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Density and Magnetic Susceptibility of Rocks from the Bowser and Sustut Basins and Underlying Stikinia, North-Central British Columbia

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Introduction

This open file presents 569 density and 539 magnetic susceptibility determinations which were conducted on rocks from the Bowser and Sustut basins, as well as underlying basement units (Stikinia) in north-central British Columbia (Figure 1). The measurements were undertaken as part of a larger, ongoing, study that is investigating the extent to which regional potential field data can constrain variations in the thickness of sedimentary fill in the basins and locate and identify intrabasinal geologic features.

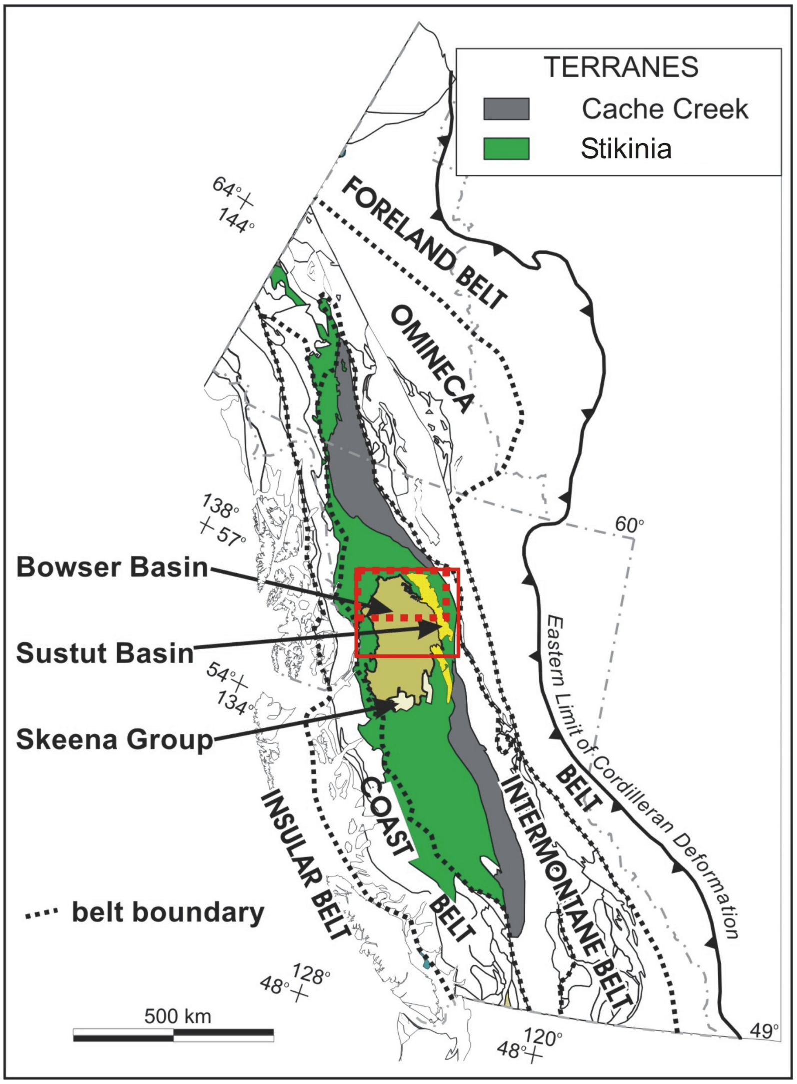


Figure 1: *Terranes and morphogeologic belts of the Canadian Cordillera and location of the Bowser and Sustut Basins (modified after Wheeler and McFeely, 1991; and Evenchick et al., 2002). The density and magnetic susceptibility samples reported in this study are from the regions outlined by the broken and solid red rectangles, respectively.*

Geological Setting

Monger et al. (1972) and Gabrielse et al. (1991) identified five distinct morphogeologic belts in the Canadian Cordillera. From east to west these are the sedimentary Foreland Belt, the metamorphic-plutonic Omineca Belt, the volcanic and sedimentary Intermontane Belt, the plutonic-metamorphic Coast Belt and the Insular Belt (Figure 1). The Intermontane Belt is composed of fault-bounded oceanic and island arc terranes which were assembled into one large superterrane, the Intermontane Superterrane, prior to accretion to the western edge of North America in Mesozoic time (Coney et al., 1980; Monger 1984; Gabrielse et al., 1991). The largest of the accreted terranes in the Intermontane Superterrane is Stikinia which forms stratigraphic basement to the overlying Bowser and Sustut sedimentary assemblages.

Stikinia

The stratigraphic and plutonic framework of northwestern Stikinia is summarized by Anderson (1993) and Gunning (1996). It is composed of volcano-plutonic arc assemblages of Devonian to Permian age (e.g., Stikine Assemblage), Late Triassic age (e.g., Stuhini Group), and Early to early Middle Jurassic age (e.g., Hazelton Group), and is overlain by the Bowser Lake Group overlap assemblage.

The Paleozoic arc succession, not widely exposed, comprises three successive subaqueous volcanic and sedimentary cycles (Gunning, 1996). Basaltic, calc-alkaline, and alkaline successions are all present. Stikine Assemblage was deformed and uplifted prior to deposition of Mesozoic arc rocks (Brown et al., 1991).

Middle and Upper Triassic volcanic and sedimentary rocks comprise the Stuhini Group. The volcanic rocks comprise a variety of aphyric to porphyritic mafic lava flows and related breccia and oliststrome. Felsic volcanic rocks are also present. Sedimentary rocks include shale, sandstone, conglomerate, and limestone. Most Stuhini Group is Late Triassic, but locally on the west and northwest sides of the Bowser Basin the group is Early and Middle Triassic. Upper Triassic Stuhini Group strata are comagmatic and cospatial with felsic to ultramafic intrusions of the Late Triassic Stikine plutonic suite (Anderson, 1993).

