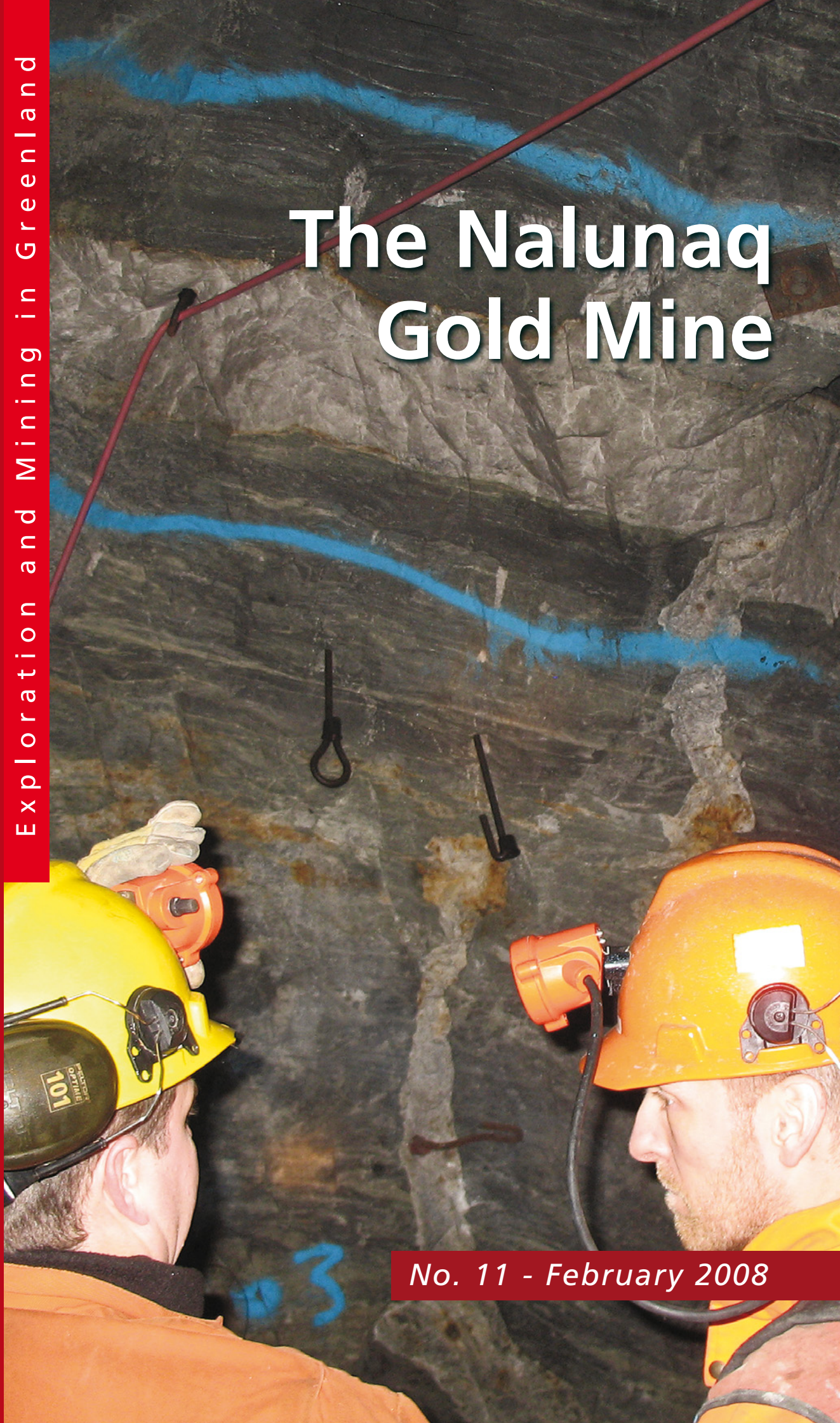
GEOLOGY AND ORE

Exploration and Mining in Greenland

The Nalunaq Gold Mine



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The Nalunaq Gold Mine

'Nalunaq' the Greenlandic name of Greenland's first gold mine means the place that is hard to find. It is located in Kirkespirdalen (Church steeple valley) near the town of Nanortalik. Since the 1970s a number of significant gold occurrences in several places in Greenland have been found and described. The Nalunaq deposit is the result of thorough geological work that included ten years of exploration prior to commercial mining. In 2004 the mining company Crew Gold Corporation was granted the final licence to exploit the gold deposit at Nalunaq, of which the operations are carried out by the Nalunaq Gold Mine A/S. The Nalunaq mine was inaugurated on 26 August 2004 as the first gold mine in Greenland.

Aerial view of the Nalunaq mining camp and the road to the mine adits (2006).

Introduction

Gold was early on the list of mineral resources that were desirable for exploitation in Greenland. Today there are several gold occurrences known in Greenland. These are primary in-situ deposits of gold. Secondary deposits of gold, i.e. placer gold, have not been found in Greenland.

Over the last three decades a number of significant gold mineralised areas have been discovered and described. One of the first was the Tartoq occurrence in South Greenland, and subsequently new occurrences were found in the Disko Bugt area, in the Godthåbsfjord area and at the Skærgaard Intrusion in East Greenland. In 1992 the discovery at Kirkespirdalen in the very south of Greenland was made, which 12 years later served as the background for the establishment of the first modern gold mine in Greenland, the Nalunaq Mine. The data gathered on the gold mineralisation in Kirkespirdalen led to many finds of other gold occurrences in the region and now the area is regarded as a major gold province.

