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Combined Seismic Refraction and Geomagnetic Surveys on Hills of Industrial Wastes of Gypsum in Aqaba for Stability Hazards

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ABSTRACT

This article deals with engineering stability against subsidence in a geological context. The Fertilizers' Factory in Aqaba/Jordan has been established in 1982. The factory disposes its industrial wastes of gypsum behind the factory since its establishment. 25 million tons of wastes had been accumulated and formed hills of gypsum which cover an area of about 1 km^2. 20-25 % of produced wastes are moisture. In november 2005, about fifty thousand cubic meters of water flooded suddenly from the hills which overlook the factory from the eastern part. These alarming phenomena led to the current study. Accompanying seismic refraction and geomagnetic investigations revealed areas of possible collapse and also assisted in subdividing the area into risk zones, where the seismic refraction results allowed delineating thickness of gypsum all over the area, while geomagnetic surveys allowed delineating nature of cavities in the hills.

On the other hand, the mentioned investigations have been used to deduce amounts of entrapped water inside hills, which were found to be around 2 million cubic meters that are still entrapped in the hills at a depth of 12 meters.

KEYWORDS: Gypsum wastes, Seismic refraction, Geomagnetic survey, Free water, Risk of collapse.

INTRODUCTION

The Fertilizers' Factory of Aqaba is part of the industrial complex which is located about 20 km south of Aqaba city in Jordan at the eastern periphery of the Gulf of Aqaba. During industrial processes the factory produces solid secondary gypsum ($CaSO_4.2H_2O$) with about 25% moisture content, which is considered for the factory as solid industrial wastes that can't be recycled or reused. High contents of impurities in the wastes prevent using them in other industries.

The followed solution by the factory for the daily produced huge amounts of the wastes (4-5 thousand tons/day) is to dispose them about 200 meters eastern of its location, where a permission was obtained from Aqaba Regional Authority at the time of the factory establishment 25 years ago. Accordingly, more than 25 million tons of gypsum wastes were collected at the eastern part of the factory, and formed hills of gypsum (Fig. 1).

Recently, dissolution voids, subsurface cavities and enlarging cracks on the surface and subsurface are considered as an alarming phenomenon in the huge bodies of gypsum hills, especially when accidents of sudden collapse at the time of trucking and disposing processes of wastes are done. In addition, sudden floods of entrapped water inside gypsum reached the factory threatening its eastern parts as has been reported by the factory's management.

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The mentioned report pointed to that the liquids started to flow from one of the hills in october 2005, and were estimated in volume at more than 50 thousand cubic meters. The liquid was a concentrated solute of a low pH.

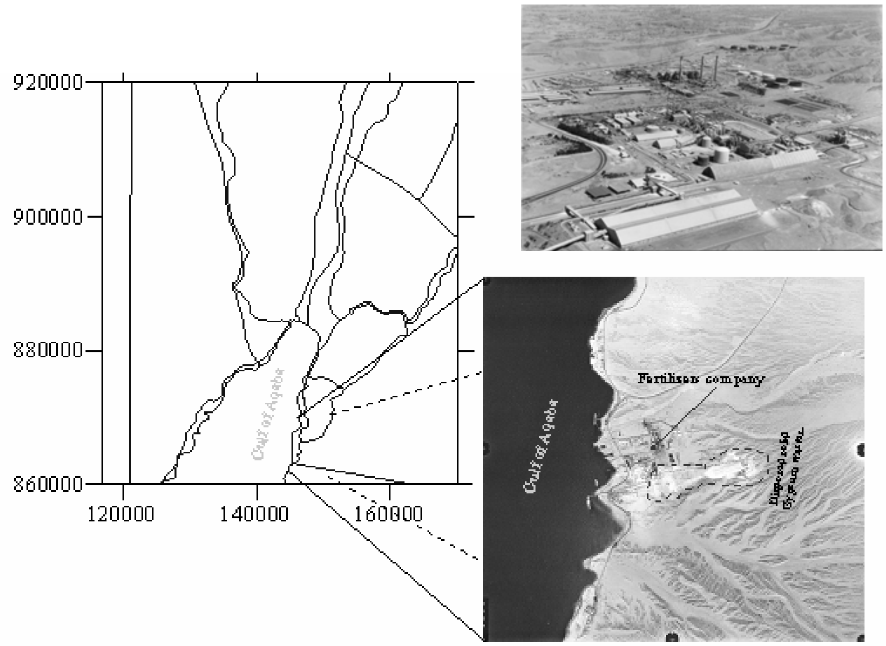

Figure (1): Location of the study area and the collected hills of gypsum. A photo of the factory is at the upper side to the right.

The relatively large holes –as this study expects- may form hazards of sudden collapse for the workers responsible for gypsum waste redistribution at the site. Also, this is the same on the trucks and bulldozers specialized for waste transportation. Besides possible injuries and/or loss in souls, these accidents -if taking place- may temporarily hinder industrial processes at the factory when emergency plans being applied at the time of risk leading to economic loss.

The potential causes of the mentioned sudden liquid floods, the nature of internal connections inside gypsum hills that calls to water circulation and collection and the presence of voids and their nature are still unknown.

This study aims at investigating the hills to assist the Industrial Complex to overcome the problem in the future, and to allow avoiding any possible engineering hazards of land collapse.

On the other hand, the vulnerable marine environment and aquatic life of the Gulf of Aqaba which is overlooked by the factory require good understanding of the problem, because the mentioned floods can reach the seawater either through the surface drainages or during subsurface groundwater discharge.

METHODOLOGY

In this research, geology and morphology of the hills in the disposal site and its surrounding have been defined, where the lineaments, joints and cracks have been measured in length, width and depth along with patterns and directions and registered using GPS of Garmin type and geologic compass. Features of collapse and collecting water in the lows of the hills have been also documented in location. This step allowed us to locate the required extensions of the profiles of the seismic refraction and the spacing between the points of the grids of the geomagnetic measurement. Depending on the findings, the site will be subdivided into micro-zones due to hazards of potential collapse.

Some calculations on the findings of the measurements will be done to approach water volumes inside gypsum hills. On the light of the results, capturing wells of the concentrated and low-pH solute will be located to avoid sudden flow in the future.

Geology and Climate of the Area

The area is a part of the south-north extending graben of the transform fault of the Dead Sea Rifting. Alluviums, alluvium fans and Pleistocene gravels are forming a thick cover which overlies the Granite Pre-Cambrian Basement in the graben (NRA, 1988). Elongated faults (north-south) are cutting the basin at the industrial complex site.

