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Hydrogeologic Characteristics of Surface-Mine Spoil in Okaba Coalfield of Kogi State

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Abstract: The nature, degree and duration of groundwater and spoil interactions need to be factored into comprehensive mine drainage predictive methods or models. However, the hydrogeology of mine spoil is poorly understood and remains one of the least analyzed aspects of mine drainage prediction. This study was designed to evaluate geological formation of the Okaba coalfield; topography of the mine site and the lithologic/hydrogeologic components of the mine site using borehole sections, map-based analysis and field measurements. The Okaba coalfield is underlain by a variety of the Mesozoic (secondary) sedimentary rocks, which are mainly non-aquiferrous. The DEM indicates that surface runoff (along with the spoil water from the coalfields) drain directly into natural drainage system (streams/rivers). This hydrologic information used in conjunction with the overburden geochemical data can be used to improve mine drainage predictive models and methods.

Key words: Nigeria, Okaba, overburden, DEM, Ashopa, receiving water

INTRODUCTION

Groundwater is an integral chemical component in Acid Mine Drainage (AMD) formation and it serves as contaminant transport medium (Hawkin, 1994). Therefore, prediction of postmining drainage quality requires the knowledge of a surface mine spoil groundwater hydrogeology.

The nature, degree and duration of groundwater and spoil interactions need to be factored into comprehensive mine drainage predictive methods or models (Hawkins and Aljoe, 1990, 1991). However, the hydrogeology of mine spoil is poorly understood and remains one of the least analyzed aspects of mine drainage prediction. In view of the foregoing, this present study was designed to evaluate the:

- Geological formation of the Okaba coalfield
- Topography of the mine site
- Lithologic/hydrogeologic components of the mine site using borehole sections, map-based analysis and field measurements/reconnaissance survey

The objective of this study, therefore is to analyze the hydrologeologic characteristic of a typical coalfield in the humid tropical environment using Okaba mine site as a case study.

MATERIALS AND METHODS

Study area: The Okaba coalfield is located in the middle belt of Nigeria and lies within latitude 7°31'30"N and longitude 8°02'11"E. The study was conducted in January 2008 (peak of the dry season). The area is a striking example of 'scarp and vale topography'. It constitutes the North-South scarp between the Anambra River and the Benue River systems. The climate of the area, as in other parts of the country is influenced by the movement of the Inter-Tropical Discontinuity (ITD). The area, which is located in the middle belt has 6-7 rainy months. The mean annual rainfall for Okaba is 1250 mm (Fig. 1).

Monthly temperature values ranges from 29°C to over 34°C in the area. The mean annual sunshine hours at Lokoja is 2300 h, while the daily mean duration of sunshine hours in July is 4-5 h during the dry season, the values of relative humidity ranges from 36-80%, while rainy season values are between 70 and 90% in January and July, respectively at Makurdi (7°44'1N 8°32'E).

The soils were characteristically loamy sand. The topsoil, which is formed from the Ajalli sandstone contains very high proportion of sand (73.80-89.80, mean of 81.30%), with low clay and silt fractions -8.65 and 10.05%, respectively. The dominant vegetation type is the derived Savanna. These environmental attributes may influence the hydrogeologic properties of mine spoils (Rogowski and Pionke, 1984).

Hydrogeologic analysis: A topographical map of the area drawn to a scale of 1; 1000 was employed in map-based analysis. The original map (geological survey plate 16, bulletin 28) was converted from imperial units to metric and elevation expressed in meters. The morphometric properties of water bodies were measured from the topographical map. Also, a digitized map showing relief

