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Electrical resistivity characteristics of mineralized and unmineralized rocks from Giant and Con mine areas, Yellowknife, Northwest Territories[1]

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Abstract: Electrical characteristics have been determined for ten mineralized and nonmineralized rock samples from the Con and Giant mines, Yellowknife, Northwest Territories. These samples represent the main lithologies present around the mineralized shear zones: sericite schist, chlorite schist, chlorite-sericite schist, basalt, and gold-bearing ore. The purpose was to obtain information required to help develop exploration strategies.

Results indicate that mineralized to moderately mineralized rocks investigated in this study show electrical resistivities (ρ_r) in the ranges of 37–130 Ω·m and 360–980 Ω·m, with electrical anisotropy (λ) values in the range of 2:1 to 46:1. A clear relationship is seen between the foliation and the electrical anisotropy in these samples. The ρ_r for the poorly to nonmineralized rocks are in the range of 1500–24 000 Ω·m, with λ values of 2:1 to 7:1.

Résumé : On a déterminé les caractéristiques électriques de 10 échantillons de roches minéralisées et non minéralisées provenant des mines Con et Giant à Yellowknife (Territoires du Nord-Ouest). Ces échantillons sont représentatifs des principales unités lithologiques présentes autour des zones de cisaillement minéralisées : séricitoschiste, chloritoschiste, basalte et minerai aurifère. Ces déterminations visaient à obtenir l'information nécessaire pour aider à élaborer des stratégies d'exploration.

Les résultats indiquent que les roches minéralisées à modérément minéralisées étudiées présentent des résistivités électrique (ρ_r) de l'ordre de 37 à 130 Ω·m et de 360 à 980 Ω·m, ainsi que des valeurs de l'anisotropie électrique (λ) de l'ordre de 2:1 à 46:1. Une nette relation est observée pour ces échantillons entre la schistosité et l'anisotropie électrique. Les ρ_r pour les roches faiblement à non minéralisées sont de l'ordre de l 500 à 24 000 Ω·m, et les valeurs de λ de 2:1 à 7:1.

[1] Contribution to the 1999-2003 Yellowknife, Canada-Northwest Territories Exploration Science and Technology (EXTECH III) Initiative

INTRODUCTION

Electrical characteristics have been determined for ten mineralized and nonmineralized rock samples from the Con and Giant mines, Yellowknife, Northwest Territories (Fig. 1). This report is a summary of the results of the 3-D electrical resistivity measurements described in a separate study (Scromeda et al., 2000), followed by an analysis of their relationship to the visual textural characteristics of these rock samples. This preliminary study is part of a larger project to determine the electrical characteristics, including the electrical anisotropy characteristics, of rocks in the Yellowknife mining district. This information is required to analyze electrical conductivity mechanisms (Connell et al., 2000) and to help set up exploration strategies for use in the district. These ten samples were selected from a suite of 34 samples that were collected in the Yellowknife mining district. The main lithologies present around the mineralized shear zones: sericite schist, chlorite schist, chlorite-sericite schist, basalt, and gold-bearing ore are represented. In this paper, the results of the electrical characterization of these samples are described, following a summary of the electrical resistivity measurements of a separate study (Scromeda et al., 2000).

