Facial and Paleogeografic Understanding of Tertiary Sediments as Basis to Predict their Specific AMD Release

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Abstract Acid Mine Drainage (AMD) is a known problem for many mining companies. In future overburden, metal sulphides are weathered, such as pyrite and marcasite. In lignite mining, eocene, oligocene and quarternary sediments of different genesis and lithological-geochemical composition are recovered and dumped. The aim of a modern opencast mining is to prevent or at least minimize AMD during the operation by structured excavation and tilting. This is done by mixing acidifying sediments and sediments containing carbonates. Therefore, it is necessary to know the facies formation of the sediment layers or aquifers, which will be the future overburden.

Key words lignite mining, pyrite weathering, AMD, genesis of sediments, facies, buffering carbonates, advanced mining technology, dump structure, geochemistry, glacial till

Introduction

Non-cohesive sediments in lignite mine sites contain partially pyrite (FeS_2), marcasite or other metal sulphides. So lignite mining stimulates sulphide weathering connected with AMD phenomena and massive mobilisation of acidity, sulphate and cation metals after groundwater rerise (Figure 1). The weathering of the sulphides is embedded in hydro-geochemical buffering reactions. To reduce the acidification of groundwater around the lignite dumpsites, it is necessary to get knowledge about the sediments by evaluating the acidification and buffer potentials of the overburden units. For sustainable strategic activities, these investigations need to consider the geology, paleogeographic-genesis of sediments, the applied mass management and mining technology.

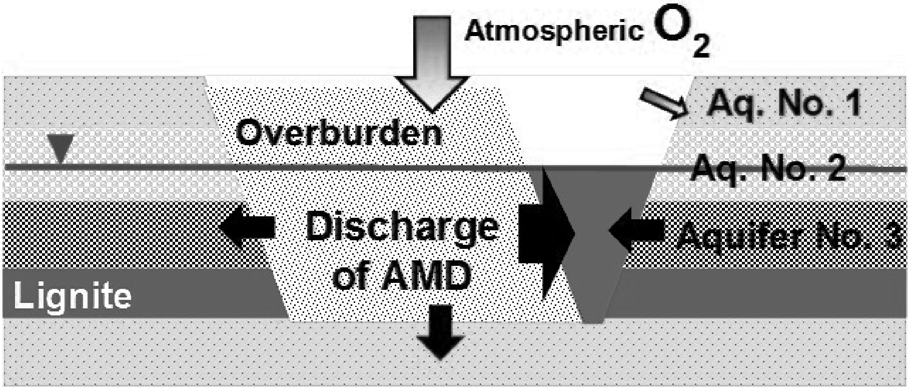


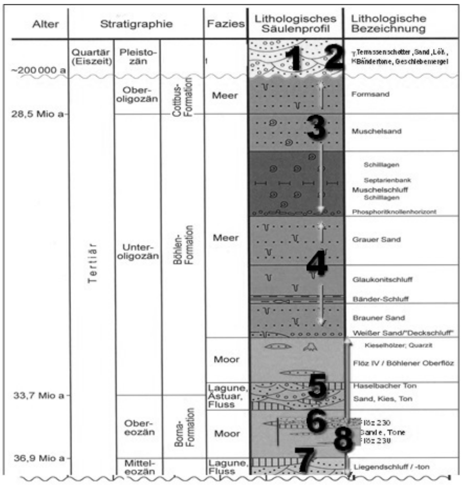
Figure 1 *Scheme of discharge of AMD caused by different sediments*

The main intention of the research was to identify technological reduction measures to minimise groundwater acidification based on the hydro chemical situation within the mining field considering the mining technology. A complete avoidance of the acidity generated through mining operations is impossible up to now. It is rather a question of minimising the negative effects by applying appropriate technology from the initial mine development to the final reclamation.

Methods

To solve the AMD problem sustainably, a working scheme was created including the three sections of geology, geochemistry and the production technology. Each of these sections were investigated in parallel processing.

In collaboration with colleagues from the company GEOmontan GmbH Freiberg, Germany, a geological model for the Mid-German region was improved by analyses of drillings in the forefront of the mine sites and by evaluated known data. A geological and facial examination of the drilling materials makes it possible to assign the sediments to individual units.



nr.	Geological investigation unit
1	Quaternary sediments (sandy)
2	Quaternary sediments (cohesive)
3	Böhlen Formation, upper part (Aq. 2.1-2.4)
4	Böhlen Formation, lower part (Aq. 2.5-2.8)
5	Tertiary Aquifer 3
6	Tertiary Aquifer 4
7	Tertiary Aquifer 5
8	Cohesive tertiary substrates

Figure 2 *Geological Scheme and investigation units of the future overburden (Simon, 2016A).*

The Mid-German geological units above the lignite seam has to be divided into eight geological investigation units (IU), shown in Figure 2. For example, the sandy (IU 1 – aquifer 1) and cohesive quaternary (IU 2) can be defined as summarising geological units. The tertiary sediments are subdivided into the aquifer two (upper/lower part) to five and the cohesive sediments (IU No. 8).