The Hazelton Group on the west side of the Bowser Basin is a result of four alkaline and calc-alkaline to tholeiitic magmatic episodes of latest Triassic-earliest Jurassic through early Middle Jurassic age (Anderson, 1993). Earliest Jurassic and Middle Jurassic volcanic belts trend north, whereas Early Jurassic ones trend northwest (Anderson, 1993). Lower Jurassic strata there consist of fine- to coarse-grained volcaniclastic rocks, overlain by a distinctive welded and non-welded tuff unit, and Upper Lower and lower Middle Jurassic strata, called the Salmon River Formation, consist of a lower bioclastic, member and an upper calc-alkaline volcano-plutonic (arc) assemblage. At the north end of the basin the Hazelton Group is divided into three distinct lower Jurassic volcanic successions. From the base up these include a unit of mafic to intermediate lava flows, and intermediate to felsic, ignimbrite, airfall tuff, and sills (Griffith

Creek volcanics); a composite felsic and mafic volcanic succession largely subaerially deposited, with minor epiclastic rocks and limestone (Cold Fish Volcanics); and a top unit divided into a mainly mafic and intermediate lava flow unit, and a dominantly felsic pyroclastic and volcaniclastic unit, deposited in a mainly subaerial environment (Mt. Brock volcanics) (Thorkelson, 1992; Evenchick and Thorkelson, in press). Intercalated with and overlying the volcanic successions in the north is a dominantly clastic unit called the Spatsizi Formation. On the northeast side of the basin felsic volcanic rocks of the Early Jurassic Toodoggone Formation were deposited in subaerial conditions. In the southeast and south, the volcanic Early Jurassic Telkwa Formation is overlain by the primarily clastic, Early and early Middle Jurassic Nilkitkwa and Smithers formations.

Bowser Lake Group

The Bowser Lake Group ranges in age from late Middle Jurassic to mid-Cretaceous and includes at least 5000 m of strata that were deposited in environments ranging from distal submarine fan, to deltaic, to fluvial, and lacustrine (Tipper and Richards 1976, Evenchick et al., 2001 and references therein). Siltstone, shale, sandstone and conglomerate are the predominant lithologies. The Bowser Lake Group was deposited directly on Stikinia, and clasts were derived primarily from the Cache Creek Terrane to the east, as a result of closure of the Cache Creek ocean and the accretion of the Stikinia to North America in Middle Jurassic (Gabrielse 1991; Rickets et al., 1992). The Bowser Lake Group is called an overlap assemblage in terrane terminology (Gabrielse et al., 1991).

Sustut Group

The Sustut Group ranges in age from mid-Cretaceous to latest Cretaceous and consists of more than 2000 m of sedimentary rocks that were deposited primarily in fluvial and lacustrine environments. The Sustut Group rests unconformably and disconformably on Bowser Lake, Spatsizi and Hazelton groups (Eisbacher 1974; Evenchick and Thorkelson, in press). Eisbacher (1974) divided the Sustut Group into the Tango Creek and the Brothers Peak formations. The Tango Creek Formation consists of sandstone and siltstone, whereas the overlying Brothers Peak Formation also includes tuff and thick sheets of conglomerate.

Tertiary and Quaternary Volcanic Successions

Tertiary and younger volcanic successions overlying Bowser Lake and Sustut strata include Pliocene Maitland Volcanics and unnamed Tertiary and Quaternary volcanic rocks. Maitland Volcanics are volcanic flows and associated necks confined to an upland area of about 1000 km^2 in the northwest Bowser Basin Region (Evenchick and Thorkelson, in press). They were deposited in the Pliocene (4.6-5.2 Ma) on nearly flat surfaces. Lava flows are up to 400 m thick and primarily aphyric to slightly feldspar-phyric basalt. Other Tertiary and/or Quaternary volcanic rocks occur as relatively small erosional remanents in several parts of the Bowser/Sustut region. The ages of few are precisely known (Evenchick and Thorkelson, in press).

Measurement Methodology

a. Density measurements

The density measurements reported here were undertaken by the 'weight-in-air - weight-in-water' method (Muller, 1967; Hutchinson, 1974). In all cases measurements were conducted on hand-sized rock samples taken from the archival collection of the Geological Survey of Canada (Vancouver). Many of the rocks to be measured were porous, therefore, all samples were submerged in water for a minimum of 24 hours prior to measurement and only removed immediately prior to weighing. Upon removal, rock samples were agitated to eliminate surface water and any adhering bubbles. The weight-in-air (Wa) measurement was conducted first and followed immediately by the weight-in-water (Ww) measurement. For the weight-in-water measurement samples were completely submerged in water at ambient temperature. The sample volume is essentially the difference between the weight-in-air (Wa) and weight-in-water (Ww) measurement and therefore, the density (ρ) of the rock sample is readily computed from the following relation:

$$\rho = (Wa)/(Wa-Ww)$$

An electronic balance with automatic tare adjustment was used for all weight measurements. Instrument and operator errors were monitored by occasional tares (i.e. no-sample readings), and by repeat sample measurements.

b. Magnetic susceptibility measurements

Magnetic susceptibility measurements were undertaken using a GF Instruments SM-20 pocket magnetic susceptibility meter. Of the more than five hundred measurements reported in this open file, fifty-six were conducted on field outcrops and the remainder on hand-sized rock samples taken from the archival collection of the Geological Survey of Canada (Vancouver). In all cases multiple (between 3 and 10) readings were taken and the results averaged to yield the reported values.

The SM-20 has an automatic range from 0.000 to 999 x 10^{-3} SI units and a sensitivity of 10^{-6} SI. As the actual sensor is an air-cored coil with a diameter of 50 mm and, as 90% of the measured response comes for the upper 20 mm of the sample, all measured hand-samples were required to have dimensions that exceeded these values. Furthermore, measurements were restricted to samples that presented at least one, relatively smooth (i.e. flat), surface.

Distribution of measured rock samples

Density measurements were conducted on rock samples from a 150 km wide x 120 km long, area encompassing the northern parts of the Bowser and Sustut basins and adjacent basement units

(Figure 2 and Appendix A). Magnetic susceptibility measurements were conducted on rocks from a significantly larger area that encompassed much of the central part of the Bowser Basin (Figure 3 and Appendix A). No measurements were conducted on rock samples from the southern part of the Bowser basin limiting the capacity of this study to examine spatial variations in measured properties throughout the Bowser Lake Group as a whole.

The proportion of lithologies measured in each geologic unit is shown in figures 4 (overlap assemblages) and 5 (Stikinia). In general, predominant lithologies in the Bowser and Sustut basins are well sampled. In the case of Stikinia, predominant lithologies in the Hazleton Group are well sampled, those in the Stuhini Group are moderately well, but there was limited sampling of the older Stikine Assemblage (7 density and 5 magnetic susceptibility measurements) and of intrusive rocks (Appendix A).

