Acta Geodyn. Geomater., Vol. 8, No. 3 (163), 335–344, 2011

# MONITORING SYSTEM FOR OBSERVATIONS OF ROCK MASS DEFORMATIONS CAUSED BY SUBLEVEL CAVING MINING SYSTEM

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(*Received* January 2011*, accepted* June 2011)

**ABSTRACT**
The Rana Gruber iron oxide mining company in Norway has started to develop a new underground production level in order to continue operation in the Kvannevann mine. The planned change of mining system to sub-level caving (SLC) involves the removal of protective pillars below the former Kvannevann open-pit. Surface deformation on the hanging-wall and footwall sides of the deposit and caving of rock into the old pit is expected. When uncontrolled, this represents a threat to the underground mining operation below the open-pit. Trial removal of the protective pillar in the western part of the deposit has already caused fracturing of the rock mass on the hanging-wall side. Therefore, with the aim to monitor and control the rock mass deformation process in this area and ensure safe operation of the mine, a monitoring system based on periodic total station and GPS measurements in a three-tier control-measurement network has been developed and tested. In this paper the concept of this system, results of field work and recommendations for the system implementation is presented.
The proposed concept has been used to implement a real system in the mine.

**KEYWORDS:** rock deformation, sub-level caving, monitoring, Kvannevann mine,

## 1. INTRODUCTION

Reliable monitoring of rock mass surface deformations associated with mining activity and taking the correct counter-measures requires a carefully designed and implemented control-measurement system. Such a system should provide high quality data necessary to complete required analyses to ensure the safe operation of the mine and minimisation of threats to its surrounding.

The Kvannevann iron oxide mine in Northern Norway is currently using sublevel stoping system (SLS) to extract the hematite / magnetite ore. However, in order to increase mining capacity and reduce production costs, decision has been made to change this system to sublevel caving system (SLC). The SLC requires the ore body and surrounding rock mass to fracture under controlled conditions to ensure the safety of mining operation. The mine area is characterised by very specific rock mass conditions in the form of large horizontal stresses (Trinh and Sand, 2011). At the present time, the mine does not have any rock mass deformation monitoring system, which could provide information on rock mass surface behaviour.

In 2009 the mine started preparatory removal of the first protective pillars in the western part of the abandoned Kvannevann open-pit and parts of the crown pillar separating the stopes from the surface (bottom of the pit). This activity has already caused rock mass deformations manifested on the surface in the form of cracks parallel to the hanging-wall of the pit. In order to monitor state of the rock mass and possible rock failure during mining activity the company considers implementation of a control-measurement system providing data on geometrical state of surface to prevent possible losses associated with uncontrolled rock mass movements. The system should provide information on rock mass surface changes with several cm accuracy. The mine expects to start the new production level at the end of 2011.

In the paper a concept of a complete monitoring system designed for measurements and analysis of magnitude and rate of rock mass surface deformations and taking into account specific conditions (among other things location and climate) of the mining operation in Kvannevann, as well as expected deformations, based on numerical modelling realised by the SINTEF Rock Engineering (Trinh and Sand, 2011), has been described.

## 2. DESCRIPTION OF THE KVANNEVANN MINE

The mine is located in the Ørtfjell mining area approximately 6 km northeast of the village of Storforshei (Northern Norway). It extends approx. between E14.64–14.74 degrees and N66.41–66.43 degrees. The nearest town Mo i Rana is

