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Phosphate Mining Wastes at Abu Tartur Mine Area, Western Desert of Egypt

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Abstract: Solid and liquid wastes associated with the phosphate mining and beneficiation activities at Abu Tartur phosphate mine were collected from the tailing pond. Characterization methods were used to assess the physical and chemical properties that may impose environmental and/or human health risks. The hydraulic conductivity of the sampled slurry can be described as slow to extremely slow, therefore the potential of groundwater contamination by seepage from tailing ponds containing appreciable amount of clays is over estimated. Plasticity Characteristics of the collected slurry show wide variation in the plasticity index and reflect a significant volume change characteristic to "Fat" or plastic clays. The measured cation exchange capacity (CEC) is moderately high and reflects the abundance of clay minerals, probably illite or montmorillonite. The values of P_2O_5 in the waste slurry range from 21.99 % to 24.27% which makes the idea of reproduction of phosphate from the waste slurry attractive. Generally the tailing sediments have higher silica, alumina, K_2O, and MgO, and lower P_2O_5 and Na_2O/K_2O than the original ore. As to trace elements, they are generally rich in Zr, Li, Zn, Cd, and Ba while depleted in As, Nb, Mo, and Ni compared to the original fresh ore. The REE pattern of both the original ore and the wastes is generally similar except for a distinct trough at Eu that distinguishes the original ore from the slurry waste. The adverse environmental impacts and human health risks associated with phosphate mining wastes are discussed. Mitigation measures to reduce these impacts are also suggested.

Key words: Phosphate mining wastes, Geotechnical measurements, Risk assessment, Abu Tartur

INTRODUCTION

Most of the mining activities are hazardous, they threaten the occupational health and deteriorate the environment (Coelho *et al*. 2011), as heavy metals, radiations, and acids are significantly released into the environment (Ledin and Pedersen 1996). Much of this potential impact is associated with the disposal of large volumes of mining wastes. Mine wastes include all the materials, geological or otherwise, that is not enclosed in the beneficiation feed, and the output materials from the beneficiation process that is not part of the beneficiated ore. In this regard mine wastes include waste rock stockpiles, mine spoil, overburden, both liquid and solid tailing slimes. Many of these wastes represent main sources of heavy metals and toxins in nearby soils. Different wastes are generated and released into the environment causing air and water pollution and deterioration of the environment. Those pollutants are toxic to aquatic life at certain levels of concentration, and many are also hazardous to human life and health when contact is made in a concentrated form, or when there are significant populations within close proximity to the mines and mineral processing sites (Coelho *et al*. 2011). Communities living near mines, including miners, are commonly suffered from health problems related to mining activities. Those health problems are commonly persistent even after the closure of the mine. Mining wastes are involved in regulation of wide range of diseases including the chronic silicosis, emphysema, asbestosis, pneumoconiosis, bronchitis, cystic fibrosis, obstructive airways disease, inflammation, genotoxicity, cytotoxicity, hemolysis and target cell death.

Information on the properties of mine wastes is also needed to select the most reliable and cost-effective site reclamation and restoration. The composition of mine waste depends on several factors e.g. the type of ore deposit, the geologic environment which the waste rock came from, the type of mining that produced the waste rock, and the beneficiation method used to concentrate the ore. This range of mine waste types that differs in origin, presents numerous challenges to the analyst trying to provide physical, chemical, and mineralogical characterization of the mine waste. The more important parameters that characterize the waste with regard to undesirable physical properties and the fate of potentially toxic elements (e.g. heavy metals) are at the top of the priority list of the mine environmental management plan.

If not appropriately managed, waste created by phosphate mining has the potential to create extensive environmental damage. The size of the mine, the possibility of toxic material release during mining operations, and the huge amount of organic and inorganic chemical reagents input during the beneficiation processes, all contribute to the degradation of both community health and the environment. These adverse impacts may change the surrounding landscape or cause contamination to the surface and ground waters. Air quality can also

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be affected by dust emissions and gas exhaust released during crushing, blending, transportation, and beneficiation activities.

The degree of impact to the subsurface environment and ground water systems depends on the type of contaminant, toxicity, seepage potential, hydraulic conductivity of the soils, direction and rate of migration of the contaminant, site hydrogeology, soil/contaminant interaction and general geology of the area. Additionally, other factors also affect the susceptibility of the chemicals in a particular environment such as temperature, rainfall, wind, topography, soils, hydrology and microbial activities and bioavailability. Those factors interact simultaneously in the same location.

The purpose of this work is to characterize and assess the adverse environmental and human health impact associated with the mining and beneficiation activities at the Abu Tartur phosphate mining area, with the intention of elucidating the evidences of environmental pollution caused by the phosphate mining wastes. Possible suggestions for appropriate mitigation measures that may need to be developed are discussed.

1.1. The Mine:

Abu-Tartur phosphate mine is the largest phosphate mine in Egypt. The mine located adjacent to Abu Tartur plateau, some 50 Km to the west of El Kharga Oasis, Western Desert of Egypt (Figure 1). The estimated phosphate ore reserves in the area may reach up to billion tons. An extensive geological drilling exploration program had been commenced in 1970 covering an area of 112 Km^2 of the plateau. The geological reserves were found in the explored area of 112 km^2 to be about 980 MT.

The mine is a shallow underground phosphate mine, based on long-wall retreating mining technique. The project consists of two main production units, the mine and the beneficiation plant. The Run-Out-of Mine (ROM) storage consists of 5 hoppers with holding capacity of 1035 ton per each. The ore rocks are crushed through rotary crusher, sorted to get rid of oversize grains (+60 mm), and separating the dolomite and clay. The ore is then blended and stored in the blending yard on 2 piles each have a 40 thousand tons capacity. The ore is then moved to the beneficiation plant to produce the wet rock (concentrate) through a consequence of processes including washing, thickening of slime, attritioning, hydroclassifying, pumping to cyclones, screen filtering, magnetic separation, and dewatering. The beneficiation line has been constructed with designed output capacity of 730 thousand tons of rock phosphate yearly out of 1.3 MT of ROM. This means that 570 thousand tons of rock wastes are produced annually, provided that the beneficiation line is working in full capacity.

After drying the wet rock in drying drums equipped with a furnace, the beneficiated ore is then stocked in huge piles ready to sale or to go directly to phosphoric acid chemical plants. Different processes are commonly used for concentrating the ore; these include physical, chemical and thermal treatment techniques. The beneficiation stages include grain size reduction, attrition, scrubbing, desliming, screening of slurry, dewatering, flotation using organic acids, gravity separation, and/or calcinations and defluorination. Electrostatic and magnetic separators are also used to concentrate the flotation products.

Generally, the phosphate ore is naturally of lower grade and should be upgraded to a marketable P_2O_5 % suitable for the phosphate industry. High percentage of gangue minerals e.g. silicates, carbonates, feldspar, calcite, mica and clays are generally not acceptable. In most fertilizer industries, it is common to have ores with P_2O_5 content equal or larger than 30%, CaO/ P_2O_5 less than 1.6, MgO smaller than 1%, Fe_2O_3 and Al_2O_3 content: not greater 2.5% (Heidarpour 2009).

There are several chemical and physical beneficiation techniques to upgrade phosphates depending on the type of the ore, the existing phosphate mineralogy, and the type of gangue minerals present. For example, if the gangue minerals are silicates or clays, simple techniques including crushing, screening, scrubbing, and desliming can be (Ray and Robert 1969, Good 1976, Hignett *et al*.1977, Lawver *et al*.1982, Lodha *et al*.1984, Hsieh 1988).

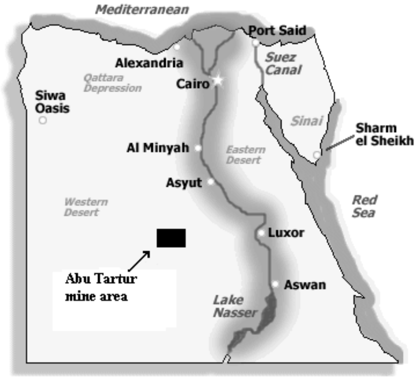

Fig. 1: Location map of Abu Tartur Mine

MATERIALS AND METHODS

Samples from the rock waste stock piles representing the original mined ore were collected as a reference material. Two types of ore were collected, fresh ore and weathered ore samples. Slurry waste materials (Phosphatic clay) were collected from the tailing pond. Tailings waters were collected in five-gallon buckets directly from discharge pipes coming from the beneficiation plant to the decantation pond. Relatively clear water was decanted from each bucket and mixed to create a composite water sample for use in the study.

