Bergforsk

Significant Achievements

May 23 2007

Luleå

Programme

Extended Abstracts

Preface

The Swedish Mining Foundation MITU in co-operation with LTU and Georange decided to expand the programme for the 3rd Annual Bergforsk meeting 2007 and include an afternoon for technical presentations.

The purpose is not only to share recent advancements relevant to the mining industry but also to meet across the several technical and scientific disciplines to gain a broader perspective and understanding of key issues for the future.

Several distinguished researchers accepted to participate and share their findings May23rd and we all look forward to informative presentations and constructive discussions!

May 2007

Göran Bäckblom	Björn Öhlander
Managing Director MITU	Dean Faculty of Engineering, LTU

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Bergforsk May 23rd
Significant achievements

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18.00	**Summary and closure**	Björn Öhlander and Göran Bäckblom

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[1] This presentation combines previous announced presentations on smelting and recycling

1 The anatomy of three commodity booms

Author: Marian Radetzki[1]
Affiliation: [1]Guest Professor in Economics at LTU

Presentation file

Three major commodity booms since the Second World War are identified and analyzed. In all three, demand shocks predominated as triggers to the commodity price rises. The first boom, in 1950-51, was caused by the massive inventory buildup in response to the Korean War. The second, in 1973-74, was accentuated by widespread harvest failures and by OPEC's market management which tripled the price of oil. The third boom started in 2004 and has not yet run its course. This time, the explosive growth of China's and India's raw materials demand has played a key role. The first two booms collapsed as the world economy went into recession and excessive inventories were sold out. The third boom may prove more durable since the world economy continues to expand briskly and commodity inventories have remained small.

2 Mergers in the mineral industries

Author: Patrik Söderholm, Professor of Economics
Affiliation: Economics Unit, Luleå University of Technology, Sweden

Presentation file

2.1 Introduction

The mining and minerals industries have gone through fundamental structural changes during the last several decades. These can be classed into two main categories, viz., pro-competitive globalization; and anti-competitive consolidation.

Globalization has been triggered by a number of factors. The most important are: (i) abandonment of state ownership in mining on a large scale, facilitating cross-border operations by firms; (ii) a more relaxed attitude to supply security, favouring imported supplies where such supplies could be obtained more cheaply; and (iii) falling transport costs, promoting the development of global markets even for low value bulk commodities like iron ore and coal. Globalization has tended to suppress the prices of mineral products, first, because it has shifted production towards low cost sources, and second, because the removal of geographical monopolies has tended to accentuate competition.

Given the importance of minerals as inputs into strategic production processes, this has greatly benefited the world economy.

However, while globalization has intensified competition during the last decades, a relatively recent wave of consolidation, involving horizontal mergers and acquisitions, has left the industries with far fewer and more dominant units. This has reawakened the old concerns among importers about security of supply, and raised fears about market control and monopolistic pricing. During 2006 a staggering US$ 140 billion were spent on mining mergers worldwide, am increase by about 5-6 times compared to 2005.

The above developments and concerns raise a number of questions about the impacts of the recent wave of mergers and acquisitions in the minerals industries. Will the bigger companies be able to influence prices or will the mergers create new entities that are more cost efficient and thus profitable than their predecessors? What analytical techniques are appropriate for evaluating the market power and efficiency impacts of mining mergers? What should be the attitude of national and international antitrust authorities towards mining and minerals mergers, especially given their cross-border nature? These are some of the most important questions that have bee scrutinized within a research project, funded by the Swedish Competition Authority, and conducted in close collaboration with the Raw Materials Group of Stockholm (see also Wårell, 2007).

2.2 Research Objectives

The purpose of the project has been to evaluate the competitive and efficiency impacts of horizontal mergers in the mining and minerals industries. Recent mergers in the coal and iron ore industries form the basis of the empirical investigation. For each case the analysis has involved two consecutive steps: (a) the determination of the relevant *geographic* markets using price and shipments data; and (b) *ex ante* simulation of the competitive effects using Cournot equilibrium models and event study techniques.

Below we illustrate some results of the investigation by focusing on the merger case Rio Tinto and North Ltd. in 2000. Emphasis is here placed on the merger assessment analysis, the methods used and the results obtained.

2.3 The Rio Tinto/North Merger

On June 30, 2000, Rio Tinto informed the European Competition Commission of their plan to pursue a public bid for all outstanding shares of North Ltd. Rio Tinto had to get clearance for the merger from three agencies, the Australian Competition and Consumer Commission, the Canadian Competition Bureau, and the European Competition Commission, and in the end they got clearance from all these Agencies. Regarding the definition of the relevant geographic market the European Commission acknowledges that metals and minerals are traded on a global basis, and thus the relevant geographic market should be considered world-wide. Nevertheless, the merger did raise concerns about both the relevant market definition issue and about the competitive effects.

Competition authorities generally rely heavily on market shares and concentration measures (e.g., the Hirschman-Herfindahl Index, HHI) in their assessment, and therefore tends to neglect the nature of the competition in the market. In the following we therefore test two different merger assessments approaches, which all can be used to ex ante analyze the presence of any anti-competitive effects of a merger: (a) event studies using stock market data; and (b) merger simulation methods using numerical models.

2.4 Results from the Event Study

Event study analyses employ stock prices to evaluate the effects of a horizontal merger by examining who gains and loses when mergers, merger challenges or an antitrust complaint are announced (e.g., Mullin et al., 1995). In this way, different hypotheses regarding expectations about market power and/or efficiency can be tested. Specifically, the event study consists of modelling the abnormal return on the stock of the firms involved (as well as any close competitors) and adding to it a set of dummy variables for each relevant event. This is also the approach taken in this project.

On the merger announcement date, the abnormal return for Rio Tinto is estimated at 1.21%. However, we also find a statistically significant and substantial increase in the stock price of North Ltd on the day of the merger announcement, and an abnormal return of 12.33%. This is expected given that the offer for North Ltd was higher than the stock price on the event day. The merger announcement thus seems to have increased the value of the target firm but not significantly for the acquiring firm. Given that the return for one of the closest competitor, BHP, was slightly negative, this provides some support for the efficiency hypothesis, stating that the new combined firm will be more efficient that he previously separated units.

However, it is also worth considering that the takeover bid for North Ltd was followed by several distinct information releases, and it is useful to examine the abnormal returns between the merger announcement and the completion of the bid. Table 2-1 presents the major events in the merger deal and the corresponding abnormal returns of participating firms. Te cumulative impacts of these results are consistent with the above conclusion of efficiency gains following the merger.

Table 2-1 Major Events Around the Takeover of North Ltd and the Corresponding Percentage Abnormal Returns of Involved Firms (t-ratios in parentheses)

Event	North Ltd*	Rio Tinto	BHP
June 23, 2000: Rio Tinto announced a cash offer of A$3.80/share for all shares outstanding of North Ltd, after taking a 14.5% stake in North. North's directors declared the offer of A$2.8 billion inadequate.	**12.33** **(38.35)**	1.21 (1.63)	-0.12 (-0.15)
June 30, 2000: Mitsui & Co (a 33% holder of Robe River) has voiced their concern to the takeover of North Ltd to the Australian government.	**-0.81** **(-2.49)**	0.98 (1.31)	0.70 (0.30)
July 7, 2000: Rio Tinto has concluded that the conditions of its bid for North Ltd	**-0.83**	**1.37**	0.11

Event	North Ltd*	Rio Tinto	BHP
have been breached.	**(-2.57)**	**(1.84)**	(0.14)
July 13, 2000: Japanese steel mills are threatening not to renew contracts with Rio Tinto in an effort to block the takeover of North Ltd.	0.19 (0.60)	0.51 (0.68)	0.01 (0.02)
July 21, 2000: Rio Tinto announced that it has noted Anglo American's A$4.20 counter offer for North Ltd.	**3.33** **(10.33)**	**-2.02** **(-2.70)**	0.44 (0.56)
August 2, 2000: The European Commission announced that they accept the merger.	-0.04 (-0.12)	-0.04 (-0.05)	-0.32 (-0.41)
August 3, 2000: Rio Tinto announced an increase in its offer for North Ltd to A$4.75/ share. The offer is unconditional and ends August 13.	**1.24** **(3.87)**	-0.56 (-0.75)	0.12 (0.15)
August 4, 2000: Anglo American announced that they will not proceed with their offer for North Ltd. ACCC gave their approval to the merger. Deal is practically finalized.	**3.00** **(9.34)**	**-1.84** **(-2.47)**	0.07 (0.09)

* The bold numbers indicate that they are statistically significant at either the 1% or the 5% significance level.

Source: Wårell (2007).

