

## **Transitional Phase for Small Steeply Dipping Ore Bodies from Open pit to Underground Mining: A Case Study from Scandinavian Mining Industry.**

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The transition from open pit to underground mining involves drastically changes in the production system. The equipment for underground mining will change as well as the logistics and the transportation system. Demands of rock stability and control will also change in nature and in equipment needed. At the same time the large investments in underground infrastructure and equipment require short lead times to maintain a high cash flow for the companies. Without proper planning many problems can arise influencing the production flow. Therefore it is essential to have detailed planning and modeling before reaching the transitional depth of the mine. Computer software like Surpac can be a suitable tool for simultaneously planning of both the open pit and the underground mining operation.

This paper presents some experiences from Björkdal Gold mine, one of the earliest and largest Gold mines in Scandinavia. The paper presents the mine and how the transition from surface to underground mining has been handled and optimized.

**Keywords:** Open Pit to Underground Transition, Simultaneous Planning, Surpac as a Planning Tool, Gold Mining and Metal Price.

### **1.0 Introduction**

Mining is basically extraction of ore carried out through mining methods; either from surface or underground. Surface mining has advantages over underground mining regarding recovery, production capacity, mechanize ability, grade control, flexibility of operation, economics and safety Chen et al., (2003). From environmental perspectives underground mining is considered more acceptable than surface mining since underground mining have smaller footprints than an open pit of comparable capacity. For near surface deposits with a vertical extent open pit mining is usually used first, but with increasing mining depth there is a point where decision has to be taken whether to continue deepening the surface or changing to underground mining Flores, G. (2004). This transition point from open pit to underground is nowadays being focused by many companies and researchers.

Extension of an open pit with a new push-back often involves removal of millions of tons of material generating huge capital investment. Therefore decisions to expand or deepen an open pit required extreme care. Careful ore body modeling and financial modeling are the precursor of the interfacing study Tulp, T. (1998). The point at which economic considerations dictate the change of mining method from open pit to underground is termed as transitional depth. Accurate determination of this transition depth from surface to underground is of utmost importance Bakhtavar, E. et al. (2009).

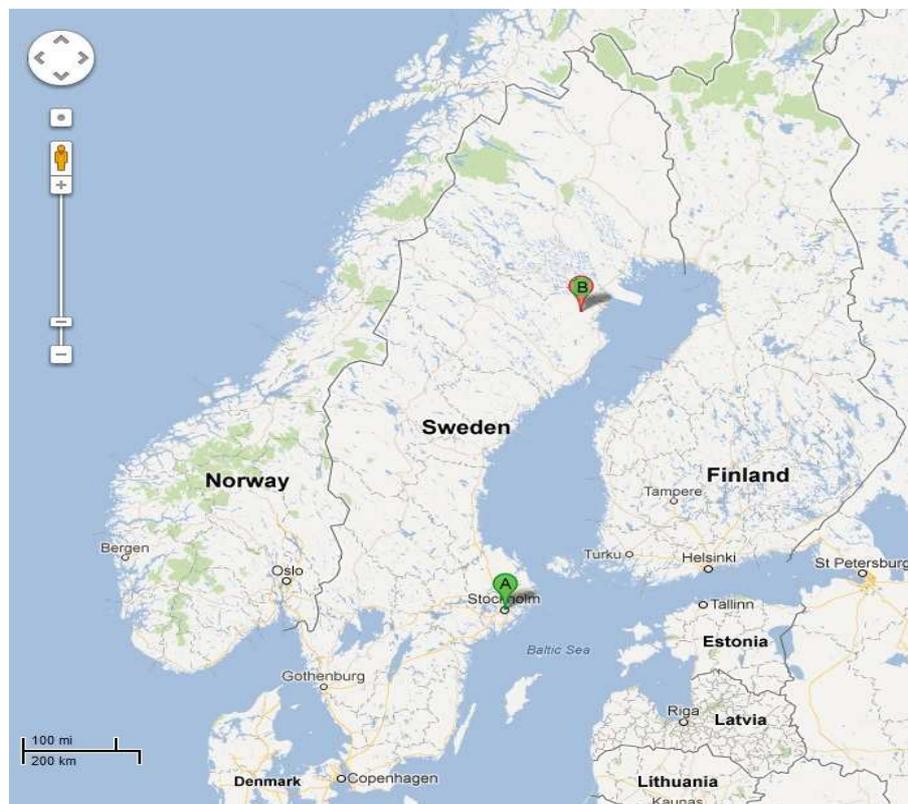
Some of the biggest open pit mines worldwide will reach their final pit limits in the next 10 to 15 years S.S.Fuentes (2004). Furthermore, there are many other mines which are planning to change from open pit to underground due to increasing environmental requirements Chen et al. (2003). For low grade mines usually block or panel caving and stoping methods are used after transition to achieve high production rate at low costs Arancibia, E., Flores, G (2004).

