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Geological and geochemical data from the Canadian Arctic Islands. Part X: Core petrophysical data from petroleum exploration boreholes

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SUMMARY

Conventional core petrophysical analyses have been compiled for 4369 samples from 80 wells in the Canadian Arctic Islands. The dataset contains porosity, permeability, grain density, residual oil and water saturation measurements. The main objective is to present a broad overview of distributions of core porosity, permeability and grain density, and porosity-permeability trends for different reservoir lithologies, and individual stratigraphic unit for sandstone reservoir. The core analysis data provides a direct measure of key petrophysical parameters used for reservoir evaluation and forms the basis for a quantitative analysis of important reservoir parameters for petroleum assessment in the Arctic Islands.

INTRODUCTION

A previous report presented core analysis data ranging in location from between 115° to 136° in longitude and between 60° to 68° 40' in latitude for the Mackenzie Corridor region (Hu, 2009). These data are from cores of Mesozoic, Paleozoic and Precambrian age. Most of the data are from limestone core of Devonian age.

A detailed description on conventional (112 wells) and specialized (24 wells) core petrophysical analyses for the Beaufort-Mackenzie Basin has been presented (Hu and Issler, 2009), the analysed core wells cover from 128° to 141° in west and 68° to 71° in north. Over 70% of the core samples are from Cenozoic, and only about 2% of the data are from Paleozoic, the rest samples are from Mesozoic. 98% of the 9302 core samples are sandstone and siltstone.

In a similar manner, this report presents conventional core analysis data from 80 wells that are located in Arctic Islands (Figure 1). In this region, wells with core analysis data range in location from between 82° to 128° in longitude and between 71° to 81° in latitude. These data are from cores of Mesozoic, Paleozoic and Precambrian age. Over 80% of the core samples are sandstone from Jurassic and Triassic in Mesozoic.

The purpose of this report is: (1) to provide a digital compilation of this data, (2) to display various attributes of the data.

The section entitled "Core petrophysical data compilation" describes the detailed content of digital core analysis data (Table 1).

The section entitled "Core data distribution by lithology" illustrates the histogram plots and cross-plot of core permeability and porosity for all the samples from different major types of lithology.

The section entitled "Core data distribution by stratigraphic units" shows histogram plots and cross-plots of the reservoir data for different major stratigraphic units.

CORE PETROPHYSICAL DATA COMPILATION

For the Arctic Islands, conventional core analyses of 4369 samples from 80 wells were compiled (Table 1). Table 1 lists all available core petrophysical analysis results and tabulates information under headings that include: 1) well information (unique well identification and well name); 2) sample information including samples number, measured interval depths and thickness; 3) core measurements including core porosity, permeability (maximum permeability, horizontal permeability and vertical permeability), residual oil and water saturation information and grain density; 4) core type shows the sample type whether it is conventional core or sidewall core; 5) formation lists the stratigraphic unit; 6) lithology contains detailed information related to major rock type such as sandstone, siltstone, limestone, dolomite, conglomerate, shale, ironstone, etc. and supplementary mineral (calcite, pyrite, clay, etc.), and grain size for sandstone; 7) pore character presents the pore types such as vugs, fracture, intergranular, cracks, fine pore, and etc.; 8) character of rock contains fossil, stylolite, pyrobitumen and oil stain information; and 9) plug condition shows the unusual samples status such as broken or fractured.

More detailed descriptions of symbols used in core analyses are listed in Appendix A. Terminologies used in the pore types are dependent on the description in well history reports dealing with these core analyses. There is no comparison between some of the items used in this report and the widely used classification of porosity for carbonates presented by Choquette and Pray (1970) and Lucia (1999).

All the core analyses data are from Core Laboratories-Canada Limited and are included in the well history files of the National Energy Board which are publicly available at the Geological Survey of Canada in Calgary.

The 4369 core samples are mainly from 5 lithologies (Figure 2): sandstone (3875, 88.69%), dolomite (222, 5.08%), limestone (188, 4.30%), conglomerate (49, 1.12%), and siltstone (30, 0.69%). “others” includes four samples for shale and one sample for ironstone (5, 0.11%).

CORE DATA DISTRIBUTION BY LITHOLOGY

Seven figures were generated to display the distribution of porosity, permeability, grain density and porosity-permeability trend for different lithologies.

Core porosity distribution

Figure 3 illustrates porosity distributions for different lithologies. For the sandstone samples, core porosity shows approximately a normal distribution ranging from <5% to 35%, with majority in a range from 16% to 24% (for 66% of the sandstone samples), some samples show higher porosity of greater than 24% (12% of the total), and about 22% of the samples have lower porosity of less than 12% due to presence of calcareous, limy, carbonaceous, pyritic, shaly, and silty materials (Figure 3a).