2.5 Results from the Merger Simulation Models

Two different merger simulations methods were tested: one which assumes so-called Cournot-competition and homogenous product and one which assumes differentiated products in a Bertrand competition setting. The results from the first model shows an increase in firm efficiency but this is outweighed by the consumer price effect, indicating an increase in price by about 5 percent. The second model generates a more modest price increase of about 2-3 percent, but it fails to address any changes in firm efficiency. In both cases the results are rather sensitive to the assumed elasticities of demand, at the market level in the Cournot model and at both the industry level and the firm level in the Bertrand model. The more sensitive is the iron ore demand to price changes, the less severe are the anti-competitive impacts. This highlights the empirical importance in merger assessments of estimating these elasticities both over the long-term and the short-term.

References

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3 Exploration in Sweden: Potential, opportunities and current R&D

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Presentation file

Sweden constitutes part of what is know as the Fennoscandian Shield, which is a geological unit of mainly Precambrian rocks occupying large areas of Finland, Norway, NW Russia and Sweden. This area has long mining traditions and documented mining dates back to pre-medieval times in the Falun mine which produced copper ore for around 1000 years, arguably one of the mines with the longest life span in the world. As a Precambrian Shield area the Fennoscandian Shield is one of the most prosperous mining areas of Europe and the Shield also attracts a lot of interest from exploration companies, domestic as well as international. In this presentation I will discuss the geological potential of the Swedish part of the Fennoscandian Shield, current exploration opportunities (with my bias) and finally say a few words about the current research within economic geology in Sweden.

3.1 Geological potential

The geological conditions in Sweden are excellent for discoveries of a number of different ore types. Unlike most other Precambrian Shield areas the Fennoscandian Shield, and hence Sweden, has not hitherto been prospective in Archaean (>2500 m.y. old rocks) areas, but in the Palaeoproterozoic (2500-1600 m.y. old rocks). Arguably the Palaeoproterozoic of Sweden and Finland is the most prospective units of this age on earth. The geological potential for new discovery of new mineralization of the following ore types is judged as excellent: 1) Volcanogenic Massive sulphide deposits (Zn-Cu-Pb-Au-Ag deposits), 2) SEDEX-deposits (Pb-Zn deposits), 3) Orogenic gold deposits (Au-deposits), 4) IOCG-deposits (Cu-Au-(Fe) deposits), 5) Mafic and ultramafic (incl. layered intrusions) hosted Ni-Cu-PGE deposits and 6) U-deposits. Furthermore, the geological potential for Fe-ore (both apatite-Fe and upgraded BIF) is excellent, and lately we have seen exploration money invested in Fe-ore exploration in Sweden. Other metals with a good potential based on the geological conditions include Sn, W and REE. Figure 1-1 shows the main mining district in the Fennoscandian Shield and as can be seen many of the major districts and deposits are located in Sweden, including world class deposits like Kirunavaara (Fe) - operating, Aitik (Cu-Au) - operating, Boliden (Cu-Au-Zn-Pb-Ag) - closed, Falun (Cu-Au) - closed, Laisvall (Pb) - closed and Zinkgruvan (Pb-Zn) - operating.

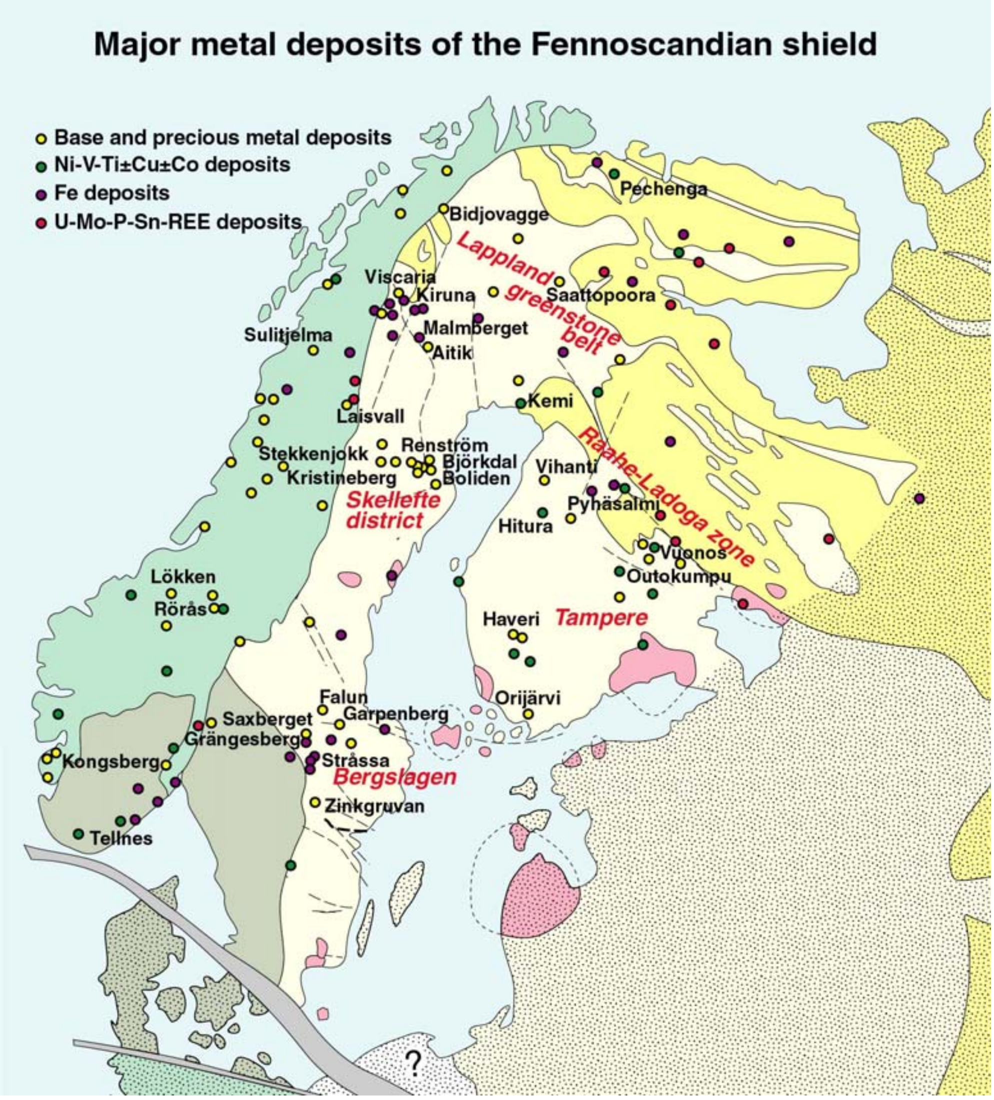

Figure 3-1 *Major deposits and mineral belts of the Fennoscandian Shield (from Weihed et al. 2005)*

3.2 Current opportunities

Current exploration investments in Sweden exceed 300 MSEK (33Meuro) and are estimated to be at an all time high level in 2007. Most of the current exploration and hence opportunities is within mature mining districts like the Skellefte district and Bergslagen. We have seen an increase in the interest for especially Bergslagen the last years and a slightly decreased interest in Northern Norrbotten. In the Skellefte district new interesting results are reported from further drilling of known prospects and mines, for instance in Kristineberg and Copperstone. Further exploration is warranted on VMS deposits in all parts of the Skellefte district and the potential for remobilized gold in economic grades from VMS ore is judged as high (Weihed et al. 2001). Intrusive hosted Cu-Au has documented potential in the Skellefte district and further north. Current exploration is evaluating some interesting mineralization. The potential for further base metal deposits in the Bergslagen district is excellent and this old extremely mineralized district is severely under explored by modern techniques. Potential for more mineralization of the same style as in Zinkgruvan, Garpenberg and Falun is judged as excellent. The Bergslagen district also holds all key ingredients of an IOCG-district and further exploration for this style of deposits is recommended. Less know is perhaps the good potential in Bergslagen for economic mineralization of Mo and W. Current prices should make Bergslagen and interesting target for these metals. Also parts of the Skellefte district and Northern Norrbotten hold a high potential for W (and Sn) and especially Mo, Boliden is currently developing a Mo-line at Aitik. Sweden has for several decades been known for its good potential for Uranium. Although it is at a high political risk the potential for economic mineralization is definitely there. Sweden with regard to its geological potential is severely under explored for Ni and PGE´s. Recent new drilling results from known deposits at Lainejaur and in the Ni-line south of the Skellefte district shows very promising results for Ni and thus Sweden might se a new Ni-mine in the near future. Finally gold has been and still is the focus for many junior companies in Sweden. Discoveries in the gold-line the last decade are promising, and although grades are not great in these deposits several holds potential for mining and the next mine opening in Sweden might well be situated in the gold line. Gold should also be evaluated as a stand alone target in orogenic gold type deposits elsewhere in Sweden. The Skellefte district is an obvious target, but less know potential also exist in Bergslagen, southern Sweden and northern Norrbotten.

