SEALING OF AQUIFEROUS LAYERS WITH A VIEW TO LIMITING INFLOWS OF SUBTERRANEAN WATERS INTO MINERAL RAW MATERIAL MINES BASED ON THE EXAMPLE OF SEVERAL SELECTED DEPOSITS

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INTRODUCTION

Inflows of subterranean waters into mine workings during the exploitation of various types of mineral raw materials have been known since ancient times[1]. Inflows of subterranean waters frequently prevented the continuation of deposit exploitation due to the highly primitive drainage conditions[2]. The development of technology and drainage equipment has meant that mine drainage problems have stopped constituting a determining factor with regard to the possibilities relating to the opening out and production of particular raw materials. The ability to carry off natural subterranean waters flowing into mine workings has however not eliminated the problem connected with water hazards, which generally arise in circumstances where drainage measures have not been adapted to take into account hydrogeological conditions that have been insufficiently identified. The issues linked with water hazards are not the subject of the present discussion, although the discussed technology, which limits the inflows of subterranean waters into mineral raw material mines has a direct impact on eliminating them.

Currently inflows of subterranean waters into mine workings considerably increase the deposit exploitation costs and have a negative environmental impact due to the effect of the funnel shaped depression that arises on the surface. The ever more stringent environmental protection regulations mean that this issue also has an economic dimension. In light of both of these factors attempts to mine new mineral raw material deposits bring about considerable doubts with regard to their profitability due to economic factors and the environmental hazards which are difficult to predict accurately. A factor favouring sealing of aquiferous levels for the purposes of the mining industry is the considerable progress that has been achieved over the last twenty years with regard to the production of all types of relatively cheap sealing components and solutions[3].

Freezing the rock mass constitutes a highly effective, although also very expensive sealing process. This is a temporary measure and is generally only carried out over a limited segment of specific mine workings (shafts, tunnels) and encompasses a whole block of pervious and impervious aquiferous layers. This system that has been known and applied for years is not the subject of the present discussion.

The sealing method presented here based on various types of binding materials constitutes a permanent solution for given mine workings or even for an entire mine and it is characterised by the precise selection of specific aquiferous levels and layers based on the natural conditions of their deposition and tectonic engagement.

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[1] C.F. Tolman- Ground Water. Nwe York and London 1937.

[2] G.N. Kamienski, P.P.Klimentow, A.M.Owczynnikow – Hydrogeologia złóż surowców mineralnych [The hydrogeology of mineral raw material deposits]. Warsaw 1956.

[3] Kuś R. – Wykorzystanie mieszanin hydroizolacyjnych na bazie gliny do wykonania przesłon hydroizolacyjnych w obiektach hydrotechnicznych. Mat. Konf. Ochrona Odry przed zasoleniem. [The utilisation of clay based waterproofing mixtures to carry out waterproofing barriers in hydrotechnical facilities] Lubin, 1995

1 ELEMENTS OF THE MODEL OF THE HYDROGEOLOGICAL CONDITIONS THAT ARE SIGNIFICANT FOR THE SEALING OF AQUIFEROUS LAYERS DETERMINING THE INFLOWS OF SUBTERRANEAN WATERS TO MINERAL RAW MATERIAL MINES

Taking into account the sealing technology and the possibilities with regard to its effective application in the hydrogeological model, the aquiferous levels should be characterised by the following parameters:

a) impervious layers should occur in the roof and floor, which insulate the given aquiferous layer from other aquiferous layers,

b) the thickness of the aquiferous layer should be limited to a few up to a dozen or so metres depending on the particular conditions, which include i.a. the amount of the filtration coefficient, the water conductivity, etc. and consequently wide ranging deviations may exist in this regard.

c) lower substrate of mined deposit layers should be impervious and similarly in the cross-section of deposit layers impervious formations should dominate.

d) sand – gravel aquiferous layers should be characterised by average and good filtration coefficients, as opposed to fissure – cavernous aquiferous layers, which should be within the range of average and low values.

