Seismic Velocities of Crustal Samples from the Torngat Peninsula and Nain: ECSOOT'96

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ABSTRACT

The subsurface geology of central and northern Labrador, as well as the Labrador Shelf, is presently being interpreted through the use of various seismic techniques. In the fall of 1996, LITHOPROBE funded a wide-angle seismic refraction experiment (ECSOOT'96) off the coast of Labrador to determine the subsurface geology of *in situ* mid-lower crust along the Labrador coast to Moho depth. Forty representative samples were collected from two areas of Labrador, namely the Torngat Peninsula and southern Nain Province. Laboratory measurements of compressional and shear wave velocities to confining pressures of 600 MPa were performed on the sample set, the results of which will be used for comparison with offshore seismic data to determine the lithologic nature of the mid-lower crust.

Seismic velocities from both sample sets fall within two overlapping fields, felsic and mafic. Felsic samples from the Torngat Peninsula have compressional wave velocities (Vp) ranging from 6.2-6.6 km/s and shear wave velocities (Vs) from 3.6-4.0 km/s, while mafic samples have Vp between 6.5-7.2 km/s and Vs between 3.8-4.2 km/s. Felsic samples from the southern Nain Province have Vp between 6.2-6.7 km/s, and Vs between 3.5-3.7 km/s, while mafic samples have Vp between 6.7-7.0 km/s and Vs between 3.7-4.0 km/s.

Anisotropic samples were found in both regions of Labrador, as determined by both compressional and shear wave velocity data. Anisotropic samples were typically mafic and/or displayed a definite foliation and/or lineation defined by the orientation of anisotropic minerals.

Based on this data it can be concluded that strong reflections would most likely be produced by contrasts between mafic and felsic rocks. Based on seismic refraction data from the Torngat Peninsula, the predominantly felsic rocks that occur onshore in outcrop continue at depth and become increasingly mafic within the lower crust (20-40km depth).

Key words: Lithoprobe, ECSOOT'96, Torngat Peninsula, Nain, compressional wave velocity, shear wave velocity, anisotropic, foliation, lineation, reflection, refraction.

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1.0 Introduction

1.1 Introduction

It is often difficult to determine the composition and structure of the lithospheric crust along continental margins because of its inaccessibility. Drilling is costly when the objective is to determine the geology of a large area, and is ineffective when the goal is to determine the lithological composition to mid-crustal levels because of depth limitations. One technique used is to measure the physical properties of *in situ* mid-lower crust by means of seismic refraction. Seismic properties measured in the field can then be compared to laboratory measurements on lithologies comparable to those expected at depth.

In the fall of 1996, Lithoprobe performed a wide-angle seismic refraction experiment to characterize the seismic velocity structure of the lower crust and upper mantle of Archean and Proterozoic terranes in Labrador and northern Québec. As well as gathering onshore and offshore seismic data, samples were collected from two regions of Labrador (the Torngat Peninsula and southern Nain Province) for seismic velocity measurements and comparison with the onshore/offshore data.

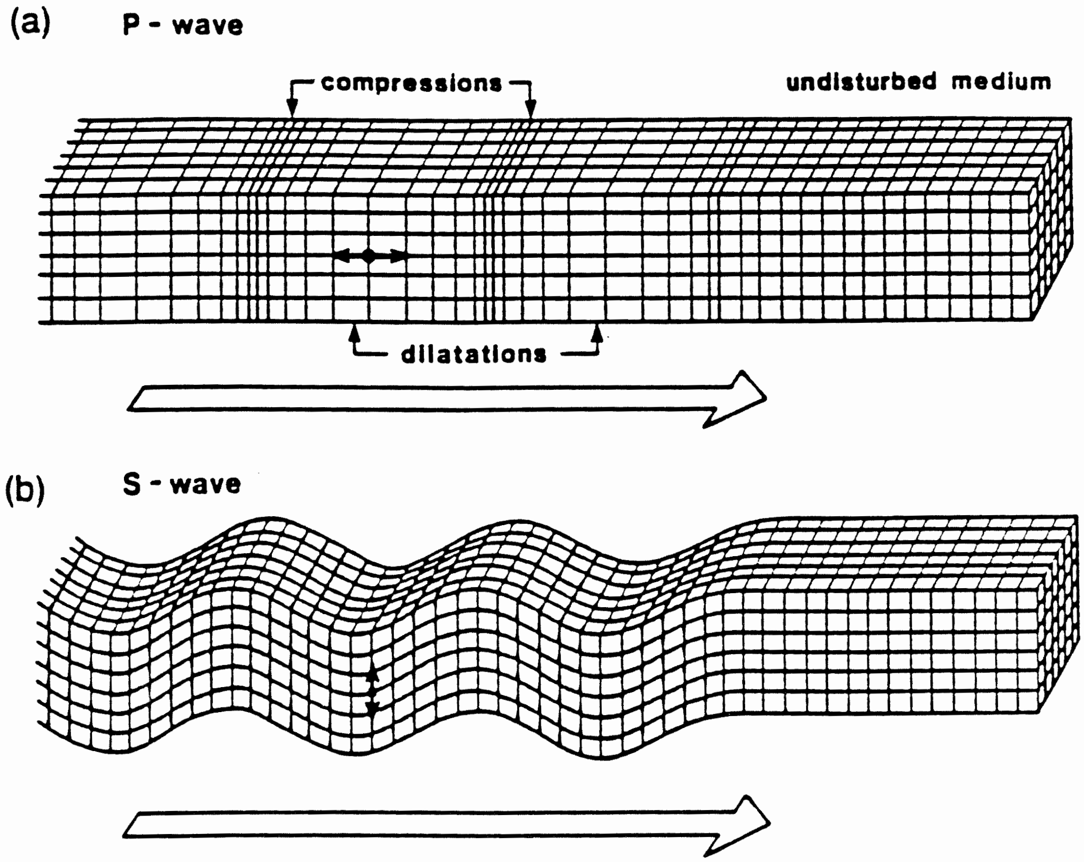
1.2 Purpose and Extent of Study

The purpose of this study is to determine the compressional and shear wave velocities (Fig. 1-1) of rocks from the Torngat Peninsula and southern Nain Province, which will aid in the interpretation of recent seismic refraction data . This study examines the relationships between seismic velocity, mineralogy and density for these rocks, as well as possible causes of variations in velocity with depth. The samples were examined for anisotropy (variations in velocity with propagation direction within individual samples) and Poisson's ratio values were calculated. Thin section analyses were also performed to provide a quantitative basis for interpreting the seismic data in terms of petrology. This study assumes that the rock units that are present in outcrop onshore, occur offshore.

1.3 Seismic Refraction Surveys

Seismic refraction experiments involve sending seismic waves through different layers of the Earth's crust and recording the time it takes for first arrivals and any subsequent signals to return to the surface. In refraction, when a seismic wave crosses a boundary between different velocity layers at an oblique angle, the energy is refracted and travels along the boundary before returning to the surface. The velocity at which seismic waves travel through the crust is directly related to factors such as lithology, density and depth (pressure). The refraction method produces generalized models of subsurface structure based on velocity information, but these models lack the structural

Figure 1-1: The elastic deformation produced in a rock by the transmission of (a) compressional waves (P-waves) and (b) shear waves (S-waves) (Bolt, 1982).



detail or the resolution of specific structures associated with reflection seismology (Kearey et al., 1991).

1.4 ECSOOT'96

In 1992, LITHOPROBE conducted a seismic reflection experiment along the coast of Labrador as part of the Eastern Canadian Shield Onshore-Offshore Transect (ECSOOT). The transects ran through Ungava Bay, around the tip of northern Labrador, and along the Labrador Shelf to the Strait of Belle Isle. The primary objective of this seismic experiment, was to resolve and correlate the offshore Precambrian basement structure with the known onshore geology (McLaren and Hall, 1992).

In late 1993, LITHOPROBE decided to conduct a wide-angle seismic refraction experiment to complement the 1992 reflection study. Several gaps along the Labrador coast were left after the initial reflection transect, and data from deeper in the crust was needed. The seismic refraction experiment (Fig. 1-2) was conducted in the fall of 1996 and was divided into both land and marine components for logistics purposes. A land party headed by Dr. K. Louden from Dalhousie University was responsible for the deployment and retrieval of land seismometers by helicopter, while a marine party based onboard the CSS HUDSON, headed by Dr. I. Ried from the Danish Lithospheric Institute, was responsible for the deployment and retrieval of airguns and ocean bottom seismometers and for shooting to both the land and marine seismometer arrays.

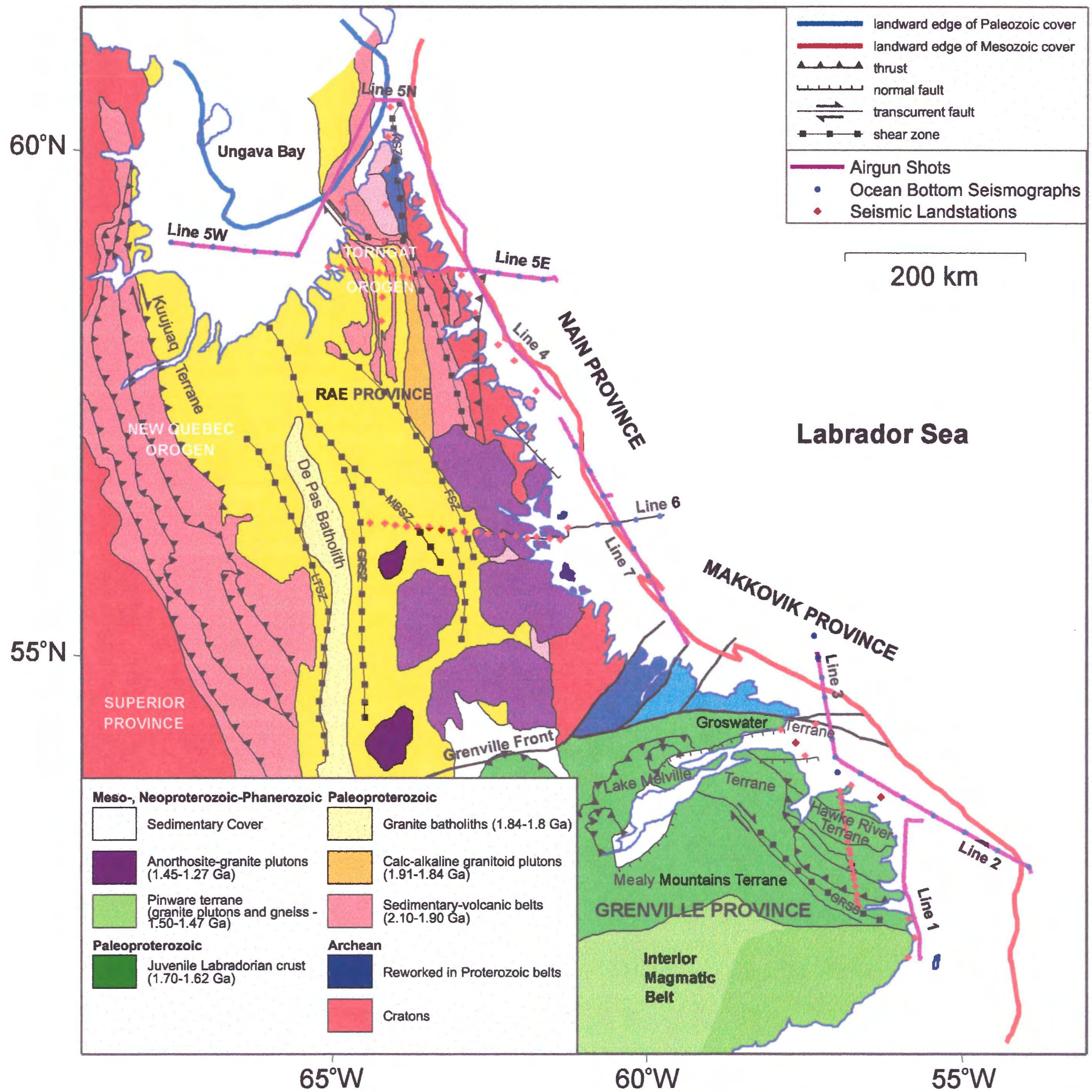


Figure 1-2: Geological map of Labrador and northern Quebec showing transect line locations from ECSOOT'96 (modified from Hall et al., 1995).

1.4.1 Line 5W / Southern Ungava Bay, Lines 5N and 5E / Eastern Ungava Bay/Northern Labrador

The goal of this series of transects was to characterize lateral crustal variations across the Torngat and New Quebec Orogens, and to determine the depth to the base of the crust. Another goal was to identify any rapid variations in the deep crustal velocity structure that might be indicative of deep sub-vertical strike-slip zones in the Torngat Orogen (Louden et al., 1994).

1.4.2 Lines 6 and 7 / Central-Eastern Labrador

Lines 6 and 7 are meant to provide the velocity structure of lithospheric crust associated with the Nain Plutonic Suite, for comparison to that of the undisturbed Nain Province. These lines would also test for the presence of unusually high velocities in the lower crust below the Nain Plutonic Suite. The extension of line 6 across the shear zone boundary to the west would provide a test of the downward continuity of the shear zone through the Moho (Louden et al., 1994). These lines would also help to fill in the gap between the two reflection profiles performed in 1992.

The discovery of a large nickel-copper-cobalt deposit in the Voisey Bay area of Labrador has sparked interest in the local crustal geology. The deposit is located in a troctolite dike of the Nain Plutonic Suite, very close to the shear zone boundary. Information learned from lines 6 and 7 would be very useful for determining how this important deposit formed, and might lead to the discovery of new deposits. One of the current ideas on the formation of the Voisey Bay deposit includes the possibility that the "shear zone focused the upward flow of mantle-derived magmas which then scavenged sulfides from the mid-crustal basement, depositing them in and around the magma pools in the upper crust" (Louden, 1996).

2.0 Geology of the Focus Areas / Sampling

2.1 Introduction

The present geology of northern and central Labrador was formed by the collision of three Archean blocks, the Superior, Rae and Nain Provinces, respectively, around 1.8 Ga (Fig. 2-1). Samples used in this study came from the Nain Province, the Nain Plutonic Suite, and the Eastern Churchill Province (Rae Province and Torngat Orogen). Samples were collected along the transects in Labrador, rather than relying on past laboratory experiments on similar rocks from other locations, because seismic velocities vary with metamorphic grade and tectonic setting. The seismic velocity of a fresh mid-ocean ridge basalt, for example, will differ from the velocity of a greenschist facies basalt or a mafic granulite because metamorphism encourages the growth of new crystal phases with different characteristic velocities. This experiment assumes that there are no great changes in seismic velocity within rock units, and that the units offshore have been subjected to the same tectonic and metamorphic conditions as those onshore.

2.2 The Southeastern Churchill Province

The Southeastern Churchill Province is situated between the Superior Province to the west, and the Nain Province to the east. The area is about 400km wide and consists of three separate units, the New Quebec Orogen, the Rae Province and the Torngat Orogen

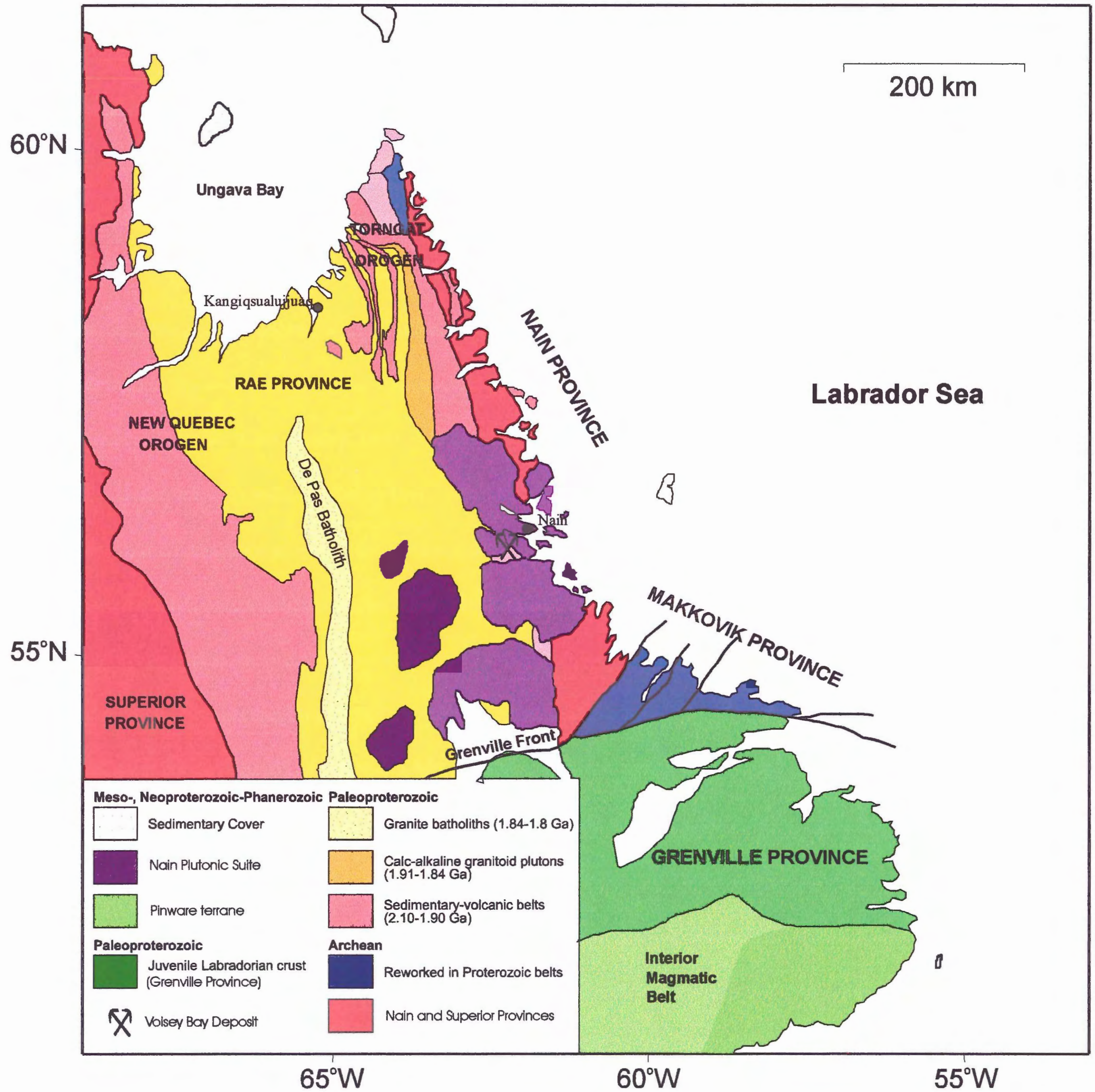


Figure 2-1: Geological map of Labrador and northern Quebec showing the various geological provinces (modified from Hall et al., 1995).

(Fig. 2-1). The Southeastern Churchill Province is believed to have developed by "the oblique convergence of the Superior and Nain cratons during their indentation into the Churchill hinterland" (Hoffman, 1990) and consists of Archean gneisses "sutured against the adjoining Superior and Nain cratons by the New Quebec and Torngat Orogens respectively" (Hoffman, 1988). The interior region consists of transcurrent shear systems while the exterior region is composed of fold and thrust belts.

The Torngat Orogen is a Palaeoproterozoic belt between 75 and 200 km wide, separating the Nain craton to the east from the Archean rocks of the Rae Province to the west (Park, 1995). The area consists of re-worked Archean and Palaeoproterozoic granitic and dioritic plutons, mafic dikes and a band of high-grade (amphibolite-granulite) metasediments called the Tasiuyak gneiss. The Tasiuyak paragneiss consists of semipelitic, pelitic and graphitic schists and quartzite, and is thought to have been derived from an accretionary prism (Scott and Machado, 1994). Early structures within the belt are west-vergent ductile thrusts or shear zones, attributed to oblique convergence between the Nain and Rae cratons (Park, 1995). Later movements involved strike-slip movements along steep shear zones and east-vergent thrusts onto the Nain craton, attributed to subsequent shortening across the belt and backthrusting onto the Nain craton (Park, 1995).

2.3 The Nain Province / Nain Plutonic Suite

The Nain Province is located along the eastern coast of Labrador (Fig. 2-1) and is a classic example of an Archean, high-grade craton. It consists of an amphibolite to granulite facies gneiss complex with a long and complex supracrustal, igneous and metamorphic history between 3.8 and 2.6 Ga (Bridgwater and Schiotte, 1991). The area was intruded by several dike swarms (Napaktok and Avayalik dikes) in the Palaeoproterozoic, and the western edge of the Nain Province, including the dikes, was strongly reworked under amphibolite and granulite facies conditions during the Torngat orogeny (Rivers et al., 1996). The Nain Province consists of the early-Archean Saglek block to the north and the mid-Archean Hopedale block to the south. The Saglek block is believed to be continuous with the Akulleq terrane in Greenland (Bridgwater and Schiotte, 1991).

Scattered throughout the Nain Province is the Nain Plutonic Suite (Fig. 2-1), which was intruded during the mid-Proterozoic into the Nain Province across the shear zone boundary between the Nain and Rae Provinces. The suite consists of mantle-derived calc-alkaline plutons ranging in age from 1.91 to 1.87 Ga (Scott and Machado, 1994). Until recently it was believed that the Nain Plutonic Suite had not experienced any deformation; however, according to Ryan (1991), deformational fabrics were discovered along the contact between the plutons and the surrounding gneisses, and in the dioritic and granitoid rocks within the interior of the suite.

2.4 Sample Locations / Lithologies

Samples from each major lithologic unit were collected from two areas of Labrador, a northern transect along Nachvak Fjord to the coast of Ungava Bay which crossed the Torngat Orogen, and a transect across the central region of the Nain Province

(Figs. 2-2, 2-3, 2-4, 2-5 and 2-6). Sampling was performed by Dr. M. Salisbury, Dr. K. Louden, and Mr. R. Iuliucci by helicopter and by foot. Large, fresh hand samples were collected from outcrop or autochthonous float in both areas. In total, 40 samples were taken from the field; however, in consultation with Dr. M. Salisbury, 23 samples representing the major lithologies in the northern region, and nine from central Nain were selected for laboratory analysis. Surficially weathered samples were trimmed, leaving enough material for a minimum of three cores to be extracted for anisotropy analysis.

The northern transect allowed for sampling across the transition from the Archean gneisses of the Nain Province to the Paleoproterozoic sedimentary-volcanic belts and more calc-alkaline granitoids of the Torngat Orogen (Fig. 2-3). The central transect sampled the intrusive plutons of the Nain Plutonic Suite as well as the Paleoproterozoic calc-alkaline granitoid plutons of the Rae Province (Fig. 2-6).

Sample lithologies encompassed a wide range of igneous and metamorphic rocks. In the northern region, sample lithologies ranged from felsic rocks such as granites, tonalite gneisses, granitoid gneisses, bio-qtz-fs gneisses, paragneisses and psammitic gneisses, to mafic rocks such as mafic gneisses, anorthosites and basalt dikes. The samples from the central region included migmatites, mafic gneisses, anorthosites, hypersthene-quartz-feldspar (hy-qtz-fs) granulites, quartz diorites, and biotite-quartz-feldspar (bio-qtz-fs) gneisses. Since most samples experienced some degree of metamorphism, metamorphic grade varied across the Torngat Orogen (Fig. 2-4). Samples collected on the east coast (L11a, L11b`, L12, L13, L14, L15 and L16), all within the Nain Province, have experienced greenschist grade retrogression (Wardle, 1996). Samples from further inland, but still within the Nain Province (L10a and L10b), have

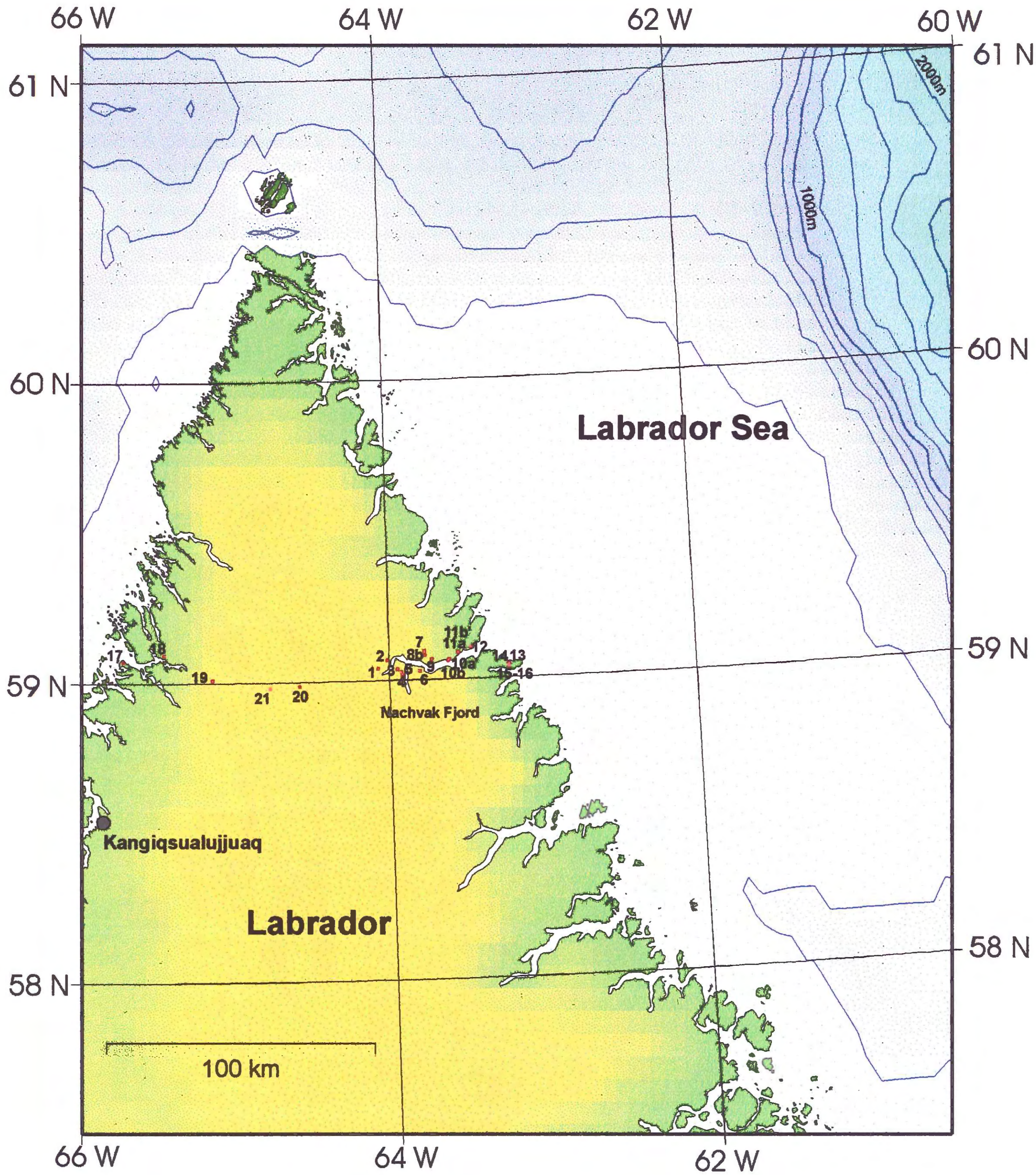


Figure 2-2: Topographic map of northern Labrador showing sample locations (modified from Hall et al., 1995).

