ENVIRONMENT-COMPATIBLE, SAFE AND FEASIBLE MINING OPTIONS IN THE VICINITY OF AQUIFERS

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ABSTRACT

Appropriate geological barriers, namely argillaceous rocks under self-healed condition provide continuous safety for the mining against the water-induced risks as well as a long-term confinement for the aquifers against the mining-induced risks (e.g. water withdrawal, pollution). Economic feasibility of this environment-compatible mining option may need an additional profit making activity namely the waste disposal into the underground cavities, because the high manpower and environmental costs in the developed, densely populated countries practically excludes the economic feasibility of any underground mining activities. A mined disposal with long-term retrievability of the wastes meet fully the ethic principles of the OECD derived from the inter-generation responsibility. This paper presents the principles and a concise guide for an integrated barrier-evaluation for these two purposes as well as sealing barrier-wounds. Alternative way for getting public acceptance for this ethically-professionally well-based option is also introduced.

MINES AND AQUIFERS AT INTERACTING RISKS

Mining-induced natural processes in the vicinity of aquifers causes risks for mining and miners as well as for aquifers (Chüan; Fernández Rubio et al., 1986; Gvircman, 1977; Kesserü 1991 and 1995).

In one hand mining-induced processes cause water-inflows, water and gas-inflows, water-induced rock movements/collapses (e.g. quick sand inrushes wet clay inflows etc.). Hot waters damage the in-mine climatic conditions. These water-induced processes cause life and health danger for the miners, as well as risks and extra costs for investors operators of mines.

In other hand mining induced processes often cause long term damages for aquifers, namely water withdrawal in connection with inflows or drainage as well as water pollution from operating or abandoned mines (Fernández Rubio et al., 1986; Kesserü, 1995).

Drinking water is an irreplaceable basis of the human life. Drinking water resources must be preserved for us and for the future generations. Mining investors also worry to hold extra costs and risks in connection with water hazard. Absolute priority of protecting the water resources and the risks of the investors due to water danger have already blocked all new investments into mineral resources under water hazard and have pressed to close almost all mines under water hazard in the countries of developed economy and legislation.

Special geological conditions, namely the *appropriate geological barriers* may promise environment-compatible and safe mining options. However the underground mining of the developed countries is usually not competitive due to the high manpower costs in comparison with the mineral producers in the not-populated areas of the Globe. An additional profit making activity is also necessary by utilising the appropriate geological barriers. This highly profitable activity is the waste-disposal in the mine that must meet all requirements of long-term safety as well as the responsibility-principles for the next generations.

Mines as licensed waste repositories are already operating *in rock salt* for radioactive wastes (in WIPP Texas USA (Callager, 1998); and in Asse (GSF, 1989); Morsleben (BfS, 1998), FRG) and for toxic wastes from EU (in Herfa-Neurode, FRG (Kühn, 1995)). Konrad iron ore mine as a repository under licensing procedure for low heat-generating radioactive wastes of FRG is also an important case example in two relations (BfS, 1998): 1/ The disposal cavities are separated from the biosphere by *argillaceous geological barriers*. 2/ However the long term safety of the site for the disposal of low and medium activity short-lived radioactive wastes is supported by strong direct evidences from mining experience its licensing was delaying by the green movements for more that ten years. The actual public acceptance policy was not capable to manage this problem.

An appropriately safe and economically feasible solution cannot be realised against public opinion, therefore proposals on the ethically-based managing the public acceptance problems should also be introduced.

ETHIC PRINCIPLES, CONFLICTING INTERESTS AND TASK-SPECIFIC PRACTICAL IMPLICATIONS

Ethic principles versus mined disposal options

Ethic principles of the inter-generation responsibilities have already formed and declared as a common opinion of the professionals to nuclear waste disposal and independent experts on environmental ethics. This common opinion born in a workshop organised by the OECD's Environmental Directorate and NEA in Paris 1994 (OECD-NEA, 1995). Essence of these statements is as follows:

- This generation must not transmit uncontrollable processes, because our generation must not suppose that the next generation shall have more economic power and stable social/political conditions for managing our relicts;
- This generation must not transmit one-way decision routes for the next generations. They should have free hands to modify our solutions basing on larger information bases and new findings of sciences & technology.

Two practical implications should be derived for our cases:

- Mined disposal with long-term retrievability of wastes meets fully the ethic principles in comparison with a surface disposal with continuous surveillance and safeguarding (OECD-NEA 1995; Rybach 1999).
- The barrier-evaluation for the complex safety assessment should include the whole period of the mining activity (exploration, construction, mineral extraction, abandonment closure) as well the post-closure period.