e) in light of the costs of drilling work, the aquiferous layers subject to sealing should occur relatively shallowly below the surface of the ground, i.e. up to a depth of approx. 200 m, with considerable deviations being possible depending on the specific circumstances, the limits of which are defined by the entire project's economic profitability.

f) the aquiferous levels, and in particular the impervious layers that divide them should be continuous in type and have a horizontal dimension of hundreds of metres up to several kilometres.

h) tectonic phenomena limiting horizontal and vertical hydraulic contacts generally play an advantageous role in the process of sealing and restricting the inflows of subterranean waters.

The majority of the postulated conditions would appear to be obvious and do require explanation. For the purposes of explanation „the substrate of the mined deposit layers" needs to be defined in more detail. The layer occurring in the floor of working levels is often considered to constitute this type of substrate. If this interpretation of the term were accepted in this form, then it would frequently have no practical significance. This is made very clear by the example of mined brown coal deposits, where in the floor of the mined bed a aquiferous sand layer usually occurs with limited feeding and diffusion, lying on lower metamorphic, crystalline or a on calciferous – dolomite and cavernous – fissure substrate. In this case the type of this lower substrate is of key significance with regard to inflows to the mine workings – and not the sole fact of its occurrence in the floor of the mined deposit layer of the sandy aquiferous level, which has static and dynamic reserves that are usually easy to carry off if they are not fed by the aquiferous level of the lower substrate.

It is also understandable that impervious formations should dominate the cross-section of the aquiferous levels subject to sealing, as the lesser the thickness of the layer subject to sealing, the

greater the certainty as to the effectiveness of this process and the lower its costs. The sealing process of the cavernous – fissure aquiferous levels, particularly those with well developed karst phenomena is generally very difficult to realise and sometimes nearly impossible. This is due to the rapid and turbulent flow of water within the region of funnels, cavities and karst fissures, which causes the sealing medium to be washed out of the aquiferous layer.

2 OUTLINE OF THE TECHNICAL CONCEPT FOR SEALING AQUIFEROUS LAYERS

The basic method for sealing aquiferous layers consists in boring several bore holes into their floor and pumping in the appropriate amount of sealing agent. The type of hole may be bored from the surface or from the mine workings depending on the situation at hand. As a rule the choice of sealing agent is decisive for the effectiveness of the entire process. In light of the fact that as a rule a wide range of such works are carried out, it is desirable for the sealing agent to be as cheap, easily accessible and harmless for the environment as possible. Initial investigations indicate that this requirement is fulfilled by the clay based waterproofing mixture[4]. The most important characteristics of this type of waterproofing mixture include the following:

- The 100% stability of the sealing material, which means that when a given portion of the mixture is pumped in, it retains the same volume in a given space without giving off process water,
- The rapid obtention of yield stress in the initial stage of structure creation, which ensures that the sealing mixture is resistant to being washed out, even by water with significant flow dynamics,
- The plasticity of the sealing mixture following its stabilization, which ensures its resistance to the occurrence of fracturing as a result of boring work and blaster work being carried out and also resistance to deformation caused by mining work being undertaken in the proximity.
- Corrosion resistance in conditions where aggressive subterranean waters arise,
- Good adhesion in rock,
- The high permeability of the sealing mixture into fissures of small width,
- The high technological efficiency making it possible to use relatively simple equipment in the preparation and pumping process,
- Favourable thixotropic properties facilitating the location of the injection pumps at a considerable distance from the site of the sealing work,
- Using generally accessible clays as the main component of the sealing mixture,
- The fact that the hydro-insulating solution does not contain compounds that are harmful to the environment and it has a low filtration coefficient characteristic for impervious solutions.

[4] Kuś R., Litowczenko W., Zastosowanie spoiw na bazie glin polimineralnych do tworzenia przesłon hydroizolacyjnych. Gospodarka wodna nr 6-7 [The application of polymineral binding agents to create waterproofing barriers. Water management no. 6-7] (582-583). 1997.

