



**GEOELECTRICAL LABORATORY MEASUREMENTS OF
MATERIALS FROM THE MAY DAY MINE DUMP,
SOUTHWESTERN COLORADO**

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¹ Denver, Colorado

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INTRODUCTION

As part of a project to investigate formation of acid mine drainage, our USGS group has been doing integrated geological, geochemical, and geophysical studies of mine dumps in Colorado and New Mexico. One of these is the May Day Mine dump, near Silverton, Colorado (site map, Fig. 1). The May Day Mine dump has two benches, an upper bench and a middle bench (Fig. 2). Our work included making spectral induced polarization (SIP) profiles on the upper dump face (Line 50E, Fig. 2) and on the middle bench (Line 100E, Fig. 2). The results of these field SIP measurements have been reported elsewhere (Campbell and others, 1998, 1999, 2000). In order to characterize the May Day Mine dump material geochemically, composite samples were taken from several different parts of the dump (Smith and others, 2000). In particular, composite samples were taken from segments M1-M8 of the upper dump face (Fig. 2), as well as a bulk composite sample that included material from the entire dump. In addition, we collected 10 separate grab samples exactly along Line 50E on the upper dump face (Fig. 2). We measured electrical properties of the composite samples and grab samples in the USGS Petrophysical Laboratory, Denver, Colorado (PetLab). In PetLab, resistivity and phase of each sample are measured at (usually) 3 points per decade over the frequency range from 2×10^{-2} Hz to 1×10^6 Hz. PetLab procedures and apparatus are described by Olhoeft (1979), Jones (1997), and Campbell and Horton (2000). This report gives detailed graphs and tables of the SIP properties of May Day Mine dump materials that were measured in PetLab.

COMPOSITE SAMPLES

Measurements were made on splits of samples from sectors M1-M8 of the upper dump face of the May Day Mine dump. These composite samples were collected primarily for geochemical analysis, and were air dried accordingly. Therefore, their natural pore waters had evaporated by the time they got measured in PetLab, so that the samples were too resistive to make "as received" measurements. Consequently, they were rehydrated using de-ionized water and measured wet. To test the effect of different water contents, the sample from sector M5 was measured with 6%, 11% and 15 % water, and the sample from sector M6 with 8% and 10% water. The sample from sector M8 was measured at five different levels of applied voltage (0.1, 0.2, 0.3, 0.4 and 0.5 Volts) to check for possible non-linear responses. The spectra for these different voltage levels were all alike, so only one of them is shown below (Fig. 14).

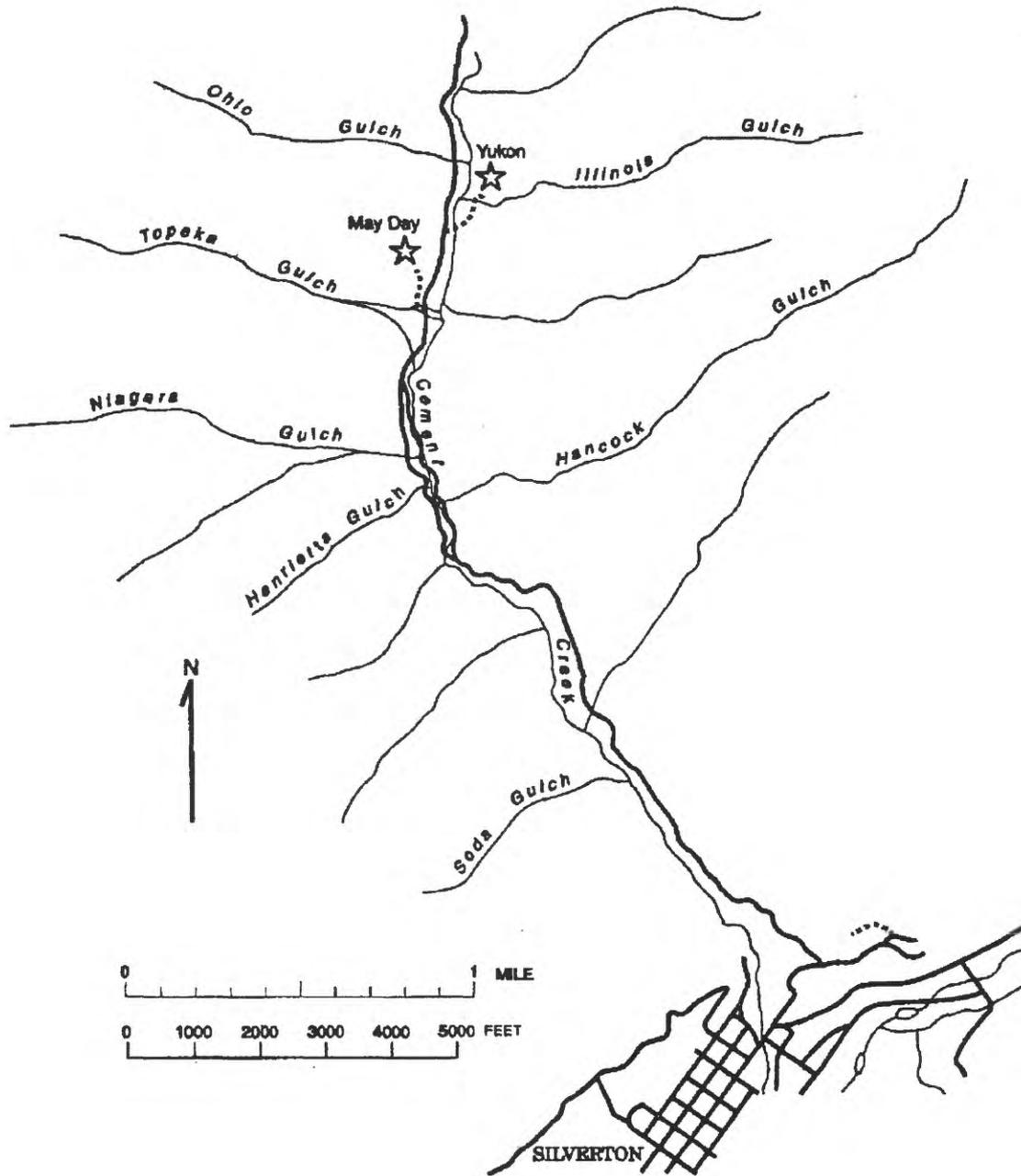


Figure 1. Location of May Day (also called “BLM60”) and Yukon Mine sites near Silverton, Colorado.

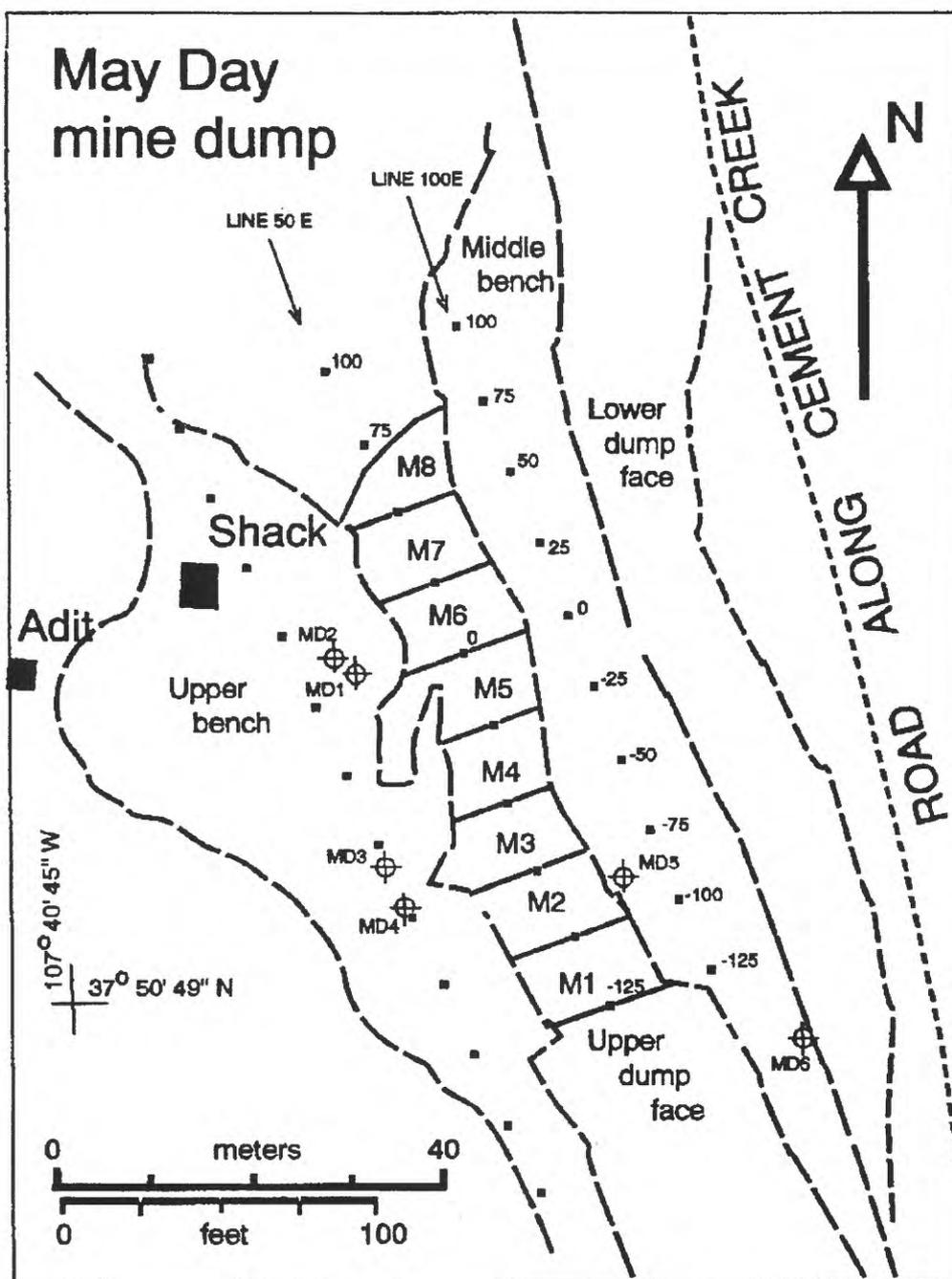


Figure 2. Map of May Day Mine dump. Broken lines are drawn along breaks in slope, so as to outline the upper bench, upper dump face, middle bench, and lower dump face. The upper dump face is divided into segments M1--M8 from which composite samples were collected. Small squares indicate survey points spaced 25 ft apart along Lines 0EW (not labeled), 50E and 100E. Ten local grab samples were collected along Line 50E. Circled plus symbols indicate locations of drill holes MD1--MD6.