Fifteen individual samples were collected using hand auger. The samples represent the top 20 cm of the tailing pond bottom surface precipitated solids from the discharge of the washing and beneficiation waste slurry. The sample was obtained from the surface near a spillway and, hence, is characteristic of the more recent clays. Those samples are composited to produce three composite samples. Each five individual samples contributed to one composite sample, making sure that each individual sample is contributed the same amount to the composite sample. The samples were transported to the lab using zip-lock bags to prevent moisture loss. The rest of the samples were preserved for further physical tests.

A portion of each sample was dried (gentle air-drying at room temperature). Following air-drying, the samples were disaggregated and mechanically sieved through a 2mm stainless steel sieve for removing coarse fragments. Selected samples were ground using ceramic grinders to be digested for chemical analysis. The rest of the >2mm were subject to further grain size analysis for the purpose of separating sand, clay, and silt size fractions. The grain size was determined using the wet sieving method combined with the pipette technique (Schlichting *et al*., 1995).

Dry samples were crushed and powdered to a grain size > 75mm. Samples chemical analyses were done at the chemical laboratories of the Saudi Geological Survey (SGS). Major oxides were analyzed using XRF technique (Philips PW 1480 sequential spectrometer) on glass disks according to the procedure of Hartmann and Wedepohl (1993). Trace elements and rare earth elements were analyzed using ICPE-9000 Shimadzu Plasma Atomic Emission Spectrometer. A mixture of 0.5 g of sample and 2.5 g of pre-existed borate flux was fused in a muffle furnace at 1000 °C using 30 mL platinum crucible for 35–45 minutes. Samples are placed into solution by means of acid digestion. Quantitative volumetric solutions were made using 5 mL of concentrated $HClO_4$, then adding double distilled water till get the desired volume.

For liquid waste samples, various physicochemical parameters like hydrogen ion activity (pH) and conductivity were electrometrically measured with the help of calibrated portable systronic pH meter and conductivity meter. Compleximetric titration was used to estimate calcium and magnesium concentrations. Bicarbonate (HCO_3) was determined by titration according to (2320B) standard method for waters with low alkalinity, chloride was measured by argentometric technique, and fluoride was measured by colorimetric technique (APHA 4500 F D). Sulfate was measured by precipitation as $BaSO_4$ by adding solution Jelserin and sodium chloride to the sample. Nitrogen, in the form of nitrite and nitrate, was estimated using spectrophotometry technique. A photometer was used to measure ammonium (NH^+), iron (Fe), and phosphate (PO_4).

Geotechnical measurements, including bulk density, total solids content, porosity, hydraulic conductivity (permeability), Cation Exchange Capacity (CEC), and Atterberg limits, were done according to standard methods. These measurements were done in the engineering geology laboratory of the Geological Survey in KSA (SGS). The determination of bulk density was achieved by the measurement of bulk volume of slurry samples. The samples are dried for 24 hr at 105°C; the weight is divided by the measured volume buoyancy in mercury. For total solid content, approximately 50 grams of sample were dried for 24 hours at 105°C for this test. Wet sieving was used to determine the percentage passing a No. 140 mesh standard sieve.

The porosity was obtained by measuring the grain volume of dried material by porosimeter, where the volume of sample and the dead volume (vacuum) were measured. The absolute or intrinsic permeability was measured by air permeameter using Darcy's law. The values of absolute permeability measured in darcys were then expressed in square centimeters by multiplying by a factor of 9.89×10^{-9}. Core samples of nearly 2.5-cm diameter and 2.5-cm length were prepared and then allowed to dry. The sample was subjected to N_2 gas at 400 psi (psi = 6894.76 Pa) to make hydrostatic pressure around the sample. Then air gas was allowed to get in the sample through the inlet valve and flows through pores of samples. The outlet air from the sample denotes the change in the head of sample because of permeability and by applying Darcy's law.

The CEC and principal exchangeable species were measured using the sodium acetate method (Rhoades 1982), by washing the samples three times with 1.0 normal sodium acetate, followed by a wash with ethanol, and then extracting the adsorbed sodium by several washings with ammonium acetate. The amount of extracted sodium was measured and expressed as the CEC. The cations extracted by the initial washings with sodium acetate were determined as well. The Atterberg limits (liquid limit and the plastic limit) were determined following ASTM standards (ASTM 1994).

RESULTS AND DISCUSSION

3.1. Waste Physical Characterizations:

Mining and beneficiation of phosphates consume a large amount of water for the purpose of washing. After washing, the waste water suspension becomes rich in effluents and other toxic chemicals that can be released to the environment. The suspended sand and phosphatic clays represent the main bulk tailings commonly known as Phosphate mine slime (PMS). For each ton of produced phosphate there is a similar ton of PMS produced, thus causing a serious problem regarding waste disposal (Hatira *et al*. 2005, Morto *et al*. 2007, Rimawi *et al*. 2009).

Wastes associated with phosphate mining and beneficiation activities are composed of both solid and liquid wastes. The solid wastes are represented by waste rock stock piles and the solid tailings and slurry composed mainly of sand and clays produced during crushing, blending and beneficiation processes. Other solid wastes are also produced during the flotation process in the form of different gangue minerals such as calcite, dolomite, quartz, and gypsum. Liquid waste is represented by the process water produced during washing and dewatering operations. These waters are disposed off in a tailing pond where sand, silt, phosphatic clay, and fine grained gange minerals are precipitated.

Chemical analysis of five bulk samples of the original ore (run-out-of mine), as well as three composite clay rich slurry sampled from the tailing pond are given in Tables 4 and 5. The chemical analysis of three liquid waste samples is also given in Table 6. Primary water treatment of the ore results in removing unwanted fine-grained rock and gangue mineral particles (quartz, carbonate, and gypsum). The result is a partially concentrate ore that goes directly to further beneficiation steps. The unwanted low grade ore and gangue minerals (tailings) are commonly discarded in tailings heaps. Fifteen samples from the clay rich sediments deposited on bottom surface of the tailing pond (Phosphate Mine Slimes PMS) were saved for physical, Chemical, and geotechnical measurements.

3.1.1. Particle Size Analysis:

Grain size analysis of the clay-rich phosphate mine slimes are given in Table 1 and plotted on the sand-silt-clay ratios diagram of Picard (1971), for the purpose of classification (Fig. 2). The obtained results of particle size analysis indicate that the studied tailings are composed of more than 77 % fines (silt and clay), whereas coarse sand-size sediments are subordinate in amount. The diagram shows that most of the samples occupy the sandy clay and the silty clay fields of the diagram. Few samples occupy the fields of the clayey mud and silty mud. The particle size distribution is important physical properties, which are intimately related to many environmental and industrial applications of phosphate clay and other wastes (Negm and Abouzeid 2008).

