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*N. Scromeda-Perez*

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## Author's address

***N. Scromeda-Perez*** *(nperez@nrcan.gc.ca)*
*Mineral Resources Divison*
*601 Booth Street*
*Ottawa, Ontario K1A 0E8*

# Formation-factor measurements for Giant mine and Con mine samples from the Yellowknife mining district, Northwest Territories[1]

N. Scromeda-Perez
Mineral Resources Division, Ottawa

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**Abstract:** Formation resistivity factor (F) and pore-surface resistivity ($\rho_c$) values were determined for three mineralized and nonmineralized rock samples from the Giant mine and Con mine areas of the Yellowknife mining district, Northwest Territories. The purpose was to provide basic information required to understand the electrical conductivity mechanisms of these rocks, and to aid interpretation of geophysical surveys that have been conducted in these areas.

Results indicate that F and $\rho_c$ values are in the range of 125–12 600 and 35–3000 Ω•m, respectively. Preliminary examination of the relationship between these data for F and $\rho_c$ and previous bulk electrical resistivity ($\rho_r$) data suggest that the samples have pore surfaces that are highly altered, or are completely lined with conductive minerals of some kind. The $\rho_r$ values are in the range of 33—3.5 x $10^3$ Ω•m, for these samples after saturation in 0.02 N NaCl. These results are consistent with values previously reported in the literature for similar rocks.

**Résumé :** On a déterminé le facteur de résistivité de formation (F) et les valeurs de la résistivité ($D_c$) de la paroi des pores de 3 échantillons de roches minéralisées et non minéralisées provenant des régions de la mine Giant et de la mine Con, dans le district minier de Yellowknife (Territoires du Nord-Ouest). L'objectif poursuivi était de fournir les renseignements de base nécessaires pour comprendre les mécanismes de la conductivité électrique de ces roches et de faciliter l'interprétation des levés géophysiques que l'on a effectués dans ces régions.

Les résultats indiquent que les valeurs de F varient entre 125 et 12 600 Ω•m et celles de $\rho_c$ entre 35 et 3 000 Ω•m. D'après l'examen préliminaire de la relation entre les données pour F et pour $\rho_c$ et les données sur la résistivité électrique apparente ($\rho_r$) précédemment recueillies, les parois des pores des échantillons seraient très altérées ou complètement tapissées de minéraux conducteurs. Les valeurs de $\rho_r$ de ces échantillons, après saturation dans une solution de NaCl 0,02 N, varient entre 33 et 3,5 x $10^3$ Ω•m. Ces valeurs correspondent à celles qui figurent dans des documents traitant de roches semblables.

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## INTRODUCTION

Formation resistivity factor, F, and pore-surface resistivity, $\rho_c$, values have been determined on a suite of three mineralized and nonmineralized rock samples from the Giant mine and Con mine areas of the Yellowknife mining district, Northwest Territories. The purpose was to provide basic information required to understand the electrical conductivity mechanisms of these rocks and to aid interpretation of geophysical surveys that have been conducted in these areas. The samples include rocks from sericite schist and chlorite-sericite schist formations that run parallel to a gold-bearing vein, and one ore sample (Katsube et al., 2000; Scromeda at al., 2000). This paper describes the methods and processes used to obtain the formation-factor data and document the results, in as much detail as considered necessary, for use in subsequent studies.

The F and $\rho_c$ values are determined by measuring bulk electrical resistivity ($\rho_r$) of the rock samples for a multiple number of NaCl solutions with different values of pore-fluid resistivity, $\rho_w$, and then by inserting the results into the Patnode and Wyllie (1950) equation:

$$1/\rho_r = 1/(F\rho_w) + 1/\rho_c. \qquad (1)$$

According to this equation, the relationship between the two variables, $1/\rho_r$ and $1/\rho_w$ should be linear. This linear relationship is used to determine F and $\rho_c$. This relationship, however, sometimes deviates from linearity and can become a source of reduced accuracy when determining F (Katsube and Scromeda, 1993). Five different NaCl concentrations of 0.02 N to 0.5 N (Katsube, 1981) are used to determine F and $\rho_c$. The accuracy problem is usually eliminated by using NaCl concentrations greater than 0.02 N, and saturation times greater than 240 minutes (Katsube and Scromeda, 1993; Katsube et al., 1995).

## METHOD OF INVESTIGATION

### *Sample preparation*

The three samples used in this study were selected from a set of 34 hand samples, collected underground by Jonathan Mwenifumbo and John Kerswill, from the Giant and Con mines, Yellowknife mining district, Northwest Territories. Two samples are from the Giant mine and one is from the Con mine. Information on sample location and lithology can be found elsewhere (Scromeda et al., 2000; Connell et al., 2000, 2001).