Figures 3-14 show the variation with frequency of resistivity (left legend, triangular symbols) and of phase (right legend, 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—the value is plotted as a diamond (e.g., the low frequency values on Fig. 22). A vertical whisker through each symbol indicates error bars. The continuous lines through the data points represent numerical fits to the data using the Cole-Cole dispersion equation, discussed below.

An important limitation of the present PetLab apparatus is that it cannot accurately measure phase and resistivity of high-resistivity samples at frequencies greater than about 10^4 Hz. Whenever a sample has a frequency-impedance product greater than about 2×10^8 , the instrumental limits of the PetLab subsystems are exceeded. In such cases the system typically returns constant and low resistivity values and high positive (plotted as diamond) phase values (see Figs. 5-8, among others). In fact, however, no reliable measurement was possible at those frequencies, so that such “data” values should be ignored. Empirically, we have found that if a sample has a resistivity greater than about 100 ohm-m at 2×10^2 Hz, its plotted resistivity and phase values above about 10^4 Hz should be ignored.

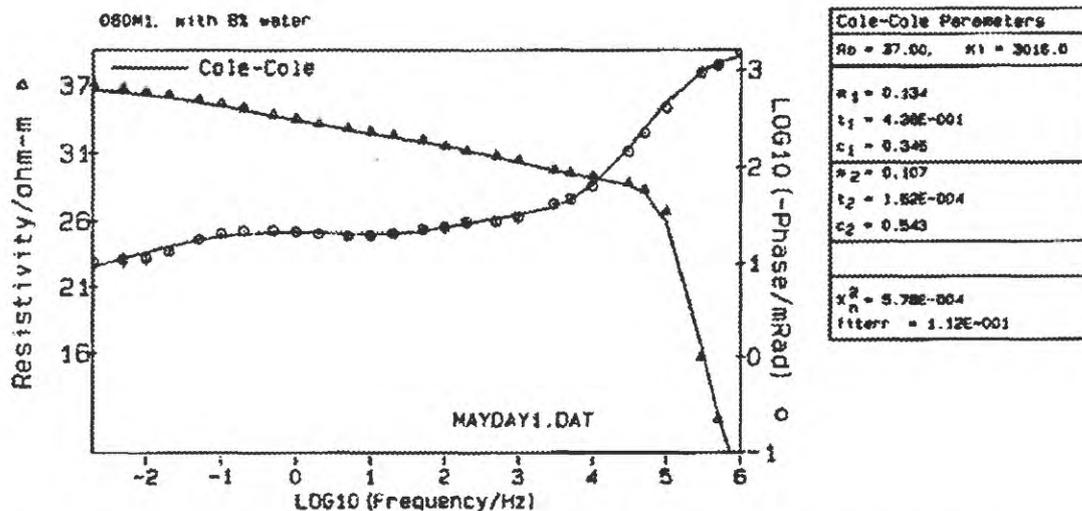


Figure 3. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for rehydrated composite sample from sector M1.

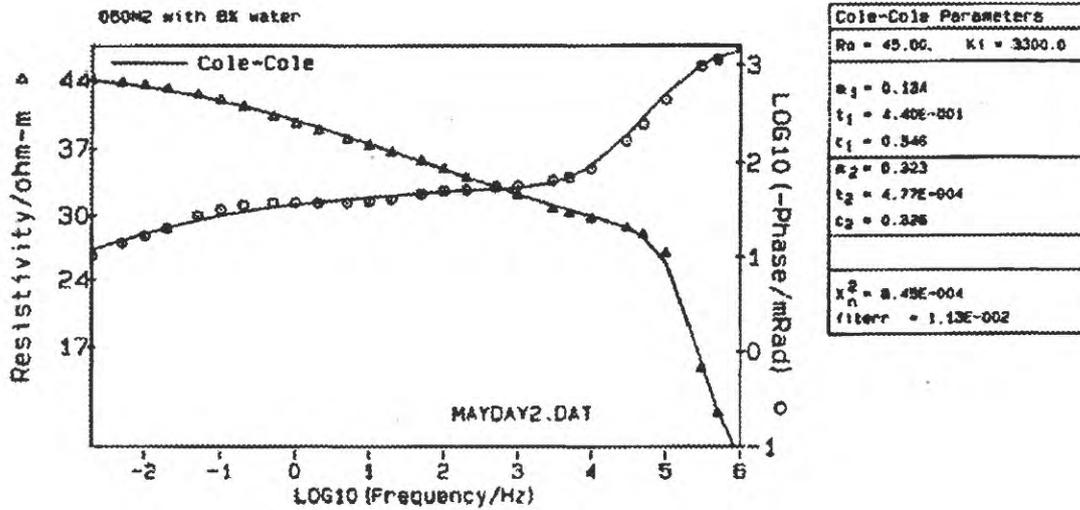


Figure 4. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for rehydrated composite sample from sector M2.

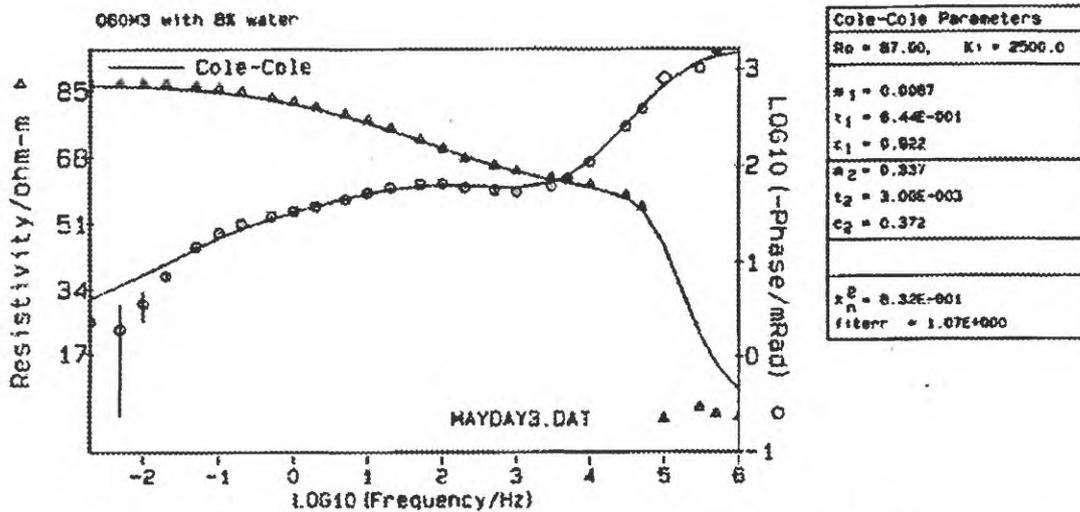


Figure 5. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for rehydrated composite sample from sector M3.

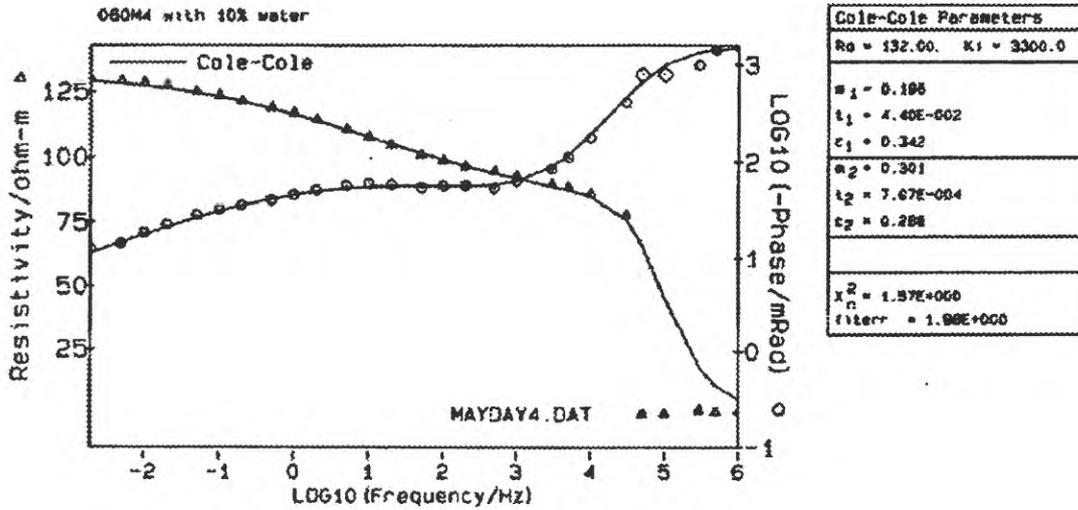


Figure 6. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for rehydrated composite sample from sector M4.

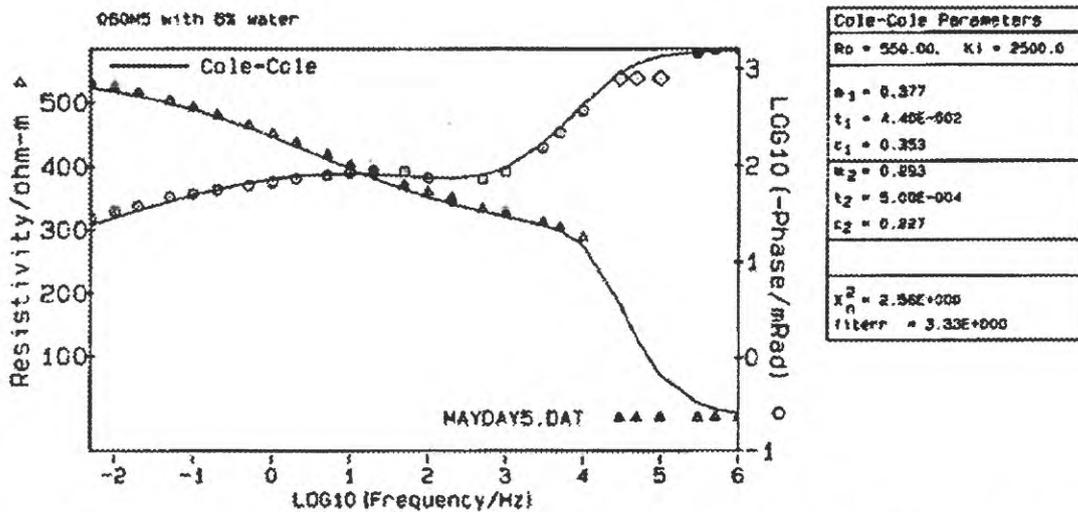


Figure 7. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for rehydrated composite sample from sector M5. Sample contains 6% water.