The wide range and diversity of sealing materials available on the market creates the convenient situation in which it is possible to apply them in accordance with present requirements and the geological – mining conditions of individual mineral raw material deposits

3 PROPOSALS FOR SEALING SUB-TERTIARY OUTCROPS OF DEPOSIT LAYERS OF THE PERMIAN LIMESTONE W-1 PRIMARY DOLOMITE AQUIFEROUS LEVEL

An outcrop of Permian limestone deposits, including the W-1 primary dolomite aquiferous level subject to drainage lies at a depth of approximately 400 m under tertiary and quaternary formations on the Fore-Sudetic monocline in the region of copper ore mining. Outcrops of this level arise in the form of a 100 m to 1.5 km wide zone of a length of approx. 50 km subject to investigation. The thickness of this level in the region of the sub-tertiary outcrops amounts to approx. 50 – 70 m. It lies at an angle of 2 – 5 º to 3 – 7 º in a NE direction. The characteristic property of this level (from the perspective of the possibilities with regard to sealing it) is the fact that impervious layers with thicknesses measured in tens and hundreds of metres arise in its floor and roof. In the roof these are anhydrites of a thickness from 70 m to 200 m and rock salt of a thickness of up to 75 m. In the floor these are fine-grained new red sandstones with a silty binding material and of which the average thickness amounts to approx. 300 m. The aquiferous layer of dolomite deposits with a thickness limited to 70 m in the region of the outcrops lying between two series of impervious formations constitutes the sole source of subterranean water inflows to copper ore mines. This inflow has remained at a constant level amounting to approximately 50 m^3/min for nearly twenty years and increases copper mining and production costs in the amount of approximately PLN 200 /1 tonne of copper. The total costs of draining the deposits amount to PLN 80 million per annum. The issue of sealing sub-tertiary outcrops of deposit layers is significant in that mine workings in the “Polkowice – Sieroszowice” mine have already reached deposit layer outcrops and are approximately 500 m away in the “Lubin” mine. In light of the fact that over the next few years further mining work is to be discontinued in the direction leading towards the deposit layer outcrops, continuing the drainage of this level is losing its practical justification (working the deposits in the zone of intensive flooding and increased inflows) and the related economic justification.

A factor favouring the sealing of sub-tertiary outcrops of deposit layers is the intensive fault tectonics creating numerous block structures in the form of horsts, trenches and steps of varying sizes and amplitudes. Observations indicate that in the mine workings that have been opened out the zones bordering on faults are generally slightly flooded and on occurrence of intensive water inflows these disappear relatively quickly, which is evidence of limited static resources being drawn upon and of a lack of hydraulic connections. The Main Lubin fault is characteristic in this respect and it has been ascertained over a length of approximately 35 km. This is a scissors fault, which is flooded in its eastern section, where the northern section constitutes the downthrow side and it is slightly flooded in the western section, where the southern section constitutes the downthrow side. The course of faults parallel to the outcrop zone generally forms a barrier that hinders the inflow of subterranean waters from the direction of the outcrop to the mine workings. This type of geological structure and the hydrogeological conditions occurring in the environs of the outcrop zone of the primary dolomite aquiferous layer results in minimal inflows to mine workings located far to the south of the mine workings in the central section of the exploited copper ore deposit, with their concentration in both downthrow sides in the region of East Lubin and East Polkowice. The size of inflows from the direction of the downsides of the aforementioned outcrops in relation to the mine workings being carried out comes to

approximately 80% of the totality of inflows of subterranean waters to the exploited copper ore mines[5].

This type of model of the hydrogeological conditions makes it possible to water-proof the perpendicular of the aquiferous layer carrying subterranean waters to copper ore mines. According to initial investigations, with regard to the 50 km length of the sub-tertiary outcrop of this layer which is predominantly insulated by a system of faults parallel to its course, a zone of increased inflows in the downsides of this structure occupying only about 5 – 10 % of its total length remains to be sealed and this may turn out to be a realistic undertaking from a technical and economic perspective.

