Utilising the Experience of Mine Water Engineering for Siting Deep Waste Repositories

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ABSTRACT

The selection, evaluation of candidate sites operational for several thousands years, require to utilise observations, experience on long standing analogous processes as well. Some " analogous programs" are already in progress under the sponsorship of relevant international organisations.

The century long experience and observations of mine water engineering have not been utilised yet. The paper presents analyses and results based on mining experience and observations

-- on earthquake resistance of geological barriers,
-- on the impacts of tectonic displacements into the protective effects of different geological barriers.

The experience on sedimentary barrier layers (clays, marls, mudstones, etc.) crossed by tectonic faults between strongly karstified aquifers and coal mining operations relating to seizmically quiet areas (in Hungary) and to seizmically strongly impacted areas (in China) have been compared. Earthquake impacts have not been detected yet in thick barrier layers. This empirically based statement can also be interpreted by analysing the impacts of earthquakes into the governing parameters of failure due to water pressure.

During the undermining of water bodies the overburden barriers (impacted by faults) are tested under strong displacements. The protective capability of the undermined overburden strongly depends on the material-properties of the rocks, and on the stress conditions. Under proper stress conditions the soft barriers remained watertight even after large displacements along faults.

Some new possibilities for discovering other usable experience are also drafted.

PROBLEMS AND REASONS OF UTILISING MINING EXPERIENCE

One of the siting problems of final geological repositories is to assess the protective ability of the site for several thousands-years on the basis of data, measurements and observations collected within much shorter periods. The uncertainties of studies for site selection/investigation are well known. Professionals are forced to discover, to search and to utilise information of geological analogies (e.g. to study the migration processes of nuclides through the geological barriers around the uranium ore deposits during geological times). [7]

Although the big majority of efforts, tests, studies, investments were/are paid for final disposal of nuclear wastes into geological structures, key professionals have already expressed, that the final deep disposal of dangereous chemical wastes requires similar professional considerations, studies [18]. Consequently analogeous experience will also be required for siting chemical disposals into geological structures.

An approach of utilising "quasi-analogous" data from the experiences of mine water engineering is proposed in this paper. The feasibility of the proposal is illustrated with the first results on the impacts of earthquakes and slow tectonic displacements into the geological barriers.

Mining analogies

Mines as waste repositories and as underground laboratories located into geological structures analogous with the rocks (salt, granite) of candidate disposal sites already are in operation.[7, 8]. Mines are utilised to study geologically long analogous processes [1, 8]as well. The everyday experience and observations of mining have not been utilised systematically.

In order to utilise the experience, and observations of mines relating to their operating or abandoned status some general considerations should be taken:

On the one hand: the lifetime of mines, the test period of the surrounding geological structures takes only about 20~100 years, which period is shorter with two three magnitudes, than the lifetime of final repositories.

On the other hand: the test period realised by mines were/are longer with one-two magnitudes, than the in situ tests of site investigations. The number of test points or the areal extension of mining may also give advantageous comparison with numbers and areal extensions over a candidate site of final repositories.

As a conclusion of the considerations above, the quasi-analogies of a number of mines cannot substitute the special studies on geological analogies, but a big mass of data and observation surely able to provide useful information for site evaluations.

Usable experience of mine water engineering

Many experience of mine water control relate to the underground reservoirs, and to the geological barriers. The same two ones are the main objects of the evaluations of candidate disposal sites. consequently, the experience and observations of mine water engineering should provide useful information for siting repositories in geological structures. For illustrating the possibilities, and for initiating further studies, the paper present the first results, and drafts other possibilities as listed below:

The first results relate to the impacts of earthquakes and slow tectonic displacements into the protective ability of the natural geological barriers.

The study of the impacts of abandoned flooded mines into the water quality of the surrounding reservoirs is mentioned as an iniciative for further studies.

MINING EXPERIENCE ON THE EARTHQUAKE-RESISTANCE OF THE GEOLOGICAL BARRIERS

The actual practice and researches of waste disposal engineering

All actual guidelines, prescription require "seismically quiet regions" for siting [4, 18, 22, 26]. The assessment of seismic risk is one of strongly required chapters of all site selection studies [2, 18,]. The assessment of seismic risks should forecast the maximum earthquake for geologically long periods basing on observations, notes of hundreds of years and on geological considerations. This kind of assessments are appropriate to select the inappropriate sites, but they are uncertain ones to determine the quiet sites. The Thangshan area of China was regarded as seismically quiet one before the big earthquake. (MKS>11) After the earthquake historical notes has been discovered on a big earthquake 2600 years ago.[24, 28].