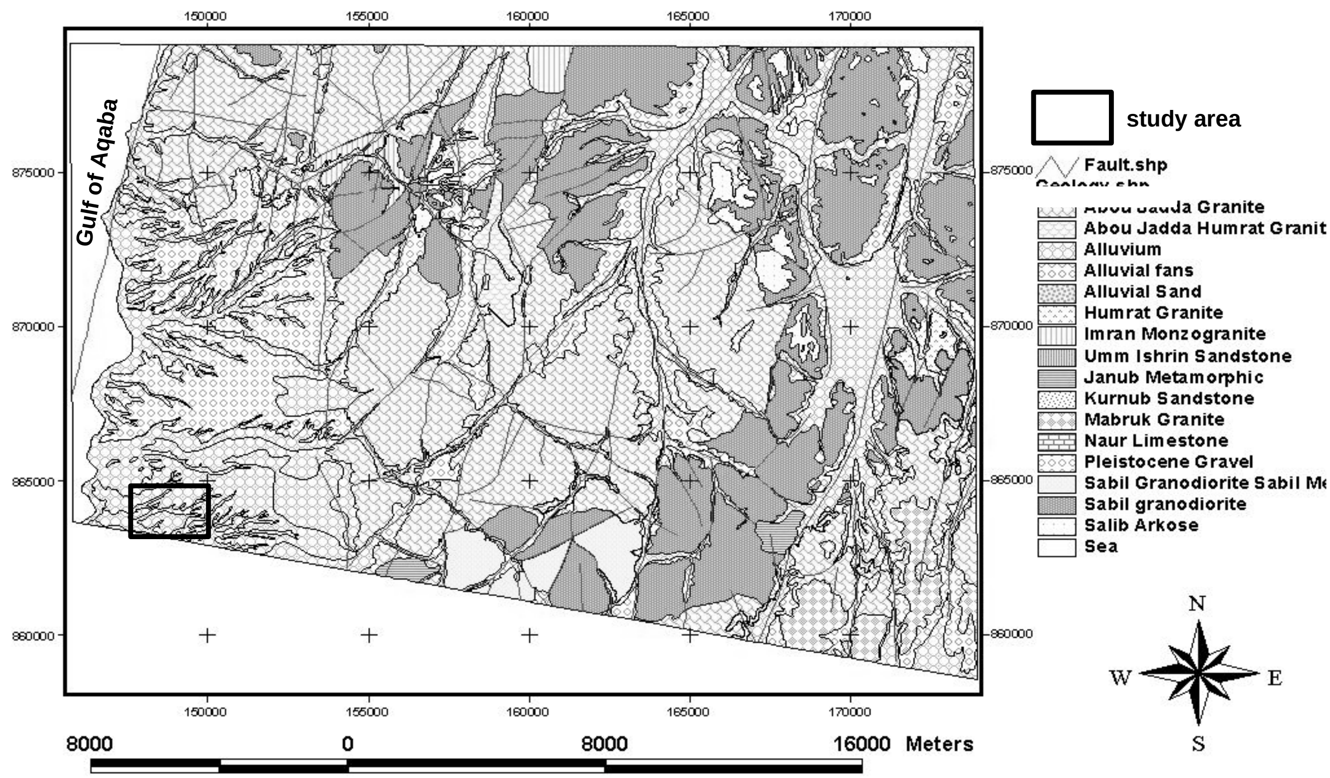

Figure (2): Geological map of the study area.

A vertical section in the basin shows the following lithological sequences:

0-25m. Coarse grained reddish to yellowish sandstone inter-bedded with gravel.

25-27m. Very fine grained, yellowish, sandy silt.

27-34m. Reddish, ferrogenous, coarse to medium grained, unconsolidated sandstone.

34-36m. Very fine grained, reddish and yellowish sandy silt.

36-42m. Reddish, coarse to medium grained unconsolidated sandstone.

42-44m. Flat lying younger terrace material of fine to coarse grained sand with some gravel.

A GIS based geological map obtained from the Natural Resources Authority of Jordan (NRA) (2005) (Fig. 2) shows the different rock units in the area.

In general, the climate of the study area is dry and hot. June, july and august are the hottest months of the year. During these months, the average monthly temperatures range between 30.6 and 32.1 ºC. December, january and february are considered as the months of winter. Mean temperatures are ranging between 14.9 and 17.6 ºC. The proximity to the Gulf of Aqaba and the changes in the topography play a noticed role in the variation of the temperature in the different locations of the city. The most moderate months of the year regarding the temperature are march-may and september-november. Rainfall amounts are around 37 mm/y, and evaporation rates exceed 90%, thunder storms may take place and form relatively destructive floods (Al-Farajat 2002).

Nature of Gypsum Waste Hills

Hills of gypsum extend with a width of about 1000 meters directing northwest – southeast, while they extend with a length of about 1500 meters directing northeast – southwest.

(a) **(b)**

Figure (3): (a) Transportation belt of gypsum wastes. (b) Redistribution of wastes in the disposal site.

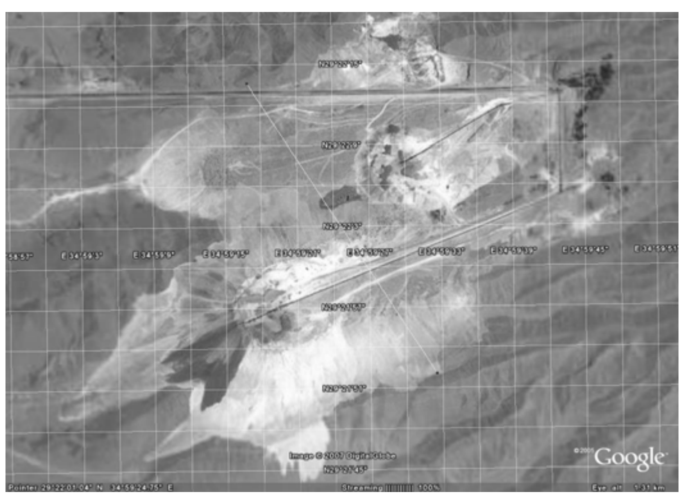

Figure (4): Tone of colors of gypsum hills pointing to relative age of them (Google Earth, 2008).

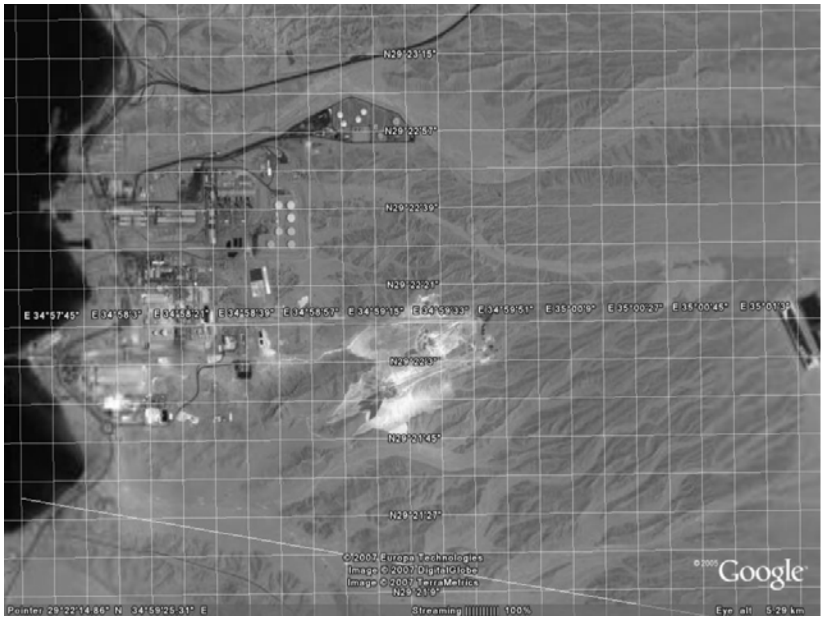

Figure (5): Space photo showing gypsum disposal site (white color) surrounded by coastal wadis.

