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Pore-size distribution characteristics of Yellowknife mining district rocks, Northwest Territories[1]

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

Abstract

Previous studies have indicated a distinct difference between the porosity of similar rock types from Con and Giant mines, Yellowknife mining district, Northwest Territories. As a result, a detailed pore-size distribution study was carried out to determine the reason for the existence of these differences, and to provide information that might be used in interpreting ground and airborne electromagnetic survey data.

Results indicate that Giant mine samples generally have higher porosity values which are more evident when comparing similar rock types. High sulphide content is associated with higher porosities in the intermediate pore-size range (10–50 nm) for some samples. Con mine samples have a higher connecting porosity than storage porosity, whereas Giant mine samples have a considerably higher storage porosity than connecting porosity.

Résumé

Des études antérieures ont montré qu'il existait une différence évidente dans la porosité de types de roches semblables provenant des mines Con et Giant (district minier de Yellowknife, Territoires du Nord-Ouest). En conséquence de quoi, une étude détaillée de la distribution dimensionnelle des pores a été entreprise pour déterminer la raison de ces différences et pour recueillir des informations susceptibles de servir à l'interprétation des données électromagnétiques de levés au sol et de levés aériens.

Les résultats ont révélé que les échantillons prélevés dans la mine Giant présentent des valeurs de porosité plus élevées et que ce caractère est plus manifeste lorsqu'on dresse des comparaisons avec des types de roches semblables. Dans un certain nombre d'échantillons, de fortes concentrations de sulfures sont associées aux valeurs de porosité plus élevées dans la gamme des pores de dimension intermédiaire (10-50 nm). Les échantillons prélevés dans la mine Con ont une porosité ouverte plus élevée que la porosité close alors que dans la mine Giant la porosité close est considérablement plus importante que la porosité ouverte.

INTRODUCTION

Studies have previously been conducted to determine the electrical conductivity mechanisms (Connell et al., 2000a, 2001) of rock samples collected from the Giant and Con mine areas of the Yellowknife mining district, Northwest Territories. These studies have identified electrical conductivity paths due to sulphides and those due to pore water in the interconnected pores. These studies have also indicated that a distinct difference exists between the porosity of similar rock types from Con and Giant mines (Scromeda et al., 2000; Connell et al., 2000b; T.J. Katsube, J. Mwenifumbo, J. Kerswill, S. Connell, and N. Scromeda-Perez, online, http://www.nrcan.gc.ca/gsc/mrd/extech3/2000_geo_forum_e.html); however, little work has been done on the pore structure system that affects these conductivity paths or the porosity differences between rocks from the two mines.

A detailed pore-size distribution study has been carried out to provide data that might be used to explain why these differences exist between the two mines and to explain the electrical conductivity characteristics of the pores. Pore-size distribution analysis has been performed on a suite of 10 mineralized and nonmineralized rock samples from the Giant and Con mines. The suite consists of two ore samples from a gold-bearing quartz vein, and two chlorite schist, three sericite schist, one chlorite-sericite schist, and two basalt samples from host rock lithologies further removed from the vein. The pore-size distribution data was obtained by mercury intrusion porosimetry measurements. The purpose of this paper is to document, within the framework of the Yellowknife EXTECH-III program, results of the pore-size distribution analysis, which are likely to provide information to be used in setting up exploration strategies and to aid interpretation of ground and airborne electromagnetic survey data.

METHOD OF INVESTIGATION

Ten chip specimens were prepared for mercury injection porosimetry testing by AGAT Laboratories (Calgary, Alberta). These specimens were prepared from a suite of ten samples, which had been previously used for petrophysical characterization (Scromeda et al, 2000; Connell et al., 2000c). At AGAT Laboratories, each specimen was oven dried at 80°C then individually placed in a pentrometer assembly under vacuum. The pentrometer was then filled with mercury at a hydrostatic head of approximately 10 kPa. The volume of the mercury injected was recorded after stabilization at each pressure step up to 414 MPa (60 000 psi) at which time the mercury was assumed to have invaded 100% of the pore space. Further details of the procedures are described elsewhere (Katsube et al., 1997, 1998). Information on the samples, such as sampling location and lithology, are listed in **Table 1**.