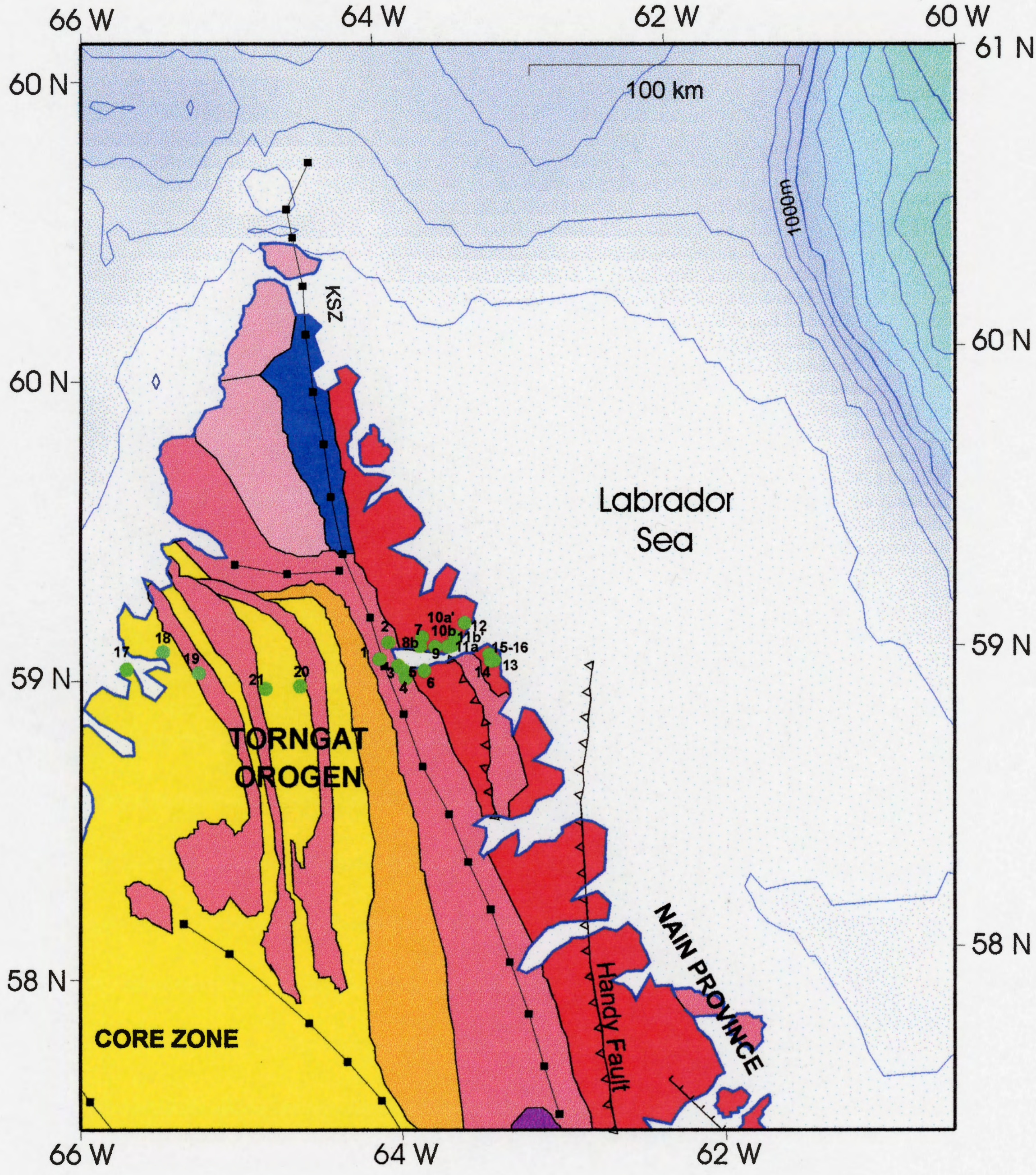


Figure 2-3: Tectonic map of northern Labrador showing sample locations (modified from Hall et al., 1995).

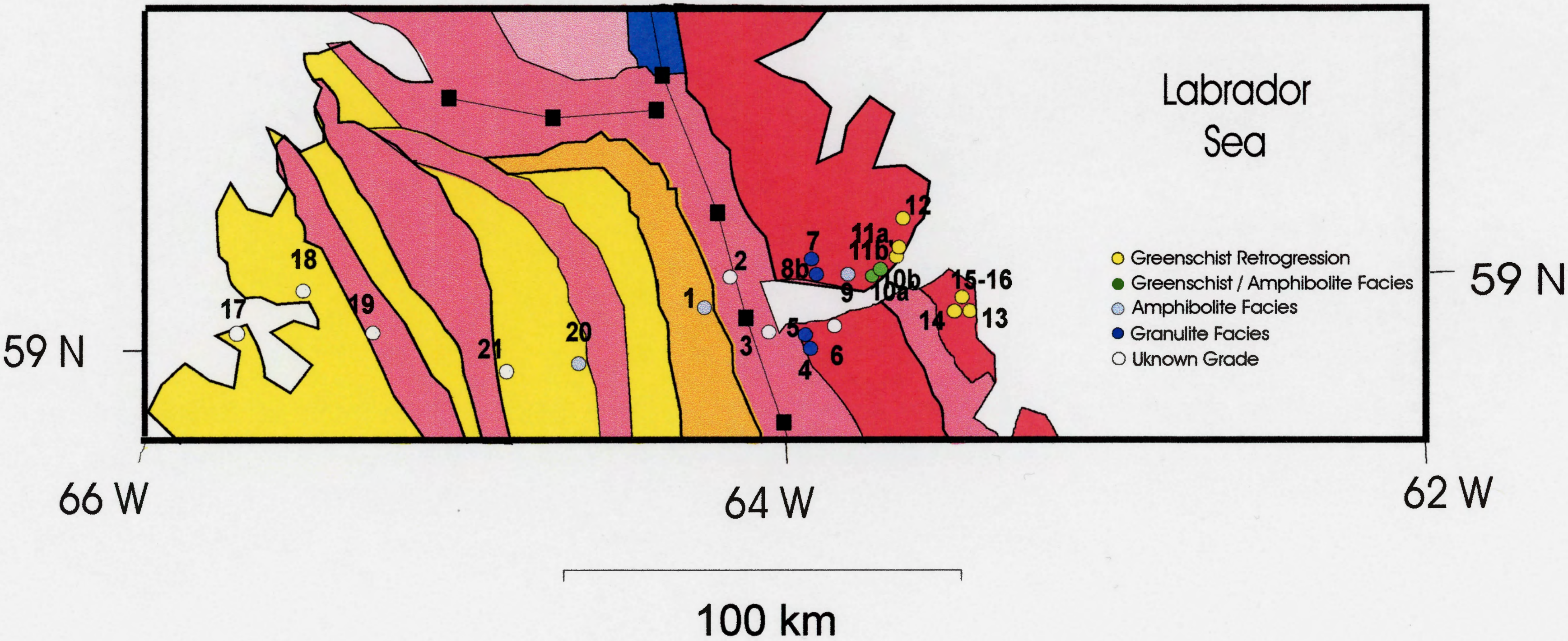


Figure 2-4: Detailed geologic map from the Torngat Orogen / Nachvak Fjord region showing metamorphic grades of samples (after Hall et al., 1995, and Wardle, 1996). Refer to Figure 2-1 for legend.

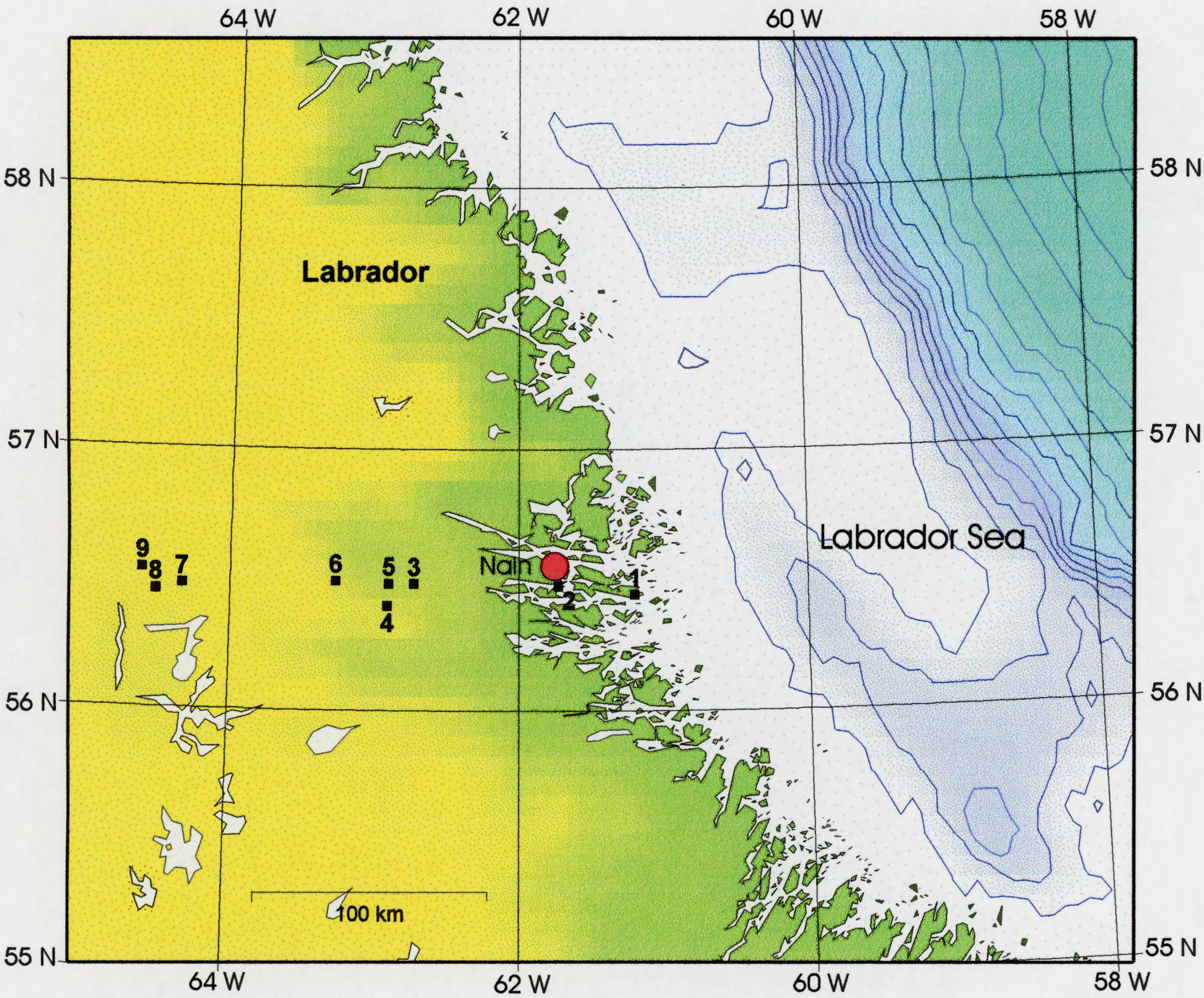


Figure 2-5: Topographic map of central Labrador showing sample locations (modified from Hall et al., 1995).

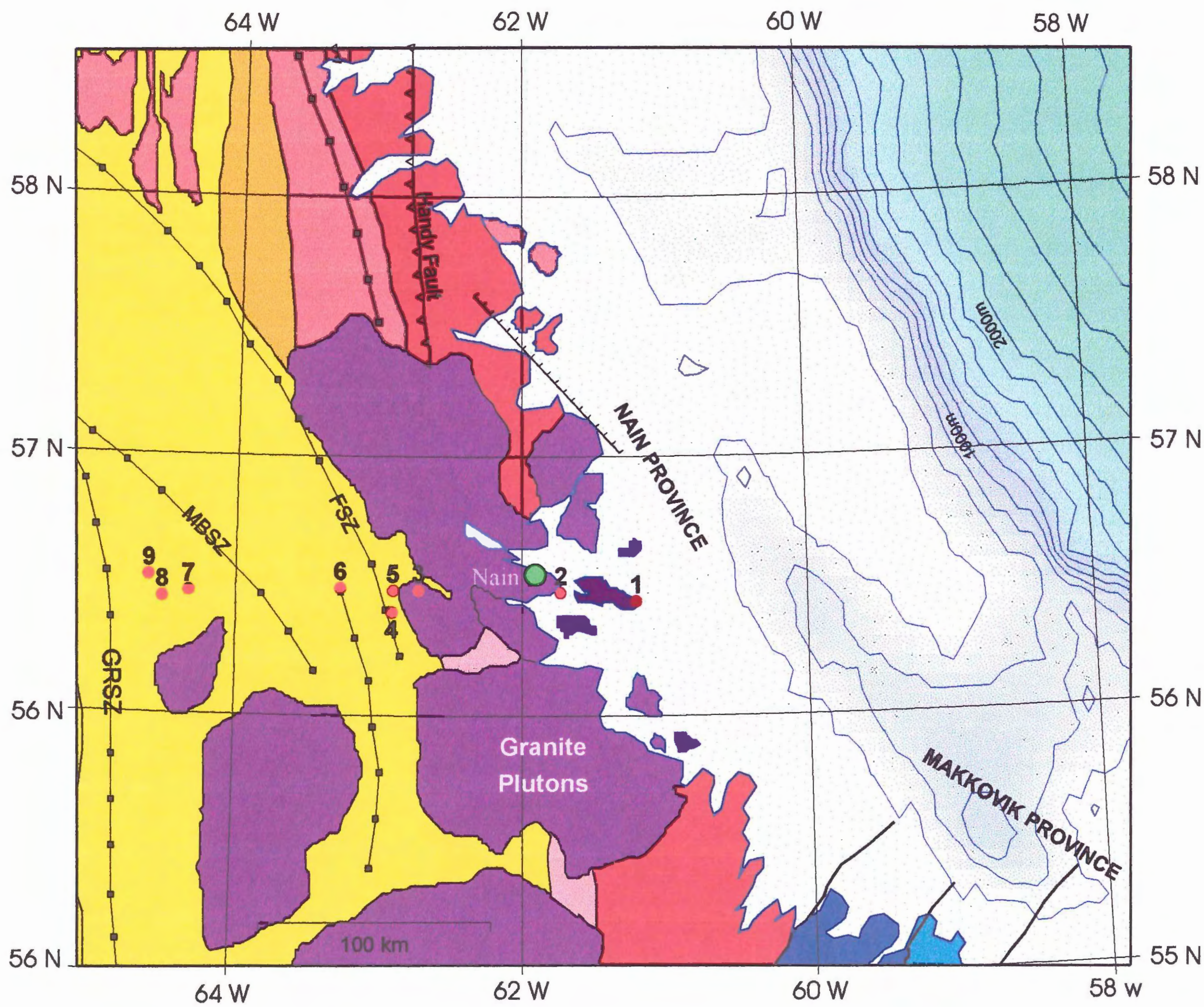


Figure 2-6: Geological map showing sample locations (modified from Hall et al., 1995).

experienced greenschist to amphibolite facies metamorphism (Wardle, 1996). Samples from the western edge of the Nain Province have experienced amphibolite (L9) and granulite facies metamorphism (L4, L5, L7 and L8b) (Wardle, 1996). In general, the metamorphic grade within the Nain Province increases to the west because of the presence of the Abloviak shear zone which lies within the Tasiuyak gneiss on the western edge of the Province. Samples from the central transect around Nain appear to have undergone much less metamorphism than samples from the Torngat Orogen. Most samples still contain their original igneous textures with some alteration of plagioclase or pyroxene (Appendix A and B). Any evidence of elevated pressures or temperatures is represented by foliation in selected samples.

2.5 Thin section Analyses

Thin sections were made from each analyzed sample and observed under refracted light microscopy. Only one thin section was cut per sample, and if the sample contained foliation, the thin section would be cut perpendicular to the foliation. A total of 33 thin sections were made. The purpose for this analysis was to gain a better understanding of the modal mineralogy of each sample (Table 2-1), to see if foliation could be seen in thin section, and to identify which minerals are responsible for the foliation (Appendix A). The thin section work was also performed to explain any discrepancies in the compressional and shear wave velocity results. For example, sample L10b was thought to be a mafic gneiss,

Table 2-1: Estimated modal mineralogy for all samples, listed in lithological groupings. For more detailed descriptions, refer to Appendix A and B.

Sample #	Lithology	Density g/ml	% Qtz	% Fspr	% Pyrx	% Bio	% Amph	% Chl	% Epid	%Gnt	% Other
L6 - xy	anorthosite	2.80	30	30		20	20				
N2	anorthosite	2.73		95	5						2% opaques
L14	basalt dike	3.06		50	35			5			10% opaques
L9	dike	3.00	20?	60	20						
N8 - xy	bio-qtz-fs gneiss	2.75	50	20		30					
L21 - xy	bio-qtz-fs gneiss	2.66	50	30		15				5	
L4 - y	felsic gneiss	2.64	45	50		5					
L11a - xy	felsic gneiss	2.70	45	25		15					
L10a - xy	felsic gneiss	2.68	45	35							15% clay, 5% opaques
L10b - xy	felsic gneiss	2.79	35	35		25			5		
L13 - xy	felsic gneiss	2.62	50	50							
L3 - y	felsic gneiss	2.82	20	40	35	5					
L7 - x	felsic gneiss	2.83	20	65	10						
L1 - xy	tonalite gneiss	2.68	40	40	15	5					
L12 - xy	granite	2.62	45	50		5					
L20 - xy	granitoid gneiss	2.87	25	20	10	10	25				10% opaques
L17 - y	granitoid gneiss	2.75	50	30		10	10				
N3	granite/qtz monzonite	2.67	20	65	6	2	5	2			
N5 - xy	hy-qtz-fs granulite	2.6	20	10	70						
N1 - xy	migmatite	2.64	45	30	5	15		<1%			2% opaques
N6 - xy	migmatite	2.63	25	60		7.5			7.5		
L8b - y	mafic gneiss	3.09	15	20	20		45				
L11b' - xy	mafic gneiss	3.05	5	25			30	25	15		
L5 - y	mafic gneiss	2.97	15	35	15			35			
L15 - xy	mafic gneiss	3.04	5	30	10	15				40	
N4 - xy	mafic gneiss	2.99	20	20	10	30	10		5		5% opaques
N7 - xy	qtz diorite	3.02	20	20	50	5					5% opaques
L18	marble	2.86									60% dolomite, 40% calcite
L2 - x	paragneiss	2.83	35	25	10	5	<5			20	
L19 - xy	psammitic gneiss	2.72	35	30		30				5	
L16	quartzite	2.68	95								5% clays
N9a	quartzite	2.58	50	40		10					

Qtz = quartz, Fspr = feldspar, Pyrx = pyroxene, Bio = biotite, Amph = amphibole, Chl = chlorite, Epid = epidote, Gnt = garnet.

but the compressional wave velocity was found to be 6.14 km/s, quite slow compared to the results for other mafic gneiss samples (~7km/s). After examining the prepared thin section, the mineralogy showed that the sample was not a mafic gneiss, but a felsic gneiss, which would be consistent with both the compressional and shear wave velocities. Typically most samples from the Torngat Orogen / Nachvak Fjord region of Labrador have been metamorphosed to greenschist-amphibolite facies, with some altered to granulite facies. In general, felsic gneisses, bio-qtz-fs gneisses, tonalite gneisses, granites and granitoid gneisses contained abundant quartz and feldspar with varying amounts of mafic minerals, depending on the sample. Mafic samples contained abundant biotite, pyroxene and amphibole with minor amounts of quartz, feldspar, chlorite and epidote. As previously mentioned, samples from Nain tend to display their original igneous textures, with a few samples having foliation defined by biotite, pyroxene, amphibole and oriented quartz grains.

3.0 Sample Preparation and Testing

3.1 Introduction

Seismic velocity tests were performed at the Dalhousie University / Geological Survey of Canada High Pressure Testing Facility located at Dalhousie University. The facility is equipped to measure compressional and shear wave velocities of rocks at confining pressures ranging from 0 - 1.2 GPa. As compressional waves (P-waves) travel through rock, the particles oscillate parallel to the propagation direction, while for shear waves (S-waves), they oscillate perpendicular to the propagation direction (Fig. 1-1). The first arrival times for P and S-waves differ because P-waves are generally faster than shear waves by a factor of about 1.7.

3.2 Sample Preparation

Mini-cores ranging from 2.8 - 5 cm in length with an average diameter of 2.5 cm, were taken from each sample using a drill press mounted with a diamond drill bit. Depending on whether or not the sample contained foliation and/or lineation, up to three oriented mini-cores were taken to test for anisotropy. If a sample contained neither foliation nor lineation, only one core was taken in an arbitrary direction. If the sample displayed foliation, two cores were extracted, one parallel to the foliation (xy), and one perpendicular to foliation (z). If a sample displayed both foliation and lineation, three cores were taken, one perpendicular to the foliation (z), one parallel to both the foliation and lineation (x), and one parallel to the foliation but perpendicular to the lineation (y) (Fig. 3-1).

After the cores had been drilled, the ends were trimmed using a diamond saw and machine-lapped to make the ends parallel. The dimensions and weights of the samples were then measured using a digital vernier caliper and a top loading balance which was precise to 0.01 grams (Table 3-1). The cores were then wrapped in a copper jacket which acts as an electrical ground and prevents the pressure medium from invading the sample at elevated pressures.

From the data in Table 3-1, it can be seen that the densities ranged from 2.61 g/ml (felsic gneiss) to 3.12 g/ml (mafic gneiss) for samples from the Torngat Orogen/Nachvak Fjord region, while for the Nain region, sample densities ranged from 2.58 g/ml (quartzite) to 3.02 g/ml (quartz diorite).

3.3 High Pressure Runs

Once a sample was prepared or 'jacketed', a thin copper shim (0.0005cm thick) was placed on each end and the sample was placed between two 1MHz lead-zirconate-titanate transducers, followed by 1" brass electrodes. The entire package was then placed in gum-rubber tubing to protect against saturation from the pressure medium (ESSO MONOPLEX).

