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## **Editorial Preface**

We have great pleasure in presenting the First Issue of the Fifth Volume of *The Jordan Journal of Earth and Environmental Sciences* (JJEES), a refereed and indexed scientific journal issued by the Higher Committee for Scientific Research with the support of the Scientific Research Fund of the Ministry of Higher Education and Scientific Research in the Hashemite Kingdom of Jordan. The Deanship of Scientific Research and Graduate Studies at the Hashemite University is responsible for preparing and publishing this journal.

The Chief Editor, on behalf of the editorial board, extends his sincere thanks and gratitude to the former Chief Editor and the editorial board for the good efforts they exerted to make this journal a success during the past period, over which four volumes, included dozens of scientific research papers on the various areas of Earth and Environmental Sciences, had been published.

The editorial board of this journal will put their utmost efforts to continue with publishing high quality refereed scientific research, that will be of paramount interest to researchers in academic institutions and vocational institutions, be they local, Arab and/or international. The editorial board looks forward to receiving research from such institutions. Such contributions will be received with great accuracy, honesty, professionalism and quick review process. They will be published as soon as possible according to the highest scientific standards, to be available for specialists, interested parties and the research community at large.

Prof. Dr. Eid Abdel Rahman Al Tarazi

Editor-in-Chief

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# Geochemical evaluation of groundwater quality in Abakaliki area, Southeast Nigeria

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## Abstract

The study area comprises Abakaliki town and the mineralized villages in the south, 14km away from the town. It lies between latitudes 6008'N and 6024'N, and longitudes 8000'E and 8016'E, and is underlain by the Abakaliki Shale which belongs to the Asu River group of Albian age. The study aimed at determining the groundwater quality of the area as evaluated from both physical and chemical conditions. Eighteen (18) parameters, (11 chemical and 07 physical) were analyzed for each of twenty (20) samples collected from three different sources; sixteen (16) from boreholes, three (03) from hand-dug wells and one (01) from pipe borne town water supply. Spectrophotometer of HACH DR/ 2010 series was used to analyze the ions. The laboratory results were compared with water quality criteria according to the World Health Organisation (WHO, 2004), European Union (EU, 1998) and United States Environmental Protection Agency (USEPA, 2004) for drinking water. Results showed that about 50% of the samples are polluted with nitrate (NO<sub>3</sub>) with values above the maximum permissible limit of 50mg/l in many places. Concentrations of Fe are also above the permissible limits of 0.30mg/l, in some places, especially in the southern part of the study area. The sources of nitrates are suspected to be from agricultural fertilizers as well as sewage effluents. The iron is suspected to be from dissolution of iron-rich ore minerals (siderites and pyrites) which occur in the southern part of the area. The groundwater of the area is moderately hard (due to bicarbonate (HCO<sub>3</sub>)) and fresh (due to TDS < 1000 mg/l at temperature range of 270C to 310C), and is dominantly alkaline.

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**Keywords:** Groundwater Quality, Aquifer, Contamination, Chemical Elements.

## 1. Introduction

The importance of groundwater as an alternative water supply is increasingly recognized in response to escalating costs of portable surface water (Emmanuel et al., 2008), especially in the developing countries. By estimation, approximately one third of the world population use groundwater for drinking and other purposes (Zottan, 2004). This enormous use of groundwater has resulted to over- abstraction and consequently, the drastic reduction in groundwater level, which is sometimes accompanied by degradation of its quality. Among the various reasons for over-abstraction, the most serious are the poor availability of portable surface water and the general belief that groundwater is purer due to the protective quality of the soil cover. But then, the soil which is supposed to be protective, is most often not free from adverse effect of chemicals from indiscriminate discharge of sewage and solid wastes, agricultural/industrial effluents especially in developing countries, and natural mineralization, all of which contaminate the groundwater via the soil partition, and cause health hazards. Contamination of groundwater in Abakaliki area, southeastern Nigeria is believed to be high because of the availability of sulfide ore deposits, and because anthropogenic and geogenic effects increase the rate at which these mineral deposits weather and release

elements into the soil. Subsequent rainfalls leach the elements from the soil zone into the groundwater regime through the structural pathways in the sediments. The plume disperses within the groundwater environment and introduces some hydro geochemical reactions between the groundwater and the hosting rock. According to Prasanna et al. (2011), geochemical processes occurring within the groundwater and reaction with aquifer minerals have profound effect on water quality. That is why Atwia et al. (1997) stated that the hydro geochemical character of groundwater in different aquifers over a space of time has proven to be important in solving groundwater management problems. It is therefore important that the quality of the groundwater of Abakaliki area where iron, sulfate, bicarbonate, nitrates, chloride, calcium, magnesium, sodium, and potassium, which are associated with Pb-Zn mineralization are commonly present. Although the mining of the lead-zinc has been abandoned, the devastating effects on the groundwater may have continued to linger. Thus, the poor handling of mine drains constitute a potential threat to the quality of the usually shallow groundwater in the mining axis of Abakaliki (Uma, 2004). This study aimed at evaluating the groundwater quality in the area as such evaluation will assist in groundwater resource management as stated by Atwia et al. (1997).

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## 2. Local Geology and Hydrogeology

Abakaliki, the study area lies between latitudes  $6^{\circ}08'N$  and  $6^{\circ}24'N$  and longitudes  $8^{\circ}00'E$  and  $8^{\circ}16'E$ . It includes Abakaliki town and the highly mineralized rural communities (Amagu, Ameri, Enyigba and Ameka) which are about 14km, south of the metropolis (fig 1). The area is underlain by poorly bedded shales of the Abakaliki Shale Formation, which is part of the Asu River Group of Albian age. The shales are dark, occasionally sandy with intercalations of fine-grained sandstone, mudstones and limestone lenses. They are often calcareous and pyritic, because, the Formation is locally rich in ammonites, such as the mortoniceras and elobicerias, which paleo-ecologically indicate that the Asu River sediments were deposited under stagnant shallow marine environment

(Reyment, 1965). According to Offodile (2002), Abakaliki Shale is about 200 meters thick. Dip varies from 50 at Abakaliki town to the highest value of about 800 around Ameka hill. Pyroclastics, tuffs and agglomerates occur along the axis of the Abakaliki Anticlinorium (a major structural feature of the Benue Trough which houses the Abakaliki Basin and the anticlinorium) and within the series of hills at the central part of Abakaliki town. The Abakaliki Shale sandwiches many mineral veins, anomalous bodies and mineral lodes, all of which are associated with lead-zinc mineralization in the area. Hydrogeologically, the Abakaliki Shale forms an aquiclude, which is a problem to groundwater occurrences, but it is aquiferous where the shale is extensively weathered and fractured.

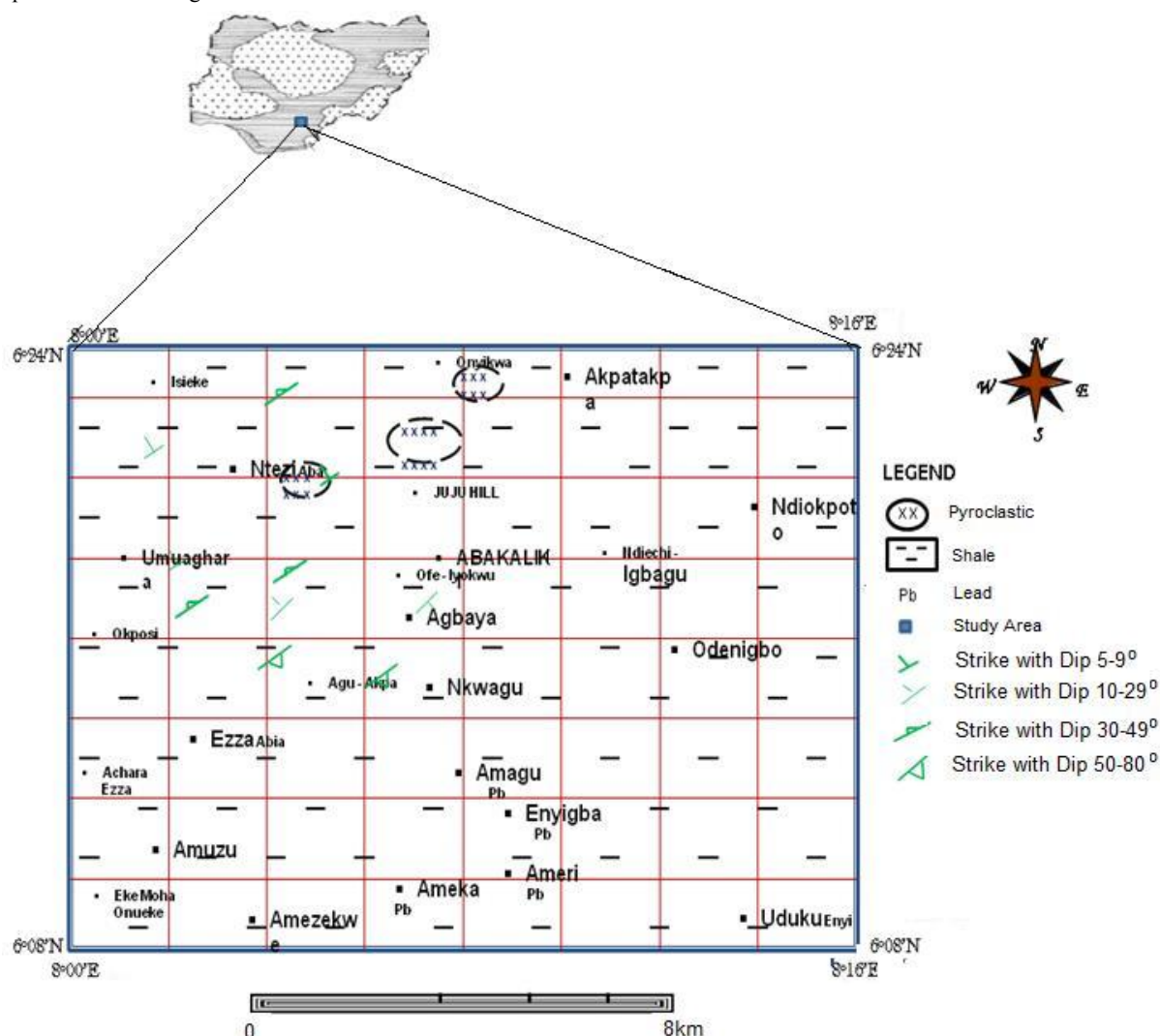


Figure 1. Geological map of the study area

## 3. Methodology

### 3.1. Sample collection

Sample locations were determined using a Global Positioning System (GPS) of eTrex model and were plotted in Fig 2. Twenty (20) groundwater samples were collected from different locations spread across the study area, sixteen (16) from boreholes, three (03) from hand-dug wells and one (01) from the city water supply

reservoir. The reservoir sample was collected in order to compare the quality of the pipe-borne water with that of the groundwater. Each sample (groundwater and pipe-borne water) was collected and filtered with 0.45 micro meter filter membrane into a clean 1 litre plastic water bottle and labelled according to the location name. Each plastic bottle was rinsed with the same water to be sampled before the collection to avoid any contamination from the bottle. Physical parameters such as the electrical

conductivity (EC) and temperature relevant to the study were measured in situ using a portable WTW LF 90 conductivity meter. pH was also measured in-situ using

HACH pH sension meter. All samples were transported for analysis within 24 hours after collection.

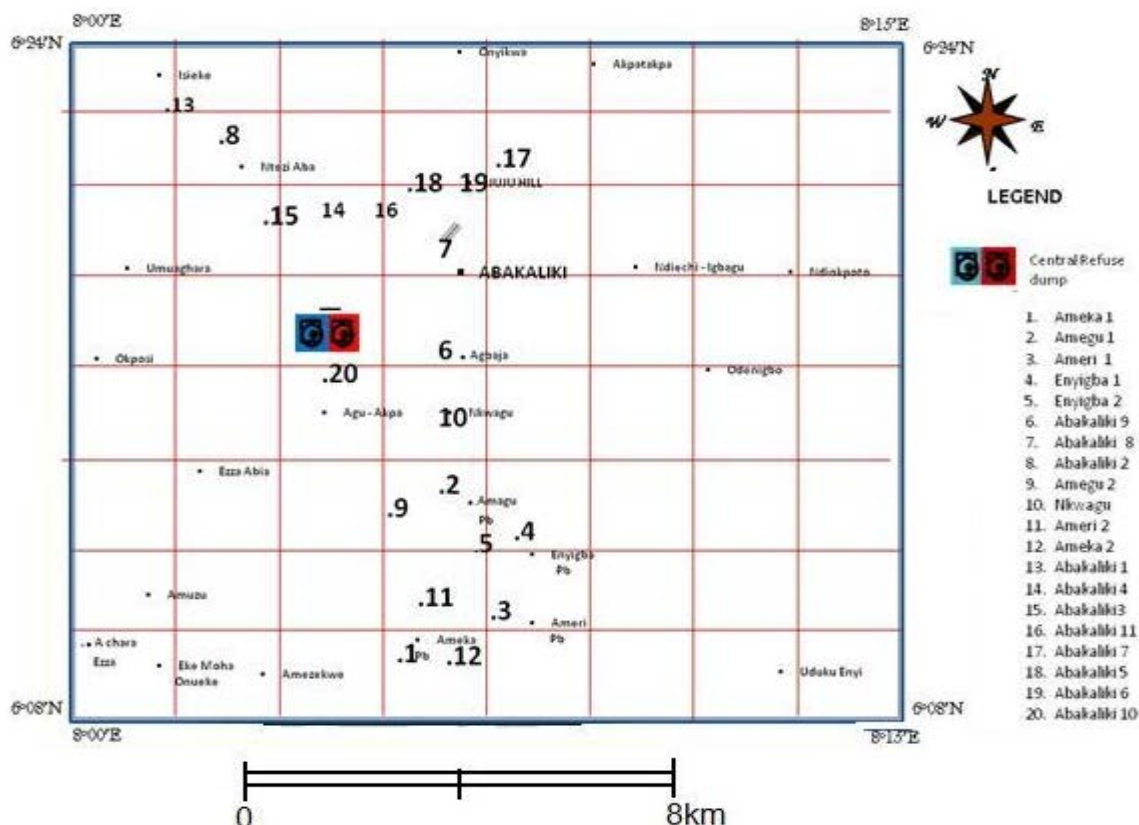


Figure 2. Map showing the distribution of sampled locations

### 3.2. Laboratory Analysis

Fifteen (15) parameters were analyzed for, in each of the 20 samples, giving rise to 300 results. The analytical procedure was according to the World Health Organization (WHO, 2004) as follows:

Total Dissolved Solids (TDS) was measured with TDS meter while Total Suspended Solids (TSS) was determined photometrically with the HACH DR/2010 spectrophotometer at the wavelength of 810nm. The instrument was zeroed with de-ionised water while the sample was mixed thoroughly before being placed in the sample holder and measured. Total Solids (TS) was calculated arithmetically from the other parameters using the equation

$$TS \text{ (mg/l)} = TSS \text{ (mg/l)} + TDS \text{ (mg/l)}.$$

Alkalinity was determined titrimetrically with standard solution of sulphuric acid ( $H_2SO_4$ ). The sample was titrated with the 0.1N  $H_2SO_4$  using phenolphthalein and methyl orange indicators. 100ml water was measured into a conical flask and 3 drops of phenolphthalein indicator added. When the sample remained colourless, it indicated in all cases that phenolphthalein alkalinity was zero. A few drops of methyl indicator was then introduced, and the titre value noted when the first perceptible colour change from yellow to orange took place. Alkalinity was calculated as

$$\text{Alkalinity (HCO}_3^-) \text{ [mg/l CaCO}_3\text{]} = \text{Volume of 0.1N H}_2\text{SO}_4 \text{ acid used (ml)} \times 50$$

Turbidity was determined spectrophotometrically at wavelength of 450nm on the HACH DR/2010 spectrophotometer. The instrument was zeroed with

filtered deionised water (the blank) while the turbidity was measured. Total Hardness was determined titrimetrically using 0.01N tetra sodium salt of Ethylene Diamine Tetra Acetic acid (EDTA). 50ml of each water sample was put in the conical flask; 1 ml of buffer hardness solution was added, followed by 2 drops of a solution of eriochrome black indicator. The water sample was immediately titrated with continuous stirring using the standard EDTA till the end point when some blue colouration was observed. Total hardness was calculated as

$$CaCO_3 \text{ (mg/l CaCO}_3\text{)} = \frac{\text{Volume of 0.01M EDTA (ml)} \times 1000}{\text{Volume of water sample taken (ml)}}$$

For the determination of Calcium Hardness and Bicarbonate, the water sample was titrated using 0.01N EDTA solution. 50ml of each water sample was placed in the conical flask followed by 2 ml 10N sodium hydroxide and 3 drops of calcon indicator. The end point was taken when the colour changed. Calcium hardness was calculated as

$$\text{Chloride (Cl)} \text{ (mg/l)} = \frac{\text{Volume of silver nitrate solution used (ml)}}{\text{Volume of water sample taken (ml)}}$$

For the determination of Chloride, 25ml water sample was placed in a conical flask followed by 1ml of solution of potassium chromate indicator. The sample was titrated with a standard solution of silver nitrate. The end point was when the colour changed from yellow to dirty brown. Chloride was calculated as

$$\text{CaCO}_3 \text{ (mg/lCaCO}_3\text{)} = \frac{\text{Volume of 0.01M EDTA (ml)} \times 1000}{\text{Volume of water sample taken (ml)}}$$

Nitrate was determined using the HACH DR/2010 spectrophotometer by the principle of the cadmium reduction method. The instrument was zeroed with a fresh sample and the nitrate measured at a wavelength of 500nm while placing the treated sample in the sample holder. Sulphate was determined using the HACH DR/2010 spectrophotometer by the principle of turbidimetry. The instrument was zeroed with a fresh sample and the sulphate measured at a wavelength of 450nm while placing the treated sample in the sample holder. Iron, Calcium and Magnesium were determined from the water samples using the Bulk Scientific Atomic Absorption Spectrophotometer (AAS), 200A Series model while Potassium and Sodium were determined with the aid of flame photometer.

#### 4. Results and Discussion

Table 1 presents the summary results of the physical parameters while table 2 presents the major ions concentration of the analysed groundwater samples. The pH ranges from 5.28 to 8.10 with an average of 7.26. All samples except five show pH values above 7.0 thus, indicating minor variability in pH. The groundwater in the area will therefore be described as being dominantly neutral to weakly alkaline and falling within 6.5 to 8.5 pH range of the World Health Organization (WHO 2004) for water quality standards. It is observed from the table that two out of the three samples with pH values in the acidic range are from hand dug wells (samples 10 and 16) while the most acidic sample (lowest pH, sample 18) is pipe borne water. The acidity may be due to the influence of carbonic acid at the near surface because of high  $\text{CO}_2$  dissolution in the area, while the treatment of the pipe borne water with chlorine could be responsible for the increased acidity of the pipe-borne sample. The major ions are indiscriminate of the pH range (compare Tables 1 and 2). High dissolution of  $\text{CO}_2$  is attributed to the temperature of the groundwater, which ranges from 27°C to 31°C with average of 29.4°C. At such temperature range, gases such as  $\text{CO}_2$  are held in solution and increase the solubility of minerals (Freeze and Cherry, 1979). The electrical conductivity (EC) values are moderate with mean value of 583.5  $\mu\text{S/cm}$  except sample 7 with 1130  $\mu\text{S/cm}$ , a value which could be attributed to high concentration of TDS, although still within the WHO (2004) tolerable limit of 1400  $\mu\text{S/cm}$  specified for drinking water. The TDS concentration of the groundwater is generally less than 1000 mg/l; hence, the groundwater can be classified as fresh groundwater (Carroll, 1962).

Turbidity values range up to 45 NTU, although most of the waters are less than 3.4 NTU, which is the average value. This parameter, which is a measure of cloudiness of water or suspended (such as clay, silt, colloidal inorganic and/or organic particles) matters in water and used to indicate water quality and filtration effectiveness is noticed mostly in hand dug wells, particularly sample 16 (Table 1). It may be due to flow alterations in the unsaturated zone. American Public Health Association (APHA, 1998) reported that although 2.5 NTU is the aesthetic guideline value, highly turbid water does not necessarily constitute a

health hazard. While turbidity above 1 NTU can protect harmful micro-organisms from the effects of chlorine disinfection, the particles can also adsorb toxic organic or inorganic compounds. In the later case, turbid water can be said to adsorb toxic elements that would have polluted the water, making it safer for use after a simple means of treatment, perhaps filtration. The order of cation chemistry for most of the groundwater samples is  $\text{Ca}^{2+} > \text{K}^+ > \text{Na}^+ > \text{Mg}^{2+}$  with few in the order  $\text{Ca}^{2+} > \text{K}^+ > \text{Mg}^{2+} > \text{Na}^+$ . The concentrations of major cations are all below WHO (2004) water quality criterion (see Table 2). The sources may be from geologic materials of clay residue (illite, and montmorillonite in some places) that intercalate the shale of Asu River Group in the area. Freeze and Cherry (1979) had opined that when  $\text{CO}_2$  charged groundwater with low TDS encounters clay residue such as kaolinite, illite, or montmorillonite,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$  and  $\text{Ca}^{2+}$  are released to the groundwater system.

The dominant order of anion concentration is  $\text{HCO}_3^- > \text{NO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$ . The concentration of bicarbonate can be attributed to natural processes such as dissolution of carbonate minerals in the presence of soil  $\text{CO}_2$  by the action of percolating water from precipitation. Bicarbonate with average concentration of 62 mg/l could mean that the area is generally recharged by water from precipitation.