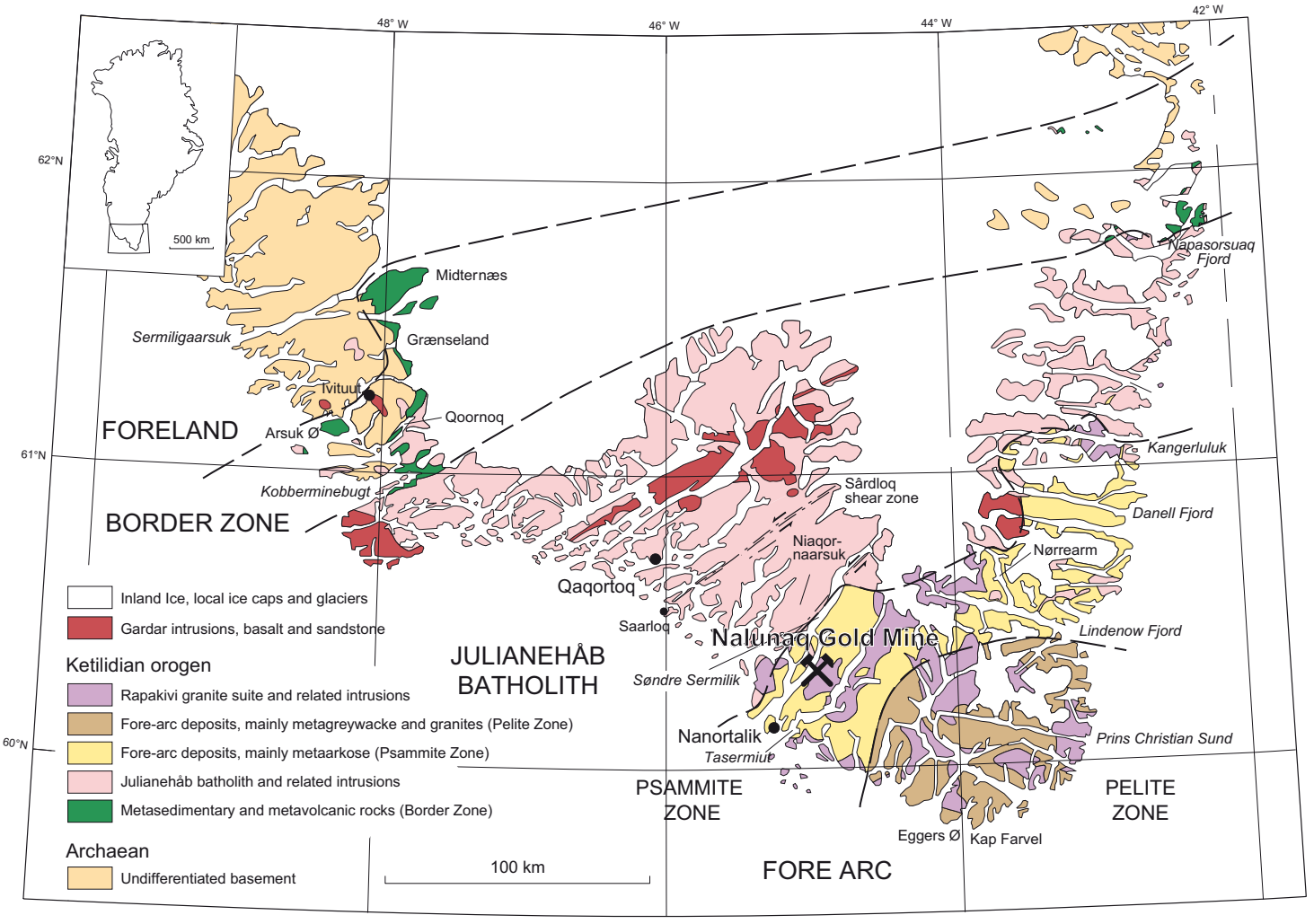
Geological setting

The geological setting of the Nalunaq gold mine is the south Greenland basement, where it is concluded that the Palaeoproterozoic Ketilidian juvenile orogen evolved during northward subduction of an oceanic plate under the southern margin of the Archaean craton. The evolution of the Ketilidian orogen spans from 1850 Ma to 1725 Ma. The orogen is subdivided into four domains. The central part of the Ketilidian orogen is dominated by one large, multi-phase, continental calc-alkaline batholith, the Julianehåb batholith, which is emplaced (1854–1795 Ma) along the southern margin of the North Atlantic craton over a north-dipping subduction zone. The major phases of the deformation formed several NNE- or NE-trending, sinistral shear zones through the batholith.

The region north of the batholith is named the Border Zone and consists of reworked Archaean basement of the craton and unconformable overlaying Ketilidian supracrustal rocks, which become progressively involved in the Ketilidian metamorphism and deformation towards the south. These well-preserved (1800 Ma) Ketilidian supracrustals are located on Midternæs and in Grænseland within the north-western Border Zone.

The region south of the batholith comprises extensive areas of supracrustal rocks, the Psammite and Pelite Zones. The supracrustal rocks occupy a minimum width of 100 km and with an estimated pre-erosional thickness of over 15 km. The Psammite Zone rocks include basic volcanic rocks, variably migmatised pelitic and semi-pelitic rocks, calcareous metasediments, bedded massive-pyrrhotite/graphitic-cherts, dolerites, syn- to post-kinematic appinite dykes as well as post-kinematic rapakivi granites. The psammites are interpreted to represent intra- and fore-arc sediments, eroded from the Juliane-håb batholith and deposited in fluvial and shallow marine environments between the batholith and an oceanic environment to the south. The Pelite Zone at the southern tip of Greenland comprises

View towards the south-west of the valley with the Nalunaq gold mine (centre right) and the 9 km connecting road to the harbour at the Saqqa Fjord (centre upper).



Geological map of South Greenland with the location of the Nalunaq Gold Mine.

mainly flat-lying, intensely migmatised pelitic rocks. The pelitic rocks consist mainly of turbidite sediments, deposited in deeper offshore settings compared with the fluvial and shallow marine environments of the psammites. The mafic volcanic rocks and granitoids are gold bearing, as observed at the Nalunaq mine.