Proposals for promoting an ethically-based public acceptance

Due to the strongly conflicting interests and emotions the actual public acceptance policy could not manage the problems in several cases. An alternative approach is introduced here for promoting the realisation of the technical proposals of this paper:

- A consensus of the society on the ethic principles should be formed first on the basis of OECD's common opinion that is valid for all operations with long term impacts without speaking on technical solutions. These principles should be inserted into the relating acts. These beautiful ethic principles surely meet the opinions/efforts of the society. Political decision-makers and the media shall agree accordingly. Honest environmentalists cannot protest against these principles.
- Actual managing-philosophy and practice of the human activities with long-term impacts (e.g. waste disposal, mine's closure) should be compared with these principles. This comparison should be done in strong professional basement and published/discussed within the professional community and in the media as well. This step shall surely initiate strong discussions. In the frame of such discussions we have strong arguments/evidences. In spite of all uncertainties in selecting, evaluating an appropriate geological confinement for a geologically long period the reliability of this estimation is higher in magnitudes than our capability to foresee the political-social processes for the next hundreds years (Rybach, 1999). The political history of the past twelve years provides several case examples.
- Country-wide screening or re-evaluation of the information of a former screening may discover appropriate geological conditions for a combined mining and disposal activity and for mined disposal without mineral extraction. In case of small countries a simultaneous disposal of nuclear and specified an-organic, non-gas generating toxic wastes in the same host rock at separated mining fields may also promise a safe and feasible option (Kühn, 1995). This third step shall demonstrate for the citizens of several small and densely populated countries, that their geological conditions cannot provide a number of appropriate sites (Kühn, 1995). The government shall not able to promise for the society that the disagreement of the local community shall exclude an appropriate site. The safety of the today-s society and the next generations do not allow such promises. This ethically-geologically based conclusion shall surely induce very strong protest of the relating local communities.

- A full re-compensation of the local communities and individuals including all direct and indirect losses is the only ethically based solution. This re-compensation should be originated from the hands of the Nation. This is necessary for preserving the dignity of the citizens holding extra difficulties, losses for the interest of the whole society.

REQUIREMENTS VERSUS GEOLOGICAL BARRIER TYPES

Safety of the miners and mining need safety against strong inflows, however small inflows do not disturb the safety and feasibility of mining. This safety can be provided either by an aquifer depressurisation or by appropriate geological barriers between the mining cavities and aquifers preventing strong barrier failure (Kesserü, 1995).

Prevention of aquifers needs more rigorous barrier-criteria. Drainage impacts should be minimised during mining and the geological confinement should provide long-term prevention namely diffusion dominating conditions against pollutant transfer from the flooded mining cavities to the aquifers (Fernández Rubio et al., 1986; Kesserü, 1995).

Capability of different geological barrier types in fulfilling simultaneously the above two requirements differs strongly.

Fissured hard rock barriers can provide safety for mining, however their confinement properties against pollutants are often weak due to advection-dominated pollutant transfer along the fissures (Fernández Rubio et al., 1986; Gvircman, 1977; Kesserü, 1995).

Rock salt in an appropriate geological environment that prevents the salt body against water can fulfil both criteria. Case examples on disposal mines have demonstrated that this option is already utilised (BfS, 1998; Callager, 1998; GSF, 1989).

All criteria can be fulfilled by proper thickness of argillaceous barriers under self-healed conditions (Kesserü, 1999).

Essential argillaceous barrier and confinement properties

Dominance of the colloid size sheet-silicates with large surfaces and small inter-particle pores provide (Horseman et al., 1996; Mitchell, 1993; Neuzil et al., 1998).

- high adsorption-capability and
- diffusion-dominated pollutant transfer.

Deformability of the micro-fabric and the reversible feature of the clay-type inter-particle bonds provide the self healing capability (Kesserü, 1995 and 1999) namely

- it preserves the confinement during large displacement (e.g. during mining-induced impacts) *under appropriate rock stress conditions*, and/or
- it restores the confinement (e.g. after re-consolidation of the undermined barrier) *after rebuilding the appropriate rock stress conditions.*

These argillaceous features promise to fulfil both requirements because a safe barrier thickness preventing the inflows shall also be a safe long-term confinement, due to decreasing the mining impacted zone in time (Figure 1).

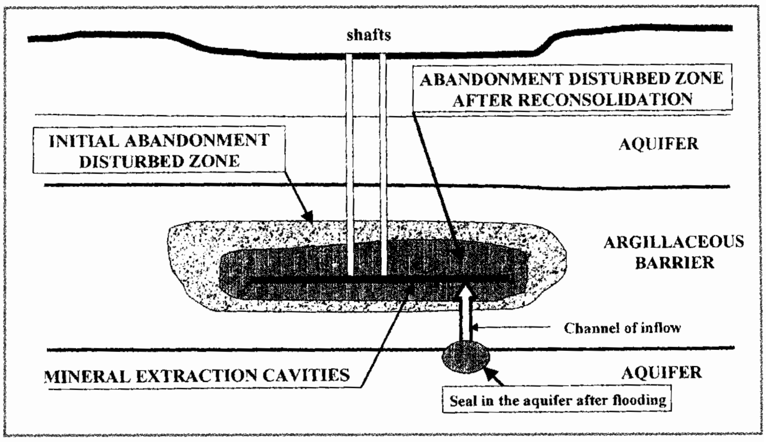

Figure 1. Mining and closure under protection of a permanent confinement.