It should also be noted that in any given geological unit the proportion of lithologies measured for density may differ from that of magnetic susceptibility, as both measurements were conducted on just 21% of all density samples (Appendix A).

Results

Individual measurements together with some additional details of the measured rock samples are listed in Appendix A (Sheet 1: stratified rocks; Sheet 2: intrusive rocks).

Discussion

Tables 1 and 2 show the mean density and magnetic susceptibility of the geologic units sampled. Examination of these tables reveals several interesting features:

1: The mean magnetic susceptibility of Maitland Volcanics is 34 times larger than the underlying Bowser Lake Group. This suggests that magnetic anomaly data should facilitate the ready delineation of these volcanic rocks.

2: The Sustut Group is less dense and more magnetic than the underlying Bowser Lake Group. Density differences are greatest in the case of the Brother Peak Formation (-130 kg/m^3 relative to the mean density of the Bowser Lake Group).

3: Importantly, the mean density of the Bowser Lake Group is identical (2611 kg/m^3) to that of the underlying Hazelton Group. This implies that gravity data cannot be used to map the thickness of basin-fill in the Bowser Basin. In contrast, the mean magnetic susceptibility of the Hazelton Group is six times larger than the Bowser Lake Group, suggesting that it may be possible to estimate the thickness of basin the fill using magnetic anomaly data.

4: The mean density of rocks in Stikinia increases with increasing geologic age, such that the oldest rocks (Stikine Assemblage) have a mean density (2811 kg/m^3) that is 200 kg/m^3 higher than the youngest (Hazelton Group).

Tables 3 and 4 summarize the density and magnetic suscpetibilities of the predominant lithologies in each of the geologic units sampled. Examination of these tables shows that siltstones and sandstones in the Sustut Group have lower mean densities and higher magnetic susceptibilities than similar lithologies in the Bowser Lake Group. Conglomerates, sandstones and siltstones in the Hazelton Group all have slightly lower mean densities and magnetic susceptibilities than similar litholgoies in the overlying Bowser Lake Group. The mean density of volcanic rocks in Stikinia increases with increasing geologic age.

Figure 6 shows the observed magnetic field over north-central British Columbia. The image was generated from data acquired during 15 individual airborne surveys undertaken between 1962 and 1989. Details of the individual surveys are provided on the Geological Survey of Canada web site at http://gdcinfo.agg.nrcan.gc.ca/gdcinfo/index_e.html. Most of the region was surveyed on east-west trending flight lines that were spaced 800 m apart and flown at a mean terrain clearance of 305 m. To generate the seamless magnetic grid shown here data from the individual surveys were compiled using the procedures outlined in Dods et al. (1985).

A simple visual inspection of this image shows significant variations in the character of the magnetic field across the region. These variations correspond closely with the mapped geology and with measured variations in the measured magnetic susceptibility of the surface exposures.

Over much of the Bowser Basin the amplitude of the magnetic field rarely exceed 350 nT and magnetic gradients are very gentle (typically less than 3 nT/km). This subdued magnetic character reflects the low magnetic susceptibility of the Bowser Lake Group and the considerable depth to basement (Stikinia) beneath. The smooth character of the magnetic field over the basin is punctuated by two distinct types of anomalies, labelled “M” and “G” on the magnetic image. “M” type anomalies typically have intensities of 30-80 nT, wavelengths < 10 km, and gradients > 9 nT/km. Many correspond with mapped outcrops of Maitland Volcanics basalt (outlined in grey on image) which have measured magnetic susceptibility values that are considerably higher than the Bowser Lake Group sedimentary rocks which they overlie (Table 2). In some cases the magnetic anomalies are more extensive than the mapped volcanic outcrops, suggesting that the volcanic rocks may be more extensive in the shallow subsurface. In most instances “M” type anomalies consist of a single peak or trough. Peaks predominate, and indicate intrusions during periods of normal magnetization, whereas troughs of decreased magnetic intensity indicate a reversed field at the time of emplacement. In a few cases, more complex magnetic responses are associated with individual outcrops of Maitland Volcanics, suggesting multiple flows, or shallow intrusions magnetized at different times. These more complex magnetic responses and the existence of both normal and reversed magnetizations indicate extrusions of the Maitland

Volcanics spanned one or more field reversals.

"G" type anomalies are invariably normally magnetized, with wavelengths in excess of 10 km, peak magnetic intensities of 100-350 nT, and gradients of 8-30 nT/km. Many of the smaller such anomalies are associated with mapped outcrops of Mesozoic granitoids (outlined in white on Figure 6). Several of the larger anomalies, e.g. those labelled "A" and "B"on the magnetic image, show no correspondence with the mapped geology. Although these latter anomalies may simply reflect a shallowing of magnetic basement in this portion of the basin we note that: a) relatively high vitrinite reflectance indices have been measured in the sedimentary rocks that outcrop in this area (Evenchick et al., 2002); and b) that the northern part of anomaly A overlies the Groundhog Coalfield where high maturity anthracite occurs. Collectively, these observations suggest that anomalies A and B may result from intrusions in the deeper parts of the Bowser Basin or in the basement beneath.

Outside of the Bowser Basin the magnetic field is considerably more complex reflecting the juxtaposition of rocks with contrasting magnetic properties. Magnetic amplitudes are typically 100-200 nT higher over the Sustut Basin compared with the Bowser Basin reflecting, in part, the higher magnetic susceptibilities of the Sustut Group, and the comparatively shallower depth to basement beneath the Sustut Basin. West of Bowser Basin exposed volcanic and volcaniclastic rocks in Stikinia are typically several times more magnetic than the Bowser Lake Group, as are the granites, granodiorites, and quartz monzonties that intrude the western part of the Stikine Terrane and comprise most of the Coast Belt farther to the west (Lowe et al., 2003). Several of the short-wavelength, high intensity, sub-oval magnetic anomalies observed in these regions correspond with mapped intrusions. To the east and northeast of the Bowser Basin the dominant northwest-trending structural fabric of the region is well reflected in observed magnetic data as numerous northwest-trending magnetic lineaments parallel mapped faults including the Pelly, Swannell and Kutcho faults identified in Figure 6.

Figure 7 shows the observed gravity field over north-central British Columbia. The image was generated from 1625 individual gravity measurements acquired by the Geological Survey of Canada. Typically, measurements were spaced 10 km apart, although, closer spaced measurements (~2-3 km apart) were obtained along some highways and along a northeast-trending profile that crosses the northern portion of the Bowser Basin (see Lowe et al., 1992 for details). The data are considered accurate to ± 1 mGal.