Iron concentrations are low and within the WHO (2004) limit of 0.30 mg/l (average of 0.26 mg/l) except for samples 4, 5, 9, 11, 17 and 18 with values of 0.64 mg/l, 0.81 mg/l, 0.67 mg/l, 0.98 mg/l, 0.78 mg/l and 0.40 mg/l respectively, which are above the specified limit of 0.30 mg/l. Thus, about 30% of the samples (six out of 20) are contaminated of iron. According to Freeze and Cherry, (1979) ferric ion is absent above a pH of 3.0 and ferrous ion diminishes rapidly as pH increases above 6.0. Thus, the observed concentration of iron agrees to a very reasonable extent with the pH conditions of the area as presented in Table 1. The high iron concentrations in samples 4, 5, 9 and 11 are attributed to the presence of iron-rich ore deposits (siderite and pyrite) in those locations (Enyigba, Amagu and Ameri) from where the groundwater samples were taken. Dissolution of these minerals may have allowed for the release of irons to the groundwater even to the extent of pollution. The value of 0.40 mg/l of iron in the pipe-borne water (sample 18) may have resulted from rusting of the distribution pipe which rusting may have raised the concentration of iron, as iron oxide, in the water.

Sulfate and chloride ions are high only in sample 14 with 150 mg/l for sulfate, and samples 7, 10 and 14 with respective value of 98 mg/l, 100 mg/l and 80 mg/l for chloride. Each value is nevertheless below the 250 mg/l standard limit of WHO (2004). The chloride and sulfate concentrations may be attributed to the leaching of sewage effluents down to the groundwater system in the highly populated areas (mechanic site, site 7; Nkwagu Central School, site 10 and Ebonyi State University Teaching Hospital, site 14) where indiscriminate disposal of sewage is suspected to be responsible for the pollution of groundwater by sewage effluent. Meanwhile the total hardness as equivalent  $\text{CaCO}_3$  (carbonate hardness due to calcium ion) ranges from 57 mg/l to 228 mg/l except in samples 4 and 18 with 21 mg/l each.

**Table 1:** Results of Physical Parameters of Ground water samples in the study area

Sample Number	Sample Location	Water Sources	pH	EC ( $\mu\text{S}/\text{cm}$ )	TDS (mg/l)	TSS (mg/l)	TS (mg/l)	Turbidity (NTU)	Temperature ( $^{\circ}\text{C}$ )
1	Ameka 1	BH	7.49	760	494	1	495	2	29
2	Amegu 1	BH	7.27	300	195	1	196	0	30
3	Ameri 1	HW	7.37	560	364	0	364	1	29
4	Enyigba 1	BH	6.00	80	52	0	52	1	30
5	Enyigba 2	BH	7.91	650	422.5	0	422.5	0	30
6	Abakaliki 9	BH	7.37	520	338	1	339	0	30
7	Abakaliki 8	BH	7.91	1130	734.5	0	734.5	0	30
8	Abakaliki 2	BH	8.10	420	273	3	276	0	31
9	Amegu 2	BH	7.35	690	448.5	0	448.5	0	29
10	Nkwagu	HW	6.92	280	186	3	189	8	27
11	Ameri 2	BH	6.54	620	403	0	403	0	30
12	Ameka 2	BH	7.74	650	422.5	5	427.5	0	29
13	Abakaliki 1	BH	7.27	300	195	0	195	0	30
14	Abakaliki 4	BH	7.21	920	598	2	600	3	30
15	Abakaliki 3	BH	8.10	420	273	7	280	0	30
16	Abakaliki 11	HW	6.68	880	572	4	576	45	28
17	Abakaliki 7	BH	7.09	290	188.5	25	213.5	5	29
18	Abakaliki 5	PW	5.28	100	65	2	67	1	30
19	Abakaliki 6	BH	7.16	500	325	1	326	0	28
20	Abakaliki 10	BH	7.48	950	617.5	0	617.5	2	29
Mean			7.26	583.5	373.35	2.75	376.1	3.4	29.40
Minimum			5.28	80	52.00	1.00	52.00	1.00	27.00
Maximum			8.10	1130	734.00	25.00	734.00	45.00	31.00
WHO (2004)			6.5-8.5	1400	500	5**	500**	5***	

BH =Bore hole; PW= pipe borne water; HW= Hand dug Well; \*\*\*= USEPA (1975); \*\*= WHO (1993)

**Table 2:** Results of chemical parameters

Sample Number	Sample Location	$\text{Ca}^{2+}$ (ppm)	$\text{Mg}^{2+}$ (ppm)	$\text{Na}^{+}$ (ppm)	K (ppm)	Fe (ppm)	Cl <sup>-</sup> (mg/l)	$\text{SO}_4^{2-}$ (mg/l)	$\text{HCO}_3^{-}$ (mg/l)	$\text{NO}_3^{-}$ (mg/l)	Total hardness (mg/l)	Ca hardness (mg/l)
1	Ameka 1	37.8	13.67	12.151	26.198	0.12	12	4	110	55.00	150	94
2	Amagu 1	24	2.19	12.136	20.986	0.05	12	15	40	55.88	69	60
3	Ameri 1	20	1.70	13.775	24.198	0.01	14	21	42	62.04	57	50
4	Enyigba 1	8	0.24	8.25	10.216	0.64	2	10	20	44.22	21	20
5	Enyigba 2	32	4.64	9.741	18.741	0.81	24	13	70	85.67	99	80
6	Abakaliki 9	43.2	10.99	12.138	20.841	0.09	46	9	124	68.84	153	108
7	Abakaliki 8	24	1.47	9.981	19.216	0.02	98	21	28	35.20	66	60
8	Abakaliki 2	36	11.72	7.251	16.721	0.04	12	7	122	43.56	138	90
9	Amagu 2	40	8.55	9.081	31.081	0.67	24	58	92	35.64	135	100
10	Nkwagu	24	6.35	9.751	16.581	0.01	100	12	34	75.68	86	60
11	Ameri 2	32	9.77	11.241	27.341	0.98	16	15	82	66.08	120	80
12	Ameka 2	49.6	10.26	8.975	19.095	0.03	34	0	102	35.20	228	124
13	Abakaliki 1	27.2	0.24	12.136	27.986	0.18	12	7	38	31.68	69	68
14	Abakaliki 4	74.4	10.26	10.025	21.061	0.03	80	150	82	41.36	228	186
15	Abakaliki 3	40	2.44	10.841	24.181	0.12	8	3	100	28.60	110	100
16	Abakaliki 11	40	7.81	9.225	17.316	0.06	24	41	80	64.24	132	100
17	Abakaliki 7	32	9.77	10.986	25.097	0.78	20	21	68	38.28	120	80
18	Abakaliki 5	8	0.24	10.092	22.081	0.40	12	29	8	33.44	21	20
19	Abakaliki 6	60	12.21	9.981	27.198	0.02	8	20	20	51.48	200	150
20	Abakaliki 10	48.8	14.16	10.986	21.981	0.01	56	4	98	38.72	180	122
Mean		35.05	6.93	10.45	23.11	0.264	30.70	23	62.0	47.84	119.10	83.60
Minimum		8	0.24	7.25	10.22	0.01	2.00	4.00	8.00	28.60	21.00	50.00
Maximum		74.4	14.16	13.78	31.08	0.98	80.00	150.00	124.0	85.00	228.00	24.00
WHO (2004) limit		75	50	200.00*	12*	0.30	250.00	250.00		50	100 **	

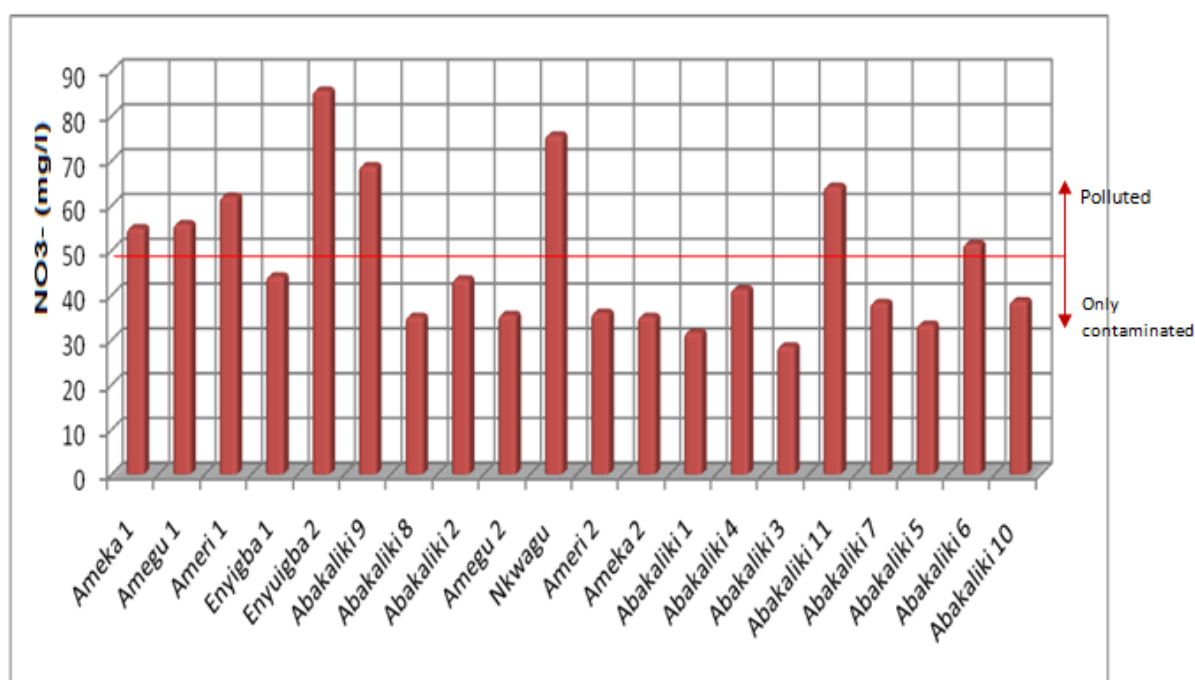
\*=Pratt, 1972\*\*=WHO, 1993



The mean concentration of the total hardness is 119.1 mg/l (Table 2) which falls between 75mg/l and 150 mg/l acceptable range of water hardness prescription according to Sawyer and McCarty (1967). The result shows that the hardness of the groundwater of the area is generally moderate, but up to the hard water range in samples 12, 14 and 19.

All the groundwater samples are contaminated with nitrate ( $\text{NO}_3^-$ ) (concentrations less than 50mg/l) but only samples 1, 2, 3, 5, 6, 10, 11, 16 and 19 are polluted with their concentrations above 50mg/l maximum limit for drinking water standard specified by WHO (2004). A close look at Table 2 reveals that although boreholes samples are among those polluted (samples 1, 2, 5, 6, 11 and 19), most borehole samples are only contaminated (10 of them) but

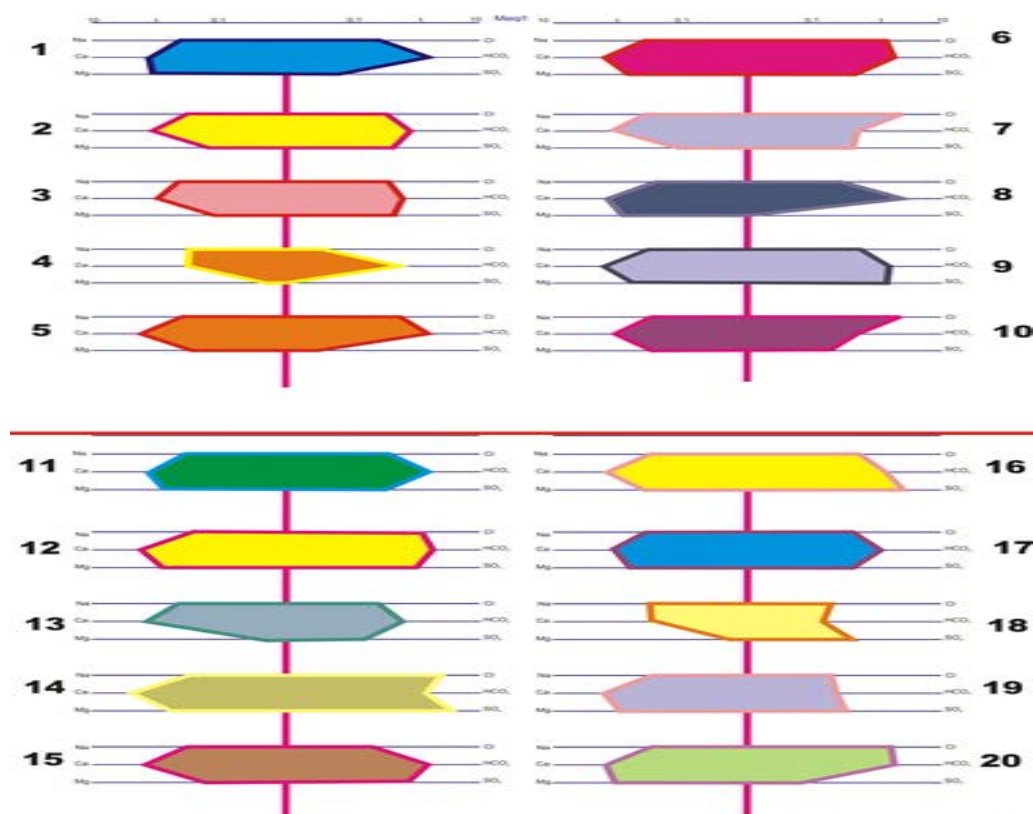
not polluted. All the three hand-dug wells sampled (samples 3, 10 and 16) are polluted. The variability and wide spread concentration of nitrate in the study area (fig 3) indicates its origin from nonpoint sources, probably sewage and agricultural land use such as the general fertilizer application to rice plantations in the area. This implies therefore, that the sources of the nitrate to the groundwater environment could be as a result of leachates from urban and farm wastes. Excessive concentrations of nitrates in groundwater have the potential to harm infant human beings and livestock if consumed on a regular basis (Freeze and Cherry, 1979). It follows therefore that the groundwater of the study area poses threat to the health of users especially the infants, because of the nitrate pollution.



**Figure 3.** Spread of nitrate ion ( $\text{NO}_3^-$ ) concentration in the study area.

In order to facilitate rapid comparison of ionic strengths, Stiff diagram was constructed for each sample. Stiff's diagram gives information on the ionic strength of a water sample which information can be used to deduce the type of water the sample represents, whether soft or hard. Figure 4 shows Stiff diagrams that represent each of the 20 water samples in this study. In almost all the diagrams, the graphs point towards calcium ions ( $\text{Ca}^{2+}$ ) indicating that  $\text{Ca}^{2+}$  is the dominant cation, followed by  $\text{Mg}^{2+}$  with  $\text{Ca}^{2+}$  and  $\text{Na}^+$  being proportional in fig.4[4]. 75% of the Stiff diagrams point towards the dominance of bicarbonate ion ( $\text{HCO}_3^-$ ) showing that water hardness due to the  $\text{HCO}_3^-$ , otherwise called carbonate hardness or temporary hardness characterizes almost all the waters of the study area. Carbonate hardness is that part of total hardness equivalent to  $\text{HCO}_3^-$  and  $\text{CO}_3^{2-}$  of calcium and magnesium (or alkalinity) (Kelvin, 2005), and can be removed by boiling. In fig. 4[18], sulfate ion ( $\text{SO}_4^{2-}$ ) is dominant, making the

total hardness to exceed the hardness due to  $\text{HCO}_3^-$  and  $\text{CO}_3^{2-}$  of calcium and magnesium. The excess, termed non carbonate hardness is traditionally called permanent hardness which cannot be removed by boiling.  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$  are in equal proportion in fig. 4[14] representing sample from EBSU Teaching Hospital while Chloride ( $\text{Cl}^-$ ) is prevalent in figs 4[7] and 4[10] representing samples from Mechanic site and Central School Nkwagu respectively.  $\text{Cl}^-$  and  $\text{HCO}_3^-$  are in equal proportion in fig 4[20] representing sample from Nkaliki while  $\text{HCO}_3^-$  and  $\text{SO}_4^{2-}$  are in the same proportion in fig 4[9] representing water sample from Amagu. Waters from the above-mentioned sites are likely to exhibit permanent hardness and can only be softened by addition of sodium carbonate and lime and filtration through natural or artificial zeolites, which absorb the hardness producing metallic ions and release sodium ions to the water.



**Figure 4.** Stiff diagram showing ionic strength of the major cations and anions concentration in meq/l of the groundwater samples.

## 5. Conclusions

Abakaliki area is underlain by poor groundwater yielding aquiclude (the Abakaliki Shale of the Asu River Group), but produces prolific aquifers where the shale is weathered and fractured. Prior to this work the quality of the water and the contributing factors to that quality have not been studied nor documented. This study has shown that the groundwater is moderately hard due to bicarbonate ( $\text{HCO}_3$ ), calcium ( $\text{Ca}^{2+}$ ), and magnesium ( $\text{Mg}^{2+}$ ) ions as delineated in the Stiff diagrams where the ionic strength of all the samples are shown to be controlled by  $\text{HCO}_3$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ . The groundwater is also fresh as total dissolved solids (TDS) is less than 1000mg/l at the temperature range of 27°C to 31°C. Samples from hand dug wells and boreholes have comparable acidity; while those from hand-dug wells have pH range of 6.68 to 7.37, those from boreholes have pH range of 6.00 to 8.10. Generally, however, acidity seems to decrease with depth indicating that its source may be from near surface processes. Analyses of the groundwater samples showed that much of the groundwater is of poor quality as a result of contamination of inorganic matters and particularly polluted with iron (Fe) and nitrate ( $\text{NO}_3$ ).

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# Evaluation of the Potential use of Municipal Solid Waste for Recovery Options: A Case of Ma'an City, Jordan

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## Abstract

Ma'an city faces serious administrative challenges in managing their municipal solid waste (MSW) due to the lack of adequate information of the composition and quantities of generated solid waste. The overall objective of this research is to gain more reliable information about quantities and composition of MSW stream in Ma'an city. In this work, field survey along with a separation study at waste generation source was conducted to quantify and determine the waste composition of Ma'an MSW stream. Main physical and chemical parameters were determined experimentally in order to assess the suitability of using the organic fraction of Ma'an MSW for recovery options. The results of this study reveal that the total waste generated daily are 72.5 tons per day with food waste comprising the largest component of Ma'an MSW stream (65%) followed by paper products (15.5 %), plastic (11 %), metals (3.4 %), glass (2.8 %), and others (2.3 %). In general, MSW in Ma'an city is characterized by high organic content comprising some 90% of the total waste stream. The estimated calorific value of collected SW (2661 Kcal/Kg) indicates that it can't be incinerated without providing additional fuel. Additionally, high moisture content (44 %) and low quantities of SW generated revealed the unsuitability of Ma'an MSW as an energy recovery option. High biodegradable organic fraction (~80 %) and good nutrient contents suggest that composting under natural conditions can be carried out efficiently if biodegradable organic waste is separated from the remaining waste stream.

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**Keywords:** Municipal Solid Waste, Waste Recovery, Waste Characterization, Jordan..

## 1. Introduction

The generation of municipal solid wastes (MSW) has increased steadily over the past two decades as a result of rapid population growth and rise in living standards causing its management to be a serious environmental challenge confronting local authorities in many cities around the world particularly in the cities of developing countries (Seo *et al.*, 2004, Zhen-Shan *et al.*, 2009; Batool and Ch, 2009; Chung and Carlos Lo, 2008; Imam *et al.*, 2008; Berkun *et al.*, 2005; Metin *et al.*, 2003). Implementing of appropriate solid waste management practices requires reliable information about the composition and quantities of solid waste generated. The lack of adequate information is posing a serious obstacle for decision makers to implement the necessary changes in solid waste management practices in any city. Ma'an city, located in the southern part of Jordan, falls into this category and faces serious administrative challenges in managing their MSW due to the lack of adequate information. Therefore, quantification and characterization of MSW is of paramount importance to help planners and

decision makers in implementing a suitable system of waste management.

Several published papers have reviewed the trends of municipal solid waste management (MSWM) in different cities in Jordan. For example, Abu Qdais (2007) discussed the various practices and challenges of MSWM in three major cities in Jordan (Amman, Irbid and Zarqa). Abu hejleh *et al.* (1998) studied the feasibility of using MSW incineration plant in Jordan. Abu Qdais, M. and Abu Qdais H. (2000) studied the applicability of MSW in Jordan for energy recovery. Mrayyan and Hamdi (2006) assess the current operational and management practices of solid waste in active industrialized zone (Zarqa city) in respect to collection, storage, transport, disposal, and recycling issues. Al-Dabbas (1998) conducted an evaluation study of utilization of MSW in Amman city for energy recovery and its effect on reduction of methane emissions. Other studies have addressed the impact of Jordanian solid waste landfills on the environment to provide design and operational guidance to minimize future impacts (Chopra and Abu-El Shaar, 2001; Aljaradeen and Persson, 2010). While these studies have mainly focused on MSW practices in major cities in Jordan, local municipalities to

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quantify MSW in small cities like Ma'an city did little attempts to date.

This paper provides an overview of the status of MSWM in Ma'an city, analyzes the existing problems in management strategies, and provides recommendations for system improvement. The overall objective of this research is to gain more reliable information about quantities and composition of MSW stream in Ma'an city. The results obtained can be used to assist target city in implementing the main elements of integrated solid waste management (ISWM) systems which involves evaluating local needs and conditions and selecting the most appropriate waste management activities (Pichtel, 2005). This study has been carried out by means of field survey along with a separation study at waste generation source in addition to the sampling and laboratory analysis.

## 2. Current SWM practices in Ma'an City

Ma'an city is located in the southern part of Jordan (218 km south of the capital Amman) (Figure 1) with current population of 80,000 and an average population growth rate of 3.9% estimated for 25 years (1979-2004).



**Figure 1.** Location of study area.

The average family volume in Ma'an city as estimated based on 2004-population census is 6-7 persons (Department of statistics, 2004). The present level of MSWM in Ma'an city is low and disordered and lack of unified organization and management on waste collection, transportation, and sorting. Mixed collection is the only used method for waste collection in Ma'an city. No any recovery option of the waste is implemented and a large number of resources are wasted. Six types of solid wastes can be recognized in Ma'an including food, paper, plastic, metals, glass, and others (textiles, leather and rubber, and

miscellaneous) that are generated mainly from households, commercial facilities, and institutional areas. Table 1 summarizes the main waste generation sources with number of establishments.