ANALYTICAL RESULTS

The results of the mercury intrusion porosimetry tests are listed in Table 2. They are plotted in a standard format where one decade of pore sizes are divided into five cells of equal physical spacing (Katsube and Issler, 1993). The partial porosity for each sample, ϕ_a, is the porosity contributed by each pore-size range of the cell. The parameter, d_a, is the geometric mean for each pore-size range (nm). The data for the bulk parameters derived from the pore-size distribution are listed in the lower section of Table 2a and 2b. They are mercury porosities (ϕ_{Hg1}, ϕ_{Hg2}), bulk density (δ_{BD}), skeletal density (δ_{SD}), pore surface area (A), residual or storage porosity (ϕ_s), residual porosity ratio (ϕ_{rr}), connecting porosity (ϕ_c), and mode of pore-size distribution (d_m). The results of the pore-size distribution for each lithology were plotted in Figure 1, in a format that allows comparison between the two mine sites. For the most part, the mercury porosities are consistent with the immersion porosities (Table 3; Scromeda et al., 2000) with the exception of the basalt sample MYQ-1 from Giant mine and the sericite schist sample MYC-2 from Con mine. Both these samples have a considerably lower ϕ_I value, less than half that of ϕ_{Hg1}. Some variation is to be expected between differing methods of porosity determination.

DISCUSSION AND CONCLUSIONS

The ranges of porosity determined by mercury porosimetry (ϕ_{Hg1}) for these samples are 0.49–3.33%. The Giant mine samples generally tend to have the higher porosity values and the Con mine samples the lower ϕ_{Hg1} values (Fig. 1).

The pore-size distribution patterns in **Figure 1**, for each rock type, clearly show a higher porosity in the Giant mine samples mainly in the nano (<10 nm) to intermediate pore-size range (10–300 nm). This is also evident in **Figure 2** which shows the pore-size distributions for Giant mine samples (Fig. 2a) and Con mine samples (Fig. 2b). The averaged pore-size distribution of these samples is trimodal (Fig. 2c). The porosities for the three pore-size ranges are nano-pore porosities (ϕ_{np}: d=2.5–10 nm), intermediate pore porosities (ϕ_{ip}: d=10–500 nm) and micropore porosities (ϕ_{mp}: d=500 nm to 10 μm). These data are used to characterize these samples. The main difference in porosities between the two mine sites are in the intermediate range where Giant mine samples are consistently higher.

The pore-size distribution patterns for the sericite schist samples are compared in **Figure 3a**. It is interesting that sample MYG-11 (Giant mine) displays a very different pore-size distribution pattern than the other three samples, with its partial porosity peaking in the intermediate pore-size range (10–500 nm). Samples MYG-13, MYC-1, and MYC-2 all have a similar pore-size distribution patterns. Ore sample MYG-9 shows a somewhat similar trend (Fig. 3b) to that of MYG-11. Both samples (MYG-11 and MYG-9) have a higher sulphide content ($\geq$5%) compared to the other samples ($\leq$3%).

Giant mine samples generally have a higher porosity in the intermediate pore-size range (Fig. 1, 2). This increased intermediate porosity appears to be associated with increased sulphide content with the exception of chlorite schist sample MYG-8.

The average storage (ϕ_s) and connecting porosities (ϕ_c) for each rock type are compared in **Figure 4**, with ϕ_s being considerably higher for the Giant mine samples. Con mine samples have higher ϕ_c than ϕ_s, whereas, Giant samples have a higher ϕ_s than ϕ_c values.