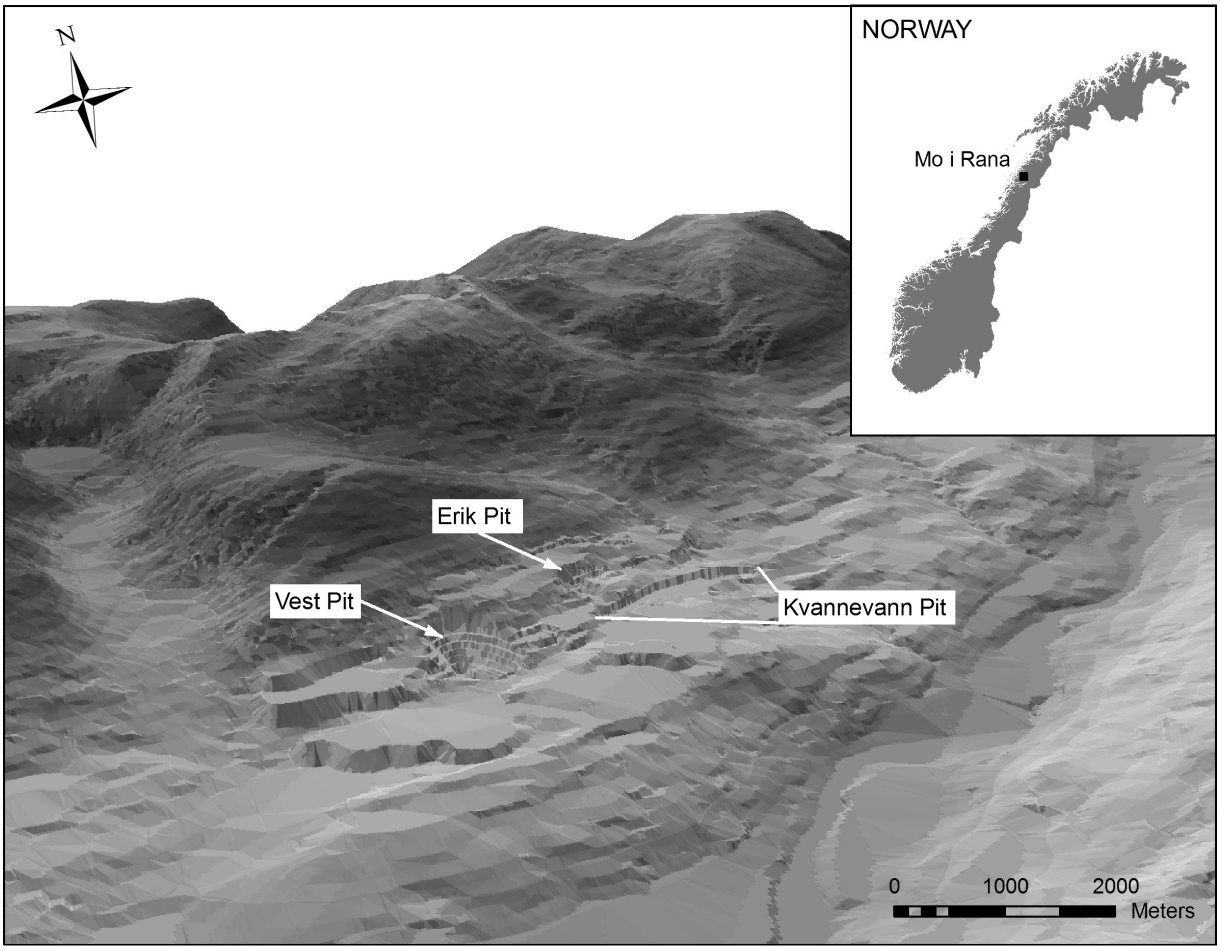


**Fig. 1** Digital elevation model of the analysed area with marked three old open pits - Kvannevann iron oxide mine.

located about 27 km to the South. The mine is operated by the mining company Rana Gruber AS (Rana Gruber, 2007).

The analysed area shown in Figure 1 is situated on the south facing slope of the Dunderlandsdalen Valley. The valley floor lies at about 80 m above the mean sea level, the mountain ridge, to the North of the mine, reaches over 1000 m (with the Eiterågfjellet being 1020 m high). Elevation of the mining area varies from about 250 m to 550 m above mean sea level.

There are three old open pits in the area: the West Pit, the Erik Pit, which is partly filled with water and the Kvannevann Pit, under which underground mining now takes place. There are also numerous waste rock dumps. The mining area, measured as the circumference described on the above-mentioned objects covers approx. 4.5 sq km. The Kvannevann open-pit is about 1 200 meter long and 100 meter wide with the floor at approximate elevation of 360 m. The height of the hanging-wall face from the pit floor ranges from 40-45 m in the western part to approx. 70-75 meter in the eastern part. The footwall face is about 15-30 m high in the western part of the pit, the eastern part is open.

The West-, Erik- and Kvannevann pits are the remains of surface mining that ended in 1999 when the sublevel stoping (SLS) mining system was introduced. In the SLS method, the ore body has been divided into separate stopes, about 40 m wide, 100 m high and from 50 to 70 m long with protection pillars left between them to support the hanging-wall. There are two main production levels at elevations 320 m and 250 m respectively. The upper production level is separated from the surface (bottom of pit) by a crown pillar approx. 30 m thick. The locations of the production levels are shown in Figure 5. The length of production levels is about 1.1 km (Ellefmo, 2005). The mining company will open a new production level approximately 125 m below the current 250 m level (Rana Gruber, 2007). Preparations for the SLC mining system have already started. These include: developing of access for the new underground level, removing of pillars in the western part of the Kvannevann pit and parts of the crown pillar and the development of a underground crusher, which is going

