The Nalunaq gold prospect, South Greenland: test mining for feasibility studies

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The Nalunaq narrow-vein gold prospect is situated 40 km north-east of Nanortalik, the southernmost town in Greenland, 6 km inland from the fjord Saqqaa (Fig. 1). The exploration licence is held by Nalunaq I/S, a company jointly owned by Crew Development Corporation, Canada (67%) and NunaMinerals A/S, Greenland (33%).

A pre-feasibility study of March 1999 by an independent mining consulting company commented positively on the Nalunaq prospect (Nalunaq I/S, personal communication 1999). However, assessment of the sample database demonstrated considerable variation in grade estimates depending on the use of drillcores, chip or saw-cut samples as well as the capping levels (reducing the highest assay values to a fixed value). To advance this project to the feasibility level, the pre-feasibility study stressed the need for improved grade verification and demonstration of grade continuity.

In preparation for a feasibility study, a Can$ 9 million underground test mining and bulk sampling programme was executed during the summer 2000 field season. Strathcona Mineral Services Limited (Canada) designed the programme in conjunction with Nalunaq personnel. This report focuses on the field aspects of the programme; processing of field and laboratory data is still in progress (January 2001).

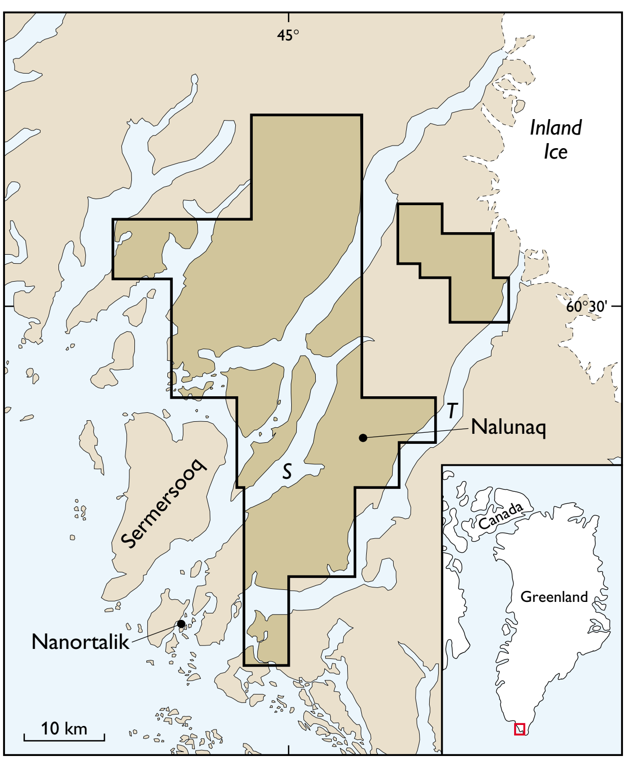

Fig. 1. Map of the Nanortalik region showing the location of the Nalunaq prospect. The framed area is the exploration licence outline. ***S***: Saqqaa; ***T***: Tasermiut.

Geological setting and previous investigations

The Nalunaq gold prospect (see Kaltoft *et al.* 2000 and references therein) is hosted by a Palaeoproterozoic sequence of mafic metavolcanics and dolerite sills metamorphosed under amphibolite facies conditions. The mineralisation is located in a shear zone, and consists of a system of quartz veins associated with calc-silicate alteration referred to as the 'Main Vein' (MV; Fig. 2). Gold occurs mainly in native form with grain size ranging from 1 micron to 4 mm (Fig. 3). The mineralised zone has a strike of *c.* 50° and dips at 25°–55° to the south-east. Two major dextral faults divide the MV into the 'Southern Block', 'Target Block' and 'Upper Block' (Fig. 2). Since 1992 the MV has been mapped and sampled for a distance of *c.* 2000 m on surface outcrops. Diamond drilling, totalling 11 452 m of core from 78 holes, has focused on the 'Target Block' and adjacent parts of the 'Upper Block' and 'Southern Block'. In 1998 a 288 m exploration adit at level 400 m above sea level was excavated in the MV for 205 m along strike within the 'Target Block'. In addition, two upwards-directed shafts (raises) totalling 39 m were excavated in the MV up-dip direction. Significant grade variations on a metre scale were