Even if the economic impact by transition from open pit to underground mining is lower for smaller mining operations, the transition phase must be equally carefully determined. In both cases there are similar issues to consider with change of equipment, common planning tools for both operations and the importance of having a high and controlled production rate throughout the entire transition period. For smaller operations these issues may sometimes be more important when the economic resources, that many large companies have, is not available.

## 2.0 BJÖRKDAL

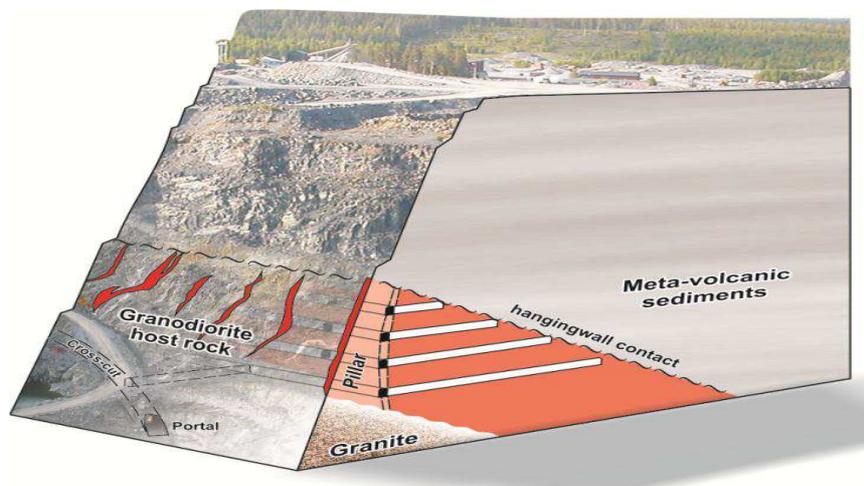
### 2.1 Location

Björkdal is an open pit and underground mine located 750 Km north of Stockholm and 30 Km NW of the city of Skelleftea, Sweden. The area is Västerbotten County, has a long history of mining and a strong economic tie to the industry as well as it has low cost hydropower and a skilled labour force.



**Figure 1 Location of Björkdal Gold Mine B, ([www.maps.google.se](http://www.maps.google.se))**

## 2.2 Geology of the Björkdal Area



**Figure 2 Geology of Björkdal Area (www.goldore.ca)**

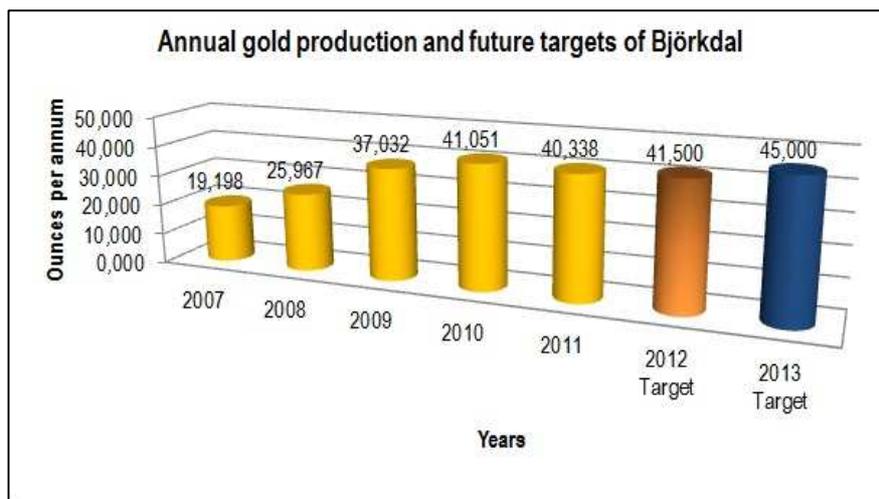
The ore in Björkdal consists of scattered quartz veins (varying in thickness; 20 cm to 200 cm) with associated gold in or in the vicinity of the quartz veins. In Figure 2, the geology and the ore zone is schematically presented. Going from surface bulk mining to a more selective underground operation, demanding better control of the quartz veins, is not an easy task to plan. Initially open pit mining method was adopted and on later stage mining is done by both open pit and underground mining method.

