Safety Management Plan - Geotechnical Drilling Program		**Project Number: H352034**
	• Any other project safety responsibility issues?	Weekly progress meeting/reports
3. Risk Assessment and Management	• Has a risk assessment with representatives from the plant, subcontractors and other stakeholders in the project been held? If not, how will project hazards be identified?	BLY has prepared and will be reviewed with all site staff. Individual daily assessments will be conducted and reviewed at the pre-shift meetings.
	• Where are the results of the risk assessment documented? Is the level of documentation commensurate with the risks involved?	BLY has provided RA and safe work procedure which has been reviewed and accepted by Hatch.
	• What is the plan for managing and regularly reviewing the risks and documenting any additionally identified risks?	Pre-shift meeting will be used for risk review of the work activities and drilling locations. JHA's will be updated if major changes occur.
	• Is any other risk assessment required on this project? (e.g. HAZOP, CHAZOP, HAZAN?)	NA
	• How will changes in the construction process that might affect the health and safety of any person on the construction site be identified and communicated?	Pre-shift meeting will be used for risk review of the work activities and drilling locations. JHA's will be updated if major changes occur.
	• How will an emergency on site be handled? How will people be trained in these procedures?	Will use the existing BIM emergency procedures. Need to obtain a copy, assess applicability, make any necessary modifications and review with site Team.

Safety Management Plan - Geotechnical Drilling Program				Project Number: H352034
	• Any other risk management issues? e.g. do any national or state standards apply to any of the hazards identified?	Travel issues for specific drill locations off of the Tote Road.		
	Consider the other following commonly encountered hazards, indication whether they are an issue on this project and what measures will be taken or put in place to control the hazard:			
	Hazard Will project be exposed to hazard?	**Yes / No**	**Details**	**Control Measure(s) to be implemented**
	Existing services (including electrical, gas or fluid)	No		
	Flammable or toxic gases	Yes	Diesel fuel transport to drills.	Diesel fuel will be transported in closed and safe containers.
	Hazardous materials and dangerous goods (including presence of asbestos)	Yes	BLY	As stated in the BLY RA and procedures.
	Molten metals	No		
	Electrical	Yes	Portable generators.	As stated in the BLY RA and procedures.
	Fire safety	Yes	Portable heating equipment and fuel powered equipment.	As stated in the BLY RA and procedures.
	Internal road safety/ traffic control/ access and egress.	Yes	Tote Road Procedure and BIM Training for individuals driving on the Tote Road.	BIM Procedures and communication requirements, Training by BIM trainer. All other controls to be established in pre-shift meetings and JHA's.

Safety Management Plan - Geotechnical Drilling Program				Project Number: H352034
	Mobile equipment	Yes	BLY equipment and loaned BIM equipment.	BIM Procedures and communication requirements.
	Rail interactions	No		
	Overhead cranes	No		
	Isolations and stored energy.	Yes	BLY equipment	As stated in the BLY RA and procedures.
	Access to or working around .continuous plant	No		
	Manual handling.	Yes	Drill rods and cores and core boxes, handling tools and equipment.	As stated in the BLY RA and procedures.
	Work at heights.	Yes	Possibly required to access drill mast.	As stated in the BLY RA and procedures.
	Falling in (Excavations etc.) or falling on (overhead work/ loads).	No		
	Management of safety by contractors.	Yes	BLY with Hatch oversight.	
	Other interfaces with operations.	Yes	Tote Road use by Operations and Services.	BIM communication requirements.
	Other conditions on the construction site eg: lighting, security, disposal of waste.	Yes	Procedures to meet BIM requirements as stated by Environment. Weather conditions are evaluated on a shift basis – weather conditions reviewed and responsible Hatch site leads to monitor during the shift.	Hatch site leads responsible to shut down work due to weather conditions.

Safety Management Plan - Geotechnical Drilling Program				Project Number: H352034
	Commissioning	NA		

Of the hazards identified above and in the project risk studies, the top ten safety-related risks associated with the project are listed as follows. The list includes the control measures and the person responsible for ensuring that the measures are implemented. The list should consider all phases of the project including design, installation, erection and commissioning and handover to the owners of the plant. **(L = likelihood C=Consequence RR=Risk Rating Resp. = Responsible for control of the risk)**

Risk No.	Description	L	C	Raw RR	Controls	Resp.	L	C	Controlled RR
1	Hazardous materials and dangerous goods.	1	2	3	**MSDS and procedures, BLY with Hatch oversight.**	BLY	1	2	3
2	Electrical – portable generators.	2	2	4	**BLY Procedures and Grounding of portable generators.**	BLY	1	2	3
3	Fire Safety – portable heating equipment.	2	2	4	**BLY Procedures and MSDS.**	BLY	1	2	3
4	Internal road safety/ traffic control/ access and egress.	2	2	4	**Tote Road Procedure and Training for individuals driving on the Tote Road. All travel away from the Tote Road will be assessed and appropriate corrective actions applied.**	BLY/Hatch	1	2	3
5	Mobile equipment.	1	2	3	**BLY Procedures. BIM procedures for borrowed mobile equipment.**	BLY	1	2	3
6	Isolations and stored energy.	2	2	4	**BLY Procedures.**	BLY	1	2	3

Safety Management Plan - Geotechnical Drilling Program					**Project Number: H352034**				
7	Manual handling	1	2	3	**BLY Procedures.**	**BLY**	1	2	3
8	Work at heights	2	2	4	**BLY Procedures. BLY with Hatch oversight.**	**BLY**	1	2	3
9	Other interfaces with operations.	1	2	3	**BLY Procedures. BLY with Hatch oversight.**	**BLY**	1	2	3
10	Management of safety by contractors.	1	2	3	**BLY Procedures. BLY with Hatch oversight.**	**BLY/Hatch**	1	2	3
11	Other conditions on the construction site e.g.: lighting, security, disposal of waste.	1	2	3	**BLY Procedures. BLY with Hatch oversight.**	**BLY/Hatch**	1	2	3

4. Design	• How will you ensure that the safety hazards and risks (including those associated with the construction phase) will be communicated to the designers and considered through the design process?	**NA**
	• What process will be used to review and verify the design to ensure that the plant/equipment is safe, eliminates, minimizes or controls any OHS risks (including those during construction) and complies with appropriate legislation and standards?	**NA**
	• Does the project include items of plant for which the design or actual item of plant requires registration with government institutions?	**NA**
	• Any other safety related design issues? e.g. process for approving design changes; obtaining appropriate OHS information from suppliers of plant, equipment and materials; designers providing risks identified during design etc.	**Individual drill locations will be assessed for safety accessibility by BLY and supported by Hatch.**

Safety Management Plan - Geotechnical Drilling Program		Project Number: H352034
5. Occupational Health & Safety Training	• What are the minimum induction requirements for access to project site to ensure that work can be undertaken safely? (Tick box if required)	□ Legislative requirement □ Client Specific □ Dept./Hatch Induction (specify)___BIM Site Orientation________________ □ Project Specific Induction □ Other (specify): _BLY procedures and BIM procedures/training ______________________
	• How will records of attendance at inductions be kept?	**It will be reported in the weekly meetings/reports**
	• How will records of the type of induction training (including a description of the content of the training) be kept?	**NA**
	• How will you ensure that all personnel have been appropriately inducted before starting work?	**Review with contractor leadership.**
	• How will you ensure that visitors to the site are kept safe and made aware of any safety hazards?	**Visitors will be escorted**
	• How will you ensure that any additional training (required for safe performance of the work) necessitated by a change in the work site is identified and implemented?	**Pre-shift meetings will be used to detail any additional hazards and controls.**
	• Any other training or induction issues?	**NA**
6. Incident Management	• Who will be available to respond to any injury or illness?	**BLY site leadership supported by Hatch. BIM ERT for serious injuries or incidents.**

Safety Management Plan - Geotechnical Drilling Program		Project Number: H352034
	• What first aid facilities are available for the project site(s)?	**BLY remote FA Kit**
	• How will incidents be reported?	**BLY leadership to BIM safety**
	• Who will be responsible for investigating incidents and ensuring any corrective actions are followed up and completed?	**BLY leadership supported by Hatch**
	• How will any serious incidents be reported to Hatch management (or Legislative instances if required)?	**By Hatch Site staff**
	• How will records of incidents be kept?	**Records will be documented on a daily basis and included in weekly progress reports.**
7. Communication	• Where will the signs, containing the name and contact telephone numbers of the principal contractor, be located?	**NA**
	• Where will this safety management plan be kept to ensure that it is available to all people involved in working on the project (including those working on the work site(s))?	**Onsite with BLY leadership and Hatch.**
	• How will the project safety targets be communicated to all personnel involved with the project?	**Site orientation and reviewed in pre-shift meetings.**
	• How will the project safety rules be communicated so that all personnel involved with the project, including personnel on, and visitors to, the work site are made aware of them?	**Site orientation and reviewed in pre-shift meetings.**

Safety Management Plan - Geotechnical Drilling Program		Project Number: H352034
	• How will you ensure that sub-contractors or other service providers are provided with the relevant parts of the safety management plan before commencement of work?	**NA – no subcontractors.**
	• How will you ensure that any change to the safety management plan is communicated to project stakeholders including subcontractors and other service providers?	**Pre-shift meetings.**
	• How will you ensure that any changes to the work site likely to affect health and safety are quickly communicated to all affected personnel? (eg. daily pre-start/toolbox meetings)	**Pre-shift meetings.**
	• Other means to communicate safety matters among the project participants? e.g. safety committees, safety meetings, keeping records of all safety communication etc.	**All BIM safety information will be reviewed at Pre-shift meetings.**
8. Access Control and Work Clearance	• How will you restrict access to the work site(s) to people authorized to do so? (including members of the public)	**NA**
	• How will you ensure that other people in the area of the work site (e.g. adjacent operations facilities), or effected by activities on the site, are kept up to date with activities on the site?	**Drilling locations will be communicated in Baffinland daily toolbox memo.**
	• How will interactions with adjacent or effected sites and stakeholders be managed?	**NA**
	• What Personal Protective Equipment will be required to be worn on the work site(s)?	**BLY and Baffinland requirements and weather dependant.**

Safety Management Plan - Geotechnical Drilling Program		Project Number: H352034
	• Any other access or work clearance issues?	**NA**
9. Audits	• What systems will be used to ensure that project team members, subcontractors, other service providers will comply with this safety management plan and other site safety rules?	**BLY and Hatch site leadership.**
	• What types of audits will be conducted?	**Weekly visible felt leadership inspections.**
	• Who will be involved in audits?	**NA**
	• How often will they be done?	**NA**
	• Any other auditing issues?	**NA**
10. Safe Work Method Statements (for Job Hazard Analysis)	• How will you ensure that subcontractors provide job safety and environmental analysis (JHA), for all work activities assessed as having safety risks, before commencement of work?	**Hatch will oversee work activities based on JHA's.**
	• How will you ensure that the subcontractors comply with the JSEA they have provided?	**NA**
	• What action will be taken if the subcontractor does not comply with the JHA?	**NA**
	• How will you ensure that the JHA is promptly updated to reflect any changes in the way the work is planned to be carried out?	**NA**

Safety Management Plan - Geotechnical Drilling Program			Project Number: H352034
	• Any other issues regarding JHA?	NA	
11. Hazardous Materials Register	• How will you keep and maintain a record of the hazardous substances used during the course of the work? This register should include hazardous substances contained in pipes or vessels which are considered a hazard to the project.	**BLY Procedure and requirements.**	
	• How will you ensure the register is made accessible to all persons working at the work site?	**NA**	
	• Any other hazardous materials issues?	**NA**	
12. Review and Update of SMP	How will this plan be monitored, maintained and kept up to date during the course of the project? Who will be responsible for this?	**BLY and Hatch site leadership.**	
13. Other Issues	Off road travel, Emergency rescue availability – Stand-down work, Deteriorating weather conditions – decisions/communications, wildlife encounter.		

Safety Management Plan Prepared by:	Date Prepared:	Reviewed by Principal Contractor: Date: Oct 31, 2016
Warren R. Hoyle (signature) Warren Hoyle	2016-10-12	BLY Leadership Jarrett Campbell (signature) Principal Contractor Representative: Jarrett Campbell Position: Project Manager Signature (signature)

Job Hazard Analysis Form

PROJECT/TASK: ZG003 Geotechnical Marine Drilling Milne Inlet					**Department: Projects Boart Longyear**				**JOB No.:ZG003**
SUPERVISOR: Emile Beauchamp					**LOCATION: Future Ore Dock Milne Inlet**				**DATE: March 12 ,2017**
JOB STEP Break the job into steps. Listing work which may be hazardous.	**HAZARDS** List the hazard or type of harm identified with each step.	**Inherent** Consequence	Likelihood	Risk Ranking	**CONTROL MEASURE** List the necessary control measures to be followed to eliminate/reduce the identified hazards.	**Residual** Consequence	Likelihood	Risk Ranking	**ACTION** Person who will ensure this happens
1. Pre-job JHA Review.	Missing critical items on the JHA that can lead to an incident	3	2	5	Conduct a pre-job JHA review with Safety and critical team members All workers will have the opportunity to identify changes needed Any changes will be added to this document	1	1	2	Marlon Coakley/Warren Hoyle
2. Workers to complete FLRA card in the field at location prior to starting work.	Additional hazards in the area that may not have been identified on the JHA and daily changes that may pose additional danger to the health and safety of workers, the environment and property	3	3	6	Look at immediate work area for hazards that may exist, not identified on the JHA. Have other workers in the group sign off on the FLHA	1	1	2	All workers
3. Load Weights – The number and types of vehicles and equipment and their maximum gross weights	Not knowing load calculations will run the risk of breaking through the ice.	5	3	8	All equipment and material shall have posted GVW or gross equipment weight or maximum pull back loads available for use with load-ice thickness tables and shall follow the Ice Safety Plan. Refer to Attachment B for minimum ice thickness required for the drilling operations and Attachment C for further guidelines regarding Ice Safety	4	2	6	Warren Hoyle

4. General Site	Ice Conditions – Slip falls Ice Conditions – Adequate load bearing capacity Inadequate lighting Interaction with a Polar Bear Cold Whiteout conditions Emergency Procedures	3	2	5	Construct a working platform for outside of drill shack to store drill steel and allow the use of salt Use of traction aids on work boots will be required for work on ice surfaces. Apply salt to drill shack decks Engineered Assessment of minimum ice thickness as referenced in Attachment B for ice thickness required for the drilling operations and Attachment C for further guidelines regarding Ice Safety Place delineators in the snow marking access from the drilling location to the shoreline Existing Baffinland procedure "Safely Working On Fresh And Salt Water Ice" shall be followed Polar Bear Monitor will be available at all times Employees will have appropriate PPE including clothing available for safely working in -40 C and windy conditions Worksite location is approximately 300 meters from the shoreline. No work will be conducted in whiteout conditions and a safety shelter will be available immediately adjacent to the work area Site emergency procedures will be provided and reviewed at site	2	1	3	All Crew

5. Working around water and sea ice	Water may appear to be completely frozen over, but not enough to support persons Falling in water Equipment breaking through ice Workers unaware of potential dangerous conditions	5 5 4 3	1 1 2 1	6 6 6 4	Ice thickness to be assessed before walking on ice as per BIM Policy. Initial ice profiling will be conducted with an ice auger Floatation suit will be used for the initial ice profiling using an ice auger. Survival Bag (sleeping bag) will be available to reduce the risk of hyperthermia Follow the BIM Working On Ice Procedure (BAF-PH1-320-PRO-005, Rev 0, March 1, 2016) All workers will be required to complete the Alberta Working Safely on Ice Procedure online training	2	1	3	Marlon Coakley/Warren Hoyle
6. Drill testing for ice thickness	Water may appear to be completely frozen over, but not enough to support persons. Large ice cracks or crevices Falling in water Strains/Sprains Slipping on ice Drilling ice with power auger Changes in ice conditions	3	4	7	Traction aids will be used for any ice work Ice thickness to be assessed before walking on ice Floatation suits will be worn by workers while ice auguring, the worker is to be tethered to a primary rescue worker at a distance of 30m Snow must be removed at the hole location so ice can be examined for quality as described in the Ice field guide. Hand shovelling may be necessary If crevices/ cracks greater than 50% of the ice thickness are present, repairs must be made if there is risk of falling through ice into deep water	2	2	4	Warren Hoyle / Marlon Coakley

					Ice thickness for a person to walk on must be a minimum 13 cm. **STOP** all work if this condition is not met and return to shore. Be aware when using power ice auger that auger bit could bind or jam, have secure footing and grip on auger The ice auger hole spacing will be 20 m along the centreline access and the grid established in the designated work area. Secondary test holes will be augured at 10 m spacing within 250 m of the shoreline, if required based on the variable ice thickness Complete daily inspections of ice surfaces and record on ice log inspection sheet				
7. Access from Land to Sea Ice Snow removal equipment, drill rig and access vehicles are to be used for borehole access	Long distances to walk Exposure to cold White Out conditions Risk of falling under sea ice along the shoreline	4	1	5	Proper warm winter wear to be used Sat phones and digital radio use. Rig mats to be used to bridge over the fractured ice transition area if the transition between sea ice and shoreline needs leveling Buddy system is important to verify presence of frost bite or other cold related concerns **Vehicle operators and passengers are not to wear seat belts when working on ice**	1	1	2	All workers