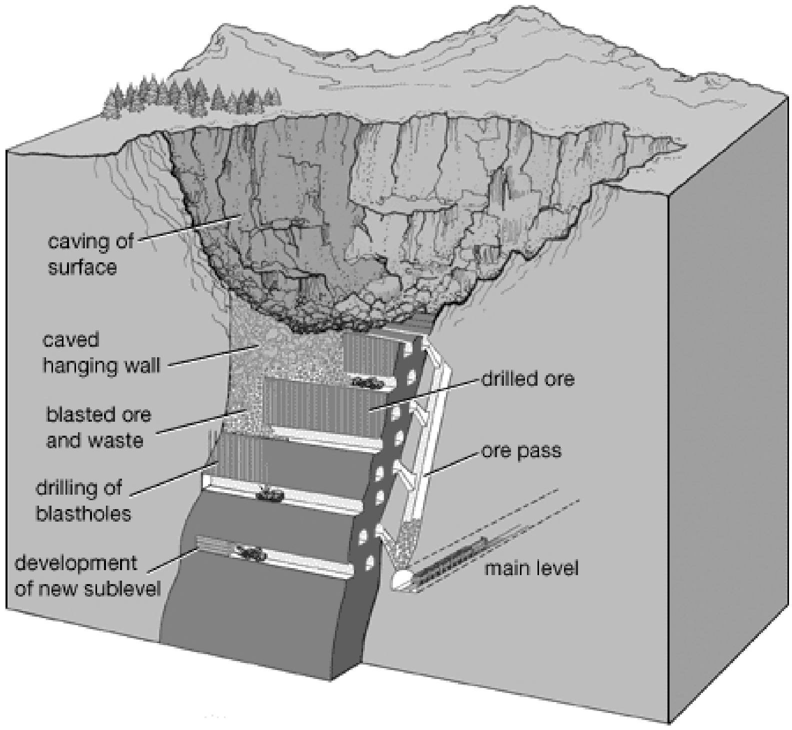


**Fig. 2** Illustration of the sublevel caving (SLC) mining system (Hamrin, 1980).

to be coupled to the existing silo- and tramming system via a new belt drift.

## 3. SUBLEVEL CAVING MINING SYSTEM

The sublevel caving (SLC) mining system is used for large, steep, continuous ore bodies such as at Kvannevann one. The deformations caused by this method are considerable and result from gravitational forces and redistribution of stresses induced in the rock mass. In this mining system ore is extracted through sublevels, which are developed in the deposit at regular vertical spacing. Each sublevel features a systematic layout with parallel drifts along or across the ore body (Smith, 2003). The rock is excavated without backfilling and the hanging-wall caves into the void left behind. As a consequence hanging-wall and to a lesser extent foot-wall deformation is an anticipated effect as the rock is expected to fracture and collapse following the cave. The general scheme of the SLC system to be used in the Kvannevann mine is shown in Figure 2.

Three distinctive deformation zones, parallel to the production levels, can be identified on the surface above mine. These are: caving, fracture and continuous deformation zones. The first one occurs vertically above the exploited level. The second one consists of fractures on the surface that can be hidden due to vegetation or waste rock deposits. The deformation zone is identified as the area where rock mass surface deformations due to mining can be measured.

The extent of the deformation zone can be expressed as the angle between the horizontal and the line joining the actual mining level and the furthest measured deformation, described on a section perpendicular to the axis of the orebody. According to (Henry et al., 2004; after Lupo, 1996) this angle is estimated at 40 to 60 degrees. The angle of the line separating deformation and fracture zones varies between 60 to 80 degrees to the horizontal. The area influenced by ground deformation and fracturing increases with depth of mining.

## 4. ROCK MASS DEFORMATION ANALYSIS

As has been mentioned, SLC mining system requires adequate and controlled caving of the rock mass surrounding the mined deposit. In order to estimate the influence of mining on hanging-wall and footwall of the deposit, the Rana Gruber mining company has commissioned studies or rock mass deformations. The calculations have been done using 2D Finite Element Method (FEM) model and RocScience Phase 2 software. The results have been presented, among other things, in (Sand and Trinh, 2011) and (Trinh and Sand, 2011). The model has been constructed for six stages (present condition, crown pillar and vertical pillars removed and four sublevel caving levels at 221, 187, 153 and 123 m respectively). The model extends perpendicularly to the Kvannevann pit in its middle.