There are many countries (e.g. Japan), where seismically quiet regions are not available within the border of the country. According to the Japanese approach: the disadvantages of the country's seismic conditions are planned to compensate by the "high tech" of Japan [30].

The published researches are focussed to estimate the impacts of seismic waves into the geological barriers by applying sophisticated numerical simulations (FE models). [9, 19, 32]. Even the best model studies include many model and parameter uncertainties.

The experience of mine water engineering have not been used yet.

Analyses of experience on the protective layers against mine water inrushes

Experience and observation on the protective ability of the bottom protective layers in coal mines under similar geological and mining conditions but with quite different seismic character was selected for comparison to analyse the seismic impact of earthquakes on the barriers. One of the tested region was in Hungary and the other one in China, where consulting and research projects on karst water danger had been led by the author. Both coal mining areas are endangered by underlying karstified reservoir with high water head [14, 15].

Similarities:

- Geological conditions: sedimentary layers (argillite, silt stone) are between the strongly karstified aquifers and the coal seams with low inclination (0-15°).

- Tectonics: Pull-apart tectonic zones with different vertical throw ranging from some decimetres to some hundred meters cross the barriers. The total length of faults over a unit area is 5-15 km/km^2.

- Hydrogeology: the faults in the barriers are considered watertight. Reservoirs consist of dolomite and karstified limestone. The tectonic lines within the reservoirs are usually high conductivity zones. Water head over the mining areas varies between 0 and 60 bars.

- Mining conditions:
  - the main method is the full extraction with longwall faces without backfilling.
  - broken, fissured zones of 5-8 meters were detected in the bottom of mining openings.
  - maximum extension of the secondary stress zones in the floor was estimated and measured as 25 - 30 m.
  - observations over both sites were related to the protective effect of the geological barrier:
    - ♦ in water dangerous regions the total number of inrushes was over one thousand over both areas. The water head and the thickness of barriers were estimated, measured and interpolated, respectively. Majority of inrushes were connected to the tectonic lines.
    - ♦ in endangered mining regions of hundreds km² no inrushes occurred above the reservoir with high water head because of sufficient protective effect of barriers crossed even by faults.

Differences:

- Seismological conditions:
  The maximum of earthquake intensity was 5 MKS in the coal basins of Hungary during the last two hundred years of the coal mining. This country can be featured with rather low seismic activity. The investigated coal fields in China: Jiaozuo, Fengfeng and Zibo locate along a very active zone [28]. Marks of medium size earthquakes are frequent, but some event with intensity of 8 MKS are also marked on the map published in the paper [28].

- Mechanical property of barrier's rocks:
  Hungary: Eocene clay and marl,
  $\sigma_B \approx$ (3-10 MPa);
  China: medium-hard sandstone, mudstone, Permian-Carboniferous,
  $\sigma_B \approx$ (25-40 MPa).

The data of water inflows specified in the Mine Safety Regulations of Hungary had been recorded by mine staffs. They were filed in the data store of the Hungarian Mining Institute and they were evaluated by the author and his colleagues (T. Willems and Dr. A. Schmieder).

The Chinese data were published in the paper of Li Jinkai (1978). Data of inrushes were completed with co-ordinates, with the thickness of barriers and with water head values [17]. These data are stored in the Institute of Geology and Coal Exploration (Xian, China). Data were interpreted by means of author's method in China [14].

The numbers of mine water inrushes versus estimated or interpolated thickness of protective barrier are presented in Figure 1 [14].

HUNGARY (Dorog, Tatabánya coal)
maximum of earthquakes: **4.5** MKS

CHINA (Jiaozuo, Zibo, Fenfeng coal)
maximum of earthquakes: **8** MKS

safe barrier thickness: **50** m.!