8. Refueling of equipment	Fuel spills Regulatory or social impacts Spills into water bodies	3	2	5	Use of duck ponds with any refueling Have sufficient spill cleanup supplies on hand to respond to potential spills Maximize space between refueling vehicle	3	1	4	All workers
9. Extreme weather exposure when working outdoors or driving to and from the Borehole Location	Stranded work crew in white out conditions Cold emergencies or cold injuries Mechanical equipment failure	4	2	6	BIM has a procedure that is designed for white out conditions – it would be announced on the radio An emergency shelter to be used when in the Marine Drilling areas Emergency Shelter: Heated wooden shack (7' 8" by 7' 8") set on platform with skis Crews to radio from Hatch leads Buddy system to watch out for fellow workers who may not realize they are developing frost bite Workers to dress in arctic gear and layered clothing Proper PPE required Equipment check list Review Tidal charts on a daily basis Workers to take warm up breaks to stay warm and alert At toolbox review weather forecast with crew and prepare accordingly	2	1	3	All workers

10. Chemical handling- No unusual chemicals other than equipment needs are anticipated to be used.	Spills, leaks Chemical splash Chemical exposure	2	2	4	All products to be stored in secondary containment MSDS to supplied to BIM for review MSDS books to be accessible at the work front MSDS training and WHMIS training completed before arriving to site PPE will be followed as per MSDS recommendations as will first aid and environmental responses Spills response training and supplies to be kept with the equipment	1	1	2	Boart Longyear
11. Waste management and Wildlife Encounters	Risk of wildlife encounters due to improper waste controls Regulatory non compliance	3	2	5	Crews will collect waste daily and transport it back to camp Crews will follow BIM waste management guidelines No placing or storing of food in the back of pickup trucks Secure all small tools and PPE as foxes may carry away small articles from the site	2	2	4	All workers
12. Ecological and Cultural sensitive areas	Risk of causing damage to archeological areas Destroying vegetation Sensitive wildlife and marine life areas Regulatory and reputation damage	3	3	6	Crews have been instructed that there will be **NO** entry to the area east of the sealift ramp Crews are not to build or alter any inukshuk's or other rock formations on the tundra Permits will be required for the work	2	2	4	All personnel

13. Assemble Drill on skid platform skid and construct four walls and roofs	General hazards associated with drill assembly Inadequate communication between Boart Longyear and Site Services / mobile equipment operators	2	2	4	FLRA to be complete by Boart Longyear supervisor prior to executing work Boart Longyear Drilling operations SOPs to be followed including Boart Longyear Procedure 4001	1	1	2	Warren Hoyle / Marlon Coakley
14. Auguring holes in ice for sonic drilling and CPT work	Large ice cracks or crevices Falling in water Strains/Sprains Slipping on ice Drilling ice with power auger Changes in ice conditions	3	3	6	Wear traction aids for any ice work PFDs to be worn by workers while ice auguring during the sonic drilling and CPT operations Snow must be removed at the hole location so ice can be examined for quality. Hand shovelling may be necessary Be aware when using power ice auger that auger bit could bind or jam, have secure footing and grip on auger Complete daily inspections of ice surfaces and record on ice log inspection sheet All holes must be marked using an orange spray paint Any hole in ice over 30 cm in diameter must have a physical barrier around the hole	3	2	5	
15. Working around rotating equipment	Entanglement injuries	3	2	5	All equipment guards to be in place and in good working condition No loose clothing or drawstrings that can get pulled into rotating equipment Long hair must be contained to prevent entanglement into rotating equipment	2	1	3	All workers

					If any maintenance is required then energy isolation procedures to be followed				
16. Isolation of energy sources	Potential energy release that causes injury	3	2	5	All crews will follow the BIM Zero Energy State (ZES) procedure Crews to be given the BIM ZES training on site and fully understand the BIM requirements	1	1	2	Boart Longyear Crews BIM H&S
17. Working on equipment	Slip and trip hazards around railings, stairs and uneven ground.	2	2	4	Rails are installed around deck and to be properly maintained in good condition Stairs to be used on equipment A head cage will be used to reduce chance of contact with the rotating head Estops to be in good working order and easily accessible FLRA to be completed daily to review hazards All crews will follow the BIM Zero Energy State (ZES) procedure	1	1	2	Boart Longyear crew
18. Ice monitoring during drilling activities	Excessive deflection in ice	4	3	7	Hatch geotechs crew will monitor ice conditions during drilling including cracks around the work area, monitor freeboard in drilled holes for signs of ice deflection	2	2	4	All crew

19. Spotter activities	Equipment could come in contact with Spotter	4	2	6	Spotter to maintain eye contact with driver Spotter to review FLRA Agreed hand signals to be used with drivers in conjunction with BIM spotter procedure Agreed hand signals will be documented on the FLRA Drivers to immediately stop if the Spotter is out of eye contact	1	1	2	Boart Longyear crew
20. Manual lifting	Pinch point, back injuries, muscle and joint sprains and strains	2	3	5	Work in pairs, FLRA reviews Work with a buddy on heavy or awkward lifts Use proper lifting techniques 100 pound pipes to be handled by two workers	1	1	2	All crew
21. Working with pressure systems	Pressurized water and hydraulic fluids are used on drill and support equipment	3	2	5	Pre operational inspection Follow all safe work procedures. ZES when maintenance is required.	1	1	2	Boart Longyear crew
22. Falling objects	Potential exists for falling of drill rod and casing falling from overhead	3	2	5	Rigging and slinging training required when working with suspended loads and overhead hazards Perform FLRA	1	1	2	Boart Longyear Hatch Geotec EHS techs
23. High noise and vibration areas on the rigs	Hearing damage	2	2	4	Hearing protection is required by use of ear plugs or muffs.	2	1	3	Boart Longyear Hatch Geotec EHS techs

24. Housekeeping	Potential exists for poor housekeeping causing slip/trips and other hazards	3	2	5	Daily site assessments and toolbox meetings by drillers and site supervisors BIM EHS techs to perform daily inspections	2	2	4	All Crew
25. Fatigue	Potential exists for crew fatigue	2	2	4	Fit for duty confirmation required for all employees, daily FLRA reviews Micro breaks to stretch Proper rest during off shift period	1	1	2	All Crew
26. Working at night or 24 hour darkness	Higher risk of injury due to poor visibility	3	3	6	Hi-vis work gear to be used Use of flashlight and headlamp Workers to stay within 10 meters (30 feet) of the worksites at any time Use of wobble lights and light tower Emergency shelter	1	1	2	All Crew
27. Hot work - welding	Fire risk Burn injuries Welders Flash	2	2	4	Hot work training Use of hot work permits and JHA for any Hot Work Fire Watch required Proper PPE Welding training required	1	1	2	Boart Longyear crew

28. Rescue Plan	Rough terrain Further injuries to casualty during transit. Snow storm, white out conditions. Darkness	3	3	6	The track unit will be used to pull the survival shack (survival shack is 7' 8" x 7' 8" square) on platform with skis. When an incident has occurred, the Geotechnical Engineer must call a Code 1. Provide first aid treatment to the injured person until MRT arrives on site MRT will be dispatched to the location. MRT will transport the casualty. Visibility (whiteout conditions) will hinder rescue time, rescuers will have to wait out the storm, or until the whiteout conditions have subsided.	2	2	4	Marlon Coakley/ Warren Hoyle
29. Cleanup and Demob	Unfrozen open holes Complacency	3	3	6	All drill holes must be filled in with water and snow upon completion of drilling operations A Hatch site representative will confirm safe conditions upon demob All debris must be removed from ice surface and disposed off site per waste management plan BIM safety and environment representatives to attend a post project closeout inspection to document the completion of the clean-up	2	2	4	Boart Longyear

Comments:

Baffinland

Baffinland Iron Mines Corporation - Mary River Project - ERP
Job Hazard Analysis Form

Score	CONSEQUENCE		
	People	Plant	Environment
5 – Very High/ Catastrophic	Multiple Fatalities.	Greater than $10 Million Loss	Catastrophe, destruction of sensitive environment, worldwide attention. Likely EPA prosecution. More than 30 days delay.
4 – High/ Major	Fatality or Permanent Disabilities.	$1 Million to $10 Million Loss	Disaster, high levels of media attention, high cost of clean-up. Offsite environmental harm; more than 10 days delay.
3 – Moderate	Major Injuries – Incapacitations or requiring time of work.	$100 Thousand to $1 Million Loss	Major spills, onsite release, substantial environmental nuisance, more than 1day delay. (Leads to additional resources call out i.e. SES).
2 – Low/ Minor	Significant Injuries – Medical Treatments, non-permanent injury.	$10 Thousand to $100 Thousand Loss	Significant spills. (Leads to a call out of Site Emergency Response Group).
1 – Very Low/ Insignificant	Minor Injuries – First Aid Treatments (cuts/bruises).	Less than $10 Thousand Loss	Low environmental impact. Minor Spills less than 80 Litres.

Score	LIKELIHOOD
5 – Almost Certain	The event is expected to occur in most circumstances. Likely to occur frequently - More than 1 per year.
4 – Likely/ Probable	The event will probably occur in most circumstances. Likely to occur several times – 1 per year.
3 – Moderate/ Occasional	The event should occur at some time. Likely to occur at some time – 1 per 5 years.
2 – Remote/ Unlikely	The event could occur at some time. Unlikely but possible. 1 per 10 years.
1 – Rare/ Very Unlikely	The event may occur only in exceptional circumstances. Assumed it may not be experienced. 1 per 100 years.

Job Hazard Analysis Attendees: Darryl Finlay, Marlon Coakley, Warren Hoyle, Usman Khan, Alex Boissonneault

	Name	Signature	Date
Written by:	Marlon Coakley	Marlon Coakley	Mar 20/2017
Reviewed by:	Warren Hoyle (Hatch)	Warren Hoyle	March 20, 2017
	Darryl Finlay (BIM Safety Coordinator)	[signature]	March 20, 2017

Risk Rating = Consequence + Likelihood

Consequence	Risk Rating				
5	6	7	8	9	10
4	5	6	7	8	9
3	4	5	6	7	8
2	3	4	5	6	7

Risk Rating - Definitions

Risk Rating	Definitions	*Action Required*
8 - 10	Intolerable	Task not to start till the risk is eliminated or reduced. Bring to the immediate attention of management. Formal assessment required. MUST reduce the risk as a matter of priority.
7	High	Bring to the immediate attention of management. Task not to start till the risk is eliminated or reduced. Further Assessment required. MUST reduce the risk as a matter of priority.
6	Significant Risk	Bring to the attention of supervision. Review risks and ensure that they are reduced to as low as reasonably practicable. To be dealt with as soon as possible, preferably before the task commences. Introduce some form of hardware to control risk.
5	Moderate Risk	Needs to be controlled but not necessarily immediately, an action plan to control the risk should be drawn up. Review effectiveness of controls. Ensure responsibilities for

								control are specified.
1	2	3	4	5	6	2-4	Low Risk	If practical reduce the risk. Ensure personnel are competent to do the task. Manage by routing procedure. Monitor for change
	1	2	3	4	5	**A JHA considers a variety of activities/tasks involved in a job scope and analyses the key hazards (sources of harm) and their consequences (types of harm) eg. Sources of harm – lifting a heavy pipe - manual handling. Types of harm – Back strain.**		
	Likelihood							

Main Points – On how to write a JHA.

1. Define the task – what is to be done.
2. Review previous JHA if any – have we done it before?
3. Identify the steps – what is to be done.
4. Identify the hazards of each step.
5. Identify who or what could be harmed.
6. Give the task a risk rating – Consequence + Frequency
7. Develop solutions to eliminate or control hazards in each step.
8. Review the risk rating after the control system has been implemented.
9. If risk rating unacceptable review the solutions till risk rating acceptable.
10. Agree who will implement the control system.
11. Document the JHA and discuss with the relevant personnel.

Hierarchy of Hazard Management – Control Measures

These steps outline what should be planned for when deciding what control measures are to be put in place. Whenever possible the highest step should be used first and then progress down the list.

1. Eliminate the hazard.
2. Substitution.
3. Reducing the frequency of a hazardous task.
4. Enclosing the hazard.
5. Additional procedures.
6. Additional supervision.
7. Additional training.
8. Instructions / information.
9. Some personal protective equipment.

Worker / Visitor review	Signature
Warren Hoyle	Warren Hoyle March 19/2017
Marlon Coakley	Marlon Coakley March 19/2017
Usman Khan	[signature]
Alex Boissonneault	[signature] March 19, 2017
Emile Beauchamp	Emile Beauchamp March 19/2017
Samuel Flynn	[signature] March 19/2017
Ruben Gross	Ruben Gross MARCH 19/2017
Justin Gross	Justin Gross March 19/2017
Chris Entz	Chris Entz March 19/2017
Doug Roach	
Robbie Jordan	

Enclosed:

Attachment A – BIM Working on Ice Procedure
Attachment B – On Ice Platform for Geotechnical Drilling
Attachment C – Best Practice for Building and Working Safely on Ice Covers in Alberta
Attachment D – Ice Thickness Assessment
Attachment E – Ice Assessment Drawing

Appendix J
Geophysics Assessment

GEOPHYSICS GPR
INTERNATIONAL INC.

GEOPHYSICAL INVESTIGATION FOR BAFFINLAND RAILWAY, MARY RIVER PROJECT, NUNAVUT

Prepared for:
Baffinland Iron Mines Corporation

Presented to:
HATCH

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June 2017 T-17001

Project T17001-Revision#006 **April 2018**

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1 INTRODUCTION

Geophysics GPR International Inc. was requested by Hatch Ltd. to carry out a geophysical survey to aid in projection and planning of a proposed railway for the Mary River Project, Baffin Island, Nunavut.

The purpose of this investigation was to determine the depth to bedrock and to measure the thickness and extent of subsurface ice.

The seismic refraction and the ground penetrating radar (georadar) methods were applied to measure the depth to bedrock and the georadar method was applied to ice thickness measurements.

Data were collected from April 21st to May 2nd, 2017.

The investigation included the following:

1) Georadar mapping of subsurface ice at three sites approximately at Km 26, Km 47, and Km 76 along the proposed rail alignment.

2) Depth to bedrock measurements using the seismic refraction and georadar methods at seven sites in the limited access area ("Deviation area") of the proposed rail alignment (approximately from Km 63 to Km 68).

3) Depth to bedrock measurements using the seismic refraction method at the rail unloading area site at Milne Port.

4) Depth to bedrock measurements using the seismic refraction and georadar methods at the proposed rail alignment Km 4.5 site.

Figure 1 presents an overview map of the investigation area with the locations of the respective sites.

The following report describes the various aspects of the survey including field techniques, survey design, interpretation techniques, and finally an interpretation in the form of bedrock profiles and ice thickness maps.

