PHASE 2
DRAFT ENVIRONMENTAL IMPACT STATEMENT

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Glossary and Abbreviations

Terminology used in this document is defined where it is first used. The following list will assist readers who may choose to review only portions of the document.

HBVB Hope Bay Volcanic Belt

Ma Mega-annum (million years)

Ga Giga-annum (billion years)

NRCan Natural Resources Canada

The Project Hope Bay Project

4. Geology

4.1 INTRODUCTION

In this section a description of the geology of the Hope Bay Volcanic Belt is provided, outlining the regional geological setting and evolution of the bedrock geology and surficial Quaternary geology. This is followed by a more detailed review and description of each of the three deposits found within the belt. These include the Boston, Doris and Madrid deposits.

4.2 EXISTING ENVIRONMENT AND BASELINE INFORMATION

4.2.1 Regional Setting

4.2.1.1 Bedrock Geology

The Hope Bay Volcanic Belt (HBVB) is a greenstone belt that is located in the northeast portion of the Slave Structural Province and represents one of many Archean age belts that characterise the Slave Structural Province (Figure 4.2-1). Greenstone belts of the Slave province are subdivided into mafic volcanic-dominated (Yellowknife-type) and felsic volcanic-dominated (Hackett River-type; Padgham 1985) and are intruded by felsic to intermediate plutons.

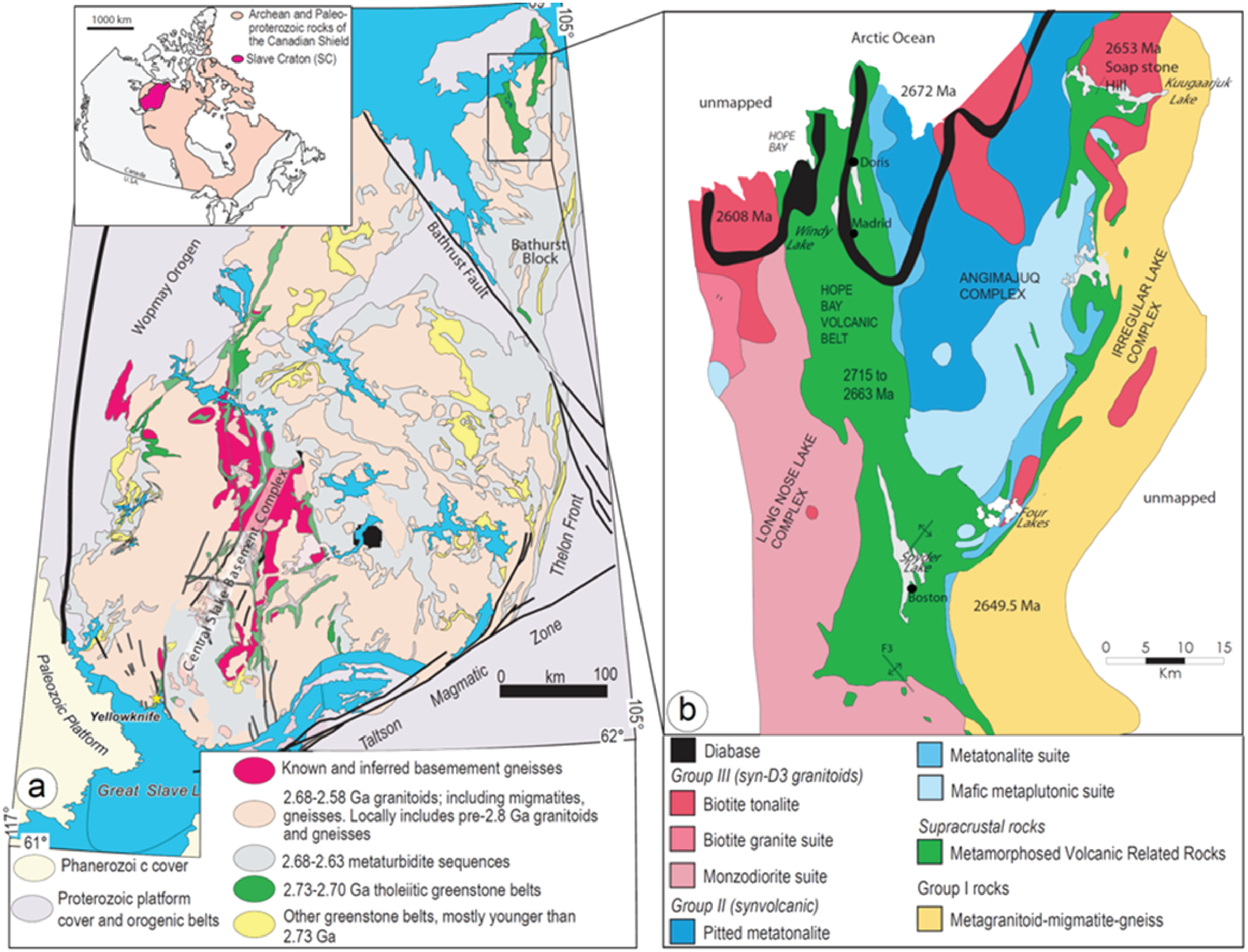
The HBVB is classified as a Yellowknife-type, typified by massive to pillowed tholeiitic flows interbedded with calc-alkaline felsic volcanic and volcaniclastic rocks, clastic sedimentary rocks, and rarely synvolcanic conglomerate and carbonates. Rifting and associated bimodal volcanism in the Slave province occurred between 2,715 Ma and 2,697 Ma (Davis and Bleeker 1999; Bleeker and Hall 2007) and was followed by widespread arc-like volcanism adjacent to and locally overlying the basements and volcanic cover at 2,687 Ma to 2,660 Ma (Henderson 1970; Bleeker and Hall 2007). This volcanic phase was followed at approximately 2,600 Ma by regional transtensional deformation resulting in north-south (N-S) trending folding, uplift and deposition of a series of fault bounded “Timiskaming-type” conglomerates and sandstones (Fyson and Helmsteadt 1988; Padgham 1996; Villeneuve and Relf 1998; Bleeker et al. 1999a, 1999b). The plutonic rocks that intrude the greenstone belts comprise 2.70 Ga to 2.64 Ga predeformation tonalite and diorite; 2.62 Ga to 2.59 Ga K-feldspar megacrystic granite, and post-deformation 2.60 Ga to 2.58 Ga two-mica granites (Villeneuve et al. 1997).