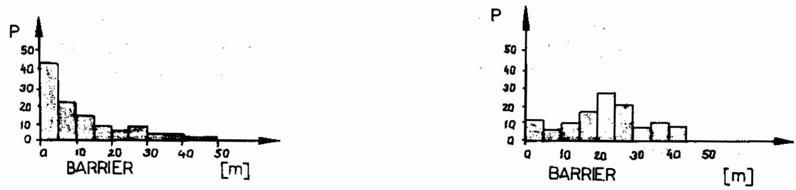

Fig. 1. Density of karstic water inrushes versus thickness of the barrier

The "specific thickness" of barrier versus risk of occurrences, called "sealing coefficient" by A. Schmieder, [23] are compared in Figure 2 [15, 16]. The "specific thickness" is an empirical parameter of the risk analysis and safety criterion has been used in Hungary since 1952.

It means the rate of thickness of barrier and water head of reservoir at the spot of inrush [m/bar].

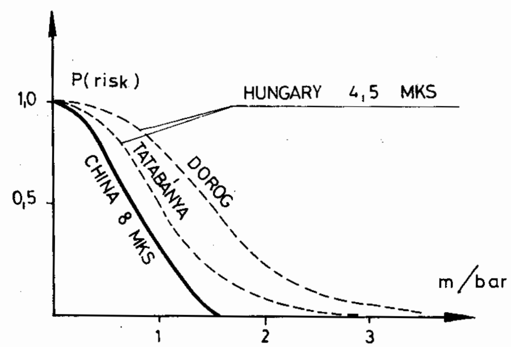

Fig. 2. The risk of karstic water inrush versus specific barrier thickness

In spite of more intensive seismic over Chinese sites, the risk of water inflows under similar condition of barrier seems to be lower than in Hungary. The better protective effects of barriers in China are caused by the favourable rock mechanical parameters. No impact of earthquakes on the number of water inrushes over a large area and during several years can be concluded.

A unique case example of the author's consulting practice can also be mentioned. A huge earthquake with intensity of about 11 MKS was recorded in Thangshan (China) [24] Due to the earthquake all of surface buildings and infrastructures (including electric supply) damaged strongly. The mines of nearby Kailuan Coal field (~10 MKS) were flooded because of damage of electric supply of pumping stations. The successful dewatering the mines demonstrated indirectly, that no significant fracture through the geological barrier with thickness of 270-350 m was initiated by the earthquake. The available pumping capacity would not be suitable to pump out the water yield recharged from the karstified bedrock in case of a new fracture through the barrier. Thick geological barriers were not destroyed even by enormous earthquakes. Lower values of thickness seem to be safety according to the comparison in Figures 1 and 2.

Empirical conclusion

Extension of mining experiences to the evaluation of geological barriers for waste disposals is realistic. The mining impact on the underlying barriers with thickness of some hundred meters can be negligible. This can be referred even to geological barriers for waste disposals. The occurrences of water inflows, however, don't reflect on small changes in the barrier directly. The lack of inflows demonstrates that no dramatic changes of the effectiveness of barriers occurred. The large area of barriers tested seismically gives high reliability of this conclusion.

THE PROTECTIVE EFFECT OF UNDERMINED BARRIERS - THE HYDRAULIC CONDUCTIVITY OF TECTONIC LINES DURING DISPLACEMENT

Undermining as a quasi-analogy for slow tectonic displacements

The mechanical conditions of the overburden are strongly affected by full exploitation without backfilling of mineral seams. The maximum of vertical displacement can reach up to 80% and the horizontal one may be 20-40% of the extracted thickness. The majority of deformations develop within some weeks or months in case of weak or medium hard rocks but depending on the depth of exploitation and on rock conditions. The rate of deformation varies between cm-m per month. The displacement of tectonic zones can be separated characteristically from the trends of general deformation field of undermined barriers. New fissures and faults were generated by undermining. Main features of deformations in the undermined overburden have been summarised and published in many papers, monographs [5, 6, 10, 15, 27].

Mining under water bodies can be considered as long term and full scale test at large areas for hydraulic resistance of overlying geological barrier being deformed.

Mining experience on the safe thickness of undermined overburdens

Safety thickness depending on the rock properties, on the depth, on the mining method and on its geometry can be specified quite well [5, 6, 10, 15, 27]. In spite of deformation of the whole undermined overburden this "safe thickness" provides sufficient protective effect against water inrushes.

