Importance of Applied Geology in Mining

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Abstract

Mining sector provides most of the raw materials used on a daily basis in infrastructure, food and energy production, electronics and agriculture. The sector continues to play a leading role in Facilitation of improvement to life for mankind across the globe. Mining activities of the sector Require knowledge and technical skills from geoscientific and engineering specialties to yield Optimal results. Applied geology as one of the geoscientific specialties contributes a fair share of the required knowledge and skills. It has continued, in the past decades, to play an important role in mining by focusing on the application of geological knowledge in harnessing of natural resources while simultaneously addressing issues that are related to mining activities and Environmental impact caused to the mining sector. The geological knowledge focuses on core areas of; volcanology, engineering geology, ore deposits, environmental geology, hydrogeology, mineral resources, energy resources, marine geology, soil mechanics, rock mechanics, applied geophysics, applied geochemistry, geo-hazards and allied mitigation measures. These core areas are of great significance as they need to be captured in the engineering design of mining and mineral processing systems before carrying out any mining operations. Indeed, these core areas provide vital information on the genesis of natural deposits, their geotechnical perspectives and methodologies on how to locate residence of the deposits.

It all begins with gathering the relevant geological information that is essential for surveying Geological environments in which natural resources occur. The natural resources that are surveyed include; petroleum, natural gas, coal, geothermal, ore deposits, gemstones, ground water and geological materials for construction needs. Vital geotechnical information is learned from surveys that are usually in the areas of remote sensing, geological, geophysical and geochemical mineral explorations, and/or drilling. The information learned also provides useful leads to environmental issues that need to be mitigated. Furthermore, provision of impact assessment and audit report for mining engineering projects is mandatory for approval and implementation of such projects that are of national concern. Learning applied geology is also vital for understanding dynamics of natural hazards, particularly on earthquake and landslide related events since relevant geotechnical parameters learned can be factored in engineering designs. The parameters are also of benefit to construction needs for projects that are related to mining engineering. Furthermore, understanding past geological processes, including geohazards, climatic and hydrogeological processes enhances capabilities of designing 90% of remedies for environmental problems that occur in mining and construction industries. Applied geology provides appropriate technologies for making relevant objective decisions that are practical. The decisions made can then be reviewed and evaluated as projects progress thereby enhancing optimal economic performance. Thus, applied geology will develop a firm foundation for understanding fundamental concepts and solving pertinent problems that are related to mining engineering for self-reliance and to the satisfaction of stakeholders in the mining, geological and infrastructural industries. This paper aims at evaluating the importance of applied geology in mining activities because success of future mineral exploration and mining investments will highly depend on the input realized from its core areas if applied appropriately while protecting the environment forthwith.

Keywords: Applied geology, mining engineering, natural resources, mineral exploration, mineral extraction, geohazard, environment impact and mitigation

1.0 Introduction: Applied geology is one of the specialties in geosciences. It has continued, in the past decades, to play a noble role in mining by focusing on the application of geological knowledge in harnessing of natural resources while simultaneously addressing issues that are related environmental protection. Application of geological concepts and skills are required in design of mining systems both for surface and underground mining activities. An applied geologist is well acquainted with the necessary concepts, from understanding of mineralization processes to exploration methods and techniques that are applied and related environmental aspects including geological challenges that can be encountered in different geological mining environments.

There are mineral deposits that occur in unique geological environments. Such mineral deposits include gold which occurs in slightly metamorphosed Archean Rock formations, diamond in ultrabasic intrusives, evaporites in saline water bodies, gemstones in orogenic belts etc. Archean rocks, in which gold occurs as a mono-mineralic crystalline substance, were subjected to orogenic processes that were related to plate techtonics. Similarly, diamond is a constituent of elemental carbon which occurs as a native element similar to gold. It is also prevalent in unique geological environment. The mineral occurs in ultrabasic intrusives, particularly kimberlitic lamproite pipes at great depths of high rock pressure. Studies have revealed that single crystalline diamonds were formed in a free fluid environment by growth mechanisms of layer by layer, (Bulanova, 1995). Other types of minerals that are not monomineralic include evaporites, gemstones etc. Evaporites refer to naturally occurring chemical compounds that develop in supersaturated water bodies. Typical evaporites that are widely used in chemical industry, construction activities and agricultural farming practices include; Trona ($Na_2CO_3.NaHCO_3.2H_2O$) from which soda ash is derived, gypsum ($CaSO_4.2H_2O$) that retards setting time in Portland cement (a widely used construction material), Rock salt ($NaCl$) that is also referred to as common salt etc. Mining and processing of these compounds is accomplished in a shorter duration and at a cheaper cost compared to ore deposits. Gemstones, unlike evaporates are prevalent in pegmatitic bodies, mainly in orogenic belts, having been evolved from hydrothermal processes. The pegmatites can contain gem minerals like corundum, tourmaline, garnet, beryl, fluorite, apatite, topaz etc. They may also be enriched with rare elements such as uranium, tungsten, and tantalum etc.

Mineral mining requires that a mineral deposit be quantified and valued so as to determine viability of a proposed mining venture. The information is required by the mining engineer for planning and mine design purposes. Field occurrence of the deposit provides necessary information in terms of rock types, nature of the mineralization, geotechnical features as well as hydrogeological conditions of the proposed site. An applied geologist has to undertake these investigations which include interpretation of geological maps of the area to capture drawing of geological cross sections and determination of deformational structures. Usually, Mineral exploration can be carried out on large scale by using remote sensing and geospatial information system followed by field visits to confirm the actual geological status and to undertake field sampling for detailed laboratory analysis and even recommend drilling. In addition, geophysical and geochemical methods can be employed. Geophysical investigations can be conducted on the surface of the earth to determine various features of rock strata which include discontinuities and intrusive structures such as ore bearing rock bodies etc. The investigations carried out depend on variation of physical parameters like rock density, velocity, conductivity, resistivity, magnetic and electromagnetic as well as radioactive elements if present in rock mass dealt with. Geophysical methods involve measuring signals from a natural or an induced phenomena of physical properties for sub surface formations with the aim of determining localities that have different magnitudes of those properties (anomalies). The main geophysical methods which can be used to locate the potential zones of ore bodies for further investigation particularly drilling are Electrical, Seismic, Gravity, and Magnetic methods. Geochemical prospecting for minerals also involved delineating anomalies. In this case, geochemical anomalies refer to any high or low chemical element variation that is not explained by a natural geochemical variation. Anomalies may be formed either at depth by igneous and metamorphic processes or at the earth's surface by agents of weathering, erosion, and surficial transportation as sedimentary processes.

Mining activities are expected to be undertaken while addressing the safety of workers in compliance with occupational health and safety act. For instance, when using heavy excavation plant on a site of weak deposits particularly weathered sedimentary deposits a mining engineer has to consider ability of the deposits to support the heavy earth moving machines, thereby avoiding possible failure of the floor of the mine. Furthermore, slopes for subsurface mines requires to be engineered of which benched geometry is the most common practice for minimizing impact caused by rock fall. Geotechnical information for mine formations is provided by an applied geologist to be captured in the engineered design for the slopes. Other than rock fall, other challenges associated with mining include excessive seepage of ground water into both surface and underground mines, high temperatures, inflammable gasses and poisonous gasses.

Rock blasting has continued to be an excavation method for hard rocks for several decades. It results into weakening and fragmentation of rock mass for a purpose. In mining activities, the blasting design has to capture rock characteristics amongst other constraints. After excavation has been performed, support of the exposed rock mass may be required, particularly for underground works. The support system to be adopted requires to be engineered so as to guarantee safety and durability of the structure to be installed. Indeed, the design to be done has to utilize geological knowledge of which an applied geologist has to provide

2.0 Unique natural resources

There are mineral deposits that occur in unique geological environments. If a mining engineer were to prospect for such mineral then the engineer has to have relevant knowledge for such environments, of which the applied geologist is already acquainted with. Mineral deposits that occur in unique host rocks include gold in slightly metamorphosed Archaen formations or hydrothermal bodies of similar age, diamond in ultrabasic intrusives, evaporites in saline water bodies, gemstones in orogenic belts etc. Furthermore, Hydrocarbon fluids are not minerals but energy resources. These fluids, represented by petroleum and natural gas, are normally prospected in stratigraphical traps and when encountered are pumped out from their hideouts after rock drilling has been perfected.

(a) Archean orogenic Gold deposits

Gold is a mono-mineralic crystalline substance which is normally prospected in rocks that are unique in both character and age. The rocks can be named based on age alone or type of rock itself. However, the most widely accepted term is Archean orogenic gold deposits. The Archean orogenic gold deposits are found in specific rock types in which the gold formed in zones of high strain caused by orogenic processes that were related to plate tectonics in the Archaean times, particularly, at convergent plate boundaries. The increased pressure and temperature forced fluids from the mantle up into the crust along major structural features and rock boundaries. Typical goldbeating rocks and rock sample as shown in figure 1.

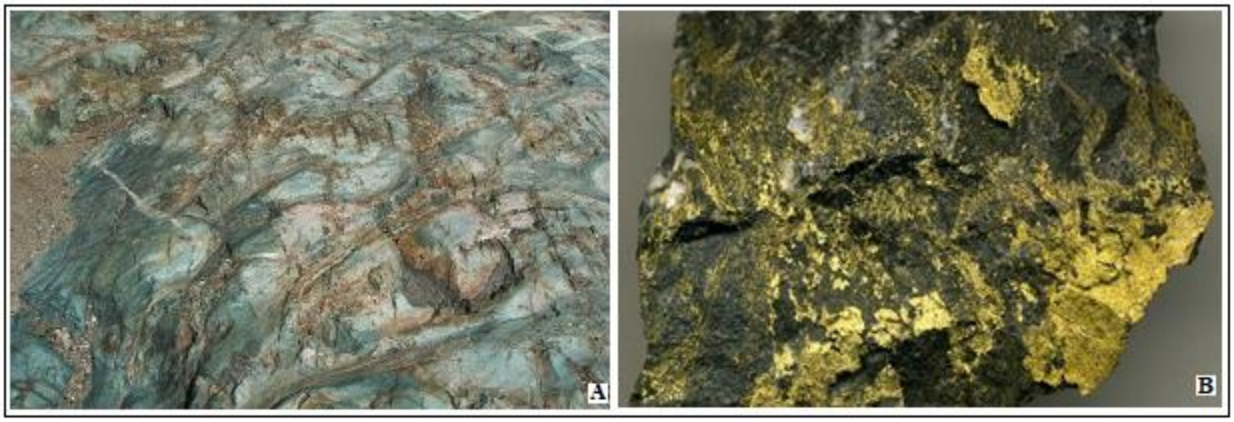

Fig.1: Pillowed basaltic gold bearing exposure of green schist facies (A) and Spectacular gold ore sample from the Red Lake greenstone belt, Ontario, Canada (B)

Archaean Greenstone Belts are most widespread and are basically metamorphosed volcanic belts. The belts have been interpreted as having been formed at ancient oceanic spreading centers and island arc terranes. They primarily consist of volcanic rocks, dominated by basalt, with minor sedimentary rocks inter-layered between the volcanic formations. The Greenstones, apart from containing basalts, also contain several types of metamorphic rocks particularly; greenschist, whiteschist and blueschist. The rocks earn the term ‘Greenstone’ due to the crystallization of green coloured minerals i.e. chlorite, serpentine, epidote, and platy minerals such as muscovite. The Greenstones are prevalent in the Slave craton, northern Canada, Pilbara craton and Yilgarn Craton, Western Australia, Gawler Craton in South Australia, and in the Wyoming Craton in the US. Similar gold bearing cratons are found in South Africa i.e. Kaapvaal craton and Eastern Africa as well as in the cratonic core of Madagascar and West Africa. Cratonic land masses also occur in Brazil, northern Scandinavia and the Kola Peninsula of Baltic Shield. The distribution of greenstone crustal rocks in Northern Tanzania and western Kenya is as shown in figure 2.