BARRIER EVALUATION

Principles

Multidisciplinary view in searching and utilising the information as well as in analyses provides benefits (Figure 2) e.g.

- it cut costs and time and
- it improves the reliability of barrier evaluation/utilisation.

This paper also utilises the benefits of the multidisciplinary view as it is referred in the next chapters.

Historic view in understanding characterising the virgin barrier properties (e.g. analysing the parent rock, settling conditions, and stress, thermal, geo-chemical history of the diagenesis as well as uplifting, stripping) is highly necessary (Horseman et al., 1996; Tóth, 1995).

- for understanding the modern barrier/confinement properties (Kesserü, 1998; Mitchell, 1993) and
- for applying information from similar sites (Kesserü, 1998).

View to the full operational time of the barrier/confinement namely to the exploration, construction, mineral extraction, cavity-abandonment, closure, and to an appropriately long post closure period is required due to the full inter-generation responsibility (OECD-NEA, 1995; Rybach, 1999). This is the ethical basis for getting the public acceptance.

Guide to evaluating the virgin barrier properties in nutshell

Virgin barrier properties are the modern properties of the rocks without any human impacts. Both modern confinement and geotechnical properties are important for assessing the modern virgin confinement and for foreseen the further human and geological impacts.

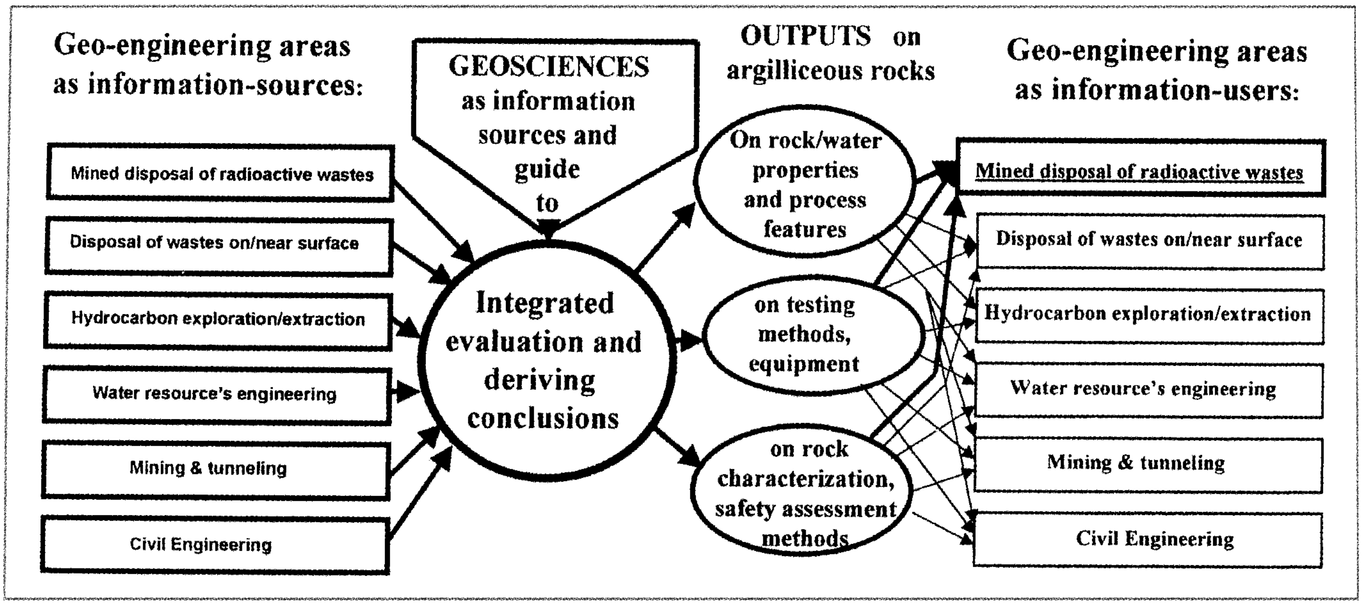

Figure 2. Multidisciplinary approach and benefits.

