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Hydrological Problems Associated With Mineralizations in the Middle Benue Trough: Implications for Mine Development and Possible Solutions

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***Abstract**: The Benue Trough hosts a variety of metallic and non-metallic mineral deposits. The hydrologic conditions associated with the lithologic units hosting some of these deposits has presented substantial problems to its exploitation. This study was carried out in a bid to proffering viable methods of managing excessive water flow associated with the ore deposits as present mine development and water management practices seem inadequate. A combination of diversion and dewatering techniquesis seen as the best possible solution to handling hydrological conditions associated with mineralizations in the Benue Trough. It is hoped that incorporating these suggestions into mine design and groundwater inflow management during mining can help abate the problems.*

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I. Introduction

The Benue Trough is host to several mineral deposits which can be majorly classified as pre and post Santonian mineralizations that are beset by hydrological problems which make mining difficult even in otherwise impermeable formations. Due to the semi-mechanized nature of most of the mining operations in the Benue Trough, a lot of time is lost every day to pumping water from overnight accumulations in the mine before work can resume.

The hydrological problems have so far proven difficult to handle and has resulted in a lot of abandoned mine projects. For instance, Offodile (2013) noted that some shaft sections of the intensely fractured Onyema coal field in Enugu had to be abandoned due to difficulty on how to deal with heavy groundwater flow of about $90{,}000m^3$ per day.

Groundwater inrush from run offs, fractures and faults is not a problem peculiar to the Benue Trough but a widespread problem in sedimentary basins across the world with some notable examples being the Fangezhuang and the Beidajing coal mine, China with maximum flow rates of $2{,}956{,}320m^3$/day and $800{,}640m^3$/day respectively (Zhang and Shen 2004).

In mining, dry working conditions are optimal as they reduce wear and tear on machinery, reduce earth moving costs, ensure better mine slope stability and improve mine working conditions (Ngan et al., 1984; Morton and Merkerk, 1993). This is usually difficult to achieve in areas where the mining penetrates the local and regional water tables. Furthermore, the permeability and tectonic characteristics of the lithologic units in the areas factor heavily in groundwater inflow regimes.

II. Regional Geologic Setting

The Benue trough is geographically divided into upper, middle and lower regions. The area under study is the Middle Benue Trough in Northcentral Nigeria (Fig 1). Basin strata in the region directly overly the basement complex. Stratigraphy of the Cretaceous sediment fill of the middle Benue trough can be divided into six (6) depositional units. These units measuring about 6km (Offodile, 1980) of sediments were laid down as a result of marine transgressions and regressions resulting from the opening of the South Atlantic in the early Cretaceous.