Apart from the direct economic benefits resulting from the sealing of the levels that have hitherto been drained, the fact that in connection with this process the causes of the large area phenomena connected with the funnel shaped depression associated with the drained mines have been eliminated should be noted. Over the course of the exploitation period of the copper ore deposits on the Fore-Sudetic monocline spanning over more than forty years, the funnel shaped depression in the tertiary, sub-coal aquiferous level has attained a surface area of approx. 2400 km^2 (i.e. approx. 0.8 % of the country's area). The removal of mining damage connected with the subsidence of the surface in the central section of this funnel shaped depression increases the deposit exploitation costs in the amount of 5 – 10 % relating to its drainage costs. Costs of a similar scale are incurred in connection with carrying off saline mine waters to the Odra River (approx. 12% of the river's salinity). The proposed process of sealing the primary W-1 dolomite aquiferous level drained by copper ore mines leads to the stoppage of the further development of the funnel shaped depression and subsequently its reconstruction up to the natural conditions that existed prior to the commencement of deposit exploitation.

4 POSSIBILITIES WITH REGARD TO SEALING INFLOWS OF SUBTERRANEAN WATERS FROM TERTIARY AND QUATERNARY AQUIFEROUS LEVELS INTO THE PLANNED "LEGNICA" BROWN COAL MINE

Since documentation of the reserves of the "Legnica" brown coal mine deposits commenced in the 60s of the last century up to the present, there has been discussion concerning the possibilities with regard to the management of this deposit. Recently circles associated with the NOT (Chief Technical Organisation) Central Board have made considerable contributions to this discussion[6]. The issues related to managing this deposit are regularly raised at International Brown Coal Congresses (1994, 1996). According to the forecasts of the international scientific conference (Kraków Mining and Metallurgy Academy, 06 1999) entitled "Mining - Practice and Science – A look in the 21st century" the „Legnica" opencast mine on the brown coal deposit shall constitute the main raw material base for the national power industry. In the post conference materials, according to the standpoint of the Association of Mining Engineers and Technicians by 2040 output will totally cease in the active brown coal mines constituting the basis for the production of 40% of the country's electrical energy. This deficit could be met by the Legnica region, which is the most suitable for development and has great potential. It would be possible to attain coal output of about 25 – 50 million tonnes of brown coal over a period of 40 – 70 years. The construction of the "Legnica" mine and the activation of mining shortly

[5] Praca zbiorowa, Monografia KGHM Polska Miedź S.A.[Collective work, A Monograph of KGHM Polska Miedź S.A], Lubin, 1996.

[6] Stanowisko Stowarzyszenia Inżynierów i Techników Górnictwa w odniesieniu do polityki państwa wobec problemów krajowej gospodarki paliwowo – energetycznej. Katowice 2000. „Górnictwo – Praktyka i Nauka – Spojrzenie w XXI wiek" [Standpoint of the Association of Mining Engineers and Technicians concerning the state's policy on issues connected with national fuel and energy management. Katowice 2000 "Mining – Practice and Science – A look in the 21st century"]

before 2020 would coincide with the slow reduction of production in the copper basin and thus help to extend the period of economic activity of this region.

Preparations for designing the future exploitation of the "Legnica" brown coal deposit should also take into account the possibilities with regard to sealing the aquiferous levels, which are decisive for the inflows to this mine's drainage system and consequently for the reduction of the costs of opening out the deposit and limiting or even liquidating the funnel shaped depression which usually has a negative impact on the environment.

The impervious properties of the Palaeozoic shale and tertiary silt occurring in the substrate of the lower brown coal bed, of which floor lies at a depth of approx. 140 – 180 m is significant for the hydrogeological model of the "Legnica" brown coal deposit[7]. An equally important element of this model is the occurrence of the brown coal deposit in the wide radius tectonic depression divided by horsts and upheavals of the substrate into three separate areas with similar reserves of subterranean waters of this region.