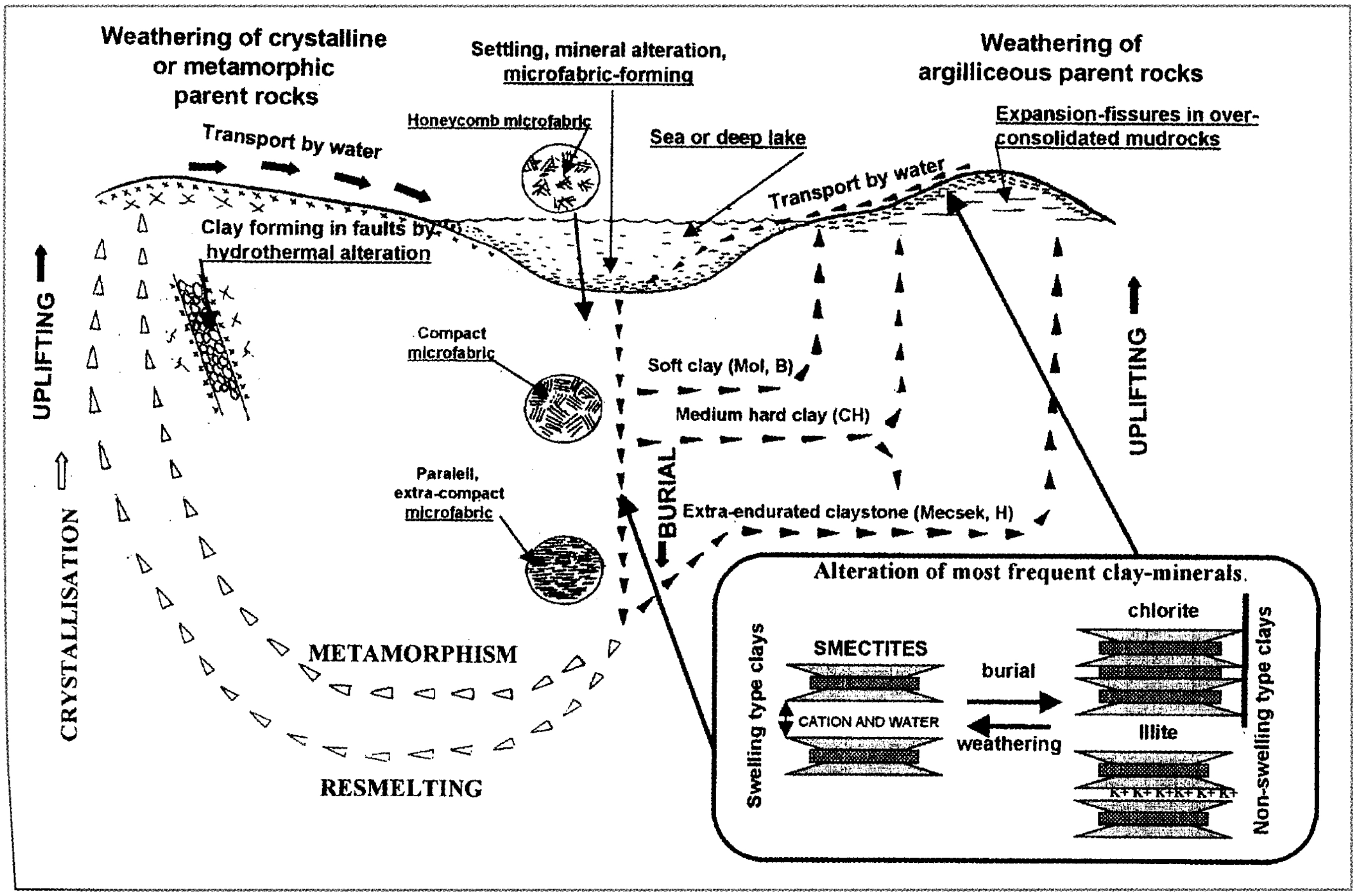

Figure 3. Clay-forming in the rock cycles and changes of barrier properties.

Confinement assessment in basin-scale and in details

Pore-pressure anomalies and/or water chemistry relicts are strong evidences on formation- or layer-size confinement properties namely on diffusion dominated conditions. Case examples are known near the hydrocarbon traps (Osborne et al., 1997) from basin analyses (Neuzil et al., 1998; Tóth, 1995) and at several potential disposal and reference sites for nuclear waste disposal (ANDRA, 1996; Gautschi, 1997, HADES, 1996, Horseman et al., 1996; Cappella, 1994; Kesserü, 1999; Marinate et al., 1996).Zones of the negative pore pressure anomaly (hydrogeological "black holes") should be preferred for disposal, because a strong positive anomaly may hold the risk of spontaneous hydro-fractures (Horseman et al., 1996).

In lack of such anomalies more detailed studies are required e.g.

- Potential fast pathways (e.g. sandy interbeddings).
- Zones of secondary fissure-permeability namely:
  - * fault-seal conditions: (filling, near-field fissures (Boisson et al., 1998; BfS, 1998; Csicsák, 1996; Gautschi, 1997; Kesserü, 1999; Neuzil et al., 1998)) (Figure 4);
  - * impact of folding especially in hard beds (Gautschi, 1997; Horseman et al., 1996; Kesserü, 1998 and 1999; Neuzil et al., 1998; Rybach, 1999);
  - * expansion-fissures in over-consolidated, uplifted rocks (Horseman et al., 1996) (Figure 3);
  - * modern- and paleo-weathering zones should be analysed (Gautschi, 1997; OECD-NEA, 1995) (Figure 3).
- Parameters determining the waste specific adsorption capabilities of the rocks (mineral content, accessibility of inter-particle pores by the pollutants, geo-chemical environment) should also be analysed and tested.