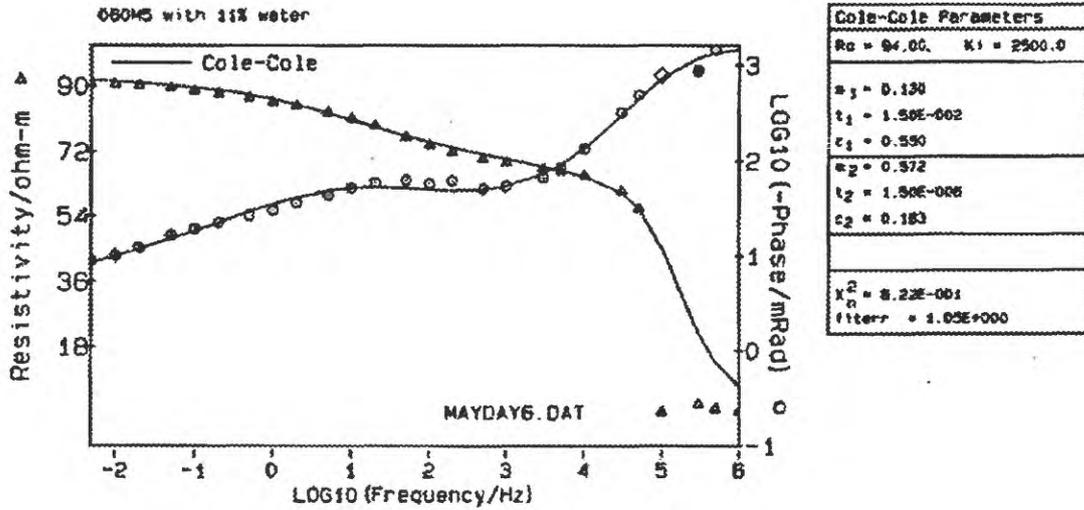


Figure 8. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for rehydrated composite sample from sector M5. Sample contains 11% water.

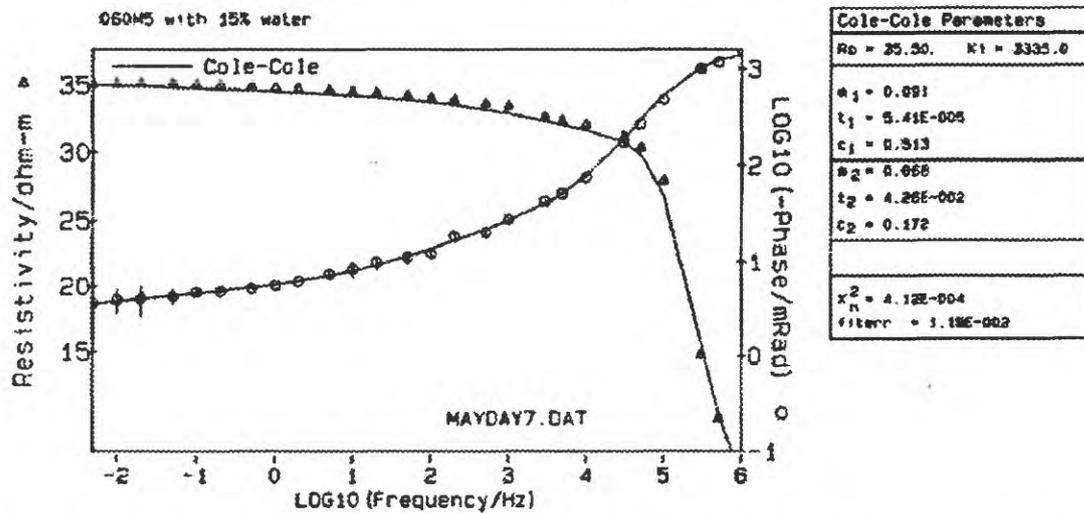


Figure 9. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for rehydrated composite sample from sector M5. Sample contains 15% water.

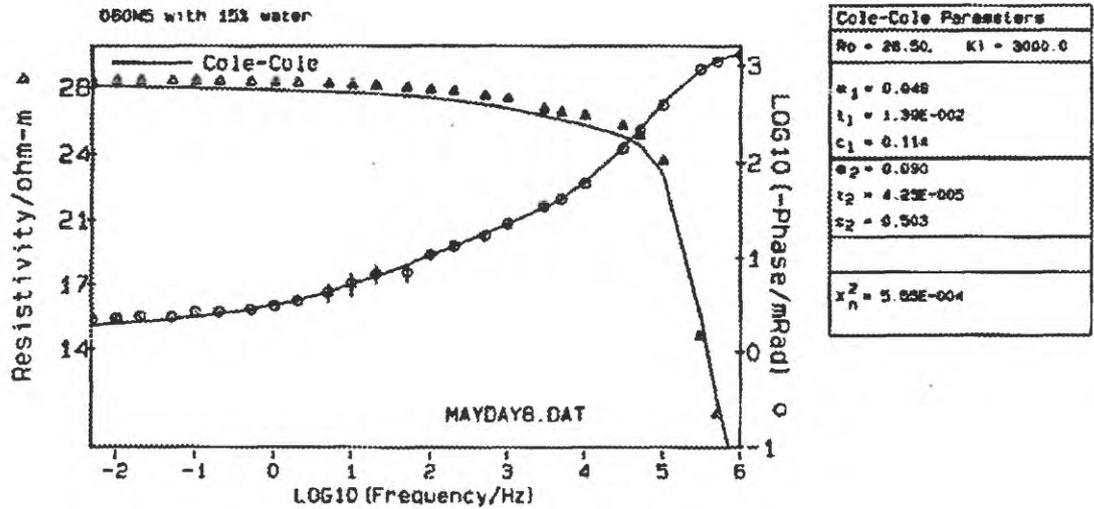


Figure 10. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for rehydrated composite sample from sector M5. Sample contains 15% water, and was measured about 24 hours after the run shown in Fig. 9.

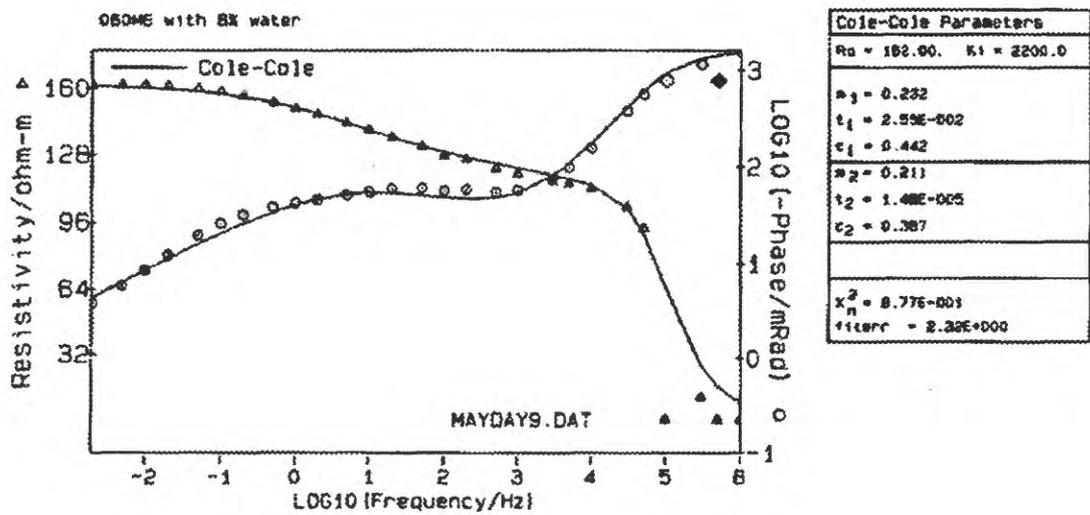


Figure 11. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for rehydrated composite sample from sector M6. Sample contains 8% water.

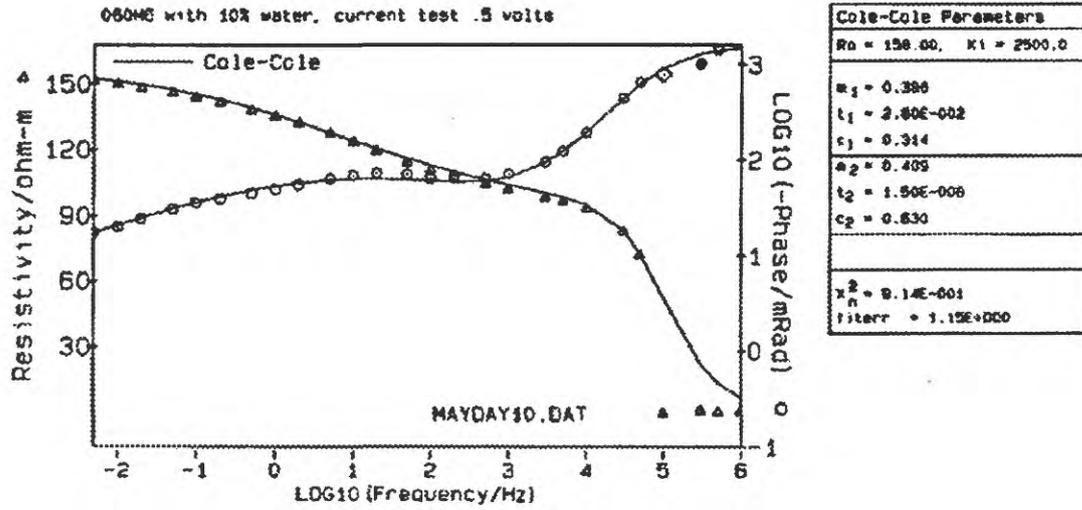


Figure 12. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for rehydrated composite sample from sector M6. Sample contains 10% water.