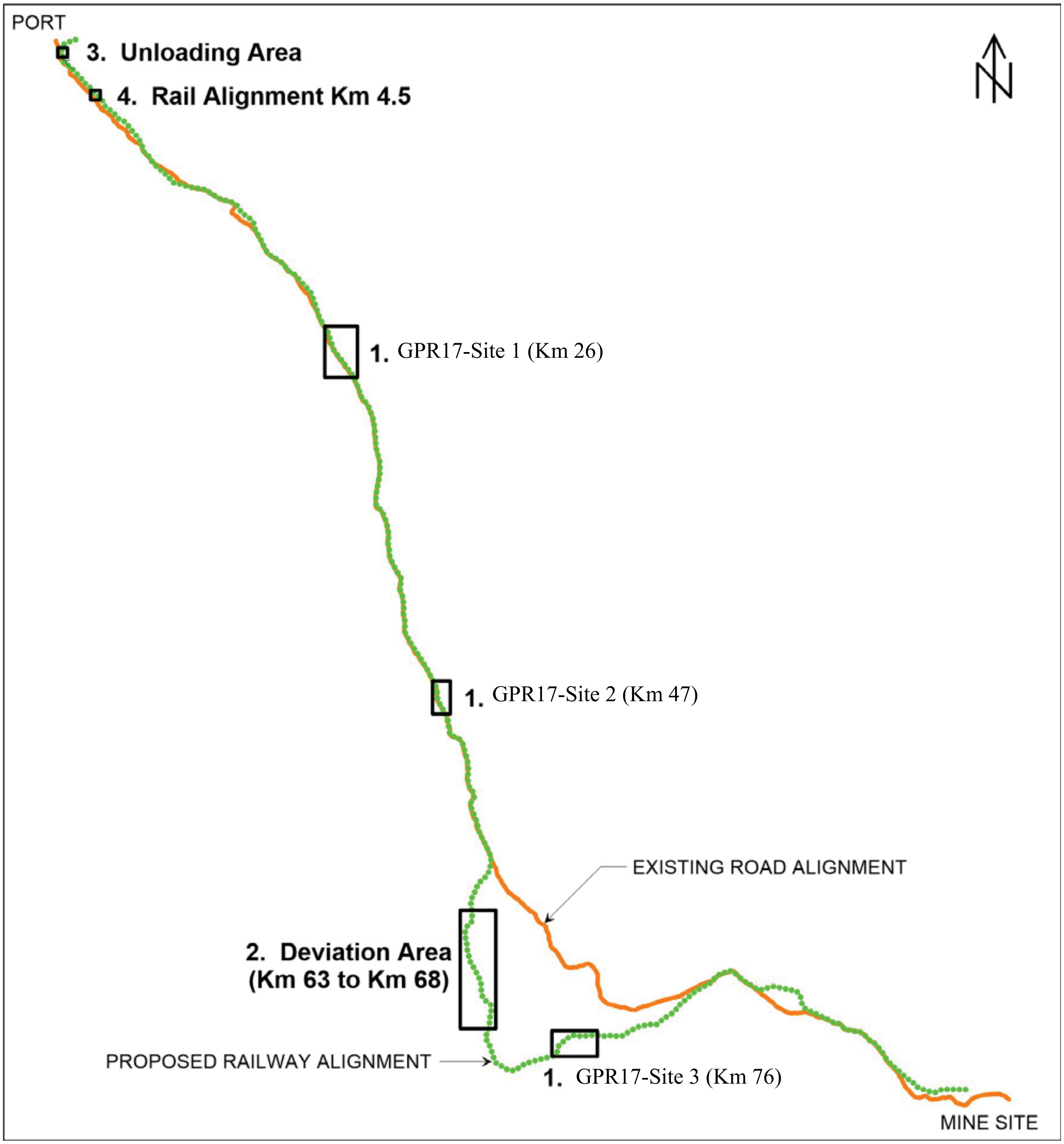


Figure 1: Overview map of the investigation area

2 METHODOLOGY

The Seismic Refraction and Georadar techniques were used for mapping the depth to bedrock. The Georadar method was used to determine ice thicknesses.

2.1 Positioning, Topography and Units of Measurement

The emplacement of the survey areas was determined by the client.

The locations of the georadar survey lines for the purpose of subsurface ice mapping were oriented to align with the design of the proposed railway. Length and number of the lines were chosen based on in-field interpretation of georadar data. Positioning was controlled by the GPS device integrated into the georadar antenna. The UTM coordinates should be accurate to within +/- 2.0 m.

Seismic data were collected along ten (10) profiles. Ground penetrating radar data for the purpose of bedrock mapping were collected along the seismic lines. Positioning was controlled by the georadar antenna built-in GPS and by a handheld GPS device. The beginning and end coordinates of the seismic lines are provided in Table 1.

Table 1: UTM coordinates of seismic lines

Area	Seismic Line	Start (0+00)		End (0+69)		Methodologies
		Easting	Northing	Easting	Northing	
Deviation Area	SL17-D1	527599.0	7919317.4	527599.9	7919386.2	Seismic, Radar
	SL17-D2	527857.7	7920710.1	527895.1	7920768.4	Seismic, Radar
	SL17-D3	527564.2	7922077.5	527527.9	7922137.9	Seismic, Radar
	SL17-D4	526825.1	7924354.0	526889.1	7924325.9	Seismic, Radar
	SL17-D5	526909.9	7924618.2	526929.1	7924684.4	Seismic, Radar
	SL17-D6	527259.7	7925605.9	527242.9	7925673.0	Seismic
	SL17-D7	527184.7	7925311.0	527207.9	7925376.7	Seismic, Radar
Unloading Area	SL17-M1	503783.5	7974922.0	503792.6	7974990.0	Seismic
	SL17-M2	503804.0	7974917.0	503816.1	7974985.0	Seismic
Km 4.5	SL17-R1	505743.6	7972485.5	505690.4	7972529.4	Seismic

The provided coordinates are NAD83/WGS84, UTM zone 17N.

The topography for the Unloading Area site has been estimated using field observations and borehole elevation data.

The depth measurements are noted as depth from surface.

All geophysical measurements were collected in SI units.

2.2 Ground Penetrating Radar (Georadar)

Basic Theory

Georadar utilises radar technology to obtain a near-continuous profile of the subsurface. The basic principle is to emit an electromagnetic impulse into the ground at a predetermined frequency rate (typically 10 to 80 scans/second). This pulse will travel through the sub-surface and reflect off boundaries of differing dielectric constants (contrasts of EM impedances). The reflected pulse returns to the surface and is recorded by a receiver and displayed in real-time as a cross-sectional image. Only by moving the antennas along a profile directly over the targets can the locations and depths be determined. Examples of radar reflecting boundaries include air/water (water table); water/earth (bathymetry); earth/metal, PVC, or concrete (pipe locating); and differing earth materials (stratigraphic profiles, including bedrock profiles).

The depth of investigation is controlled by the frequency and power of the antenna limited by attenuation and diffraction of the radar signal. Lower frequency antennas provide greater depth penetration at the expense of resolution. The radar signal is attenuated by conductive ground materials (e.g. clays, dissolved salts etc.). The radar signal is diffracted by irregular shaped material (e.g. boulders, debris etc.) that prevents the clear return of the reflected pulse.

More information on the georadar operating principle can be found in Appendix B.

Survey Design

The georadar data were collected with a MALA Ground Explorer system and 160 MHz antenna. This antennas is usually the most appropriate for resolution of stratigraphic layers at greater depths.

Positioning for the georadar survey was controlled by built-in GPS receiver.

For the bedrock mapping survey radar lines were collected along seismic profiles. Prior to data collection, test profiles were collected to determine the optimal time window and gain settings for the given subsurface conditions.

Interpretation Method

Processing of the radar images involved basic horizontal normalization, elevation corrections and gain adjustments.

The vertical scale on all radar images is a two-way time scale representing the time taken for a radar pulse to transmit to a reflector and back to the receiver. In order to convert the time scale to a depth scale a signal velocity must be applied. The velocity with which the pulse travels through the given material is determined by the dielectric constant. This dielectric will vary with the type of material.

Calculating a velocity can be done in many ways but the most reliable method is with a test pit or borehole where the real rock contact can be exposed. Based on in-situ measurements or borehole data, the dielectric value can be approximated depending on the expect material type. An underestimate of the dielectric will result in an over estimate of the signal velocity and in turn an over estimate of the depths. For this site a dielectric of 4 (velocity of 15 cm/ns) was assumed based on the expected soil type and tables of relative dielectric values for commonly encountered materials. In this case the materials were mostly frozen granular/boulders with high ice content. This velocity model showed good agreement with the borehole data and the estimated time-to-depth conversion error should not exceed 15% for this particular site.

Interpretation of the data is based primarily on the qualitative analysis of three characteristics of radar reflections: continuity, amplitude and shape. The interpreter then identifies reflectors and textures within the radar records that represent subsurface contacts, objects or zones. The true nature of the interpreted features can only be assumed without corroborating evidence.

Ice bodies have a distinctive appearance on radar images. Granular host material appears as "noise" on the images, whereas uniform ice layer looks transparent with clearly defined top and bottom contacts and can be confidently identified. An example of a uniform ice lens is presented in Figure 3.

Non-uniform ice bodies (stratified or containing layers of soil) are more challenging for interpretation since structure irregularities create multiple reflections within the ice body. Often a borehole is needed to confirm the presence of ice. Other features such as increasing depth of investigation in the presence of thick ice layer may corroborate the interpretation. Example of interpreted radar image illustrating the pattern created by non-uniform ice body is presented in Figure 4.

In summary, ability of georadar is limited by the structure of the ice layer being surveyed and its composition. The identification of an ice layer may be impacted by irregularities inside the ice body, such as layering, fractures and soil inclusions. However, it is possible to create two categories of ice lenses, the obvious and less obvious that may need some ground truthing.

2.3 Seismic Refraction

Basic Theory

The seismic refraction method relies on measuring the transit time of the wave that takes the shortest time to travel from the shot-point to each geophone. The fastest seismic waves are the compressional (P) or acoustic waves, where displaced particles oscillate in the direction of wave propagation. The energy that follows this first arrival (including reflected waves, transverse (S) waves and resonance) is not considered under routine seismic refraction interpretation. Figure 2 illustrates the basic operating principle for refraction surveys.

Survey Design

The seismic spread consisted of 24 vibration-monitoring devices (geophones) connected in line (spread) to a seismograph (ABEM Terraloc Mark 6). Spacing between geophones was 3 m for a total length of 69 m per spread. Seismic pulses (shots) were then generated at various locations with respect to the spread. Typically, six shots were executed per seismic spread: two shots on either side of the spread and two shots at a 'far' distance off either side of the spread (typically 45 m and 90 m). A sledgehammer was used as the primary energy source.

Interpretation Method and Accuracy of Results

Interpretation of the seismic data was primarily done using the Hawkins' method. The Hawkins' method allows the computation of the rock depth to every geophone. This method provides information on the thickness of the various overburden layers, depth to bedrock and rock quality. It is based on the closure times of the inner shots. It can calculate the true velocities of the rock using the apparent velocities, measured with information provided by the outer shots. A full description of the strengths and limitations of the refraction seismic method is presented in Appendix A. A basic description of the Hawkins' method can also be found in the article Seismic Refraction Surveys for Civil Engineering by L. Hawkins (1961).

The seismic refraction method typically allows the determination of the bedrock profile with a precision of 10% or better for depths greater than 10 m and a precision of 1 m for depths less than 10 m. The precision in the determination of rock velocities is plus or minus 3%. The vertical contacts (lateral velocity change), usually associated with faults and deep valleys, are generally accurate to within 5 m in width; although, this is somewhat site specific.

The two most significant problem areas for refraction mapping are the "hidden" layer and effect of velocity inversions. A "hidden" layer or "blind zone" is a stratigraphic layer that is not possible to discern from the arrival time data due to insufficient velocity variation or thickness. The unknown presence of a hidden layer has the effect of making the interpreted bedrock depth too shallow. The presence of a "hidden" layer is typically revealed through borehole or test-pit data and calculations can be made to compensate for the presence of such a layer. Without borehole or secondary bedrock depth information, it is not possible to predict the presence of a hidden layer.

Velocity inversions occur when the velocity does not increase with depth. The velocity inversion can result from the presence of a low or high velocity layer. Refractions from low-velocity layers cannot be determined from the arrival time data. The unknown presence of a low velocity layer has the effect of making the interpreted depths deeper than actual depths.

There is always the potential for "hidden" layers, although the likelihood is decreased for shallow sites. For this particular site the only possibility of velocity inversion is caused an unfrozen layer below permafrost, as the permafrost more easily transmits waves (~3000m/s) while the unfrozen layer transmits waves slower (1500-2000m/s). This results in a lower velocity after a higher velocity, resulting in the inversion.

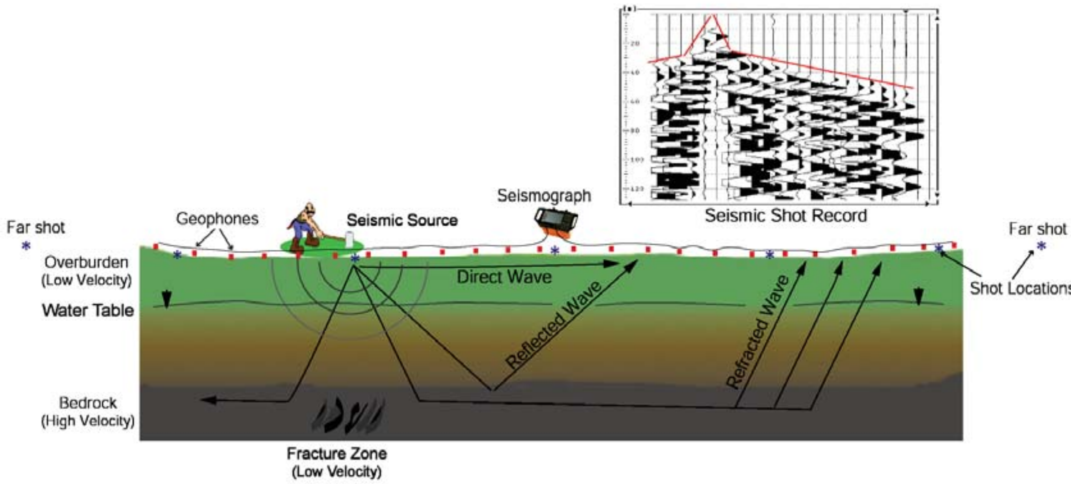


Figure 2: Seismic refraction operating principle

3 RESULTS

3.1 Subsurface Ice Mapping

Georadar data were collected at three sites approximately at Km 26, Km 47, and Km 76 along the proposed rail alignment.

Locations of the survey lines and results of the georadar survey are presented in drawings T17001-A2-1, T17001-A2-2, and T17001-A2-3.

GPR17-Site 1 (Km 26)

A long line 3300 m in length was collected from borehole BH16-R013 to borehole BH17-C004 to delineate potential ice bodies along the proposed rail alignment. The length of the line was chosen based on the borehole information. Eleven cut lines from 130 m to 410 m long were then collected to map ice extents east of the proposed railway. Scanning involved on-site data interpretation and length of the cut lines was controlled by the operator. Locations of the survey lines and results of the survey are presented in Drawing T17001-A2-1.

Distinct subsurface ice bodies were easy interpretable from the georadar images. Uniform ice was identified as a lens-shaped body with little to no signal return (reflection) from within its boundaries. Five separate ice formations were interpreted from the georadar data collected at GPR17-Site 1. Example georadar image showing a typical ice body is presented in Figure 3. The presented line is crossing interpreted ice lens #1 in NW–SE direction.

Drawing T17001-A2-1 provides ice thickness maps for each interpreted ice formation. Top of the ice layers was interpreted to be at a depth range of 1.5 m to 4 m. Ice extends to a maximum depth of 19.5 m below grade.

GPR17-Site 2 (Km 47)

The design of the survey was in general the same as at GPR17-Site 1. First a 1950 m long line was collected along the rail alignment passing the boreholes locations where the ground ice was encountered. Then eight cut lines from 80 m to 420 m long were collected to map ice extents east of the proposed railway. Locations of the survey lines and results of the survey are presented in Drawing T17001-A2-2.

Two ice formations were identified within the georadar data collected at GPR17-Site 2. The ice bodies on the georadar images were less well defined comparing to the data set at GPR17-Site 1. The interpretation was complicated by layered (stratified) ice structure that creates multiple reflections within the ice body. An example georadar image showing a fragment of ice body #2 is presented in Figure 4. The line crosses interpreted ice lens #2 in NW–SE direction. Borehole BH16-C011 is located at chainage 155 m of the presented line.

Drawing T17001-A2-2 provides ice thickness maps for each interpreted ice formation. Top of the ice layers was interpreted to be at a depth range of 1.1 m to 9.4 m. Ice extends to a maximum depth of 20.1 m below grade.