The northwest-oriented structural grain of the this region is well reflected in observed gravity data. Gravity values decrease by more than 100 mGal from the southwestern to the northeastern part of the map area. Distinct northwest-trending Bouguer anomaly lows are associated with the Hogem (HB) and Cassiar (CB) batholiths in the northeastern map area and with thick sedimentary accumulations in the Sustut Basin. Although the amplitude of the gravity field varies considerably over the Bowser Basin, there is no distinct gravity anomaly associated with it. This observation is readily explained by the measured density data which show that the Bowser Lake Group and the Hazelton Group which underlies it have an identical mean values

(2611 kg/m^3, Table 1). No significant variation in spatial variation in the density of the Bowser Lake Group is observed. Collectively, these observations imply that long-wavelength variations in the observed gravity field must be attributed to lateral density contrasts in pre-Hazleton rocks.

In general, observed gravity values are lower over the Sustut Basin compared to the Bowser Basin consistent with the measured density information which indicates that the mean density of the Sustut Group is 50 kg/m^3 lower than that of the Bowser Lake Group.

Several short-wavelength, low amplitude gravity anomalies are observed throughout the map area, many of which correspond with small granitic intrusions (outlined in white on Figure 7). Despite their relatively high densities, the Maitland and younger volcanic rocks that overlie the Bowser Lake Group (outlined in grey on Figure 7) do not generate positive anomalies because of their small spatial extents. Steep, linear gravity gradients parallel several mapped faults, including the Pelly, Swannell and Kutcho faults (east of the Sustut Basin), indicating lateral contrasts in density (lithology) and/or unit thicknesses across the faults.

Figure 2: Location of 569 density samples in this study.

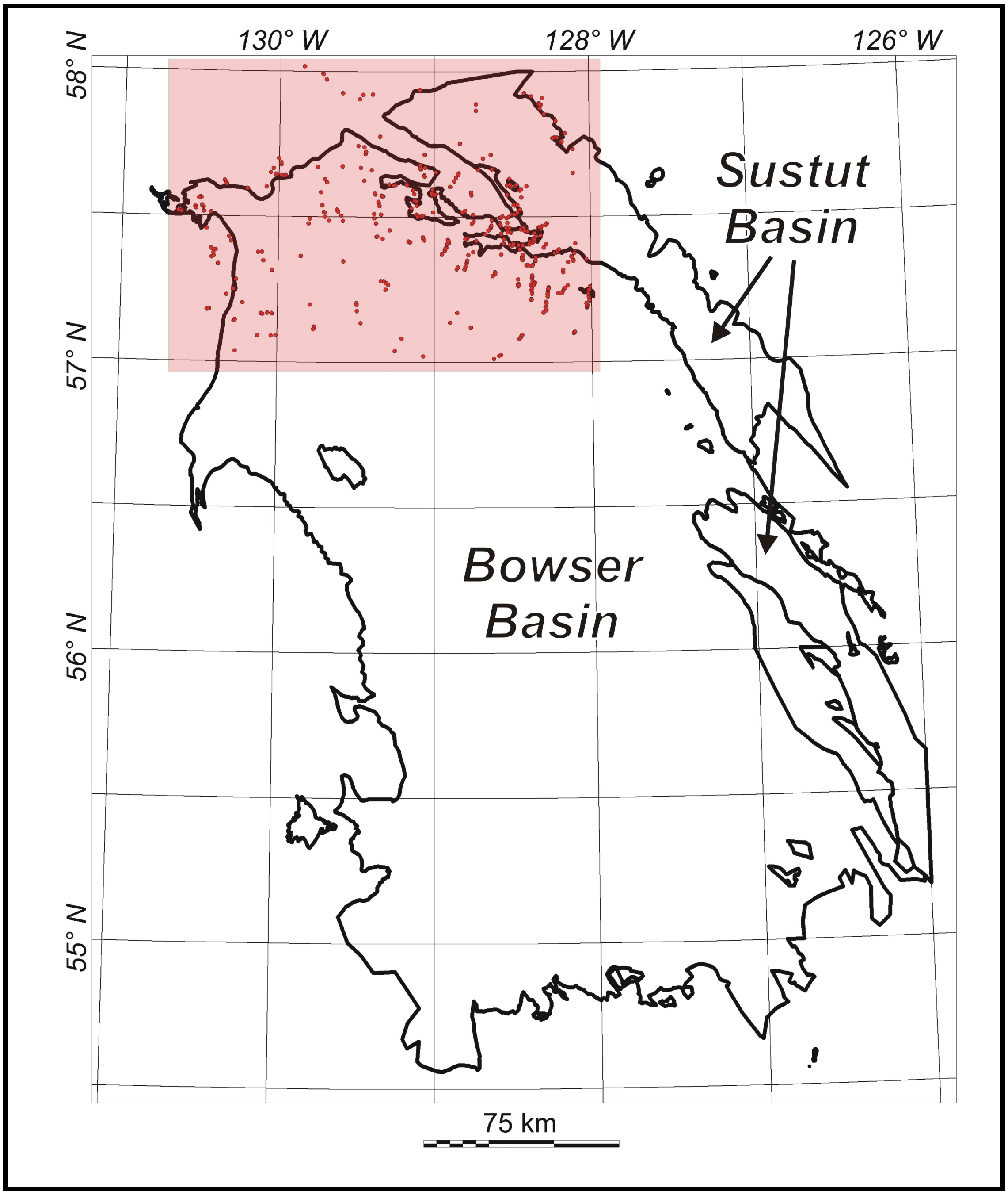


Figure 3: Location of 539 magnetic susceptibility samples in this study.