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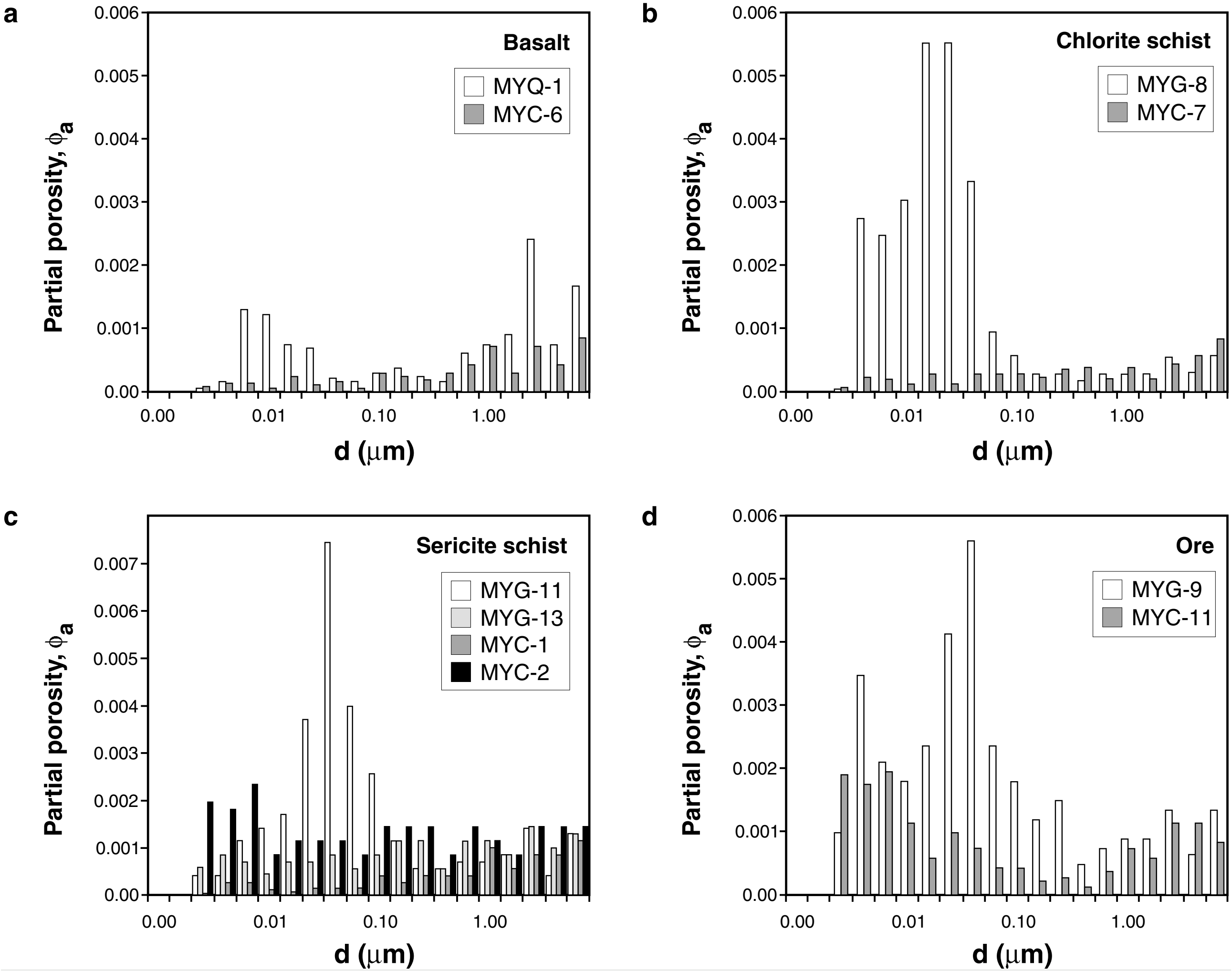
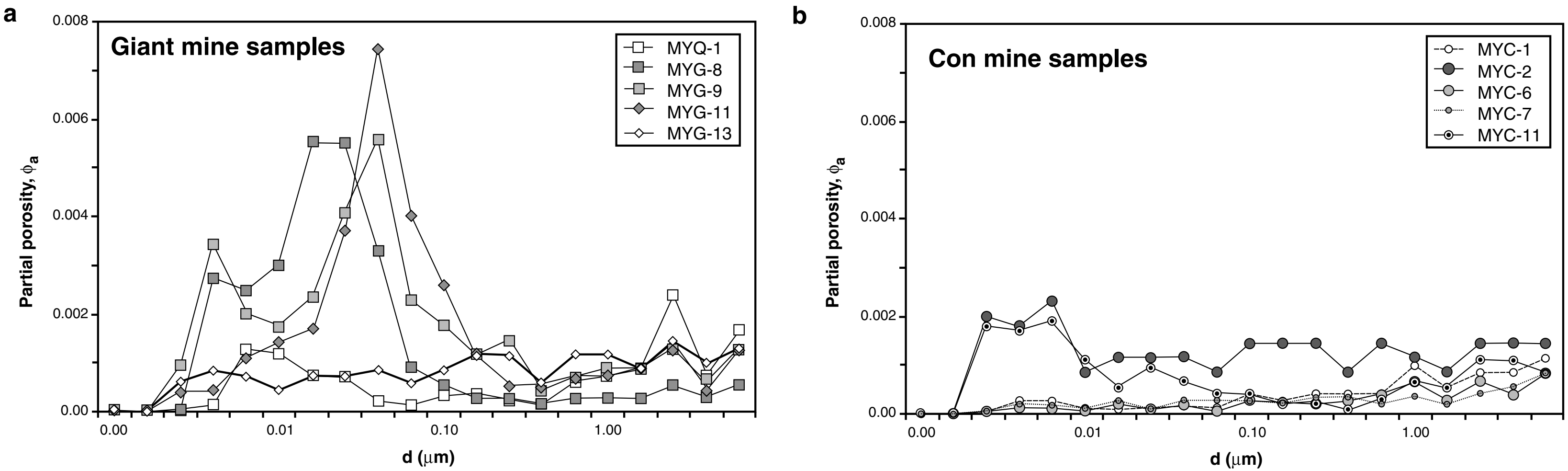