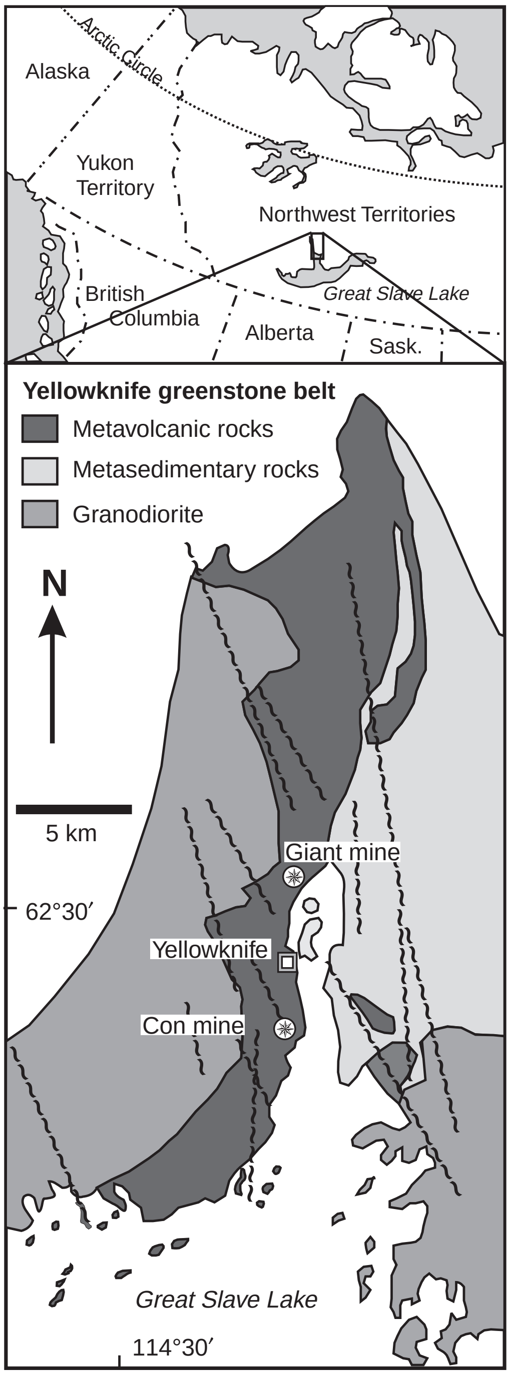

*Figure 1. Location of the Giant and Con mines within the Yellowknife mining district, Northwest Territories (*from *Van Hees et al., 1999).*

METHOD OF INVESTIGATION

Of the ten samples used in this study, five are from the Giant mine and five are from the Con mine. Two samples were chosen and prepared from each of the following five rock types: gold bearing quartz vein, sericite schist, chlorite schist, chlorite-sericite schist, and basalt. Whenever possible, similar rock types were selected from each of the two mine sites. Information on sample location and lithology is listed in Table 1.

One or two rectangular test specimens were cut from each sample. A total of 12 rectangular specimens, each with sides cut parallel and perpendicular to foliation were prepared. Detailed visual examinations were performed on these rectangular specimens and the key structural features recorded as shown in the block diagrams of Figures 2–6. The results of the 3-D electrical resistivity measurements (Scromeda et al., 2000) are compiled in Table 2 for these 10 samples (12 specimens). Detailed description of the laboratory 3-D electrical measurements and procedures can be found elsewhere (Scromeda et al., 2000).

Table 1. Rock descriptions and depths for samples collected from the Giant and Con mines (Yellowknife, Northwest Territories), and their visually estimated sulphide content.

Mine	Sample number	Stope sampled	Lithology	Sulphide content
Giant	MYG-8	370	Chlorite schist	trace
	MYG-9	370	Ore zone	≥10%
	MYG-11	370	Sericite schist	5–7%
	MYG-13	370	Sericite schist	2–3%
	MYQ-1	Surface	Basalt	trace
Con	MYC-1	3148R	Sericite schist	≤ 2%
	MYC-2	3148R	Chlorite-sericite schist	2%
	MYC-6	3148R	Basalt	trace–1%
	MYC-7	3196R	Chlorite schist	trace
	MYC-11	3322AY	Ore zone	2–5%

ANALYTICAL RESULTS

Results of the visual examinations for 12 rectangular specimens representing 10 samples are shown as block diagrams in Figures 2–6, with the three complex resistivity plots for each of the three directions measured. A previous study (Scromeda et al., 2000) has shown that the electrical resistivities (ρ_r) are in the ranges of 37–3400 Ω·m for the ore samples, 360–6600 Ω·m for the sericite schist samples, 1900–13 500 Ω·m for chlorite schist samples, 3700–24 000 Ω·m for the basalt samples, and 1500–7500 Ω·m for the chlorite-sericite schist samples (Table 2). Electrical anisotropy (λ) values range from 2:1 to 46:1, with the higher ρ_r values generally in the direction perpendicular to foliation and the lower values parallel to foliation. All samples/specimens examined in this study are foliated, except for the basalt samples which are homogenous. These results are summarized in Table 3.