Geology of Greenland Survey Bulletin 189, 70–75 (2001)

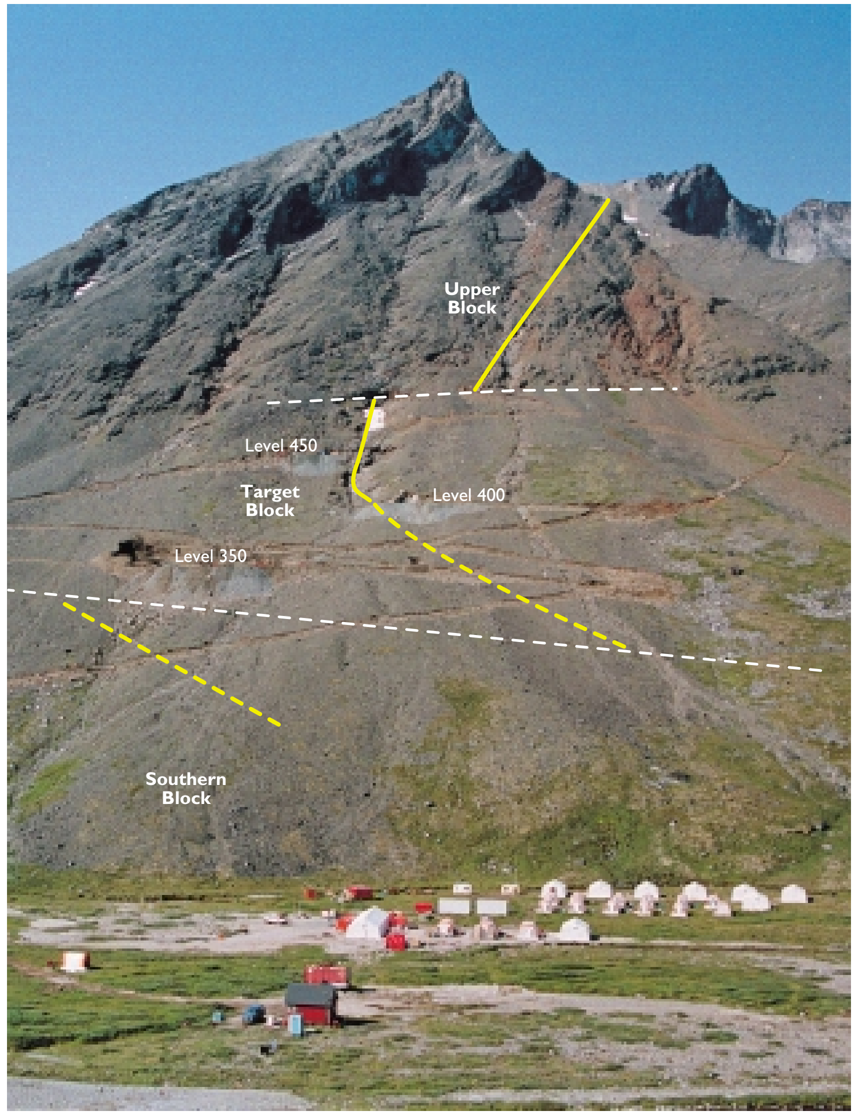

Fig. 2. The east face of Nalunaq mountain. The gold-bearing 'Main Vein' (MV) is traced in **yellow** (not to scale). **Full yellow line** indicates outcropping MV while the **dashed yellow line** indicates continuation of the MV trace below the talus as interpreted from core drilling. Two dextral faults (**dashed white lines**) divide the MV into the 'Southern Block', 'Target Block' and 'Upper Block'. The winding road provides access to the adit portals at levels 350 m, 400 m and 450 m. Mountain summit is *c.* 1100 m above the mining camp on the valley floor. Photo: Hans Christian Langager.