Figure 1. Pore-size distribution plots for **a)** basalt, **b)** chlorite schist, **c)** sericite schist, and **d)** ore samples from the Con (MYC-series) and Giant (MYG- and MYQ-series) mines.



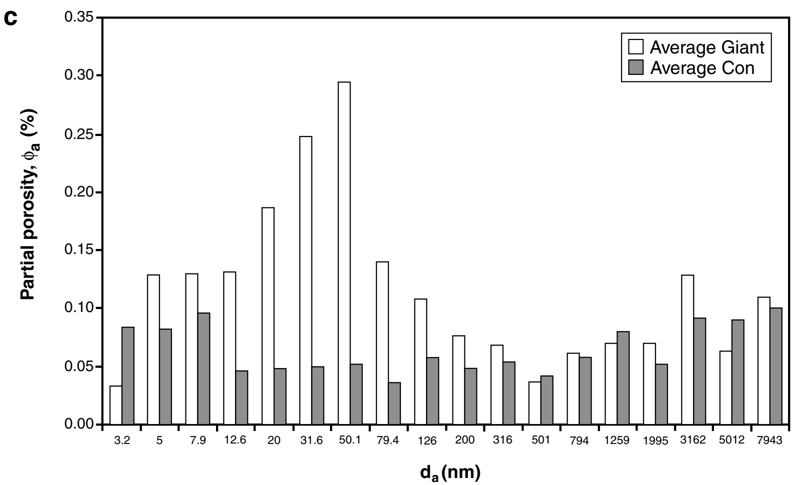


Figure 2. Plot of pore-size distributions for **a)** Giant mine, **b)** Con mine, and **c)** averaged pore-size distributions for the two mine sites.

