

Implication of the permafrost on hydrogeological conditions and on mine environment controls: case of the Amaam Coking Coal Project in north-eastern Russia

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Abstract

The Amaam Coking Coal Project is located in the extreme north-east of Russia, near the Arctic Circle and comprises the following key components; a large scale open cast mine producing premium coking coal, a sea port, and road and rail connection from the mining areas to the port. In this environment, two main groundwater systems within the project area have been identified: a shallow groundwater regime above the permafrost zone made of an active layer aquifer and post-glacial alluvial deposit aquifer(s), and a deep groundwater regime beneath permafrost made of deep bedrock aquifer(s). Within these regimes, fresh to brackish groundwater is anticipated to occur within Quaternary and post glacial unconsolidated sediments, weathered and fractured bedrock and deep bedrock formations containing the coal seams. Although the project is located within a widespread permafrost region, it is understood that the low-lying areas adjacent to surface water bodies, rivers and lagoons, are unfrozen throughout the year, and therefore lie in a talik area (or unfrozen grounds encountered within the permafrost zone). The intermediate bedrock aquifer(s) within the flood plain taliks may be hydraulically connected to the deep bedrock aquifer(s) and fractures / faults present in these areas can potentially conduct surface waters into the various water-bearing strata during seasonal thawing if not acting as groundwater barriers. Although the surface-groundwater coupling is not fully understood, the following likely changes to the groundwater conditions resulting from the mine development may include: potential changes to groundwater flow; changes to groundwater quality; changes to surface water / groundwater interactions; and changes to geotechnical conditions. Preliminary estimates of potential groundwater seepage into mine areas are in the range of 2,000 to 55,000 m³/d. Most of this flow is anticipated to originate from the unconsolidated Quaternary deposits. Refinement of these estimates will occur following a better appreciation of the thickness of permafrost and the location and thickness of talik areas. The hydrogeology of the Project is therefore substantially controlled by the permafrost characteristics and its spatial and temporal distribution.

Introduction

Permafrost is defined as ground (soil or rock and including ice or organic material) that remains at or below 0°C for at least two consecutive years. Permafrost is made of an active layer, which freezes and thaws each year, and a perennially frozen layer. Hydrogeologically, the perennially frozen layer can be described as an impermeable layer which (1) restricts recharge, discharge and the transmission of groundwater, (2) acts as a confining layer, and (3) limits the volume of aquifers where liquid water can be stored. Generally, the hydraulic conductivity of such frozen soils is so low that near-surface waters (surface water and above permafrost groundwater) are hydraulically disconnected from deeper sub permafrost groundwater systems. This setting is therefore favorable for open-pit mining in subarctic climates because the permafrost layer limits groundwater inflow to the working environment. However when talik (unfrozen ground within the permafrost zone) is encountered beneath a perennial river/stream system or lake adjacent to a mine development, groundwater within the talik may migrate towards the open pit. Should this occur potential adverse impacts on the groundwater environment through connecting water from sub-surface aquifers and deeper aquifers need to be managed. This particular setting is encountered at the Amaam Coking Coal Project. This article highlights the initial hydrogeological evaluation of this setting.