Fig. 3. Visible gold in a sample from the 'Main Vein' surface exposure between the portal at level 450 m and the snowdrift seen on Fig. 2. Grains, such as that on the left side of the photograph, are important contributors to the value of the deposit. Sample GGU 445683. Photo: Jakob Lautrup.

documented by chip and saw-cut channel sampling. Grades as high as 5240 g/t over 0.8 m were recorded from a saw-cut sample. At the current stage of exploration, indicated plus inferred gold resources of 425 000 troy ounces (~ 13.2 tonnes) with an average grade of 32 g/t are estimated. Taking into account a proposed mining method comparable to that used at a similar deposit, and including the losses due to extraction and dilution, the pre-feasibility study estimated a mill-feed grade of 27 g/t.

A geological exploration target of about 1.8 million ounces of gold (~ 56 t) is currently envisaged from the mineralised structure. This figure includes the indicated and inferred gold resources, plus an order-of-magnitude estimate based on geological modelling.

Programme objective

The prime focus of the summer 2000 programme was to investigate a section of the existing mineralised area in order to establish resources that would meet bank-financing requirements. The target amount of resources was based on the capital and operating costs detailed in the pre-feasibility study that would support a 500 tonnes-per-day (tpd) operation. Furthermore, the project needed to establish a strike length of at least 400 m in order to obtain the 500-tpd scenario of the pre-feasibility study.

To test the continuity of mineable gold grade (approximately 25 g/t over the mining width including waste dilution) the MV was exposed through the excavation of adits at three levels and construction of raises in the MV up-dip direction. This was combined with a rigorous scheme for geological mapping and sampling. The adit/raise design was set up to outline 80 × 80 m blocks within the MV plane (Fig. 4). The blocks were exposed and sampled on three or four sides, depending on their position in relation to the underground workings and the surface outcrops. Most blocks also included drill-hole intersections. The adits were advanced to expose the vein for a strike length of 400 m.

Grade verification was approached by extensive bulk sampling. This is a recommended industry practice for gold deposits with a significant nugget effect (John & Thalenhorst 1991). Each bulk sample was processed separately through a crushing/screening/sampling plant situated on the valley floor (see Fig. 6). To address the well-known problem of obtaining representative samples from broken ore, this part of the programme was based on sampling theory as formulated by Gy (1982) and extended by François-Bongarçon (1998). The purpose was to minimise the 'Fundamental Sampling Error' (FSE) occurring at each sample reduction step. To obtain calibration data for designing the sampling programme, Lakefield Research Limited (Canada) conducted bench-scale metallurgical tests on a number of existing MV samples. The overall FSE for an expected 20 000 t of Nalunaq bulk sample material at an average gold grade of 25 g/t was calculated to ± 2.5% (equivalent to ± 0.6 g/t). It should be noted that the 23 000 t actually mined to achieve the programme objective constitutes about 5% of the indicated plus inferred resources.

Underground work

Underground development totalled *c.* 1900 m of adits and raises (Fig. 4). The 1998 adit at the 400 m level was extended to a length of 400 m and two new adits were excavated at the 350 m and 450 m levels to lengths of *c.* 400 m each. In addition 13 raises were driven in the MV plane up-dip to lengths of up to 80 m. For practical reasons each advance of an adit heading (a 'round') was carried out by full-face blasting. The vein was deliberately kept in the middle of the advancing face for systematic geological sampling of both the hanging wall and foot wall structure (Fig. 5). In an actual mining operation the mineralised vein would be carried high up in the working face to allow the use of a mining technique (resuing) whereby the foot wall waste-rock of each 'round' is blasted and removed before blasting of the MV material.