Transducers differed for shear and compressional wave velocity tests. The

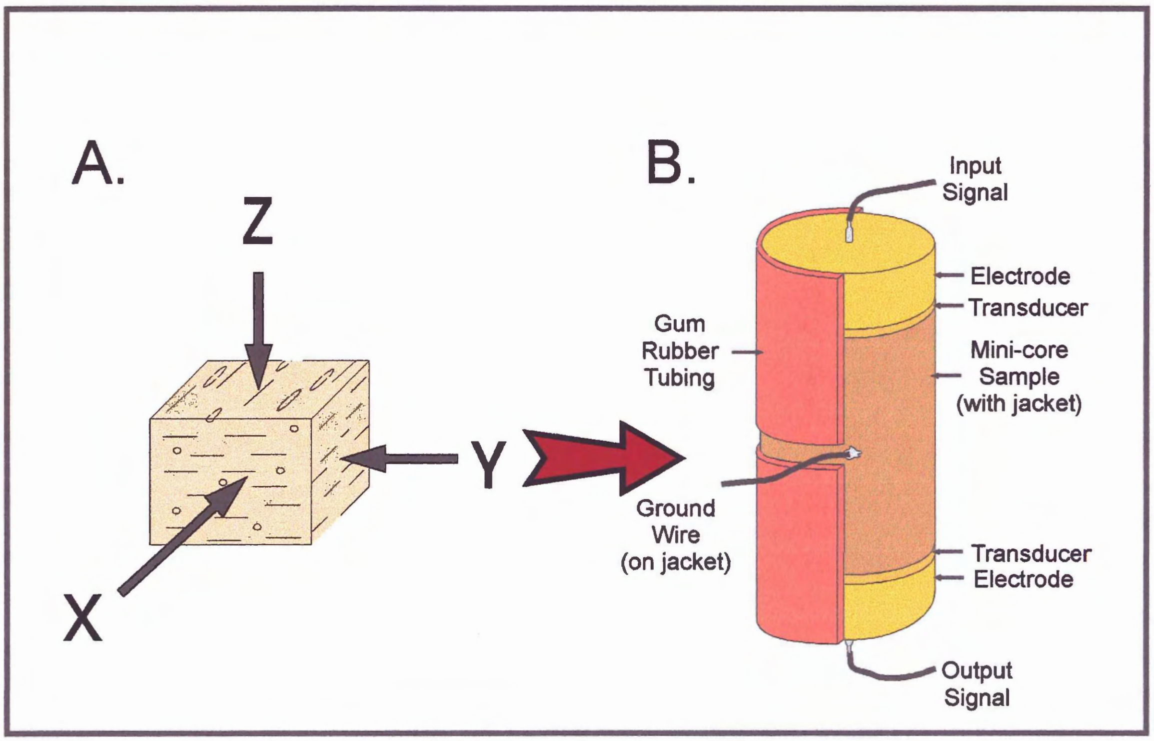


Figure 3-1: A) Schematic diagram showing the sample orientation convention. Z-direction is perpendicular to the foliation. In rock samples with lineation and foliation, the X and Y-directions lie in the foliation plane and are aligned parallel and perpendicular to the lineation, respectively. B) Sample assembly for high pressure velocity measurements (after Harvey, 1997).

Table 3-1: Sample dimensions, volume and density.

Torngat Orogen / Nachvak Fjord

Sample#	Rock Type	Weight (g)	Length (mm)	Diameter (mm)	Volume (ml)	Density (g/ml)
L1 - z	tonalite gneiss	64.65	48.02	25.35	24.15	2.68
L1 - xy	(granulite facies)	64.57	47.81	25.37	24.13	2.68
L2 - z	paragneiss	64.14	46.13	25.35	23.13	2.77
L2 - z'		65.98	45.91	25.34	23.10	2.86
L2 - x		41.36	29.10	25.36	14.64	2.83
L2 - x'		49.98	34.60	25.35	17.35	2.88
L2 - y		73.59	52.21	25.33	26.03	2.83
L3 - z	straight rock /	44.72	31.74	25.36	15.84	2.82
L3 - x	felsic gneiss	42.20	29.94	25.34	14.88	2.84
L3 - y		62.15	44.02	25.45	22.01	2.82
L4 - z	felsic gneiss	42.00	31.88	25.38	15.99	2.63
L4 - x	(granulite facies)	37.40	28.53	25.34	14.33	2.61
L4 - y		61.57	46.38	25.36	23.33	2.64
L5 - z	mafic gneiss	61.34	41.00	25.35	20.54	2.99
L5 - x	(granulite facies	60.03	39.26	25.32	19.76	3.04
L5 - y	overprint)	67.14	44.80	25.36	22.58	2.97
L6 - z	anorthosite	58.42	41.66	25.33	20.85	2.80
L6 - xy		65.61	46.64	25.32	23.46	2.80
L7 - z	felsic gneiss	52.62	36.98	25.32	18.72	2.81
L7 - x	(granulite facies)	64.23	44.79	25.34	22.64	2.83
L7 - y		68.24	49.52	25.33	24.87	2.74
L8b - z	mafic gneiss	65.24	42.08	25.31	21.05	3.10
L8b - z'''	overprint)	46.85	30.06	25.35	15.22	3.09
L8b - x		68.47	43.69	25.28	21.92	3.12
L8b - y		72.36	46.53	25.32	23.38	3.09
L9	late dike	63.37	41.99	25.27	21.14	3.00
L10a' - z	felsic gneiss	45.10	33.56	25.34	16.77	2.69
L10a' - xy	(grn.sch./amph. facies)	56.59	42.14	25.34	21.11	2.68
L10b - z	felsic gneiss	61.24	43.12	25.29	21.73	2.82
L10b - xy	(grn.sch./amph. facies)	60.40	43.01	25.32	21.62	2.79
L11a - z	felsic gneiss	55.72	41.36	25.36	20.75	2.69
L11a - xy	(greenschist facies)	46.81	34.72	25.32	17.32	2.70
L11b' - z	mafic gneiss	62.73	40.73	25.29	20.44	3.07

L11b' - xy	(greenschist facies)	71.67	46.80	25.31	23.50	3.05
L12 - z	granite	43.21	32.95	25.36	16.46	2.63
L12 - xy		45.50	34.76	25.33	17.35	2.62
L12 - xy'		40.23	30.52	25.32	15.35	2.62
L12 - xy"		49.94	37.82	25.34	19.03	2.62
L13 - z	felsic gneiss	44.30	33.80	25.30	16.92	2.62
L13 - xy	(greenschist facies)	52.06	39.55	25.35	19.90	2.62
L14'	basalt dike	58.10	37.75	25.34	18.98	3.06
L14"	(greenschist facies)	55.22	35.90	25.30	18.11	3.05
L15 - z	mafic gneiss	68.48	44.06	25.32	22.12	3.10
L15 - xy		54.80	35.73	25.33	18.03	3.04
L15 - xy'		62.77	40.66	25.35	20.45	3.07
L16	quartzite	50.89	38.06	25.35	18.98	2.68
L17 - z	granitoid gneiss	50.17	37.21	25.33	18.75	2.68
L17 - x		58.68	42.55	25.32	21.33	2.75
L17 - y		42.44	30.88	25.30	15.42	2.75
L18	marble	65.27	45.40	25.29	22.85	2.86
L19 - z	psammitic gneiss	63.09	47.82	25.31	23.29	2.71
L19 - xy		65.36	47.94	25.34	24.01	2.72
L20 - z	granitoid gneiss	64.64	44.34	25.31	22.24	2.91
L20 - xy		65.39	45.41	25.32	22.78	2.87
L21 - z	bio-qtz-fs gneiss	43.77	32.70	25.35	16.43	2.66
L21 - xy		43.21	32.33	25.36	16.25	2.66

Nain

Sample#	Rock Type	Weight (g)	Length (mm)	Diameter (mm)	Volume (ml)	Density (g/ml)
N1 - z	migmatite	57.15	42.96	25.37	21.55	2.65
N1 - xy		50.07	37.82	25.33	18.98	2.64
N2'	anorthosite	48.20	35.35	25.33	17.83	2.70
N3	granite / qtz monzonite	55.03	40.71	25.34	20.60	2.67
N4 - z	mafic gneiss	68.31	45.29	25.33	22.75	3.00
N4 - xy		63.09	42.08	25.34	21.13	2.99
N5 - z	hy-qtz-fs granulite	38.57	29.21	25.31	14.64	2.63
N5 - xy		48.39	36.90	25.33	18.63	2.60

N6 - z	migmatite	48.58	35.88	35.32	18.07	2.69
N6 - xy		52.88	40.17	25.36	20.10	2.63
N7 - z	qtz diorite	71.02	47.12	25.35	23.50	3.02
N7 - xy		74.85	49.40	25.35	24.78	3.02
N8 - z	bio-qtz-fs gneiss	63.64	45.94	25.07	23.09	2.76
N8 - xy		59.88	43.40	25.29	21.76	2.75
N9a	quartzite	37.38	28.73	25.38	14.48	2.58

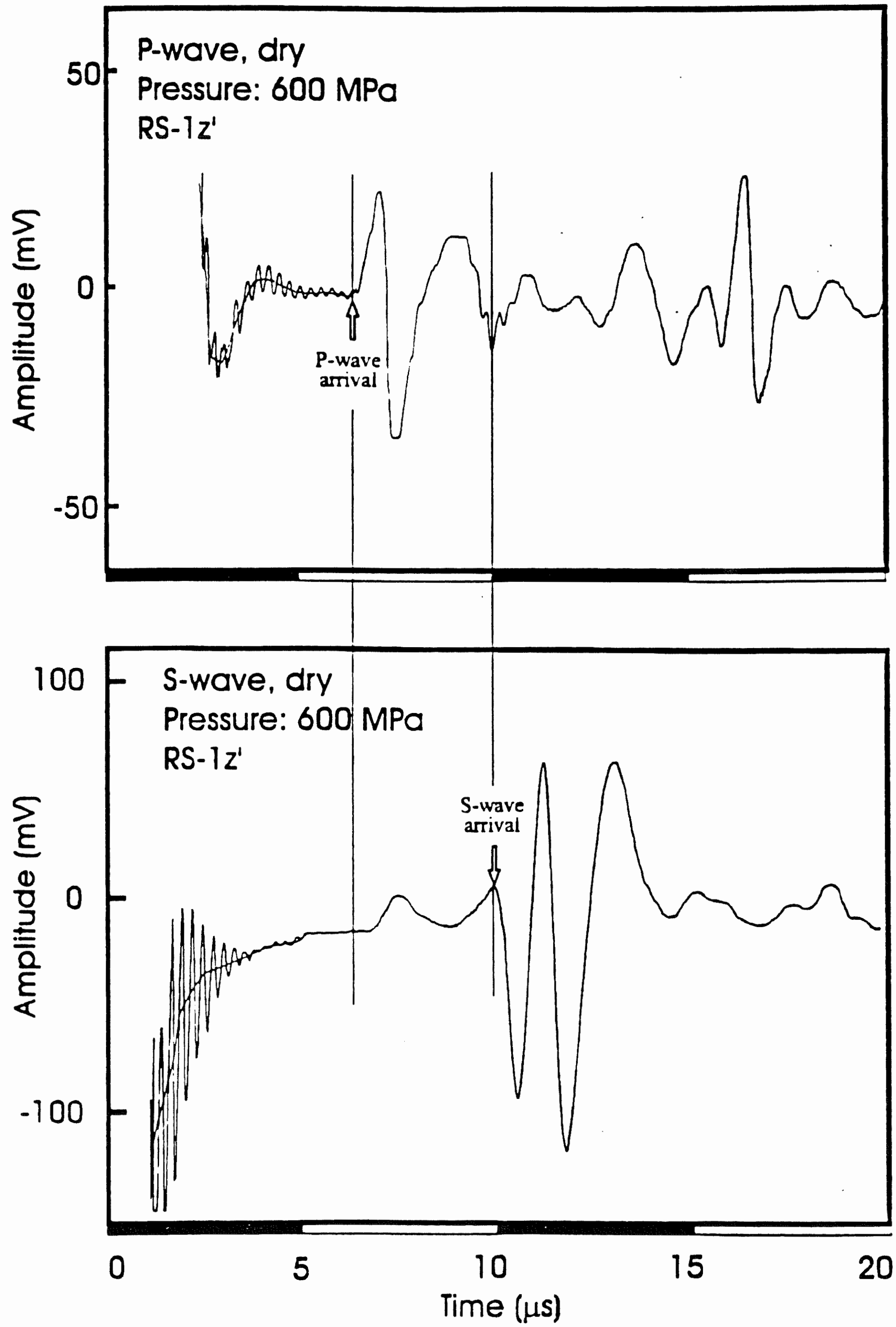
Sample # superscripts indicate material resampled to replace saturated minicores.

compressional wave velocity transducers are 2.14 mm thick, while the shear wave transducers are 1.07 mm thick with a small bevel on one edge to indicate the vibration direction. This was oriented with respect to foliation or lineation to check for anisotropy.

Up to four samples at a time were placed in a holder which was lowered into the high pressure vessel. A large threaded end closure was then fitted into place, ensuring a tight seal. Compressional and shear wave velocities were measured at hydrostatic confining pressures from 10 to 600 MPa using the pulse transmission technique of Birch (1960). First arrivals (Fig. 3-2) were measured at 20 MPa increments for confining pressures <100 MPa, then at 100 MPa increments up to 600 MPa. Once the travel times were measured, the velocities were determined from the lengths of the mini-cores and the travel times of the P and S-waves through the samples.

The shear wave velocities were determined on the same samples as the compressional wave velocity measurements, unless the initial sample had saturated. Since a much larger number of shear wave velocity measurements is needed to characterise a sample, up to six shear wave measurements were made on selected samples, depending on the fabric of the rock. For an isotropic sample such as L11a (felsic gneiss), only one shear wave velocity measurement was made. For a mildly anisotropic foliated sample such as L11b' (mafic gneiss), three measurements were made, one in the z-direction, and two in the xy-direction, with vibration parallel and perpendicular to foliation. To assess shear wave splitting in highly anisotropic samples with both foliation and lineation such as L2 (paragneiss), shear waves were measured in two vibration directions per core: one parallel and one perpendicular to the foliation and/or lineation.

Figure 3-2: Typical P and S-wave travel time traces generated at 600 MPa (after Harvey, 1997).



3.4 Saturation

Saturation occasionally occurred when the pressure medium found its way into the gum tubing and jacket and penetrated the pore spaces within the sample. Since all tests were designed to be performed under 'dry conditions', samples which saturated had to be re-cored and re-run. Saturation was detected from the presence of oil on the sample ends once the gum tubing was removed, or from anomalous signal behaviour (almost always accompanied by hydraulic oil on the sample).

4.0 Seismic Velocity Measurements

4.1 Introduction

In total, 65 compressional wave velocity measurements were successfully made on a total of 84 cores from 31 samples (some samples were re-run due to saturation), and 49 shear wave velocity measurements were made on a total of 74 cores from 26 samples. Again, some samples were run more than once due to saturation or other problems such as poor signal quality.

4.2 Compressional Wave Velocities

Compressional wave (P-wave) velocities of the deep crust are primarily determined by four factors: mineralogic composition, confining pressure, anisotropy and pore fluid pressure (Holbrook et al., 1992). The rocks in this study are assumed not to be saturated at depth, therefore pore fluid pressure will not be a determining factor in this study.

The lower continental crust tends to display a broad range of P-wave velocities which indicates considerable compositional diversity (Holbrook et al., 1992). Holbrook et al. divide the deep crust into two regions, the middle crust where P-wave velocities range from about 5.4 km/s to 7.3 km/s, and the lower crust where P-wave velocities range from about 6.0 km/s to 7.5 km/s. It should be noted that in the deep crust an increase in seismic velocity could be related to either increasing mafic composition or increasing metamorphic grade.

4.2.1 Results

Table 4-1 presents a summary of the compressional wave velocities measured for all samples from the Torngat Orogen/Nachvak Fjord and Nain regions of Labrador.

4.2.1.1 Compressional Wave Velocity Versus Pressure

All samples showed an initial sharp increase in compressional wave velocity with increasing pressure due to the rapid closure of microcracks and pore spaces. As shown in Figure 4-1, however, the curves become linear at approximately 200 MPa. It is believed that this pressure coincides with the final closure of microcracks and pore spaces within the rock and that the velocities determined after this point are representative of the mineralogy and orientation of the rock's constituent minerals. The velocities associated with decreasing pressure are typically higher than those associated with increasing pressure due to sealing of the microcracks. Thus only the velocities determined with decreasing pressure are shown in Table 4-1 because they are considered more representative of *in situ* velocities.

From the data in Table 4-1, most samples appear to represent mid-lower crustal material due to their high seismic velocities. All samples tend to range above 5.4 km/s at 600MPa, the lower range of mid-crustal rocks as determined by Holbrook et al., (1992),

Table 4-1: Compressional wave velocities of ECSOOT'96 samples

Torngat Orogen / Nachvak Fjord

Sample Number	Lithology	Density g/ml	Velocity (km/s) at Pressure (MPa) 20	40	60	80	100	200	300	400	500	600
L1-z	Tonalite gneiss	2.680	6.040	6.120	6.190	6.260	6.305	6.435	6.485	6.508	6.517	6.525
L1-xy	Tonalite gneiss	2.680	5.950	6.020	6.080	6.140	6.190	6.330	6.423	6.470	6.503	6.515
	Average	2.680	5.995	6.070	6.135	6.200	6.248	6.383	6.454	6.489	6.510	6.520
L2-z	Paragneiss	2.770	5.370	5.620	5.820	5.960	6.050	6.290	6.350	6.370	6.385	6.398
L2-x	Paragneiss	2.830	5.540	5.760	5.900	5.990	6.050	6.205	6.250	6.285	6.320	6.354
L2-y	Paragneiss	2.830	6.030	7.030	6.230	6.280	6.325	6.470	6.540	6.615	6.690	6.755
	Average	2.810	5.647	6.137	5.983	6.077	6.142	6.322	6.380	6.423	6.465	6.502
L3-z	Felsic gneiss	2.820	4.660	5.160	5.420	5.600	5.740	6.165	6.360	6.430	6.490	6.550
L3-x	Felsic gneiss	2.840	5.250	5.590	5.840	6.030	6.140	6.395	6.485	6.540	6.590	6.650
L3-y	Felsic gneiss	2.820	5.910	6.050	6.130	6.195	6.245	6.450	6.575	6.660	6.705	6.750
	Average	2.827	5.273	5.600	5.797	5.942	6.042	6.337	6.473	6.543	6.595	6.650
L4-z	Felsic gneiss	2.630	5.965	6.055	6.110	6.150	6.165	6.210	6.245	6.280	6.305	6.342
L4-x	Felsic gneiss	2.610	5.875	5.915	5.950	5.980	6.010	6.120	6.190	6.220	6.240	6.265
L4-y	Felsic gneiss	2.640	6.117	6.160	6.183	6.197	6.204	6.235	6.263	6.285	6.307	6.333
	Average	2.627	5.986	6.043	6.081	6.109	6.126	6.188	6.233	6.262	6.284	6.313
L5-z	Mafic gneiss	2.990	6.655	6.745	6.790	6.823	6.850	6.900	6.930	6.960	6.990	7.020
L5-x	Mafic gneiss	3.040	6.680	6.770	6.827	6.865	6.895	6.988	7.050	7.098	7.130	7.155
L5-y	Mafic gneiss	2.970	6.400	6.643	6.695	6.730	6.755	6.815	6.840	6.867	6.897	6.925
	Average	2.980	6.578	6.719	6.771	6.806	6.833	6.901	6.940	6.975	7.006	7.033
L6-z	Anorthosite	2.800	5.420	5.750	5.905	6.015	6.080	6.240	6.315	6.360	6.393	6.425
L6-xy	Anorthosite	2.800	5.670	5.895	6.060	6.155	6.203	6.290	6.330	6.367	6.405	6.445
	Average	2.800	5.545	5.823	5.983	6.085	6.142	6.265	6.323	6.364	6.399	6.435
L7-z	Felsic gneiss	2.810	6.200	6.355	6.430	6.475	6.515	6.630	6.685	6.720	6.745	6.770
L7-x	Felsic gneiss	2.830	6.000	6.250	6.380	6.455	6.510	6.650	6.698	6.718	6.735	6.748
L7-y	Felsic gneiss	2.740	6.150	6.240	6.320	6.350	6.367	6.420	6.433	6.443	6.450	6.460
	Average	2.793	6.117	6.282	6.377	6.427	6.464	6.567	6.605	6.627	6.643	6.659
L8b-z	Mafic gneiss	3.100	6.685	6.750	6.793	6.820	6.840	6.910	6.935	6.963	6.990	7.017
L8b-x	Mafic gneiss	3.120	7.150	7.210	7.250	7.280	7.305	7.370	7.405	7.433	7.455	7.478
L8b-y	Mafic gneiss	3.090	6.990	7.045	7.080	7.103	7.120	7.170	7.190	7.205	7.220	7.235
	Average	3.103	6.942	7.002	7.041	7.068	7.088	7.150	7.177	7.200	7.222	7.243
L9	Late dike	3.000	6.440	6.527	6.567	6.595	6.617	6.675	6.710	6.740	6.765	6.793
L10a'-z	Felsic gneiss	2.690	5.590	5.765	5.870	5.940	5.990	6.105	6.170	6.220	6.267	6.307
L10a'-xy	Felsic gneiss	2.680	5.025	5.420	5.620	5.735	5.810	5.977	6.033	6.080	6.130	6.177
	Average	2.685	5.308	5.593	5.745	5.838	5.900	6.041	6.102	6.150	6.199	6.242

L10b-z	Felsic gneiss	2.820	5.645	5.805	5.868	5.913	5.947	6.040	6.077	6.110	6.143	6.177
L10b-xy	Felsic gneiss	2.790	5.590	5.695	5.765	5.823	5.870	5.975	6.010	6.043	6.075	6.107
	Average	2.805	5.618	5.750	5.817	5.868	5.909	6.008	6.044	6.077	6.109	6.142
L11a-z	Felsic gneiss	2.690	5.550	5.810	5.905	5.970	6.030	6.167	6.230	6.287	6.345	6.405
L11a-xy	Felsic gneiss	2.700	5.470	5.770	5.875	5.955	6.010	6.160	6.240	6.300	6.360	6.420
	Average	2.695	5.510	5.790	5.890	5.963	6.020	6.164	6.235	6.294	6.353	6.413
L11b'-z	Mafic gneiss	3.070	6.280	6.390	6.460	6.510	6.557	6.705	6.770	6.810	6.840	6.865
L11b'-xy	Mafic gneiss	3.050	6.360	6.595	6.685	6.745	6.795	6.950	7.035	7.075	7.100	7.120
	Average	3.060	6.320	6.493	6.573	6.628	6.676	6.828	6.903	6.943	6.970	6.993
L12-z	Granite	2.630	5.910	6.056	6.126	6.169	6.203	6.313	6.367	6.398	6.419	6.429
L12-xy	Granite	2.620	5.580	6.100	6.300	6.385	6.445	6.585	6.647	6.680	6.705	6.730
	Average	2.625	5.745	6.078	6.213	6.277	6.324	6.449	6.507	6.539	6.562	6.580
L13-z	Felsic gneiss	2.620	5.160	5.460	5.660	5.767	5.840	6.040	6.130	6.175	6.210	6.250
L13-xy	Felsic gneiss	2.620	5.150	5.560	5.800	5.915	5.985	6.155	6.253	6.300	6.335	6.360
	Average	2.620	5.155	5.510	5.730	5.841	5.913	6.098	6.192	6.238	6.273	6.305
L14'	Basalt dike	3.060	6.645	6.727	6.775	6.805	6.827	6.897	6.937	6.960	6.975	6.990
L14"	Basalt dike	3.050	6.900	6.963	7.010	7.055	7.093	7.225	7.293	7.317	7.330	7.343
	Average	3.055	6.773	6.845	6.893	6.930	6.960	7.061	7.115	7.139	7.153	7.167
L15-z	Mafic gneiss	3.100	6.200	6.440	6.590	6.685	6.760	6.960	7.047	7.097	7.130	7.155
L15-xy	Mafic gneiss	3.040	5.900	6.300	6.440	6.545	6.625	6.895	7.035	7.077	7.107	7.137
	Average	3.070	6.050	6.370	6.515	6.615	6.693	6.928	7.041	7.087	7.119	7.146
L16	Quartzite	2.680	5.180	5.490	5.630	5.710	5.765	5.905	5.975	6.013	6.045	6.079
L17-z	Granitoid gneiss	2.680	4.590	5.080	5.395	5.605	5.725	5.955	6.030	6.070	6.100	6.138
L17-x	Granitoid gneiss	2.750	5.060	5.320	5.670	5.910	6.050	6.320	6.430	6.490	6.540	6.590
L17-y	Granitoid gneiss	2.750	4.740	5.180	5.450	5.650	5.790	6.120	6.250	6.330	6.380	6.430
	Average	2.727	4.797	5.193	5.505	5.722	5.855	6.132	6.237	6.297	6.340	6.386
L18	Marble	2.860	6.200	6.540	6.630	6.690	6.727	6.825	6.885	6.930	6.965	6.997
L19-z	Psammitic gneiss	2.710	5.550	5.633	5.710	5.773	5.820	5.983	6.053	6.100	6.135	6.160
L19-xy	Psammitic gneiss	2.720	5.690	5.790	5.900	5.970	6.023	6.157	6.197	6.230	6.260	6.293
	Average	2.715	5.620	5.712	5.805	5.872	5.922	6.070	6.125	6.165	6.198	6.227
L20-z	Granitoid gneiss	2.910	5.140	5.430	5.665	5.820	5.940	6.190	6.275	6.335	6.395	6.453
L20-xy	Granitoid gneiss	2.870	5.450	5.700	5.880	6.010	6.120	6.350	6.435	6.485	6.530	6.575
	Average	2.890	5.295	5.565	5.773	5.915	6.030	6.270	6.355	6.410	6.463	6.514
L21-z	Bio-qtz-fs gneiss	2.660	5.290	5.565	5.730	5.820	5.880	6.020	6.075	6.125	6.175	6.225
L21-xy	Bio-qtz-fs gneiss	2.660	5.435	5.835	5.929	5.980	6.010	6.082	6.099	6.114	6.131	6.147
	Average	2.660	5.363	5.700	5.830	5.900	5.945	6.051	6.087	6.120	6.153	6.186