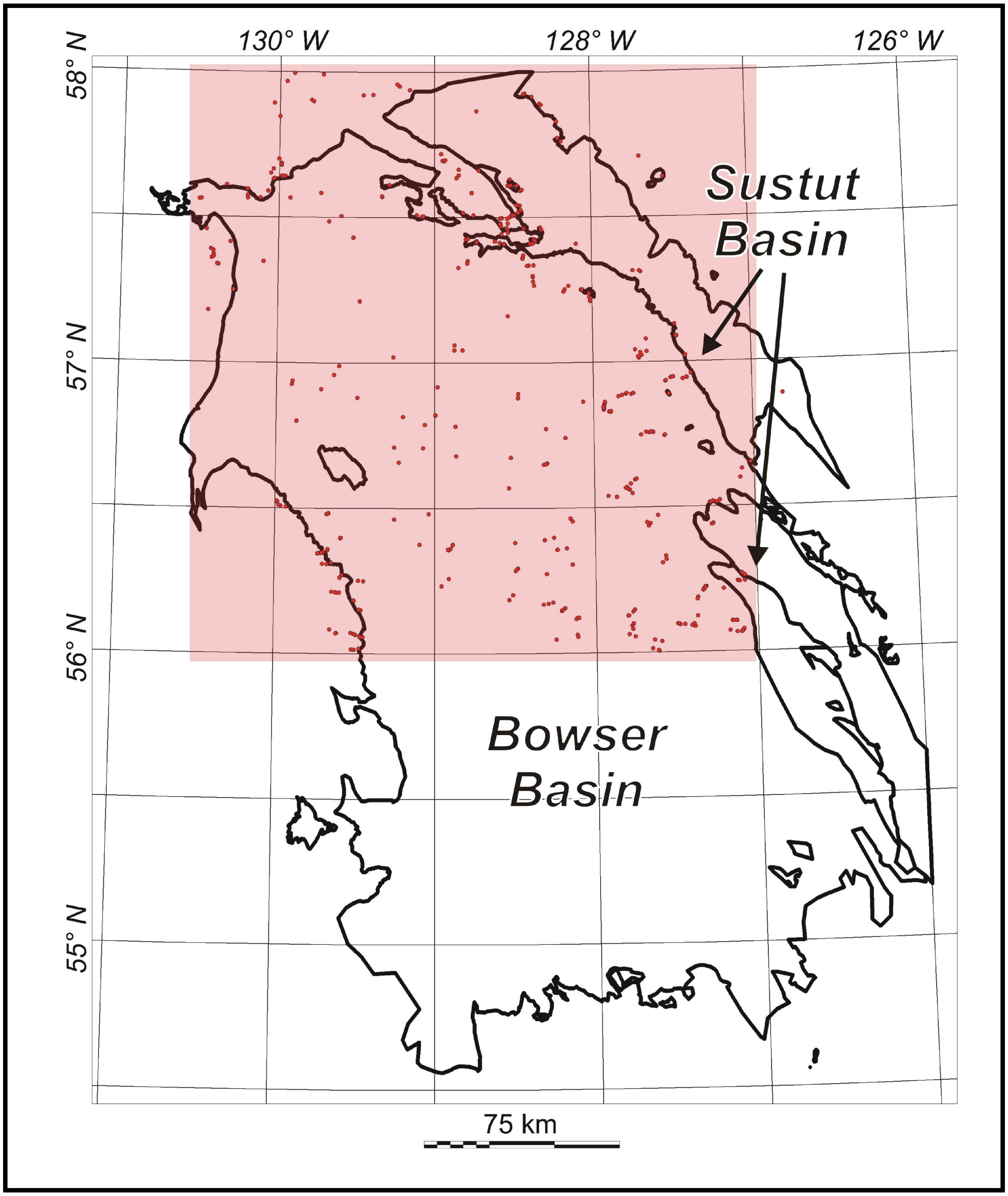


Figure 4: Lithologies measured in the sampled overlap assemblages.

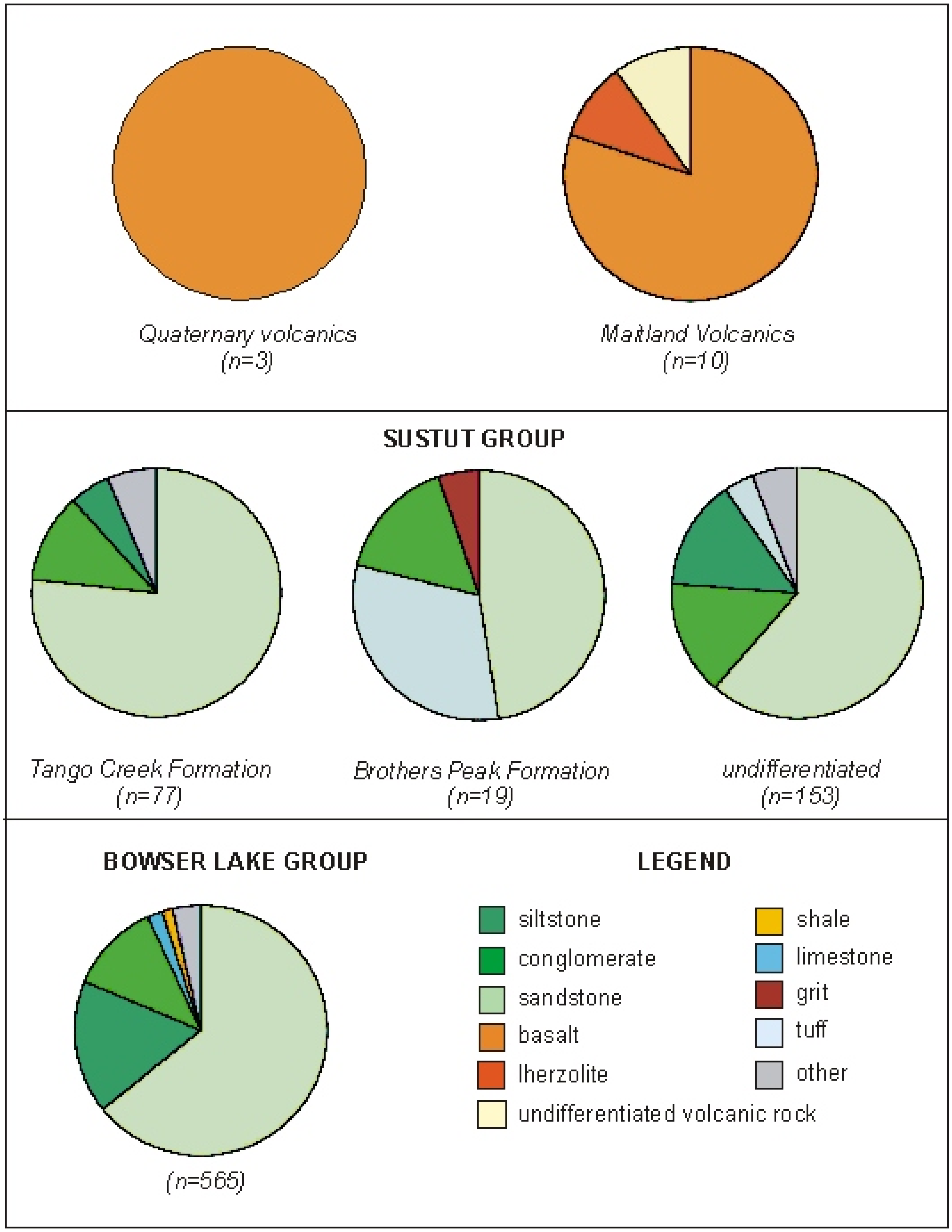


Figure 5: Lithologies measured in Stikinia.