A number of minor faults with dextral displacement were encountered during excavation of the adits. This necessitated offsetting the adits to the right to regain contact with the MV (the kinks on the adit outlines in Fig. 4). Some of the faults could be traced between the levels, and on occasions a raise was stopped prematurely in waste after intersecting the fault plane.

A 10 × 10 m test stope was mined to obtain information which will facilitate the choice of an optimal mining method of the MV between the sublevels. The aim was to test the minimum practical mining width to be achieved at conditions reflecting production mining. It would also allow observations on the rock mechanical properties of the hanging wall in particular, as this will influence the selection of stope dimensions during mine planning.

The excavated material (*c.* 70 t) from each adit 'round' was treated as a separate bulk sample. In contrast, four raise 'rounds' were combined to one bulk sample (a

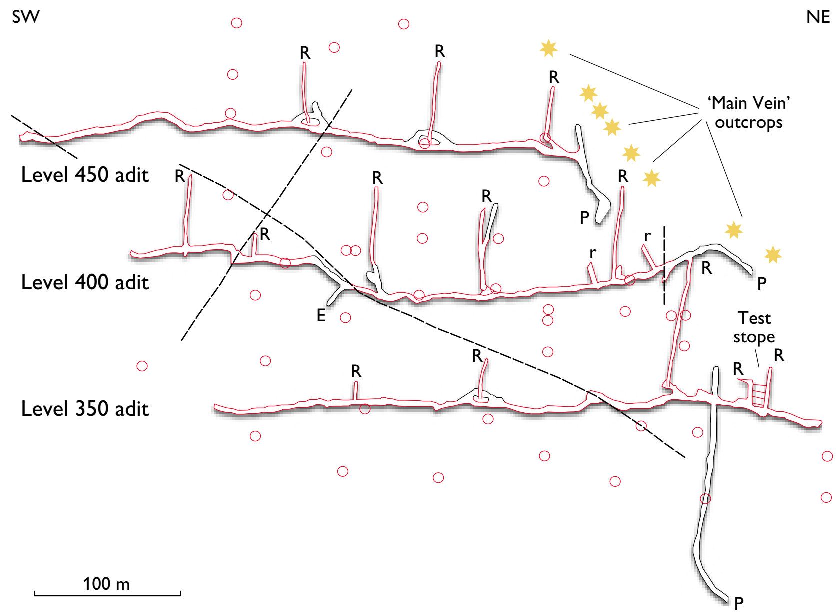

Fig. 4. Longitudinal section drawn in the plane of the 'Main Vein' (MV), which has a strike of 050° and is inclined at 40° to the south-east (average MV dip), showing adits and raises (**r**, 1998; **R**, 2000). **Black lines** indicate development in waste to access the MV; **red lines** indicate development in ore. The **red ribbed pattern** in the test stope illustrates mining of the ore by segments between the two short raises. The **dashed lines** mark the trace of minor dextral faults with metre-scale offsets. **Open red circles** indicate positions of drill-hole intersections with the MV. **Yellow stars** are MV outcrops. **E** is the end of the 1998 adit, and **P** the adit portal (visible on Fig. 2).