More than one specimen was usually cut from each sample into rectangular shapes with their edges either parallel or perpendicular to foliation. At least one specimen from each sample was used to determine the bulk electrical resistivity, $\rho_r$. In some cases, several rectangular specimens were cut from a single rock sample, in order to investigate the heterogeneities and anisotropy of the rock. The geometric characteristics of the specimens used for the 3-D $\rho_r$ measurements are listed elsewhere (Scromeda et al., 2000). In this paper results are documented for only two of the three directions "(α- and β-directions) for the Con mine sample (MYC-2a) and for all three directions (α-, β-, and γ-directions) for the Giant mine samples (MYG-9 and MYG-11a). The α"-direction is perpendicular to foliation and the β- and (γ-directions are parallel to foliation (Connell et al., 2000, 2001).

### *Formation resistivity factor measurements*

The complex electrical resistivity ($\rho^*$) is measured over a frequency range of 1–$10^6$ Hz, with $\rho_r$ representing a bulk electrical resistivity at frequencies of about $10^2$–$10^3$ Hz for the higher concentrations of NaCl (0.2 N and 0.5 N). At the lower concentrations of NaCl (0.02 N to 0.1 N) $\rho_r$ was represented by frequencies of about $10^4$–$10^5$ Hz. The $\rho_r$ is a function of the pore structure and pore-fluid resistivity, and is understood to exclude effects, such as pore surface, dielectric polarization, or electrode polarization (Katsube, 1975; Katsube and Walsh, 1987). The $\rho_r$ was measured for each sample at each

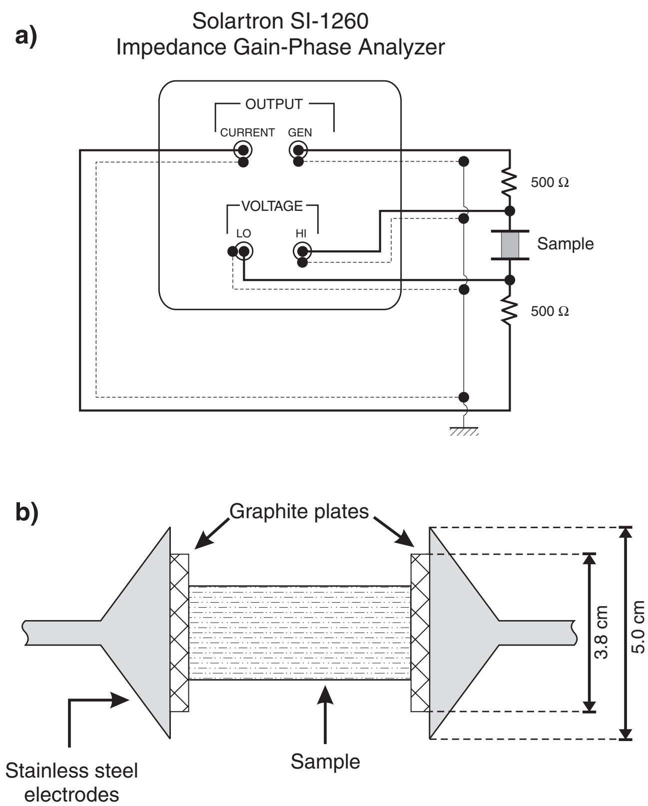


***Figure 1.*** *The measuring system used in this study: consisting of **a)** the Solartron SI-1260 Impedance/Gain-Phase Analyzer, and **b)** the two-electrode sample holder system, with stainless steel electrodes, but with graphite plates placed between the electrodes and the sample.*

concentration of NaCl. Further details of the measurement procedures used to determine F and $\rho_c$, using five different NaCl concentrations of 0.02 N to 0.5 N, are described in Katsube and Scromeda (1993). Results of the $\rho_r$ measurements for the samples presented in this paper can be found elsewhere (e.g. Scromeda et al., 2000).

### *Sample holder and measuring system*

The measuring system used in this study, the Solartron SI-1260 Impedance/Gain-Phase Analyzer, is displayed in Figure 1a. The constant current source (0.1 mA) of the generator is connected to the electrode-specimen system through 500 Ω resistors on either side of the sample holder. Although this system has the capability for making measurements in a four-electrode mode, it has essentially been used as a two-electrode system. The sample holder system has been frequently described elsewhere (Gauvreau and Katsube, 1975; Katsube and Walsh, 1987; Katsube and Salisbury, 1991). It is a two-electrode system with stainless steel electrodes, but with graphite plates placed between these electrodes and the sample, as shown in Figure 1b.

