HYDROGEOLOGICAL AND HYDROGEOTECHNICAL CONSTRAINTS IN COAL MINING AT ENUGU AREA OF NIGERIA

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ABSTRACT

The coal mining city and capital of Anambra State, Enugu, is a major industrial centre within laliutudes 6° 24' and 6°30', and longitudes 7° 30'. Mining began in 1915, coal being discovered in 1909.

Acid mine drainage poses problems causing corrosion of mining equipments and groundwater flooding. These have generated constraints in planning and management activities. The problems have menaced and bedevilled mining programmes, and resulted in huge losses in financial resources. The main geologic features are the Nsukka Formation (Upper Maestrichtian); the heavily-aquiferous Ajali Formation (Middle Maestrichtian); the coaliferous and aquiferous Mamu Formation (Lower Maestrichtian); and the oldest Formation, Enugu Shale (Campanian). The Mamu Formation has five coal seams ranging in thickness from 0.5 to 3.0 m. The No. 3 seam has been mined in Commercial quantities. The rocks are highly faulted and jointed. Both the Ajali Sandstone and Mamu Formation have thick aquifer systems overlying the coal mines. The coal and shale layers have pyrites that generate acids, high iron, sulphate and silica with dissolved oxygen from recharge water or through aeration of mines. These have caused haxardous problems, constraints to mining, and great losses to economy. Suggestions for problems-solution are proffered.

INTRODUCTION

Coal was discovered in Commercial quantities in Enugu area by British Geologists in 1909. It has been mined since 1915. Coal as the oldest industry in Nigeria has supported the emergence and existence of other industries such as transport, energy utilities, cement manufacture, etc. and the economy. Five mines (Okpara, Onyeama, Ribadu, Iva and Ekulu) were earlier opened. Three have been closed except Onyeama and Okpara mines. Coal production (estimated reserve, 1.5 million tons) has declined steadily as high as two-thirds. This was caused partly by mines flooding during the three-year-long Nigeria-Biafra war when all mines were abandoned; later the woeful failure of mechanisation of mining techniques; and the emergence of Petroleum as an alternative source of energy and foreign exchange earnings.

Enugu is the capital and administrative headquarter of Anambra State, Nigeria (Fig. 1). The urban centre grew up and developed from the emergence of the coalmining activities and hence its popular of "Coal City". The suburban and rural towns of Ngwo, Udi, Emene, etc. are equally affected. Industrial, educational and business activities have been stimulated greatly by coalmining activities. Unfortunately, because of the declining fortunes of the coal industry, the economy has suffered.

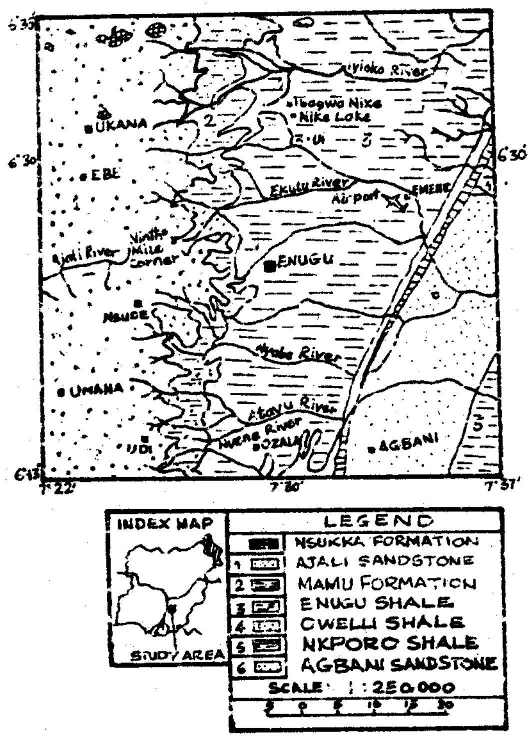
Coal is found in the Mamu Formation (L.Maestrichtian). The thick No. 3 seam is mined, leaving out Nos. 5, 4, 2 and 1 because of their smaller thicknesses. The Enugu coal is subbituminous, of medium quality, non-coking and has relatively high ash content, friable and susceptible to weathering, and low fixed carbon. The coal serves for both domestic uses and export but the myriad of problems bedevilling mining and the failure of the mechanisation process and hence reversion to old crude mining methods resulted in low production that does not satisfy internal and export markets. Thus, the Nigerian coal industry has great economic potentials if the hydrogeological, hydrogeotechnical and economic problems are solved.