Figure 4 illustrates two important fault-seal features approved by the experience from mining (Kesserü, 1991, 1995, 1998 and 1999) and hydrocarbon traps (Downey, 1984):

- Faults with clayey filling are sealed even in hard mudrocks (Csicsák, 1996; Kesserü, 1991, 1998 and 1999; RHKKT-MÉK RT, 1998) however near fault fissures may occur in an endured mudrock environment. Self-healing depth for faults and fissures differ strongly in hard mudrocks [Csicsák, 1996; Kesserü, 1998 and 1999).
- Clay smears in sandy aquifers often form zone of high hydraulic resistance (Dewhurst et al. 1996; Downey, 1984).

Geotechnical properties and their importance

Geotechnical properties are important for utilising the experience from similar sites on the self-healing (Kesserü, 1998 and 1999), the roadway-stability (Hámos et al. 1999; Kesserü, 1999; Neuzil et al., 1998) the properties and extension of the excavation/abandonment disturbed zone (Kesserü, 1991 and 1995) as well as for considering the application of empirical safety criteria from similar sites (Kesserü, 1991 and 1995).

For this reason the core-drilled sample-size and rock-mass size deformability as well as the failure-parameters of each beds, the features and the direction and the density of bedding planes, joints, fissures should be analysed and determined. These material and state parameters should be expressed by such geotechnical parameters that can be compared with the parameters of similar sites (Hámos et al., 1999; Kesserü, 1999; Mitchel, 1995).

Human impacted barrier properties

Excavation (roadway driving, tunnelling, forming extraction and disposal cavities) the abandonment of the cavities as well as the closure (flooding) of mines initiate interacting transport processes and state-transitions accordingly.

Impacts to be evaluated

An evaluation on the changes of the barrier & confinement properties, as well as its extension in time and in geometric scale should focus to the following information bodies:

- change of material properties and its dangerous consequences namely:
  - * forming of fast pathways due to mining and water-induced strong failures (e.g. broken zone and bed separation (Chüam; Gvircman, 1977; Kesserü, 1995), hydro-fracture and subsequent piping along fault planes (Kesserü, 1991), secondary collapse of the

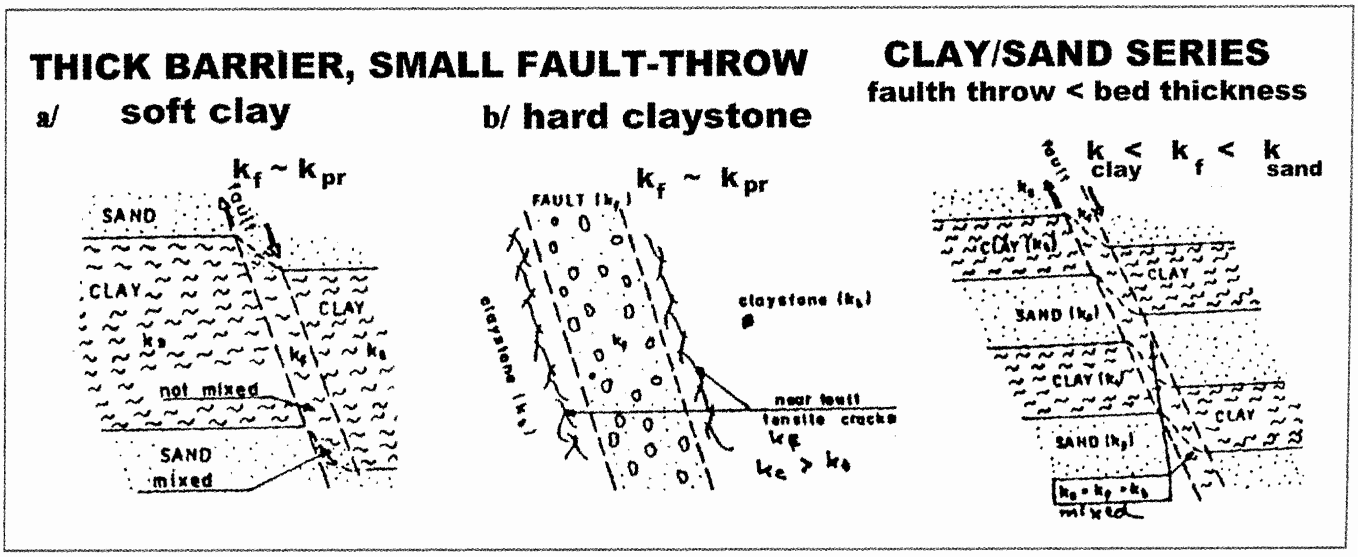

Figure 4. Fault types versus fault seal conditions.

barrier due to undrained water pressure in the water-filled fissures (Kesserü, 1995));
  * forming of the secondary fissure permeability (Chüan; Gvircman, 1977; Kesserü, 1995).
- change of the state-parameters that may initiate barrier failures (Kesserü, 1991 and 1995) e.g.:
  * increasing of the pore-pressure;
  * increasing of the deviator rock stress (especially with simultaneous decreasing the minimal principal rock stress component).