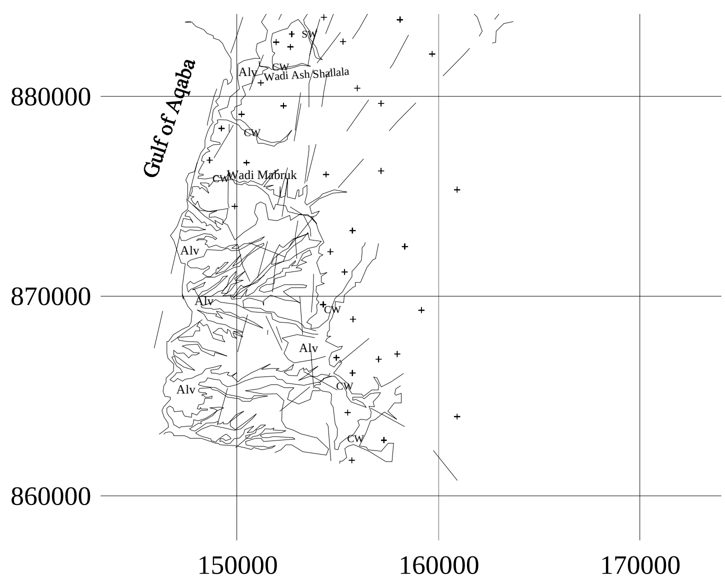

Figure (6): Extension of drainage systems of coastal wadis that drain the highlands.

Figure (7): Some joints and cracks in the gypsum hills.

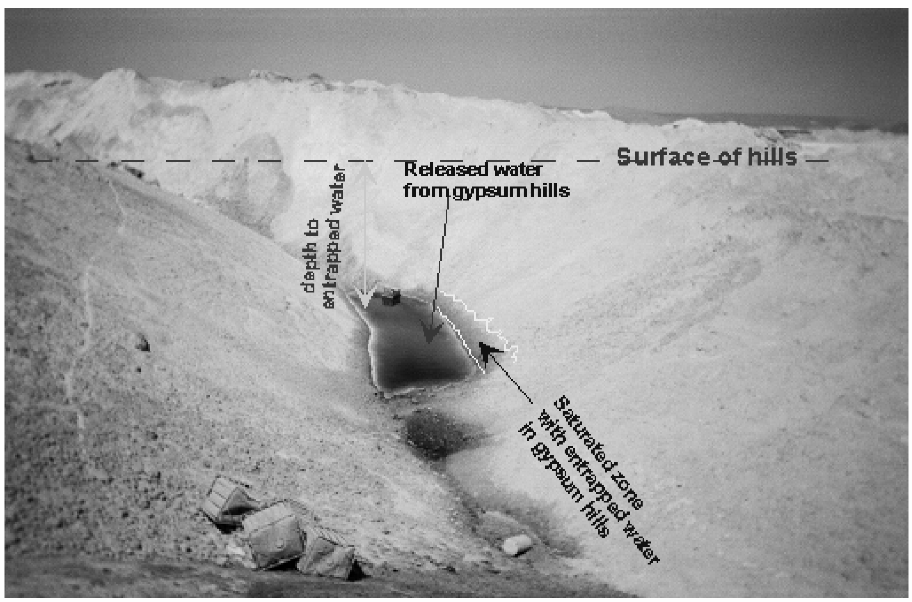

Figure (8): Gypsum water collected in a low area in the gypsum hills.

At the end of manufacturing processes in the factory, the solid wastes of gypsum are transported using long moving belts. The daily accumulation of the wastes led to hills that covered the whole area to the eastern part of the factory (Figures 3 a, b).

Sharp and dark tones of grey colors shown in Figure (4) point to that northern parts of the hills are older that those appearing with a lighter white color in the southern parts.

The hills are overlaying sub-wadis which are part of the drainage system of the area and reach the eastern part of the gulf water. They are bounded by two major wadis from their northern and southern parts. A hill of recent sediments seems to intersect partially the hills from the western part. The whole area slopes towards the sea. The bedrock under the hills is not flat, and it forms of extensions of the wadis surrounding the hills as appears in Figure 5.

Figure (6) shows the coastal wadis surrounding the disposal site of gypsum wastes. Floods from upstream after or during a flash storm may enhance dissolution of gypsum along the formed cracks and joints by widening their walls. Accordingly, the nature of these cracks and joints was investigated.

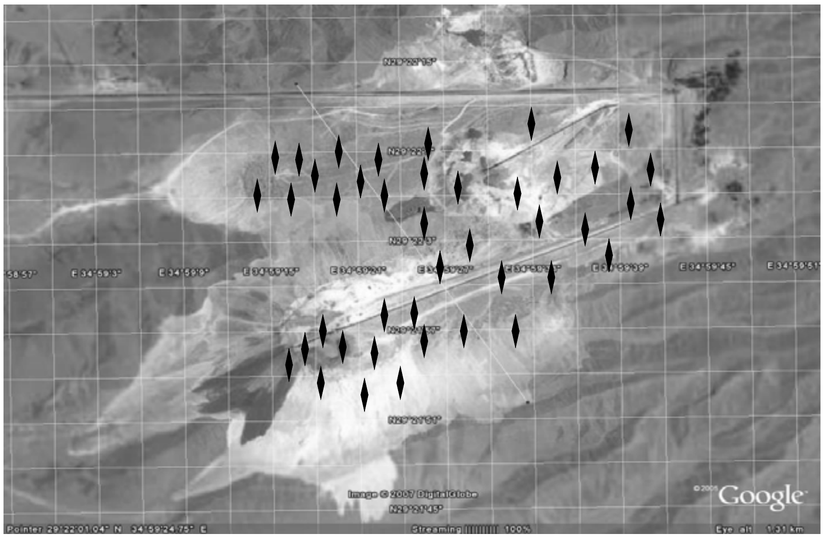

Figure (9): Locations of the conducted seismic refraction profiles (black polygons).

Figure (10): Applying field survey of geomagnetic method on gypsum waste hills.

The joints were found to extend to depths of more than 10 meters, and can reach in some cases the body of the collected entrapped water inside gypsum hills, or at least penetrate the unsaturated zone overlying it (Fig. 7).

Some gypsum water was found to be collected in a pool-like basin (Fig. 8). This is attributed to lateral leakage of gypsum water into this low topography within the hills. The water level in the pool indicates water table of gypsum water entrapped inside hills.