The two ore samples, MYG-9 and MYC-11, are from Giant and Con mines, respectively. Sample MYG-9 (Fig. 2a) shows a strong foliation, defined by layers of very fine-grained sulphide minerals and of quartz carbonate containing sericite and chlorite. It is grey-brown and is easily

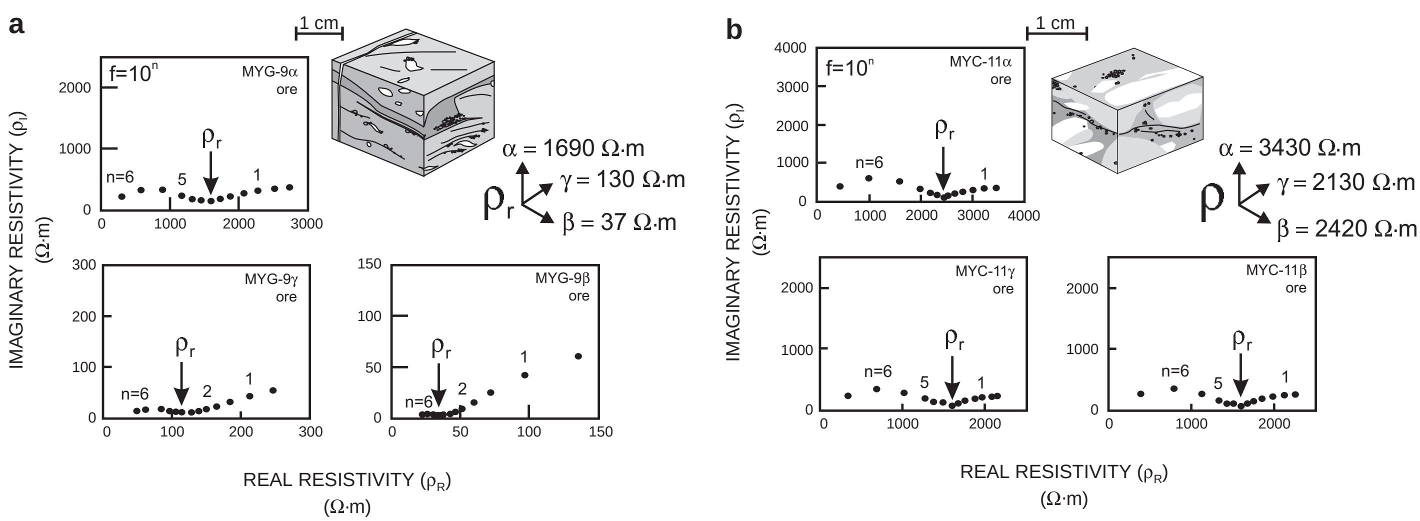

Figure 2. *Visual descriptions of the ore samples used in the measurements. Complex resistivity diagrams display imaginary resistivity (ρ_I) as a function of real resistivity (ρ_R). The bulk electrical resistivity (ρ_r) values are measured in three orthogonal directions (24 hour saturation). The ρ_r values are determined from these complex resistivity diagrams (Scromeda et al., 2000)* ***a****) MYG-9 and* ***b****) MYC-11.*

Table 2. Results of electrical resistivity measurements.

Sample	Lithology	δ_B (g/mL)	ϕ_E (%)	Mean ρ_r, (10^3 Ω·m) α	β	γ	Maximum anisotropy (λ)
MYC-1	SS	2.99	1.16	5.90 ± 2.4	0.98 ± 0.32	0.60 ± 0.16	10:1
MYC-2A	CSS	3.02	0.80	1.56 ± 0.36	3.61 ± 0.9	5.38 ± 0.23	3:1
MYC-2B				7.51 ± 0.74	4.45 ± 0.98	1.96 ± 0.32	4:1
MYC-6	Basalt	3.02	0.40	3.71 ± 1.48	7.20 ± 2.54	4.47 ± 1.62	2:1
MYC-7	CS	2.92	0.54	13.32 ± 1.68	4.45 ± 0.91	1.94 ± 0.37	7:1
MYC-11	Ore	3.12	0.56	3.43 ± 0.98	2.42 ± 0.82	2.13 ± 0.52	1.6:1
MYQ-1	Basalt	3.13	0.42	23.77 ± 1.82	12.50 ± 1.16	7.00 ± 0.76	3:1
MYG-8	CS	2.86	3.03	13.52 ± 0.39	4.24 ± 0.05	2.07 ± 0.02	6:1
MYG-9	Ore	3.12	2.55	1.69 ± 0.09	0.037 ± 0.003	0.13 ± 0.0	46:1
MYG-11A	SS	3.04	1.97	5.08 ± 0.09	0.36 ± 0.0	0.62 ± 0.01	14:1
MYG-11B		2.91	2.86	1.62 ± 0.05	2.97 ± 0.05	6.61 ± 0.31	4:1
MYG-13	SS	3.05	1.46	2.40 ± 0.26	1.25 ± 0.15	0.58 ± 0.02	4:1