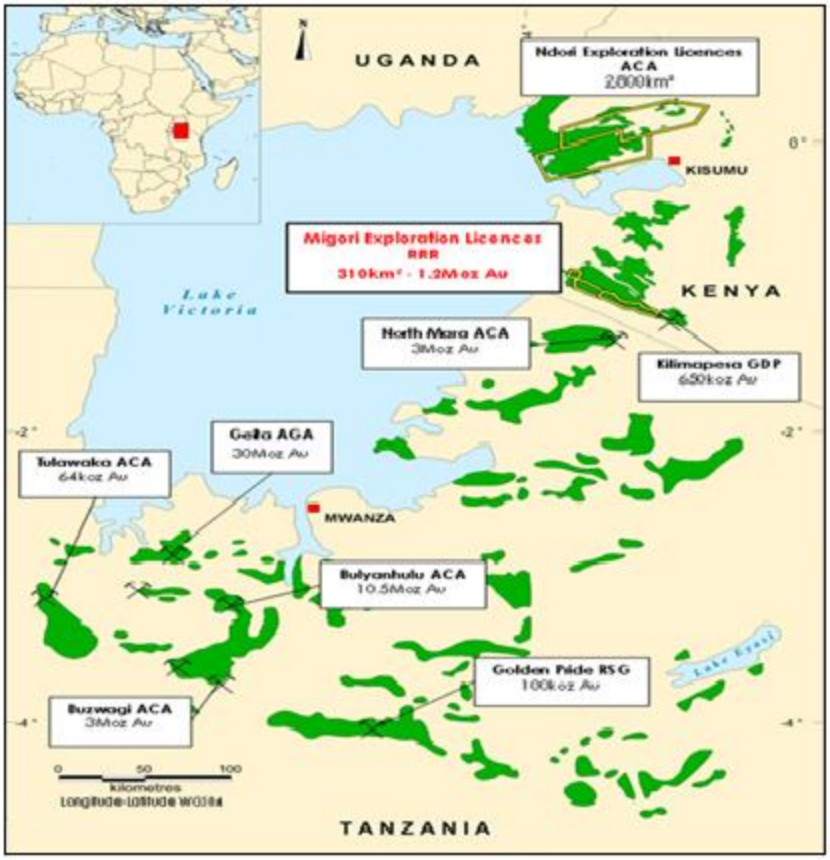

Fig. 2: Distribution of Greenstone Granite Rocks in Tanzania and Kenya

In Africa, Witwatersrand gold system, an Archean greenstone belts, continues to be one of the richest source of the invaluable natural resource while most of the gold deposits in Canada's Superior Province are hosted in Abitibi Greenstone Belt, particularly from Timmins area (Wyman, 2003). Similarly, most of the gold mined from Australia's Yilgarn Craton comes from the Kalgoorlie camp which accounts for more than half of the mined gold (Philips et al., 1996). Interestingly, although these gold bearing cratons are far apart, they have similar geology and mineralization styles. This scenario suggests that the processes leading to the formation of their ore systems must have been similar starting from the ground preparation to the mineralization process. For instance, in the Tanzania Craton the giant Bulyanhulu lode gold deposit is also similar to the giant deposits found in the Timmins and Kalgoorlie areas, of Canada and Australia respectively. The similarity is in terms of mineralization style, mafic host rocks, ages, deformation styles and the short pre-mineralization crustal history according to Bateman and Bierlein (2007).

In Kenya, Migori Greenstone belt (MGB) forms part of the Nyanzian supergroup that is a northern extension of the gold-enriched Archaean Tanzanian craton. The belt hosts world class producing gold mines i.e. North Mara and Geita mines etc. The Tanzanian craton is of a similar age to other significant orogenic gold belts such as the Yilgarn in Australia and the Lake Superior province in Canada. The mineralization and stratigraphy of the MGB is similar to that of the Lake Victoria Greenstone belts in Tanzania and other Archaean greenstone deposits such as Red Lake in Canada Gold enrichment within the MGB is predominantly found in and around shear zones associated with quartz-carbonate veining and significant alteration, as well as banded iron formations (BIFs) and poly-metallic Volcanogenic Massive Sulphides (VMS). The dominant lithologies are felsic and mafic intrusive, BIFs and metasediments of the Nyanzian system. They are overlain by younger Kavirondian volcaniclastic sediments and intruded by younger granitic intrusions.

The Migori Gold covers an area approximately 310km² of prospective greenstone geology, extending for 63km along the strike. The belt has a rich history of colonial and artisanal mining, with Goldplat Kilimapesa as a licensed active gold mining operator.

(b) Diamond

(i) Evolution of diamond: Diamond is a constituent of elemental carbon which occurs as a native element similar to gold. It is prevalent in ultrabasic intrusives such as kimberlites lamproite pipes at great depths of high rock pressure. Studies have revealed that single crystalline diamonds were formed in a free fluid environment by growth mechanisms of layer by layer, (Bulanova, 1995) . the fluids crystallized within the mantle from a slightly supersaturated solution of carbon in a sulphide-silicate melt. Most diamonds nucleated heterogeneously to form diamond monocrystals as both eclogitic and peridotitic parageneses evolved during early igneous events within the upper mantle in “diamond stability zone”. The zone was located where temperatures and pressures were favourable i.e. temperature of over 1,000 degrees Celsius and pressure of about 20Kbars at depth of about 150 kilometers below the Earth’s crust. Studies involving photoluminescence and infrared light absorption of diamonds from mantle xenoliths were carried out in Yakutian kimberlite province by Spetsius (1995). The studies aimed at identification of specific characteristics and distinctions between, the diamonds of the peridotitic and eclogitic parageneses. It was confirmed that most if not all diamonds in kimberlites were derived from mantle peridotite and eclogite. Apart from the Earth’s mantle, there are a couple of other obscure places that provided suitable condition for diamond crystallization. For instance, rsearchers at NASA found extremely small pieces of diamonds in extraterrestrial bodies. The diamonds in such bodies were considered to have been formed either in outer space or in the mantle of other planets. Some diamonds have also been encountered in subduction zones, where two different tectonic plates come together. This process can occur at slightly lower temperatures and shallower depths than those for those diamonds that develop in the "diamond stability zones.". a possible model for such formation is as shown in figure 3.

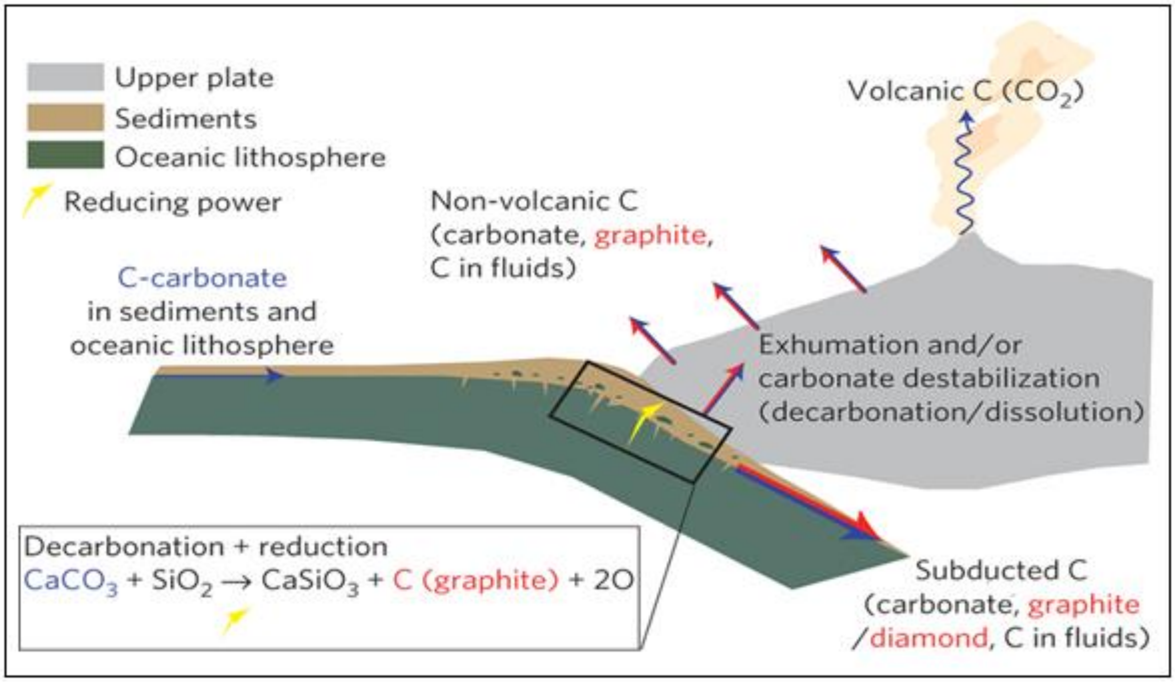

Fig.3: Model for graphite and diamond generation from carbonaceous sediments in a subduction zone

(ii) Hardness: Diamond is the hardest known natural material. The hardness is very significant in rock dressing and excavation works particularly when selecting excavation tools or excavation plant to be used. Two scales of hardness were developed i.e. Vickers scale and the Mohs scale.

The Mohs scale of mineral hardness is a qualitative ordinal scale characterizing scratch resistance of various minerals through the ability of hardest mineral being able to scratch a mineral of which crystal structure is weaker. The mineral samples that were selected are all different. Diamonds are at the top of the scale. The hardness of a material is measured against the scale by finding the hardest material that the given material of known hardness can scratch, or the softest material that can be scratch the given harder mineral. For example, if some material is scratched by apatite but not by fluorite, its hardness on the Mohs scale would fall between 4 and 5. "Scratching" a material for the purposes of the Mohs scale means creating non-elastic dislocations visible to the naked eye. The Mohs scale is a purely an ordinal scale. For example, corundum (9) is twice as hard as topaz (8), but diamond (10) is four times as hard as corundum. The table below shows the comparison with the absolute hardness measured by a sclerometer, while considering other material and mineral types as well.

