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Mineral Exploration Research Centre at the HARQUAIL School of Earth Sciences

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1- Introduction

Characterisation of petrophysical properties (i.e. density and magnetic susceptibility) plays a key role in ensuring that geophysical potential field (i.e. gravity and magnetic) data is modelled in a credible manner and/or that the interpretation is realistic. This is done by providing a significant link between the geophysical measurements and the different rock types (e.g. Clark 1997, Heincke, et al. 2010, Kamm, et al. 2015, Williams 2008). Measured values of the physical properties are also critical in helping to constrain the values ascribed to geological units to realistic values and reduce model ambiguities (e.g. Eshaghi 2017).

This report builds on a compilation of physical properties from existing sources (i.e. Chandler and Lively 2017, Footprints Project 2018, Haus and Pauk 2010, ME 2017, Muir 2013, NRCAN 2017, Rainsford 2017, Survey 2001). In these compilations, the rock types are aggregated into major rock types. Tables of physical properties available from textbooks generally have limited information, providing a single value typical value, or a range, or occasionally, the table might provide both (e.g. Reynolds 2011, Telford 1976, Telford, et al. 1990). For example, for felsic intrusive rocks, the typical value might be 2.62—2.69 g cm^{-3} and the range of values 2.41 – ~3.00 g cm^{-3} (e.g. Sanger and Glen 2003, Törnberg and Sturkell 2005, Yang, et al. 2013) There is sometimes ambiguity in these values as it is not always clear if the typical value is an mean or a median, and whether the range is from the mean minus the standard deviation to the mean plus the standard deviation, or whether is might be two standard deviations, or whether the range might be from the absolute minimum to the absolute maximum that exists in the dataset. As well, the number of samples on which the summary statistics are based is not always given and this is useful information, as statistical information is generally more reliable with larger sample sizes.

When modelling geophysical data, it helps to have an idea of all the statistical information available. For example, if the data can only be fit with a density that is close to the upper end of the range, then this might be justified if the statistics show a bimodal distribution or a skew towards higher values. Such a situation might occur if the statistics are derived from samples that are weathered and unweathered, but the subsurface rocks are primarily unweathered. For example, Eshaghi (2017) has obtained samples from depths >100 m to mitigate the weathering impact while characterising density and magnetic susceptibilities across west Tasmania, Southeast Australia.

In this paper, we describe a systematic petrophysical characterisation of key rock units within the Abitibi Greenstone Belt (AGB) including a coherent data compilation and collation, lithological/stratigraphic characterisation, analysis of property values and finally we define representative density and magnetic susceptibility values to assign to each unit. These representative values are the mean, the standard deviation, the median, the absolute minimum, the absolute maximum and the skew. In addition to the summary of the statistical data, we also provide histogram and normal probability plots as a special case of the quantile-quantile probability plot for a normal distribution (addressed as QQ plots in this report), so that the interpreter can determine the reliability and modality of the data. This might allow the user to pick other representative values when modelling data of there are peaks in the histogram above and below the mean or median.

This study of physical properties is intended to provide interpreters and modellers with knowledge that will allow them flexibility when modelling data collected in the AGB as part of the Metal Earth Project. There are a large number of samples collected in the AGB, so these data will be reliable. If there are fewer reliable values in the greenstone belts of other parts of the Superior Province, then these AGB values could be used. They could also be used in similar shields that have undergone recent glaciation (e.g. the Fennoscandian Shield). When appropriate physical property values are not available, they could even be used in the unweathered parts of shield areas buried below regolith in other parts of the world.

2- Density and magnetic susceptibility

Density is defined as the mass per unit volume of a substance (in units of kg m^{-3} or g cm^{-3}; 1000 kg m^{-3} equals to 1 g cm^{-3}). Density changes reflect lithological variations, contrasting alteration and weathering (Telford, et al. 1976). For example, sedimentary rocks generally have higher porosity resulting in typically smaller densities than igneous or metamorphic rocks. Porosity of sedimentary rocks varies as a function of pressure, decreasing with an increase in depth of burial. Within igneous rocks, density differences are primarily due to the mineral assemblage present and the rock texture. In addition, an increase in the metamorphic grade generally increases density (Telford, et al. 1976). Density is frequently a good indicator of lithology as for example, mafic minerals are denser than felsic minerals, so density is often well correlated with rock types.

Magnetisation is defined as the magnetic dipole moment per unit volume of material. The spin of unpaired electrons is the most important cause of these microscopic magnetic moments (Clark 1997). The total magnetisation of a rock is the vector sum of the induced and remanent magnetisation. The magnetic susceptibility (k) is proportional to the strength of magnetisation that a material assumes in response to an applied magnetic field (*M*), divided by the strength of the applied magnetic field (H in Formula 1; Clark 1997).

$$k = \frac{M}{H} ‘ \qquad (1)$$

In this formula, since M and H have the same dimensions, magnetic susceptibility is a dimensionless property. However, the value of k depends on the system of units and may be specified in CGS or SI with the following linear relationship:

$$k^{SI} = 4\pi \times k^{CGS}. \qquad (2)$$

Remanent magnetisation can be observed, if present, when this induced field is removed but some “permanent” magnetisation remains (Telford, et al. 1976). The induced magnetic susceptibility of rocks is controlled by the proportion of ferromagnetic minerals (mostly magnetite and/or pyrrhotite), their distribution, grain size and orientation (Hansen, et al. 2005). It is important to note that a small change in the proportion of magnetized minerals within rock samples can result in a significant change in the recorded magnetic susceptibility and this proportion should be taken into account while measuring magnetic susceptibilities. For example, Church and McEnroe (2018) investigated the magnetic susceptibility values across different core samples and found that magnetic susceptibility variations at millimetre-or centimetre-scales are caused by either a complex mineral system or serpentinization/metamorphism and alteration or a possible magnetic remanence or a combination of those factors. Typically, when the induced magnetic field is strengthened by the presence of the paramagnetic minerals, the k is positive. Whereas the magnetic field is somewhat weakened in the presence of the diamagnetic minerals causing even slightly negative values of k. For example, quartz has a weak and negative magnetic susceptibility value of $\sim -0.0134 \times 10^{-3}$ SI (Hrouda and Kapička 1986).

Because the magnetic susceptibility of rocks is strongly depended on opaque iron minerals, and these minerals are accessory and do not change the rock type classification, the magnetic susceptibility is not always a good indicator of rock type, except in rocks that generally contain a lot of iron (mafic rocks, iron formations, etc.). However, these iron minerals are often created or destroyed in alteration or metamorphism associated with mineralizing events, so magnetic susceptibility can be important in mineral exploration studies (e.g. Boroomand, et al. 2015, Cisowski and Fuller 1987).

Within this report, all values are provided in "g cm^{-3}" unit for density and "$\times 10^{-3}$ SI" unit for magnetic susceptibility. Therefore, if measurements compiled from other sources are measured based on different units, they were converted to the stated units for coherency and consistency.

3- Petrophysical Data compilation/selection

In this study, a petrophysical database was created by collating and combining existing density and magnetic susceptibility measurements of outcrops provided by different organisations/ geological surveys and projects across the Superior Craton (i.e. Chandler and Lively 2017, Footprints Project 2018, Haus and Pauk 2010, ME 2017, Muir 2013, NRCAN 2017, Rainsford 2017, OGS 2001). In addition, the Metal Earth (ME) Project is collecting density and magnetic susceptibility values across predefined transects, which are added to the database. Petrophysical measurements distributed within the AGB have been selected for a more refined petrophysical characterisation of major rock units across the belt. Table 1 outlines measurements collated and combined from different sources and the number of density and magnetic susceptibility values in the database for this project and within the AGB. As this project develops and new data are acquired, the database will be augmented.

Table 1- The number of density and magnetic susceptibilities compiled across the Superior Craton and specifically the Abitibi Greenstone Belt, categorized by source. In this table, "GSC Petrophysics" is the data collated from the Geological Survey of Canada (Haus and Pauk 2010) as updated in the Natural Resources Canada petrophysical database (NRCAN 2017); "ME petrophysics" represents measurements conducted by Metal Earth (ME 2017); "OGS_MRD 91" is the Ontario Geological Survey (OGS) report number MRD-91 (Ontario Geological Survey 2001); "MRD273_Mag_Sus" is the OGS magnetic susceptibility database (Muir 2013); "OGS_SG_LU" is the density database delivered by Rainsford (2017); "Footprints petrophysical data" is data collected by the Footprints project led by Laurentian University (Footprints Project 2018); "Minnesota Petrophysics" is the database compiled from the Minnesota Geological Survey (Chandler and Lively 2017).

Source	Number of Density measurements		Number of Magnetic Susceptibility measurements	
	Original	Abitibi	Original	Abitibi
GSC_Petrophysics	16504	2764	5369	91
ME Petrophysics	269	269	537	537
OGS_MRD91	1032	1032	1032	1032
MRD273_Mag_Sus	0	0	28985	11153
OGS_SG_LU	25581	10266	0	0
Footprints Petrophysical data	854	854	854	854
Minnesota Petrophysics	4514	0	6062	0
	48754	15185	82839	13667

In order to systematically characterise petrophysical properties of different rock units based on the lithological hierarchy, the density and magnetic measurements which are associated with a rock unit/lithology in the database have been divided into relevant hierarchies and units, whereas those measurements associated with unknown lithology are discarded. In general, the number of samples to reliably define the petrophysical properties should be guided by the number of rock units and the diversity of mineralogy and texture. For example, Tukety (1977) suggested 30 samples are required for a reliable statistical evaluation. Therefore, in this report, we try to ensure there is a minimum of 30 values for a specific rock unit for a reliable characterisation. In cases when there are <30 measurements the characterizing values will have higher uncertainties. In this study, sufficient numbers of measurements (> tens of measurements) exist for most of the rock units and there is little concern with respect to under sampling of a specific major rock unit. Figure 1 shows the spatial distribution of density and magnetic susceptibility values of the compiled database within the AGB; each sample location is indicated with a black dot. Table 2 shows the lithological/geological hierarchy which has been used to associate each petrophysical value with a specific units. Rock units in this table correlate with available rock types in the database and do not represent all possible rocks within each hierarchy.

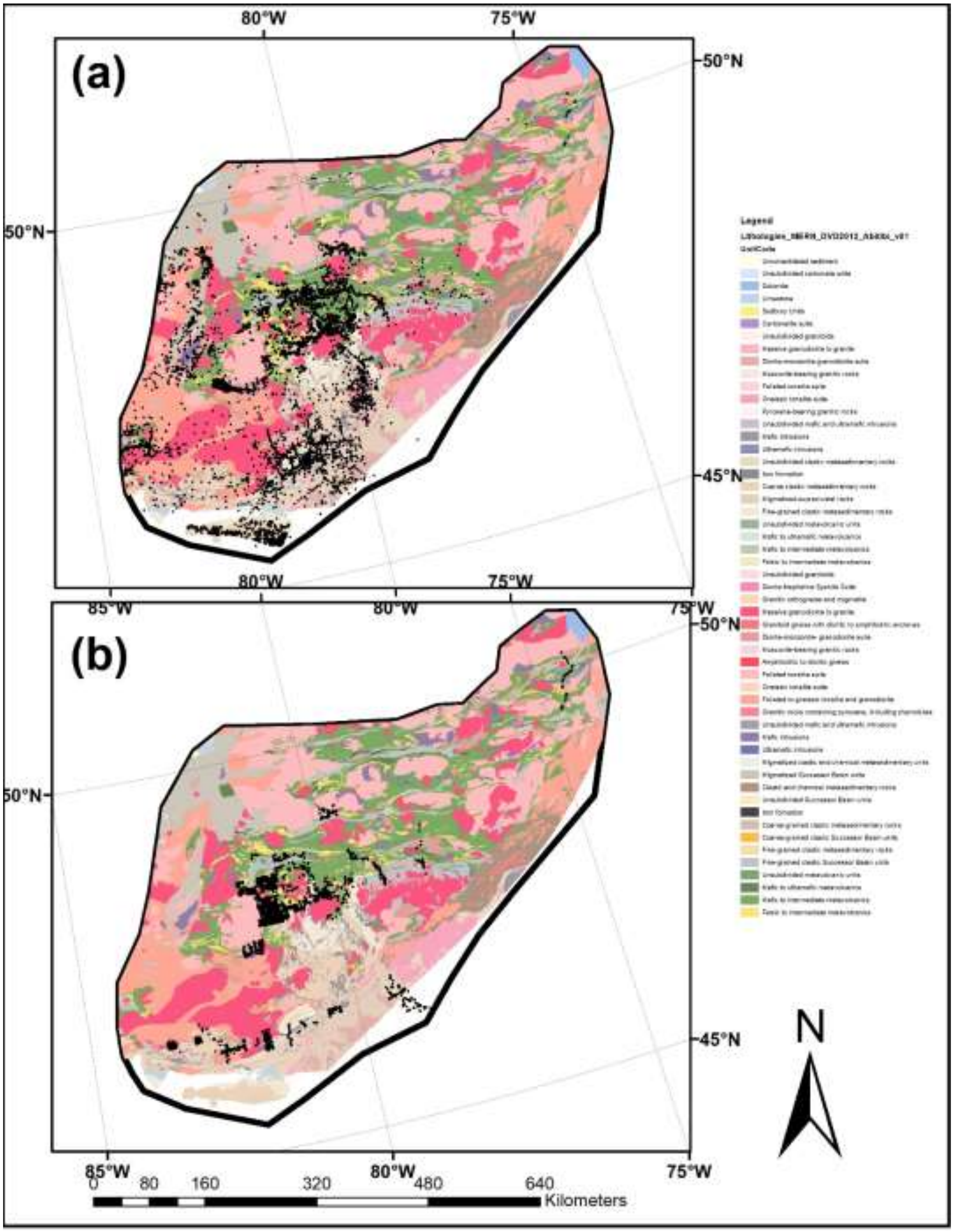


Figure 1 - Final compiled petrophysical database within the Abitibi Greenstone Belt superimposed on the Superior Compilation geological map (Montsion, et al. 2018), (a) density measurements; (b) magnetic susceptibility measurements.

Table 2- Lithological/ geological hierarchy used to characterise petrophysical properties in this study. Rock units in this table consist of rocks types used in the database.

Major domain	Groups	Sub-groups	Rock Units in the database
Igneous rocks			
	Plutonic		
		Felsic intrusive rocks	granite, granodiorite, tonalite, trondhjemite, felsic dykes, monzogranite, felsic intrusion
		Intermediate intrusive rocks	diorite, monzonite, syenite, syenodiorite, quartz diorite, monzodiorite, intermediate intrusion
		Mafic intrusive rocks	anorthosite, gabbro, norite, mafic tonalite, mafic intrusive, mafic dyke, gabbronorite, lamprophyre
		Ultramafic intrusive rocks	dunite, peridotite, pyroxenite, hornblendite
	Young Dykes		diabase
	Volcanic		
		Felsic extrusive rocks	dacite, rhyolite, felsic volcanic, dacite/felsic tuff, felsic tuff/volcanic, rhyodacite, felsic volcanic
		Intermediate extrusive rocks	trachyte, pillowed intermediate volcanic, intermediate volcanic/ tuff
		Mafic extrusive rocks	andesite, basalt, mafic volcanic/tuff
		Ultramafic extrusive rocks	komatiite, ultramafic
Sedimentary rocks			conglomerate, dolomite, greywacke, limestone, mudstone, shale, sandstone, siltstone, arkose, wacke, pelite, argillite, dolostone, chert, carbonate, breccia, ankerite
	Volcanoclastic rocks		lapilli tuff, tuff, pyroclastic, hyaloclastite, mafic volcaniclastic

Metamorphic rocks			felsic/mafic/ gneiss, albitite, amphibolite, slate, meta-sedimentary/volcanic/gabbro/diorite/greywacke, garnet, gneiss, granodiorite/granulite gneiss, graphite, greenschist, tonalite gneiss, hornfels, schist, marble, quartzite, rodingite
	Fault rocks		cataclasite, mylonite, pseudotachylite

Petrophysical characterisations were previously performed by some studies both in a regional and local scales across the AGB. Some studies generally focused on specific areas at a local scale. For instance, petrophysical properties of Sudbury were characterised by Hearst, et al. (1994) and McGrath and Broome (1994). The advantage of the large-spatial-scale systematic petrophysical characterisation in this study is to compile a more comprehensive database taking into account measurements from different sources, as well as a regional characterisation to mitigate the impact of local weathering or metamorphism, and also coherently and consistently characterise both density and magnetic susceptibility values.

4- Petrophysical Characterisation

Table 3 and 4 summarise density and magnetic susceptibility properties (i.e. number of samples, mean, standard deviation, median, minimum, maximum and skew[1]) of major rock units across the Abitibi Greenstone Belt. More detailed investigation of each rock unit is described in the following sections using histograms and QQ plots of the physical properties for different rock units. Histograms help to illustrate the number of samples in each physical property bin and this can be used to infer whether their distribution is unimodal, bimodal or multimodal within major lithological units. In addition, QQ plots have been used as a quick way to get visual confirmation whether a variable deviates from the normal distribution or not. Histograms and QQ plots are exhibited on a linear horizontal scale when characterising density values. In contrast, due a large

[1] Skewness of distribution is a characterization of the degree of asymmetry of a distribution around its mean and is calculated using this formula:

$$\text{Skew} = \frac{n\sum_{i=1}^{n}(x_i - x^*)^3}{((n-1)(n-2))s^3}$$

Where x^* is the mean, s is the standard deviation and n is the number of possible values of x.

range of magnetic susceptibility values, the magnetic susceptibilities are plotted on a logarithmic scale.

In this study, some units are characterised independent of the geological hierarchy outlined in Table 2. These exempted units are; (1) any granite unit which is classified as a felsic plutonic unit (these are independently characterised because of their spatial abundance and significant contribution to gravity anomalies); (2) younger dykes (diabase) are mafic units but are much younger compared to the Archean basement of the Abitibi, and were not metamorphosed during the major Archean metamorphism events, and are unique as they have distinct magnetic signatures; (3) similar to young dykes, carbonatite samples are characterised independently as a plutonic subgroup with a relatively younger age compared to the basement, (4) banded iron formation (BIF) are also treated independently in the magnetic susceptibility characterisation due to their anomalously high magnetic responses, and finally (5) tholeiite mafic volcanic samples are treated independently from other measurements classed as basaltic units because there are sufficient samples (574) to give a reliable characterization.

Table 3- Summary statistics of density values (g cm^{-3}) of major geological units across the Abitibi Greenstone Belt.

Lithology	Number of Samples	Mean	Standard Deviation	Median	Min	Max	Skew
Felsic intrusive rocks	566	2.69	0.06	2.69	2.41	3.03	1.19
Granite	666	2.66	0.07	2.65	2.50	3.15	2.74
Intermediate intrusive rocks	871	2.74	0.11	2.71	2.14	3.19	0.83
Mafic intrusive rocks	1354	2.88	0.14	2.88	2.29	3.50	-0.18
Ultramafic intrusive rocks	181	2.90	0.18	2.88	2.52	3.32	0.40
Young dykes (diabase)	328	2.97	0.10	2.99	2.66	3.23	-1.08
Carbonatite	88	2.95	0.21	2.91	2.64	3.71	1.77
Felsic extrusive rocks	958	2.74	0.09	2.73	2.49	3.50	1.59
Intermediate extrusive rocks	280	2.78	0.10	2.76	2.34	3.33	0.79
Mafic extrusive rocks	1384	2.89	0.12	2.89	2.40	3.81	0.38
Tholeiite mafic extrusive rocks	574	2.93	0.10	2.94	2.55	3.20	-0.32
Ultramafic extrusive rocks	344	2.89	0.10	2.91	2.58	3.22	-0.18
Sedimentary rocks	2432	2.75	0.09	2.76	2.26	3.19	-0.39
Volcanoclastic rocks	668	2.86	0.15	2.84	2.39	3.73	0.48
Metamorphic rocks	1825	2.78	0.13	2.75	2.24	3.58	1.33
Fault rocks	49	2.78	0.11	2.78	2.60	3.01	0.28

Table 4- Summary statistics of magnetic susceptibility values (× 10^{-3} SI) of major geological units across the Abitibi Greenstone Belt. BIF is Banded Iron Formations.

Lithology	Number of Samples	Mean	Standard Deviation	Median	Min	Max	Skew
Felsic Intrusive rocks	1073	2.58	6.21	0.39	-0.11	76.77	6.22
Granite	344	1.91	3.52	0.51	-0.04	33.45	4.66
Intermediate intrusive rocks	392	9.14	14.39	1.07	0	81.20	2.31
Mafic intrusive rocks	1744	10.11	19.74	0.90	0.04	269.35	4.13
Ultramafic intrusive rocks	275	62.48	89.56	47.90	0.08	763.70	4.78
Young dykes (diabase)	488	21.17	28.43	16.77	0.03	272.43	4.04
Felsic extrusive rocks	810	2.33	16.23	0.19	-0.04	345.14	15.03
Intermediate extrusive rocks	1351	1.74	7.13	0.35	0	151.23	10.84
Mafic extrusive rocks	2747	8.51	25.7	0.73	-0.011	565.60	10.04
Ultramafic extrusive rocks	473	26.85	38.04	3.32	0.04	411.20	3.16
Sedimentary rocks	1408	1.59	7.52	0.30	-0.01	195.69	9.13
Volcanoclastic rocks	16	0.34	0.10	0.31	0.20	0.48	0.33
Metamorphic rock	1111	3.44	13.48	0.36	-0.02	289.00	11.40
BIF	188	158.01	214.26	76.66	0.02	1230.47	2.08

5- Methodology

The sections below discuss the statistics of each sub-group in more detail, including in some cases a discussion of some of the specific rock units within each sub group (Table 2). For each sub-group, we generate a histogram and QQ plot. The histogram is the number of samples in a bin of density or magnetic susceptibility values. The width of the bins depends on the number of total samples in the sub-group or unit being analyzed, but, as a general rule, the smaller the number of samples the wider the bins. In addition, in order to provide a qualitative comparison between different lithologies, the horizontal axis of the histograms display the same density and magnetic susceptibility ranges (typically 2.40—3.20 g cm^{-3} for density and -2—2.5 in $\log_{10}$ scale × 10^{-3} SI for magnetic susceptibility). The histogram shows the nature of the distribution. If it is a unimodal normal distribution, there is one peak, with the values dropping off on either side in a symmetric fashion. In the case, when there are two peaks evident, then the distribution is classed as bimodal. The strength of the bimodal nature of the distribution varies. Bimodality is most obvious when there is a deep valley (with small relative counts) between the two peaks, but a subtle valley makes bimodality less obvious. This has been quantified somewhat arbitrarily by calling the distribution *strongly* bimodal when the counts at the bottom of valley are less than 33% of the smallest peak; *moderately* bimodal is when the counts in the valley are 33-66% of the smallest peak; and *weakly* bimodal is when the counts in the valley are more than 66% of the smallest peak. If there are a relatively few samples in the smaller peak, it is difficult to confidently quantify the strength of the bimodality, so the bimodality in this case is said to be *poorly defined*.

The QQ plot (the normal probability plot) shows the distribution of values as a function of the quartile, with normal distributions plotting as straight lines, with the slope a function of the standard deviation. In contrast, the QQ plot is good for determining the non-normal nature of the distribution when the plot is not linear. If the distribution is bimodal, there are two symmetric peaks evident on the histogram, with two straight lines on the QQ plot. Furthermore, QQ plots can present the right skew (if the curve appears to bend up and to the left of the normal line that indicates a long tail to the right), left skew (if the curve bends down and to the right of the normal line indicating a long tail to the left), short tails (an S shaped-curve indicating shorter than normal tails), and long tails (a curve starting below the normal line, bends to follow it, and ending above it).

The mean and/or the median can be used as the representative value for density and magnetic susceptibility. If the mean and median are the same or very close with a difference <0.02 g cm^{-3} for density and <0.5 × 10^{-3} SI, we assume the representative value is the mean-median with a higher level of certainty. Otherwise, in this study, we typically use the mean as the representative value because this value takes into account all the different measurements. However, when there is a bimodal distribution and/or the mean value is less-representative based on an inspection of the histogram and QQ plots, we have assessed two scenarios of either (1) dividing the properties into two sub-units and determining properties for each sub-unit (more typical for magnetic susceptibilities due to the wider range and inherent heterogeneity associated with magnetic values (e.g. Enkin 2018)), or (2) used the median value as the representative value for the unit.

In addition, in this study, some measurements are identified as outliers. These outlier values are not discarded from the database and histograms, they are just exempted when calculating characteristic values. Keeping the outliers can give a modeller the option of using a larger or smaller value for some units when specifying models.

In this study, the density database and the magnetic susceptibility database are two independent databases. Therefore, these two databases do not include exactly the same rock units. So, it is possible that some rock units have adequate density measurements for a reliable characterisation, while magnetic susceptibility characterisation of this unit is not valid due to the negligible number of measurements corresponding to the specific rock unit and vice versa. For example, the density database contains 45 density measurements of trondhjemite which allow us to provide a representative density value, whereas the magnetic susceptibility database has no instances of this rock unit.

5.1. Felsic intrusive rocks

Characterising density values, a total of 566 density measurements were classed as felsic intrusive rocks, excluding granite. Histograms and QQ plots are shown on Figure 2. The histogram plots show the number of samples in bins from low (2.4 g cm^{-3}) to high values (3.2 g cm^{-3}). Note that the same limits are used for each unit in this sub-group. In Figure 2, the plots indicate a relatively unimodal normal density distribution with flat tails, excluding outliers. This sub-group has the same mean and median density value of 2.69 g cm^{-3}.

Within the felsic intrusion hierarchy, there are three units with sufficient samples (30 or more) to characterize density distribution. The granodiorite unit contains 289 measurements with a unimodal normal density distribution and the mean and median values being slightly different (2.70 and 2.69 g cm^{-3}, respectively). In contrast, 45 measurements of trondhjemite indicate a unimodal distribution with a positive skew and the mean and median value are the same (2.66 g cm^{-3}). Relatively unimodal normal density distribution of felsic intrusive rock units indicates that the mean characterised values are representative of this sub-group and its more well sampled units.

In addition, the compiled database contains 122 density measurements classified as "felsic to intermediate intrusions" collated from the Footprints Project. With the exemption of some outliers (six measurements), this unit returns a relatively unimodal normal distribution with a slight positive skew and the mean density value of 2.69 g cm^{-3} and median value of 2.68 g cm^{-3}.

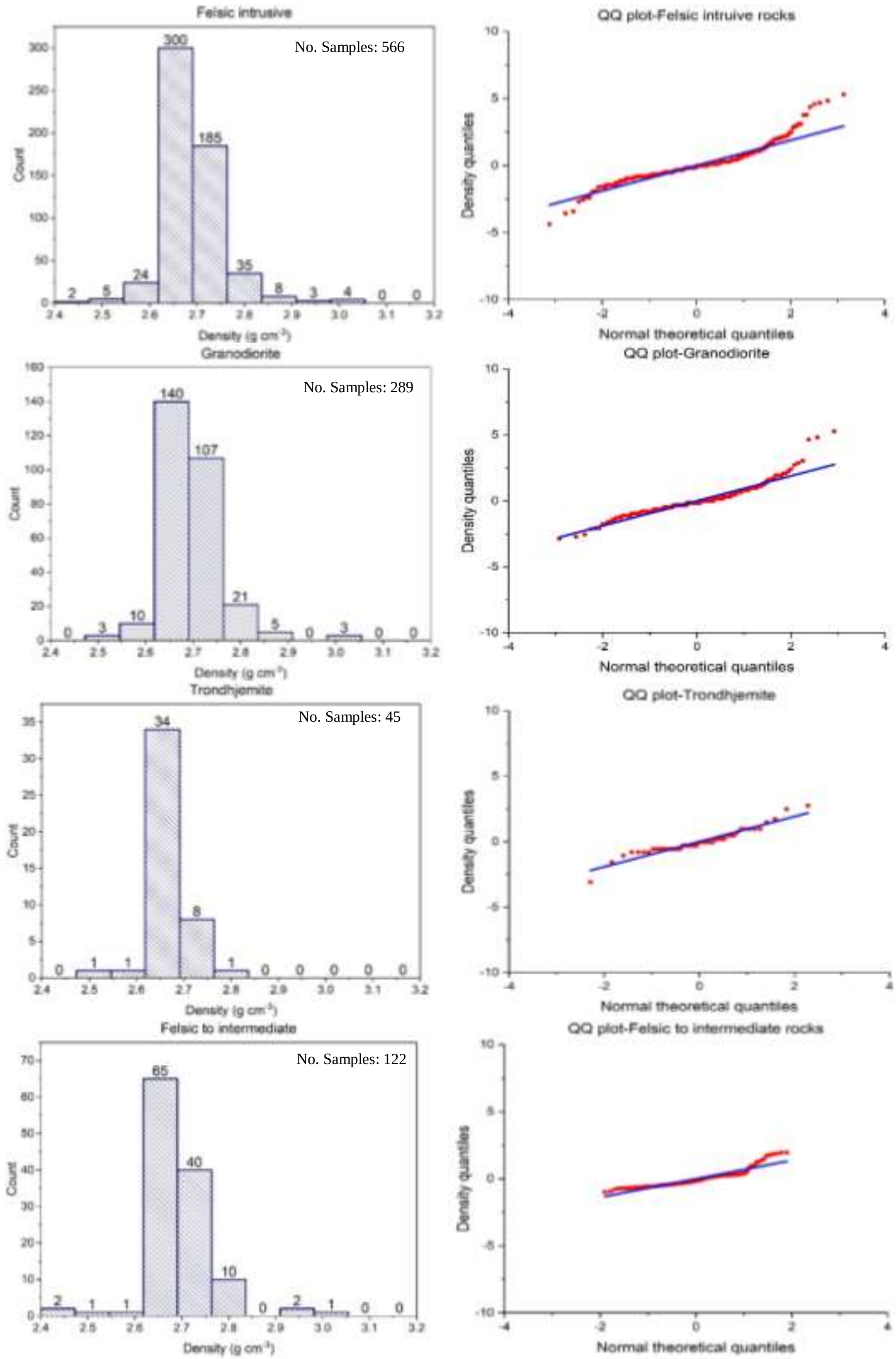


Figure 2 - Density measurements of felsic intrusive rocks and major lithological units in the Abitibi Greenstone Belt. The left column displays histograms of the values (g cm^{-3}) and the right column show the quartile-quartile (QQ) plots.