Table 1: Grain size analysis of the sampled slurry tailings

Sample	Sand%	Silt%	Clay%
WS11a	29.15	41.22	29.63
WS12a	30.94	23.19	45.87
WS 15b	13.68	34.60	51.54
WS 16c	35.11	30.32	34.57
WS 21c	34.37	29.85	35.78
WS 23a	9.64	28.97	61.39
WS 27a	20.66	19.35	59.99
WS 27b	10.52	25.76	63.72
WS29b	21.73	20.91	57.36
WS33a	15.89	13.89	70.22
WS35a	22.24	15.83	61.93
WS 36a	18.90	17.38	63.72
WS 38b	24.79	20.86	54.35
WS 40a	28.38	19.89	51.73
WS 40b	18.30	22.57	59.13

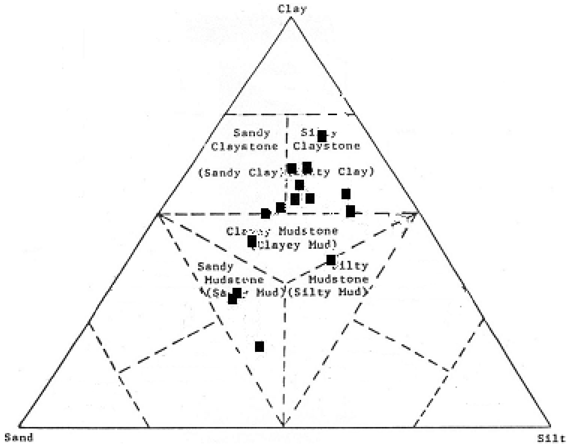

Fig. 2: Plots of sand-Silt-Clay ratios on Picard (1971) diagram

Table 2: Geotechnical parameters of the sampled slurry tailings

Sample	Bulk density	total solids content %	Hydraulic Conductivity	Porosity %
WS11a	2.08	36.84	4.13 X10^{-10}	27.85
WS12a	2.15	45.61	1.58 X10^{-9}	21.93
WS 15b	1.87	31.79	3.67 X10^{-11}	16.82
WS 16c	1.99	41.82	3.13 X10^{-8}	30.85
WS 21c	1.79	39.13	4.25 X10^{-8}	28.56
WS 23a	1.52	29.94	1.17 X10^{-11}	20.97
WS 27a	2.11	36.29	2.08X10^{-11}	26.55
WS 27b	2.01	32.65	3.07 X10^{-10}	19.61
WS29b	2.21	35.11	2.72X10^{-11}	18.02
WS33a	1.96	31.22	4.68 X10^{-11}	17.11
WS35a	2.72	38.91	4.87 X10^{-11}	28.34
WS 36a	2.26	33.74	1.11 X10^{-11}	21.39
WS 38b	2.97	40.01	3.92 X10^{-10}	19.99
WS 40a	2.18	43.96	2.37 X10^{-10}	18.43
WS 40b	2.57	36.81	2.18 X10^{-10}	20.92

3.1.2. Bulk Density:

The bulk density of the tailing slurry (phosphatic clays) sampled from the tailing pond are presented in Table 2. As shown, the bulk density is reasonably consistent, and range from 1.52 to 2.97 with an average of 2.16. Bulk density (weight/volume) measurements are important because, in the field, it is more convenient to apply treatments per unit area or volume of mine waste.

3.1.3. Total solid content (TSC):

TSC values (sand, silt, and clay) for all settling area samples are shown in Table 2. The values are ranging from 30% to 45%, averaging 37%. The slurry waste is pumped to the holding ponds at initial total solid content that is probably ranged from 5% to 8% and allowed to settle and consolidate with time under the impact of gravity to an average of 37% solids level. Further evaporation may increase the percentage of the total solid contents.

Samples which represent the bottom most parts of the accumulated sediments are relatively rich in the coarse fractions (silt and sand) and show the highest solid content values. The high solid content values i.e. low water content can be interpreted as due to higher permeability of the sand and silt relative to the clay that might have resulted in increased bottom seepage.

3.1.4. Hydraulic Conductivity:

The hydraulic conductivity (*K),* expressed as length per unit of time, is the ability of a medium to transmit water. The hydraulic conductivity of the present samples ranges from 4.25 X10^{-11} m/s to 4.68 X10^{-8} m/s reflecting the varied proportions of clay, silt, and sand. Samples with higher sand content show higher permeability (hydraulic conductivity) e.g. samples WS 16c and WS 21c, and those rich in clay have the lowest measured hydraulic conductivity e.g. sample WS33a. Measurements of hydraulic conductivity are necessary in order to compare the dewatering performance of clays. The permeability (which controls how fast slurry will dewater) shows a wide variation between the highest and lowest samples. Consolidation rates are directly dependent upon permeability values, with clays having low permeability requiring longer time to consolidate to equilibrium solids content. In general the hydraulic conductivity of the sampled slurry can be described as slow to extremely slow. Fetter (1994) claimed that, the porosity of most phosphatic clays is very low, similar to that of granite. Therefore the potential of groundwater contamination by seepage from tailing ponds containing appreciable amount of clays is sometimes over estimated by some researchers.

3.1.5. Cation Exchange Capacity (CEC):

Table 3: Cation Exchange Capacity and exchangeable cations

Sample	(CEC) meq/100 g	Na+	K+	Ca2+	Mg2+
WS11a	54	19	3	11	21
WS12a	55	14	2	16	22
WS 15b	76	29	5	18	24
WS 16c	42	17	2	11	12
WS 21c	39	15	2	14	9
WS 23a	68	27	3	19	19
WS 27a	57	24	1	22	11
WS 27b	41	16	2	13	10
WS29b	49	16	3	18	12
WS33a	63	24	1	17	21
WS35a	43	13	3	19	8
WS 36a	38	13	2	18	6
WS 38b	45	17	4	20	4
WS 40a	40	14	2	21	4
WS 40b	38	15	1	17	5

The CEC, expressed as milliequivalents per 100 grams, and exchangeable cation species were also measured on fifteen samples (Table 3). CEC measures the amount of positive cations required to neutralize the net negative charge that exists on all clay and organic particles (if any). The negative charges of the clay particles are neutralized by similar amount of positive charges of cations, taking into account the weight of the cations.

These cations are exchangeable, that is, they may be exchanged by other type's cations once the pore fluid composition changes. Higher amount of clays or organic matter result in higher cation exchange capacity (Thompson *et al*.1989). In practice CEC is estimated rather than measured directly. Estimates will be erroneous when the cations that are in the soil solution are misrepresented as exchangeable. This is may occur for example when acids are used as extracting agent such as those commonly used during phosphate ore beneficiation. The acid extractants dissolve some of the Ca^{2+} and Mg^{2+} ions and are considered exchangeable which is not true.

The exchangeable cation concentrations can be summed to obtain an estimate of the CEC. Therefore, the sum of the values of Ca + Mg + K + Na tabulated above are not exactly equal the total cation exchange capacity. The amount of CEC is probably less by an amount equal to the CEC that might be created by other cations such as H, Al, and Fe. The CEC of the sampled phosphatic clay tailings is generally increased with the increase of the fine fraction silt and clay (Figure 3). The highest CEC values corresponded to samples with high clay and silt contents (80-90%). Exceptions were found with samples WS 27b, WS 36a, WS 40b which have lower cation exchange capacity than that expected as they have relatively high silt and clay content. Martel *et al*.1978 claimed that the CEC value increases with the increase of the amount of 2:1 clay minerals e.g. illite.

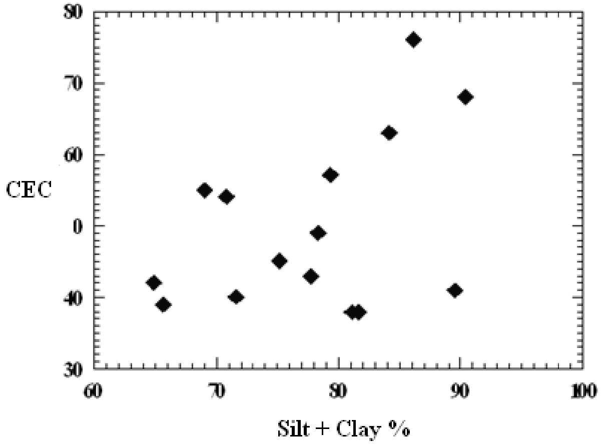

Fig. 3: Plots of CEC against silt and clay ratio

3.1.6. Plasticity Characteristics (Atterberg limits):

The plasticity characteristics of soils are determined via a series of index tests known as the Atterberg limits. The Atterberg limits have been shown to correlate with clay mineralogy and soil behavior (Carrier and Beckman, 1984). They consist of the plastic limit (PL), the plasticity index (PI). and the liquid limit (LL). The (PL), (LL), and (PI) are index properties that have both quantitative and qualitative correlations with soil composition and engineering properties (Mitchell and Soga 2005). The liquid limit (LL) can be defined as the content of water above which the clay behaves essentially as a liquid, and below which it behaves as a plastic material. The plastic limit (PL) can be defined as the content of water above which the clay is still plastic and below which it is a semi-solid. The range in water contents between (PL) and (LL), where the soil exhibits plastic behavior, is known as the plasticity index (PI) i.e., PI = LL - PL.