**Table 1:** Main waste generation sources in Ma'an city.

Generation Source	Number of Establishments
<b>Residential</b>	10800
<b>Commercial</b>	
Super and mini markets	173
Restaurants	90
Fruit/vegetables stores	30
Meat and poultry shops	43
<b>Institutional</b>	
Schools	50 (8650 students)
Colleges	2 (500 students)
University	1 (8000 students)

At present, landfill is the only used mode to dispose the solid waste in Ma'an City. Waste generated from different sources are transported by trucks to the landfill site located 20 Km east of Ma'an city with an area of 50 ha. The traditional method of MSW disposal is trench method (Figure 2). Waste received to the landfill are distributed in the trenches (500 m length, 6-8 m width, and 8-10 m depth), compressed, compacted by bulldozer, and finally covered with a layer of local soil (20-25 cm) at the end of each working day.



**Figure 2.** Trench method of waste disposal at Ma'an Landfill site.

In general, MSW in Ma'an city are poorly managed and there are no any suggested solutions to reduce the magnitude of the problem due to the lack of adequate information about percent distribution of each waste type. Consequently, there is an urgent need to quantify and characterize the MSW in Ma'an city to improve its management strategies. In this study a field survey along with direct sampling were conducted at the waste generation sources to quantify the total waste generated and the percent distribution of each waste type.

### 3. Characterization of MSW in Ma'an City

Accurate information about composition and quantities of solid waste generated serves as a basic tool for any solid waste management plan. Such data is an important issue in waste management as it affects the proposed methodology of disposal and is necessary for examining recovery options. In this study, total waste generated and waste composition in Ma'an city was determined by conducting a field survey consisting of questionnaire method along with direct sampling method at the generation source during a period of 4 weeks in spring season (April, 2011). This sampling date was chosen due to the fact that the average household generation rate in Ma'an city during the spring is equivalent to the annual average generation rate as estimated by Ma'an municipality council from 1994 till 2010 based on daily records of total amount of MSW received to the landfill (Municipality of Ma'an, personal communication, 2010). Direct sampling, involving physically sampling and sorting at the source of generation, is useful on a small scale for obtaining information about MSW composition. Although MSW can be extremely heterogeneous, direct sampling is one of the most accurate characterization methods to make accurate judgments on quantity and composition of MSW (Pichtel, 2005).

This field survey study was designed and administrated to collect the samples from different sources of MSW located in Ma'an city including residential, commercial, and institutional sources. A preliminary fieldwork was conducted in the early March, 2011 with a purpose of seeking the household's agreement to participate in this study and determination of public attitudes toward waste separation at home. Trained interviewers visited more than 200 individual households and obtained the necessary information from a responsible adult. Additional information such as monthly income and number of residents per household was also recorded at this stage. A hundred and thirty households out of the original list of 200 agreed to participate in the survey representing a response rate of 65%. Seventy households out of 130 who agreed to participate were chosen from different zones in Ma'an city with various income levels and family sizes and provided with questionnaires contained detailed questions about family size, educational level, and income level. This sample size (70 households out of the total 10800 households) gives 90% confidence level with confidence interval of 10 %. According to sampling theory, the sample means are normally distributed as long as the sample is large enough ( $n > 30$ ) (Owen and Jones, 1990). Special black plastic refuse sacks (189.3 L capacity) with labels were also provided. The householders were then asked to separate their daily waste in 6 separate bags including food waste, plastic, paper, glass, metals, and others (all materials that don't fit into previous categories such as textiles, rubber and leather, yard waste, and batteries) and to label each bag with waste type, name and location of the household. At the next day, these bags were collected by a team of city council employees using five tons tipping trucks and transferred to landfill site. At the landfill site, all bags were weighted using a scale sensitive to 5 gr and checked for waste composition by survey team. Knowing that not all paper, plastic, glass and

metals are recyclable, further separation on bags containing these materials was conducted by the survey team to quantify the recyclable portion from non-recyclable portion of the waste stream. This procedure was repeated 4 times (once every week) during the period of study. So the total samples obtained from households were 280 samples (Table 2). To account for commercial sources of MSW, same procedure was repeated by distributing questionnaires and bags for waste separation among the commercial establishments as shown in Table 2. At institutional areas, information about total waste generated daily and waste composition was obtained from institutional records. However, several samples were obtained directly from waste containers at institutional areas (Table 2) for the purpose of analysis.

**Table 2.** Solid waste sampling sources and sampling frequency.

Generation Source	Number of Establishments	Number of Sampling Sources	Sampling Frequency	Total Number of Samples per Source
<b>Residential</b>	10800	70	4	280
<b>Commercial</b>				
Super and mini markets	173	10	4	40
Restaurants	90	10	4	40
Fruit/vegetables stores	30	5	4	20
Meat and poultry shops	43	5	4	20
<b>Institutional</b>				
schools	50 (8650 students)	5	4	20
colleges	1 (500 students)	1	4	4
University	1 (8000 students)	1	4	4
<b>Total</b>				428

The daily average generation rate in each household with per capita generation was evaluated. The total amount of MSW generated from residential areas was estimated by knowing total population. Similarly, the daily average waste generation rate in each commercial establishment was evaluated first and then the total amount of MSW generated was estimated by knowing the total number of commercial establishments. In institutional areas, the total amount of MSW generated was known previously from the institutional records and then the daily average waste generation per student (for educational institutions) was evaluated.

To assess the suitability of using the organic fraction of MSW in Ma'an city for energy recovery, three samples (1 Kg each) of the combustible organic fraction (food, paper, and plastic) were selected randomly for each waste type from different bags representing different generation sources and analyzed for the main physical characteristics including moisture content, volatile solid content, and ash residue. These tests represent the proximate analysis, which is usually used as an indicator for capability of MSW as a fuel (Singer, 1981). Moisture and ash content



represent the noncombustible component of the MSW. Both are undesirable in MSW as they add weight to the fuel without adding to the heating value. The volatile matter and the fixed carbon content are the preferred indicators of the combustion capability of MSW. Similarly, to assess the suitability of using the biodegradable organic fraction (food and paper) for biological conversion, three samples (1 Kg each) of biodegradable organic materials were taken after mixing the food and paper wastes from different sources together to account for weight percentage of each waste type. These samples were analyzed for pH, moisture content, carbon, and main nutrient contents (N, P, and K). Carbon and Nutrient levels in addition to pH and moisture content are considered as principal factors regulating the speed and degree of biological conversion (Pichtel, 2005). This procedure was repeated 4 times during the period of study, thus 12 samples were analyzed for each parameter. For physical analysis, the moisture tests were performed first by oven drying at 105°C for one day until a constant weight was achieved (Moldes *et al.*, 2007). The samples were then grounded and milled in a blender and a 10 mesh Willey Mill. Approximately 200 mg of dried sample was weighed using small aluminum pans which were then placed into a muffle furnace at 550°C for 20 minutes. The samples were then removed and weighed and the volatile solids contents were reported as a percentage loss from the dried samples. Ash residue is the amount remained in muffle furnace after burning at 550°C (Alamgir and Ahsan, 2007). Moisture and ash residue together represent the non-combustible fraction of the organic waste. Calorific values of major components of the organic fraction of MSW (food, plastic, and paper) were also evaluated based on physical composition using the model developed by Khan and Abu Gharah (1991) and proximate analysis using Bento's Model (Abu Qdais, M. and Abu Qdais H., 2000) which includes assessment of the levels of combustible and non-combustible. The pH was measured by preparing a mixture of MSW and deionized water (waste:water = 1 :1). After approximately 5 hours, the measurements were taken with pH meter. For nutrient contents, the organic materials were first dried at normal temperature and then grinded into powder form. Wet oxidation Kjeldhal method was used for determination of carbon and nitrogen (Alam *et al.*, 1991). Potassium and phosphorous were determined by flame photometry (BWB, 2011) and spectrophotometry (Pierzynski, 2000) methods, respectively.

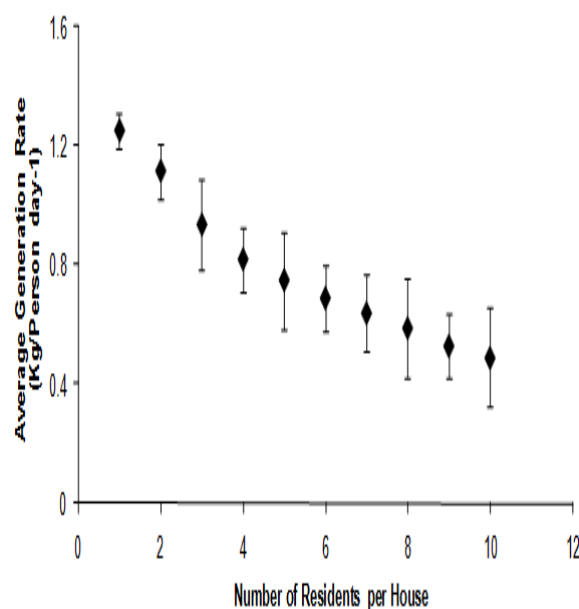
## 4. Results and Discussion

### 4.1. Waste quantity and generation rate

The 70 households surveyed in this study were 4-7 family members representing (61.54%) followed by 1-3 members having (20 %) and 8-10 members having the lowest percentage (18.46%). The average family size was 6.3 persons which agreed well with that estimated by department of statistics (6-7 persons) (2010) suggesting that the surveyed samples were representative concerning number of persons per household.

The average generation rates for different families are shown in Figure 3. Based on the obtained results, the

overall weighted average generation rate for Ma'an City is 0.78 kg per capita day<sup>-1</sup> which is lower than that recorded for Jordan (0.94 Kg/capita day<sup>-1</sup>) (Chopra, 2001; Daradki, 2008; METAP, 2008) which is attributed to the fact that the income level in Ma'an city is slightly less than that in other Jordanian cities. Table 3 summarizes the weighted average generation rates and total wastes generated from all sources. The residential sources were found to be the primary generators comprising 86.2 % of the total waste generated followed by commercial 7.4 % and institutional 6.4 %. This amount of the total waste (72,500 tons/day) is slightly higher than that estimated as total waste received daily by trucks to the landfill site (65.0 tons/day). This difference in total wastes estimated from the generation sources and the amount received to the landfill site is mainly attributed to main two factors including, the role of scavengers who collect the recyclable items from solid waste containers and the fact that not all wastes are collected in containers (some people used to burn their wastes due to the lack of containers near to their households or due to the long distance to a container).



**Figure 3.** Average generation rate for different families (Kg/person<sup>-1</sup>day<sup>-1</sup>).

Results of physical composition and typical percentage distribution of MSW in Ma'an city obtained by separation study are shown in Table 4. Food waste include uneaten food, meat, cooked food, and food preparation wastes from residences, commercial establishments (restaurants, shops), and institutional sources such as school cafeterias, comprise the largest component of Ma'an MSW stream (65%). This result is expected and agreed well with those obtained for other Jordanian cities (Mrayyan and Hamdi, 2006) where the food was found to be the major component of the solid waste stream generated. Paper and paper products comprise the second largest component of

Ma'an MSW stream (15.5%). The products that comprise paper and paperboard wastes are newspapers, magazines, office papers, tissue paper and towels, paper plates and cups, corrugated boxes, milk cartons, and egg dishes. Plastic products comprise 11.0 % of the total MSW

in Ma'an city. Plastic products were found in durable goods (appliances, furniture, carpets), nondurable goods (plastic plates and cups, trash bags, disposable diapers), and plastic containers and packaging (soft drink bottles, bags, sacks, wraps). By resin, the plastic products are consisting mainly of polystyrene (plastic food items), high-density polyethylene (trash bags, milk and water bottles), and polyethylene terephthalate (PET) (soft drink bottles). Metals comprising 3.4 % of the total MSW consists mainly of aluminum (beverage containers, food cans, foil), ferrous metals (iron and steel found in appliances, furniture, and containers and packaging materials), and non-ferrous metals (copper, zinc, and lead found in durable products such as appliances and consumer electronics).

**Table 3.** The weighted average generation rate and total wastes generated from all sources.

Waste Source	Total Number	Generation Rate	Unit	Total Waste (Kg/day)	Waste %
<b>Residential</b>	80,000	$0.78 \pm 0.035$	Kg/pers.day <sup>-1</sup>	62400	86.2.
<b>Commercial</b>					
Supermarkets	173	$9.59 \pm 0.13$	Kg/market.day <sup>-1</sup>	1659.368	
Restaurants	90	$32.7 \pm 1.2$	Kg/rest.day <sup>-1</sup>	2944.04	
Fruit/veget. store	30	$13.38 \pm 0.64$	Kg/store.day <sup>-1</sup>	401.46	
Meat/poultry shops	43	$6.84 \pm 0.87$	Kg/shop.day <sup>-1</sup>	294.404	
Sub Total				5353	7.4
<b>Institutional</b>					
Schools	8650	$0.22 \pm 0.01$	Kg/student.day <sup>-1</sup>	1908.64	
Colleges	500	$0.38 \pm 0.04$	Kg/student.day <sup>-1</sup>	190.864	
University	7500	$0.337 \pm 0.012$	Kg/s student.day <sup>-1</sup>	2528.948	
Sub Total				4628.452	6.4
<b>TOTAL</b>				72381.45	100

**Table 4:** Percent distribution of physical components of Ma'an MSW from different sources.

% By Weight							
	Food	Plastic	Paper	Metals	Glass	Others	Total %
<b>Residential</b>	58.32	8.7	12.9	2	1.94	2.14	86.00
<b>Commercial</b>	4.65	1.05	1.15	0.3	0.20	0.05	7.4
<b>Institutional</b>	1.95	1.27	1.52	1.1	0.65	0.11	6.6
<b>Total %</b>	64.92	11.02	15.57	3.4	2.79	2.3	100

Glass products comprise 2.8 % of the total MSW and occurred primarily in the form of containers as soft drink bottles, bottles and jars of food, and other consumer products. Textile (occurred in discarded clothing) and rubber and leather products (occurred in automobile and truck tires, clothing and footwear) were found in Ma'an MSW stream in small amount (<1.5 %). Yard waste includes grass clippings, leaves, and tree trimmings from residential, institutional, and commercial sources were present in small fraction (<1%). Some hazardous materials were also recognized in MSW stream of Ma'an city such as paint strippers, batteries, electric lighting, and paint residues.

Table 2 shows that about 33 % of total waste generated have a potential for recycling and consisting of paper products (14.6 %), plastic (11.8 %), metals (3.6 %), and glass (2.8 %). Knowing that not whole portion of paper, glass, and plastic are applicable for recycling; a separation study conducted to separate all materials into recyclable and non-recyclable portion showed the following trends: (1) the majority of paper products are recyclable (78%) and consist of newspaper, magazines, office paper, paper plates and cups, and cardboard. The non-recyclable portion (22%) consist of napkins and paper towels, paper plates, cigarette packages and paper contaminated with food residual such as pizza boxes (2) The majority of plastics (>70%) are recyclable and consists of most commonly recycled plastics including polyethylene terephthalate (PET) and High Density Polyethylene (HDPE) while the non-recyclable (30 %) contain mainly acrylic, some types of kid toys and nylon (plastic bags). (3) The majority of metals (>80%) are recyclable and consist of steel (or "tin") from domestic wastes, instant food Aluminum (Al) containers, Iron and steel containers for oil olive and dates, household stainless steel knives. The other remaining portion (<20%) consists of metals products represented by corroded metal scrap that are not accessible for recycling. (4) The recyclable portion of glass waste is 80% of total glass waste and consists of all glass food containers, beverage containers (food glass jars), soft drink bottles and juice containers while the other non-recyclable portion (20%) consists of light pulps, window glass and pans. In general the overall portion of recyclable products (paper, plastic, metals, and glass) is about 25% of the total MSW mixture. This suggest that applying recycling program in Ma'an city will reduce cost, minimize waste volume by 25% , and decrease pressure and prolong the lifetime of the landfill.

In general, MSW in Ma'an city is characterized by a high organic content with combustible matter consisting of food, paper, and plastic comprising some 90% of the total waste suggesting that both decomposable and combustible matter is very high. However, to assess the suitability of using the organic fraction of the MSW in Ma'an city for both energy recovery and biological conversion processes, several samples of the organic fraction were collected and analyzed. The results are discussed below

#### 4.2. Physical and Chemical Characteristics of MSW in Ma'an City

Twelve samples of the combustible organic components (food, plastic, and paper) were collected and analyzed for physical characteristics. The results obtained



are summarized in Table 5. The average value of moisture content was found to be high (44.4 %). High moisture content of solid waste has negative and undesirable effect on applicability of MSW for energy recovery as it adds weight to the fuel without adding to the heating value (Pichtel, 2005). The combustible fraction of the whole organic portion of MSW was estimated to be 46.15%. The calorific values estimated based on physical composition (Khan Model) and proximate analysis (Bento's Model) were found to be 2532 Kcal /Kg and 1825 Kcal/Kg, respectively. The results of calorific values obtained using Khan and Abu Ghrrah Model (2661 Kcal/Kg) agreed well with the measured values obtained by others for identical solid waste in Jordan (2747 Kcal/Kg) (Abu Qdais, M., and Abu Qdais, H., 2000). In their work, a good correlation was found between the experimentally measured calorific values with those predicted using Khan and Abu Ghrrah Model and weak correlation with those predicted by Bento's Model. However, the calorific value of collected SW (2661 Kcal/Kg) indicates that it can't be incinerated without providing additional fuel. Also, high moisture content and low quantities of SW generated revealed the unsuitability of Ma'an MSW as energy recovery option.

**Table 5.** Physical properties of Ma'an MSW.

Waste Type	Sample weight (Kg)	Num. of Samples	pH	Moisture Content(% FM)	Volatile Matter (% DM)	Ash Residue (% DM)	Combustible (% FM)	Non-combustible (% FM)
Food	65	8		70.25	86.25	13.75	25.7	74.3
Plastic	11	8		2.57	79.75	20.25	77.7	22.3
Paper	15	8		7.55	82.5	17.5	76.3	23.7
Total	91	24	7.5	44.4			46.15	53.85

Chemical characteristics of the biodegradable fraction of MSW samples are summarized in Table 6. The C/N ratio ranged from 22.38 to 26.46 with an average value of 24.32. The concentration of phosphorous and potassium were ranged from 0.28 to 0.36 % and 0.63 to 0.69 % with an average values of 0.322 and 0.658 respectively. Moisture content of the biodegradable portion of the organic fraction (food and paper) excluding plastic was found to be 52 %. Given that the biodegradable portion of the MSW stream in Ma'an city is ~80 %, with high moisture content and C/N ratio, composting under natural conditions can be carried out efficiently if food and paper waste are separated from the remaining waste stream. This will significantly reduce the amount of SW to be disposed in the landfill by >75%. Although other biological treatment processes like anaerobic processes for methane generation and biogas generation can also be considered for treatment, these processes are successful only on a large scale where good quality equipment and adequate technical and management skills are available (Tumpa and Sudha, 2009). This is not a case in our studied area where total wastes generated are only 72 tons per day. At small or medium scale treatment plants, biogas generation suffers

from problems like fluctuations in the quality and quantity of gas (Tumpa and Sudha, 2009).

**Table 6.** pH, moisture and main nutrient contents of MSW in Ma'an city

	pH	M%	C/N	N <sub>total</sub> (%DM)	P (% DM)	K (% DM)
Biodegradable Organic Waste	7.6	52	24.32±0.66	1.88±0.017	0.322±0.03	0.658±0.02

Segregation of materials that are applicable for recovery options from mixed waste is difficult and expensive process. Therefore, the residents should be sensitized towards the importance of segregation of wastes at source. Result of this survey study has shown that 66% are aware of the separate collection and recovery program especially if properly managed by a municipality council.

## 5. Conclusions

Field survey along with a separation study at waste generation source were conducted to quantify and determine the waste composition and to evaluate the applicability of Ma'an MSW for recovery options. MSW in Ma'an city is mainly organic comprising some 90 % of the total waste stream (72 tons/day). The estimated calorific value of collected SW was estimated to be 2661 Kcal/Kg. High moisture content and low quantities of SW generated revealed the unsuitability of Ma'an MSW as an energy recovery option. High biodegradable organic fraction (~80 %) and good nutrient contents suggest the applicability of MSW stream for implementing composting operations. Since Ma'an area is located within an arid region with low annual precipitation and it is soil type is sandy with poor quality, applying compost as soil amendment will be valuable as it will improve the soil fertility by supplying main nutrients such as N, P, K, as well as increase water holding capacity due to its high organic matter content. Additional analysis to measure more parameters such as fusion point of ash, sulfur, halogens, H, O, and trace metals would be required to gain a more complete picture about the chemical composition of MSW in Ma'an city.

Further separation of recyclable fraction of plastic, metals, and glass products would be helpful and can reduce the total waste disposed by additional 21%. Thus if composting and recycling were applied, more than 95% of the total waste stream can be used as a source materials leaving only a small portion (5%) to be disposed at the landfill. This will decrease the cost and environmental footprints dramatically.

Result of this survey study has shown that 66 % are aware of the separate collection and recovery program especially if properly managed by a municipality council

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# Charcoal Remains from the Mukheiris Formation of Jordan – the First Evidence of Palaeowildfire from the Anisian (Middle Triassic) of Gondwana

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## Abstract

During recent field work on the Triassic of Jordan fossil charcoal remains have been discovered from the Lower Member of the Middle Triassic Mukheiris Formation (Anisian) at the eastern rim of the Dead Sea. This material represents the first evidence for palaeowildfires during the Anisian of Gondwana and only the second macroscopic evidence from the Anisian on a global scale. The charcoal shows anatomical features typical of gymnosperms, but at the moment nothing can be said about the taxonomic affinity of the woods, due to the fragmentary nature of the remains. Our data suggest also that, like in other regions worldwide, the land vegetation in the Near-East region had already recovered, at least to some extent, from the devastating effects of the end-Permian ecological crisis and that wildfires occurred in these ecosystems, although nothing can be stated at the moment about frequencies and intensities of such fires.

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**Keywords:** Triassic, Anisian, Gondwana, Palaeowildfire, Charcoal.