Table 1: Typical mineral and material for Mohs Scale of hardness

Grade	Standard mineral	Chemical composition	Alternative mineral/Material
1	Talc	$Mg_3Si_4O_{10}(OH)_2$	Asbestos (Tremolite, Anthophyllite, Actinolite)
2	Gypsum	$CaSO_4{\cdot}2H_2O$	Coal, Evaporites
3	Calcite	$CaCO_3$	Mica, Copper, Arsenic
4	Fluorite	CaF_2	Iron, Nickel
5	Apatite	$Ca_5(PO_4)_3(OH^-,Cl^-,F^-)$	Zirconium, Palladium
6	Orthoclase	$KAlSi_3O_8$	Feldspars, Amphiboles, Pyroxens, Oxides,Steel
7	Quartz	SiO_2	Olivines Osmium, Vanadium
8	Topaz	$Al_2SiO_4(OH^-,F^-)_2$	Cubic Zirconia
9	Corundum	Al_2O_3	Tungsten Carbide
10	Diamond	C	Carbonado

Table 1 shows that it is not the type or number of elements that constitute a material which contributes to resistance to scratching, hence cutting. The resistance rests on bonding of the constituent elements for the mineral at hand. Indeed, diamond consists of one element only i.e. carbon but its strong bonding, having evolved under high pressure and temperature condition makes the diamond strongest possible material. The scale can aid in selection of cutting tools by a mining or construction engineer. For instance, cutting blades or drilling bits meant to excavate or dimension rock material rich in feldspars and quartz require consideration of tungsten or carbide material but not one that constitutes of steel material. Sand paper material used for smoothening timber uses hard crystal for the smothering as a polishing measure. The mineral crystals used are often garnets or corundum as exemplified in figure 4.

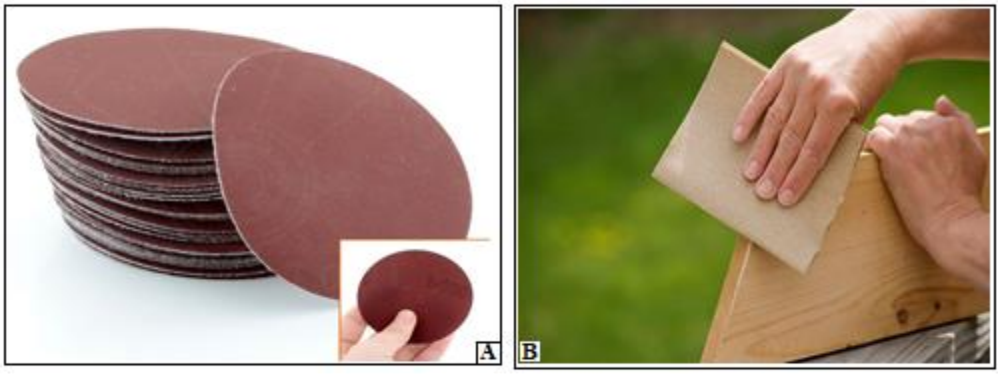

Fig.4: Typical sandpaper pieces (A) and sand paper material in use (B)

Rock panels for gladding are often produced by using cutting saws that have diamond crystals of industrial grade fitted on the saws. Likewise, drilling bits and tunneling excavation equipment have diamond crystals fitted in the system to scratch minerals that constitute the rocks to be cut. Typical drilling bits for such purpose are as shown in figure 5.

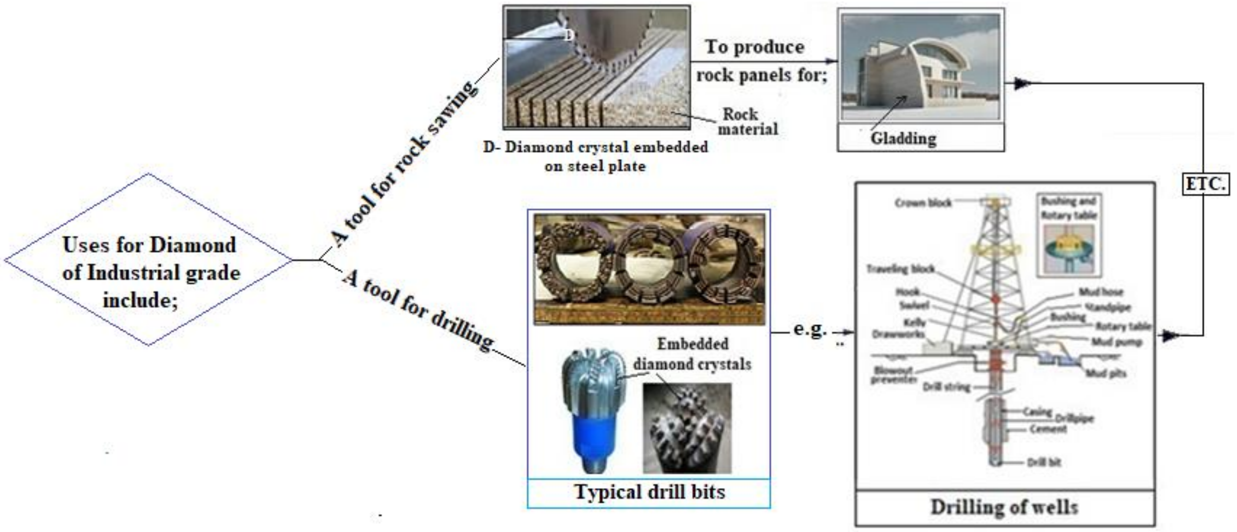

Fig. 5: Typical uses for diamond of industrial grade

(c) Evaporites

Evaporites refer to naturally occurring chemical compounds that develop in supersaturated water bodies. Mining and processing of these compounds is fairly different compared to ore mineral deposits. Processing of these compounds is accomplished in a shorter duration and at a cheaper cost. Typical evaporites that are widely used in chemical industry, construction activities and agricultural farming practices include; Trona ($Na_2CO_3.NaHCO_3.2H_2O$) from which soda ash is derived, gypsum ($CaSO_4.2H_2O$) that retards setting time in Portland cement (a widely used construction material), Rock salt ($NaCl$) that is also referred to as common salt etc. Evaporites continue to develop from geologic past to presently. For instance, figure 6 shows trona accumulation of lake Magadi Kenya and halite accumulation on shores of Dead sea being world's largest accumulation of the salt in present times. Whereas halite is a suitable material for food seasoning, the same natural crystalline material has a construction application. The halite effectively dissolves snow and ice cover on existing road surfaces during seasons of extreme decrease in temperatures. Thus, the halite has a vital industrial application in regions that experience destructive snowing and ice cover accumulations.

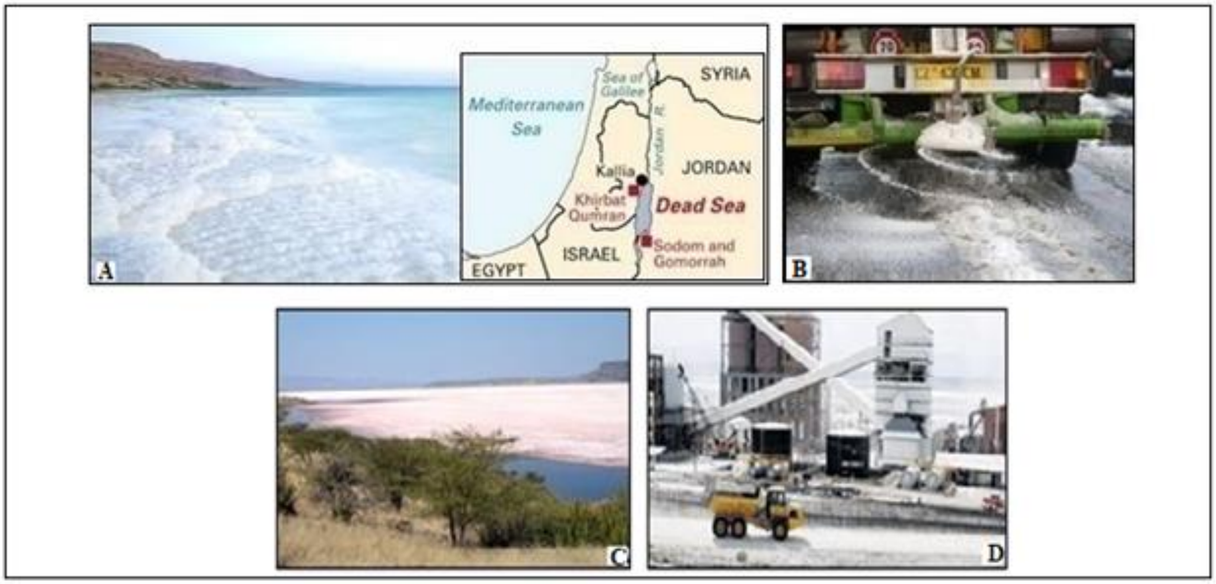

Fig. 6: Natural formation of Halite(A), Truck spreading halite on snow covered pavement(B), Trona cover (C) and Soda ash processing plant at lake Magadi Kenya(D)

Evaporites that accumulated in the geologic past are now bedded sedimentary rocks. A typical deposit is for trona formation in Green river deposit which is located in Wyoming Utah in USA(fig.7). Indeed, Wyoming mine is currently the largest producer of trona, the raw material for soda ash. With the largest reserves of naturally-occurring trona on earth, the Green River area of Sweetwater County, Wyoming is indisputably the "trona capital of the world". The Green River Basin is currently estimated to contain 134 billion tons of mineable trona. The trona extends over a 2590 km^2 area, ranging in depth from 244 to 670 m below the surface. The largest concentration of white pristine gypsum sand in the world is located at the northern end of the Chihuahuan Desert of Southern New Mexico. It constitutes a basinal structure which was formed by the collapse of a dome made up of the gypsum sand about ten million years ago.

Fig. 7: Typical bedded evaporites; Trona mining, Wyoming Utah,USA (A) and Bedded gypsum in unspecified locality(B)

(d) Gemstones

(i) Pegmatites and mineralogy: Pegmatite is a textural term that refers to a very crystalline, intrusive igneous rock of hydrothermal nature that is composed of interlocking crystals larger than 2.5 cm in grain size. The pegmatites are known to have the greatest range of grain sizes compared to other rock bodies of any rock types and range from sub-millimeter to tens of meters. They are renowned for their spectacular development of giant crystals. Almost all of the world's largest crystals that are well developed (euhedral) to partly developed (subhedral) come from pegmatites. These rock bodies are known to be the source of the world's finest gemstones. The minerals present are a source of more than 70% colored gemstones. Although pegmatites contain important rare earth elements, they are mined mainly for gemstones instead of ore minerals that they contain. Pegmatites have a composition that is quite similar to that of other intrusive igneous rocks and are normally distinguished by using a modifier, e.g., granitic pegmatite or gabbroic pegmatite. However, pegmatites occur most commonly in granitic composition, when traversing granitic bodies. The term applied alone, usually refers to a medium to coarse grained hydrothermal body of granitic composition enriched with other elements. A simple granite pegmatite may contain only quartz, feldspar, and mica. While More complex pegmatites are often zoned and can contain gem minerals like tourmaline, garnet, beryl, fluorite, lepidolite, spodumene, apatite, topaz etc. Pegmatites may also be enriched with rare elements such as uranium, tungsten, and tantalum etc.

