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Electrical characteristics of rock samples from the central Baffin region, Baffin Island, Nunavut

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Abstract: The electrical resistivity characteristics have been determined for five black graphitic shale samples collected from the Astarte River formation, Piling Group of the central Baffin region, Baffin Island, Nunavut. This work consists of analysis and interpretation of data obtained by 3-D electrical resistivity measurements. The samples were selected to characterize the resistivity of the Astarte River formation, and determine the effect of strong foliation with porous layers, and of disseminated sulphide minerals oriented parallel to foliation. The purpose of this paper is to document results of the electrical resistivity characteristics for use in interpreting ground electromagnetic surveys which were conducted in the area. The bulk electrical resistivities (ρ_r) of the five samples investigated in this study are in the range of 8 Ω•m to more than 40 000 Ω•m with anisotropy values ranging from 5:1 to 275:1. The disseminated sulphide minerals with poor connectivity showed the highest ρ_r values (more than 28 000 Ω•m to more than 40 000 Ω•m).

Résumé : On a déterminé les caractéristiques de la résistivité électrique dans cinq échantillons de shale graphitique noir prélevés dans la formation d'Astarte River du Groupe de Piling, dans la région centrale de l'île de Baffin, au Nunavut. Le travail consistait à analyser et à interpréter les données tirées des mesures de la résistivité électrique en trois dimensions. Les échantillons ont été choisis afin de pouvoir représenter la résistivité de la formation d'Astarte River et déterminer l'effet sur la résistivité d'une foliation marquée avec des couches poreuses et de la présence de sulfures disséminés orientés parallèlement à la foliation. Ce document présente les caractéristiques de la résistivité électrique obtenues dans le but de les utiliser pour l'interprétation des levés électromagnétiques exécutés au sol dans la région. Les cinq échantillons analysés dans le cadre de cette étude présentent tous une valeur de la résistivité électrique apparente (ρ_r) comprise entre de 8 Ω•m et plus de 40 000 Ω•m et des valeurs d'anisotropie s'échelonnant entre 5/1 et 275/1. Les sulfures disséminés de mauvaise connectivité présentaient les plus hautes valeurs de ρ_r (de plus de 28 000 Ω•m à plus de 40 000 Ω•m).

INTRODUCTION

The electrical resistivity characteristics have been investigated for five black graphitic shale samples collected from the Astarte River formation, Piling Group (Corrigan et al., 2001) of the central Baffin region, Baffin Island, Nunavut. This work consists of measurement and analysis of data obtained by 3-D electrical resistivity measurements and follows similar works previously performed on mineralized and nonmineralized sericite schist samples of the Yellowknife mining district (Connell et al., 2000; Connell and Scromeda-Perez, 2002). The samples were selected to characterize the resistivity of the Astarte River formation and determine the effect of strong foliation containing porous layers and of disseminated sulphide mineralization oriented parallel to foliation. The purpose of this paper is to document, within the framework of the Central Baffin Project, results of the electrical resistivity characteristics for use in interpreting ground electromagnetic surveys that have been conducted in the area.

METHOD OF INVESTIGATION

Sample preparation

Graphitic shale samples were collected by Alan Jones (GSC) from the Astarte River formation in the central Baffin region of Baffin Island. Five were selected for electrical resistivity measurements in order to understand the electrical resistivity anisotropic characteristics of these rock types for application to exploration by electromagnetic methods in the central Baffin region. Further information on the samples are listed in Table 1.

Table 1. Results of rock descriptions and bulk electrical resistivity measurements for Baffin Island samples.