## 1. Introduction

In the modern world fires are an important source of disturbance in a number of different ecosystems (Bowman et al., 2009) and it is known from the fossil record of charcoal that fires occurred ever since the invasion of the continents by embryophytic plants in the Silurian (Glasspool et al., 2004). However, when we have a closer look at the fossil record of charcoal we will see that there are some periods where we have no or almost no evidence for the occurrence of wildfires (Scott, 2000, 2010; Diessel, 2010). One of these periods is the Early and Middle Triassic (Scott, 2000, 2010; Uhl et al., 2008; Diessel, 2010; Abu Hamad et al., 2012). There is only a single record of microscopic charcoal from the entire Early Triassic as well as from the Anisian (both from the Barents sea: Mangerud and Rømuld, 1991), a single record of macroscopic charcoal from the Anisian (from SW-Germany: Uhl et al., 2010), and only two records from the

Ladinian (one from Argentina: Mancuso, 2009; and one from S-Germany: Kelber, 1999, 2001, 2003, and 2007).

Here we report the first record of fossil charcoal from the Anisian of Jordan, a finding that represents not only the first record of Anisian charcoal from the Gondwana but also only the second substantiated record of macroscopic charcoal from the Anisian on a global scale (cf. Uhl et al., 2010).

This report is also interesting from a regional point of view, as the Early and Middle Triassic macrofloras are rare in many areas worldwide (Rees, 2002; Grauvogel-Stamm and Ash, 2005) and almost nothing is so far known about such floras for the entire Near East region. Although a number of studies have dealt with the palynology of Triassic sediments from Jordan and adjacent countries (e.g. Cirilli and Eshet, 1991; Abu Hamad, 2004; Buratti and Cirilli, 2007), not much is currently known about macroscopic plants from this period and region. So far several authors briefly mentioned the occurrence of unspecified fossil plant remains and especially “driftwood” in sediments of the Middle Triassic (Anisian) Mukheiris

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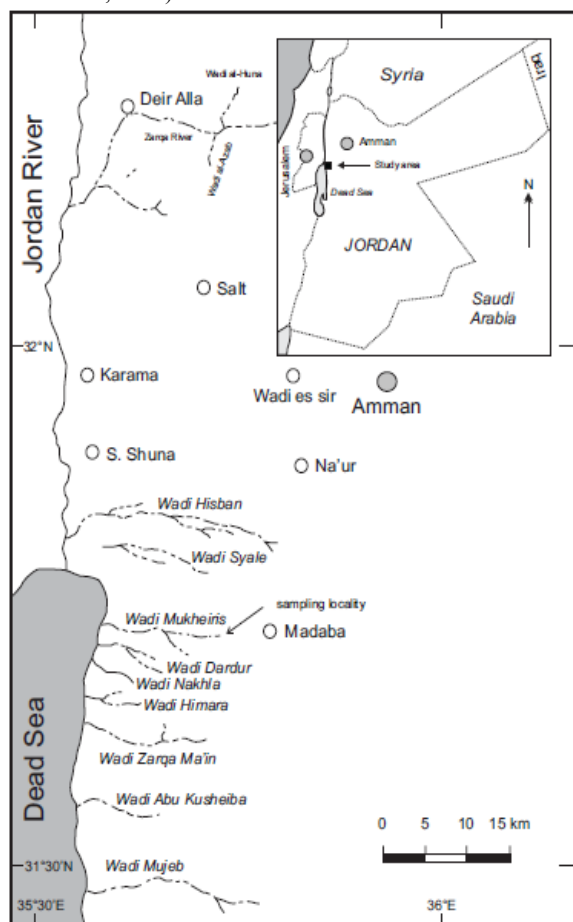
Formation in Jordan (e.g. Bandel and Khoury, 1981; Abu Hamad, 2004; Makhoulf, 2006) without providing any detailed information about the nature of these plants.

Recent palaeobotanical surveys on the Permian succession in Jordan revealed several so far unknown occurrences of abundant and excellently preserved fossil plant remains (Mustafa, 2003; Kerp *et al.*, 2006; Uhl *et al.*, 2007; Abu Hamad *et al.*, 2008) and additional Triassic localities bearing fossil plants have been discovered during recent field work by the authors. Thus this study provides the first description and palaeoenvironmental interpretation of fossil plant macro-remains from the Anisian of Jordan and, as far as we know, for the entire Near East region.

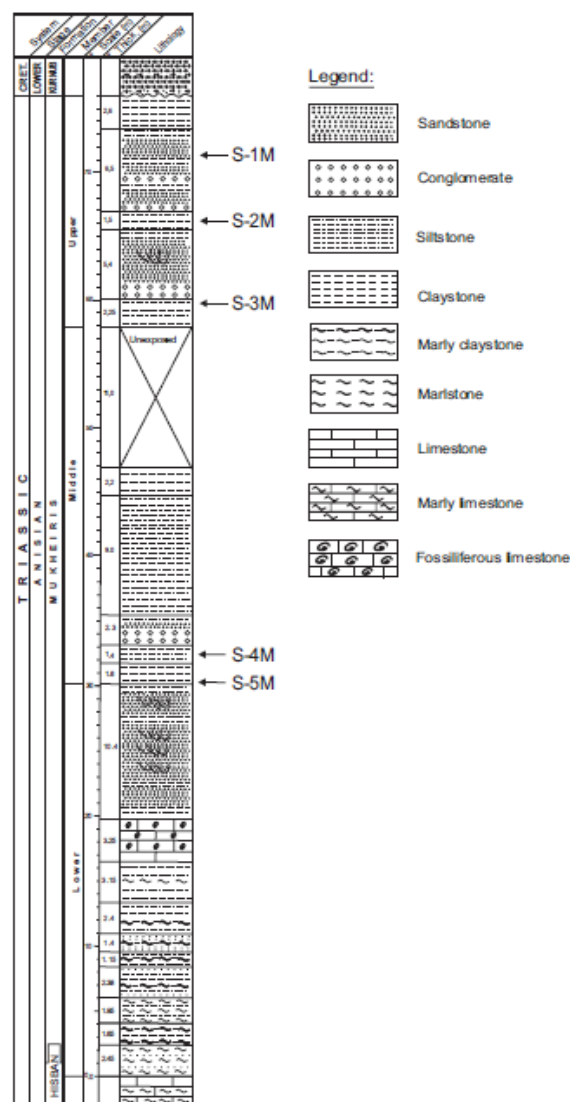
## 2. Geological and Stratigraphical Setting

The material investigated for this study came from a single horizon from the Anisian Mukheiris Formation of Jordan. The location of the samples and the stratigraphic horizon from where the wood samples were collected are shown in Figures 1 and 2.

The Mukheiris Formation has been named by Bandel and Khoury (1981) after Wadi Mukheiris at the NE strip of the Dead Sea (Fig. 1). This formation represents all the sediments preserved above the Hisban Formation, and is truncated by the Lower Cretaceous unconformity in the Dead Sea area (Khalil and Muneizel, 1992; Andrews *et al.*, 1992; Makhoulf *et al.*, 1996; Shawabekeh, 1998; Makhoulf, 2003).



**Figure 1.** Location map of showing the sampling locality at Wadi Mukheiris.



**Figure 2.** Columnar section of Mukheiris Formation at Wadi Mukheiris, showing positions of samples with fossil wood remains. The fossil charcoal comes from sample S-1M.

The Mukheiris Formation conformably overlies the carbonate dominated Hisban Formation with sharp contact. According to Bandel and Khoury (1981) it is comprised of 90 m thick three well-defined members each 30 m thick. The present study recorded about 76 m thick of the incomplete Mukheiris Formation which was subdivided into three members:

(a) A Lower Member about 30 m thick consists of fine-grained, cross-bedded sandstones interbedded with thinly bedded soft, rippled, marly claystones, marlstones and siltstones channel-fill, lenticular, bedded siltstone and clay-stones with driftwood and abundant leaf fragments still bearing cuticles are common on the bedding planes of the siltstones and the clay-stone beds. In the middle part of this member a fossiliferous limestone bed was observed, it shows some macro fauna e.g. bivalves, brachiopods (Makhoulf, 2003) and crinoids. Wood remains under study originated from this part of the Formation, which also yielded the remains of non-marine stereospondyl amphibians (Schoch, 2011).

(b) A Middle Member about 28 m thick, consisting predominantly of fossiliferous (mainly the brachiopod

*Lingula*) siltstones intercalated with clay-stones, and fining-upward cycles commenced with pebbly sandstones to very fine-grained sandstones capped with siltstones.

(c) An Upper Member about 18 m thick, consisting of cross bedded, fining-upward cycles of medium to coarse-grained sandstones capped with siltstones interbedded with thinly laminated clay-stones and siltstones. Plant remains are abundant in the uppermost beds of siltstones and claystones. Common are so far undescribed leaves on the bedding planes of the laminated clay-stone. The formation is unconformably overlain by the Early Cretaceous Kurnub Sandstones.

The depositional environment of the Lower Member of Mukheiris Formation was proposed as marine environment based on bioturbation and presence of glauconitic sand (Bandel and Khoury, 1981).

In a more recent and detailed lithofacies study by Makhlof (2003) a thicker section was measured attaining a 108 m thickness for the Mukheiris Formation, that was subdivided into two units; a lower 30 m thick tidal unit contains fossiliferous limestones and marlstones, thin, rhythmic tidal bedding, flaser bedding and oscillation ripple marks, and accordingly a tidally influenced shallow water marine depositional environment was proposed for this unit (Makhlof, 2003). The upper part assigned by (Makhlof, 2003) comprises 78 m thick fluvial unit. The lower part of the fluvial unit was deposited within a braided mixed load fluvial system changing up ward into a more meandering fluvial system as indicated by the increase proportion of fines ratio through the upper part of this unit (Makhlof, 2003).

The Mukheiris Formation was assigned a Middle-Late Anisian age by Bandel and Khoury (1981), while Sadeddin (1990, 1992, 1995, and 1998) and Sadeddin and Kozur (1992) had assigned a Late Anisian to Early Ladinian age. Using palynomorphs index taxa; Abu Hamad (2004) assigned a late Anisian age for this formation.

### 3. Methods

Charcoal samples were extracted mechanically from the sediment with the aid of preparation needles and tweezers under a binocular microscope in the laboratory. Due to the very fragile nature of some specimens, these could not be cleaned with water or any acids to remove adhering mineral remains. Samples that showed evidence of anatomical preservation under the binocular were mounted on standard stubs with LeitC (Plano-GmbH, Germany), sputter coated with gold-palladium and subsequently examined with the aid of a JEOL JSM 6490 LV Scanning Electron Microscope (SEM) with secondary electron imaging at 15 kV at the Senckenberg Forschungsinstitut und Naturmuseum Frankfurt, Germany.

### 4. Results and Discussion

#### 4.1. Preservation

Charcoal fragments are scattered within a single sandstone bed in the Anisian Mukheiris Formation (sample S-1M in Fig. 2). They are relatively small, ~ 2 – 10 mm in diameter, with generally well rounded edges, indicating a considerable transport prior to sedimentation (e.g. Nichols *et al.*, 2000; Scott, 2000). In some specimens lumina of

tracheids are partly filled with so far unidentified minerals (Fig. 3A).

The following characters were considered by (Scott, 2010) as charcoal indicators are apparent in this material: (a) black streak, (b) silky lustre, (c) splintery appearance, (d) excellent preservation of anatomical details (Fig. 3), (e) homogenized cell walls (Fig. 3F). Based on this, the material from the Mukheiris Formation can be identified unambiguously as fossil charcoal or fusain (Scott 1989, 2000, and 2010).

Pycnoxylic wood (Fig. 3), with tracheids, 17 – 22 µm wide, with uniserial (Fig. 3C, E) pitting on the walls. Pits contiguous, with elliptical apertures (Fig. 3C, E). Wood rays are uniseriate, 4 – 6 cells high (Fig. 3D), composed of parenchymatous cells. Cross-field pitting and growth rings could not be observed.

The observed anatomical characters indicate a gymnosperm affinity of the material from the Mukheiris Formation, but a more specific identification is not possible due to the very fragmentary nature of the specimens and the missing information about taxonomically important features like cross-field pitting. Anatomical characters of all specimens investigated are very uniform and thus it is not possible to differentiate between different wood types, which may belong to different taxa or would come from different parts/growth stages of a single taxon.

#### 4.2. Palaeoecological Interpretation

This material can be identified as fossil charcoal and thus represents the direct evidence for palaeo-wildfire during deposition of the sediments of the Middle Triassic (Anisian) Mukheiris Formation in Jordan. To the best of our knowledge this is the second substantiated evidence of macroscopic charcoal that has been discovered in Anisian sediments worldwide only. The only other report came from the early Anisian *Voltzia* Sandstone Fossil Lagerstätte in SW-Germany (Uhl *et al.*, 2010). Additionally there is also a single published report on microscopic charcoal from palynological samples originating from the Anisian of the Barents Sea (Mangerud and Rømdal 1991) (the latter study also represents the only published report on fossil “micro-charcoal as evidence of palaeo-wildfire from the Early Triassic). Thus this study represents the first evidence for palaeo-wildfires during the Anisian within the entirety of Gondwana.

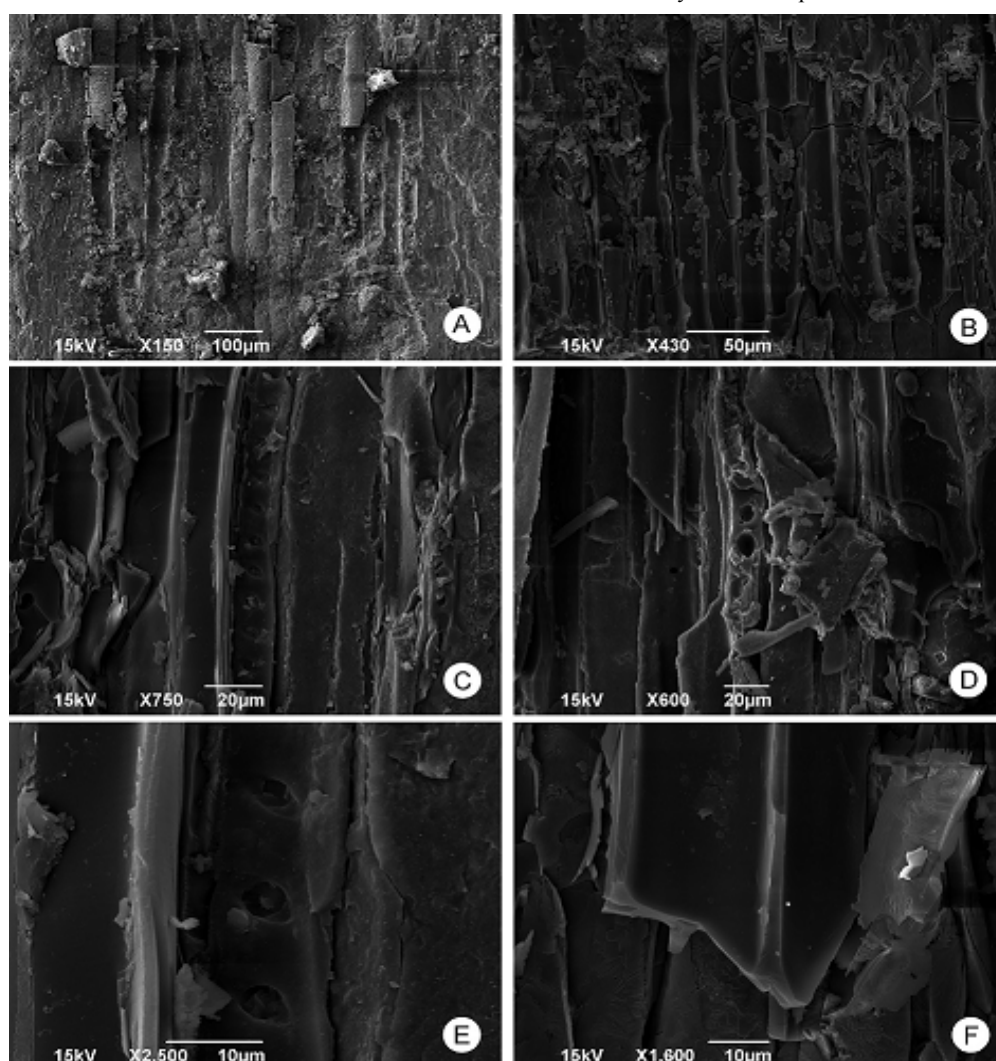
So far detailed macropalaeobotanical data are lacking from this period for the entire Near East region, although unspecified occurrences of plant remains and especially driftwood have occasionally been mentioned in the literature (e.g. Bandel and Khoury, 1981; Abu Hamad, 2004; Makhlof, 2006). Our data, together with previous palynological data (e.g. Abu Hamad, 2004), demonstrate that during the Anisian woody vegetation could existed somewhere in the source region of the sediments of the Mukheiris Formation. Due to the transport prior to sedimentation it is clear that we have to consider major taphonomic biases, including taphonomical sorting and filtering (e.g. Nichols *et al.*, 2000). Due to this fact nothing can be said at the moment about the type of vegetation that existed in this region at the moment, although woody gymnosperms (the source plants of the charcoal) must have been a component of these ecosystems. It is also

impossible to say anything about the growth form (i.e. tree or shrub) of these gymnosperms at the moment. Nevertheless, we can state that wildfires must have occurred in the potential source area but again nothing can be said about the intensity and frequency of these fires.

According to Grauvogel-Stamm and Ash (2005) the land flora, especially conifer dominated floras, had recovered to a great extent from the late Permian extinction event during the Anisian in several areas worldwide; however, it should be mentioned that it is not yet clear to what extent the terrestrial flora suffered from this event or, whether gaps in the fossil record of fossil plants have been explained by other, maybe taphonomical reasons (e.g. Rees, 2002; Gastaldo *et al.*, 2005; Uhl *et al.*, 2010). The present data show that a gymnospermous component of the vegetation existed in this region during this period. Also, palynological studies of Anisian sediments in Jordan show a significant increase in abundance and diversity of bisaccate pollen (which were extremely rare in early Triassic samples from Jordan) (Abu Hamad, 2004), supporting the idea of a re-establishment of vegetation types with a considerable gymnospermous component during this period in this region.

It should also be mentioned that we discovered so far gymnospermous wood remains from four additional horizons of the Anisian Mukheiris as well as from five horizons of the Carnian Abu Ruweis Formation, which show no evidence of charring. The latter is so far somewhat in contrast to the study of Dill *et al.* (2012) who reported the occurrence of pyrogenic polyaromatic hydrocarbons (another indicator of palaeo-wildfires) in sediments of the Abu Ruweis Formation. However, we are confident that this discrepancy will be solved in the future by additional fieldwork in the Abu Ruweis Formation to locate macroscopic or microscopic charcoal remains.

Despite a lot of effort in the field, we found no charred or uncharred wood remains from the Lower Triassic strata of Jordan so far. At the moment it is not clear why there are so few records of charcoal from the Early and Middle Triassic (Uhl *et al.*, 2008, 2010; Scott, 2010) but it seems likely that a combination of factors, like low atmospheric oxygen concentrations, taphonomic bias and a scarce source vegetation near the areas of sediment deposition may be responsible for the scarcity of charcoal during this period (for a more detailed discussion see Uhl *et al.*, 2010 and Abu Hamad *et al.*, 2012). The solution of this question is however beyond the scope of the current contribution.



**Figure 3.** SEM images of charcoal from the Anisian Mukheiris Formation. A) tracheids with mineral infillings; B) shattered tracheids without mineral infillings; C) tracheids with uniseriate pitting; D) wood ray in tangential view; E) detail of tracheid and uniseriate pitting; F) shattered tracheid walls with homogenized cell walls. Description and Taxonomic Affinity

## Acknowledgements

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# Cenomanian ammonites of the Shuayb Formation, Jordan

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## Abstract

Four species of ammonites belonging to the Family Acanthoceratidae (HYATT 1900) are described herein from sediments of the Late Cenomanian of northwestern Jordan. Calycoceras (Proeucalycoceras) guerangeri (SPATH, 1926), Calycoceras (Proeucalycoceras) picteti WRIGHT and KENNEDY, 1990, Calycoceras (Newboldiceras) asiaticum asiaticum (JIMBO, 1894), and Pseudocalycoceras harpax (STOLICZKA, 1864), are reported from marly layers of the top of the Shuayb Formation outcropping in Ibin within the Ajlun District. This assemblage of ammonites allowed for the assignment of these Jordanian sediments to the basal Late Cenomanian Calycoceras (Proeucalycoceras) guerangeri Zone of the standard biozonal scheme for the Mediterranean Faunal Province. The descriptions of these specimens of ammonoid genera and their species for Jordan shed additional information on their paleobiogeographic distribution through the Late Cenomanian interval.

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**Keywords:** : Ammonites, Acanthoceratidae, Cenomanian, Shuayb Formation, Jordan.

## 1. Introduction

The sedimentary cover of northwestern Jordan consists mainly of Upper Cretaceous fossiliferous marine facies. During the Cenomanian and Turonian stages, shallow warm seas largely covered Jordan depositing the strata of the Ajlun Group, which includes well-established lithostratigraphic units formally described as the Naur, the Fuheis, the Hummar, the Shuayb, and the Wadi As Sir Formations (Figure 1). Previous studies of these sedimentary rocks concentrated mainly on the petrography, micropaleontological interpretations and occasionally on macrofossil analyses (Bandel and Geys, 1985; Powell, 1989; Abed and Kraishan, 1991; Aqrabawi, 1993; Nazzal and Mustafa, 1993; Shinaq and Bandel, 1998; Bandel et al., 1999; Neumann, 1999; Sabaheen and Mustafa, 2000; Ahmad and Al-Hammad, 2002; and Perrilliat, et al., 2006).