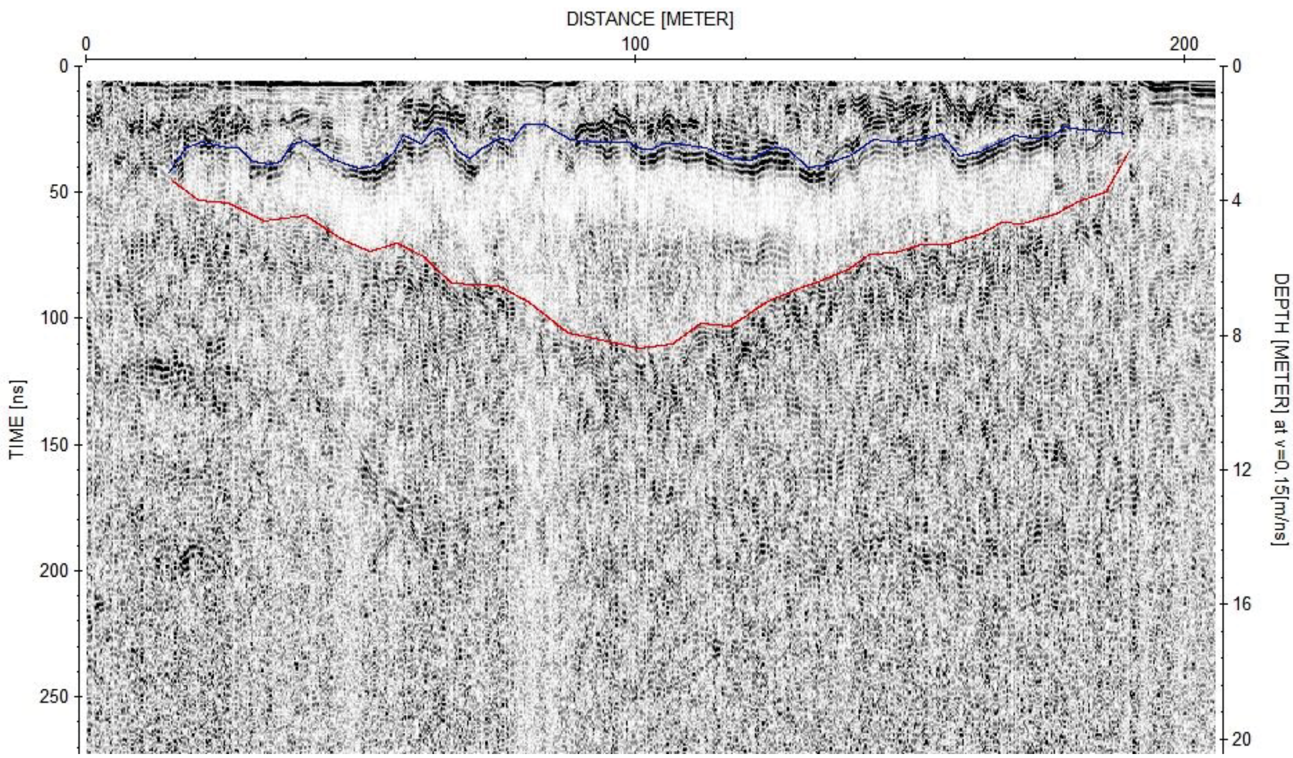


Figure 3: Interpreted georadar image showing a typical ice body at GPR17-Site 1

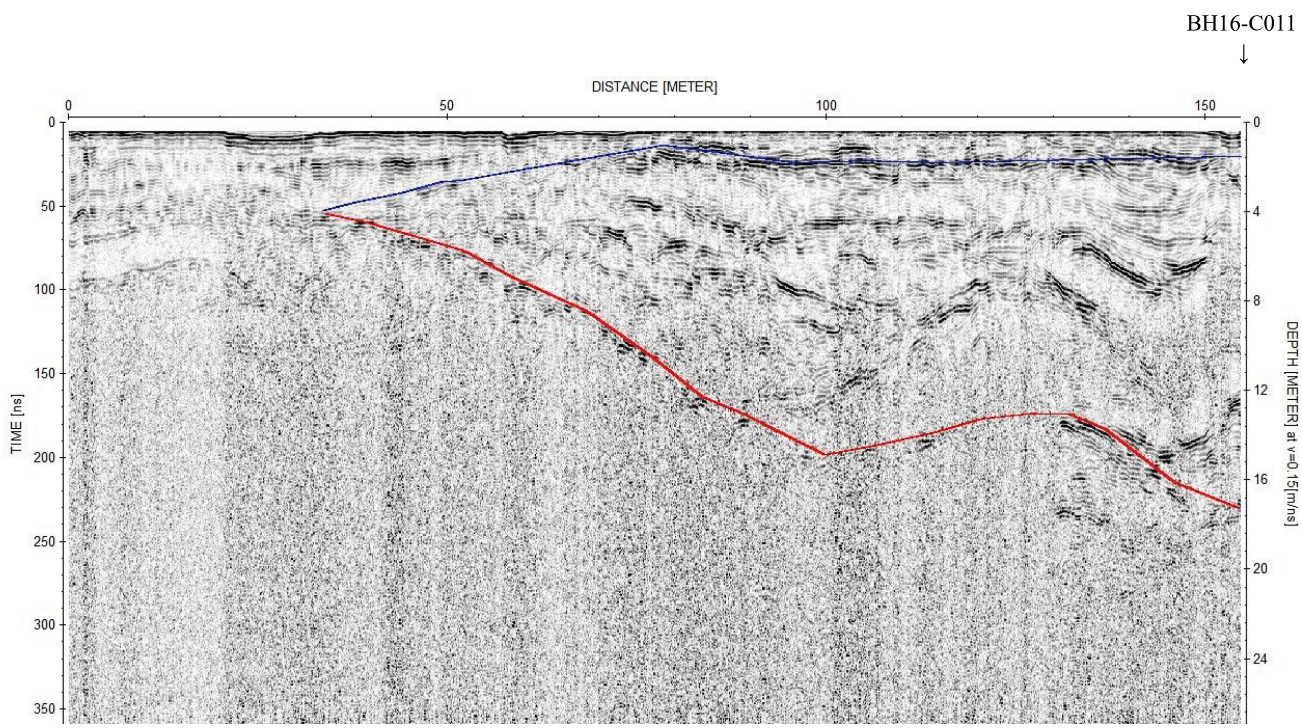


Figure 4: Interpreted georadar image showing a fragment of ice body # 2 at GPR17-Site 2.

GPR17-Site 3 (Km 76)

No large ice bodies were found within the geotechnical boreholes at this site, however, some ground ice and individual ice inclusions were encountered. A 3150 m long line was collected along the rail alignment from borehole BH17-C011 to borehole BH17-C013. Two ice lenses were identified within the data collected between boreholes BH17-C011 and BH17-C012. Two cut lines 460 m and 500 m long were then collected to map ice extents east and west of the proposed railway.

Locations of the survey lines and results of the survey including ice thickness maps for each interpreted ice formation are presented in Drawing T17001-A2-3. Of the two lenses interpreted from the georadar images at GPR17-Site 3 lens #1 was clearly identified as an ice body, whereas lens #2 was interpreted with a lesser level of confidence. The pattern on the radar images of the supposed ice lens #2 was similar to that observed at GPR17-Site 2, however, there is no borehole data to confirm that this formation contains ice.

Top of the ice layers was interpreted to be at a depth range of 1.2 m to 4.9 m. Ice extends to a maximum depth of 9.4 m below grade.

3.2 Deviation Area Bedrock Depth Mapping

A total of 7 sites were investigated at the Deviation Area of the proposed rail alignment. Initially it was presumed that the depth to bedrock should not exceed 10 meters and the survey methodology was chosen to ensure the depth of investigation approximately 20 meters below grade. The interpretation of the data proved that at 4 sites top of bedrock was deeper than the maximum investigation depth of the applied refraction technique.

Analysis of the complete data set collected for this project showed that the general compressional (P) wave velocity model consists of three layers.

The upper layer, with a velocity range of 1200 m/s to 3000 m/s, is interpreted as frozen active layer of overburden (layer with lower ice content). This layer extends from surface to a maximum depth of approximately 3.5 m below grade.

The second layer, with a velocity range of 3700 m/s to 5000 m/s, is interpreted as permafrost overburden. Higher velocity values for this layer imply higher boulder content.

The third layer, with a velocity range of 4700 m/s to 5900 m/s, is interpreted as bedrock. According to geotechnical investigation report provided by the client, from Km 0 approximately to Km 40 of the proposed railway the bedrock is granitic gneiss and from Km 40 to Km 90 the bedrock is limestone. Average measured P-wave velocities were approximately the same for both types of bedrock, with slightly lower values for limestone bedrock.

As it might be seen, there is an overlap in observed velocity ranges for permafrost overburden and bedrock complicating the interpretation of the refraction data and providing additional source of error. To help the interpretation two refraction lines at two different test sites with known bedrock depth were acquired. Test #1 was done above bedrock outcrop with less than 1 m to 1.5 m of overburden and test #2 was done at a borehole location with bedrock 5 to 7 m deep. The second test showed velocity range from 3500 m/s to 4000 m/s for permafrost overburden and both test showed velocity of 5700 m/s for limestone bedrock.

Interpretation of the Deviation area data set was done following these general considerations:

- The three-layer model described above. According to borehole data, the permafrost extends to a considerable depth and probability of a velocity inversion is low.
- The overburden permafrost velocities should not be at a higher end of the observed velocity range (4500 to 5000 m/s) as these values were only observed at sites close to the Milne Port with visibly higher large-size gneiss boulder content on the surface. The average permafrost overburden velocity measured at Deviation area sites was 3900 m/s.
- Velocities higher than 5000 m/s are expected for limestone bedrock.

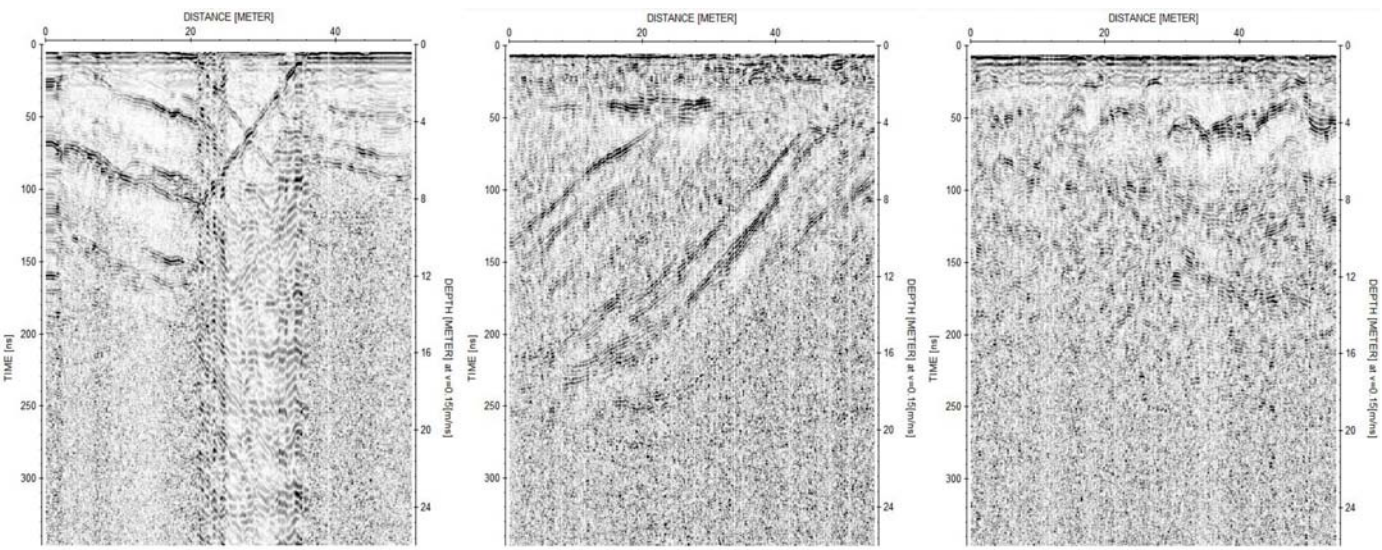
The radar data was also used in the refraction data interpretation. Analysis of the radar data collected at the Deviation area sites as well as at Km 47 showed that the limestone bedrock have a distinct pattern on the georadar images. It could be described as “parallel layering” appearing at the images as a series of parallel reflections. Figure 5 provides examples of georadar images showing limestone bedrock.

Locations of the survey lines and results of the survey are presented in Drawing T17001-A2-4. The drawing presents P-wave velocity models based on refraction data.

Bedrock was identified at 3 sites. At sites 1 and 6 bedrock depth ranged from 21 m to 26 m. At Site 6 (SL17-D6) depth to bedrock was calculated approximately as the interface was too deep to perform full reciprocal time analysis.

At Site 4 (SL17-D4) a shallow interface was interpreted with the layer velocity of 4700 m/s, which is borderline between permafrost overburden and bedrock. This interface was interpreted as bedrock contact as the georadar image taken at line SL17-D4 was the only one of the seven lines in the Deviation area which had the clear “parallel layering” pattern characteristic to limestone (Figure 5).

At sites 2, 3, 5, and 7 there was no indication of bedrock refraction on seismic records. Some calculations using the above described velocity model show that the bedrock at these locations should be more than 20 m deep.



Test Site #1 (outcropping bedrock) SL17-D4 SL17-D3

Figure 5: Example georadar images at Test Site #1 and SL17-D4 showing "parallel layering" pattern typical for limestone bedrock. Image SL17-D3 is typical for sites with deep bedrock contact.

3.3 Rail Unloading Area Bedrock Depth Mapping

Two seismic refraction lines were performed at the Rail Unloading Area to determine depth to bedrock. The seismic spreads were oriented perpendicular to the actual line of interest (which was the line from borehole BH16-M008 to borehole BH16-M007) due to a busy road crossing the line. Thus, depth to bedrock was determined at two points along the line of interest.

Position of the seismic lines and results of the survey in the form of bedrock profiles are presented in Drawing T17001-A3-1.

Three-layer velocity model described above was used for the interpretation. The upper layer, with a velocity range of 1800 m/s to 3000 m/s, extends from surface to a maximum depth of approximately 2.4 m below grade. The second layer interpreted as permafrost overburden has a velocity of 4300 m/s.

True bedrock P-wave velocities ranged from 5800 to 5900 m/s. Based on the refraction interpretation, the bedrock depth ranged approximately from 12 m to 19 m below grade for line SL17-M1, and approximately from 10.5 m to 12 m below grade for line SL17-M2.

The calculated depth to bedrock at intersections of the seismic profiles with the line of interest is 12.0 m for SL17-M1 and 10.9 m for SL17-M2. It should be noted that these values are not vertical distances from points on surface to bedrock interface, but rather shortest distances which will be different from vertical distances in case of dipping bedrock interface.

3.4 Bedrock Depth Mapping at Proposed Rail Alignment Km 4.5

One seismic refraction line and seven georadar lines were performed at the Proposed Rail Alignment Km 4.5 site for the purpose of bedrock depth mapping.

Position of the survey lines and results of the survey in the form of seismic velocity model and bedrock depth map are presented in Drawing T17001-A3-2.

Seismic refraction interpretation utilized the three-layer velocity model described above. The calculated bedrock depth ranged from 5.0 m to 6.5 m below grade.

Seven georadar lines from 50 m to 85 m long were collected with distance between lines ranging from 20 m to 40 m. Although bedrock contact was not always clearly apparent on the georadar images, corroboration of the georadar data by seismic refraction results allowed to identify bedrock reflection with higher level of confidence. Interpreted example georadar image taken at RL-4 can be seen in Drawing T17001-A3-2.

The interpreted bedrock depth from combined seismic and georadar data sets ranged from 3.0 m to 7.5 m below grade.

4 CONCLUSIONS

A geophysical investigation involving seismic and georadar methodologies was carried out at the Mary River Project, Baffin Island, Nunavut.

The seismic refraction and georadar methods were applied to measure the depth to bedrock and the georadar method was applied to ice thickness measurements.

Subsurface ice mapping was carried out at three sites along the proposed rail alignment. Results of the survey are presented in Drawings T17001-A2-1, T17001-A2-2, and T17001-A2-3 as ice layer extent and thickness maps. Overall georadar data quality was excellent. The subsurface ice was easily identifiable on most of the lines. Total of 9 lens-shaped ice bodies have been delineated. It is possible that these bodies have a high ice percentage. If there are formations with lower ice content and the ice presence is masked by the sand and gravel content it is not certain they can be delineated. However, with some ground truthing through boreholes it may be possible to create a second catagory of ice lense.

Bedrock depth mapping at the Deviation area of the rail alignment using seismic refraction and georadar methods proved the bedrock contact to be deeper than 20 m at all of the investigated sites with the exception of Site 4 (SL17-D4). The bedrock depths at Site 4 ranged from 2.5 m to 3.5 m below grade. Results of the survey are presented in Drawing T17001-A2-4 in form of P-wave velocity models.

Two seismic refraction lines were performed at the Rail Unloading Area to determine depth to bedrock between boreholes BH16-M008 and BH16-M007. Results of the survey in the form of bedrock profiles are presented in Drawing T17001-A3-1.

One seismic refraction line and series of parallel georadar lines were performed at the Proposed Rail Alignment Km 4.5 site to map bedrock depth. Results of the survey in the form of seismic velocity model and bedrock depth map are presented in Drawing T17001-A3-2. The interpreted bedrock depth from combined seismic and georadar data sets ranged from 3.0 m to 7.5 m below grade.

Interpretation of the geophysical data has been performed by Ilia Gusakov, GIT. This report has been written by Milan Situm, P.Geo.

Milan Situm, P.Geo.

Manager

APPENDIX A

Seismic Equipment and Methodology Fact Sheets

TERRALOC MK6 FEATURES

Great features in a small seismograph

The Terraloc mark 6 is a high resolution multi-channel seismograph with an 18-bit A/D converter and 3-bit instantaneous floating point (IFP) amplifier. Overall resolution is thus 21 bits. Its dynamic range, 126 dB, eliminates all gain setting hassles and satisfies the most stringent shallow reflection requirements.

7,8" full colour daylight-visible backlit display with VGA resolution
Armoured glass LCD protection
Sealed, Rugged aluminium case protects against weather and rough handling
sealed 1.44 MB 3.5" floppy drive
Numeric keyboard
Command keyboard

Added Terraloc advantages:

Great for tomography thanks to high sampling rates starting at 25 µs.

Usable with various energy sources (even mini-vabrators) thanks to long record lenghts, auxiliary source signature channel input and built-in correlation software.

provides sophisticated automation. Aversatile digital (TTL) interface (trigger IN/OUT,arming IN/OUT signals) makes it easy to connect several Terralocs and supports handshaking with vibrators and marine seismic energy sources.