Casagrande (1932) devised a plasticity chart (Figure 4), in which an empirical boundary known as the "A" line separates inorganic clays (above A-line) from silty and organic soils (below A-line). In the chart, M denotes silty soil with no or very little plasticity, where the C symbol indicates clayey soil. The (CL), (CH), and (CE) symbols stand for clay groups having low, high, and extreme compressibility respectively. Inorganic clay samples usually plot above the A-line. Sandy clays, gravelly clays, and silty clays are commonly included in the (CL) group. Inorganic clays that possess high plasticity and the so called fat clays constitute most of the (CH) group.

Plots of fifteen samples on the plasticity chart show that the samples plot median between the line (A) and line (B), and generally occupy the fields of CL, CH and CE which correspond to low, high, and extremely high compressibility clays respectively. The wide variation in the plasticity index reflects a significant volume change characteristic to "Fat" or plastic clays. The range of plasticity values for the analyzed samples is quite large, with LL values generally between 61 and 171, and PI generally between 36 and 92. High values of LL and PI reflect high percentages of active clay minerals (Skempton 1953). The phosphatic clays fall in the CH range of the chart, indicating a highly plastic clay material.

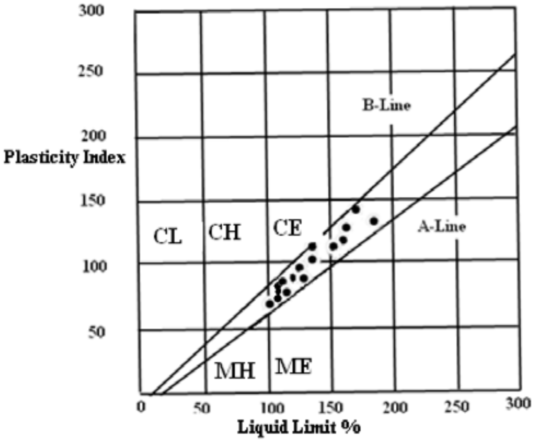

Fig. 4: Plots of the Plasticity Index against the Liquid Limit on the Plasticity Chart

The plasticity of phosphatic clays at a mine site appears to vary significantly over the life time of the mine (FIPR 1992). The degree of plasticity related to the clay content is called the activity of the clay. The values of the Atterberg Limits of a certain clay species can reflect its mineralogy. For example, inactive clays with low Atterberg Limits values reflect a pure kaolin composition, while high Atterberg Limits values reflect active clay probably of illite or montmorillonite composition. The liquid limit values of the samples occupy the area between the border lines 100 and 200 i.e. moderate to moderately high indicating that the samples represent active clays having illite and/or montmorillonite composition. A "typical" phosphatic clay has a liquid limit of about 170, and a plasticity index of about 110 (Bromwell 1982). High values of liquid limit and plasticity index reflect high percentages of active clay minerals. If the soil possesses plastic behavior, consequently it will have more compressibility and higher shrinkage-swell potential and the lower is its permeability will be (Abramson *et al*. 1996).

3.2. Waste Geochemical Characterization:

3.2.1. Major Oxides:

Representative samples of the original fresh phosphorite ore, the weathered ore, as well as three composite samples representing the waste slurry tailings were analyzed for major, trace and REE. The distribution of the oxides wt % is shown in Table 4. The major bulk oxides in the sampled slims were found to be mainly CaO and P_2O_5, significant amounts of silica, alumina, and iron were also observed.

Table 4: Chemical analysis of the Major oxides

Sample	SiO_2	Al_2O_3	Fe_2O_3(T)	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	L.O.I.
FO 100	14.50	0.77	7.14	<0.05	38.00	3.33	0.33	0.07	0.23	22.97	12.34
FO 101	11.75	0.80	4.86	0.05	43.20	0.35	0.43	0.07	0.11	30.22	7.63
FO 102	15.14	1.01	6.95	0.05	36.20	3.77	0.31	0.07	0.20	21.88	13.97
WO 100	13.20	0.57	2.75	<0.05	44.20	0.37	0.40	0.08	0.26	29.67	7.97
WO 101	12.25	0.50	2.90	<0.05	45.20	0.39	0.45	0.07	0.20	29.25	8.25
W10	17.75	1.53	3.95	0.15	38.20	1.45	0.34	0.20	0.15	24.27	11.44
W11	19.45	1.85	4.17	0.18	36.00	1.65	0.33	0.28	0.15	23.26	12.17
W12	19.35	2.16	4.40	0.20	35.00	1.94	0.32	0.29	0.15	21.99	13.71

At first glance, the weight percent of P_2O_5 in the waste slurry makes the idea of reproduction of phosphate from the waste attractive. Similar observation on the waste of other phosphate mines were noted (Seifelnassr and Ahmed 1998). Several experimental works have been done to reproduce high grade phosphate out of the waste generated from the beneficiation of the phosphate ore at Abu-Tartur mines (El-Shafei and Abu-Gharib 1977, Mostafa *et al*.1980, and Seifelnassr and Ahmed 1998). The values of P_2O_5 of the waste slurry range from 21.99 % to 24.27 %, with average value of 23.17 %. The high concentration of P_2O_5 indicate that apatite is the dominant non-clay mineral.

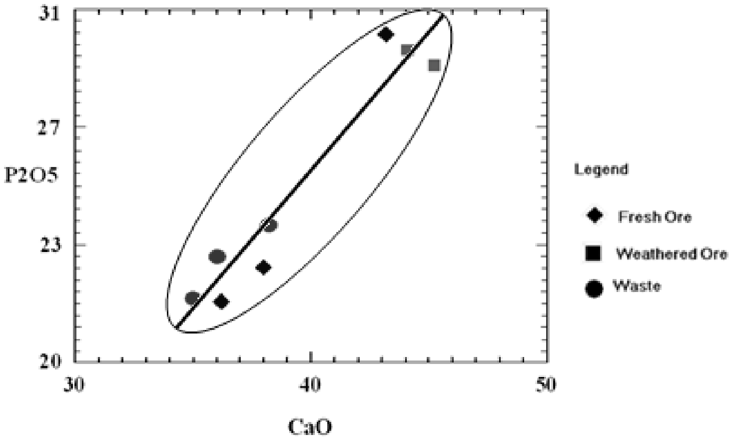

Fig. 5: plots of P_2O_5 against CaO

Plots of CaO against P_2O_5 (Figure.5) show that P_2O_5 increases with the increase of CaO, indicating the coexistence of apatite and calcite minerals. SiO_2 is generally higher in the waste due to the continuous accumulation of sand in the slurry pond due to washing and beneficiation activities. In the original ore samples P_2O_5 significantly decreases as silica increases particularly in the fresh ore, while the weathered ore shows consistent P_2O_5 with the increase of silica (Fig. 6).

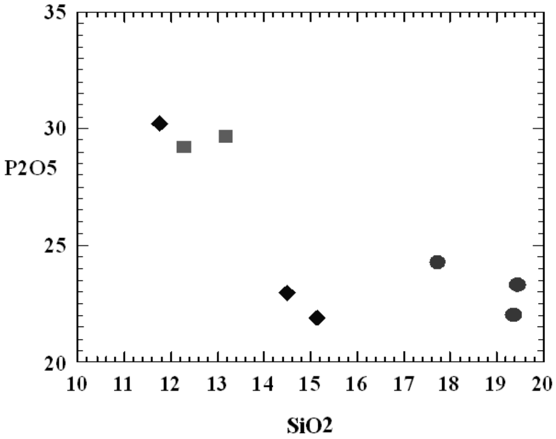

Fig. 6 plots of P_2O_5 against SiO2 (Symbols as in Figure 5.)