Nain

Sample Number	Lithology	Density g/ml	Velocity (km/s) at Pressure (MPa) 20	40	60	80	100	200	300	400	500	600
N1-z	Migmatite	2.65	5.680	5.850	5.940	5.995	6.033	6.147	6.203	6.253	6.300	6.353
N1-xy	Migmatite	2.64	5.180	5.620	5.810	5.900	5.960	6.112	6.177	6.230	6.285	6.335
	Average	2.65	5.430	5.735	5.875	5.948	5.997	6.130	6.190	6.242	6.293	6.344
N2	Anorthosite	2.73	6.040	6.410	6.525	6.580	6.620	6.702	6.745	6.790	6.840	6.885
N3	Granite/qtz monzonite	2.67	5.765	6.085	6.215	6.290	6.335	6.465	6.530	6.580	6.630	6.680
N4-z	Mafic gneiss	3.00	5.200	5.660	5.890	6.000	6.070	6.255	6.320	6.360	6.400	6.440
N4-xy	Mafic gneiss	2.99	6.185	6.480	6.610	6.670	6.710	6.825	6.865	6.892	6.920	6.947
	Average	3.00	5.693	6.070	6.250	6.335	6.390	6.540	6.593	6.626	6.660	6.694
N5-z	Hy-qtz-fs granulite	2.63	5.870	5.997	6.063	6.113	6.150	6.250	6.297	6.330	6.365	6.400
N5-xy	Hy-qtz-fs granulite	2.60	5.920	6.080	6.145	6.190	6.223	6.315	6.365	6.405	6.443	6.480
	Average	2.62	5.895	6.039	6.104	6.152	6.187	6.283	6.331	6.368	6.404	6.440
N6-z	Migmatite	2.69	5.269	5.590	5.750	5.835	5.888	6.006	6.065	6.125	6.180	6.240
N6-xy	Migmatite	2.63	5.695	5.950	6.053	6.100	6.140	6.250	6.300	6.340	6.380	6.420
	Average	2.66	5.482	5.770	5.902	5.968	6.014	6.128	6.183	6.233	6.280	6.330
N7-z	Quartz diorite	3.02	5.560	6.275	6.490	6.585	6.660	6.860	6.940	6.980	7.020	7.057
N7-xy	Quartz diorite	3.02	5.835	6.300	6.480	6.580	6.647	6.810	6.883	6.920	6.960	7.000
	Average	3.02	5.698	6.288	6.485	6.583	6.654	6.835	6.912	6.950	6.990	7.029
N8-z	Bio-qtz-fs gneiss	2.76	5.420	5.530	5.590	5.635	5.665	5.745	5.785	5.820	5.858	5.895
N8-xy	Bio-qtz-fs gneiss	2.75	6.010	6.085	6.125	6.152	6.173	6.230	6.255	6.283	6.310	6.340
	Average	2.76	5.715	5.808	5.858	5.894	5.919	5.988	6.020	6.052	6.084	6.118
N9a	Quartzite	2.58	5.500	5.870	5.965	6.019	6.058	6.186	6.257	6.300	6.345	6.393

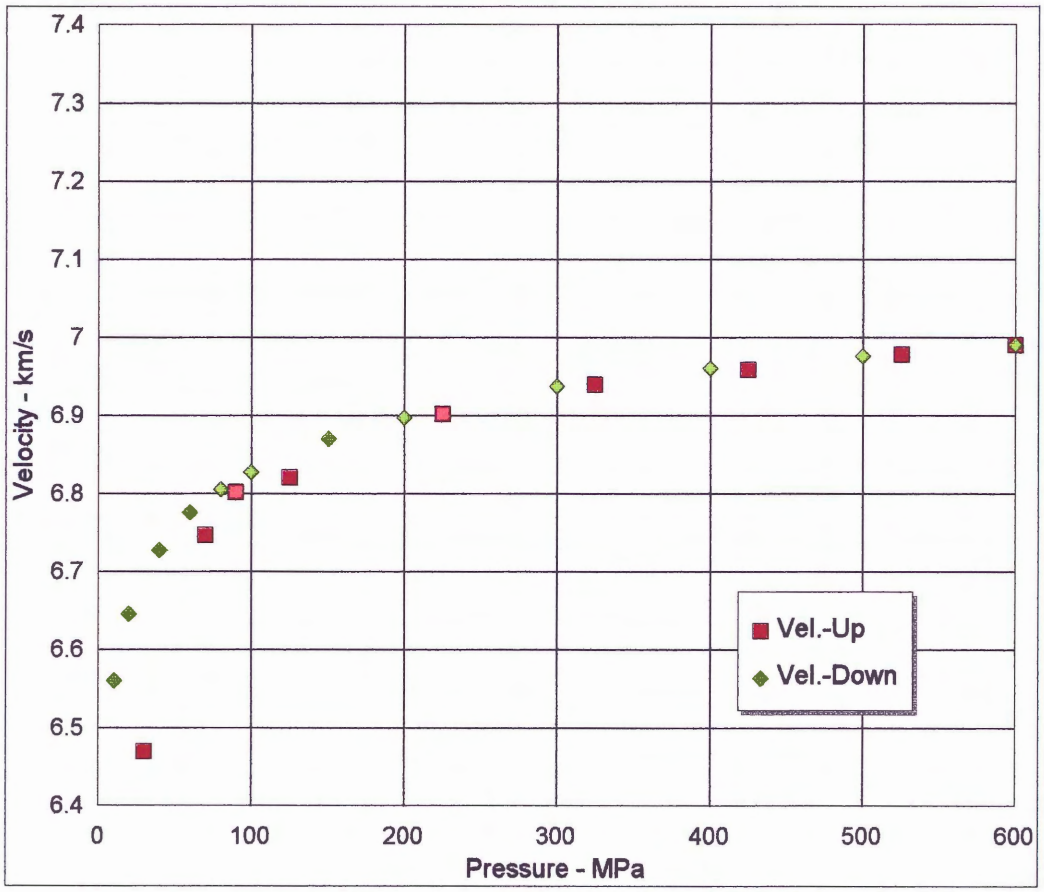


Figure 4-1: Compressional wave velocity versus pressure for sample L14'.

with most compressional wave velocities being above 6.0 km/s. The sample with the highest compressional wave velocity is sample L8b, a mafic gneiss from the Torngat Orogen, with an average velocity of 7.24 km/s. After all of the measurements were made, the velocities of samples with similar lithologies were compared. The anorthosite sample (N2) from Nain displayed the usual characteristics of an anorthosite, a high seismic velocity associated with a low density; however, the anorthosite from Nachvak Fjord (L6) displayed a similar density with a lower seismic velocity. Since L6 was intruded much earlier than N2, the source material could have had a different composition, or differentiated further, thereby producing an anorthosite of different composition. Petrographic analysis shows that sample N2 contains ~ 95% plagioclase (labradorite) and ~ 5% pyroxene, while sample L6 contains ~ 30% feldspar (plagioclase and microcline), ~ 30% quartz, ~30% amphibole and ~ 20% biotite, an assemblage more characteristic of an intermediate gneiss.

Samples L16 and N9a are both quartzites; however, they vary in both composition and seismic character. Sample L16 from the Torngat Orogen is a classic example of a quartzite (~95% quartz), while sample N9a from Nain contains roughly 50% quartz, 40% feldspar and 10% biotite. Sample L16 has a compressional wave velocity of 6.08 km/s while N9a has a compressional wave velocity of 6.39 km/s at 600 MPa. Clearly there is a difference between the quartzites from the two regions.

4.2.1.2 Compressional Wave Velocity Versus Density

Figures 4-2, 4-3, 4-4, and 4-5 are plots of compressional wave velocity at 600 MPa versus density for all samples from the two regions of Labrador examined in this study, with Figures 4-2 and 4-4 showing the velocities in all directions, and 4-3 and 4-5 showing showing the average velocities for each sample. The Torngat Orogen / Nachvak Fjord samples display an increasing linear relationship between compressional wave velocity and density while the samples from Nain tend to group within two distinct areas on the graphs. As shown in Figures 4-4 and 4-5, samples with densities > 2.9 g/ml tend to plot in the upper right hand corner and are generally mafic in composition, while samples with densities < 2.9 g/ml tend to plot in the lower left hand corner and are generally felsic to intermediate in composition. Comparison with Figures 4-2 and 4-3 shows that this grouping is not as well-defined for the samples from the Torngat Orogen / Nachvak Fjord region, possibly due to increased lithologic variation and better sampling.

4.3 Shear Wave Velocities

In addition to compressional wave velocity measurements, shear wave velocity measurements were made to further help distinguish rock types from the two regions. Because shear and compressional waves reflect somewhat different physical properties of the rocks through which they propagate, combined shear and compressional wave velocity studies will give more information about rocks than compressional wave studies

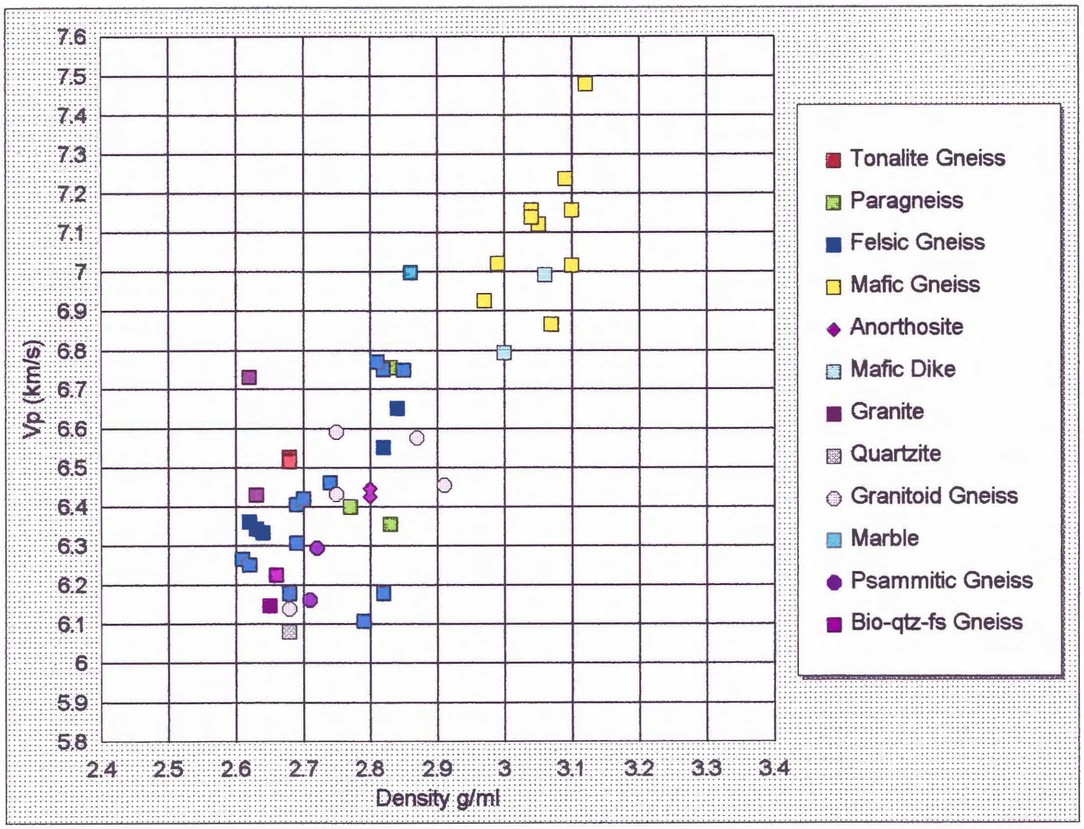


Figure 4-2: Compressional wave velocity versus density for samples from the Torngat Orogen / Nachvak Fjord region of Labrador (all sample directions plotted).

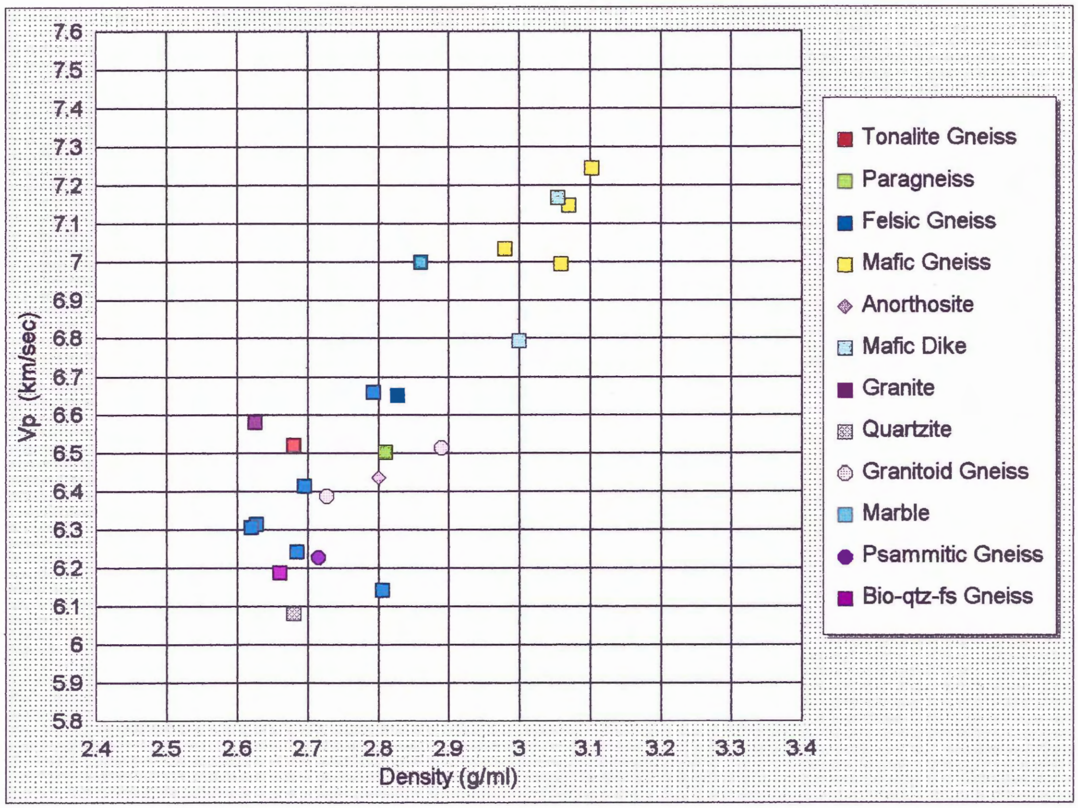


Figure 4-3: Compressional wave velocity versus density for samples from the Torngat Orogen / Nachvak Fjord region of Labrador (sample directions averaged).

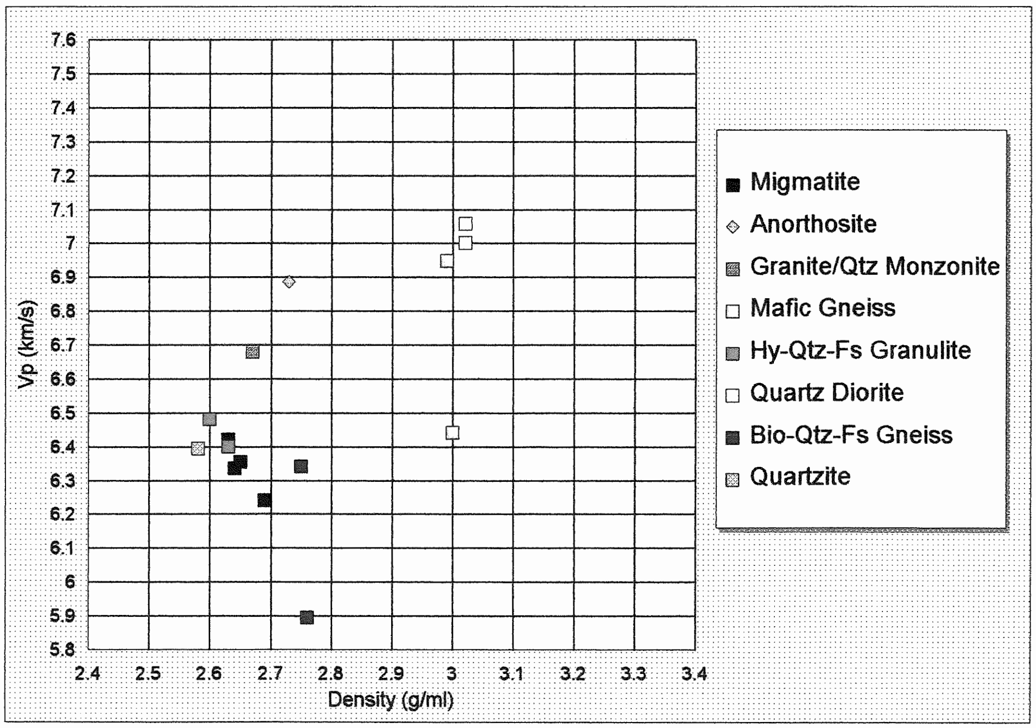


Figure 4-4: Compressional wave velocity versus density for samples from Nain (all sample directions plotted).

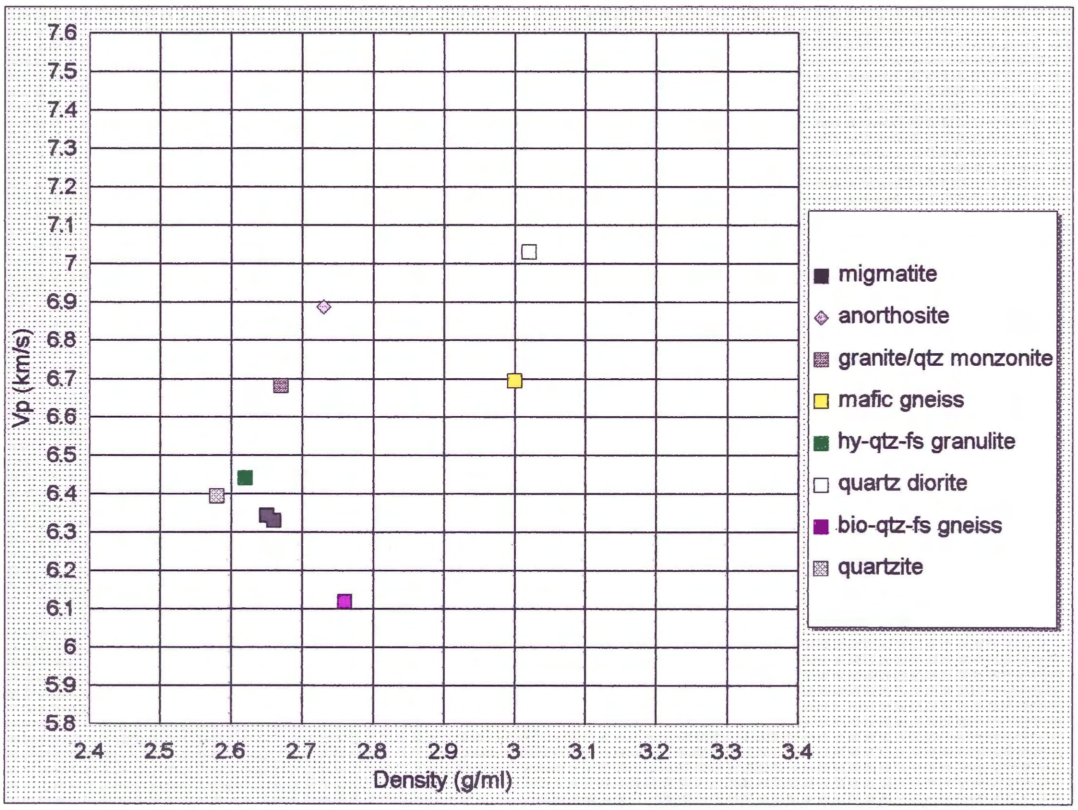


Figure 4-5: Compressional wave velocity versus density for samples from Nain (sample directions averaged).

alone (Holbrook et al., 1992).

4.3.1 Results

Table 4-2 contains a summary of the shear wave velocities from the Torngat Orogen/Nachvak Fjord and Nain regions of Labrador. From the data, most samples appear to represent mid-lower crustal material due to their high shear wave velocities. All samples tend to range above 3.6 km/s, except L1 (tonalite gneiss, Vs = 3.58 km/s), N5 (hy-qtz-fs gneiss, Vs = 3.49 km/s), and N8 (bio-qtz-fs gneiss, Vs = 3.57 km/s) .

4.3.1.1 Shear Wave Velocity Versus Pressure

All samples showed an initial sharp increase in shear wave velocity with increasing pressure similar to that observed for Vp. As shown in Figure 4-6, above approximately 200 MPa, the velocity increases slowly and linearly. One difference between the compressional and shear wave velocity results involves the amount of change in seismic velocity with changing confining pressure. The compressional wave velocities can increase by as much as 2.5 km/s between 10 and 600 MPa, while for shear wave velocities, the velocity range between low and high pressure is approximately 0.5-1.0 km/s. This is due in part to the fact that shear waves are relatively insensitive to cracks.

A comparison of rocks of similar lithology shows that samples L6 and N2, both anorthosites, display different shear wave velocities. Sample L6 has a shear wave velocity

Table 4-2: Shear wave velocities for ECSOOT'96 samples.

Torngat Orogen / Nachvak Fjord

Sample Number	Lithology	Vibration direction vs. foliation *	Density g/ml	Velocity (km/s) at Pressure (MPa) 20	40	60	80	100	200	300	400	500	600
L1-xy	Tonalite gneiss	45 deg	2.680	3.420	3.460	3.485	3.503	3.517	3.558	3.576	3.580	3.582	3.584
L2-z	Paragneiss	parallel to lin.	2.770	3.491	3.574	3.622	3.666	3.690	3.772	3.804	3.814	3.823	3.835
L2-z'	Paragneiss	perpendicular to lin.	2.860	3.525	3.655	3.717	3.788	3.781	3.856	3.888	3.901	3.912	3.923
L2-x'	Paragneiss	parallel	2.880	3.720	3.820	3.878	3.914	3.942	4.025	4.063	4.078	4.094	4.106
L2-x'	Paragneiss	perpendicular	2.880	3.570	3.680	3.750	3.790	3.815	3.904	3.954	3.970	3.980	3.990
L2-y	Paragneiss	parallel	2.830	3.660	3.729	3.770	3.800	3.821	3.888	3.916	3.930	3.945	3.960
L2-y	Paragneiss	perpendicular	2.830	3.504	3.595	3.650	3.690	3.720	3.820	3.865	3.878	3.890	3.902
	Average		2.842	3.578	3.676	3.731	3.775	3.795	3.878	3.915	3.929	3.941	3.953
L4-y	Felsic gneiss	45 deg	2.640	3.595	3.622	3.640	3.652	3.662	3.685	3.691	3.694	3.697	3.700
L5-y	Mafic gneiss	45 deg	2.970	3.750	3.788	3.813	3.828	3.842	3.872	3.888	3.899	3.906	3.913
L6-xy	Anorthosite	45 deg	2.800	3.400	3.490	3.527	3.553	3.573	3.623	3.638	3.648	3.660	3.670
L8b-z''	Mafic gneiss	parallel to lin.	3.100	4.080	4.113	4.125	4.135	4.140	4.158	4.165	4.171	4.177	4.184
L8b-z'''	Mafic gneiss	perpendicular to lin.	3.100	3.757	3.794	3.818	3.834	3.847	3.892	3.917	3.930	3.941	3.952
L8b-x	Mafic gneiss	parallel	3.120	3.990	4.065	4.090	4.107	4.120	4.143	4.151	4.155	4.160	4.164
L8b-x	Mafic gneiss	perpendicular	3.120	4.120	4.145	4.160	4.170	4.178	4.194	4.201	4.208	4.215	4.223
L8b-y	Mafic gneiss	parallel	3.090	4.120	4.144	4.158	4.167	4.177	4.198	4.205	4.212	4.219	4.227
L8b-y	Mafic gneiss	perpendicular	3.090	3.961	3.980	3.993	4.002	4.007	4.028	4.036	4.043	4.052	4.059
	Average		3.103	4.005	4.040	4.057	4.069	4.078	4.102	4.112	4.120	4.127	4.168
L9	Late dike	parallel to crease	3.000	3.720	3.755	3.770	3.782	3.790	3.808	3.816	3.822	3.830	3.838
L10a'-xy	Felsic gneiss	45 deg	2.680	3.345	3.430	3.461	3.486	3.505	3.565	3.594	3.613	3.632	3.653
L10b-xy	Felsic gneiss	45 deg	2.790	3.438	3.531	3.571	3.598	3.615	3.650	3.665	3.679	3.692	3.709
L11a-z	Felsic gneiss	parallel to crease	2.690	3.350	3.490	3.530	3.560	3.580	3.647	3.680	3.699	3.717	3.735
L11b'-z	Mafic gneiss	parallel to crease	3.070	3.770	3.810	3.840	3.862	3.879	3.921	3.940	3.950	3.958	3.968
L11b'-xy	Mafic gneiss	parallel	3.050	3.830	3.910	3.940	3.960	3.980	4.039	4.069	4.083	4.100	4.113