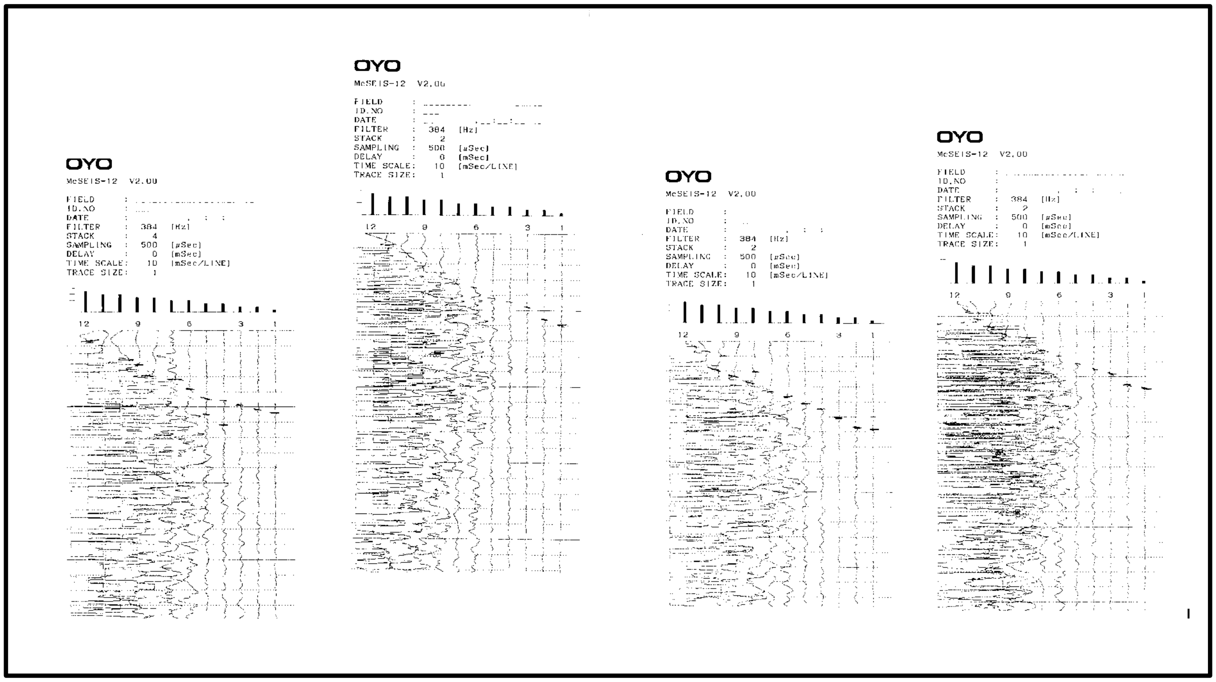

Figure (11): Sample of field data on seismograms represent picking of first arrivals of P-waves in the study area.

Table (1): First arrivals of P-waves obtained from the sample seismograms of Fig. (11).

distance in meters	first line arrival times (mili seconds)	second line arrival times (mili seconds)	third line arrival times (mili seconds)	fourth line arrival times (mili seconds)
5	10	8	8	5
10	17	10	10	10
15	23	15	12	18
20	27	22	22	21
25	34	29	25	24
30	38	32	32	32
35	39	39	35	36
40	53	45	42	42
45	55	46	45	45
50	58	49	48	48
55	63	53	56	55
60	64	54	60	58

Shallow Seismic Refraction Study

Shallow seismic refraction is a geophysical method that benefits from propagated waves by a hammer to delineate contacts between geological layers and geological structures, and also to decide rock types depending on velocity differences of the waves inside the layers. Waves produced are collected at different locations using geophones. Arrival times and distances between source of energy (hammer) and geophones are considered to calculate layers’ velocities and thicknesses.

Telford (1990) and Michaels and Woods (1996) emphasized the method in delineating depth to bedrock, and also in investigating near subsurface geology with karstic and sinkhole features.

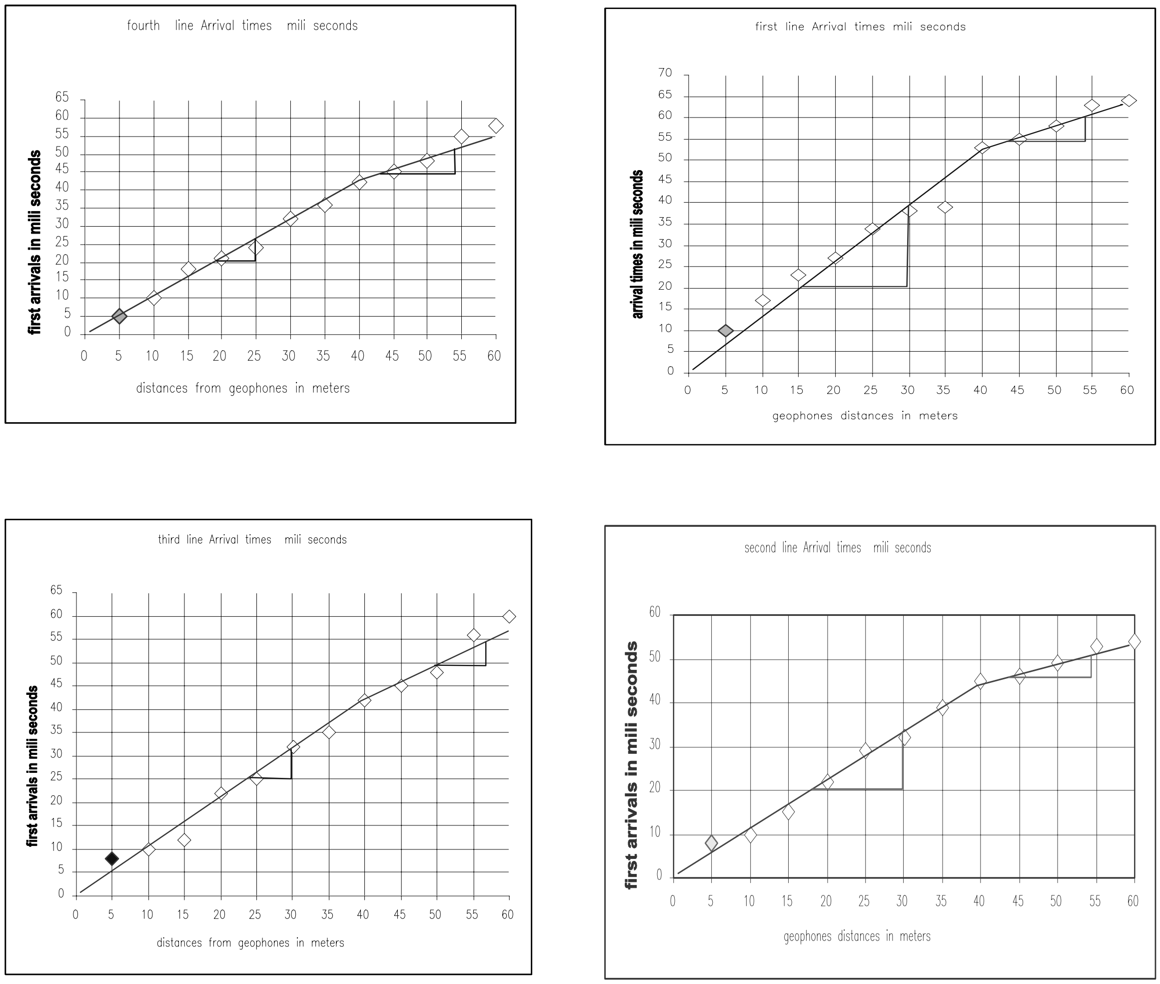

Figure (12): T-X graphs to calculate velocities of layers of gypsum and the overlaid alluvium.

