MINEFILL 2011 - International Conference on Mining with Backfill
21-25 March 2011 Cape Town South Africa

Fliß, T.; Marx, H.; Thoma, H.; Stäubert, A.; Lindenau, A. & Lack, D.
K-UTEC AG Salt Technologies, Sondershausen, Germany

Backfilling and Pillar Re-Mining in Potash Industry

It will present an overview about backfilling and pillar re-mining operations of the German potash industry, applied for an optimized utilization of the mineral resource especially for the mining of high grade deposits.

This procedure was applied successfully in German potash industry since more than 100 years as an economical and ecologically sound mining operation. It is shown a short historical review of applied methods and principal procedures. Furthermore will explained geomechanical issues around the backfilling activities and material properties of the placed backfilling materials. The explanation will be supplemented with information about monitoring and measuring activities during backfilling and pillar re-mining operation and technical information about the production of the backfilling material.

To minimize the cost for backfilling material, waste materials from potash processing were used as major part of the backfilling material. By this way disposal and usage of waste materials combined with a significant decrease of the environmental impact is possible. Finally we comment the demands and benefits in view of the technical realization and overall resource utilization.

1 Backfilling in German Potash and Salt Industry

As first historical review should illustrate the origin and the meaning of backfilling and pillar re-mining in the German Potash and Salt Industry. In principle the backfilling of mined out cavities in potash mines, was needed since the first major water inflows and resulting abandonments of the whole mine occur during the eighties of the ninety century. As a result of these first disasters, the mining authorities decree a regulation for backfilling all working cavities in potash mines. These regulation was valid up to the year 1967, were the principal switch of the excavation method to trackless high capacity equipment occurred.

The first backfilling activities based on excavated rock salt from so called “Bergemühlen” as a bulk material, filled in the mined out workings. The hydraulic backfilling method has been applied in the German Potash Industry since 1908. At the beginning mainly used for the stowing of residues from processing of the raw salt (flotation residue and hot leaching residue) and to guarantee the filling of the mined out working areas, later used to optimise the mass extraction ratio under safe geomechanical conditions during a secondary mining phase with pillar re-mining. In the 1980’s the application of pillar re-mining for the extraction of Carnallitite as a material with lower mechanical strength was developed.

Since the 1990’s various mines in Germany are practising recycling of industrial waste materials as backfilling to stabilise excavations, minimise convergences and subsidence. Recently a lot of potash mining projects were developed without environmental emissions based on modified backfilling cycles. This seams the future course for potash mining projects according the actual ecological and political trends worldwide and especially in densely populated Europe.

The following chapter should illustrate the main application fields for backfilling. This comprises the usage of backfilling for stabilisation, for pillar re-mining and to ensure a low or a non-emission operation.

1.1 Backfilling for Stabilisation

As described in the introduction, the first application of backfilling in the German Potash Industry was the stabilisation of mined out workings to avoid negative effects of hanging wall deformation an therefore inflow or flooding of the mine. As backfilling material in principal additional excavated Rock Salt or waste materials from salt processing were in use. The principal procedure and conditions should be illustrated by the following example of the mine „Glückauf“ at Sondershausen.

The abandoned mine “Glückauf” is the oldest active potash and Rock Salt mine in the world, have been produced Sylvinite, Carnallitite and Rock Salt since 1898. The central part of the mine field covers an area of 6x10 km², partially beneath settlements of the town of Sondershausen. The production depths vary between 600 m and 1000 m beneath the ground surface. Until 1991 a total amount of 110 million tons mine-run salt was extracted with a maximum annual production of 2.5 million tons of salt. The production was stopped in 1991 and the mine was stabilized by backfilling the existing cavities with non-mining-related waste materials.