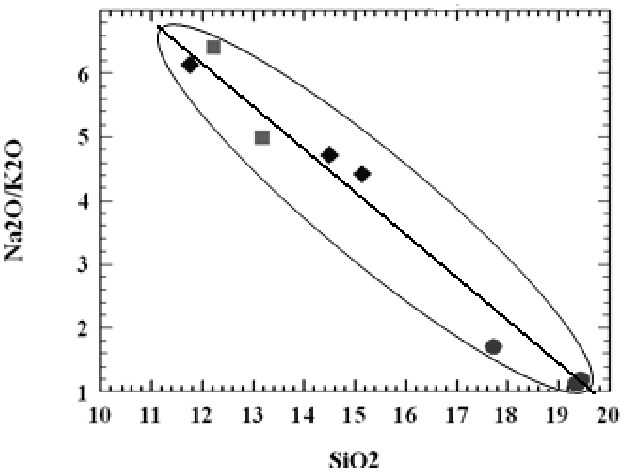

Fig. 7: plots of Na_2O/K_2O against silica (Symbols as in Figure 5.)

Plots of Na_2O/K_2O versus silica (Fig. 7) were able to separate the waste products from the original ore into two distinct populations where the wastes have higher silica and much lower Na_2O/K_2O ratio than the original ore. Na_2O/K_2O ratio decreases significantly with the increase of silica in both the wastes and the ore. The behavior of K_2O is quite different in both the ore samples and the waste samples. K_2O content of the ore samples does not change significantly with the increase of silica (Fig. 8), while it shows abrupt enrichment with the increase of silica in the waste samples.

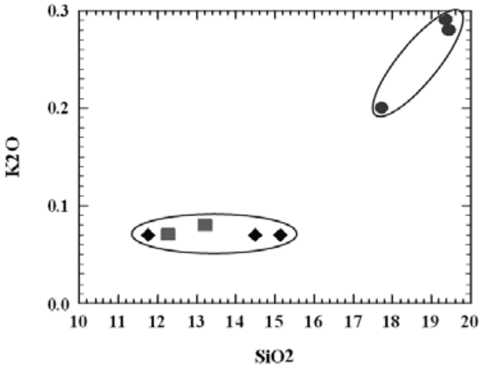

Fig. 8: plots of K_2O against silica (Symbols as in figure 5.)

A reverse relationship can be observed when $Na_2O + K_2O$ were plotted against silica (Fig. 9). $Na_2O + K_2O$ of the original ore decrease abruptly with the increase of silica, while those of the wastes are significantly increased with the increase of silica. The behavior of Al_2O_3 and CaO is similar in both the waste samples and the ore samples; Al_2O_3 shows a consistent increase as silica content increases, while CaO decreases with increasing silica (Fig. 10). Generally the tailing sediments have higher silica, alumina, MgO, and K_2O, and lower P_2O_5 and Na_2O/K_2O than the original ore. The MgO content reflects the presence of dolomite as a gangue mineral. The enrichment of MgO in the slurry waste is probably related to the flotation and calcination of carbonates including dolomite [$CaMg(CO_3)_2$] during the beneficiation of the ore. It could also be due to the abundance of palygorskite (a magnesium rich clay mineral) in the clay fraction of the slurry waste.

3.2.2. Trace elements and REE:

Mine waste often contains potentially toxic levels of metals (e.g., Ni, Cu, V, Cr, Mo, Mn, Zn, A1, Cd, and Pb) and metalloids (e.g. As, Se). Data on the chemical properties of mine waste are needed to select appropriate remediation treatments. The presence or absence of those toxic metals is originally related to the geology and geochemistry of the mineral deposits from which the mine waste is derived. Plots of uranium against silica show no significant changes of U with increasing silica, while Ba is significantly enriched in the waste samples compared to the fresh and weathered ore; Sr is significantly lower in abundance compared to the weathered ore (Fig. 11). Generally the waste slurry is rich in Zr, Li, Zn, Cd, and Ba while depleted in As, Nb, Mo, and Ni compared to the original fresh ore. The waste slurry is also depleted in CaO, P_2O_5, Be, Ce, Co, Sc, Sr, and U and has higher MgO compared to the weathered ore (Table 5).

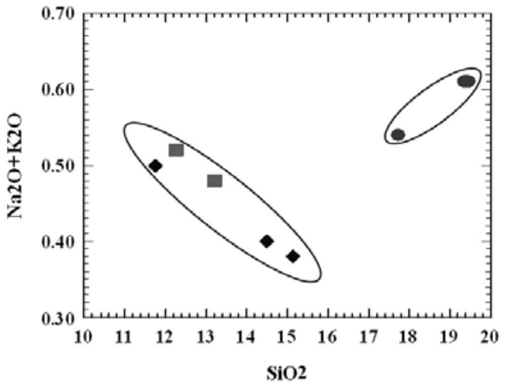

Fig. 9: plots of Na_2O+K_2O against silica (Symbols as in Figure 6.)

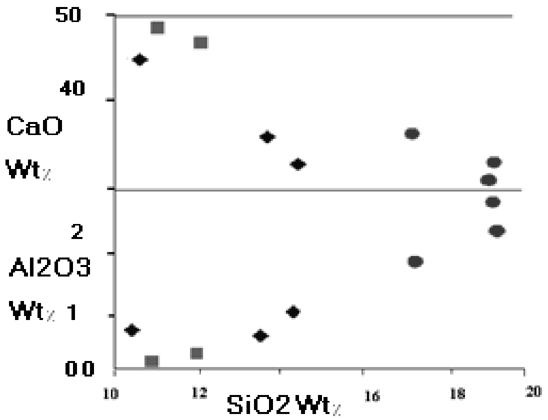

Fig. 10: plots of CaO and Al_2O_3 against silica (Symbols as in Figure 5.)

Table 5: Chemical analysis of the trace elements in ppm (*ppb)

Elements	Au	Ag	As	Ba	Be	Bi	Cd	Co	Cr	Cu	Ga
FO 100	<0.02	<0.5	23.62	105.10	2.27	<10.00	0.89	10.00	30.01	26.00	<1.00
FO 101	<0.02	<0.5	27.26	135.32	4.15	<10.00	0.94	12.00	46.96	24.00	2.25
FO 102	<0.02	<0.5	22.17	108.64	2.68	<10.00	0.90	11.00	36.38	25.00	<1.00
WO 100	<0.02	<0.5	15.11	128.41	4.41	<10.00	1.06	27.00	52.04	20.00	<1.00
WO 101	<0.02	<0.5	16.70	115.68	4.43	<10.00	0.95	19.00	52.92	20.00	<1.00
W10	<0.02	<0.5	15.15	479.91	3.73	<10.00	1.19	10.00	44.88	21.00	<1.00
W11	<0.02	<0.5	15.67	545.92	3.53	<10.00	1.23	12.00	44.65	23.00	<1.00
W12	<0.02	<0.5	20.02	437.59	3.55	<10.00	1.44	12.00	56.01	19.00	<1.00

Table 5: Chemical analysis of the trace elements in ppm (*ppb) Continued

Elements	Ge	Y	Li*	Mo	Nb*	Ni	Pb	U	Sc	Sr*	V
FO 100	2.39	145	1.94	9.89	20.56	35.00	25.00	9.22	14.02	1120	34.58
FO 101	<1.00	248	2.33	7.91	21.43	34.00	32.00	11.26	26.95	1960	64.80
FO 102	<1.00	177	2.55	12.19	24.83	52.00	37.00	6.70	15.77	1131	45.14
WO 100	<1.00	287	3.60	4.66	13.34	40.00	35.00	8.24	30.49	2228	63.19
WO 101	<1.00	268	3.44	4.32	13.48	42.00	27.00	8.16	30.04	2461	62.40
W10	1.68	243	4.51	4.89	19.08	23.00	50.00	6.33	27.54	1726	60.80
W11	<1.00	232	5.10	5.54	19.10	22.00	34.00	7.27	26.01	1636	61.30
W12	<1.00	210	6.02	5.46	19.44	24.00	29.00	7.66	24.89	1608	75.32

Table 5: Chemical analysis of the trace elements in ppm (*ppb) Continued

Elements	Zn	Zr	Th*
FO 100	53.00	15.44	29.96
FO 101	46.00	33.34	19.60
FO 102	77.00	20.09	35.68
WO 100	74.00	29.65	16.29
WO 101	63.00	25.20	16.56
W10	125.00	36.55	26.37
W11	127.00	34.27	26.52
W12	141.00	36.49	27.45