δ_B = Bulk density (g/mL)
ϕ_E = Effective porosity (%)
ρ_r = Mean bulk electrical resistivity for measurements made after 24 and 48 hours saturation (Scromeda et al., 2000)

CSS = Chlorite sericite schist
CS = Chlorite schist
SS = Sericite schist
α, β, γ = Three directions of the electrical measurements

scratched with a knife. The ρ_r values are 1690 Ω·m and 37–130 Ω·m perpendicular and parallel to foliation, respectively, with a λ value of 46:1. Sample MYC-11 (Fig. 2b) is predominantly quartz and carbonate with patches of fine-grained sulphide minerals. The ρ_r values are 3430 Ω·m and 2420–2130 Ω·m perpendicular and parallel to foliation, respectively, with a λ value of 1.6:1. Sample MYG-9 has a stronger, well defined foliation and higher sulphide content (≥10%) compared to MYC-11 (2–5%), which provides an explanation for its larger λ value (46:1 versus 1.6:1). The higher sulphide content for MYG-9 explains the reason for its generally larger right-hand arcs (e.g. MYG-9β in Fig. 2a), compared to those of MYC-11 (Fig. 2b). The right-hand arcs are due to electrode polarization and characterize the mineralized section of a rock sample (Katsube and Walsh, 1987). When compared to the other samples, both of these ore samples have larger right-hand arcs, reflective of their higher sulphide content. The complex resistivity plots for MYG-9 (Fig. 2a), for all three directions, are typical of low resistivity samples with high sulphide content (e.g. Katsube et al., 1997). The left-hand arcs characterize the electrical characteristics of the nonmineralized section of a rock sample.

The three sericite schist samples: MYG-11, MYG-13, and MYC-1 (two specimens for MYG-11A, MYG-11B), are from Giant and Con mines (Fig. 3a, 3b, 4a, 4b). The sulphide content varies between the three samples (≤2–7%), with the highest in MYG-11A and lowest in MYC-1. All samples are pale greenish-grey and are easily scratched with a knife, due to the high sericite content. All samples have a moderate to strong foliation and sample MYG-13 is highly fractured (Fig. 4a). The ρ_r values are in the ranges of 2400–6610 Ω·m and 360–2970 Ω·m in the directions perpendicular and parallel to foliation, respectively, and their λ values in the range of 4:1 to 14:1. They are generally medium to large ρ_r values with little variation between samples suggesting poor connectivity between sulphide grains. The anisotropy is likely a result of the parallel alignment of nonsulphide grains or connected pores. Each complex resistivity plot shows distinct left-hand arcs (Fig. 3a, 3b, 4a, 4b). The higher sulphide content (5–7%) of sample MYG-11A is reflected in the larger right-hand arcs (Fig. 3a) of this set of three samples.

The chlorite schist samples from Giant (MYG-8) and Con mines (MYC-7) are similar in grain size and texture. They have moderate to strong foliation with discontinuous, chlorite-rich bands and are dark greenish-grey. They both have similar electrical resistivity characteristics (Fig. 5a, 5b), with ρ_r values in the range of 13 320–13 520 Ω·m and 1940–4450 Ω·m for the directions perpendicular and parallel to foliation, respectively, and λ values of 6:1 to 7:1. It is not certain whether this electrical anisotropy is due to the alignment of mineral grains or connecting pores in association with the moderate to strong foliation. Formation factor measurements may provide useful information to explain the electrical anisotropy.

The chlorite-sericite schist sample, represented by two specimens (MYC-2A, MYC-2B), is moderately to strongly foliated (Fig. 6a, 6b) with some folding evident in specimen MYC-2A. The ρ_r values are in the ranges of 5380–7510 Ω·m and 1560–4450 Ω·m for the directions perpendicular and parallel to foliation, respectively, and the λ values are 3:1 to 4:1. The λ values are considerably lower than would be expected given of the distinct and strong foliation. The complex

Table 3. Summary of the electrical resistivity measurements.