## 2.3 History

The Björkdal mine was initially discovered by Terra Mining AB by regional till sampling. The first anomalous gold values in till samples were found in 1983 and bedrock contain gold was discovered in 1985. Definition drilling was started in early 1986 and the feasibility study was finished in May 1987. The production decision was made in July 1987 and the first shipment of gold concentrate was made in September 1988.

In late 1996, The Canadian company Williams Resources Inc. purchased Terra Mining including Björkdal mine. However, since gold prices plummeted shortly after the purchase, Williams Resources Inc. in June 1999 placed the mine into receivership. The property was dormant until 2001 when a local group purchased the assets from the banks and started processing low grade stockpiles. In March of 2003 The Irish company Minmet Plc. acquired 50% of the mine and in October, 2003 the remaining 50% of the company. Minmet extracted ore from the open pit during 2 short periods in 2003 and in 2004 but the majority was low grade stockpile material

In 2006 Gold-Ore Resources Ltd. acquired an option from Minmet plc to purchase the holding company for the mine, Björkdalsgruvan AB. In December 31, 2007 Gold-Ore exercised its option and acquired all the shares of Björkdalsgruvan AB. Björkdalsgruvan is now a wholly owned subsidiary of Gold-Ore. In Figure 3, the annual production of gold since Gold-ore took over the mine is presented.



**Figure 3 Annual production history and future targets of Björkdal gold mine ( production data from Björkdal)**

## 2.4 Production

Today Björkdal consists of three active pit areas. Bench height is 5 meter and stripping ratio is 4:1. Truck and shovel operation is performed by contractors. The contractor also operates two Atlas Copco Coprod rigs and one top hammer drill rig. The Coprod rigs provide a major advantage when drilling in loose material.

At the end of year 2011, the proven and probable reserve estimate for open pit unit was 4.8 million tonnes of ore grading 1.4 g/t of gold. With the current mining rate of 550,000 to 650,000 tonnes of ore production, open pit has approximately 8 years life of production and as for as underground is concerned it has proven and probable estimate about 2.06 million tonnes of ore grading 1.69 g/t of gold. According to the current production rate, underground reserves will be for 4 years but due to the additional information about the reserve via diamond core drilling, hopefully life of the underground mine will be enhanced.

## 2.5 Processing Plant

The processing plant at the mine, was built in 1988 operates at a capacity of 3,400 tonnes per day and has been well maintained over the years with different owners. The plant consists of a coarse crusher, a rod and ball mill, gold gravity concentration circuit (including a Knelson concentrator) and flotation circuit for gold bearing pyrite. Feed material is sourced from both underground, open pit and operations as well as from the stockpiles. Gold recoveries average almost 90%. The process involved is free from Cyanide and any type of leaching. The tailings from the plant are very benign, containing no deleterious material, and have been classified by Swedish authorities as non-toxic.

### 3.0 Transition from surface to underground mining



**Figure 4 View of gold bearing quartz veins and main tunnel from open pit (www.goldore.ca)**

#### 3.1.0 Transitional Phase:

In Björkdal the transition to underground mining started in 2006 with an experimental mine which was reached through a development tunnel from the open pit, seen in Figure 4.

Since 2009 underground production has been in operation in Björkdal. The mining method used is long hole stoping with 20 m level spacing. The stopes are 3 to 5 m wide and up to 100 m long. The Emulsion as an explosive is used in 64 mm blast holes. To open the blast 127 mm reamed big holes are used. Mucking is done with remote controlled LHDs and no back filling is done.

Björkdal is managing its transitional phase timely. In 2011 50% of the production comes from the open pit and 50% of the production from the underground mine. In 2012 the underground production will increase to 60% and the remaining 40% comes from the open pit. Björkdal will continue to reduce its open pit production percentage and in a couple of years Björkdal will get all production from the underground mining operation.

Björkdal is a good example of how production can be regulated while considering the transitional phase ahead in their planning.

#### 3.2 Mine planning and scheduling

From 2011, Björkdal is using Gemcom Surpac; a computer aided software for mine planning and production. Gemcom Whittle is being used for open pit production scheduling and for underground operation only Microsoft Excel is used.