Sample	Special features and comments	Anisotropy (λ)	ρ_r (10^3 Ω•m)		
			α	β	γ
BAF-1	Strong foliation, fissile, porous lenses, trace pyrite	275:1	3.58	0.013	0.082
BAF-2	Strong foliation, fissile, porous lenses	44:1	2.13	0.048	0.061
BAF-3	Strong foliation, fissile, porous layers, trace pyrite	49:1	0.39	0.008	0.036
BAF-A	Fine-grained disseminated sulphides with poor connectivity, weak-moderate foliation	5:1	>40.0	>16.0	>8.0
BAF-B	Same as BAF-A	12:1	>28.0	2.50	2.30

ρ_r = Bulk electrical resistivity determined after 24 hours saturation.
α = Measurement made in the direction perpendicular to bedding (foliation).
β, γ = Measurements made in directions parallel with bedding (foliation).

Table 2. Dimensions of specimens cut out from the samples for electrical resistivity measurements.

Sample /Ms-Dir	a_1 (cm)	a_2 (cm)	ℓ (cm)	W (g)	V (cm^3)	K_G (10^{-2}m)	δ_B (g/mL)
BAF-1α	1.539	2.038	0.619	5.0881	1.94	5.07	2.62
BAF-1β	0.619	2.038	1.539	5.0881	1.94	0.82	2.62
BAF-1γ	0.619	1.539	2.038	5.0881	1.94	0.47	2.62
BAF-2α	1.501	2.028	0.774	6.0430	2.36	3.93	2.56
BAF-2β	0.774	2.028	1.501	6.0430	2.36	1.05	2.56
BAF-2γ	0.774	1.501	2.028	6.0430	2.36	0.57	2.56
BAF-3α	1.601	2.136	0.642	5.5504	2.20	5.33	2.53
BAF-3β	0.642	2.136	1.601	5.5504	2.20	0.86	2.53
BAF-3γ	0.642	1.601	2.136	5.5504	2.20	0.48	2.53
BAF-Aα	1.793	2.048	1.308	14.3356	4.80	2.81	2.98
BAF-Aβ	1.308	2.048	1.793	14.3356	4.80	1.49	2.98
BAF-Aγ	1.308	1.793	2.048	14.3356	4.80	1.15	2.98
BAF-Bα	1.655	2.108	0.981	10.4633	3.42	3.56	3.06
BAF-Bβ	0.981	2.108	1.655	10.4633	3.42	1.25	3.06
BAF-Bγ	0.981	1.655	2.108	10.4633	3.42	0.77	3.06

Ms-Dir = Direction of measurement: α, β, γ.
a_1, a_2 = Length of the two sides of the rectangular specimen.
ℓ = Thickness of specimen.
W = Weight of specimen under room dry conditions.
K_G = Geometric factor (Katsube et al., 1996).
δ_B = Bulk density

Each sample was cut into a rectangular specimen with surfaces parallel to and perpendicular to foliation in order to investigate the inhomogeneities and anisotropy of the rock. The geometric characteristics of the specimens used for the 3-D resistivity measurements are listed in Table 2. In this paper results are documented for all three directions for each specimen. The α-direction is perpendicular to foliation and the β- and γ-directions are parallel to foliation (Connell et al., 2000, 2001). Detailed visual examinations were performed on these specimens and the key structural features recorded as shown in the block diagrams of Figures 1–4.

Bulk electrical resistivity measurements

The bulk electrical resistivity (ρ_r) is determined from the complex electrical resistivity, ρ^*, measurements described in recent publications (e.g. Katsube and Salisbury, 1991). The complex electrical resistivity (ρ^*), consisting of real (ρ_R) and imaginary (ρ_I) resistivities, is measured over a frequency range of 1–10^6 Hz, with ρ_r generally representing a bulk electrical resistivity at frequencies of about 10^2–10^3 Hz. It is a function of the pore structure and pore-fluid resistivity, and is understood to exclude effects such as pore surface, dielectric,