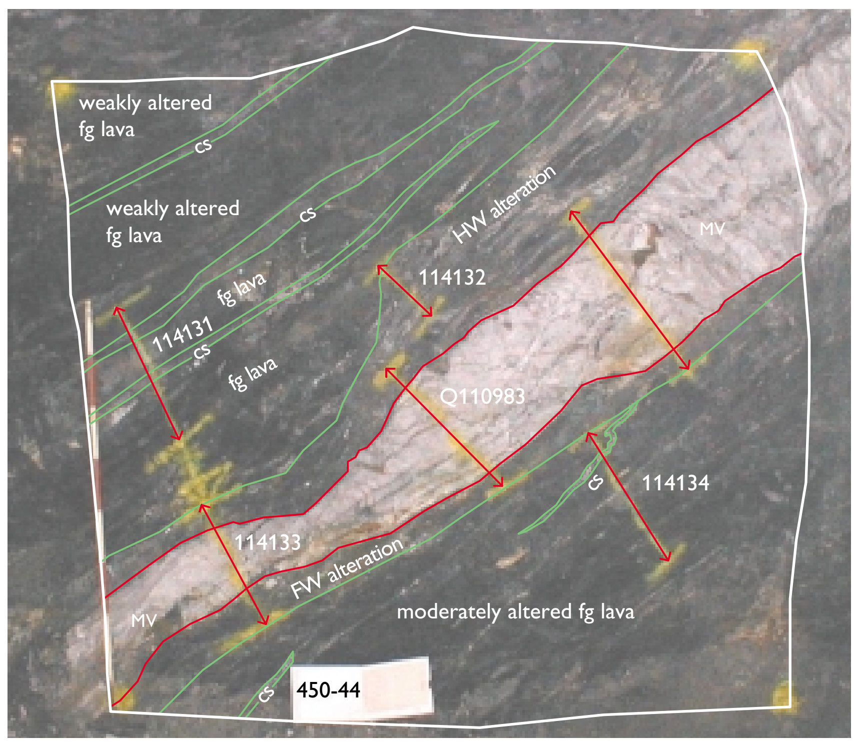

Fig. 5. Face for round 44 at level 450 (face limits shown by **white frame** with **white label** at the bottom of the face). The mapping and sampling routine is described in the text. **Green lines** indicate limits of calc-silicate alteration (**cs**). Other abbreviations – **fg**: fine-grained; **FW**: foot wall; **HW**: hanging wall; **MV**: 'Main Vein'. The **red lines** show the positions of the channel samples – **114131**: HW sample; **114132**: alteration zone; **114133**: MV sample (material from the three channels across the MV is combined to one sample); **114134**: FW sample; **Q110983**: 'quick' sample (chip) for immediate analysis (obtained parallel to the centre MV sample). **Bars** on the ranging rod are 20 cm long.

'raise segment') of about the same weight as one adit 'round'. Much attention was paid to recovery of all broken rock at the adit headings and below the raises. Temporary stockpiling during haulage was on a 'round-by-round' basis on numbered concrete pads. Each time a bulk sample was moved, the pad was thoroughly cleaned, and the recovered fines added to the sample in order not to lose gold grains liberated during blasting and haulage of the broken rock.

Each face was geologically mapped and sampled. The face map for 'round' 44 at the 450 m level is illustrated in Fig. 5. The position and outline of each face was surveyed in relation to the mine grid. 'Main Vein', alteration halo, shearing and other features were traced in

Fig. 6. Crushing and sampling plant at the valley floor below the 'Nalunaq' mountain (*c.* 500 m south of the camp in Fig. 2). See text for description of sample flow. Note the front-end-loader beside the sample tower and the person near centre of photograph for scale. Photo: Hans Christian Langager.

detail and the presence of visible gold noted. The layout for the saw-cut channel samples (2–4 kg) is shown on Fig. 5. Three samples were taken across the MV extending a few cm into the wall-rock to include gold located at the MV/wall-rock contact. The material from the three MV samples was combined to one sample. Depending on the width of the alteration zone, this phase was sometimes sampled independently in continuation of one of the MV samples. Samples were also obtained from the hanging wall (HW) and the foot wall (FW). A supplementary chip sample was taken parallel to the centre MV sample for immediate analysis. Raises were chip-sampled only, due to practical considerations. All map and sample information was digitised and saved together with a digital photograph of the face as individual layers in MapInfo (Geographical Information System). The area of the map units (MV, alteration zone, HW and FW) was determined for each face as part of the digital processing.

All the face samples were analysed by XRAL Laboratories (Canada) by the Screen Fire Assay method. When assay data become available, the corresponding sample grade will be assigned to each of the geological map units together with a specific gravity from the calibration tests on Nalunaq reference samples by Lakefield Research Limited. The grade of each face will then be estimated by weighting grades by area and specific gravity. The estimated grade of a 'round' is the average of the two enclosing faces and will be compared to the grade of the corresponding bulk sample.