Magnetic susceptibility characterisation of felsic intrusive rocks was conducted using 1073 measurements displaying a relatively normal distribution with a wide range of magnetic properties from non-magnetic to relatively high magnetic susceptibility values with the mean and median values of 2.582 and 0.39 × 10^{-3} SI, respectively. A total number of 32 measurements have values greater than 16× 10^{-3} SI (of these, 11 were felsic-intermediate intrusions, 11 granodiorites, six feldspar porphyry, three felsic intrusions, and one was tonalite). The spatial location of these 32 samples suggests that they can be considered as outliers based on their correlation with other intrusions, metamorphism or the variable impacts of the original protolith. The new database, with the exemption of these 32 outliers, have a mean of 1.759 and median of 0.36 × 10^{-3} SI. Figure 3 displays histograms and QQ plots of magnetic susceptibility values of the felsic intrusive sub-groups and some representative rock units of this hierarchy.

Focusing on the well sampled rock units within the felsic intrusive database, 460 measurements are classed as granodiorite rocks and these indicate a weak bimodal distribution with the mean and median magnetic susceptibility values of 2.82 and 0.73 × 10^{-3} SI, respectively. This unit can be divided into two subpopulations of (termed unit 1 and unit 2 on Table 5) with the lower magnetic susceptibility values associated with unit 1 centred on 0.28 × 10^{-3} SI (245 measurements) and unit 2 with the higher magnetic susceptibility values centred around of 5.79 × 10^{-3} SI (212 measurements). Tonalite consists of 236 magnetic susceptibility measurements and the distribution shows a relatively unimodal normal distribution with the mean and median values of 1.43 and 0.30 × 10^{-3} SI, respectively. Magnetic susceptibility measurements of the "felsic to intermediate intrusions" from the Footprints Project (113 measurements) have a mean of 2.27 and median of 0.16 × 10^{-3} SI, with the outliers excluded. This unit displays a strong bimodal distribution with two populations: the major relatively non-magnetic population (70 measurements with a mean susceptibility of 0.08 × 10^{-3} SI) and a minor highly magnetized population (35 measurements with a mean value of 14.90 × 10^{-3} SI). In this database, a single mean value of 2.27 × 10^{-3} SI could be used to characterize all rocks in the category "felsic to intermediate intrusions". However, in detail investigations/modelling, two different magnetic susceptibility values can be used with the mean magnetic susceptibility of 0.80 × 10^{-3} SI for unit 1 (86 measurements) and the mean value of 14.90 × 10^{-3} SI for unit 2 (40 measurements).

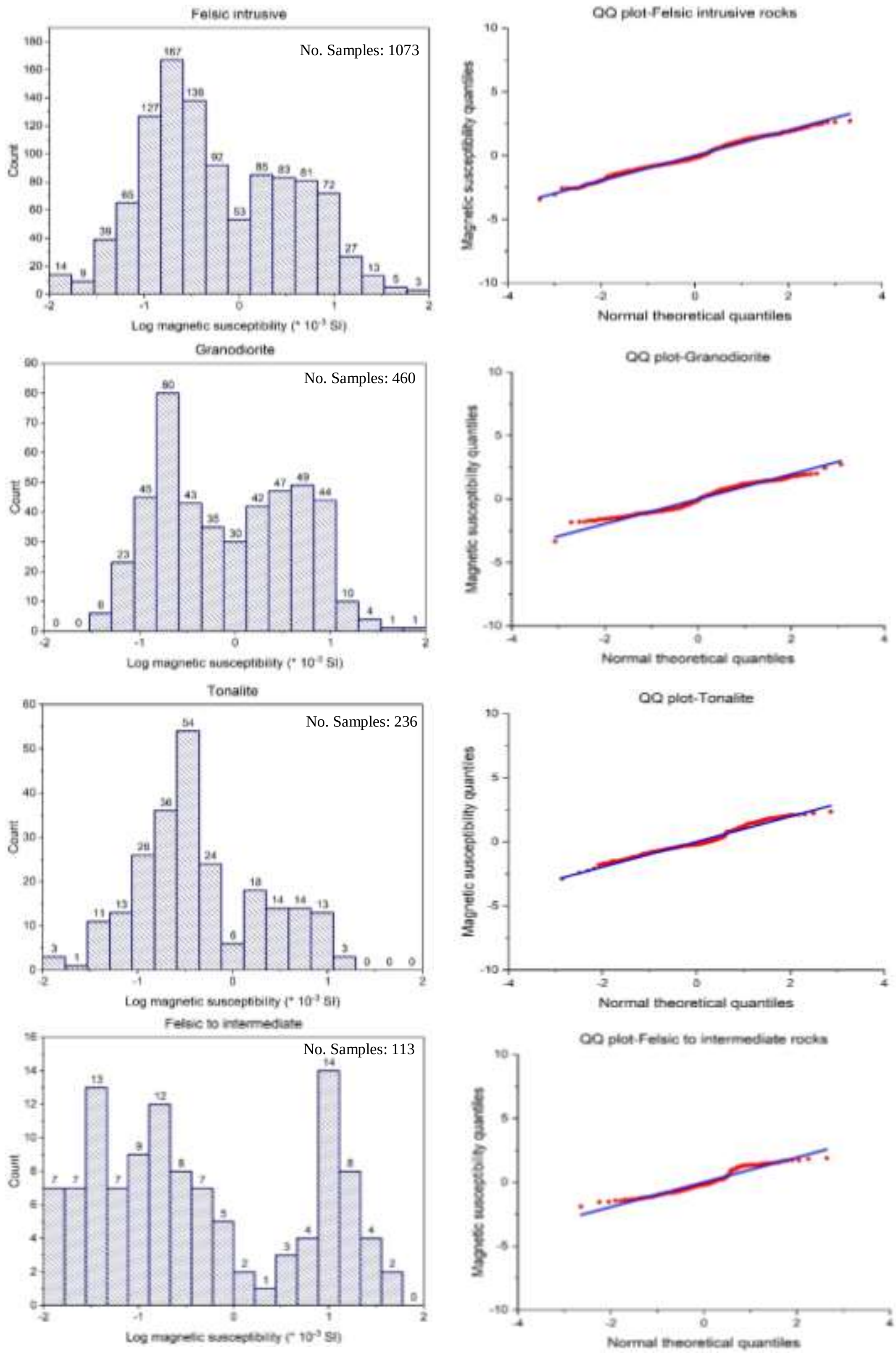


Figure 3- Magnetic susceptibility measurements of felsic intrusive rocks and major lithological units in the Abitibi Greenstone Belt shown on a $\log_{10}$ scale. The left column displays histograms of the values ($\times 10^{-3}$ SI) and the right column shows the quartile-quartile (QQ) plots.

5.1.1. Granite

As already stated, due to the abundance of granites across the study area and their significant contribution to gravity anomalies, this unit was independently characterised as a sub-unit of felsic intrusive rocks. In this database, a total number of 666 density and 344 magnetic susceptibility measurements are classed as granites. The database contained some anomalously large density and magnetic susceptibility measurements, which are typically spatially associated with edges of the outcrops or halos likely affected by metamorphism and interaction with surrounding rock units (e.g. the Huronian Supergroup, Diorite-monzodiorite-granodiorite Suite, Foliated tonalite Suite). Therefore, those anomalous outliers are exempted resulting in analyzing 632 density measurements and 331 magnetic susceptibility values.

Characterisation of density values of granites infers a unimodal normal distribution of measurements with the mean and median values of 2.65 and 2.64 g cm^{-3}, respectively. The magnetic susceptibility investigation of granite rocks indicates a relatively unimodal normal distribution with the mean and median magnetic susceptibility values of 1.45 and 0.49×10^{-3} SI, respectively. Figure 4 shows the histograms and QQ plots for density and magnetic susceptibility values of granite.

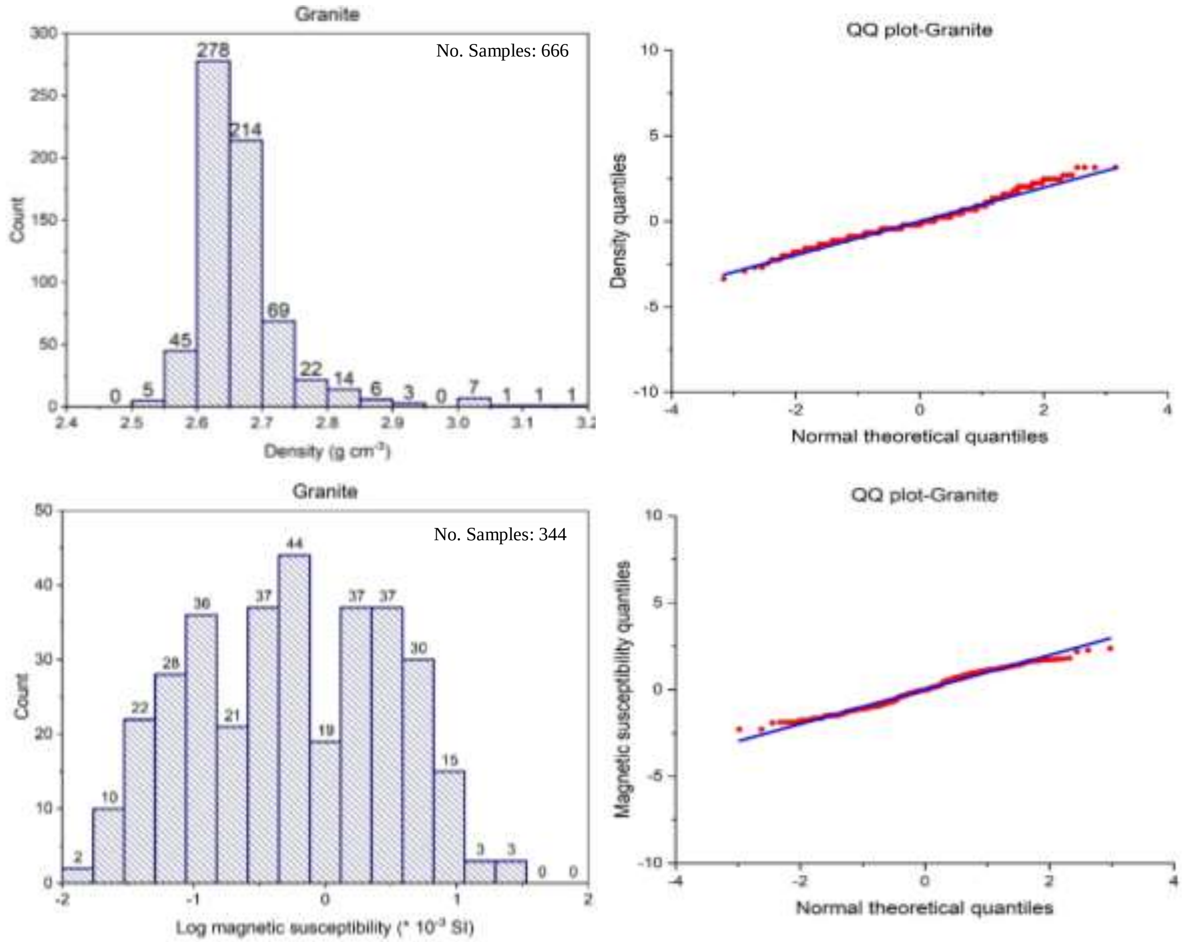


Figure 4 - Petrophysical measurements of granite in the Abitibi Greenstone Belt. The top row displays density (g cm^{-3}) measurements (left column is the histogram and the right column is quartile-quartile (QQ) plot). The bottom row indicates magnetic susceptibility (× 10^{-3} SI) values shown on a $\log_{10}$ scale (the left column is the histograms and the right column is the QQ plots).

5.2. Intermediate intrusive rocks

Density values of the intermediate intrusive rocks were characterised using 871 measurements. While measured densities highlight a wide range of density values, this sub-group shows a relatively unimodal distribution with a positive skew of 0.83 and the mean and median values of 2.74 and 2.71 g cm^{-3}, respectively. Figure 5 highlights histograms and QQ plots of density values of intermediate intrusive rocks and three well-sampled rock units of this package.

A total of 40 density measurements classed as monzonite-monzodiorite show mean and median values of 2.70 and 2.66 g cm^{-3}, respectively. This unit shows a normal distribution with a tail of larger values evident on both the histogram and QQ plot because of outliers. Therefore, the median density value of 2.66 g cm^{-3} is more representative for this unit.

In contrast, measurements classed as syenite (592 measurements) imply a unimodal distribution with the mean and median values of 2.71 and 2.70 g cm^{-3}, respectively and some outliers at high values. Similarly, 217 density measurements of diorite exhibit a unimodal normal distribution with the mean and median values of 2.83 and 2.82 g cm^{-3}, respectively.

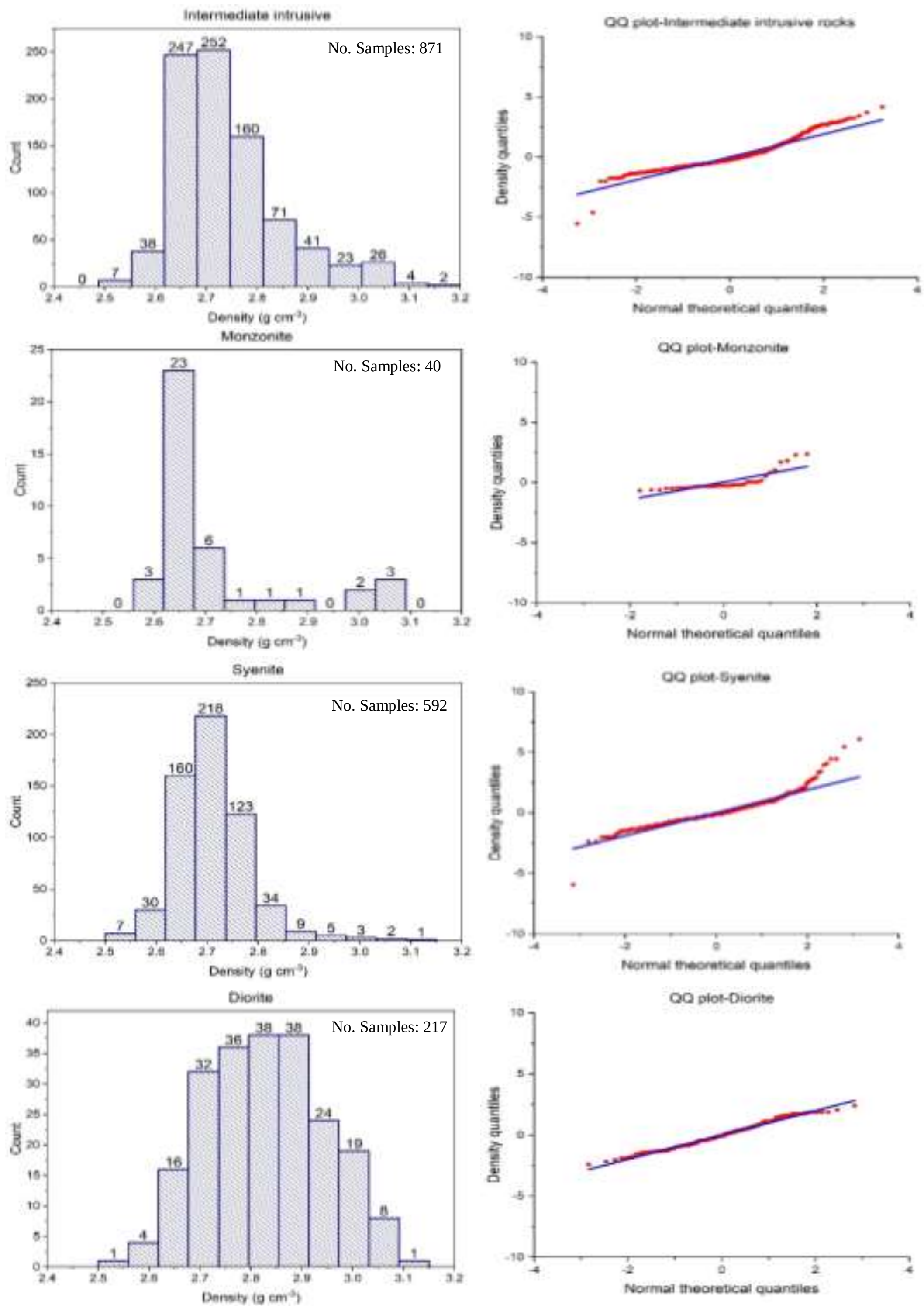


Figure 5- Density measurements of intermediate intrusive rocks and major lithological units of this hierarchy in the Abitibi Greenstone Belt. The left column displays histograms of the values (g cm^{-3}) and the right column shows the quartile-quartile (QQ) plots.

The magnetic susceptibility database contains 392 measurements classed as intermediate intrusive rocks showing a mean and median of 9.14 and 1.07 × 10^{-3}, respectively. Figure 6 summarises histograms and QQ plots of magnetic susceptibility measurements of the intermediate intrusive rocks and two of its rock units. This sub-group displays a moderate bimodal distribution with two major populations of non-magnetic and highly magnetized samples. The non-magnetic unit (226 measurements) return a mean magnetic susceptibility of 0.57 × 10^{-3} SI and the other unit (167 measurements) have a mean of 20.74 × 10^{-3} SI.

Focusing on different rock units of this package, magnetic susceptibility measurements of syenite consist of 183 readings which generally show a rock unit with a normal distribution, characterised by relatively high magnetic susceptibility values (the mean and median values of 11.801 and 7.88 × 10^{-3} SI, respectively). In contrast, 151 measurements of diorite return a poorly defined bimodal distribution with an extended right tail, but the vast majority of measurements belong to the relatively non-magnetic subpopulation resulting in characterising this unit as a non-magnetic unit. The total mean and median magnetic susceptibility values of this unit are 4.58 and 0.45 ×10^{-3} SI, respectively, where the median values of 0.45 × 10^{-3} SI are considered more representative. Therefore, it can be concluded that in this hierarchy, diorite is mostly a non-magnetic unit while syenite has relatively high magnetic susceptibility values.

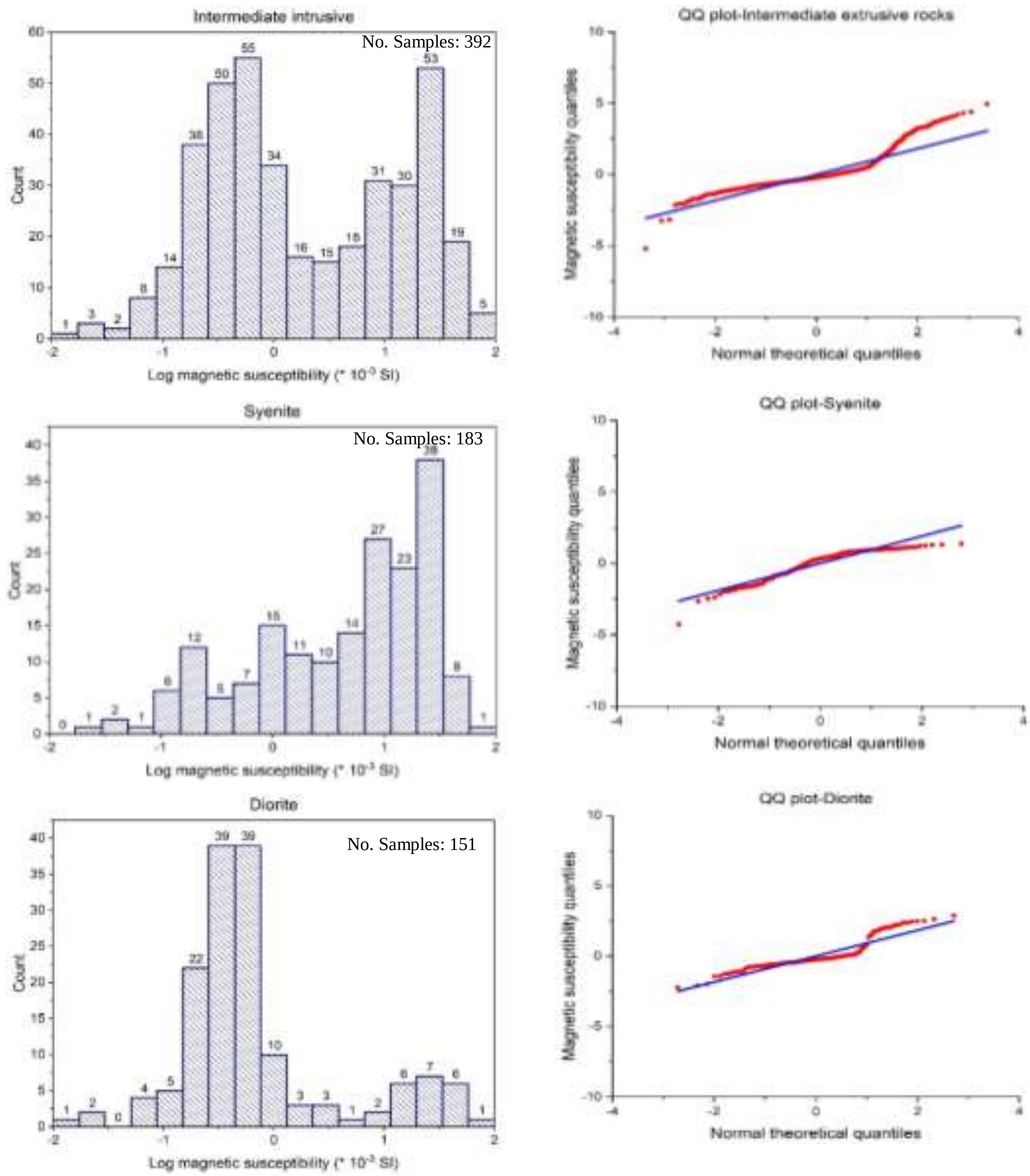


Figure 6- Magnetic susceptibility measurements of intermediate intrusive rocks and major lithological units of this hierarchy in the Abitibi Greenstone Belt shown on a $\log_{10}$ scale. The left column displays histograms of the values ($\times 10^{-3}$ SI) and the right column shows the quartile-quartile (QQ) plots.

5.3. Mafic intrusive rocks

The total number of 1354 density measurements classed as associated with mafic intrusive rocks show a relatively unimodal normal distribution with the same mean and median value of 2.88 g cm^{-3}. However, this intrusive package consists of a lot of samples and a great variety of rock units highlighting a wide range of density variations (>1 g cm^{-3}). Histograms and QQ plots of density values of different lithological units of the mafic intrusive rocks are presented in Figure 7.

Focusing on rock units of this hierarchy, the database contains five units with an adequate number of density measurements for a reliable characterisation (i.e. norite, gabbro, mafic dykes, lamprophyre, anorthosite). Norite consists of two different rock units of the “norite” and “norite massive” returning different density values. A total of 53 measurements classed as norite displays a unimodal normal distribution with the mean and median densities of 2.82 and 2.81 g cm^{-3}, respectively. In contrast, 348 measurements of norite massive display a unimodal distribution of measurements with the lower mean and median values of 2.76 and 2.79 g cm^{-3}, respectively, and a higher range of variations (a standard deviation of 0.14 g cm^{-3} for norite massive compared to the 0.06 g cm^{-3} for norite).

In addition, the gabbro unit contains 681 samples exhibiting a unimodal normal distribution with a mean and median value of 2.94 and 2.95 g cm^{-3}, respectively. Moreover, 146 density measurements of mafic dykes collected by the GSC, OGS, Footprints and ME display a unimodal normal distribution with a mean of 2.91 g cm^{-3} and the median of 2.90 g cm^{-3}. Lamprophyre density values (43 measurements) show a unimodal normal density distribution with a flat right tail and the higher mean and median density values of 2.92 and 2.88 g cm^{-3}, respectively. Finally, 30 anorthosite samples have a normal density distribution with the mean and median density of 2.86 and 2.84 g cm^{-3}, respectively.

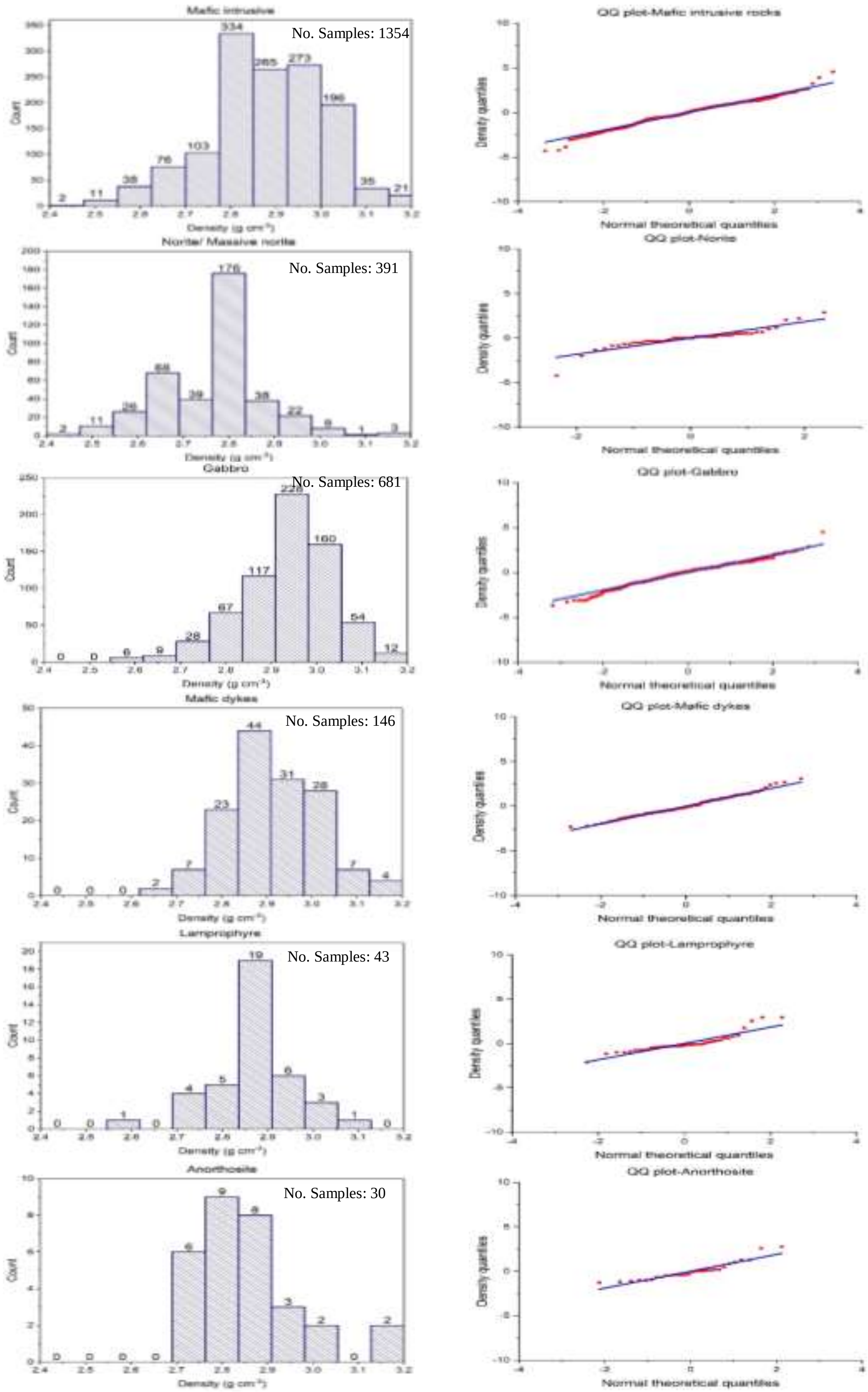


Figure 7- Density measurements of mafic intrusive rocks and major lithological units of this hierarchy in the Abitibi Greenstone Belt. The left column displays histograms of the values (g cm^{-3}) and the right column shows the quartile-quartile (QQ) plots.

The magnetic susceptibility database of mafic intrusive rocks, consisting of 1744 measurements, infer a moderate bimodal non-normal distribution with a mean of 10.23×10^{-3} SI and a median of 0.88×10^{-3} SI for all measurements. Of the two modes, the one with the largest population (1141 measurements) has low magnetic susceptibility values with the mean of 0.81×10^{-3} SI and the latter population (524 measurements) exhibits a mean of 31.40×10^{-3} SI. Therefore, the median value of 0.88×10^{-3} SI is assigned to the sub-group with a wide range of allowed values. Histograms and QQ plots of the magnetic susceptibility for different lithological units of this hierarchy are presented in Figure 8.

In detail, norite contains the lowest number of 24 magnetic susceptibility measurements, with a mean and a median of 4.26 and 1.63×10^{-3} SI, respectively. This unit has three subpopulations, but they are not well characterized because of the low number of readings, therefore, this unit can only be characterised approximately, with a high level of uncertainty. Further measurements are required to improve the understanding of this unit. The majority of measurements (16 measurements out of 24) indicate that the unit generally exhibits low magnetic susceptibility and the median value of 1.63×10^{-3} SI is assigned to be representative of the group.

In contrast, gabbro contains a high number of measurements (1295) with the mean and median magnetic susceptibility values of 10.53 and 0.87×10^{-3} SI, respectively. This unit shows a moderate bimodal non-normal distribution which is evident in both histogram and QQ plot. The main subpopulation has relatively low magnetic susceptibility (732 measurements) with the mean and median values of 0.60 and 0.59×10^{-3} SI, respectively. Whereas, the more magnetic subpopulation (386 measurements) returns a mean and median of 32.79 and 27.31×10^{-3} SI, respectively. The mean value of 10.53×10^{-3} with the range of variations from 0 to 31.02×10^{-3} SI (based on the standard deviation) might take into account the high degree of heterogeneities. Alternatively, this unit can also be divided into two units.

The other major rock unit within this hierarchy is mafic dykes (123 measurements) exhibiting a generally non-magnetic unit with a unimodal normal distribution with an extended right tail and the mean and median values of 2.311 and 0.56×10^{-3} SI, respectively. Finally, lamprophyre is under sampled (28 measurements) returning a mean value of 2.55×10^{-3} SI. Further measurements are required to improve the understanding of this unit.

