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# Alunite Associated with Kaolin Beds, South Jordan

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**Abstract:** The objectives of this study are to record the occurrences of the alunite in the Kaolinite beds of the Hiswa Clay Deposits, South Jordan and to explain its possible mode of origin. The results of the field, chemical and mineralogical studies indicated that the alunite is present as minor and trace constituents (0.79-2.65%) in kaolinite bed of the Hiswa clay deposits, South Jordan. The alunite occurs as small white spots along bedding planes within the lower part of the Shale Member, which belongs to the lowest part of Hiswa Sandstone Formation. The Hiswa Sandstone Formation contains well preserved graptolite of middle Ordovician. The sulfur trioxide ($SO_3$) content (0.42-1.44%) is related to the presence of gypsum and alunite. Iron sulfides (source of sulfur) could be originally produced by mineral replacement of chitinous tests of graptolites in oxygen deficient marine environment.

**Key words:** Alunite, Kaolin, Jordan

## INTRODUCTION

Alunite is a very fine hydrous sulfate mineral with hydroxyl in its structure. The formula for pure alunite is $KAl_3(SO_4)_2(OH)_6$. Alunite has a rhombohedral crystal structure. Secondary precipitation of alunite is present in voids and along the bedding planes. The formation of alunite within the kaolinite beds indicates the presence of a sulfur source, which is a possibly sulfide. Alunite was recorded for the first time in Jordan by Khoury (1987) in the kaolinite bed of the Kurnub Sandstone Formation of the Lower Cretaceous age. Khoury (1987) indicated that alunite is possibly formed as a result of both digenetic and supergene processes. Sulfuric acid originated from the oxidation of pyrite. The source of potassium is the result of hydrolysis reactions of feldspars and illite-muscovite. The reaction of such water with kaolinite could form alunite.

In general, different types of alunite were investigated by many authors in different areas around the world. Long *et al*. (1992) studied the formation of alunite, jarosite and hydrous iron oxides in a hypersaline system: Lake Tyrrell, Victoria, Australia. The study concluded that Alunite ($KAl_3(SO_4)_2(OH)_6$) and jarosite ($KFe_3(SO_4)_2(OH)_6$) are common weathering products of aluminosilicates and pyrite. Mutlu *et al*. (2004) studied the geochemistry and origin of the Şaphane alunite deposit, Western Anatolia, Turkey. They mention a replacement type alunite deposit occurs in the studied area. Frost *et al*. (2005) discussed a Raman spectroscopic study of alunites. They mention that the minerals are characterized by well-defined hydroxyl stretching patterns, which give two groups of hydrogen bonds with calculated hydrogen bond distances of 2.90 and 2.84 Å.

The objectives of this study was to record the occurrences of the alunite in the Kaolinite beds of the Hiswa clay deposits, South Jordan and to explain its possible mode of origin.

## LOCATION AND GEOLOGICAL SETTING OF THE STUDY AREA

The investigated area is situated in southern Jordan. The area is located 20 km to the southeast of Ad-Disa Village at a distance of about 100 km east of Aqaba (Fig. 1). The investigated area is located north of Sahl As Suwan. It covers 6.0 km$^2$.