The tertiary inter-coal aquiferous level of sands with an average thickness of approx. 35 – 40 m, which occurs relatively regularly in all three areas is of considerable significance from a hydrogeological point of view. On assuming simplified generalisation principles for these purposes, it is possible to assume that nearly 50% of discontinuous aquiferous layers occur in the overburden as a whole above the upper brown coal bed. An exceptional aquiferous layer of the overburden is the quaternary erosion gully, in which the thickness of sands and gravels of good permeability can reach 120 m. It is characteristic that there is no sub-coal aquiferous layer.

In this model there are two basic natural elements that facilitate the process of sealing the aquiferous levels with a view to limiting the inflows of subterranean waters into the drainage system of the opencast mine. The first of these consists in the impervious substrate and the lack of a sub-coal aquiferous layer, which eliminates all inflows of subterranean waters from the floor of the future opencast mine. The second of this type of element are tectonic horsts dividing the deposits into individual areas, where the impervious substrate occurs relatively shallowly, which means that the system of holes sealing the lateral inflows to the opencast mine may be relatively shallow, for example 120 m and not at a depth of for example 160 – 180 m as the depth at which the aquiferous levels in the central section of the trough lie would indicate. In the region of this type of tectonic upheaval a reduction of the thickness of aquiferous levels occurs as a rule, which should additionally facilitate the process of sealing them. The quaternary erosion gully causes certain difficulties for the sealing of aquiferous levels that impact on the flooding the deposits. Accurate analysis of its course and of the morphology of the deposit should indicate the zones of its narrowings and smallest thicknesses, where the sealing process would be carried out most efficiently and cost effectively.

The natural division of such a large deposit (approx. 100 km^2) into individual areas is also a factor favouring the process of sealing the aquiferous layers, as the initial work in this respect may be carried out exclusively in relation to a given mining task and not in relation to the entire deposit at the same time, which should increase the economic benefits of this undertaking. In this way, the process of sealing the aquiferous levels may be precisely adapted in line with the deposit exploitation plans. The natural result of sealing the aquiferous levels around the projected opencast mine is the prevention of the occurrence of a funnel shaped depression around the drainage system of the future mine, which is to take up an area of approx. 400 km^2. This is also the result of less measurable ecological benefits connected with protection.

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[7] E. Ciuk – Węgiel brunatny. Surowce mineralne Dolnego Śląska. [Brown Coal. The Mineral Raw Materials of Lower Silesia] Ossolineum. Wrocław 1979.

The insulation of the opencast mine workings that is obtained also constitutes a benefit in itself for the purposes of the local copper industry. The location of the "Legnica" brown coal deposit between the town of the same name and the town of Lubin, where the copper industry is concentrated, as a matter of course indicates the necessity of identifying the common interests of both these mining sectors. Such a joint venture could consist in storing flotation tailings from the copper industry in the brown coal open cast mine workings. It should be noted that the flotation tailings are neutral from a chemical perspective, as they constitute finely-ground exploited rock, which occurs commonly in nature. These are dolomites, sandstones and shales. The copper mineral ore content they contain, as well as the degree of radioactivity are also not harmful to health[8].