The main input parameters used for numerical modelling have been shown in Table 1. For waste

**Table 1** Input rock mass and ore body parameters for FEM numerical modelling (Sand and Trinh, 2011).

| Parameter | Unit | Rock mass (mica schist) | Ore body |
|---|---|---|---|
| Max. principal stress [$\sigma_1$] | MPa | 20 | 20 |
| Min. principal stress [$\sigma_3$] | MPa | 10 | 10 |
| Poisson's ration [ν] | - | 0.20 | 0.25 |
| GSI | | 70 | 60 |
| Deformation modulus [E] | MPa | 32000 | 23000 |

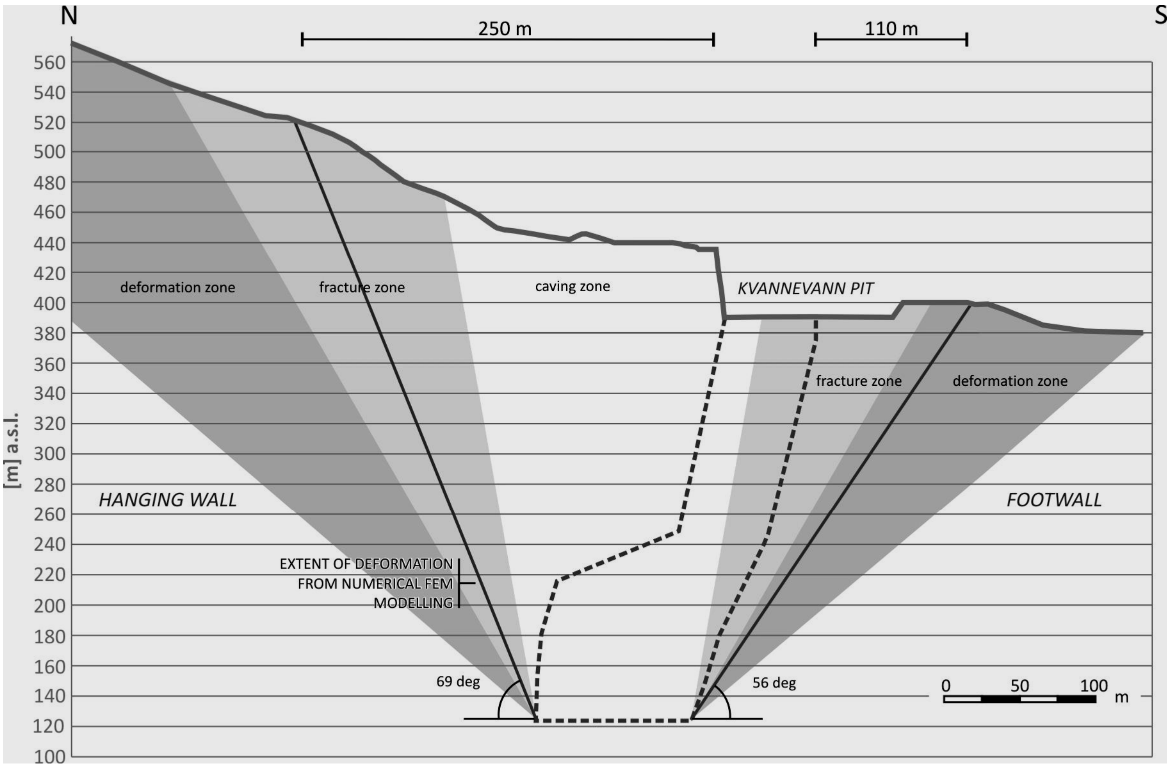


**Fig. 3** Simplified cross-section through the Kvannevann pit and generalised orebody (dashed line) with the estimated zone of deformations given by the inclined lines (after Sand and Trinh, 2011) and representation of deformation values found in literature (grey zones).

rock the following parameters have been assumed, stress equal to body weight, unit weight = 0.02 MN/m$^3$, Poisson's ratio [ν] = 0.25, angle of fiction [ϕ] = 20 degrees and deformation modulus [E] = 250 MPa.

It can be seen from the table that rock mass in the mine area is characterised by very high horizontal stresses that have to be taken into consideration when planning and carrying out mining activity there (Sand and Trinh, 2011).

Results of numerical modelling with FEM indicate that the maximum extent of deformation zone when SLC mining reaches the bottom sublevel at 123 m will be approx. 250 meters from the edge of the Kvannevann pit on the hanging-wall side (Sand and Trinh, 2011) and approx. 110 meters on the footwall side (Trinh and Sand, 2011). On the hanging-wall side deformations may reach the edge of the old Eric pit and on the footwall side operational road. The extent of estimated deformations given by angles between the horizontal and the line joining the actual mining level and the calculated deformation against the range of values found in literature is presented in Figure 3.