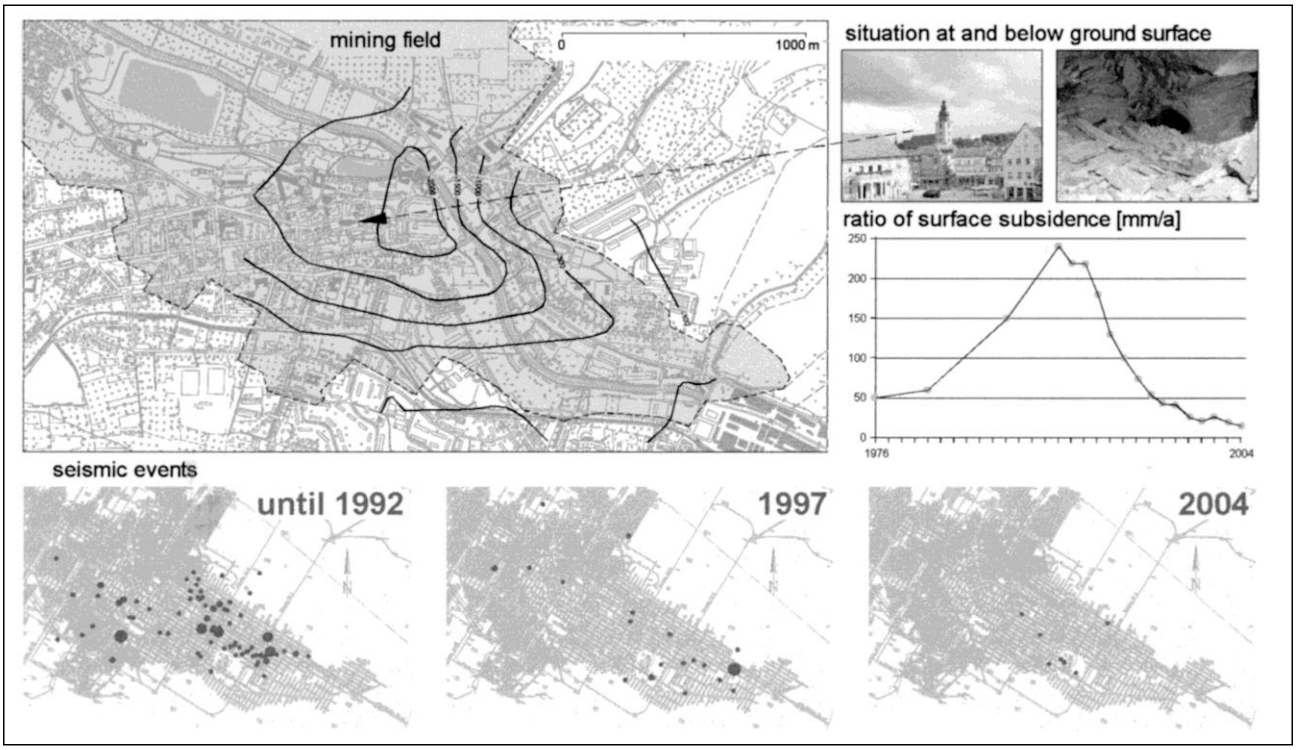

Figure 1: *Location of the backfilling beneath the town of Sondershausen. Subsidence rates (isobath's and graph of the diagram) and seismic events (red dots) are also indicated [9].*

After the production was terminated in 1991, critical deformation and instabilities occurred in a mine field located directly beneath the town of Sondershausen (pop. 25,000). The subsidence rates, determined at the surface, amounted to up to 25 cm per year and were accompanied by seismic events with magnitudes up to ML=1.8. From 1991 to 1997 the corresponding part of the mine was exclusively backfilled with Rock Salt that was excavated for that purpose from a different part of the mine. After the backfilling had been finished in 1997 the number and the magnitude of seismic events that were observed in that particular mine field gradually decreased, so that presently merely very weak seismic activity is recorded. The development of the observed seismicity in the years 1992, 1994 and 2004 is shown in the lower section of *Figure 1*.

The backfilling was accompanied by in situ geomechanical measurements, including hydraulic fracturing, convergence and extension measurements at pillars. These measurements were performed by K-UTEC using proprietory measurement devices and sensors (see example in *Figure 2*). As an example of a pillar in the centre of an extraction field *Figure 2* depicts the loading status at different times. The pillar's capability to act as a supporting element is clearly reduced over time, which is due to internal fracturing and deformation processes. This leads to large scale changes of the stress distribution and subsidence of the hanging wall or of the ground surface.

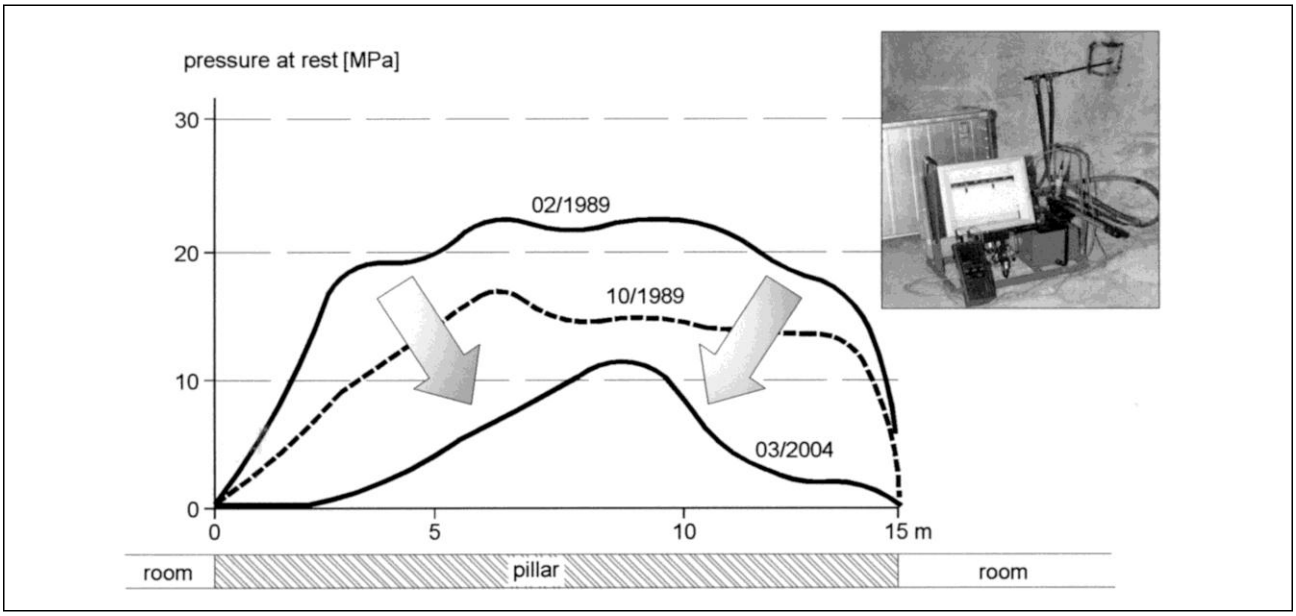

Figure 2: Decreasing pressure at rest within a pillar in the center of a mining field in an advanced state of collapse for different times [9].

The subsidence rates constantly decreased after the start of the backfilling activities in 1992. Since approximately 1994 the backfilling has been showing the desired large scale effects. *Figure 1* contains a diagram of the subsidence rates at ground surface versus the history of the backfilling. This example shows that major negative effects on the town of Sondershausen, such as strong seismicity and subsidence, were indeed prevented due to timely and effective application of the backfilling techniques. An important prerequisite for the optimized application of backfilling is the accompanying monitoring as provided by K-UTEC.