Geographical, Geological and Hydrogeological Settings

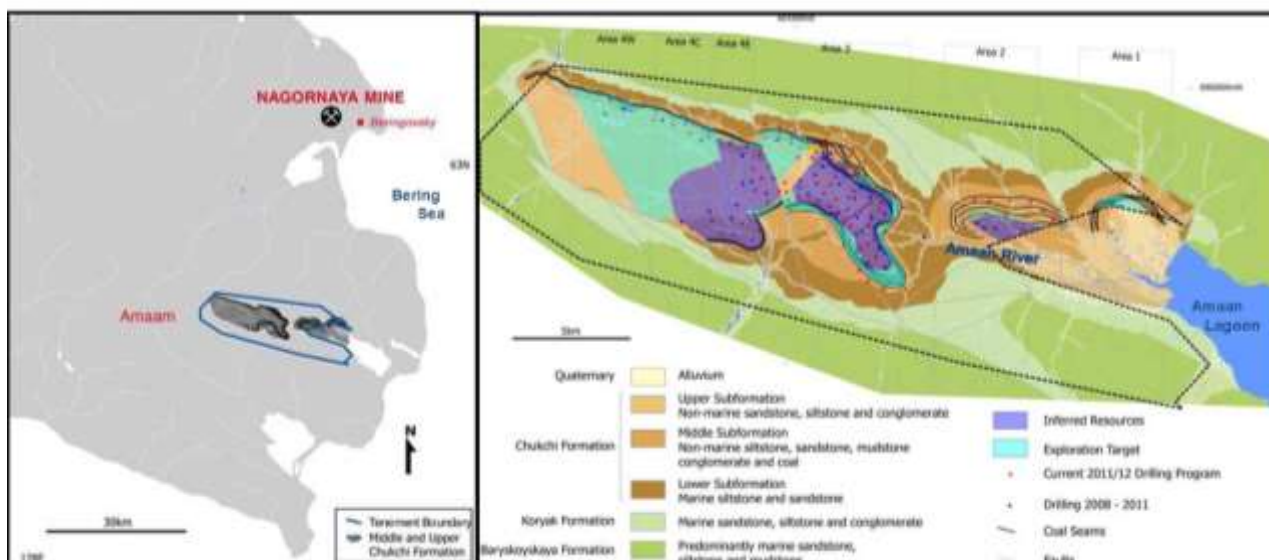


Figure 1: Location and Geological map of the Amaam deposit

The Amaam Project is located in the Bering Coal Basin, in the extreme north-east of Russia, near the Arctic Circle (Figure 1). The tenement is approximately 230 km south of the regional capital of Anadyr and the administrative centre of Ugolnye Kopi, and some 40 km to the south of the existing coal mining operations of Nagornaya and its supporting town of Beringovskiy. The mean annual temperature is minus 4°C. The project is located 20 km inland from the Bering Sea and along the low lying area of the watershed and estuary area of the Amaam River.

The coal deposit is Palaeocene in age (Chukchi Formation) and within a Cretaceous-Palaeocene synclinal basin with longitudinal and cross cutting faults that divided the deposit into four main areas. The deposit is made of a 90-110 m thick sand-coaly unit, which contains six to seven coal seams. This sedimentary sequence is unconformably over-lain by Quaternary deposits that are typically glacial sediments and fluvial gravels and sands.

Groundwaters occur within two main groundwater regimes at the Amaam deposit (Figure 2): the shallow groundwater system above the permafrost zone made of an active layer aquifer and post-glacial alluvial aquifer(s), and a deep groundwater regime beneath permafrost when present made of fractured bedrock aquifer(s).

ERA	PERIOD	SEQUENCE	Groundwater regime	Watershed area	Talik area
CENOZOIC	QUATERNARY		Shallow groundwater regime	Active layer aquifer	Active layer aquifer (< 2.5 m) and Post glacial alluvial aquifer(s) (2 - 4.8 m)
	PALAEOGENE	CHUKCHI FORMATION			
MESOZOIC	CRETACEOUS	KORYAK FORMATION	Deep groundwater regime	Deep bedrock aquifer(s)	Deep bedrock aquifer(s)
		BARYSKOYSKAYA FORMATION			

Note: * maximum depths of permafrost encountered in investigations to date

Figure 2: Groundwater regimes and aquifers present at the Amaam deposit

The active layer aquifer. Groundwater occurs in the active layer above the permafrost layer. This is an ephemeral system that is primarily frozen in winter (from December to April) and thaws in summer. It is mainly recharged directly from atmospheric precipitation and indirectly from snow- and ice-melt water. The inflow rates are larger in summer and autumn than in winter and spring when they are greatly reduced or even non-existent when the aquifer freeze-up.

The post glacial alluvial aquifer(s). These aquifers are present only within the flood plain talik along the Amaam River and the Amaam Lagoon. They comprise unconsolidated sand, pebbles, clay, and organic soil of variable thickness (1.4 to 26 m). Their hydraulic conductivities, ranging between 30 and 150 m/d, are typical of unconsolidated sand and gravel deposits.