Special attention should be paid to the confinement properties during a properly long post-closure period namely to the:
- re-consolidation of the abandonment disturbed zone and re-consolidation induced self-healing;
- excavation disturbed zone around shafts, roadways crossed the confinement and on the possibilities of spontaneous or forced self-healing;
- flooding impacts (e.g. flooding-induced cavity or pillar collapses, water-chemistry in the flooded cavities (Gautschi, 1997);
- possibilities on a-posterior sealing the wounds intersected the confinement (water inflow channels, non sealed faults, water conducting dykes) (see Figure 1).

Methods for evaluation

Surface based site information (borehole exploration) should serve for discovering similar mining sites. Experience form similar sites can be applied as a preliminary information basis for estimating the self-healing conditions and the impacts of excavation, abandonment and closure. Figures 5, 6, and 7 present case examples on mining impacted barrier features especially on full extraction.

In spite of mining-impacted zones an appropriate barrier-thickness provides safety against water inflows. Due to clayey fault filling appropriate bottom barrier thickness provides dry conditions even in endured mudrocks. According to the visual observations and high-accuracy measurements in the underground laboratories in clay environment visually dry conditions refer to diffusion dominated conditions (Gautschi, 1997; HADES, 1996; Marivoet at al., 1996). Features of the overburden barrier depend on the modern self-healing conditions. Soft clays provide dry conditions (Kesserü, 1995). Water drops, small inflows remained below the undermined medium and hard mudrocks (Kesserü, 1995).

However the empirical safety criterions for the bottom and overburden barriers against the barrier failures appeared in different forms the critical way of barrier failure is the same: hydro-fracturing induced by mining-induced rock stress changes and the subsequent piping (Kesserü, 1994 and 1995).

Soft clays are self-healed at the usual depth of mining. In spite of extreme deformations an appropriate barrier thickness provides dry conditions. Fast rebuilding of the quasi-virgin rock stress condition restores the confinement even in the broken zone.