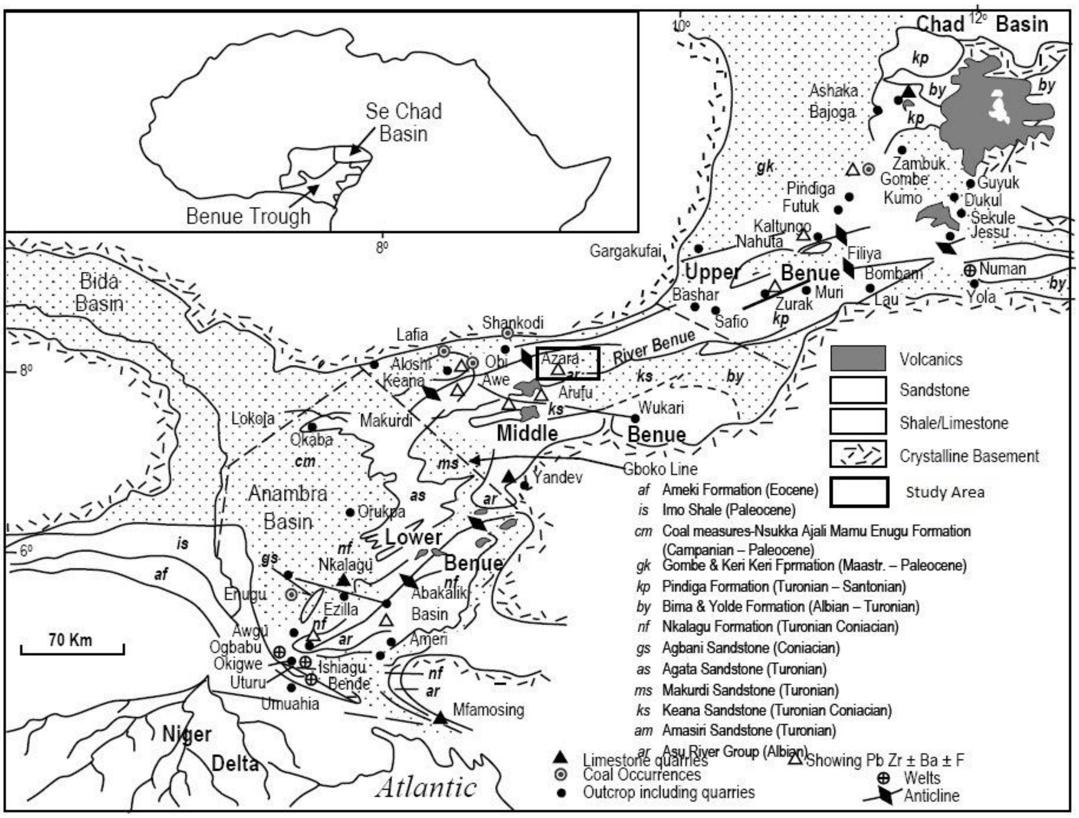

Fig 1: Geological map of the Benue Trough showing the Upper, Middle and Lower Benue basins (Adapted from Akande et al 2011)

The Asu River Group (Middle-Late Albian) is the oldest known marine formation in the middle Benue. It consists of dark shales, siltstones and fine-grained sandstones, passing upwards into shales and limestones (Offodile, 1976). The Asu River Group is overlain by 'transitional' beds of the Awe Formation (Late Albian to Early Cenomanian) and its type section basically comprises of a sequence of fine grained pinkish sandstone, siltstone and mudstone overlain by typical transitional medium to coarse sandstone alternating with shale limestone and clay (Offodile, 1980). The Keana Formation (Late Cenomanian) overlies the Awe formation unconformably. The Keana Formation consists of poor-finely sorted feldspathic, medium to coarse grained sometimes pebbly sandstones (red beds). The formation is capped at the top by thin beds of limestone, siltstone and mudstone with a fluvio-deltaic system laying down the sediments (Offodile and Reyment, 1976). The Ezeaku Formation (Early Turonian) consists mainly of grey to black shales with clay horizons, fine to medium grained sandstones and limestone beds. The deposition took place in a presumably shallow marine coastal environment (Obaje, 2004). The Agwu formation is made up of bluish-grey to dark-black carbonaceous shales, calcareous shales, shaly limestones, limestones, sandstones, siltstones, and coal seams. The occurrence of low diversity arenaceous foraminifera in the Awgu Formation indicate deposition in marshy, deltaic and shallow marine conditions (Obaje, 1994). The Lafia Formation (Maastrichtian) is the youngest formation and is characterized by ferrugenised sandstone, loose sands, flaggy mudstones, clay and claystones (Offodile, 1976).
The mid-Santonian was a period of folding throughout the Benue Trough. The post-folding Campano-Maastrichtian Lafia Formation ended the sedimentation in the Middle Benue Trough, after which widespread volcanic activities took over in the Tertiary.

III. Typical Hydrogeological Characterictics Of The Lithologic Units In The Middle Benue

Typically the different formations in the Middle Benue trough have varying hydrogeological characteristics. The Asu River Group is not known to have good aquifers as it consists mainly of tightly folded shales and siltstones although in highly fractured areas small quantities of water can be obtained from it. The Awe Formation although known to be water-bearing is not a very good aquifer due to the saline nature of groundwater associated with the formation mainly resulting from brines which are known to issue from the formation. (Offodile, 1992)

The Keana/Makurdi Formations comprise of sandstones which are highly indurated with pore spaces filled by feldspathic minerals. Primarily the continental sandstones of the Benue trough have very low values of primary petrophysical flow properties including porosity and permeability (Offodile, 1992). Due to this, groundwater yields from the sandstones are usually low and erratic, although in fractured areas this improves considerably. The overlying Ezeaku Formation is less indurated, is more permeable and generally has better aquifer prospects. Although Offodile and Reyment (1976) has shown that outcrops of Ezeaku Formation in the core of the Keana anticline are very hard and impermeable, this is not particular to the whole Middle Benue especially in areas overlain by shales of the Awgu Formation where artesian conditions are possible.