The primary objective here is to present and discuss more findings on the hydrogeological and hydrogeotechnical problems and mining constraints of Enugu coal mines, and proffer suggestions for solutions. Although new coal mines have been opened in other parts of Nigeria, the scope of study shall be Enugu area which may serve as a case example of similar mining activities not only for Nigeria but other developing countries in similar situations.

CLIMATE AND PHYSIOGRAPHY

Enugu area is strongly affected by two major seasons of the year in Nigeria, namely, dry season and rainy season. The dry season covers months of October to March, caused by airmass that advances from the Saharan region southwards bearing dusty, dry and cold conditions and making life most unconfortable. It causes leaf fall and general lowering of surface and subsurface waterlevels. The rainy season spans the months of March to October with warmer humid conditions and heavy rainfall that may reach 1,500 to 2,000 mm per year. The rains occur mainly as thunderstorms, strong showers causing extensive flooding and groundwater recharge, sheet outwash, rill, channel and gully erosion (Egboka, 1983). During the rains there are large discharges from rivers and their tributaries in the area, some flowing out from the mines (Fig. 1).

Fig. 1 GEOLOGICAL MAP OF ENUGU AREA

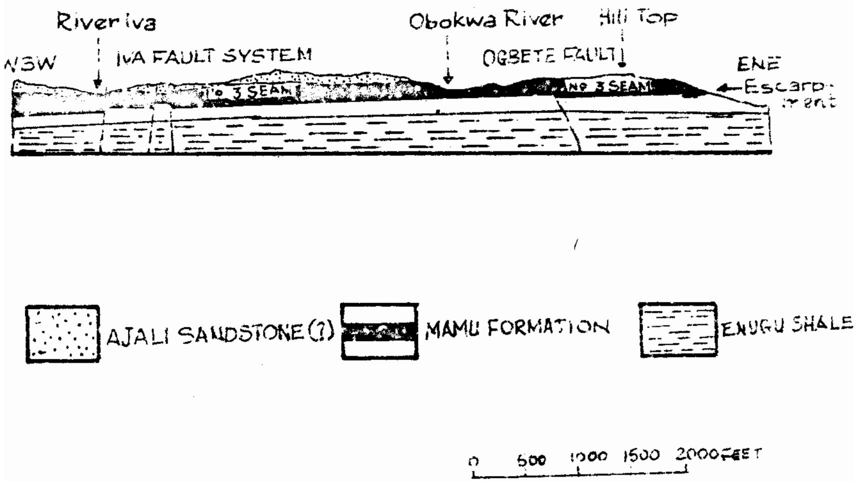


Enugu area is bounded by latitudes 6° 24' and 6° 30' and longitudes 7° 26' and 7° 30', in the west by the Nsukka-Udi-Awgu escarpment and in the east by the Cross River plains (Egboka and Uma, 1985). The imposing northsouth trending escarpment with steep scarp facing Enugu town, has hills of elevation up to 1000 m.a.m.s.l. While the scarp with slopes between 75° and 90° faces eastwards, the gentle dip slope of about 30°-45° faces westwards. Both sides are ravaged by soil and gully erosion. The Enugu shale, Mamu Formation, Ajali Sandstone and Nsukka Formation form the cuesta. Major rivers with source areas in Enugu area Cuesta flow down deep valleys with many water falls. They include: Ekulu, Nyaba and Atavu Rivers emanating below the scarp face and flowing into Eboine River that discharges into Cross River; Ajali River and tributaries flow out from dip slope into Anambra River that discharges into River Niger. The escarpment forms major surface water and groundwater divides for these rivers and the complex aquifer systems. Thus, Enugu area provides a complex hydrological, hydrogeological and geotechnical framework that cry for solutions before successful economic activities can be executed (Egboka, 1985). The rainforest belt in the area has given way to the Savannah. This is caused by antropogenic activities. The Enugu urban with all its economic and social activities sits on top or very close to the coalmines.