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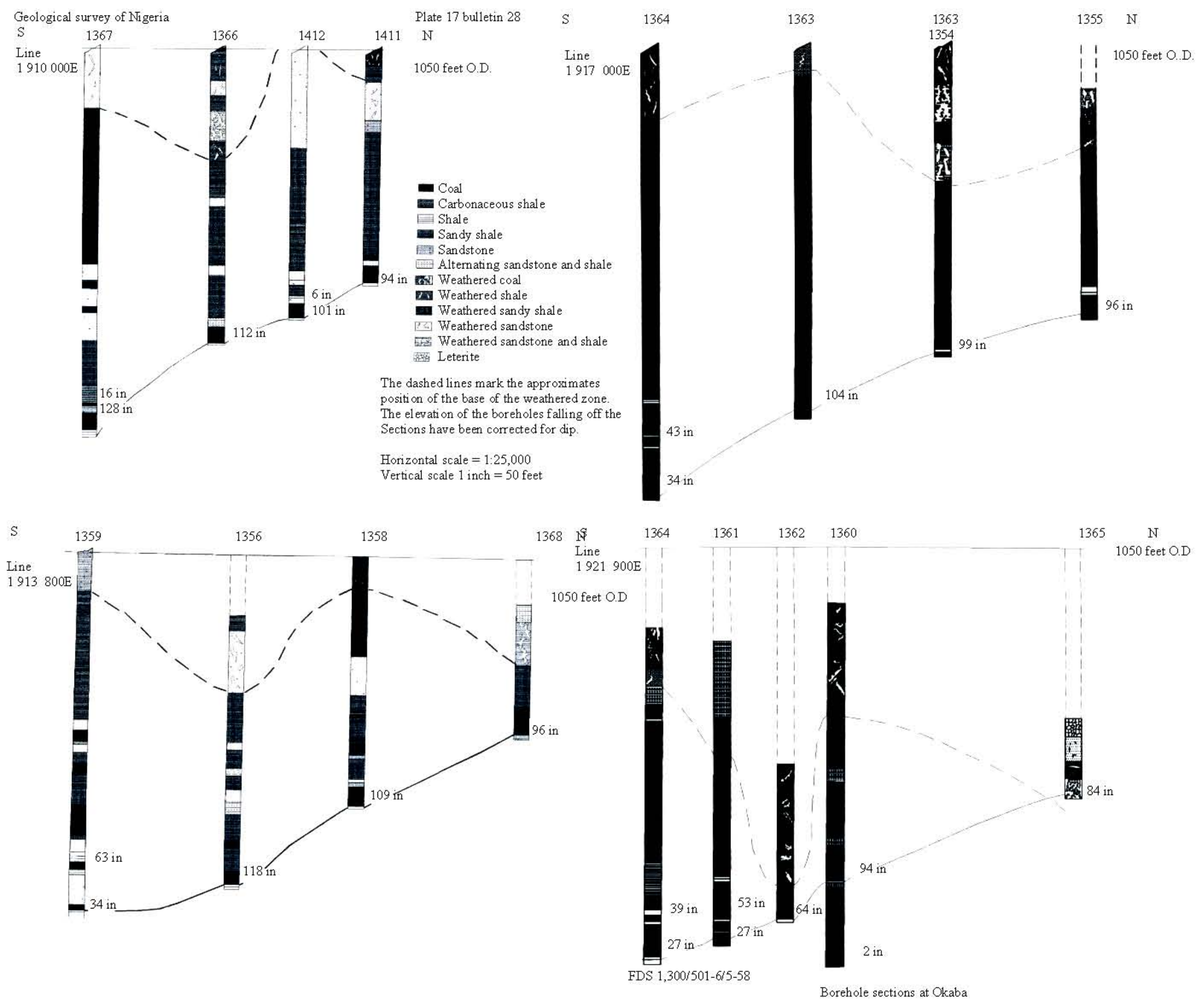

Fig. 1: Map of Nigeria showing the location of Kogi state

and water bodies as well as a Digital Elevation Model (DEM) were generated for the study area. Information on stratigraphic units were extracted from the borehole sections of Okaba-Geological Survey of Nigeria plate 17, bulletin 28 No. 1367, 1359, 1367. A block diagram of the lithologic units in the area was drawn to show a cross section of the Okaba coal mine, near the spoil water, while a hand held Magellan Spor Trak model GPS was used in taking coordinates and elevation during field survey. These analytical procedures are in consonance with the recommended methods described by Hawkins (1994).

RESULTS AND DISCUSSION

Surface hydrology: Okaba coalfield designated OK-1-5 is drained by two mature river systems located in the extreme North and South. These are the Okpokwu and Otonu streams, respectively. The morphometry of these rivers are provided in the Table 1 and 2.

Table 1 and 2 indicate that both of them are order-3 basins (based on Strahler's method), average bifurcation ratio of Okpokwu is 4.5, while that of Otonu is 3.9. However, in Okpokwu basin, every order-2 segment contains an average of six unbranched streams, while barely three fingertip streams are found in each order -2 basin in Otonu river system. The wide variation in the rate of stream abstraction may be due to the effect of environmental heterogeneity particularly geology on drainage basin geometry (Udosen, 2008; Jeje, 1976).