## EXPERIMENTAL RESULTS

Results of the bulk electrical resistivity ($\rho_r$) measurements used for formation resistivity factor (F) and surface resistivity ($\rho_c$) determination are listed in Table 1. The results of the F and $\rho_c$ determinations using the Patnode and Wyllie equation (Katsube and Scromeda, 1993) are listed in the last two columns of this table. The reduced major axis is used in these determinations. The percentage errors, listed in these columns, are determined by taking the differences in the F and $\rho_c$ values obtained by using the three regression lines: the reduced major axis and the two normal regression lines. The two normal regression lines in each case, are derived from interchanging the data sets which are used in the dependent and independent variable. The principles of reduced major axis are described in Davis (1986), and examples of related applications are found in Katsube and Agterberg (1990). These F and $\rho_c$ values are also listed in Table 2 which includes ρr values obtained by previous studies (Scromeda et al., 2000) for comparison.

Two types of $1/\rho_r$ versus $1/\rho_w$ relationships have been observed in these data, as shown in Figures 2a and 2b. No nonlinear relationships similar to those observed for shale samples (Katsube and Scromeda, 1993), showing deviations from linearity at the lower NaCl concentrations (lower $1/\rho_w$ values), have been seen in this study. A case where a good linear relationship exists between $1/\rho_r$ and $1/\rho_w$ for a high-resistivity sample is shown in Figure 2b for MYG-11aα. An example of a linear relationship between $1/\rho_r$ and $1/\rho_w$, with some scatter, for a low-resistivity sample (MYG-9β) is shown in Figure 2a.

Typical examples of the amplitude of complex resistivity ($\rho^+$) plots: $\rho^+$ as a function of frequency, f, and imaginary resistivity ($\rho_I$) as a function of real resistivity ($\rho_R$) are shown in Figures 3 and 4 for sample MYG-9β. Figures 3b and 4b were used to determine $\rho_r$ for MYG-9β at a low concentration of NaCl (0.02 N) and at a high concentration of NaCl (0.5 N), respectively.

## DISCUSSION AND CONCLUSIONS

The formation resistivity factor (F) values obtained in this study (Tables 1, 2) are in the range of 125–12 600. The lower values are in the range of rocks containing relatively large amounts of sulphides (Keller, 1982), and the higher values

**Table 1.** Formation resistivity factor (F) and surface resistivity ($\rho_c$) values for rock samples from the Con and Giant mine areas saturated with different concentrations of NaCl solutions.

| Sample | $\rho_r$ ($\times 10^3$ Ω•m) | | | | | F ±% ($\times 10^2$) | $\rho_c$ ±% ($\times 10^3$) (Ω•m) |
|---|---|---|---|---|---|---|---|
| $\rho_w$ (Ω•m) NaCl (N) | 0.24 ± 0.001 0.5 | 0.53 ± 0.002 0.2 | 0.94 ± 0.003 0.1 | 1.78 ± 0.01 0.05 | 4.46 ± 0.02 0.02 | | |
| MYC-2aα | 0.18 | 0.32 | 0.62 | 0.83 | 0.82 | 12.3 ± 4.2 | 0.988 ± 2.1 |
| MYC-2aβ | 0.37 | 0.70 | 1.25 | 1.53 | 1.32 | 38.4 ± 8.1 | 1.47 ± 1.8 |
| MYG-9α | 0.47 | 0.66 | 0.92 | 1.02 | 1.12 | 32.9 ± 0.2 | 1.22 ± 0.0 |
| MYG-9β | 0.022 | 0.025 | 0.025 | 0.027 | 0.033 | 1.25 ± 2.1 | 0.035 ± 0.4 |
| MYG-9γ | 0.053 | 0.059 | 0.064 | 0.065 | 0.070 | 5.97 ± 0.3 | 0.072 ± 0.0 |
| MYG-11aα | 1.56 | 2.42 | 2.88 | 3.26 | 3.51 | 126 ± 0.1 | 3.76 ± 0.0 |
| MYG-11aβ | 0.22 | 0.27 | 0.32 | 0.33 | 0.34 | 26.0 ± 0.1 | 0.354 ± 0.0 |
| MYG-11aγ | 0.32 | 0.41 | 0.50 | 0.53 | 0.57 | 26.8 ± 0.1 | 0.601 ± 0.0 |