The sandstones of the Awgu formation is known to be a water bearing member which may be confined and give pressure water (Offodile, 1992). The coal bearing measures in the formation are highly fractured with coal shafts at Agwatashi associated with continuous groundwater inflow.

The Lafia formation is known to be water bearing, albeit in its basal sandstone member. It is highly permeable with most streams and some rivers in the Lafia area being sustained by discharge from this aquifer (Offodile, 1976). There is a water divide in the Agyaragu area from which the waters of the basal sandstones flow northwest-wards and southeast-wards.

However, near ore deposits in the Benue Trough, this typicality is usually perturbed as most mineralizations when exploited are associated with large amounts of water even in otherwise impermeable formations. This results from secondary porosity introduced by way of tectonic deformation that is known to have affected the trough in the Santonian and Post Maastrichtian (Offodile, 1992) and from heavy run-off flows.

IV. Mine Planning In The Middle Benue And Asssociated Hydrological Problems

Although mining activities in the Benue Trough have been growing over the past decade they are mostly fairly local mine setups or semi-mechanized at best. Most of the manual & semi-mechanized mines utilize open strip methods where the inclination of the mineralized bodies guides extraction trends. This is further encouraged as some of the inclination angles for the mineralized strata are quite high (>35^o) (Offodile, 1980; Omada, 1985). A good understanding of mine planning and design as presently obtained in the trough can be gleaned by taking the Azara Baryte and the Adudu-Abuni Zn-Pb deposits as case studies.

4.1 Azara Baryte Mines

The Azara baryte veins were discovered in the 1950's and was intermittently mined by the Nigerian Mining Corporation before being sold to EMO Energy Ltd (Ashafura) in 2005. They are located in Azara, Nassarawa State (8^o 20' 40'' N and 9^o 14' 10'' E) and covers an area of over 10km^2 (Fig 2). Most of the exploratory work going on in the area are local and/or semi-mechanized with little or no mine planning and design. Although hosted by the continental Keana Formation which otherwise is known to be have poor groundwater potentials, the Baryte deposits are beset by water logging problems (Fig 3) from surface run-off and inflows from fractures and joints. This problems are not peculiar to the Benue trough but affects baryte deposits all over the trough (Fig 4)