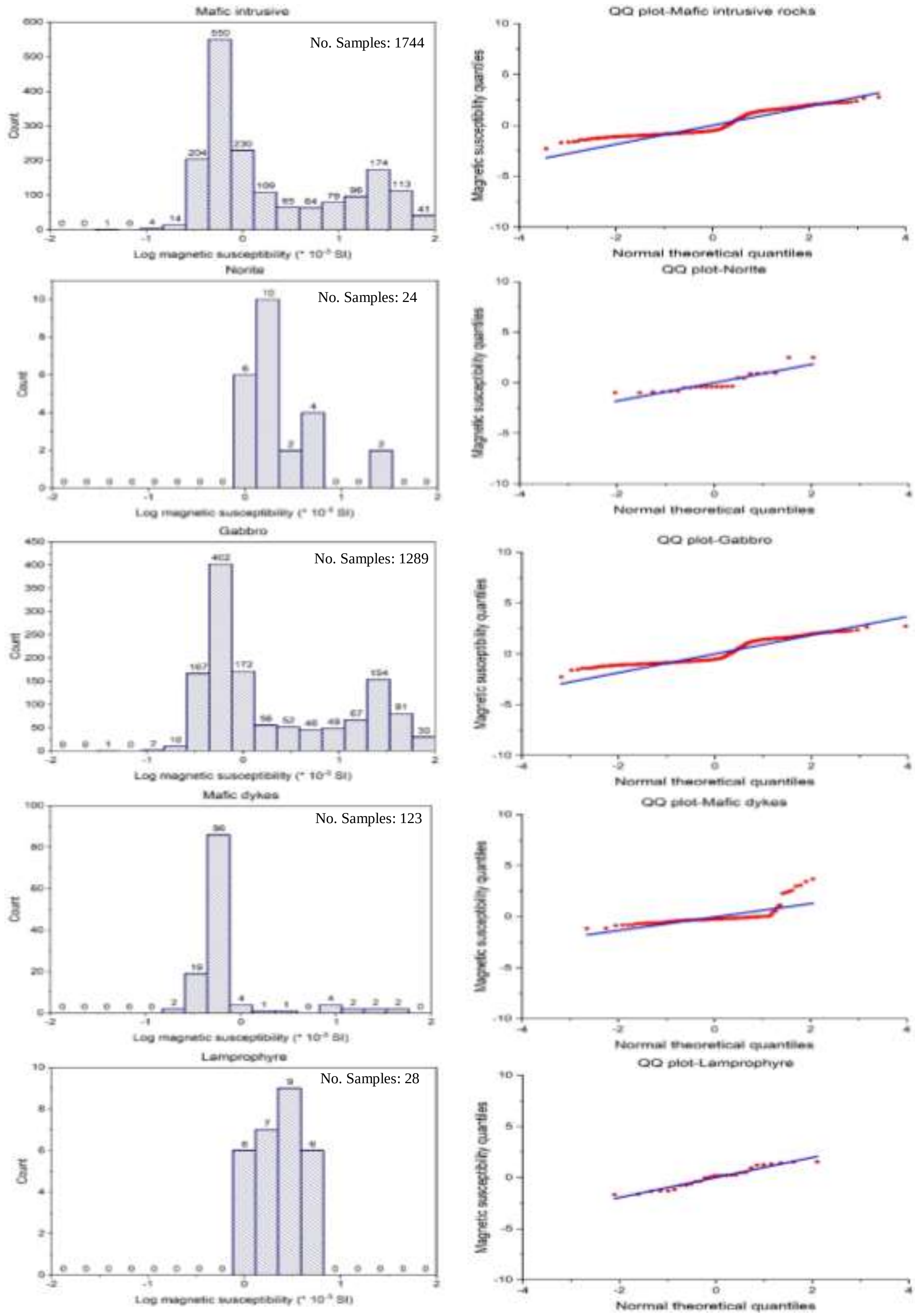


Figure 8- Magnetic susceptibility measurements of mafic intrusive rocks and major lithological units of this hierarchy in the Abitibi Greenstone Belt shown on a $\log_{10}$ scale. The left column displays histograms of the values ($\times 10^{-3}$ SI) and the right column shows the quartile-quartile (QQ) plots.

5.4. Ultramafic intrusive rocks

In this database, ultramafic intrusive rocks have 181 associated density measurements with a unimodal normal distribution and mean and median density values of 2.91 and 2.87 g cm^{-3}, respectively. Nevertheless, since this sub-group consists of a combination of different rock units, it shows a wide range of density values between 2.51 g.cm^{-3} and >3.40 g.cm^{-3}. Major rock units within this hierarchy with adequate density measurements are the peridotite and pyroxenite. Figure 9 summarises the histograms and QQ plots of the density of this hierarchy.

Within the ultramafic intrusive category, 121 peridotite unit samples return a unimodal normal density distribution with mean and median density values of 2.84 and 2.83 g cm^{-3}, respectively. Finally, 40 density measurements of pyroxenite display a unimodal normal distribution with anomalously high mean and median density values of 3.13 and 3.14 g cm^{-3}, respectively. Within ultramafic intrusive rocks, the database contains nine measurements classed as dunite with the mean density of 2.70 g cm^{-3}, and six hornblendite measurements with a mean density of 3.10 g cm^{-3}. While less than ten samples are insufficient, the mean measurements of these latter two units may be considered as approximate values that may be useful to some extent.

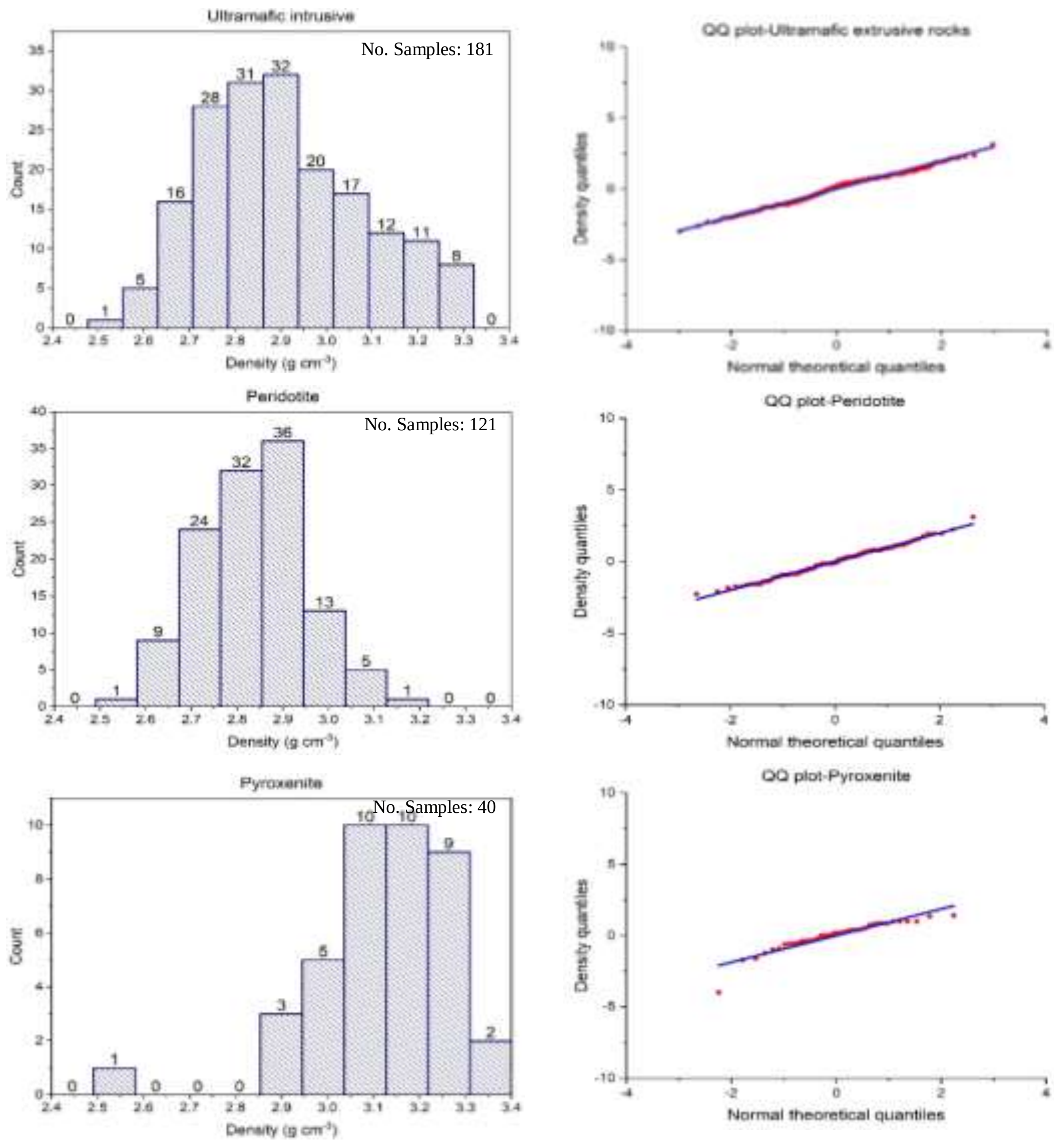


Figure 9- Density measurements of ultramafic intrusive rocks and major lithological units of this hierarchy in the Abitibi Greenstone Belt. The left column displays histograms of the values and the right column shows the quartile-quartile (QQ) plots.

Magnetic susceptibility characterisation of intrusive ultramafic units (275 measurements) is very complex because they display a wide range of magnetic susceptibility values, varying from non-magnetic (minimum of 0.08×10^{-3} SI) to anomalously high magnetic susceptibility (maximum of 763.7×10^{-3} SI). Overall, ultramafic rocks exhibit an extended tailed distribution and large mean and median values of 59.95 and 42.45×10^{-3} SI, respectively. In order to obtain representative values, different lithologies are studied independently. Histograms and QQ plots of magnetic susceptibility for this hierarchy are presented in Figure 10.

One non-magnetic unit of dunite has 41 magnetic susceptibility measurements displaying a relatively unimodal normal distribution with the mean and median values of 0.47 and 0.53 × 10^{-3} SI, respectively. There are 12 measurements classed as hornblendite (mean value of 13.35 × 10^{-3} SI), 129 measurements classed as peridotite (a unimodal distribution with a negative skew and the mean and median values of 36.60 and 38.20 × 10^{-3} SI, respectively), and 26 measurements classed as pyroxenite (unimodal normal distribution with the mean and median values of 63.18 and 69.70 × 10^{-3} SI). The unit with the largest number of samples (peridotite) dominates the histogram for this subgroup as a whole.

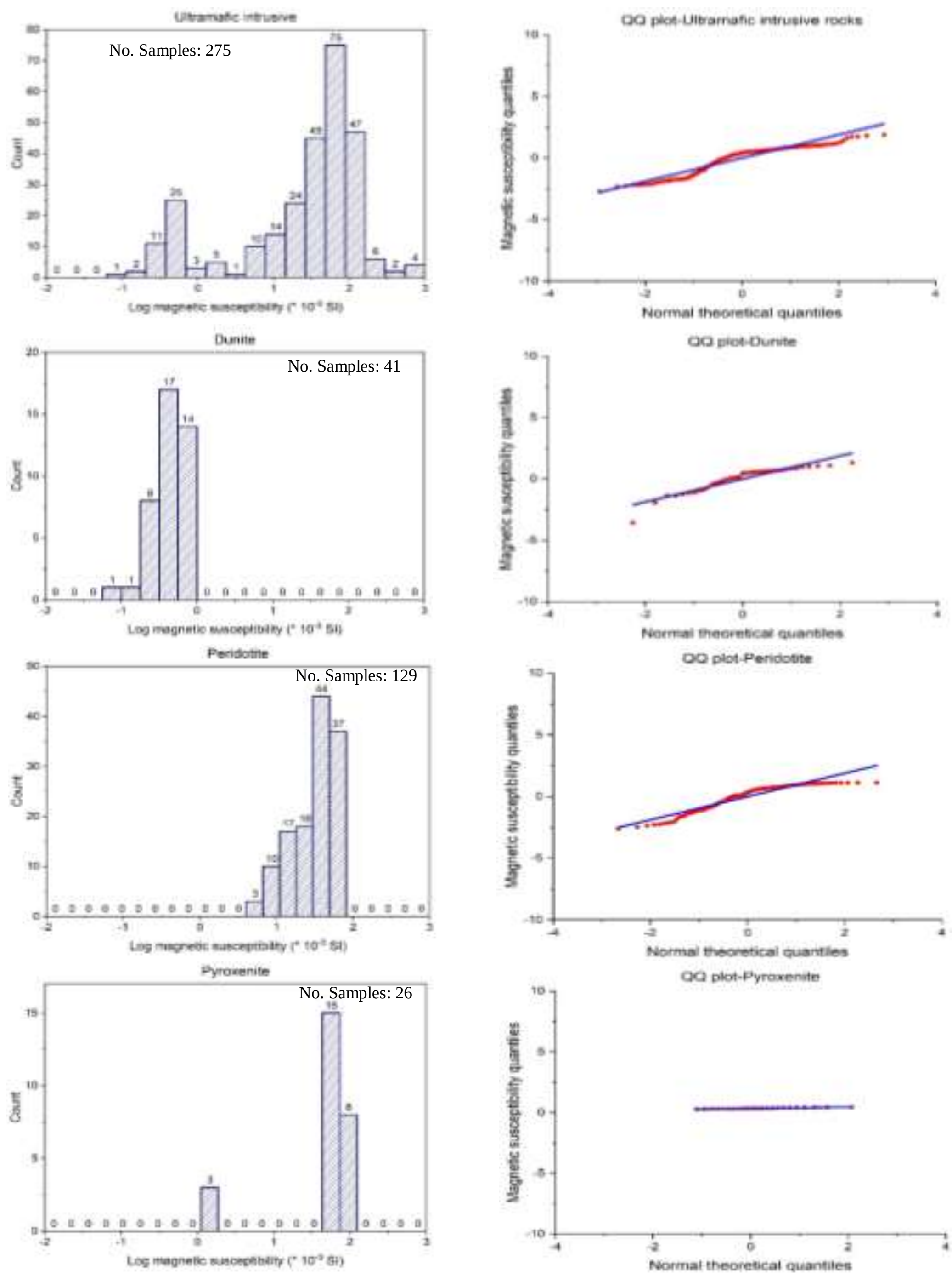


Figure 10- Magnetic susceptibility measurements of ultramafic intrusive rocks and major lithological units of this hierarchy in the Abitibi Greenstone Belt shown on a $\log_{10}$ scale. The left column displays histograms of the values ($\times 10^{-3}$ SI) and the right column shows the quartile-quartile (QQ) plots.

5.5. Young dykes (diabase)

Young dykes typically consist of diabase rocks including the Matachewan dyke swarm (2450 Ma), Nipissing sills (2217—2210 Ma), Biscotasing (2167 Ma), Sudbury dyke swarm (1240 Ma) and

Abitibi dyke swarms (1141 Ma) which post-date the main Archean metamorphism event. This young dyke unit consists of 328 density samples having a unimodal left tailed distribution with the mean and median values of 2.97 and 2.99 g cm^{-3}, respectively.

In contrast, magnetic susceptibility measurements of young dykes clearly indicate two subpopulations of relatively non-magnetic unit (unit 1) and highly magnetized unit (unit 2). Unit 1 consists of 168 measurements and returns mean and median magnetic susceptibility values of 0.83 and 0.76 × 10^{-3} SI. Whereas, unit 2 (317 measurements) has a mean of 32.12 × 10^{-3} SI and median of 26.78 × 10^{-3} SI. Histograms and QQ plots of physical properties for this unit are presented in Figure 11.

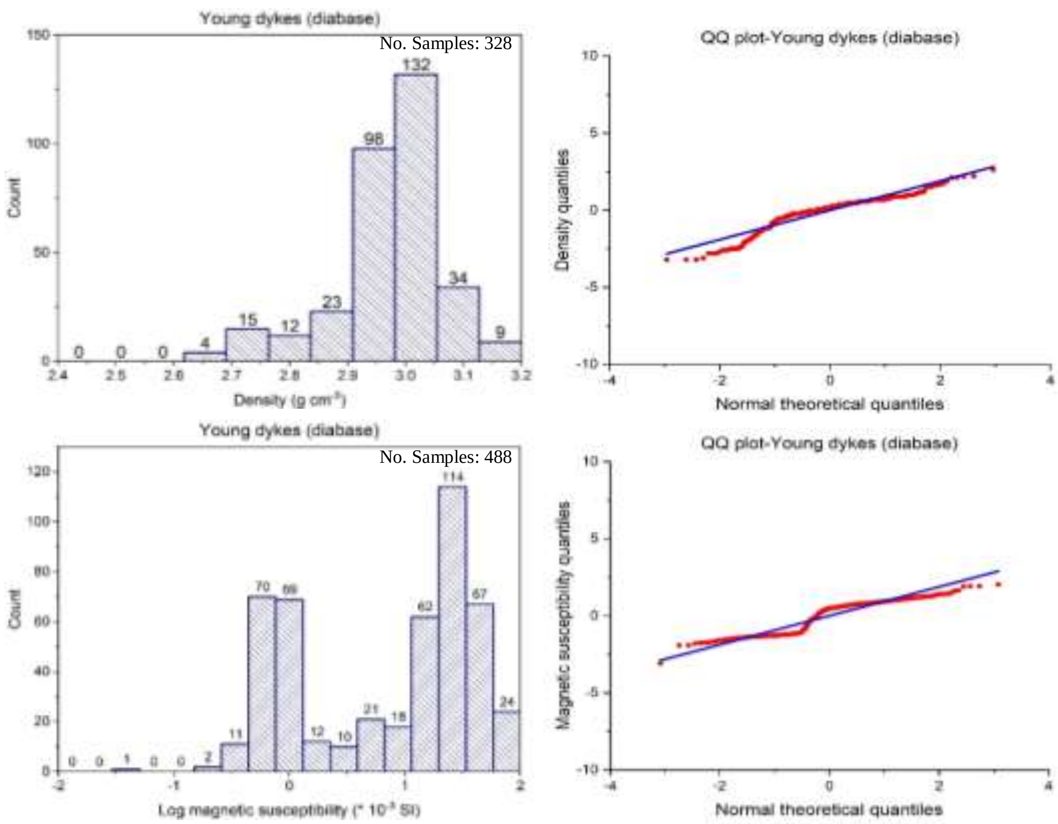


Figure 11- Petrophysical measurements of young dykes (diabase) in the Abitibi Greenstone Belt. The top row displays density (g cm^{-3}) measurements. The latter row indicates magnetic susceptibility (× 10^{-3} SI) values shown on a $\log_{10}$ scale (the left column is the histogram and the right column is the QQ plots).

5.6. Carbonatite:

Carbonatites, in this hierarchy, are a plutonic subgroup and similar to diabase are Proterozoic in age. This unit consists of 88 density measurements classed as carbonatite, fenite and soviet in this database; the values exhibit a unimodal distribution. Whereas, the QQ plot shows that the unit is an extended right-tailed distributed unit with the mean and median density values of 2.95 and 2.91 g cm^{-3}, respectively. Therefore, the median density value of 2.91 g cm^{-3} was assigned to this group to mitigate the influence of high-density measurements in the right tail. Figure 12 displays the histogram and QQ plot of density values for this package.

This unit does not contain any magnetic susceptibility measurements.

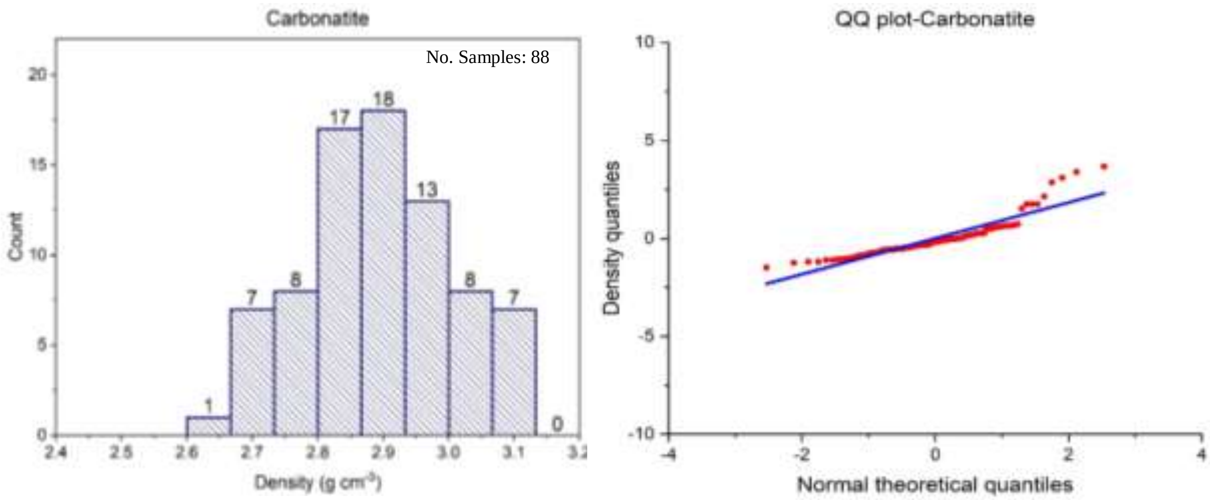


Figure 12- Density measurements of carbonatite rocks in the Abitibi Greenstone Belt. The left plot displays the histogram of the values (g cm^{-3}) and the right plot is the quartile-quartile (QQ) plot.

5.7. Felsic extrusive rocks

A total of 958 measurements of felsic extrusive rocks show a unimodal distribution with a positive skew or a flat right tail and mean and median values of 2.74 and 2.73 g cm^{-3}, respectively. Within this hierarchy, with the exemption of outliers, there are 117 density measurements for felsic tuffs, which have a unimodal, relatively normal, distribution with a mean density value of 2.73 g cm^{-3} and a median of 2.72 g cm^{-3}. In addition, 424 measurements of rhyolite return a unimodal and relatively normal distribution with the mean and median densities of 2.72 and 2.71 g cm^{-3}, respectively. Rhyodacite has 29 associated density measurements showing a normal distribution with the same but somewhat larger mean and median value of 2.77 g cm^{-3}. The low number of density measurements of rhyodacite leads to an estimation associated with a relatively high level of uncertainty. This hierarchy also contains 253 measurements of dacite which have a unimodal normal distribution with a mean density of 2.78 g cm^{-3} and a median value of 2.76 g cm^{-3}. Histograms and QQ plots of the physical properties for this unit are presented in Figure 13.

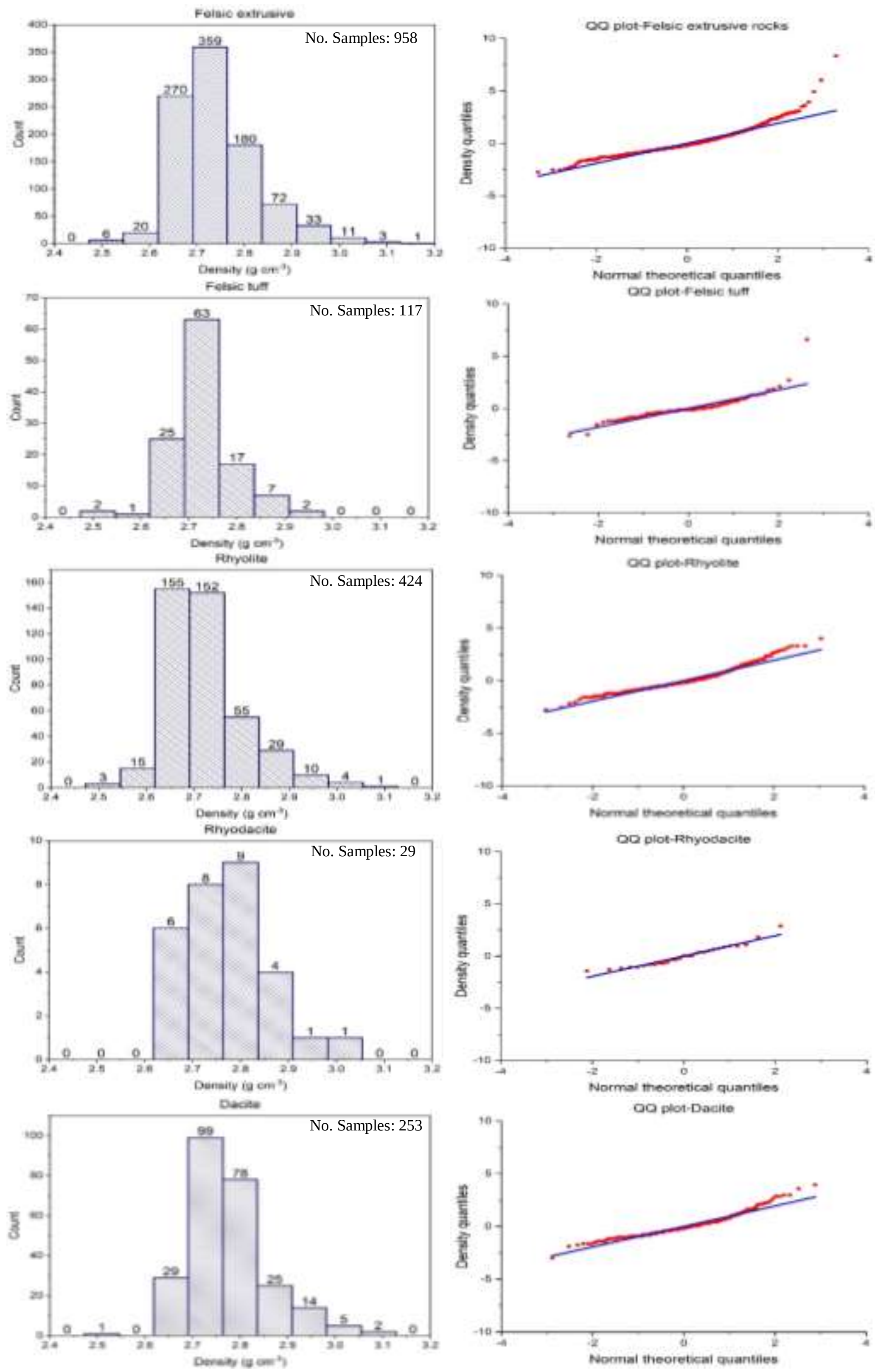


Figure 13- Density measurements of felsic extrusive rocks and major lithological units of this hierarchy in the Abitibi Greenstone Belt. The left column displays histograms of the values g cm^{-3}) and the right column shows the quartile-quartile (QQ) plots.

The magnetic susceptibility of felsic extrusive rocks is characterised using 810 measurements; these have a unimodal distribution with an extended right tail and the mean and median values of 2.33 and 0.19×10^{-3} SI, respectively. The database does not specify more precise rock units as the lithology of the majority of measurements (785 readings) are labelled generically as “felsic volcanics”, so it is not possible to further characterise the magnetic susceptibility of lithological units of this hierarchy. Figure 14 displays the histogram and QQ plot of the magnetic susceptibility of this unit.

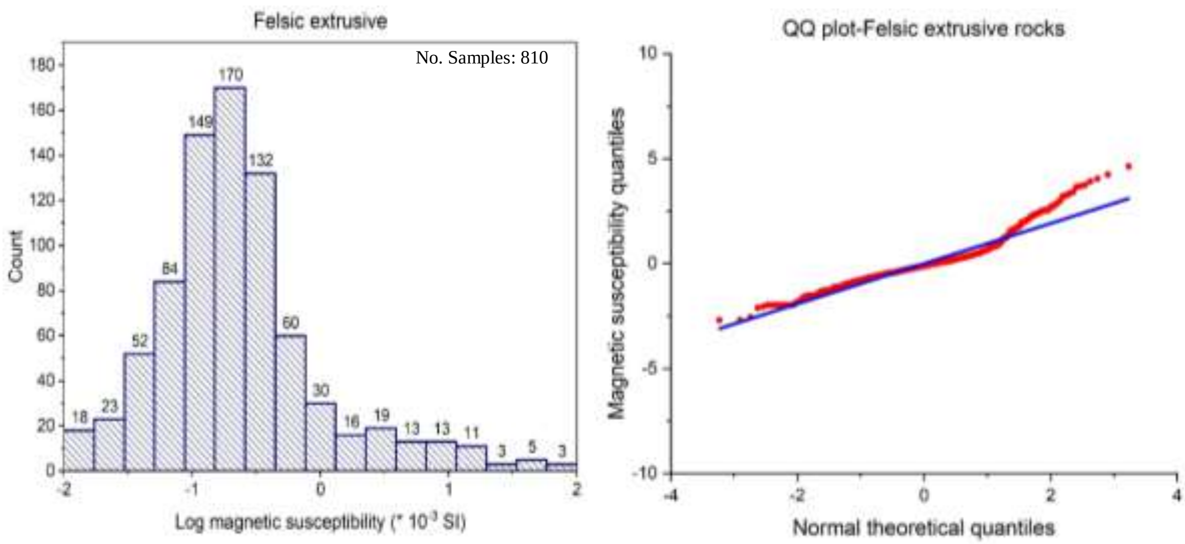


Figure 14- Magnetic susceptibility measurements of felsic extrusive rocks in the Abitibi Greenstone Belt shown on a $\log_{10}$ scale. The left plot displays a histogram of the values ($\times 10^{-3}$ SI) and the right plot is the quartile-quartile (QQ) plot.

5.8. Intermediate extrusive rocks

The intermediate extrusive sub-group in this database consists of 280 density measurements having a unimodal normal density distribution with the mean and median values of 2.78 and 2.76 g cm^{-3}, respectively. The majority of intermediate extrusive rock units in the database with sufficient measurements include intermediate tuff and trachyte. Intermediate tuffs (48 measurements) shows a unimodal and relatively normally distributed density population with the same mean and median density value of 2.75 g cm^{-3}. Similarly, 104 density measurements of trachyte have a unimodal normal distribution with mean and median values of 2.76 and 2.75 g cm^{-3}, respectively. Histograms and QQ plots of physical properties for this package are presented in Figure 15. There is little observed heterogeneity in the density of the intermediate extrusive rocks.