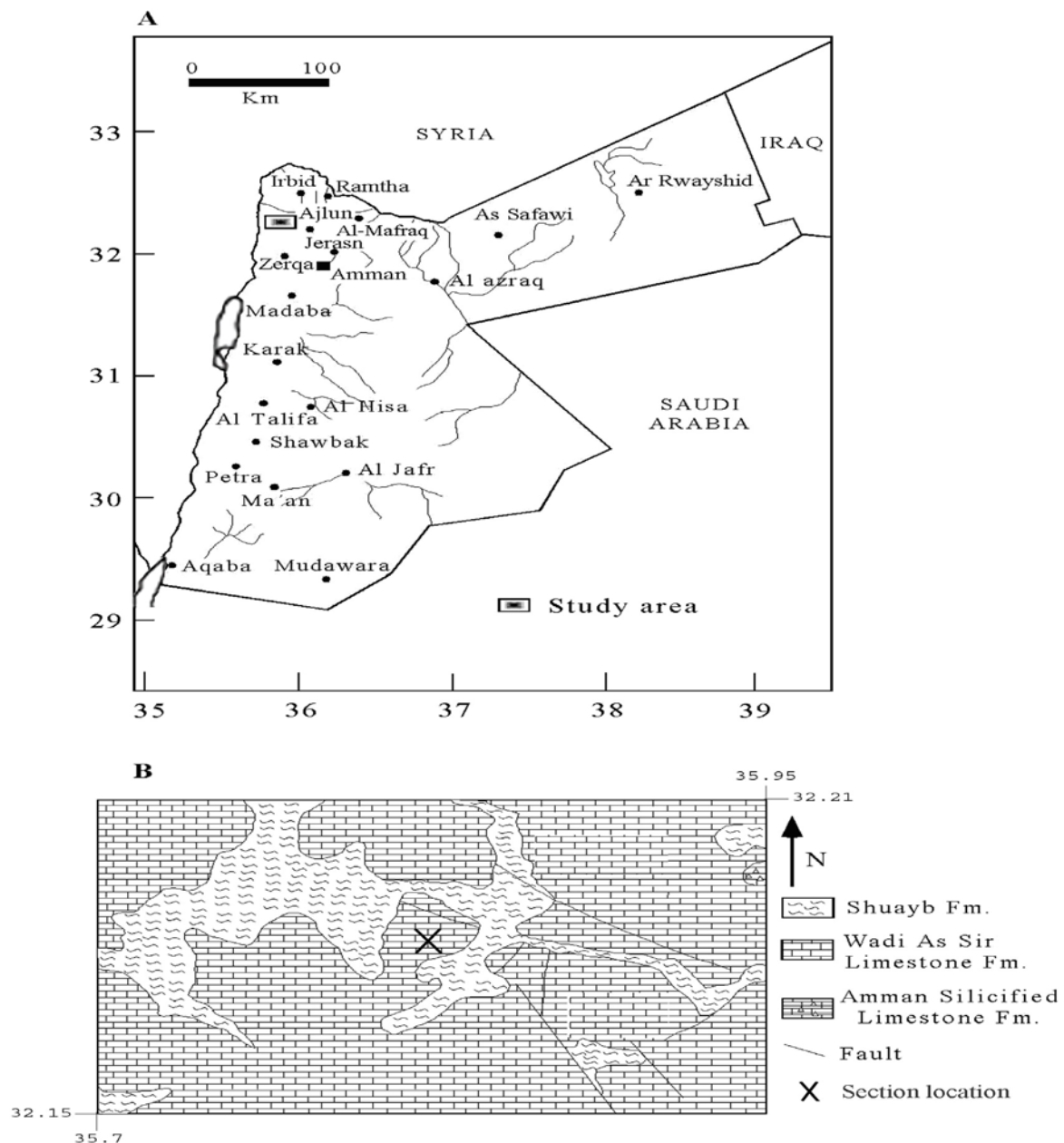
In northwestern Jordan, the Shuayb Formation is overlain by the limestones of the Wadi As Sir Formation (Figure 2). The Shuayb Formation consists of a rhythmic alternation of thinly bedded limestones and mostly fossiliferous marly limestones. The overall composition of

this formation becomes totally marly towards its top Powell (1989).

GROUP	STAGE	FORMATION
Ajlun	Turonian	Wadi As Sir
	Middle-Late Cenomanian	Shuayb Hummar
	Middle Cenomanian	Fuheis
	Late Albian- Early Cenomanian	Naur

**Figure 1.** Regional stratigraphy of northwestern Jordan. The Ajlun Group includes well established lithostratigraphic units formally described as the Naur, the Fuheis, the Hummar, the Shuayb, and the Wadi As Sir Formations Powell (1989).

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**Figure 2.** Location of the area of study. A) Geographic map of Jordan displaying the quadrant of the area of study to the northwest of the country. B) Geologic map of the area of study displaying the lateral relation of the Shuayb Formation on regards to the Wadi As Sir Limestone Formation.

Nazzal and Mustafa (1993) assigned a Middle Cenomanian age to the Shuayb Formation, restricting its deposition to the span of time of the ammonite biozone *Acanthoceras rhotomagense*. However, the exact age of this Upper Cretaceous stratigraphic unit remained uncertain, because most of the published fauna lacked precise stratigraphic control impeding broad regional correlations. In the publication of Naji (1996), a stratigraphic chart places the

Shuayb Formation into the Late Cenomanian, although the author himself had not provided nannofossil data from this formation. In contrary, Schulze *et al.* (2004) followed the works of Powell (1989) and Schulze *et al.* (2003), who put the age of the formation into the Early Turonian.

Thus, brief support was given to this assignment and in consequence, further work based on better material was desirable for a more complete understanding of the time of deposition of this lithostratigraphic unit. Recent collections of several well-preserved specimens referable to the genera *Pseudocalycoceras* and *Calycoceras* from the top of the Shuayb Formation set the basis for this new study. The newly ammonite findings reported herein suggest that even though this lithostratigraphic unit initiated its deposition in the Middle Cenomanian, this may have continued at least through the Late Cenomanian ammonite biozone *Calycoceras* (*Proeucalycoceras*) *guerangeri*.

## 2. Brief History of Ammonite Studies in Jordan and Palestine

Studies on Mid- and Late Cretaceous ammonites of Jordan and adjacent areas go back to the beginning of the twentieth century (i.e., Douvillé, 1916; Taubenhaus, 1920). The works of Mahmoud (1956), Wetzel and Morton (1959), Avnimelech and Shores (1962), Parnes (1964), Lewy (1989), Nazzari and Mustafa (1993), and Mouty *et al.* (2003), also gave a glimpse of the ammonite fauna of the area. In the past few years, the complex paleontological and lithostratigraphical researches of the central carbonate platform of Jordan were in focus (Schulze *et al.*, 2003, 2004). In Schulze *et al.* (2004), the Albian-Turonian ammonite data for the west-central Jordan carbonate platform is given mentioning that "*N. vibrayanus* locally occurs together with *Proeulycoceras haugi*, *Pseudocalycoceras harpax* or with *Turrilites acutus*", and that "these association indicates a Middle to middle-Late Cenomanian age". These data fit to our ammonoid biostratigraphical results presented herein.

## 3. Systematic Paleontology

The studied ammonites from the Shuayb Formation are generally preserved as internal complete and fragmentary casts. The systematic nomenclature and diagnoses used herein are followed the "Treatise on Invertebrate Paleontology (Wright *et al.*, 1996)" to the genus level. Descriptions, diagnoses, synonyms, and references used for specific determinations are also included. In the descriptions, the following abbreviations are used for measured parameters: (D) for the shell diameter of reference, (Ud) for the diameter of the umbilicus, (Wh) for the whorl-height, and (Ww) for the whorl-width. All measurements are expressed in millimeters. The ammonite specimens subject of this study are housed in the Invertebrate Collection of the Museum of Paleontology at the Institute of Geology, Universidad Nacional Autónoma de México, Ciudad Universitaria, 04510 México, UNAM under catalogue numbers IGM-9541 through IGM-9555.

Order Ammonoidea Zittel, 1884

Suborder Ammonitina Hyatt, 1889

Superfamily Acanthoceratoidea Grossouvre, 1894

Family Acanthoceratidae Grossouvre, 1894

Subfamily Acanthoceratinae Grossouvre, 1894

Genus *Calycoceras* Hyatt, 1900

**Type Species.** *Ammonites navicularis* Mantell, 1822, p. 198.

**Diagnosis.** Rather evolute to semiinvolute, with whorl section depressed and subcircular, oval, polygonal, or subquadrate; ribs strong, generally straight, continuous over rounded or flat but not concave venter; on early whorls at least umbilical, ventrolateral, siphonal, and, in most specimens, midlateral tubercles. In multituberculate forms umbilical tubercle more prominent than midlateral; tubercles may disappear with age and may or may not be rejuvenated on last part of shell. Marked dimorphism in

size apparently general. Due to significant morphological and time gaps between species groups, the genus embraces several subgenera.

Subgenus *Calycoceras* (*Proeulycoceras*) Thomel, 1972

**Type Species.** *Calycoceras* (*Eulycoceras*) *besairiei* Collignon, 1937, p. 37: by original designation.

**Diagnosis.** Inner whorls relatively compressed; sides and venter commonly flat; ribs dense, fine, and flexuous, with weak to strong umbilical bullae and weak outer ventrolateral clavi; inner ventrolateral and siphonal tubercles present initially but disappearing early; whorl section tending to become square, with blunt, well-rounded ribs.

*Calycoceras* (*Proeulycoceras*) *guerangeri* (Spath, 1926)

Figures 3a-c, 4a-b

*Ammonites rothomagensis*? "Lamck" – Guéranger, 1867, p. 5, pl. 4, fig. 4.

\**Metacalycoceras guerangeri* Spath, 1926, p. 431.

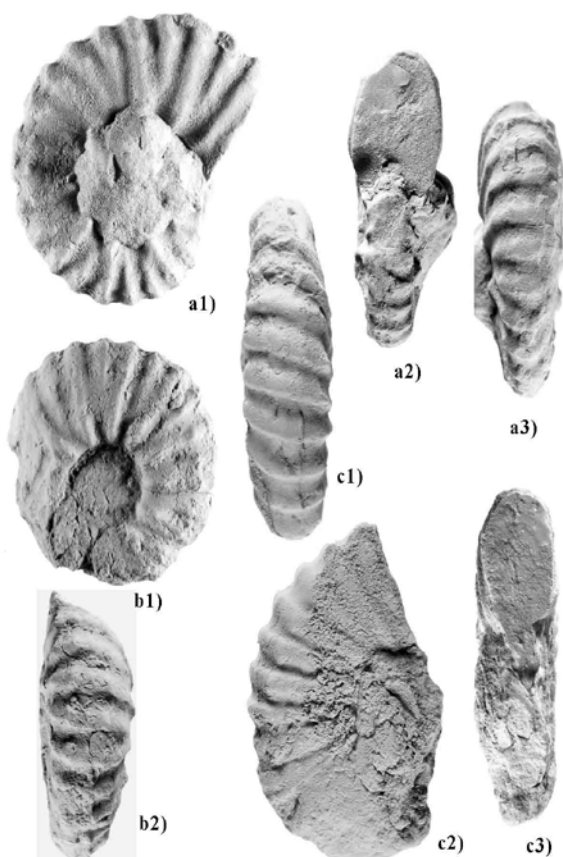
*Calycoceras* (*Proeulycoceras*) *guerangeri* Spath, 1926; Cobban, Hook and Kennedy, 1989,

p. 25, figs. 26, 27 p-r, t, u; Wright and Kennedy, 1990, p. 277, pl. 60, fig. 1, pl. 70, fig. 1, pl. 73, figs. 1-2, 4, pl. 74, fig. 2, pl. 75, fig. 1, text-figures 118, 119d-e, 120a-e, 121, 122, 123b; Thomel, 1992, pl. 37, figs. 1-2, pl. 40, figs. 4-5, pl. 41, figs. 11-12, pl. 42, figs. 8-10; Kennedy and Juignet, 1994, p. 478, figs. 6 a-c, 7 a-d, 8 a-d, 9 a-d.

**Material.** Eight specimens. The specimens illustrated are identified with catalog numbers IGM-9541 through IGM-9545.

**Dimensions of the illustrated specimens (mm).** IGM-9541, D: 78, U: approximately 20, Wh: 27, Ww: 23; IGM-9542, D: 65, U: 23, Wh: 25, Ww: 21; IGM-9543, D: approximately 90, U: ----, Wh: 35, Ww: 21; IGM-9544, D: 98, U: approximately 34, Wh: 32, Ww: 28; IGM-9545, D: 73, U: approximately 25, Wh: 33, Ww: 28.

**Description.** Rather involute (U/D ranging from 0.25 to 0.35), medium-sized specimens around the diameter of 60-80 mm. The umbilical region not observable due to sediment infill. The involution of the shell can be interpreted only on the specimen identified as IGM-9542 (Figure 3b), where the umbilical region is not occluded completely. Whorl section is slightly compressed, but most of the specimens are deformed. The ornamentation consists of the alternation of very distinctive, rigid ribs. The rib index in almost every case is 21. Primary ribs arise in a well-developed umbilical bullae and cross the flanks and the venter straight. On the last whorl some ribs tend to be slightly rursiradate. Sometimes an intercalated rib is present between two primaries on the inner flank. The intercalated ribs do not wear umbilical or inner lateral tubercle or bullae. Otherwise, primary ribs are quadrituberculate and additionally a slight siphonal tubercle may appear. The most prominent tubercles are the umbilical and the outer ventrolateral. Venter is well rounded or flat-topped. The siphonal tubercle is very weak.



**Figure 3.** a-c: *Calyccoceras* (*Proeulalycoceras*) *guerangeri* (Spath, 1926), a: IGM-9541, a1: flank view, a2: whorl section view, a3: ventral view; b: IGM-9542, b1: flank view, b2: ventral view; c: IGM-9543, c1: ventral view, c2: flank view, c3: whorl section view. All figures at natural size Shuayb Formation, northwestern Jordan.

**Remarks.** The rather involute coiling; the rigid, distinctive ribbing together with the strong tuberculation are characteristic features of the species. Furthermore, Kennedy and Juignet (1994) mentioned the “flattened venter” as a diagnostic feature as well. In this case most of the specimens are deformed or the venter is not flat, so in this pre-adult stage of the ontogeny, the flat venter is not a specific character. Some of the specimens assigned to *Calyccoceras* (*Proeulalycoceras*) *guerangeri* (Spath, 1926) in this work, resemble to *C. (P.) haugi* (Pervinquier, 1907), whose morphology is very similar and has also been reported from the region previously (Schulze *et al.* 2004). However, their flattened flanks are more characteristic of *C. (P.) guerangeri*.

**Occurrence.** The species has been reported from lower Upper Cenomanian deposits of France, England, Portugal, and the Western Interior of the USA.

***Calyccoceras* (*Proeulalycoceras*) *picteti* Wright and Kennedy, 1990**

Figures 4c, 5a-b

*Ammonites cenomanensis* d’Archiac, 1846, pp. 62, 78 (*nomen nudum*); Pictet, 1863, p. 28, pl. 3, Fig. 2.

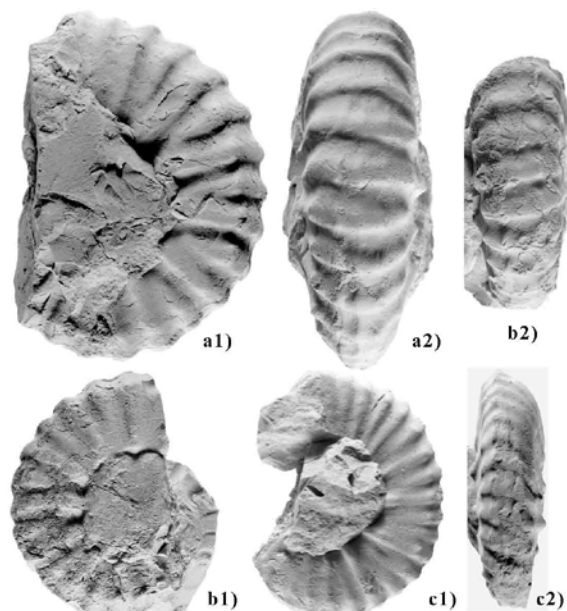
*Calyccoceras* (*Proeulalycoceras*) *picteti*, Wright and Kennedy, 1990, p. 264, pl. 54, fig. 2, pl. 64,

fig. 4, pl. 68, figs. 1-2, pl. 74, fig. 3, pl. 75, figs. 2-6, text-figs. 110 d, g, 113, 114, 116 a-d, 117, 119 a-c ;

Kennedy and Juignet, 1994, p. 471, figs. 1 a, 2 a-b, 3 a-d, 4 a-d, 5 a-d, 13 a.

**Material.** Eight specimens. The specimens illustrated are identified with catalog numbers IGM-9546 through IGM-9548.

**Dimensions of the illustrated specimens (mm).** IGM-9546, D: 70, U: 25, Wh: 25, Ww: approximately 18; IGM-9547, D: approximately 88, U: approximately 38, Wh: approximately 30, Ww: approximately 32; IGM-9548, D: approximately 75.



**Figure 4.** a-b: *Calyccoceras* (*Proeulalycoceras*) *guerangeri* (Spath, 1926), a: IGM-9544, a1: flank view, a2: ventral view; b: IGM-9545, b1: flank view, b2: ventral view. c: *Calyccoceras* (*Proeulalycoceras*) *picteti* Wright and Kennedy, 1990, IGM-9546, c1: flank view, c2: ventral view. All figures at natural size Shuayb Formation, northwestern Jordan.

**Description.** Considering the genus, the specimens assigned to this species are rather evolute (U/D ranging from 0.35 to 0.43). The umbilical areas are more or less occluded by sediment in a way that early whorls are not visible. Whorl sections of some specimens are compressed as in IGM-9546 (Figure 4c), but in others as in IGM-9547 (Figure 5a) are strongly depressed. Otherwise, the whorl section is moderately depressed as in specimen IGM-9548 (Figure 6b). Most of the specimens are deformed, so the shape of the whorl section is rather uninformative. The ornamentation consists of strong, distant, alternating long and short ribs. Rib index is variable between 14 and 20 ribs per half whorl. There are distinct, strong umbilical tubercles from where primary ribs start their development. Primary ribs are straight, sometimes slightly rursiradate. Between the primaries, one or two intercalated secondary ribs appear on mid-flank. The pattern of alternating short and long ribs is characteristic. Both ribs wear well visible outer lateral and ventrolateral tubercles. The inner lateral tubercle is missing in most cases. Siphonal clavi are present but get less prominent through ontogeny. Venter is deformed, but supposedly rounded or slightly flattened.

**Remarks.** Wright and Kennedy (1990, p. 264) have discussed the original species of *A. cenomanensis* d’Archiac as “*nomen nudum*” and interpreted *C. (P.) picteti* based on the description of *A. cenomanensis* of

Pictet (1863). "The evolute coiling, depressed whorl section, somewhat flattened, broadly rounded flanks and venter, and characteristic very distant, narrow, high flared ribs which are alternately long and short" (Kennedy and Juignet, 1994), characterize the species. Moreover, ribs are more numerous and less rigid than those of *C. (P.) guerangeri*.

**Occurrence.** This species has been reported from lower Upper Cenomanian deposits of Jordan, and Dorset and Devon, England.

***Calycoceras (Proeulycoceras) aff. picteti* Wright & Kennedy, 1990**

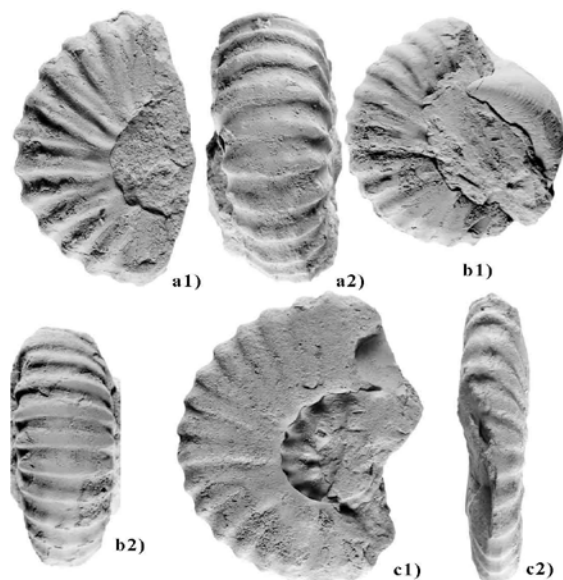
Figure 5c

**Material.** One specimen identified with catalog number IGM-9549.

**Dimensions of the illustrated specimen (mm).** IGM-9549, D: 95, U: 38, Wh: 30, Ww: 18.

**Description.** This specimen is different from the rest of the assemblage of the species because of its greater size and less prominent ornamentation of the outer whorl, which can be interpreted as the body chamber. The inner whorls are strongly tuberculated, the umbilical and the inner ventrolateral tubercles very big.

**Remarks.** The ornamentation of the inner whorls resembles that of *C. (P.) picteti* Wright and Kennedy, 1990. However, the greater evolution and the weak ornamentation of the outer whorl make the relation dubious and it is preferably to keep an open nomenclature. This specimen is in consequence much more evolutes, and its weak ornamentation of the last whorl, especially the lack of the umbilical tubercles, makes it different from the rest of the specimens assigned to this species.



**Figure 5.** a-b: *Calycoceras (Proeulycoceras) picteti* Wright and Kennedy, 1990, a: IGM-9547, a1: flank view, a2: ventral view; b: IGM-9548, b1: flank view, b2: ventral view. c: *Calycoceras (Proeulycoceras) aff. picteti* Wright & Kennedy, 1990, IGM-9549, c1: flank view, c2: ventral view. All figures at natural size Shuayb Formation, northwestern Jordan.

subgenus *Calycoceras (Newboldiceras)* Thomel, 1972

**Type Species.** *Acanthoceras newboldi* Kossmat, 1897, p. 112: by original designation.

**Diagnosis.** Large; whorl section tending to be polygonal with marked ventrolateral facet or subquadrate throughout; outer ventrolateral and in many cases inner ventrolateral and siphonal tubercles persisting.

***Calycoceras (Newboldiceras) asiaticum asiaticum* (Jimbo, 1894)**

Figures 6a-b

*Acanthoceras rothomagensis* var. *asiatica* Jimbo, 1894, p. 177, pl. 20, fig. 1.

*Acanthoceras Newboldii* n. sp. Kossmat, 1897, p. 5(112), pl. 1(12), figs. 2-3, pl. 3(14), fig. 2.