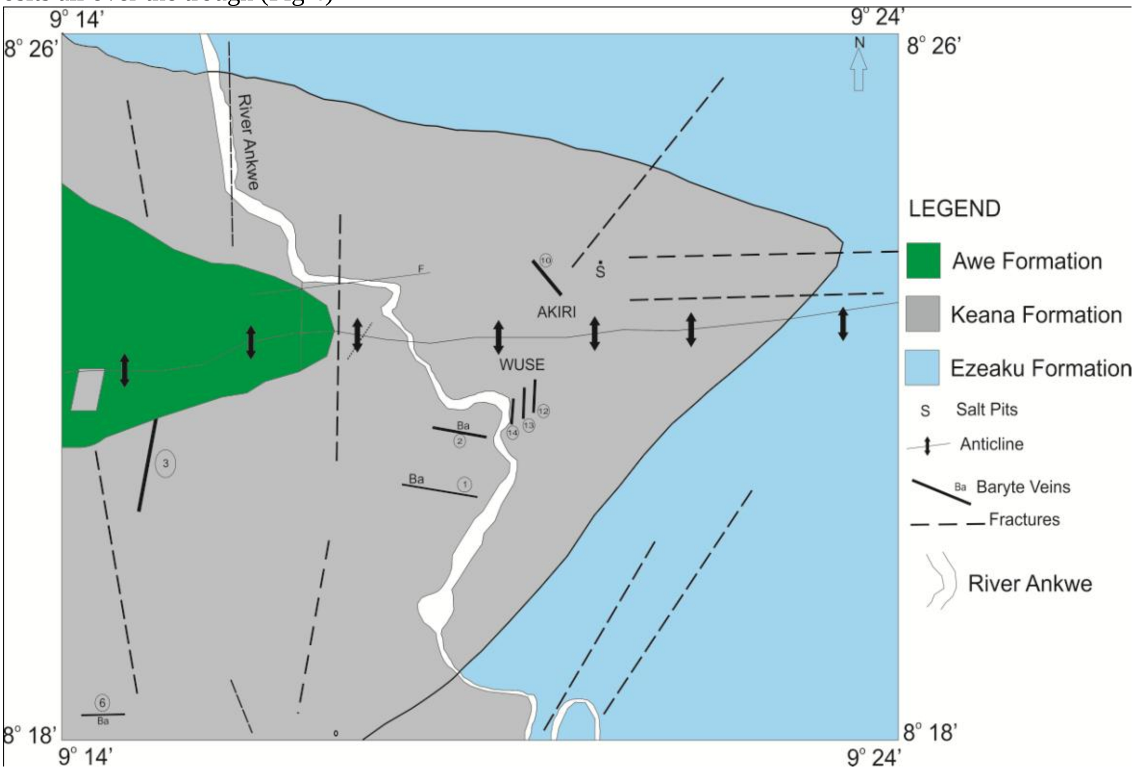

Fig 2. Geologic Map of the Azara-Wuse Baryte Field

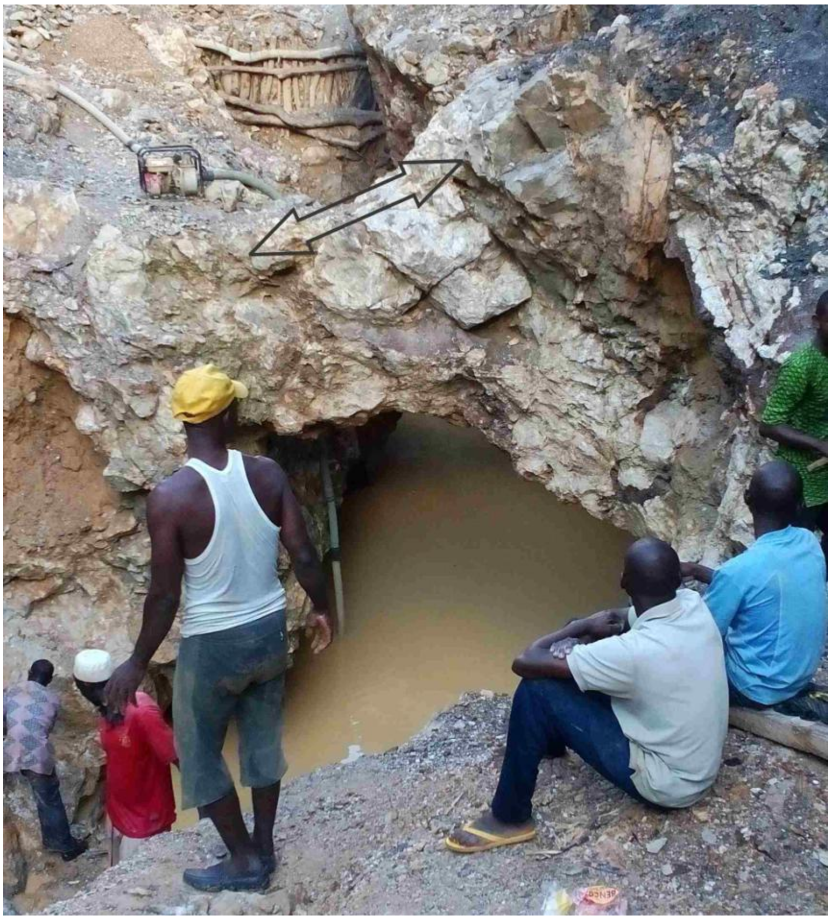

Fig 3. Azara Baryte Vein 17 (Note: Water level in pit and poor overpass which is already failing)