A refraction seismic survey was conducted to measure compression-wave seismic velocities using OYO Seismometer, to aid in the evaluation of the depths of bedrock beneath gypsum hills, and on the other hand to define thicknesses of gypsum layers in the subsurface, and to realize any subsurface with cavities. Refraction seismic data were acquired along forty one lines selected through field survey phases in different places on the hills of the gypsum wastes (Fig. 9).

The seismic refraction data (Fig. 10) were acquired using a 12-channel seismograph (OYO type) with P-wave geophones, and a 5-kg sledgehammer source. The geophones were located 5 meters apart from each other and source impacts were made at various distances offset and along the seismic profile. The geophones were located on a straight line and distances were measured using a tape. The seismic data were stacked, nominally, eight times at each source point to increase the signal-to-noise ratio. Stacking, or signal enhancement, involved repeated source impacts at the same point into the same set of geophones. Overall, the quality of the seismic data was excellent and easily identifiable first breaks (first arrivals of seismic energy) were present.

Table (2): Thickness of gypsum layers in the sample profiles.

line	velocity of gypsum m/sec.		velocity of condensed alluvium m/sec.		thickness of gypsum in meters
1	833	gypsum	1818	compact alluvium	12.2
2	1000	gypsum	1909	compact alluvium	11.2
3	857	gypsum	1166	unconsolidated alluvium	7.8
4	1090	gypsum	1571	compact alluvium	8.5

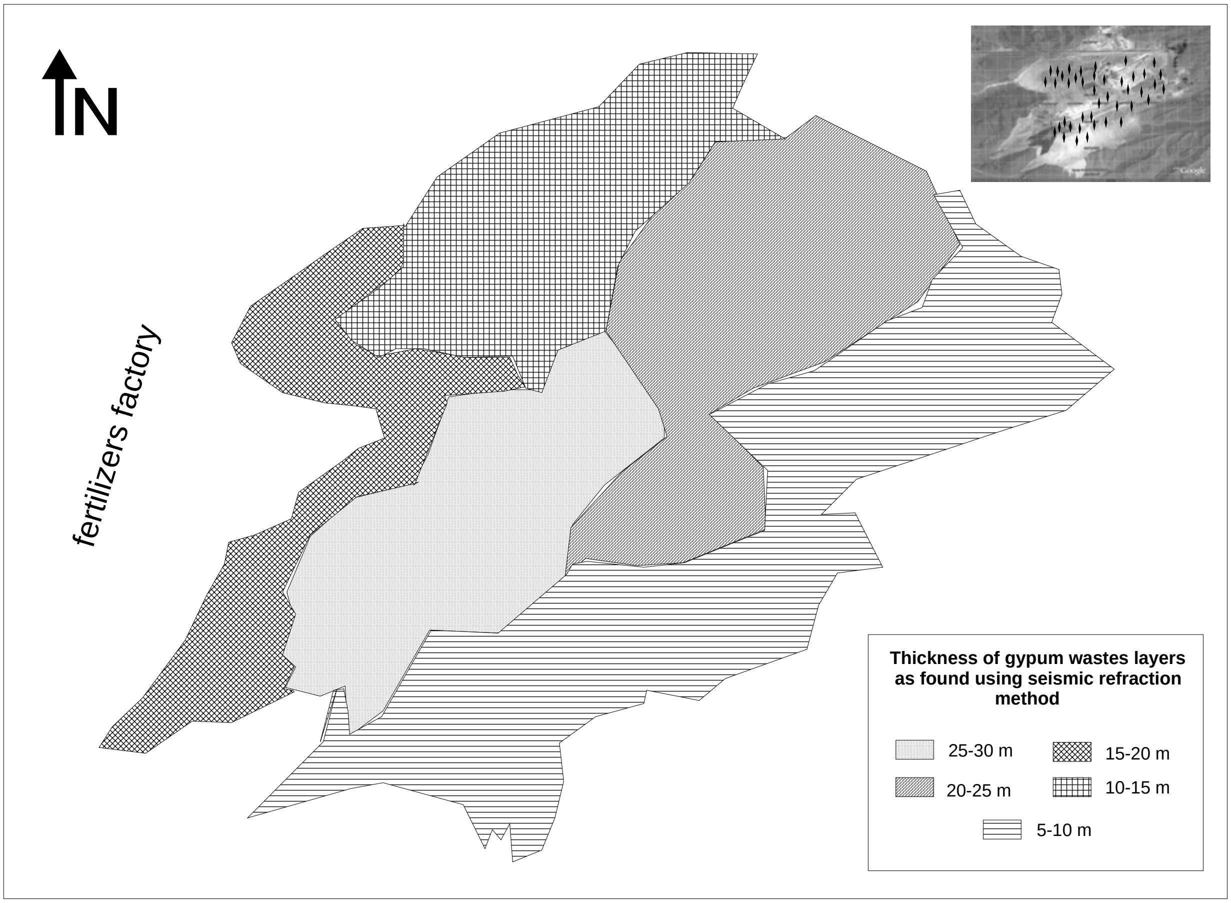

Figure (13): End map of the gypsum thickness as modelled using seismic refraction data.