Figure 3b illustrates the porosity distributions for dolomite and limestone samples. Dolomite samples show their porosity ranges from <1% to 13.8%, with a peak value of 2% (Figure 3b), some samples have higher porosity due to fractures. Comparison with dolomite samples, limestone samples have lower porosity values (Figure 3b).

As shown in Figure 3c, core porosity for conglomerate samples ranges from <4% to 28%, and siltstone samples have lower porosity, with a peak value of 8%.

Core permeability distribution

Figure 4, 5 and 6 illustrate maximum, horizontal and vertical permeability distributions for different lithologies respectively. For sandstone samples, maximum, horizontal and vertical permeability have similar distributions, and their values are dominantly between 100 to 1000 mD (Figure 4), but Fig.4c illustrates more samples have lower vertical permeability value of less than 1 mD.

Most dolomite maximum and horizontal permeability values are between 0.1 and 10 mD (Fig.5a, b), but the vertical permeability shows a two mode distribution with the lower one at <=0.01 mD (Fig.5c). Compared with dolomite samples, most limestone samples have lower maximum, horizontal and vertical permeability which have the same peak value of <=0.01 mD (Fig.5). Results from core analysis show higher maximum and horizontal permeabilities (Fig.5a, b) than vertical permeability as indicated by the histogram plot (Fig.5c).

For conglomerate samples, the core maximum permeability values range from 10 to 1000 mD (peak at 100 mD, Fig.6a), but horizontal and vertical permeabilities show lower values range from 1 to 100 mD (Fig.6b,c), and more samples have lower vertical permeability values (Fig.6c). For siltstone samples, core maximum permeability values range from <0.01 to 1 mD (Fig.6a).

Core grain density distribution

Figure 7 and 8 show core grain density distributions for different lithologies. For sandstone samples, most core grain density values are between >2620 and 2680 kg/m^3 (peak at 2650 kg/m^3), some samples have lower grain density values due to admixture of shale and silt. The higher grain density values probably are from the contributions from the admixtures of dolomite, calcite, pyrite, ironstone and anhydrite.

Fig.7b illustrates grain density distributions for analysed dolomite and limestone samples. Much dolomite samples are from pure dolomite with a peak value of 2860 kg/m^3, but most samples have lower values than expected (see the numbers of core sample <2860 kg/m^3 in Fig.7b) probably due to admixtures of calcite, gypsum, chert, shaly and silty material, whereas the higher grain density values are due to presence of anhydrite and pyrite. For limestone samples, core grain density is approximately 2710 kg/m^3 (Fig.7b). Dolomite, pyrite and anhydrite occur in small number of samples, and this contributes to variable higher grain density values. However some samples show low grain density values (<2710 kg/m^3) due to perhaps admixture of shale and silt.

Fig. 8a displays grain density distribution for analysed conglomerate samples. The core grain density show a wide range of variation from <=2620 to >2890 kg/m^3. Ironstone, dolomite, pyrite and anhydrite are the main contributions to variable higher grain density values with a peak value of >2890 kg/m^3, and a small number of samples have lower grain density due to admixtures of shale and silt (Fig.8a).

Siltstone grain density values are mainly between 2620 to 2680 kg/m^3 (peak at 2650 kg/m^3), but some samples have higher grain density values probably due to admixtures of quartz and pyrite (Fig.8b).

Core permeability versus porosity

Of the 4369 samples with conventional core analysis results, 4304 samples have both porosity and permeability data. Figure 9 shows the relationship between core permeability and core porosity for the analysed core samples from different lithologies. Sandstone permeability increases with porosity, showing a fair linear relationship between core permeability and porosity at on semilogorithmic axes (Fig.9a).

Fig.9b illustrates the porosity-permeability trends for conglomerate and siltstone samples. Conglomerate permeability increases with porosity within a big range, but data show considerable scatter for both of conglomerate and siltstone samples.

For analysed dolomite samples, both porosity and permeability measurements have a wide range due to variations in the contribution to total porosity from intergranular pore, pin point pore, vugs and fractures (Fig.9c) and the data show scatter. Comparison with dolomite, limestone have a narrow porosity and permeability ranges, the data also show scatter (Fig.9d).

CORE DATA DISTRIBUTION BY STRATIGRAPHIC UNITS

According to the study on time-stratigraphic chart of the Cambrian to Pliocene of the central Canadian Arctic Islands (Dewing and Embry, 2007), the 4369 core analysed samples are from 45 stratigraphic units of Mesozoic and Paleozoic age, including 29 stratigraphic units in Mesozoic and 16 stratigraphic units in Paleozoic.