4.2.1.2 Quaternary Geology

Multiple Quaternary Ice Ages produced an extensive glaciated landscape that was covered by successive Laurentide ice sheets. The last Ice Sheet, which formed during the Late Wisconsin Glacial Episode, reached its climax approximately 25,000 to 21,000 years ago (Last Glacial Maximum) with ice flow directions towards the north-northwest and north. The Ice Sheet started receding about 8,800 years ago (Dyke and Prest 1986), melting back towards the southwest, leaving an extensive blanket of basal till. Immediately following the de-glaciation the entire Hope Bay region was submerged approximately 200 metres below present mean sea level (Dyke and Dredge 1989). Fine sediment, derived from meltwater (rock flour), was deposited onto the submerged Hope Bay shelf as marine clays and silts onto the basal tills. The greatest thicknesses accumulated in the deeper water zones, now represented by valleys.

Figure 4.2-1

Regional Geology of the Slave Structural Province and Simplified Geology of the Hope Bay Volcanic Belt



Isostatic rebound after the de-glaciation, resulted in emergent landforms and reworking of the unconsolidated marine sediments and tills along the prograding shoreface (EBA 1996). Sediments were easily stripped off the uplands and redeposited in valleys, leaving relatively continuous north-northwest trending bedrock ridges and elongate lakes. The unconsolidated overburden, now up to 30 m in thickness, comprises locally and regionally derived tills and boulder tills with lacustrine and marine sediments and clay up to 15 m thick in the larger valleys.