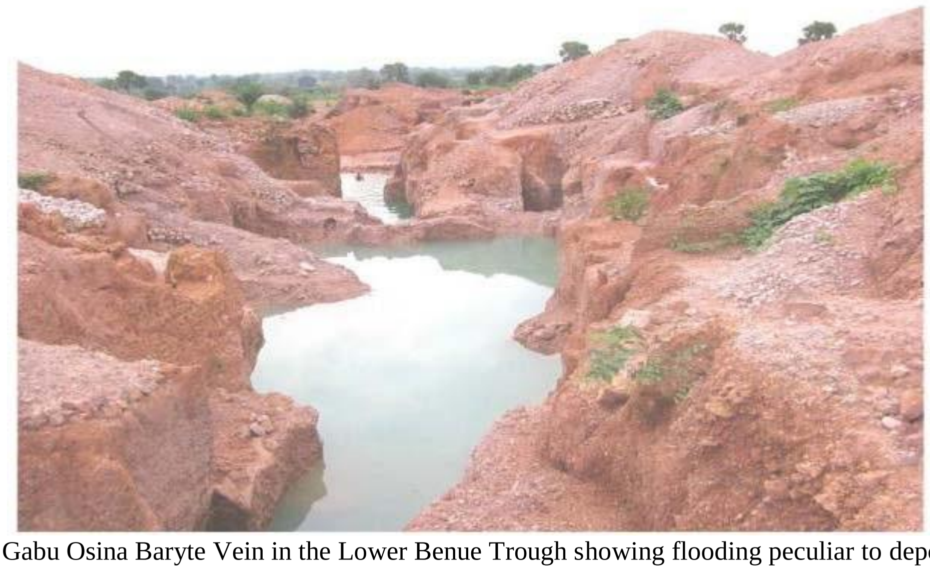

Fig 4. The Gabu Osina Baryte Vein in the Lower Benue Trough showing flooding peculiar to deposits across the trough (Oden, 2012)

4.2 Adudu-Abuni Zn-Pb Deposits

The Adudu-Abuni Zn-Pb deposits are epigenetic shale hosted mineralization within the Awe Formation. It is a relatively new mining district with mining only beginning within the past decade. They are located around the Adudu-Abuni area, Nassarawa State (8^{o} 13' 41'' N and 9^{o} 01' 00'' E) and covers an area of over $10km^{2}$ (Fig 5).

Fig 5. Geologic Map of the Adudu-Abuni Pb-Zn Deposit

Most of the mining here is semi-mechanized with a huge reliance on manual labour. To a certain extent better planned than the Azara mines, the Adudu-Abuni deposits also use a crude open strip method to mine the lead-zinc. Although some bench allowance is given for workers and some machinery to move in, it is so poorly designed that most of the benches fail due to improper support and overweight. Workers assisted by excavators and drilling equipment chip away and blast the compact shale to strip the lead-zinc. The tightly folded but fractured shales are water bearing with significant recharge coming from run-off water from higher ground into the mine pits.

Fig 6. Mine pit after about 2 hour of pumping (Approximate depth to pit base from present water surface is 3m)

Presently, water management techniques practiced by most miners in the Trough is crude and elementary at best with more effort being placed on dewatering than diversion. In-pit pumping is presently the most adopted dewatering technique used across the trough with pooled and descending water being pumped out by the simple use of a water pump and hoses. It has been observed that this method is widely adopted among small scale mines across Africa as it is viewed as the most obvious and cost effective method (Morton and van Merkerk, 1993). In-Pit pumping is potentially disadvantageous due to the amount of power & time needed to lift the water from the lowest point of the mine pit to the surface. Also water collated in mine pits can be contaminated on contact with the mined resource (eg. coal), thus potentially leading to high clean-up costs before the water can be disposed. The effect of unmanaged run-off waters on the stability of mine bench slopes and steps in mining excavations is well documented (Ene and Okogbu, 2013; Ngan et al, 1984) and this effects present a potential hazards to mines in the trough. These unmanaged run-offs are further increased by overflows from streams and rivers which criss cross the sedimentary rocks and bound the mines (See Fig 2 & 5)