The Nalunaq deposit is a high-grade gold mineralisation associated with quartz-veins in a major shear zone. As genetic type, the deposit is an orogenic-type gold mineralisation (mesothermal lode gold), hosted in Palaeoproterozoic amphibolite facies metavolcanic rocks. Visible gold is found in sheeted quartz veins which are located in a large-scale shear structure that appears to be related to regional thrusting. The most pronounced structure at Nalunaq is a narrow zone of ductile shearing surrounded by relatively brittle margins. The gold carrying quartz veins vary from 0.05 m to 1.8 m in width and often display pinch and swell structure. The so-called Main Vein within the deposit is hosted in a 1–2 m wide shear zone with a remarkably constant orientation.

Exploration history

The exploration prior to commercial mining began at the end of the 1980s when geologists from the exploration company Carl Nielsen A/S observed small flakes of gold in the gravel at the coast at the foot of the mountain named Kirkespiret. The systematic geological mapping of the area was carried out already in the 1960s by the Geological Survey of Greenland (later GEUS) and thus provided a good foundation for the exploration work. In 1990 the Greenland-Danish exploration company Nunaoil A/S was granted an exploration licenses and the company's chief geologist pursued the idea that loose gold at the coast must be due to in-situ gold in the mountains. In 1992 primary gold was finally located almost 500 m above sea level on the slopes of the valley Kirkespirdalen.

The gold was visible in outcropping quartz veins and appeared to occur over an area of 800 m in length. Later, new players joined the exploration, carrying out the first drilling at the location, and in 1998 the first

View of the mining area at Nalunaq.

investigation adit was established. From here it was possible to obtain enough ore to carry out pilot production and processing. The UK-based Crew Gold Corporation took over the majority of the shares in the gold exploration in 1999, whilst 17.5 per cent were held by the Greenland company Nunamin-erals A/S. On 26 August 2004 the mine was officially opened. In November 2007 Crew Gold Corporation acquired all shares in the gold mine.

The terrain surrounding the mine is alpine with mountain peaks reaching 1,200–1,600 m above sea level. The Nalunaq Mountain is 1,340 m high and is located in a wide glacial valley reaching into the Saqqa Fjord about 9 km from the mine site. Deep fjords allow access for shipping and the overall climate is sub-arctic allowing full operations around the year.

Preparing a mine

Crew Gold Corporation was granted the final licence to exploit the gold deposits at Nalunaq, which was operated by the Greenland company Nalunaq Gold Mine A/S. This licence does not include on-site extraction of the gold from the ore on-site, but rather the company will ship the ore to a processing plant abroad. During the first two years, the extraction was carried out in Spain at the plant of Rio Narcea Gold Mines. Following this, the extraction was moved to Canada at the Nugget Pond plant in Newfoundland, which Crew Development had acquired in 2006. The harbour

The mining camp at Nalunaq. The wooden barracks and facilities are situated along the river draining the valley. In the front, one of the 25-tonne trucks en route to the mine.


TEXACO

Underground exploration drilling inside the Nalunaq mine.

Exploration drilling at the slope of the Nalunaq mountain on the northern side of Kirkespirdalen looking towards the north-east.

The study of an underground face of the gold bearing quartz vein in the Nalunaq mine.

facilities constructed at Nalunaq take advantage of the fact that there is deep water at the coast enabling large ore vessels to dock and to be loaded directly from the ore storage facility at the harbour.