(ii) Geo-environment for Pegmatites: Pegmatites are widely distributed in metamorphic orogenic belts, the Mozambique belt being a typical example. The belt. About 1200 to 400MA in age, traverses Kenya from Mozambique through Eastern Africa towards Ethiopia and Sudan up to Sinai in Egypt. The belt is well represented by Turoka Grop in Taita-Taveta County, Ukamba Group in Machakos and Kitui, Turbo Group in Turbo area as it extends into Kitale to west Pokot towards north of the country. The youngest metamorphics for this belt is represented by Ablun series in Embu area including other low grade meta-sediments of Moyale Area. Orogenic eposodes that evolved rocks of the belt involved folding, faulting and granitization to produce rocks of different grades and metamorphic facies. Rocks of highest grade occur in Taita-Taveta county. The county is blessed with a wealth of gemstones in the orogenic belt. The gemstones have continued to be mined by artisanal small scale miners for decades. They occur in many different and varied geological settings, and each deposit usually has its own characteristics (Simonet et al, 2000). Typical gem varieties in Taita-Taveta county, that are significant include; Corundum (red coloured variety- commercial name ruby), Blue coloured corundum known as sapphire, tourmaline (a beryl mineral variety) and iolite as well as rhodolite. These gems developed as a result of metasomatic phenomena involving felsic rocks, fluids of metamorphic origin, and ultramafic rocks (Rop and Namwiba, 2018; Pohl and Horkel,1980; Key and Ochieng, 1991). Tsavorite and tanzanite deposits are also locally available. They are usually hosted in Graphite-rich gneisses (Pohl and Niedermayr, 1979; Key and Hill, 1991, etc.). A typical green variety of garnet being Grossularite (commercially known as Thavorite) prevalent in Taita-Taveta county is as shown in figure 7.

Fig.7: Thavorite when raw (A) and when faceted (B) (Rop, 2014)

Some gemstones such as aquamarine, amazonite or topaz occur in medium-size pegmatite bodies (Keller, 1992). According to Simonet (2000b) minerals such as spinel, ruby, and tourmaline, are associated with meta-limestones, either as rock forming minerals or as the product of metasomatic reactions between fluids and the meta-lime-stones. Typical mining activity for gemstones in the Taita-Taveta county is as shown in figure 8.

Fig.8: Kasigau mine in Taita-Taveta County (A), Marble hosting Sapphire (B) and Ruby(C)

3.0 Exploration

Mineral mining requires that the mineral be quantified and valued so as to determine viability of a mining venture. The information is required by the mining engineer for planning and mine design purposes. Field occurrence of the deposit provides necessary information in terms of rock types, nature of the mineralization, geotechnical features as well as hydrogeological conditions of the proposed site. Mineral exploration can be carried out on large scale by using remote sensing and geospatial information system followed by field visits to confirm the actual geological status and to undertake field sampling for detailed laboratory analysis and even recommend drilling.

(a) Geological information

An applied geologist has to undertake these investigations which include interpretation of geological maps of the area to capture drawing of geological cross sections and determination of deformational structures. Geological cross sections for faulted areas are very vital since they reveal clearly the effect caused to the affected strata. For instance, a reverse fault results in repetition of faulted beds unlike a normal fault which results into lateral separation. Reverse faults are prevalent in coal bearing beds. If a shaft were to be sunk at the ground surface between locality W and H i.e. between lateral separation caused by a normal fault (Heave) then, the shaft would completely miss a targeted mineralized host rock such as for the case illustrated in figure 9. Such information should not be missed by a mining engineer.

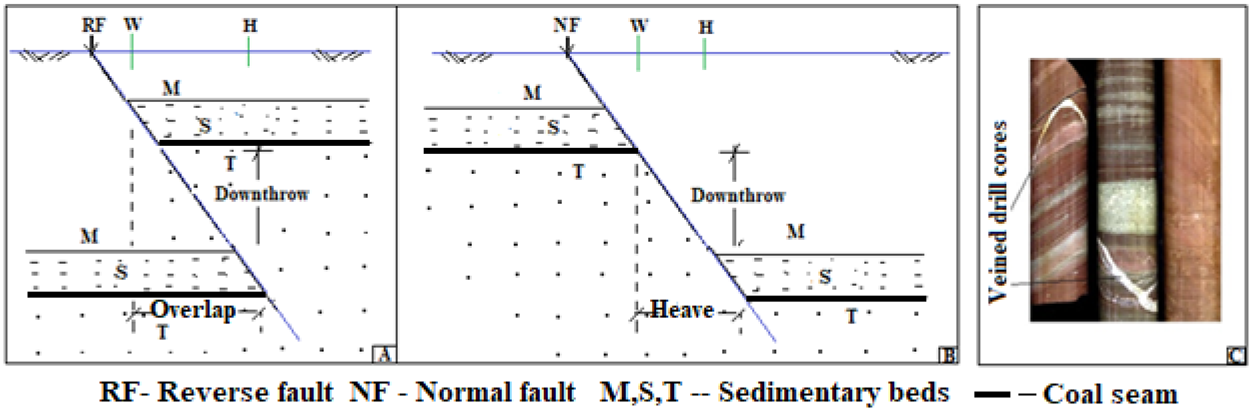

Fig.9: Geometric distinction between Normal fault (A) and Reverse fault (B) and typical drill core samples(C)

Rotary drilling with core recovery, recommended after preliminary investigations, is undertaken to intercept anticipated deposits. The drilling done does reveal more information particularly, microstructures, position of water table, presence of tectonic joints and even faults if present in the area mapped but are concealed. Normally, core logging is performed and provides best fresh rock samples from underneath for laboratory investigations. Such typical core samples that can be realized are as shown in part ‘C’ of figure 9.

(b) Geophysical Survey

Geophysical investigations can be conducted on the surface of the earth to determine various features of rock strata which include discontinuities and intrusive structures such as ore bearing rock bodies etc. The investigations carried out depend on variation of physical parameters like rock density, velocity, conductivity, resistivity, magnetic and electromagnetic as well as radioactive elements if present in rock mass dealt with. Geophysical methods involve measuring signals from a natural or an induced phenomena of physical properties for sub surface formations with the aim of determining localities that have different magnitudes of those properties (anomalies). The main geophysical methods which can be used to locate the potential zones of ore bodies for further investigation particularly drilling are Electrical, Seismic, Gravity, and Magnetic methods. For instance, Geoelectrical prospecting for a copper-sulfide mineralization was conducted in Camaquã sedimentary basin, Southern Brazil in 2016 (Ariena et al,2016). A summary of the geology for the surveyed area is as shown in figure 10.

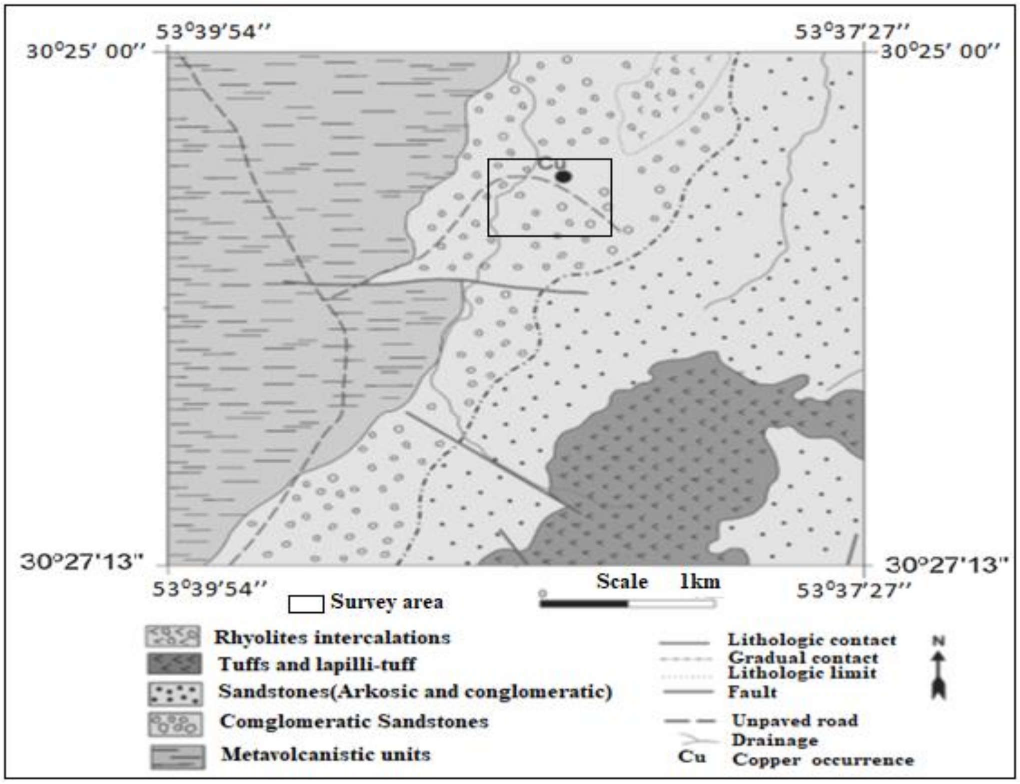

Fig.10: Lithology for the surveyed area

The copper mineralization is hosted in a metamorphosed, silicified and fractured sandstone with abundant presence of malachite and azurite in the fractured planes of the rock. The DC resistivity method was employed by electrical resistivity tomography technique (ERT) in Wenner-Schlumberger array. The Wenner-Schlumberger array is a hybrid arrangement that combines the Wenner and Schlumberger arrangements. The arrangement consisted of a set of electrodes with the same constant spacing of 10m and 520 m long (Milson & Erikssen, 2011). The 10m spacing between non-polarizable porous-pot electrodes allowed percolation of $CuSO_4$ supersaturated solution in the ground. The configuration aimed at reducing the contact resistance and nullification of parasitic currents generated by the use of metallic electrodes. The lines were arranged in a regular grid, according to the structural criteria established in previous works which considered crossing of major regional structures (Silva, 2010). In this way, lines 1, 2 and 3 were distributed in the direction N125 and lines 4, 5 and 6 were arranged in the direction N215, all

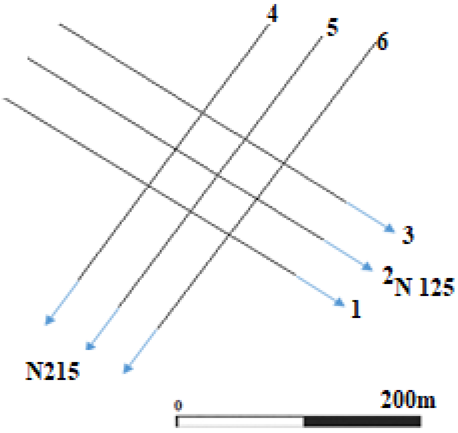

Fig.11: Survey profiles

spaced 40 m from each other as illustrated in figure 9. Topographical data was acquired using a Differential Global Positioning System (DGPS) and a vibrant Trimble software.

Resistivity results obtained for 2D sections were obtained in terms of distance *versus* depth, with a logarithmic color scale. The values ranged between 6 Ω.m and 590 Ω.m. In general, the sections exhibited a predominance of high values at shallow depths and intermediate portions as well as low values at higher depths. A graphical plot for profile 5 is as shown in figure 12.