The potential and actual hazards connected with storing flotation tailings consist in the spreading of dust of the fine-grained mass of waste materials during stronger winds and the safety of the stored mass in the "Żelazny Most" ("Iron Bridge") tank. Currently approximately 350 million m^3 are stored in an area of approximately 1670 ha, with the height of the barriers being approximately 50 m above ground level. An International Team of Experts monitors the safety of the waste dump on a constant basis. At present permission for doubling its size to 700 million m^3 is being applied for. The planned height of the tank embankments is to reach the ordinate of 180 m npm, i.e. approx. 70 m above ground level. These decisions are however stopped and blocked by the local councils of Grębocice and Polkowice. All of the problems mentioned above disappear when this waste is stored in the former coal mine workings of the "Legnica" opencast brown coal mine. Waste is transported in a system of enclosed pipelines that is safe for the environment similar to the "Żelazny Most" ("Iron Bridge") waste dump. The flotation tailings stored in the place of the excavated brown coal cannot endanger the environment, as they are located in a ground depression at a depth of approx. 100 m and will be covered with a previously excavated silty – sandy overburden layer, which previously occurred in the same place. The saline waters and possible solutions connected with the transport of waste, which may arise as a result of the long-term impact of water on the residues of mineralised rock shall remain at the site of their storage without any possibility of their impacting on the environment. In this case this is guaranteed by the impervious substrate on which the flotation tailings will be stored and also by the prevention of horizontal flows of any liquid solutions by means of sealing the aquiferous layers which has previously been carried out in order to limit the inflows of subterranean waters into the opencast mine. The stored layer of the leak-proof overburden of a thickness of approximately 100 m should sufficiently protect the environment from possible hazards stemming from the flotation tailings stored in the workings. If a layer of flotation tailings of approx. 20 m is stored on an area of 1 km^2 the annual output of waste from all of the copper ore mines could be disposed of in a manner not harmful for the environment so that the aforementioned problems relating to safety and the impact of the "Żelazny Most" on the environment are avoided. This type of storage of flotation tailings is more likely to gain the acceptance of the local administrative authorities. The overall cubature of the excavated brown coal deposit amounting to approx. 2 billion m^3 facilitates the storage of flotation tailings up to the end of the existence of the copper industry.

6. Summary

The work connected with sealing the aquiferous layers for the various requirements of the construction industry, environmental protection, water management, etc as an area of technology is becoming an ever more common phenomenon. These processes are being

[8] Chruściel E. – Oddziaływanie promieniotwórcze w kopalniach i wokół kopalń rud miedzi- zagrożenie radiacyjne – analiza i interpretacja istniejących danych pomiarowych. AGH Wydział Fizyki i Techniki Jądrowej. Instytut Fizyki Jądrowej. Kraków 1996 (maszynopis). [Radioactive impact in copper ore mines and around copper ore mines – radiation hazard – an analysis and interpretation of existing measurement data. Mining and Metallurgy Academy. Physics and Nuclear Technology Department. Institute of Nuclear Physics. Kraków 1996 (typescript)]

favoured by the increasing accessibility of sealing media and their practical effectiveness. In Polish underground and opencast mining sealing work has hitherto been carried out relatively infrequently and in selected one-off circumstances. There is nowhere in the country where a sealing system has been applied with a view to ensuring the comprehensive restriction of the inflows of subterranean waters into individual mines, particularly those that have been subject to the most flooding. The proposed system of sealing aquiferous levels carrying subterranean waters to mine workings and their drainage systems should above all be considered from a economic and ecological perspective. The limitation of inflows of subterranean waters to mines causes the funnel shaped depression to be filled or even liquidated in particularly favourable hydrogeological conditions. The two selected examples of copper ore mines on the Fore-Sudetic monocline and the example of the planned "Legnica" brown coal mine indicate that the sealing proposal should be preceded by a thorough investigation of its geological structure and of the model of hydrogeological conditions in order to ensure that the aquiferous levels are sealed in the most effective and economically efficient manner. On the basis of the example of the "Legnica" brown coal deposit it has also been demonstrated that the sealing process of the aquiferous levels may have be multi-functional in type. It may also limit the inflows of waters to the planned mine as well as at the same time preventing the potential contamination of subterranean waters as a result of storing flotation tailings from the copper industry in the workings remaining after the excavation of brown coal. In light of the new possibilities with regard to applying methods of sealing aquiferous levels within the mining industry, it would be expedient to apply them in all active and planned mineral raw mineral mines in Poland.