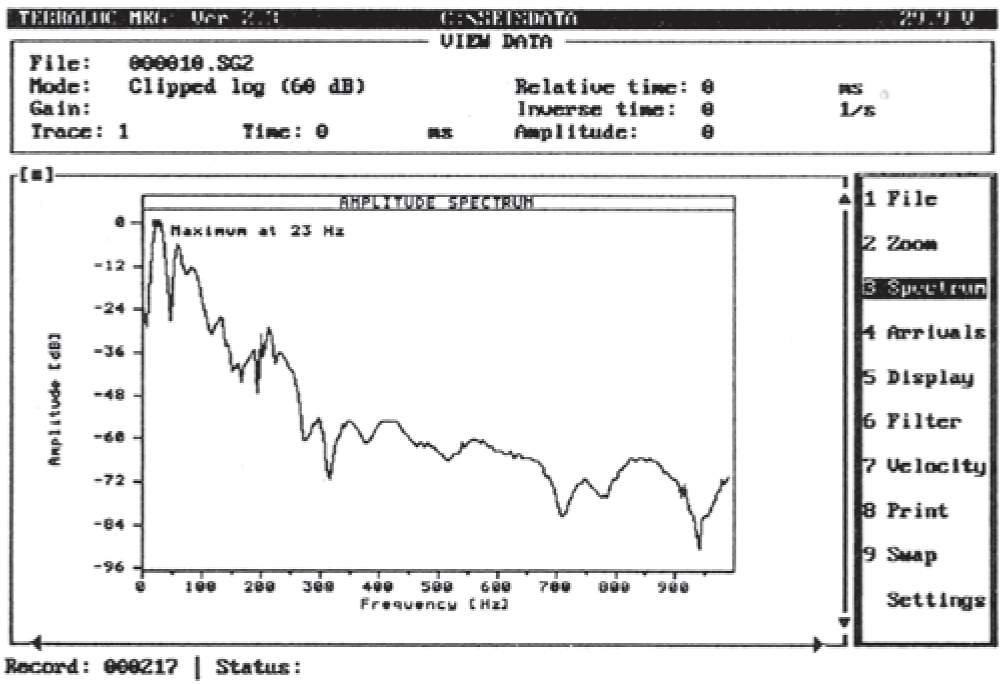
Ideal for refraction as well as shallow reflection seismics thanks to built-in roll-along function and a broad spectrum of analog and digital filters

In-field quality control. On-site geophone testing, cable testing and noise monitoring. Wide choice of multi- or single-trace view modes and frequency spectrum analysis (FFT)

Powerful computer

Fully compatible with your office computer thanks to MS-DOS 6.0 or higher, an internal hard disk, a built-in 1.44mb floppy disk, and compliance with the international SEG-2 format for storing of seismic traces and header information.

Interpretation software can be installed and run right in your Terraloc field unit.



Spectrum analysis helps you select the right filter, and it can also reveal soil properties

Lightweight and easy to use

The compact, lightweight Terraloc mark6 weighs only 16kg (24-channel version) and is less than half the size of its predecessor the popular Terraloc mark 3.

Carefully prepared, logically arranged documentation includes a copies of the operators manual (one for the field, and one to keep in the office), a user's manual for the computer , a complete description of the SEG-2 format and a service manual loaded with detailed technical information and schematics. Also included are a DOS manual and practice records to get you started.

Broad range of viewing provisions.

Scroll through records
Change display settings as desired
Select different time-scales
Select display mode
Select trace mode
Select AGC window length and set time and amplitude scale factors
Analyse single-trace frequency content (FFT)
Calculate refractor velocities
Analyse ground noise
Re-Scale traces individually
Create a geophone test report
Enlarge traces individually (Zoom)

Broad Printer support

The terraloc mark 6 supports a wide range of printers through dynamic link libraries (DLLs) via either the parallel or serial port and new printers can be added easily if required in the future.

Roll-along optimum offset

You can type in numerical values for roll-along start-trace, end-trace and step, you can roll along part of your receiver spread a step at a time . This feature is used in reflection surveys that include CDP stacking.

Expand your system

Two or more Mark 6's can easily be linked together to form a larger system. The print-out below is from a 96channel survey in which four 24-channel Terraloc's were connected

Technical Specifications for the Terraloc

- Number of channels (smaller unit)................. 4-24 in steps of 4
- Number of channels (larger unit).................... 4-48 in steps of 4
- Additional channels....................................... Easily obtained by linking two or more units together
- Up-hole channel.. Yes
- Sampling rate (selectable).............................. 25, 50, 100, 200, 500,1000 & 2000 µs
- Record length (selectable).............................. 128, 256, 512, 1024, 2048,4096, 8192 or 16384 samples per trace equivalent to: 3.2 ms - 32.7 s
- Pre-trig record (selectable)............................. 0-100 % of record length
- Pre stack correlation..................................... Yes, cross correlation with reference or any other channel
- Delay time .... Related to sampling rate May be set (for example) from: 0-0.8 s at 25 ps ,sampling rate 0-131 s at 2 ms sampling rate
- Stacking.. 32 bits, up to 999 impacts
- Unstack.. Remove last shot from stack
- First-arrivals picking.................................... Automatic or manual. Times can be saved with record
- Trigger inputs.. Trigger coil, make/brake, geophone, TTL
- A/D converter resolution.............................. 21 bits (18 bits plus 3-bit IFP)
- Dynamic range (theoretical/measured).......... 126 / 114 dB
- Max input signal... 500 mV p-p
- Frequency range.. 1 - 4000 Hz (at 25 ps sampling rate)
- Total harmonic distortion............................. - 80 dB
- Crosstalk... - 86 dB
- Input impedance.. 3 k
- Noise monitor.. Amplitude or full waveform display available on-line

Analog filters

- Low cut (selectable)... 12 or 24 dB/octave 16 steps from 12 to 240 Hz
- Notch.. 50 or 60 Hz specify when ordering
- Anti-aliasing.. set automatically based on sampling rate

Digital filters

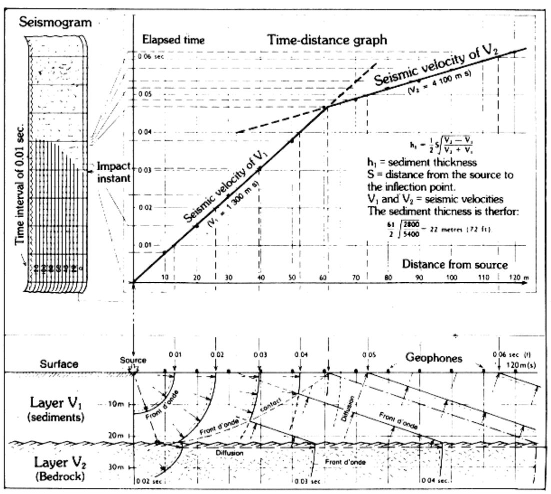
- Bandpass, low-cut, high-cut, bandreject, alpha-beta and remove DC offset Spectrum analysis...... Any single trace

GEOPHYSICS G P R INTERNATIONAL INC.

SEISMIC REFRACTION

Seismic refraction consists of recording the length of time taken for an artificially provoked surface vibration to propagate through the earth. By processing the data, the seismic velocities and depths of the underlying rock layers can be determined. These velocities are characteristic of the nature and quality of the bedrock; a fissured, fractured or sheared rock will be characterized by reduced seismic velocities.

The method is generally used to obtain a better geological analysis of the sub-surface and to determine the following characteristics: the quality, profile and depth of bedrock, its nature, degree of alteration and any other physical contrasts. Seismic refraction ensures that maximum information may be gained from geological field work, and that direct investment costs (drilling, excavation), will be reduced.



PRINCIPLE OF SEISMIC REFRACTION

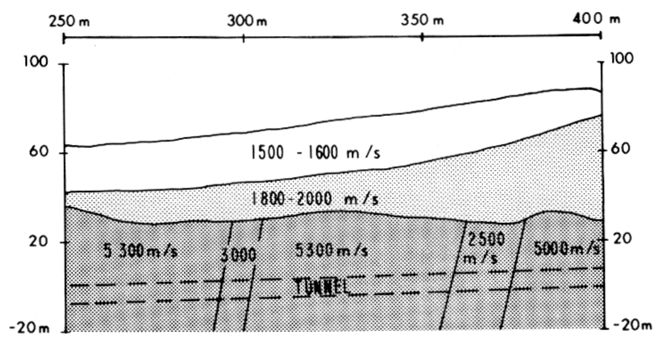
FEATURES

- Precise determination of soil thickness .
- Precise determination of the seismic velocities (rock type and quality).
- Localization and identification of geological units.
- Detailed analysis of soil.
- Year-round use.
- Sea and land surveys (above and below ground).
- Great accessibility possible to rough terrain and remote regions.

AREAS OF APPLICATION

Civil Engineering/Mining Exploration - Exploitation/Petroleum and Gas Sectors/ Geotechnology/Geology/ Hydrology.

- Identification of faults, fractures, shear zones.
- Detection of rock differences (veins, dykes, cavities, etc.).
- Determination of rock topography.
- Evaluation of volume of soil present or to be excavated.
- Excellent complement to geological mapping.
- Recognition of geophysical anomalies such as VLF, gravimetry, etc.
- Drill site selection, better target identification.
- Evaluation of the size, thickness and condition of surface shafts (mining exploitation).
- Mass Rock Quality Determination (MRQD).
- Detection of rock irregularities and breaks.
- Hydrogeology (detection of water tables, veins, reservoirs).
- Excellent complement to any geological analysis.



Interpretation results of a seismic profile

ADDITIONAL REMARKS

Geophysics GPR International Inc. has been recognized for the past fifteen years as a leader in both the application and the development of seismic methods. Seismic refraction is currently used in both civil and mining engineering; the use of lighter high-performance equipment and better tomographical interpretation of the results have contributed to its growing popularity.

GEOPHYSICS G P R INTERNATIONAL INC.

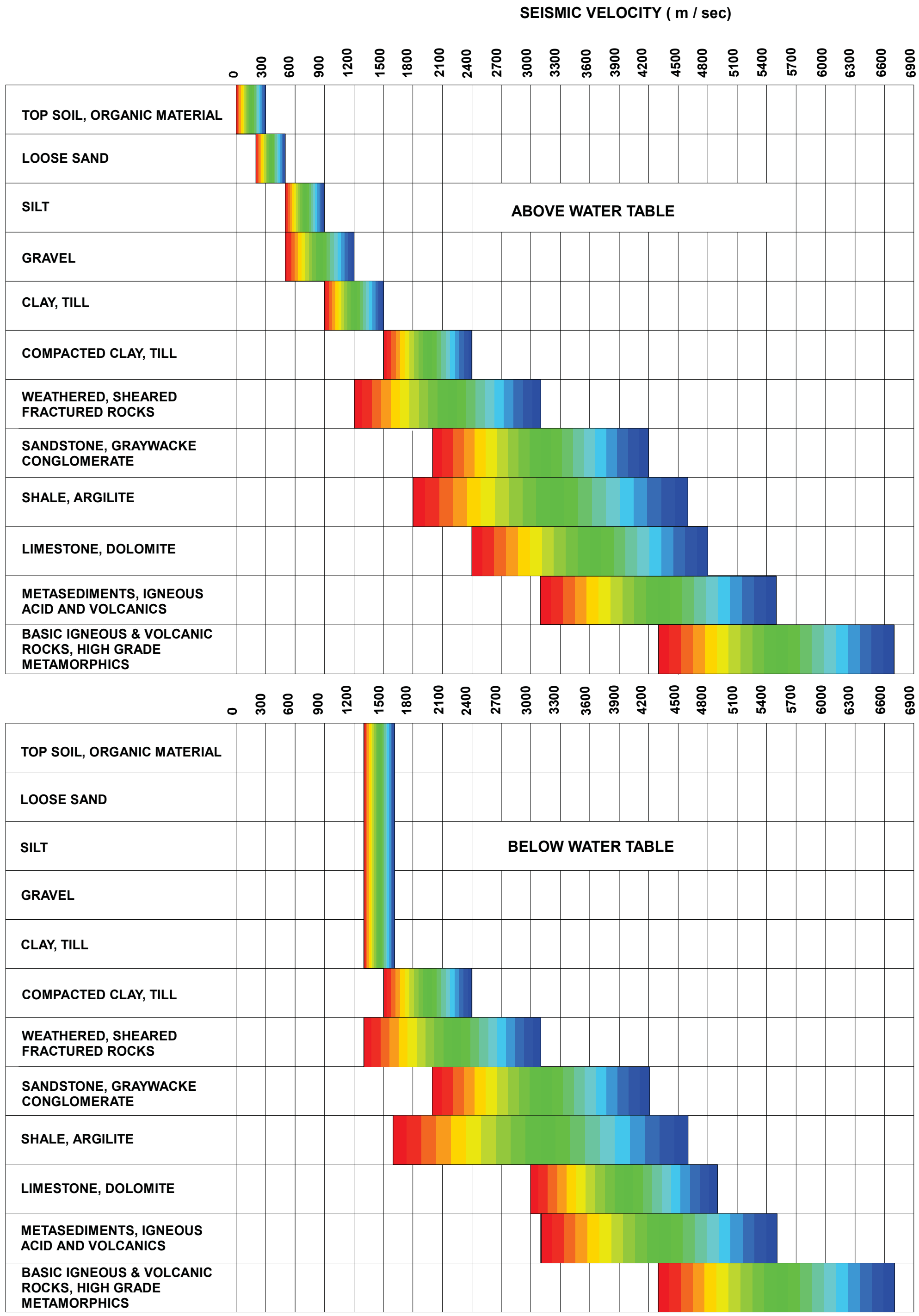
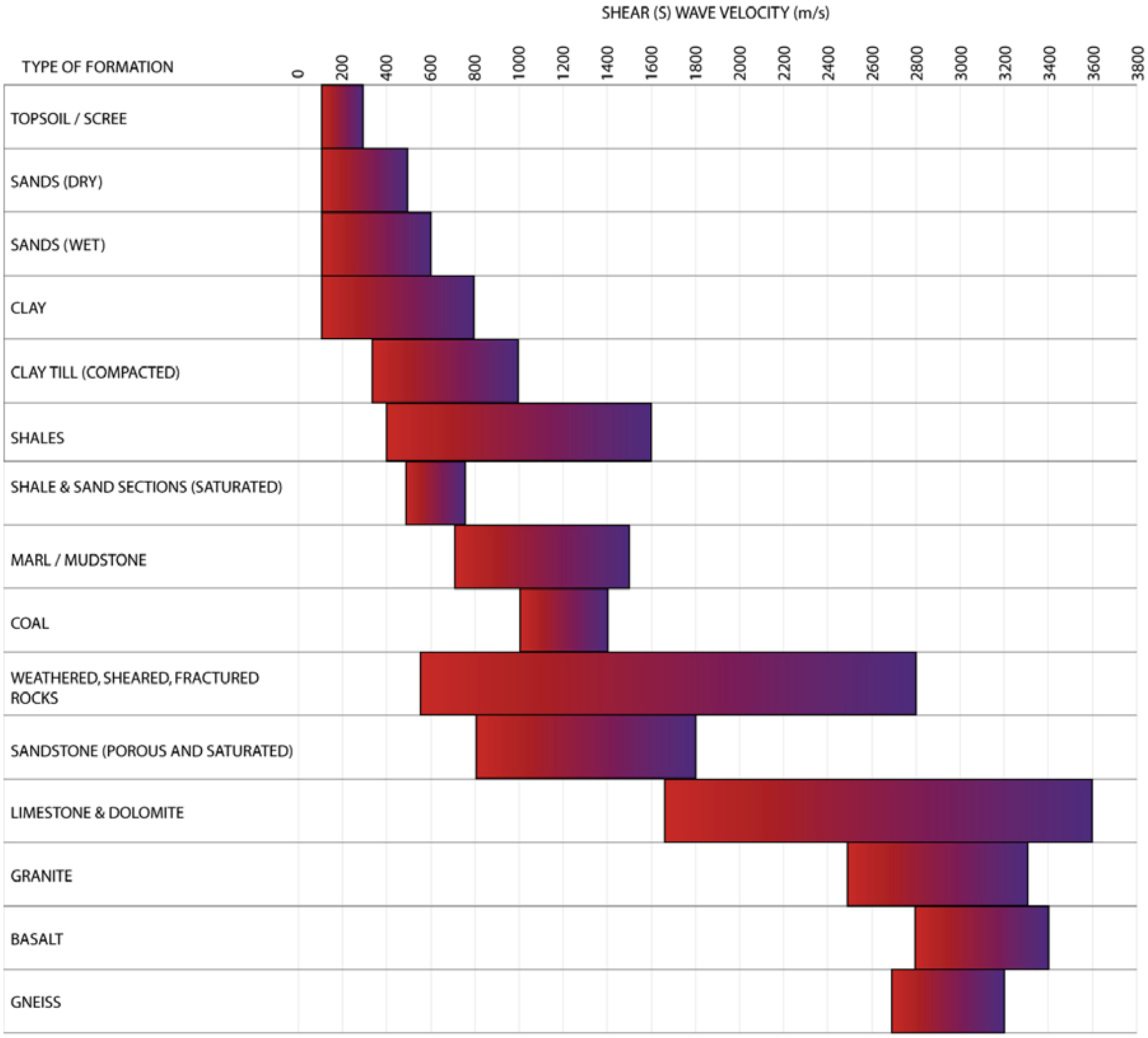