The Mesozoic samples contain three formations in Cretaceous, nine formations in Jurassic, and seven formations in Triassic (Fig.10a). Paleozoic samples include six Permian formations, one Carboniferous formation, six Devonian formations, four Silurian formations and two Ordovician formations, also as shown in Fig.10a, which indicates 50% of the core samples are from Mesozoic formations.

Figure 10b illustrates the samples distribution with respect to rock era, which shows that total core samples are 4620 due to 251 core samples belong to two successions. 95 samples are from Cretaceous, 2.1% of the total analysed samples; 3053 samples are from Jurassic, 66.1% of the total analysed core samples; 844 samples are from Triassic (18.3%); 106 (2.3%) from Permian; and 45 (1%) from Carboniferous; 303 samples are from Devonian (6.6%); 110 (2.4%) samples are from Silurian; and 64 (1.4%) samples are from Ordovician.

Core samples from Cretaceous succession

Cretaceous sandstone core samples are from three formations including Hassel, Isachsen and Deer Bay formations. The 95 sandstone samples show good porosity and fair to good permeability (Figure 11a, b), their grain density values have a large range due to variable grain size, and possible admixture of shale and carbonate, pyrite (Fig.11c). Fig.11d illustrates the relationship between core permeability and porosity.

Core samples from Jurassic succession

Figure 12 illustrates histogram plots of porosity, permeability and grain density, as well as the relationship between porosity and permeability for all samples from Jurassic. For most of the Jurassic samples, core porosity values lie between 16 and 24% (peak at 20%, Fig.12a), maximum permeability values are between 100 and 1000 mD (peak at 1000 mD, Fig.12b), grain density values are between 2650 and 2680 kg/m^3 (peak at 2650 kg/m^3, Fig.12c). Of the 3053 samples, 2816 core samples have both porosity and permeability data; Figure 12d shows the relationship between core maximum permeability and core porosity for different types of lithology. A fair linear relationship is observed between core permeability and porosity on semilogorithmic axes for the sandstone samples.

Jurassic aged core samples are from nine formations from the following rock successions: the Upper Jurassic Deer Bay Formation (6 samples); Awingak Formation (424 samples, 64 of the samples are from Cape Lockwood Member); Ringnes Formation (14 samples); Sandy Point Formation (20 samples); Jameson Bay Formation (231 samples, only 2 of the samples are from Snowpatch Member, 3 of the samples are from Cape Canning Member, and 177 of the samples are from Intrepid Inlet Member); the Lower Jurassic King Christian Formation (1512 samples, 167 of the samples are from Whitefish Member; 43 of the samples are from Stupart Member; 118 of the samples are from Drake Point Member); Heiberg Formation (598 samples, 38 of the samples are from Remus Member, 153 of the samples are from Fosheim Member); Lougheed Island Formation (87 samples); and Maclean Strait Formation (160 samples).

Figures 13, 14, 15 and 16 display core porosity, maximum permeability, and grain density distributions and the relationship between core permeability and core porosity for the major formations: including Awingak, Jameson Bay, King Christian, and Heiberg formations.

For Awingak Formation samples, core porosity values range from 12 to 20% (peak at 20%, Fig.13a), most permeability values are between 1 and 1000 mD (peak at 1000 mD, Fig.13b), core grain density values are mainly between <=2620 and 2650 kg/m^3 (peak at <=2620 kg/m^3, Fig.13c), which indicates most sample are silty and shaly. An exponential model is fitted to the data as shown in Fig.13d.

Figure 14 shows the distributions of core porosity, permeability, grain density, and porosity-permeability trend for Jameson Bay Formation samples. Most samples porosity values have a similar distribution as from Awingak Formation, which range from 12 to 24% (peak at 20%, Fig.14a). Core permeability values are between 1 and 1000 mD (peak at 10 mD, Fig.14b). Fig.14c shows grain density values have a large range with two peaks, the first peak is at 2680 kg/m^3 due to some samples are from conglomerate even though sandstone are dominant for the formation, and higher grain density values (the second peak at >2770 kg/m^3) probably are contributed by small number of ironstone, carbonate, and pyrite. Core porosity and permeability data show very high degree of scatter (Fig.14d).