$\rho_w$ = pore-fluid resistivity
$\rho_r$ = bulk electrical resistivity of the rock for solutions of different salinities
F = formation resistivity factor
$\rho_c$ = surface resistivity

**Table 2.** Formation resistivity factor (F), surface resistivity ($\rho_c$), and bulk electrical resistivities ($\rho_r$) for mineralized and nonmineralized rocks from the Con and Giant mine areas.

| Sample | Mine | Lithology | $\rho_r$ ($x10^3$ Ω·m) | F ±% ($x10^2$) | $\rho_c$ ±% ($x10^3$) (Ω·m) |
|---|---|---|---|---|---|
| MYC-2aα | Con | Chlorite-sericite schist | 1.56 | 12.3 ± 4.2 | 0.988 ± 2.1 |
| MYC-2aβ | | | 3.61 | 38.4 ± 8.1 | 1.47 ± 1.8 |
| MYG-9α | Giant | Ore | 1.69 | 32.9 ± 0.2 | 1.22 ± 0.0 |
| MYG-9β | | | 0.037 | 1.25 ± 2.1 | 0.035 ± 0.4 |
| MYG-9γ | | | 0.13 | 5.97 ± 0.3 | 0.072 ± 0.0 |
| MYG-11aα | | Sericite schist | 5.08 | 126 ± 0.1 | 3.76 ± 0.0 |
| MYG-11aβ | | | 0.36 | 26.0 ± 0.1 | 0.354 ± 0.0 |
| MYG-11aγ | | | 0.62 | 26.8 ± 0.1 | 0.601 ± 0.0 |

$\rho_r$ = bulk electrical resistivity
F = formation resistivity factor
$\rho_c$ = pore-surface resistivity

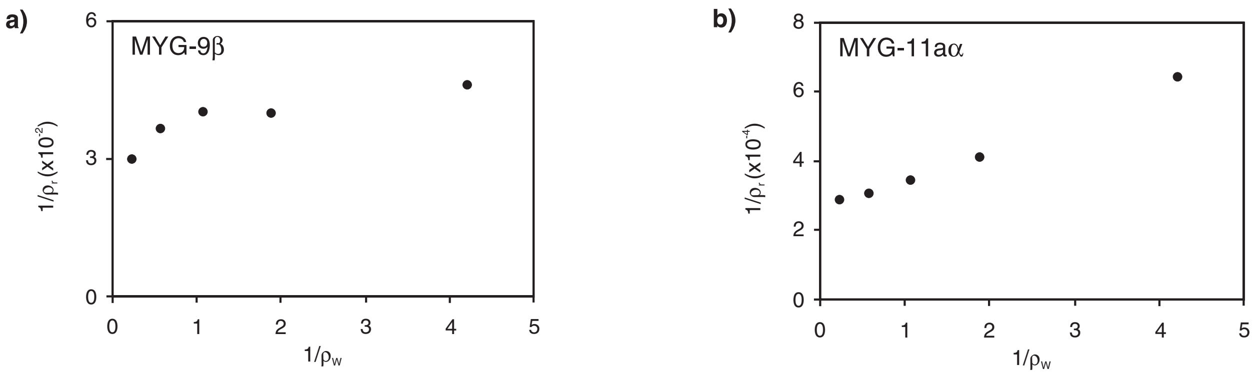


***Figure 2.*** *Typical examples of $1/\rho_r$ as a function of $1/\rho_w$ for:* ***a)*** *a low resistivity direction (β) parallel to foliation for an ore sample/specimen, MYG-9, displaying a good linear relationship, but with some scatter and* ***b)*** *a high-resistivity direction (α) perpendicular to foliation for a sericite schist sample/specimen, MYG-11a, displaying a good linear relationship with little scatter.*