Preparations for the new production level, that is removal of parts of protective pillars described in section 2, have already caused rock mass deformations. Several fractures of various sizes have

**Fig. 4** View of the largest fracture (photo taken, 22.05.2009)

developed on the hanging-wall in the area of the removed pillars (western edge of the Kvannevann pit). The width of the largest fractures, extending for several dozen meters, reached over 20 cm shown in Figure 4 - a photograph taken, by the authors, during field investigations in May 2009 when fractures were discovered. Since then (in Autumn 2009) the part of rock mass between the edge of the pit and the first set of fractures has collapsed into the cavity and new fractures (2010) have developed also on the footwall side (Trinh and Sand, 2011). The Rana Gruber Company plans to finish preparatory work by the Autumn of 2011.

## 5. ROCK MASS DEFORMATION MONITORING SYSTEM

Caving of the rock mass, surrounding the mined deposit, in a controlled manner to ensure safe operation of the mine, as well as verification of the numerical modelling results suggested by (Sand and Trinh, 2011) requires a geodetic or other control-monitoring system providing actual information on rock mass behaviour.

The authors have proposed a system for the Kvannevann pit following extensive research that included: analysis of principles of deformation monitoring on mining grounds, functionality of available measurement techniques for the Kvannevann area, examination of similar examples found in literature and selection of design criteria corresponding to the site characteristics.

The control-measurement system has been designed taking into account two sets of co-dependent factors, spatial and temporal. The first group includes: accurate locations and stability of reference and controlled points, fixed reference system and accuracy of measurements. The second one includes starting time of measurements, interval of measurements, and processing time of results (Cacon, 2001). The most important spatial factors are location and stability of points. These should correspond to, among other things, local geological and rock mass conditions, mining plans and expected area of mining influence for construction and placing of network points (reference, observation and controlled) (Pielok, 2002). Starting time of measurements is significant as