Figure 15 displays the core parameters distributions not only for King Christian Formation samples, but also samples from the Whitefish, Stupart and Drake Point members. Fig. 15a shows that most of analysed core porosity values range from 16 to 28% (peak at 20%) for King Christian Formation; and porosity values for Whitefish Member have a narrow range from 20 to 24% (higher porosity peak at 24%); the porosity values from Stupard Member samples have a large range of variation from 8 to >28% but with a lower porosity peak at 12%; most porosity values from Drake Point Member range from 20 to 28% (peak at 24%). Fig.15b illustrates core permeability distributions for different formation/members, Whitefish Member and King Christian Formation samples show similar trend, and Drake Point Member samples have a highest permeability peak at >1000 mD, whereas most samples from Stupart Member have lower permeability (peak at 10 mD). King Christian Formation and its three members have similar core grain density range which is shown in Fig.15c. Core porosity-permeability cross plot (Fig.15d) illustrates a non-linear relationship between porosity and permeability, but Drake Point Member samples have a higher permeability and better coefficient (the blue line and its equation in Fig.15d).

In Figure 16, core samples are from Remus Member, Fosheim Member and Heiberg Formation. Among the 598 samples, 153 samples from the Fosheim Member that spans both the Jurassic and Triassic. Fig.16a shows that most core porosity values are dominantly between 20 to 24% (peak at 20%). The Heiberg Formation samples show good permeability, with a main range from 100 to >1000 mD (Fig.16b). Figure 16c indicates that most of the samples are pure quartz sandstone (with a peak of 2650 kg/m^3), and some samples contain carbonate (with a peak of 2680 kg/m^3), small number of samples include ironstone and pyrite which contribute to the higher grain density (>2770 kg/m^3). Figure 16d shows porosity-permeability trend for Heiberg Formation, it is seen that Fosheim Member samples are scattered, two statistically fitted lines are obtained for all the samples from Heiberg Formation (the green line and equation) and Fosheim samples are excluded (the red line and equation), a very small number of samples have low porosity but higher permeability due to fractures (the circled points in Fig.16d), some samples with high porosity and permeability values are also associated with fractures, as evidenced by visual examination and core description.

Core samples from Triassic succession

The distributions of porosity, permeability and grain density and porosity-permeability trend for core from the Triassic succession are shown in Figure 17a, b, c and d respectively. Most core porosity values have a large range from 8 to 24% (Fig.17a). Core permeability values are mainly between 1 and 1000 mD, with a peak of 1000 mD (Fig.17b). Figure 17c shows that most grain density values are dominantly between 2650 to 2680 kg/m^3, the first peak is at 2680 kg/m^3, indicating must samples are calcareous, small number of samples have higher grain density values due to presence of iron and pyrite. Fig.17d includes 833 core samples, their permeability value increases with porosity with a good linear equation on semilogorithmic axes.

The 844 Triassic samples include 153 samples from Fosheim Member of the Heiberg Formation (discussed above in Jurassic succession); 74 samples from Skybattle Formation; 97 samples from Pat Bay Formation; 78 samples from Hoyle Bay Formation; 271 samples from Roche Point Formation (154 of the samples from Chads Point

Member, 3 samples from Cape Caledonia Member, 114 samples from Eldridge Bay Member); 120 samples from Bjorne Formation; and 51 samples from the Blind Fiord Formation.

For Skybattle Formation samples, core porosity values are low, mainly between <=4 and 12%, with a peak value of 8% (Fig.18a). Core permeability values vary from 0.1 to 10 mD, with a peak value of 1 mD (Fig.18b). Figure 18c shows that most of the samples are limy sandstone, some samples contain pyrite. Core porosity-permeability cross plot (Fig.18d) indicates that most of the samples have low porosity (0 to 10%) and low permeability range (0.01 to 1 mD).

Comparison with Skybattle Formation samples, Pat Bay Formation core measurements have larger ranges, their core porosity values are higher (peak at 12%, Fig.19a), some samples have higher permeability values even though the peak value is the same as in Skybattle Formation (Fig.19b). Most of the samples are very limy and some of them contain carbonate and pyrite (Fig.19c). Core permeability and porosity have a good linear relationship at half logarithm axis (Fig.19d).

Hoyle Bay Formation samples are fine sandstones with 3 conglomerate, much core porosity values are between 12 to 28% (peak at 28%, Fig.20a), permeability values are high, mainly range from 10 to >1000 mD (peak at 1000 and >1000 mD in Fig.20b). Figure 20c illustrates that most of the samples are pure sandstone and shaly sandstone, some samples are limy, and some samples with higher grain density probably contain minor pyrite and ironstone, as also evidenced by visual examination and core description. As shown in Figure 20d, the measured porosity and permeability have a very good linear relationship at half logarithm axis.