3.3 Research within economic geology and exploration

Current economic geology research is Sweden is carried out by Luleå University of Technology. Sweden is at this moment launching a new mining research programme which includes one key area on exploration. We aim at combining geology and geophysics in new robust 4D models of part of the Skellefte district. If granted there is a potential to expand this project into a European project of a similar type that is discussed within the framework of ETP-SMR. Other new research projects include: 1) Relationship between iron ore and base metal mineralization in Bergslagen (joint project between LTU, UU, Boliden and Dannemora Mineral funded by industry and SGU), 2) Intrusive hosted Cu-Au in the Skellefte district (LTU-Boliden and funded by SGU), 3) Process mineralogy in Fe-ores (LTU-LKAB funded by HLRC).

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4 Modelling of failure in rock: Recent developments

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Presentation file

Rock mechanics design involves the calculation of stresses and deformations and the evaluation of the stability of rock constructions. For simple shapes of underground constructions the calculation of stresses and deformations can be done using closed form solutions. However, relatively simple opening geometries result in quite complex mathematical manipulations and final expressions for the stresses and displacements. Therefore, in many practical cases the shape of the underground openings is often not simple enough to be analysed using analytical methods. Furthermore, shallow depth, loading applied by soil and buildings, the influence of mining on drifts and shafts or a true three dimensional geometry makes it necessary to use numerical methods.

The evaluation of the stability can be done in several ways depending on the rock mass properties, the expected failure mechanism, analysis method (analytical or numerical), input parameters available and the used method. The simplest way of carrying out a stability analysis is to assume linear elastic conditions, calculate the elastic state of stress and compare, for every point, the state of stress with the strength. This will, however, only give an estimate of how critical the stress state is with respect to the strength in individual points in the rock mass. It will not answer questions like: Which is the failure mechanism? Is rock falling out or is only the strength exceeded meaning that small cracks have been initiated and/or propagated?

A numerical analysis can be done assuming continuous conditions as well as discontinuous conditions. A continuum approach is relevant for intact rock conditions as well as for cases when the discontinuities are so pervasive and closely spaced relative to the size of the problem domain that the rock mass can be represented as a continuum with equivalent rock mass properties. If the rock mass could be treated as a continuum or not, depends on the rock mass as well as on the rock mass volume of interest. In the continuum approach the equivalent properties of the jointed rock mass are used. Discontinuous deformations in individual joints are therefore not considered and not possible to study. In the discontinuous approach the rock mass consists of a finite number of discontinuities defining discrete, interacting blocks of intact rock. Discontinuous deformations and rotations of blocks can therefore be analysed.

The choice of method depends on the rock mass response to the change in loading conditions taking place when rock is removed and a slope or an underground construction is made or when a load is applied at the ground surface. In modern software, normally a number of different constitutive models are available. They range from linear elastic, homogeneous and isotropic to anisotropic, plastic models and models which can simulate creep behaviour and coupling between mechanical stresses, fluid flow in the material and thermally induced stresses and deformations.

The development of numerical analysis has been remarkable during the last decades. For 30 years ago numerical analyses of rock mechanics problems were mainly carried out by experts using their own programs. It involved manual discretization of the model by specifying the coordinate of each node and printing that into an input file together with the material properties and virgin stresses. The results from an analysis were, e.g., values for the different stress components and displacements. A graphical representation of the result was made by manually drawing displacement arrows or contours. The development of the computer technology including much faster processors and user interfaces such as Windows have been beneficial for the software used for numerical analyses.

Rock is a brittle material and fails through the initiation and propagation of cracks/joints. Depending on the loading conditions and the rock type this can lead to spalling and/or shear failure. If the rock is anisotropic failure modes such as bending, buckling and combined bending and buckling may take place.

There are at least two different approaches that can be used to study behaviour of the rock during the process of failure. The first is the continuum approach which has the advantage of being quite fast, easy to setup but with the disadvantage of being unable to simulate the propagation of individual discontinuities (cracks, joints). The constitutive models available today in commercial codes are based on the initiation of yielding when the peak strength has been exceeded. The most common post-peak behaviour used in these constitutive models that the rock behaves perfectly plastic. This gives a smeared out failure development, not localisation of the failure to individual fractures which is the case in reality. A capability of simulating strength loss with increased straining of the material is available in the strain-softening models. However, the fundamental problem associated with using a strain-softening constitutive model is that the rate of decrease with strain is strongly grid-dependent and inversely related to the element size of the finite difference mesh in the model. In reality the shear band thickness depends on some material characteristics – e.g., grain size and block size. In the finite difference program FLAC (developed by Itasca Consulting Group, Inc), the shear band thickness will be governed by the smallest width that the grid can resolve, i.e., one grid-width if the band is parallel to the grid, or three grid-widths if it is cuts across the grid. Smaller elements will thus give a thinner shear band, which will give more softening.

The other approach is to use programs which are developed for simulation of fracture propagation. One example is using a boundary element formulation in combination with the theory of fracture mechanics. The advantage with this approach is that fracture propagation is taking place in the model. One of the disadvantages is how to take into consideration the natural cracks and larger discontinuities and how to handle a large amount of fractures in a model. The propagation of fractures can also be simulated using a discontinuous concept in which the whole rock mass is built up by spheres. The interaction of the spheres is governed by the tensile and shear strength of the contacts between the spheres as well as the stiffness of these contacts. Since the propagation of discontinuities will take place between spheres, the size of the spheres will be the key factor for the accuracy of the analyses. Furthermore, an increasing number of spheres increase the calculation time. There are, however, attempts where the particle flow formulation is combined with a continuum formulation, so that the part of the model where the propagation of discontinuities is expected will be modelled with spheres and the rest of the model with a continuum. This may be one of the methods used in the future.

The Synthetic Rock Mass (SRM) approach is a method in which different rock masses with different properties including jointing are “tested” using the particle flow (Itasca Consulting Group Inc.). The behaviour of the rock mass obtained in these numerical “laboratory tests”, are then used as input to continuum analyses.

The main issue for the design of underground constructions is still whether blocks of rock wall fall out or not. One of the greatest challenges today and in the future will be develop such tools that can simulate the failure of rock including fracturing, fall-outs and caving.

5 Application of seismic systems to pin-point the location of the drill-bit in real time

Authors: Calin Cosma[1], Anders Nordqvist[2]
Affiliations: [1]Vibrometric OY, [2]LKAB

Presentation file

5.1 Background

Drilling is perhaps the most important operation in mining. Accurate drilling reduces the mining cost in many different ways:

- Makes it possible to increase the distance between sublevels and reduce the development which is the most expensive part of the mining operation.
- Reduces dilution, overbreak, damage and ore losses.
- Improves fragmentation and reduces disturbances in the whole mining process from mucking to the mill.
- Reduces specific drilling and charging.

Gellivare Hard Rock Research (GHRR) initiated in year 2002 the project ”Guided drilling with coil tube – a possible step change in production drilling”. An essential part of that project was determining the location of the drill bit. Magnetic methods, optical laser gyros, inclinometers and gyro-accelerometers were explored, among others, but these were either not precise enough, or too expensive, or not fitting slim borehole diameters, or not withstanding the strong forces appearing close to a drill hammer. The project finally opted for a seismic technique, which was deemed to fulfil in principle the precision, cost and ruggedness requirements mentioned above. The key idea of the method has been to pinpoint the location of the drill bit by inverting the seismic travel times from the drill bit hitting the rock to sensors at known locations in tunnels and boreholes. The GHRR project was completed in year 2005. An important contribution to the project, especially signal analysis, was brought by LTU (Luleå University of Technology). However many problems remained to be resolved.

GHRR commissioned Vibrometric Oy in year 2005 to provide an independent study of the feasibility of building the apparatus envisaged. They concluded that seismic methods might be viable, but that accuracy would probably be less than the required ± 0.1 m for a 40-50 m long borehole, mainly due to a possibly uneven seismic velocity distribution throughout the rock mass.

5.2 Project concept

A continuation project started in 2006, managed by RTC (Rock Tech Centre) and with LKAB and Swedish Nuclear Fuel and Waste Management (SKB) as present sponsors. The project is divided in four phases:

- Phase 1: In-depth feasibility study and pre-planning of a field-test at the LKAB Kiruna mine.
- Phase 2: Further analysis and evaluation of the data recorded as part of the GHRR project mentioned above.
- Phase 3: Preparation and execution of a new field-test at the LKAB Kiruna mine.
- Phase 4: Evaluation of the prior three project phases and recommendations for further actions. A related effort could be launched at this point aimed at selecting technology for actively steering the drill bit using real-time positioning information.

The main objective is to develop and test seismic techniques able to pinpoint the location of the drill bit. A second important product would be the build-up of a 3D seismic velocity distribution image. To date, Phases 1 and 2 of the project have been completed, and preliminary activities started for Phase 3.

The field test in Phase 3 is planned to be carried out in the Kiruna mine. A large number of sensors (accelerometers) will be used. The drill depth will be recorded during drilling as well as the zero time (the time when the drill bit impact the rock). The data recorded in Phase 3 will be analysed in Phase 4 of the project. A number of boreholes will be drilled through the upper level enabling conventional surveying of the endpoint coordinates.