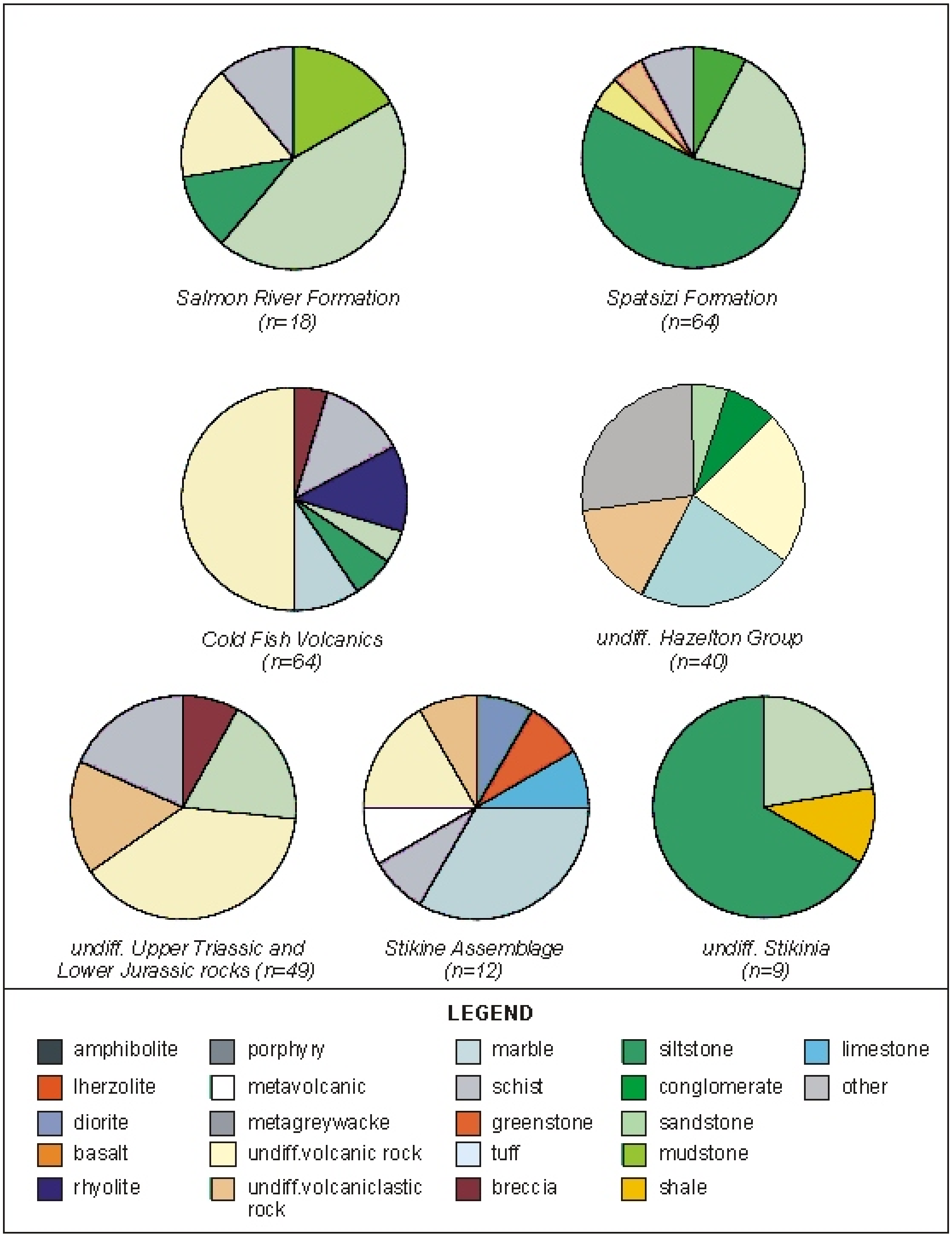


Table 1: Density of sampled geologic units.

Geologic unit	**Density (kg/m^3)**		
	mean	**range**	**#**
Overlap Assemblages			
Quaternary volcanics	2785	2750-2820	2
Maitland Volcanics	2652	2330-2870	5
Sustut Group (all)	2561	2170-2750	65
Tango Creek Formation	2579	2170-2750	53
Brothers Peak Formation	2481	2270-2610	12
undifferentiated			
Bowser Lake Group	2611	1880-3400	311
Stikinia			
Hazelton Group (all)	2611	2210-2970	134
Salmon River Formation	-	-	0
Spatsizi Formation	2578	2410-2770	59
Cold Fish Volcanics	2642	2440-2970	54
Griffith Creek volcanics	2690	-	1
undifferentiated	2621	2210-2760	20
undifferentiated Late Triassic and Early Jurassic rocks	2678	2420-2980	45
Stikine Assemblage	2811	2680-3070	7
undifferentiated	-	-	0

Table 2: Magnetic susceptibility of sampled geologic units.

Geologic unit	**Magnetic susceptibility (x 10^{-3} SI)**		
	mean	**range**	**#**
Overlap assemblages			
Quaternary volcanics	6.231	3.527-8.934	2
Maitland Volcanics	9.057	0.275-32.50	10
Sustut Group (all)	0.576	0.040-5.920	109
Tango Creek Formation	0.420	0.084-3.942	39
Brothers Peak Formation	0.189	0.047-0.650	9
undifferentiated	0.773	0.040-5.920	59
Bowser Lake Group	0.268	0.015-16.0	280
Stikinia			
Hazelton Group (all)	1.590	0.03-24.53	107
Salmon River Formation	0.179	0.072-0.355	18
Spatsizi Formation	0.149	0.035-0.335	35
Cold Fish Volcanics	2.489	0.029-16.675	29
Griffith Creek volcanics	6.615	-	1
undifferentiated	3.000	0.033-24.53	24
undifferentiated Late Triassic and Early Jurassic rocks	8.610	0.099-37.771	18
Stikine Assemblage	2.106	0.063-9.833	5
undifferentiated	0.30	0.13-0.47	9

Table 3: Density of predominant lithologies in sampled geologic units.