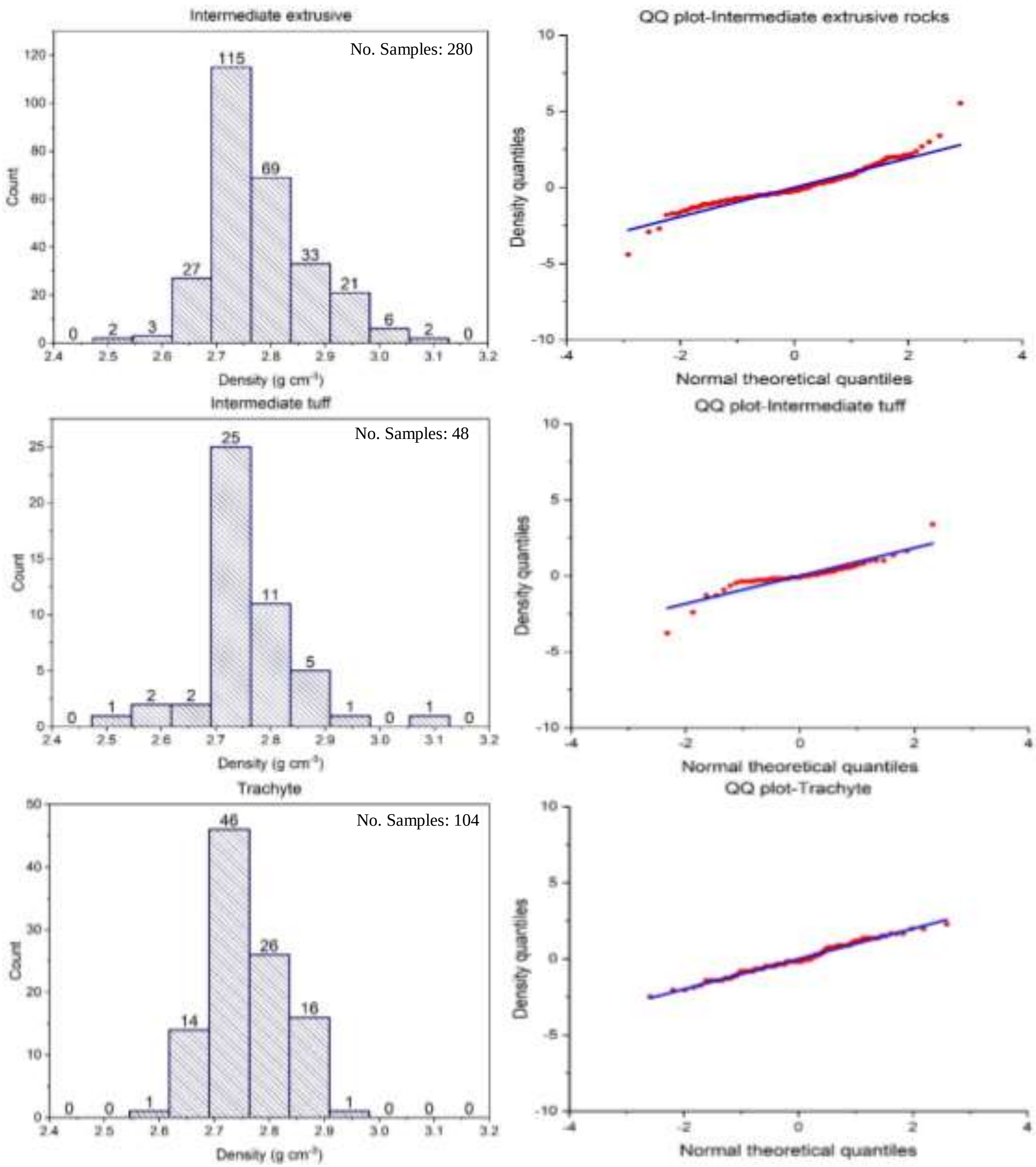


Figure 15- Density measurements of intermediate extrusive rocks and major lithological units of this hierarchy in the Abitibi Greenstone Belt. The left column displays histograms of the values (g cm^{-3}) and the right column shows the quartile-quartile (QQ) plots.

A total of 1351 magnetic susceptibility measurements classed as intermediate extrusive rocks show a unimodal distribution with an extended right tail and mean and median values of 1.743 and 0.35 $\times 10^{-3}$ SI, respectively. Similar to the felsic extrusive measurements in this database, the majority of rocks are labelled as “intermediate volcanics/extrusive” and do not specify a more specific rock unit, preventing detailed characterisation. Figure 16 displays the histogram and QQ plot of the magnetic susceptibility of this unit.

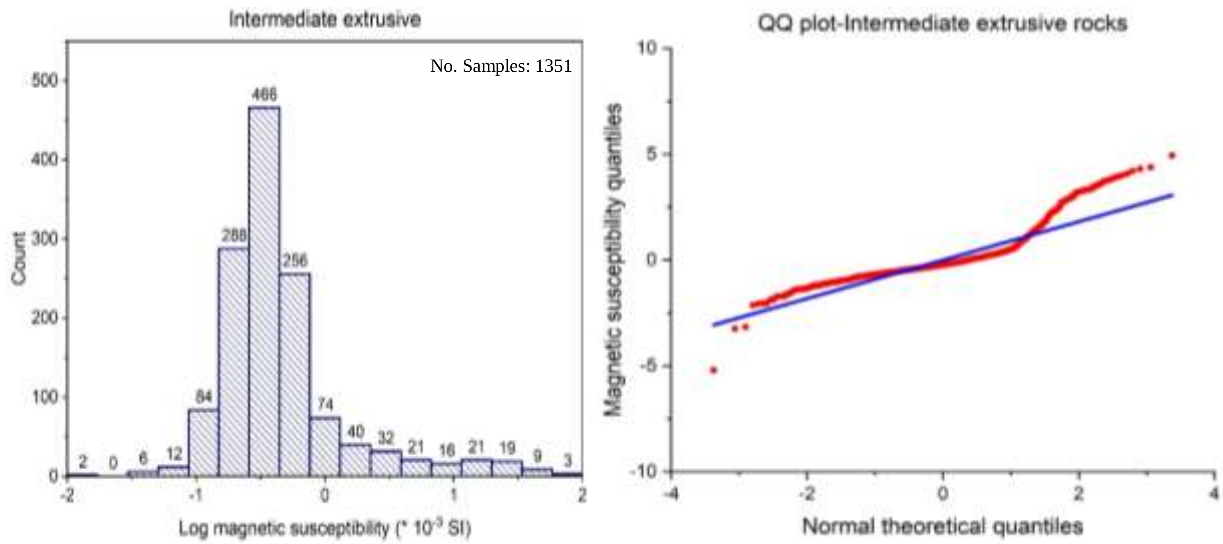


Figure 16- Magnetic susceptibility measurements of intermediate extrusive rocks in the Abitibi Greenstone Belt shown on a $\log_{10}$ scale. The left column displays a histogram of the values ($\times 10^{-3}$ SI) and the right column shows the quartile-quartile (QQ) plot.

5.9. Mafic extrusive rocks

The mafic extrusive package consists of 1384 density measurements with a unimodal normal distribution, exempting outliers, we obtained the same mean and median density value of 2.89 g cm^{-3}. In this database, three major rock units of this hierarchy are andesite, andesite/basaltic andesite, and basalt. Andesite (426 measurements) shows a unimodal normal distribution exhibiting mean and median values of 2.85 and 2.84 g cm^{-3}, respectively. In comparison, andesite/basaltic andesite (36 measurements) have a unimodal normal distribution with the higher mean value of 2.87 g cm^{-3} and the same median density of 2.84 g cm^{-3}. In contrast, basalt samples (45 measurements) display a unimodal distribution with a negative skew and relatively high mean and median value of 2.95 g cm^{-3}.

The tholeiite rock unit was treated independently in this characterisation because of the great number of measurements and also because it allows a comparison of values with other type of basalt in the database. Tholeiite has 574 associated density measurements exhibiting a unimodal normal distribution with the mean and median of 2.93 and 2.94 g cm^{-3}, respectively. Histograms and QQ plots of the density for this package, including tholeiite, are presented in Figure 17.

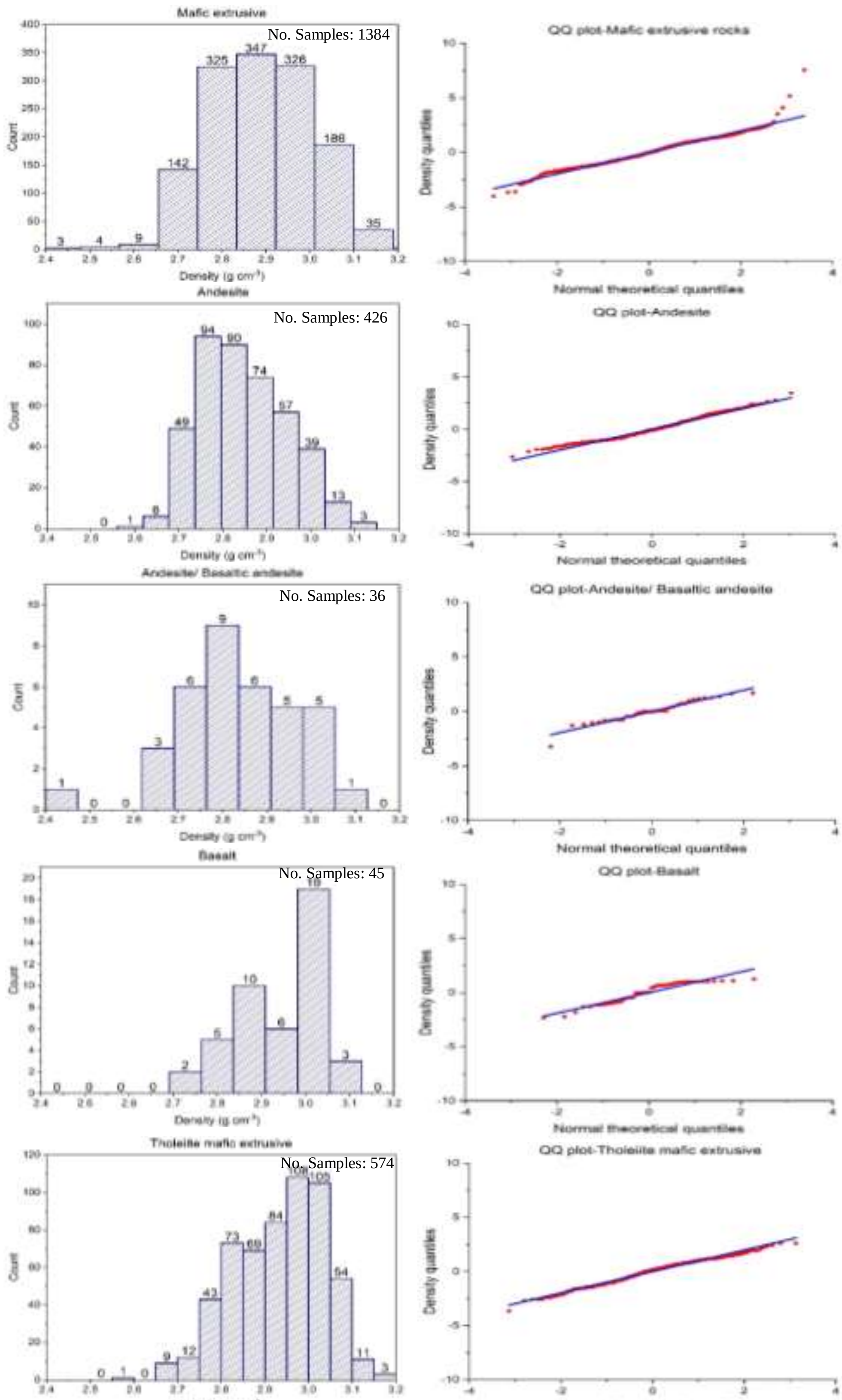


Figure 17- Density measurements of mafic extrusive rocks and major lithological units of this hierarchy in the Abitibi Greenstone Belt. The left column displays histograms of the values (g cm^{-3}) and the right column shows the quartile-quartile (QQ) plots.

Magnetic susceptibility investigations of mafic extrusive rocks were performed using a total of 2747 measurements returning a wide range of magnetic susceptibility values (0—565.60 × 10^{-3} SI) with mean and median values of 8.51 and 0.73 × 10^{-3} SI, respectively. Based on the QQ plot, the overall unit indicates either a significant right skewed distribution or an extended right tailed distribution. However, the majority of magnetic susceptibility measurements (2226 out of the total 2747 measurements) display relatively non-magnetic values (< 10 × 10^{-3} SI) exhibiting a unimodal normal distribution with mean and median magnetic susceptibility values of 1.24 and 0.65 × 10^{-3} SI, respectively. This character is indicative of overall heterogeneity in this sub-group.

Andesite has 22 associated magnetic susceptibility measurements which are not adequate for a reliable characterisation. However, these magnetic susceptibility measurements return generally a non-magnetic unit with the mean and median values of 0.51 and 0.53 × 10^{-3} SI, respectively, which these values may be considered as useful approximate values that may be useful to some extent. There are 32 measurements of the magnetic susceptibility of basalt, which show a unimodal normal distribution with the mean and median magnetic susceptibilities of 7.48 and 0.86 × 10^{-3} SI, respectively. This unit contains three anomalously high measured values (>50 × 10^{-3} SI) which are not compatible with the other measurements, hence, they have been exempted from the characterisations. The mean magnetic susceptibility after removing outliers is 0.84 × 10^{-3} SI which is close to the median and is the characteristic value assigned to this unit. Figure 18 shows the histogram and QQ plots of magnetic susceptibility measurements of this hierarchy.

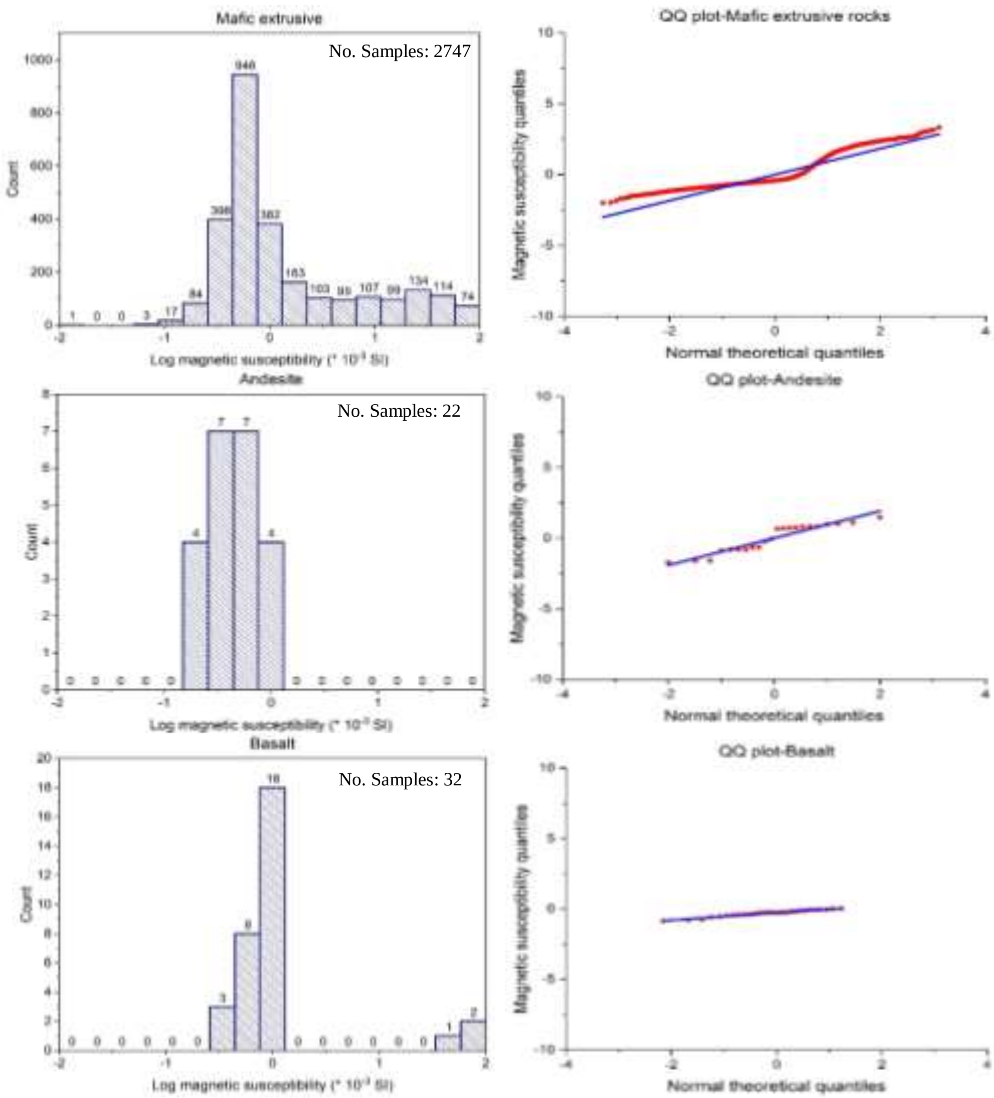


Figure 18- Magnetic susceptibility measurements of mafic extrusive rocks and major lithological units of this hierarchy in the Abitibi Greenstone Belt shown on a $\log_{10}$ scale. The left column displays histograms of the values (× 10^{-3} SI) and the right column shows the quartile-quartile (QQ) plots.

5.10. Ultramafic extrusive (komatiite) rocks

This hierarchy mainly consists of komatiite and "ultramafic volcanics". Totally, there are 344 density measurements classed into this package, which express a wide range of densities with a weak bimodal distribution. Both populations return relatively high density values that allow us to estimate one property for this unit. This population returns a mean density of 2.89 g cm^{-3} and a median value of 2.91 g cm^{-3}. The bimodal distribution of this unit and the presence of outlying density values led to selecting the median density of 2.91 g cm^{-3} as the representative density of this unit.

Characterising magnetic susceptibility values of the ultramafic extrusive rocks was performed using a total of 473 measurements. The susceptibility values associated with this unit has a weak bimodal distribution with two main subpopulations. Therefore, this hierarchy is divided into two units based on their magnetic susceptibility values. Unit 1 (104 measurements) has low magnetic susceptibility values with mean and median values of 0.37 and 0.39 × 10^{-3} SI, respectively. In contrast, unit 2 (366 measurements) highlights high magnetic susceptibilities with a mean value of 32.33 × 10^{-3} SI and a median value of 23.92 × 10^{-3} SI. Figure 19 shows the histograms and QQ plots for the density and magnetic susceptibility of ultramafic extrusive.

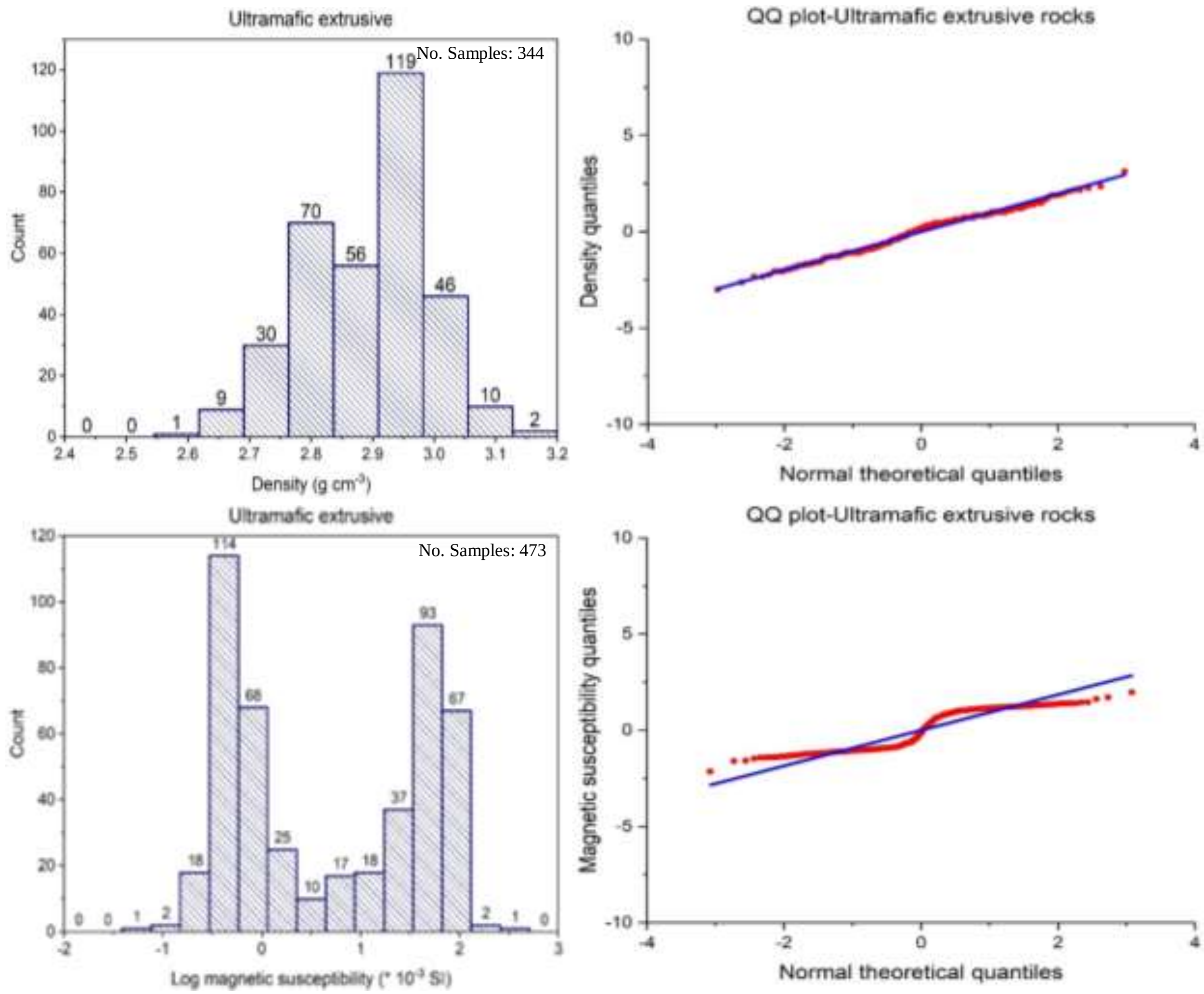


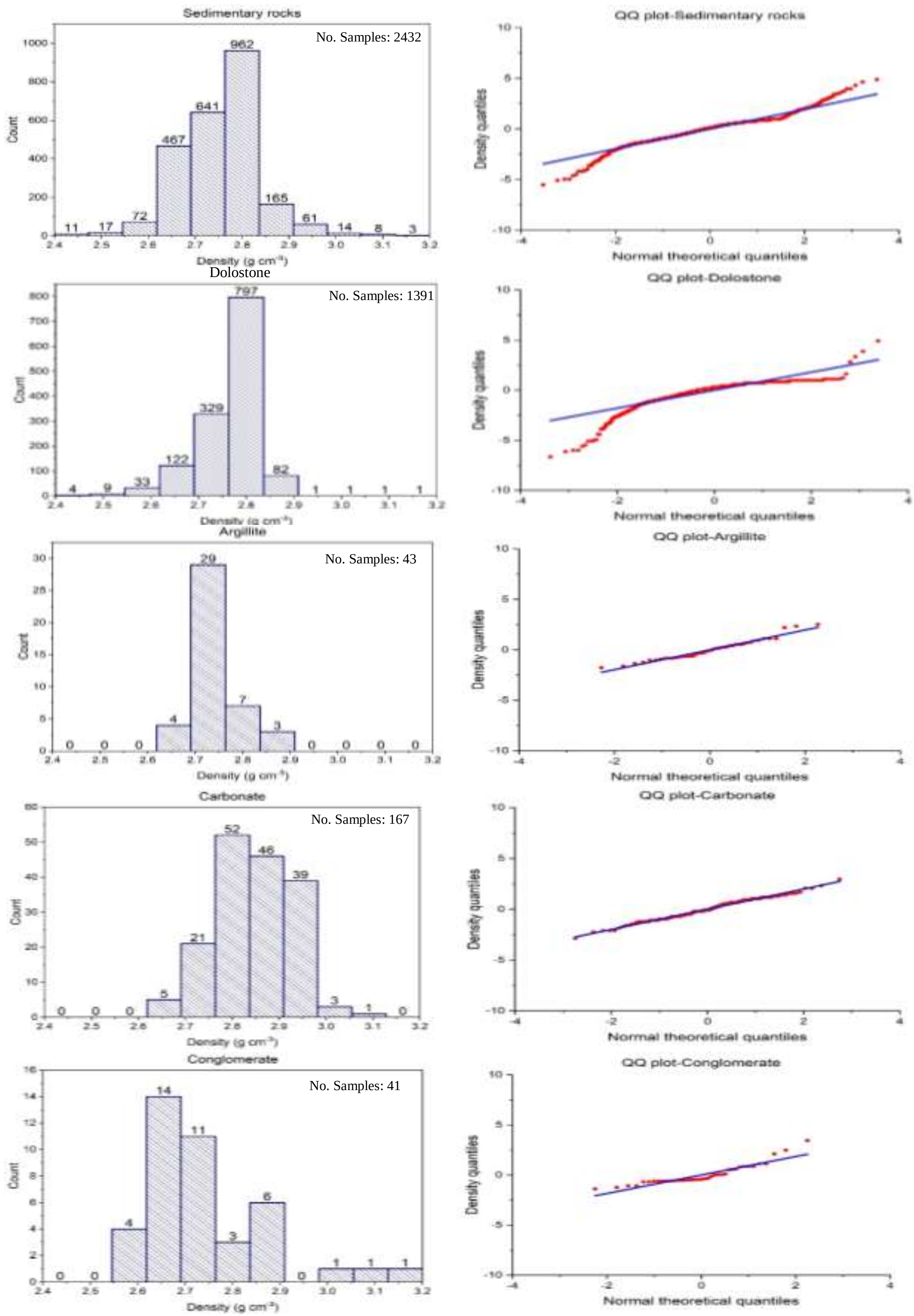
Figure 19- Petrophysical measurements of ultramafic extrusive rocks in the Abitibi Greenstone Belt. The top row displays density (g cm^{-3}) measurements. The bottom row indicates magnetic susceptibility (× 10^{-3} SI) values at $\log_{10}$ scale. The left column displays the histograms and the right column shows the QQ plots).

5.11. Sedimentary rocks

The statistical characterization of the density of sedimentary rocks utilized a great number of density measurements (a total of 2432), which display a wide range of values from 2.30 g cm^{-3} to >3.10 g cm^{-3}. This wide range of density variations associated with different rock units result in a non simple unimodal normal distribution. Therefore, the QQ plot of this package indicates a relatively asymmetrical distribution with flat tails. This hierarchy has mean and median density values of 2.75 and 2.76 g cm^{-3}, respectively. These values are not reliable and representative because of the inhomogeneity associated with different rock units within the hierarchy.

The majority of measurements in this sub-group are classed as dolostone with a total of 1391 associated density measurements. Most of the dolostones are assigned to the Silurian period (416—443.7 Ma) and exhibit a wide range of density values with mean and median values of 2.77 and 2.79 g cm^{-3}, respectively. While this package does not exhibit either a simple unimodal nor a normal distribution, high number of density measurements allow us to assign the mean value of 2.77 g cm^{-3} to this unit and this value should be considered with a higher level of uncertainty and caution.

Some of the other sedimentary units include argillite (43 measurements, displaying a unimodal normal distribution with mean and median values of 2.74 and 2.73 g cm^{-3}, respectively), arkose (18 measurements, with a mean of 2.72 g cm^{-3}), and carbonate (167 measurements, unimodal normally distributed with a mean of 2.85 g cm^{-3} and a median of 2.84 g cm^{-3}). In addition, 41 measurements of conglomerate, including the Huronian conglomerate, show a poorly defined bimodal distribution with a positive skew and a mean of 2.74 g cm^{-3} and a median of 2.69 g cm^{-3}, respectively. Because of the bimodal distribution, and the presence of outliers with the main density accumulation between 2.60 and 2.70 g cm^{-3}, the median density value of 2.69 g cm^{-3} was assigned to this unit. Greywacke had 49 associated measurements and these show a relatively unimodal normal distribution with mean and median values of 2.74 and 2.73 g cm^{-3}, respectively. There are 139 measurements of the density assigned to limestone, and these display a unimodal and relatively normal distribution with the same mean and median value of 2.68 g cm^{-3}. Exempting outliers, mudstone density values (112 measurements) display a unimodal normal distribution with the same mean and median density value of 2.77 g cm^{-3}. Sandstone (310 measurements) also has a unimodal distribution with a positive skew and the mean and median density values of 2.68 and 2.67 g cm^{-3}, respectively. Finally, wacke contains 109 density measurements that exhibit a unimodal and a right-tailed distribution with the mean density of 2.76 g cm^{-3} and median value of 2.75 g cm^{-3}. Histograms and QQ plots of the density for different sedimentary lithological units are presented in Figure 20.