4.2.2 Local Setting

The Hope Bay Project area covers most of the land underlain by the HBVB and includes the Boston, Doris and Madrid deposits (Figure 4.2-2). Gold mineralization is variable in terms of mineralization style and relationship to the host volcanic sequences (Sherlock et al. 2012). The Boston deposit is located near the south end of the belt and is associated with a flexure in the Hope Bay regional structure. The Doris deposit consists of a steeply dipping, four kilometre long quartz vein system in folded and metamorphosed pillow basalts and is situated on an inferred inflexion in the regional Hope Bay Break.

The Madrid deposit, consists of three styles of veining and brecciation specific to the Matrim, Perrin, and Rand zones.

The Hope Bay belt, together with the Elu belt forms part of the Bathurst Block, a large area dominated by granitoids and gneissic migmatites that is isolated from the Slave province by Proterozoic platform cover of the Kilohibok Basin (Campbell and Cecile 1976; Figure 4.2-1). A granodiorite northeast of the Hope Bay belt gave a U-Pb zircon age of 2,672 +4/-1 Ma (Figure 4.2-1), suggesting a syn- to late-volcanic age of emplacement (Bevier and Gebert 1991). In contact with the southeastern belt (Figure 4.2-1) is a heterogeneous gneiss terrane that yielded a U-Pb zircon age of 2,649.5 +2.9/-2.5 Ma and a younger titanite age of 2,589 Ma, possibly representing a metamorphic age (Hebel 1999). To the northwest of the belt, plutonic rocks contain foliated mafic fragments at 2,608 ± 5 Ma. This places a lower limit on the age of deformation and metamorphism (Bevier and Gebert 1991), which is of lower greenschist facies within the belt and amphibolite facies near the belt margins. Structural geology of the belt is complex with three major ductile deformation events (D_1, D_2, and D_3) recognised (Sherlock et al. 2012). The earliest tectonic fabric, developed during D_1, is represented by an S_1 fabric that parallels the lithological layering, representing an early transposition fabric. This may contain isoclinal (F_1) folds with an S_1 axial planar fabric (Sherlock et al. 2012). S_1 is overprinted by an S_2 fabric with associated F_2 folds representing the D_2 deformation event. S_2 forms the dominant penetrative to spaced planar foliation in the belt, is generally oriented N-S, and commonly forms a composite $S_0/S_1/S_2$ transposition fabric (Sherlock et al. 2012). F_2 folds and associated mineral fold axis parallel stretching lineations, are steeply plunging. D_3 is recognised as a spaced, locally developed S_3 foliation associated with NE-SW trending domains that are axial planar to open F_3 upright folds.

As is typical of Archaen greenstone belts, a complex system of compressional structures are found within the Hope Bay Volcanic Belt (Figure 4.2-3). The structural architecture is dominated by a N-S trend, which parallels the greenstone belt and comprises a system of anastomosing Archean to Proterozoic structures. A series of mainly eastward directed thrusts are recognised as well as NE and SE structural trends.

Mineralisation is associated with D_2 structures and specifically N-S, S_2 parallel shear zones. These host auriferous quartz carbonate shear veins associated with widespread ion-bearing carbonate alteration developed as an ankerite-ferroan dolomite-sericite-pyrite assemblage. Shear zones range in width from 1 to 10 m and may extend for several kilometres (Sherlock et al. 2012). Evidence of late reactivation of the N-S shear zones has also been observed displacing the NE-trending Proterozoic diabase dykes (Sherlock et al. 2012) that cut the Archean stratigraphy (Figure 4.2-1). This was followed by a system of Late NE or NW striking brittle faults with a subvertical dip and normal displacement (Sherlock et al. 2012).