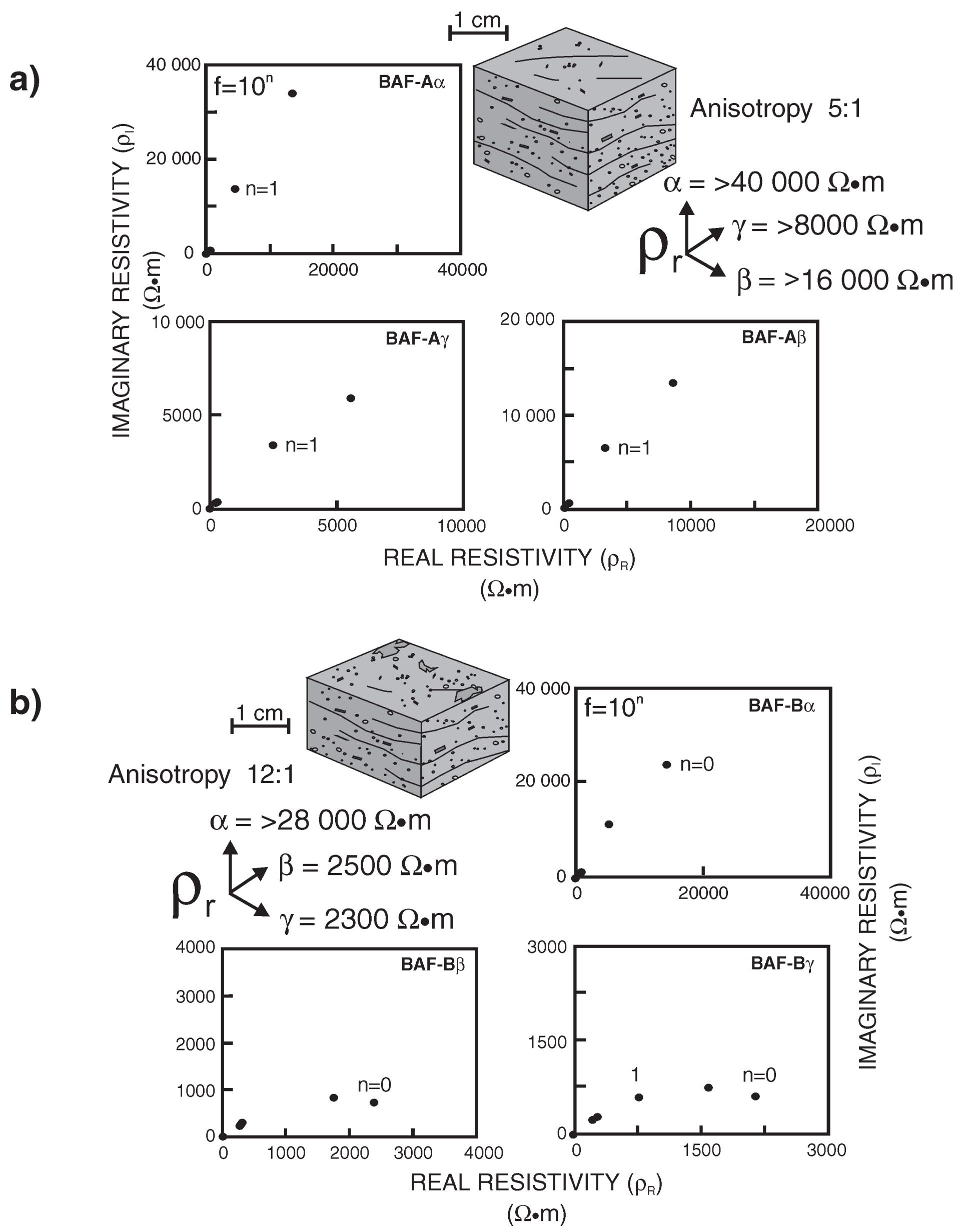

Figure 1. *Schematic presentation of two specimens from a graphitic shale sample with disseminated sulphide mineralization, represented by block diagrams with sketches of the rock texture and 3-D bulk electrical resistivity (ρ_r) values shown below (argon plots are displayed for surfaces perpendicular to the α-, β-, and γ-directions) for **a)** sample BAF-A and **b)** sample BAF-B.*