Rock type	Resistivity range (ρ_r)	Anisotropy range (λ)
Ore	37–3400 Ω·m	1.6:1–46:1
Sericite schist	360–6600 Ω·m	4:1–14:1
Chlorite schist	1900–13 500 Ω·m	6:1–7:1
Chlorite-sericite schist	1500–7500 Ω·m	3:1–4:1
Basalt	3700–24 000 Ω·m	2:1–3:1

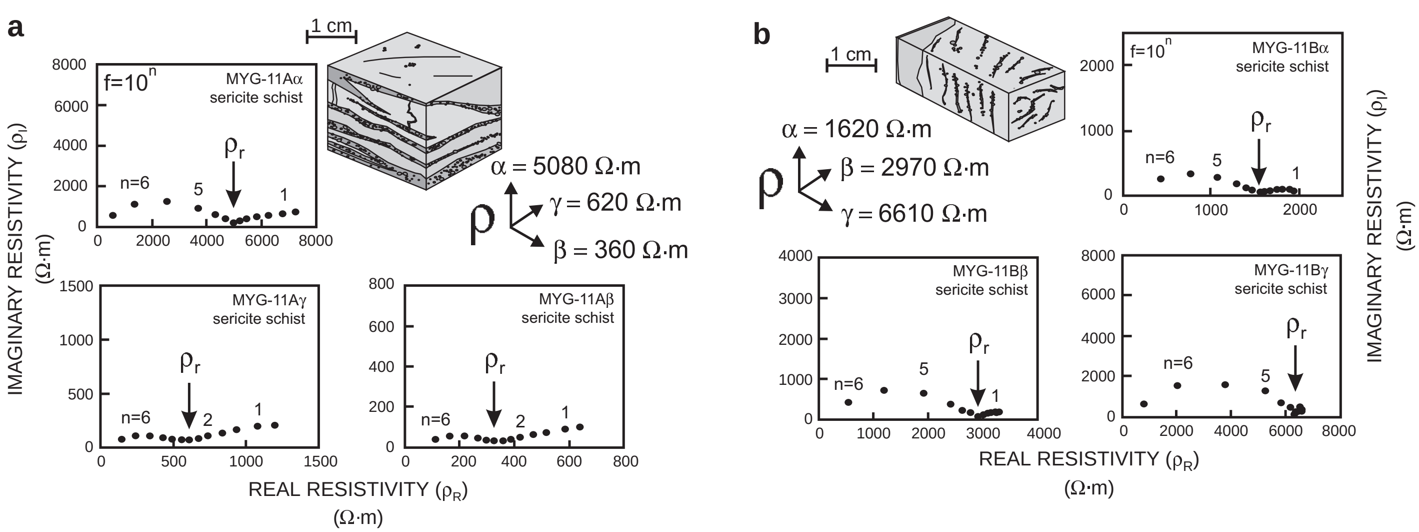

Figure 3. *Visual descriptions of the sericite schist samples used in the measurements. Complex resistivity diagrams display* ρ_I *as a function of* ρ_R*, and* ρ_r *values measured in three directions (24 hour saturation),* ***a****) MYG-11A and* ***b****) MYG-11B.*