### 3.3 Equipment and equipment transition

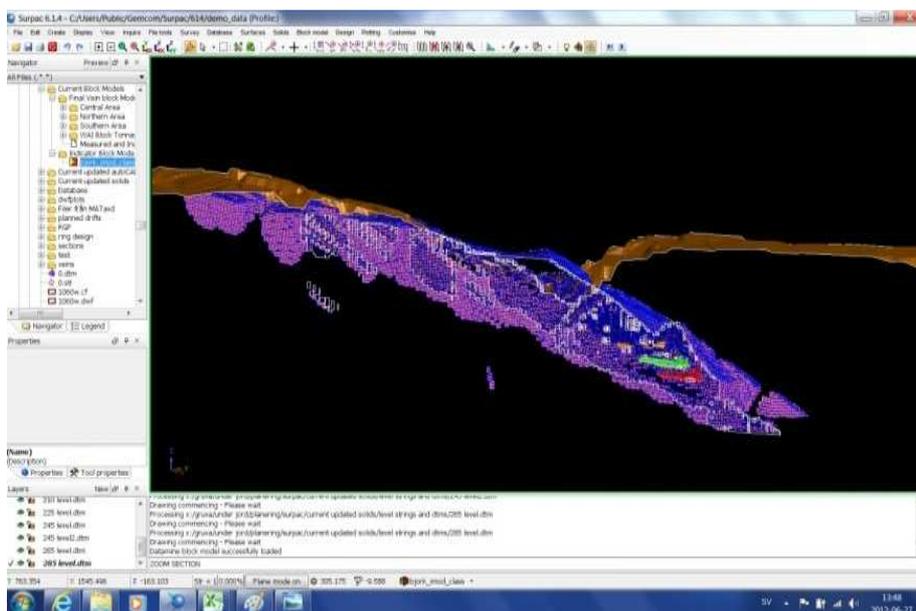
Mainly mine use Contractors for both open pit and underground mine operations. In addition to equipment owned by the contractors Björkdal has some key machinery for long term operations, like Long hole drill rigs and two remote controlled LHDs. More over some pick-up trucks, service wheel loaders, Emulsion charger and a wet shortcreting unit are also the property of the mining company.

In Europe it is easier to find out Contractors even for small operations in mining industry so mainly mining companies wisely get rid of the pain of purchasing expensive machinery by involving different contractors into the operation. But in 3rd world countries transition from open pit to underground mine is still a big challenge due to the shortage or lack of contractors. For short life open pit mining operations contractors are the best solution. Another benefit of knowledge can also be gained from the contractor's performance for future assistance.

### 4.0 Computerized planning using Gemcom Surpac

Björkdal gold mine has been using a computer software named Gemcom Surpac since the start of year 2011. With Surpac it is easier to plan and schedule mining activities. The open pit and underground mining are done separately using Surpac.

#### 4.1 Block model:



**Figure 5** Block model for open pit and underground Björkdal gold mine (Surpac image of Björkdal gold mine)

WAI (Wardell Armstrong International Ltd.) completed a Pit Optimization Study on the open pit resources to estimate open pit reserves. An economic model was generated first and then an ultimate pit was created. A review of the economic parameters yielded economic cut-off grades of 0.39, 0.33 and 0.28 grams/tonne gold, which was used to adjust the ore blocks selected by the model so as to yield more

representative ore reserve numbers. A minimum sub cell dimension of 2.5 meters is used and the base of the model has been extended to a depth of 370 meters. It is also noticeable that model is not rotated.

Planning engineers also considered nugget effect of gold and results obtained from diamond core drilling continuously. According to them block model dependency with varying thickness of veins and with specific grade can mislead them regarding production. They have obtained good results of production while considering diamond core drilling results with their specific block model.

#### 4.2 Lime stone contact projection in Surpac:

In the Figure 6, given below green layer shows limestone contact projection and above it there is only waste rock. It is interesting to know that lime stone contact is boundary limit for quartz veins as well.