The average length of first order streams in Okpokwu basin is 0.64 km, while the corresponding value in Otonu basin is 0.53 km stream lengths of oreder-1 segments in Okpokwu Basin ranges from 0.18 km to about 1.22 km (Okriko stream). In Otonu basin, the values range from 0.12-1.04 km. These river basins are neither elongated nor circular in shape, rather they are almost pear-shaped with a sharply defined point at the source. The implication is that the concentration of pollutants in the higher order channels (from NCC coalfield) in the surface water system

Table 1: Aspects of morphometric properties of Okpokwu stream

Stream order	Stream number	Bifurcation ratio	Average stream length (km)
1	18	6	0.64
2	3	3	0.92
3	1	-	-

Average bifurcation ratio of Okpokwu = 4.5; Field work (2007); Analyzed from Okaba Coalfield map scale 1; 10,000

Table 2: Aspects of morphometric properties of Otonu Stream

Stream order	Stream number	Bifurcation ratio	Average stream length (km)
1	14	2.8	0.53
2	5	5	0.87
3	1	-	-

Average bifurcation ratio of Otonu = 3.9; Field work (2007)

Table 3: Ashokpa stream morphometry

Stream order	Stream number	Bifurcation ratio	Average stream length (km) (order-1)
1	5	5	Ajamala = 1.54
2	1	-	Otorkpo -0.43
	-	-	Majoda = 0.37
	-	-	0.49
	-	-	= 1.38
Average length-order-1	-		= 0.84

Field work (2007)

is mild, as the flow of water into the main channel from its tributaries is non uniform. Discharge from each segments enters the main channel at different times, thus distributing the total volume of polluted water over a long period of time. Equally water from the rain-swollen tributaries has dilution effect on the level of concentration of the pollutants.

In Ikpa river basin underlain by the Coastal Plains Sands, Udosen (2008) reported higher values of mean length of stream segments -0.99 km, n = 172 of order-1 basins while, Jeje (1991) observed that values in Effon Alaaye area of Osun state, underlain by alternating bands of highly fissured quartzite and quartz-schist have a mean length of 0.37 km (n = 16). In the current study, the first order streams flow through fairly steep channels and have straight courses (mean sinuosity index is 1.19, CV = 21.45% and the channel gradient of Okaba stream for instance is 2°).

Also located north of Okaba is another order -2 basin known in local parlance as Ashopa stream. Ashopa stream and its tributaries-Majoda and Otokpa streams drain the NCC Open Cast Mine site, which is centrally located. These streams are the receiving water of the existing water pollution discharges from the NCC plants in Okaba. The details of their morphometric characteristics are shown in the Table 3.

Topography: Detailed map-based analysis, supplemented with ground truthing, using a hand held GPS indicates that the highest elevation in the Okaba coalfield is 433 m above sea level. The terrain slopes eastwards towards the confluence where the streams/rivers draining Okaba coalfield empty into the Benue river system, around Makurdi (the DEM).

The foot of the scarp slope is actually the headwaters of the numerous order -1 streams draining the area. Hence, the peak of the dissected plateau-like ridge constitutes the watershed separating the Anambra river basin from the Benue trough to the North. Okaba stream for instance, rises from the foot of the scarp slope at an elevation of 305 m a.s.l. and flows eastwards.

The Eastern axis of Okaba coalfield is heavily dissected by several fingertip tributaries of the main channel viz; Majoda, Otokpo Ashokpa, Okponkwu, Enewala streams, among others (Fig. 2). The obvious conclusion to draw is that surface runoff (along with the spoil water from the coalfields) drain directly into natural drainage system (streams/rivers). Figure 3 clearly shows the slope inclination towards the stream channels. However, as would be expected, the concentration of pollutants decreases with increasing distance from the NCC coalfield due to the dilution effects of large water bodies-main river channels (Udosen, 2008).

Geology: The Okaba coalfield is underlain by a variety of the Mesozoic (secondary) sedimentary rocks. The North-South trending Lower Coal Measures around Enugu is sharply deflected towards northwest near Okaba (Fig. 4).