The Crew Gold Corporation owns 100% of the Greenland limited liability company, Nalunaq Gold Mine A/S (NGM). The mining license, granted by the Governments in Greenland and Denmark in 2004, has a duration of 30 years. The license covers an area of 16 km² around the mine site.
In 2004 the basis for the operation of the mine, according to Nalunaq Gold Mine A/S, was estimated to be ore reserves of 400,000 t with a gold grade of 21 grams per tonne. Furthermore there is indication of extra resources at 1,670,000 t with an average gold grade of 18 grams per tonne. Production in 2006 comprised 108,000 t of ore with an average grade of gold of 17.9 grams per tonne. Depending on the production rate in the mine, there will probably be enough ore for an operating period of

Schematic 3-D presentation of the mining method used with demonstration of the long-hole open stoping system. 3D figure: Carsten E. Thuesen, GEUS.

An underground view of a hanging wall of a mined-out 1.2 m stope.

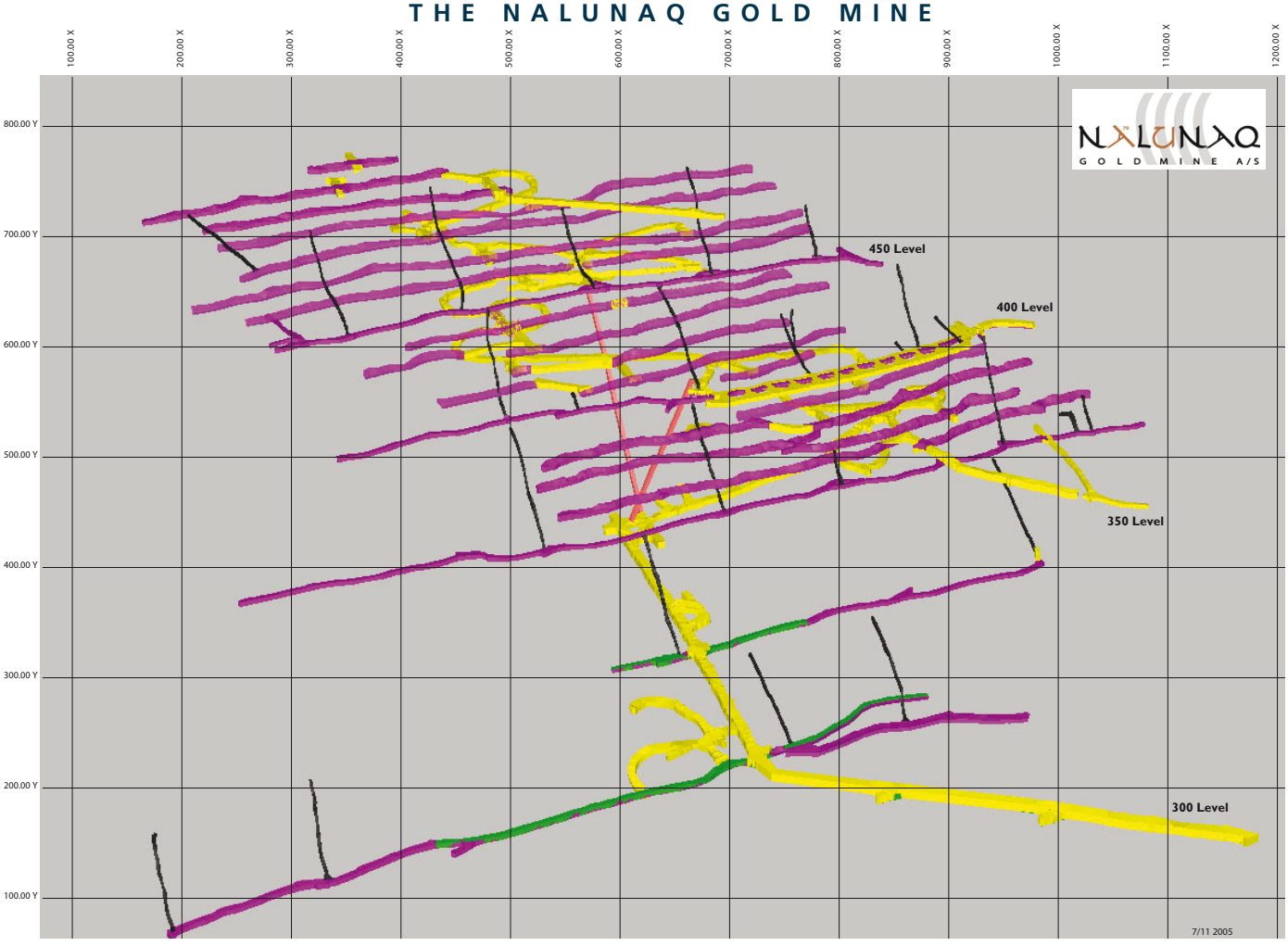
between three and ten years. Nalunaq is equipped with a fully functional assay laboratory, consisting of a preparation lab, a wet chemistry lab and an assay section with computerized AAS instrumentation.