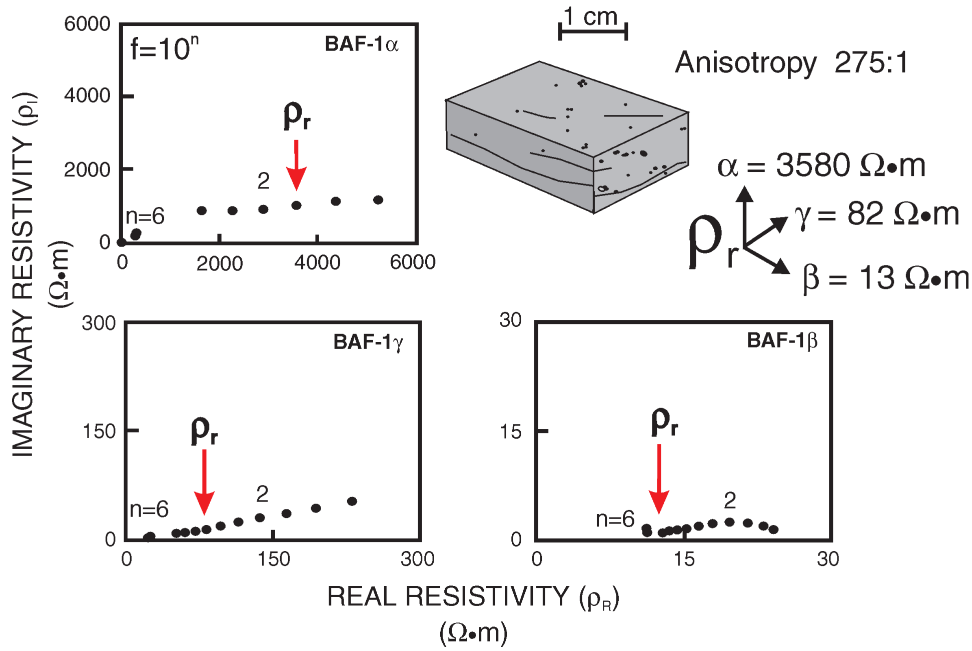

Figure 2. *Schematic presentation of a highly anisotropic (275:1) graphitic shale sample BAF-1, represented by block diagrams with sketches of the rock texture and 3-D bulk electrical resistivity (ρ_r) values shown below.*