L11b'-xy	Mafic gneiss	perpendicular	3.050	3.835	3.883	3.913	3.935	3.953	4.013	4.040	4.055	4.070	4.085
	Average		3.057	3.812	3.868	3.898	3.919	3.937	3.991	4.016	4.029	4.043	4.055
L12-z	Granite	arbitrary	2.630	3.470	3.578	3.620	3.653	3.682	3.760	3.785	3.795	3.805	3.815
L12-xy'	Granite	parallel	2.620	3.460	3.585	3.644	3.678	3.701	3.759	3.777	3.791	3.805	3.819
L12-xy'	Granite	perpendicular	2.620	3.480	3.607	3.664	3.693	3.712	3.759	3.780	3.791	3.799	3.809
	Average		2.623	3.470	3.590	3.643	3.675	3.698	3.759	3.781	3.792	3.803	3.814
L13-z	Felsic gneiss	parallel	2.620	3.340	3.423	3.464	3.492	3.511	3.567	3.588	3.610	3.632	3.654
L15-z	Mafic gneiss	arbitrary	3.100	3.598	3.735	3.806	3.840	3.865	3.921	3.946	3.959	3.969	3.980
L15-xy'	Mafic gneiss	parallel	3.070	3.710	3.839	3.879	3.907	3.927	3.984	4.008	4.025	4.041	4.060
L15-xy'	Mafic gneiss	perpendicular	3.070	3.690	3.834	3.968	4.008	4.030	4.076	4.087	4.093	4.097	4.103
	Average		3.080	3.666	3.803	3.884	3.918	3.941	3.994	4.014	4.026	4.036	4.048
L16	Quartzite	arbitrary	2.680	3.660	3.782	3.855	3.895	3.914	3.977	4.007	4.016	4.025	4.037
L18	Marble	arbitrary	2.860	3.600	3.685	3.729	3.756	3.775	3.828	3.848	3.858	3.869	3.879
L19-xy	Psammitic gneiss	45 deg to foliation	2.720	3.455	3.552	3.602	3.631	3.653	3.723	3.757	3.770	3.784	3.798
L20-xy	Granitoid gneiss	45 deg to foliation	2.870	3.489	3.571	3.633	3.690	3.719	3.782	3.794	3.800	3.806	3.813
L21-z	Bio-qtz-fs gneiss	parallel to joint	2.660	3.425	3.550	3.600	3.630	3.650	3.705	3.719	3.727	3.734	3.743
L21-xy	Bio-qtz-fs gneiss	parallel	2.660	3.510	3.670	3.753	3.802	3.830	3.901	3.923	3.934	3.943	3.954
L21-xy	Bio-qtz-fs gneiss	perpendicular	2.660	3.310	3.615	3.738	3.788	3.819	3.886	3.905	3.914	3.924	3.933
	Average		2.660	3.415	3.612	3.697	3.740	3.766	3.831	3.849	3.858	3.867	3.877

Nain

Sample Number	Lithology	Vibration direction vs. foliation *	Density gm/ml	Velocity (km/s) at Pressure (MPa) 20Mpa	40	60	80	100	200	300	400	500	600
N1-z	Migmatite	parallel joint	2.650	3.195	3.440	3.535	3.587	3.618	3.679	3.700	3.703	3.708	3.713
N2'	Anorthosite	45 deg to crease	2.700	3.413	3.580	3.660	3.693	3.715	3.762	3.776	3.785	3.795	3.806
N3	Granite/qtz monzonite	parallel joint	2.670	3.402	3.438	3.464	3.483	3.499	3.546	3.578	3.608	3.638	3.668
N4-z	Mafic gneiss	arbitrary	3.000	3.120	3.255	3.306	3.332	3.351	3.405	3.430	3.450	3.470	3.492

N4-xy	Mafic gneiss	parallel	2.990	3.698	3.830	3.880	3.901	3.916	3.958	3.971	3.982	3.993	4.007
N4-xy	Mafic gneiss	perpendicular	2.990	3.383	3.489	3.520	3.540	3.556	3.594	3.609	3.618	3.628	3.636
	Average		2.993	3.400	3.525	3.569	3.591	3.608	3.652	3.670	3.683	3.697	3.712
N5-z	Hy-qtz-fs granulite	parallel joint	2.630	3.100	3.212	3.253	3.278	3.295	3.345	3.359	3.365	3.371	3.379
N5-xy	Hy-qtz-fs granulite	parallel	2.600	3.357	3.382	3.402	3.417	3.429	3.469	3.502	3.537	3.569	3.605
	Average		2.615	3.229	3.297	3.328	3.348	3.362	3.407	3.431	3.451	3.470	3.492
N7-xy	Quartz diorite	45 deg to foliation	3.020	3.640	3.731	3.780	3.815	3.840	3.910	3.930	3.933	3.939	3.943
N8-z	Bio-qtz-fs gneiss	parallel crease	2.760	3.168	3.224	3.251	3.270	3.287	3.329	3.340	3.350	3.359	3.369
N8-xy	Bio-qtz-fs gneiss	parallel	2.750	3.720	3.774	3.795	3.810	3.820	3.840	3.851	3.859	3.866	3.873
N8-xy	Bio-qtz-fs gneiss	perpendicular	2.750	3.339	3.367	3.382	3.392	3.400	3.420	3.430	3.440	3.451	3.460
	Average		2.753	3.409	3.455	3.476	3.491	3.502	3.530	3.540	3.550	3.559	3.567

* Unless otherwise specified

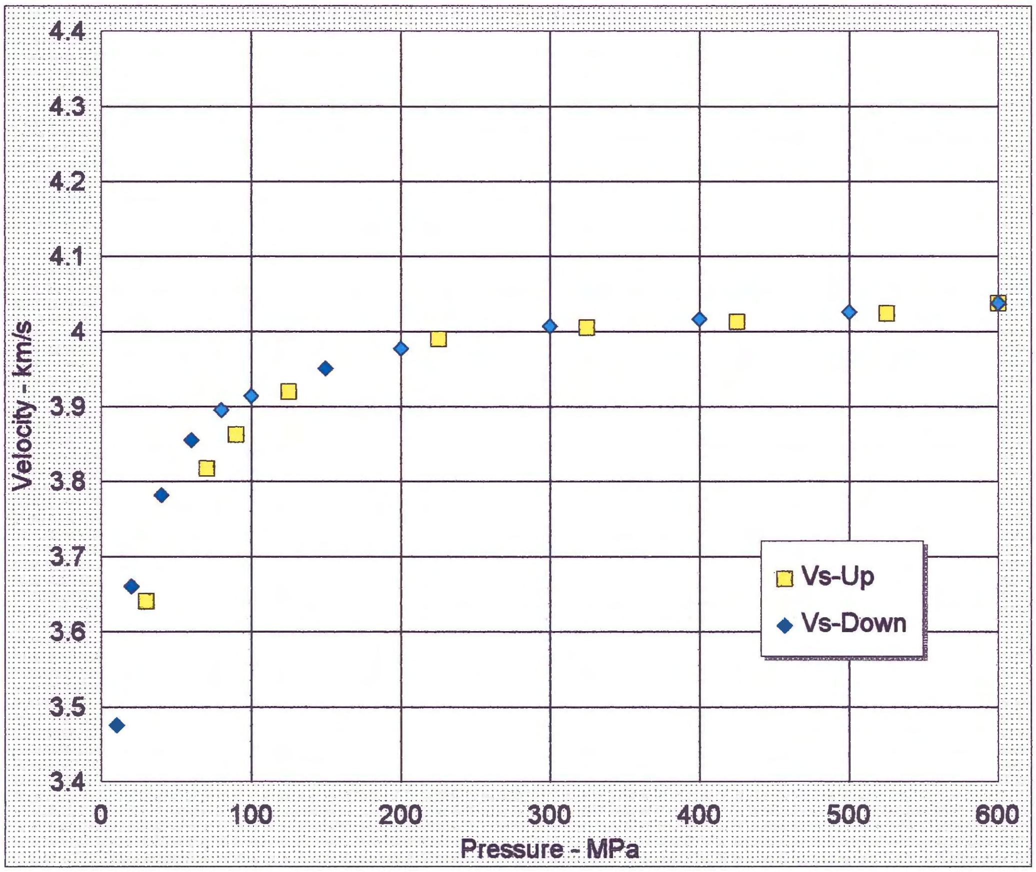


Figure 4-6: Shear wave velocity versus pressure for sample L16.

of 3.67 km/s at 600 MPa, while sample N2 has a much higher shear wave velocity of 3.81 km/s. The shear wave data clearly emphasises the differences in lithology between the two anorthosites.

4.3.1.2 Shear Wave Velocity Versus Density

Figures 4-7 and 4-8 are plots of shear wave velocity versus density for selected samples from the Torngat Orogen/Nachvak Fjord region. Figure 4-7 shows data from all directions in each sample, while Figure 4-8 plots the average velocity for each sample. Figures 4-9 and 4-10 are plots of shear wave velocity versus density for samples from Nain and are arranged in the same manner as Figures 4-7 and 4-8.

Samples from both regions of Labrador show an linear, increasing velocity relationship with increasing density. As for the compressional wave velocity data, the lithologies tended to fall within distinct mafic and felsic groups, as well as an intermediate group in which the paragneiss, granitoid gneiss and psammitic gneiss samples lie. Samples with density < 2.8 g/ml tend to be felsic, samples between 2.8 g/ml - 2.95 g/ml tend to lie in the intermediate zone, and samples with densities >2.95 g/ml tend to be mafic. As for Vp, samples from both the Torngat Orogen/Nachvak Fjord and Nain regions display shear wave velocities and densities typical of mid-crustal material, as determined by Holbrook et al. (1992).

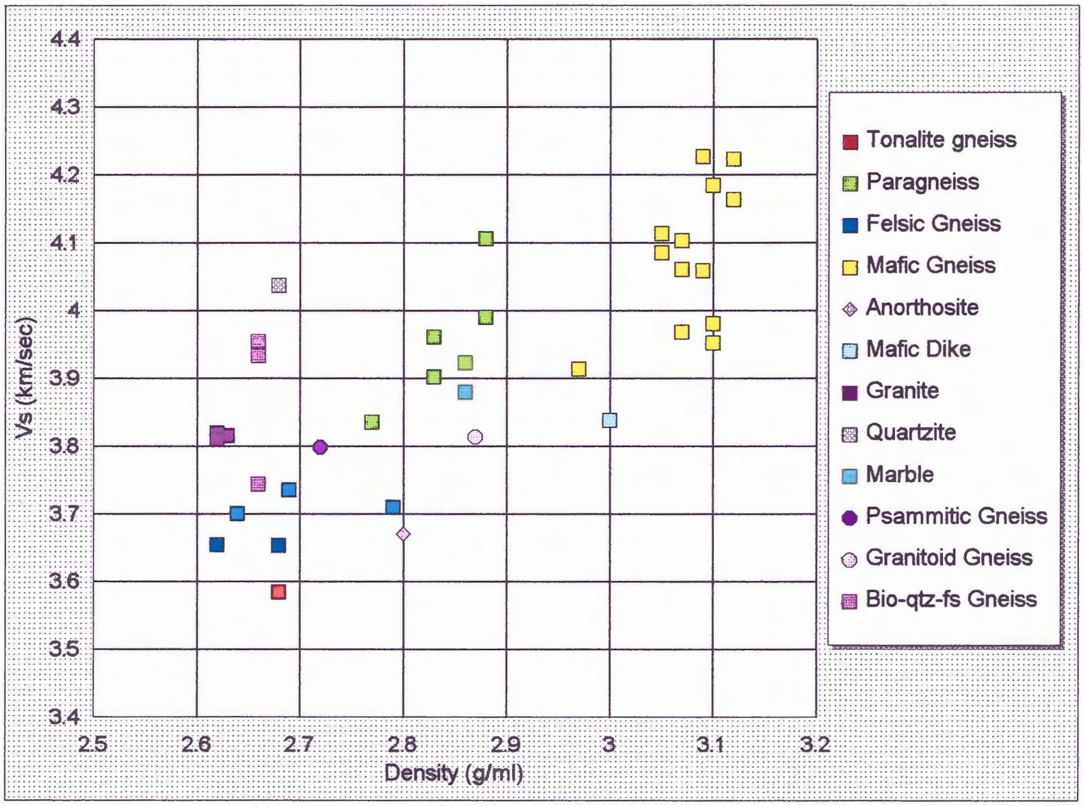


Figure 4-7: Shear wave velocity versus density for selected samples from the Torngat Orogen / Nachvak Fjord region of Labrador (all sample directions plotted).

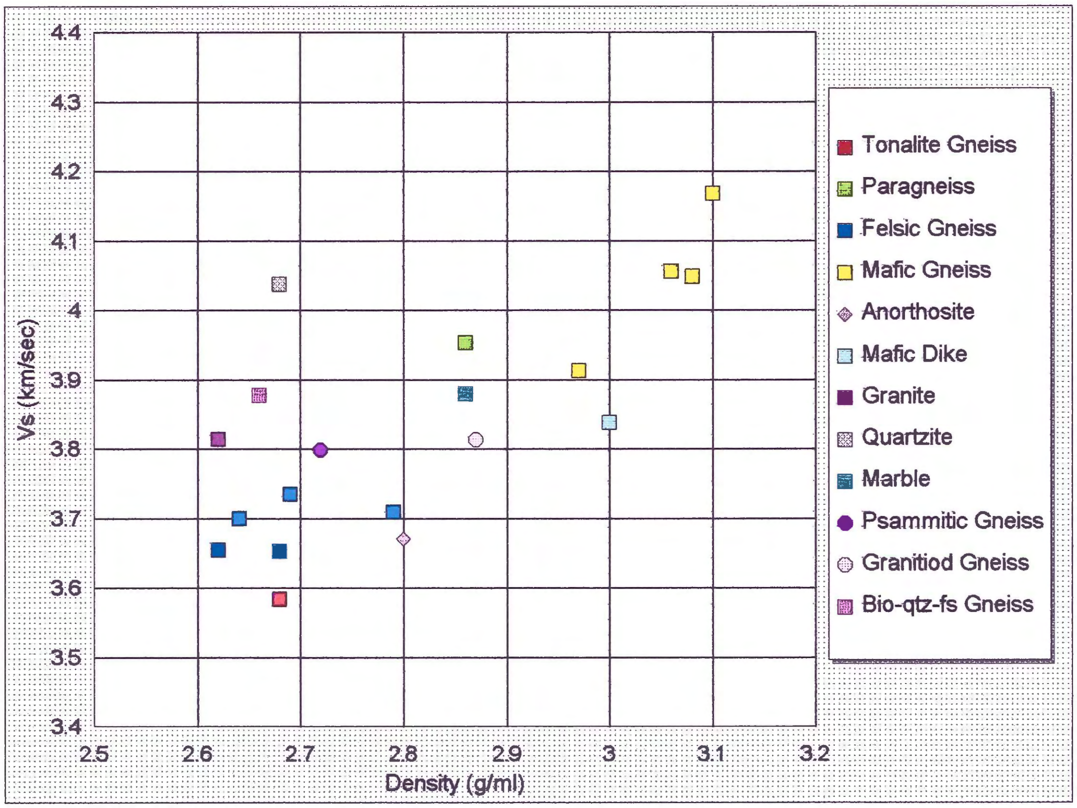


Figure 4-8: Shear wave velocity versus density for selected samples drom the Torngat Orogen / Nachvak Fjord region of Labrador (sample directions averaged).

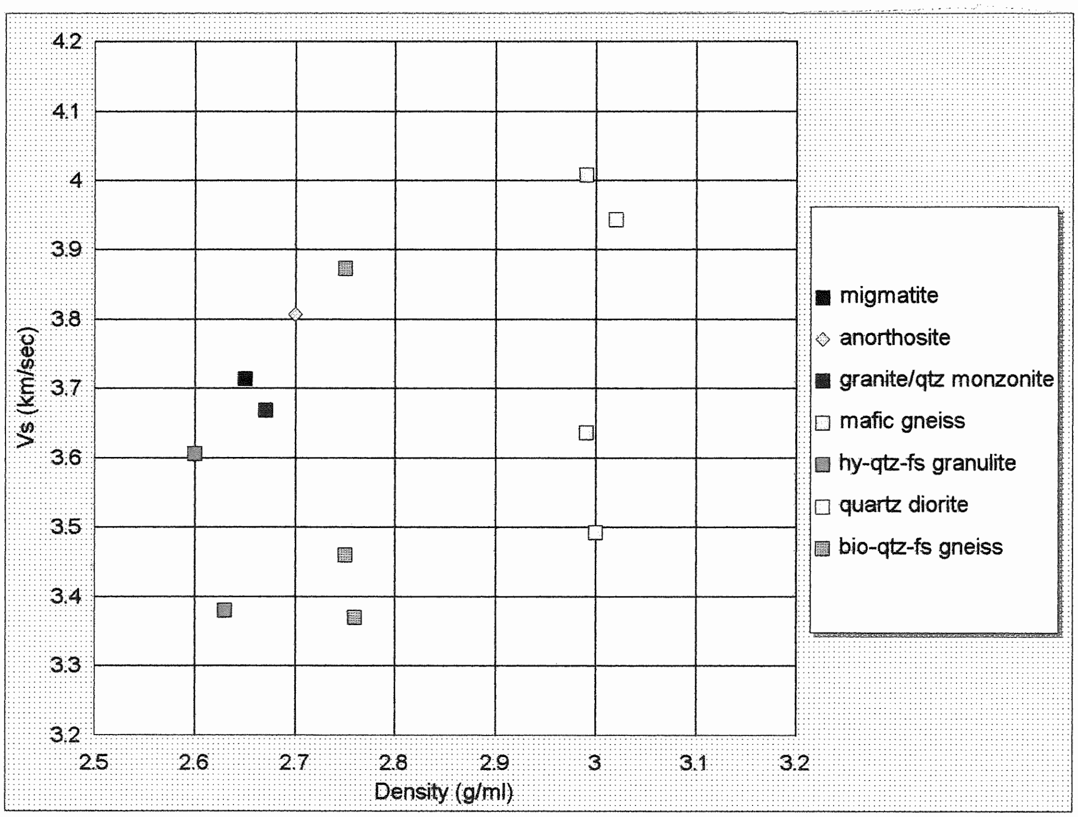


Figure 4-9: Shear wave velocity versus density for selected samples from the Nain region of Labrador (all sample directions plotted).

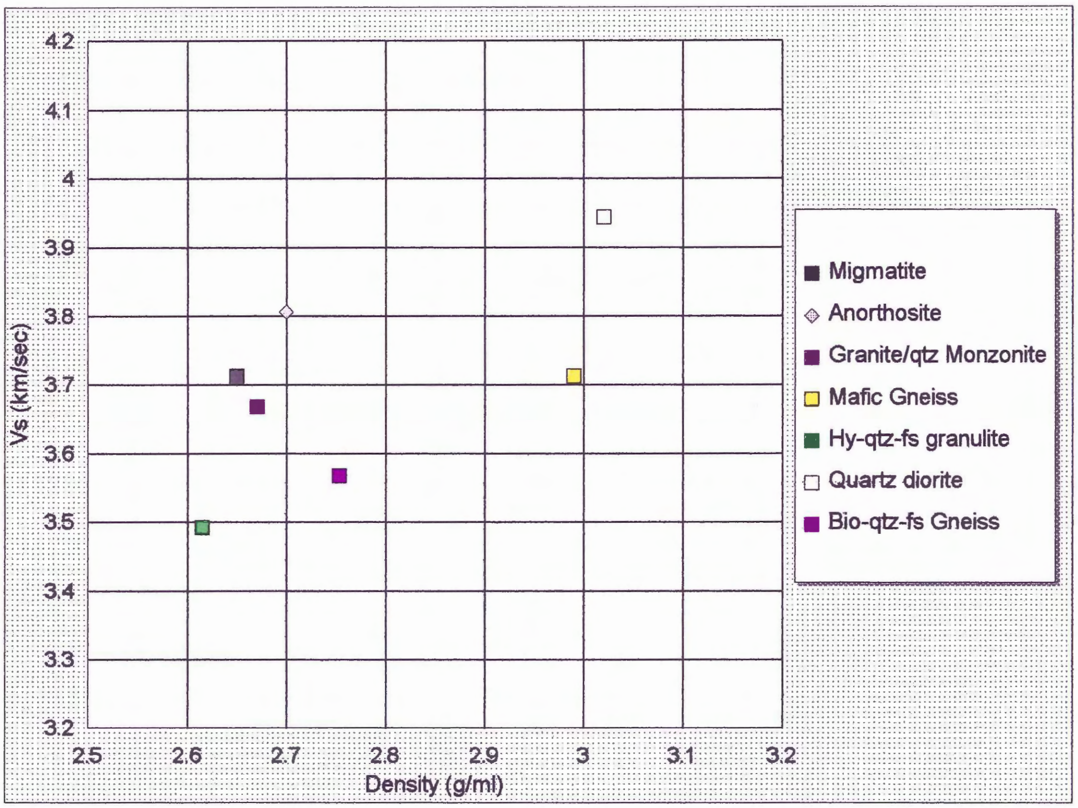


Figure 4-10: Shear wave velocity versus density for selected samples from the Nain region of Labrador (sample directions averaged).

4.4 Seismic Anisotropy

Seismic anisotropy is defined as the percent difference between the maximum and minimum seismic velocity with respect to the mean velocity. Anisotropy occurs because crystal alignment can cause certain rocks to have different seismic velocities in different directions (e.g. x, y and z directions). Typically, the z direction is the slowest because the path is perpendicular to the foliation, therefore perpendicular to the long, or fast axis of minerals which make up the foliation. The fastest direction is usually the x direction because it is parallel to both the foliation and lineation, therefore parallel to the long axis of the minerals that make up the lineation and foliation. The y-direction is the intermediate velocity direction, being parallel to the foliation, but perpendicular to the long axis of the minerals comprising the lineation.

Mafic rocks often have strong anisotropy formed by the alignment of minerals such as amphiboles, pyroxenes and biotite. Felsic rocks tend to display lower anisotropy because they lack such anisotropic minerals and contain abundant quartz and feldspar.

Using the standards set by Burke (1991), a sample with an anisotropy value <1% is considered virtually isotropic (as for example, a sample with an original igneous texture). A sample may contain abundant anisotropic minerals but if they are oriented in a random fashion, the sample as a whole will be isotropic. A sample with a value >1% but <4% is considered to have a low seismic anisotropy while a rock with a value >4% is considered to be anisotropic.

4.4.1 Results

Tables 4-3 and 4-4 contain anisotropy data from the Torngat Orogen / Nachvak Fjord and Nain regions based on Vp and Vs data, respectively. Figures 4-11 and 4-12 are graphs of compressional wave velocity in the z direction (Vp-z) versus compressional wave velocity in the xy or (x+y)/2 direction for samples from the Torngat Orogen / Nachvak Fjord and Nain regions of Labrador, respectively. This type of graph helps to relate differences in anisotropy to lithology. As can be seen, most samples tend to lie along the diagonal line representing a 1:1 relationship (isotropic); however, there are some samples (e.g. mafic gneisses) in which the velocity in the xy or (x+y)/2 direction is faster than in the z direction (anisotropic).

4.4.1.1 Anisotropy based on Compressional Wave Velocities

As can be seen from Table 4-3, samples L1 (tonalite gneiss), L6 (anorthosite), L11a (felsic gneiss), L15 (mafic gneiss), N1 (migmatite), and N7 (quartz diorite) are virtually isotropic based on compressional wave velocity values at 600 MPa. Sample L11a was the only felsic gneiss to be isotropic, the majority displaying low anisotropy; however, sample L7 shows strong anisotropy, probably due to the presence of layers of pyroxene aligned parallel to the foliation. Samples L6 (anorthosite) and L15 (mafic gneiss) range from having anisotropy to being totally isotropic. Sample L15 was the only mafic gneiss to display such low anisotropy, most likely due to the abundance of feldspar and garnet, and the lack of definite foliation.

Table 4-3: Seismic anisotropy data based on compressional wave velocities.