Mine operations

The camp accomodate 100 people to manage the operation within the mine, in the camp and harbour. Mining operations and maintenance are contracted to Procon Mining and Tunnelling Ltd. of Canada on a labour hire basis. Mining equipment is owned by NGM and the Crew Gold Corporation. Locally contractors out of Nanortalik are engaged for surface ore haul, on-site construction work, catering and janitorial work. In total, over 35% of the employees are locally hired.

On-site, the ore is hauled by 25-tonne trucks to a 60,000 t capacity stockpile area at the harbour facility established on the Saqqaa fjord about 11 km from the mine site. When there is sufficient ore, a ship is requested from Western Bulk Carriers with whom the mine has an annual contract. Bulk carriers with 20–30,000 t capacity are loaded at the Nalunaq port for delivery to the Nugget Pond processing facilities.

The Nalunaq mine has posed considerable challenges due to the geometry of the

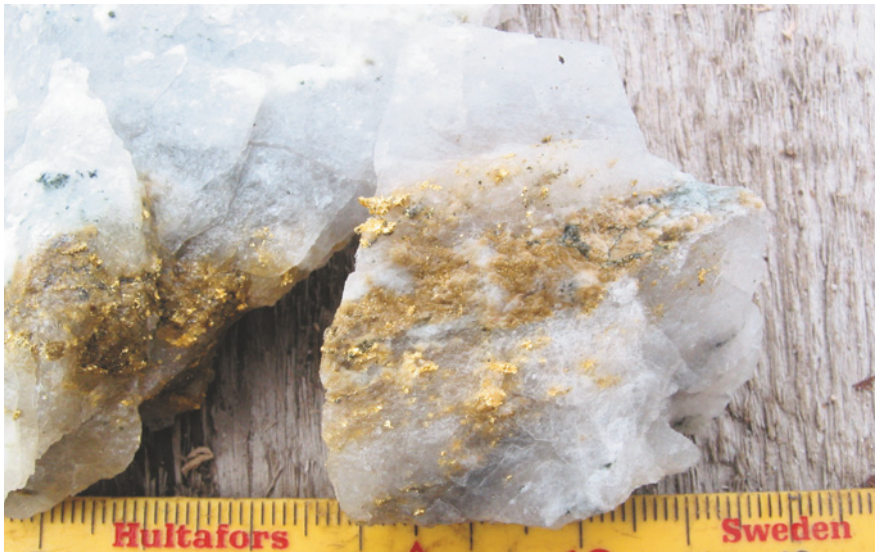


The layout of the Nalunaq Gold Mine with the three main levels, drifts and raises in a 3-D model presentation, November 2005.

Main Vein. The typical situation in the mine is a narrow average vein width of 0.7 m, with a 30–40 degree dip. The narrow width calls for a high degree of drilling and blasting accuracy to prevent dilution, and the dip both precludes efficient footwall layouts for mechanised mining and requires additional rock handling activities to ensure that the ore is successfully transferred to the bottom of the stope for later pick-up.