Sedimentary rocks
No. Samples: 2432
Count
Density (g cm⁻³)
QQ plot-Sedimentary rocks
Density quantiles
Normal theoretical quantiles
Dolostone
No. Samples: 1391
QQ plot-Dolostone
Argillite
No. Samples: 43
QQ plot-Argillite
Carbonate
No. Samples: 167
QQ plot-Carbonate
Conglomerate
No. Samples: 41
QQ plot-Conglomerate

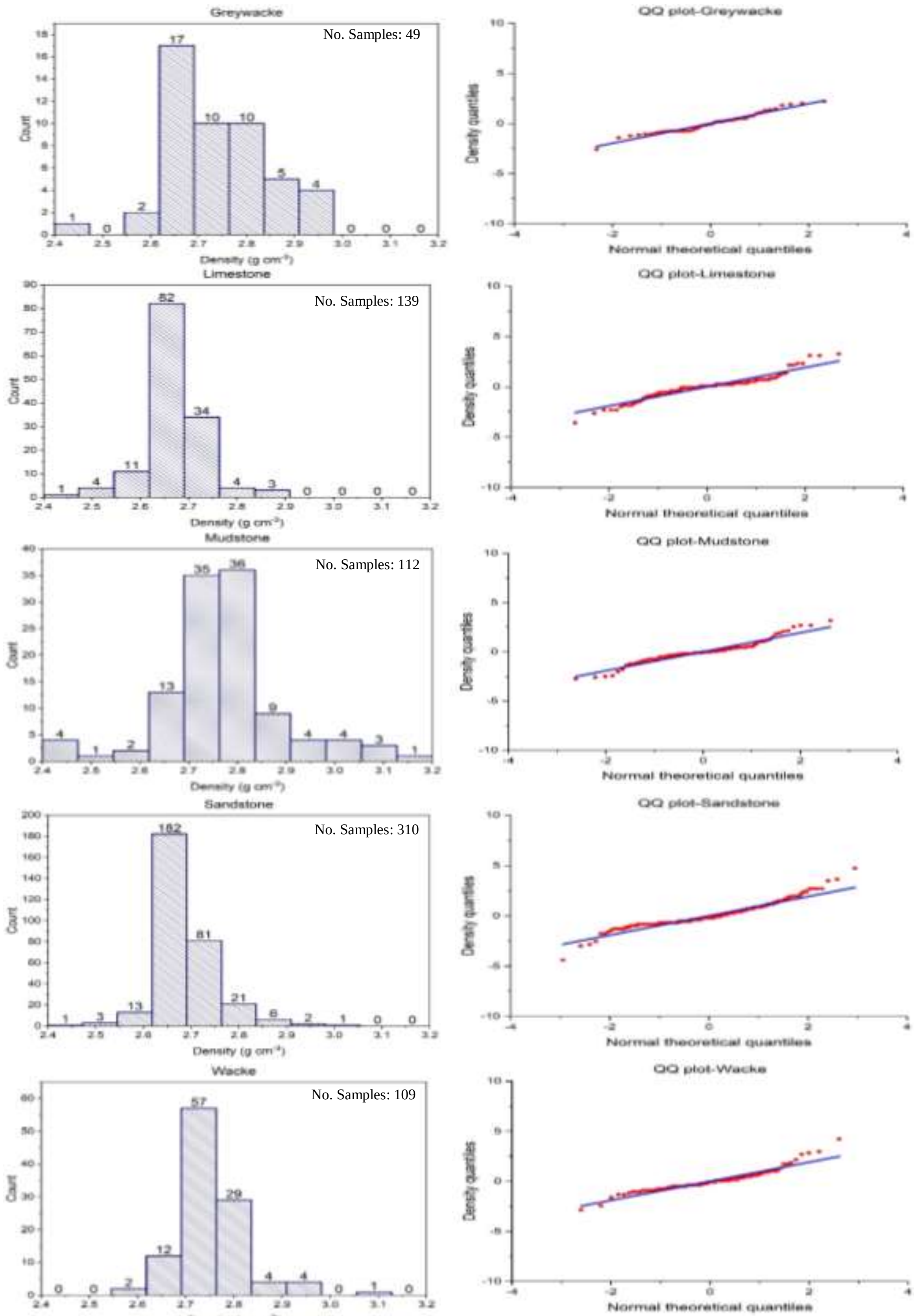
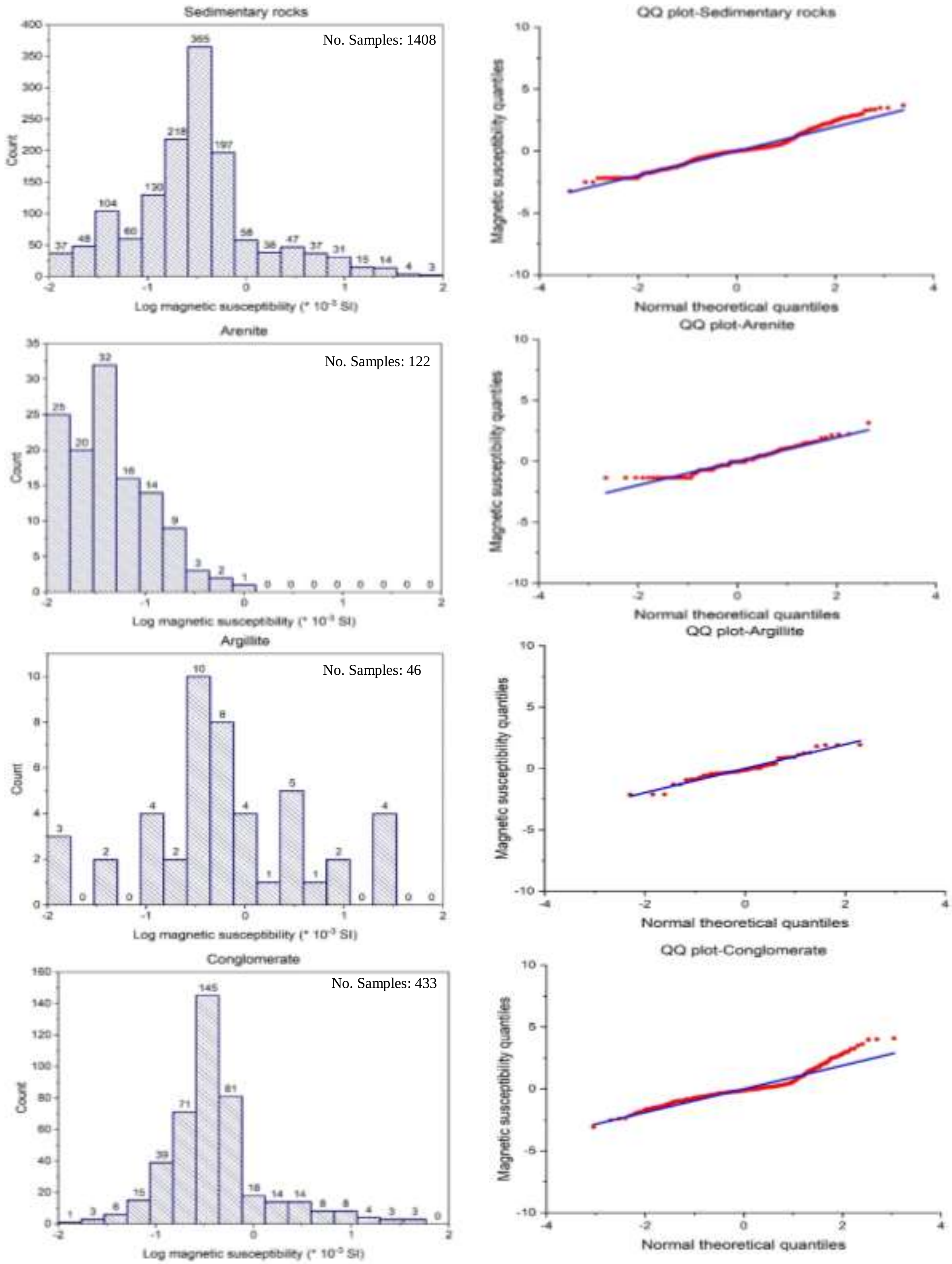


Figure 20- Density measurements of sedimentary rocks and major lithological units of this hierarchy in the Abitibi Greenstone Belt. The left column displays histograms of the values (g cm^{-3}) and the right column shows the quartile-quartile (QQ) plots.

Magnetic susceptibility measurements of sedimentary rocks consist of 1408 readings exhibiting a generally relatively unimodal normal distribution of dominantly non-magnetic material. The mean and median magnetic susceptibility values of this package are 1.45 and 0.30 × 10^{-3} SI, respectively.

Focusing on sedimentary rock units, arenite consists of 122 magnetic susceptibility measurements displaying a relatively non-magnetic normal distribution with the mean and median values of 0.08 and 0.04 × 10^{-3} SI, respectively. Similarly, 46 measurements of argillite return a unimodal distribution of generally non-magnetic units with the mean and median of 3.37 and 0.48 × 10^{-3} SI, respectively. Likewise, conglomerate includes 433 measurements of a unimodal, generally non-magnetic unit with a positive skew and a mean of 1.39 × 10^{-3} SI and a median of 0.34 × 10^{-3} SI. Greywacke also consists of 23 typically non-magnetic values normally distributed with mean and median values of 0.77 and 0.40 × 10^{-3} SI, respectively.

In addition, 78 measurements classed as mudstone show a primarily unimodal distribution of a non-magnetic unit, excluding the right-tail, with the mean and median values of 3.06 and 0.32 × 10^{-3} SI, respectively. The existence of the right tail suggests that the median value of 0.32 × 10^{-3} SI is representative for mudstone. For sandstone, there are 222 measurements with a unimodal normal distribution and a mean of 0.69 × 10^{-3} SI and a median value of 0.11 × 10^{-3} SI. Finally, wacke has 159 associated measurements that show a non-magnetic unimodal distribution with a right-tail and mean and median values of 1.25 and 0.33 × 10^{-3} SI, respectively. Figure 21 displays the histograms and QQ plots of magnetic susceptibility values for different sedimentary lithological units.



Sedimentary rocks
No. Samples: 1408
Count
Log magnetic susceptibility (* 10⁻³ SI)
QQ plot-Sedimentary rocks
Magnetic susceptibility quantiles
Normal theoretical quantiles
Arenite
No. Samples: 122
QQ plot-Arenite
Argillite
No. Samples: 46
QQ plot-Argillite
Conglomerate
No. Samples: 433
QQ plot-Conglomerate

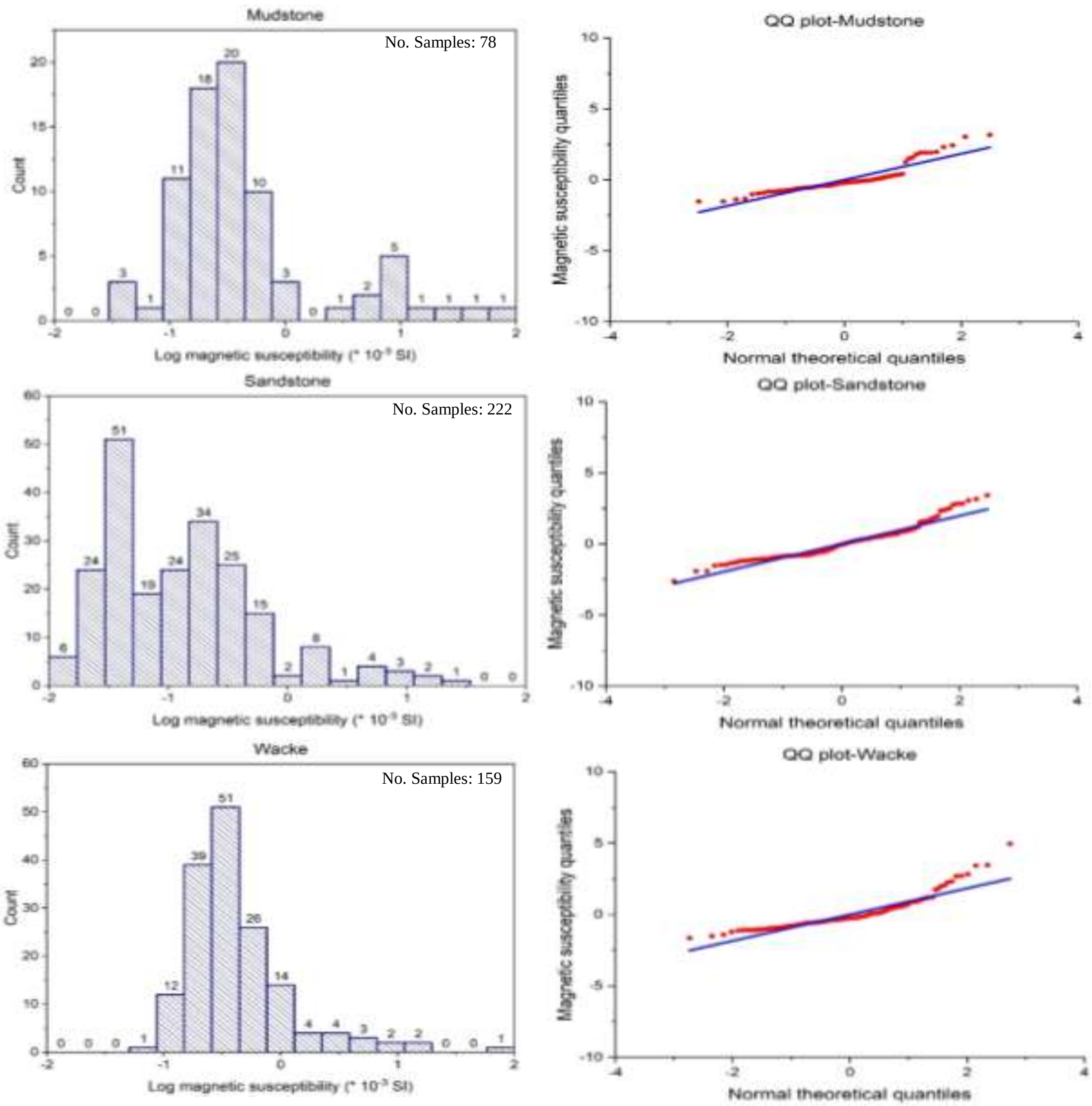


Figure 21- Magnetic susceptibility measurements of sedimentary rocks and major lithological units of this hierarchy in the Abitibi Greenstone Belt shown on a $\log_{10}$ scale. The left column displays histograms of the values ($\times 10^{-3}$ SI) and the right column shows the quartile-quartile (QQ) plots.

5.12. Volcanoclastic rocks

There are 668 density measurements associated with volcanoclastic rocks in this database; they exhibit a weak bimodal distribution that is interpreted as an extended right-tailed distribution based on the QQ plot. This package has mean and median values of 2.86 and 2.84 g cm^{-3}, respectively, with two major populations evident. The first population occupies a density range between 2.66 and 2.80 g cm^{-3}, and the other one lies in a range of 2.95 to 3.10 g cm^{-3}.

The major rock units within this sub-group in the database are pyroclastic and tuff. There are 34 density measurements of the pyroclastic unit, which display a unimodal and relatively normal distribution with the same mean and median of 2.74 g cm^{-3}. Measurements of tuff that do not fall into the felsic, intermediate or mafic sub-group are assigned to the volcanoclastic unit. There are 629 measurements which show as a weak bimodal distribution with a right-tail and the mean and median values of 2.87 and 2.85 g cm^{-3}, respectively. This rock unit is weakly bimodal with two peaks between 2.71—2.74 g cm^{-3} (82 measurements) and 3.03—3.06 g cm^{-3} (84 measurements). This indicates that tuffs can be divided into two sub-groups characterised by either medium density (2.76 g cm^{-3}) or high density (3.03 g cm^{-3}) values. Histograms and QQ plots of the density for different lithological units of the volcanoclastic sub-group are presented in Figure 22.

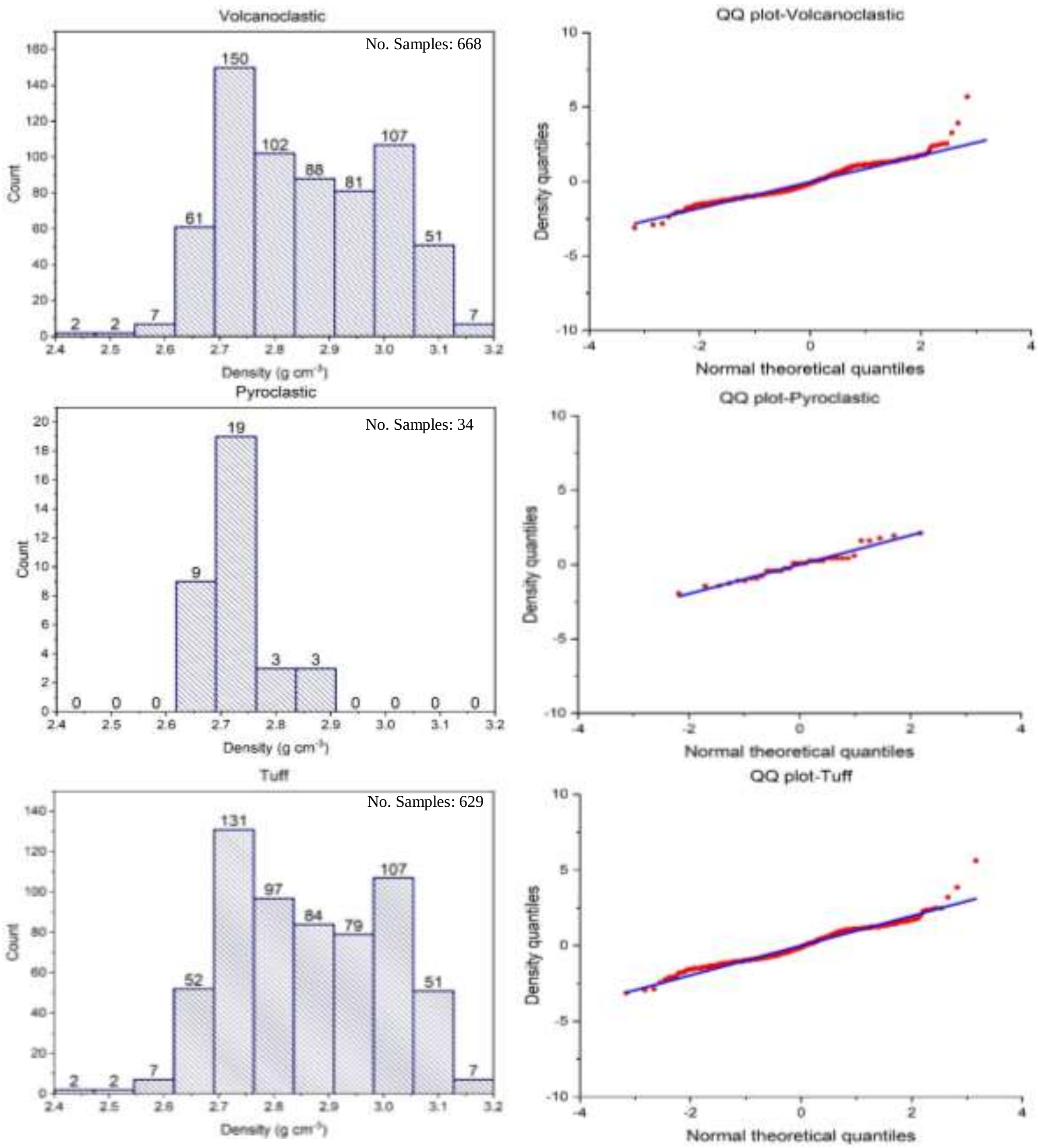


Figure 22- Density measurements of volcanoclastic rocks and major lithological units of this hierarchy in the Abitibi Greenstone Belt. The left column displays histograms of the values (g cm^{-3}) and the right column shows the quartile-quartile (QQ) plots.

There are only 16 magnetic susceptibility measurements in the database, so volcanoclastic rocks are under sampled, preventing a reliable classification. However, these low number of measurements have the mean and median values of 0.34 and 0.31 × 10^{-3} SI, respectively. These values may be considered as useful approximate values that may be useful to some extent.

5.13. Altered-metamorphic sub-group

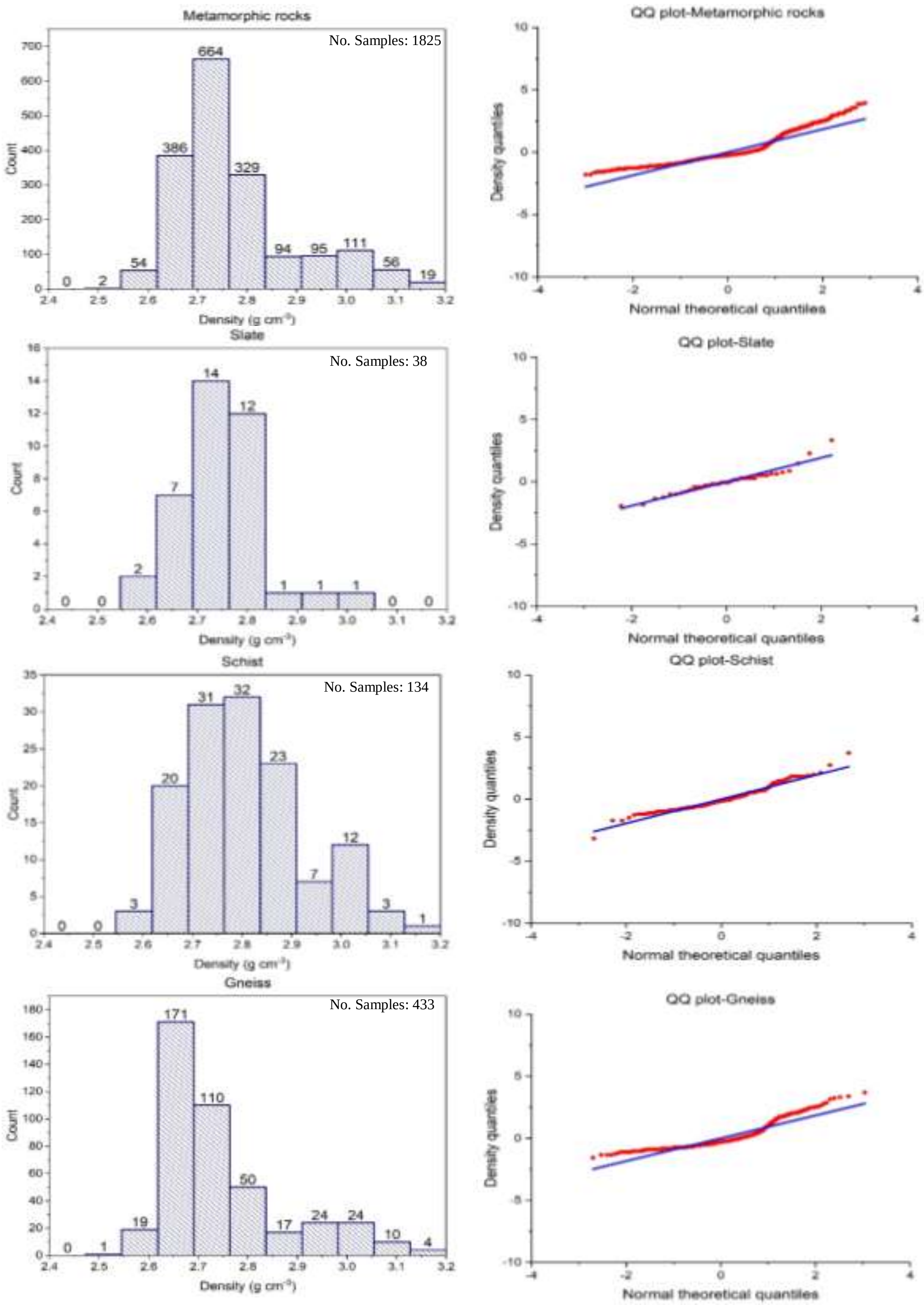
Altered and metamorphic rocks in this database are associated with 1825 density measurements. The values in this hierarchy display a wide range of density values (2.24—3.58 g cm^{-3}) highlighting a unimodal distribution, with either a positive skew or an extended right tailed distribution based on the QQ plot, and the mean and median values of 2.78 and 2.75 g cm^{-3}, respectively.

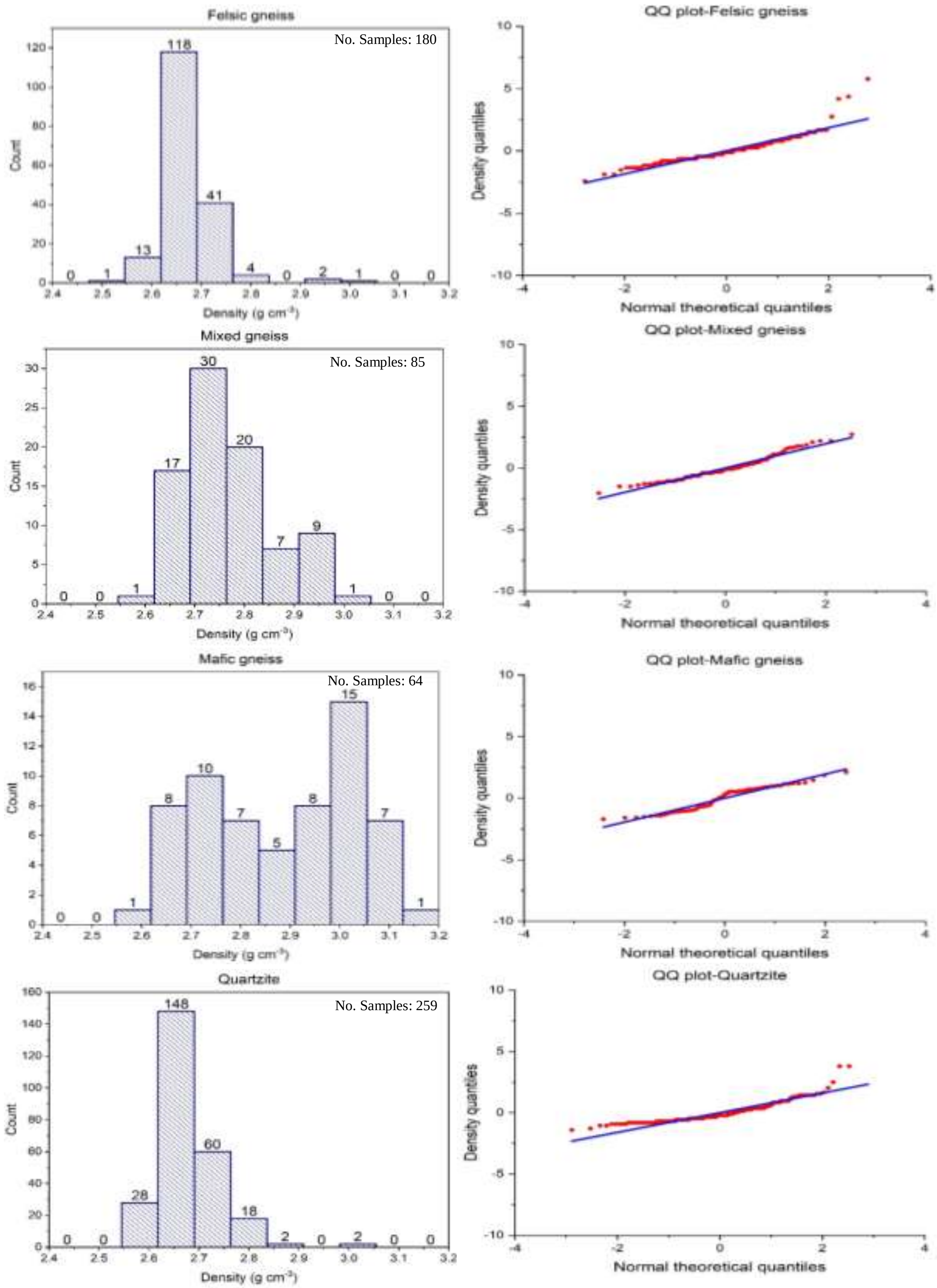
Based on the degree of metamorphism, the database contains density measurements of slate, schist and gneiss. Density values of slate consist of 38 measurements that show a unimodal normal distribution with mean and median values of 2.75 and 2.74 g cm^{-3}, respectively. Density measurements classed as schist consist of 134 measurements highlighting a wide range of density values with the strongest accumulation between 2.65 and 2.85 g cm^{-3}. After exempting outliers, this unit shows a relatively unimodal distribution with a slightly positive skew and mean and median density values of 2.81 and 2.79 g cm^{-3}, respectively. Based on the skew of the distribution, the median value of 2.79 g cm^{-3} is assigned to schist.

In addition, density measurements of gneiss rock type consist of 433 measurements classed as felsic, mixed, and mafic gneiss. These gneisses show a unimodal distribution, based on the histogram, and non-normal distribution, based on the QQ plot, with either a positive skew or a right-tailed distribution, and a wide range of density values with mean and median density values of 2.75 and 2.71 g cm^{-3}, respectively. In further detail, felsic gneiss (i.e. felsic gneiss, tonalite gneiss and granite gneiss) has 180 measurements indicating a unimodal normal distribution, exempting outliers, with the mean and median of 2.68 and 2.67 g cm^{-3}, respectively. Mixed gneiss (85 measurements) show a unimodal largely normal distribution with a mean density of 2.75 g cm^{-3} and a median value of 2.74 g cm^{-3}. In contrast, mafic gneiss (64 measurements) exhibit a strongly bimodal non-normal distribution with relatively high mean and median density values of 2.90 and 2.95 g cm^{-3}, respectively. The skewed distribution suggests that the median density value of 2.95 g cm^{-3} is assigned as the typical value of the mafic gneiss.

The altered metamorphic sub-group also contains different rock units with adequate measurements for characterisation, such as quartzite, metasedimentary rocks of the Pontiac Group, migmatite (migmatized supracrustal rocks) and amphibolite. Density measurements classed as quartzite (259 measurements) show a unimodal distribution with a positive skew, exempting outliers, and mean and median density values of 2.68 and 2.66 g cm^{-3}, respectively. Density values of metasedimentary rocks of the Pontiac Group were measured by the Footprints and ME projects and comprise 595 measurements displaying a unimodal and right-tailed distribution, excluding outliers, with the identical mean and median density value of 2.75 g cm^{-3}. A total number of 147 measurements classed as amphibolite have a unimodal and relatively normal distribution with the mean and median densities of 2.97 and 2.99 g cm^{-3}, respectively.

Migmatite rocks (39 density measurements) return a strongly bimodal and uniform distribution with two completely distinct populations (range of 2.66—2.84 g cm^{-3} and density values > 3.00 g cm^{-3}). Overall mean and median values of these measurements are 2.95 and 3.01 g cm^{-3} respectively, but it is not really appropriate to assign a simple density value to this unit. Therefore, while this report does suggest using the median value of 3.01 g cm^{-3} as the typical value for this unit, collecting more density measurements for this unit could assist in assigning a more representative value. Histograms and QQ plots of the density for different lithological units of the altered metamorphic hierarchy are presented in Figure 23.