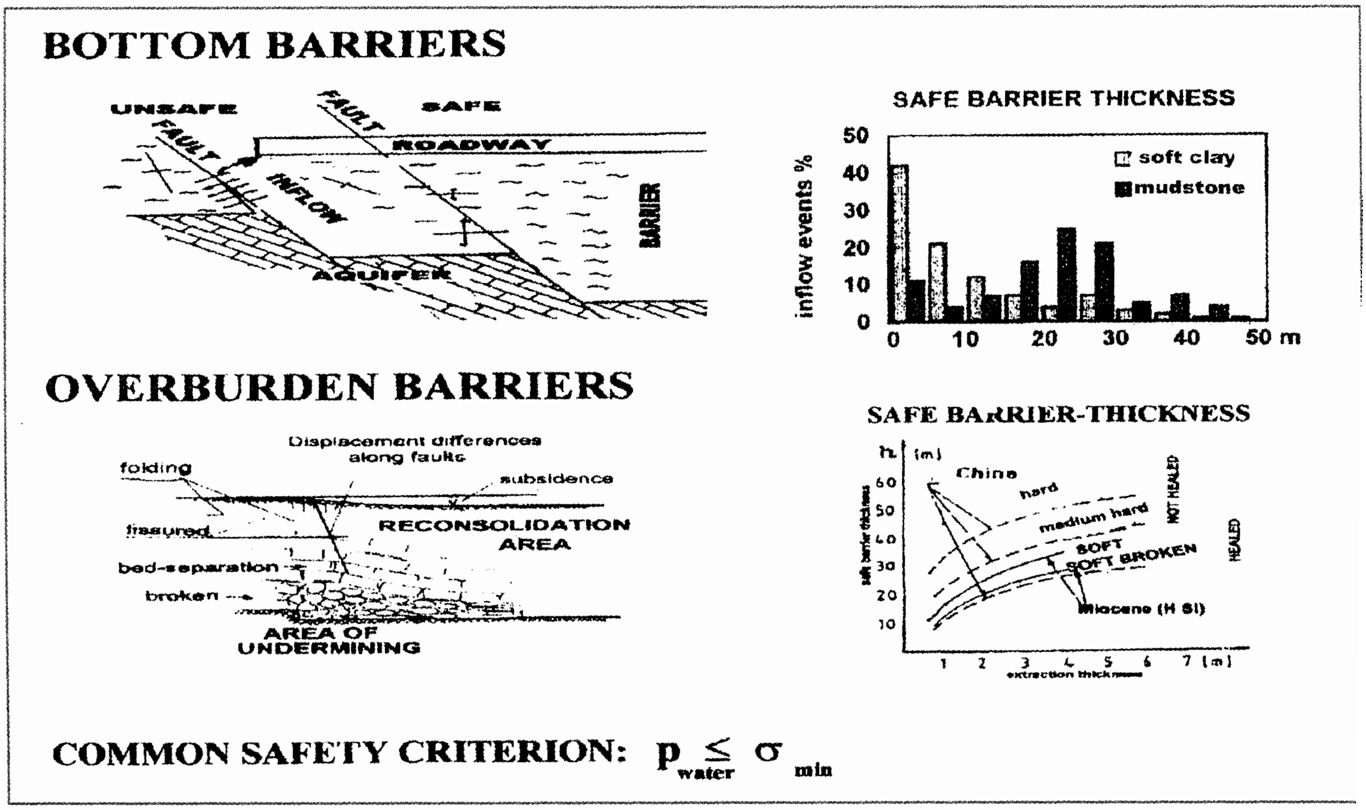

Figure 5. Mining experience on the safe barrier thickness for full extraction.

Figure 6 presents a case example from Velenje Lignite Mine in Slovenia. 100 m thick lignite seam is extracted by slicing (by applying 3,6 m or 10 m slice thickness) at a depth of 350-400 m. The overburden barrier is a Miocene marly clay (illite is the dominating clay mineral however smectites are also present.) The thickness of the barrier varies among 60-120 m below several sandy aquifers. 20-40 m deep lakes have been formed due to extraction induced subsidence. Figure 6a presents the rate of rock stress rebuilding that is faster in the multiple undermined overburden due to its softened features. Figure 6b presents a compressed clay breccia sample from the broken and fully remedied overburden. As a result of 6 mounts period of re-consolidation 15 m thick such barrier provided dry conditions against 8 bars aquifer pressure in the roadways driven below this barrier. Figure 6c compares the failure envelopes of rock samples from virgin and broken-re-consolidated overburdens form two mines in Slovenia. Clay from Hrasnik Mine is a marine Miocene clay. The cohesion of the broken, re-consolidated samples refers to partial restoration of inter-particle binding forces, the differences between the failure envelopes refer to the softening of the multiple undermined, re-consolidated barriers. It is due to the presence of sealed micro-fissures.

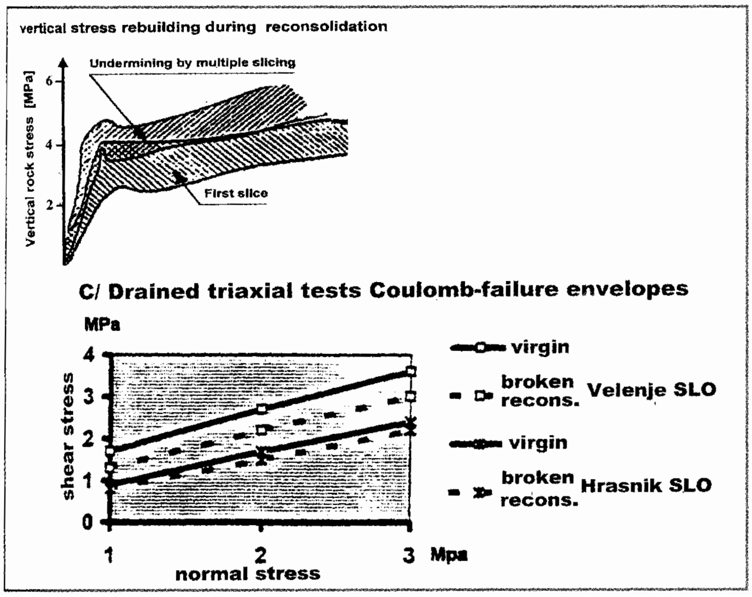

Figure 6. Full restoring the confinement due to re-consolidation.

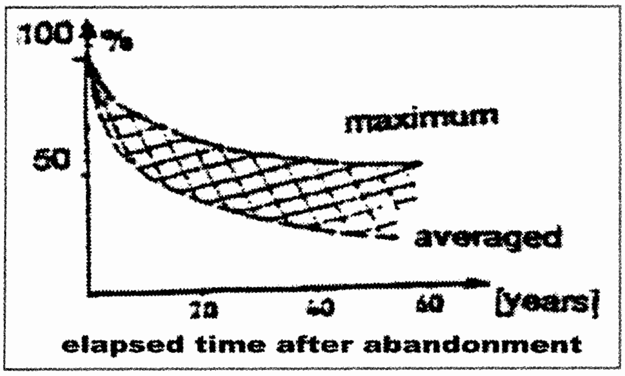

Figure 7. Partial restoration

Figure 7 present a case example on partial, long term restoration of the confinement at a shallow depth 120-200 m due to hydration of the fissure-planes of a medium soft, marly Eocene clay (Tatabánya Coalfield, Hungary). This process had been detected by the losses of the boring fluids during crossing the abandoned zones for exploring of deeper coal seams.

Case examples presented on cases of total mineral extraction (figures 5, 6 and 7) have demonstrated, that the re-consolidation of the fully undermined barrier restores fully or partially the confinement below the self-healing depth of fissures. Shut in tests in a special triaxial cell can provide preliminary information on the self-healing rock pressure (Kesserü, 1999).