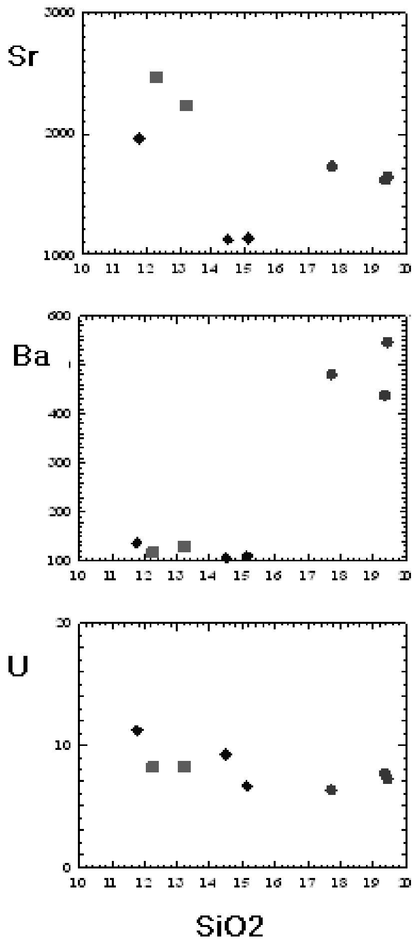

Fig. 11: Plots of U, Ba, and Sr against silica (Symbols as in Figure 5.)

The chondrite normalized rare earth elements pattern of the analyzed samples shows a general consistency for both tailing wastes and original ore (Fig. 12). All the samples show light REE enrichment with distinct depression at Pr, and a flat heavy REE pattern. A distinct depression at Eu distinguishes the fresh ore from the waste slurry, the former exhibit a distinct depression while the later lacks this depression. The weathered ore exhibit the same REE pattern as the waste slurry. The presence of Eu depression may indicate the abundance of detrital plagioclase within the original ore, while the lack of this depression from the weathered ore indicates the dissociation of the plagioclase into clay minerals (sercite) during weathering.

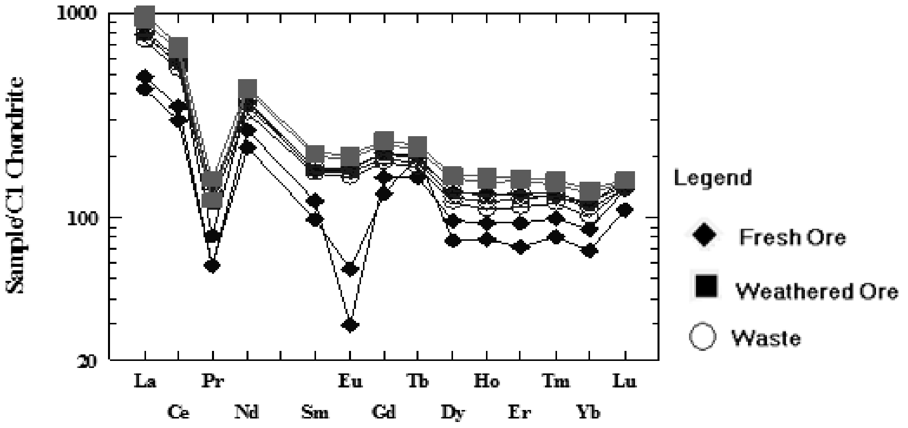

Fig. 12: Chondrite normalized REE pattern

3.2.3 Liquid waste:

The water chemistry of three unfiltered and one filtered samples is summarized in Table 6. The pH, total hardness and TDS values in all unfiltered samples (WU-101, WU-102, and WU-104) show consistent increase as compared to the filtered sample (WF-103). The pH of mine waste is one of the most useful indicators of mine waste quality for supporting future remediation strategies. The pH of a 1:1 liquid mine waste/deionized water mixture was measured and found to be slightly acidic averaging 6.595.

In situ bulk EC of the filtered and unfiltered liquid waste of the tailing pond was measured using a portable pH/conductivity electrode kit (Mettler-Toledo pH Metter Model S47-K). The increase in electrical conductivity of unfiltered samples from 2060 to 2800 µmhos/cm denotes the presence of high ionic constituents in the liquid samples.

Table 6 shows that calcium and magnesium are the dominant cations, while the SO_4^{-2} and HCO_3^{-1} are the main anions. The piper diagrams (Fig.13 & 14) showed the typical proportion of cations (Ca, Mg and Na) and anions (SO_4^{-2}, HCO_3^{-1} and PO_4^{-3}). The diagram depicts the dominance of $CaSO_4$ and Mg $(HCO_3)_2$ in the liquid samples carrying unwanted wastes. The predominance of Ca and Mg may indicate much higher dolomite content in the slimes fraction. The presence of these inorganic complexes also illustrates the significant hardness of liquid waste samples and the considerable total dissolved salts (TDS). The filtered sample showed intermediate value for cations like Ca, Mg, Na and K while other cations like Fe and NH_4 show a prominent decrease in concentration compared to unfiltered samples. The unfiltered sample shows also a prominent decrease in anions like Cl^{-1}, PO_4^{-3} and NO_3^{-1}. The liquid waste analyses indicate that the clay environment is a calcium magnesium- sulfate bicarbonate dominated system, with slight acidity and a relatively high specific conductivity.

Table 6: Chemical analysis of the liquid waste

Sample	Ca	Mg	Na	K	Fe	NH_4	Cl	HCO_3	NO_3	SO_4	F	NO_2	PO_4	SiO_2	T.D.S	Cond	pH	Total hardness
WU-101	406	86	9.9	6.3	0.13	0.49	15.20	52	7	1320	1.01	0.63	12.75	0.20	1340	2060	6.63	1368
WU-102	412	120	15.9	8.6	0.11	0.23	16.90	38	7	1000	1.12	0.33	9.50	0.20	1610	2620	6.63	1623
WF-103	404	98	12.6	7.7	0.03	<0.04	17.80	42	5	1600	1.08	<0.03	0.26	0.20	1600	2340	6.53	1412
WU-104	406	126	16.0	8.4	0.10	0.30	18.60	53	8	1660	1.16	0.38	13.0	0.10	1610	2600	6.59	1632

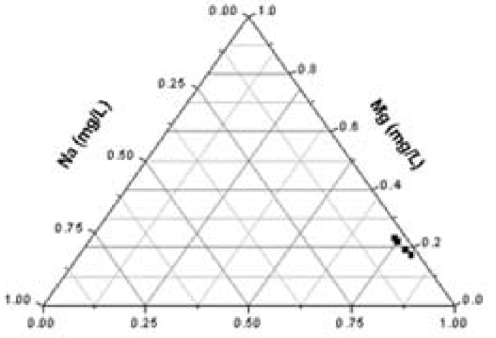

Fig 13

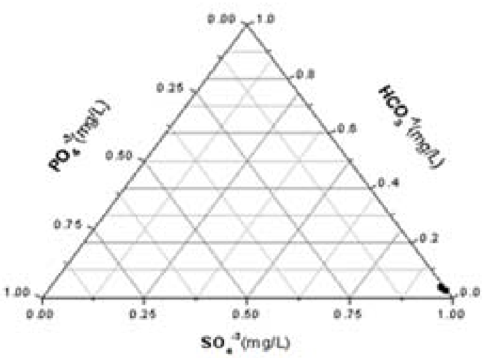

Fig 14

Fig. 13 and 14: Piper diagrams showing the chemical environment of the liquid waste

3.3 Environmental Adverse Impacts:

The adverse impacts on the environmental that is commonly connected with mining activities appear to be due mainly to poor management of the different types of mining wastes. Mismanagement of tailings can result in the discharge into the environment of wastes that rich in toxic heavy metals. Alteration in the water table, acid mine drainage, and potential surface and ground water pollution are common environmental challenges in mine areas. Dust emissions during loading, en route, and unloading of the ore, and during crushing affect the quality of urban air in the vicinity of the mine area. Chemicals and reagents added during the beneficiation of the ore can have adverse environmental impacts as well as impose health risks if not appropriately handled and controlled. Inappropriate disposal of solid and liquid mine wastes may lead to leaching of pollutants from disposal areas and can result in soil and groundwater contamination. Flooding caused by tailings dams failure and dump heaps collapse can contaminate both surface and groundwater. Loss of surface vegetation and consequent soil erosion in mining areas can have serious long-term ecological consequences.