1.2 Backfilling for Pillar Re-Mining

While for stabilising of pillar structures the backfilling material have to ensure a support of pillar and perhaps roof structures, for pillar re-mining the backfilling material has to provide an effective support of the hanging wall. For pillar re-mining the backfilling material have to hold adequate strength to ensure the required support for the hanging wall structures after mining of the primary pillars. Adequate material properties for this intention could reach only using hydraulic backfilling. The backfilling material has to be placed short after excavation of the primary workings to utilise the maximum convergence of the hanging wall structures to form a stable and strong backfilled mass in the primary working.

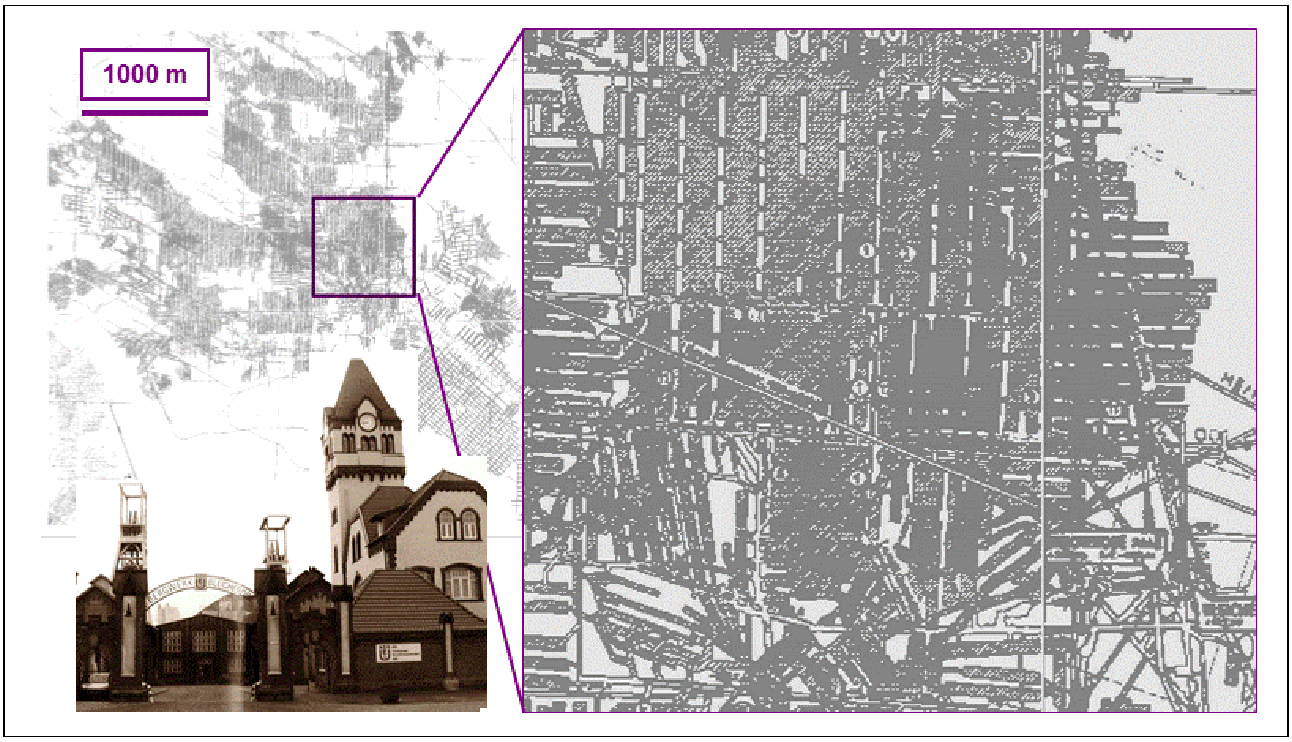

Figure 3: Area of total pillar re-mining in the central field of the mine Bleicherode as a detail figure on the right side and in the principal mine layout on the left side.

The first application of hydraulic backfilling for pillar re-mining was in 1908 in the Royal Potash Mine of Bleicherode. The principal working layout includes special designed long room workings with identically dimensions of rooms and pillars of 10 m. This layout holds ideal conditions for the primary and the following secondary mining phase. The mined thickness of the potash seam was about 12 m and K_2O- content varies between 27 and 32 %.

The extraction method based in principal on drill and blast mining. The full mining height was reached by the application of overhand stoping on the excavated material. After the complete excavation of the working the backfilling were realised immediately.

After consolidation and the forming of a stable backfilling structure starts the backfilling operation. In a first phase of pillar re-mining the extraction of every 2nd pillar and finally in a 2nd phase the complete pillar structures were mined. The first phase of pillar re-mining at Bleicherode was between 1918 and 1937. The second phase follows between 1950 and 1953. During this phase a total annual amount of 100,000 t potash salt were mined out of the pillar structures of the mine Bleicherode. This amount could be increased up to 260,000 t per year between 1978 and 1980 [2].

The principal applied methods of pillar re-mining in South-Harz Potash District are:

Long room method with special designed rooms and pillars (identic dimensions of rooms and pillars) (1),

Long room method with different dimensions of pillars and rooms (greater depths or lower material strengths e.g. Carnallitite) (2),

Overhand stoping on backfilling material for the development of a larger thickness of the deposit (3).

The *Figure 4* should illustrate these methods in principal.