Figure 4.2-2

Geology Map of the Hope Bay Volcanic Belt

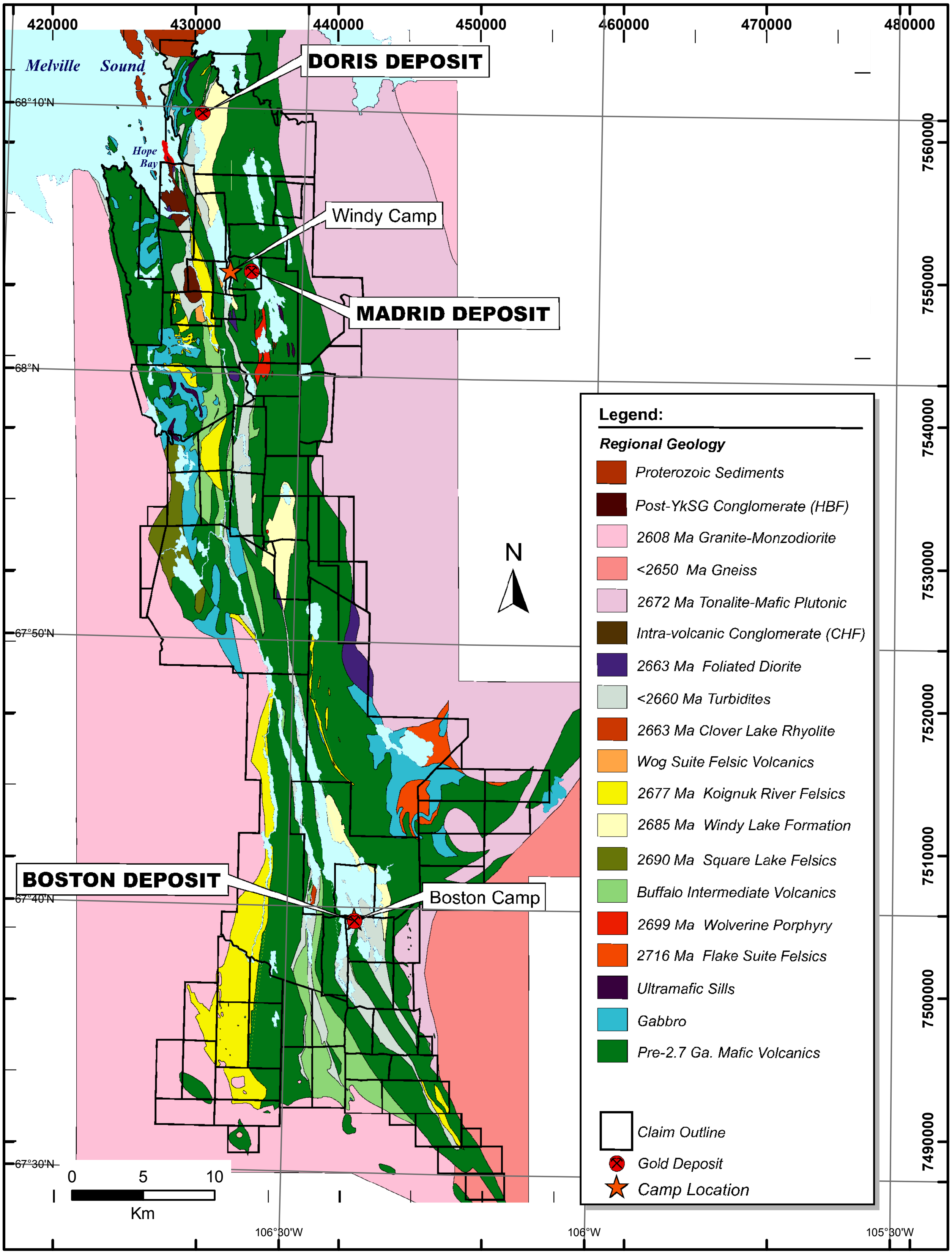
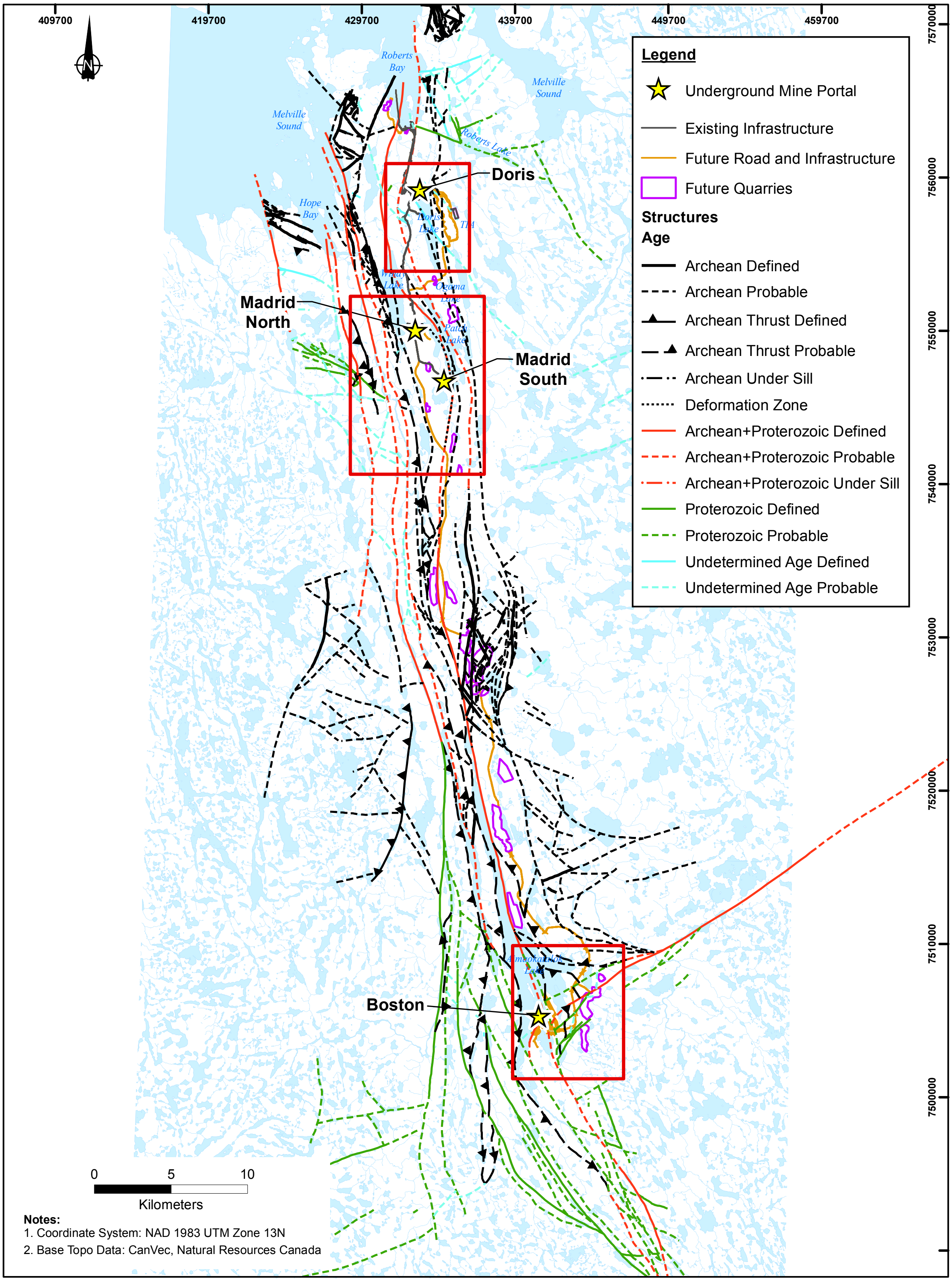