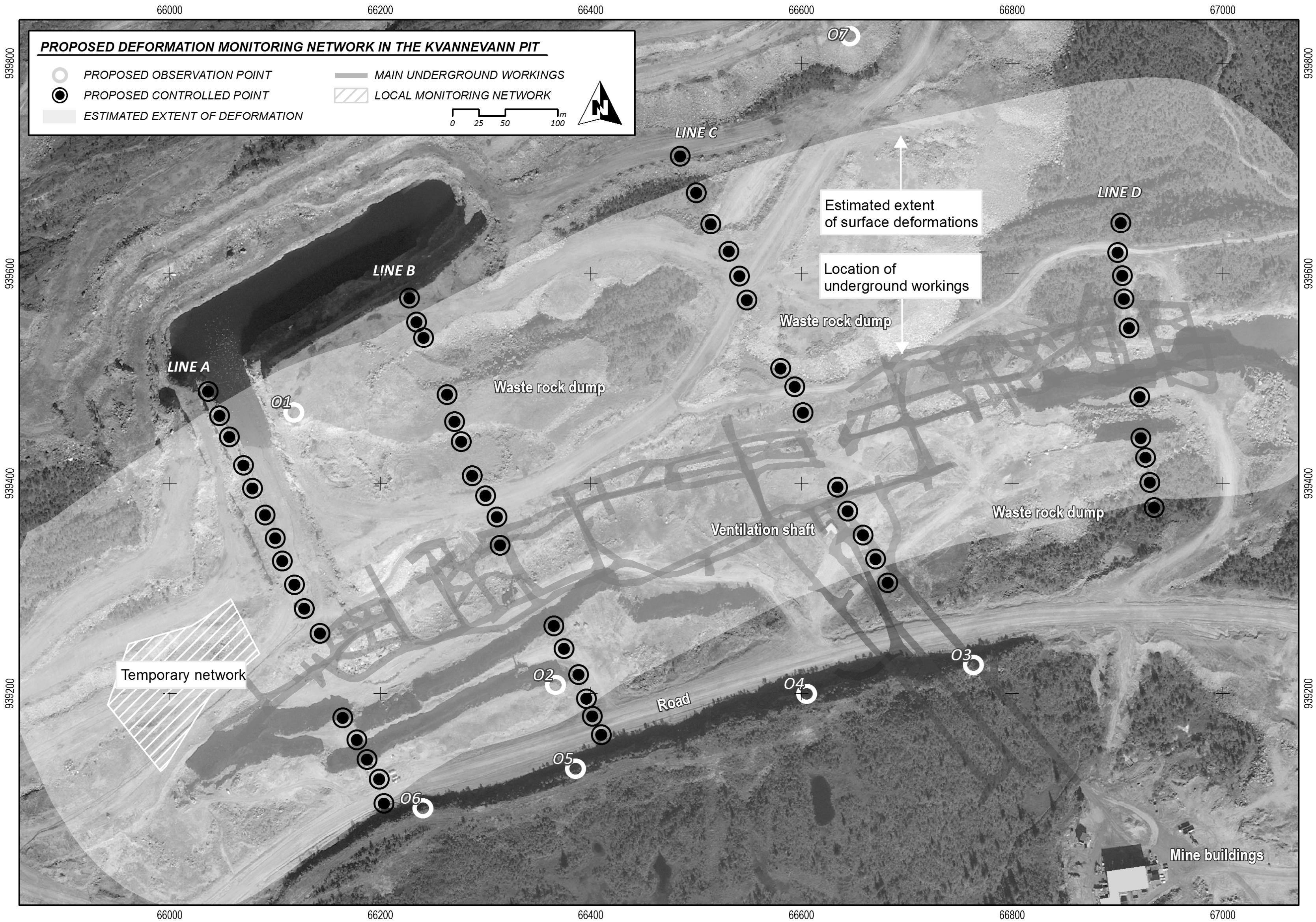


**Fig. 5** Locations of controlled and observation points against the background of the production levels, estimated zone of deformation and surface features.

observations started late i.e. during construction or operation stages provide data for analysis and interpretation of effects only as the state of undisturbed rock mass remains unknown. Knowledge (from measurements) of the initial (undisturbed) state of rock mass allows a more thorough analysis of what causes the deformations.

The main criteria considered for developing the deformation monitoring system in Kvannevann mine included:

- varied topography of the area characterised by sloping surface, waste rock dumps, old pits and other mine features described in section 2,
- local climate characterised by long winters and long lasting snow cover,
- geological and rock mass conditions,
- history of mining and plans of mining operation (staged development of SLC production level),
- required accuracy (several cm), interval of measurement (twice a year) and density of controlled points suggested by rock mass engineers and mine planners,
- available surveying equipment and geodetic expertise of mine personnel.

Various, available measurement techniques have been analysed in terms of their applicability for the Kvannevann site: satellite GPS observations, Total Station angle-distance measurements, aerial laser scanning, satellite interferometry, relative measurements (extensometer) and other (Blachowski, 2009). Combined satellite GPS observations and total station measurements have been selected as the best technique. The proposed solution is based on repeated total station angle-distance measurements, taken from stable observation points in a network of controlled points set up in the rock mass surface. Observation and reference points are measured with GPS receivers.

### *5.1. CONTROL AND MEASUREMENT NETWORK*

The proposed control-measurement network for the Kvannevann mine to be measured with Total Station and GPS consists of three groups of points: reference, observation and controlled points. Preliminary locations of the points have been chosen taking into account the above mentioned factors and detailed field investigations.

The network design has been shown in Figure 5, against terrain features (aerial photography), underground workings and estimated zone of deformations. The controlled points are located in lines approximately perpendicular to the Kvannevann pit and underground mining levels. The length of each line is approx 250 to 300 m on the hanging-wall side and 100 to 150 m on the footwall side and exceeds the estimated extent of deformation on both sides of the old pit (section 4). There are four lines parallel to each other and spaced approximately 250-300 m apart. Distance between the lines has been set in consultation with rock mass engineers and mine planners. Location of the lines takes into account mine plans (e.g. line C is located near existing ventilation shaft) and surface features. The lines avoid waste rock dumps (e.g. those visible between lines B and C, as well as C and D on the hanging-wall side) and end at the edge of the Eric pit (lines A and B) (Fig. 5). The distance between controlled points in each line has been set on average at 30 m depending on topography and surface features. However, the controlled points will be spaced further apart approaching boundary of calculated deformation zone (40-50 m).

Seven locations for observation points used to measure controlled points have been selected. These are located both within the mining area (two) and outside (five). The proposed locations allow observations of all of the controlled points irrespective of land features. Points located on the ridge south of the road leading to mine buildings (named O3 to O6) can be used to measure most of the controlled points on the footwall side and hanging-wall side. The remaining ones can be measured from locations O1 and O7.

Two reference points made of national GPS network points located several km away from the mining ground will be used for control of the deformation monitoring network. Positions of observation points will be determined with satellite GPS measurements in relation to reference points located in stable conditions.