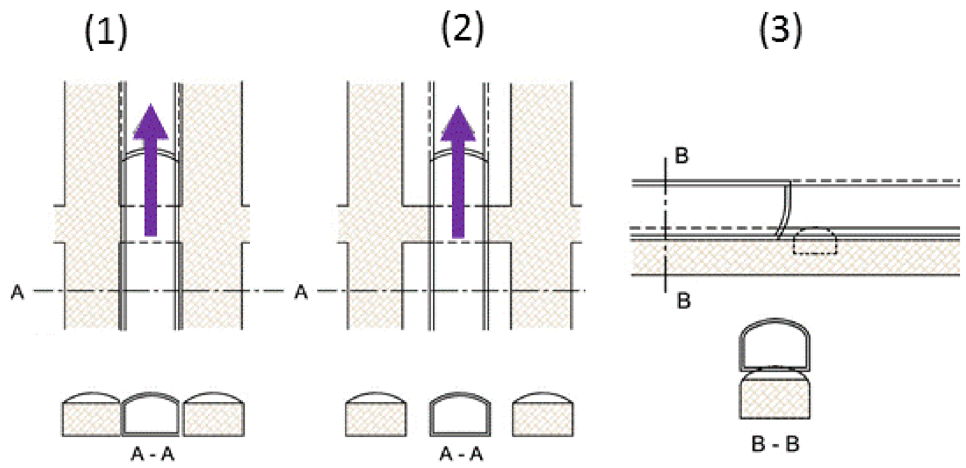

Figure 4: Applied Methods of Backfilling and Pillar Re-Mining in German Potash and Salt Industry in South Harz Potash District [9].

1.3 Backfilling for non-emission Operations

With the increasing population density and an enhanced utilisation of natural resources, like ground water or arable land, the question about a non-emission mining operation with marginal environmental impacts gets more and more significance. Especially for potash mining in dense populated areas, like central Europe or in sensitive ecological systems with high agricultural production capacities, this item is often a major fact for the official permission.

Beside various modification of the process design to produce the final products, a key factor is an optimized backfilling cycle to guarantee a non-emission operation. This optimised backfilling cycle base on maximised utilisation of the available mined out space in the underground mine. This requires special placement technologies and an optimised development work amongst others. A complete utilisation of the mined out space is impossible for underground mining, due to required infrastructure network of galleries and drifts.

On the other hand, the technology of solution mining to extract potash salts from underground has large benefits in view of the environmental impact. For the application of this technology, a complete utilisation of the mined out space is possible in principle. Besides the ensuring of a non-emission operation, a much higher yield happens by using the pressed out production brine. Various projects runs or were developed world-wide. The K-UTEC Salt Technologies finished currently the basic engineering for a solution mining project in south-east Asia for a Chinese client.

2 Technology of Backfilling

The production the backfilling suspension generally the available residues from the potash salt processing were used, which contain between 60 and 90 VOL. - % Rock Salt contained. Beside the Rock Salt the material contains furthermore Anhydrite as well as subordinated of Polyhalite, Glaserite and Sylvinite.

The material was conditioned in appropriate mixture and agitators and transported by means of pipings to the placing location. Beside steel tubes in recent time also PE-pipes are in use, which exhibit the necessary pressure strength. After the placing of the suspension into the mined out workings a dwell phase followed before the next placement be applied could.