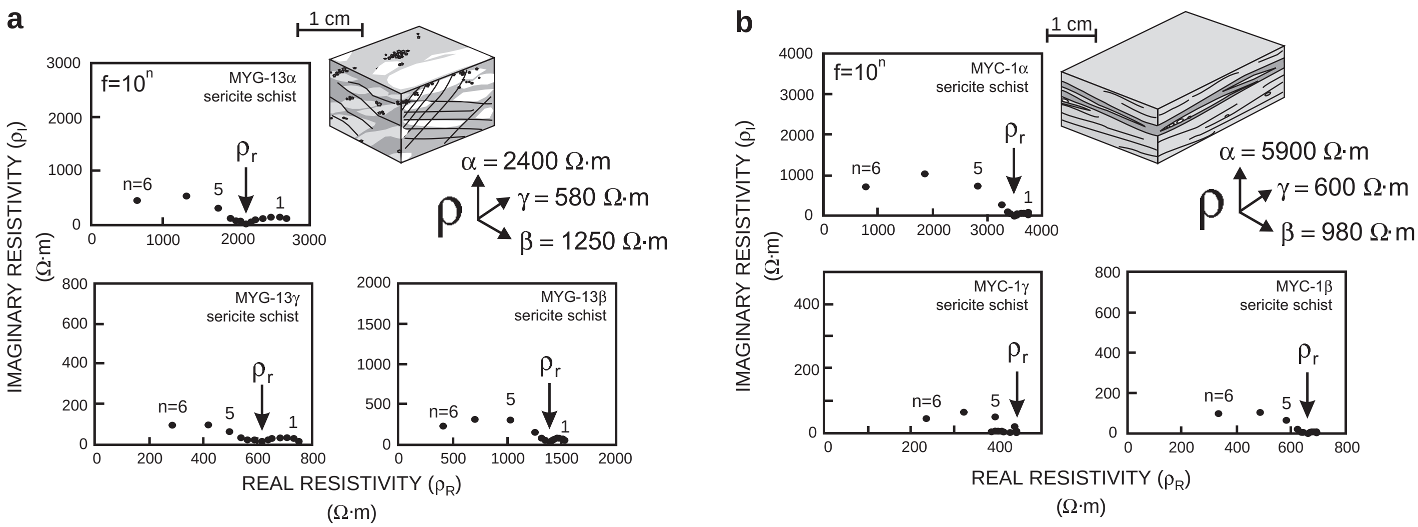

Figure 4. *Visual descriptions of the sericite schist samples used in the measurements. Complex resistivity diagrams display* ρ_I *as a function of* ρ_R*, and* ρ_r *values measured in three directions (24 hour saturation)* ***a)*** *MYG-13 and* ***b)*** *MYC-1.*

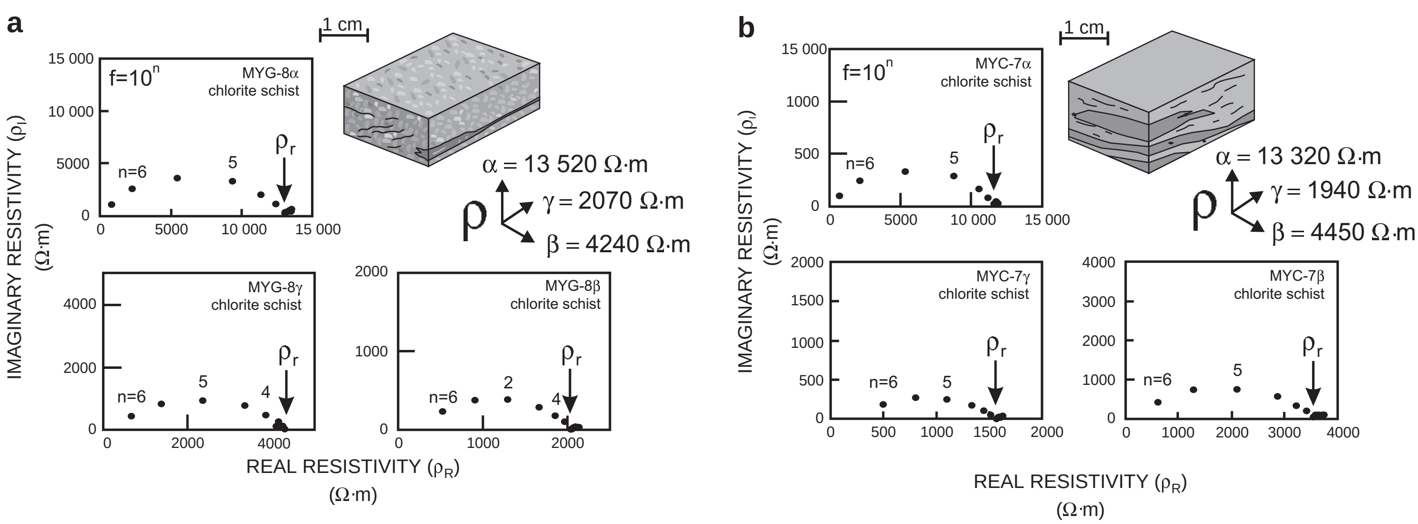

Figure 5. *Visual descriptions of the chlorite-sericite schist samples used in the measurements. Complex resistivity diagrams display* ρ_I *as a function of* ρ_R*, and* ρ_r *values measured in three directions (24 hour saturation)* ***a)*** *MYC-2A and* ***b)*** *MYC-2B.*

resistivity plots all display normal arcs which are characteristic of intermediate to high resistivity rocks (Katsube et al., 1996), except for the γ-direction of sample MYC-2B (Fig. 6b), which is slightly distorted. This is a feature uncommon for a rock with high ρ_r values, such as this one (1960 Ω·m).