Figure 21, 22 and 23 show core porosity, permeability, grain density distributions and porosity-permeability cross-plot for Chads Point Member, Eldridge Member, and Bjorne Formation respectively. The three stratigraphic samples have same permeability peak value of 1000 mD, but their core porosity values exhibit different distributions, and core porosity-permeability trends are different. From the three stratigraphic units, fine sandstone samples contain variable limy, siltstone and shale.

Blind Fiord Formation samples have lower porosity and permeability (Fig.24a, b). Most fine sandstone samples are limy, and pyrite exists in small number of samples (Fig.24c). Core porosity-permeability values have a poor to fair quantitative relationship (Fig.24d), with a low porosity and low permeability range.

Core samples from Permian succession

106 samples are from Permian succession of Paleozoic, including one sample from Degerbols Formation; three samples from Van Hauen Formation; 50 samples from Sabine Bay Formation; 11 samples from Great Bear Cape Formation; 6 samples from Belcher Channel Formation, and 45 samples from Canyon Fiord Formation. Most of the samples are sandstone, some are conglomerate and small number of are limestone.

Core histogram plots of core porosity, permeability and grain density, and core porosity-permeability trend are displayed for all the Permian samples (Fig.25). For most of the core samples, core porosity values are dominantly between <=4 and 12%, with a peak value of 8% (Fig.25a); but their permeability values have a large range (Fig.25b).

Most sandstone samples are very limy (Figure 25c). Fig. 25d shows core porosity-permeability has a poor to fair linear relationship on semilogorithmic axes.

Core samples from Carboniferous succession

Only 45 samples are from the Carboniferous succession, all of which are from the Canyon Fiord Formation (the samples may also belong to Permian as the Canynon Fiord does span both). The samples show fair to good porosity, with a peak value of 8% (Fig.26a). Core permeability values have a large range from <=0.01 to 1000 mD (peak at 1 mD, Fig.26b). Core grain density ranges predominantly from 2650 to 2710 kg/m^3 (Fig.26c), the peak value is 2650 kg/m^3, but most of the samples have higher grain density values, indicating the most of samples contain carbonate, and small number of samples are conglomerate. From core porosity-permeability trend shown in Figure 26d, it is seen that a good non-linear relationship exhibits between measured permeability and porosity.

Core samples from Devonian succession

Devonian aged core samples are from 6 stratigraphic units including Beverley Inlet, Hecla Bay, Weatherall, Blue Fiord, Goose Fiord formations and Read Bay Group. The samples contain limestone (159 samples, 52.5%), dolomite (113, 37.3%), siltstone (21, 6.9%), sandstone (8, 2.6%) and shale (2, 0.7%).

Of the 303 analysed core samples in Devonian, 251 samples (~83%) are from Blue Fiord Formation. Figure 27 displays the analysed core parameter distributions of porosity, permeability, and grain density. It shows that much porosity values range from <=2 to 4% (Fig.27a), and their permeability values are between <=0.01 and 10 mD (Fig.27b). Fig.27c shows that most samples are pure limestone (the first peak at 2710 kg/m^3) and dolomite (the second peak at 2860 kg/m^3).

Figure 28 shows the porosity-permeability trend for all the Devonian samples with respect to lithology (Fig.28a) and stratigraphic units (Fig.28b).

Core samples from Silurian and Ordovician successions

110 analysed core samples are from Silurian, 27 of the 110 samples are from units that span both Silurian and Ordovician successions. 38 cores are from Ordovician succession. These 148 cores include 128 dolomite, 18 limestone and 2 shale samples.

Figure 29a, b and c display the core parameters distributions of porosity, permeability and grain density respectively. Core porosity values are mainly between <=2 and 4% (Fig.29a). Permeability measurements predominantly range from 0.1 to 10 mD (Fig.29b). Most dolomite grain density values are between 2830 and 2860 kg/m^3, indicating the samples contain limestone, and some dolomite samples have higher grain density probably due to presence of anhydrite and pyrite (Fig.29c). It is seen that limestone samples are not pure, contain abundant dolomite.

Core porosity-permeability data show scatter for both dolomite and limestone samples (Fig.30a). Core permeability values have large range due to vugs and fractures even though most samples have low porosity (Fig.29b, Fig.30a). Figure 30b illustrates the porosity-permeability trends for different stratigraphic units. It is seen that the samples from Read Bay Group exhibit higher porosity but lower permeability. For the unnamed Formation samples, core porosity and permeability values have larger ranges of variation. For the samples from Allen Bay and Thumb Mountain formations, core permeability increases rapidly due to vugs and fractures even though their porosity values are low (the blue diamond points and green triangle points in Fig.30b). A non-linear relationship is observed for Cape Philips Formation samples between measured porosity and permeability (see the pink square points and fitted line, as well as the statistical equation in Fig.30b).

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