Torngat Orogen/Nachvak Fjord

		Anisotropy (%) at Confining Pressure (MPa)									
Sample #	**Lithology**	**20**	**40**	**60**	**80**	**100**	**200**	**300**	**400**	**500**	**600**
L1	Tonalite gneiss	1.50	1.65	1.79	1.94	1.84	1.64	0.96	0.59	0.22	0.15
L2	Paragneiss	11.69	22.98	6.85	5.27	4.48	4.19	4.55	5.14	5.72	6.17
L3	Felsic gneiss	23.70	15.89	12.25	10.01	8.36	4.50	3.32	3.52	3.26	3.01
L4	Felsic gneiss	4.04	4.05	3.83	3.55	3.17	1.86	1.17	1.04	1.07	1.22
L5	Mafic gneiss	4.26	1.89	1.95	1.98	2.05	2.51	3.03	3.31	3.33	3.27
L6	Anorthosite	4.51	2.49	2.59	2.30	2.00	0.80	0.24	0.11	0.19	0.31
L7	Felsic gneiss	3.27	1.83	1.72	1.94	2.29	3.50	4.01	4.18	4.44	4.66
L8b	Mafic gneiss	6.70	6.57	6.49	6.51	6.56	6.43	6.55	6.53	6.44	6.36
L10a'	Felsic gneiss	10.65	6.17	4.35	3.51	3.05	2.12	2.25	2.28	2.21	2.08
L10b	Felsic gneiss	0.98	1.91	1.77	1.53	1.30	1.08	1.11	1.10	1.11	1.14
L11a	Felsic gneiss	1.45	0.70	0.52	0.25	0.33	0.11	0.16	0.21	0.24	0.23
L11b'	Mafic gneiss	1.27	3.16	3.42	3.55	3.57	3.59	3.84	3.82	3.73	3.65
L12	Granite	5.74	0.72	2.80	3.44	3.83	4.22	4.30	4.31	4.36	4.57
L13	Felsic gneiss	0.19	1.81	2.44	2.53	2.45	1.89	1.99	2.00	1.99	1.74
L14***	Basalt dike	3.77	3.45	3.41	3.61	3.82	4.65	5.00	5.00	4.96	4.93
L15	Mafic gneiss	4.96	2.20	2.30	2.12	2.02	0.94	0.17	0.28	0.32	0.25
L17	Granitoid gneiss	9.80	4.62	5.00	5.33	5.55	5.95	6.41	6.67	6.94	7.08
L19	Psammitic gneiss	2.49	2.75	3.27	3.36	3.43	2.87	2.35	2.11	2.02	2.14
L20	Granitoid gneiss	5.85	4.85	3.72	3.21	2.99	2.55	2.52	2.34	2.09	1.87
L21	Bio-qtz-fs gneiss	2.70	4.74	3.41	2.71	2.19	1.02	0.39	0.18	0.72	1.26

Nain

Sample #	Lithology	Anisotropy (%) at Confining Pressure (MPa) 20	40	60	80	100	200	300	400	500	600
N1	Migmatite	9.21	4.01	2.21	1.60	1.22	0.57	0.42	0.37	0.24	0.28
N4	Mafic gneiss	17.30	13.51	11.52	10.58	10.02	8.72	8.27	8.03	7.81	7.57
N5	Hy-qtz-fs granulite	0.85	1.37	1.34	1.25	1.18	1.03	1.07	1.18	1.22	1.24
N6	Migmatite	7.77	6.24	5.13	4.44	4.19	3.98	3.80	3.45	3.18	2.84
N7	Quartz diorite	4.82	0.40	0.15	0.08	0.20	0.73	0.82	0.86	0.86	0.81
N8	Bio-qtz-fs gneiss	10.32	9.56	9.13	8.77	8.58	8.10	7.81	7.65	7.43	7.27

Table 4-4: Seismic anisotropy data based on shear wave velocities.

Torngat Orogen / Nachvak Fjord

		Anisotropy (%) at Confining Pressure (MPa)									
Sample #	**Lithology**	**20**	**40**	**60**	**80**	**100**	**200**	**300**	**400**	**500**	**600**
L2	Paragneiss	6.40	6.69	6.86	6.57	6.64	6.52	6.62	6.72	6.88	6.86
L8b	Mafic Gneiss	9.06	8.69	8.43	8.26	8.12	7.46	7.00	6.84	6.74	6.60
L11b'	Mafic gneiss	1.71	2.58	2.57	2.50	2.57	2.96	3.21	2.18	3.51	3.58
L12	Granite	0.58	0.81	1.21	1.09	0.81	0.03	0.21	0.11	0.16	0.26
L15	Mafic gneiss	3.06	2.73	4.17	4.29	4.19	3.88	3.51	3.33	3.17	3.04
L21	Bio-qtz-fs gneiss	5.86	3.32	4.14	4.60	4.78	5.12	5.30	5.37	5.40	5.44

Nain

		Anisotropy (%) at Confining Pressure (MPa)									
Sample #	**Lithology**	**20**	**40**	**60**	**80**	**100**	**200**	**300**	**400**	**500**	**600**
N4	Mafic gneiss	17.00	16.35	16.08	15.85	15.66	15.14	14.74	14.44	14.14	13.87
N5	Hy-qtz-fs granulite	7.96	5.16	4.48	4.15	3.99	3.64	4.17	4.98	5.70	6.47
N8	Bio-qtz-fs gneiss	16.19	15.92	15.65	15.47	15.13	14.47	14.43	14.33	14.24	14.13

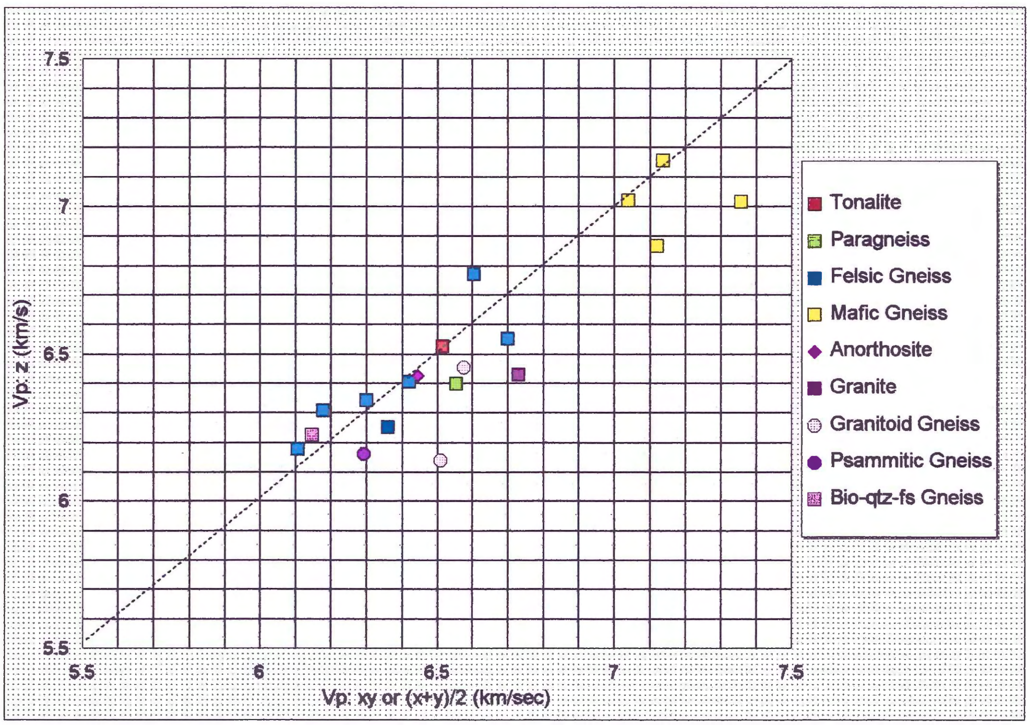


Figure 4-11: Graph displaying the relationship between lithology and anisotropy in samples from the Torngat Orogen / Nachvak Fjord region of Labrador. Dached line represents an isotropic relationship between the two core directions.

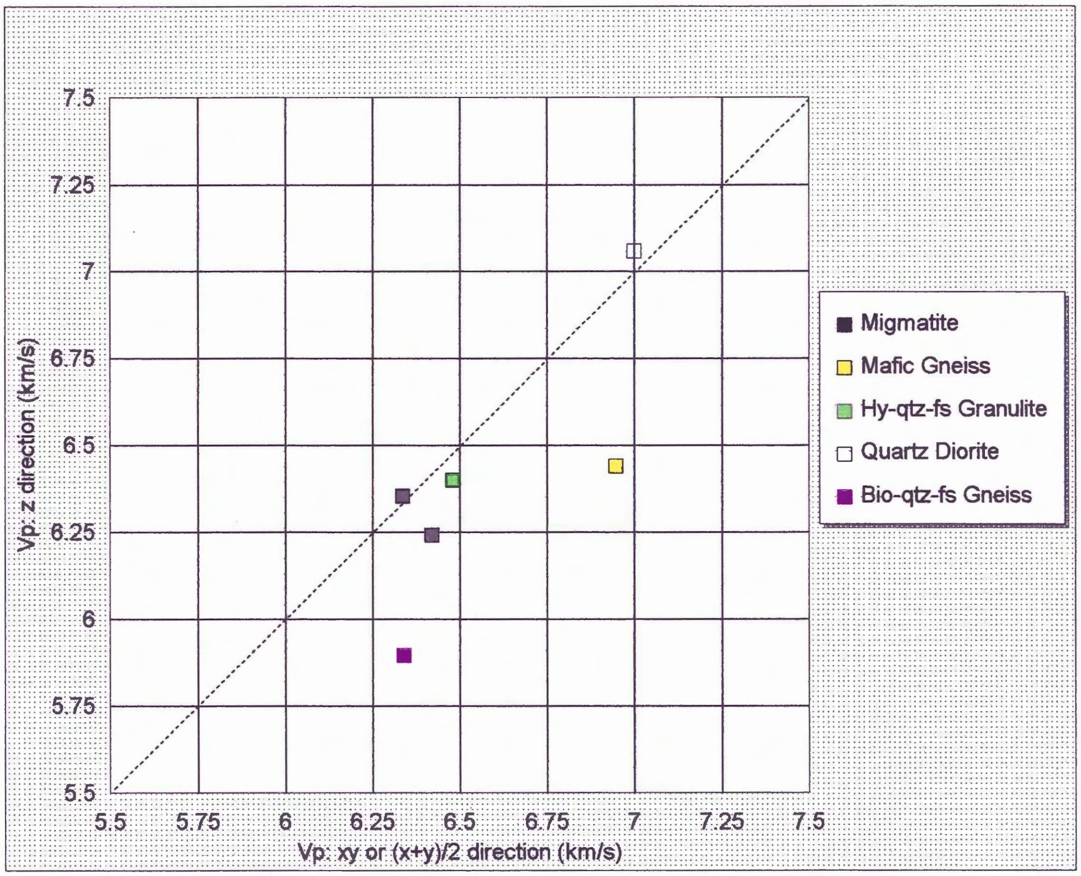


Figure 4-12: Graph showing the relationship between lithology and anisotropy for samples from Nain. Dashed line represents an isotropic relationship between the two core directions.

Psammitic gneisses, felsic gneisses, and samples N6 (migmatite) and N5 (hypersthene-quartz-feldspar granulite) display low seismic anisotropy. Migmatite sample N1 ranged from having strong anisotropy at low pressures to being virtually isotropic at high pressures. Extreme anisotropy at low pressures is probably related to oriented microcracks, and may be sympathetic to, or opposed to anisotropy related to the preferred orientation of anisotropic minerals (Christensen, 1965). Once the microcracks close at higher pressures, the anisotropy is solely due to the anisotropic minerals. This occurs in samples L2 (paragneiss), L3 and L10a' (felsic gneiss) and N4 (mafic gneiss).

The mafic samples vary in their degree of anisotropy. L10b, originally defined as mafic, displays weak anisotropy, but this sample is now referred to as felsic in charts and diagrams on the basis of its mineralogy in thin section. Sample L5 also displays low seismic anisotropy. In thin section, a definite foliation defined by mafic/felsic layering was observed, but there was no apparent alignment of mafic minerals parallel to the foliation. Sample 11b' also shows low anisotropy but displays no visible foliation in thin section. Anisotropy in samples L8b and N4 is high.

Anisotropy in bio-qtz-fs gneisses, granites, granitoid gneisses, and paragneisses was generally high due to the presence of mafic minerals such as biotite and hornblende which defined the foliation. In samples such as L17 (granitoid gneiss), the quartz grains were arrayed parallel to the foliation and lineation, which would help explain the presence of anisotropy in a rock dominated by felsic minerals.

4.4.1.2 Anisotropy Based on Shear Wave Velocities

Analysis of the shear wave velocity data in Table 4-4 shows that sample L12 (granite) appears to be isotropic which is very surprising since the same sample displays strong anisotropy based on compressional wave velocity data, while samples L11b' and L15 (mafic gneiss) show weak anisotropy. Samples L2 (paragneiss), L8b and N4 (mafic gneiss), N5 (hy-qtz-fs granulite) and L21 and N8 (bio-qtz-fs gneiss) all show strong anisotropy.

Anisotropy values could not be calculated for all samples because only certain representative samples were selected for shear wave velocity measurements, and even fewer samples were measured in more than one vibration direction, as needed for complete anisotropy calculations.

4.5 Poisson's Ratio

Poisson's ratio, defined as $\sigma = ½ [1 - (1/ (\{Vp/Vs\}^2 -1))]$, provides a way of determining lithology from seismic data if both the compressional and shear wave velocities are known. Most rocks have a Poisson's ratio of less than 0.5, with granite having a value of 0.25, anorthosite around 0.31, and quartzite around 0.1 (Hatcher, 1995). Due to the fact that quartz has an anomalously low Poisson's ratio, it is useful for distinguishing quartz-rich rocks at crustal levels which cannot be sampled directly.

Table 4-5 shows Poisson's ratio values for samples from both the Torngat Orogen / Nachvak Fjord and Nain regions of Labrador. As one can see, most samples from the Torngat Orogen / Nachvak Fjord region have values between 0.204 (L19, psammitic gneiss) and 0.284 (L1, tonalite gneiss). However, samples L16 (quartzite) and L21 (bio-qtz-fs gneiss) have values of 0.106 and 0.177, respectively, consistent with their higher quartz contents. No samples from Nain displayed this characteristically low value, with most samples ranging between 0.239 (N1, migmatite) and 0.292 (N5, hy-qtz-fs granulite).

Figures 4-13 and 4-14 are plots of compressional wave velocity versus shear wave velocity for both regions of Labrador. The lines represent constant Poisson's ratio values. As can be seen from Figure 4-13, samples from the Torngat Orogen / Nachvak Fjord region tend to lie between values of 0.2 - 0.28, the majority being around 0.26. From figure 4-14, samples from Nain tend to lie along two lines of constant Poisson's ratio, the 0.26 and 0.28 lines. The anorthosite sample from Nain (N2) displays a higher Poisson's ratio value (0.28) compared to the sample from the northern region (L6) which has a lower value of around 0.26 due to its quartz content. The bio-qtz-fs gneiss samples from the two regions also differed in Poisson's ratio. Sample L21 from the Torngat Orogen has a value of 0.177, while sample N8 from Nain has a value of 0.243. Since these samples have similar quartz contents, the differences in their Poisson's ratios must be due to other causes.

Table 4-5: Poisson's ratio data for all samples.

Torngat Orogen / Nachvak Fjord

Sample	Lithology	P-ratio
L1	Tonalite gneiss	0.284
L2	Paragneiss	0.207
L4	Felsic Gneiss	0.238
L5	Mafic gneiss	0.276
L6	Anorthosite	0.259
L8b	Mafic gneiss	0.252
L9	Late dike	0.266
L10a'	Felsic gneiss	0.240
L10b	Felsic gneiss	0.213
L11a	Felsic gneiss	0.243
L11b'	Mafic gneiss	0.247
L12	Granite	0.247
L13	Felsic Gneiss	0.247
L15	Mafic gneiss	0.264
L16	Quartzite	0.106
L18	Marble	0.278
L19	Psammitic gneiss	0.204
L20	Granitoid gneiss	0.239
L21	Bio-qtz-fs gneiss	0.177

Nain

N1	Migmatite	0.239
N2	Anorthosite	0.280
N3	Granite-qtz monzonite	0.284
N4	Mafic gneiss	0.278
N5	Hy-qtz-fs granulite	0.292
N7	Quartz diorite	0.270
N8	Bio-qtz-fs gneiss	0.243

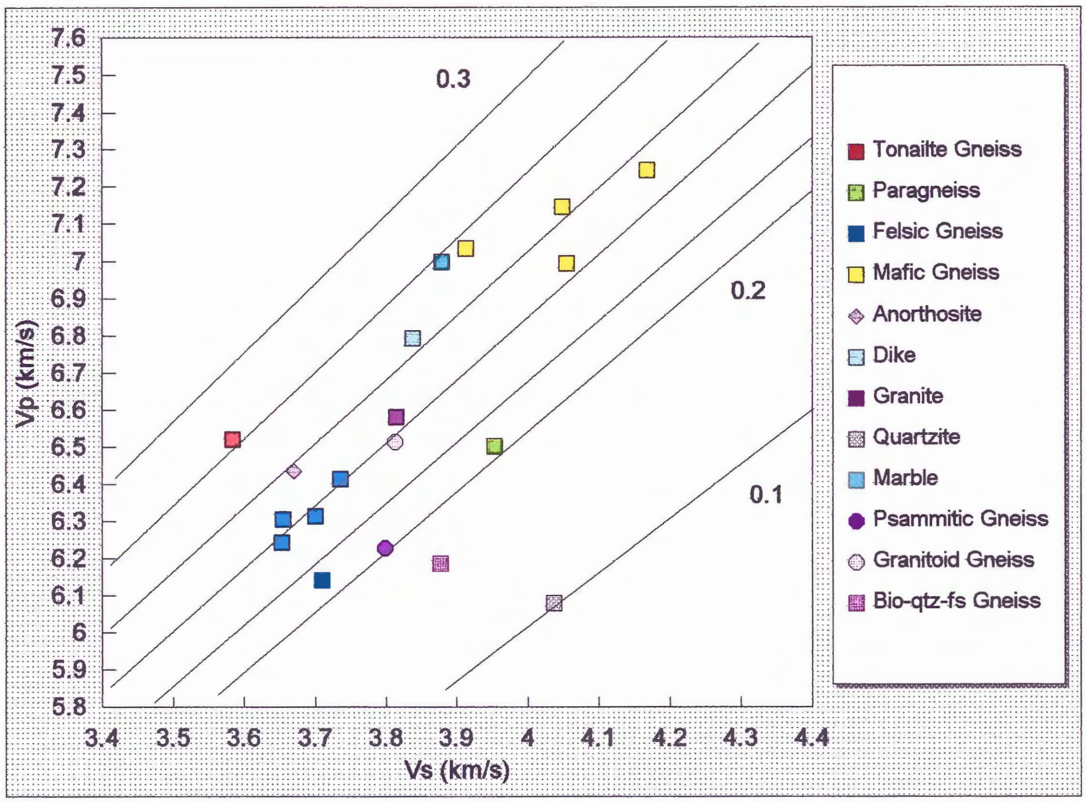


Figure 4-13: Plot of Vp versus Vs for samples from the Torngat Orogen / Nachvak Fjord region of Labrador. Diagonal lines represent lines of constant Poisson's ratio.

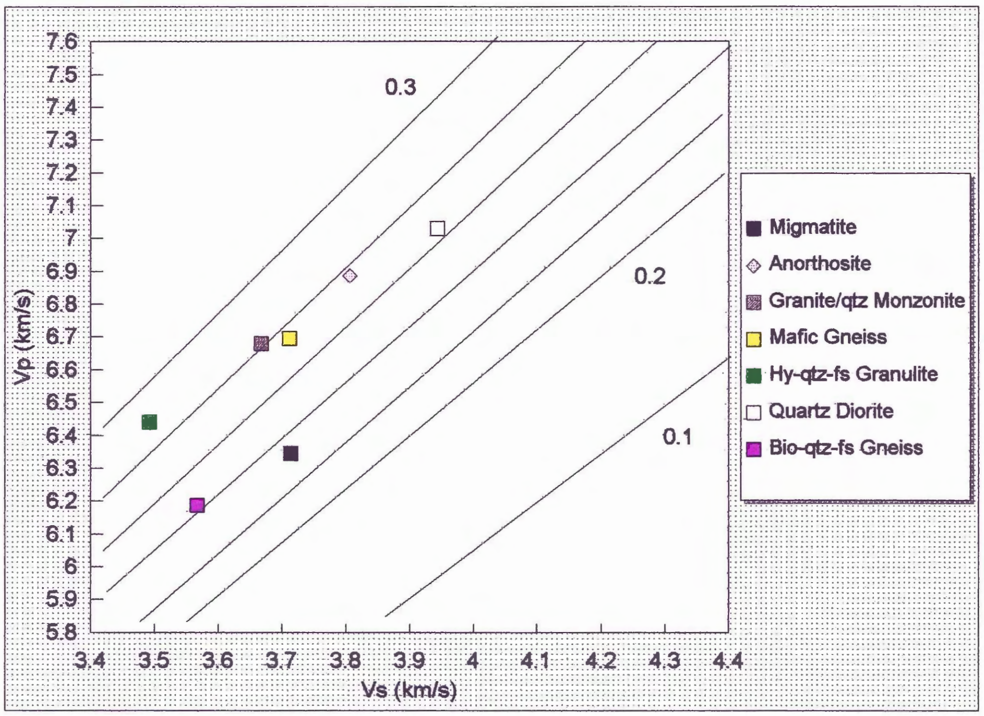


Figure 4-14: Plot of Vp versus Vs for samples from Nain. Diagonal lines represent lines of constant Poisson's ratio.

5.0 Conclusions

5.1 Summary

This project was undertaken to determine the compressional and shear wave velocities of a suite of samples from Labrador for use in interpreting ECSOOT'96 reflection and refraction data in terms of petrology. A total of 65 compressional wave velocity measurements were successfully made on a set of 84 cores from 31 samples, and 49 shear wave velocity measurements were made on a total of 74 cores from 26 samples. Some samples saturated and had to be re-cored and re-measured.

5.2 Results

5.2.1 Compressional Wave Velocities

Table 5-1 presents a summary of the average compressional wave velocity for each lithology measured at 600 MPa.

Table 5-1:

Lithology	Number of Samples Measured	Average Density (g/ml)	Compressional Wave Velocity (km/s)
Torngat Orogen / Nachvak Fjord			
Quartzite	1	2.68	6.08
Bio-qtz-fs gneiss	1	2.66	6.19
Psammitic gneiss	1	2.72	6.23
Felsic gneiss	6	2.72	6.39

Anorthosite	1	2.80	6.44
Granitoid gneiss	2	2.81	6.45
Paragneiss	1	2.81	6.50
Tonalite gneiss	1	2.68	6.52
Granite	1	2.63	6.58
Dike	2	3.04	6.98
Marble	1	2.86	7.00
Mafic gneiss	4	3.05	7.10
Nain			
Bio-qtz-fs gneiss	1	2.76	6.12
Migmatite	2	2.65	6.34
Quartzite	1	2.58	6.39
Hy-qtz-fs granulite	1	2.62	6.44
Granite-qtz monzonite	1	2.67	6.68
Mafic gneiss	1	3.00	6.69
Anorthosite	1	2.73	6.89
Quartz diorite	1	3.02	7.03

As one can see from Table 5-1, samples from the Torngat Orogen / Nachvak Fjord range in compressional wave velocity from 6.08 km/s (quartzite) to 7.10 km/s (mafic gneiss) while samples from Nain range in from 6.12 km/s (bio-qtz-fs gneiss) to 7.03 km/s (quartz diorite). Figures 5-1 and 5-2 are graphs of the average compressional wave velocity at 600MPa versus density with lithologic fields added, for samples from both regions of Labrador. As one can see from Figures 5-1 and 5-2, samples from the Torngat Orogen / Nachvak Fjord region fall into two overlapping fields composed of felsic and mafic rocks, whereas the fields do not overlap for the Nain samples.

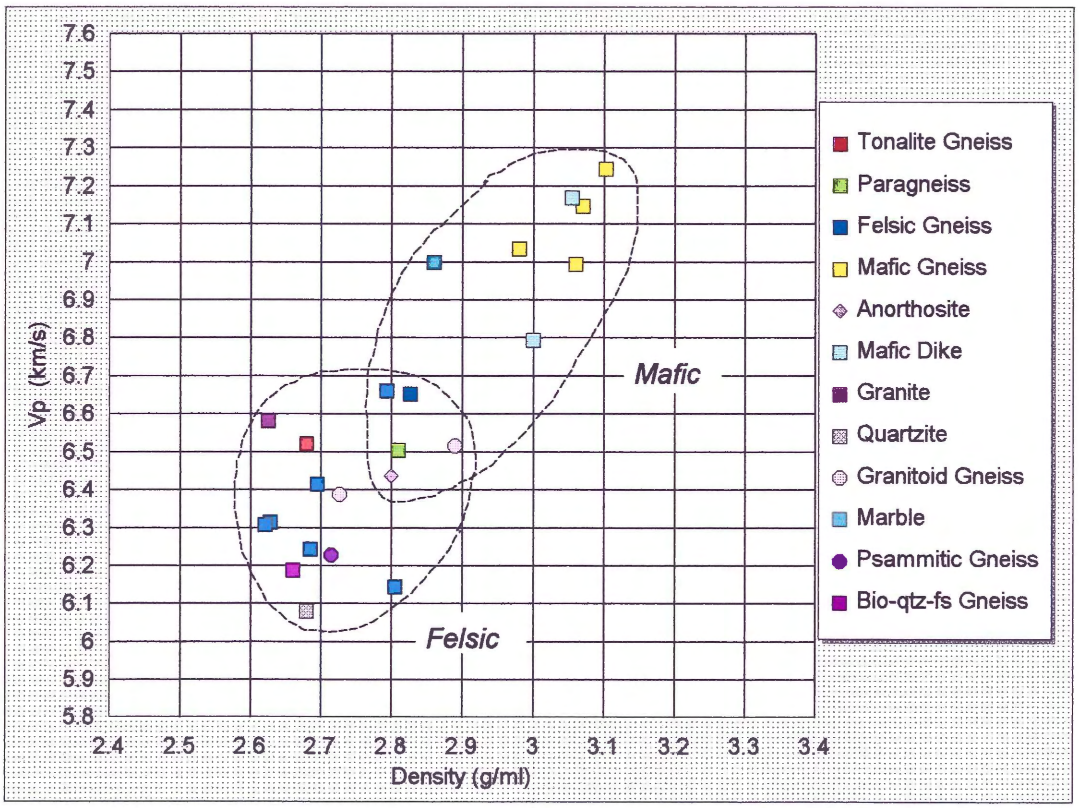


Figure 5-1: Plot of average Vp versus average density for samples from the Torngat Orogen / Nachvak Fjord region of Labrador. Mafic and felsic lithologic fields added.