The two basalt samples; MYQ-1 and MYC-6, are from Giant and Con mines, respectively. Both are dark green in colour and similar in grain size and texture with little or no visible foliation. Sample MYQ-1 (Fig. 7a) was sampled above ground. Sample MYC-6 (Fig. 7b) is moderate to strongly magnetic. Both samples are electrically anisotropic, with λ values of 3:1 and 2:1. The maximum and minimum ρ_r values are 23 770 Ω·m and 7000–12 500 Ω·m, respectively, for sample MYQ-1 and 7200 Ω·m and 3710–4470 Ω·m, respectively, for sample MYC-6. Although no foliation is visible in these samples, the relatively distinct electrical anisotropy imply that either hidden foliation or some other type of textural anisotropy exists. Complex resistivity plots reveal normal arcs, characteristic of medium to high resistivity rocks, in all three directions for sample MYC-6 (Fig. 7b). The arcs for MYQ-1 are very distorted (Fig. 7a), the type of distortion characteristic of extremely high resistivity rocks (Katsube et al., 1992).

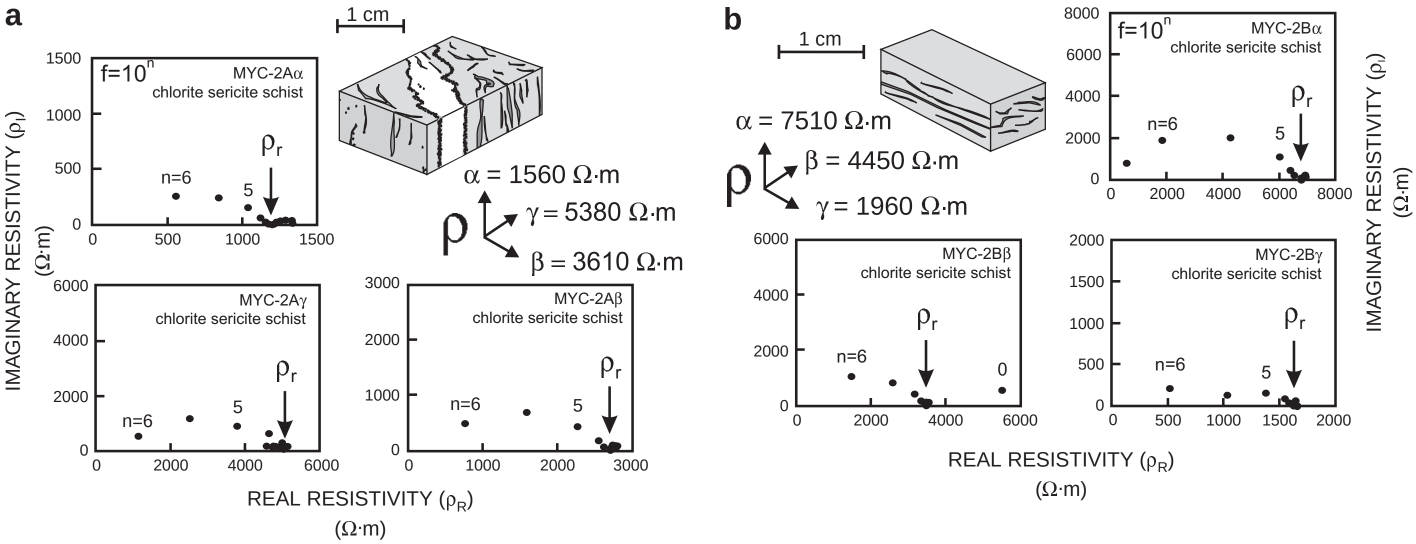

Figure 6. *Visual descriptions of the chlorite schist samples used in the measurements. Complex resistivity diagrams display* ρ_I *as a function of* ρ_R*, and* ρ_r *values measured in three directions (24 hour saturation)* ***a)*** *MYG-8 and* ***b)*** *MYC-7.*