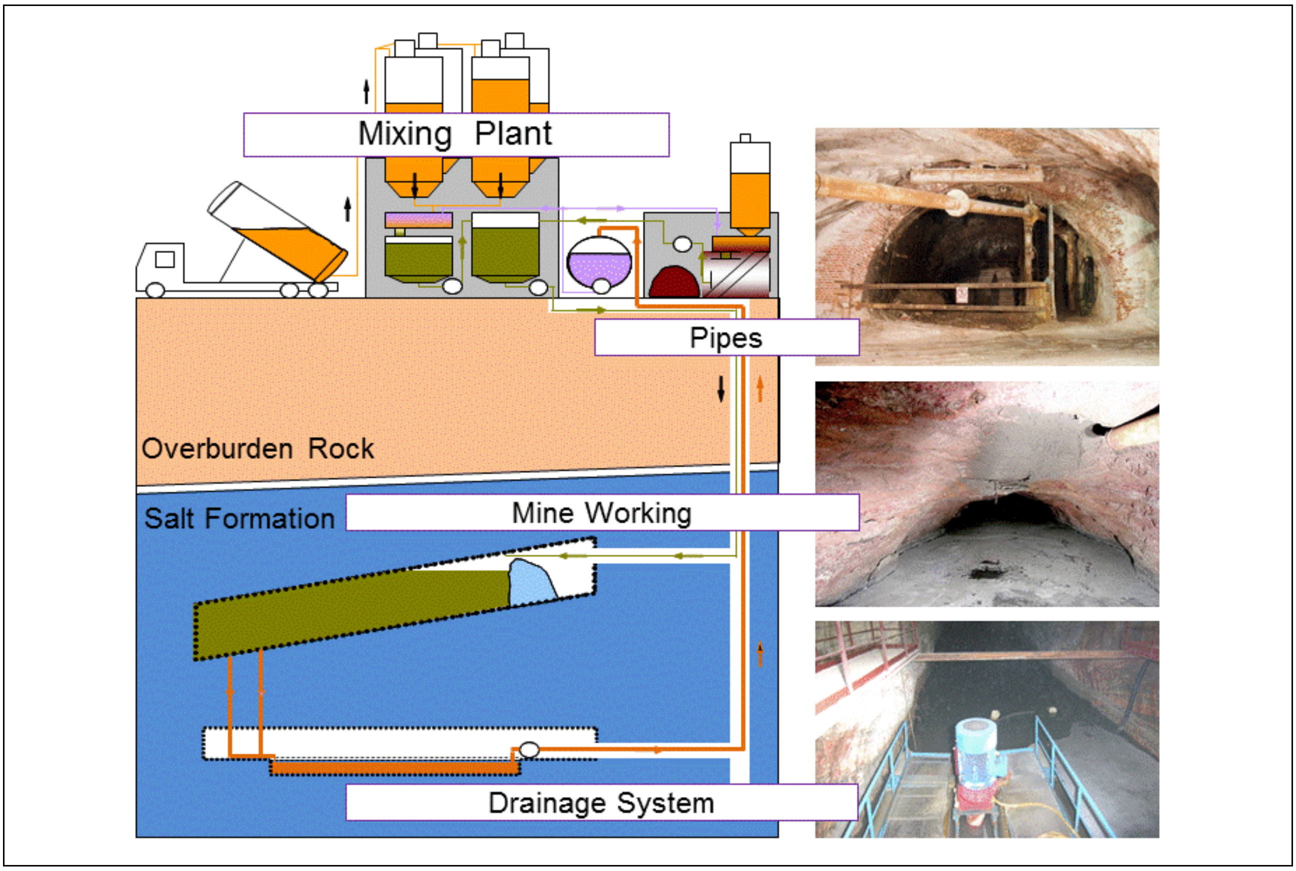

Figure 5: Principal Backfilling Cycle including some mine images on the right side.

To produce hydromechanical backfilling material in principal finely grained and grained wastes from salt processing or dusts, ashes, products of chemical flue gas treatment from waste incineration, foundry sands, boiler slags and sludge can be processed into a flowable (flushing backfilling) or pumpable (backfilling by viscous slurry) backfilling material mix with adding a concentrated salt solution. The applied transporting solution has to be chemical inactive against the host rock.

K-UTEC Salt Technologies is able to develop special recipes for backfilling mixtures according to the special requirements. The adjustments and measurements were executed in our own pilot plant facilities. K-UTEC holds a lot of expert knowledge and experience for the usage of various industrial waste materials for backfilling materials.

We divide flushing backfilling and backfilling by viscous slurry due to the fluid mechanical properties. In the process of flushing backfilling the backfilling suspension is produced on the surface according to various mix designs with a procedure of referring to material groups. The mixture with a considerable excess of mixing liquid remains in a reaction drum to reduce exothermal effects and a possibly existing gas formation potential. After a residence time of 2 to 4 h on average the backfilling suspension is transported into the backfilling rooms by means of a piping system thus using the geodesic difference in height. The salt solution applied in this procedure serves as a transporting medium for solid particles and reactant for the setting process.

For backfilling by viscous slurry no or only low excess of mixing liquid is required compared with flushing backfilling. Therefore no brine drainage system is necessary; a small amount of excess transporting solution is removed by weathering or admitted by excavation disturbed zone. The pore liquid can be controlled effectively so a high saturation is possible. This is an important fact for the application in sensitive host rocks. The transportation of backfilling material requires the installation of high performance pumps (e.g. plunger pumps) due to the higher viscosity.

The placement of the backfilling material took place shortly after the end of the production work, to utilize a maximum of the activated convergence for compaction of the placed material. The periods between placement and secondary mining phase were between 9 and 14 years.

The placement of the backfilling requires the preparation of the mined out workings to isolate the backfilling area from the active mine workings. For this purpose, so called semipermeable dam constructions were erected for a controlled drainage of the placed backfilling material. These dams were set on the lowermost point of the working to guarantee an optimal draining. The dams were commonly of Rock Salt placed as bulk good and compacted. In recent time however also dams from steel sections with different geo textile situations are used.

The backfilling material contains about 50 % of salt brine ($MgCl_2$ – brine) as transport medium. A part of the medium will crystallize to form cement like binding structure and a part will pressed out.

The excess fluid were collected in special sump areas and transported via pipes to a central brine reservoir. The transportation from central brine reservoir to daily surface occur using high pressure pumps. In the backfilling plant, the brine was used again to compose the next backfilling material as a closed cycle.

3 Technology of Pillar Re-Mining

The following chapter should describe the principal procedure of the pillar re-mining. After placing the backfilling material inside the primary workings, the pillar structures of original salt rock deform continuously and compact the set backfilling material. With the time the backfilled material becomes more and more stiffness and an increasing strength. By active convergence, the included fluids of the backfilling material were pressed out and have to be collected in sumps.

After some time the backfilling material becomes more and more strength caused by consolidation, re-crystallisation and convergence. The final mechanical behaviour of this structure is similar to the natural salt minerals. Achievable material properties were described in the next chapter.

The pillar mining starts after the properties of the pillars of backfilling material are adequate for re-mining the original pillars of the salt. The mining of the pillars were realized in several steps: in a first phase usually every 2nd pillar with or without backfilling and finally the complete pillar structures with or without backfilling.

The major cause for forming the mechanical properties is an effective compaction due to the running convergence of the hanging of the backfilled workings. The *Figure 6* shows the closure behaviour in the mining horizon pillar during backfilling and pillar re-mining operation in South Harz Potash District of Middle Germany.

The closure behaviors of the underground workings were deduced from the observed subsidence on surface. For each stage cold observed the following convergence:

Primary excavation phase and backfilling: 0.60 m (about 6 % according the original working height of about 10 m)

Backfilled working structures (compaction due to convergence): 1.63 m (17 % in view of the backfilling pillar height of 9.40 m)

Backfilled working structures (deformation after secondary mining phase): 2.30 m (25 % in view of the backfilling pillar height of 9.40 m).