To mark controlled points metal (aluminium) rods able to withstand harsh weather conditions will be used. These are approximately 3 meter long (3-5 cm in diameter) and will be placed in holes drilled in the ground to a depth of approximately 2 meter, below ground freezing level and protrude above possible snow cover. The rods will have metal spheres firmly mounted to the top and total station measurements will be taken to the centre of a sphere. A prototype of the aluminium sphere (5 cm diameter) is shown in Figure 6. Such a construction has been designed as these points will be too dangerous to access by mine personnel during mining operation with the SLC method. This is also why GPS measurements of controlled points have been rejected.

The observation and reference points will be constructed as reinforced concrete pillars with heads for forced centring of measurement equipment and cover protecting it from possible damage. These points are stabilised on bedrock or in the ground to a depth below ground freezing level.

### *5.2. FIELD WORK*

As have been mentioned, during field investigations proposed locations of controlled and observations points have been analysed and chosen and their positions recorded with GPS unit. These locations take into account land features: waste

**Fig. 6** Prototype of the metal sphere mounted on a drilling rod (photo Gunnar Nilsen, 2010).

dumps, pits, roads, routes of mining equipment, etc. Visibility between the controlled and observation points has been verified and applicability of mine's total station equipment tested.

A temporary local monitoring network consisting of seven lines (5 to 7 controlled points in each one), one observation and two reference points has been set up on the hanging-wall side in the western part of the Kvannevann pit. Its general location is shown in Figure 5 and detailed in Figure 7. It has been used to detect possible further rock mass deformation in the area where fractures were detected and to test the proposed monitoring scheme on a local scale (Blachowski, 2009*)*. Periodic observations carried out in May and June of 2009 on this site proved functionality of the adopted control-measurement network design. The network was surveyed four times at 24-hour interval and then 20 days later with mine blasting activity in between.

The results have been analysed as a time series for given points and movement of points in a given line perpendicular to the pit. Results indicate significant horizontal movements of 1.6 to 6.1 cm (more than double value of measurement error) in all the lines for points located between the edge of the pit and the first line of fractures (Fig. 7) between the first and last series of measurements. No significant movements have been registered for the first four measurements. These preliminary results could indicate movement of rock mass towards the pit, which could be a reaction caused by mining activity on pillars between analysed measurements. However, as the measurements had to be stopped definite conclusions on the source cannot be given. Detailed results of the tests have been presented in (Blachowski et al., 2009; Blachowski, 2009).

## 6. RECOMMENDATIONS FOR THE MONITORING SYSTEM

The purpose of the proposed deformation monitoring system is to collect data for analysis of rock mass changes in time (movement, shape) and