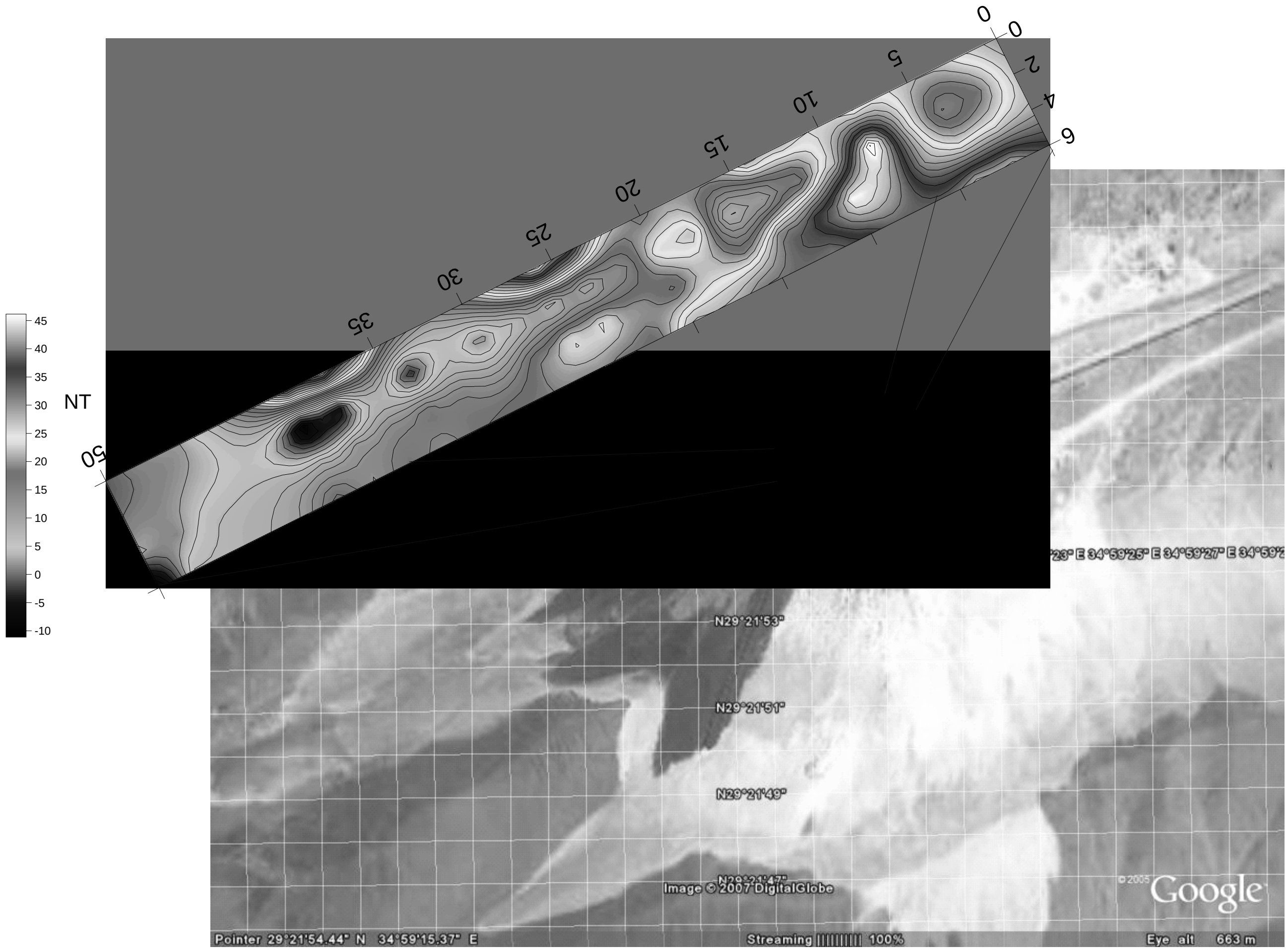

Figure (14): A sample from the results of the geomagnetic survey. Dark colors and closed contours decreasing towards the center point to possible presence of large voids or cavities.

The profiles were directed east-west so as to avoid the problem of dipping layers, because the general dip direction of the surface of the alluvium before disposing of gypsum wastes was towards the west. With that, both up and down dip measurements for each profile were applied to deduce presence of dipping layers. The contact between the land surface and gypsum layers along all profiles showed no dipping in south-north direction.

Geomagnetic Study

Magnetics are one of the most commonly employed methods in environmental and engineering site audits, remediation and assessment. The high level of use in industry, research and teaching reflects the versatility, efficient data acquisition, ease-of-use and effectiveness of magnetics for various types of applications.

Geologic mapping of soils is another application that is increasingly feasible with higher sensitivity magnetometers and highly sampled datasets.

The key to the use of magnetics is the ability to quickly find buried ferrous objects (related to human activity) that threaten the environment. This requires a basic level of experience in equipment operation as well as knowledge of different types of environmental and engineering targets and the types of anomalies to expect from each target. Generally, environmental and engineering targets provide large and definitive anomalies as they are located near the surface. However, they may be affected by cultural noise and near surface debris. These effects are mitigated by the use of a gradiometer (i.e. configuration with two sensors).

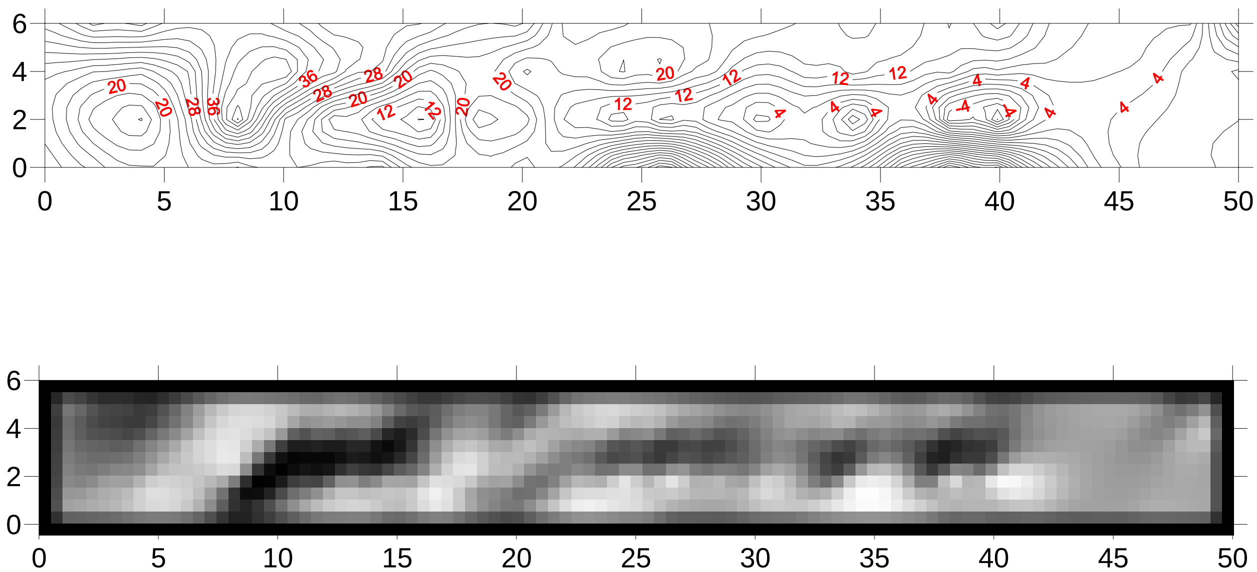

Figure (15): Representation of results using shaded relief.

Arzate et al. (1990) used the geomagnetic method in mapping cavities and voids in pre-Hespanic city of Teotihuacan in Central Mexico. After isolation of anomalies, he was able to delineate locations of voids. Contrast in gamma units between host rock and voids ranged from 100-200. The host rock was pyroclastic flows, while the voids were at depths of about 5-10 meters. Their volume ranged about 7-9 meters in diameter.

In this study, 100 profiles were applied directing east-west, using a Proton Magnetometer. The obtained data were corrected due to daily variations and depending on a reference station which was installed in the middle of the surveying area. Reduction to the pole was made because the area exceeded dimensions of 500x500 meters. The profiles were in lengths ranging between 20-200 meters depending on the locations of survey and accessibility to measurement points. The resolution of survey between points was each 2 meters, and about 2-10 meters between profiles (Fig. 10). The values of the corrected results ranged from 2 to about 46 NT after the baseline value of the base station has been reduced. The operator was asked to get rid of all metals that can disturb the survey process, and a reference station was installed in the middle of each profile to ease recording of daily variations for the purposes of data reduction. Measurement points were regular, and a 100 meter long plastic meter was used for this concern. No sun storms were detected at that day, in reference to the regularity of the readings.

DISCUSSION

Geological observations in the field point to that the area suffers karstic processes which are taking place inside the hills. It is worth to mention here that dissolution in rock formations (karst) can contribute to a severe damage to the projects and cause unwanted consequences of both human and money loss.