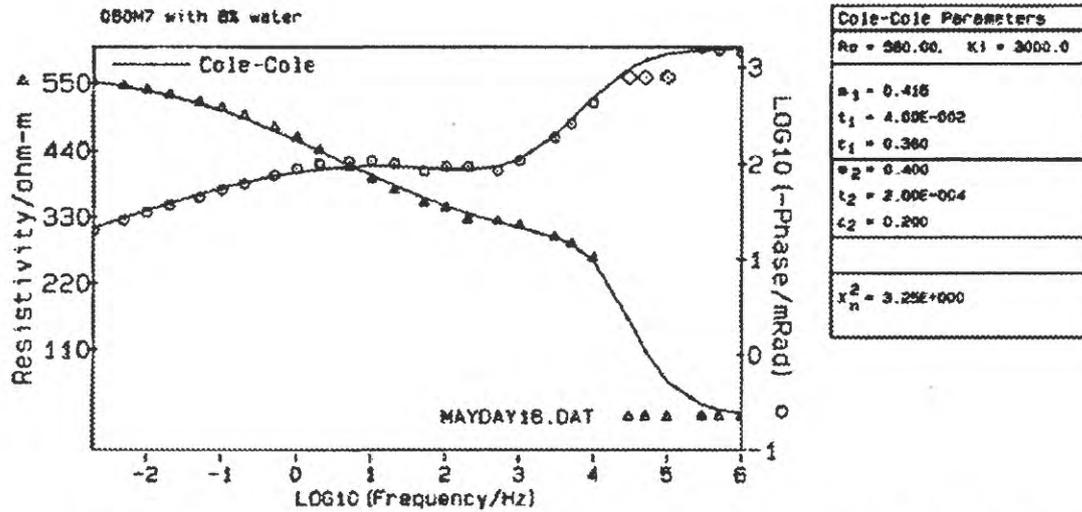


Figure 13. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for rehydrated composite sample from sector M7.

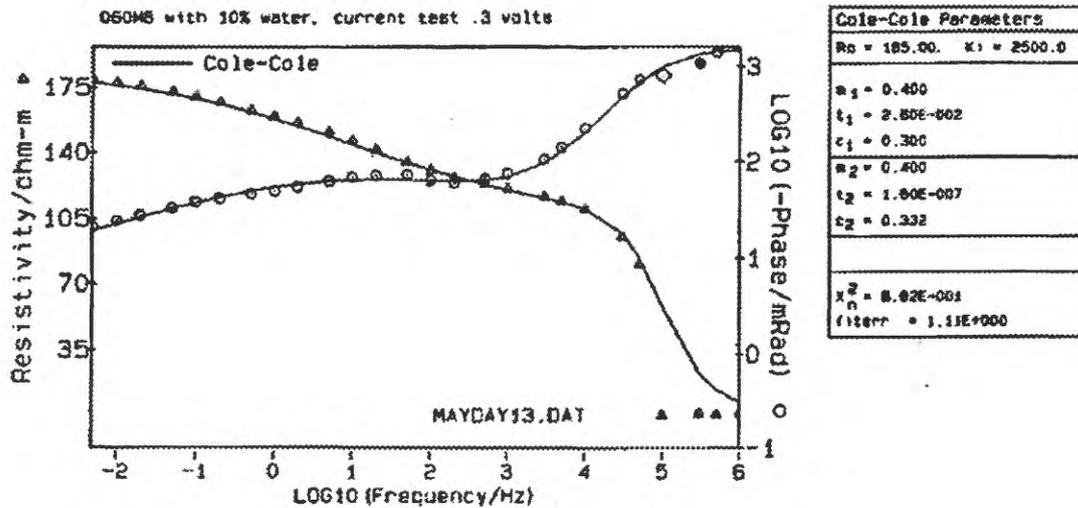


Figure 14. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for rehydrated composite sample from sector M8.

Figures 7-9 all show measurements made on the sample from sector M5, as it was rehydrated to different levels. These figures demonstrate the central lesson of this report:

Both resistivity and phase spectra of mine dump samples can change substantially depending on their water content.

The resistivity of most rock and soil samples primarily reflects the flow of electric current through pore waters by ionic conduction processes. We therefore expected the resistivity of the samples to drop as the water content was increased, and that was what happened. However, we also had expected that adding water would not greatly affect the phase spectra. The phase response of a sample primarily reflects the electrochemical processes related to current flow. If the water and matrix do not chemically interact, then once the mineral grains are wet enough to form a water layer a few molecules thick the phase should not change significantly as additional water fills empty pore spaces. In other words, we expected there would be a grain-wetting threshold at only a few percent water, but above that the phase spectra would remain constant. The fact that that did not happen suggests that water-matrix chemical reactions must be taking place.

One factor in this process may involve our use of de-ionized water to rehydrate the dried samples. We had hoped that dissolved solids left behind when the original pore fluids evaporated would go right back into solution, so that the rehydrated pore fluid would resemble the original pore water. Figures 9 and 10 show measurements of the same sample taken within a few hours of rehydrating it from 11 to 15% water (figure 9) and about 24 hours later (figure 10). We see that the resistivity of the sample dropped further during the next day, suggesting that solid phases continued to dissolve and diffuse into the

pore water during that time. In other words, the matrix had not reached equilibrium with the hydration water due to the slow dissolution kinetics and diffusion limited processes.

Systematic changes were observed in the shape of the resistivity and phase spectra as a function of water content and over time. Note that sample M5 has a resistivity inflection and a phase dispersion (a hump) at about 10 Hz when the sample has 6% water (figure 7). The inflection and dispersion shift to higher frequency (to about 100Hz) and increase in amplitude when the water content is increased to 11% (figure 8), and then they essentially disappear at 15% water (figure 9 and 10). These different spectra usually typify samples with different compositions and/or grain-sizes, but here they are observed in the same sample. We infer that different chemical processes are taking place within the sample at different water contents and at different times. The samples are known to contain different soluble mineral phases (Hageman and others, 2000). The changes observed in the resistivity and phase spectra may result from non-equilibrium dissolution of mineral phases having different solubility constants and dissolution rates. In particular, when the samples dried out, certain mineral phases (e.g., jarosite) may have precipitated which take a long time to re-dissolve. This would have given the rehydrated samples a different chemical makeup than the fresh ones.

Whatever the mechanism that leads to different PetLab spectra as samples are rehydrated, there is a clear practical lesson:

The SIP properties of rehydrated samples measured in PetLab are unlikely to match those of the same materials measured in situ in the field.

There are at least two reasons for this unfortunate conclusion: 1) we have to closely match in the laboratory the natural water content in the mine dump, which is unknown; and 2) even if we do so, de-ionized water still may not equilibrate back to resemble natural pore water.

GRAB SAMPLE MEASUREMENTS

Geoelectrical properties were measured in PetLab of 10 local grab samples taken along Line 50E. The samples were labeled 50N, ..., 110S, according to the location where they were collected along Line 50E (see Fig. 2, on which N coordinates are denoted positive and S coordinates negative). The grab samples were chosen to represent the different colors and textures of materials on the dump face, in hopes that they might reflect mineralogical extremes thereof. They were collected explicitly for measurement in the Denver Petrophysical Laboratory (PetLab), and were sealed in plastic to keep their pore waters intact. All grab samples had grains the size of coarse sand and smaller, and were not sieved before being measured. Because the grab samples were measured with pore waters (more or less) intact, we think their measured electrical properties may typify those of similar material in the dump.

Figures 15-24 show PetLab spectra for the 10 local grab samples taken along line 50E on the upper dump face of the May Day Mine dump.

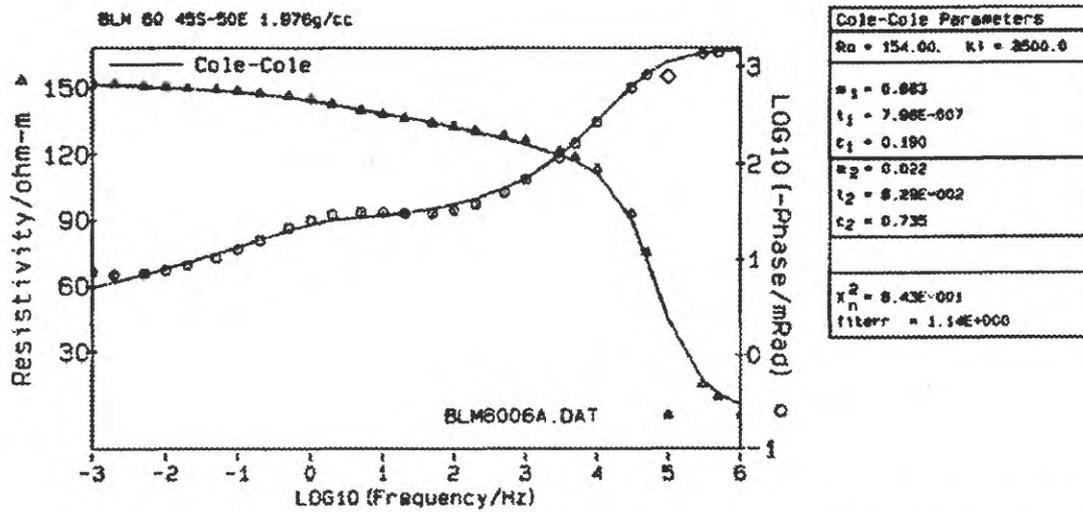


Figure 15. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for local grab sample 45S.

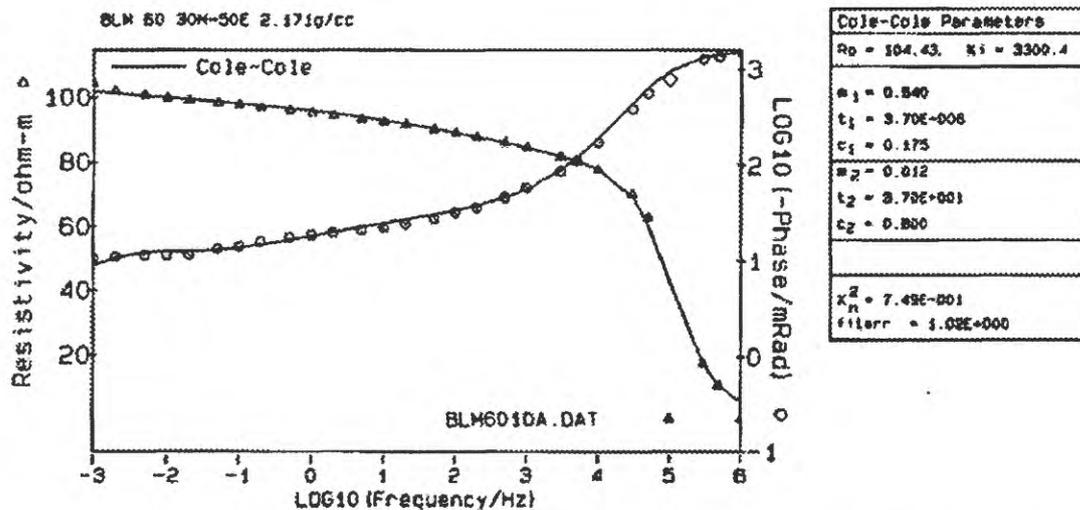


Figure 16. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for local grab sample 30N.