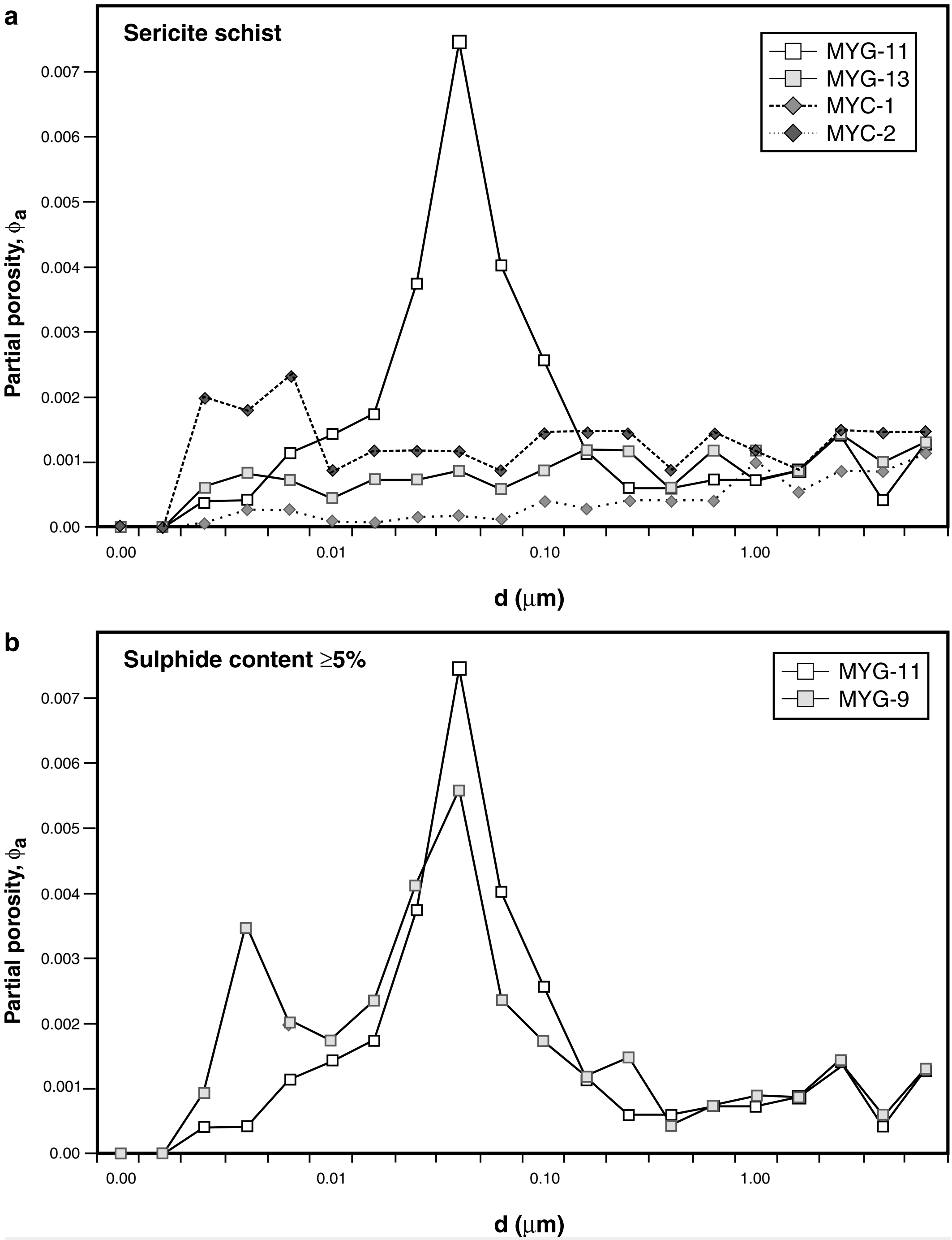


Figure 3. Pore-size distributions for **a**) the four sericite schist samples (MYC-1, MYC-2, MYG-11, and MYG-13) and **b**) sericite schist and ore samples (MYG-11 and MYG-9) with a sulphide content of 5% and greater.