Karst topography is a landscape shaped by the dissolution of a layer or layers of soluble bedrock, usually carbonate rock such as limestone or dolomite. Due to subterranean drainage, there may be very limited surface water, even to the absence of all rivers and lakes. Many karst regions display distinctive surface features, with sinkholes or dolines being the most common. Some karst regions include thousands of caves, even though evidence of caves that are big enough for human exploration is not required. Karst regions contain aquifers that are capable of providing large supplies of water. More than 25 percent of the world's population either live on or obtain their water from karst aquifers. Natural features of the landscape such as caves and springs are typical for karst regions. Karst landscapes are often spectacularly scenic areas (White et al., 1989). Common geological characteristics of karst regions that influence human use of their land and water resources include ground subsidence, sinkhole collapse, groundwater contamination and unpredictable water supply. Much of the present knowledge on the hydrogeology of karstic regions is found in textbooks by Ford and Williams (1989) and White (1988). Engineering aspects in karst regions are discussed in textbooks by James (1992), Breznik (1998) and Milanovic´ (2000). Al-Farajat (1997) studied the role of karstification in the Tertiary rocks in north Jordan in enhancing human impacts on the local groundwater resources. He functioned the horizontal geoelectirc method to reveal extensions of the tunnels and caves.

The refraction seismic data (Fig. 11) were processed and interpreted. The general processing and interpretation flow consisted of the initial selection, or "picking", of the seismic first breaks. For the direct arrivals through the first layer, the velocity is computed by dividing the distances (relative to elevation and horizontal, versus slope, distance) from each source point to each geophone by the corresponding arrival times. Arrival times of the sample profiles of Fig. 11 have been listed in Table (1).

Using simple T-X graphs (Fig. 12), it was possible to calculate velocities of gypsum layer and alluvium beneath it, and to delineate contact between bottom of gypsum layers and top of alluviums overlaid by gypsum (Table 2). The profiles were documented due to geographical locations, and an end map of the gypsum thickness was produced (Fig.13). Thickness was found to range from 7 meters in the peripheries of the hills to more than 30 meters in the centres of the hills. In the areas where the disposal site covered coastal wadis (lows), the thickness was more than 25 meters, where sites covering elevated areas (saddles) were of a thickness of less than 10 meters. Shape and extension of drainage system covered by gypsum wastes appear clearly on the previous figure, and this emphasizes the role of seismic refraction method in such studies. Results have been used to build the risk map of engineering hazards, coming later in this article. Differences in elevations between outcropped surface of the alluvium in the disposal site and the elevations of gypsum hills were estimated by GPS, their values emphasize the thicknesses of gypsum layers revealed by seismic refraction method used here.

Laletsang et al. (2007) applied a seismic refraction on Lake Ngami, NW Botswana, to determine the structure and stratigraphy underlying the lake. A geomagnetic survey was also carried out along the same line. The seismic refraction showed a low velocity layer (400–1600 m/s) extending at the surface which revealed unconsolidated sediments and was underlain by more compact and saturated material with seismic velocities of 1600–3600 m/s. The magnetic profile showed a high that was attributed to shallow basement, and a magnetic low that indicated a thickened sediment section at the study lake. Schwarz (1990) detected potential of collapse features related to subsidence hazards in mining areas in Newcastle near Seattle, Washington. He attributed the reduction of seismic velocities in bedrock to distressed rocks. It is visible in Table 2 that layers of gypsum show a wide range of velocities, and this is attributed to weakness zones within refraction lines.

The corrected geomagnetic data have been plotted using Surfer 8.0 and then overlaid on a space photo of the area under study (Fig. 14). Black dark colors point to low magnetism, which in turn points to cavities and voids. Closed contours with values decreasing towards the center point to areas with suspected zones to contain low magnetism, which refers to the absence of mass, in other words, cavities or rests of dissolved gypsum.

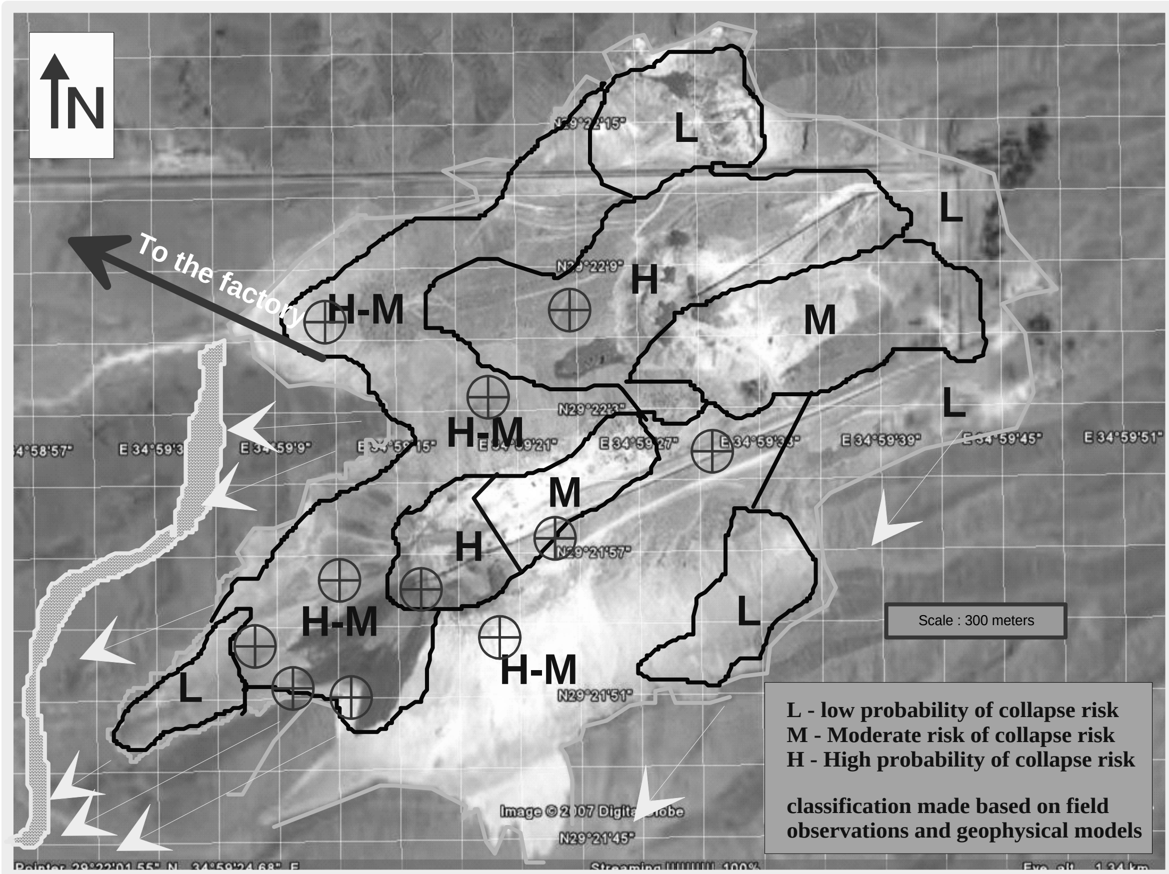

Figure (16): End map of engineering risk produced after integrating field survey with seismic and geomagnetic studies. Crossed circles show suggested locations of capturing wells to be drilled in the hills to extract gypsum water solutes.