*Calycoceras newboldi newboldi* (Kossmat), Kennedy, 1971, p. 75, pl. 39, figs. 2 a-c, pl. 40, figs. 2 a-b.

*Calycoceras (Newboldiceras) asiaticum asiaticum* (Jimbo), Wright and Kennedy, 1990, p. 239, pl. 58, fig. 1, pl. 64, figs. 1-2, pl. 65, figs. 1-3, 5, 7, pl. 72, fig. 3, text-figs. 87 a-c, 88 f, 97, 98; Thomel, 1992, p. 94, 328, pl. 7, fig. 1, pl. 15, figs. 5-6, pl. 17, figs. 1-2, p. 340, pl. 41, figs. 8-9; Kennedy and Jolkicev, 2004, p. 375, pl. 3, fig. 1, pl. 4, figs. 6-7, pl. 5, fig. 1-4.

**Material.** Three specimens. The two specimens illustrated are identified with catalog numbers IGM-9550 and IGM-9551.

**Dimensions of the illustrated specimens (mm).**

IGM-9550, D: 75, U: 25, Wh: 28, Ww: approximately 23; IGM-9551, D: 75, U: 17, Wh: 25, Ww: approximately 22.

**Description.** The following description is based on specimen IGM-9551 (Figure 6b). Relatively involute (U/D ranging from 0.22 to 0.33) internal mould with flattened sides and deformed compressed whorl section. Slightly rounded venter. The umbilical wall is steep with well-rounded umbilical shoulder. More than thirty-four, slightly prorsiradiate, alternated short and long ribs on the last whorl. Primary ribs arise on the umbilical seam and strengthen into a sharp, strong bullae on the umbilical shoulder. Ribs are crowded and strong but no rigid, and wear prominent inner and outer ventrolateral tubercles and row of weak siphonal tubercles.

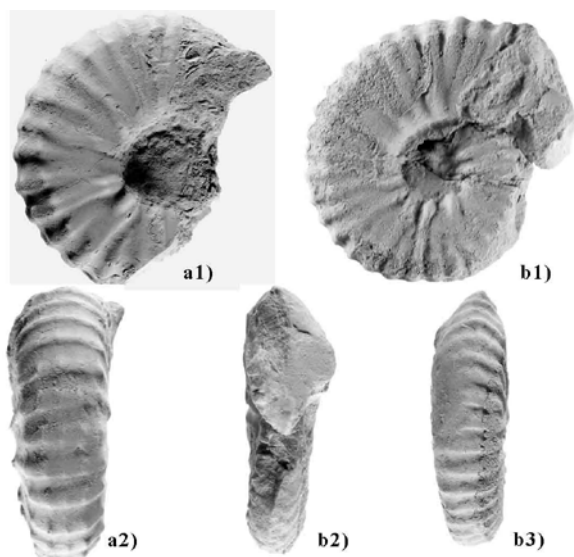
**Remarks.** The alternating long and short ribs make *Calycoceras (Newboldiceras) asiaticum asiaticum* (Jimbo, 1894) very similar to *Calycoceras (Proeulycoceras) canitaurinum* (Hass, 1949 fide Cobban and Kennedy, 1990). However, *C. (P.) canitaurinum* displays a flat venter, less number of ribs, and an early loss of the siphonal tubercles.

**Occurrence.** This species has been reported from lower Upper Cenomanian deposits of Japan, southern India, Madagascar, Zululand, southern England, France, Spain, Bulgaria, Romania, and Tunisia.

Genus *Pseudocalycoceras* Thomel, 1969

**Type Species.** *Ammonites harpax* Stoliczka, 1864, p. 72: by original designation

**Diagnosis.** Slightly compressed to slightly depressed; ribs flexuous to convex and prorsiradiate, more or less regularly branching or long and short; primaries arising from umbilical bullae, characteristically twisted; all ribs with inner ventrolateral nodes or clavi and outer ventrolateral and siphonal clavi; on latter part of body chamber ribs narrow, approximate, and generally recurve; tubercles dissapear.



**Figure 6.** a-b: *Calycceras* (*Newboldiceras*) *asiaticum* (*Jimbo*, 1894), a: IGM-9550, a1: flank view, a2: ventral view; b: IGM-9551, b1: flank view, b2: whorl section view, b3: ventral view. All figures at natural size Shuayb Formation, northwestern Jordan.

***Pseudocalycceras harpax* (Stoliczka, 1864)**

Figures 7a-b

*Ammonites harpax* Stoliczka, 1864, p. 72, pl. 39, figs. 1, 1a.

*Acanthoceras harpax* (Stoliczka), Collignon, 1937, p. 33, pl. 1, figs. 1, 1a, pl. 1, figs. 1-2.

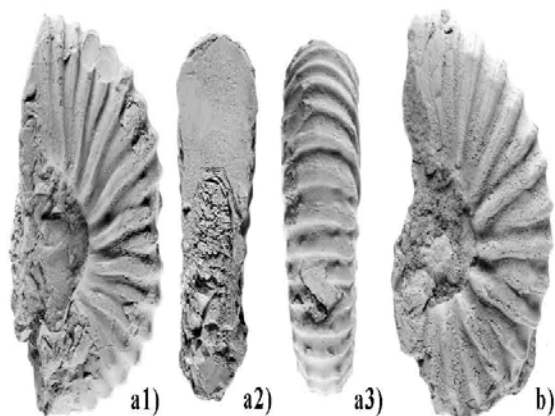
*Eucalycceras harpax* (Stoliczka), Porthault, Thomel and De Villoutreys, 1966, p. 428.

*Pseudocalycceras harpax* (Stoliczka), Thomel, 1972, p. 88.

*Pseudocalycceras* ex. gr. *harpax* (Stoliczka), Vašiček, 1992, p. 70, pl. 5, figs. 1-2.

**Material.** Two specimens identified with catalog numbers IGM-9552 and IGM-9553.

**Dimensions of the illustrated specimens (mm).** IGM-9552, D: approximately 70, U: approximately 25, Wh: 25, Ww: 24; IGM-9553, D: approximately 75, U: approximately 28, Wh: 26, Ww: approximately 22.



**Figure 7.** a-b: *Pseudocalycceras harpax* (Stoliczka, 1864), a: IGM-9552, a1: flank view, a2: whorl section view, a3: ventral view; b: IGM-9553, ventral view. All figures at natural size Shuayb Formation, northwestern Jordan.

**Description.** The following description is based on specimen IGM-9552 (Figure 7a). Moderately evolute (U/D ranging from 0.35 to 0.37) fragment of a half whorl. The umbilical region and the inner whorls are completely destroyed. The whorl section is compressed with the maximum diameter around the outer ventrolateral tubercle. The umbilical wall is steep and rounded. The ornamentation consists of nine primary ribs together with ten intercalated ones in a half whorl. Ribs are prominent, flexuous, and slightly rursiradiate. The umbilical bullae are strong when present, otherwise ribs wear umbilical, inner and outer ventrolateral, and siphonal tubercles. The venter is well rounded. Specimen IGM-9553 (Figure 7b) is very similar, apart from the lack of the flexuosity of the ribs.

**Remarks.** The alternating prominent, flexuous, long and short ribs characterize the species. Moreover, the prominent umbilical tubercles allow the differentiation of this species from *P. angolaense* (Spath, 1931) to which is very similar. Kennedy, Juignet and Hancock (1981) referred four subspecies (*harpax tulearensis*, *ankomakensis*, *ramondaense* and *talinoense*) of Collignon (1937, pl. 1) as synonyms of *P. harpax* (Stoliczka).

**Occurrence.** This species has been reported from lower Upper Cenomanian deposits of India, Madagascar, England, France, and the Bohemian Basin in the Czech Republic.

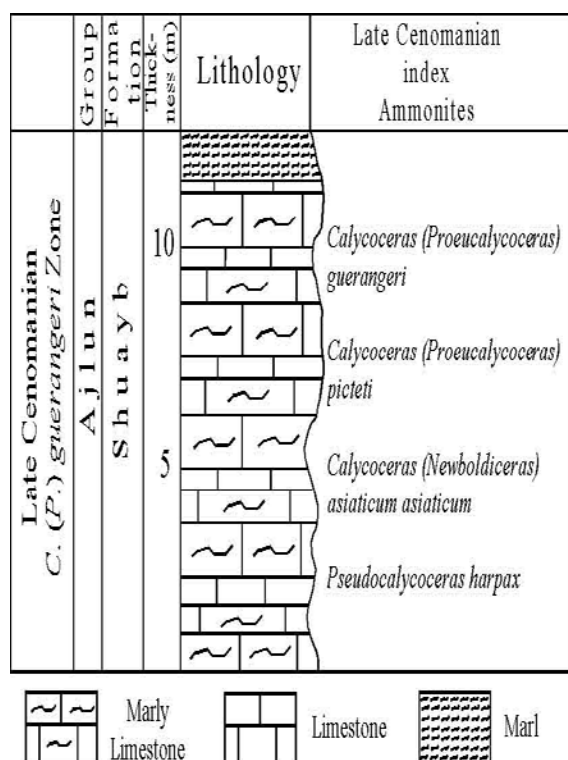
#### 4. Conclusions

Taxonomy and biostratigraphy of Upper Cretaceous ammonite assemblages have been useful conventional media used in stratigraphic correlation in Jordan and other areas of the region, as advocated in the works by Mahmoud (1956); Wetzel and Morton (1959); Avnimelech and Shores (1962); Parnes (1964); Lewy (1989); Nazzari and Mustafa (1993); and Mouty *et al.* (2003).

Locally, the Shuayb Formation (Ajlun Group) in northwestern Jordan has been assigned a Middle Cenomanian age (Nazzari and Mustafa, 1993), a Late Cenomanian age (Naji, 1996), and even an Early Turonian age (Schulze *et al.*, 2003). In this work, abundant specimens belonging to three species of the genus *Calycceras*, namely *C. (Proeucalycceras) guerangeri*, *C. (P.) picteti*, *C. (Newboldiceras) asiaticum asiaticum*, have been found associated with specimens of the species *Pseudocalycceras harpax*.

Despite the lack of precision in the assignment of the age of deposition for rocks of the Shuayb Formation, this ammonoid association fits well with the idea that the stratigraphic interval studied herein, can be regarded as part of the Upper Cenomanian *C. (P.) guerangeri* Zone, *sensu* Western European zonal scheme (Tröger *et al.*, 1996; Gradstein, Ogg and Smith, 2004; and Kennedy and Jolkevic, 2004) (Figure 8).

By means of these reports, this work also sheds new light on the paleobiogeographic distribution of the elements of the family Acanthoceratidae (Ammonoidea) in the Middle East seas.



**Figure 8.** Stratigraphic framework of the section of the Shuayb Formation (Ajlun Group) from northwestern Jordan studied herein, displaying lithology and ammonite assemblage. Based on the index ammonites identified, the interval studied is regarded to the Upper Cenomanian *C. (P.) guerangeri* Zone (*sensu* Western European zonal scheme).

## Acknowledgements

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# Deformed Fossils and Related Structures in Jordan

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## Abstract

This study of the deformation of fossils due to tectonic activities is the first study to be carried out in Jordan. Deformed fossils were found in a variety of locations such as Ajlun (Shtafina), Umm Dananier, Wadi Mujib and Jabal Waqf as Suwwan areas.

The different stress fields that produced folding, stylolization and reverse flexuring, are believed to have also produced the deformation of the fossils. Folding, stylolization and reverse flexures are structures, which can unambiguously be referred to defined stress fields. The deformation directions of the fossils are in this study correlated to the structures having unambiguous stress field producing them. The correlation was very clear and accordingly therefore, deformed fossils can be used as very good indicators on the stress fields which produced them irrespective, whether these stress fields have left any macrostructures in the rocks which indicate at them or not.

Deformed fossils from Jabal Waqf as Suwwan area have a different history, because the stress field producing them was a different one. It was a meteoritic impact stress field, which due to the very high velocity of around 18 Km/s caused all rock types to behave in a competent way for a very short time. After which rock block movements of sliding, rotation and tilting took place gradually.

According to the results of the study of deformed fossils, Jordan was during its geologic history exposed to different stress fields; in an ESE-WNW direction which produced the Syrian Arc structure, followed by a SE-NW strong stress field and finally by a NNW-SSE another strong stress field which resulted in the formation of the Dead Sea Transform Fault and accompanying structures.

The deformation of fossils was not always of a ductile type where fossils were compressed in a certain direction and expanded in the other, but some fossils show shear along certain directions, with very prominent shear surfaces.

The study concludes that deformed fossils can be used as excellent indicators of stress fields, even if other structures indicating at them are not found.

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**Keywords:** Deformation of Fossils, Deformation Structures, Paleostress Indicators, Stylolites, Slickenside.

## 1. Introduction

Deformation of rocks by stress fields whether vertical, horizontal or oblique may be portrayed in the fossil remains and casts. The Upper Cretaceous rocks of Jordan show a variety of deformation structures, such as folding with explicit force plane direction, a complex faulting pattern of less clear stress directions, vertical stylolites because of vertical load and compaction and horizontal stylolites with distinct stress action. Fossils in the Upper Cretaceous rock units in the northern part of the country show vertical, horizontal and oblique deformations. These deformations are categorized in brittle and plastic types.

Although stress fields causing fossil deformation are reversible, the deformation of fossils themselves is irreversible. Therefore, deformed fossils are considered as a historic register of stress fields. The methods of elaborating on the deformational processes depend on how much is known about the original shape and composition

of the deformed fossil (Ramsay, 1967; Davis and Reynolds, 1996). Undeformed and deformed fossils may be found in the same general area or in the different parts of the same structures. Therefore, the study of both deformed and undeformed fossils is expected to reveal information on the stress fields, which have affected the different study areas and probably Jordan as a whole.

Deformed fossils are found in several areas in Jordan. For purposes of this study, some of these are selected. The locations of these areas are shown in Figure (1).

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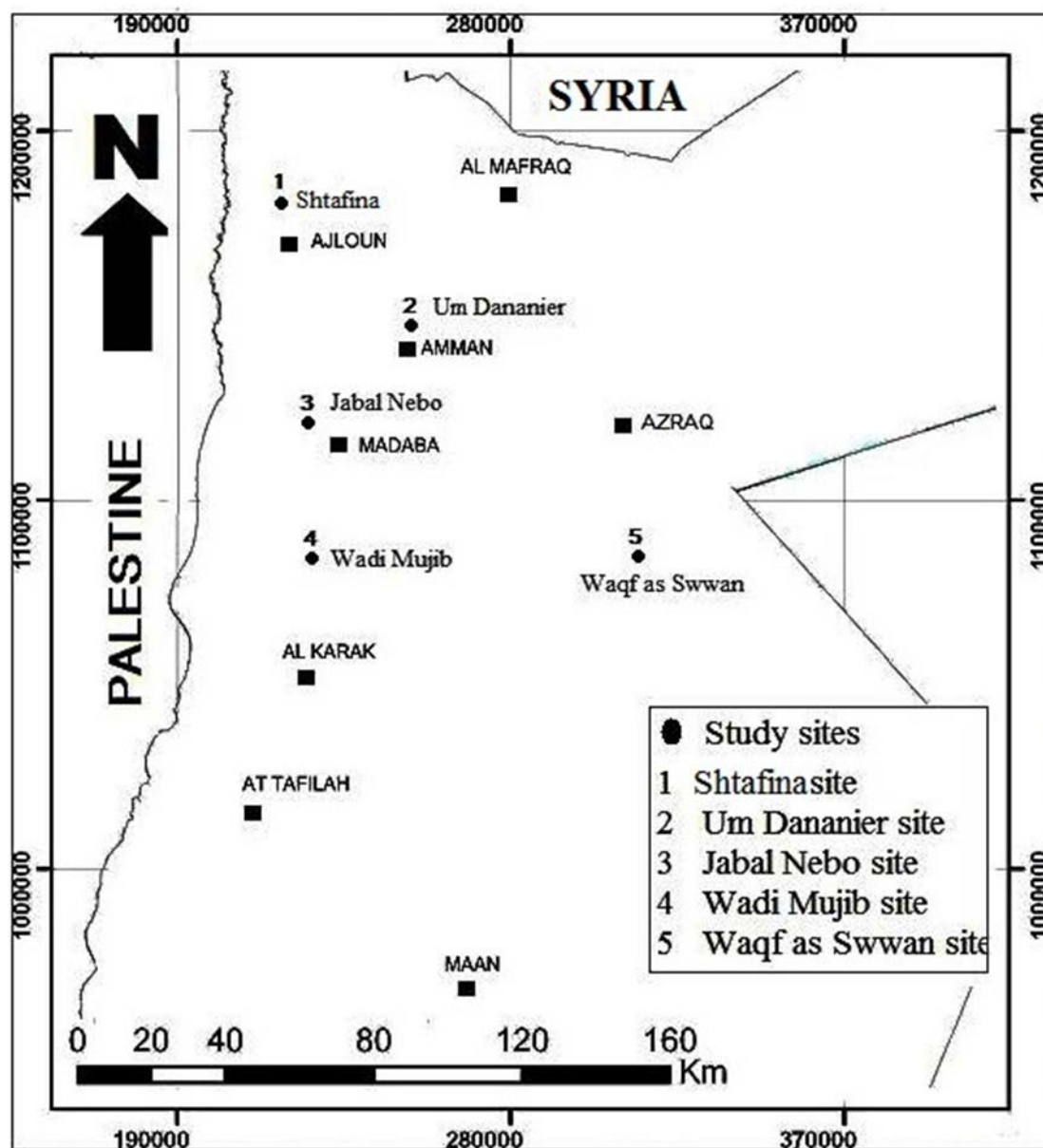


Figure1. Location map of the inspected sites (1, 2 etc... are numbers of studied sites).

## 2. Previous Work on Deformed Fossils

Phillips (1843) first studied deformed fossils in his study about slate cleavage, which was later studied by Sharpe (1847). Both indicated that fossils were deformed in the same direction causing the cleavage of slates. Shortening in slates because of the stress field was calculated by Sorby (1853).

Henderson et al. (1986), Jenkins (1987), Wright and Henderson (1992), Goldstein et al. (1995) studied also the percentage of shortening on deformed fossils and concluded that large volume losses accompanied the deformation of fossils in a variety of locations. Hills and Thomas (1944), Cloos (1947), Breddin (1956), Subieta, (1977), Blake (1878), Wright and Platt (1982), Ramsay and Huber (1983), Cooper (1990), Tan et al. (1995), Goldstein et al. (1995), Rocha and Dias (2003), Boyd and Motani (2008) studied the different types of deformations on different types of fossils, such as graptolites, ammonites, brachiopods etc. Deformed fossils were in

addition used as good tools to study the strain using the volume losses.

In Jordan many studies were carried out on fossils and their remains in the different geologic units such as Blake and Lonides (1939), Wetzel and Morton (1959), Quennell (1959), Bender (1968), Basha (1978), Bandel (1981), Bandel and Geys (1985), Dilley (1985), Powell (1989), Mustafa and Bandel (1992), Aqrabawi, (1993), Nazzal, and Mustafa, (1993), Bandel and Mustafa (1996), Neumann, (1999), Abu Hamad (2004). None of the studies dealt with the deformation of fossils.

In this article the deformed fossils found in the Cretaceous rocks of Jordan are studied on deformation types and magnitudes of the causing stress fields and their relation to existing geological structures such as folding, stylolites and slickenside.

The outcropping rocks where the deformed fossils are found consist of Upper Cretaceous sedimentary rocks. These rocks are mainly composed of limestone, marls, cherts, and dolomites of Cenomanian to

Maastrichtian ages. The distribution of these sedimentary rocks shows a wide variation in their thickness related to the transgression of the Tethys Ocean to the south and

southeast of Jordan where the granitic basement complex (Bender, 1968).

The lithostratigraphic description of the rock units of the Upper Cretaceous are given in Table 1.

**Table.1:** Stratigraphic nomenclatures and lithology of the Upper Cretaceous rocks in Jordan.

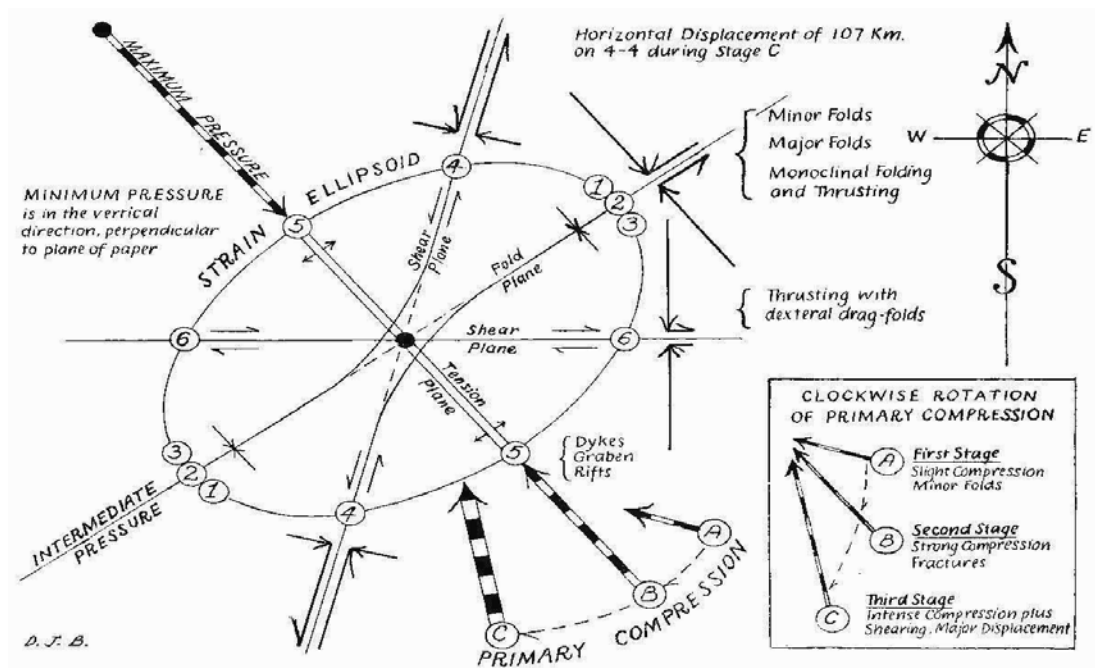
Period	Age	Quennell (1951)	Powell (1989) Formation	Lithology
Upper CRETACEOUS	Maastrichtian	Belqa Group	Muwaqqar Chalk Marl	chalk, marl
	Campanian		Al Hisa Phosphonite	phosphonite, marl
			Amman Silicified Limestone	massive chert limestone
	Coniacian		Wadi Umm Ghudran	chalk, chalky marl
	Turonian	Ajlun Group	Wadi As Sir Limestone	massive limestone, dolomite
			Shueib	marly limestone
	Cenomanian		Hummar	dolomatic limestone
			Fuheis	marl
			Na'ur	marly limestone

### 3. Tectonic Framework and Effects on the Upper Cretaceous Rocks Sequence.

Quennell (1951 and 1956) suggested that three stress fields were responsible for the formation of the major structures in Jordan (Figure 2). These stress fields have since Upper Cretaceous times

rotated in a clockwise direction starting from a direction of ESE-WNW through SE- NW to NNW- SSE directions.