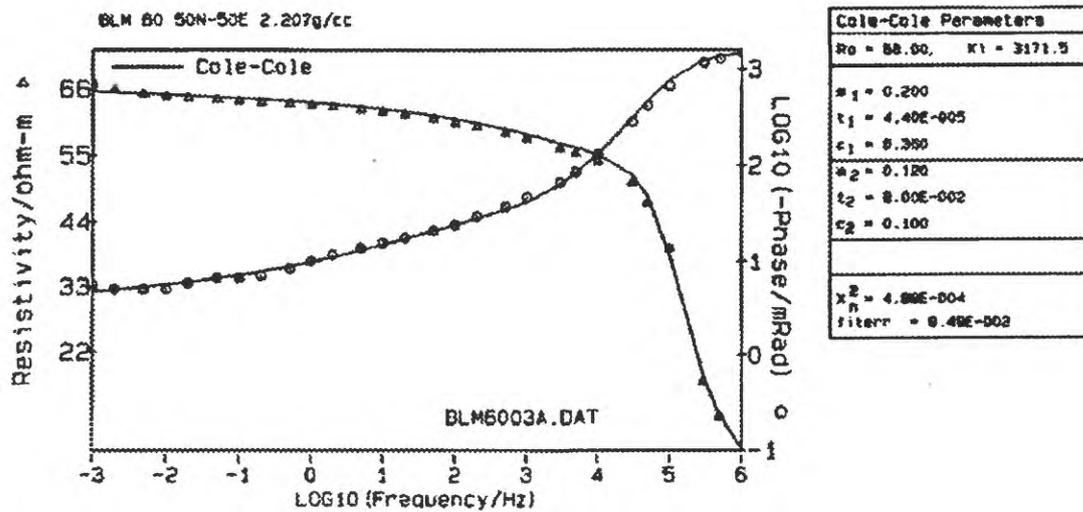


Figure 17. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for local grab sample 50N.

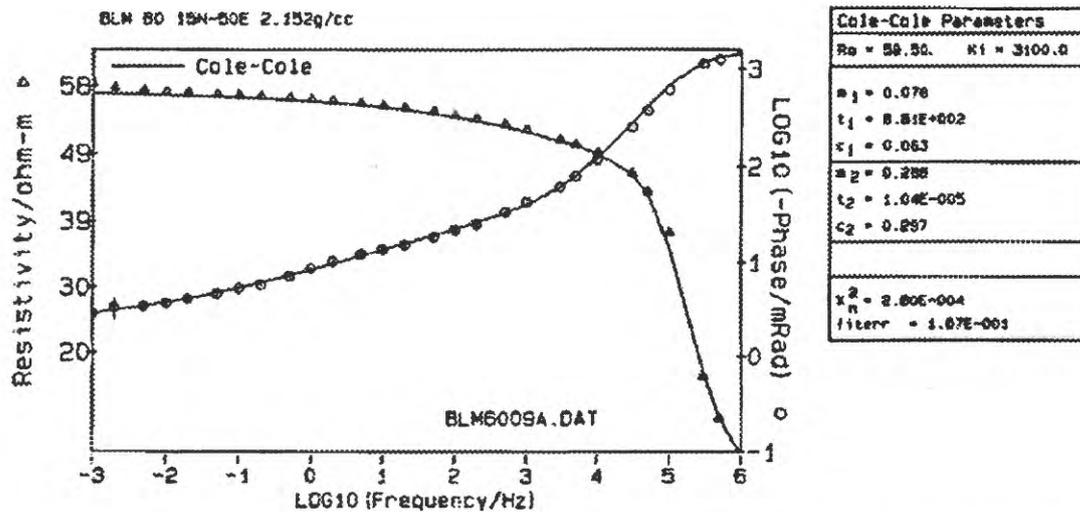


Figure 18. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for local grab sample 15N.

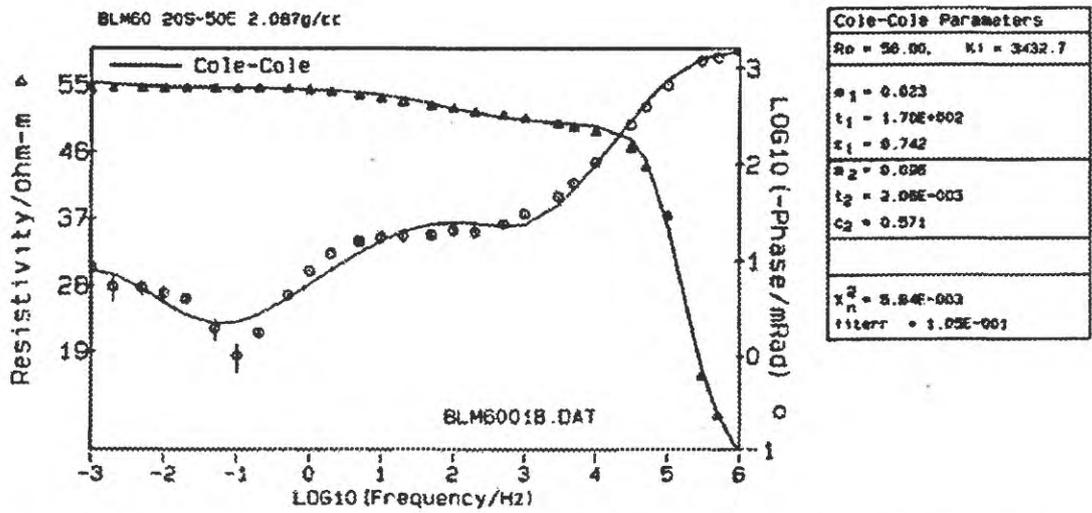


Figure 19. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for local grab sample 20S.

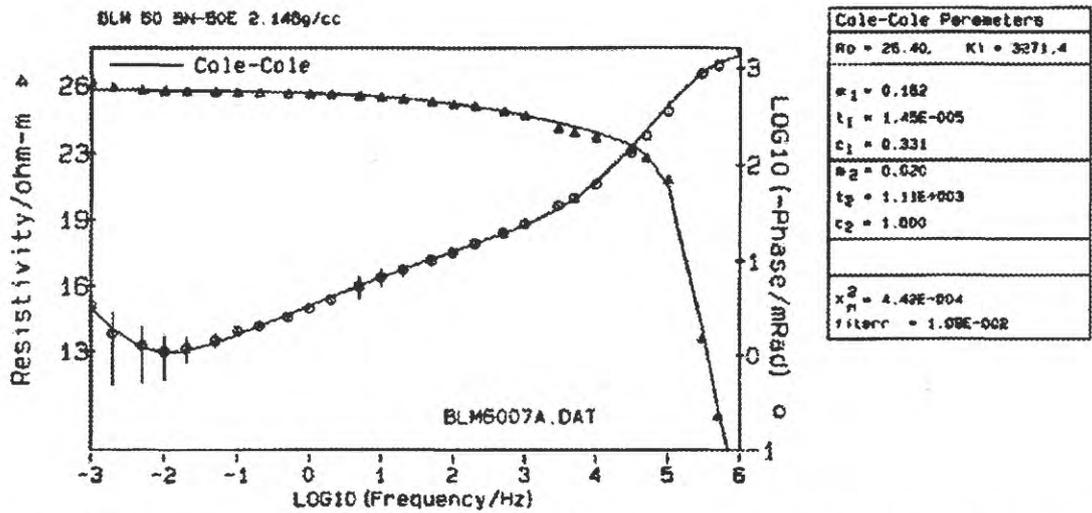


Figure 20. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for local grab sample 5N.

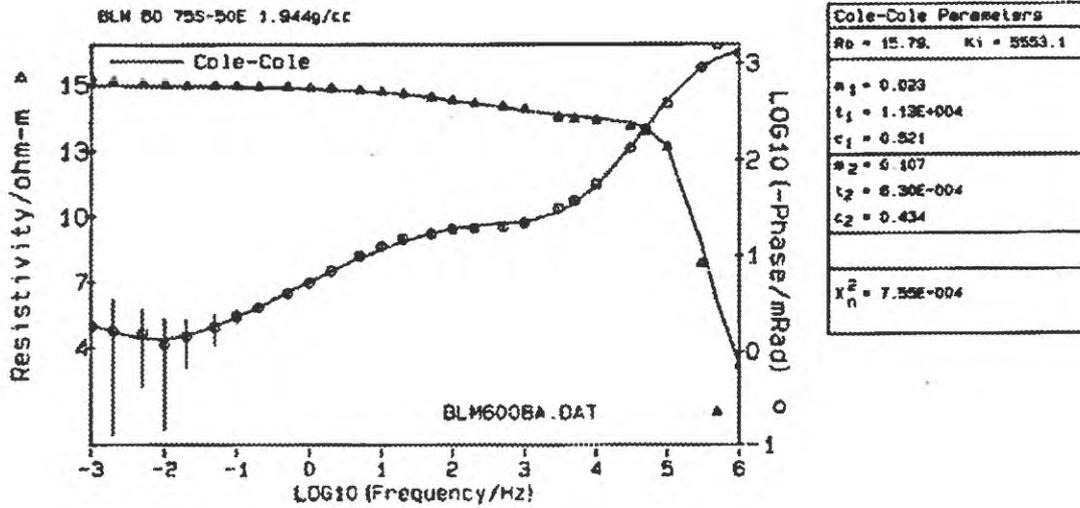


Figure 21. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for local grab sample 75S.