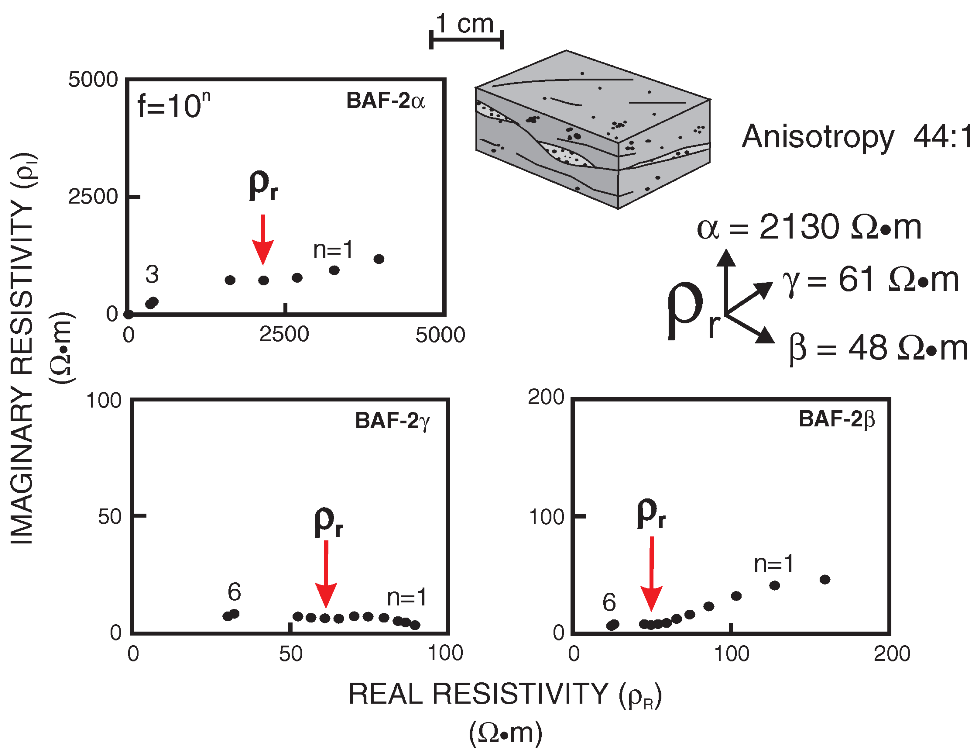

Figure 3. *Schematic presentation of a graphitic shale sample BAF-2, with porous lenses, represented by block diagrams with sketches of the rock texture and 3-D bulk electrical resistivity (ρ_r) values shown below.*

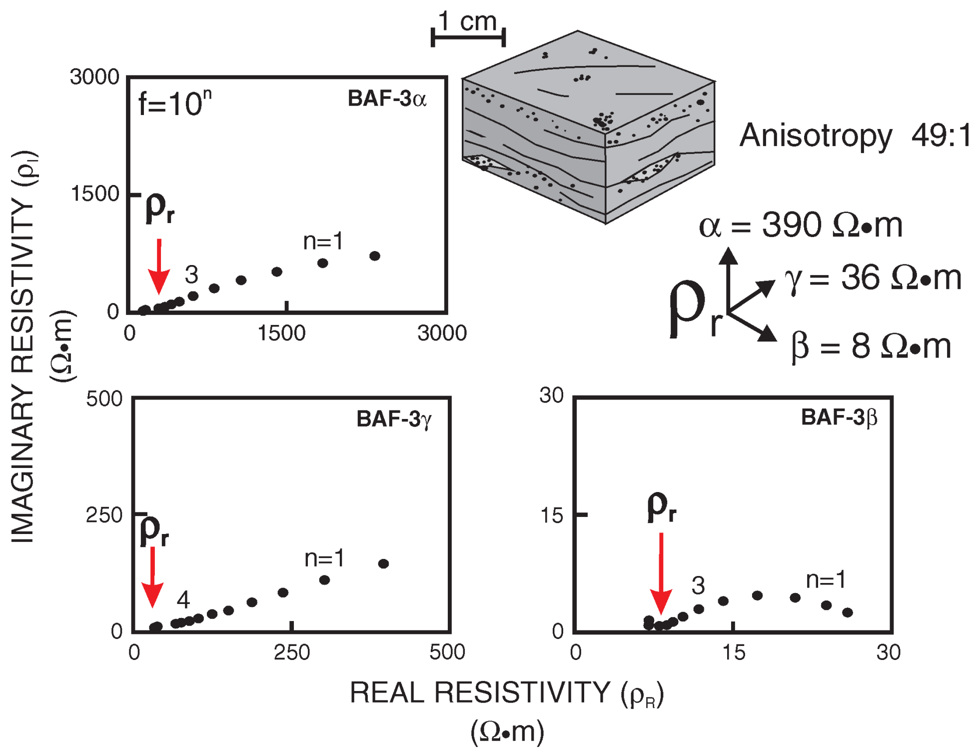

Figure 4. *Schematic presentation of a graphitic shale sample BAF-3, with porous layers, represented by block diagrams with sketches of the rock texture and 3-D bulk electrical resistivity (ρ_r) values shown below.*

or electrode polarizations (Katsube, 1975; Katsube and Walsh, 1987). Further details of the analytical procedure are described in Katsube et al. (1996). Detailed description of the laboratory 3-D electrical measurement system and procedures can be found elsewhere (Scromeda et al., 2000).