The total deformation of the backfilling pillar since their placement is about 42 %. The deformation on the surface is measured with 3.6 m at maximum in the central part of the pillar re-mining area. This value could be further reduced by the additional use of backfilling for the secondary workings.

This case example shows that the application of the pillar re-mining method is possible in principle in densely populated areas without negative influences for the surface and the public safety. The ensuring of the mine safety is possible in any case by adequate monitoring and measuring.

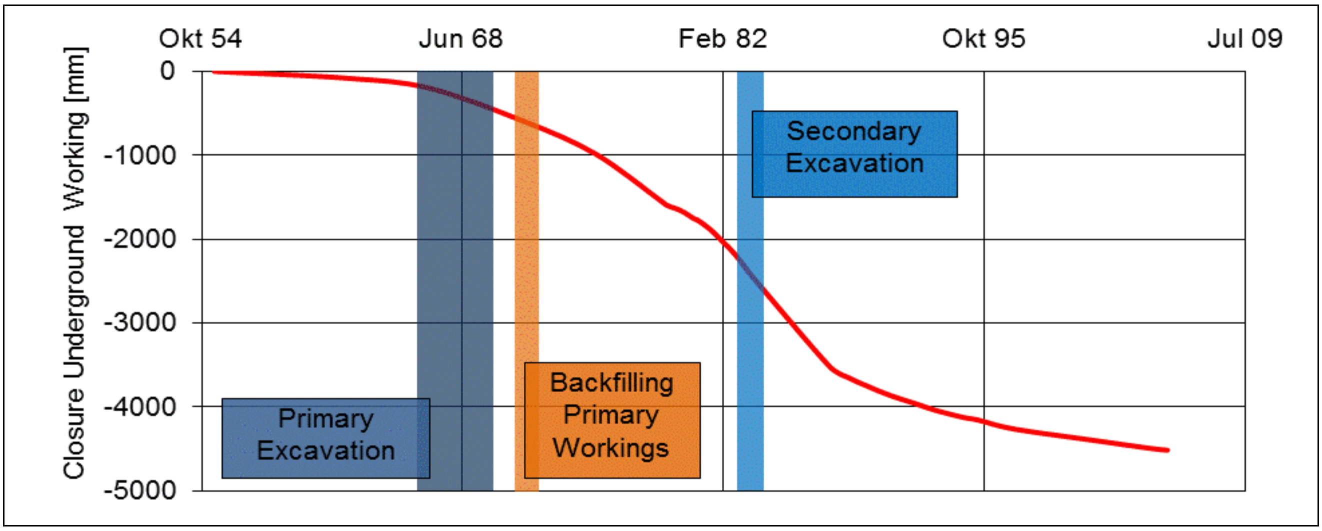

Figure 6: *Closure behaviour of the underground workings during backfilling and pillar re-mining operation in the central part of the mining field.*

4 Properties and Behaviour of Backfilling Material

Material samples of various backfilling materials show a strong and stable material, holding relative high strength and lower permeability. These mechanical properties results from the material composition with a relative high content of Rock Salt combined with the used medium $MgCl_2$ - brine for transportation and the principal hydromechanical placement method [8]. The main reason for the forming of a strong backfilling structure is a three axial stress state inside the backfilling material due to the convergence of the backfilled working areas. This process results an effective re-crystallisation and compaction of the Rock Salt grains with the new formed binding cement [5].

The overall backfilling structure shows a significant difference in view of the mechanical properties and behaviour, depending on the overall closure conditions, the principal material composition and the location in view of the intake point for the backfilling material. The mostly observed backfilling materials inside central areas of re-mined pillar structures holds uniaxial compressive strength between 55 and 65 MPa and other mechanical properties as shown in Table 1. Beside this stronger material typs I and II, exist some areas with porous materials holding lower strength between 5 and 10 MPa. These areas are mostly characterised by uniform grain size distribution without larger structural compaction.

Table 1 Mechanical properties of stronger backfilling types I and II [3]

Youngs Modulus	$E_{stat.}$	GPa	22.8 ± 3
	$E_{dyn.}$	GPa	33.5 ± 2
Poisson's ratio	ν_{Stat}	-	0.24 ± 0.09
	$\nu_{dyn.}$	-	0.27 ± 0.017
Compressive modulus	$K_{stat.}$	GPa	16.0 ± 4.8
	$K_{dyn.}$	GPa	24.0 ± 1.4
Shear Modulus	$G_{stat.}$	GPa	9.4 ± 1.6
	$G_{dyn.}$	GPa	13.2 ± 0.4
Density	ρ	g/cm^3	2.13 … 2.24

The *Figure 7* shows the stress state inside a pillar of backfilling material after a time of about 40 years since the placement of the material in the primary working panel (left side of the figure including the graph for equilibrium pressure). The secondary working is actual air filled on the right side of the figure. The included samples shows the contact area between the backfilling material (type I) and the originally Sylvinite rock.