Geologic unit	Lithology	Density (kg/m^3)		
		mean	range	#
Overlap assemblages				
Quaternary volcanics	basalt	2785	2750-2820	2
Maitland Volcanics	basalt	2733	2470-2870	3
Sustut Group				
Tango Creek Formation	sandstone	2583	2390-2750	40
	conglomerate	2596	2540-2640	5
	siltstone	2607	2520-2690	3
Brother Peak Formation	sandstone	2530	2400-2610	7
	tuff	2487	2360-2570	3
	conglomerate	2300	2270-2330	2
Bowser Lake Group	sandstone	2617	1990-2970	192
	siltstone	2640	2190-3400	57
	conglomerate	2584	2240-2710	43
	limestone	2638	2340-2730	8
Stikinia				
Hazelton Group				
Spatsizi Formation	conglomerate	2574	2500-2660	5
	sandstone	2586	2410-2740	12
	siltstone	2561	2450-2680	32
	undiff. volcanic	2663	2580-2770	3
	undiff. volcaniclastic	2620	-	2
Cold Fish Volcanics	tuff	2640	2540-2700	4
	rhyolite	2620	2490-2680	6
	breccia	2507	2460-2570	3
	sandstone	2607	2470-2710	3
	siltstone	2555	2440-2620	4
	undiff. volcanic	2677	2490-2970	29
	other	2640	2530-2710	5
Undifferentiated	tuff	2510	2210-2660	4
	undiff. volcanic	2686	2550-2760	7
	undiff. volcaniclastic	2675	2630-2750	4
undifferentiated Late Triassic and Lower Jurassic rocks	breccia	2750	2640-2800	4
	sandstone	2609	2440-2810	9
	undiff. volcanic	2758	2540-2980	15
	undiff. volcaniclastic	2643	2420-2800	8
Stikine Assemblage	diorite	3070	-	1
	greenstone	2760	-	1
	limestone	2710	-	1
	marble	2705	2680-2730	2
	schist	2750	-	1
	undiff. volcanic	2980	-	1

Table 4: Magnetic susceptibility of predominant lithologies in sampled geologic units.

Geologic unit	Lithology	Magnetic susceptibility ($x10^{-3}$SI)		
		mean	range	#
Overlap assemblages				
Quaternary volcanics	basalt	6.231	3.527-8.934	2
Maitland Volcanics	basalt	9.057	0.275-32.5	10
Sustut Group				
Tango Creek Formation	sandstone	0.286	0.084-1.932	33
	conglomerate	1.303	0.085-3.942	5
	siltstone	0.435	-	1
Brother Peak Formation	sandstone	0.316	0.126-0.650	4
	tuff	0.086	0.057-0.110	3
	conglomerate	0.047	-	1
	grit	0.132	-	1
Bowser Lake Group	sandstone	0.219	0.015-.0553	191
	siltstone	0.223	0.080-0.476	43
	conglomerate	0.781	0.030-16.00	25
	limestone	0.131	0.060-0.245	3
	shale	0.227	0.113-0.338	8
Stikinia				
Hazelton Group				
Salmon River Formation	mudstone	0.113	0.072-0.188	3
	sandstone	0.206	0.109-0.355	8
	siltstone	0.154	0.134-0.173	2
	undiff. volcanics	0.178	0.161-0.194	3
Spatsizi Formation	conglomerate	0.142	0.045-0.335	4
	sandstone	0.137	0.049-0.273	7
	siltstone	0.147	0.035-0.254	21
	undiff. volcaniclastic	0.203	0.162-0.252	3
Cold Fish Volcanics	rhyolite	0.171	0.069-0.265	5
	tuff	0.193	0.108-0.360	3
	undiff. volcanic	1.952	0.029-16.68	17
undifferentiated	conglom	0.197	0.132-0.248	3
	tuff	4.505	0.033-16.28	5
	undiff.volcanic	10.527	0.378-16.28	3
undiff. Upper Triassic and Lower Jurassic rocks	breccia	13.829	0.344-38.65	3
	undiff. Volcanic	11.090	0.099-39.77	10
	undiff. Volcaniclastic	0.189	0.106-0.301	4
	other	1.863	-	1
Stikine Assemblage	marble	0.137	0.063-0.210	2
	undiff. metavolcanic	0.113	-	1
	undiff. volcanic	9.833	-	1
	undiff. volcaniclastic	0.313	-	1

Figure 6: Observed magnetic field, north-central British Columbia.