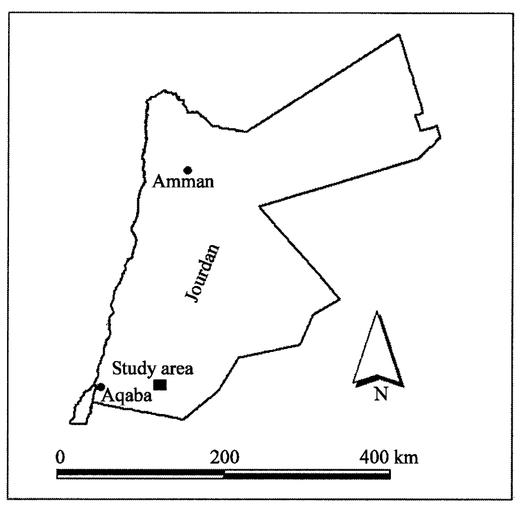


Fig. 1: General map showing the study area

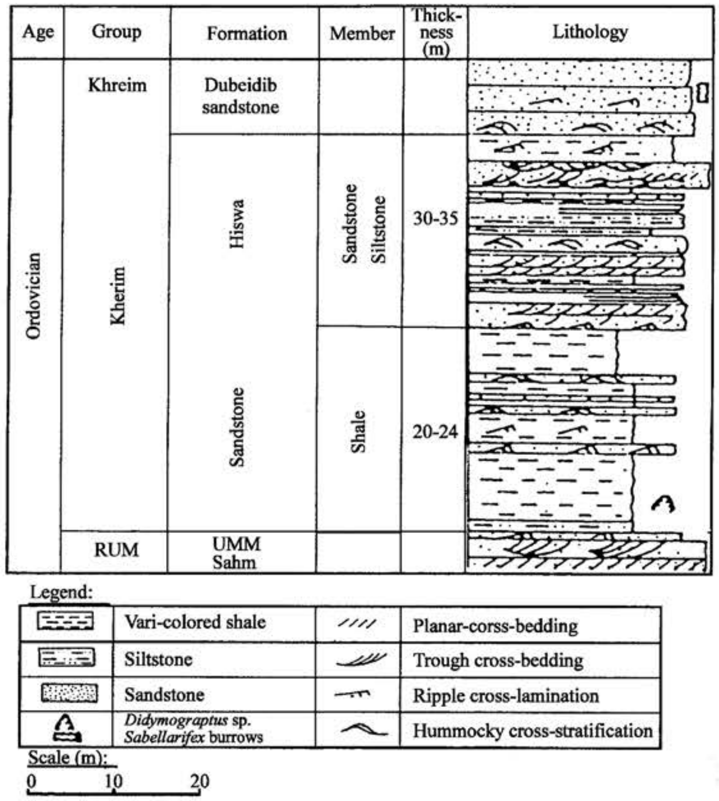


Fig. 2: Geological columnar section of Hiswa sandstone formation in the study area (Modified after Powell, 1989)

Fig. 3: Well preserved oxidized Ordovician graptolites (*Didymograptus* sp.) in the Hiswa sandstone formation

The Hiswa Sandstone (Graptolite Sandstone Formation) of Khreim Group is subdivided into the Shale Member and the Sandstone-Siltstone Member. The Shale Member consists of kaolinite of various colors, which range from light gray, dark gray, violet, brown-red and red. It is intercalated by few thin beds (10-20 cm) of ferruginous and hard siltstone.

The kaolinite deposits are the essential constituents of the Shale Member, which belongs to the lowest part of the Hiswa Sandstone Formation. The formation covers most of the study area in scattered outcrops and at the surface. In the study area the formation is divided into two members: lower Shale Member (24 m) and upper Sandstone-Siltstone Member (18 m). Figure 2 (Modified after Powel, 1989) shows a columnar section representing the Hiswa Sandstone Formation.

The Hiswa Sandstone Formation contains well-preserved graptolites. *Didymograptus bifidus* (Fig. 3) of

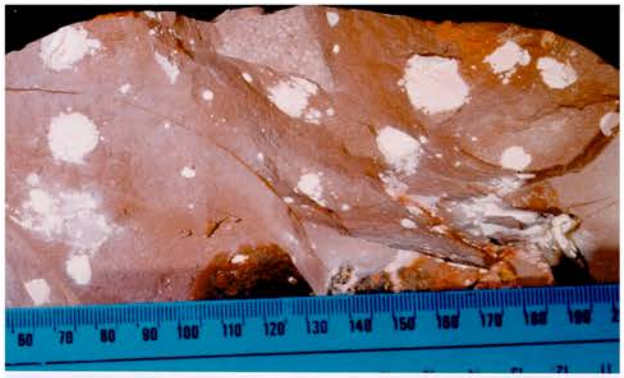

Fig. 4: Alunite (white patches) in the Shale Member, mainly along the bedding planes

Middle Ordovician. The clay beds consist of fine kaolinite particles. Intercalations of ferruginous and hard siltstones horizons are common. Joints are perpendicular to the bedding planes and are filled with iron oxides. Jointing is very common in the Shale Member and the joints are filled with ferruginous siltstone, clay and/or gypsum. Most of the joints are vertical and inclined with various directions.