Figure 6: Classification of Geological Materials by Seismic Velocities

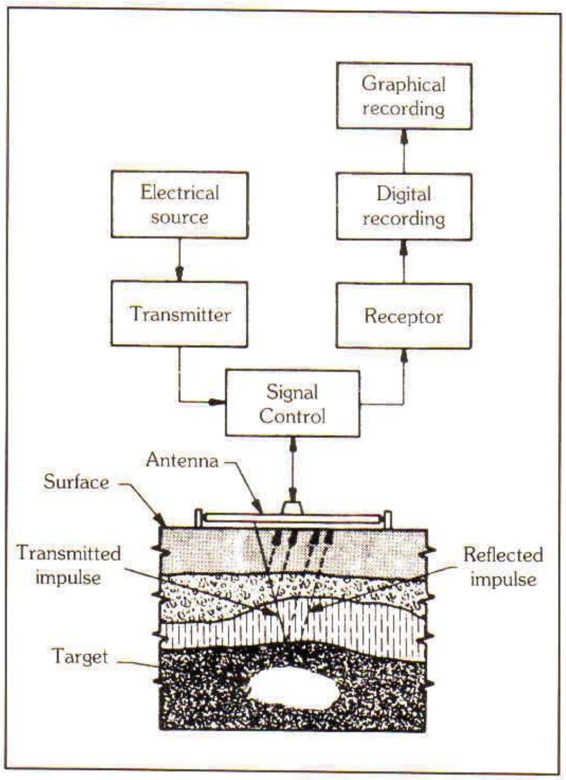


Typical rock velocities, Based on Bourbie, Coussy and Zinszner, Acoustics of Porous Media, 1987
with modifications by Geophysics GPR. Rev A.1 July 2011

Figure 7: S-wave velocities for given materials

GEORADAR

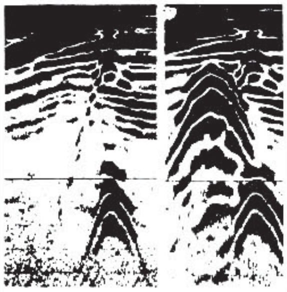
As indicated by its name, georadar combines high resolution radar with geology. The underlying principle is based on the propagation of electromagnetic wave impulses (VHF) that are reflected by anomalies in the terrain (joints, irregularities, interfaces, etc.) at different depths, and then captured by the antenna. The georadar records the time taken by each transmitted signal to complete the cycle in order to calculate the depth of the anomaly. The result is similar to a seismic reflection profile where all the reflections are displayed graphically. This technique is used to solve problems for which there had previously been no practical solution.



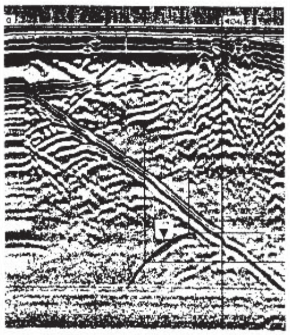
PRINCIPLES OF GEORADAR

FEATURES

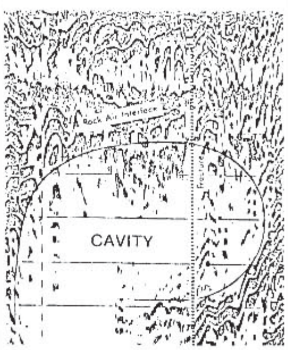
- Penetration of more than 20 metres in certain materials (penetration being inversely proportional to conductivity).
- Surveying in continuous mode.
- Identification of objects measuring only a few centimeters.
- Light and manoeuvrable equipment.
- Detection of conductivity, open spaces and/or holes (cavities).
- Detection of breaks: faults, fractures, joints, cavities.
- Results similar to seismic reflection: continuous underground profile.
- Results available immediately.
- Can be used in land, sea or airborne surveys.



PIPES



JOINTS



CAVITIES

FIELDS OF APPLICATION

Civil Engineering / Mining Exploration-Exploitation / Research / Archaeology / Environment

- Geotechnology: investigation of soils and surface deposits.
- Optimal selection of anchor bolts in mines and quarries.
- Detection of buried pipes before beginning excavation.
- Detection of liquid or gas leakage in soils.
- Detection of cracks in concrete structures.
- Checking material homogeneity.
- Detection of cavities beneath road pavement.
- Determination of water saturation level.
- Detection of girders in reinforced concrete.
- Detection of pollutant leakage in water bodies.
- Inspection of buried disposal sites and or dangerous deposits.
- Continuous measurement of ice thickness.
- Archaeological research: ancient foundations, artifacts.
- Non-destructive method for measuring road pavement thickness.
- Localization and measurement of soil's thickness (swamps, peat bogs).
- Determination of rock beddings (location and thickness).
- Bathymetric studies (depth sounding).
- Calculation of the thickness of permafrost and ice.
- Geotechnical studies for the installation of aqueducts.

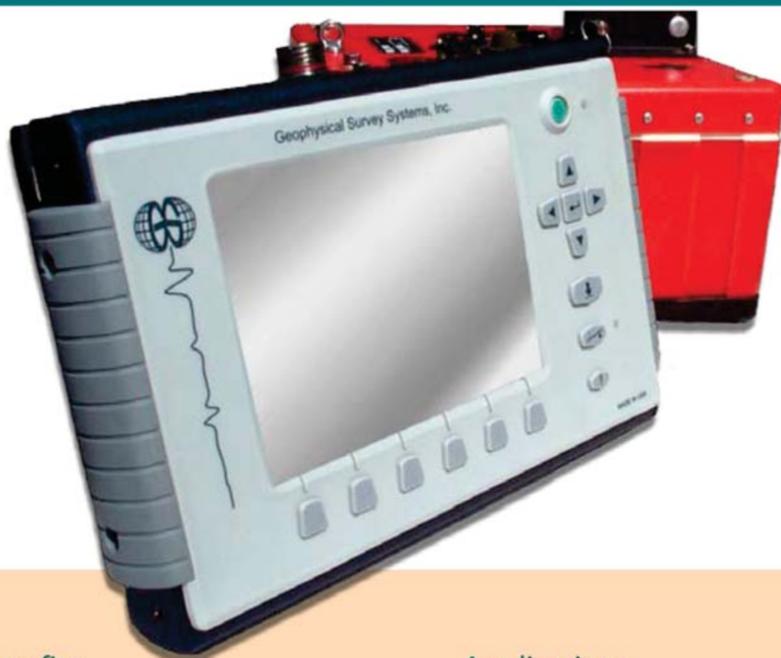
SPECIAL FEATURES

The equipment is practical, easy to manoeuvre, and multi-faceted. The field of application of georadar continues to expand in various sectors, particularly in geotechnology (aqueducts), civil engineering (excavation, structures) and mining (structures).

GEOPHYSICS G P R INTERNATIONAL INC.

SIR-3000 System by GSSI

Rugged, high-performance
GPR data acquisition system



Benefits

- Rugged, lightweight, hand-held and portable
- User-friendly
- High-resolution screen—easy to read in daylight
- Large data storage capacity
- Compatible with all GSSI ground-coupled antennas
- Built with pride in the U.S.A.

Applications

Concrete Inspection
Utility Mapping
Bridge Deck Inspection
Geological Investigation
Archaeology
Forensics/Law Enforcement
Snow/Ice Thickness Measurement
Research

GSSI The World Leader in Subsurface Imaging™

Geophysical Survey Systems, Inc.
www.geophysical.com

APPENDIX B

Georadar Fact Sheet and Equipment

SIR-3000 System Specifications

System

Antennas:
Compatible with all GSSI ground-coupled antennas

Number of Channels: 1 (one)

Data Storage:
Internal memory: 1 GB Flash memory card

Compact Flash port: Accepts industry standard CF memory up to 2 GB (user provided)

Processor: 32-bit Intel StrongArm™ RISC processor @ 206 MHz

Display: Enhanced 8.4" TFT, 800 x 600 resolution, 64K colors

Display Modes: Linescan, O-scope, 3D

Data Acquisition

Data Format: RADAN (dzt)

Scan Rate Examples:
220 scans/sec at 256 samples/scan, 16 bit
120 scans/sec at 512 samples/scan, 16 bit

Sample size: 8-bit or 16-bit, user-selectable

Scan Interval: User-selectable

Number of samples per scan:
256, 512, 1024, 2048, 4096, 8192

Operating Modes:
Free run, survey wheel, point mode

Time Range:
0-8,000 nanoseconds full scale, user-selectable

Gain: Manual or automatic, 1-5 gain points (-20 to +80 dB)

Filters:
Vertical: Low-Pass and High-Pass IIR and FIR
Horizontal: Stacking, Background Removal

Operating

Operating Temperature:
-10°C to 40°C ambient

Charging Power Requirements:
15 V DC, 4 amps

Battery: 10.8 V DC, internal

Transmit Rate: Up to 100 KHz

Input/Output

Available Ports:
Antenna input
DC power input
Serial RS232 (GPS port)
Compact Flash memory
USB master and slave

Mechanical

Dimensions:
31.5 (L) x 22 (W) x 10.5 (H) cm
12.4" x 8.7" x 4.1"

Weight: 4.1 kg, (9 lbs) including battery

Environmental: Water resistant

System Includes:

- SIR-3000 data acquisition system
- Transit case
- 2 batteries
- Battery charger
- AC adapter (also works as charger)
- User manual
- Sunshade
- Carrying harness (optional)

Antennas and antenna control cables sold separately

FCC Compliant

13 Klein Drive, PO Box 97
North Salem, NH 03073-0097
Tel: (603) 893-1109 Fax: (603) 889-3984
Sales@Geophysical.com

GSSI
Geophysical Survey Systems, Inc.
www.geophysical.com

 December, 2005

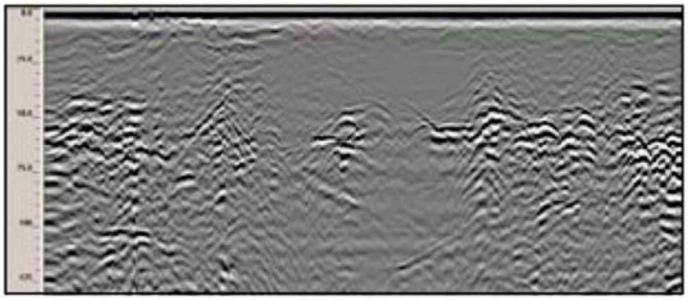
Antennas

Model 5104 - 270MHz

Utility Detection and Mapping
Engineering/Environmental
Geotechnical

The Model 5104 is suited for deeper utility, engineering and geotechnical applications.

Center Frequency:	270 MHz
Depth Range:	0- 6 m (0 - 18 ft)
Dimensions:	45 x 45 x 17 cm (18 x 18 x 6.5 in)
Weight:	8.6 kg (18.5 lbs)



GPR profile showing bedrock interface.

Model 3207 - 100MHz

Bistatic and Monostatic Operation

Geotechnical/Environmental
Mining

Center Frequency:	100 MHz
Depth Range:	2 - 15 m (5 - 50 ft) monostatic 0 - 30 m (0-100 ft) bistatic
Dimensions:	25 x 96 x 56 cm (10 x 38 x 22 in.) monostatic 25 x 96 x 200 cm (10 x 38 x 79 in.) bistatic
Weight:	13 kg (28 lbs) monostatic 28 kg (61 lbs) bistatic

The Model 3207 antenna is used for deep subsurface applications. The 3207AP (monostatic, left) combines the transmit and receive electronics in a single antenna housing. The 3207P (bistatic, right) is a versatile antenna pair that can operate in three different configurations to optimize performance.

Note: This antenna is currently for use outside the U.S.

Geophysical Survey Systems, Inc.
12 Industrial Way, Salem, NH 03079-4843 USA
Tel: 603-893-1109 / Fax: 603-889-3984
www.geophysical.com / sales@geophysical.com

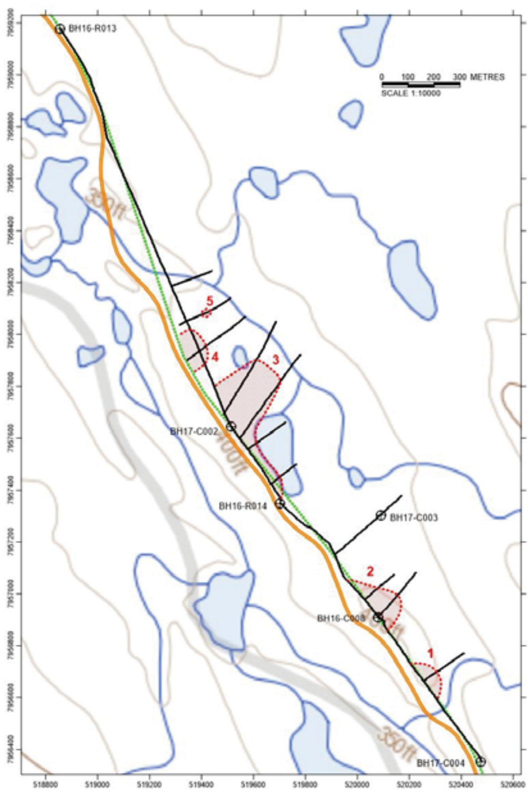
APPENDIX C

Drawings T17001-A2-1, T17001-A2-2,

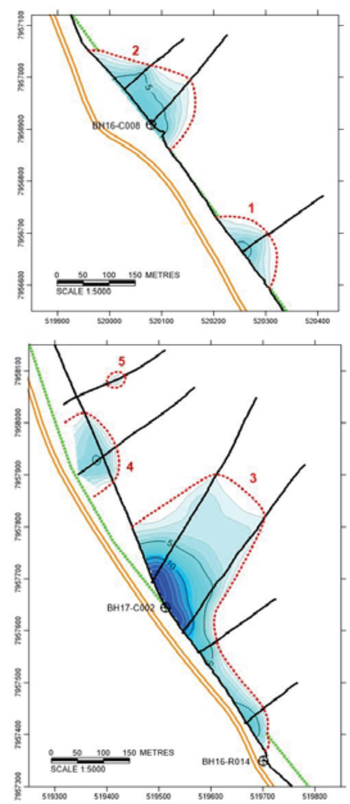
T17001-A2-3, T17001-A2-4, T17001-A3-1,

T17001-A3-2

GPR17-**SITE 1**

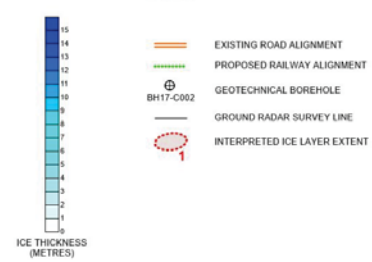


ICE THICKNESS MAP



OVERVIEW MAP

LEGEND



No	NOTES	No	DATE	MODIFICATIONS	GPR APP
1	THE RADAR SURVEY WAS EXECUTED BY GEOPHYSICS GPR INTERNATIONAL INC. APRIL 2017				
2	COORDINATE SYSTEM: WGS84 UTM ZONE 17W				
3	REFER TO FULL REPORT FOR DISCUSSION OF METHODOLOGIES, RESULTS AND LIMITATIONS				
4	BOREHOLE DATA PROVIDED BY THE CLIENT FOR REFERENCE PURPOSES				
5					
6					

SCEAU PROFESSIONNEL

PROFESSIONAL SEAL

GEOPHYSICS GPR INTERNATIONAL INC.