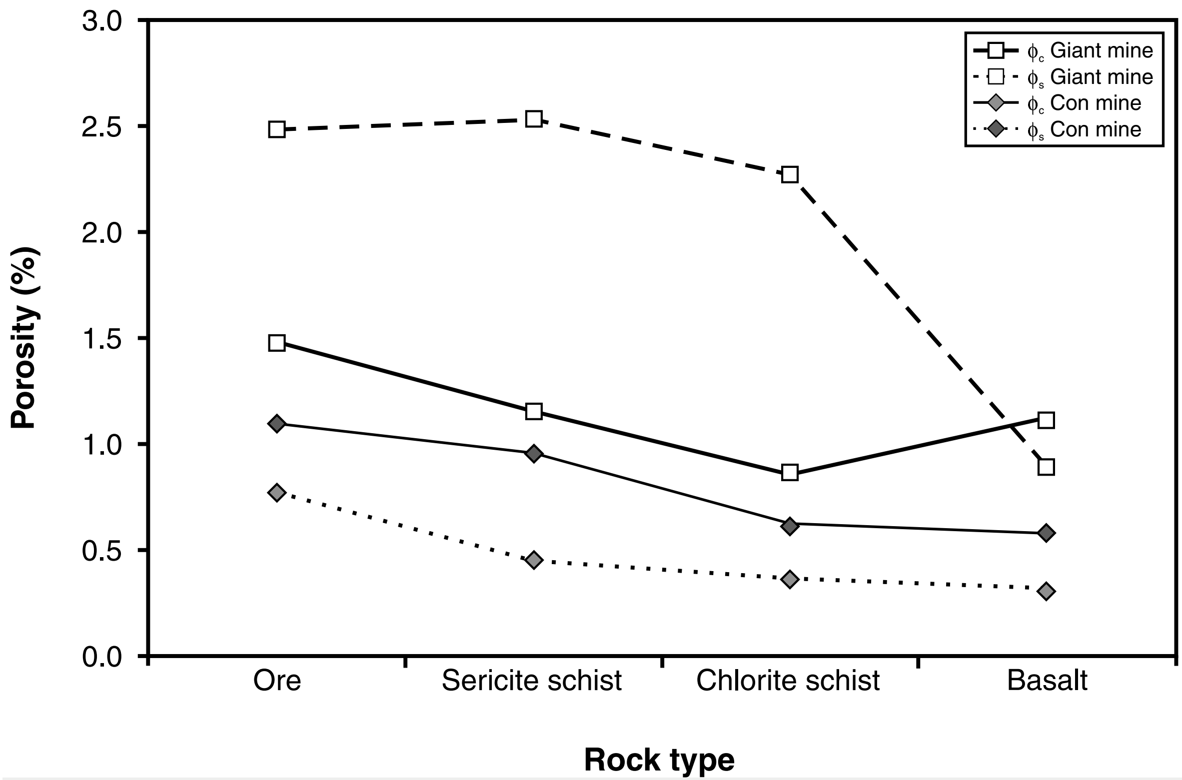


Figure 4. Comparison of the representative storage (ϕ_s) and connecting porosities (ϕ_c) for the four rock types from the two mine sites.

Table 1. Rock descriptions and locations of samples from the Con and Giant mines, Yellowknife mining district, Northwest Territories, and their visually estimated sulphide content.

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

Table 2a. Pore-size distribution data for different pore-size ranges, d, obtained by mercury porosimetry for six rock samples from the Yellowknife mining district.

Sample # d_a(nm)	MYC-1	MYC-2	MYC-6	MYC-7	MYC-11	MYG-8
	ϕ_a (%)					
3.2	0.01	0.2	0.01	0.01	0.19	0
5.0	0.03	0.18	0.01	0.02	0.17	0.27
7.9	0.03	0.23	0.01	0.02	0.19	0.25
12.6	0.01	0.09	0.01	0.01	0.11	0.3
20.0	0.01	0.12	0.02	0.03	0.06	0.55
31.6	0.01	0.12	0.01	0.01	0.1	0.55
50.1	0.02	0.12	0.02	0.03	0.07	0.33
79.4	0.01	0.09	0.01	0.03	0.04	0.09
126	0.04	0.15	0.03	0.03	0.04	0.06
200	0.03	0.15	0.02	0.02	0.02	0.03
316	0.04	0.15	0.02	0.03	0.03	0.03
501	0.04	0.09	0.03	0.04	0.01	0.02
794	0.04	0.15	0.04	0.02	0.04	0.03
1259	0.10	0.12	0.07	0.04	0.07	0.03
1995	0.06	0.09	0.03	0.02	0.06	0.03
3162	0.09	0.15	0.07	0.04	0.11	0.05
5012	0.09	0.15	0.04	0.06	0.11	0.03
7943	0.11	0.15	0.08	0.08	0.08	0.06
ϕ_{Hg1}	0.77	2.45	0.54	0.53	1.5	2.7
ϕ_{Hg2}	1.42	3.21	0.91	1	1.89	3.14
d_{hg}	4449.5	493.6	3599.9	3639	266.4	88.5
δ_{BD}	2.85	2.918	2.828	2.779	2.773	2.755
δ_{SD}	2.891	3.015	2.854	2.807	2.827	2.844
A	0.1803	1.8	0.131	0.164	1.668	2.222
ϕ_s	0.46	1.18	0.32	0.37	0.79	2.49
ϕ_{rr}	0.60	0.48	0.59	0.69	0.53	0.75
ϕ_c	0.96	2.03	0.29	0.63	1.10	1.48
d_m	7943	7.9	7943	7943	3.2	20

d_a = Geometric mean pore sizes for the different pore-size ranges (nm).
d_{hg} = Geometric mean of the entire pore-size distribution (nm).
ϕ_a = Partial porosity (%).
ϕ_{Hg1} = Total porosity measured by mercury porosimetry for pore sizes up to 10 μm (%).
ϕ_{Hg2} = Total porosity measured by mercury porosimetry for pore sizes up to 250 μm (%).
δ_{BD} = Bulk density (g/mL).
δ_{SD} = Skeletal density (g/mL).
A = Surface area (m^2/g).
ϕ_s = Residual or storage porosity (%).
ϕ_{rr} = ϕ_R / ϕ_{gml}
ϕ_c = Connecting porosity (%).
d_m = Pore size of the major pore-size mode (nm).