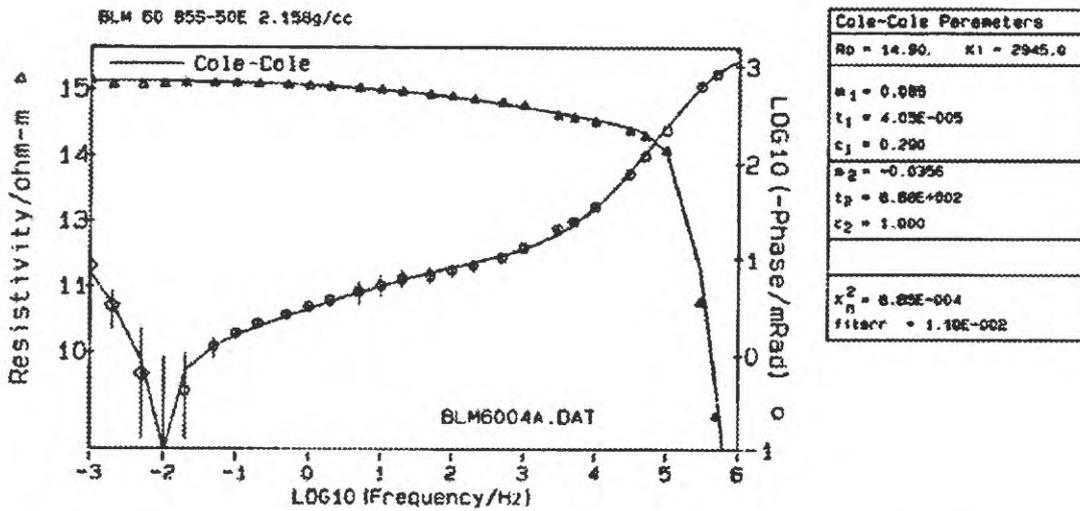


Figure 22. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for local grab sample 85S.

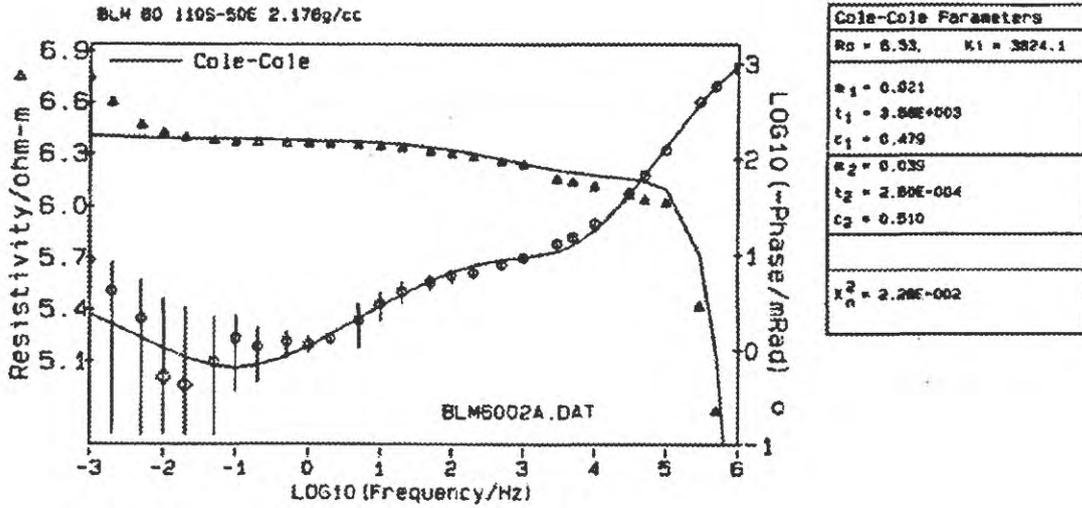


Figure 23. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for local grab sample 110S.

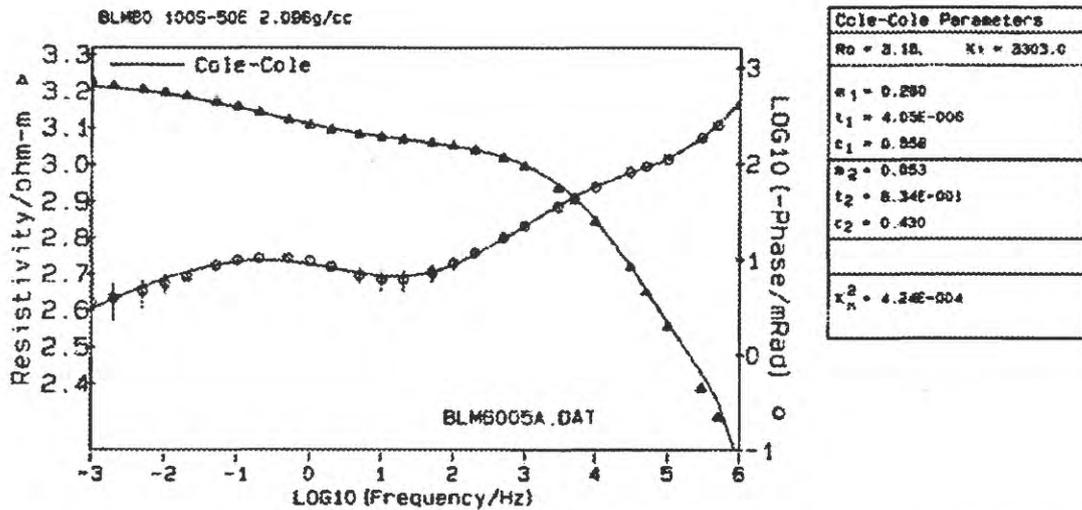


Figure 24. Resistivity and Phase spectra, with a 2-term Cole-Cole fit, for local grab sample 100S.

Simple indices

Some of the parameters that have historically been used to characterize induced polarization response, as measured in the field (Sumner, 1976), can be directly read or calculated from petrophysical curves. These include “dc” resistivity and phase—those at the lowest frequency used in a frequency-domain IP survey—and “percent frequency

effect” (PFE), the percentage change between resistivity at this lowest frequency and that at some higher frequency. The particular frequencies one uses generally are those measured by the field equipment one has, typically about 0.1 Hz for the lowest frequency and 1 or 10 Hz for the higher one. By analogy, then, we define the following simple indices to characterize petrophysical curves that can be calculated from measured values of resistivity, R, and phase, P:

$$\text{LowRes (low resistivity)} = R(0.1 \text{ Hz}).$$

$$\text{PRE (percent resistivity effect)} = 100 \times [R(0.1 \text{ Hz}) - R(1.0 \text{ Hz})] / R(1.0 \text{ Hz}).$$

$$\text{LowPhz (low phase)} = -P(0.1 \text{ Hz}).$$

$$\text{PPE (percent phase effect)} = -100 \times \{ P(0.1 \text{ Hz}) - P(1.0 \text{ Hz}) \} / P(1.0 \text{ Hz}).$$

These simple indices are described in more detail by Campbell and Horton (in prep.).

Table 1 lists these indices for the 10 grab samples from line 50E on the upper dump face of the May Day Mine dump.

Table 1. Simple IP indices and leachate properties for grab samples from Line 50E, In order of increasing SAG (surrogate for acid generation, defined in the text).

Sample	LowRes (ohm-m)	LowPhz (mRad)	PPE	Leachate pH	Leachate σ ($\mu\text{S/cm}$)	SAG
45S	146.58	12.78	50.31	3.4	223	1.45
30N	97.79	14.33	24.46	3.6	162	1.55
50N	63.78	6.62	33.60	3.4	122	1.67
15N	56.73	5.26	38.77	3.4	192	1.70
20S	54.42	0.99	87.26	3.2	291	1.71
5N	25.72	1.83	42.09	3.2	363	1.91
75S	15.43	2.32	55.13	2.8	705	2.04
85S	15.35	1.69	47.02	2.9	551	2.04
110S	6.38	1.33	-15.65	2.7	794	2.28
100S	3.11	9.73	-1.35	2.6	1304	2.47

Cole-Cole fits

The simple indices defined above are useful for making gross comparisons between petrophysical curves, and for correlating such curves with field data. However, they gloss over details of the curves, particularly the phase curves, that 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 Pet Lab, we fit them numerically using the Cole-Cole formula (Cole and Cole, 1941):

$$\text{Complex conductivity } \sigma(\omega) = \{1 + m [(i\omega\tau)^c / (1 + (1-m)(i\omega\tau)^c)]\} / R_o + i\omega\epsilon_o K_{oo}$$

where ω represents angular frequency and $i = \text{SQRT}(-1)$. The above equation has 5 adjustable parameters:

R_o , *low frequency resistivity*, sets the low frequency asymptotic value for the resistivity curve.

K_{oo} , *the high-frequency dielectric value*, sets the high frequency asymptotic values for both resistivity and phase curves.

The remaining 3 parameters describe a single relaxation mechanism due to a particular electrochemical process. Such a mechanism results in a down step in the resistivity curve and a hump in the phase curve (Jones, 1997).

τ , *the time constant*, is related to a characteristic frequency where the phase curve hump has its maximum and where a corresponding down step in the resistivity curve has bottomed out. Higher τ means lower characteristic frequency.

m , *the chargeability*, reflects the size of the down step in the resistivity curve and the value of the peak of the phase curve. Higher m means greater step size and peak value. Practical limits: $0 < m < 1$. For some fits, $m < 0$. If $m = 0$, the Cole-Cole term vanishes.

c reflects the steepness of the resistivity step and width of the phase hump. Higher c , steeper step and narrower hump. Small values of c imply the described process takes place over a wider frequency band. Practical limits: $0 < c < 2$. The value $c = 1$ implies a sharp single-frequency relaxation.

The above equation follows the form of Major and Silic (1981), except that term including the dielectric constant K_{oo} has been added (Jones, 1997). See Campbell and Horton (in prep.) for a fuller description of Cole-Cole fits.

Most spectra display more than one relaxation, so that the sum of several Cole-Cole terms is used to describe the shape of the complete spectrum. Figures 3-24 list two-term Cole-Cole fits to the data plotted thereon.