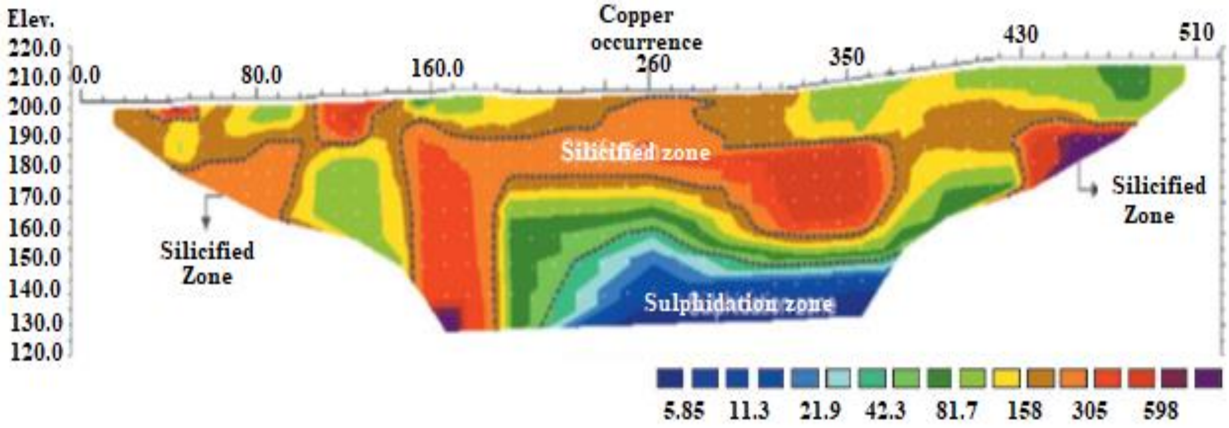

Fig.12: Variation of resistivity with depth

The top resistive zone i.e. area above the sulfide zone represented intense silicified rock outcrop, cut by subvertical veins of copper carbonate. The area with low resistivity values on the other hand indicated an occurrence of highly conductive materials. Normally, electronic conduction in metallic minerals, due to free movement of electrons, reduces the resistivity of metal-bearing rocks, particularly at high ore concentrations. This feature confirmed the existence of a zone enriched in metal ore minerals, probably represented by copper sulfide minerals, as such as chalcopyrite, calcosite and bornite that were then confirmed from geochemical analysis. Accordingly, the conductive area located at 60 m depth represented a possible area of sulphide ore body that was elongated and oriented in the NW-SE direction, surrounded by the silicification zones. Ultimately, it was concluded based on the results obtained from the resistivity method, combined with geological data and field recognition that the surveyed are was characterize by mineralization of copper carbonates (malachite and azurite), which occur in form of silicified and impregnations in fractured metarenite deposits. The mineralized area was concluded as being a promising target for direct prospecting campaigns through drilling surveys.

(c) Geochemical Survey

(i) General: Geochemical prospecting for minerals involves a systematic process of investigating chemical properties of naturally occurring materials by analyzing concentration for elements of interest in those materials. Normally, investigations are carried out so as to identify locations of geochemical anomalies i.e. any high or low element variation that is not explained by a natural geochemical variation. Anomalies may be formed either at depth by igneous and metamorphic processes or at the earth's surface by agents of weathering, erosion, and surficial transportation as sedimentary processes. Geochemical anomalies are referred to as either primary when deep seated or secondary when occurring at shallow depth. A typical geochemical survey was carried out on gold mineralization in Ilesha northwest of Nigeria by Elueze and Olade (1985). The area has a humid tropical climate with an annual rainfall of 1500 mm. Although the area lies in a zone tropical rain forest, the vegetation now consists of secondary growth on account of intensive cultivation and deforestation. Chemical weathering is generally intense, penetrating to depths in excess of 20 m, particularly in areas that are underlain by greenstone rocks.

The geochemical survey was initiated by the Nigerian Mining Corporation through strem sediment sampling followed by geochemical analysis. The stream sediment survey was undertaken in the Ilesha district so as to delineate areas that were potential for gold mineralization in correlation with distribution of selected path finders.

(ii) Topography and geology of the Area of study: Ilesha area consists of an undulating topography with an average elevation of 400 m above sea level and an inselberg landscape to the southwest of the area. The area is drained by a few main streams and numerous tributaries. Upper parts of the drainage system are covered by alluvial sediments that are dominated by sandy silt. However, downstream parts of the area often comprise of clays which are rich in organic matter.
The area of interest was geological map of Ilesha district which showed that the area was consisting mainly of mafic rocks that were known to be associated with gold mineralization. Indeed, the dominant rocks for the area were are metamorphosed mafic volcanics and volcaniclastics which included amphibolites, ta1c-tremolite schists, chlorite and mica schists. A summarized geology for the area is as shown in figure 13.

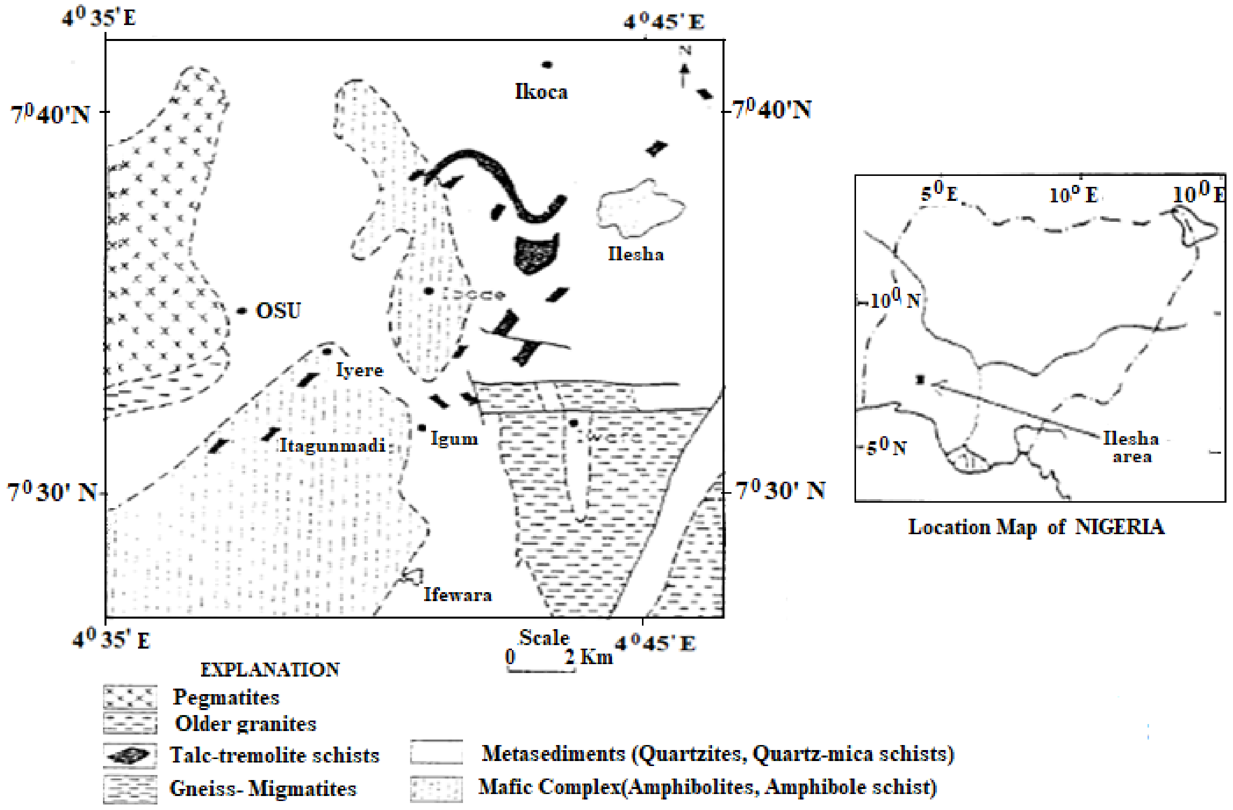

Fig.13: Study Area-Ilesha, Nigeria

(iii) Sampling and analysis: More than 300 stream-sediment samples were collected from carefully selected sites which represents a sample density of about one sample per km^2. A strong acid digester is most suitable for all round multi-element detection where the target and pathfinder elements are both weakly and strongly bound in ferruginous and weathered lithic components. Aqua regia, a mixture of concentrated nitric and hydrochloric acids, being one part of nitric acid to three parts of hydrochloric acid by volume, was used as a digester. It was able to dissolve elemental gold, as well as breakdown iron and manganese oxides/oxyhydroxides, carbonates, sulphates, sulphides and many clays. Usually the agua regia not release elements or minerals included within quartz (including silcrete) or other insoluble silicates nor dissolve resistive minerals such as chromite, rutile, cassiterite, ilmenite, zircon. The digested samples were then analyzed using atomic absorption spectrophotometry to determine concentrations for various elements including Arsenic, Nickel, Gold etc. Statistical treatment of the analytical data obtained involved construction of frequency distribution and probability plots. The statistical results obtained assisted in determining threshold for the anomalous values. Similarly, maps to facilitate assessment of the geochemical patterns were also prepared (Fig. 14 and 15).

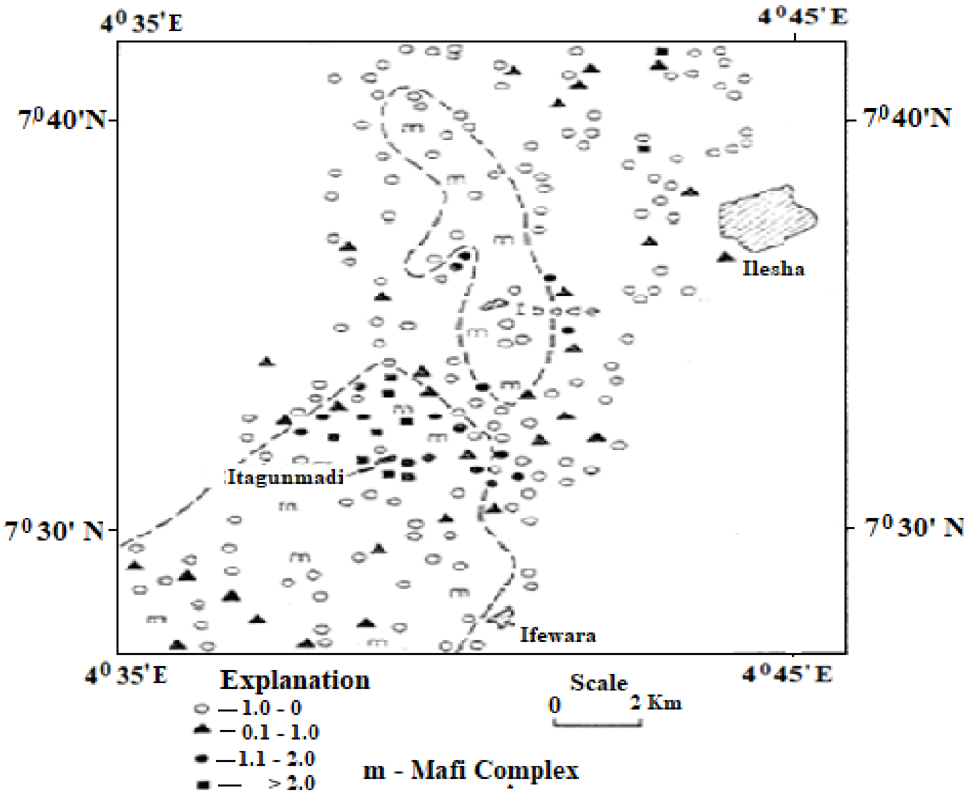

Fig.14: Distribution of As in stream-sediments in the Ilesha area (after Elueze and Olade, 1985)