EXPERIMENTAL RESULTS

Results of the visual examinations for the five rectangular specimens, representing a section of the Astarte River formation, are shown as block diagrams in Figures 1–4, with the complex resistivity plots shown for each of the directions measured. The complex resistivity plots in Figures 2–4 display the method for determining ρ_r. The dimensions of the specimens cut out from the samples for the electrical resistivity measurements are listed in Table 2. The bulk electrical resistivities (ρ_r) are in the ranges of 8 Ω•m to more than 40 000 Ω•m and are listed in Table 1. The electrical anisotropy (λ) values range from 5:1 to 275:1, with the larger of each of these values generally representing the direction perpendicular to foliation and the smaller values parallel to foliation. The λ is defined elsewhere (Katsube et al., 1997). These values are also found in Table 1. The results of the 3-D electrical resistivity measurements at each measured frequency ($1–10^6$ Hz) are compiled in Table 3 for typical samples represented by samples BAF-1, BAF-2, and BAF-3. The specimens cut from samples BAF-1, BAF-2, and BAF-3 are strongly foliated because they were sampled from an area of high deformation. Samples BAF-A and BAF-B both contain fine-grained disseminated sulphide mineralization and have weak to moderate foliation.

Each of the samples have somewhat similar descriptions and mineralogy, as they were collected from the same formation. Minerals identified under the SEM include quartz, muscovite, phlogopite, graphite, rutile, pyrite, pyrrhotite, sulphur, and zircon. Sphene, sphalerite, chalcopyrite, and replacement montmorillonite were identified in BAF-A and BAF-B only. Common recrystallized patches and replacement lenses consisted of quartz, pyrite, microcline, muscovite, pyrrhotite, and chalcopyrite (Connell-Madore et al., 2004). The sulphide content is 3–5% with poor connectivity and weak to moderate foliation. The only variation between specimens are the sulphide content and vein or other special features which were selected for characterization by the measurements.

DISCUSSION AND CONCLUSIONS

The bulk electrical resistivities (ρ_r) of the samples investigated in this study are in the range of 8 Ω•m to more than 40 000 Ω•m (Table 1). Three of the samples (BAF-1, BAF-2, and BAF-3) have ρ_r values in the direction perpendicular to foliation ranging from 390 Ω•m to 3580 Ω•m. The values

Table 3. Results of the 3-D (α-, β-, and γ- directions) electrical resistivity measurements (24 hour saturation) for Baffin Island rock specimens. Note: the ρ_r (bulk electrical resistivity) values in bold text are those taken as the representative ρ_r value.