5.3 Results and discussion

Phase 1 comprised a rock quality assessment and a seismic data modelling study. The experimental geometry and the physical properties were derived from the rock quality assessment carried out on real data from the Kiruna mine. Real seismic data recorded as part of the former GHRR project were used to derive drill bit seismic signatures, which were then convolved with the response of the rock, derived from its physical properties. A fragment of a modelled multi-impact record is shown in Figure 5-1. One can note the relatively large noise level allowed through the modelling, to mimic a realistic field situation. There are two repeated patterns, at a time interval of approximately 35 ms. these being the repeated impacts of the drill bit. A rather unsuccessful attempt has been done to automatically pick arrival times on the record from Figure 5-1 represented by the red line. Figure 5-2 represents the 4-second long record from Figure 5-1, after synchronised shift-and-stack.

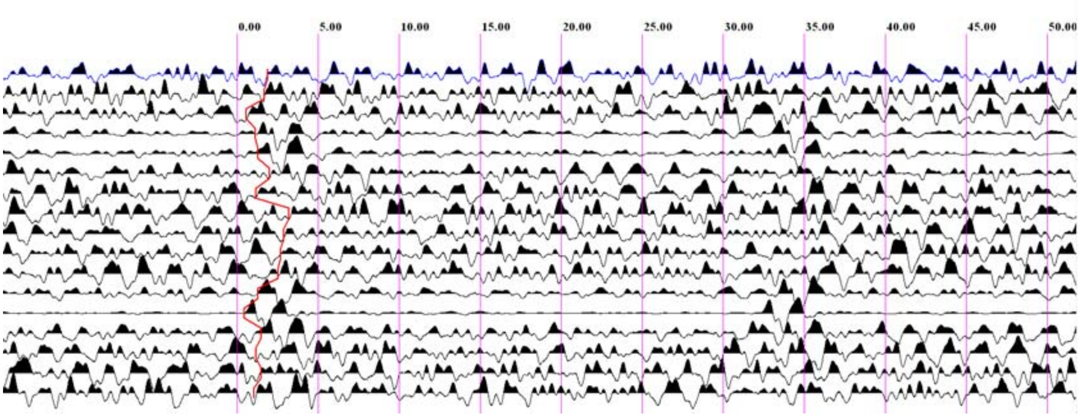

Figure 5-1. *Detail of the model generated with repeated bit impact.*

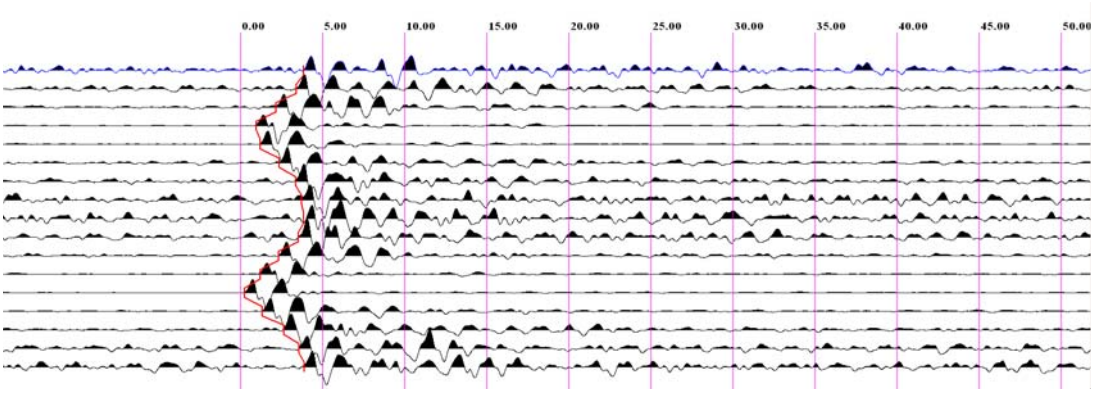

Figure 5-2. *Decoded 4-second time sequence fr*om Figure 5-1. *Picked times are displayed with red.*

Clearly, the arrival time picking became significantly more successful. Time picking procedures themselves were studied attentively to select the procedure most adequate for the purpose. Velocity corrections were also applied and several algorithms were tested. Performing the localization and evaluating the velocity field iteratively produced more stable results than the simultaneous inversion for both velocities and positions.

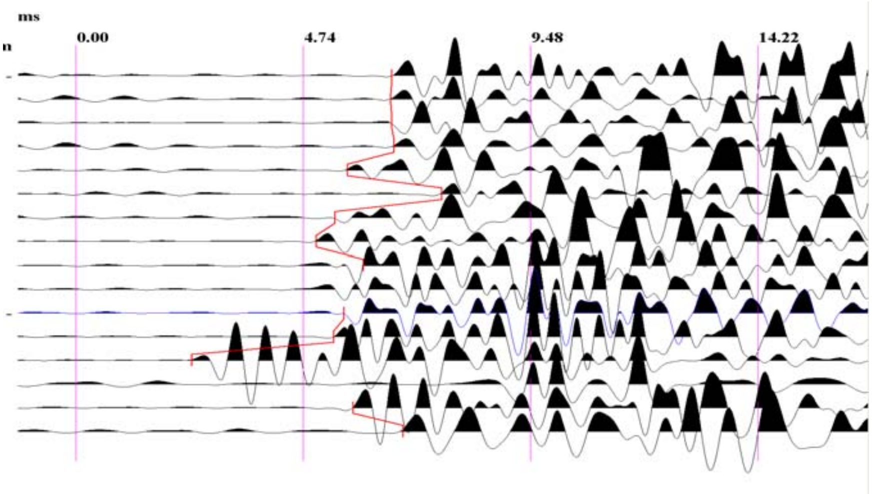

Figure 5-3. *Decoded 10-second real-life time sequence, recorded in the GHRR project. Picked times are displayed with red.*

Phase 2 consisted of the application of the signal processing and drill bit localization techniques developed in Phase 1 to the data recorded in the GHRR project. Figure 5-3 displays a section of a real-life record, processed in a similar manner with the modelled traces from Figure 5-2. The different vertical distribution of arrival times is due to the actual positions of the sensors being different. However, the signal-to-noise ratio and the accuracy of the time picking are comparable.

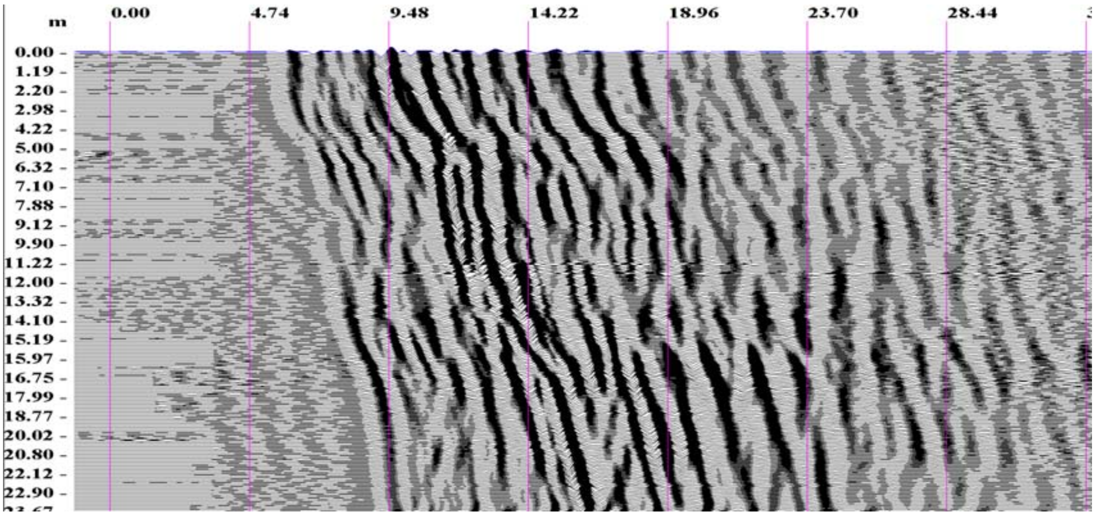

Figure 5-4. *Records from the first sensor, appearing on trace 1 in* ***Figure 5-3*** *shown at incremental depths, as the drilling advances.*

In Figure 5-4 variations of velocity with the drilling depth show as wiggles of the first onsets. Later arrivals, which can be associated with rock structures, can also be noted.

Figure 5-5 shows a comparison between localization attempts with and without compensating for local variations of the seismic velocity within the rock mass. Arrival times have been picked automatically. When velocity variations are considered, the RMS error is below 0.25 m. This has however to be regarded as an interim result. The RMS error can in fact be brought down to below 0.2 m with a minimum of manual intervention in the time picking. Phase 3 of the project has started by producing rules and recommendations for improving the resolution to the desired level. The specific objective of the field tests planned for phase 3 is to produce the experimental material for a test automatic run. For that, an extended geometrical coverage and a more stable sensor affixing to the rock will be considered.