Metamorphic rocks
No. Samples: 1825
0
2
54
386
664
329
94
95
111
56
19
Count
Density (g cm⁻³)
QQ plot-Metamorphic rocks
Density quantiles
Normal theoretical quantiles
Slate
No. Samples: 38
0
0
2
7
14
12
1
1
1
0
0
Count
Density (g cm⁻³)
QQ plot-Slate
Density quantiles
Normal theoretical quantiles
Schist
No. Samples: 134
0
0
3
20
31
32
23
7
12
3
1
Count
Density (g cm⁻³)
QQ plot-Schist
Density quantiles
Normal theoretical quantiles
Gneiss
No. Samples: 433
0
1
19
171
110
50
17
24
24
10
4
Count
Density (g cm⁻³)
QQ plot-Gneiss
Density quantiles
Normal theoretical quantiles


Felsic gneiss
No. Samples: 180
Count
Density (g cm⁻³)
QQ plot-Felsic gneiss
Density quantiles
Normal theoretical quantiles
Mixed gneiss
No. Samples: 85
Count
Density (g cm⁻³)
QQ plot-Mixed gneiss
Density quantiles
Normal theoretical quantiles
Mafic gneiss
No. Samples: 64
Count
Density (g cm⁻³)
QQ plot-Mafic gneiss
Density quantiles
Normal theoretical quantiles
Quartzite
No. Samples: 259
Count
Density (g cm⁻³)
QQ plot-Quartzite
Density quantiles
Normal theoretical quantiles

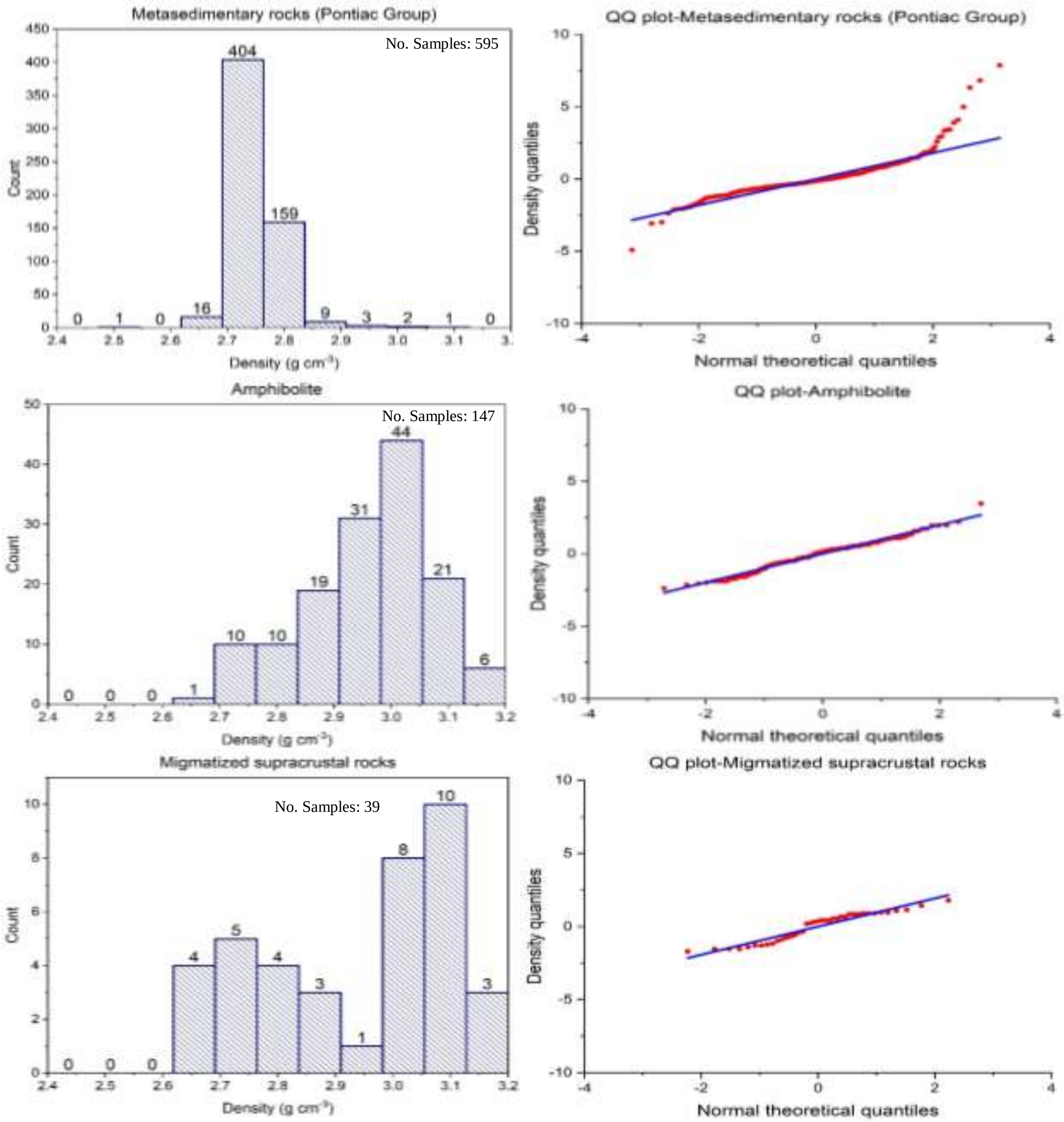


Figure 23- Density measurements of metamorphic rocks and major lithological units of this hierarchy in the Abitibi Greenstone Belt. The left column displays histograms of the values (g cm^{-3}) and the right column shows the quartile-quartile (QQ) plots.

Magnetic susceptibility characterisation of altered metamorphic rocks was performed using 1111 measurements, which show a generally unimodal distribution, excluding outliers. These measurements return mean and median magnetic susceptibility values of 3.45 and 0.36 × 10^{-3} SI, respectively. While the unit presents a unimodal distribution, there is a positive skew and both left-and right-tailed distribution with a wide range of magnetic susceptibility values from non-magnetic to highly magnetic. However, the vast majority of measurements have low-magnetic values with few magnetic susceptibility measurements returning significantly large values (14 measurements with magnetic susceptibility values > 50×10^{-3} SI).

Within this hierarchy in the database, slate is under sampled with 13 measurements; the values infer a non-magnetic unit with mean and median values of 0.89 and 0.63×10^{-3} SI, respectively. Rock units with sufficient number of measurements include gneiss, quartzite, metasedimentary rocks of the Pontiac Group and amphibolite. A total of 277 measurements are classed as gneiss and these show a weak bimodal distribution with mean and median values of 5.60 and 0.73×10^{-3} SI, respectively. This unit consists of a major population (unit 1) characterised by low-magnetic values and the second minor population (unit 2) with relatively high magnetic values. The differences in susceptibility could be due to the texture of the gneiss, similar to density database (felsic or mafic gneiss). However, gneiss is not differentiated based on their texture in the magnetic database.

Quartzite consists of 26 magnetic susceptibility measurements displaying a coherently non-magnetic, normally distributed unit with similar mean and median magnetic susceptibility values of 0.24×10^{-3} SI. As with the density measurements, the Footprints project collected magnetic susceptibility measurement across metasedimentary rocks of the Pontiac Group, consisting of 581 magnetic susceptibility measurements, exhibiting a non-magnetic unimodal and extended tailed distribution with the mean and median values of 0.86 and 0.29×10^{-3} SI, respectively. This unit exhibit some minor populations of outliers which resulted in a non-normal distribution based on the QQ plot which were excluded in the characterisations. Finally, 166 measurements are classed as amphibolite and these show a unimodal distribution with a positive skew and a mean magnetic susceptibility of 7.20×10^{-3} SI and a median of 0.83×10^{-3} SI. Figure 24 shows the histograms and QQ plots of magnetic susceptibility values of the metamorphic hierarchy.

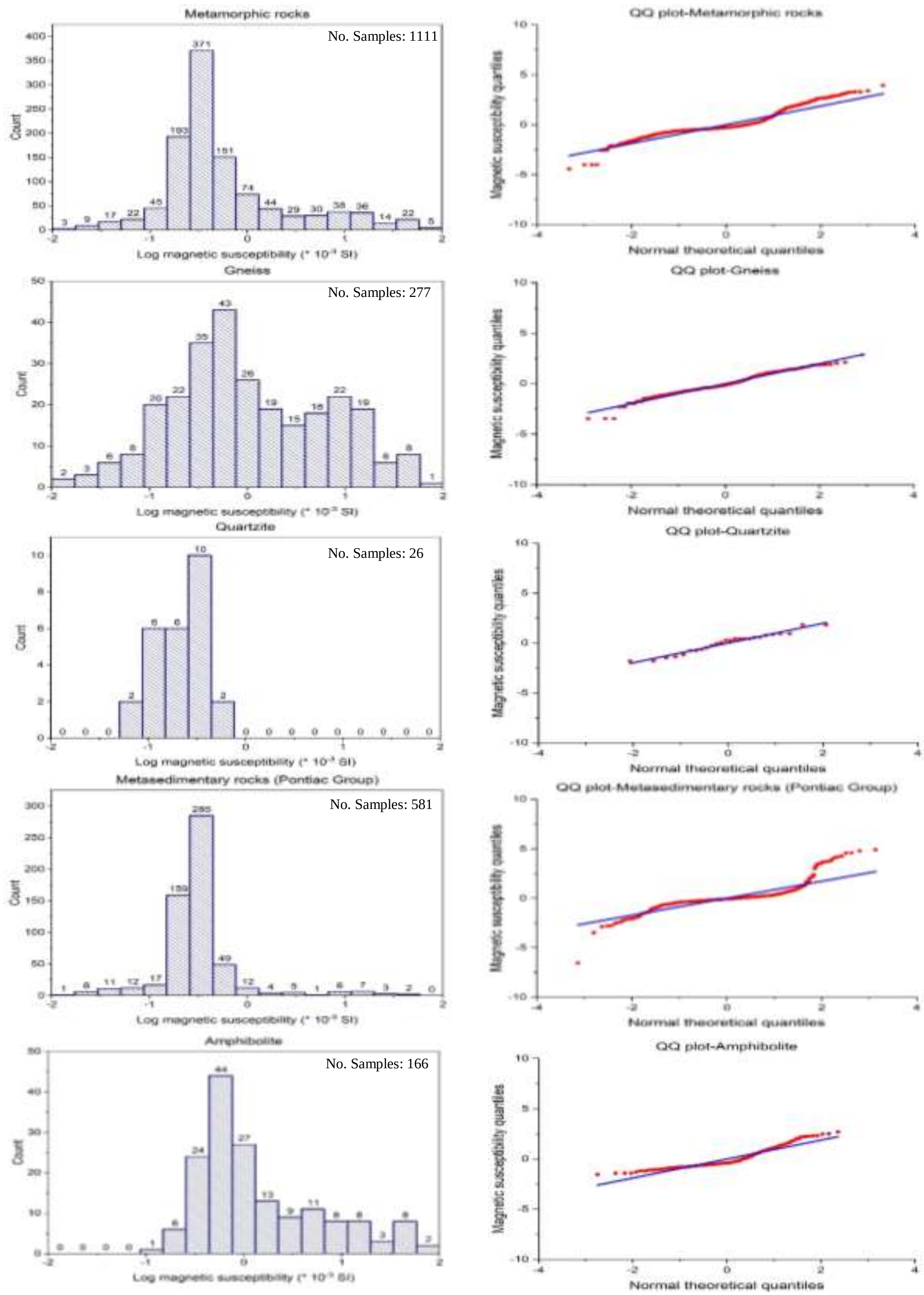


Figure 24- Magnetic susceptibility measurements of metamorphic rocks and major lithological units of this hierarchy in the Abitibi Greenstone Belt shown on a $\log_{10}$ scales. The left column displays histograms of the values ($\times 10^{-3}$ SI) and the right column shows the quartile-quartile (QQ) plots.

5.14. Fault rocks

In this database, density values classed as rock types typical along faults (i.e. cataclasite, mylonite and pseudotachylite) are characterised independently. When these are grouped together, the database consists of 49 density measurements displaying a unimodal normal distribution with the same mean and median value of 2.78 g cm^{-3}. This unit does not have magnetic susceptibility measurements for characterisation. Figure 25 presents the histogram and QQ plot of density values for fault rocks.

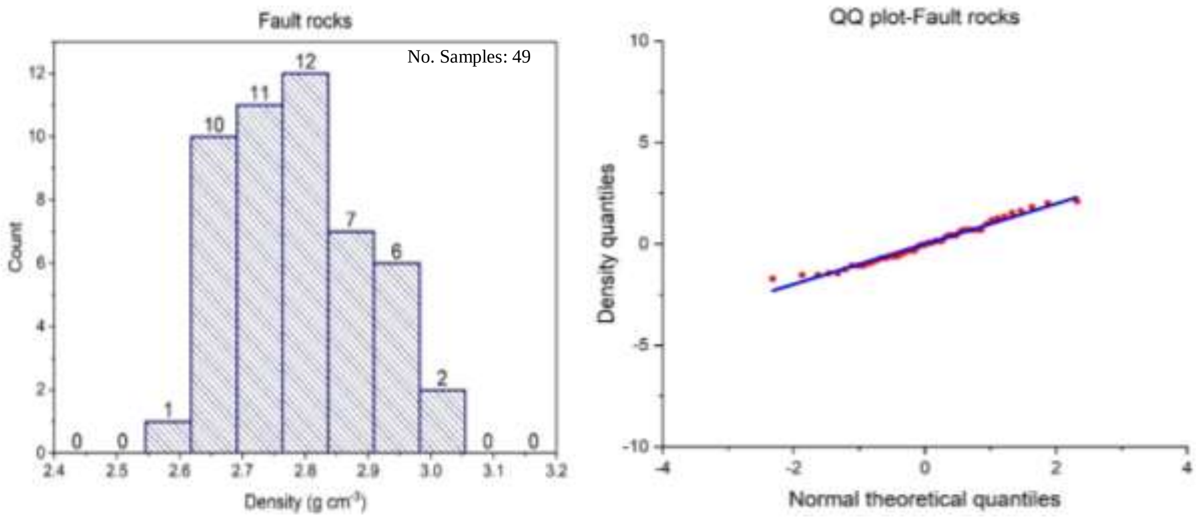


Figure 25- Density measurements of fault rocks in the Abitibi Greenstone Belt. The left column displays the histogram of the values (g cm^{-3}) and the right column shows the quartile-quartile (QQ) plot.

5.15. Banded Iron Formation (BIF)

There are no density measurements classed as banded iron formation (BIF), but there are 188 associated magnetic susceptibility measurements in the database. Typically, the values are large and based on the histogram and QQ plots exhibit a moderate bimodal distribution consisting of magnetic values with overall mean and median values of 158.01 and 75.66 × 10^{-3} SI, respectively. The histogram shows two populations, the first, with low-magnetic values have a mean susceptibility of 1.47 × 10^{-3} SI, and the second population returns a significantly higher mean value of 226.11 × 10^{-3} SI. So, it is difficult to provide one simple representative value for the entire hierarchy.

Two major units with sufficient number of measurements within this hierarchy are iron formation (IF)-sulphide and IF-oxide. The IF-sulphide (73 measurements) displays slightly uniform distribution with a wider range of magnetic values from relatively non-magnetic to high magnetic susceptibility values. In contrast, the IF-oxide contains 109 measurements that have an extended left-tailed distribution and typically high magnetic values, disregarding a small number of low-magnetic outliers. In summary, IF-sulphide presents highly heterogeneous magnetic values from relatively non-magnetic to highly magnetic values and the lower mean and median magnetic susceptibilities of 52.61 and 2.12 $\times 10^{-3}$ SI respectively, whereas, IF-oxide units are more homogeneously magnetized with high mean and median magnetic susceptibility values of 214.40 and 136.39 $\times 10^{-3}$ SI, respectively. Histograms and QQ plots of the magnetic susceptibility values for BIF are presented in Figure 26.

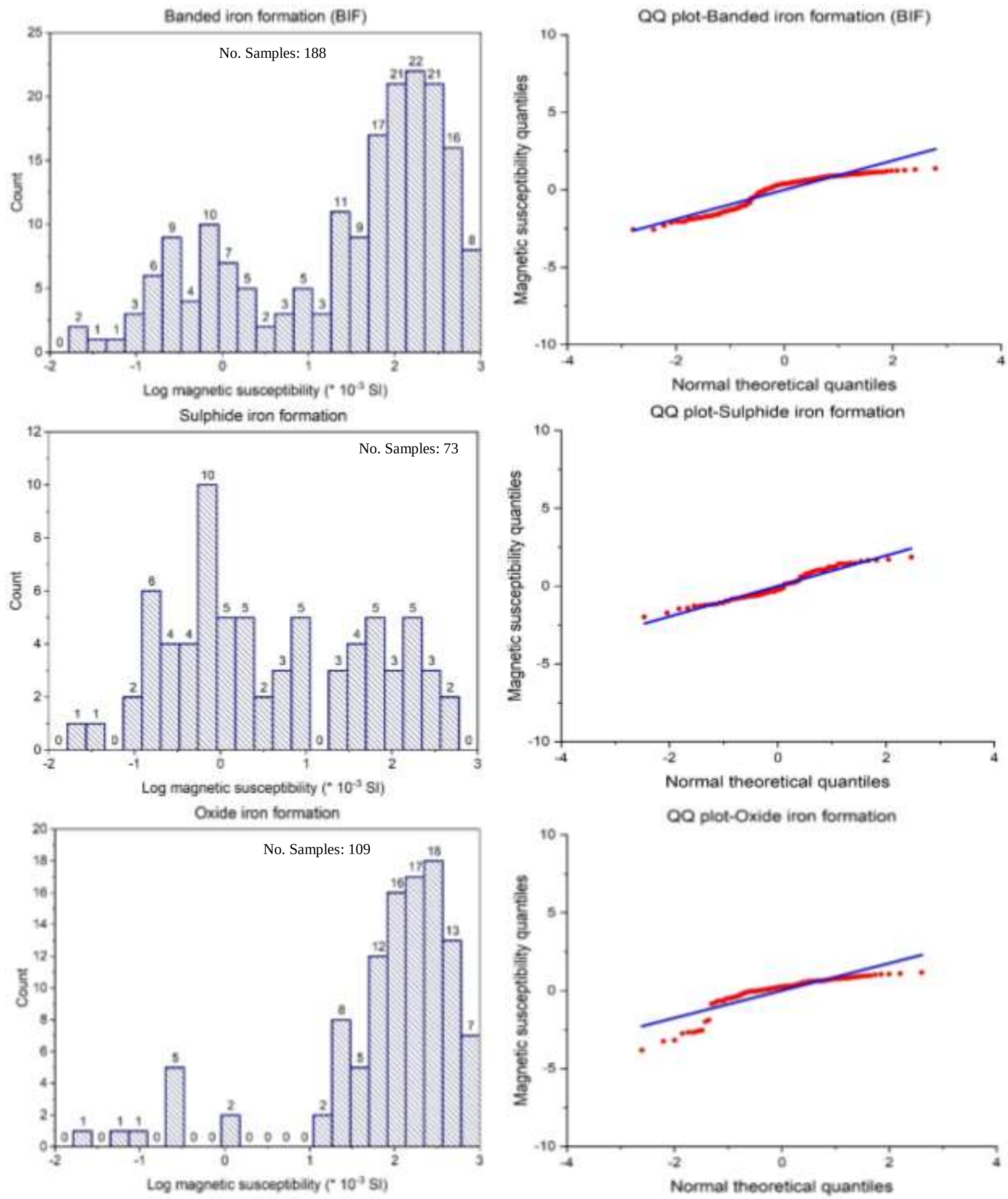


Figure 26- Magnetic susceptibility measurements of banded iron formation (BIF) rocks and major lithological units of this hierarchy in the Abitibi Greenstone Belt shown on a $\log_{10}$ scales. The left column displays histograms of the values ($\times 10^{-3}$ SI) and the right column shows the quartile-quartile (QQ) plots.

6- Petrophysical summary

Petrophysical properties of rock units across the Abitibi Greenstone Belt were systematically analyzed from a database collated from historical databases and augmented with measurements taken by ME field crews. The resulting characterisation is based on a sufficiently large number of measurements that have been classed as different rock units to provide typical values that can be used to constrain the values of physical properties used in future geophysical models. A summary of typical petrophysical values for all rock units is given in this section, where the values or the range of values is explained and a comparison between different hierarchies and units is provided. This section uses box-and-whisker diagrams, where the box spans the range from the 25 to the 75% quartile, the small square is the mean, the central horizontal line is the median and the whiskers show 1.5 × the interquartile range (IQR). IQR is the difference between upper and lower quartiles and is often used to find outliers in data which are typically defined as observations falling below quantile 1 − 1.5 IQR or above quantile 3 + 1.5 IQR. These box and whisker plots are used to display the range of the petrophysical properties for major hierarchies to provide an insight into density and magnetic susceptibility values.

A boxplot of density data for all major hierarchies is shown in Figure 27. Detailed boxplots of different sub-groups are presented in the appendix. Based on the boxplot, there is a general trend of increasing density from felsic igneous rocks toward ultramafic rocks. Granite exhibits the smallest median and the minimum range of density values which emphasises the significance of this units on negative gravity anomalies. In contrast, young dykes (diabase) have anomalously high-density values compared to other units. Based on the composition of diabase, it was initially thought that this unit should have lower densities compared to ultramafic rocks; however, in fact diabase returns higher density values. This could be because metamorphism occurring prior to the emplacement of the younger dykes has resulted in a decrease in the density of the country rock. Another instance is the characterized density properties of ultramafic intrusive dunite. While unaltered dunite is composed mostly of olivine with densities >3.2 g cm^{-3}, nine density measurements of this unit in this database return a mean of 2.70 g cm^{-3} which can show it has altered to serpentine/talc resulting in lower values.

Therefore, based on this data, perhaps metamorphism has reduced the density across the Abitibi Greenstone Belt. In addition, in this boxplot, sedimentary rocks and metamorphic rocks have relatively low-density values, while the volcanoclastic package returns a wide range of density variations.

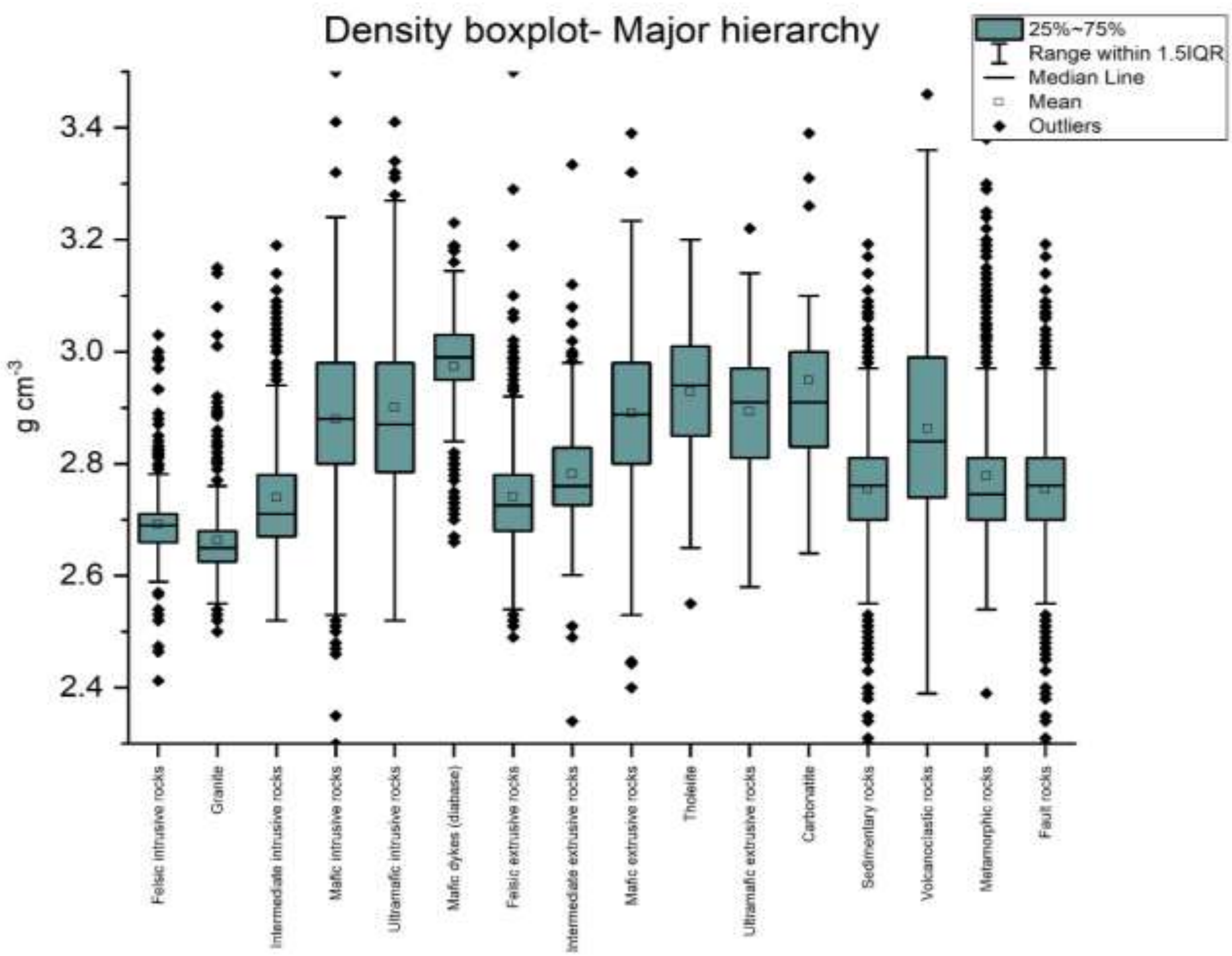


Figure 27- Boxplot analysis of density measurements represented by major lithological units.

Figure 28 displays a boxplot summary of the logarithm of magnetic susceptibility for all major hierarchies. Detailed boxplots of sub-units are presented in the appendix. Felsic and intermediate igneous rocks, sedimentary rocks and metamorphic rocks typically return non-magnetic to low-magnetic values. In contrast, ultramafic igneous rocks, young dykes (diabase) and BIF exhibit large magnetic susceptibility values. These sub-groups are those that are mostly responsible for the anomalous magnetic responses evident on magnetic maps. This boxplot shows a great degree of magnetic susceptibility variations (orders of magnitude) with the highest magnetic heterogeneity belonging to BIF and ultramafic igneous rocks. In general, the larger the values, the greater the spread of values.

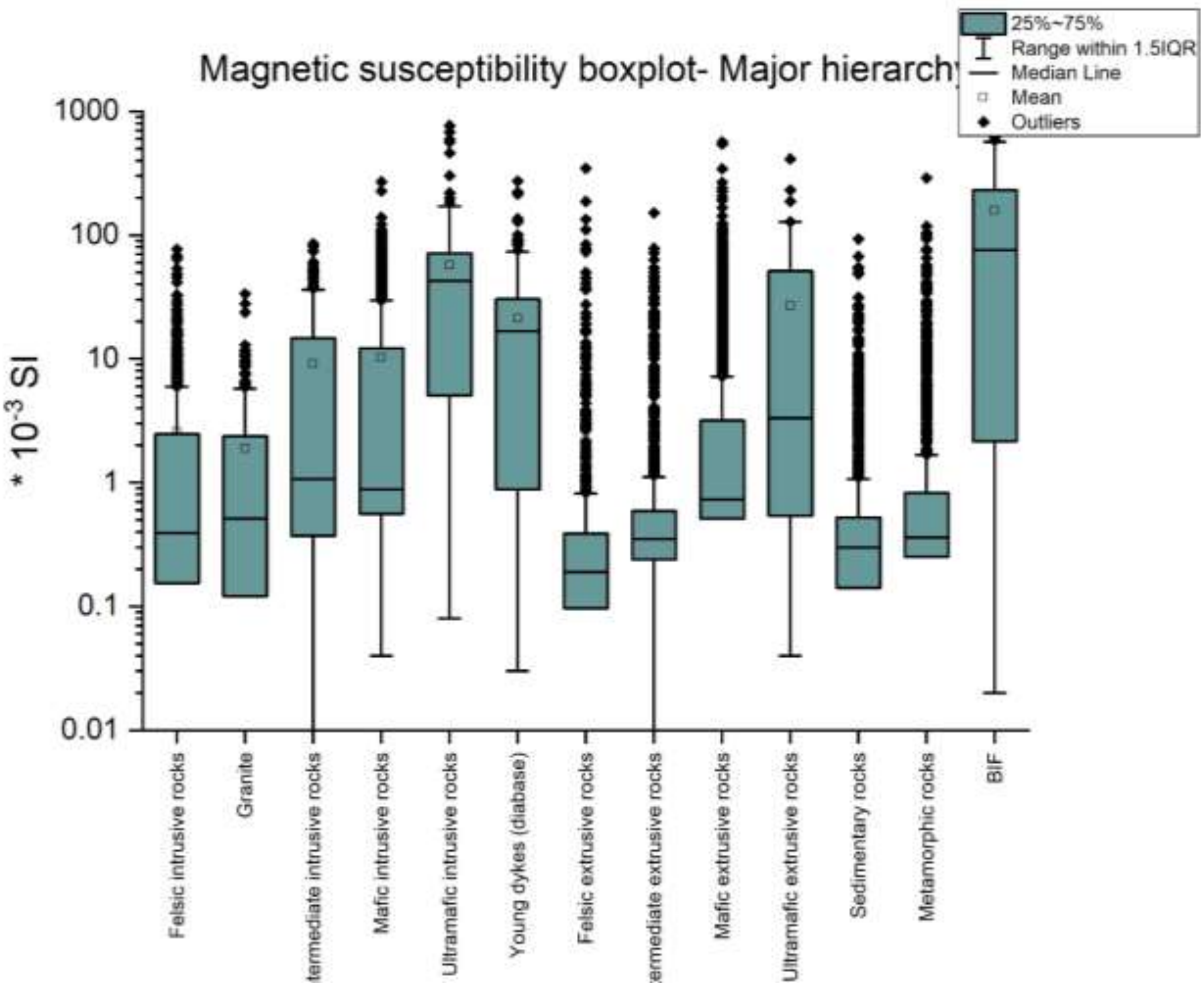


Figure 28- Boxplot analysis of magnetic susceptibility measurements represented by major lithological units.

A comparison between density and magnetic susceptibility values indicates that density values are more homogenous and the degree of variations in magnetic susceptibility is significantly greater. Histograms and QQ plots show that density distribution of units are more unimodal and normally distributed compared to scattered and relatively variable magnetic susceptibility measurements.