This formation splits the Okaba field into two unequal parts, the Eastern flank, which is somewhat restricted is underlain by the Awgu Formation, while the Western flank is covered by the Upper Coal Measures/False bedded Sandstones. The Agwu Formation is dominantly composed of well-bedded shale that has intercalations of calcareous sandstones and limestone.

The formation is santonian in age and like most formations South of Benue trough are non-aquiferrous.

The upper cretaceous marine sedimentary are mainly sandstones, Shales and Mudstones and include the Mamu Formation (Maastrichtian) made up of sandstones, shales and stones and sandy shale with coal seams-most of which are in exploitable quantities but requires underground mining. The formation is moderately porous and permeable but the ground water stored in it is generally acidic. The acidity results directly from the oxidation of iron pyrites, along with other metallic sulphide with dissolved oxygen. South of this Formation is the Nsukka Formation/Ajali Sandstone (Maastrichtian) which sometimes overlay the Mamu Formation in some areas. They are mainly made up of thick friable poorly sorted cross-bedded sandstone. In the study area, it is iron stained.

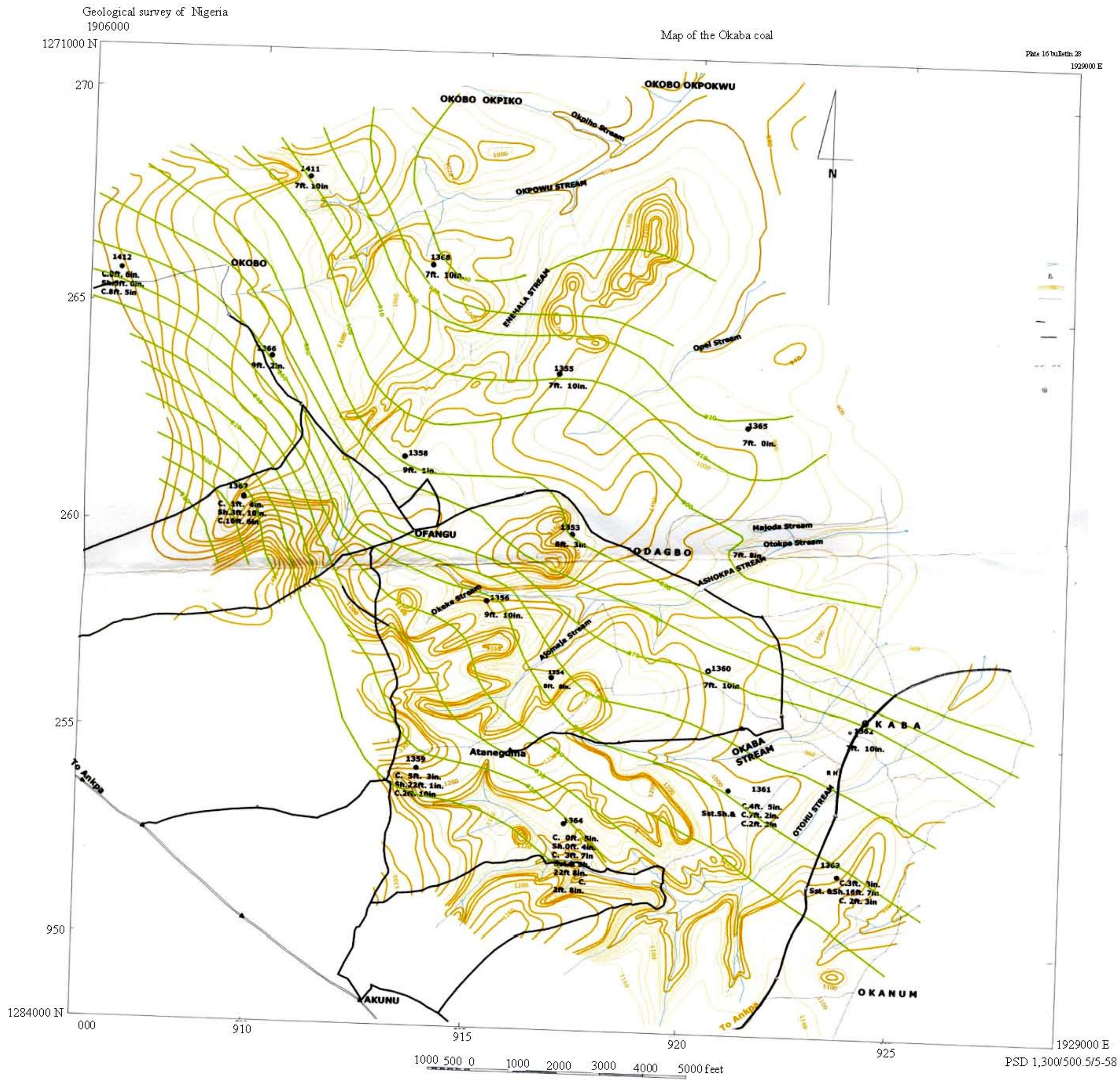

Fig. 2: Digitized Map of Okaba coal mine

This formation is extensive and is of considerable thickness. Overlying, the Ajali Sandstone, is the Nsukka Formation which marks the end of the cretaceous marine sedimentary rocks in the area. It is equally thick (max 400 m).

A number of perched springs emerge from it and quite a number of low yield wells also tap the perched aquifers in the Nsukka area. The formation also has other economic importance, as coal seams are present at various horizons. As in the other formations, the Nsukka formation consists of alternating successions of sandstones, shale and sandy shale.

Hydrogeology: The types of aquifers in Okaba coalfield are presented in Table 4.

Shales have similar porosity/permeability properties as clay i.e., slightly porous but not permeable, hence inhibits downward movement of infiltrating water from the shallow mantle of sandstones overlying it. In the study area, shales inhibit the flow of water underground. This retarded or slow flow of water gives rise to aquitards (Table 4).

Table 5 are the representative values of porosity and permeability recorded at the coalfield. These properties are relevant not only to discussions of groundwater availability in the study area, but also in issues such as sources of pollutants to surface flow (streams); lateral and downward movement of Acid Mine Drainage (AMD)/water pollutant and waste disposal.