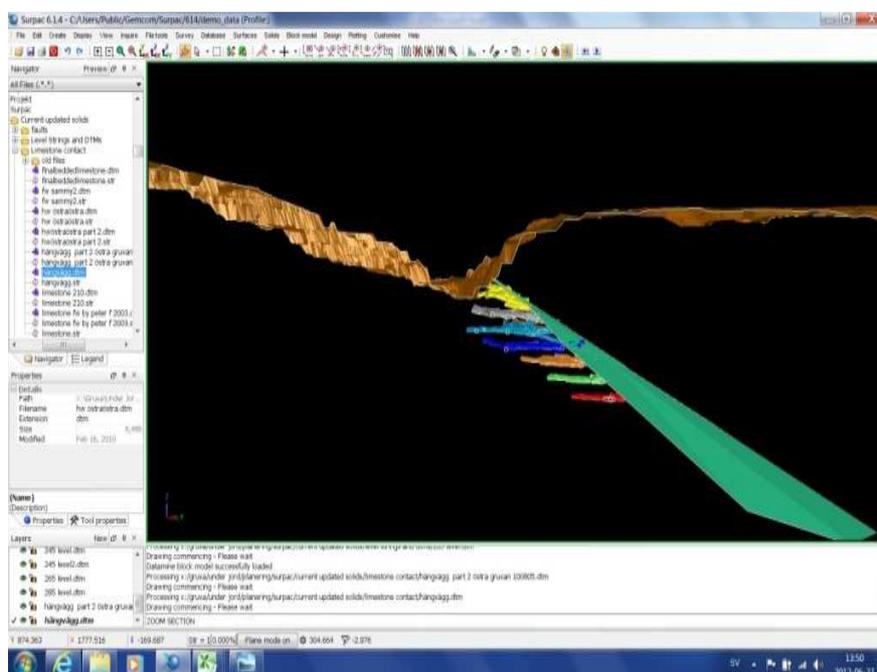


Figure 6 Lime stone Contact projection in Surpac (Surpac image of Björkdal gold mine)

#### 5.0 Long term and short term planning

Björkdal Gold mine underground uses two shifts of 10 hours each. Blasting is done at 2 late night then four hours ventilation. Planning is based on one year long term plan which is further divided into short term 3 months plans and then one month short plan. Interesting thing in Björkdal is that they have weekly meeting on every Tuesday with contractors and main mine staff. The planning engineer handed over next week's plan to contractors and also recorded previous week's performance to update monthly plans and yearly plans accordingly. They are using Excel spreadsheet for making long term and short term planned activities. Different colors are used to see different activities and proper scheduling etc. Scheduling sheet was also confidential. According to Håkan a senior mining engineer at Björkdal, "experience tells that weekly plan is more effective than a single monthly plan in achieving specific target."

## 6.0 Metal price and Market

### 6.1 Gold price Chart:



**Figure 7 Gold price trend chart (www.goldprice.org)**

From the last decade it can be seen from the international metal market that prices of metals are raising sharply especially in case of gold. In Figure 7, this trend of sharp increase in metal prices also attracts the mines considering transitional phase from open pit to underground and it also attracts those mines as well which were abandoned due to the fall in metal prices. Metal price shows that it is also key factor considering transitional phase from open pit to underground mining.

## 7.0 Discussion

We know that the metal price is always a governing factor for any mining industry. In case of Björkdal Gold mine same thing can be seen while considering the gold price. The material generated from the mine (i.e. Gold) is of high economic and financial value which stabilizes the position of the mining company and keeps it profitable. Gold is a precious metal which is eventually a need for every country in the world. We can see from the above chart that there has been an increasing drastic change in the market value of Gold. In 2006, Björkdal mine took a good decision to shift to underground mining keeping in mind the increasing value of gold. The development of underground caves started taking place while the mine was going through open pit methods. The investment needed to start the underground mining came from the profit generated through open pit mining. Over the years since 2006 the market value of gold has risen abruptly which added the plus point for the transition of Björkdal mine. Now it is a successful mine in a transitional phase, it is also obvious that underground option is usually costly but high metal price can make it suitable for mining operation. Freedom of tracing good grade ores can also be possible while doing underground mining.

For the regulation of mine operation and for them to flow smoothly it is viable that the mining company think effectively and use their capital in a suitable way to maximize their profit and minimize the risk factors. In Björkdal mine, the company has hired short term period contractors for different tasks involved in both open and underground methods. The machinery required for a particular task is brought by the

contractors and it is their job to complete it. This saves the amount of investment done on equipment selection and minimizes the risk of overflowing of capital. Moreover with the equipment and knowledge of these short period contractors, future mining can be performed with ease and less tediously through experience. It is a good saving technique for the mine companies and areas to hire short term period contractors regarding transition phase, where expensive machinery is needed to carry out both mining methods.

## 8.0 Conclusions

Rise in gold price in metal market from the past decade opened new horizons for underground mining. Many open pit mines are considering transition from open pit to underground mining in Scandinavia as well. Björkdal Gold Mine is a recent example of transitional phase. Now experience has showed that simultaneous working on open pit and underground mining brings not only the profit but also the smooth flow and outcome of operations. Björkdal provides information that how efficiently one can mine even a scattered veins deposit using computerized software. Moreover the performance of short term contractors shows that it is less risky to involve hired contractors than buying the expensive equipment used only for short duration and also these contractors are suitable for all those mines which will face transitional phase with existing open pit mines having a short mine life.

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