Alunite is present as a minor and trace components. The separated patches of the white soft material mainly along the bedding planes are identified as alunite (Fig. 4).

## SAMPLING AND LABORATORY TECHNIQUES

Field work was carried and focused on the Hiswa Shale Member in March-April 2005. Five boreholes (B3, B5, B6, B7 and B9) were drilled by the Jordanian Co. for Mining and Processing of Kaolin, Amman, Jordan and have been chosen for the study. Samples were collected in accordance to lithological variations with depth. Twenty five samples were collected from the five boreholes: Nine (53 - 59) from borehole (B 3), ten (0, 1 8, 9, 11, 14, 15, 18, 19 and 20) from borehole (B 5), three (43-45) from borehole (B 6), one (49) from borehole (B 7) and four (24, 25, 36, 42) from borehole (B 9).

The mineralogy of the samples was determined by X-ray powder diffraction (XRD). The random samples were scanned from (2 to 65) degree 2θ using Cu Kα radiation at 35 kV and 25 mA with a Philips - Xpert MPD diffractometer available at the laboratories of Natural Resources Authority (NRA), Amman Jordan. Scanning Electron Microscopy (SEM) analyses on selected samples were carried out using (SEM FEI Quanta 200-Netherlands) at the Department of Earth and Environmental Sciences, Yarmouk University, Irbid, Jordan. Chemical analyses of samples (major oxides) were performed at the laboratories of the research center of Jordan Phosphate Mines Co.

Semi-quantitative mineral composition calculations of Hiswa clay are based on the chemical results (Olphen and Fripiat, 1979; Worrall, 1982; Chapman, 1983; Weaver, 1989; Chen *et al*., 1997).

## RESULTS

The Scanning Electron Microscopy (SEM) photomicrographs (Fig. 5) indicated the presence of alunite crystals within the kaolinite beds of Hiswa clay deposits, South Jordan.

Figure 6 and 7 show typical X-ray diffractograms of the bulk rock. The results of the X-ray diffraction analyses for the twenty five bulk rock samples are shown in Table 1.

The identified clay and non-clay minerals are kaolinite, quartz, muscovite, alunite, feldspars, gypsum and iron oxides (mainly hematite). Kaolinite, quartz and alunite are present in all samples. The results of the X-ray diffraction analyses of the bulk rock indicate that kaolinite and quartz are the most abundant minerals. Quartz is present as a major component. The results of the X-ray diffraction analyses of the separated patches of the white soft material mainly along the bedding planes are identified as alunite (Fig. 8).

Muscovite/illite are present in most of the borehole samples. Gypsum is identified as a filling material in joints and fractures. Feldspars and iron oxides (mainly hematite) are present in a few borehole samples in low concentrations.

The chemical composition of the analyzed 25 bulk rock samples from the five boreholes is given in Table 2.

The $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ are usually present in all of the studied samples as major constituents and low concentrations of MgO, $TiO_2$, $Na_2O$, $SO_3$ and $K_2O$ present as minor components. The important major oxides are $Al_2O_3$ and $SiO_2$, which are the chemical constituents of kaolinite.