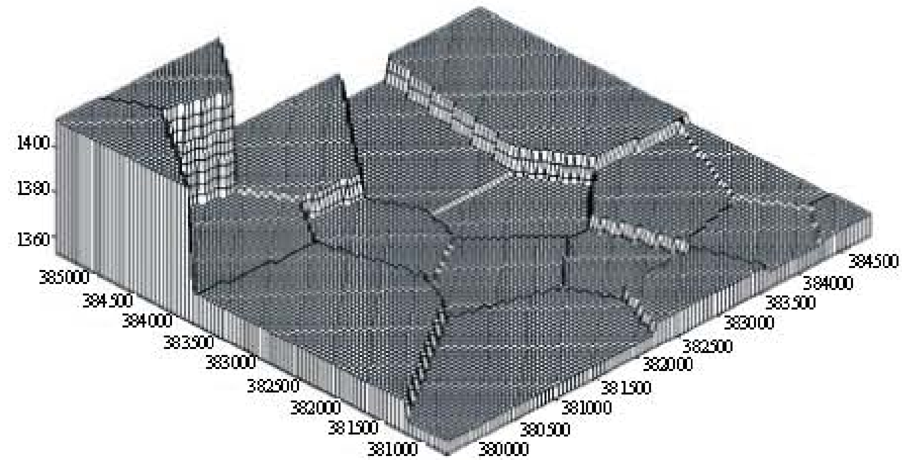

Fig. 3: Digital elevation model of Okaba Coal field

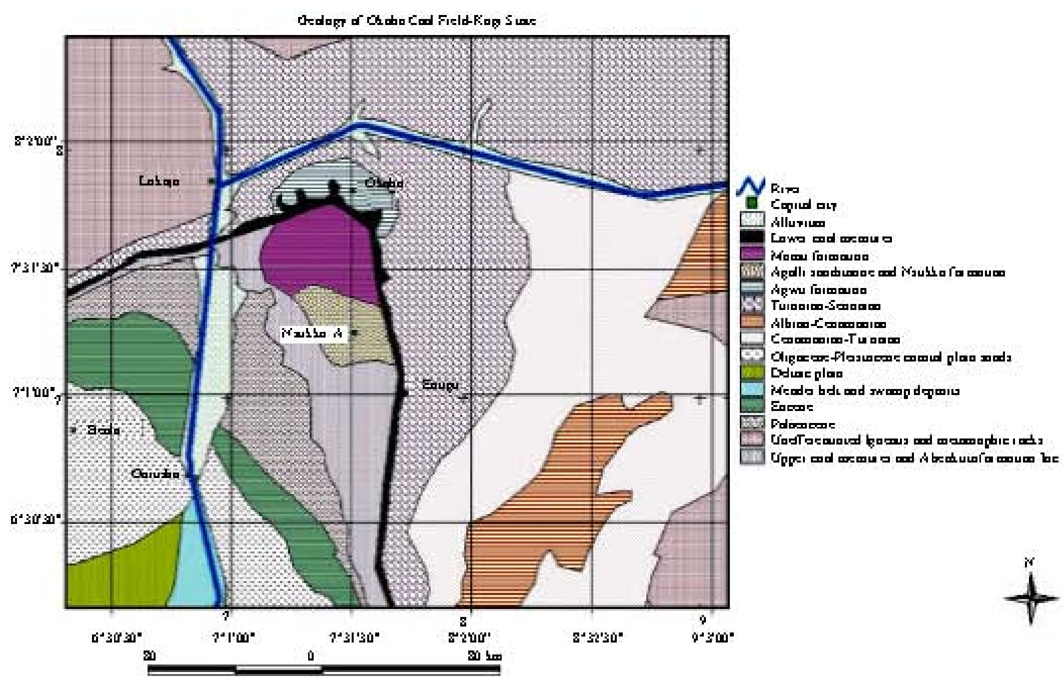

Fig. 4: Geological map of Okaba

It could be inferred from the results that the pyritic shales with restricted porosity/permeability of <0.01 m day^{-1} overly the coal seams. This layer of shales with thickness ranging from 2-11 m tends to inhibit the downward movement of infiltrating and/or percolating water. We do know that sandstone-rich spoil zones tend to have larger fragments than shale rich zones. Hence, the deflected water flows at the sub-surface zone above the shale (clay horizon) and contributes significantly to surface water pollution. This contribution is enhanced by the topographic disposition of the area. Thus, water in the vadoze zone flows laterally through the permeable regolith of coarse-medium grained sandstones from higher elevations to lower slope segment (towards the stream channels). The processes of mining explained earlier, may facilitate spoil heterogeneity by creating zones comprised predominantly of one lithology. During mining, a dragline or fronted loader often will remove the overburden in

Table 4 Types of aquifer in Okaba coalfield

Geologic formation	Hydrostratigraphic units	Lithology	Aquifer type
Nsukka	Nsukka aquitard	Clayey, sandstone, coal	Perched aquifer
Ajali sandstone	Ajali sandstone aquifer	Coarse-medium sand with clay interbed	Aquiferrous artesian in places
Mamu formation	Mamu aquiclude	Siltstone, shale, coal	Aquitard
Agwu shale	Agwu aquitard	Shale,siltstone and coal alteration	Aquitard
Lower coal measures	LCM aquitard	Coal	Aquitard

Table 5: Representative values of porosity and permeability of geological materials