Recording of magnetic susceptibility values across a sample is typically heterogeneous, specially within magnetic rocks, due to contribution of nearby magnetite/pyrrhotite to the measurement. For example, a small percentage of magnetite content distributed heterogeneously (in an uneven spatial manner) within a rock sample can change the magnetic values by an order of magnitude.

7- Estimated representative values for sub-groups, units and sub-units

The typical values or maximum and minimum values of rock units, that can be used as constraints during forward modelling and inversion are summarized in this section. There can be a large amount of spatial variabilities within geological units in many properties (e.g. chemical composition, mineralogy and porosity) and/or tectonic evolution factors (e.g. alteration, metamorphism, diagenesis, weathering, hydrothermal or magnetic fluid flow) which can affect physical properties. Therefore, this study tried to mitigate this inherently associated uncertainty in the characterisation by taking into account a range of components and variables impacting on the density and magnetic values. This mitigation was limited by the geological information provided, which was limited to the unit names, so it does not provide a lot of information that might be relevant (e.g. protolith, alteration, etc).

Table 5 provides a summary of the systematically estimated representative density and magnetic susceptibility values and the representative ranges. These ranges are defined based on the representative value ± standard deviation which include ~66% of measurements for major rock units across the Abitibi Greenstone Belt. These typical values can be assigned to lithological units during potential field data inversions.

Although representative values have been selected in Table 5, in some cases a geological unit may be comprised of rock that has an outlier value of the physical property, and the modeller needs to know what these outliers are, so they can be included in the modelling when required, so these outliers have been shown on the histograms. Hence, the recommended procedure for assigning physical properties values to geological units is to start with the representative value in Table 5. If this is not suitable, some value within the range, could be selected (perhaps the mean or medians in tables 3 and 4). If these do not work, the modeller could look at the histograms and perhaps after experimentation one of the outliers might be selected as appropriate.

Table 5- Estimated values derived in this study for major rock units across the Abitibi Greenstone Belt. This value given is either the mean, or the median if there is a distribution that makes using this more appropriate. Values using median as the representative values are shown by asterisk. Some sub-group rocks are divided into different sub-units based on bi-modality in one of their physical properties. Typically, there is no bimodality in the other physical property.

Group	Sub-group	Sub-unit	Density (g cm^{-3})		Magnetic susceptibility (×10^{-3} SI)	
			Value	Range	Value	SD
Felsic intrusive rocks			2.69	2.63—2.75	1.76	6.21
	Granodiorite		2.69	2.63—2.75	2.82	5.53
		Unit 1			0.28	0.21
		Unit 2			5.79	7.06
	Trondhjemite		2.66	2.62—2.70		
	Tonalite				1.44	2.62
	Granite		2.65	2.61—2.69	1.45	3.52
	Felsic to intermediate intrusion		2.69	2.62—2.76	2.27	8.87
		Unit 1			0.21	0.32
		Unit 2			14.90	10.70
Intermediate intrusive rocks			2.74	2.63—2.85	9.14	14.39
	Monzonite		2.66*	2.50—2.82		
	Syenite		2.71	2.63—2.79	11.80	12.37

	Diorite		2.83	2.70—2.95	0.45*	12.01
Mafic intrusive rocks			2.88	2.74—3.02	0.9*	19.74
	Norite		2.88	2.74—3.02	1.63*	6.59
		Unit 1			0.60	0.20
		Unit 2			32.79	26.51
	Norite massive		2.82	2.76—2.88		
	Gabbro		2.94	2.83—3.05	10.53	20.49
	Mafic dykes		2.91	2.81—3.01	2.31	7.41
	Lamprophyre		2.92	2.75—3.09	2.55	1.42
	Anorthosite		2.86	2.75—2.97		
Ultramafic intrusive rocks			2.90	2.72—3.08	62.48	89.55
	Dunite				0.47	0.17
	Peridotite		2.84	2.73—2.95	36.60	17.96
	Pyroxenite		3.13	2.98-3.28	63.18	23.16
Young dykes (diabase)			2.97	2.87—3.07		
		Unit 1			0.83	0.37
		Unit 2			32.12	30.03

Carbonatite			2.91*	2.70—3.12		
Felsic extrusive rocks			2.74	2.65—2.83	2.33	16.23
	Felsic tuffs		2.73	2.65—2.81		
	Rhyolite		2.72	2.64—2.80		
	Rhyodacite		2.77	2.69—2.85		
	Dacite		2.78	2.70—2.86		
Intermediate extrusive rocks			2.78	2.68—2.88	1.74	7.13
	Intermediate tuff		2.75	2.64—2.86		
	Trachyte		2.76	2.70—2.82		
Mafic extrusive rocks			2.89	2.78—2.90	1.27	1.71
	Andesite		2.85	2.75—2.95	0.51	0.27
	Andesite/basaltic andesite		2.87	2.74—3.00		
	Basalt		2.95	2.85-3.05	0.84	0.24
Ultramafic extrusive (Komatiite) rocks			2.91*	2.81—3.01		
		Unit 1			0.37	0.10
		Unit 2			32.33	32.45

Sedimentary rocks			2.75	2.66—2.84	1.45	5.46
	Arenite				0.08	0.14
	Dolostone		2.77	2.69—2.85		
	Argillite		2.74	2.69—2.79	3.37	7.16
	Carbonate		2.85	2.77—2.93		
	Conglomerate		2.69*	2.56—2.82	1.39	5.07
	Greywacke		2.74	2.64—2.84	0.77	3.08
	Limestone		2.68	2.62—2.74		
	Mudstone		2.77	2.65—2.89	0.32*	10.13
	Sandstone		2.68	2.62—2.74	0.69	2.56
	Wacke		2.76	2.69—2.83	1.25	5.59
Volcanoclastic rocks			2.85	2.70—3.00	0.34	0.11
	Pyroclastic		2.74	2.68—2.80		
	Tuff		2.87	2.72—3.02		
Metamorphic rocks			2.78	2.65—2.91	0.36*	13.48

	Slate		2.75	2.66—2.84		
	Schist		2.79*	2.66—2.92		
	Gneiss		2.75	2.62—2.88		
		Unit 1			0.58	0.56
		Unit 2			13.39	12.29
		Felsic Gneiss	2.68	2.62—2.74		
		Mixed Gneiss	2.75	2.66—2.84		
		Mafic Gneiss	2.95	2.79—3.11		
	Quartzite		2.68	2.60—2.76		
	Pontiac Metasedimentary Rocks		2.75	2.71—2.79		
	Amphibolite		2.97	2.84—3.10		
	Migmatite		3.01*	2.84—3.18		
Fault rocks			2.78	2.77—2.89		
Banded Iron Formation (BIF)						
	IF-Sulphide				52.61	107.31
	IF-oxide				214.40	217.83

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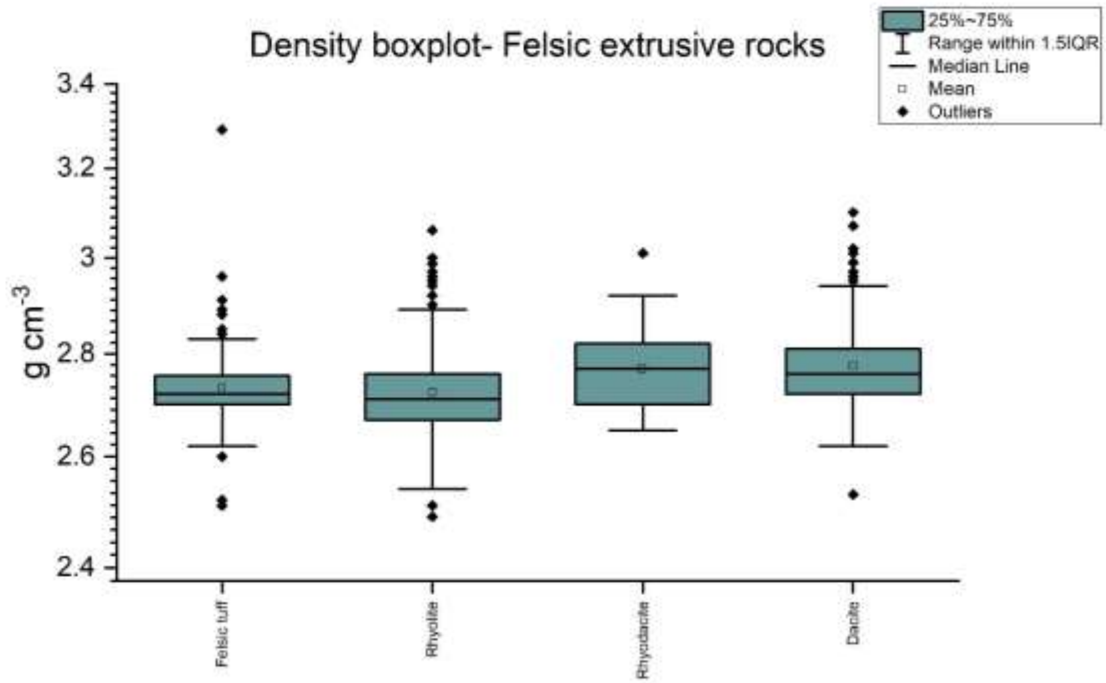
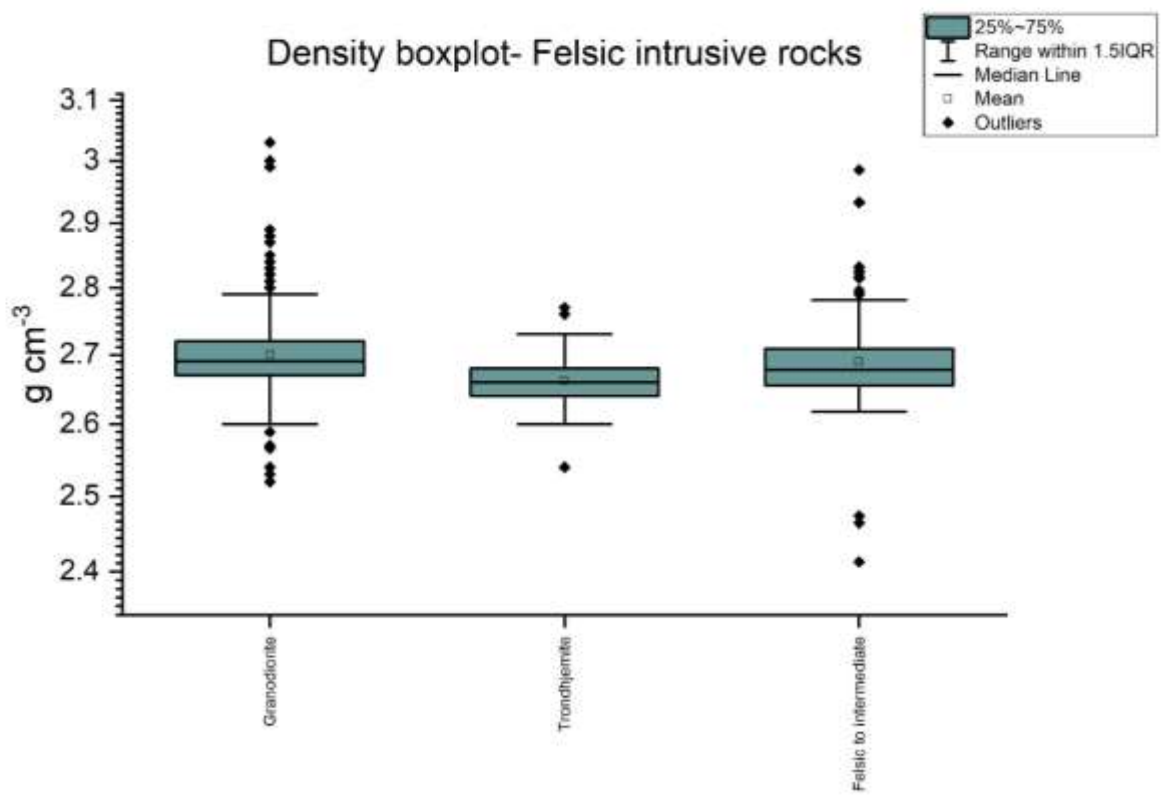
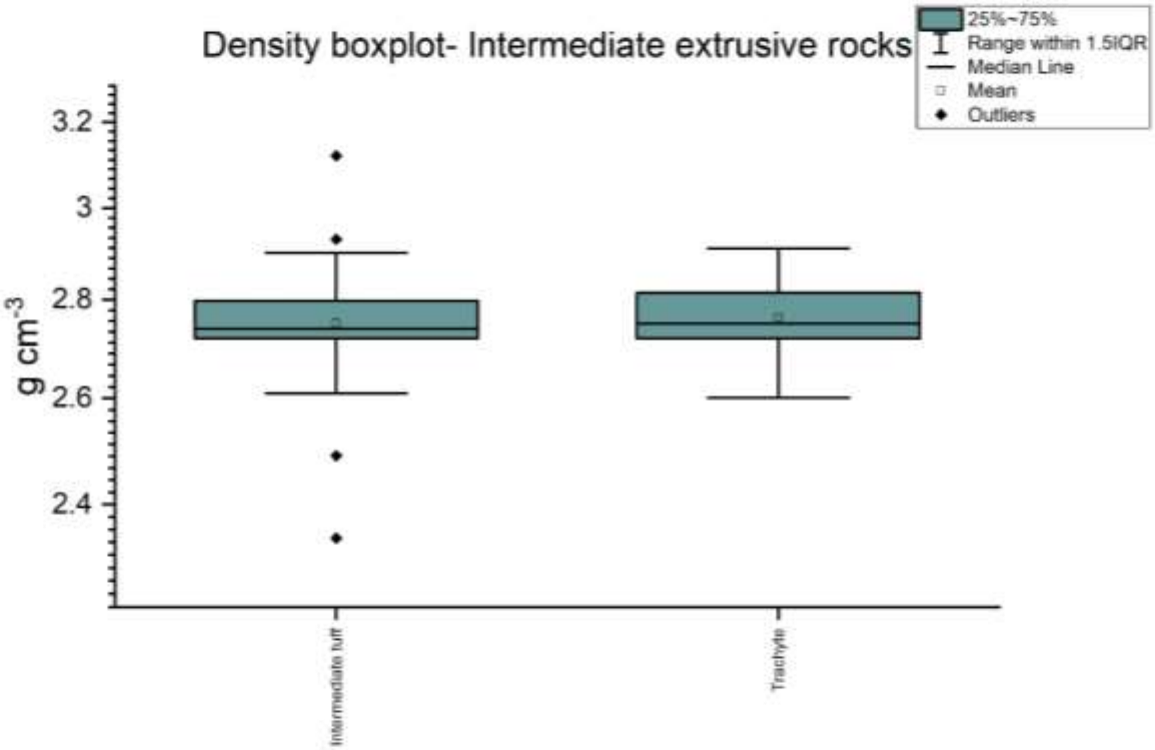
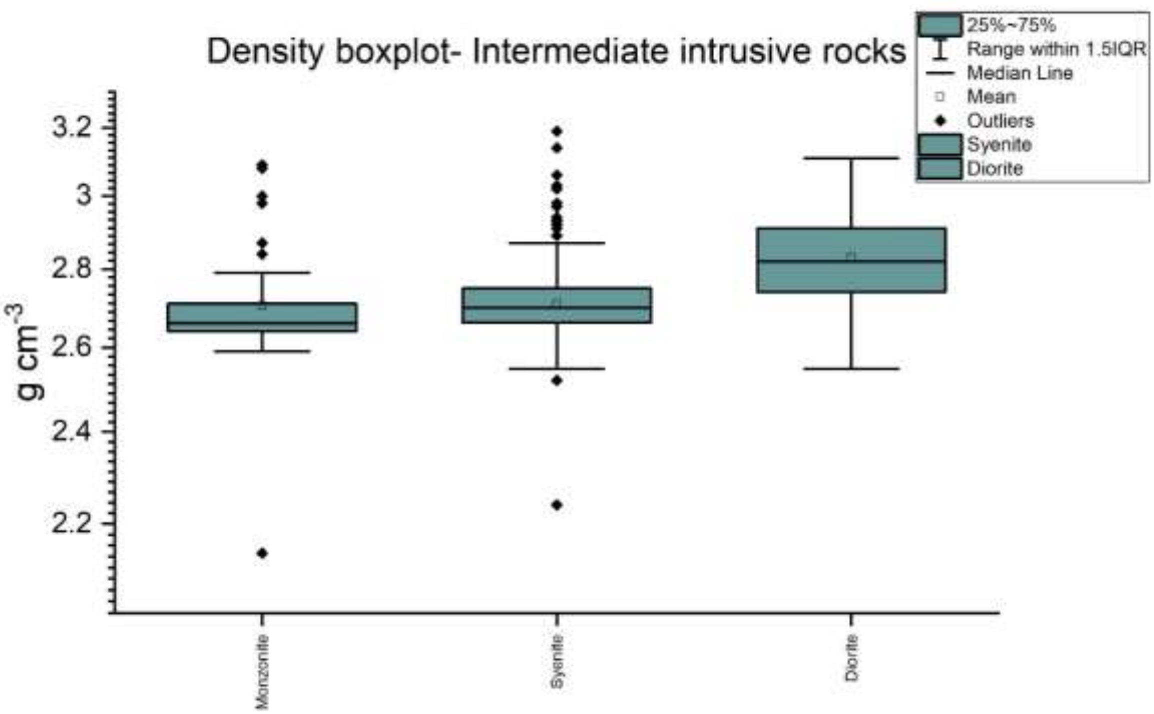
9- Appendix

Boxplots of different hierarchies






Density boxplot- Intermediate extrusive rocks
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
g cm-3
3.2
3
2.8
2.6
2.4
Intermediate tuff
Trachyte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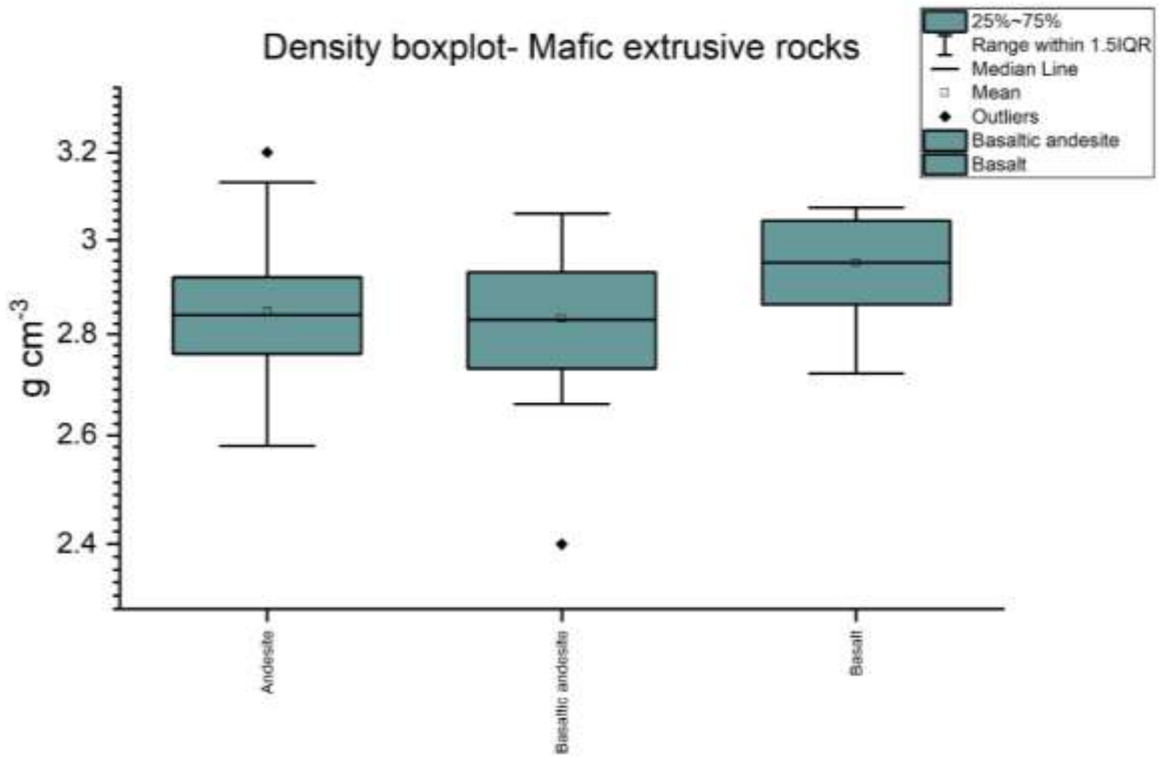
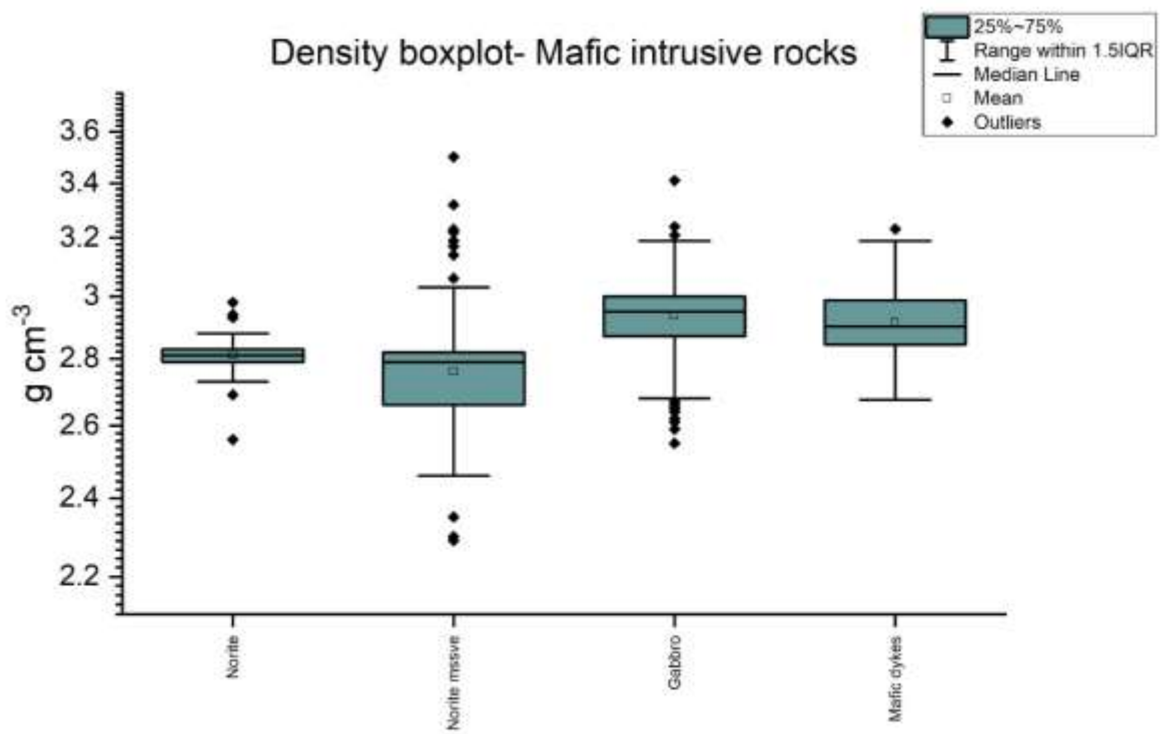
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
Syenite
Diorite
g cm-3
3.2
3
2.8
2.6
2.4
2.2
Monzonite
Syenite
Diorite


Density boxplot- Mafic extrusive rocks
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
Basaltic andesite
Basalt
g cm-3
3.2
3
2.8
2.6
2.4
Andesite
Basaltic andesite
Basalt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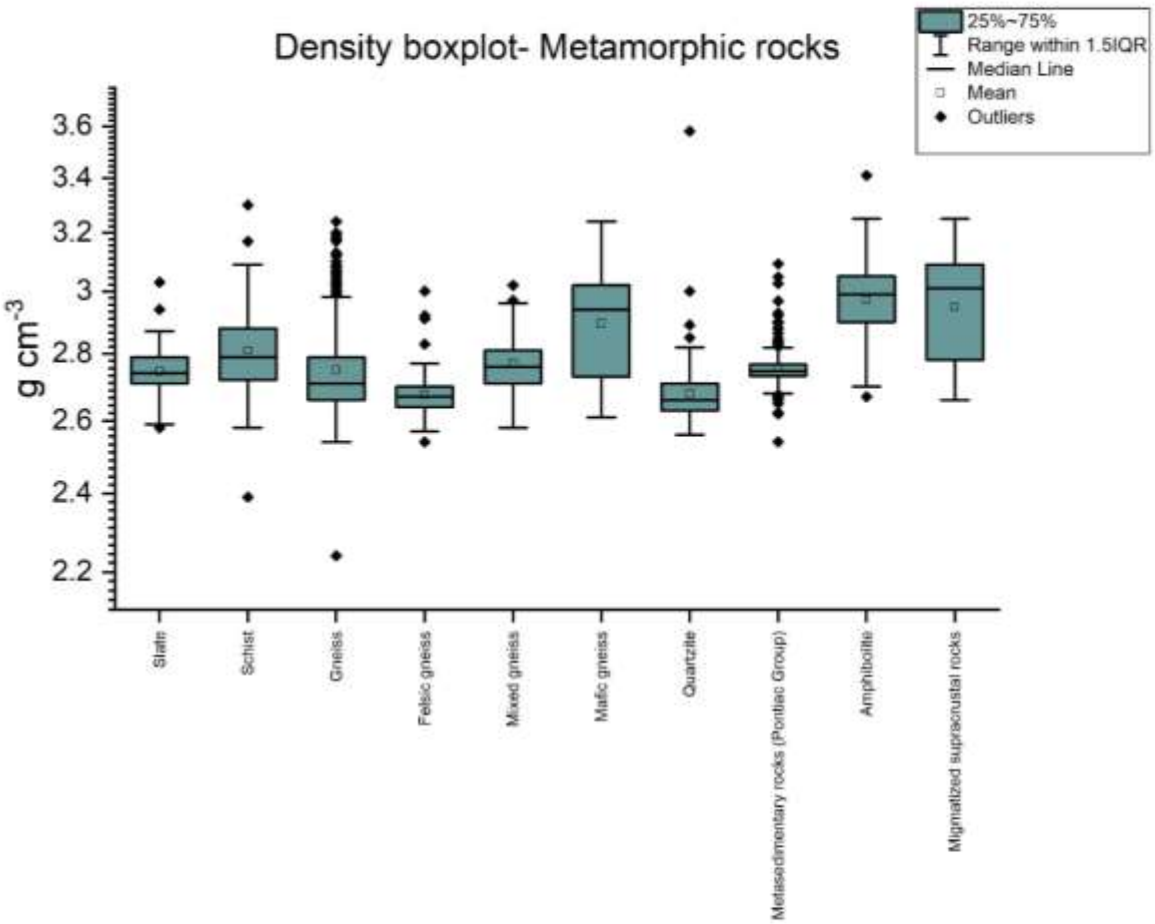
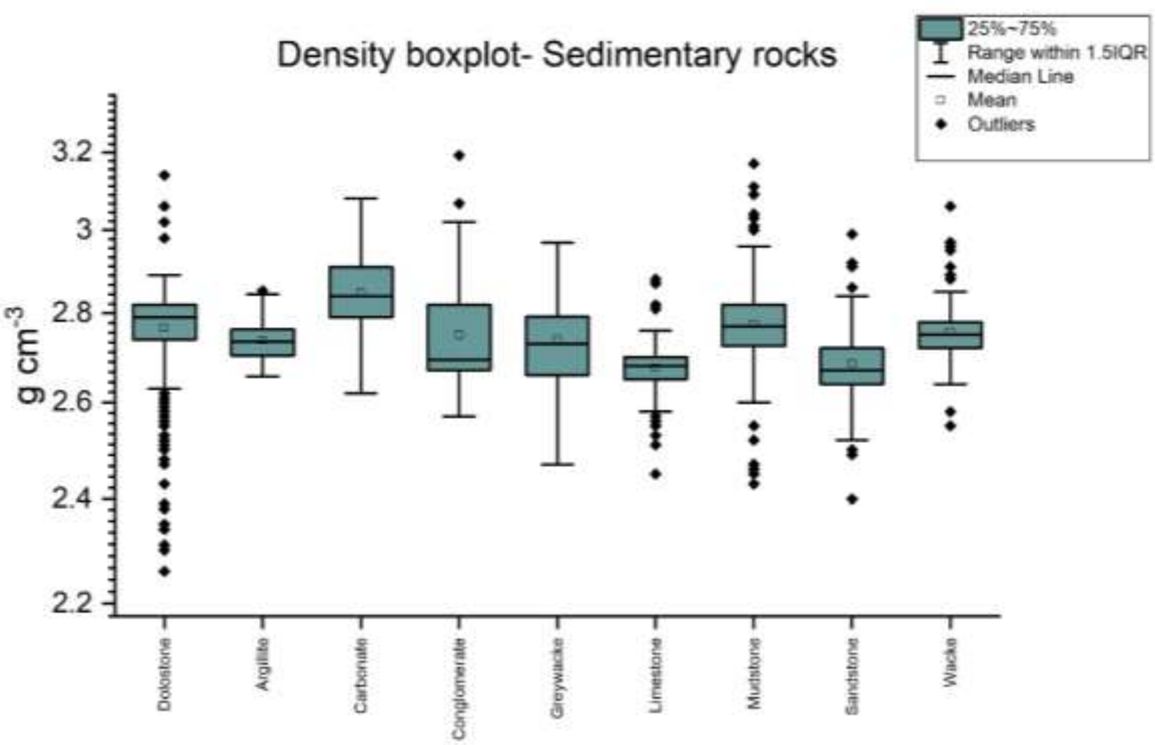
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
g cm-3
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
Norite
Norite mssve
Gabbro
Mafic dykes