Table 2b. Pore-size distribution data for different pore-size ranges, d, obtained by mercury porosimetry for five rock samples from the Yellowknife mining district.

Sample # d_a(nm)	MYG-9	MYG-11	MYG-13 (1)	MYG-13 (2)	MYQ-1
	ϕ_a (%)				
3.2	0.09	0.04	0.06	0	0.01
5	0.35	0.04	0.08	0.01	0.02
7.9	0.21	0.11	0.07	0.01	0.13
12.6	0.18	0.14	0.04	0.01	0.12
20	0.24	0.17	0.07	0.01	0.08
31.6	0.41	0.37	0.07	0.02	0.07
50.1	0.56	0.74	0.09	0.03	0.02
79.4	0.24	0.4	0.06	0.03	0.02
126	0.18	0.26	0.09	0.03	0.03
200	0.12	0.11	0.12	0.04	0.04
316	0.15	0.06	0.12	0.03	0.02
501	0.04	0.06	0.06	0.02	0.02
794	0.07	0.07	0.12	0.02	0.06
1259	0.09	0.07	0.12	0.03	0.08
1995	0.09	0.09	0.09	0.03	0.09
3162	0.13	0.14	0.15	0.06	0.24
5012	0.06	0.04	0.1	0.07	0.08
7943	0.13	0.13	0.13	0.04	0.17
ϕ_{Hg1}	3.33	3.06	1.63	0.49	1.26
ϕ_{Hg2}	3.97	3.7	2.18	0.74	2.02
d_{hg}	190.1	270	900.5	2253.8	2081.2
δ_{BD}	2.943	2.864	2.907	2.845	3.008
δ_{SD}	3.065	2.975	2.972	2.867	3.069
A	2.25	1.143	0.719	0.087	0.444
ϕ_s	2.49	2.54	0.89	0.4	0.9
ϕ_{rr}	0.75	0.83	0.55	0.81	0.71
ϕ_c	1.48	1.16	1.29	0.34	1.12
d_m	31.6	50.1	3162	5012	3162

d_a = Geometric mean pore sizes for the different pore-size ranges (nm).
d_{hg} = Geometric mean of the entire pore-size distribution (nm).
ϕ_a = Partial porosity (%).
ϕ_{Hg1} = Total porosity measured by mercury porosimetry for pore sizes up to 10 μm (%).
ϕ_{Hg2} = Total porosity measured by mercury porosimetry for pore sizes up to 250 μm (%).
δ_{BD} = Bulk density (g/mL).
δ_{SD} = Skeletal density (g/mL).
A = Surface area (m^2/g).
ϕ_s = Residual or storage porosity (%).
ϕ_{rr} = ϕ_R / ϕ_{gml}
ϕ_c = Connecting porosity (%).
d_m = Pore size of the major pore-size mode (nm).

Table 3. Comparison of porosities for the four rock types from the two mine sites.

Petrophysical property	Sericite schist		Chlorite-sericite schist	Chlorite schist		Basalt		Ore	
	Giant	***Con***	***Con***	***Giant***	***Con***	***Giant***	***Con***	***Giant***	***Con***
ϕ_I	1.46 2.86	1.16	0.8	3.03	0.54	0.42	0.4	2.55	0.56
ϕ_{Hg1}	1.63 3.06	0.77	2.45	2.7	0.53	1.26	0.54	3.33	1.5
ϕ_s	0.89 2.54	0.46	1.18	2.49	0.37	0.9	0.32	2.49	0.79
ϕ_c	1.29 1.16	0.96	2.03	1.48	1.1	1.12	0.29	1.48	1.1
ϕ_{rr}	0.55 0.83	0.6	0.48	0.75	0.69	0.71	0.59	0.75	0.53

ϕ_I = Immersion porosity (%) (Scromeda et al., 2000).
$\phi_{H\gamma l}$ = Total porosity measured by mercury porosimetry for pore sizes up to 10 μm (%).
ϕ_s = Residual or storage porosity (%).
ϕ_c = Connecting porosity (%).
ϕ_{rr} = ϕ_R / ϕ_{gml}