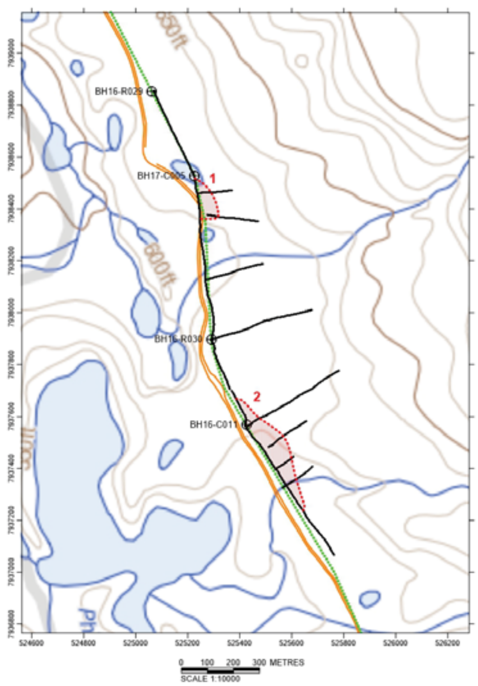
DESSINÉ PAR / DRAWN BY	I.Gusakov, GIT
VÉRIFIÉ PAR / CHECKED BY	
APPROUVÉ PAR / APPROVED BY	M.Situm, P. Geo
# CONTRAT / CONTRACT #	T17001
ÉCHELLE / SCALE	AS SHOWN
# DESSIN / DRAWING #	T17001-A2-1

CLIENT / CLIENT: **HATCH**

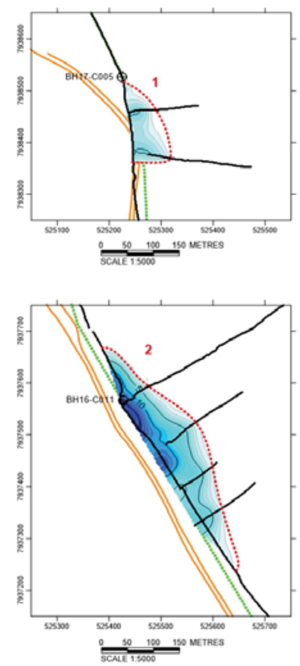
PROJET / PROJECT: **BAFFINLAND EXPANSION**

TITRE / TITLE: **GROUND RADAR SURVEY GPR17-SITE 1**

GPR17-**SITE 2**

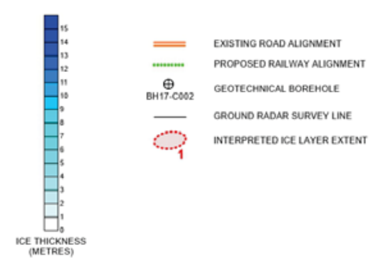


ICE THICKNESS MAP



OVERVIEW MAP

LEGEND



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6	

No	DATE	MODIFICATIONS	GPR APP.

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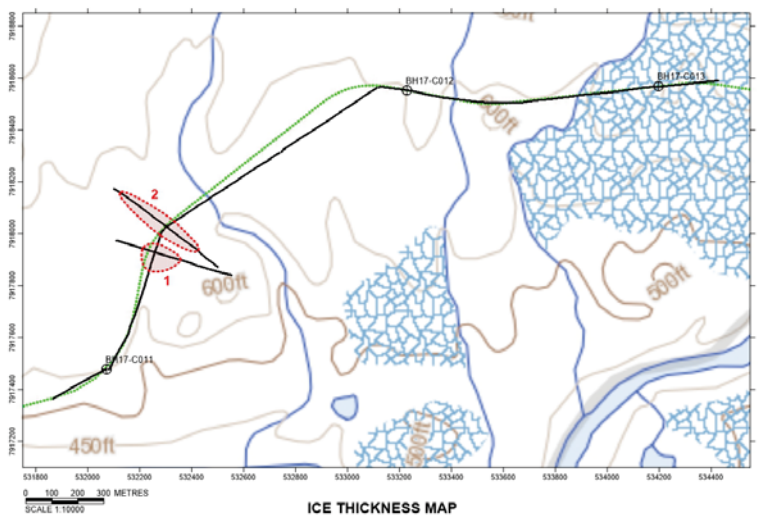
# CONTRAT / CONTRACT #	T17001
ÉCHELLE / SCALE	AS SHOWN
# DESSIN / DRAWING #	T17001-A2-2

CLIENT: **HATCH**

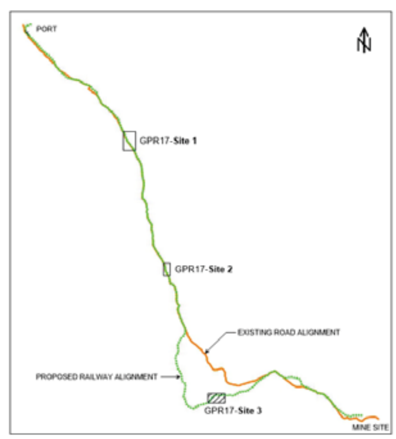
PROJET / PROJECT: **BAFFINLAND EXPANSION**

TITRE / TITLE: **GROUND RADAR SURVEY GPR17-SITE 2**

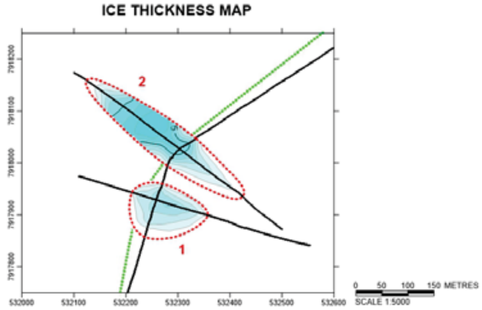
GPR17-SITE 3



OVERVIEW MAP



ICE THICKNESS MAP



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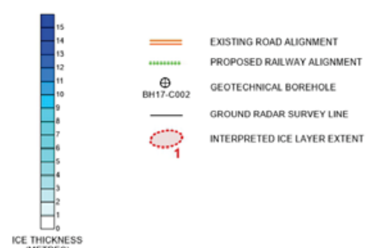

No	NOTES	No	DATE	MODIFICATIONS	GPR APP
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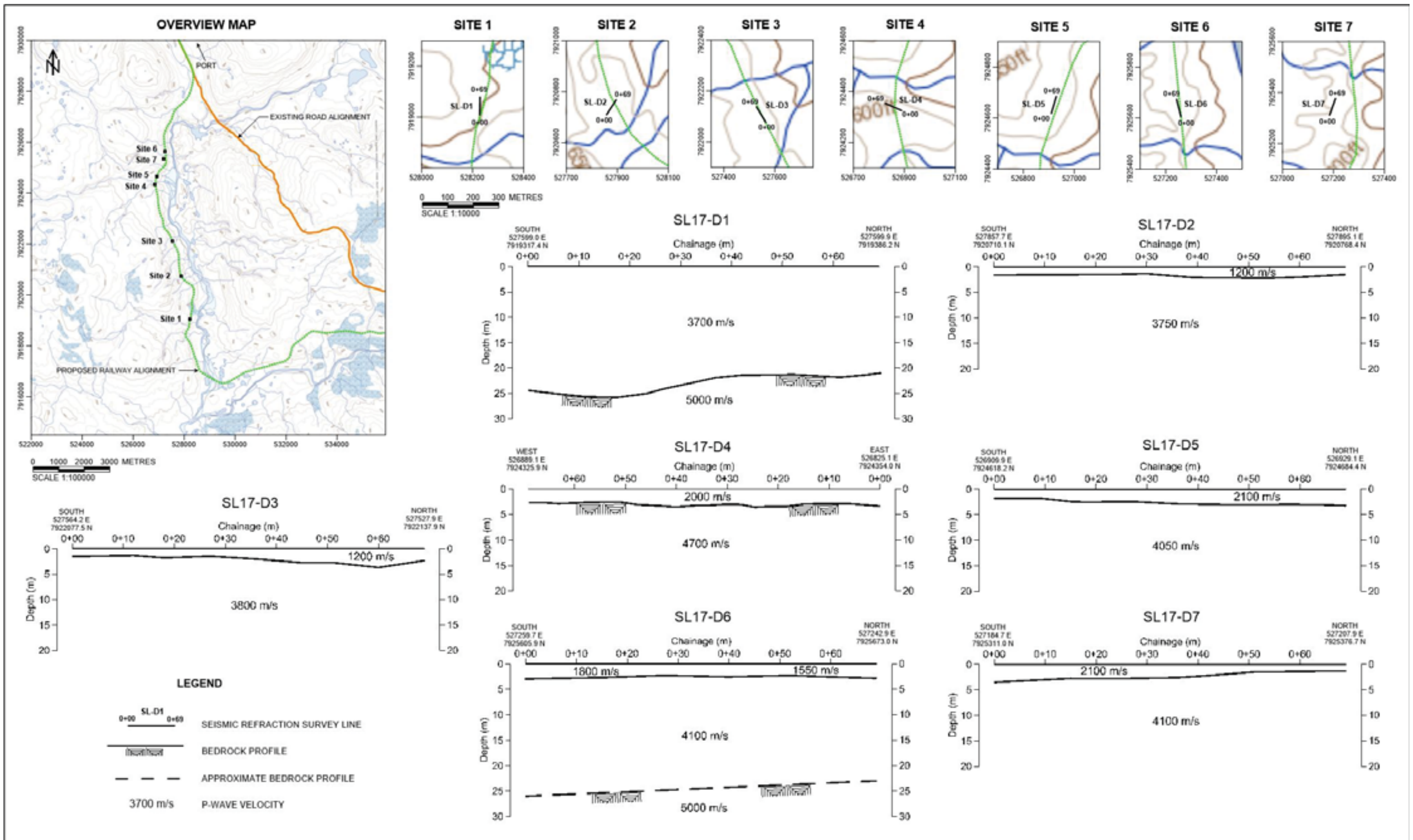
# CONTRAT / CONTRACT #	T17001
ÉCHELLE / SCALE	AS SHOWN
# DESSIN / DRAWING #	T17001-A2-3
CLIENT	HATCH
PROJET / PROJECT	BAFFINLAND EXPANSION
TITRE / TITLE	GROUND RADAR SURVEY GPR17-SITE 3



No	NOTES
1	THE SEISMIC SURVEY WAS EXECUTED BY GEOPHYSICS GPR INTERNATIONAL INC. APRIL 2017
2	COORDINATE SYSTEM: WGS84 UTM ZONE 17W
3	DEPTHS ARE RELATIVE TO GROUND SURFACE
4	REFER TO FULL REPORT FOR DISCUSSION OF METHODOLOGIES, RESULTS AND LIMITATIONS
5	
6	

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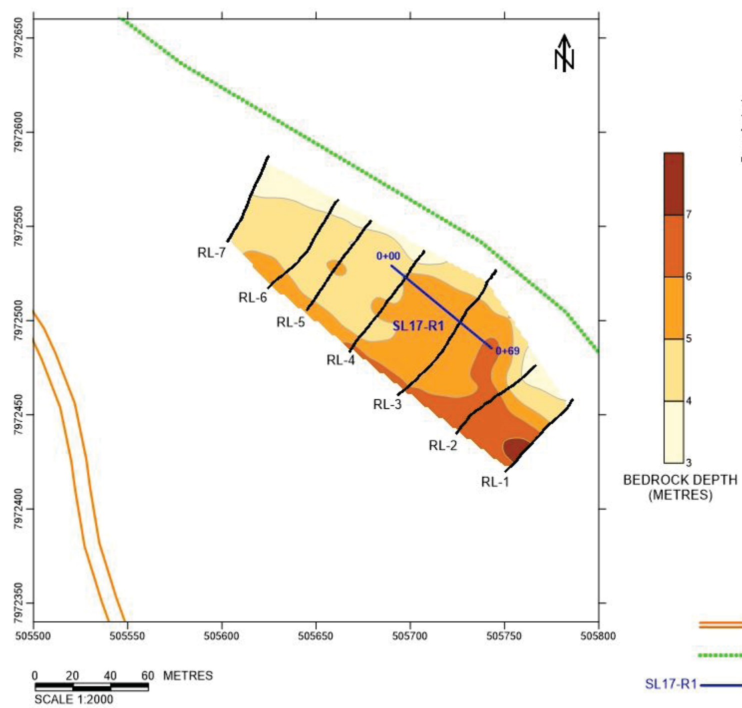
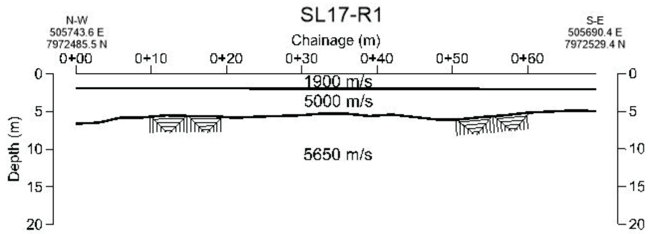
CONTRAT / CONTRACT #: T17001
ÉCHELLE / SCALE: AS SHOWN
DESSIN / DRAWING #: T17001-A2-4

CLIENT: HATCH
PROJET / PROJECT: BAFFINLAND EXPANSION
TITRE / TITLE: SEISMIC REFRACTION SURVEY DEVIATION AREA

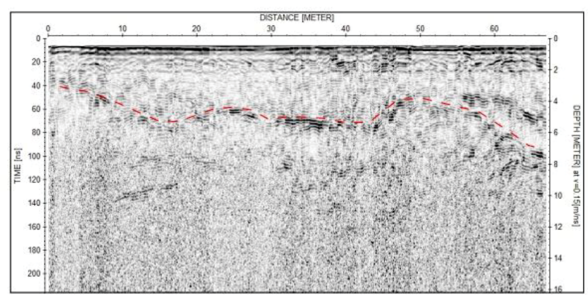
BEDROCK DEPTH MAP



SL17-R1



EXAMPLE RADAR IMAGE (RL-4)



LEGEND

EXISTING ROAD ALIGNMENT

PROPOSED RAILWAY ALIGNMENT

SL17-R1 — SEISMIC REFRACTION SURVEY LINE

RL-1 — GROUND RADAR SURVEY LINE

BEDROCK PROFILE

5650 m/s — P-WAVE VELOCITY

NOT VALID FOR CONSTRUCTION

No	NOTES
1	THE SEISMIC SURVEY WAS EXECUTED BY GEOPHYSICS GPR INTERNATIONAL INC. APRIL 2017
2	COORDINATE SYSTEM: WGS84 UTM ZONE 17W. POSITIONING ACCURACY +/- 2 METRES
3	ELEVATION DATA PROVIDED BY THE CLIENT. DEPTHS ARE RELATIVE TO GROUND SURFACE
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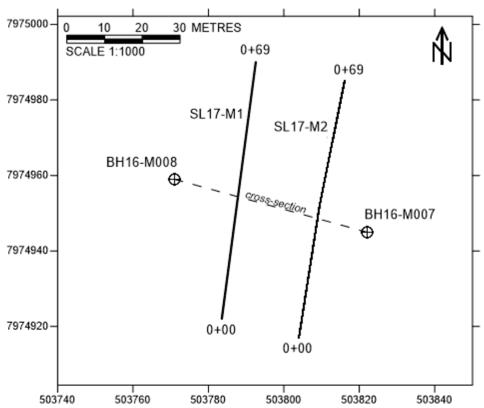
# CONTRAT / CONTRACT #	T17001
ECHELLE / SCALE	AS SHOWN
# DESSIN / DRAWING #	T17001-A3-2

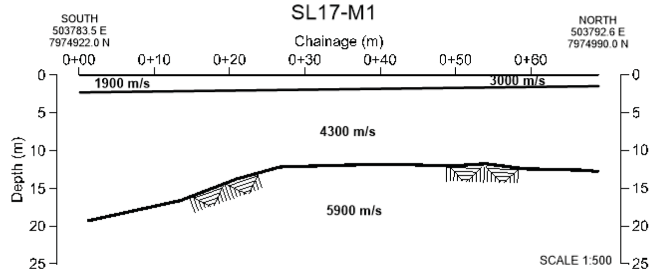
CLIENT / CLIENT: HATCH

PROJET / PROJECT: BAFFINLAND EXPANSION

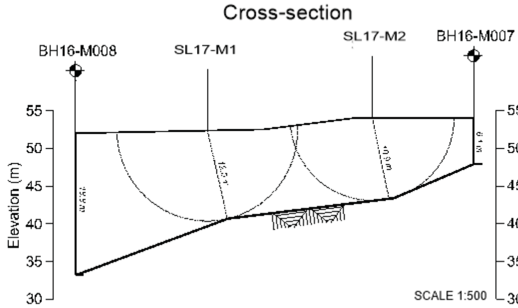
TITRE / TITLE: SEISMIC AND GEORADAR SURVEY PROPOSED RAIL ALIGNMENT KM 4.5



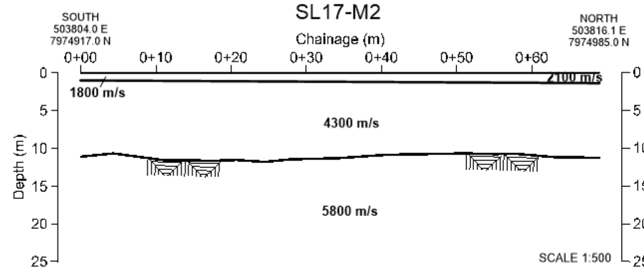
SL17-M1



Cross-section



SL17-M2



No	NOTES
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2	COORDINATE SYSTEM: WGS84 UTM ZONE 17W. POSITIONING ACCURACY +/- 2 METRES
3	ELEVATION DATA PROVIDED BY THE CLIENT. DEPTHS ARE RELATIVE TO GROUND SURFACE
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APPROUVÉ PAR / APPROVED BY	M.Situm, P. Geo
# CONTRAT / CONTRACT #	T17001
ECHELLE / SCALE	AS SHOWN
# DESSIN / DRAWING #	T17001-A3-1

CLIENT / CLIENT: HATCH

PROJET / PROJECT: BAFFINLAND EXPANSION

TITRE / TITLE: SEISMIC SURVEY RAILWAY UNLOADING AREA

GEOPHYSICS GPR INTERNATIONAL INC.