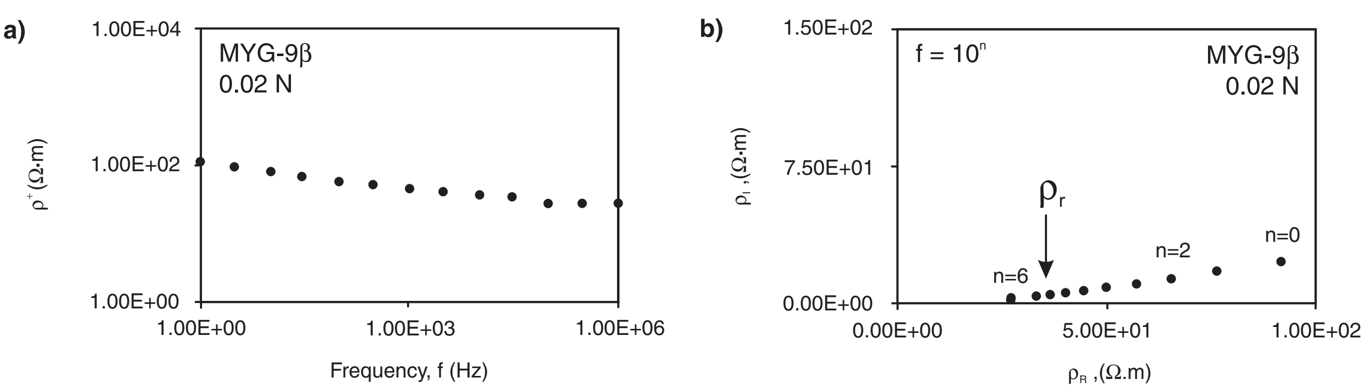


***Figure 3.*** *Typical examples of complex resistivity diagrams for the low resistivity direction (β) parallel to foliation for an ore sample/specimen, MYG-9, measured after saturation in 0.02 N NaCl:* ***a)*** *amplitude of complex resistivity ($\rho^+$) as a function of frequency (f), and* ***b)*** *imaginary resistivity (ρ") versus real resistivity (ρ').*

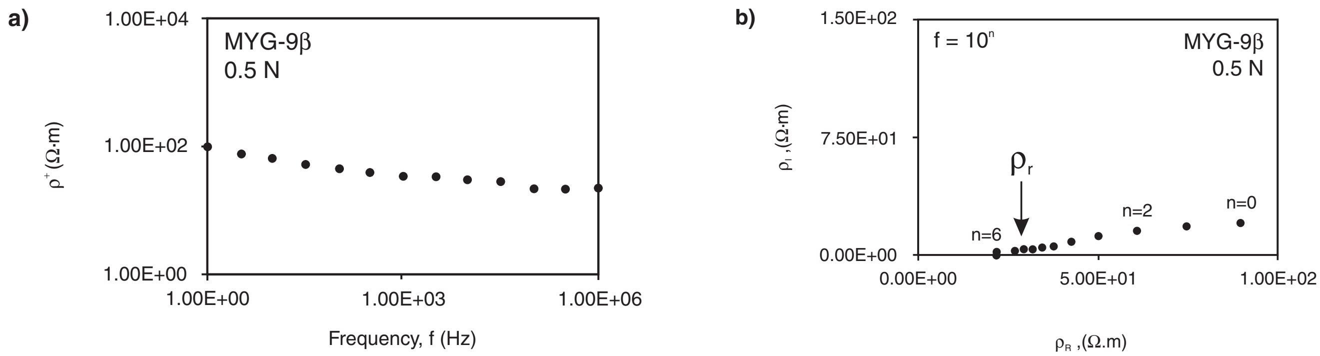


*Figure 4. Typical examples of complex resistivity diagrams for the low resistivity direction (β) parallel to foliation for an ore sample/specimen, MYG-9, measured after saturation in 0.5 N NaCl:* ***a****) amplitude of complex resistivity ($\rho^+$) as a function of frequency (f), and* ***b****) imaginary resistivity (ρ”) versus real resistivity (ρ’).*

are typical of crystalline rocks (Katsube and Mareschal, 1993). All of the samples display surface resistivity ($\rho_c$) values close to that of the bulk electrical resistivity ($\rho_r$)(Table 2). This would suggest that the samples have pore surfaces that are highly altered, or are completely lined with conductive minerals of some type.

The $\rho_r$ obtained for the samples at 0.02 N NaCl (Table 1) are consistent with the $\rho_r$ measurements previously reported (Table 2), except for samples MYC-2aβ and MYG-11aα, which have $\rho_r$ values at 0.02 N that are slightly lower than those previously reported (Scromeda et al., 2000).

Typical complex resistivity diagrams (Fig. 3b, 4b), used to determine the $\rho_r$ values for a low-resistivity sample (MYG-9) in the β-direction, display a decrease in $\rho_r$ from 330 Ω·m (Fig. 3b) to 220 Ω·m (Fig. 4b) as the NaCl concentration is increased from 0.02 N to 0.5 N. The effect of the sulphide minerals are likely being reflected in these results. This is expected from previous results of the $\rho_r$ measurements (Connell et al., 2000, 2001) for this sample. Further detailed analyses of this data are planned for future studies.

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