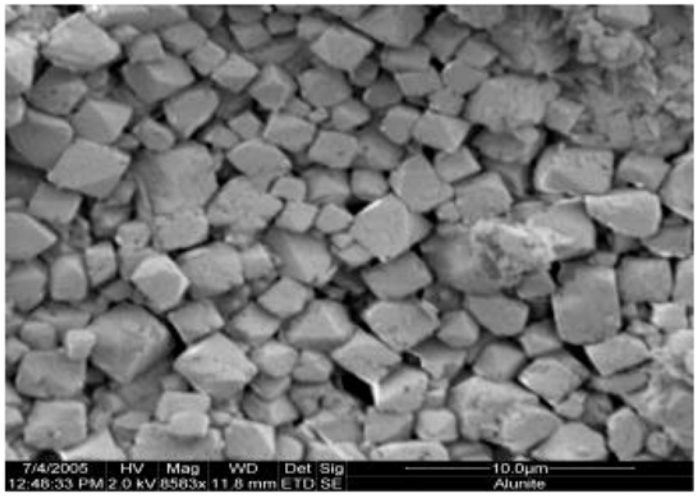


Fig. 5: Scanning electron micrograph showing aggregates of rhombohedral idiomorphic alunite

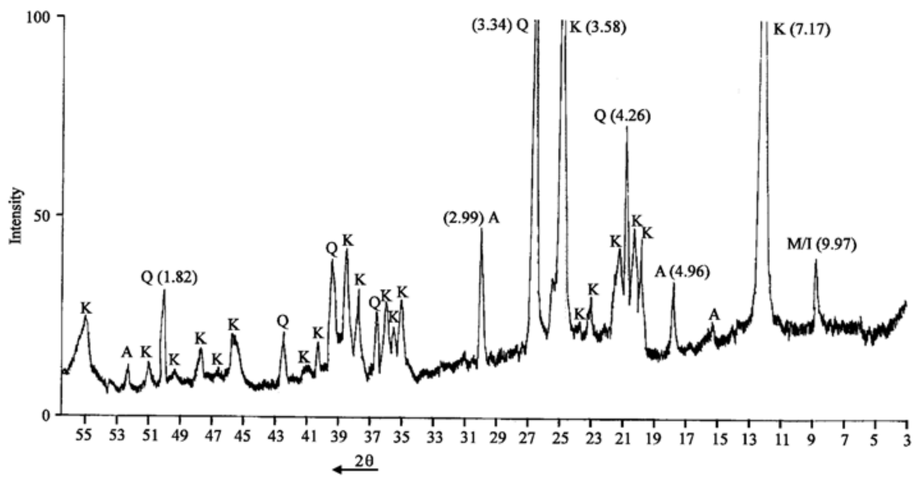


Fig. 6: Typical random XRD pattern for the bulk rock samples. Numbers between brackets indicate d-spacing. (K: Kaolinite; Q: Quartz; M/I: Muscovite/Illite; H: Hematite; F: Feldspars)

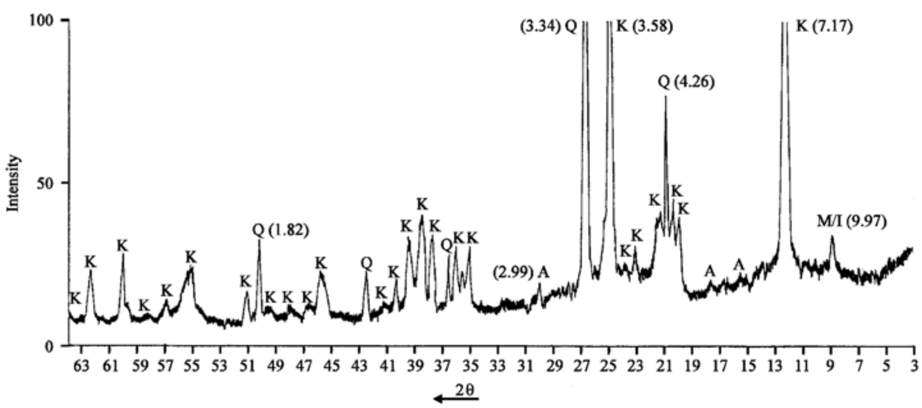


Fig. 7: Typical random XRD pattern for the bulk rock samples. Numbers between brackets indicate d-spacing. (K: Kaolinite; Q: Quartz; M/I: Muscovite/Illite; H: Hematite; F: Feldspars)