(A) First stage of deformation started with a compression force acted in a WNW-ESE direction. Minor folds resulted from this stage of deformation. The folds trend SSW- NNE such as the folds around Irbid area with axis strikes N15° direction.



**Figure 2.**Horizontal Section through the strain Ellipsoid for the Dead Sea Region (QUENNELL 1951).

(B) The Second stage acted in a NW-SE direction. The compressive stress became stronger than during stage A. This stage produced the major folding and fracture system such as, Ajlun Dome, Basalt feeder Dykes, the Wadi Sirhan Graben, the Karak Graben, normal faults of Petra and the Wadi Khuneizira.

(C) The Third stage, which is still acting, has been still more intensive. It has been acting in a NNW-SSE trend, and it is responsible for the formation of the Dead Sea Rift Valley. The sinistral movement along the Dead Sea Transform resulted in a total horizontal movement of 107Km (Quennell, 1959).

Vorman (1961) found that the tensional stresses, which opened the Red Sea, caused also NW- SE normal faults and volcanic activity in the Middle East.

Ruef (1967) studied the undulations, in the Silicified Limestone Unit and the joint systems in Jordan. He

concluded that the major fractures trend  $170^\circ$  and the minor ones trend  $30^\circ$ .

Letouzey and Trémolières (1980) studied the paleostress fields around the Mediterranean; their measurements of microtectonic elements in Jordan show a shortening zone with a NW-SE trend in the Upper Cretaceous rocks.

Salameh and Zacher (1982) studied the stylolites in the Uppermost Cretaceous rocks of northern Jordan and east of the Dead Sea as paleostress indicators and concluded that the stress field affecting Jordan had two dominant directions namely  $130^\circ$  to  $140^\circ$  and  $170^\circ$ . Recently, Salameh (personal communication) measured weak horizontal peak stylolization is found in the Upper Cretaceous rocks in an ENE- WSW direction;  $70^\circ$ . Field evidence shows that this weak horizontal stylolization in older rocks than those affecting the most Upper Cretaceous rocks. Figure 3 shows the main structural features in Jordan

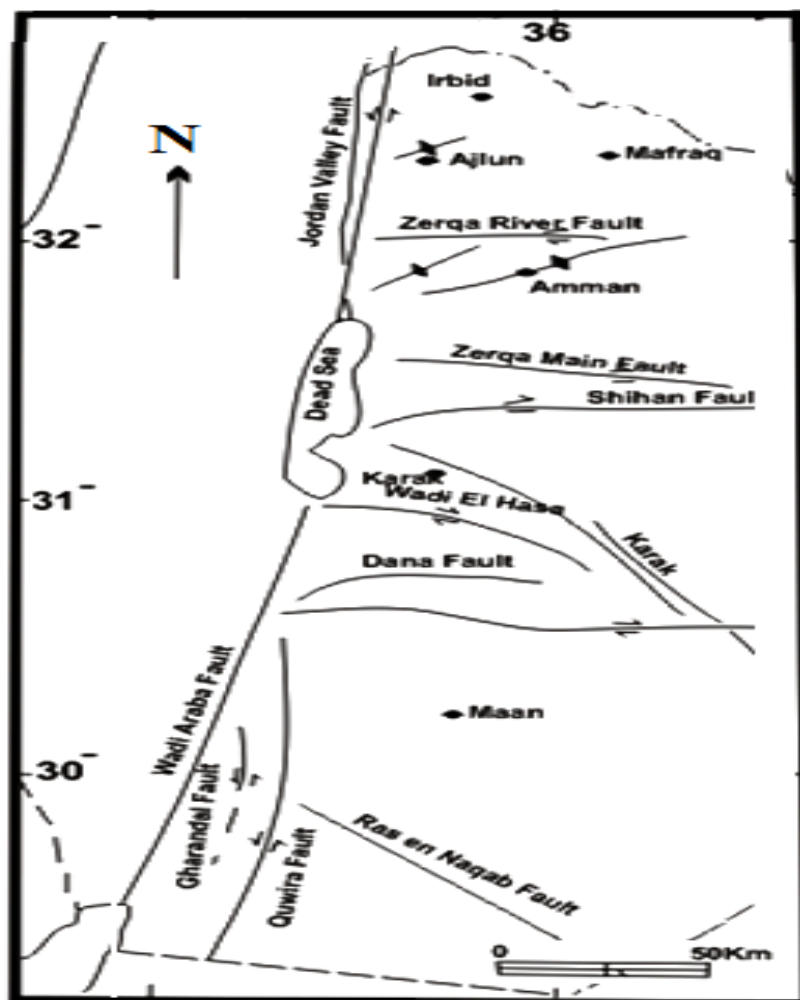


Figure 3: Major geologic structures map of Jordan (Al Diabat 2004).

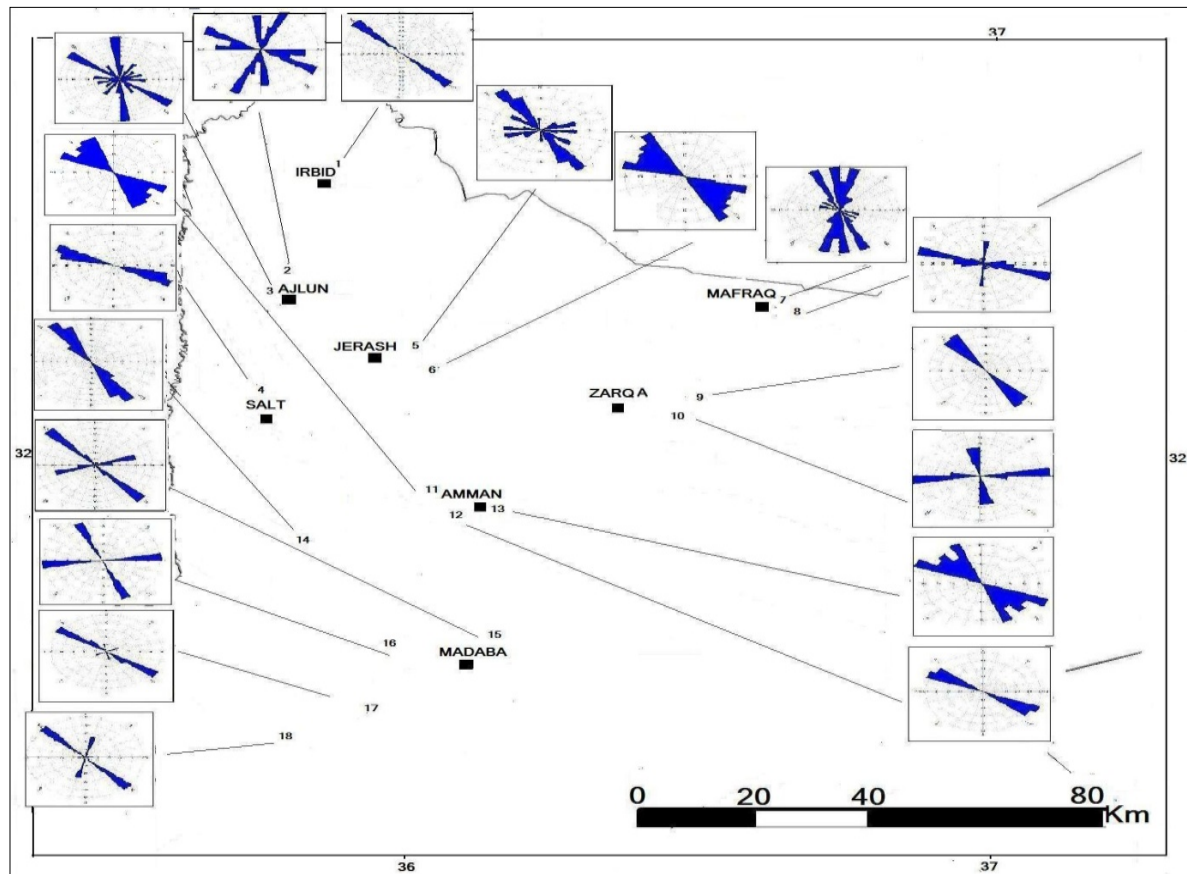
#### 4. Main Deformation Structures In The Upper Cretaceous Rocks In Jordan

The Upper Cretaceous rocks in Jordan show several types of deformation features, including; Fractures, faults, fold, slickenside, stylolites and deformed fossils. These deformation elements give good indicators on paleostress orientation, and allow interpreting stress conditions of the past.

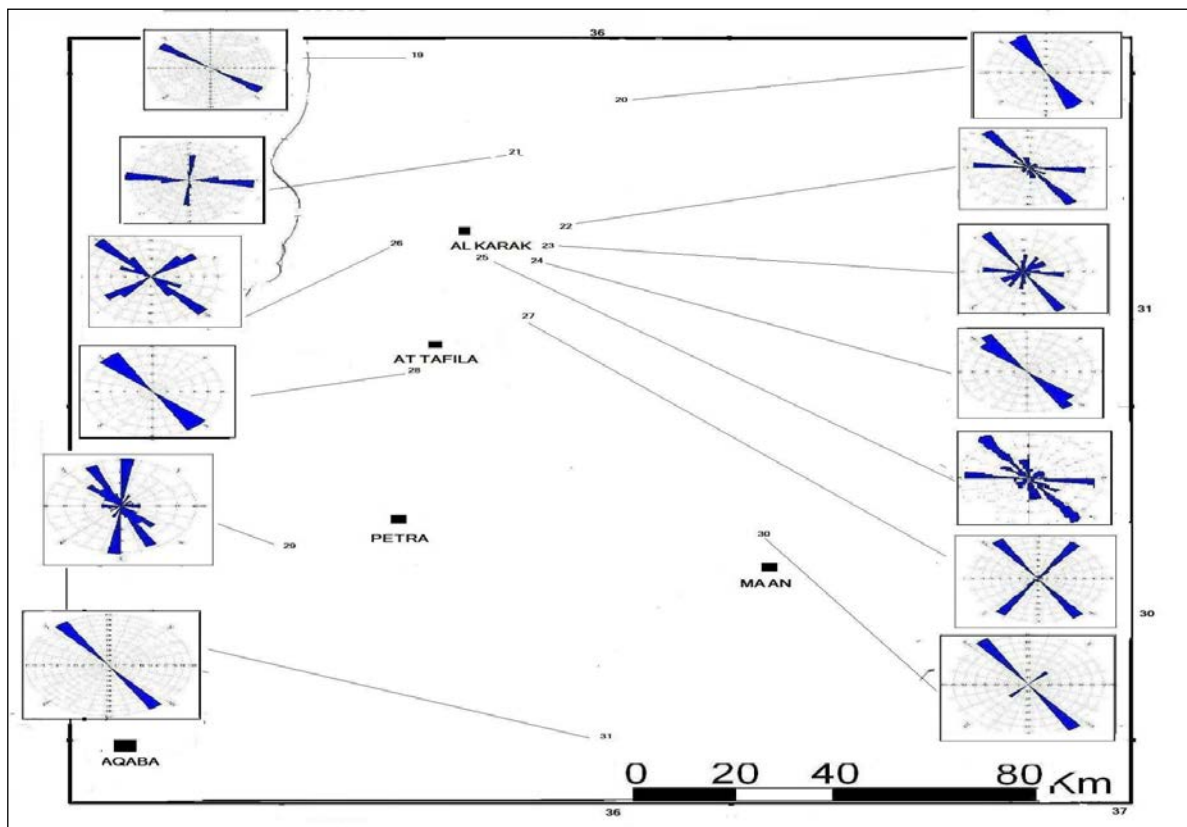
##### 4.1. Fractures

Field observations, measurements of joint trends in outcrop and also data collected from previous work on the structural evolution of Jordan (Burdon, 1959; Bender, 1968; Beicip, 1981; Barjous, 1986; Sahawneh, 1991; Atallah, 1992; Ibrahim, 1993; and Al Diabat, 1999) are used to represent the major orientation of fractures in Jordan, where Upper Cretaceous rocks crop out (Figures 4 and 5).





**Figure 4.** Fractures systems in the Upper Cretaceous rocks of northern Jordan. (Obtained from field observations, Burdon 1959, Bender 1968, Beicip 1981, Barjous 1986, Sahawneh 1991, Atallah 1992, Ibrahim 1993, and Al Diabat 1999.



**Figure 5.** Fractures systems in the Upper Cretaceous rocks of southern Jordan. (Obtained from field observations, Burdon 1959, Bender 1968, Beicip 1981, Barjous 1986, Sahawneh 1991, Atallah 1992, Ibrahim 1993 and Al Diabat 1999.

According to Figures 4 and 5 four directions of joint orientations are recognized; NNW± SSE, WNW±ESE, NW±SE and NE-SW.

Depending on the work of Quennell and own measurements and observations of joint trends which are given in Figures 4 and 5, the stages of stress can be classified as:

1. First stage WNW-ESE direction.
2. Second stage NW-SE direction.
3. Third stage NNW-SSE direction.

These observations in addition to other structures such as folds, faults, flexures indicate that the same stress field systems produced all these structures. The fractures trend WNW±ESE may be associated with the Syrian Arc fold system that affected the area in Turonian, and the NNW±SSE trending fractures sets are compatible with Dead Sea Stress Field System which is the youngest stress field system which started in Early Miocene, and was responsible for the major deformation process and structural elements in Jordan (Quennell 1956).

#### 4.2. Slickensides

Slickensides were very clearly observed during the field investigations, their trends and relative directions of movement between the blocks were measured. Table 2 lists that the NW-SE and NE-SW directions of slickensides are Riedel shear of the first stress field acting in a WNW-ESE direction.

**Table 2:** Different trends and directions of movement along the slickenside in several locations of Jordan.

Location name	Type of movement	Trend
Ras El-Ain (Naur road), Amman	Dextral	110°
El Sarrow, (Amman- Salt road).	Dextral	115°
Kufr Huda , Amman	Sense of movement not clear	180 ° and 80°
Ain Al Basha , Amman	The movement along the inclined layers surfaces with dip 65°	180°
Anjarah, Ajlun.	Sinistral	20°
Wadi Mujib	Sense of movement not clear	145°
	Dextral	90°
	Sinistral	170°
Wadi Al Karak	Sinistral	110°
Ain Sara, Al Karak	Sinistral	20 ° and 330°
Al Hallabat, east of Zarqa	Dextral	135°
Dhuleil, east of Zarqa	Dextral	100°
	Sinistral	160°
East of Jarash about 20 Km	Sinistral	40°
Zenah, South of Mafraq	Sinistral	180°

Jebel Nebo area, Madaba	Dextral	120° – 135°
	Dextral	70° - 80°
Wadi Himarah, NE of Dead Sea.	Dextral	135°
Makawer area	Dextral	90°
Wadi Safsaf near Karak	Dextral	140°
	Sinistral	45°
Wadi Al-Hasa	Dextral	125° -145°
	Sinistral	35°
Umm Dananier, Amman	Dextral	100°-145°
Ras En Naqb	Sinistral	10°
	Dextral	110°

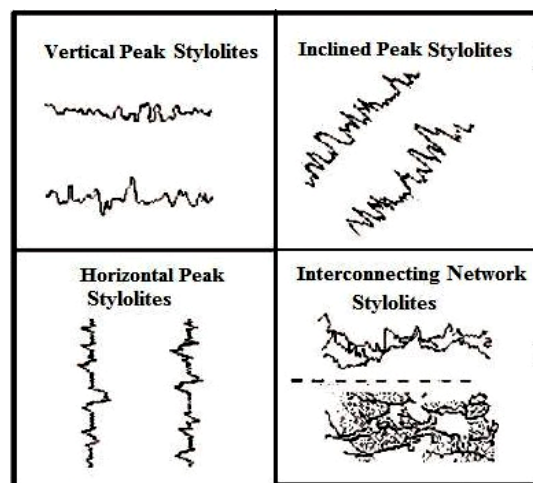
#### 4.3. Stylolites

The stylolites described here are found mainly in the carbonate rocks of Upper Cretaceous age, with various types and amplitudes. Stylolites characterization in this study depends on the direction of their peaks (teeth) which allows their easy recognition without confusion. Vertical peak stylolites are defined where the peak (teeth) direction is vertical, and perpendicular to bedding planes. Horizontal peak stylolites are defined where the peaks (teeth) direction is horizontal and parallel to bedding planes. Inclined peak stylolites where the oblique peak direction, is between vertical and horizontal peak stylolites (Figure 6).

The previous studies on stylolites in Jordan, concentrated mainly on the tectonically more interesting horizontal peak stylolites caused by horizontal stress.

Beicip (1981) studied the horizontal peak stylolites in the Upper Cretaceous rocks in several areas in Jordan and concluded that there is a relationship between the horizontal peak stylolites and the orientation of stress affecting their areas.

Salameh and Zacher (1982) studied also the horizontal peak stylolites, east of the Jordan Valley and the Dead Sea, they concluded that the area was affected by two stress fields an old system : 130° to 140° and a younger system 170°

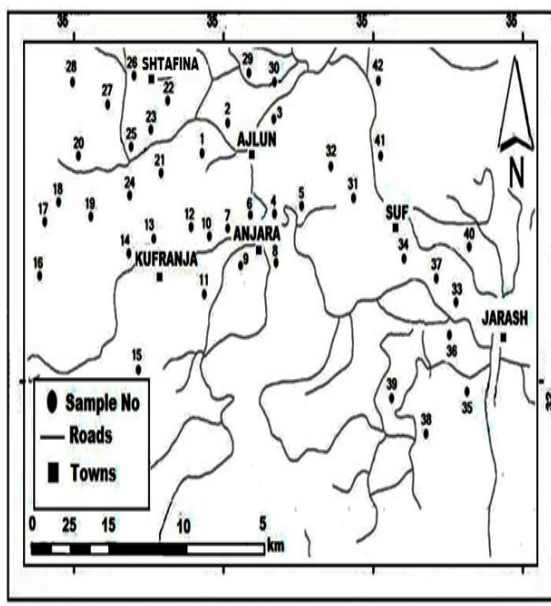


**Figure 6.** Stylolites classification depending on the direction of the stylolites peak as used in the present study.

The stylolitization of a sedimentary body causes deformation of rocks which changes the shape and reduces the thickness so stylolites accommodate volume reductions of up to 50% in some rocks (Stockdale, 1922). To estimate shortening percentages of deformed rocks due to vertical peak stylolitization calculations were made by measuring and adding stylolites amplitudes of peaks and dividing the result by the thickness of the whole rock  $\times 100\%$ . For example in the sample in Figure 7, the sum of stylolite peaks is 8mm while the whole rock measures about 70mm. The vertical shortening ratio is around 11%. About 40 measurements were carried out in several locations near Ajlun and Jarash areas (Figure 8).



**Figure 7.** Vertical peak stylolite, sharp peak with high amplitudes, the shortening ratio in this sample is 11% as a result of stylolitization (Shtafina area).



**Figure 8.** Differentiate stations according of stylolite types, see Table 3 for more explanation.

The results of shortening ratio were calculated in the same way as mentioned in Table 3.

During the field investigation numerous stylolites; vertical, horizontal, interconnected network and inclined, were observed especially, in Shtafina area (Figures 9 and 10).



**Figure 9.** Interconnected network of stylolites (in Wadi Es Sir Formation Shtafina area).



**Figure 10.** Tectonic (horizontal peak) stylolites cross- cut the bedding surface in the Upper Cretaceous Limestone rocks in Shtafina area. (Bedding is horizontal).

## 5. Deformed Fossils

The fieldwork revealed several locations where deformed fossils are found in Jordan. These locations show different lithologies, structural and tectonic elements. Deformed fossils showing brittle and ductile deformation types were collected and described to analyze the forces that affected them. The sites where distorted fossils are found in the Upper Cretaceous rocks in Jordan are described below.

### 5.1. Site 1 : Shtafina Site

The field observations show vertical, horizontal and oblique deformation of fossils and fossil remains or casts (Figures 11, 12 and 13). Two behaviors of deformation namely, ductile and brittle were observed. Figure 11 shows highly deformed rudists in a limestone rock with crack marks.





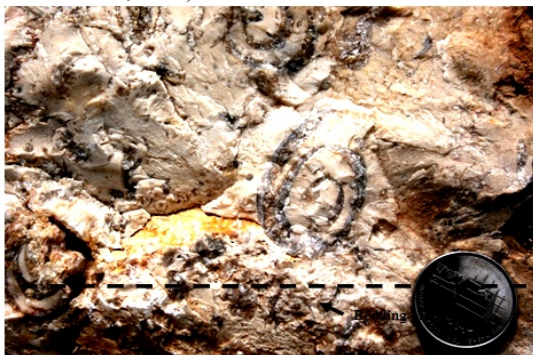
**Figure 11.** Broken and deformed fossils from Wadi Es Sir Limestone Formation (Shtafina site).

These deformed fossils indicate that the deformation affected the fossils and led to the formation of crack marks, which can only take place after the consolidation and lithification processes. This means that deformation in these fossils took place during post lithification stages because of tectonic deformation.