The fractured bedrock aquifers (intermediate and deep groundwater). The intermediate bedrock aquifer(s) are found in the shallow fractured/weathered bedrock within the flood plain talik while the deep bedrock aquifer(s) are found below the permafrost layer at a depth of about 45 to 148 m. Artesian conditions are common in the deep bedrock aquifers. Hydraulic conductivities of the fractured bedrock below the permafrost layer are reported to be at ~ 10-3 and 10-2 m/d. In the fractured bedrock where no permafrost was encountered during drilling, the hydraulic conductivity values are higher and range between 10-2 and 0.3 m/d. The higher hydraulic conductivity values can be interpreted as either the result of a hydraulic connection between surface water/shallow groundwater and the fractured/weathered rock through talik, or fractured zones or weathered sections of more permeable sandstone and conglomerate horizons. Recharge to the intermediate and deep bedrock aquifers is assumed to occur through the talik areas. Recharge may also occur through features such as open faults / fractures that can conduct surface water to the various strata underneath.

In the shallow active system, the hydraulic gradients follow the topography and static water levels are generally encountered 5 to 10 m below the ground level except in the estuary area of the Amaam Lagoon where static water level is near surface.

Implication on Mine Environment Controls

Open Pit Development

The excavation of open pits (~ 150 to 240 m depth) below the water table and below the permafrost layer will change the groundwater regime.

The open pits will act as sinks for groundwater flow and seepage faces are expected in the pits.

Water may flow through:

- unconsolidated post glacial alluvial deposits located near the surface of the pits,
- unfrozen shallow fractured/weathered bedrock in taliks, and
- deep fractured bedrock below permafrost layer and through faults where high permeability zones are intersected.

Preliminary estimates of potential groundwater seepage into the planned open pits penetrating the permafrost are in the range of 2,000 to 55,000 m³/d. These are similar as those determined for the Nagornaya Mine and the Bukhta Ugolnaya deposit located north of the present project in the Beringovsky Province. Most of this flow is anticipated to originate from the superficial unconsolidated post glacial alluvial deposits located in low-lying areas and adjacent to permanent or temporary surface river/streams.

A reduction of water head in the bedrock may also cause either direct (through open fractures) or indirect (leakage from surface water bodies connected to aquifers) flow of water from neighboring surface water bodies (rivers, streams, swamps, lagoons, etc.) in the talik. A result of this potential leakage may be a change in the quality of the groundwater. The implementation of a surface and groundwater monitoring network will be essential to assess any future potential change in the groundwater environment.

Pockets of unfrozen saline water in the permafrost layer may also be encountered which may lead to sudden intense discharges to the pit. The duration of the discharge will depend on the hydraulic conductivity of the country rock mass, the size of the unfrozen pocket and / or the presence of open fractures that may be connected to the surface/groundwater system.

Potential Groundwater Control Options

Mitigation strategies being investigated to reduce the inflow of water to the pits at Amaam include:

- intersecting the shallow groundwater inflow before it reaches the pit(s), through, for example, the installation of perimeter production boreholes in the more permeable zones (e.g. post glacial alluvial deposits),
- diversion of the surface river / stream systems, and
- installation of waterproof curtains/screens along the permanent rivers/streams that feed the shallow groundwater regime.

Waste Rock And Infrastructure Development

Disturbance of the ground surface by placing waste rock on the surface or infrastructure will change the soil temperature and therefore change the thickness of the active layer and the characteristics of the permafrost layer. This may result in the development of temporary talik underneath these various developments and contribute to additional groundwater inflow to the pits. Waste dump seepage may also contribute to the surface and shallow groundwater systems. The implementation of a thermal and groundwater monitoring network around the waste rock dump and infrastructure will assist to assess change in soil condition during mining and post mining.

Potential Seepage Control Options

Potential control options associated with controlling changes to the groundwater regime due to the waste rock dumps and other infrastructure may consist of:

- limiting the surface disturbance as much as possible,
- insulating the infrastructure, and
- designing drainage systems to minimize groundwater infiltration (e.g. installation of cut-off trenches and/or seepage collection systems).

Summary

The hydrogeological assessment of the Amaam project identified two groundwater systems within the project area: a shallow groundwater regime above the permafrost zone and a deep groundwater regime beneath permafrost. However, the presence of taliks in the low lying area of the project, adjacent to the proposed open pits, suggests some connectivity between both systems. Preliminary estimates of potential groundwater seepage into mine areas indicate that most of the flow originates from the unconsolidated post glacial alluvial deposits. The hydrogeology of the project is therefore likely to be substantially controlled by the permafrost characteristics and its spatial and temporal distribution.

In this particular setting, the identification of the talik areas and permafrost thickness, as well as the understanding of the shallow groundwater system and its interaction with the surface water are of primary importance for the development of a successful mine.

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