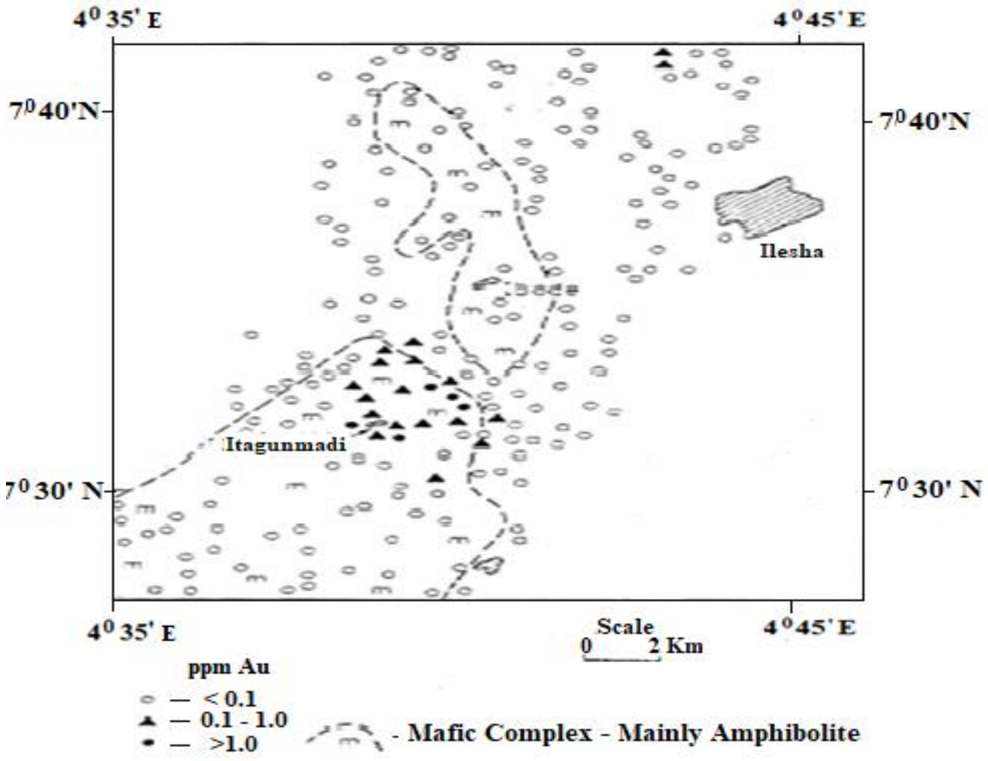

Fig.15: Distribution of Au in stream-sediments in the Ilesha area (after Elueze and Olade, 1985)

(iv) Results and Conclusion

- Arsenic values were found to range from less than 10 to 97 ppm, those in excess of the regional threshold of 21 ppm being confined to the area around Itagunmodi and also in an area 3 km north of Iyere (Fig.14). In these areas, the occurrence of sulphide-bearing auriferous quartz stringers and disseminations in amphibolite had already been reported.
- Enhanced arsenic values that were obtained was related the formation of sulphide-bearing auriferous quartz stringers in the area of study, particularly arsenopyrite veins.
- Gold values in active stream sediments were generally low and erratic, only a few values exceeding 1 ppm as shown in figure 15. The area around Itagunmodi, that contained highest density of old gold values was characterized by Au values that exceeded 0.1 ppm.
- Elueze and Olade (1985) concluded that the interpretation of stream-sediment reconnaissance geochemical data from the greenstone belt of the Ilesha area had showed that the areal distribution of trace elements is subject to strong lithological and environmental controls.
- The high background concentrations and the viability in abundance of the chalcophile elements was attributed easily to the mafic-ultramafic bedrock and to the compositional variations within it. Arsenic, which is widely used as a pathfinder for gold in other greenstone belts, showed no clear-cut relation to any of the known mineralization in the Ilesha district. That was attributed to the masking effect of the compositional variation in the bedrock. However, a general correlation between the Gold and Arsenic existed for Itagunmodi and Iyere areas.
- Although slightly enhanced gold values are associated with streams that drain known alluvial workings, such as the area studied, gold cannot be regarded as a reliable indicator element in itself because of its erratic distribution and the possibly widespread distribution of natural background values caused by artisanal small scale alluvial mining.
- Although the exact nature of the primary gold mineralization in the area did not reveal a clear picture, it was known that the rich gold ore Shoots were closely associated with abundant arsenopyrite veins of the area studied. Such areas were identified as most promising for further investigations, particularly the areas around Itagunmodi extending northwards to Iyere as shown in figure 15.
- Further detailed stream-sediment geochemical analysis was recommended including geochemical soil survey and drilling which could be carried out at selected localities.

4.0 Benched excavations

Mining activities are expected to be undertaken while addressing the safety of workers in compliance with occupational health and safety act. For instance, when using heavy excavation plant on a site of weak deposits particularly weathered sedimentary deposits a mining engineer has to consider ability of the deposits to support the heavy earth moving machines. This is necessary so that the floor does not cave in or collapse leading to possible accidents. Adequate bearing capacity for weak deposits to support heavy dynamic loads such as the one illustrated in figure 16 has to be pre-determined.

Fig.16: Giant multipurpose plant(A) and agiant loader in action (B)

Mining or quarrying in hard rock deposits usually requires different techniques to those employed in unconsolidated deposits such as sand and gravel size deposits. Overall considerations for influencing factors, to be done by an applied geologist, are essentially similar. The considerations include; establishing a viable resource, determining the available area for development, assessing volumes of waste, overburden and other allowances as well as identifying requirements for excavation, haulage and processing plant to be used. Furthermore, primary fragmentation is then pre-determined by the mining engineer so as to reduce the rock mass to a particle size that can be scooped from a loose pile. The fragmentation is indeed influenced by effectiveness of drilling and blasting that will have been carried out. Depending on the degree of weathering and fracturing of the rock mass, the fragmentation can be achieved by ‘ripping’ using a dozer or a combination of ripping and blasting. blasting, combined with the inherent rock fractures and weathering, creates kinematically free blocks of rock material. Other forces such as pore water pressure from groundwater etc. also contribute to rockfalls which can become a disaster if not addressed adequately. A designed benched profile is adopted as excavation progresses. A typical geometry for a benched excavation to address rock fall and ease transportation of material by tippers is as shown in figure 17. The benches arrest falling material from further downwards movement.

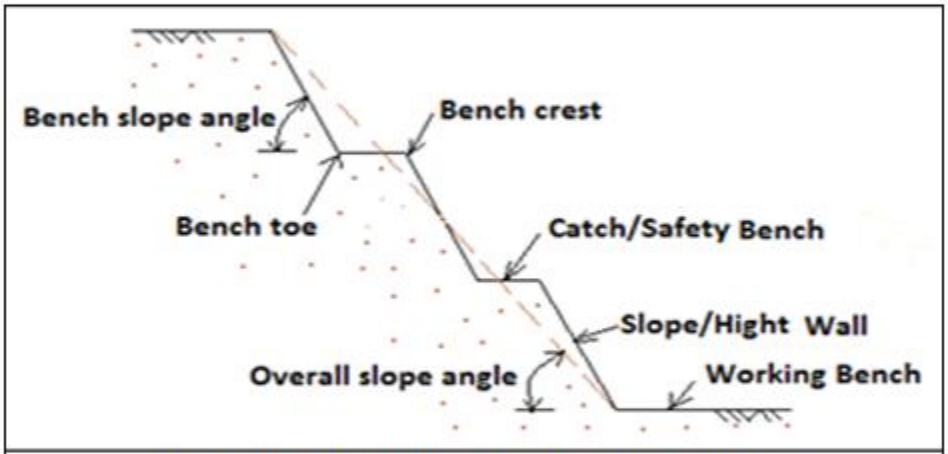

Fig.17: Typical benched quarry slopes for open cast mine

Stable slopes and minimizations of rock fall can also be addressed, for inclined strata by excavating in the direction of the dip of the strata. Figure 18 shows well developed bedding in a hard rock quarry site. The spacing and orientation of these discontinuities, and their dip, have influenced the development of the quarry benches. Design rules put in place addressed aspects such as direction of working and identification of areas to be approached cautiously. The direction of working can materially influence face stability and will therefore be a prime consideration in the preparation of the quarry or mining phasing plans.

C - Catch berm
W - Bench Wall
H - Haul road
T - Haul track
B - Shovel for loading haul tracks
⬅ Dip direction for inclined beds

Fig.18: A typical benched excavation for an inclined strata

5.0 Mine environment

Mine environments poses several challenges in actual practice. The challenges range from discontinuities that may have been concealed including associated problems such as excessive ground water seepage into both surface and underground mines, high temperatures, inflammable gasses poisonous gasses, rock fall etc.

(a) Ground water seepage

Fissures, pores and other voids in rocks are potential reservoirs for liquids and gases in rock masses. Sedimentary strata are the main hosts for these fluids. Ground water is the most common fluid that is encountered especially in rocks of well-developed interconnected fissure systems. Occurrence of the ground water can be investigated by using geophysical surveys, especially electrical resistivity methods. The investigations carried out should involve estimation of flow rate for the ground water. The flow rate as a discharge parameter can then be used to select suitable pump for dewatering mines when the water is encountered during actual practice. Usually, presence of ground water increases excavation costs and often halts some operations especially in mines during rainy seasons. Caverns are prevalent in limestones or permeable sandstone. Excavation done through calcareous rock formations may require intensive rock boring so as to determine the extent of cavern formation. Thus, underground works in such rocks require adequate preparations for de-watering activities. Similarly, Joints and faults are the main source of water in igneous rocks while in recent lavas, presence of vesicles that are undergoing chemical weathering contribute to seepage problems.

Fig.19: Encounter with underground water problem

For instance, San Jacinto tunnel in California (fig.19) had high water pressure encountered in large dry granite which had also been traversed by a major fault. Metamorphic rocks such as gneisses and schists are usually dry unless traversed by faults. However, in water bearing deposits like sands and gravels, cementation results into reduction of seepage that occurs through the deposits.

(b) Inflammable and poisonous gasses

Some gases which are inflammable or poisonous and may be encountered include; carbon monoxide, methane and hydrogen sulphide.

Carbon dioxide: Carbon monoxide (CO_2) is usually produced by slow oxidation of carbonaceous sediments such as coal or may be associated with magmatic activity in volcanic areas. The gas is nearly 1.5 times heavier than ordinary air.

Carbon monoxide**:** This gas is more toxic than CO_2 and is usually associated with coal bearing strata. Most explosive accidents in coal mines resulted from this gas when it became accidentally in contact with sparks.

Methane**:** This gas is carbonaceous in nature and diffuses readily from its source especially in organic material found in beds such as shales and clay stone as well as oil bearing rocks. Methane forms a highly explosive mixture when it comes in contact with hot air or is ignited by error.

Hydrogen sulphide: This gas is highly toxic and explosive when mixed with air. It originates from decay of organic substances, disintegration of unstable minerals or from magmatic activity.

(iii) ***Other gases***: Other gasses include sulphur dioxide, hydrogen, nitrogen and nitrous oxide which may be held in voids, under pressure. Sudden liberation of such gases leads to rock burst which occurs in excavations, particularly in underground mines.