Bulk sample processing

The crushing and sampling plant is shown in Fig. 6. A total of 388 bulk samples were processed. A front-end loader feeds coarse blasted rock from one of the pads to a two-stage crushing circuit for reduction to less than 20 mm ('fine ore'). This material is hauled to one of the 'fine ore' bins.

'Fine ore' is fed to the top of the sample tower (Fig. 6) by a conveyor belt. On its way down the tower the 'fine ore' is passed through three consecutive sample splitters. A roll crusher is positioned between the second and third splitter for further reduction of the sampled 'fine ore' to less than 6 mm. The sample material from the third splitter is manually fed through a riffle splitter, until the field sample of *c.* 35 kg is obtained. This is equivalent to 0.05% of the 70 t tower feed from a typical adit 'round' or 'raise segment'.

The rejects from the two first splitters are discharged to a pile beside the tower. Rejects from the two last splitters are collected in a numbered tote bag. After weighing (0.8–1 t) the tote bag is stored as reference material.

The tower rejects were hauled to either the 'high grade' or 'low grade' rejects pile (Fig. 6). This distinction is based on the geological face mapping, where observations of visible gold in the corresponding face automatically classify a bulk sample as 'high grade'.

The field samples were shipped to Lakefield Research Limited for laboratory treatment. At the laboratory, gold was determined by the Screen Fire Assay method following several stages of screening/crushing/splitting.

Implications for mining

With respect to adding tonnage to the resource, the 400 m and 450 m levels are encouraging, as they were both advanced beyond the innermost drill section, and thus tested new ground (Fig. 4). Grade data are not yet available, but repeated observations of visible gold are a positive indicator.

The bulk sampling results from the adits and raises cannot be taken as a direct prediction of a production mill-feed grade, because the full-face advance would include a substantial amount of waste, compared to the resuing method to be applied during production mining. However, the grade of the bulk sample can be calculated over the width of the MV due to the detailed measurements of face size and MV size during the development. The bulk sampling results will provide a reliable estimate of the amount of gold contained in the excavated material. As this information is available on a 'round-by-round' basis, these numbers can be used both to test the continuity of gold mineralisation and to outline patterns in gold distribution in strike and dip directions. These figures can be compared to the calculated grades from the face samples, to ascertain how channel/chip sampling can be used to predict grades. This will also allow selection of capping levels based on the specific conditions of the deposit, rather than using standard statistical techniques.

The geological mapping programme provides information for detailed mine planning. The pre-feasibility study suggested mining by development of sublevels using the resuing technique. Extraction of the blocks between the sublevels would then be undertaken by long-hole stoping. A detailed control on fault geometry will be essential for stope layout. The acute angle of intersection observed between some of the faults and the MV (Fig. 4) indicates that a fault may influence a substantial part of a stope block, and this will have to be taken into account during stope design. The work in 2000 also demonstrated that much of the waste development required to access the vein for mining in the 'Target Block', as proposed in the pre-feasibility study, will not be required as the mineralised material can be brought to the surface and taken down to the process plant. Furthermore, observations from the raises showed the vein to be much straighter than anticipated between the levels, which should allow for longer dimensions between the sublevels thereby reducing the required access development.

If a mine is established, then the existing adits can be incorporated as sublevels in the mine. Furthermore, the 23 000 t of tower rejects will constitute a measured resource.

Acknowledgements

We thank Nalunaq I/S for generous permission to use unpublished exploration information. M.L. wishes to thank Nalunaq I/S and the Bureau of Minerals and Petroleum, Government of Greenland, for the invitation to visit the project site, and Henrik Thalenhorst, Strathcona Mineral Services Limited, Canada, for his thorough introduction to bulk sampling practice.

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