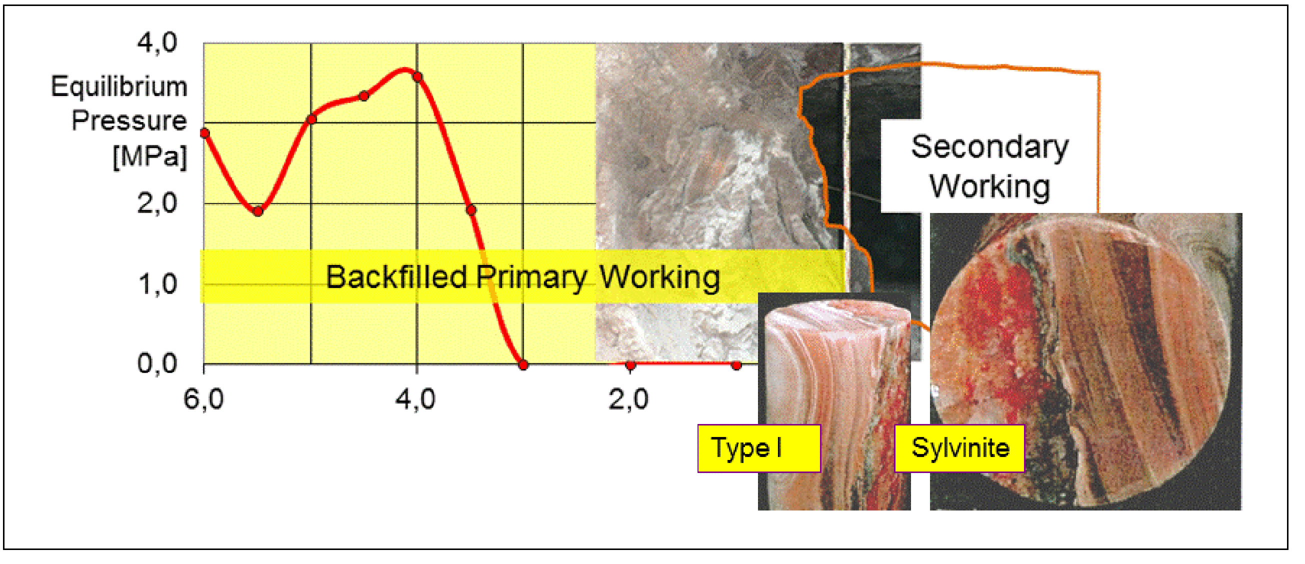

Figure 7: Stress State inside a pillar of backfilling material (left side) and backfilling material type I in contact to Sylvinite (right side).

5 Resume, Potentials and Benefits

The backfilling and pillar re-mining method is a proven procedure to optimise the mass extraction ratio in the German Potash Industry. Waste materials from processing and perhaps other industries can be recycled as hydraulic backfilling material in load bearing structures in salt mines. The mechanical behaviour of this structures is analogue the natural salt minerals. They can be designed or dimensioned like pillars from salt and serve as effective support structure to bear hanging wall. By this way a high safety level could be ensured.

The explained examples shows, that nearly a complete re-mining of pillar structures in local areas is possible. The application of the method requires some additional efforts, like backfilling equipment, modified excavation procedures and panel designs amongst others compared to commonly used room and pillar layouts. This additional effort has to be considered with special view of possible environmental effects and governmental restrictions.

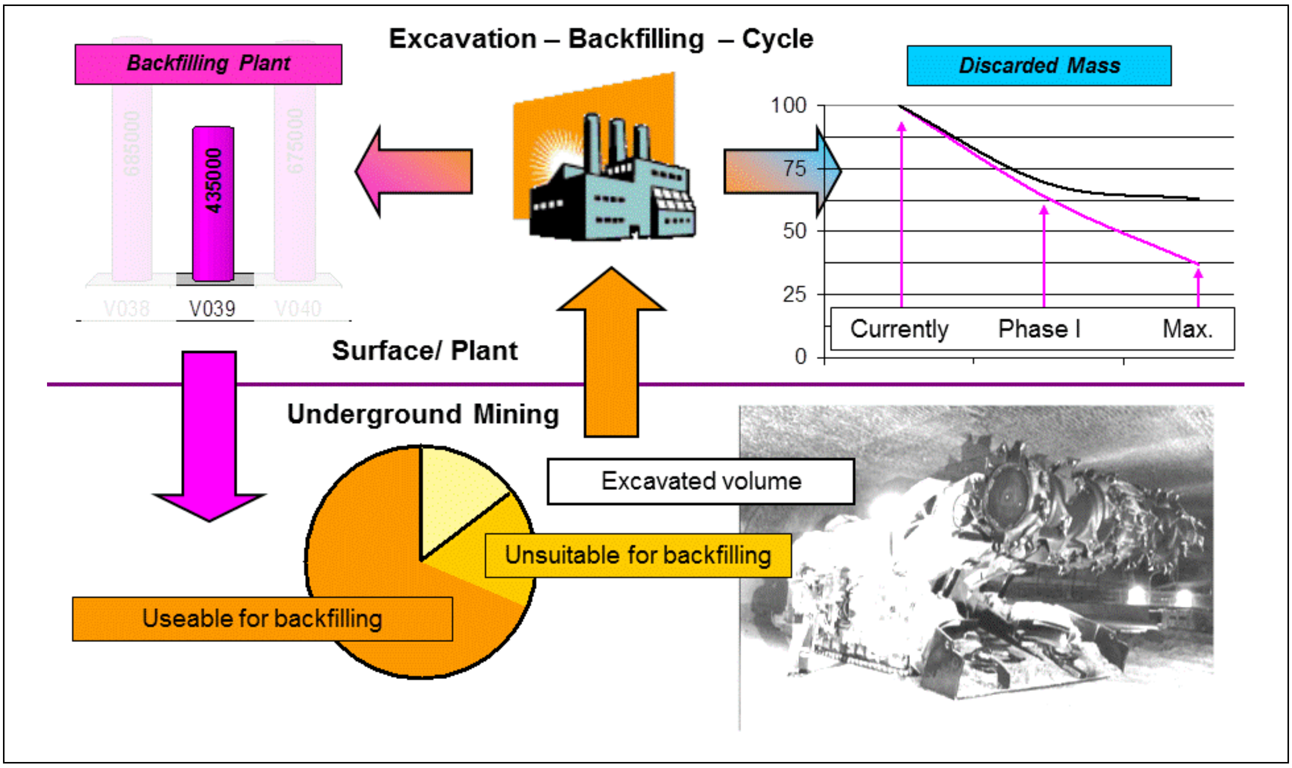

Figure 8: Principal backfilling cycle and decreasing discarded masses (on the right side above).