The formation of these sediments is very different. Quaternary and sandy sediments (IU 1) are glacial-fluviatile formed and cohesive sediments (IU 2) are glacialy formed. High carbonate contents, more than 1 M%, were measured in cohesive quaternary sediments by carbon-sulfur analysis. The units of aquifer 2 are marine, but the upper part (IU 3) is more related to tidal flat, the lower part (IU 4) to shallow sea. The Mid-German aquifer 3 (IU 5) is related to estuary formation, mean a deposition of sandy materials in a river delta. Aquifer 4 and 5 (IU 6 & 7) are fluvial sediments, disposals in a river basin. Cohesive tertiary sediments (IU 8) are limnical deposits.

The sequence of sedimentation from fluvial (oldest tertiary sediments) to estuarine to marine (youngest tertiary sediments) is shown in Figure 3. The different geochemical properties of the geological investigation units can be explained by different forms of sedimentation.

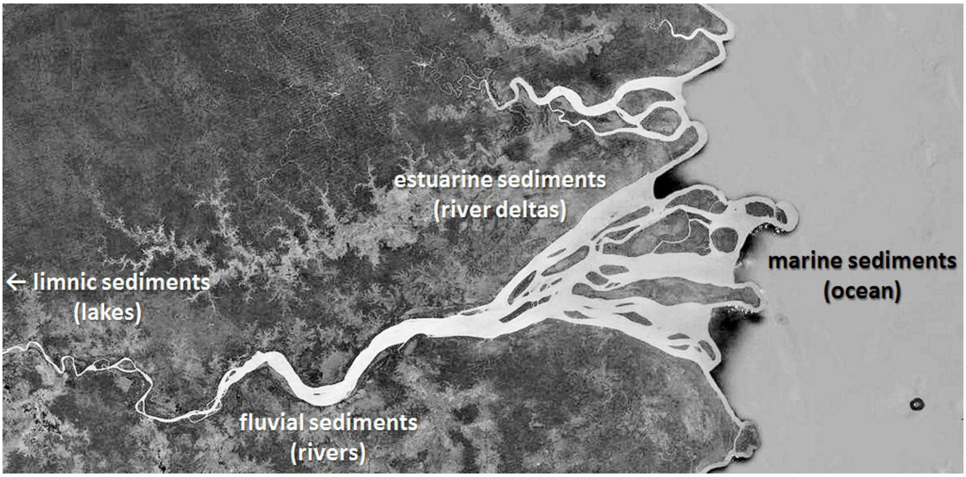


Figure 3 *Sedimentation types of tertiary aquifers. (image Landsat / Copernicus via google earth)*

To characterize the accessibility and weathering potentials for the major geological units several weathering tests were performed. The different Mid-German sediment materials were stacked in photo bowls, exposed to weathering by atmospheric oxygen, humidificated and stirred in intervals. The investigated sediments were stored at a constant temperature of about 10°C in the refridgerator, the mean soil temperature in the Mid-German area.

The weathered materials were analysed in intervals after approximately 0, 7, 21, 50, 100, 250 and 500 days. The wide spectra of analyses includes pH-value, electric conductivity, iron and sulphate photometry, trace metals concentration (like lead, zinc, cobalt, chromium and hydrolytic acidity (HA).. To determine the hydrolytic acidity, as a measure for the tendency of acidification, 40 g field-moist sediment has to filled in wide neck bottles. It is loaded with 100 mL of a 0.1 molar calcium acetate solution and shaken for 1 hour by overhead shaker. A centrifuge separated solid and liquid fractions before the supernate was titrated with 0.1 M NaOH solution to a pH value of pH 8.2.

Results and Implementation

By superposing the results of the weathering test with the results of the analyses of the hydrolytic acidity and geological and facial examination, it is possible to mark problematic aquifers and implement suitable technological countermeasures. In Table 1 the sediments and their facial formation are listed, sorted by the shown hydrolytic acidity after a weathering of 250 days.

It could be shown, glacial and glaci-fluviatil sediments are unproblematic. Likewise, the sediments with a marine formation in the tidal flat are not acidifying after 250 days. They have nearly no release of iron and sulphate too. The fluviatile sediments or river sediments have also nearly no acidification potential (HA < 11 mmol/kg DM). Estuarine sediments or aquifers formed in a river delta have moderate acidification potential (HA 10-50 mmol/kg DM). Marine sediments formed in shallow basins of the ocean have an acidifying potential of 50 mmol/kg up to 200 mmol/kg DM.