GEOPHYSICAL INVESTIGATION FOR BAFFINLAND RAILWAY, MARY RIVER PROJECT, NUNAVUT

PREPARED FOR:
Baffinland Iron Mines Corporation

Baffinland

Presented to:

HATCH

4342 Queen Street, Suite 500
Niagara Falls, Ontario
L2E 7J7

Project T17001B-Revision#004 **April 2018**

Geophysics GPR International Inc.
6741 Columbus Road, Unit 14
Mississauga (Ontario) L5T 2G9
Tel. : +1 905.696.0656
info@geophysicsgpr.com
January 2018 T-17001B

TABLE OF CONTENTS

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APPENDIX B – Georadar Fact Sheet

1 INTRODUCTION

Geophysics GPR International Inc. was requested by Hatch Ltd. to carry out a geophysical survey to aid in projection and planning of a proposed railway for the Mary River Project, Baffin Island, Nunavut.

The purpose of this investigation was to determine the extent of, as well as the thickness of subsurface ice.

The ground penetrating radar (georadar) method was applied to determine the presence of ice and calculate its thickness.

Data was collected from November 3rd to November 15, 2017.

The investigation included the following:

1) Georadar mapping of subsurface ice at nine sites approximately at Km 0, 19.4, 20.5, 39.5, 49.3, 82.2, 97.0, 100.1 and 109 along the proposed rail alignment. Further exploration with gridded georadar lines was conducted in regions both with and without the presence of ice.

Figure 1 presents an overview map of the investigation area with the locations of the respective sites.

The following report describes the various aspects of the survey including field techniques, survey design, interpretation techniques, and finally an interpretation in the form ice thickness maps.

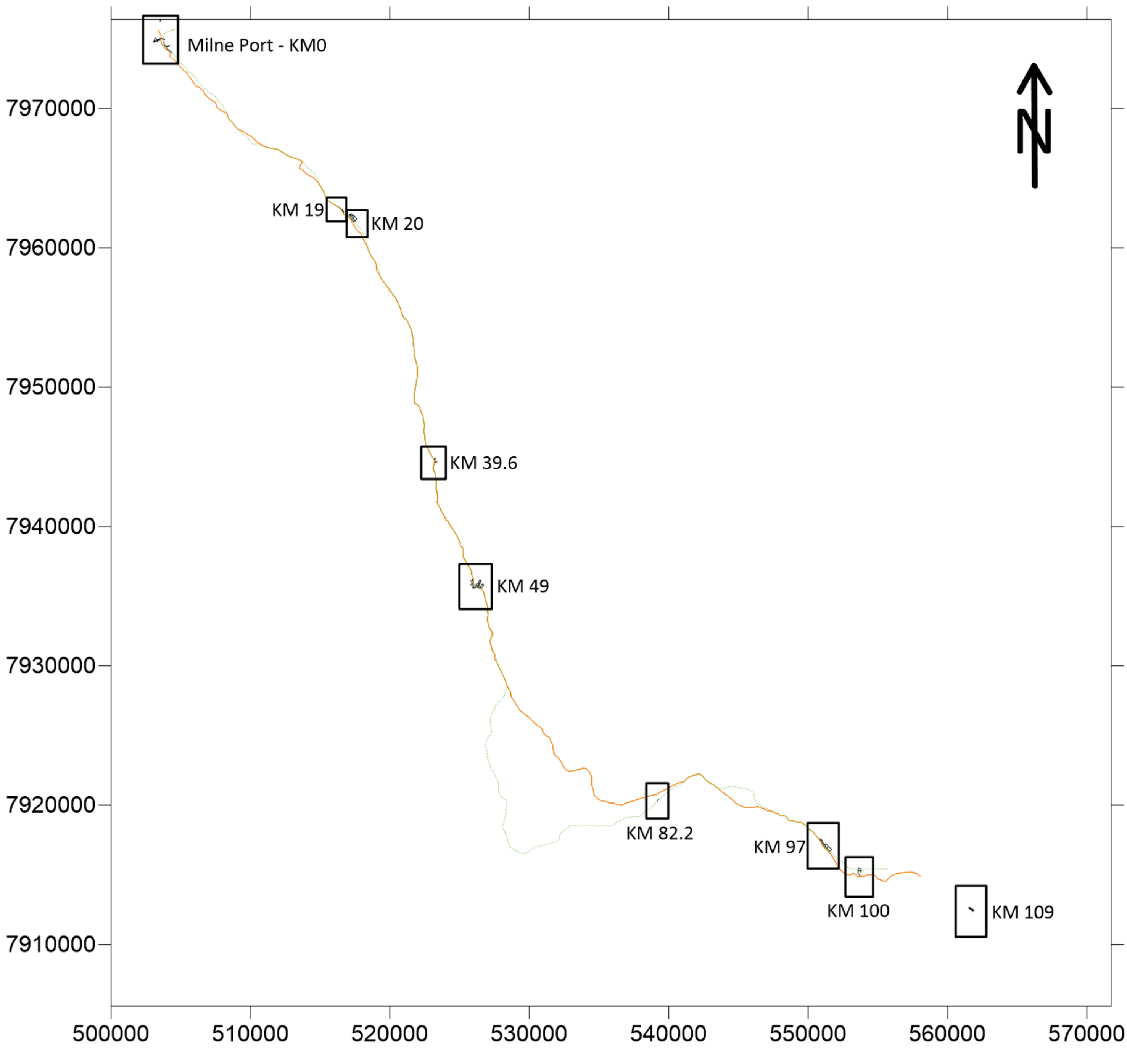

Figure 1: Overview map of the investigation area

2 METHODOLOGY

Georadar was used to determine the presence and thickness of ice.

2.1 Positioning, Topography and Units of Measurement

The emplacement of the survey areas was determined by the client.

The locations of the georadar survey lines for the purpose of subsurface ice mapping were oriented to align with the design of the proposed railway. Length and number of the lines were chosen based on in-field interpretation of georadar data. Positioning was controlled by the GPS device integrated into the georadar antenna. The UTM coordinates should be accurate to within +/- 2.0 m.

Table 1: UTM coordinates of GPR survey lines

Line No.	Start (0+00)		End (0+69)		Chainage (km)		Notes
	Easting	Northing	Easting	Northing	Start	End	
Line 0	502871.8	7976754.0	504000.0	7974502.0	0	2	Milne Port Area
Line 19.4	516252.0	7962974.0	516644.0	7962535.0	19.25	19.85	
Line 20.5	517047.0	7962251.0	517390.0	7961888.0	20.46	20.9	
Line 39.6	523146.0	7944888.0	523216.0	7944604.0	39.6	39.9	
Line 49.3	525992.0	7935880.0	526497.0	7935589.0	49.5	49.9	Rough Terrain
Line 82.2	539154.0	7920274.0	539291.0	7920419.0	82.2	82.4	
Line 97.0	551121.0	7917097.0	551250.0	7916944.0	97.0	97.6	Rough Terrain
Line 100.1	553584.0	7915318.0	553779.0	7915281.0	100.1	100.3	
Line 109.0	561530.0	7912604.0	561844.0	7912356.0	109.0	109.4	

The provided coordinates are NAD83/WGS84, UTM zone 17N.

The depth measurements are noted as depth from surface.

All geophysical measurements were collected in SI units.

In addition to Table 1, further georadar survey lines were created to further explore the given areas. These additional survey lines were generated in a grid-like fashion with the topography dictating the spacing of the lines.

2.2 Ground Penetrating Radar (Georadar)

Basic Theory

Georadar utilises radar technology to obtain a near-continuous profile of the subsurface. The basic principle is to emit an electromagnetic impulse into the ground at a predetermined frequency rate (typically 10 to 80 scans/second). This pulse will travel through the sub-surface and reflect off boundaries of differing dielectric constants (contrasts of EM impedances). The reflected pulse returns to the surface and is recorded by a receiver and displayed in real-time as a cross-sectional image. Only by moving the antennas along a profile directly over the targets can the locations and depths be determined. Examples of radar reflecting boundaries include air/water (water table); water/earth (bathymetry); earth/metal, PVC, or concrete (pipe locating); and differing earth materials (stratigraphic profiles, including bedrock profiles).

The depth of investigation is controlled by the frequency and power of the antenna limited by attenuation and diffraction of the radar signal. Lower frequency antennas provide greater depth penetration at the expense of resolution. The radar signal is attenuated by conductive ground materials (e.g. clays, dissolved salts etc.). The radar signal is diffracted by irregular shaped material (e.g. boulders, debris etc.) that prevents the clear return of the reflected pulse.

More information on the georadar operating principle can be found in Appendix B.

Survey Design

The georadar data were collected with a MALA Ground Explorer system and 160 MHz antenna. This antenna provides a favourable trade off between depth and resolution for ice detection. As well, this antenna has sufficient durability for the terrain and weather conditions for Baffin Island.

Positioning for the georadar survey was controlled by built-in GPS receiver.

Interpretation Method

Processing of the radar images involved basic horizontal normalization, elevation corrections and gain adjustments.

The vertical scale on all radar images is a two-way time scale representing the time taken for a radar pulse to transmit to a reflector and back to the receiver. In order to convert the time scale to a depth scale a signal velocity must be applied. The velocity with which the pulse travels through the given material is determined by the dielectric constant. This dielectric will vary with the type of material.

Calculating a velocity can be done in many ways but the most reliable method is with a test pit or borehole where the real rock contact can be exposed. Based on in-situ measurements or borehole data, the dielectric value can be approximated depending on the expect material type. An underestimate of the dielectric will result in an over estimate of the signal velocity and in turn an over estimate of the depths. For this site a dielectric of 4 (velocity of 15 cm/ns) was assumed based on the expected soil type and tables of relative dielectric values for commonly encountered materials. In this case the materials were mostly frozen granular/boulders with high ice content.

Interpretation of the data is based primarily on the qualitative analysis of three characteristics of radar reflections: continuity, amplitude and shape. The interpreter then identifies reflectors and textures within the radar records that represent subsurface contacts, objects or zones. The true nature of the interpreted features can only be assumed without corroborating evidence.

Ice bodies have a distinctive appearance on radar images. Granular host material appears as "noise" on the images, whereas uniform ice layer looks transparent with clearly defined top and bottom contacts and can be confidently identified. An example of a uniform ice lens is presented in Figure 2.

Non-uniform ice bodies (stratified or containing layers of soil) are more challenging for interpretation since structure irregularities create multiple reflections within the ice body. Often a borehole is needed to confirm the presence of ice. Other features such as increasing depth of investigation in the presence of thick ice layer may corroborate the interpretation.

In summary, ability of georadar is limited by the structure of the ice layer being surveyed and its composition. The identification of an ice layer may be impacted by irregularities inside the ice body, such as layering, fractures and soil inclusions. However, it is possible to create two categories of ice lenses, the obvious and less obvious that may need some ground truthing.

3 RESULTS

3.1 Subsurface Ice Mapping

Georadar data was collected at nine sites approximately at Km 0, 19.4, 20.5, 39.5, 49.3, 82.2, 97.0, 100.1 and 109 along the proposed rail alignment.

Locations of the survey lines and results of the georadar survey are presented in drawings GPR17 – MILNE INLET, GPR17 –KM19, GPR17 –KM20, GPR17 –KM39.6, GPR17 –KM49, GPR17 –KM82.2, GPR17 –KM97, GPR17 –KM100.1, GPR17 –KM109.

KM 0 - GPR17 – MILNE INLET

Multitude of survey lines conducted in the Milne Port area with no evidence of the presence of ice. Georadar penetration of the surface appeared shallow with poor signal attenuation, possibly due to material used for subsurface in port area. Total distance of 1.2km covered.

KM 19 - GPR17 –KM19

Two main survey lines conducted. No apparent ice presence in area. Area was not explored further due to time constraints. Total distance of 1.0km covered.

KM 20 - GPR17 –KM20

No apparent ice presence in area. Grid-like survey conducted to further explore region for ice; two further longitudinal lines, with three additional perpendicular cuts. Total distance of 2.9km covered.

KM 39.6 - GPR17 –KM39.6

No apparent ice presence in area. Latitudinal cuts conducted to further explore region for ice. No longitudinal lines due to topographic obstacle in area. Total distance of 1.5km covered.

KM 49 - GPR17 –KM49

Ice found in region, explored with additional lines where possible. Survey lines constrained due to topography and water in area. Total distance of 4.5km

KM 82.2 - GPR17 –KM82.2

No apparent ice presence in area. Due to distance from tote-road and time constraints no additional surveying was conducted in this area. Total distance of 200m covered.

KM 97 - GPR17 –KM97

No apparent ice presence in area. Area heavily constrained by topographic change. Additional survey lines done around topography to ensure safety maintained. Total distance of 2.2 km covered.

KM 100.1 - GPR17 –KM100.1

No apparent ice presence in area. Area constrained by water. Additional survey lines conducted in area. Total distance of 1.2km covered.

KM 109 - GPR17 –KM109

No apparent ice presence in area. Area constrained by topographic change. Additional survey lines conducted in area. Total distance of 1.2km covered.

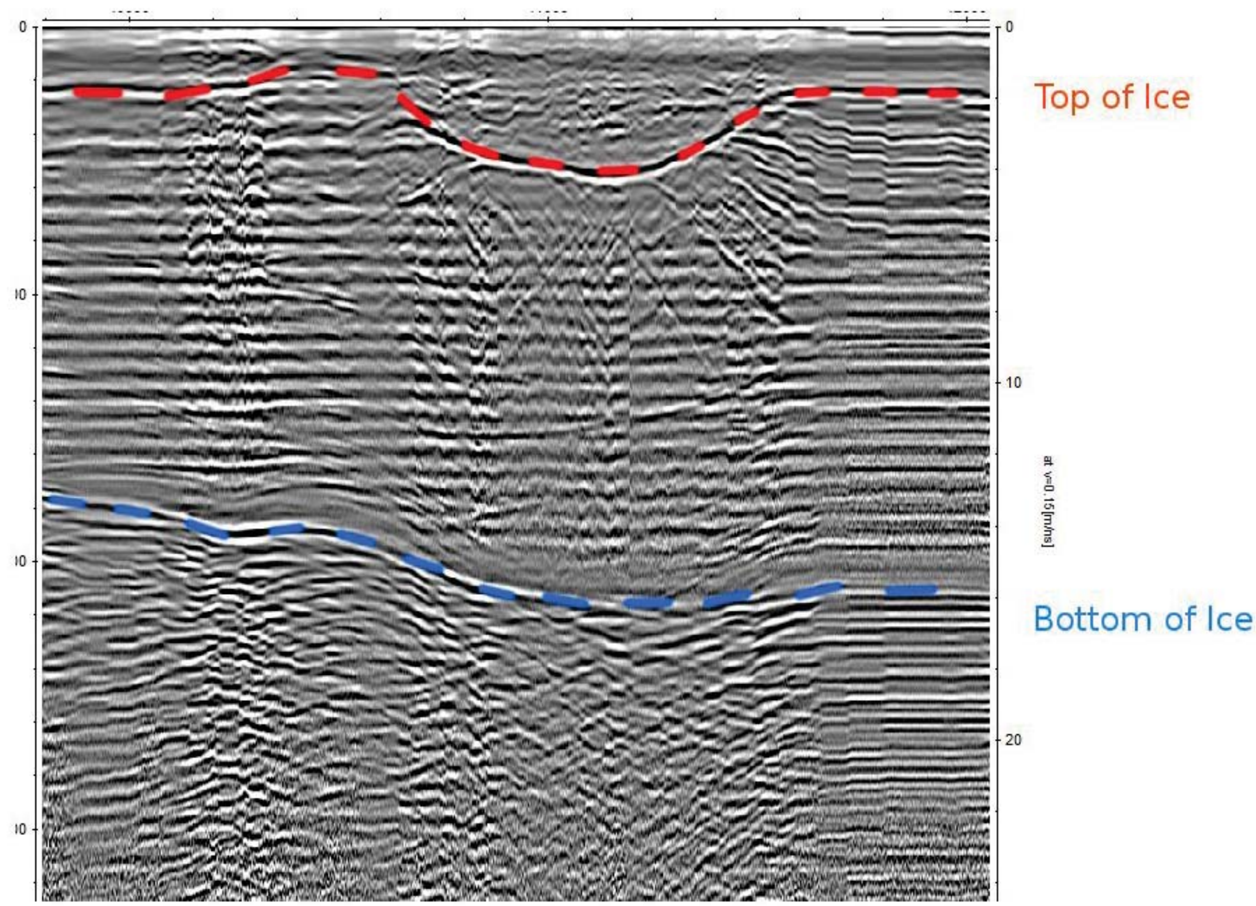

Figure 2: Interpreted georadar image showing a typical ice body