The formation of "mis-shape" of rudists in Shtafina is resulted from compaction loading (Figure 12). Field observation shows also horizontal tectonic deformations in the same site. In this case the maximum compressive stress was parallel to bedding planes.

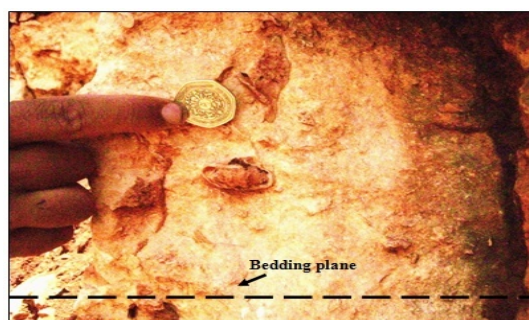
Oblique deformation can also be observed on deformed fossils in Shtafina site. The deformation of fossils is observed in a NNE-SSW and NE-SW directions (Figure 13).

From the field observations similarity between stylolites peak directions and deformation directions of fossils is recorded. Therefore, it is concluded that the stress field producing the stylolites must be the same one that produced the deformation of fossils. Shtafina site was affected by a WNW- ESE compression stress and NNE-SSW tension stress direction (Al Diabat, 1999 and Al Diabat *et al.*, 2004).



**Figure 12.** Deformed rudist in Wadi Es Sir Formation (Shtafina site) as a result of compaction processes.

The oblique compression forces between vertical and horizontal as indicated by the oblique stylolites and obliquely deformed fossils are the result of tectonic stresses directed SE- NW or ESE- WNW and vertical stresses due to overburden pressure or to transverse expansion.



**Figure 13.** Oblique deformation of fossils in Wadi Es Sir Formation (Shtafina site).

## 5.2. Site 2: Umm Dananier Site

During the field investigation, the highly flattened and squeezed ammonites resulted from compaction processes and vertical load pressures which are responsible of distortion in their shape. Another field observation is that

the deformed echinoids were affected by ductile deformation, which clearly appeared in change in their shapes as it's observed at Umm Dananier area (Figures 15 and 16.).



**Figure 15.** Deformed and undeformed regular echinoids (Umm Dananier, near Amman).



**Figure 16.** Ductile deformation appears on deformed echinoids fossils (Umm Dananier site).

Umm Dananier area was affected by tectonic deformation which is reflected in the deformation of rocks. The major geologic structure in this area is Umm Dananier flexure trending in a NNE- SSW direction. The deformed echinoid fossils have the same composition of the rock matrix. But the deformed rocks do not show their original shapes, contrary to echinoids fossils affected by the same tectonic events.

The deformation of echinoids is observed in a WNW- ESE direction parallel to the WNW- ESE stress field and perpendicular to the trend of Umm Dananier flexure, NNE – SSW.

### 5.3. Site 3: Jabal Nebo

In Jabal Nebo site different types of distorted fossils such as; bivalves, echinoids, gastropods and corals are found. Field observations show that fossils were subjected to plastic deformation especially bivalves, which is reflected in the change in their shapes (Figure 17).



**Figure 17.** Deformed bivalves fossils show the movement of a horizontal shear component (shear movement direction represented by arrows) Jabal Nebo site.

During the field work at Jabal Nebo site other deformation elements such as; Fractures, slickenside and horizontal peak stylolites were observed.

The deformed fossils, as mentioned before show shear deformation. This type of deformation indicates that strike slip movements had affected the area.

The major joint set in this site strikes  $120^{\circ} - 135^{\circ}$  and the minor set strikes  $70^{\circ} - 80^{\circ}$ . Horizontal slickensides trend  $120^{\circ} - 135^{\circ}$  with dextral movements and  $70^{\circ} - 80^{\circ}$  with sinistral movement. Deformed fossils in Jabal Nebo site were affected by the same shear stress fields producing the shear deformation elements within the Upper Cretaceous rocks.

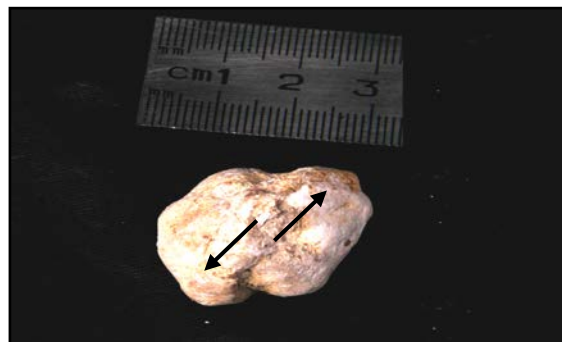
### 5.4. Site 4: Wadi Mujib Site

The deformed fossils in the area show different directions of deformation in the different types of fossils such as gastropods and echinoids. During the field investigation gastropod fossils from Amman Silicified Limestone Formation were found deformed in Mujib Site. The initial aragonite composition of shells changed and was substituted by silica composition during early diagenesis processes (Bandel *et al.*, 1999). The conical shape of turritella was distorted and became more flattened compared to the original shape of this family of gastropods (Figure 18).



**Figure 18.** Highly deformed gastropods fossils in the Upper Cretaceous rocks. The fossil impressions are extended horizontally, due to compaction or vertical pressure (Wadi Mujib Site).

The field observations indicate that the deformation of gastropods in Mujib site is the result of vertical load or compaction processes. Consequently, the overburden loading or maximum compression stresses are orientated perpendicular to layering (Figure 18). Irregular echinoids were also found in this site they are deformed in different directions (Figure 19). In Wadi Mujib and Shtafina areas fossils are highly deformed, as a result of the embedding limestone rocks, which are also rigid and competent similar to the fossils material itself.



**Figure 19:** Echinoids affected by shear forces (Wadi Mujib site).

The Mujib area was affected by NW – SE compression forces (Beicip 1981). This force caused two deformation zones and two types of strike slip movements that were recognized in the field as Riedel shear (Table 3).

**Table 3.** Shortening ratio as measured from stylolization in the different locations of Ajlun and Jarash.

Location	Number Of samples	Shortening %	Maximum amplitudes (mm)	Formation
1	8	3.3	4	A5-6
2	56	3.2	6	A5-6
3	34	3.4	4	A5-6
4	5	1.9	10	A5-6
5	31	3.5	14	A4
6	28	3.8	8	A7
7	17	5.3	5	A5-6
8	4	3.6	14	A5-6
9	5	5.2	5	A5-6
10	23	0.8	2	A5-6
11	9	0.8	2	A4
12	12	0.6	1	A5-6
13	9	3.9	2	A5-6
14	8	1.4	1	A5-6
15	60	11.5	10	A7
16	50	4.7	7	A7
17	38	1.4	5	A7
18	44	3.7	20	A7
19	44	3.1	20	A7
20	14	0.9	4	A7

21	67	3.3	8	A7
22	75	3.6	10	A7
23	31	1.4	5	A7
24	6	3.6	5	A7
25	60	8.8	15	A7
26	5	3.0	5	A5-6
27	7	5.0	3	A7
28	10	0.85	3	A7
29	43	6.5	15	A7
30	3	9.4	7	A7
31	7	4.0	3	A5-6
32	24	4.5	2	A7
33	8	3.5	12	A7
34	40	3.2	2	A5-6
35	3	3.4	6	A1-2
36	11	3.2	2	A7
37	16	2	15	A1-2
38	14	13.0	5	A7
39	17	9.0	4	A7
40	22	1.0	2	A5-6
41	50	3.6	3	A7
42	30	4.0	8	A5-6

The deformation of fossils in Mujib site appears to be a result of shear stress and compaction stress. The vertically compressed gastropods, with expansion in the horizontal direction are certainly the result of compaction or vertical stress. The rock matrix is composed of silicified and crystalline limestone and not much difference are found in the competence behavior of rocks and fossils. Therefore, fossils show partly brittle deformation.

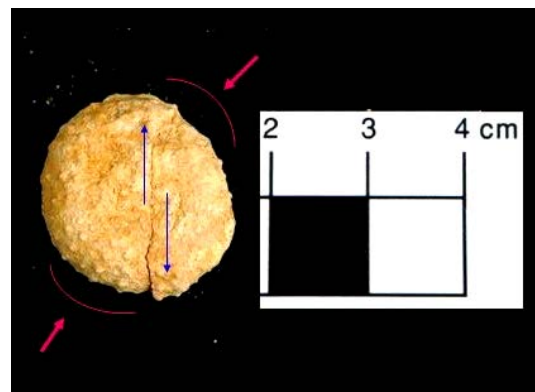
The horizontally compressed and sheared echinoids must be the result of horizontal forces causing the slickensides, strike slip movements and even horizontal peak stylolization in the area.

##### 5.5.Site 5: *Jabal Waqf as Suwwan*

Different types of deformed fossils and different forms of deformation were found. The more interesting field observations are evidenced on echinoids which originally have circular shapes but were found having elliptical or flattened shape. This allowed the easy recognition of deformation in these fossils and forces direction which produced the deformation of fossils (Figures 20 and 21).

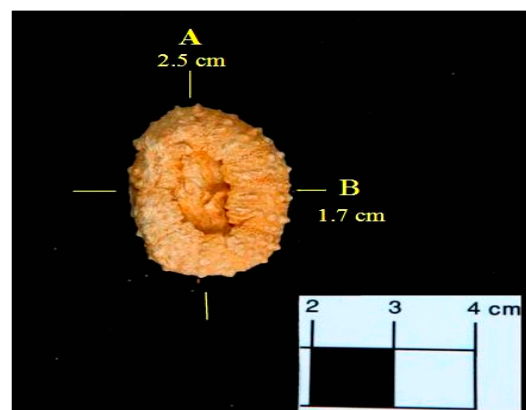


**Figure 20.** Distorted echinoids in the F/H/S Formation (Waqf as Suwwan site).



**Figure 21.** Deformed echinoids showing the displacement (blue arrows) and the shear stresses (pink arrows) that produced them, in F/H/S Formation (Waqf as Suwwan site).

Figure (22) shows the circular shape of a regular echinoid which due to lateral deformation became elliptical. To measure the change in shape it is assumed that no change in volume during deformation of this fossil has taken place (Davis and Reynolds, 1996). So the percent lengthening and shortening of this sample was calculated. The percent lengthening parallel to line A makes approximately 21% and the shortening parallel to line B, or the short axis of the ellipse makes approximately 17%.



**Figure 22.** Ductile deformation of an originally regular echinoid in the F/H/S Formation (Waqf as Suwwan site).



Other field observations reveal brittle deformation evidenced by cracking of samples, Figure (23) shows a deformed fossil with distinguished crack and fractures along the edges of this fossils.



**Figure 23.** Deformed fossils with crack marks on the surface in F/H/S Formation (Jabal Waqf as Suwwan site).

In Jabal Waqf as Suwwan site strongly deformed rocks were also observed. This originally circular concretion was deformed by the shock wave of the impact. It shows strong brittle deformation and rewelding along shear planes (Figure 24).



**Figure 24.** Highly deformed chert indicating shear stresses. Fragments were welded (Jabal Waqf as Suwwan impact structure).

The deformation of the fossils mentioned above, is the result of different processes, but mainly because of horizontal stresses affecting the area, which are also responsible for the formation of other structural features.

In Jabal Waqf as Suwwan area, the deformation of fossils is mainly of the brittle type and is referred to the recently discovered meteorite impact structure of the Jabal Waqf as Suwwan (Salameh *et al.*, 2008).

The impact is also made responsible for the shear stresses and crack marks found not only in regular echinoids but also in the area's rocks (Salameh *et al.* 2008).

As an example of rock deformation by shear stresses, Figure 24 shows the brittle deformation of chert concretion in the area. The same stress field also affected the fossils with distinguished cracks and fractures (Figure 23).

The distorted fossils of Jebel Waqf as Suwwan area are a special case of deformation that is different from those in other areas in their genesis and type of deformation.

Ductile types of deformation appear on bivalves fossils found in this site.

The reduction in thickness of the fossils was caused by the meteorite impact. An overburden of rocks of less than

500 m in that area will surely not cause lithified fossils to deform vertically.

## 6. Discussion

The Upper Cretaceous rocks of Jordan show a variety of deformation structures, such as folds, faults, Fractures, undulations and stylolites. Most of these structures were studied by authors such as: Quennell, 1951, 1956a, and 1959; Burden, 1959; Ruef, 1967; Bender, 1968; Beicip, 1981; Mikbel and Zacher, 1981; Salameh and Zacher, 1982; Atallah 1986; Bender, 1974; Andrews, 1991; Atallah, 1992; Abed, 2000; Al Diabat and Masri, 2002; and others.

As mentioned previously, none of these studies dealt with the deformed fossils in Jordan. Deformation of fossils resulting from tectonic activity can give important clues to be used as a structural geologic tool. The comparison of deformed and non-deformed fossils gives evidence about the type of forces responsible for the deformation, and the directions in which these forces were acting.

The study of deformation depends on how much is known about the original shape and composition of the deformed fossils. The deformations of fossils may be of brittle or ductile types.

The deformation of fossils in the Upper Cretaceous rocks of Jordan is generally the result of two processes:

- Tectonic processes; Represented by horizontally or obliquely distorted fossils. These in themselves are a historic register of stress fields, indicating the type of forces and their direction that lead to the deformation of rocks and fossils.

- Compaction processes due to overburden stress result in loss of volume, as fossils are initially buried, the weight of the overlying sediments linearly compacts the fossils vertically.

The deformation of fossils depends on many factors, including confining pressure, strain rate, and most importantly on the composition of these fossils and their competence relative to the embedding rocks.

Different sites were investigated in the course of this study where deformed fossils were found in the Upper Cretaceous rocks. The field investigations revealed that the deformation of fossils was caused by different forces and directions.

Shtafina study site was affected by tectonic stresses trending WNW- ESE and SE- NW (Quennell, 1959; Al Diabat 1999). The deformation of fossils is also in NNE-SSW and NE-SW directions. So the tectonic deformation of fossils in Shtafina site resulted also from WNW- ESE and NW- SE compression forces.

The field investigation of vertical and horizontal stylolites in association with the deformed fossils gives the evidence that the stress fields, which caused the deformation of fossils, are the same that produced the stylolites.

Highly deformed rudist fossils from Wadi Es Sir Limestone Formation were also observed in this area. They show brittle and ductile deformation types indicating that these deformations occur in post lithification stage, because of tectonic deformation.

Another field observation shows that some deformed rudists in Shtafina area are deformed because of the overburden pressure of the overlying sediments.

The vertically deformed fossils are accompanied with vertical peak stylolites affecting the rocks, indicating the overburden load as a cause of deformations and stylolization.

Horizontal stylolitic peaks serve as an excellent indicator of the stress field causing stylolization. The deformed fossils in Shtafina area show shortenings trends in the same directions of stylolitic peaks. This means that deformed fossils can also be used as a very good indicator on the prevailing stress field.

In Shtafina area where both vertical and horizontal stylolites were found in the same rock, even crossing each other at right angles, the rudists were deformed obliquely in a direction in between that of vertical and horizontal stylolization. Some of these rudists were even deformed beyond their plastic limit and show breakage in their shells in directions corresponding to the resultant vertical and horizontal stresses.

Umm Dananier area was also included in this study, with different forms of deformed fossils. A flattened ammonites fossil in the Upper Cretaceous rocks is believed to have been caused by vertical pressure or compaction processes.

In contrast, the distorted regular echinoids fossils indicate that Umm Dananier area was affected by horizontal tectonic deformation in a WNW- ESE direction perpendicular to the reverse flexure trending in a NNE-SSW direction.

In Jabal Nebo site tectonic deformation was found to affect bivalve and echinoids fossils and to deform them by shear stresses.

The major fractures trend in this site is  $120^{\circ}$ - $135^{\circ}$  and the minor trends  $70^{\circ}$ -  $80^{\circ}$ . Horizontal slickensides indicate that the types of movement were in  $120^{\circ}$ - $135^{\circ}$  with dextral movement and  $70^{\circ}$ -  $80^{\circ}$ , sinistral movement.

Horizontal stresses in the area were responsible for the formation of the structural features and it is the same causing the deformed fossils also.

In Jabal Waqf as Suwwan area; East Jordan, where the meteoric impact structure was found (Salameh et al., 2008), deformed fossils were found in the Upper Cretaceous rocks. Both vertical and horizontal deformations were observed.

These deformed fossils show also distinguished cracks and shears, because of the meteoric impact. These distorted fossils gave good evidence that the area was affected by shear stresses resulting from the shock waves leading to horizontal compression.

Vertically the deformed fossils in the central uplift of the impact site indicate high vertical pressure resulting from the impact event with vertical to subvertical pressure.

Horizontally deformed echinoids are mainly found on the eastern outside of the inner ring. As mentioned above they show both change in shape from circular to ellipsoidal and shear along cracks.

Finally, in Wadi Mujib area silicified gastropods fossils from the Amman Silicified Limestone Formation, are found squeezed, flattened and deformed vertically.

The deformation seems to be the result of gravitational loading during last stages of diagenetic compaction which could lead to deformation of non-tectonics origin, where the maximum shortening occur perpendicular to the bedding plane. In this location here rocks and fossils are composed of the same minerals and hence the same competence behavior of both.

Tectonically, deformed fossils are found as irregular echinoids in Wadi Es Sir Formation. The tectonic event that affected Wadi Mujib area, responsible for the deformation of the Upper Cretaceous rocks must have also deformed the fossils found there. The deformation is the result of the compression and the deformed echinoids show compression and shear fractures. Beicip (1981) concluded that the area was affected by NW – SE compression. This compression is reflected in the deformation of echinoids, resulting in their change in shape and distortion.

## 7. Conclusions

- The results of this study show that deformed fossils form very good indicators on the deformation stress affecting the rocks they are embedded in.
- The deformed fossils with a merely change in shape can be used as a very good indicator of the stress fields leading to the deformation of rocks and fossils contained in these rocks.
- Sheared fossils with relative movements indicate to the prevailing stress and the type of horizontal movement, sinistral or dextral.
- Rocks, especially when homogenous do not always show deformation features or horizontal peak stylolites, but if these rocks contain fossils, the deformation appears on the fossils, especially when the rock matrix is competent and transfers stresses to the fossils.
- Echinoids which originally have circular shapes show elliptical shapes after deformation indicating the prevailing stress field directions which led to the deformation.
- The original circle shape of regular echinoid fossils, which due to deformation became elliptical makes it easy to calculate the percent lengthening and shortening when as commonly assumed that no change in volume during deformation had taken place.
- Deformation of fossils in Shtafina site was parallel, oblique and perpendicular to bedding planes indicating at horizontal and vertical pressures and their resultants.
- In Shtafina area, the fossils were tectonically deformed with NNE-SSW and NE-SW directions, which indicate to stress fields in WNW- ESE and NW-SE directions. These are the same directions of horizontal stylolitic peaks.
- Vertical peak stylolites are used to calculate the shortening ratio of rocks, and the fossils contained in them.
- Deformation of bivalve's fossils in Wadi Mujib and Jabal Nebo shows horizontal displacement of the two valves, which indicate to shear stress.
- Highly deformed and squeezed gastropoda fossils in Wadi Mujib site show that the maximum

compressional stresses were perpendicular to bedding planes which is resulted from loading pressure.

- The meteoritic impact in Jabal Waqf as Suwwan is made responsible for the shear stresses, compressional stress and crack marks which appear on the deformed fossils in this area.
- The deformation ratio of the fossils depends on the relative competence properties of fossils and rocks.
- Ductile and brittle deformations were recognized in the different studied sites and in different fossils types indicating the relative behavior of rocks and fossils and their relative competence to deformational stresses.

## 8. Recommendations

For our case in Jordan, a well-studied area in the context of its structural geological features and the stress fields causing the structures, fossil deformation seems to form an integrative evidence to stress field recognition.

Therefore, it is highly recommended to study older geological formations than Upper Cretaceous on their deformed fossils, to shed light on the stress fields, which must have prevailed during the Pre-Cretaceous periods, especially, because the tectonic forces affecting Jordan in Pre-Cretaceous periods are not well established.

Deformed fossils can contribute to the understanding of the tectonic forces and the prevailing stress field during the different geologic eras not only in Jordan but also elsewhere. The study of deformed fossils in the other parts of the country as well as the other types of deformed fossils present in the different geologic sediments may reveal important information on the development of stress field and their evolution. The inner structures of deformed and undeformed fossils are of utmost importance for the completion of the accomplished study and other related studies.

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بعون من الله وتوفيقه يسعدنا أن نقدم العدد الأول من المجلد الخامس من المجلة الأردنية لعلوم الأرض والبيئة وهي مجلة علمية محكمة ومفهرسة تصدر عن اللجنة العليا للبحث العلمي وبدعم من صندوق البحث العلمي التابع لوزارة التعليم العالي والبحث العلمي في المملكة الأردنية الهاشمية ويشرف على إعداد ونشر هذه المجلة عمادة البحث العلمي والدراسات العليا في الجامعة الهاشمية.

باسمي واسم أعضاء هيئة التحرير فإنني أتقدم بجزيل الشكر وعظيم الامتنان للزملاء رئيس وأعضاء هيئة التحرير السابقين على جهودهم الخيرة التي بذلوها في إنجاح هذه المجلة حيث تم نشر أربع مجلدات لهذه المجلة احتوت على عشرات الأبحاث العلمية المميّزة في مجالات علوم الأرض والبيئة.

ونحن كهيئة تحرير للمجلة نحرص دوماً على الاستمرار في البحث ونشر الأبحاث العلمية المحكمة والتي ستكون بعون الله ذات فائدة للباحثين في المؤسسات الأكاديمية والتطبيقية المحلية والعربية والعالمية ونتمنى من هذه المؤسسات تزويدنا دوماً بالأبحاث والتي نعدّهم بأن يتم معاملتها بكل دقة وأمانة واحتراف مع كل الحرص على سرعة النشر وحسب الأصول العلمية المتبعة مما يساعد ويخدم الباحثين ويحقق أهداف المجلة في نشر كل ما هو مميز ومفيد والله نسأل العون والسداد.

أ.د. عيد عبد الرحمن الطرزي

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