The preferred mining method is longhole open stoping, which comprises development of sub-levels horizontally along strike at 10 m intervals in vertical spacing, resulting in ore blocks of about 14–16 m length on dip. The sub-levels are either mined as a full face or in two cuts separating the ore and the waste. The block between two sub-levels is then subdivided into 15 m wide stopes between 1.5 m rib pillars for stability. A stope thickness of 1.4 m is endeavoured and each stope is drilled with blast holes up-dip using a ring box pattern. Following stoping and removal of the ore, the stope has to be cleaned of any residual fine ore, some of which is high grade. The resulting stope cavities are unsupported and open to the sub-levels above and below. Nalunaq ore production rate is carried out close to the planned aim of 500 t per day.

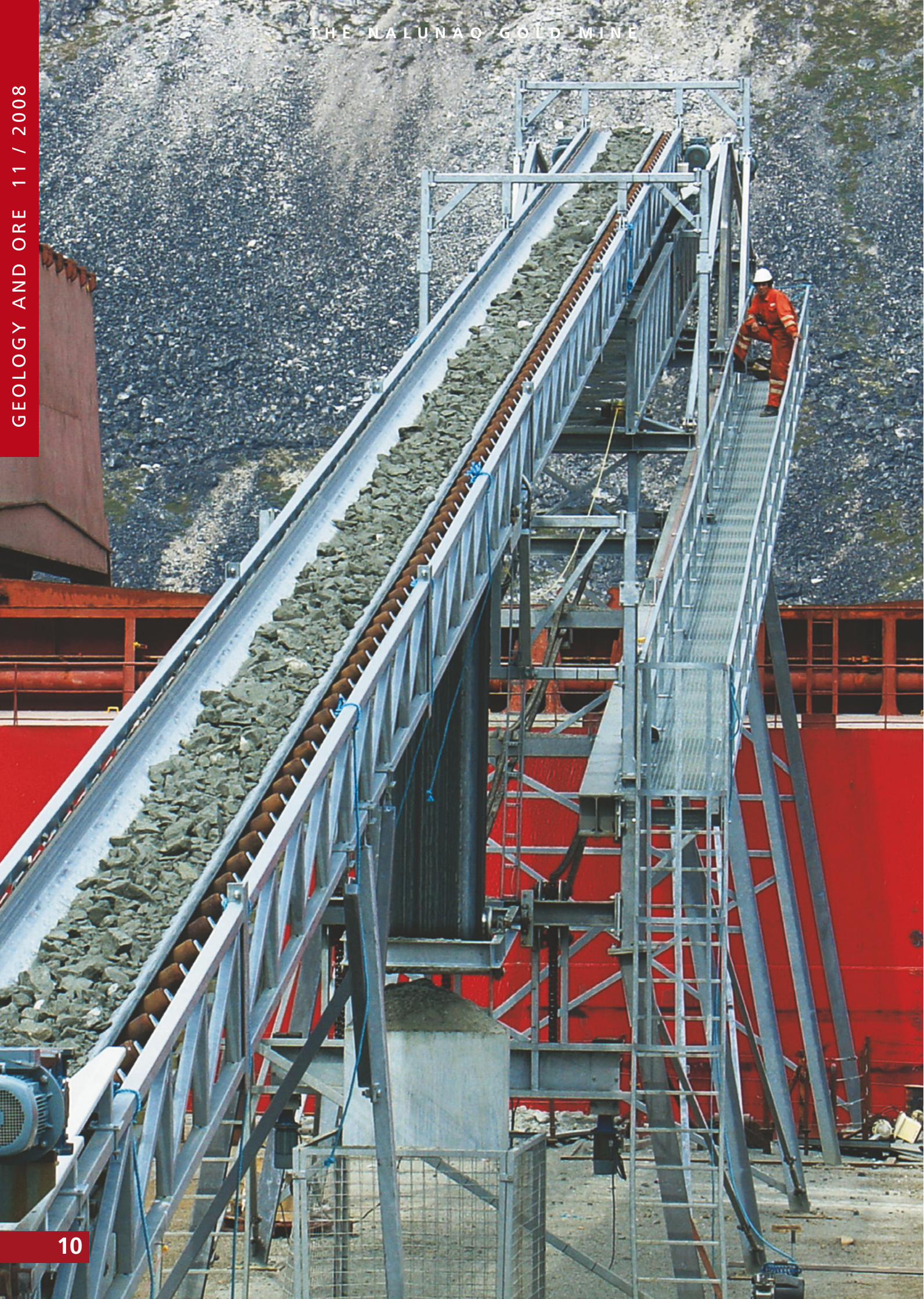
To access the sub-levels, from which all operations are carried out, a ramp and a number of mine adits have been excavated. Ore passes are used for transfer of mined ore.