A SURROGATE FOR ACID GENERATION

Campbell and others (1998) showed that the pH of mine dump leachate waters is inversely correlated with the logarithm of their electrical conductivity, for pH values less than about 5. This condition is very likely met in the May Day Mine dump, where waters draining from its toe have pH values of about 3 (Kenneth J. Leib, oral commun., 1997). Campbell

and others (1998) therefore speculated that electrical conductivities in acidic mine dumps might reflect acid generation therein. Their argument involved the following suppositions: (a) *pore* water within the dump material and *leachate* water draining from it have similar pH-conductivity dependences; (b) acid in the pore water at any particular place is produced largely from nearby grains (“nearby” can include grains some distance up hydraulic gradient), so as to reflect the amounts of acid such grains can and do produce; (c) the electrical conductivity of the pore waters is much greater than that of the matrix (grains minus pore water) throughout the mine dump, and (d) Archie’s Law holds for mine dump material. Archie’s Law (e.g., Keller and Frischknecht, 1966) states that when (c) holds, the bulk electrical conductivity of a sedimentary unit is dominated by, and proportional to, that of its pore waters. Figure 25 shows pH of leachate waters from the 10 grab samples, determined using the synthetic precipitation leaching procedure (Hageman and others, 2000), plotted versus the LowRes measure of their bulk electrical resistivity (Table 1). Fig. 25 suggests that we can roughly predict the pH of potential leachate waters by measuring electrical resistivity in situ at the May Day Mine dump:

$$\text{Predicted pH, PpH} = 2.23 + 0.61 \log(\text{LowRes}).$$

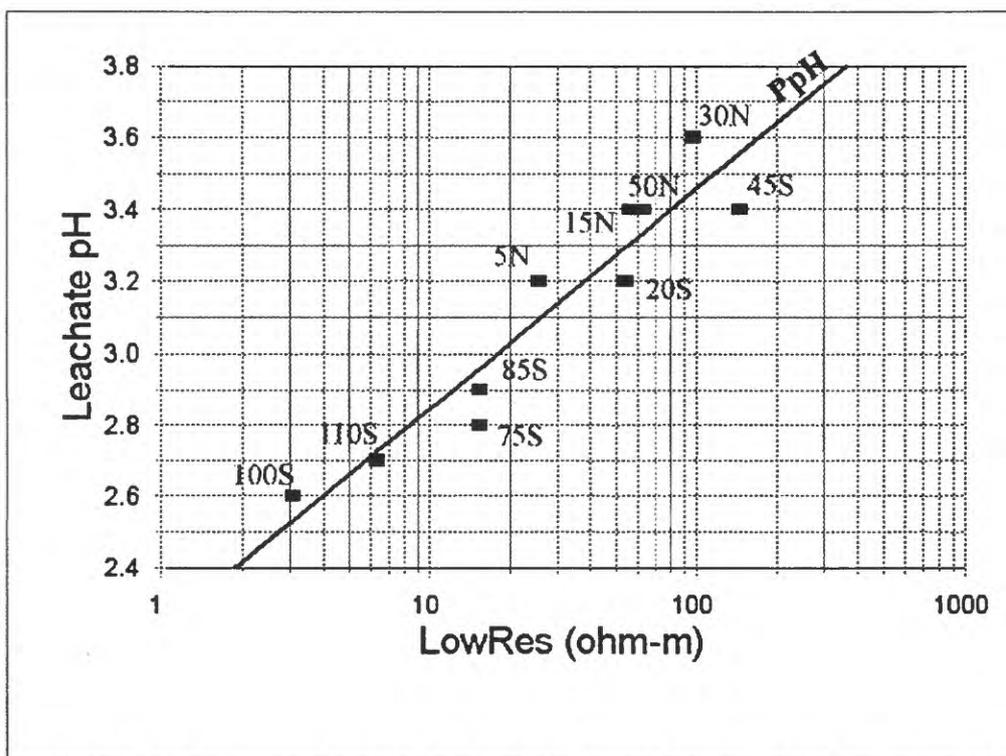


Figure 25. LowRes versus leachate pH for grab samples from May Day Mine dump. PpH = predicted pH, regression line for this data ($R^2 = 0.8946$).

To construct a numerical surrogate for acid generation (SAG), we subtract PpH from 5, the approximate value of pH above which pH and electrical conductivity fail to correlate:

$$\text{SAG} = 2.77 - 0.61 \log (\text{LowRes}).$$

Using this definition, higher values of SAG will correspond to higher potential for generating acid. SAG values for the 10 grab samples are listed in Table 1. From the SAG ranking, it appears that more acid is likely to be generated in the southern end of the May Day Mine dump than in the northern end.

Figure 26 shows amounts of Fe, Pb, Zn, and S in leachates of the 10 grab samples (Hageman and others, 2000). The samples are put in order of increasing SAG, with their relative spacing shown on a key line below the graph. With the possible exception of Zn, the amounts of these elements in the leachate waters generally increase with SAG.

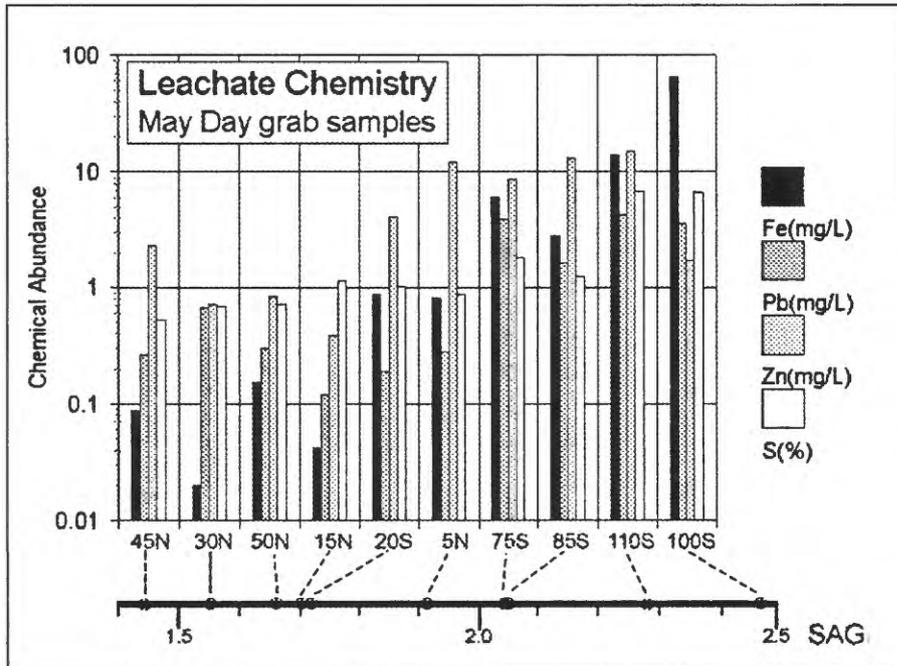


Figure 26. Chemical abundance of selected elements in leachates of May Day Mine dump grab samples, in order of increasing SAG, as indicated on the scale at bottom of the figure.

Table 2 includes brief mineralogical characterizations of the grab samples. Mineralogy was determined by two qualitative methods, X-ray Diffraction (XRD) and infrared spectroscopy (SpecLab). The XRD analysis lists detected minerals as major, minor, and present in trace amounts. All samples had major quartz, not listed. All jarosites found by XRD were of hydronium-type, $(\text{K}, \text{H}_3\text{O})\text{Fe}_3(\text{OH})_6(\text{SO}_4)_2$. XRD detects crystalline minerals only, whereas these grab samples had about 50% amorphous (non-crystalline) material. Because we suspected the amorphous fraction might include goethite, HFeO_2 , the samples were re-run in SpecLab. SpecLab analyses ignore most silicate minerals, but

are good at detecting a number of alteration minerals, including goethite. They also give a useful second opinion on jarosite abundance, possibly including additional amorphous jarosite that the XRD method might have missed.

From Table 2, it appears that sulfides are present in samples throughout the suite; Fig 26 argues, however, that sulfides and/or their alteration products (sulfates?) increase with SAG. Goethite may be more abundant in the lower-SAG samples. Jarosite dominates through the mid range of these samples, but is sparser for both the low- and high-SAG ones.

Figure 27 shows phase spectra for 5 of the 10 grab samples, and for a sample from elsewhere (Oshetski, 1999) containing 2% pyrite but no sulfate alteration minerals. Differences between such curves can arise from differences in mineralogy, grain size, and interactions between matrix and pore fluids. We believe the major factor operating here is mineralogy. It may be that increasing amounts of sulfate alteration minerals, especially hydronian jarosite, result in lower phase curves over the lower decades of the frequency range. Sample 100S's relative high at around 0.3 Hz may reflect greater pyrite and/or less jarosite.

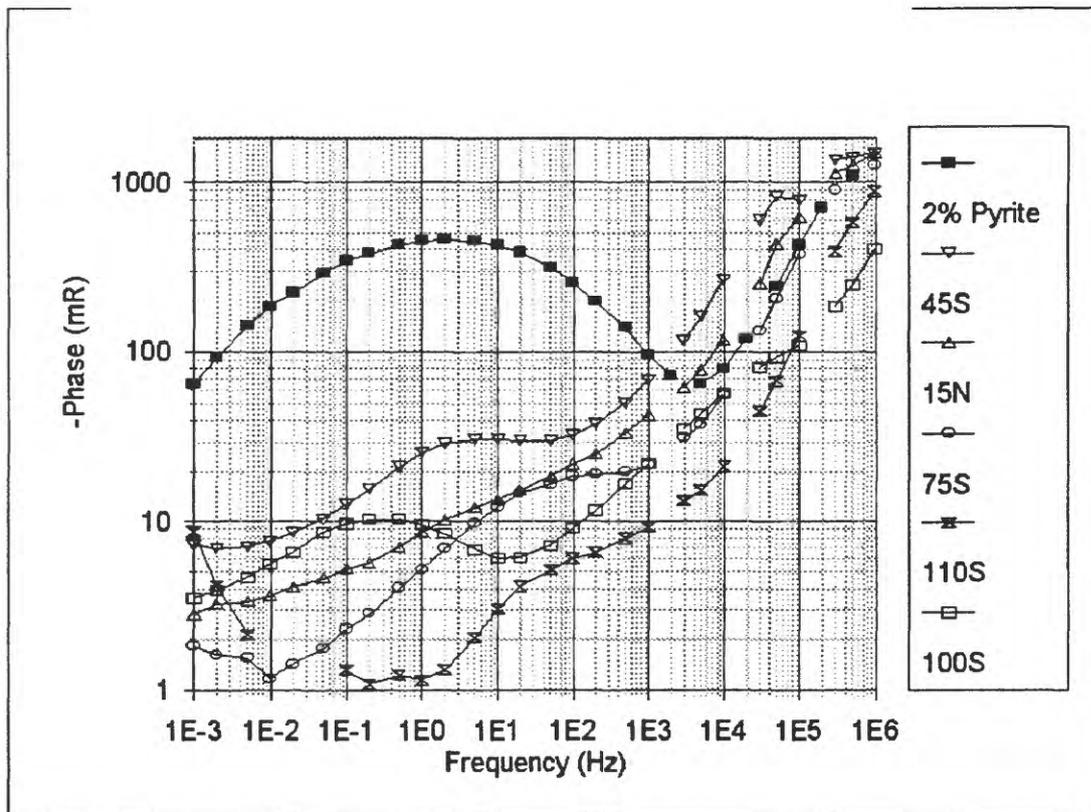


Figure 27. Phase spectra for selected grab samples from May Day Mine dump (open symbols). Also included is a phase spectrum from a sample containing 2% pyrite, collected elsewhere (filled symbols).