(c) High temperatures

Temperature gradually increases with increase in depth. The average temperature gradient is usually 1^0C per 30m increase in depth. High temperatures should be expected in areas of high volcanic activity e.g. New Zealand where Geysers are prevalent and are used for electrical power generation. Similarly, a temperature of 132 ^{0} F was encountered in Simpson tunnel, in Alps due to recent volcanic activity. The high temperature was accompanied by hot water. Another encounter of high temperature was Tecolonte tunnel in Californian. In this tunnel the temperature was as high as 65^0C and was associated with hot water.

6.0 Rock blasting and Support of Excavations

Rock blasting has continued to be an excavation method for hard rocks for several decades. It results into weakening and fragmentation of rock mass for a purpose. In mining activities, the blasting design has to capture rock characteristics amongst other constraints. After excavation has been performed, support of the exposed rock mass may be required, particularly for underground works. The support system to be adopted requires to be engineered so as to guarantee safety and durability of the structure to be installed. Indeed, the design to be done has to utilize geological knowledge of which an applied geologist has to provide.

(a) Rock blasting

(i) Detonation theory: Concepts appertaining to blasting which explain the mechanisms of rock breakage in every situation continue to be developed. No single concept has been fully developed and accepted to date. Basically an explosion is a self-propagating, exothermic reaction for which stable end products are gases that are compressed, under an elevated temperature and at very high pressures. Sudden rise in temperature and pressure from ambient conditions results into shock waves, or a detonation traveling through the un-reacted explosive. The velocity of detonation (VOD) lies in the approximate range of 1500 to 9000 m/s), well above the speed of sound in the explosive material. As a result, chemical burning of explosive ingredients referred to as deflagration occurs at a rate well below the sonic velocity. The deflagration is associated with heat only and carries no shock due to its much slower reaction rate of an oxygen-balanced mixture that leads to gaseous products of chiefly water vapor (H_2O), carbon dioxide (CO_2), and nitrogen (N_2). In actual blasting practice, small amounts of noxious gases such as nitric oxide (NO), carbon monoxide (CO), ammonia (NH_4), methane (CH_4), and solid carbon are evolved. The work done by chemical explosives in the fragmentation and displacement of rock mass depends on the shock energy as well as the energy of the expanding gases. In addition, there is a conservation of mass, momentum, and energy

(ii) Blasting constraints: Blast design requires knowledge on aspects that include; geometry, explosives, geology, sequencing, and initiation. These are the key theory, tools and techniques used for most blasting applications. Normally, blast design is a semi-empirical systematic method that involves balancing numeric and qualitative assessments of rock properties, explosives to be used, and desired blasted products. Mining law presently, requires that environmental aspects also be addressed. Thus, internal and external environments require minimization of; wall damage, flyrock and noise as well as other safety aspects of working with explosives. Other constraints to be captured are; limitations posed by pit design, bench sizes, equipment, operating room etc. in general, proper fragmentation should result into optimize loading, hauling, crushing, and grinding processes All these factors must be balanced with cost.

(iii) Geological influence on Blast Design: The geology of a site to be blasted needs to be well understood in terms of rock types, stratification and geological structures inherent in the rocks. This can be accomplished by studying existing outcrops in, around, or adjacent to the blast site. A detailed drill log indicating discontinuities at various depths, as undertaken by an applied geologist, can also prove to be useful. Blasting performance is usually influenced more by rock properties than by the properties of explosives to be used by the mining engineer when carrying out the blasting phase, whether in surface or underground works. Rock masses show numerous planes of weakness, tectonic or cooling joints, natural fissures, and cracks some of which could be due to previous blasting for sites that were once blasted. Thus, there are planes of preferential fracture orientation in any one or more directions relative to the blast hole's axis. Typical blast hole geometry is as shown in figure 20.

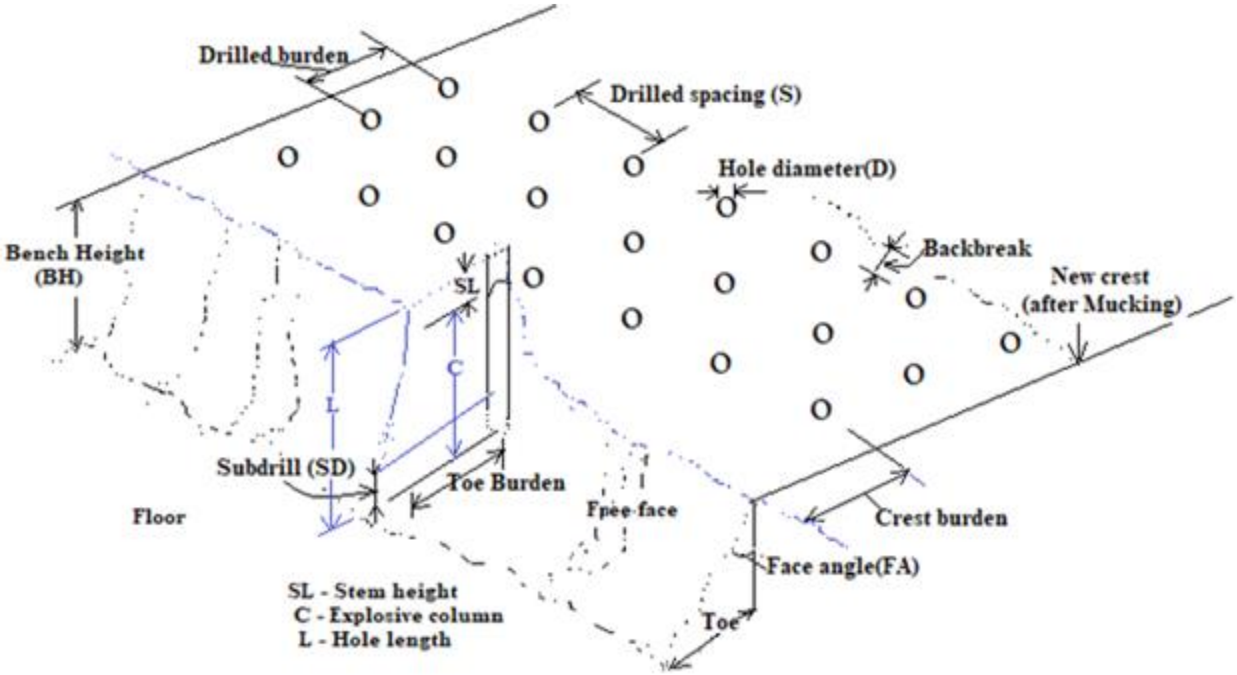

Fig.20: Typical drill hole geometry

The following properties of rock may have a significant influence on blasting results.

- **Dynamic Compressive Strength:** If the explosive's outgoing strain wave exceeds the dynamic compressive breaking strength of rock, then an annulus of crushed rock is formed around the charge. This crushed zone is detrimental to the transmission of strain waves in the surrounding rock. Hence, it is important that the dynamic compressive strength of the rocks in situ be determined, and if rocks have low compressive strength values then an explosive of low density and low sonic velocity be used for blasting.
- **Elastic Moduli:** Elastic modulus reveals behavior of rocks under stress and should be determined by using sonic techniques (dynamic moduli) rather than by the use of mechanical tests (static moduli). It has been found that the explosion pressure should not exceed 5% of the dynamic Young's modulus in order to obtain optimum results from blasting. The post-detonation gas pressure exerted in the cracks between the blasthole and the free face pushes the burden forward and produces heave. The bulk modulus of a rock has to be known so as to facilitate calculation of the heave.
- **Density:** Density of a rock is closely correlated to strength of the rock. An increase in rock density often results in a decrease in the displacement of a rock mass fragmented by blasting. Adequate displacement of a rock that has higher density can be achieved by;
  - Increasing the blasthole diameter,
  - Reducing the blasthole pattern, or
  - Changing to an explosive which has stronger heave energy.
- **Porosity:** Porosity in rocks tends to reduce the efficiency of blasting operations. The lengths of strain-wave-induced cracks in a highly porous rock were determined and found to be only about 25% of those in a non-porous rock of identical mineralogy. This implies that highly porous rocks are fragmented mainly by heave energy. Hence, post-detonated gases have to be kept trapped at high pressure until they have performed their task. This can be achieved by bottom priming and by having adequate stemming to prevent premature venting of gases.
- **Internal Friction:** Internal friction is a relative measure of a rock's ability to attenuate strain waves by the conversion of some of the mechanical energy into heat. It increases with a high degree of porosity, permeability, and jointing of the rock mass. Generally, internal friction

values for igneous or metamorphic rocks are lower than for sedimentary rocks, which require high energy explosives for satisfactory blasting. However, if the rock pores are filled with water, the internal friction factor reduces considerably, giving easier passage of the strain wave and improved fragmentation.

- **Water Content:** Water saturation considerably increases the velocity of propagation of strain waves, owing to the filling of pores with water, which is a good medium for elastic wave transmission. However, fluids in a porous rock reduce both the compressive and tensile strengths, owing to the lower friction characteristic between grain surfaces. If water is present in discontinuities adjoining a block of rock which is being blasted, strain waves may have a greater ability to weaken that rock mass by means of water being jetted considerable distances through interconnected fissures which has a wedging action that influences on overbreak and hence slope instability. It is therefore advisable in open-pit mining to dewater the rock slopes so as to ensure that minimum maintenance effort is left for the exposed rock mass.

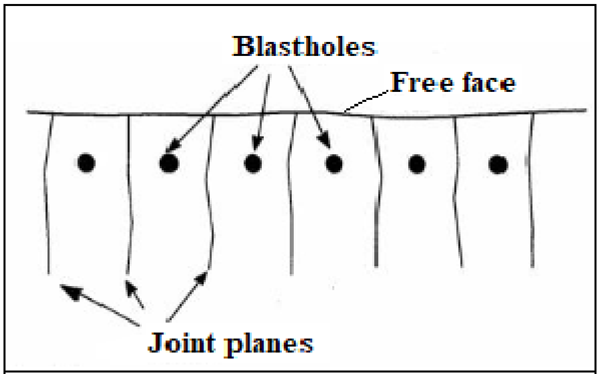

Fig. 20 :Blasthole positioning Vs Joint planes

- **In Situ Static Stress:** High in situ static stresses often exist well within the rock body and blasting results can be affected by these stresses particularly in radial cracks in which blasthole tends to curve off into the direction of the static stress field. There is also a strong possibility for closing of micro cracks by the static stress in the rock mass when confining pressure is above 100-300 MPa. Again, when a stress field exists in a direction normal to pre-existing radial cracks around a blasthole, it can be sufficiently strong to prevent extension of the cracks. Moreover, it may induce the formation of new cracks in the direction of the stress field.
- **Structure:** Bedding planes and joints in a rock mass tend to dominate the nature of the blast-induced fracture pattern. Maximum fragmentation is generally achieved where the principal joint planes are parallel to the free face. Where the angle between joint planes and the face is within a region between 30° and 60°, the blastholes may produce an irregular new face, owing to the formation of wide cracks behind the blastholes. When the joint planes are at right angles

to the free face, then each block requires at least one blasthole in order to obtain satisfactory fragmentation as illustrated in figure 20. If there is a high density of joint planes normal to the face, it is worthwhile to consider adopting smaller diameter blastholes at closer spacing.