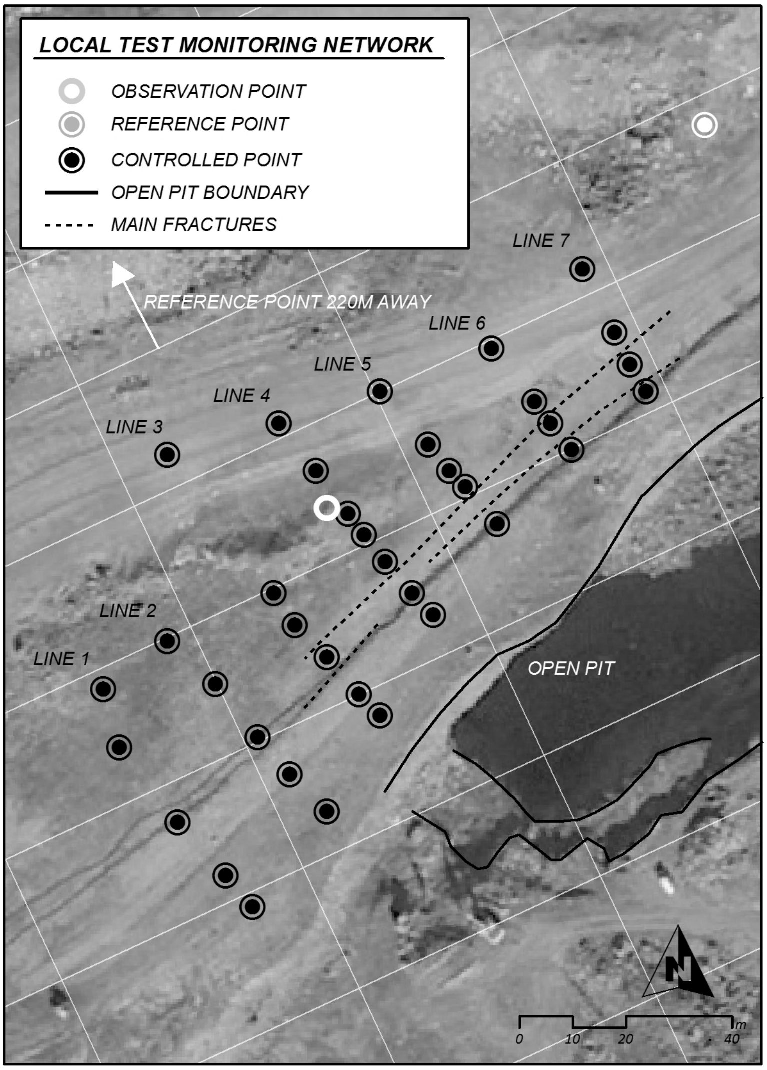


**Fig. 7** Local, temporary, monitoring network.

provide feedback information for numerical models of deformation (FEM). Repeated measurements of points provide their positions at the time of measurement. Geometrical comparison between two sets of positions (from successive measurements) produces displacement in the X, Y and Z directions in that period. Three or more sets of observations allow the determination of the velocity of movement. If the controlled points make up a line perpendicular to the mining levels then profile of displacement or velocity values can be produced in a cross-section of the ore-body.

Measurement results, coordinates (X, Y, Z) in a given measurement epoch, calculated movements of controlled points ($\Delta X$, $\Delta Y$, $\Delta Z$) between successive measurements and their velocities should be analysed in a GIS system in relation to the geology, geotechnical information, mine operating plans and with topographical and other thematic data. It should be presented graphically on maps and cross-sections (geological) along control lines.

At least two measurements of controlled points a year in Spring and in Autumn are proposed. However more frequent measurements are recommended, especially in early stages of SLC operation and after rock blasting. In addition, periodically (e.g. once a year) satellite GPS measurements of the network (with reference to national GPS network points outside the mining area) have to be made to control the stability of the mine network. It should also be noted that due to long time mining operation the initial, “undisturbed”, geometrical state of rock mass cannot be recorded. Therefore it has been advised to start the measurements as soon as possible. Deformation monitoring in the analysed area will be required through the entire stage of mining activity, to ensure safety of the mining operation and may be augmented with relative measurements (e.g. extensometers) to obtain the complete information on rock mass deformation. A project describing such a technique for the Kvannevann mine has been presented by (Persson, 2010).

## 7. CONCLUSIONS

In the paper the methodology and design of rock mass surface deformation monitoring system for planned sub-level caving mining operation in the Kvannevann has been described. The mine is characterised by specific mining conditions. The proposed system is based on a three-tier measurement network of controlled, observation and reference points and total station angle-distance measurements augmented with satellite GPS observations.

The network design, measurement procedure, data processing and analysis methodology have been adapted to specific conditions of the Kvannevann mine. The proposed accuracy (±2cm), frequency of measurements (at least twice a year) and location of controlled points provide sufficient data for analyses and interpretations of rock mass surface behaviour including feedback for numerical modelling with FEM ensuring control and safe operation of the mine over time.

The system has been tested on a temporary local network set up in the western part of the Kvannevann pit. Pilot results on a local scale have been analysed.

The Rana Gruber company will use the proposed concept to implement a simplified surface monitoring scheme before commencing production on the new level at the end of 2011. Three lines of controlled points will be set up, line A due to water issues from the Erik Pit and monitoring the western part of the Kvannevann pit, line C for monitoring stability of the ventilation shaft and other infrastructure (ramp), line D to monitor eastern part of the pit.

Results of periodic measurements in the network will be used for control of the SLC mining system and fine tune numerical modelling (FEM).

## ACKNOWLEDGMENTS

This study has been realised within the framework of collaborative research project between the Institute of Mining Engineering of the Wroclaw University of Technology (Poland) and the Department of Geology and Mineral Resources Engineering of the Norwegian University of Science and Technology in Trondheim (Norway). The project has been financed by means of a research grant no. FSS/2008/D3/W0018 *Study of mining ground surface deformations with Geographic Information Technology* with the support granted by Iceland, Liechtenstein and Norway by means of co-financing from the European Economic Area Financial Mechanism and the Norwegian Financial Mechanism as part of the Scholarship and Training Fund. The authors would like to thank the Rana Gruber AS employees: Anders Bergvik, Børre Nøst and Gunnar Nilsen and SINTEF Rock Engineering researchers, Prof. Arne Myrvang and Nghia Trinh Quoc for their assistance.

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