The impact of the beneficiation process depends largely on the chemicals and reagents added to the original ore to fit the chemical and physical properties of the end product rather than on the geological sit up of the phosphate ore body and the surrounding rocks. In all cases, land and water resource consumption and/or degradation is a common issue for both mining and beneficiation activities.

The impacts of crushing, grinding, and sorting at early stages of beneficiation process produce airborne particulates and deteriorate the air quality. At Abu Tartur mine area dust storms occur all year long, the reported values of total suspended particulate are significantly greater than the 120 mgm^{-3} maximum concentrations permissible (Ahmed 2003). Radioactive Phosphatic dust can be precipitated at and around the mine areas in the form of wet precipitation and/or dry deposition. The radioactive dust can be accumulated on surface soils, become bio-available by animals and plants and enter the food chain. Radon gas produced from phosphate piles and tailings is of concern and can be considered as a potential hazard (UNSCEAR 1993, IAEA 2004).

Phosphate mining wastes, including tailing and decantation ponds associated with the beneficiation of the ore always have a high concentration of heavy metals. Those heavy metals can find their way to the surface and groundwater, the soil, and the air. They can deteriorate the soil, impose toxicity to animals and plants, and pollute the food chain. Heavy metals are hazardous because they have a tendency to bio-accumulate in animals as well as human bodies. Monitoring heavy metals toxicity in the mining waste helps in determining the mitigation actions that should be taken during remediation and rehabilitation of the land after the closure of the mine.

Hundreds of tones of major reagents associated with phosphate beneficiation are used annually. Those reagents include fatty acids, amines, fuel oil, sodium silicate, soda ash or ammonia, and sulfuric acid. These reagents are generally considered harmless to the environment because many of them are biodegradable, some of them, remain on the rock surface and ultimately end up in the solid fertilizer products. Moreover, the acids and bases neutralize each other in the process of water recycling (FIPR 2001). Even though, concerns should be expressed about the possible effect of the reagent, particularly fuel oil on the quality of ground waters.

3.4 Human health Risk:

Adverse health impacts associated with phosphate mining are stemmed from the inhalation of particulate emissions and the intake of heavy metals, metalloids, non-metals and their oxides, either from the mining activates or from the application of the phosphatic fertilizers. Radiation hazards are also of concern as the phosphates of the Abu Tartur mine are proved to have Naturally Occurring Radioactive Materials (NORM) due to thorium and uranium decay series ^{232}Th and ^{238}U (Khater *et al*. 2001), and are considered as a radiation health hazard (Makweba and Holm 1993, Abbady *et al*. 2005). Air particulates emissions produced during processing and transportation of phosphate ore represent a potential health hazard; they might cause respiratory problems at least to the miners (Khater *et al*. 2004).

Mining of phosphate rocks and application of phosphatic fertilizers are major sources of heavy metals that enter the environment (Pinsky 1988). Phosphate mine wastes can cause environmental hazards as they contain significantly toxic elements, such as Th, U, REE, As, Cd, V, Sb, Zn, Cr, Ni, Cu, etc, depending on the origin of the phosphate deposit, the mining method, and the beneficiation technology used.

Hazardous chemicals associated with ore beneficiation and mining waste can adversely affect human cellular biology. When inhaled or enter the food chain and get into human bodies, silica remained deposited within the body tissue, due to high biopersistivity (Varki 2007, Fubini *et al*. 1995, Fubini 1997). Inhalation and ingestion of silica particles through air and agricultural food by people living near the mining industry can cause a significant pulmonary fatality including inflammation, cytotoxicity, lung cancer and histopathological lesions, proved at least in rats (US-EPA 1996, Borm *et al*. 2011). Moreover, lung cancer risks and mortalities have been linked with the exposure of non-crystalline and crystalline silica (particularly cristobalite) in mining industry (Checkoway *et al*.1993).

CaO has its direct relation with the P_2O_5 concentration as shown in figure 5. The physiological changes regulated by CaO are associated with the physico-chemical features of CaO including the particle size, aquatic solubility, heat of hydration, soil adsorption, seepage potential, biomembrane permeability, ionic exchange and interaction with the macromolecules (dehydration, organometallic stabilization and biodegradation). CaO enters the food chain and body by means of water source causing wide range of disorders including hepatic, renal, cardiac, lung, reproductive and bone diseases (Himsworth 2008, Mandinova *et al*. 1998).

The present work indicates that, the waste slurry is rich in MgO as well as Zr, Li, Zn, Cd, and Ba compared to the original ore. Some of these elements (Ba, Cd, Pb, Cr and Zn) are known to have high toxic effects to the cellular health. Several experiments indicate that the synergistic effects of heavy metal burdens are significantly more toxic than the individual heavy metal exposure. Allergic reactions are caused by the intake of Be and Cr, neurotoxicity is caused mainly by the intake of Pb, kidney and liver disorder as well as gastroenteritis are affected by the intake of Al, stomach irritation, anemia and intestinal damage are commonly caused by the intake of Cu. In addition, elements like As and Cr-VI are proved to be carcinogenic (Korallus 1986b).

Cadmium is an element that occurs naturally in all phosphate rocks. The phosphate extraction and beneficiation processes are mediating the concentration of cadmium into tailing ponds which can mediate the contamination of soil and water by increasing the cadmium concentration. The incorporation of cadmium into the food chain during phosphate mining activities or application of phosphatic fertilizers can cause lung cancer in human bodies and can develop a wide range of physiological disorders including headache, nausea, fever, chest pain, chronic bronchitis, kidney disorder, liver damage, emphysema, and pulmonary edema into human beings (Godt *et al*. 2006).

Lead in the phosphate mine waste can end up into the ground water body. Once ingested, lead can replace the calcium of bones and culminate the skeletal disorders especially in children. Lead and other toxic heavy metals can cause the formation of sulfide minerals, precipitated at the gingival border of mouth.

Chromium is another most toxic metal for many cellular aberrations. The wide range of chromosomal disorders is also linked with the chromium contamination and toxicology. Many clinical studies highlight the carcinogenetic and mutagenic behavior of chromium compounds as wastes (IARC 1991).

Although barium does not carry the carcinogenic property, it can induce toxicity like paralysis, paraesthesia, and cardiac disorders in the children and people carrying low immunity. Several reports indicate that due to the solubility of barium salts, mobility of barium ions in water and the adsorption of barium into gastrointestinal tract can mediate acute poisoning in the human and animal bodies. Additionally, barium has the chemical property to replace the calcium and induce the release of adrenal catecholamines and neurotransmitters. The cellular process inhibition in different microorganisms and decrease in reproduction and growth in daphnids are also linked with the barium accumulation in these organisms (IPCS 1990).

High fluorine content of apatite minerals can increase the total F budget of the ecosystem adjacent to the mine area. Excess F influx reaching groundwater or surface water may in the long run induce fluorosis. Since fluorine can cause toxic effects to animals that take phosphate products as a food supplement, defluorination of the original phosphate ore is thus necessary to obtain highly purified fluorine free forms of industrial phosphorus. Defluorinating agents e.g. soda compounds and phosphoric acid are commonly used to removal fluorine from phosphate rocks.

3.5 Ecosystem Mitigation Measures:

Although mining operations are considered undesirable land uses, it can be compatible with environmental protection if ecosystem mitigation measures are appropriately taken. Modern technologies and good management practices when available can counter the adverse impact of mining. A first step in sitting up a strategy for mitigation measures and remediation is to get an idea about the current pollution status, which is the essence of this work. This could be achieved by digging monitoring wells or at least use pre-existing, appropriately located wells to sample ground water for the sake of tracing pollutants and predict their horizontal and vertical migration potential and fate. Soils and other environmental samples should also be investigated systematically to assess the adverse environmental impacts and the human health risk.

Remediation of polluted soils, particularly those formed by the evaporation of tailing ponds at abandoned mining areas, is costly. Cost-effective unconventional remedial technologies can be used at mining areas that involve keeping the contaminated soil in situ and applying soil amendments to decrease their bioavailability to the lower limits possible (Basta *et al*. 2001, Brown *et al*. 2003).