More light was shed on the results to allow defining weakness zones and presence of cavities. Consequently, Figure 15 was produced to show cavities on shaded relief using surfer 8.0. Shaded relief map allowed distinguishing cavities clearly as lows, while they appeared like closed contours with values decreasing towards the centers. Applying the "half-width" method mentioned in Reynolds (1997), it was possible to estimate relative widths to the voids to be about 2-6 meters. The voids are taking spherical and elongated shapes. Elongated shapes are attributed to widening cracks and joints inside gypsum. The extension of anomalies reveals diameters of the voids inside gypsum hills of about 0.5-2 meters.

Areas in the middle of the hills have been found to show higher risk than other areas. Areas on the surrounding were found to show low to moderate risk. Thickness of gypsum layers and presence of cracks and joints played a significant role in enhancing the formation of cavities. In this study, it has been proved that reduction in velocity of primary waves in areas with void features indicates the presence of voids. Closed anomalies of magnetic surveys decreasing towards the center reflect voids. Applying the simple "half-width" method on geomagnetic results can reveal depth to voids, while the extension of the closed decreasing anomalies to the center reveals their shape.

Lines with reducing velocities in the seismic survey have been documented in location and used to delineate suspected areas with collapse potentials in gypsum hills. These areas show spatial correlation with areas with subsurface voids revealed by geomagnetic survey. This validates the results.

The mentioned voids are expected to be filled with gypsum water drained from the body of the hills with gravity. Johnson (1981, 1985 and 1987) studied the karst in salt rocks. He emphasized that the circulating water increases the karstification process by dissolving more minerals even if it was saturated, when mixing processes between water of different recharging phases take place. Such a thing is typical in the study area where different water types from the named voids get in contact inside the hills. Reaction between circulating water and gypsum leads to the enlargement of the cracks and joints inside.

Al-Farajat (2002) quantified runoff amounts in the heavy precipitation events in the coastal wadis that drain the highlands in the catchment where the disposal site is located to exceed 200,000 cubic meters. Accordingly, the amounts that strike the disposal site from the eastern part are around 5000 cubic meters coming from the wadis surrounding the site. In respect to the previous remark and regarding the presence of the cracks in the hills, gypsum hills are prone to water recharge and this will enhance dissolution processes. Shape and major directions of joints and cracks inside gypsum bodies are important because they lead to the formation of cavities with dissolution processes of gypsum by the aggressive water entrapped inside. Water circulation within internal joints and cracks contributes in enlarging voids and creating cavities.

The formed cracks were investigated at site, and found not to show a specific pattern of directions or any trend. The directions were random but elongated with lengths of some tens of meters in best cases, and in widths ranging between a few centimeters and about a half meter in best cases.

Through the phases of the field investigation, it was observed that fresh disposed gypsum includes many cracks and joints. This is attributed to that some of the entrapped water gets evaporated and this leads to the shrinkage of gypsum at the top. Another cause is that continuous collecting of gypsum amounts exposes their large body to reform itself to reach an equilibrium state to resist gravity.

Site engineers of the factory who are responsible for redistributing gypsum wastes used to refill the mentioned cracks with fresh wastes, and then to press them firmly trying to overcome the possible physical stability problem in hill peripheries that may take place. This is not an enough solution, because walls of the cracks during formation were exposed to evaporation and drying processes, and when they were refilled with fresh gypsum wastes, they have not been stuck firmly. This in turn enhances possibilities of entrapped water to circulate along the weak walls and to enlarge those forming voids and cavities in the unsaturated zone.

The whole area of the hills was calculated to be around 1 km^2. Seismic refraction profiles indicated thicknesses of gypsum layers of around 20 – 30 meters. This makes a volume of hills around 25,000,000 cubic meters. Taking into consideration the density as has been found in the labs in this study of the gypsum samples which is around 2.5 gm/cm^3, it makes a total weight of gypsum wastes in the area of about 25 million tons. Total water content (free and water in chemical lattice) in fresh gypsum samples was found to be around 25% by drying method.

According to the previous facts, we have around 6 million cubic meters of water that should be collected in the bottom of the hills. This can be true when all the system is closed and all water is free and not chemically related, but taking evaporation processes and water infiltration into soil into consideration, then we must consider amounts of collected water of not more than 2-3 million cubic meters.

Thicknesses of gypsum have been mentioned before to be around 25 meters, where the depth of water in the pool of Fig. 8 was found around 22 meters. This leads to that water layer present in the hills is of a thickness of about 2-3 meters. In respect to the previous facts, an area of 1 km^2 of gypsum hills and a layer of water of about 2-3 meters thick make a volume of collected water of around

2 million cubic meters. Both values of water volume calculated in different methods are in agreement with each other.

Geomagnetic results accompanied with seismic results emphasized the presence of cavities and voids in shapes and locations, and this allowed delineating zones of risks (high, moderate and low). Making use of seismic results and using the obtained results from the geomagnetic survey, this allowed plotting the end map of collapse risk (Fig. 16). The Figure was produced by gathering results of Fig. 13 with the field observations of gypsum water pools, highly jointed and fractured areas, zones of seismic refraction lines with decreasing velocities, and voids revealed by the geomagnetic method. The Figure shows zones of protection, risks of collapse and possible gypsum water flow. All of these are plotted on a space photo of the gypsum disposal site. Besides the use which can be made of the Figure, the study recommended the following points to the management of the industrial complex to prevent accidents of flow of gypsum water and possible collapses in the future.

1- A hedge or trench (shown in Figure 16) should be installed, or wires should be placed by bulldozers to avoid reaching of gypsum water to the factory, in the case of any sudden flow of gypsum water.
2- A drainage net should be made to lead any possible flow of gypsum water into the main wadi system directly located to the southern part of the factory, and drained into the sea or been collected.
3- Wells shown in Figure 16 can be drilled to discharge and collect gypsum water to avoid its risk, but it should be known that discharging the mentioned water will allow excessive formation of empty voids and cavities and lead to engineering risk of stability.
4- Installing pipes beneath new gypsum wastes disposing sites to drain water is a good solution.
5- Gypsum wastes are related directly or indirectly with environmental problems that they can cause. Hills of gypsum should be paid more attention and they are in need of more studies regarding their huge amounts.

SUMMARY AND CONCLUSIONS

Gypsum hills have been found to cover areas of about 1 km^2 with weights of more than 25 million tons. Layers of gypsum in the hills were found to have thicknesses ranging between 5-30 meters. Entrapped water of gypsum inside gypsum hills was found at depths of more than 12 meters. Effective thickness of water layers was found around 2-3 meters. Cracks and joints are the cause why cavities and voids form because they get enlarged with the circulating aggressive water of gypsum inside the hills. Mentioned joints and cracks have been found not to show a specific direction pattern and to be elongated and deep. Some of them are connected and shallow. They are of several meters length and some centimeters width and reach depths of a few meters. Amounts of water entrapped inside the gypsum hills were approached in different methods to be around 2 million cubic meters. Water entrapped is found in cavities and joints-like voids; these are in connection with each other and may allow good amounts of water to be discharged when an accident of flow takes place, like that in 10/2005 mentioned before in the internal reports of the factory. Risk of new flow of water from gypsum hills is possible and may badly affect safety, health and economic aspects.

The accompanied shallow seismic refraction and geomagnetic methods proved to be fit in delineating and mapping of holes and karstic features in gypsum wastes and similar salt rocks.

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