GEOLOGY OF THE AREA

The geology of Enugu area (Fig. 1) has been described (Simpson, 1954; Reyment, 1965; Offodile, 1980; and Egboka, 1985; and Uma, 1986). More detailed geological and geophysical work are still required to understand the geotechnics, tectonics, surface water/groundwater flow patterns, and recharge / discharge systems. The research programmes are in progress. The oldest rock is Enugu shale (Campanian), fractured and forming plains east of the escarpment. This overlain by the coal-bearing Mamu Formation (L. Maestrichtian) where coal is mined since 1915. It consists of 5 coal seams, shale layers, sandy shales, mudstone and sandstone members. This is fairly aquiferous. The sandstones are fine-to-medium-grained. The Formation is about 395 m thick and is highly jointed and faulted. Creep-like movements seem to be accurring along some of these faults / joints particularly in the mines. The Ajali sandstone (Middle Maestrichtian) is about 406 thick, heavily aquiferous and overlies Mamu Formation. It consists of thick friable, poorly-sorted sandstones, white in colour but ferruginised in places. It is predominantly coarse-grained, has characteristic cross-bedding, and shale/mudstone intercalations. It is overlain by the predominantly shaley and coaliferous Nsukka Formation (Upper Maestrichtian) towards the north, but by laterite / red earth southwards. As a result of the migration of the Campanian / Maestrichtian boundary westwards as indicated by the northsouth trending escarpments, many gullies, canyons, caves, new streams / springs / waterfalls and floodplains have developed. The rivers emerge from Ajali aquifers and gain tributaries downstream from the Mamu aquifers.

Geological section across Enugu Coalfield (MODIFIED FROM SIMPSON, 1954)
Fig 2



HYDROGEOLOGY AND GEOTECHNICS

The hydrogeology and geotechnics of Enugu coal mine area are complex. They are yet to be studied in enough details to enable a comprehensive description to be made. Various workers have contributed to the existing literature (Reyment, 1965; Simpson, 1954; Offodile, 1980; Egboka, 1983 and 1985; and Ugwu, 1984). The studies have still left a lot of complicated and unanswered questions on the surface water-groundwater interactions, flows and geotechnics vis-a-vis the coal mines. Ugwu (1984) described the geotechnical problems and economic losses suffered by the Nigerian Coal Corporation particularly since the failure of the mecchanisation. The Corporation has reverted to old crude mining methods.

Ajali Sandstone and Mamu Formation have aquifer horizons that contribute water to mine in-flows. The Ajali aquifers are coarse-grained and provide higher discharge while the Mamu aquifers are fine-to medium- grained and highly-fractured with lower discharge (Egboka, 1983 and 1985). Offodile (1980) argued that groundwater inflows into mines come from overlying Ajali aquifer. He suggested dewatering of Ajali aquifers to check inflows. The earlier British geologists and some officials of the Nigerian Coal Corporation tend to agree with this view (Unpublished data). However recent findings indicate that both the Ajali and Mamu aquifers contribute water to the coal mines. Egboka and Uma (1985) suggested a percentage ratio groundwater contribution by the Ajali and Mamu aquifers to be 30% and 70% respectively. More information indicate that the Mamu value may be high, but it is believed that Mamu aquifers contribute up to 50% of water inflows. The solution of the source-problem of mine water is of paramount importance if the acid mine drainage problems are to be checked.

The Mamu Formation of immense thickness and the rocks dip to the west or westnorthwest with angle of dip measuring 1 to 3°. Many fault systems (Fig. 2 and 3), majority of which strike out northwest (Simpson, 1954) inclue: The Nyaba fault with a downthrow of 18 m to Westsouthwest along which Nyaba River flows; The Hayes fault with a throw of 8.4 m in westsouthwest; The Iva fault system (Fig. 2 and 3) observed at Iva and Ogbete mines forming the deep Iva valley. It is made up of a number of faults some throwing eastnortheast or westsouthwest. Faults are exposed along many creeks, streams and rivers; Ogbete faults (Fig. 2 and 3); Obuga fault with a major throw of 18 to 24 m in westsouthwest; Juju Hill fault that cuts across Asata valley, trending norheast with a downthrow to the east of more than 60 m; and Atavu fault system along which Atavu River from a cave at Obioma-Udi flows.