Figure 4.2-3

Regional Structures for the Hope Bay Volcanic Belt



Source: SRK, 2016.

4.2.3 Data Sources

4.2.3.1 Topographic, Bathymetric and Air Photograph Data

Baseline geological investigations rely on high precision terrain data, which include:

- Air photographs (stereopair images): These include the flightlines from July 1996 at a scale of 1:15,000 covering the Hope Bay area.
- Orthophotographs: These are available from 2002, 2007, and 2010 in monochrome and colour.
- Satellite data (Photosat): Coverage of the area at 50 cm resolution from 2012.
- LIDAR: Coverage of specific sites within the Hope Bay are available from 2007.
- Topographic maps: Bathymetry maps are available. Bathymetric surveys were undertaken in 2006 of Roberts Bay, Doris Lake, Tail Lake, Patch Lake, Aimaokatalok Lake and Windy Lake. Additional bathymetric surveys were undertaken in 2010 of Aimaokatalok Lake and Stickleback Lake. Bathymetry was also obtained for Wolverine Lake.
- Contour data utilized is from 2007 orthophoto data, generated by Aero Geometrics with a contour interval accuracy of approximately 1.0 m for the Boston area and approximately 0.5 m for the Madrid and Doris areas. Additionally digital elevation models for the entire belt are with 1 m resolution were obtained from satellite data (Photosat) in 2012.

4.2.3.2 Geophysical Data

The Hope Bay volcanic belt has seen extensive geophysical coverage (Table 4.2-1). This includes full coverage by aeromagnetic, gravity, and conductivity/resistivity data. Radiometric and ground magnetic data cover approximately one quarter and one third of the belt, respectively. Induced polarization (IP)/resistivity and seismic surveys have been completed on several prospects. Newmont had collated the data from earlier programs, and in many cases, re-processed the airborne magnetic and ground magnetic data.

Table 4.2-1. Historical Geophysical Surveys of the Hope Bay Greenstone Belt

Year	Survey Type	Survey Details	Contractor	Location
1993	GMAG	552 line-km, 20 km² variable 25 m and 50 m line spacing. 2 m sensor height	Contractor not specified	Boston, Patch, Fickleduck
1993	AMAG, DIGHEM, VLF, ARAD	2,657 line-km, 263 km² 100 m line spacing, 40 m sensor height	Geoterrex	Boston, Mid-belt Corridor, QSP
1993	AMAG, DIGHEM, VLF,	925 line-km, 168 km² variable 100 m and 200 m line spacing, 40 m sensor height	Geoterrex	QSP, Chicago, Barney
1994	GMAG, VLF	82 line-km, 4.0 km² 50 m line spacing, 2 m sensor height	Geoterrex	Kamik, South-West Patch
1994	AMAG, DIGHEM, VLF	3,328 line-km, 329 km², 100 m line spacing, 40 m sensor height	Geoterrex	Patch, Boston, North and Central Corridor
1995	GMAG, VLF	182 line-km, 8.8 km², 50 m line spacing, 2 m sensor height	Contractor not specified	Doris, Discovery, Boston
1995	AMAG, DIGHEM, VLF	4,700 line-km, 466 km², 100 m line spacing, 40 m sensor height	Geoterrex	Boston Region, North Doris
1995	AMAG, DIGHEM	477 line-km, 47 km², 100 m line spacing, 40 m sensor height	Geoterrex	Flake Lake