- **Bedding Orientation:** The orientation of the major beddings can have a significant effect on blasting results. There are three cases to be considered:
    - Shooting in the dip direction of the strata,
    - Shooting against the dip direction of the strata
    - Shooting along the strike of the strata

Shooting in parallel direction to the dip (Fig.21(a)) leads to a tendency to get more back break, less toe problems, a smoother pit floor and a greater movement of blasted material away from the face and therefore a lower muckpile profile. In this case, less sub-drilling may be required owing to the fact that the explosive energy may follow the strata downward, eliminating toe problems. Furthermore, the drillholes can be inclined to the direction of dip thereby reducing backbreak although that will tend to ‘cast’ (throw) and spread the muckpile. A slight addition of delay time in the back row may provide relief to the back of the shot resulting in a more stable highwall.

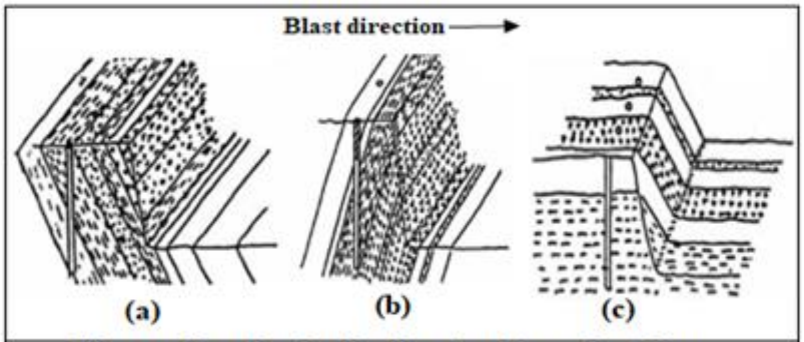

Fig. 21: Shooting in dip direction(a), against dip direction(b) and along the strike(c)

Shooting against the direction of dip (Fig.21(b)) leads to;

- Less backbreak since the strata is dipping into the wall.
- A rougher floor condition.
- Muckpile may become higher with less movement of blasted material from the face.

In this situation, the rock material produced tends to move upward, parallel to the plane of the joints. As a result of explosive energies migrating into the strata, a rock unit may cause back break. This situation may result in the creation of an unstable highwall. Also the muckpile would tend to be poorly displaced (creating more work during excavation). To eliminate toe problems, the blaster may consider using angled drill holes or high energy explosives in the toe area and/or additional subdrilling. Pre-splitting could also be used and become a highwall stabilization option.

Finally, shooting that is done along the strike (Fig.21(c)) leads to a highly saw-toothed profile due to different rock types intersecting the floor being blasted and an irregular back break. These are some of the worst conditions for those involved in drilling and blasting. To overcome them, the working face should be reoriented to a more favorable direction.

(b) Support of underground mines

Underground excavations are safer when supported by engineered steel structures. The support that is provided to transport tunnels can also apply to mine tunnels that lead to actual working areas such as stopes. The support becomes necessary due to the disturbance that arises from use of blasting method of excavations in which explosives are used. Main purpose for providing support is usually to strengthen the exposed rock mass by linking it to interior of the rock mass thereby preventing rock fall as well as seepage of ground water into the mine. Support measures can be done by use of rock bolting and or shotcreting.

(i) Rock bolting: A rock bolt is a long anchor bolt, for stabilizing rock excavations. The bolting done transfers loads from unstable exterior, to the confined and much stronger interior of a rock mass. Rock bolts were first used in mining works starting in the 1890s, with systematic use documented at the St Joseph Lead Mine in the US in the 1920s. Rock bolts are almost always installed in a pattern as shown in the figure 22A. Design for the bolting depends on the rock quality designation and the type of excavation to be used. Roc*k* bolting processes consists of anchoring the bolt in a hole in a predetermined pattern based on rock structure and applying tension to the bolt to place the rock under compression parallel to the bolt. The bolting aims at clamping together ('knitting') several roof beds to form a composite beam with strength considerably greater than the sum of the individual beds acting separately. Bolting system improves the competence of disturbed rock masses by preventing joint movements thereby forcing the rock to support itself. The system binds together a discontinued, fractured, laminated and jointed rock

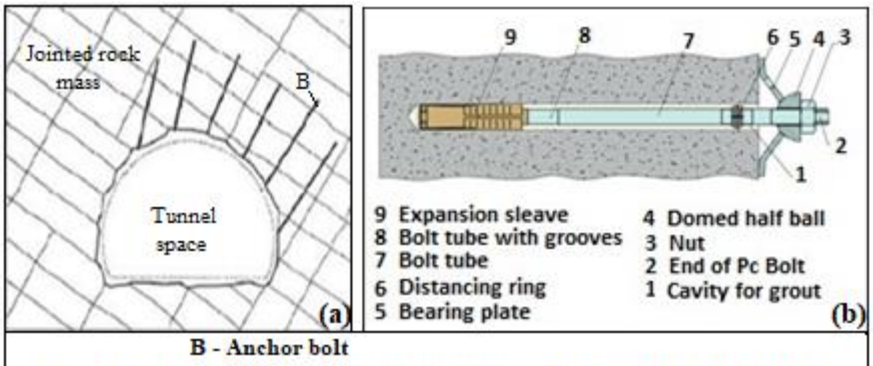

Fig. 22A: Typical rock bolting pattern(a) and a typical bolt(b)

mass. In addition, rock bolting has a marked effect on the stiffness of the rock by reinforcing rock mass through friction and suspension effects. Because of this, the technique of rock bolting is approved for mines and tunnels in all types of rock. Rock bolts are used both as an initial support and as a final rock support. They are used at the tunnel face as an initial support to ensure safe working condition for workers (Nilsen and Palmström, 2000). Rock bolts can be installed individually to fix individual loose blocks at the excavation face (called spot bolting) and afterwards with systematic bolting. Systematic bolting is a pre-planned pattern of bolts that is based on geological conditions. As with anchor bolts, there are many types of proprietary rock bolt designs such as mechanical, epoxy means of establishing the set needed or fiberglass bolts etc. They also can be used to support wire mesh as an additional function. To measure relative performance of different anchor systems in rock mass, pull out test can be performed on different anchor systems targeting different mechanical anchors, different lengths and different bond materials which are then grouted. Ultimate capacity as the maximum load sustained by the anchor system is determined including working capacity as the load on the anchor system at which significantly increasing displacement begins. In this pull out test different embedment lengths and variation in cement-water mixing ratios of grout used are also determined. The data obtained after analysis is then used to choose anchor types and select the correct bolt length, spacing and size of the bolts to be used for support works at hand.

(ii) Shotcreting: Shotcreting is a construction technique in which concrete or mortar that is conveyed through a hose is pneumatically projected at high velocity onto a surface. Shotcrete undergoes placement and compaction at the same time due to the force with which it is projected from the nozzle. It can be impacted onto any type or shape of surface, including vertical or overhead areas. The term “Shotcrete’ is usually an all-inclusive term that can be used for both wet-mix and dry-mix versions. Shotcrete, then known as gunite, was invented in the early 1900s by American (Carl Akeley) when making, plaster models of animals. He used the method of blowing dry material out of a hose with compressed air, injecting water at the nozzle as it was released. This was later used to patch weak parts in old buildings. In 1911 Carl Akeley was granted a patent for his invention named as "cement gun" as implied by the equipment used, and "gunite", the material that was produced. This method was improved and named as dry mix method since it involved placing the dry ingredients into a hopper and then conveying the ingredients pneumatically through a hose to the nozzle. A skilled nozzleman controls water that is added to the dry mix at the nozzle (Fig.23 (A)). The water and the dry mixture become completely mixed as the mixture hits the receiving surface. The water content can be adjusted instantaneously for more effective placement in overhead and vertical applications without using accelerators.

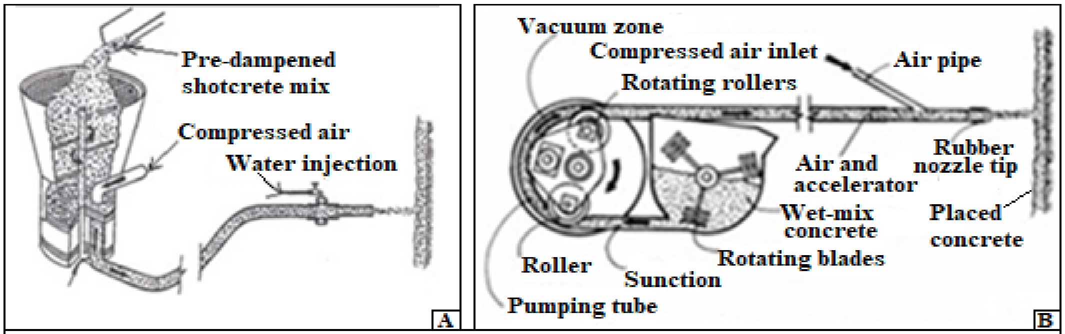

Fig.23: Dry-Mix techque(A) and Wet-Mix Technique (B)

In the 1960s, an alternative method, wet-mix method for gunning was devised with the development of a rotary gun which had an open hopper that was fed continuously. In this method, readily wet-mixed concrete is pumped to the nozzle zone. Compressed air is introduced at the nozzle to impel the mixture onto the receiving surface (23(B)). Greatest advantage of wet-mix process is that larger volumes can be placed in less time. Furthermore, the wet-gun procedure generally produces less rebound compared to the dry-mix procedure and the nozzleman does not have to be highly skilled. The sprayed concrete can be reinforced by using conventional steel rods, steel mesh, and or fibres. Fibber reinforcement of steel or synthetic material is also used for stabilization in applications such as slope stabilization or tunneling. Likewise, chain link mesh, although very strong and flexible, could be used but is not ideal for shotcrete application because it is difficult for the shotcrete to bypass the mesh up to the rock surface at the back. However, welded wire mesh which is firmly attached provides excellent reinforcement when used for shotcrete works. Typical shortening with other reinforcement provisions are as shown in figure 24.

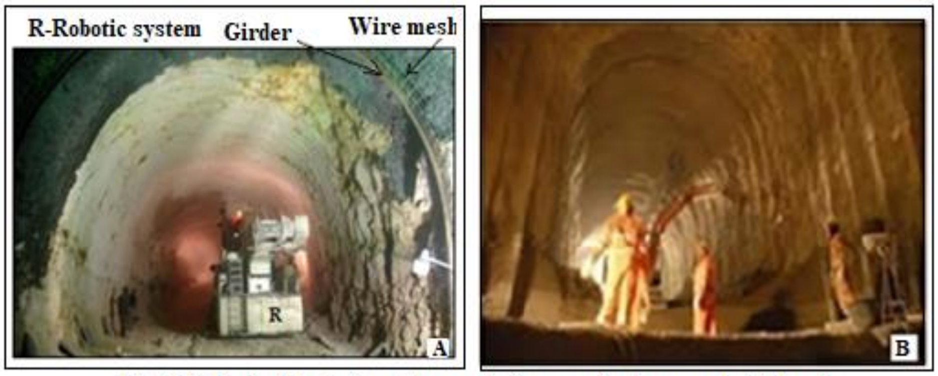

Fig.24: Robotic shotrecting , girders and wire mesh (A) and Primary support of shotcrete with lattice girders(B)

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