V. Possible Solutions

Mine planning and design is done with a view as to how best to extract a particular ore resource, with cost and quantity extractable playing a major role on what mining method to be chosen for any particular ore resource. Presently, surface stripping and crude open strip methods are widely used in the Benue trough as preferred methods for mining. Generally speaking when considering diversion and dewatering plans for a mine the run-off, drainage systems and hydrogeological characteristics of the country rock such as static water level, transmissivity, storage co-efficient and nature of the aquifer are investigated. For the Benue trough most of the mineralizations are bedded type (coal) and epigenetic vein-type (base metals) hosted by fractured rocks (El-Nafaty, 2015; Offodile, 1980; Olade and Morton, 1985; Omada, 1985). This in itself makes most of the host rocks associated with mineralizations water bearingwith prevailing water table dynamics in the lithologic units also playing a role. Considering the hydrogeological characterictics and limited success achieved through the use of dewatering method, it is reasoned that a combination of diversion and dewatering techniques is the best resolve to tackling the hydrogeological challenges presently being experienced with mining in the Trough.

5.1 Diversion

Diversion techniques are employed to divert in-flows into the mine. This can be achieved by benching, channeling and grouting. Mine planning in the middle Benue is very poor with most mines having little or no bench allowance (as shown in Fig 7) which usually lead to damage from surface run-offs with failed materials slipping into mine pits. Therefore it is important that the mines are planned and designed optimally for dry working conditions as this ensures longevity of equity and better man hours per day. The use of well-planned benches with collation trenches will not only improve working conditions and slope stability but when applied with hydrological challenges in mind can serve as a tool for handling surface and formation waters.

Fig 7. Typical mine in the Benue Trough with poor benching (Note: Dark arrow showing failed overburden with the lighter arrow showing cuts made by surface run-offs which pour into the mine)

The use of well-copnstructed channels to handle run-off water would prove very effective, especially if the channels have proper width and spacing to prevent overflows which could seep back into the mine pits. Relatedly, the deflection of groundwater flowing into the mine especially through geological structures can be done by grouting. It is used to seal off groundwater pathways and reduce ground permeability. During underground mining, pressure build up from diverted groundwater which is a potential hazard to the mine can be addressed through grouting. Phalaborwa copper mine and Northam platinum mine of South Africa are examples of sites where ground water is diverted by grouting (Morton and van Merkerk, 2013)

5.2 Dewatering

Dewatering techniques are employed to reduce and/or control the volume of water in the mine. This can be achieved by constructing deep-relief boreholes in the mine neigbourhood. As a borehole is pumped a cone of depression develops in the water table and if pumping boreholes are place close together they can create a combined interference effect that can significantly lower groundwater and dewater significant areas. Its effectiveness as a dewatering method has been shown in a diamond mine in Botswana (Morton and van Merkerk, 1993). Construction costs for such relief wells may prove too much for small scale miners so it is suggested that a joint venture partnership with government could substantially reduce the cost as the boreholes can be used as a source of water for irrigation or urban water supply. A similar view was advanced by Offodile (2013) as one of the possible ways to handle inflows in the Onyema coal fields.

VI. Conclusions

Present techniques for handling groundwater inflow from run-offs and fractures are insufficient and its seemingly cost effectiveness is negated by losses associated with damages and hazards brought about by run-off and inflows. Therefore, there is a need for mine redesign. Most of the existing mines in the trough need to adopt best mine plan practices and develop inflow management facilities to address issues of run-off, management of high water tables in some areas associated with mineralizations and eliminate the man hour losses associated with in-pit water pumping. It is however recommended that several steps be taken together to significantly reduce the inflows and manage run-offs. They include:

a. Channeling of already existing water ways to reduce effect of run-offs.
b. Proper benching should be incorporated in mine designs with collation trenches holding run-offs that would have otherwise weakened and eroded the mine faces.
c. Grouting should be used to divert groundwater inflows into the mine pits, especially in underground mining.
d. Deep relief boreholes should be constructed and used in series to create interference effect which will lower the water table.

Finally, planning and designs for new mines should incorporate hydrological investigations in addition to other geological investigations, so that the best possible strategy for handling the already established hydrological problems with mineralizations in the Benue trough can be abated.

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