Year	Survey Type	Survey Details	Contractor	Location
1996	GMAG, VLF	287 line-km, 15.7 km², 50 m line spacing, 2 m sensor height	Contractor not specified	North and South Patch, Wolverine
1996	GMAG	1,235 line-km, 81 km², 50m line spacing, 2m sensor height	Clearview Geophysics	Boston, Chicago, Daiwa, Discovery, Doris
1996	GMAG	157 line-km, 7.7 km² 50 m line spacing, 2 m sensor height	Contractor not specified	Kamik
1997	AMAG	880 line-km, 43.5 km² 50 m line spacing, 40 m sensor height	High Sense Geophysics	Madrid Corridor
1997	GMAG, VLF	19.6 line-km, 1.3 km² 100 m line spacing, 2 m sensor height	Contractor not specified	South Doris, North Patch
1997	GMAG	130 line-km, 10 km²,75 m line spacing, 2 m sensor height	Contractor not specified	North-West Boston
1997	Seismic Refraction	5.2 line-km, 7.5 m data spacing	Frontier Geoscience	Various locations in the Mid-belt
1997	Seismic Reflection	43 line-km , 7.5 m data spacing	Frontier Geoscience	Doris/Aimaokatalok Lake
1998	AMAG	3,776 line-km, 188 km², 50 m line spacing, 40 m sensor height	Geoterrex	Boston, Flake Lake, Gas Cache,
1998	Seismic Refraction	2.5 line-km, 7.5 m data spacing	Frontier Geoscience	Boston Camp
2002	Seismic Refraction	11.6 line-km, 7.5 m data spacing	Frontier Geoscience	Nexus Area
2002	Seismic Reflection	56 line-km, 7.5 m data spacing	Frontier Geoscience	Windy/Patch Lake
2003	GMAG	30 line-km, 1.3 km², 50 m line spacing, 2 m sensor height	Aurora Geoscience	Inge
2003	Seismic Refraction	10.3 line-km, 7.5 m data spacing	Frontier Geoscience	Gas Cache
2005	Pole-Dipole IP	14.8 line-km, 100 m dipole spacing	Aurora Geoscience	Nexus, Naartok, Kink
2006	Pole-Dipole IP	31 line-km, 100 m dipole spacing	Aurora Geoscience	Havana, Patch, Peanut, Twin Peaks, Kink, Koig
2007	GMAG	3733 line-km, 91 km², 50 m line spacing, 2 m sensor height	Clearview Geophysics	Boston, Flying Squirrel, Windy Corridor
2008	Pole-Dipole IP (Titan-24)	12.5 line-km variable dipole spacing	Quantec Geoscience	Madrid/Boston
2008	Pole-Dipole IP (Conventional)	20 line-km, variable dipole spacing	Clearview Geophysics	Ak1, Ak3, Amarok
2009	Pole-Dipole IP	29 line-km, 100 m dipole spacing	Clearview Geophysics	Gas Cache, Kamik, Windy Lake, Kink
2009	Airborne assisted Ground Gravity	1,800 data points, 1,700 km², 1 km data spacing	Newmont Geophysics	Entire Hope Bay Belt
2011	Seismic Refraction	17 line-km, 7.5 m data spacing	Frontier Geoscience	Kink, Ogama, Main, Omayuk, Havana
2011	Pole-Dipole IP	5.5 line-km, 50 m dipole spacing	Aurora Geoscience	Omayuk, Peanut, QSP, North Tail
2011	Gradient IP	7 km²,100 m line spacing, 50 m dipole spacing	Aurora Geoscience	Omayuk, Peanut, QSP, Kink, North Tail
2011	AMAG/ARAD	2,865 line-km, 228 km², 100 m line spacing sensor height 40 m	Newmont Geophysics	6 blocks along the Belt margins

Source: Varley, F. NI 43-101 Technical Report on the Hope Bay Project, March 2015

4.2.3.3 Geological Mapping

- A mapping campaign was completed by BHP at a scale of 1:10,000 over the Boston 18 and 19 claims and extended to cover the entire project holdings by the end of 1998. Further detailed mapping at a 1:100 scale was done for the Boston underground mine.
- Miramar undertook 1:5,000 scale geological mapping over the Project area.
- Newmont conducted numerous mapping campaigns from 2008:
  - 1:25,000 scale structural, stratigraphic, metamorphic and metallogenic mapping over the entire Project area;
  - 1:10,000 scale regional structural, metamorphic, and geological mapping of selected geological targets;
  - 1:5,000 scale structural and prospect mapping of selected geochemical and geophysical targets;
  - 1:2,000 scale structural and prospect mapping of selected prospects;
  - 1:1,000 scale prospect mapping;
  - 1:50 scale detailed mapping.
- Surficial mapping on a regional scale, from air photographs in the Aimaokatalok Lake area was undertaken by J.M. Ryder and Associates for the University of British Columbia and BHP in 1992 (Ryder 1992).
- This was followed by more detailed surficial sediment and permafrost studies in 1996 by EBA Engineering Consultants of the Boston Gold Project.
- A surficial Quaternary geology map for the area is provided by Kerr and Knight (2001) surficial Geology, Koignuk River. Geological Survey of Canada Map 1998A, scale 1:125,000.
- SRK undertook an Overburden Characterization in 2009 documenting specific geotechnical investigations of onshore and offshore overburden conditions (SRK 2009a).