In the year 2008 we evaluate for a British client various possibilities of backfilling and pillar re-mining options for a potash mine. The *Figure 8* shows the principal backfilling cycle for this study. From these consideration results in principle a possible increasing of the mass extraction ratio from 50 up to 80 % for local working panels. Depending on the capacity of the backfilling plant and the available residues from salt processing means this a saving between 500,000 and 1,000,000 t of reserves per year. The discarded masses could be minimised up to 40 %. For the application of backfilling in older abandoned mining areas, we estimate additional reserves of 12 million tonnes of potash salts. This shows large effects for the principal mineable reserves of the deposit and therefore possible additional economic benefits. Especially for high valuable minerals larger economic effects could be expected also outside of the potash industry.

However, based on backfilling with or without pillar re-mining or to ensure a non-emission operation a sustainable and valuable combination of economic, environmental and safety aspects for mining operations is possible. That is valid especially for mining operations in dense populated regions or sensitive environments.

6 Reference

[1] FULDA, D.; GRUCHOT, G. & MICHALZIK, A. (1966): Handbuch für den Spülversatz im Kalibergbau. VEB Deutscher Verlag für Grundstoffindustrie, Leipzig 1966

[2] MÜLLER, P.; REINECKE, P & VORWERK W. (1981): Totaler Pfeilerrückbau – ein Beitrag zur besseren Nutzung unserer Hartsalzlagerstätten. In Kali – Steinsalz – Spat (Reihe A), Informationen aus Wissenschaft und Technik, S. 12 – 18, Jahrgang 5, Heft 1, 1981.

[3] SITZ, P. et al. (1999): Untersuchung und Bewertung alter Spülversatzkörper aus bergbau-eigenen Rückständen der Kaliindustrie hinsichtlich ihrer Eignung für Verschlussarbeiten in Untertagedeponien. Abschlussbericht zum Vorhaben 02C0496 für das BMBF und TMLNU, Freiberg.

[4] STÄUBERT, A. (1997): Geotechnische in situ-Messungen und Untersuchungen zur Wirksamkeit von Spülversatz aus Fabrikrückstand, GVV mbH, Bergwerk Sollstedt – Totaler Pfeilerrückbau Strecke 70. Kali-Umwelttechnik GmbH, Sondershausen 09.11.1997.

[5] RAUCHE, H. & MIERDEL, K. (2001): Von der Festkörpersuspension zum tragfähigen Spülversatzkörper – Einfluss der strukturellen Entwicklung auf die mechanischen und hydraulischen Eigenschaften von Spülversatzmaterial. Vortrag anlässlich des Fest-kolloquiums zum 65. Geburtstag von Dr.-Ing. Dietrich Fulda am 12.02.1999 in Freiberg. Freiberger Forschungsheft A 858, Freiberg Akademische Buchhandlung 2001.

[6] Fliß, T. & Stäubert, A. (2006): Investigation of a backfilling field in the abandoned potash mine Sollstedt - actual review of hydraulically backfilling technology regarding the establishment of long-term-functional sealing sections for drifts and mine workings. By order of the GVV mbH Sondershausen/ Germany. K-UTEC AG Salt Technologies Sondershausen, 23.06.2006

[7] Jordan, M. & Fliß, T. (2007): GEOPHYSICAL AND GEOMECHANICAL MEASUREMENTS AS MEANS FOR THE MONITORING OF MINING INDUCED FRACTURING PROCESSES AT POTASH AND ROCK SALT MINES. Presentation and proceedings of International Geomechanics Conference, Nessebar 2007, Bulgaria.

[8] Bodenstein, J. & Schreiner, W. (2001): Reduzierung der Bergsenkungen durch Einbringen von Spülversatz – Gebirgsmechanisch-bergschadenkundliche Aspekte der Anwendung des Spülversatzverfahrens im Kalibergbau. Vortrag anlässlich des Festkolloquiums zum 65. Geburtstag von Dr.-Ing. Dietrich Fulda am 12.02.1999 in Freiberg. Freiberger Forschungsheft A 858, Freiberg Akademische Buchhandlung 2001.

[9] MENZEL, W.; SPRINGER, H.; KUYUMCU, M.; SCHREINER, W.; STÄUBERT, A.: Sicherung des unter der Stadt Sondershausen aufgefahrenen und 1990 stillgelegten Carnallitit-baufeldes durch Steinsalzversatz. - Vortrag zum 13. Nationalen Felsmechanik-Symposium am 23./24. März 1998 in Aachen (Themenkreis "Salzmechanik / Untertagedeponien")

[10] STÄUBERT, A. (2001): Geomechanische Betrachtungen zur Wirkung von Spülversatz im Kalibergbau. - In: Spülversatz im Salzbergbau. - Freiberg: TU Bergakademie, 2001; Freiberger Forschungshefte, A 858, Freiberg 2001. S. 125 – 148

[11] Marx, H.; Lack, D. & Lindenau, A. (2010): Waste Characterization and Conditioning. Workshop: underground disposal of hazardous wastes, experience of 40 years of research and practice, GRS Brunswick 30.11.2010.