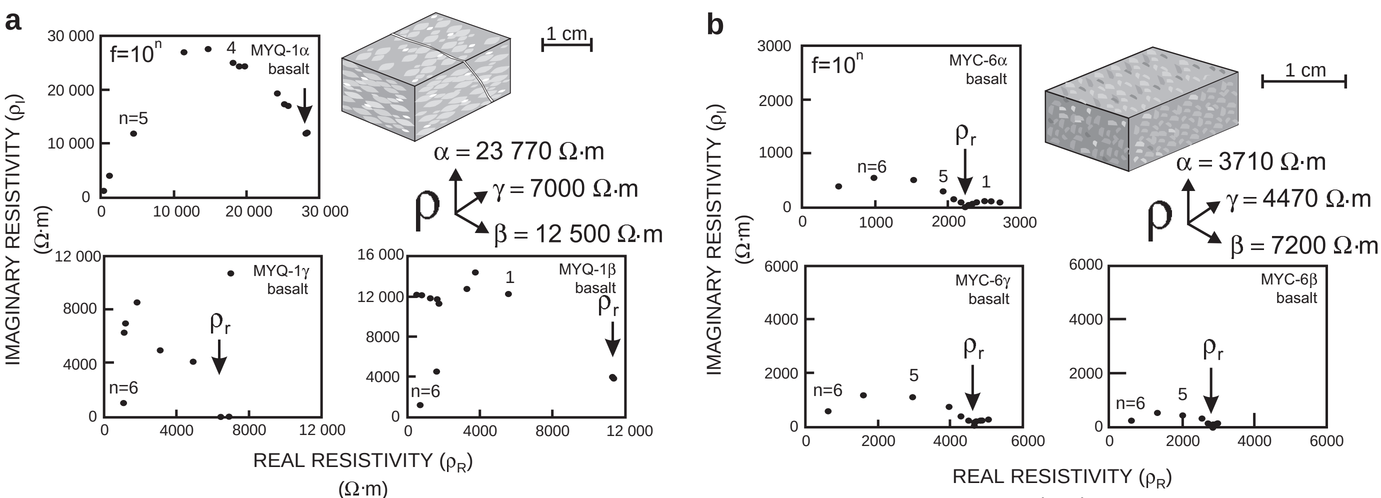

Figure 7. *Visual descriptions of the basalt samples used for measurements. Complex resistivity diagrams display* ρ_I *as a function of* ρ_R*, and* ρ_r *values measured in three directions (24 hour saturation)* ***a)*** *MYQ-1 and* ***b)*** *MYC-6.*

DISCUSSION AND CONCLUSIONS

The electrical resistivities (ρ_r) of the ten samples investigated in this study are in the range of 37–24 000 Ω·m (Table 3). The ρ_r for the poorly to nonmineralized rocks are in the range of 1500–24 000 Ω·m, values generally at the lower end of the expected range for crystalline rocks (Katsube and Mareshal, 1993). Their electrical anisotropy (λ) values are in the range of 2:1 to 7:1. The mineralized to moderately mineralized rocks investigated in this study show ρ_r values in the ranges of 37–130 Ω·m and 360–980 Ω·m, respectively, with λ values in the range of 2:1 to 46:1.

The mineralized rock samples showing low ρ_r values, in at least one direction, are relatively to strongly anisotropic (λ=14:1 to 46:1). The rest of the rocks are low to moderately anisotropic (λ=1.6:1 to 7:1). A clear relationship exists between the foliation and the electrical anisotropy in these samples, except for the basalt samples(λ=2:1 to 3:1). This may be due to hidden foliations or other textural anisotropies of the basalt. A separate study, using scanning electron microscope analysis, is expected to provide more information on this subject.

This study indicates that the mineralized ore samples do not necessarily show low ρ_r values. Some samples show low ρ_r values in only one or two directions with remaining directions displaying high ρ_r values, resulting in high λ values. The moderately mineralized sericite schist samples, while displaying a more moderate range of ρ_r values in their lower ρ_r direction, show greater consistency in their lower ρ_r characteristics, compared to the ore samples.

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