In addition to these faults, there are many intersecting horsts and grabens. The characteristic features are: the consolidated/indurated bottom layer of the Ajali Sandstone described as White Sandstone and the Mamu Formation are fractured to display joints, faults, horsts and grabens, these features being well-displayed as a badland topography on the scarp face of the cuesta; these paleotectonic features enhance the westward progression of the Campanian-Maestrichtian boundary through neotectonic activities, and gully erosion; the neotectonic activities

Fig 3a Ogbete Fault System at Old Udi Mine

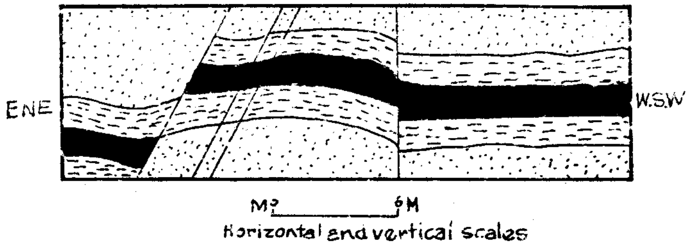


Fig 3b Ogbete Fault System at Iva Valley Railway Mine

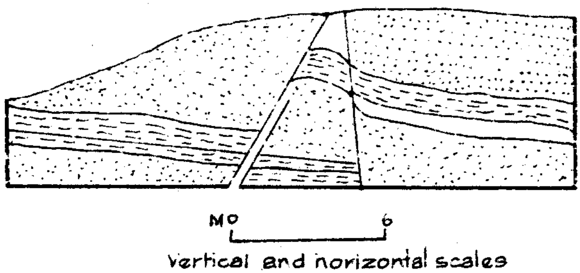
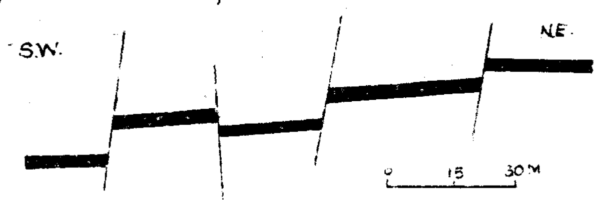


Fig 3c Iva Fault System



include creep movements along fault zones in the mines, land subsidence and slides, etc.; major rivers, streams and lakes emerge from these faulted/jointed zones and between Ajali/Mamu and Mamu/Enugu shale boundaries. The major rivers and lakes include Ekulu River, Nyaba River, Atavu River, Iyioku River, Ajali River, Nvene River and Nike Lake (Fig. 1). These are perennial and provide heavy discharge both during rainy and dry seasons and their source/recharge areas seem to be within Enugu area and environs. All these suggest a major hydrogeologic and groundwater reservoir regime still remaining unexploited despite the attendant problems.