Vangronsveld *et al*. (1995a) claimed that the chemical, physical, and biological characteristics of soils can be significantly enhanced by applying organic biodegradable residues. They also demonstrated that, organic biodegradable residues are able to raise the pH of the soil, increase its water holding capacity, increase the content of organic matter, reduce the bioavailability of toxic heavy metals, and add essential nutrients to the soil that are necessary for future plant growth. In all cases a vegetation cover is necessary as a basic rehabilitation strategy to stabilize the soil and reduce wind erosion and water percolation.

Precautionary measures are needed to minimize airborne dust produced during crushing, grinding, and transportation or even during direct application of calcinated original ore as a fertilizer. The Abu Tartur area, host more than 200,000 residents, most of them live in a less than 5 km vicinity from the mining activity and are subject to gas and dust emissions from the mine. Protecting the residential area from airborne dusts and phosphatic clay could be achieved by constructing green fans around the residential area. Methods of controlling dust emissions also include wetting the instruments and roads by using water sprays, reducing drop heights, covering conveyors and trucks, using hooding material and enclosures during screening operations and at reorientation points, and transferring the air to air pollution control points. Dump and tailing heaps should also protected against wind storms to reduce generation of dust.

Appropriate tailings management include tailings treatment, slurry thickening, appropriate design of tailings impoundments, process water recovery, treatment and recycling, should be implemented at the mine site (Ritcey

2005). Moreover, design of structures and materials that can be employed for sediment retention can help minimize the quantity of sediment moving off-site.

Bioremediation is another technology that was recently used effectively to decrease the adverse environmental impacts of mine waste (Whitehead and Prior 2005). Microorganisms such as metal-transforming bacteria, sulfate reducing bacteria, and metal accumulating microbial mats can be used effectively to reduce the environmental impacts of mine wastes. The chemical basis of remediation using sulfate-reducing bacteria involves organic matter oxidation coupled with microbially mediated sulfate reduction (Doshi 2006). Applications of new technologies in ore extraction and beneficiation that involve significant reduction in water consumption are an important requirement towards sustainable mining industry and effective environmental protection (Gunson *et al*. 2012).

Conclusions:

Extensive continuous mining may led to unsustainable use of ores and results in the accumulation of metals in the environment, exceed permissible limits, and posing human health risks. The quantity of wastes produced during mining activities is the largest compared to the amount of waste materials generated by any other industrial sectors. Much of these wastes are problematic, not aesthetical to view, and represent an environmental challenge as they impose human health risks and deteriorate the environment.

Phosphorus is the most critical elemental factor controlling the biological proliferation in many ecosystems. For this reason phosphate will continue to be mined for hundreds of years to come. Phosphate mining operations involve different activities by which several kinds of wastes are released and exposed to the environment and may cause severe damage to the general ecosystem particularly to the aquatic bodies which receive excess P influx. Mining wastes (tailings) include both solid and liquid wastes; semi-liquid wastes e.g. slimes and process waters are also not uncommon. Any environmentally sound management of mine wastes should consider the chemical, the physical, and the mineralogical characteristics of mine tailings. Mine waste characterization and information on their properties are needed to support future reclamation plans and to select the most reliable and cost-effective remediation treatments that will lead to repair the damage caused to the environment by mining operations (Amacher and Brown 2000).

The present work is a try to characterize the chemical and the physical properties of the Abu Tarure phosphate mine and to elucidate the potential environmental adverse impacts and human health risks that might occur due to the inappropriate management of the phosphate tailings

At Abu Tartur area, phosphate mining and beneficiation activities generate wastes that are composed of both solid and liquid wastes. The solid wastes are represented by waste rock stock piles and the solid tailings and slurry composed mainly of sand and clays produced during crushing, blending and beneficiation processes. Other solid wastes are also produced during the flotation process in the form of different gangue minerals e.g. dolomite, calcite, quartz, or gypsum.

The studied tailings are composed of more than 77 % fines (sandy clay and the silty clay), whereas coarse sand-size sediments are subordinate in amount. This composition is reflected on the hydraulic conductivity of the sampled slurry which ranges from 4.25 $X10^{-11}$ m/s to 4.68 $X10^{-8}$ m/s and can be described as slow to extremely slow, therefore the potential of groundwater contamination by seepage from tailing ponds containing appreciable amount of clays is over estimated. The slurry waste is pumped to the holding ponds at initial total solid content that is probably ranged from 5% to 8% and allowed to settle and consolidate with time under the impact of gravity to an average of 37% solids level. The CEC of the sampled phosphatic clay tailings is generally increased with the increase of the fine fraction silt and clay (Fig. 3).

The plasticity characteristics (atterburg limits) of the study samples corresponding to low, high, and extremely high plasticity clays. The wide variation in the plasticity index reflects a significant volume change characteristic to "Fat" or plastic clays that plot above the A-line in the Casagrand plasticity chart shown in figure 4. The range of plasticity values for the analyzed samples is quite large, with liquid limit values generally between 61 and 171, and PI generally between 36 and 92. High values of liquid limit and plasticity index reflect high percentages of active clay minerals (Skempton 1953). The phosphatic clays fall in the CH range of the chart, indicating a highly plastic clay material.

The geochemical characteristics of the slurry samples show that the concentration of P_2O_5 (up to 24.27 Wt %) in the waste slurry makes the idea of reproduction of phosphate from the waste attractive. Major oxides analyses show that, the tailing sediments have higher silica, alumina, MgO, and K_2O, and lower Na_2O/K_2O and P_2O_5 than the original ore. Trace elements contents show that the waste slurry is rich in Zr, Li, Zn, Cd, and Ba while depleted in As, Nb, Mo, and Ni compared to the original fresh ore. The waste slurry is also depleted in Be, Ce, Co, Sc, Sr, and U compared to the weathered ore. The chondrite normalized REE pattern of the analyzed samples shows a general consistency for both tailing wastes and original ore. All the samples show light REE enrichment with distinct depression at Pr, and a flat heavy REE pattern. A distinct depression at Eu distinguishes the fresh ore from the waste slurry, the former exhibit a distinct depression while the later lacks this depression. The weathered ore exhibit the same REE pattern as the waste slurry.

The liquid waste shows a relatively high electrical conductivity indicating the presence of high ionic constituents. Chemical analysis indicates that calcium and magnesium are the dominant cations, while the SO_4^{-2} and HCO_3^{-1} are the main anions. The piper diagrams (Fig. 13 & 14) depicts the dominance of $CaSO_4$ and Mg $(HCO_3)_2$ in the liquid samples carrying unwanted wastes. The predominance of Ca and Mg may indicate much higher dolomite content in the slimes fraction. The liquid waste analyses indicate that the clay environment is a calcium magnesium sulfate bicarbonate dominated system, with slight acidity and a relatively high specific conductivity.

The adverse health impacts that might be associated with phosphate mining are stemmed from the inhalation of particulate emissions and the intake of heavy metal and other elements and oxides, either from the mining activates or from the direct application of the phosphatic fertilizers. Radiation hazards are also of concern as the phosphates of the Abu Tartur mine are proved to have Naturally Occurring Radioactive Materials (NORM). The present work indicates that, the waste slurry is rich in MgO as well as Zr, Li, Zn, Cd, and Ba compared to the original ore. Some of these elements (Ba, Cd, Pb, Cr and Zn) are reported with their high toxic effects in the cellular health and body physiology.

In spite of lack of efficient monitoring system at the Abu Tartur mine-head and absence of any quantitative estimate of mine effluents, once the current pollution status at the mine site was determined, precautionary ecosystem measures need to be taken as appropriate as possible. Protecting the residential area from the adverse impacts of mining activities could be achieved by constructing green fans around the residential area, wetting the instruments and roads by using water sprays, reducing drop heights, covering conveyors and trucks, using hooding material and enclosures during screening operations at reorientation points, and transferring the air to air pollution control points. Appropriate tailings management include tailings treatment before final disposal in landfills or other destinations, slurry thickening before transport and disposal, appropriate design of tailings impoundments, process water recovery, treatment and recycling, evaporation and restoration of the site.

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