Density boxplot- Metamorphic rocks
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
g cm-3
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
Slate
Schist
Gneiss
Felsic gneiss
Mixed gneiss
Mafic gneiss
Quartzite
Metasedimentary rocks (Pontiac Group)
Amphibolite
Migmatized supracrustal rocks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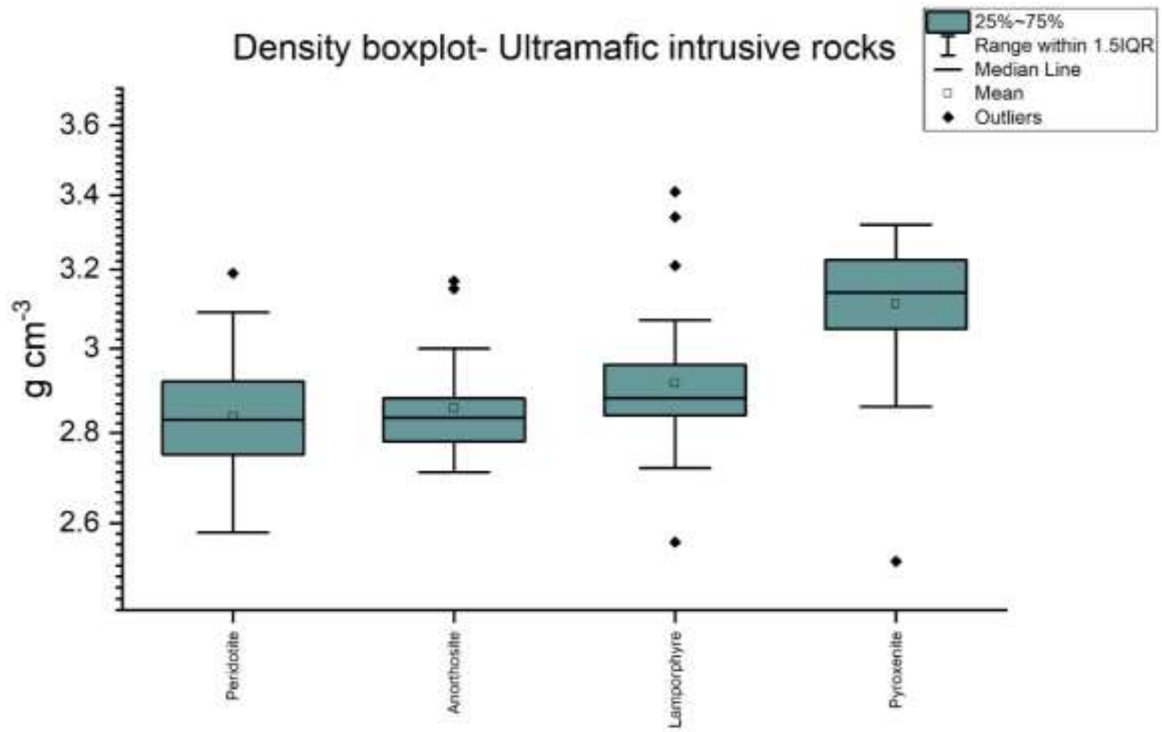
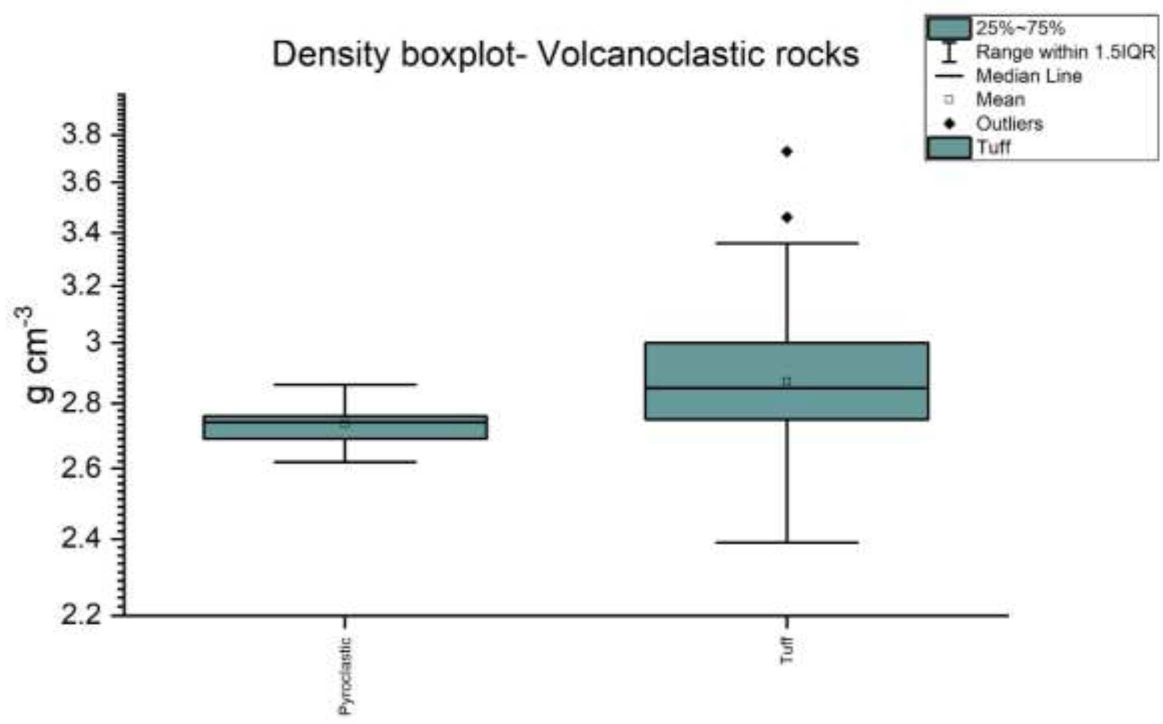
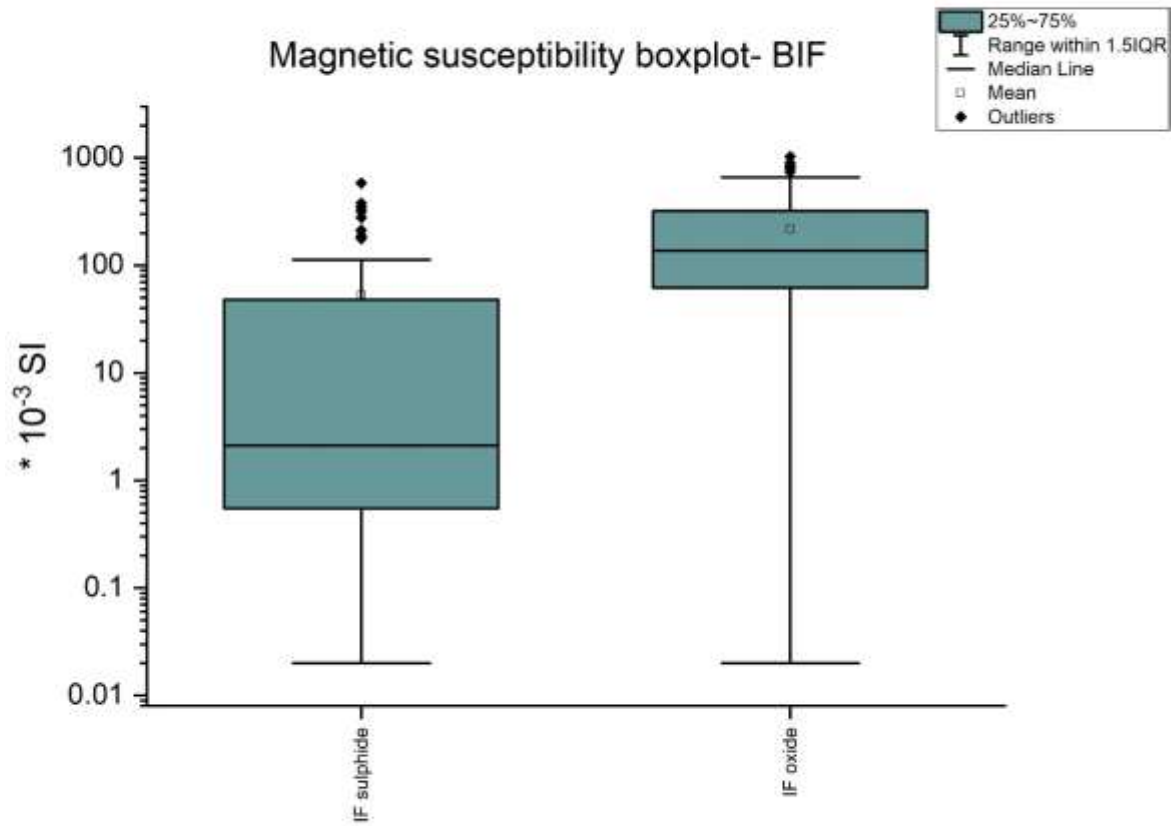
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
g cm-3
3.2
3
2.8
2.6
2.4
2.2
Dolostone
Argillite
Carbonate
Conglomerate
Greywacke
Limestone
Mudstone
Sandstone
Wacke

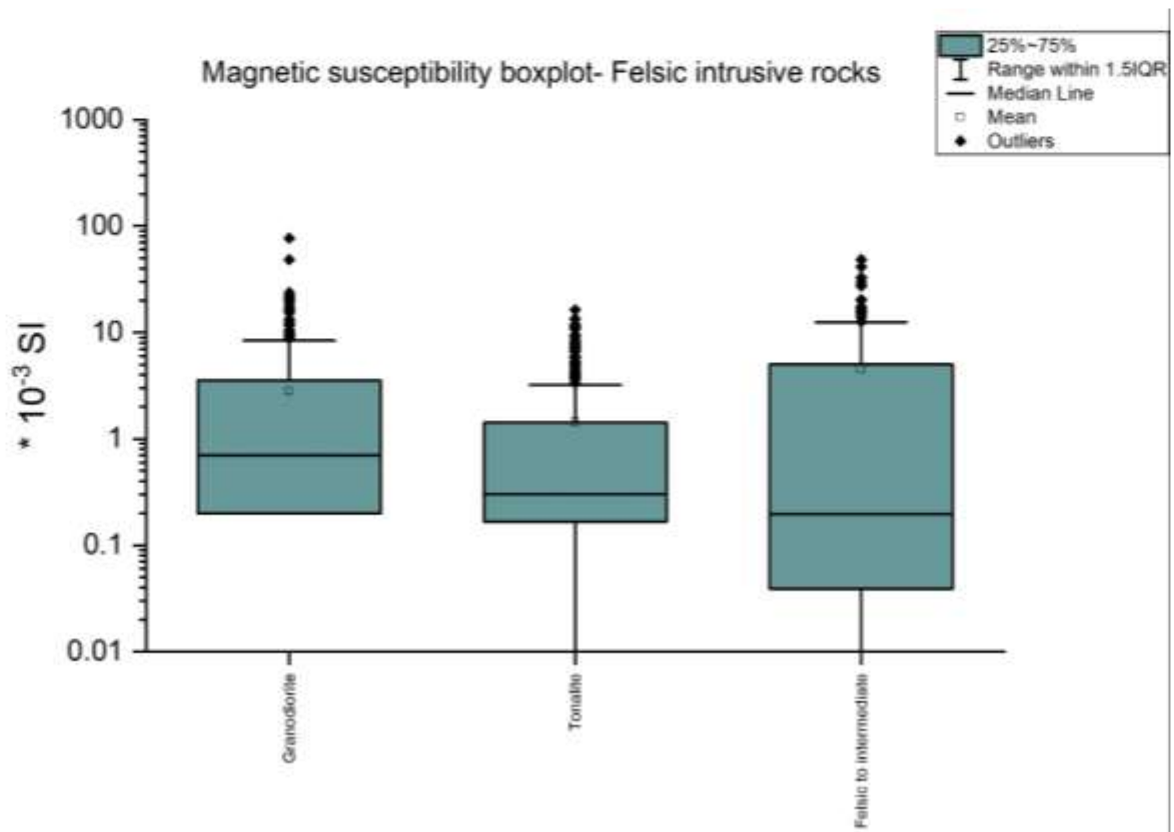


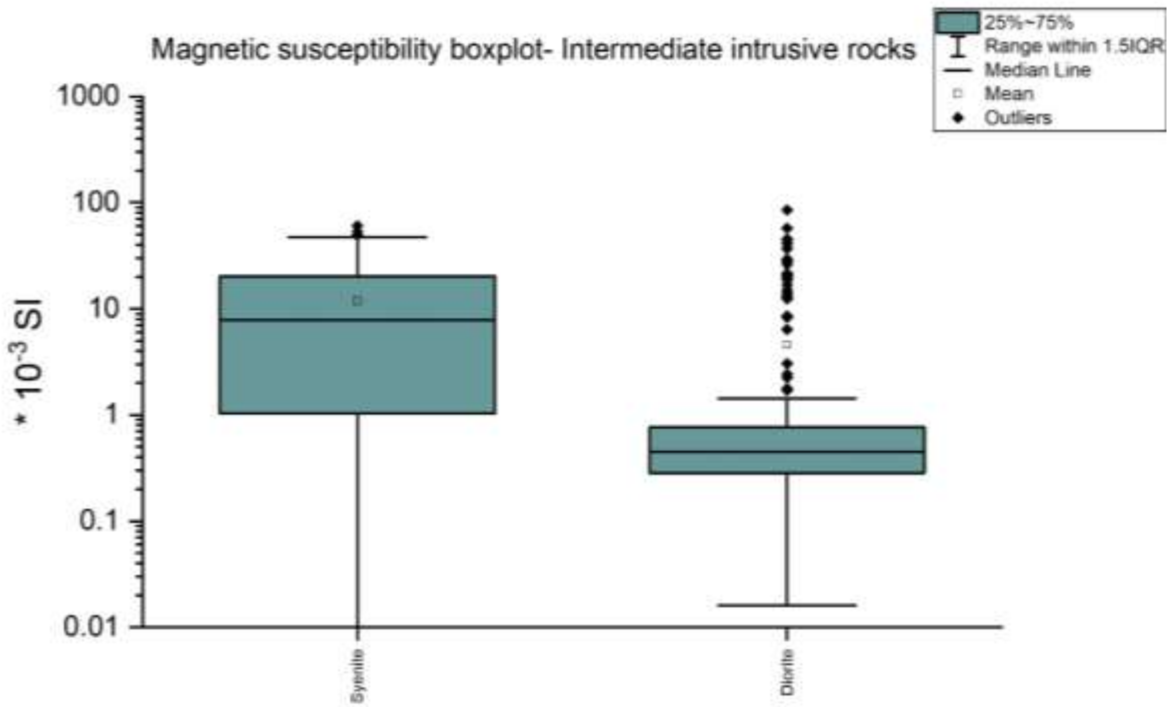
Density boxplot- Ultramafic intrusive rocks
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
g cm-3
3.6
3.4
3.2
3
2.8
2.6
Peridotite
Anorthosite
Lamporphyre
Pyroxenite



Density boxplot- Volcanoclastic rocks
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
Tuff
g cm-3
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
Pyroclastic
Tuff


Magnetic susceptibility boxplot- BIF
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
1000
100
10
1
0.1
0.01
* 10-3 SI
IF sulphide
IF oxide


Magnetic susceptibility boxplot- Felsic intrusive rocks
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
1000
100
10
1
0.1
0.01
* 10-3 SI
Granodiorite
Tonalite
Felsic to intermediate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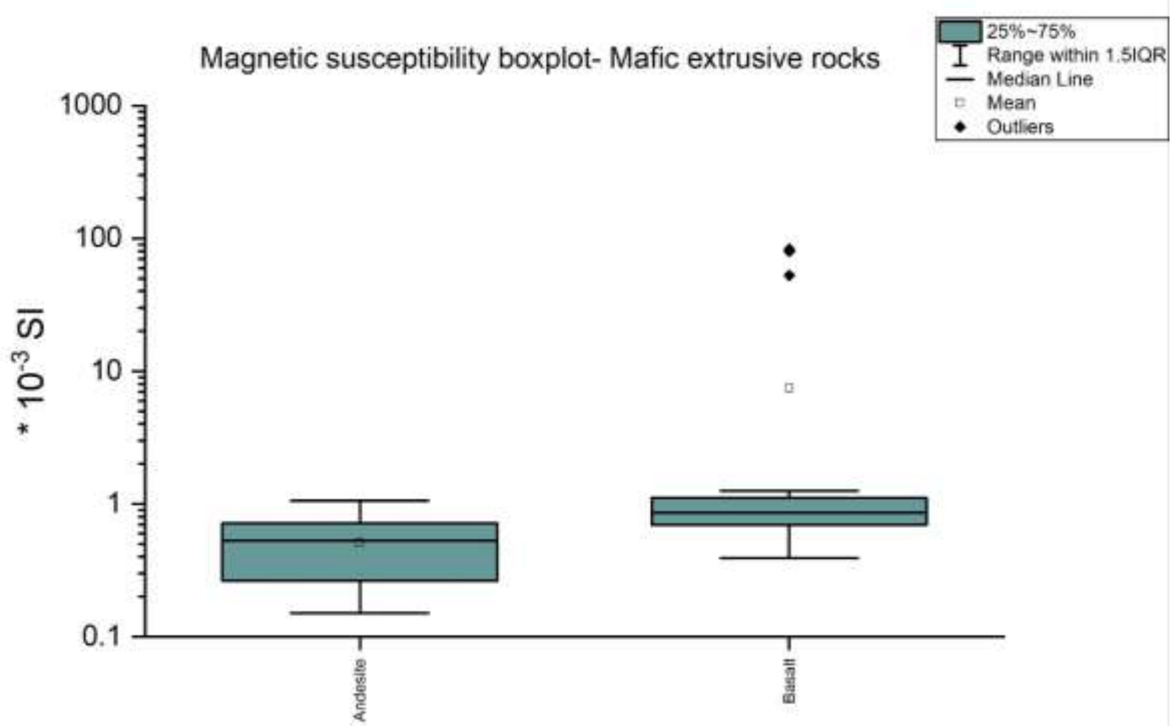
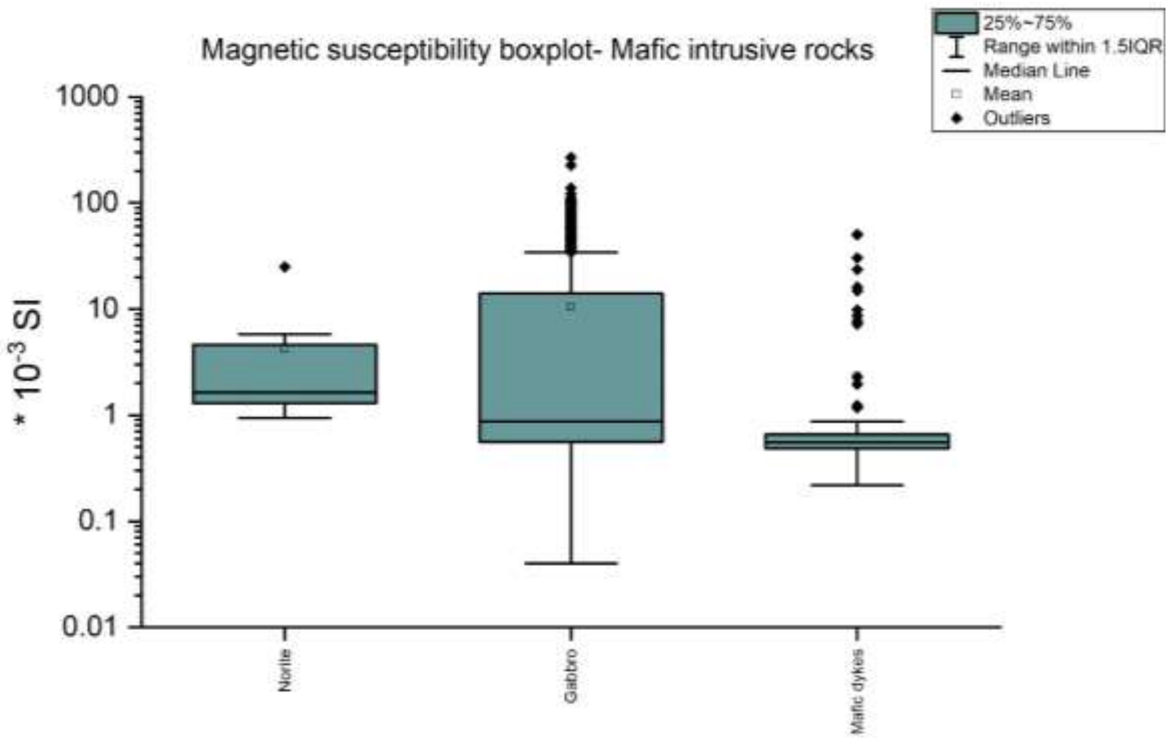
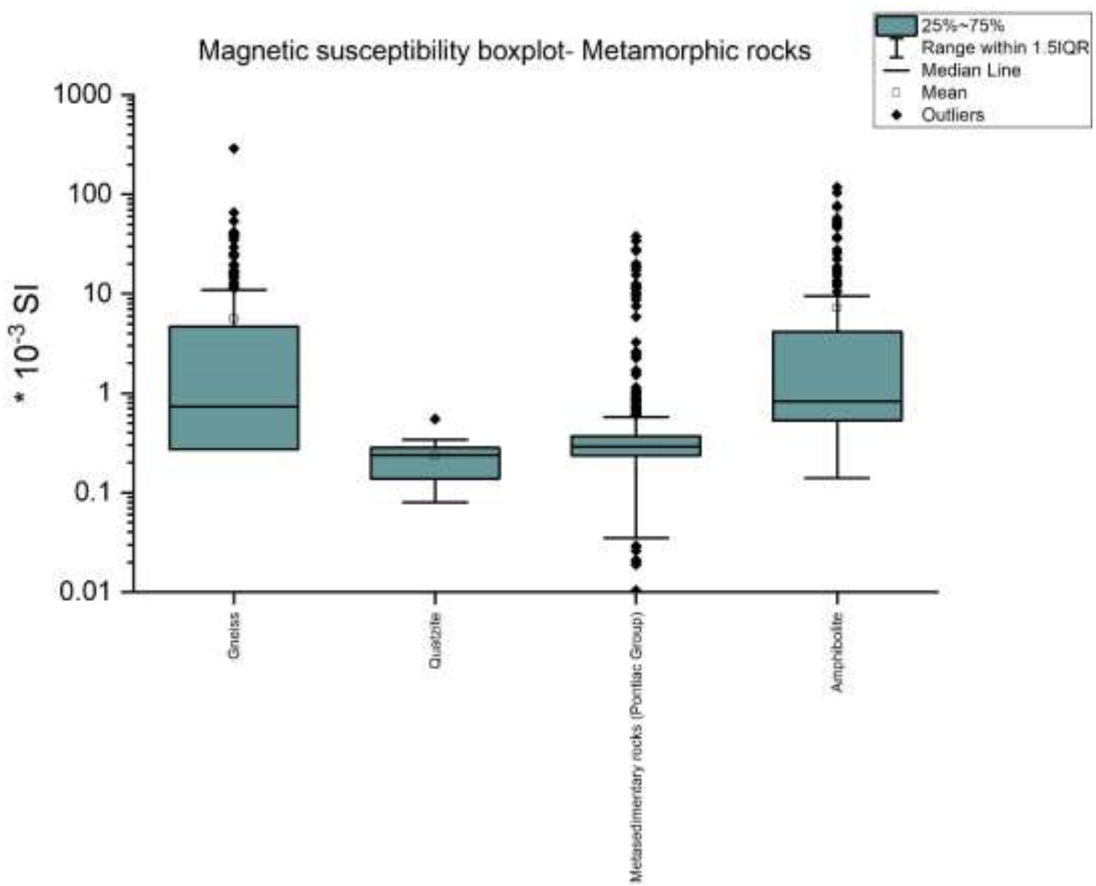
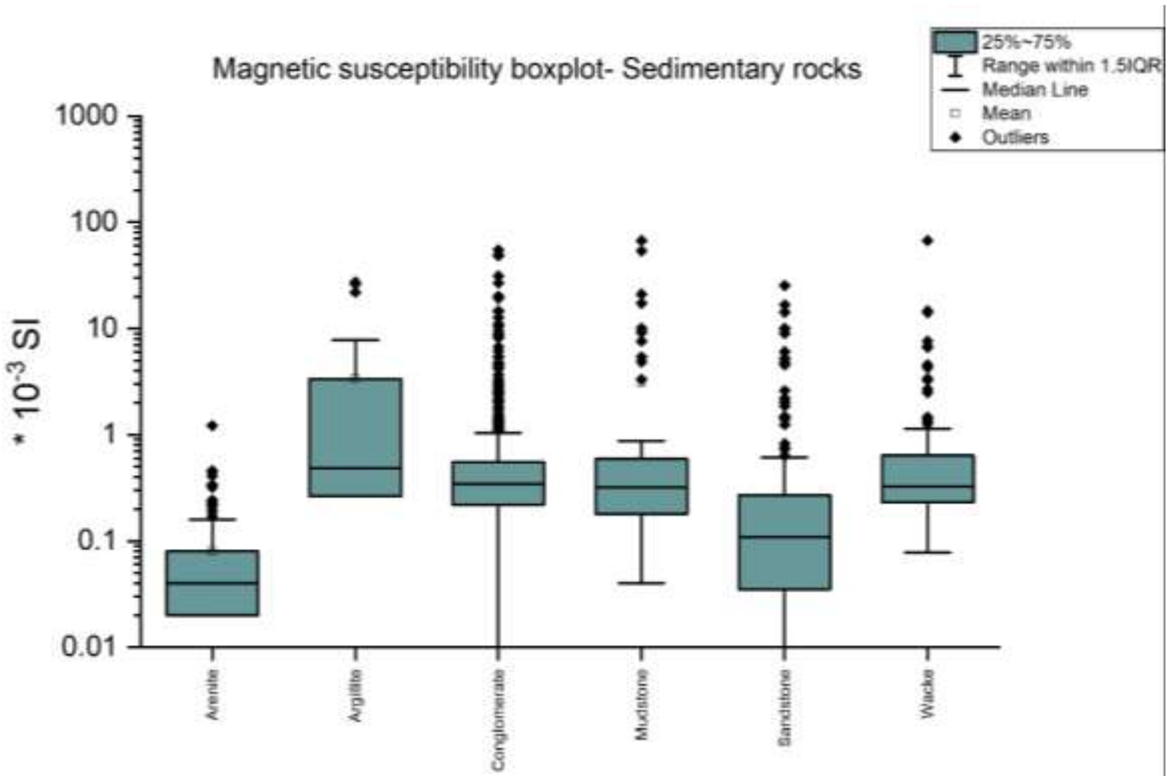
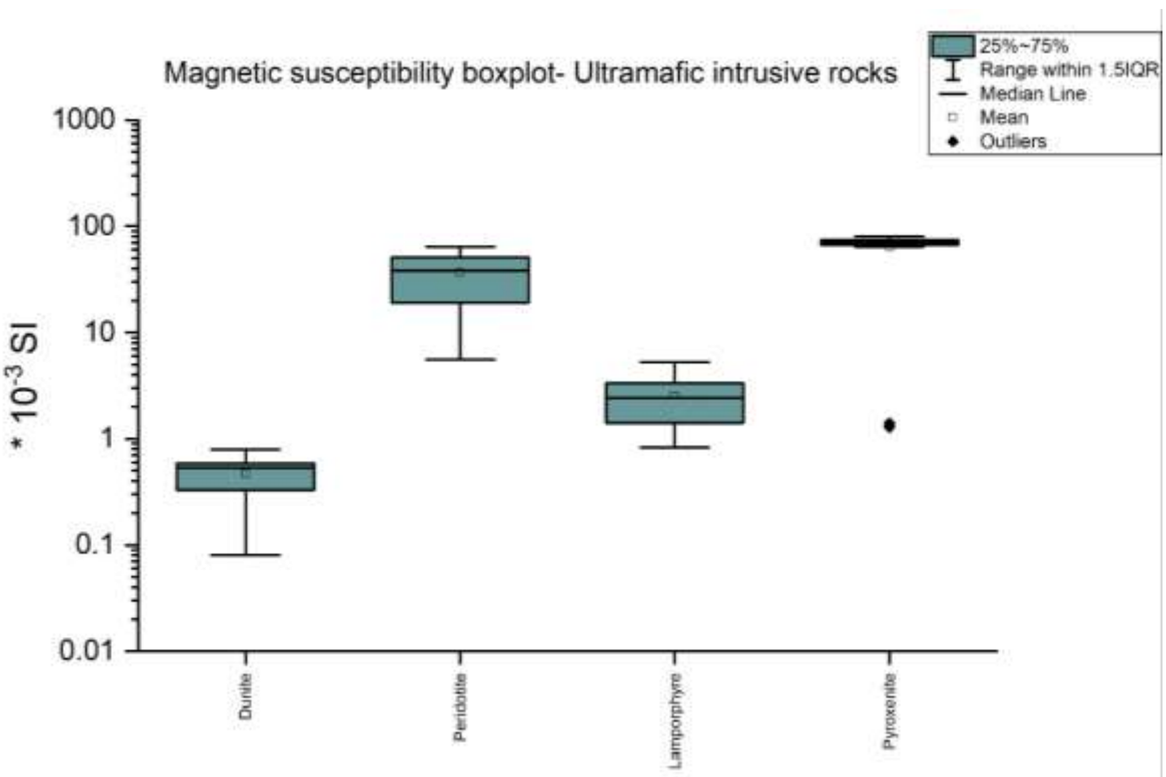
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
1000
100
10
1
0.1
0.01
* 10-3 SI
Syenite
Diorite


Magnetic susceptibility boxplot- Mafic extrusive rocks
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
1000
100
10
1
0.1
* 10-3 SI
Andesite
Basalt


Magnetic susceptibility boxplot- Mafic intrusive rocks
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
1000
100
10
1
0.1
0.01
* 10-3 SI
Norite
Gabbro
Mafic dykes


Magnetic susceptibility boxplot- Metamorphic rocks
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
1000
100
10
1
0.1
0.01
* 10-3 SI
Gneiss
Quatzite
Metasedimerdary rocks (Pontiac Group)
Amphibolite


Magnetic susceptibility boxplot- Sedimentary rocks
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
1000
100
10
1
0.1
0.01
* 10-3 SI
Arenite
Argillite
Conglomerate
Mudstone
Sandstone
Wacke


Magnetic susceptibility boxplot- Ultramafic intrusive rocks
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
1000
100
10
1
0.1
0.01
* 10-3 SI
Dunite
Peridotite
Lamporphyre
Pyroxenite