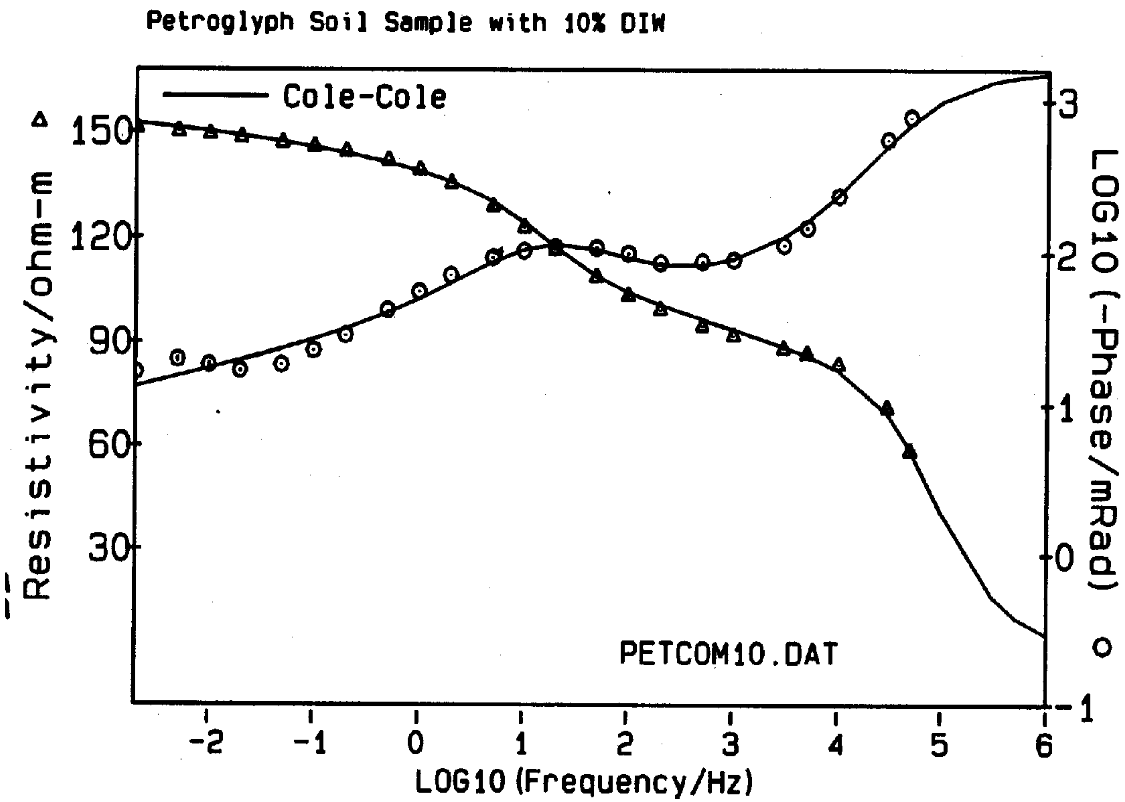
Ro = 210.00,   Ki = 3300.0

m_1 = 0.042
t_1 = 1.09E+002
c_1 = 0.946

m_2 = 0.323
t_2 = 5.25E-004
c_2 = 0.416

X_n^2 = 9.34E-004
fiterr = 1.28E+000

Petroglyph-10% water



Cole-Cole Parameters

Ro = 160.00, Ki = 3500.0

m_1 = 0.204
t_1 = 9.17E-003
c_1 = 0.799

m_2 = 0.824
t_2 = 1.06E-005
c_2 = 0.175

x_n^2 = 1.32E-003
fiterr = 1.15E+000