Rock sample of quartz vein rich in gold grains.

Gold extraction

The amount of gold in the ore is rather erraticly distributed (nugget effect) with an average of 18 grams of gold per tonne of ore, but there are locally very rich parts that contain as much as four to five kg of gold per tonne of ore. Due to the fact that the gold occurs in quartz veins, on average only 0.7 m wide, the mining of the ore may result in a reduction of the gold content as it is impossible to avoid mixing of bedrock



The Saqqa Fjord filled with icebergs. A bulk-carrier preparing for leaving with a full ore load. To the right the port and in the centre the road to the mining camp in Kirkespirdalen. The landmark of the 1590 m high Kirkespiret mountain, is seen in the background.

A docking bulk-carrier at the Nalunaq port. Close to the pier is the location of the ore storage facility with a number of ore piles. The road connection to the Nalunaq mining camp can be followed along the coast line.

A working conveyor belt as part of the loading system for the vessels at the harbour facility.

with low gold content into the ore. The minerals in the gold ore are dominated by metallic gold. Various sulphide minerals in which gold occurs as impurities account for less than one per cent. This means that when the gold is extracted, it 'only' has to be released from the surrounding silicates (mostly quartz). In practice this is done by crushing and subsequent gravity separation where the high density of gold is utilised (19.3 g/cm3). This process can achieve a high recovery rate of close to 100%. Once the gold has been extracted from the ore, it is easily melted and cast into ingots for commercial sale. In practice smelting is carried out in several stages so that the slag material (from silicate residues) and impurities of silver, bismuth, antimony and arsenic are removed before the final commercially tradable pure gold (bullion) is produced. The smelting process is carried out outside Greenland at the smelting plant at Nugget Pond in Canada.

Concluding remarks

Nalunaq is a high-grade deposit of gold in quartz veins. The individual quartz veins are between 0.1–2.0 m thick, averaging 0.7 m. The gold-bearing structure has a regional scale, and it is therefore expected that the amount of ore is much larger. Production of gold from Nalunaq is targeted to amount to four tonnes of gold per year.

In the wake of the successful start of the mine it has been natural to seek for an extension of its productive life. In order to reach the goal of extending ore reserves exploration activities have been initiated in both the mine area and in the surrounding areas with potentially gold-bearing rocks. Outside the mine area the mining company

The first output: a 1 kilo Fine Gold bullion (No. A 00001) produced from the Nalunaq Gold Mine.

An example of the use of Greenland gold: a couple of 22 K wedding rings with a Polar Bear mark visible. Artist: Goldsmith Nicolai Appel, Copenhagen, Denmark.

has been granted additional exploration licences, which in total covers an area of around 500 km^2. At present, activities within the licence area have proven occurrences of gold mineralisation at a locality 20 km SW of Nalunaq and on the Niaqornaarsuk peninsular around 20 km NW of Nalunaq. Additionally there are various indications of gold at a number of other sites with corresponding geological environments.

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Front cover photograph
Underground view of a gold carrying quartz vein in the Nalunaq mine. Blue paint is marking the ore to be mined.

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