Material	Porosity (%)	Permeability (m day^{-1})
Clay	45-55	<0.01
Fine sand	30-52	0.01-10
Sand stone	05-30	0.3-3
Limestone	01-10	0.00003-0.1

layers, spoiling strata composed mainly of one lithology at a time. Monolithic zones are also created by the tendency of large spoil fragments usually sandstone to roll to the base of spoil ridges, while the medium and smaller fragments of shale tend to remain on the sides and top.

CONCLUSION

The obvious conclusion to draw is that information/ data in this study can be used to predict the groundwater hydrologic regime in reclaimed surface mine spoils prior to mining. The data presented here should be viewed as baseline information prior to privatization of the coal mine by the Federal Ministry of Solid Mineral (under the sustainable solid mineral programme). Further research is recommended on the groundwater velocity, water table elevation, discharge rate and volume of water that will be stored in the spoil. The latter will determine to an extent the potential groundwater flow direction and flow paths.

This hydrologic information used in conjunction with the overburden geochemical data can be used to improve mine drainage predictive models and methods. Hydrologic data will give individuals involved with mine drainage prediction a better understanding of the spoil material that is contacted by the groundwater and the physical, spatial and temporal nature of this contact. This information is a prerequisite to recommendations of cost effective mitigation measures for the adverse environmental impacts of acid mine drainage.

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