Table 1: Semi-quantitative results of the X-ray diffraction (XRD) analysis of the bulk rock samples based on peak height

| Serial No. | Sample No. | 1 KA | 2 QZ | 3 M/I | 4 GYP | 5 FEL | 6 ALU | 7 HE |
|---|---|---|---|---|---|---|---|---|
| | | (Borehole No. B-5) | | | | | | |
| 1 | 0 | * | *** | * | ** | * | * | * |
| 2 | 1 | ** | *** | * | | * | * | |
| 3 | 8 | *** | *** | * | | | * | |
| 4 | 9 | *** | *** | * | | | * | |
| 5 | 11 | *** | *** | * | | | * | |
| 6 | 14 | *** | *** | * | * | | * | * |
| 7 | 15 | *** | *** | * | | | * | |
| 8 | 18 | ** | *** | * | | | ** | |
| 9 | 19 | *** | *** | * | | | * | |
| 10 | 20 | ** | *** | * | * | | | |
| | | (Borehole No. B-9) | | | | | | |
| 11 | 24 | *** | *** | * | * | * | * | |
| 12 | 25 | *** | *** | * | | * | * | * |
| 13 | 36 | ** | *** | * | | | * | |
| 14 | 42 | * | *** | * | | | ** | * |
| | | (Borehole No. B-6) | | | | | | |
| 15 | 43 | *** | *** | | | | * | |
| 16 | 44 | *** | *** | * | | | ** | |
| 17 | 45 | *** | *** | | | | * | |
| | | (Borehole No. B-7) | | | | | | |
| 18 | 49 | * | *** | | | | ** | |
| | | (Borehole No. B-3) | | | | | | |
| 19 | 53 | *** | *** | * | | | | |
| 20 | 54 | *** | *** | * | | | * | |
| 21 | 55 | ** | *** | | | | * | |
| 22 | 56 | *** | *** | * | | | * | |
| 23 | 57 | *** | *** | * | | | * | |
| 24 | 58 | *** | *** | * | | | ** | |
| 25 | 59 | ** | *** | * | | | * | |

1. KA.: Kaolinite, 2. QZ: Quartz, 3. M/I: Muscovite/Illite, 4. GYP.: Gypsum, 5. FEL.: Feldspar, 6. ALU.: Alunite, 7. HE.: Hematite, ***: Major, **: Minor, *: Trace