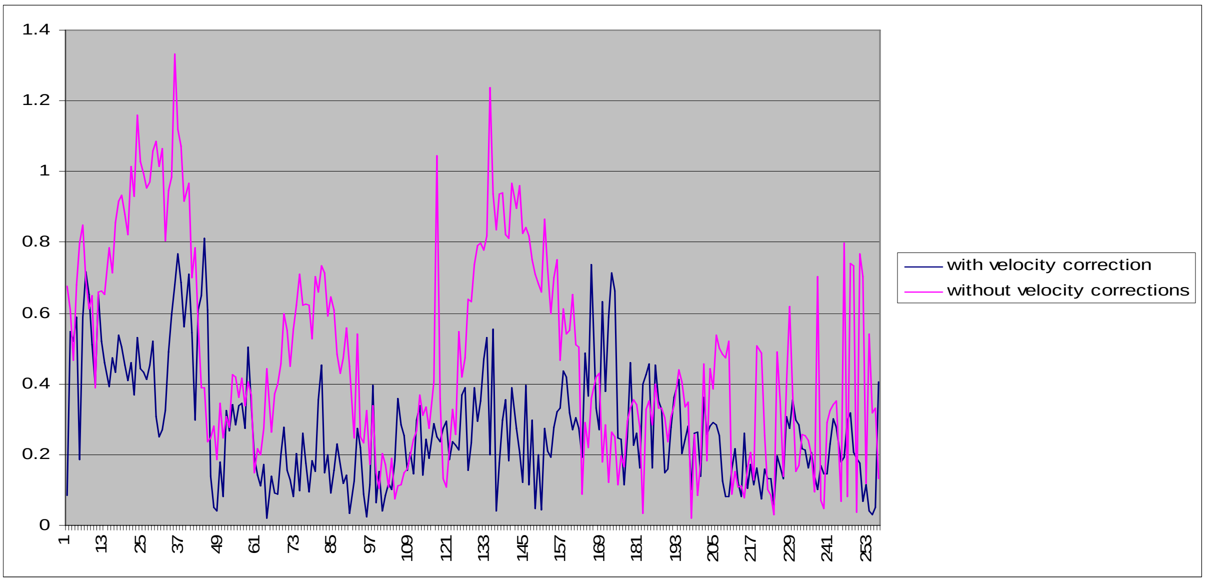

Figure 5-5. *Positioning errors with (blue) and without (magenta) local velocity variations being accounted for.*

Velocity field determination has required and still requires significant attention, as the 1% precision which can generally be obtained with tomographic velocity inversions leads only to a positioning accuracy of roughly ± 0.4 m. As seen in Figure 5-5 the precision of the localization is better than 0.4 m and in fact around 0.2 m except two regions of the graph. Careful planning of the survey geometry will reduce the velocity errors below 1%.

6 Coordination Chemistry of Adsorption in Froth Flotation

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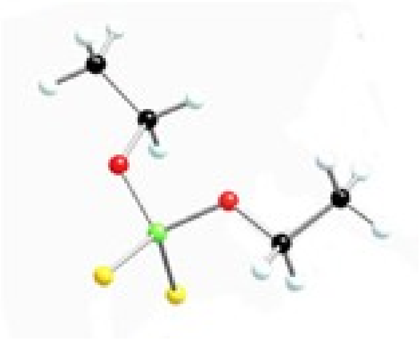
Presentation file

One step in the froth flotation process involves the adsorption of collectors to the mineral surfaces in order to form a hydrophobic mineral-collector complex. One frequently used collector for sulfide minerals is the dithiophosphate (dtp), see Figure 6-1



🟡 *Sulfur* 🟢 *Phosphorus* 🔴 *Oxygen* ● *Carbon* ○ *Hydrogen*

Figure 6-1. *The collector diethyldithiophosphate.*

The collector can bond to a mineral surface in different ways. One type of adsorption is chemisorption, in which chemical bonds are formed between the collector and metal ions at the mineral surface. The dtp can coordinate to the surface in three different ways: monodentate, in which one bond forms between the metal ion and the dtp ligand, terminal chelating, in which two bonds form between the collector and one metal ion, or bridging, in which two bonds form to two different metal ions, see Figure 6-2

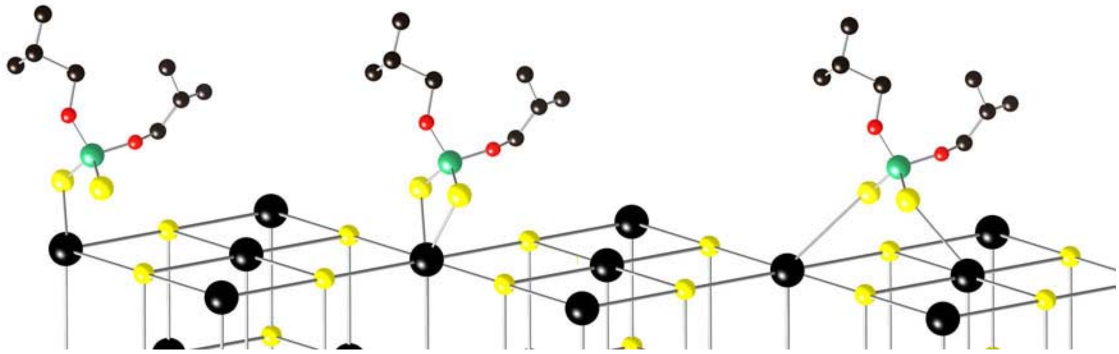


***Figure 6-2.** Possible coordination modes of di-iso-propyl dithiophosphate chemisorbed on PbS, from left to right: monodentate, terminal chelating, and bridging.*

Another type of adsorption is physisorption, in which the collector is only loosely bonded to the mineral surface, either as a metal-collector precipitate formed between dissolved metal ions and collector, or as an oxidised dimeric collector (disulfide), see Figure 6-3.

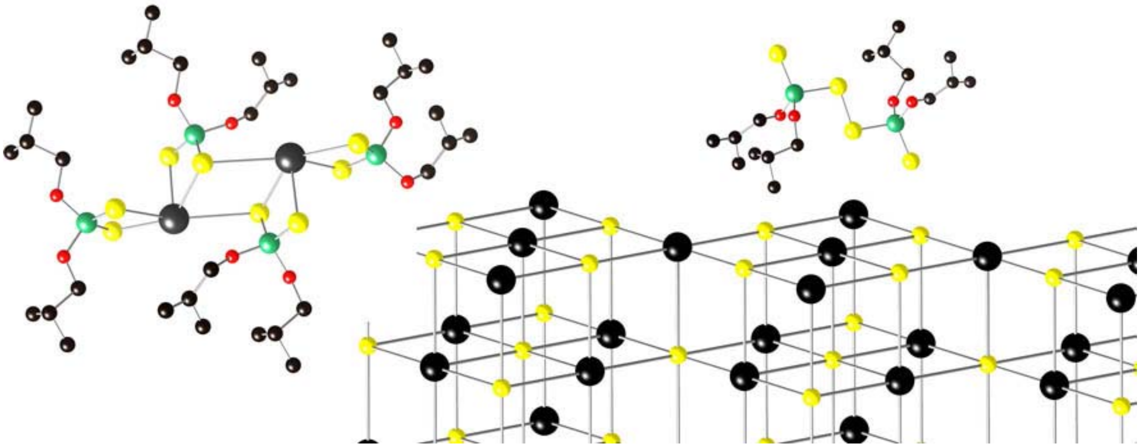


***Figure 6-3.** Possible coordination modes of di-iso-propyl dithiophosphate physisorbed on PbS, from left to right: precipitate, and disulfide.*

The dtps can also hydrolyse into monothiophosphates and orthophosphates.

With ^{31}P NMR it is possible to distinguish between these different situations. By placing the sample in a strong magnetic field and irradiate it with radiofrequency pulses of the right frequency the phosphorus nuclei are disturbed and the signals they emit as a response of this disturbance can be analyzed and give information on the electronic environment around the phosphorus /Larsson 2004/. Since the electronic environment is a bit different in all the above mentioned coordination modes they give different signals, so-called chemical shifts, see Figure 6-4.

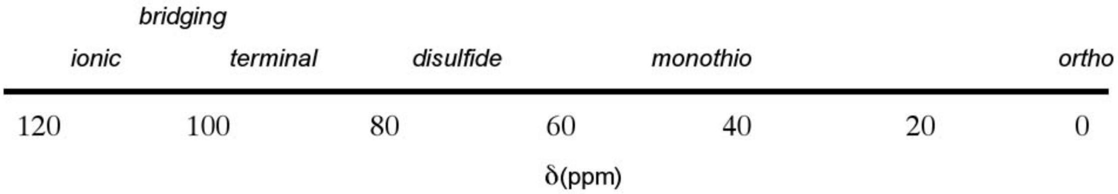


Figure 6-4. *Approximate ranges of* ^{31}*P NMR chemical shifts for different modes of coordination.*

The results of surface studies show that the dtp chemisorb with a bridging coordination to the surface of ZnS /Ivanov 2001/, and on the surface of PbS the dtp has a terminal coordination, and physisorbed precipitates and hydrolysis products are also present /Larsson, 2005/.