No water flows were detected in case of weak or medium hard barriers under high stress conditions. Not only the numbers of inflows and yields are limited, but any kind of detectable water flow is excluded by the safety thickness. The safety thickness against water flow crossing undermined overburden are illustrated on Figure 3. Curves are based on experimental data recorded in different countries (Hungary, China, Russia, Kazakhstan, Ukraine, Slovenia) [15].

Overburdens were different ones: medium hard silt stone in Russian cases [10], soft rocks in some Chinese cases [5], and weak clay-marl in Hungarian and Slovenian cases [15].

A/ The safe barrier thickness **B/ The safe ratio of H/V**

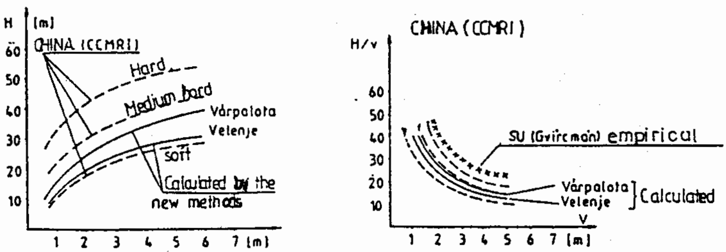

Fig 3 Experience on the safe thickness of undermined overburden barrier

Empirically based conclusions

On the basis of the above experiences it can be concluded that fault zones even in the deforming overburden remain closed, depending on stress condition and rock properties. Weak clays in depth of 150-200 meters and medium hard mudstones in depth of 600-1000 meters were proven to be watertight. The impact of the faults on the protective effect of geological barriers must be analysed specially. Weak and medium hard rocks are isolators according to the laboratory tests and mining experiences [15]. New faults or renewed old ones will open new channels in barriers of hard rocks.

POSSIBLE WAYS OF FAILURES IN DEEP GEOLOGICAL BARRIER

The empirically based conclusions can also be checked by other considerations drafted below:

Failure phenomena induced by seismic events are well known on the surface and in near zones. These are:

- development of open fissures caused by tensile strain,
- liquefaction induced by seismic vibrations in porous aquifers [1]
- landslides generated by different loading,

- change in the location and water yield of springs.

The risk of occurrence of the well known failure phenomena strongly decreased at the depth of HLW disposals as considered below:

a. On the basis of tests and experiences it is concluded, that liquefaction had never appeared in compact rocks being usually typical barriers of geological repositories [3, 12].

b. Horizontal stress components are equal or greater than vertical ones according to the insitu data recorded over sites with very different seismic character (see Figure 4)) [11, 25].

Consequently, transformation of the horizontal stress component to tensile stress can not happen in the depth of geological repositories.

c. The risk of development of tensile stress in geological barriers can be excluded, but the reopening of the fissures by water pressure should be considered. This can be initiated by changing the ratio between the minimum rock stress and water head (spontaneous hydrofracturing).

The propagation of fractured zone in protective barriers of some hundred meters takes some minutes or hours. Consequently the hydrofracturing can not be developed by seismic waves of short period.

d. Long term changes of water head or rock stress may initiate hydrofractures. Let us consider now earthquake's impact on the safety against hydrofracs (the ratio of the governing parameters). No hydrofracturing can occur if the "reopening pressure" of a fracture (p_{re}) is exceed the actual water pressure (p_w). This statement is proven by experience and observations collected over the world [15]. The shut in pressure of hydrofractures can be used as safety criteria against development of seepage channels ($p_{sh} \approx \sigma_{min}$) [15].

$$p_w {}^3 p_{sh} \approx \sigma_{min}. \qquad (1)$$

Maximum changes of water heads were 5-10 meters what had been recorded before, during and after strong earthquakes[21]. Variation of water head [21] and results of in situ rock stress measurements [11, 25] are shown in Figure 4.

Some meters change of water head can modify the ratio of p_w and σ_{min} over shallow areas, but no significant change is initiated in great depths when changing water head little. That is why the mining experiences have not indicated any impacts of intensive earthquakes on the thick geological barriers.