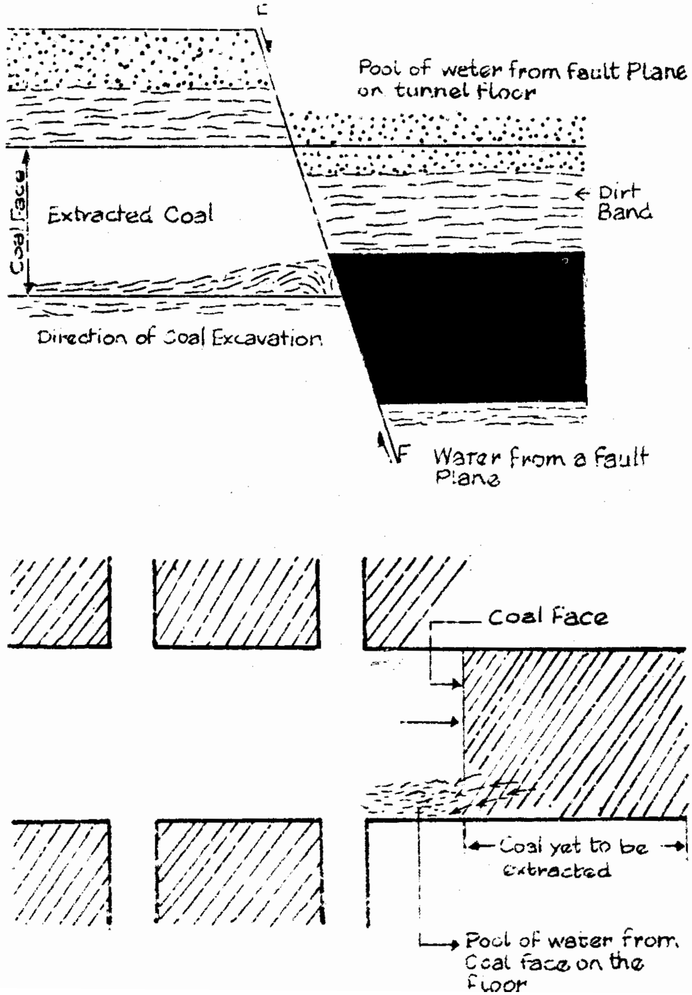
The hydrogeochemistry and hydrogeomicrobiology have been discussed not-in-detail by Egboka and Uma (1985). The mine water is acidic, has high iron, silica and sulphate concentrations, low dissolved oxygen and strong odour of hydrogen sulphide gas in the mines. The bad quality water is continuously discharged through pumping into adjoining rivers which are thereby polluted even though rural dwellers downstream use them for various purposes. For an example, over 18.1 million litres of untreated mine water are discharged into Ekulu River from Onyeama mines daily. The shales and carbonaceous layers have pyrite. Incoming dissolved oxygen in recharge water react with pyrite to produce reddish scums of iron hydroxide, sulphate and hydrogen ions (acidity). These activities which may have been occurring even during the coalification history must have been mediated by bacteria to produce such high levels of hydrogeochemical parameters now recorded. These are being investigated.

HYDROGEOLOGICAL AND HYDROGEOTECHNICAL CONSTRAINTS

The above hydrogeological, hydrogeochemical and hydrogeotechnical parameters have caused great declines in coal production, mine accidents and hazards resulting in loss of lives, and downturn in economy of the Nigerian Coal Corporation. The major constraints are as follows:

1. Mine Water inflows and flooding are a major problem hindering mining as dewatering bear great financial costs. The mining environment seems to be within the recharge area of major aquifers. Sources of water into the mines include: surface waters (streams/rivers) entering shallow workings; Mine water in shafts sunk through aquifers from above; Feeders from fault zones/fissures and complex joint network in fractured rocks (Fig. 2, 3 and 4); Water entering from outcrops under overlying strata; Water-bearing overlying and underlying strata in contact with or in close proximity to coal seams or coal bearing units (Fig. 4); Water from adjacent mines whether closed or working and sometimes water logged; during the Nigerian-Biafra War that lasted for about three years (between 1967 and 1970), all mines were abandoned resulting in their heavy flooding and great damages; Water dripping down continuously from the roof of arch ring supports, water at boundary of fault planes forming a pool; water dripping from coal face between layers and fractures (Fig. 4); Water from a place where mining has intersected an abandoned borehole at the bottom, possibly some other boreholes sunk during explorations for coal

Fig. 4 SOURCES OF WATER IN ONYEAMA COAL MINE



and water may pose similar hazards; and roof collapse of mines. The Iyicfe stream at Aboh (Fig. 5) disappeared underground where the roof cracked, and flooded parts of Onyeama mine, forcing the design of a new course for the stream. Use of explosives and blasting devices causes mine instability, generation of new fractures and development of old ones (faults/joints). This should be discouraged.

2. Paleotectonic and neotectonic activities have made mining hazardous. The old tectonic features seem to be active neotectonically particularly as mining progresses. Roof and wall collapse, tunnel-floor upward heave, landslides, creep-movements along fault lines, collapse of tunnels and supports, cracking of buildings above ground surface, and subsidence are recorded.

3. Corrosion of Mining Equipments was the major cause of the woeful failure of the machanisation process in which huge financial losses occurred. Any metal or material that is not acid resistant is corroded or damaged inside the mines. Thus acid resistance materials are required.