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7 Challenges and opportunities in modern smelting

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Presentation file

7.1 Background

Base metals are already today produced by coupled processes from primary and secondary raw materials, where by-products from production of one metal are raw material for the production of another metal. Recycling of metals from "end of life" metal containing waste and materials from other industrial sectors becomes more important in order to have a sustainable usage of metal resources.

Often competing smelters make use of their competitors' specialized facilities and capacities. A limiting factor to the "complete extraction" of the whole periodic table is naturally set by income (limited use and willingness to pay) and costs. Other factors are set by limited knowledge. Another challenge stems from the precautionary principle when dealing with concentrated stream, be it from primary ore secondary feed.

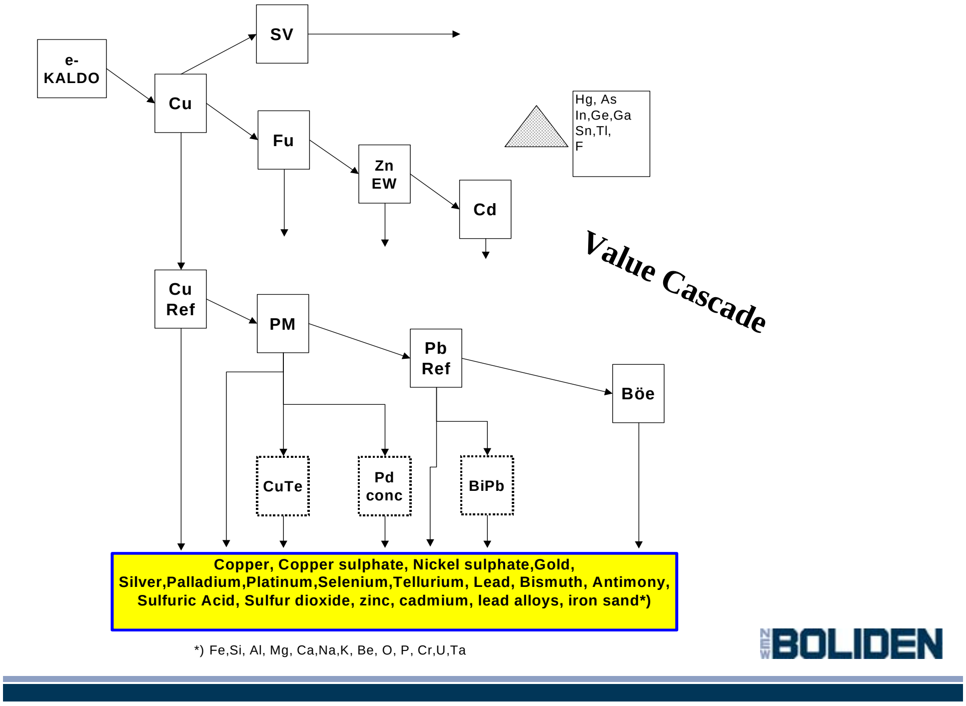
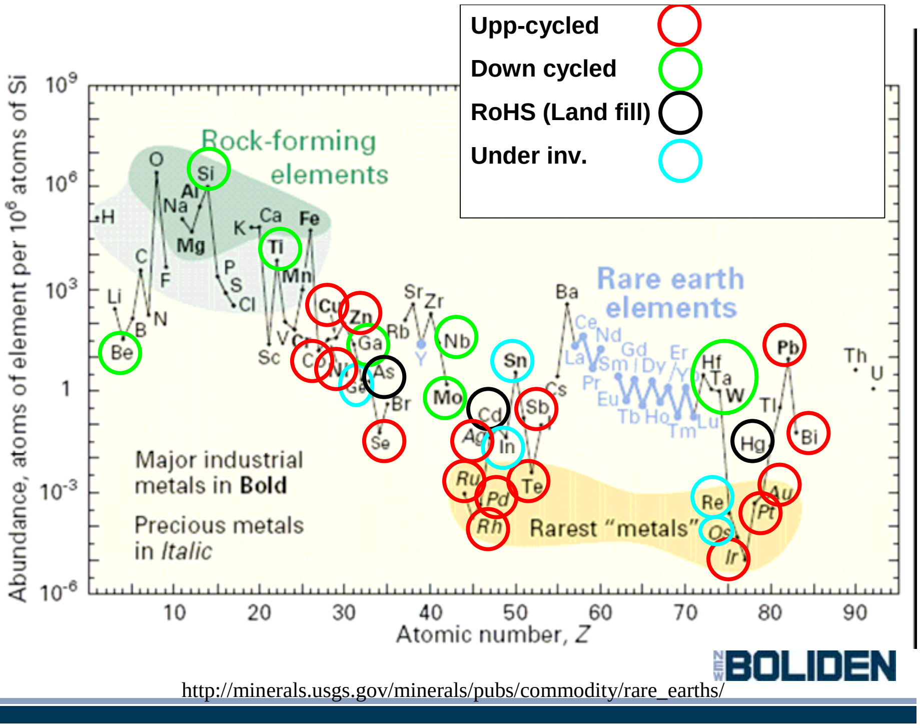


Figure 7-1. Using the cascade to extract values from primary and secondary raw material



http://minerals.usgs.gov/minerals/pubs/commodity/rare_earths/

Figure 7-2 *illustrates the elements recycled by smelters.*

7.2 Mining and Recycling potential

The doomsday prophets are trumpeting “We are running out of metals “. Figure 7-3 shows that even today’s known giant Cu and Cu-Au mines should contain enough copper for all of us if we handle and use it wisely! Still to come: research and development into extraction from primary and secondary sources will make even more metal available – at lower cost.

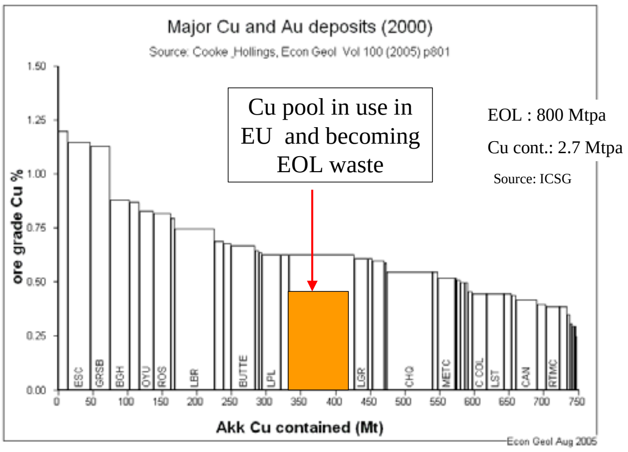


__Figure 7-3.__ Major Cu and Au deposits

As a consequence of all these new materials entering the metal production facilities the metallurgy of many “new” elements has to be considered. The increasing complexity of the materials entering the metal extraction plants requires an increased knowledge of metallurgical reactions, thermodynamics and kinetics.

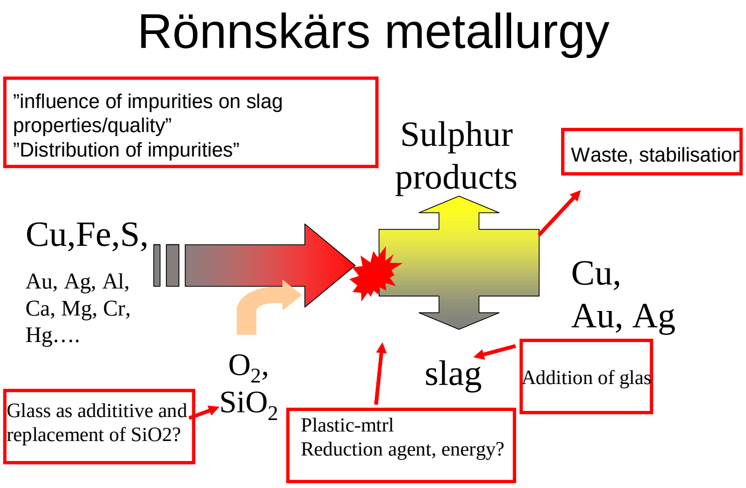


***Figure 7-4** Schematic description of the metallurgy at the Rönnskär smelter.*

In a smelter such as Rönnskär, primary and secondary raw material are treated in an integrated system where materials are recirculated and treated in several different steps, and several products leaves the smelter; pure metals, Cu, Au, Ag, Pb, metal concentrate, Pt/Pd, zinc clinker, slag, sulphur products.