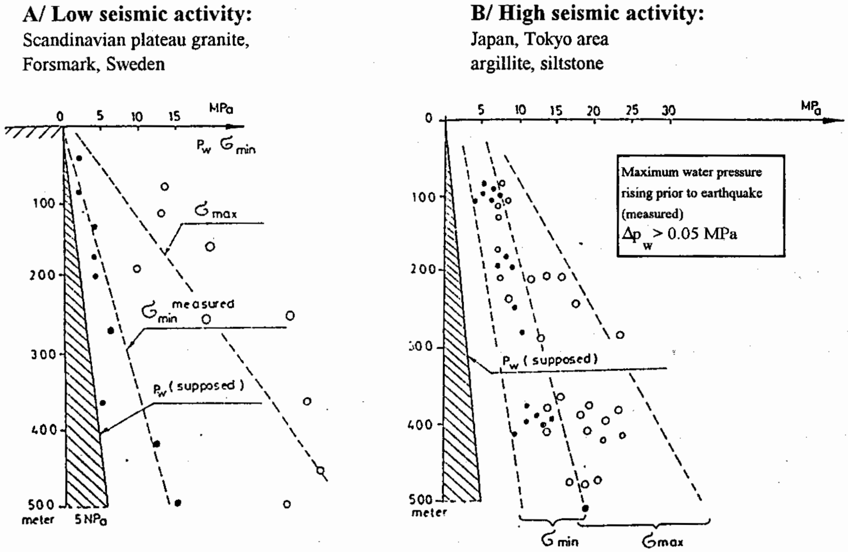

Fig .4. Comparison of the governing parameters of the spontaneous hydrofracturing: the water pressure (p_w) and the minimal principal rock stress (σ_{min}) under different conditions of seismic risk

Note: The virgin water head is supposed to be quasi equal with the surface

CONCLUSIONS

- Experiences of mine water engineering have not indicated any impacts of intensive earthquakes on the thick geological barriers, because any changes in occurrence of water inrushes could not be detected. The same conclusion can also be derived by analysing the impacts the earthquakes into the governing parameters of failures.Different behaviour of rocks at different depths is mainly caused by the impact of earthquakes on the ratio of stress and water pressure.

- The rate and velocity of displacement in geological barriers below undermined water bodies have the same magnitude as the displacement at tectonic lines during strong earthquakes. The impact of tectonic displacement on the protective effect of geological barrier seems to depend on the properties of the rocks and on the state of stress. On the basis of the mining experiences it can be concluded that fault zones even in the deforming overburden remain closed, depending on stress condition and rock properties. Weak clays in depth of 150-200 meters and medium hard mudstones in depth of 600-1000 meters were proven to be watertight.

- More extended and detailed studies of relating analogous mining experiences are proposed by international teams of mining engineers and experts involved in site selection of geological repositories for checking the above conclusions of practical importance.

PROPOSALS ON FURTHER STUDIES

Observations and experience on the reservoir layers, (virgin and impacted ones) .and on the abandoned flooded mines may also provide useful information for waste disposal siting. In order to initiate further studies the possibilities of the studies on the abandoned flooded mines are drafted hereto.

Abandoned flooded mines as test sites for study the disposal of liquid wastes

In the fields of mine water and environmental engineering the flooded mines are studied frequently as sources of pollutants interacting with waters in underground and on the surface because of different pollutant contents (chemicals, nuclides, solids) of the wastes in the abandoned areas.

In the fields of deep waste disposal there were/are strong discussions on the disposal of liquid wastes by injecting them into deep reservoirs of small hydraulic contact with the biosphere. These methods were used in USA, are applied in Canada, but there are strongly forbidden in West-Europe (except re injecting the produced waters of oil fields and geothermal reservoirs into the same reservoir) [2, 20, 31]. One of the reasons of the strongly contradicting opinions is the lack of sufficient information.

Many flooded mines are available for special studies in the globe, with different pollutants in the old man, under different depths, geological/hydrogeological conditions. At many sites observations on the impacts into the surroundings are also available. Many quasi-analogous case examples should exist. The only problem is to find the proper ones.

The declination of the mining industry, coupled with the crises of national economies in the East-European countries caused the closure of hundreds of state owned mines. Due to the shortage of state budgets there are risk of loosing many valuable data and observation. During the session of waste-disposal committee of IAEG the author proposed actions to support the preserving the data of public interest. As the first action preparation of catalogues of cases was proposed. The catalogue help to find the proper quasi-analogous cases and the partners of common interest for further co-operative studies. The Commission accepted the proposal. Representatives of intergovernmental organisations promised their supports, but nothing happened yet. This is the last minute call to preserve the valuable data for their multipurpose utilising in the environmental control.

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