4. Public Health problems are not yet considered as serious constraints. The acid mine water, H_2S gas, high iron and sulphate, and coal dust are threats to miners and others who work within the area. The public health implications are not known to have been investigated.

5. Urbanisation activities disturb mining. The mines are close to or beneath of Enugu, and pass under Udi, Aboh, Ninth Mile, etc. and below the Enugu-Onitsha expressway. The urban developmental programmes contribute to generation of high runoff and mine flooding, structural settlements and slope stability, landslides, gully erosion and seepage/foundation problems.

SUMMARY AND SUGGESTIONS

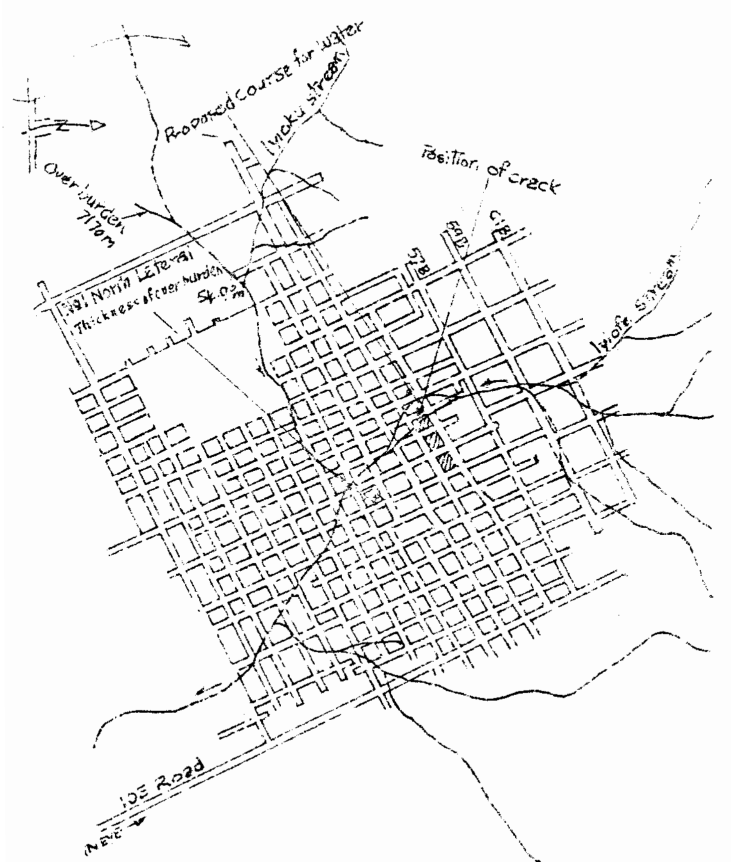
Mining activities particularly in many develping economies such as this case study discussed above pose very hazardous problems. It is a common event to read of mine failures and accidents causing loss of lives and monies from different parts of the wordl, even in some developed countries. These problems arose because mine planners and managers rarely seriously consider hydrogeologic and geotechnical data of the coal mines and their implications before mining. The following suggestions could make coal mining in Enugu area safer and more productive if considered and implimented:

1. The recharge areas of major aquifers now discharging into mines must be defind and properly establish sources of water from the different aquifers. These information would facilitate dewatering programmes;

2. The sources and types of acidity and gases within the mines must be investigated and defined for control;

3. The present crude mining methods should be replaced by a

Fig 5 Iyiofa stream at Abor showing the position of crack



remechanisation process after proper consideration of the various physical, chemical and biological characteristics;

4. Redirect major surface waters flowing above mines away from mine areas;

5. Redirect planning and development of urban areas away from mine areas;

6. Investigate public health implications of coalmining and take remedial actions against deleterious ones;

7. Socio-political interferences in coalmining, planning and management must be discouraged. The Nigerian Coal Corporation should be funded adequately to be able to pay its staff, initiate applied research programmes for the benefit of the coal industry, be provided with better working conditions for better productivity, and foreign markets be found for Nigerian coal; and

8. Monitoring and maintenance programmes should be on a continuous basis. Complete cooperation, integrated in nature, must exist among, the geologists, hydrogeologists, engineers and administrators in tackling the coal industry problems.

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