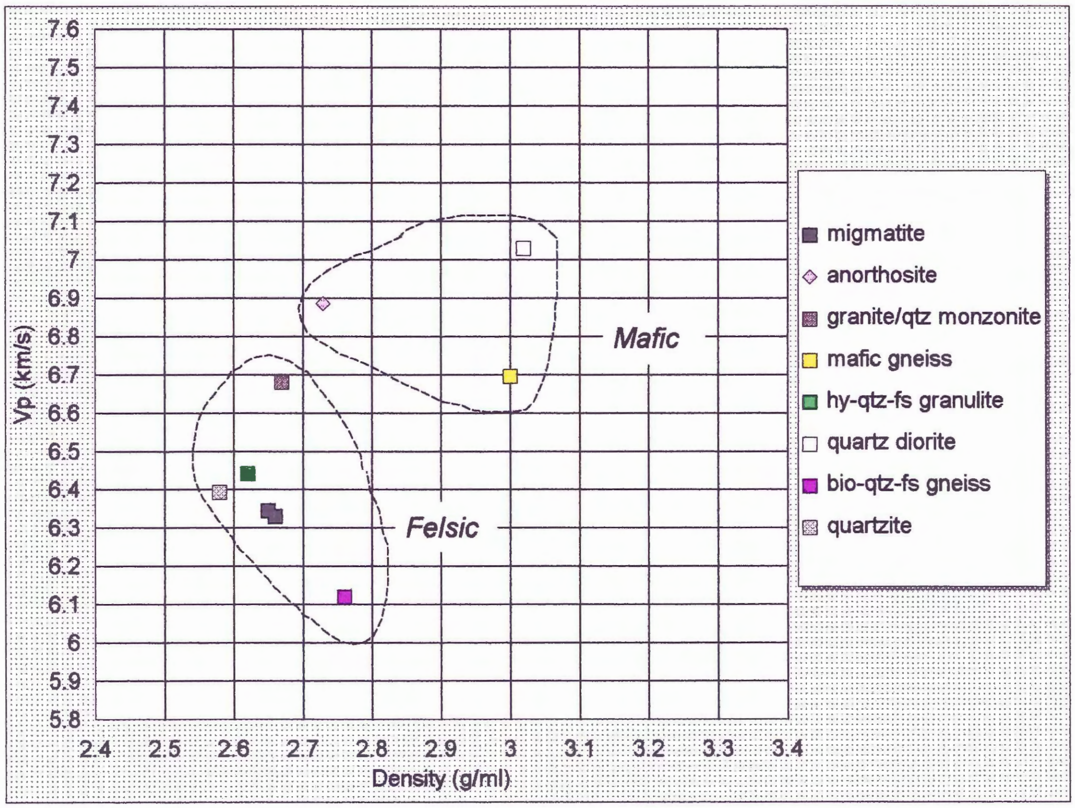


Figure 5-2: Plot of average Vp versus average density for samples from Nain.
Mafic and felsic lithologic fields added.

5.2.2 Shear Wave Velocities

Table 5-2 summarizes the shear wave velocities for each lithology measured at 600 MPa.

Table 5-2:

Lithology	**Number of Samples Measured**	**Average Density (g/ml)**	**Shear wave velocity (km/s)**
Torngat Orogen / Nachvak Fjord			
Tonalite gneiss	1	2.68	3.58
Anorthosite	1	2.80	3.67
Felsic gneiss	5	2.68	3.69
Psammitic gneiss	1	2.72	3.80
Granite	1	2.62	3.81
Granitoid gneiss	1	2.87	3.81
Dike	1	3.00	3.84
Bio-qtz-fs gneiss	1	2.66	3.88
Marble	1	2.86	3.88
Paragneiss	1	2.84	3.95
Quartzite	1	2.68	4.04
Mafic gneiss	3	3.05	4.05
Nain			
Hy-qtz-fs granulite	1	6.15	3.49
Bio-qtz-fs gneiss	1	3.75	3.57
Granite-qtz monzonite	1	2.67	3.67
Migmatite	1	2.65	3.71
Mafic gneiss	1	2.99	3.71
Anorthosite	1	2.70	3.81
Quartz diorite	1	3.02	3.94

As one can see from Table 5-2, samples from the Torngat Orogen / Nachvak Fjord region range in shear wave velocity from 3.58 km/s (tonalite gneiss) to 4.05 km/s (mafic gneiss), while samples from Nain range from 3.49 km/s (hy-qtz-fs granulite) to

3.94 km/s (quartz diorite). Figures 5-3 and 5-4 are graphs of the average shear wave velocity versus density for samples from both regions of Labrador. As for Vp, the samples from both regions fall within two fairly distinct fields based on shear wave velocity, one dominated by felsic rocks and one by mafic rocks.

5.2.3 Anisotropy

Several samples from the Torngat Orogen / Nachvak Fjord region and Nain were anisotropic at 600 MPa. These included L2 (paragneiss), L7 (felsic gneiss), L8b and N4 (mafic gneiss), L14 (basaltic dike), L12 (granite) and L17 and N8 (bio-qtz-fs gneiss). Based on the shear wave velocities, however, only a few samples were anisotropic. These included L2 (paragneiss), N4 (mafic gneiss), N5 (hy-qtz-fs granulite) and N8 (bio-qtz-fs gneiss).

5.2.4 Poisson's Ratio

Most samples from the two regions of Labrador have Poisson's ratio values between 0.2 and 0.3, while two samples from the Torngat Orogen / Nachvak Fjord region have values less than 0.2 (L16, quartzite, 0.106; and L21, bio-qtz-fs gneiss, 0.177). Felsic samples from the Torngat Orogen / Nachvak Fjord region tend to have Poisson's ratio values < 0.245 due to the presence of quartz, while mafic samples tended to have values > 0.245 (Table 4-5).

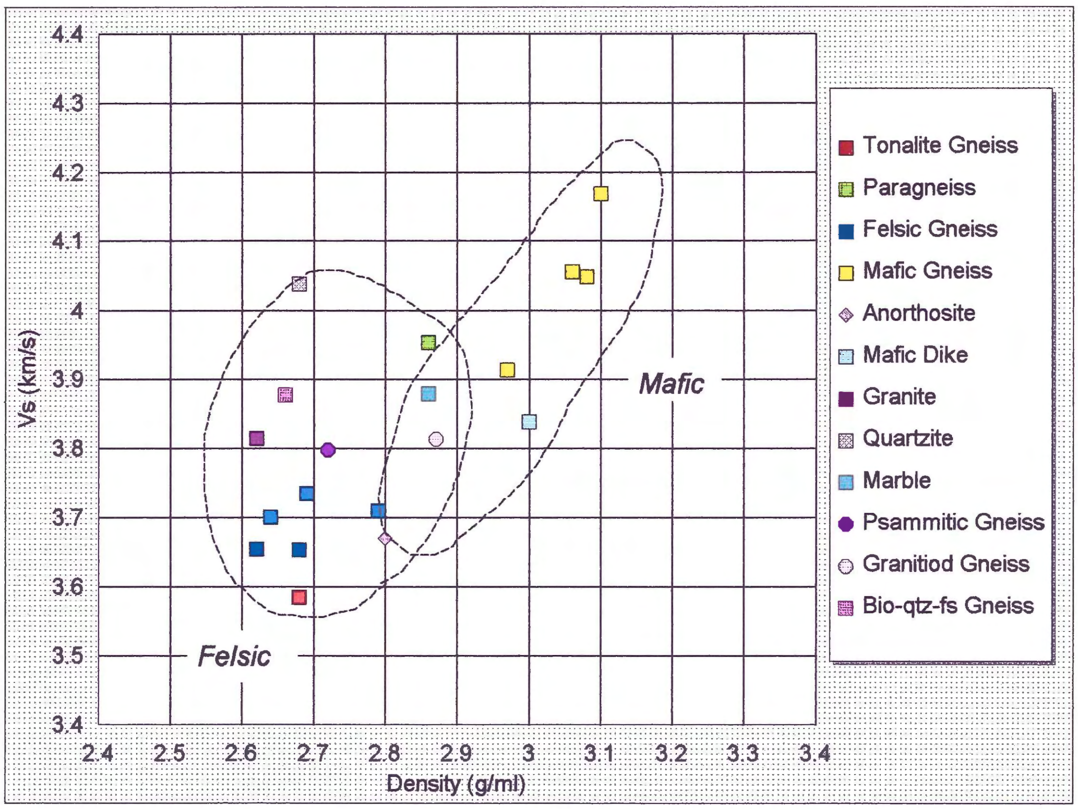


Figure 5-3: Plot of average Vs versus average density for samples from the Torngat Orogen / Nachvak Fjord region of Labrador. Mafic and felsic lithologic fields added.

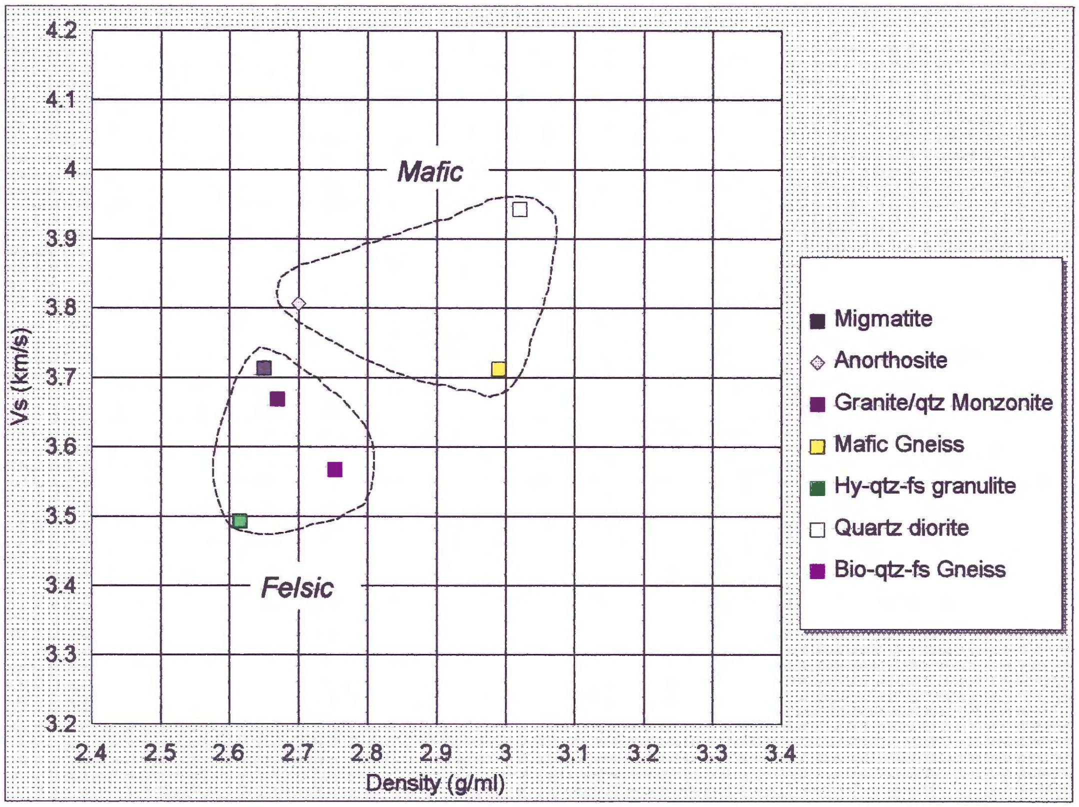


Figure 5-4: Plot of average Vs versus average density for samples from Nain. Mafic and felsic lithologic fields added.

5.3 Expectations for Seismic Data

5.3.1 Refraction Data

Figures 5-5 and 5-6 are graphs of Vp vs. Vs for both regions of Labrador with lithological fields and lines of constant Poisson's ratio added for reference. As shown in Figure 5-5, samples from the Torngat Orogen / Nachvak Fjord region of Labrador fall into two distinct fields corresponding to felsic and mafic rocks. Felsic samples include tonalite gneiss, felsic gneiss, granite, quartzite, granitoid gneiss, bio-qtz-fs gneiss, paragneiss and psammitic gneiss . These tend to have Poisson's ratio values less than 0.245, compressional wave velocities between 6.2 - 6.6 km/s and shear wave velocities between 3.6 - 4.0 km/s. Unlike most felsic samples, the quartzite sample displays an extremely low Poisson's ratio value (0.106) due to its high quartz content. Mafic samples include mafic gneisses, basaltic dikes, marbles and anorthosites. These rock types have Poisson's ratio values above 0.245, compressional wave velocities between 6.5 - 7.2 km/s and shear wave velocities between 3.8 - 4.2 km/s.

Figure 5-6 shows Vp vs. Vs for samples from Nain. As can be seen, the samples again plot within felsic and mafic fields. The felsic samples include migmatites, granite/qtz monzonite, hy-qtz-fs granulite and bio-qtz-fs gneiss. These have Poisson's ratio values ranging from 0.24 - 0.29, compressional wave velocities between 6.2 - 6.7 km/s and shear wave velocities between 3.5 - 3.7 km/s. Mafic samples include anorthosite, mafic gneiss and quartz diorite and have Poisson's ratio values of about 0.28, compressional wave velocities between 6.7 - 7.0 km/s, and shear wave velocities between 3.7 - 4.0 km/s.

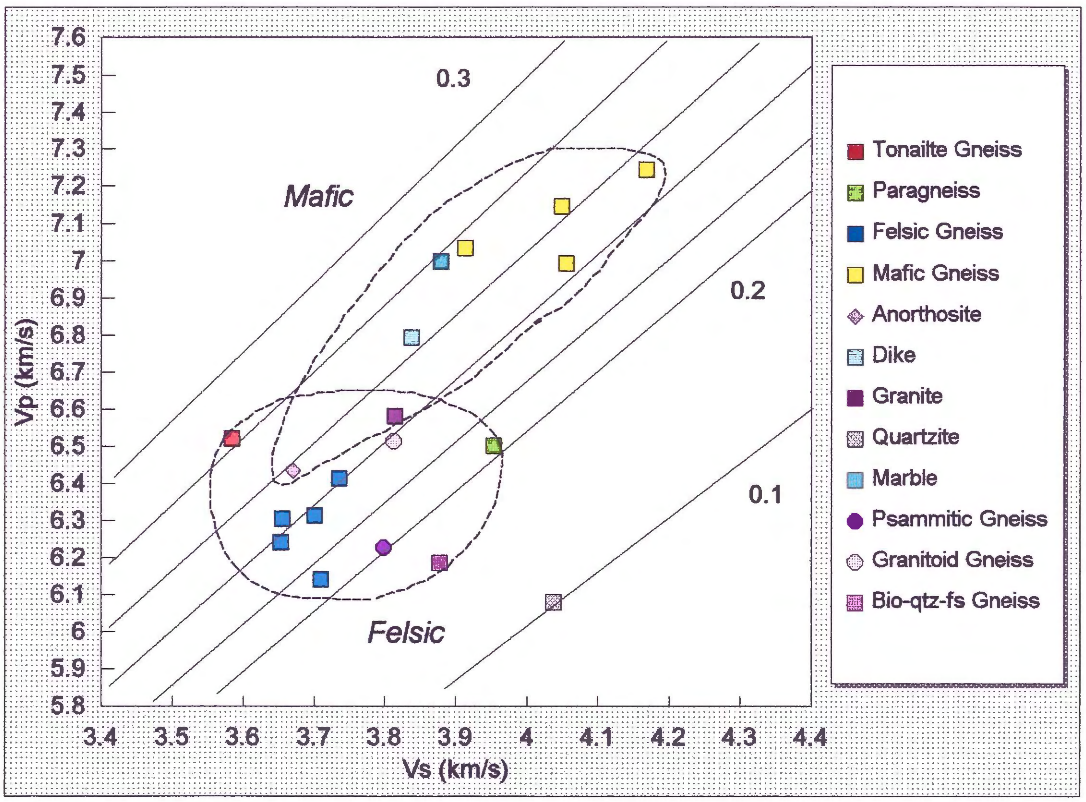


Figure 5-5: Plot of Vp versus Vs for samples from the Torngat Orogen / Nachvak Fjord region of Labrador. Also shown are velocity fields for mafic and felsic rocks and lines of constant Poisson's ratio.

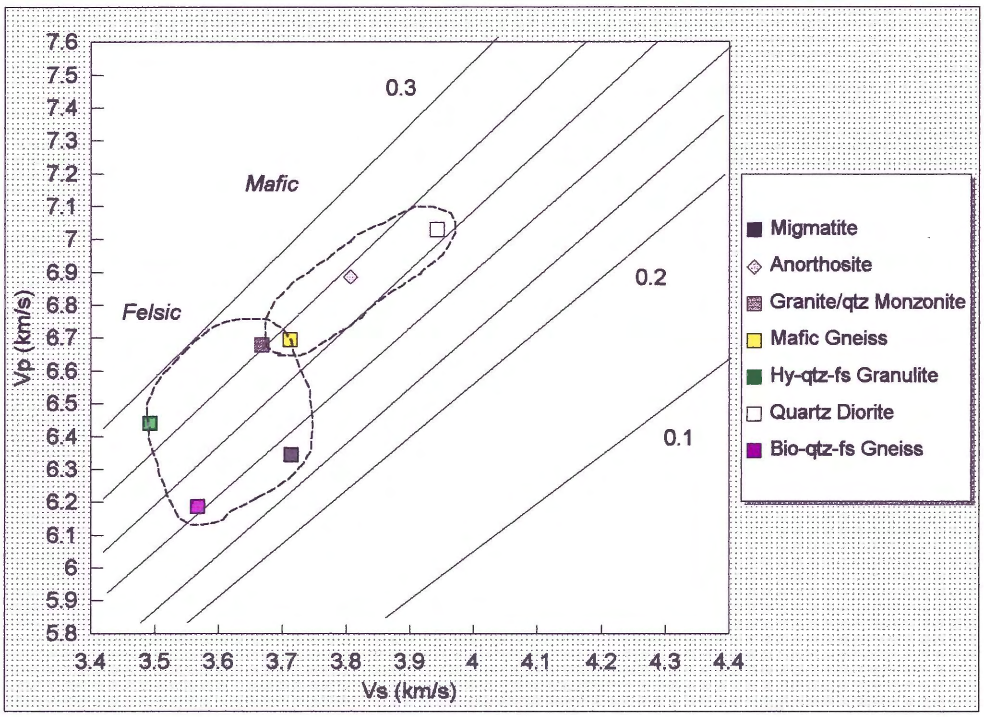


Figure 5-6: Plot of Vp versus Vs for samples from Nain. Also shown are velocity fields for mafic and felsic rocks and lines of constant Poisson's ratio.

5.3.2 Reflection Data

Figures 5-7 and 5-8 are graphs of compressional wave velocity versus density for samples from both the Torngat Orogen / Nachvak Fjord and Nain regions of Labrador. Lines of constant acoustic impedance and lithological fields have been superimposed for reference. Acoustic impedance is simply the compressional wave velocity multiplied by the density of a rock. The greater the contrast in acoustic impedance across a rock interface, the smaller the proportion of energy transmitted through the interface and the greater the proportion reflected back to the surface. The minimum acoustic impedance contrast required to make a strong reflection is 2.5 $x10^5$ g/cm^2s. From Figures 5-7 and 5-8, it is clear that any strong reflections in either areas would most likely be produced by contrasts between mafic and felsic rocks.

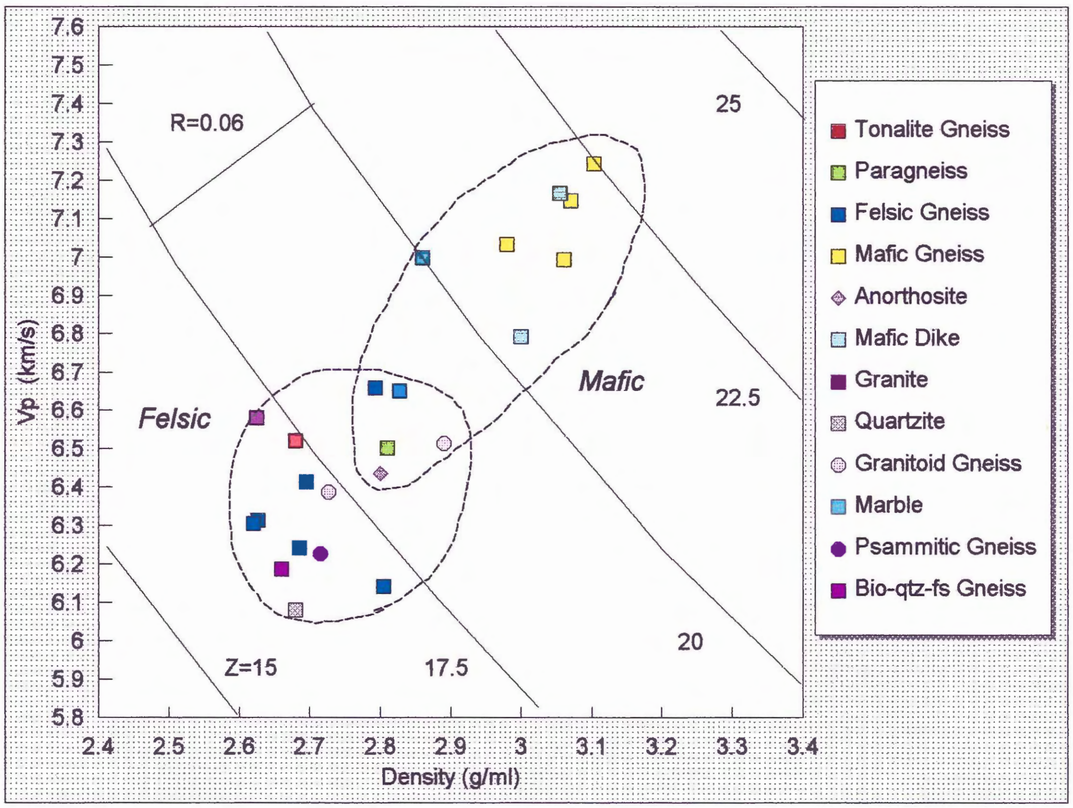


Figure 5-7: Average compressional wave velocity (Vp) vs. density for Torngat Orogen / Nachvak Fjord samples. Lines of constant acoustic impedance (Z) are superimposed at intervals which show the minimum impedance contrast (~2.5x10e5 g/cm2s) required to produce a strong reflection (coefficient R=0.06).

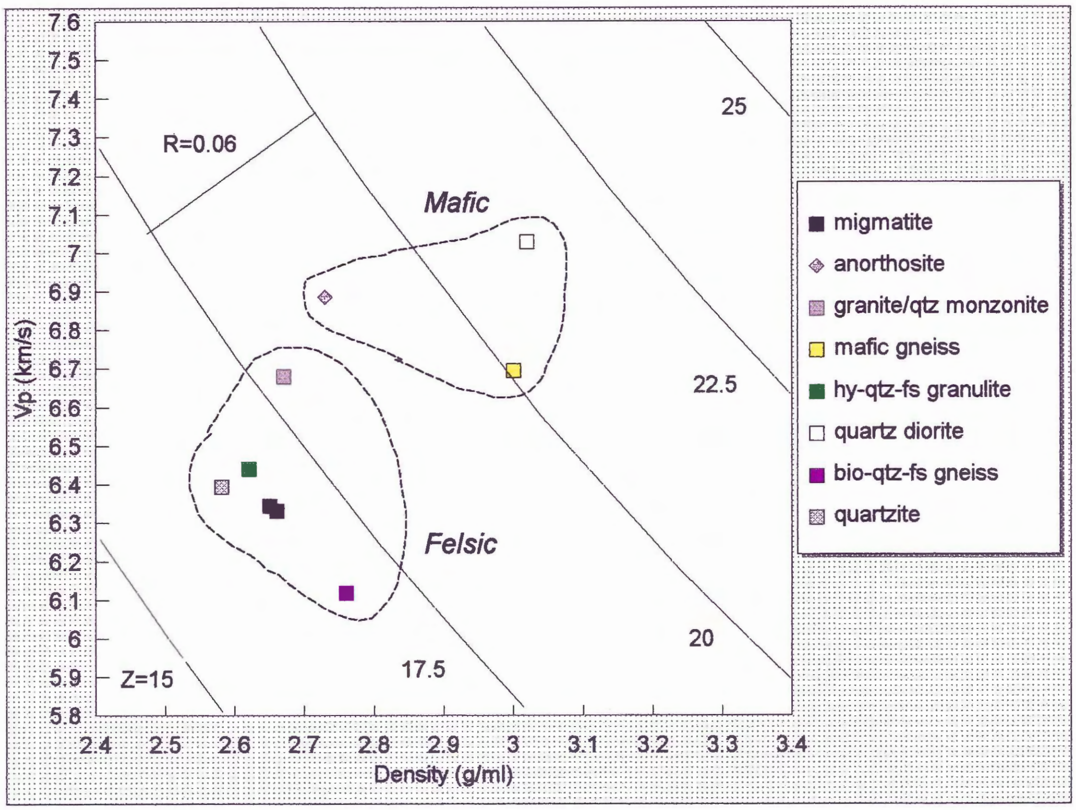


Figure 5-8: Average compressional wave velocity (Vp) vs. density for Nain samples. Lines of constant acoustic impedance (Z) are superimposed at intervals which show the minimum impedance contrast (~2.5x10e5g/cm2s) required to produce a strong reflection (coefficient R=0.06).