Sample ID	Frequency (Hz)	Real Resistivity ρ_R (Ω•m)	Imaginary Resistivity ρ_I (Ω•m)
BAF-1α	1	xxxx	xxxx
K_G: 5.07x10^{-2}	3.16	xxxx	xxxx
	10	xxxx	xxxx
	3.16x10^1	6090	1090
	10^2	5240	1150
	3.16x10^2	4370	1100
	10^3	**3580**	1000
	3.16x10^3	2890	907
	10^4	2270	862
	3.16x10^4	1630	851
	10^5	308	252
	3.16x10^5	301	249
	10^6	264	196
BAF-1β	1	24.1	1.26
K_G: 8.20x10^{-3}	3.16	23.0	1.80
	10	21.5	2.22
	3.16x10^1	19.7	2.38
	10^2	17.9	2.21
	3.16x10^2	16.4	1.86
	10^3	15.2	1.50
	3.16x10^3	14.2	1.21
	10^4	13.4	0.99
	3.16x10^4	**12.8**	0.82
	10^5	11.2	0.90
	3.16x10^5	11.2	0.91
	10^6	11.1	1.45
BAF-1γ	1	232	55.8
K_G: 4.67x10^{-3}	3.16	194	48.2
	10	163	41.1
	3.16x10^1	137	33.9
	10^2	115	28.2
	3.16x10^2	96.7	22.9
	10^3	**82.3**	18.4
	3.16x10^3	70.8	15.1
	10^4	61.1	13.3
	3.16x10^4	52.1	12.9
	10^5	24.2	9.13
	3.16x10^5	23.9	9.03
	10^6	22.0	7.43
BAF-2α	1	xxxx	xxxx
K_G: 3.93x10^{-2}	3.16	xxxx	xxxx
	10	xxxx	xxxx
	3.16x10^1	xxxx	xxxx
	10^2	xxxx	xxxx
	3.16x10^2	3940	1170
	10^3	3230	926
	3.16x10^3	2650	784
	10^4	**2130**	732
	3.16x10^4	1590	726
	10^5	393	269
	3.16x10^5	384	269
	10^6	337	224
BAF-2β	1	158	45
K_G: 1.05x10^{-2}	3.16	126	39.9
	10	101	31
	3.16x10^1	84.2	22.4
	10^2	72.2	15.9
BAF-2β	3.16x10^2	63.7	11.4
K_G: 1.05x10^{-2}	10^3	57.4	8.54
(Continued)	3.16x10^3	52.6	6.92
	10^4	**48.4**	6.26
	3.16x10^4	44.4	6.66
	10^5	25.2	7.62
	3.16x10^5	24.9	7.59
	10^6	23	6.17
BAF-2γ	1	89.2	2.69
K_G: 5.73x10^{-3}	3.16	87.0	3.67
	10	83.8	4.89
	3.16x10^1	79.6	5.92
	10^2	74.8	6.41
	3.16x10^2	69.9	6.34
	10^3	65.3	6.10
	3.16x10^3	**61.0**	5.95
	10^4	56.9	6.13
	3.16x10^4	52.5	6.94
	10^5	32.6	7.51
	3.16x10^5	32.3	7.49
	10^6	30.4	6.17
BAF-3α	1	2320	753
K_G: 5.33x10^{-2}	3.16	1820	646
	10	1400	534
	3.16x10^1	1060	423
	10^2	798	322
	3.16x10^2	611	235
	10^3	478	168
	3.16x10^3	**385**	120
	10^4	318	88.3
	3.16x10^4	267	70.3
	10^5	143	48.9
	3.16x10^5	142	48.9
	10^6	128	40.7
BAF-3β	1	26.0	2.35
K_G: 8.57x10^{-3}	3.16	24.1	3.39
	10	21.1	4.41
	3.16x10^1	17.5	4.62
	10^2	14.3	3.88
	3.16x10^2	12.0	2.80
	10^3	10.4	1.88
	3.16x10^3	9.46	1.28
	10^4	8.76	0.91
	3.16x10^4	**8.22**	0.65
	10^5	7.23	0.92
	3.16x10^5	7.23	0.92
	10^6	7.22	1.46
BAF-3γ	1	393	141
K_G: 4.81x10^{-3}	3.16	300	108
	10	233	81.6
	3.16x10^1	185	60.4
	10^2	150	44.9
	3.16x10^2	123	33.7
	10^3	103	25.7
	3.16x10^3	87.4	19.9
	10^4	75.1	16.0
	3.16x10^4	64.9	14.2
	10^5	**35.9**	7.78
	3.16x10^5	35.5	8.14
	10^6	32.9	6.39

xxxx = Invalid data point.
K_G = Geometric factor.

measured parallel to foliation range from 8 Ω•m to 82 Ω•m. The anisotropy values for these three samples range from 44:1 to 275:1. Overall, the ρ_r range of values for samples BAF-1, BAF-2, and BAF-3 are very low, probably due to the strong foliation. These low ρ_r values are typical of graphitic shale samples as can be seen in the literature (e.g. Katsube et al., 1991). Samples BAF-A and BAF-B display higher ρ_r values ranging from more than 28 000 Ω•m to more than 40 000 Ω•m in the direction perpendicular to foliation and 2300 Ω•m to more than 16 000 Ω•m parallel to foliation. These higher values can probably be attributed to poor connectivity of disseminated sulphide mineralization and weak to moderate foliation.

The electrical measurements have produced two types of argon arc plots. Sample BAF-A produced large partial arcs, samples BAF-1, BAF-2, and BAF-3 produced small arcs, and sample BAF-B produced both types of arcs depending on the direction measured.

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