4.2.3.4 Geochemical Sampling

- BHP collected approximately 24,000 samples of glacial till during the period 1991 to 1998. In 1994, a study of the variability of the soil geochemistry was undertaken.
- Miramar collected 15,300 rock and till samples in the Doris, North Madrid, and Daiwa areas from 2000 to 2008.
- In 2008, Newmont compiled the existing geochemical data. In addition to the compilation, Newmont collected 7,149 rock and tillite samples. Data collated included whole rock, inductively-coupled plasma (ICP) analyses, and gold assay data.

4.2.3.5 Underground Sampling

- BHP conducted an underground exploration and bulk sampling program on the Boston deposit between 1996 and 1997 for detailed analysis of grade, recovery, and metallurgical characteristics.

4.2.3.6 Petrology, Mineralogical and Research Studies

A number of studies have been completed on the Project, including the following theses:

- Clark D. B. 1996. *The Geology of the Boston Deposit, Hope Bay volcanic belt, Northwest Territories, Canada*. Unpubl. MSc Thesis, Queens University, Ontario, 94 p.

- Hebel, M.U. 1999. *U-Pb Geochronology and Lithogeochemistry of the Hope Bay greenstone belt, Slave Structural Province, Northwest Territories, Canada*. Unpubl. M.Sc. thesis, University of British Columbia, 96 p.
- Stemler, J. U. 2000. *A Fluid Inclusion and Stable Isotopic Examination of the Boston greenstone belt Hosted Archean Lode-Gold Deposit, Hope Bay volcanic belt, Nunavut, Canada*. Unpubl. MSc Thesis, University of Alberta, Edmonton, 212 p.
- Shannon, A.J. 2008. *Volcanic Framework and Geochemical Evolution of the Archean Hope Bay greenstone belt, Nunavut, Canada*. Unpubl. M.Sc. thesis, University of British Columbia, 211 p.

4.2.3.7 Geotechnical and Hydrological Studies

- SRK provided geotechnical and hydrological assessments for the Boston, Madrid and Doris pit designs and underground development in 2009 (SRK 2009b; SRK 2009c; SRK 2009d).
- SRK conducted a rock mass characterisation study of the Doris portal combing surface mapping and drill hole data (SRK 2010).
- SRK conducted a hydrogeological study of the system for the Doris project (SRK 2011a).
- SRK provided a geotechnical and hydrological assessment for the Doris central and Connector Underground Mines in 2011b (SRK 2011b).

4.2.3.8 Drilling

- Since 1991, approximately 924,000 m has been drilled in 5,062 core and RC drill holes on the Project. Details of the various drilling programs are summarized in Table 4.2-2.

Table 4.2-2. Summary of Holes Drilled on the Hope Bay Project

Company	Years	No. of core holes	Metres drilled	No. of RC Holes	Metres drilled
BHP	Pre 1999	933	195,269	328	6,111
Miramar/ Cambiex JV	1999-2002	730	110,293	587	13,389
Hope Bay Maximus JV	2001-2009	58	9,536	-	-
Miramar	2003-2007	847	258,116	383	6,774
Newmont	2008 to date	873	212,617	108	15,081
TMAC	2013	63	29,622		
TMAC	2014	152	67,530		
Total		**3,656**	**882,983**	**1,406**	**41,354**

4.2.4 Boston Area

The Boston deposit is the larger of the known gold resources in the belt. Located in the south end of the greenstone belt, it is associated with an extensive Fe carbonate alteration system with a strike length of over 9 km. The country rock geology comprises a bimodal assemblage of mafic pillowed basalts that have been subdivided texturally and geochemically (Figure 4.2-4). These are overlain by a sedimentary succession of greywacke to argillite. The transitional zone between the two successions, comprising reworked mafic-dominated epiclastic rocks is the main host to the Boston deposit (Sherlock et al. 2012).