Nevertheless, no rule without exceptions. By the treatment of tertiary sands during the ice age, quaternary sediments can also object acidity potentials. However, this occurs only marginally in erosion channels. In our example, a quaternary aquifer had a hydrolytic acidity of 27 mmol/kg DM.

In summary, the marine sediments (shallow sea) and the estuarine sediments are the main polluter of AMD in the Mid-German lignite mining region. Linking these acidifying and buffering potentials of the quaternary sediments with their thickness ratios an adapted dumping system can be established.

Conclusions

The Mid-German lignite mines are able to prevent AMD by the admixing of quaternary masses with tertiary sediments (main-AMD-polluter) without an addition of external buffers.

Short exposure times of the problematic sediments to atmospheric oxygen, prompt covering of acidic sediments in combination with the dump structure by tilting thin layers of acidic and buffering sediments will minimize AMD. It is possible to save the cost-intensive admixing of buffer materials such as lime or dolomite.

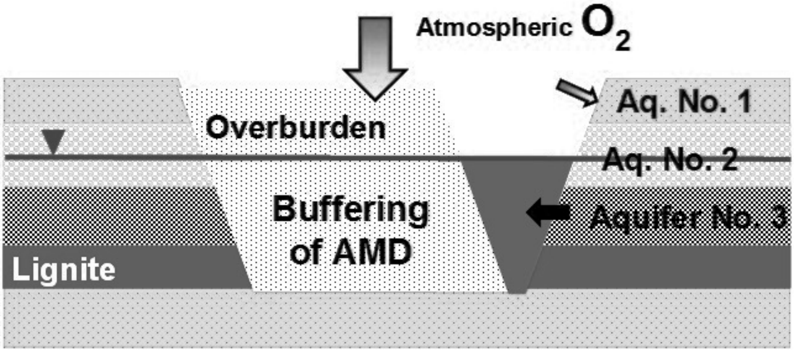


Figure 4 *Scheme of buffering of AMD coursed by targeted extraction and dumping*

Table 1 *Sedimentation vs. Hydrolytic Acidity (HA)*

facies formation	sediment	HA (250d) mmol/kg
glaci-fluviatil	Aq. 18	0.2
glacial	Glacial Till	0.4
glaci-fluviatil	Aq. 16o	0.4
marine (tidal flat)	Aq. 24	0.7
glacial	Glacial Till	1.0
marine (tidal flat)	Aq. 24	1.5
marine (tidal flat)	Aq. 25	1.6
glaci-fluviatil	Aq. 16o	3.6
glacial	Glacial Till	4.2
glaci-fluviatil	Aq. 16o	7.1
fluviatil	Aq. 5251	7.7
fluviatil (estuary)	Aq. 42	8.6
limnic-fluviatil	Clay	10.3
limnic-fluviatil	Clay	10.9
estuary	Aq. 31	11.4
estuary	Aq. 32	15.6
marine (shallow sea)	Aq. 26/28	22.4
estuary	Aq. 32	23.3
glaci-fluviatil	Aq. 16o	26.6
estuary	Aq. 31	32.8
estuary	Aq. 3231	35.6
estuary	Aq. 32	36.6
estuary	Aq.3	44.0
marine (shallow sea)	Aq. 282	55.2
marine (shallow sea)	Aq. 26	91.3
marine (shallow sea)	Aq. 26	156.3
marine (shallow sea)	Aq. 27	174.3

By superposing the geology, technology and hydrogeochemistry, the opencast mining technology can be adapted and effective countermeasures can be introduced to avoid the discharge of AMD from dumps to aquifers, rivers and residual lakes.

Fortunately, the realization of the technology transition requires no additional major equipment. The implementation in MIBRAG mines can be done with the present excavators, conveyors, conveyor switches and spreaders. Nevertheless, a qualified technological control of mining, transport and deposit is necessary.

Transfer of knowledge

Looking at the geological situation in central German lignite mines, parallels can be drawn to other lignite mining regions. For example, in the lignite mine of Schöningen (HSR GmbH) the same paleographic and hydrochemical linkages exist. The marine sediments from shallow seas show high acidification potential. Figure 5 shows typical AMD discharges from marine – shallow sea – sediments with a pH-level of ≈ pH 2, high release of sulphate, iron and other metals.

Figure 5 *Picture of the discharge AMD- water from marine sediments, mine Schöningen, Germany 2017*

In Schöningen mine after ending active mining AMD is still an issue. In necessary reclamation and recultivation work, targeted mass management must be carried out. This is the only way to prevent further release of acid, iron, sulphate and metals such as cobalt, nickel, zinc, lead and cadmium into the planned residual lake and into groundwater. While supporting the embankment and flattening the edge of the mine, which takes place anyway, it is possible to cover marine sediments from shallow sea by quaternary, glacial or glaci-fluviatile formed sediments. This investment will be amortized by lower follow-up costs.

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