Preliminary similarity-based information on the excavation/abandonment impacts should be verified by underground site investigations (e.g. by shut in pressure and deformation measurements in the excavation-abandonment disturbed zone, by pore-pressure records, etc (ANDRA, 1996; Boisson et al., 1996; Chüan; Csicsák, 1996; Gautschi, 1997; HADES, 1996; Kesserü, 1991 and 1994; OECD-NEA, 1995).

CONSIDERATIONS ON THE ENCAPSULATION OF THE ABANDONED MINES

Mines, applied full mineral extraction that have not provoked any inflows due to sufficient barrier conditions can be regarded as properly encapsulated liquid waste disposals, because the long-term post closure processes inside the barriers are favourable for preserving the self healed conditions that had been existed during mining/abandonment. Results of tests, investigations on actual self-healing status are valid for the long-term status as well.

Locations of former inflows through argillaceous barriers should be considered as existing/potential hydraulic connections between abandoned mining openings and the aquifer, because these inflows formed piping channels (locating usually inside the fault's filling). According to mining experience small inflow-channels were usually sealed by rock stress rebuilding in soft clays. Channels of stronger inflows remained open even decades after abandonment/closure of mines (Kesserü, 1991 and 1999). The actual connection can be detected directly by water injection/withdrawal into/from abandoned mines. Sealing inside the hard karstified/fissured aquifer (Figure 1) were feasible and safe solutions for eliminating dangerous connections between flooded mines and aquifers (Kesserü, 1994).

Partial extraction (panel and pillar mining is an effective way of controlling the abandonment disturbed zone during the mining period. This way was/is applied at several mining operations under water bodies (lakes, rivers and even below the seabed (in UK, AUS, CDN, J) (Kesserü, 1995) however the long term post closure processes inside the partially undermined overburden are less-predictable than under conditions of full extraction.

The gradient manipulation by water withdrawal through shafts of closed mines is a general temporary prevention method because small withdrawal-yields are often sufficient to reverse the flow direction or to prevent uncontrolled discharges of polluted water of abandoned mines into the surface. This possibility provides an option for us and for the next generations to control the pollution-transfer for any cases. Due to this reason the author disagrees strongly the filling/sealing of all shafts of closed mines.

ADDITIONAL CONSIDERATIONS ON WASTE DISPOSAL MINES

Waste disposal with buffer inside the extraction cavities before the collapse of these cavities can be regarded as a back-filling. According to the long-term experience of mining on partial extraction with back-filling this method decreases effectively the abandonment disturbed zone and also decreases the risk of forming unforeseen collapses. Consequently a back-filling the mined cavities with wastes improves the long-term stability of the confinement. Two disposal concepts are applied depending on the features of waste.

Simple back-filling of extraction by partially demobilised non-toxic wastes (e. g. by cavities fly ash with calcium-hydrate) is an acceptable, safe solution however its economic feasibility was questionable at several sites (e.g. in FRG).

High-level radioactive wastes are planned to dispose in lined, long-term stable cavities with additional engineered barriers (long-life strong metal capsule, clay-based dense buffer) according to the multi-barrier conception. High-accuracy URL based measurements have already demonstrated that this way of disposal minimises the extension of the excavation disturbed zone (ANDRA, 1996; BfS, 1998; Gautschi, 1997; RHKKT-MÉK RT, 1998). Safety evaluation (Marivoet et al., 1996) promises safe disposal even in an 80 thick clay layer, below the self-healing depth that meets the IAEA & ICRP prescriptions.

According to the case example of the disposal-mines the mineral extraction from the disposal cavities has secondary importance. The main business is the safe waste disposal. For this reason the main aspect of the confinement evaluation and excavation planning is the safety of the disposal according to the best international knowledge (ANDRA, 1996; Boisson, et al., 1996; BfS, 1998; Gautschi, 1997; HADES, 1996; Horseman et al., 1996; Kühn, 1995; Marivoet et al., 1996; RHKKT-MÉK RT, 1998; Rybach, 1999) and prescriptions/conventions. Simultaneous disposal of an-organic, non-gas generating toxic wastes in a separated field of the same host rock promises improved feasibility, however waste and site specific analyses of the confinement is strongly required according to the best international knowledge.

CONCLUSIONS

Utilisation of the barrier and confinement properties of the self-healed argillaceous rocks promise environment-compatible options for mining at some sites, however their economic feasibility may be questionable.

Combination of mining with mined waste disposal shall be a feasible option that also meets the ethic principles derived from the inter-generation responsibility and sustainability. Long-term safety of the confinement should be analysed rigorously according to the best international knowledge.

This paper provides principles and concise guide to barrier/confinement evaluation as well as some practical considerations.

This paper is a message for mine water engineering, that professional, ethic and political considerations of other professional fields seems to improve the feasibility of mined waste disposals and safe combinations of mining with waste disposal. This activity promises possibility for utilising several experience of mine water engineering.

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