5.4 Interpretation of Lines 5W and 5E through the Torngat Orogen

Figure 5-9 is a cross section through northern Labrador along LITHOPROBE lines 5W and 5E showing the layered structure of the upper, middle and lower crust with corresponding compressional wave velocities for each layer determined from seismic refraction data (after Funck, 1998). The upper crust (<10 km) is composed of rocks with compressional velocities between 5.9 - 6.3 km/s. Comparison with Table 5-1 suggests that this would result from the upper crust being composed of mainly felsic rocks such as felsic gneiss, quartzite, bio-qtz-fs gneiss and perhaps psammitic gneiss. The middle crust (10 - 20 km), is composed of rocks with compressional wave velocities between 6.2 - 6.6 km/s, which suggests a middle crust of felsic to intermediate composition. It would be comprised of such lithologies as psammitic gneiss, felsic gneiss, granitoid gneiss, anorthosite, granitoid gneiss, paragneiss, tonalite gneiss, and granite. The lower crust (20 - 40 km), contains rocks with compressional wave velocities between 6.6 - 7.1 km/sec. Lithologies with this range of velocity include marbles, mafic dikes and intermediate to mafic gneiss. It is most likely that the lower crust is composed predominantly of intermediate to mafic gneisses which become increasingly mafic with depth. From Figure 5-9, a mafic crustal root is visible which extends into the mantle. It is quite interesting that the root of this mountain range has survived for billions of years and has not been removed by tectonic erosion.

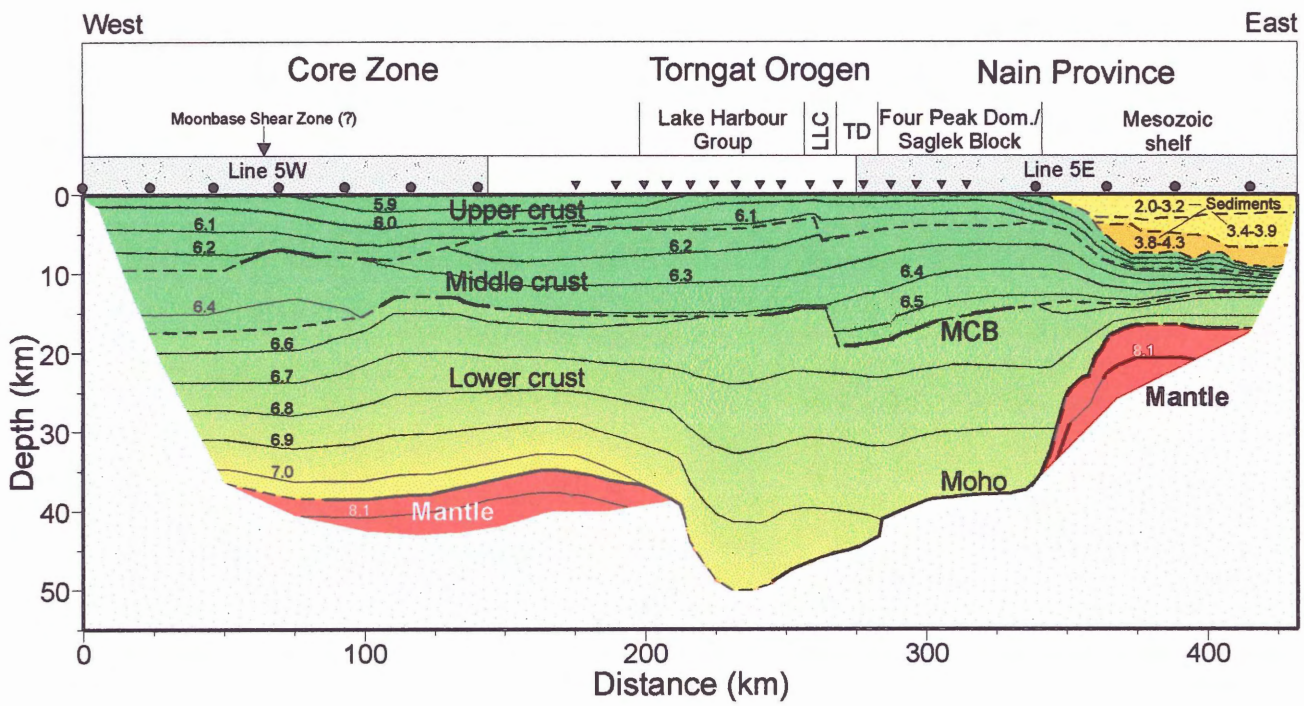


Figure 5-9: Seismic cross section across the Torngat Orogen including marine seismic lines 5W and 5E (Funck et al., 1998). Circles show locations of ocean bottom seismometers; triangles represent land stations.

References

Birch, F., 1960, The velocity of compressional waves in rocks to 10 kilobars, part 1, *J. Geophys Res.*, **65**, 1083-1102.

Bridgwater, D. and Schiøtte, L., 1991. The Archean gneiss complex of northern Labrador. A review of current results, ideas and problems. Bulletin of the Geological Society of Denmark, **39**: 153-166.

Bolt, B.A., 1982. *Inside the Earth.* Freeman, San Francisco.

Burke, M., 1991. Reflectivity of Highly Deformed Terranes Based on laboratory and In Situ Velocity measurements from the Grenville Front Tectonic Zone, Central Ontario, Canada. PhD Thesis. Dalhousie University, Nova Scotia, Canada.

Christensen, N.I., 1965. Compressional wave velocities in metamorphic rocks to 10 kilobars, J. Geophys. Res., **70,** 6147-6164.

Funck, T., Louden, K.E, Hall, J. and Wardle, R., 1998. Wide-angle seismic transect across theTorngat Orogen, northern Labrador, Submitted to J. Geophys. Res..

Hall, J., Wardle, R., Gower, C., Kerr, A., Coflin, K., Keen, C. and Carroll, P., 1995. Proterozoic orogens of the northeastern Canadian Shield: new information from the Lithoprobe ECSOOT crustal reflection survey. Canadian Journal of Earth Sciences, **32**, no. 8: 1119-1131.

Harvey, C. W., 1997. Shear wave velocities of sulphide-bearing assemblages as determined from high pressure laboratory measurements. Masters Thesis, Dalhousie University, Halifax, Nova Scotia, pp 227.

Hatcher, R.D., Jr., 1995. Structural Geology: Principles, Concepts, and Problems, 2nd ed. Prentice Hall: New Jersey.

Hoffman, P.F., 1988. United Plates of America, the birth of a craton: Early Proterozoic assembly and growth of Laurentia. *Annual Review of Earth and Planetary Sciences*, **16**: 543-603.

Hoffman, P.F., 1990. Dynamics of the assembly of northeast Laurentia in geon 18 (1.9-1.8Ga). *Geoscience Canada*, **17**: 222-226.

Holbrook, W.S., Mooney, W.D. and Christensen, N.I. 1992. The seismic velocity structure of the deep continental crust. *In* D.M. Fountain, R Arculus and R.W.

Kay (eds.), Continental Lower Crust, Elsevier, Amsterdam, 1-43.

Louden, K., Hall, J. and Wardle, R., 1994. Proposal for ECSOOT wide-angle seismic experiments. *In* Wardle, R.J. and Hall, J. (compilers). Eastern Canadian Shield Onshore-Offshore Transect (ECSOOT'96), Transect Meeting (November 28-29, 1994), École Polytechnique, Report No. 45.

Louden, K., 1996. Personal communication.

McLaren, S. and Hall J., 1992. *In* Wardle, R.J. and Hall, J. (compilers). Eastern Canadian Shield Onshore-Offshore Transect (ECSOOT), Transect Meeting (November 21-22, 1991), Atlantic Geocience Centre, Report No. 27.

Park, R.G., 1995. Palaeoproterozoic Laurentia-Baltica relationships: a view from the Lewisian, *In* Early Precambrian Processes, Geological Society Special Publication, No. 95. Coward, M.P. and Ries, A.C., ed. London.

Rivers, T., Mengel, F., Scott, D., Campbell, L. and Goulet N., 1996. Torngat Orogen - a Paleoproterozoic example of a narrow doubly-vergent collisional orogen. *In* PreCambrian Crustal Evolution in the North Atlantic Region. Brewer, T., ed. Geological Society Special Publication No. 112.

Ryan, B., 1991. Deformation in the Nain Plutonic Suite and shear zones in its gneissic envelope. LITHOPROBE: Report of transect meeting. No. 27, 70.

Scott, D. and Machado, N., 1994. U-Pb geochronology of northern Torngat Orogen; implications for the evolution of NE Laurentia. *Terra Abstracts*, **6**, 2, 17.

Wardle, R. J. and Kranendonk, M.J., 1996. The Palaeoproterozoic Southeastern Churchill Province of Labrador-Quebec, Canada: orogenic development as a consequence of oblique collision and indentation. *In:* Brewer, T.S., ed *PreCambrian Crustal Evolution in the North Atlantic Region.* Geological Society Special Publication **12**, 137-153.

Wardle, R., 1996. Personal communication.

Appendix A: Detailed petrological descriptions for samples from the Torngat Peninsula.

Sample #: L1 - xy
Rock Type: tonalite gneiss
Grade (if known): granulite facies
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation
Main minerals: 45% quartz (xenoblastic)
35% feldspar (xenoblastic)
15% orthopyroxene (idioblastic)
5% biotite (subidioblastic)
Accessory Minerals: opaques
Texture: medium grained with several large quartz grains up to 2.5mm in length
Fabric / Foliation: defined by bands of opx, biotite, opaques and elongated quartz grains
Other features: none

Sample #: L2 - x
Rock Type: paragneiss
Grade (if known): unknown
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation, parallel lineation
Main minerals: 35% quartz (xenoblastic)
25% plagioclase feldspar (xenoblastic)
20% garnet (xenoblastic)
10% pyroxene (cpx and opx) (subidioblastic)
5% spinels? (idioblastic)
Accessory Minerals: opaques
Texture: medium to coarse grained
Fabric / Foliation: defined by the orientation of quartz grains and elongate clusters of clinopyroxene and biotite
Other features: none

Sample #: L3 - y
Rock Type: felsic gneiss (straight rock)
Grade (if known): unknown
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation, perpendicular to lineation
Main minerals: 40% feldspar (xenoblastic)

35% opx and cpx (xenoblastic)
20% quartz (xenoblastic)
5% biotite (idioblastic)
Accessory Minerals: opaques
Texture: fine-medium grained
Fabric / Foliation: defined by strings of pyroxene and biotite (not continuous)
also by elongated quartz grains
Other features: none

Sample #: L4 - y
Rock Type: felsic gneiss
Grade (if known): granulite facies
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation, perpendicular to lineation
Main minerals: 60% plagioclase (xenoblastic)
35% quartz (subidioblastic)
5% biotite (subidioblastic)
Accessory Minerals: clays, opaques
Texture: fine-med grained
Fabric / Foliation: defined by aligned quartz grains, plagioclase grains slightly aligned
Other features: quartz grains up to 1.5mm in length

Sample #: L5 - y
Rock Type: mafic gneiss
Grade (if known): granulite facies overprint
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation, perpendicular to lineation
Main minerals: 35% plagioclase (microcline?) (subidioblastic)
35% hornblende (subidioblastic)
25% orthopyroxene (xenoblastic)
5% quartz (subidioblastic)
Accessory Minerals: opaques
Texture: medium - coarse grained
Fabric / Foliation: defined by layers of pyroxenes and hornblende altered with more felsic layers
Other features: none

Sample #: L6 - xy
Rock Type: anorthosite

Grade (if known): unknown
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation
Main minerals: 45% feldspar (xenoblastic)
25% biotite (idioblastic to subidioblastic)
20% amphibole (hornblende) (xenoblastic)
10% quartz (xenoblastic)
Accessory Minerals: opaques
Texture: medium-coarse grained
Fabric / Foliation: defined by compositional layering 1) qtz+fsp+minor biotite
2) qtz+fsp+amph+bio
Other features: abundant fracturing of grains, filled with opaques

Sample #: L7 - x
Rock Type: felsic gneiss
Grade (if known): granulite facies
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation, parallel lineation
Main minerals: 70% plagioclase (xenoblastic)
15% clino and orthopyroxene (xenoblastic)
10% quartz (xenoblastic)
5% hornblende (xenoblastic)
Accessory Minerals: minor opaques
Texture: med-coarse grained
Fabric / Foliation: defiend by bands of pyroxene and hornblende
alternating with qtz and feldspar bands
Other features: large accumulation of plagioclase crystals in the center of the thin sectio

Sample #: L8b - y
Rock Type: mafic gneiss
Grade (if known): granulite facies overprint
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation, perpendicular lineation
Main minerals: 45% hornblende (subidioblastic)
30% plagioclase and microcline (subidioblastic)
20% ortho and clinopyroxene (subidioblastic)
5% quartz (subidioblastic)
Accessory Minerals: opaques
Texture: med-coarse grained
Fabric / Foliation: defined by alternating bands of quartz and feldspar with bands of

pyroxene, amphibole, and smaller quartz and feldspar grains
Other features: pyroxenes have been alterd in the cores, plagioclase shows evidence of strain, undulatory extinction, irregular twinning

Sample #: L9
Rock Type: late dike
Grade (if known): unknown
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: unoriented
Main minerals: 60% sanidine (euhedral)
20% clinopyroxene (subhedral)
20% groundmass
Accessory Minerals: clays, opaques
Texture: medium grained porphyroclasts, fine graiend groundmass
Fabric / Foliation: none, igneous texture
Other features: groundmass quite altered

Sample #: L10a - xy
Rock Type: felsic gneiss
Grade (if known): greenschist - amphibolite facies overprint
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation
Main minerals: 45% quartz (subidioblastic-xenoblastic)
35% feldspar (subidioblastic-xenoblastic)
15% biotite (fibrous, idioblastic)
5% opaques (xenoblastic)
Accessory Minerals: none
Texture: medium-coarse grained
Fabric / Foliation: defined by thin layers of biotite and opaques, quartz grains are large and are elongated parallel to the foliation
Other features: biotite seems to be replacing the feldspar, quartz shows undulatory extinction

Sample #: L10b - xy
Rock Type: felsic gneiss
Grade (if known): greenschist / amphibolite facies overprint
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation
Main minerals: 35% plagioclase (xenoblastic)

35% quartz (xenoblastic)
25% biotite (subidioblastic - idioblastic)
5% epidote (subidioblastic - idioblastic)

Accessory Minerals: opaques
Texture: fine-medium grained
Fabric / Foliation: no vivble fabric in thin section, larger quartz grains somewhat elongate
Other features: quartz grains show undulatory extinction

Sample #: L11a - xy
Rock Type: felsic gneiss
Grade (if known): greenschist facies
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation
Main minerals: 45% quartz (xenoblastic)
25% feldspar (xenoblastic)
15% biotite (subidioblastic - idioblastic)
10% epidote (subidioblastic - idioblastic)
5% chlorite (subidioblastic)
Accessory Minerals: opaques with rim of unknown material
Texture: fine-coarse grained
Fabric / Foliation: defined by patches of biotite, epidote and minor amounts of quartz
Other features: quartz has undulatory extinction showing evidence of strain
epidote infills cracks in the larger quartz and feldspar grains

Sample #: L11b' - xy
Rock Type: mafic gneiss
Grade (if known): greenschist facies
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation
Main minerals: 30% amphibole (subidioblastic)
25% plagioclase (subidioblastic)
25% chlorite (xenoblastic - idioblastic)
15% epidote (idioblastic)
5% quartz (subidioblastic)
Accessory Minerals: opaques
Texture: medium grained, equigranular
Fabric / Foliation: no visible foliation in thin section
Other features: amphibole highly altered
epidote found along grain boundaries of plagioclase

Sample #: L12 - xy
Rock Type: granite
Grade (if known): unknown
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation
Main minerals: 50 % feldspar (perthite?) (subidioblastic - xenoblastic)
45% quartz (subidioblastic - xenoblastic)
5% biotite (idioblastic - subidioblastic)
Accessory Minerals: opaques
Texture: medium grained
Fabric / Foliation: defined by alternating quartz and feldspar aggregates
Other features: quartz unaltered, feldspar quite altered

Sample #: L13 - xy
Rock Type: felsic gneiss
Grade (if known): greenschist facies
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation
Main minerals: 50% feldspar (xenoblastic)
50% quartz (xenoblastic)
Accessory Minerals: opaques, minor chlorite
Texture: medium - coarse grained
Fabric / Foliation: defined by changes in grain size between the quartz and feldspar:
layer 1) coarse grained quartz and feldspar
layer 2) medium grained quartz and feldspar
Other features: quartz unaltered
feldpar contains myrmektic intergrowths and some grains are perthitic

Sample #: L14
Rock Type: mafic dike
Grade (if known): unknown
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: unoriented
Main minerals: 50% plagioclase (euhedral)
35% clinopyroxene (anhedral)
10% opaque grains (skeletal)
5% chlorite (anhedral)
Accessory Minerals: none
Texture: medium grained, igneous texture remains
Fabric / Foliation: none

Other features: none

Sample #: L15 - xy
Rock Type: mafic gneiss
Grade (if known): greenschist facies
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation
Main minerals: 40% garnet (xenoblastic)
30% plagioclase with albite twinning (xenoblastic)
15% hornblende (xenoblastic)
10% altered clinopyroxene (xenoblastic)
5% quartz (xenoblsatic)
Accessory Minerals: chlorite
Texture: medium - coarse grained
Fabric / Foliation: no foliation visible in slide
Other features: none

Sample #: L16
Rock Type: quartzite
Grade (if known): unknown
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: unoriented
Main minerals: 95% quartz (xenoblastic) (rounded grains)
5% opaques (idioblastic)
Accessory Minerals: clays?
Texture: equidimensional, medium grained
Fabric / Foliation: none
Other features: none

Sample #: L17 - y
Rock Type: granitoid gneiss
Grade (if known): unknown
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation, perpendicular lineation
Main minerals: 50% quartz (xenoblastic - subidioblastic)
30% plagioclase (xenoblastic - subidioblastic)
10% amphibole (xenoblastic)
10% biotite (subidioblastic)
Accessory Minerals: opaques
Texture: medium grained

Fabric / Foliation: defined by alternating, elongate quartz+feldspar crystals and hornblende biotite layers
Other features: none

Sample #: L18
Rock Type: marble
Grade (if known): unknown
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: unoriented
Main minerals: 60% dolomite (xenoblastic)
40% calcite (xenoblastic)
Accessory Minerals: opaques
Texture: coarse grained
Fabric / Foliation: none
Other features: dolomite appears cloudy

Sample #: L19 - xy
Rock Type: psammitic gneiss
Grade (if known): unknown
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation
Main minerals: 35% quartz (xenoblastic)
30% biotite (subidioblastic)
30% plagioclase and orthoclase (xenoblastic)
5% pink garnet (xenoblastic)
Accessory Minerals: opaques
Texture: medium grained
Fabric / Foliation: defined by oriented biotite grains
no obvious compositional layering
Other features: none

Sample #: L20 - xy
Rock Type: granitoid gneiss
Grade (if known): unknown
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation
Main minerals: 25% quartz (xenoblastic)
25% hornblende (xenoblastic)
20% plagioclase (xenoblastic)
10% biotite (subidioblastic)

10% opaques (xenoblastic)
10% clinopyroxene (xenoblastic)
Accessory Minerals: none
Texture: medium grained, some quartz grains up to 1.5mm in length
Fabric / Foliation: defined by two areas 1). Qtz+fsp+minor bio+minor hbl
2) bio+opaques+hbl+qtz+fsp
Other features: none

Sample #: L21 - xy
Rock Type: biotite-quartz-feldspar gneiss
Grade (if known): unknown
Location: Torngat Orogen / Nachvak Fjord
Orientation of thin section: parallel foliation
Main minerals: 50% quartz (xenoblastic)
30% plagioclase (xenoblastic)
15% biotite (subidioblastic - idioblastic)
5% garnet (xenoblastic)
Accessory Minerals: opaques
Texture: medium grained
Fabric / Foliation: defined by oriented biotite laths
Other features: garnet only occurs in one corner of the thin section, representative?

Appendix B: Detailed petrological descriptions for all samples from Nain.

Sample #: N1 - xy
Rock Type: migmatite
Grade (if known): unknown
Location: Nain
Orientation of thin section: parallel foliation
Main minerals: 45% quartz (subidioblastic)
30% plagioclase (xenoblastic-subidioblastic)
5% biotite (subidio-idioblastic)
2% orthopyroxene (xenoblastic)
Accessory Minerals: minor opaques and chlorite
Texture: medium-coarse grained
Fabric / Foliation: hard to distinguish, small groupings of mafic minerals (biotite, opx, and opaque phase), no visible layers in thin section
Other features: albite twinning well developed in plagioclase
no undulatory extinction in quartz
extensive alteration of plagioclase, to a fine-grained, dark mineral

Sample #: N2
Rock Type: anorthosite
Grade (if known): not metamorphosed
Location: Nain
Orientation of thin section: unoriented
Main minerals: 95% plagioclase (labradorite) (subhedral)
5% orthopyroxene and augite (anhedral)
Accessory Minerals: unknown green/brown mineral
Texture: coarse grained!
Fabric / Foliation: none visible
Other features: several clinopyroxene grains show opaque inclusions and lamellae

Sample #: N3
Rock Type: granite / qtz monzonite
Grade (if known): unknown
Location: Nain
Orientation of thin section: unoriented
Main minerals: 65% plagioclase (perthite?) (anhedral)
20% quartz (anhedral)
6% clinopyroxene (anhedral)
5% amphibole (anhedral)

2% chlorite (anhedral)
2% biotite (anhedral)

Accessory Minerals: feldspar alteration product (unknown), opaques
Texture: medium-coarse grained
Fabric / Foliation: none
Other features: quartz is relatively unaltered, while plagioclase is extensively altered.

Sample #: N4 - xy
Rock Type: mafic gneiss
Grade (if known): unknown, greenschist?
Location: Nain
Orientation of thin section: parallel foliation
Main minerals: 30% biotite (idio-subidioblastic)
20% plagioclase (xenoblastic)
20% quartz (xenoblastic)
10% amphibole (subidioblastic)
10% clino and orthopyrxene (subidioblastic)
5% epidote (xenoblastic)
Accessory Minerals: 5% opaques
Texture: medium grained porphyroclasts with finer grained qtz, epidote and opaques surrounding them
Fabric / Foliation: defined by oriented biotite laths, elongate cpx, opx, and amphibole
larger quartz grains somewhat elongate
Other features: slight crenulation visible
plagioclase shows straine twinning
amphibole rich layer with cpx / amphibole poor layer with biotite

Sample #: N5 - xy
Rock Type: hypersthene-quartz-feldspar granulite
Grade (if known): granulite?
Location: Nain
Orientation of thin section: parallel foliation
Main minerals: 70% hypersthene (xenoblastic)
20% quartz (xenoblastic)
10% feldspar (xenoblastic)
Accessory Minerals: limonite?
Texture: coarse-grained with med-grained groundmass of quartz and feldspar
Fabric / Foliation: not visible in thin section, was dificult to distinguish in hand sample
Other features: hypersthene quite altered, quartz unaltered

Sample #: N6 - xy
Rock Type: migmatite
Grade (if known): unknown
Location: Nain
Orientation of thin section: parallel foliation
Main minerals: 60% plagioclase (microcline) (xenoblastic)
25% quartz (xenoblastic)
10% biotite (subidioblastic)
5% chlorite (ubidioblastic)
Accessory Minerals: feldspar alteration product
Texture: fine-coarse grained
Fabric / Foliation: two zones: 1) plag + qtz + minor biotite
2) plag + qtz + (bio + chlorite in bands)
Other features: sample plagioclase grains quite altered

Sample #: N7 - xy
Rock Type: quartz diorite
Grade (if known): unknown
Location: Nain
Orientation of thin section: parallel folation
Main minerals: 50% ortho and clinopyroxene (anhedral)
20% orthoclase and plagioclase (anhedral)
20% quartz (anhedral)
5% biotite (sub-anhedral)
5% opaques
Accessory Minerals: minor chlorite
Texture: mediun grained (equidimensional)
Fabric / Foliation: defined by elongate pyroxene grains
Other features: none

Sample #: N8 - xy
Rock Type: biotite-quartz-feldspar gneiss
Grade (if known): greenschist?
Location: Nain
Orientation of thin section: parallel foliation
Main minerals: 50% quartz (xenoblastic)
30% biotite and muscovite (idio-subidioblastic)
20% plagioclase (xenoblastic)
Accessory Minerals: opaques
Texture: medium-grained

Fabric / Foliation: defined by individual granis and bands of oriented muscovite and biotite
Other features: schist-like

Sample #: N9
Rock Type: quartzite
Grade (if known): unaltered
Location: Nain
Orientation of thin section: unoriented
Main minerals: 50% quartz (anhedral)
40% feldspar (anhedral)
10% biotite (sub-euhedral)
Accessory Minerals: opaques
Texture: med-coarse grained
Fabric / Foliation: none
Other features: grain size of quartz much larger than that of plagioclase