Whatever the cause of the above differences, it is clear that phase spectra contain a great deal of information. Table 1 lists two simple IP measures that arise from phase spectra, LowPhz and PPE, but there clearly is much more here that we still must learn to exploit. Tentatively, we take LowPhz to indicate mineralogy. Values of LowPhz in the hundreds very likely indicate high sulfide content, whereas values in the 10's and single digits very likely indicate abundant alteration minerals (cf., Campbell and others, 1999, 2000). Speaking very generally, therefore, we suppose that the lower the LowPhz value, the more such alteration minerals there are. The subject needs substantially more work, however.

Geoelectrical field measurements

Induced polarization (IP) measurements were made along two lines at the May Day Mine dump: Line 50E, located halfway up the upper dump face and sounding into it at an angle of about 30 ° from the horizontal, and Line 100E, trending along the center of the middle bench and sounding vertically down (Fig. 2). A Zonge NT-20 transmitter and GDP-32 receiver were used in an N=5 dipole-dipole configuration with 5 ft dipoles. Resistivity and phase were measured at a fundamental frequency of 0.125 Hz. Such values should be similar to the LowRes and LowPhz values measured in PetLab at 0.1 Hz. The data were inverted using the University of British Columbia computer program DCIP2D, and are plotted in Figure 28. Coordinates are in feet with north positive, so that these sections look west, facing the dump slope. The resolution of the method deteriorates with depth, so that features deeper than about 10 ft on the figure are increasingly uncertain.

Because of a program convention, the electrical results in the upper two panels of Fig. 28 are shown as conductivity in mS/m rather than resistivity in ohm-m ($1 \text{ mS/m} = 1000 / \text{ohm-m}$). The color scale for these conductivity panels is such that 63.1 mS/m (the darkest red) corresponds to a PpH of about 3.0, whereas 1.58 mS/m (the light blue – light green boundary) corresponds to a PpH of about 4.0. It appears that conductivities in the upper dump face are substantially higher than those under the middle bench. If our PpH interpretation is right, this says that acid mine drainage (AMD) is generated in several hot spots 5-15 ft deep in the midsection of the upper dump, and that this AMD may be percolating downward both to the north (coordinates 15-35 ft) and, less surely, to the south (coordinates -50 to -70 ft). By the time it drains under the middle bench, however, the AMD is weaker. There is a hint that the northern AMD lobe may persist under the middle bench, whereas the southern one either has shifted more than 40 ft to the south or has disappeared. Whether or not it has disappeared, the deep high on Line 100E at -80 to -100 ft may partially represent ground water from the Topeka Gulch catchment area that is draining along the sole of the May Day Mine dump. The top of this conductivity high is at about 10 ft depth, and is located in the vicinity of borehole MD5, which hit bedrock at about 8 ft depth. The conductivity interpretation process is such that a thin, higher conductivity layer, such as groundwater moving along the dump-bedrock interface, can appear on section view as a thicker, lower conductivity lobe, as we see here.

The lower two panels on Fig. 28 show interpreted phase at 0.125 Hz, analogous to the LowPhz values reported in Table 1. As discussed above, these section views may reflect mineralogy, with the warmer colors possibly indicating sulfide minerals or lower amounts of alteration minerals. We expect silicate minerals to have very low phase values. The blues at depth on both lines, therefore, probably reflect silicate bedrock. Line 100E, the middle bench line, has generally higher IP phase values than Line 50E, possibly indicating that alteration processes are less complete there. The highest interpreted IP phase on these lines is 18 mRad, at 80 ft in Line 100E. This value is probably still too low to reflect fresh sulfide minerals (see Fig. 27). The surrounding IP-phase high from about 60 ft on north may reflect some characteristic of bedrock, which is thought to be shallow there.

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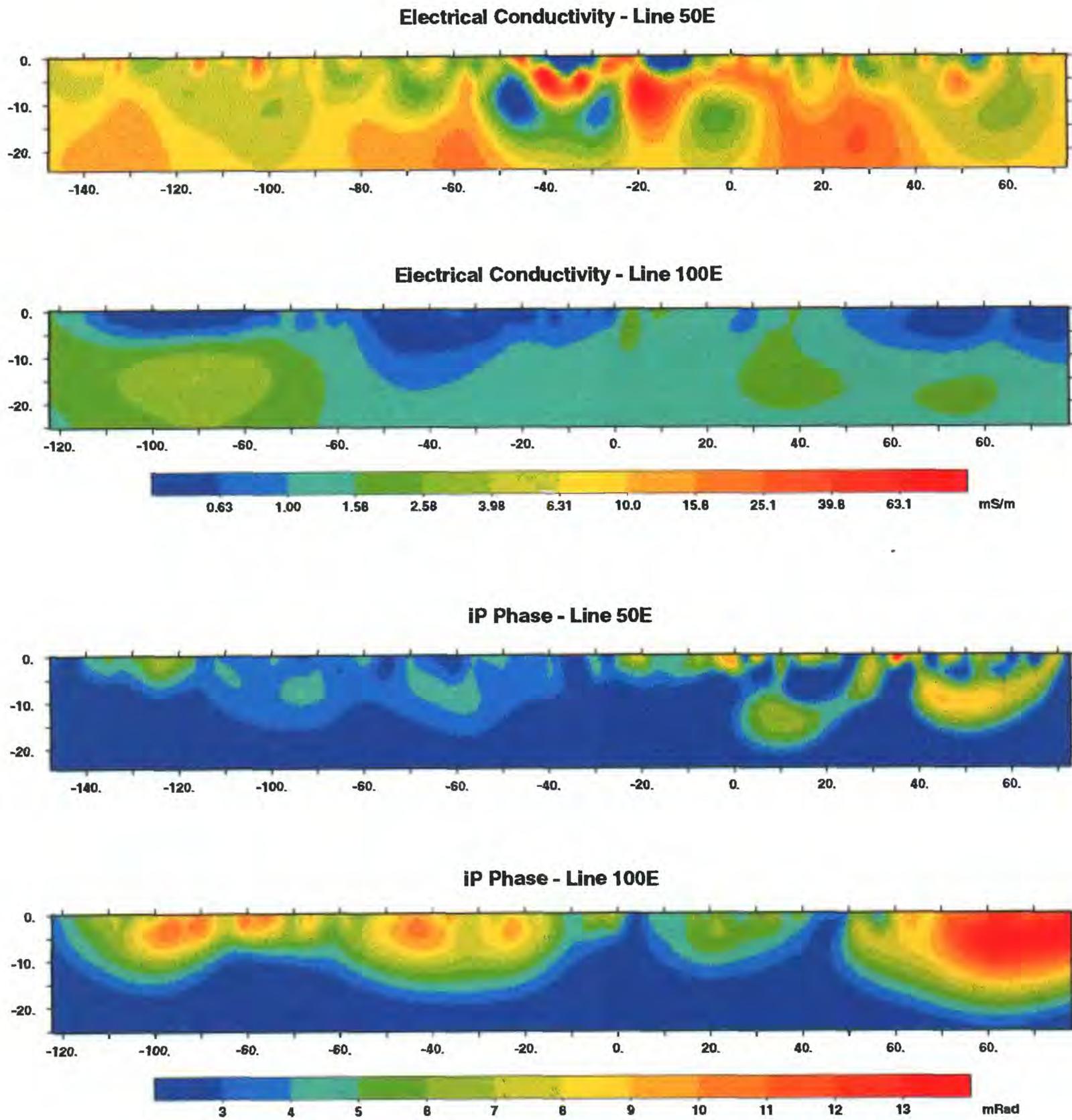


Figure 28. Section views showing interpreted conductivity (upper panels) and IP phase (lower panels) along Lines 50E and 100E at the May Day Mine dump. Coordinates are in feet. North is to the right.

Table 2. Qualitative mineralogy of grab samples from Line 50E, along the upper dump face of the May day Mine dump. Samples are in order of increasing SAG. XRD columns show X-ray diffraction determinations, whereas the SpecLab columns show Spectroscopy Laboratory determinations. Py = pyrite, Sph = sphalerite, Ga = galena, Hem = hematite, Orth, Or = orthoclase, Cl = clinoclase, Ill = Illite, Pyro = pyrophyllite, N/D = not detected.

Coord	Color	XRD minerals				SpecLab minerals			
		Muscovite	Jarosite	Clino	Sulfides	Other	Jarosite	Goethite	Other
45S	red tan	Minor	Minor	Minor	Py	Pyro, Or, Ill	?	Dominant	Clinoclase?
30N	red tan	Minor	Minor	Trace		Orth, Ill	Trace	Dominant	
50N	lite tan	Minor	Minor					Dominant	Trace
15N	red tan	Minor	Minor		Sph, Ga	Ill		Dominant	N/D
20S	red tan	Minor	Minor	Trace	Ga	Pyro, Orth		Dominant	Trace
5N	lite tan	Minor	Minor	Trace	Sph, Py	Ill		Moderate	Trace
75S	yel	Major	Minor			Anatase		Some	N/D
85S	tan	Minor	Minor		Py			Moderate	Moderate
110S	tan	Minor	Minor		Sph, Ga	Anglesite		Some	Dominant
100S	gry wht	Minor	Trace		Py, Sph	Hem, Ill		Some	N/D
									Py?