Dust and slag are re-circulated within the plant, the fuming slag are graulated and used for road construction purposes, and some material has to be landfilled. Recirculation of materials causes enrichment of impurities and it is therefore of importance to have a knowledge of the distribution in different phases to remove them from the system. Some metals present in very small amounts may have a large economical value and it would therefore be of interest to investigate the possibilities to extract those metals from the material streams.

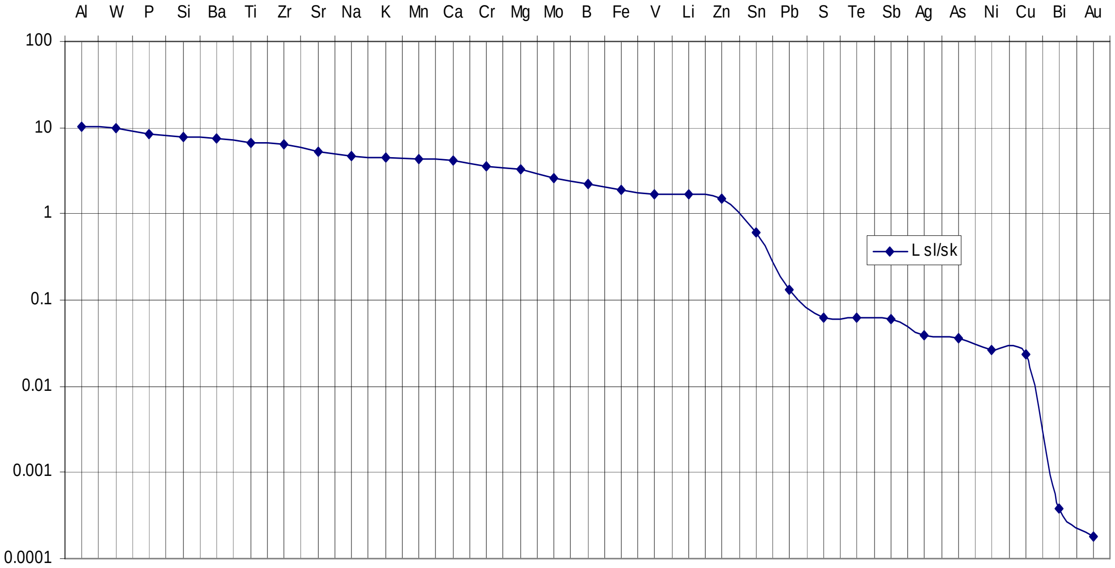


Figure 7-5. *Distribution of elements based on plant data.*

The influence of impurities on slag properties, e.g. melting point, viscosity, leachability and impact on solubility of valuable metals are of fundamental importance.

7.3 Illustration of Research activities

On-going projects in the area concerns:

- Recycling of Cathode ray tubes (CRT) and liquid crystal displays (LCD) in a smelter
- Flame retardants and filler in plastic and rubber –
    - alumina oxide capacity of fayalite slag
    - chlorine distribution between matte and slag

7.4 Results and discussions

The results presented below are preliminary results from on-going studies, further studies will be carried out and more thorough results presented in the future.

7.4.1 Recycling of CRT glass

Bench scale experiments have been carried out to investigate the possibilities to add CRT and LCD glass to fayalite slag. The slag used was taken from the fuming plant and the glass was received from a scrap dealer. Methods used include melting of mixtures of glass and slag, characterization of the material with X-ray diffraction analysis, (XRD), scanning electron microscopy (SEM), thermal analysis (TGA-DTA) and leaching tests. Results show that a mixture composed of more than 35 weight% glass will result in a visual phase separation. The XRD analyses show that CRT glass is amorphous but crystalline peaks are found in mixtures of slag and glass. Fayalite can only be detected in the slag sample. Magnetite and hematite is found in pure slag as well as with a mixture of 10 and 35weight % glass. Results from thermogravimetric analysis shows that lead is evaporated at around 1000ºC. Leaching tests showed no increased leaching of metals when a mixture of up to 50 weight % CRT and LCD glass was added to the slag. Results also indicate that the copper content in the slag decreases when adding glass.

7.4.2 The influence of alumina oxide on the properties of fayalite slag

Brominated flame retardants in e.g., electronic equipment are today common, but due to the toxicity of bromine new flame retardants based on e.g. Al-containing materials are developed. This may cause problems in the smelter as alumina may affect the slag properties. A study has therefore started to investigate the impact of alumina oxide on slag properties.

Based on a literature survey, one can conclude that the effect of alumina oxide on melting properties of the slag largely depend on gas atmosphere, pO_2, slag composition, ratio between Fe/SiO_2. The solubility of copper in slag has shown to be decreased with addition of Al_2O_3.

Experimental test in bench scale equipment is currently carried out using slag from the smelter and adding pure alumina oxide. Mixtures of slag and alumina oxide have been melted and the samples will be characterized using optical microscopy, SEM and XRD to determine if any phase changes will occur. Leaching test is carried out to investigate the effect on the leaching properties of the slag.

7.4.3 Distribution of chlorine between matte and slag

Chlorine is present in some plastic materials which end up in a smelter. The main part will be vaporized and be found in the dust; however it is possible that part will be retained in the melt phases. A study is carried out to determine the distribution of chlorine between slag and matte.

A mixture of matte and slag from the plant doped with sodium chloride has been melted. Results shows that the main part of the chloride added report to the gas phase. A distribution coefficient between matte and slag was determined based on experimental work.

The distribution coefficient defined as $L_{Cl}^{s/m} = \frac{(wt\%Cl)}{[wt\%Cl]}$ $\quad ( ) = slagphase \quad [ ] = mattephase$

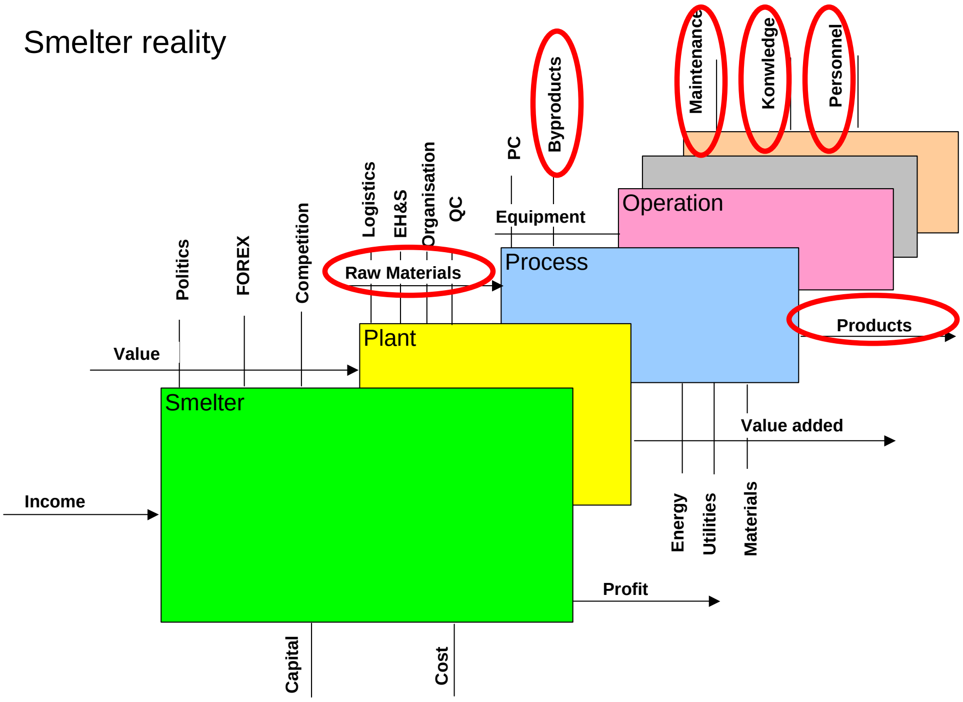
was determined to approximately 2.5.

Analysis of the gas phase with mass spectrometer indicates evaporation of NaCl and $ZnCl_2$.

7.5 Conclusions

To obtain a fundamental knowledge of the effect of elements on processes and products is a challenge for researchers and an aid for smelters in processing of various raw materials, both primary and secondary. Using a combination of experimental techniques, theoretical modeling, thermodynamics, and plant experience will give a good understanding of the behavior of various elements and its effect on smelting praxis.