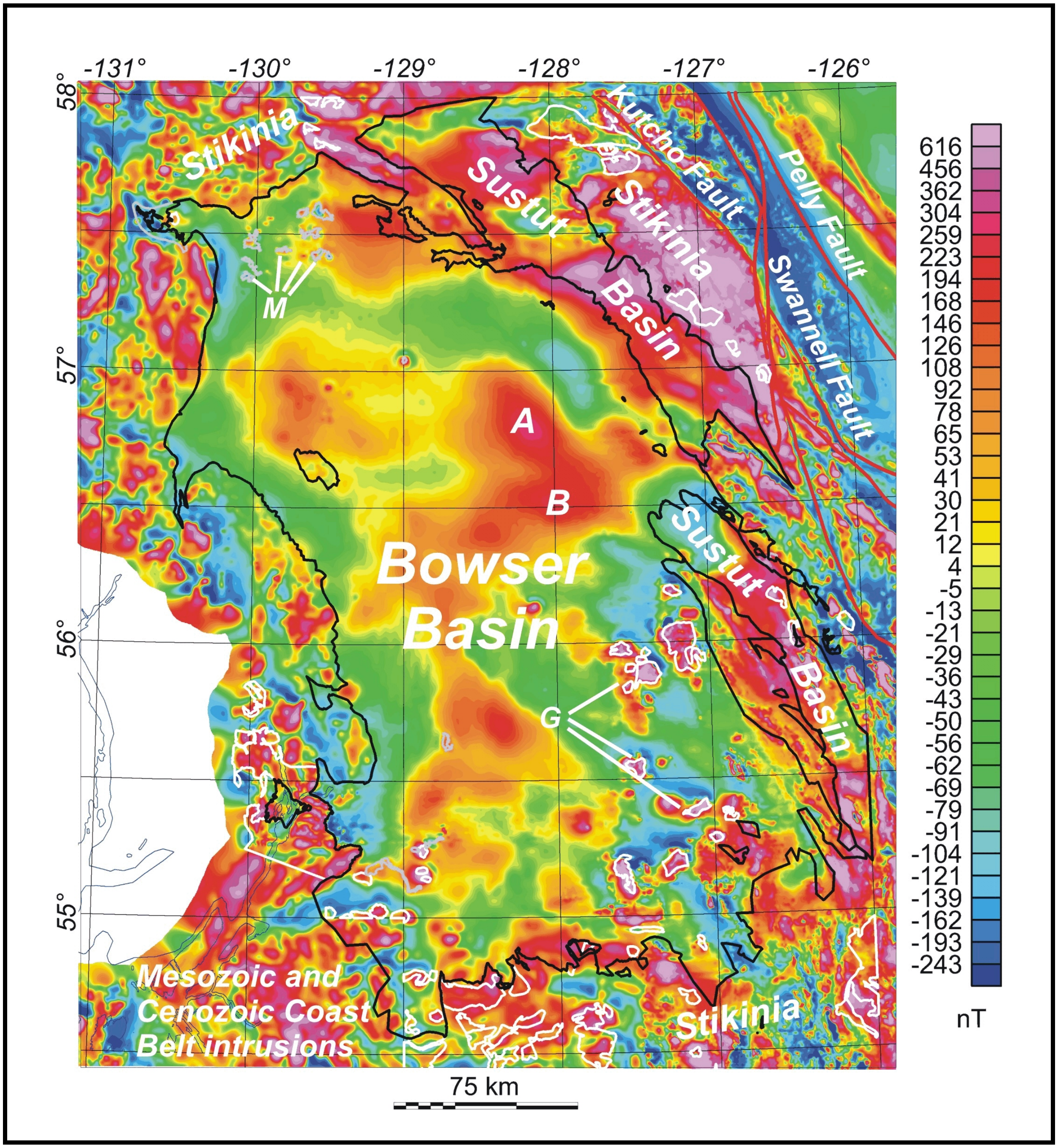
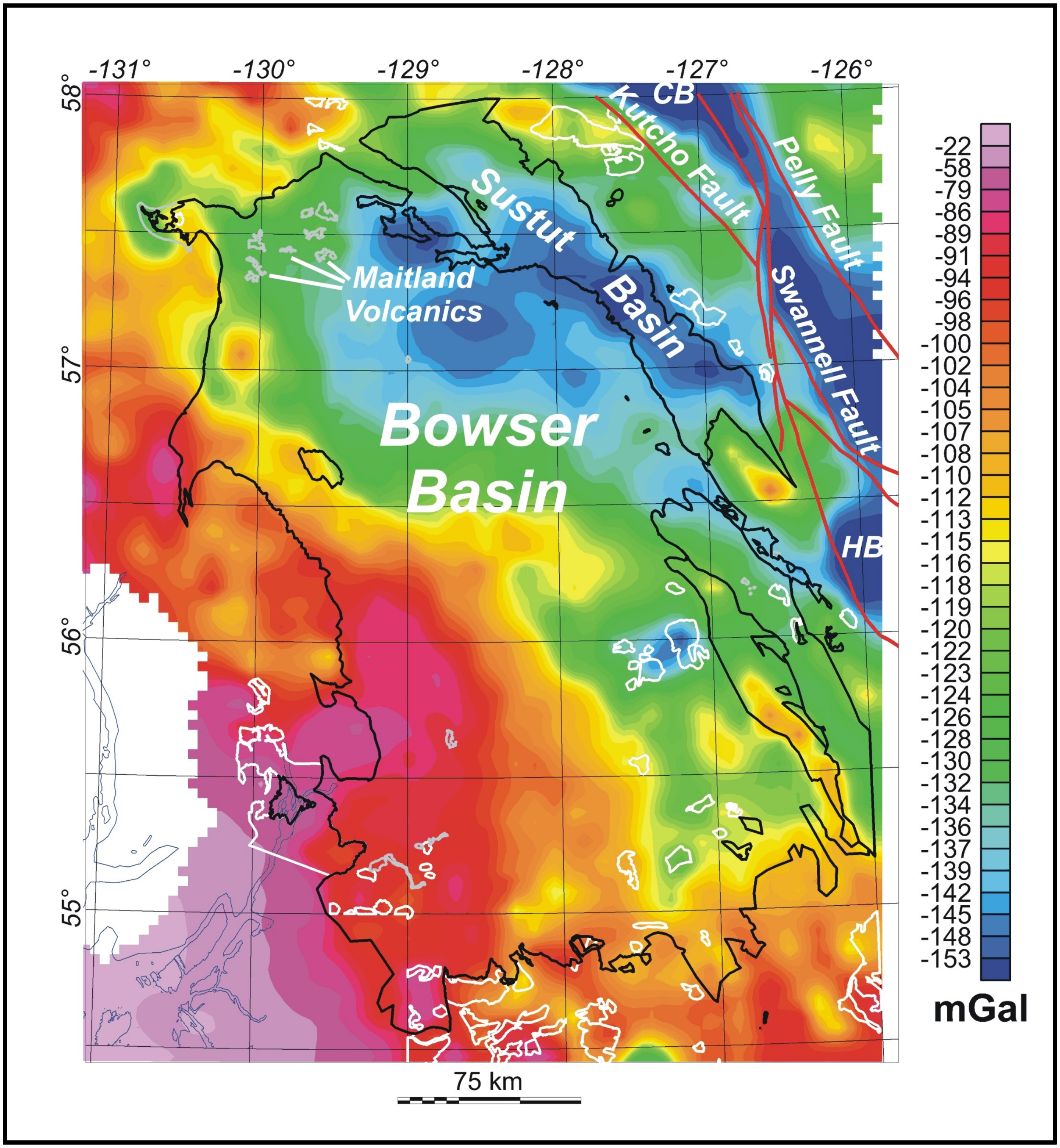


Figure 7: Observed gravity field, north-central British Columbia.



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Appendix A

Microsoft ExCel spreadsheet of individual measurements: Sheet 1: measurements conducted on stratified basement and overlapping rock units; Sheet 2: measurements conducted on intrusive rocks.

Filename = openfile_results.xls