Smelter reality



1. Raw Materials
    a. access to raw materials
    b. access to energy
    c. foresight on change
    d. legally driven EOL feed
    e. need for new processes
    f. feed stock recycling
2. Products
    a. New applications
    b. New properties
    c. Certify properties
3. By-products
    a. New income at lower cost
    b. Market knowledge
    c. New entrants
    d. New recyclables
4. Knowledge
    a. Process Fundamentals
    b. Metallurgical melts
    c. Thermodynamics
    d. Physical properties
    e. Process mineralogy
    f. up-dated process evaluation
    g. experimental play mind
5. Maintenance
    a. Corrosion
    b. Basic measurement methods
    c. Furnace integrity and cooling
    d. on-line measurements
6. Personnel
    a. There is world beyond google and English !
    b. Maintain curiosity
    c. LTU (Universitas !)
    e. network outside home town

7. **There is a future !**

8 Embedded systems for extreme and harsh conditions. Present status and outlook for the future

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Presentation file

8.1 Introduction

Products of the 2100 century will rely heavily on ubiquitous inclusion of software and electronics /IST, 2003/. Today we already see examples of this in the automotive industry where most functions would not be possible without the inclusion of electronics and programmable embedded systems. The development of such products very quickly becomes complicated since the physical product and its functions are made out of mechanical parts and its control via sensors and actuators which in turn are controlled by embedded microcomputers and the thereto associated software. Moreover all individual embedded devices will be networked in the future adding functionality based on fusion of embedded device services. It is obvious that such networking will enable fusion of functionality found not only within e.g. a car and airplane or a power distribution system. It is also very clear that systems will be very complex to design and implement.

8.2 Todays technology and hinders

There are numerous areas of application for ubiquitous embedded systems. We will find them in health care, our homes, in sports etc. An area with strong strong desire for more embedded systems is industry with harsh environment. Here embedded systems today are applied in measurement and control, communication, labor monitoring and support, etc. An example of embedded system usage in connection to monitoring and maintenance is given in Figure 8-1. Here human communication and machine communication is intended to become seamless enabling both system management, maintenance, engineering and control information to be supported to a single worker.

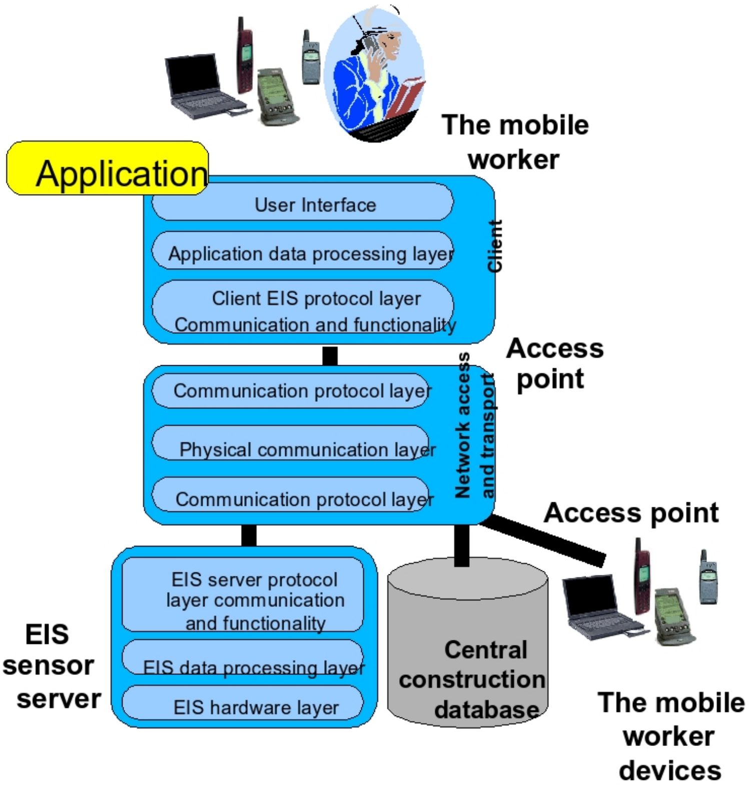

Figure 8-1. *An example of the mobile worker that is emerging today. Integrating back ground design and engineering data with process status and operation information in a mobile real time environment.*

We still don't see these applications massively in industry yet. Major reasons for this are:

- Technology not robust enough for the application environment
- System integration not seamless
- System and human interactions not understood well enough
- Slow development of industrial equipment and competence structures

Regarding robust technology we find that electronics can be made to live for many year (10-20) in highly vibrative environment like cars and lorries etc. Another example is electronics in missiles where very high acceleration can be managed. There are also examples of doing measurements even in liquid steel at 1,700 C° where the sensor survive for about a minute. Apart from jut mechanical robustness also electrical and software robustness is required. It is still very clear that electronics reliability both in ordinary and extreme environments can be much improved.

For system integration there still is a long way to the desired seamless ad-hoc integration projected and envisioned by many. Interestingly the identification is that the complexity of today and tomorrows systems is so large that the development and maintenance methodologies present today is not capable of handling the complexity. In my opinion a major reason therefore is the batch oriented programming and computing paradigm used in today computer systems.

Regarding system and human interaction it is very clear that human user interaction with today computer systems still is very limited. The major reason therefore is the very different way computers and humans 'think'. This again comes back to how computers are programmed since I think we can not redo the human way of thinking. At least this is not possible in short term. What we though can do is to improve the education level of human about how today's computers think and are programmed. This will certainly improve usability of today's technology and its short comings.

Regarding the last point industry often take a healthy conservative approach to new technology requiring technology to become mature for industrial usage. Here harsh environment maturity is most often missing.

8.3 Future perspectives

For the future a potential usage of embedded electronics in harsh environment is in-situ monitoring of the processes. This means that sensors will be put like submarines into the process flow from where they will report on the process status including with both time and location. This opens for new ways of managing, maintaining, engineering and controlling a process.

This submarine approach is starting to become possible for friendly environments like in the human body. In most process industry like mining and metallurgy this means that the submarine has to survive sometimes extreme conditions of accelerations, temperature etc. Imagine a sensor going through a crusher, a mill or a steel furnace. To meet these requirements a lot of research is still needed.

To focus embedded system and electronics research European industry is now gathering under the umbrella of Artemis /Artemis, 2007/. Artemis has defined a Strategic Research Agenda, SRA that will form the basis for European funded research on embedded system for the next seven years. This research agenda can still be improved and provide more focus on harsh and extreme environment issues.

For the purpose of improving the SRA and over all strengthening of Artemis working groups are now organized. The Process-IT initiative hosted by LTU has been presented to Artemis and is now in the process to form an Artemis working group.

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Artemis, 2007 http://www.artemis-ofice.org, last visited May 2007.

9 Remediation of tailings impoundments: Time evolution of groundwater quality

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Presentation file

Oxidation of pyrite and/or pyrrhotite in mine waste deposits causes formation of acid mine drainage with subsequent release of metals from sulfides such as chalcopyrite, galena and sphalerite, and also from other minerals. The initial oxidation of iron sulfides needs oxygen and water. Remediation of sulphidic mining waste is, therefore, usually directed towards limiting oxygen transport to the waste. Important remediation methods are to cover the waste with water, or to cover the waste with material with low conductivity for oxygen and water. In both cases the supply of oxygen to the waste is limited, and, in the case of dry cover, the supply of water may also decrease.

Modelling based on extensive lab- and - and field studies perfomed within the MiMi (Mitigation of the environmental impact of mining waste) showed that the oxygen flux through the most common type of dry cover for covering of tailings in Sweden tailings (a sealing layer of clayey till and a protective cover of unclassified till) will be about one mole O_2/m^2 per year, a very strong reduction compared to pre-remediation conditions.

To study the evolution of groundwater quality in tailings impoundments with time after such a strong decrease of oxygen intrusion, a field study was performed at the Kristineberg mine in northern Sweden. Here sulphide-rich tailings left open for 50 years were remediated in 1996 by applying double dry cover on one part of an impoundment, and raised groundwater level combined with simple till cover on the other part. Fifteen groundwater pipes installed in the impoundment were sampled from 1998 during a period of 6 years.

The results showed that the groundwater quality varied considerably in the impoundment, even under the same type of cover. Secondarily retained Fe, S, Mg, Mn and Z were remobilised when the groundwater was raised. In the part with raised groundwater level, the average concentration in the different wells ranged from 2700 to 9000mg/l in 1998, and the range for S was 2200 to 7000mg/l. During 2003 the average concentrations had decreased and ranged between 150 and 900 mg/l for Fe and between 130 and 900 mg/l for S. The strong improvement of water quality was caused by decreasing sulphide oxidation rate, and inflow of less contaminated groundwater. The redox potential generally decreased and pH increased. This will probably continue until steady-state groundwater conditions are established. The concentration decreases in Fe, S, Mg, Mn and Zn were less obvious in the part with dry cover than in the part with raised groundwater level. The concentrations of Cd, Cu and Pb in groundwater decreased rather rapidly all over the impoundment after remediation. In areas with high pH (c. 6) and low redox potential (<200 mV), Al, Cd, Co, Cr, Cu, Fe, Ni, Pb and Zn were almost depleted. In areas with low pH (<5) and higher redox potential (>200 <400mV) the concentrations of Co, Cr and Ni remained almost unchanged. Arsenic was the only element that showed increased concentrations in some areas after remediation when pH increased and the redox potential decreased.