Table 2: Results of chemical analysis (major oxides) of the bulk rock samples

| Sample no. | Major oxides (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $TiO_2$ | $Na_2O$ | $K_2O$ | MnO | MgO | CaO | $P_2O_5$ | $SO_3$ | LOI | Total |
| 0 | 57.99 | 18.6 | 8.82 | 0.65 | 0.45 | 1.33 | 0.020 | 0.74 | 0.04 | 0.08 | 0.81 | 10.92 | 100.450 |
| 1 | 57.80 | 20.48 | 7.36 | 0.79 | 0.42 | 1.27 | 0.010 | 0.64 | 0.02 | 0.06 | 0.63 | 10.68 | 100.160 |
| 8 | 50.17 | 27.32 | 4.90 | 0.78 | 0.33 | 1.14 | 0.010 | 0.52 | 0.01 | 0.05 | 0.73 | 13.56 | 99.520 |
| 9 | 57.20 | 22.08 | 7.56 | 0.86 | 0.19 | 0.98 | 0.010 | 0.39 | 0.08 | 0.05 | 0.50 | 10.92 | 100.820 |
| 11 | 55.98 | 22.74 | 5.38 | 0.76 | 0.08 | 1.08 | 0.010 | 0.48 | 0.01 | 0.04 | 0.44 | 12.37 | 99.370 |
| 14 | 55.50 | 20.48 | 8.67 | 0.84 | 0.26 | 0.92 | 0.010 | 0.17 | 0.07 | 0.04 | 0.60 | 13.11 | 100.670 |
| 15 | 51.82 | 26.94 | 2.65 | 0.79 | 0.32 | 1.06 | 0.010 | 0.28 | 0.01 | 0.05 | 0.74 | 14.71 | 99.380 |
| 18 | 50.54 | 28.55 | 2.43 | 1.08 | 0.18 | 1.02 | 0.020 | 0.20 | 0.00 | 0.04 | 0.78 | 13.48 | 98.320 |
| 19 | 54.91 | 26.75 | 2.67 | 0.79 | 0.09 | 0.89 | 0.005 | 0.18 | 0.00 | 0.04 | 0.57 | 12.33 | 99.225 |
| 20 | 66.47 | 15.62 | 7.61 | 0.76 | 0.08 | 0.56 | 0.010 | 0.16 | 0.10 | 0.05 | 0.42 | 7.95 | 99.770 |
| 24 | 52.96 | 20.89 | 8.51 | 0.81 | 0.26 | 1.43 | 0.020 | 0.17 | 0.10 | 0.04 | 0.43 | 14.62 | 100.240 |
| 25 | 54.14 | 19.87 | 8.63 | 1.09 | 0.32 | 1.60 | 0.020 | 0.70 | 0.12 | 0.05 | 0.53 | 12.01 | 99.080 |
| 36 | 54.40 | 21.06 | 7.20 | 0.71 | 0.10 | 0.99 | 0.010 | 0.56 | 0.10 | 0.04 | 0.46 | 14.87 | 100.500 |
| 42 | 60.84 | 18.81 | 9.58 | 0.67 | 0.04 | 0.50 | 0.010 | 0.10 | 0.00 | 0.06 | 1.42 | 7.65 | 99.380 |
| 43 | 51.74 | 27.54 | 4.43 | 0.79 | 0.11 | 0.89 | 0.005 | 0.41 | 0.09 | 0.04 | 0.65 | 14.04 | 100.740 |
| 44 | 49.85 | 28.78 | 1.38 | 0.84 | 0.15 | 1.05 | 0.005 | 0.24 | 0.10 | 0.05 | 1.44 | 16.39 | 99.975 |
| 45 | 49.12 | 26.74 | 6.01 | 0.83 | 0.12 | 0.89 | 0.010 | 0.35 | 0.10 | 0.05 | 0.45 | 15.04 | 99.710 |
| 43 | 56.86 | 24.07 | 2.94 | 0.78 | 0.10 | 0.87 | 0.005 | 0.37 | 0.08 | 0.02 | 0.44 | 12.81 | 99.345 |
| 49 | 56.20 | 24.15 | 5.31 | 0.93 | 0.01 | 1.01 | 0.010 | 0.32 | 0.10 | 0.03 | 0.76 | 11.14 | 99.970 |
| 53 | 51.31 | 23.94 | 7.63 | 0.81 | 0.01 | 0.86 | 0.005 | 0.38 | 0.10 | 0.04 | 1.18 | 12.43 | 98.695 |
| 54 | 50.98 | 26.55 | 5.42 | 0.78 | 0.01 | 0.87 | 0.010 | 0.12 | 0.10 | 0.04 | 0.92 | 13.40 | 99.200 |
| 55 | 46.60 | 28.96 | 5.52 | 0.81 | 0.06 | 0.86 | 0.005 | 0.26 | 0.00 | 0.04 | 1.13 | 14.96 | 99.205 |
| 56 | 51.60 | 26.96 | 5.43 | 1.01 | 0.01 | 0.62 | 0.020 | 0.35 | 0.00 | 0.03 | 0.56 | 12.52 | 99.110 |
| 57 | 51.90 | 28.66 | 4.88 | 1.06 | 0.01 | 0.57 | 0.010 | 0.40 | 0.10 | 0.06 | 0.58 | 12.02 | 100.250 |
| 58 | 61.39 | 19.39 | 7.49 | 0.86 | 0.01 | 0.49 | 0.010 | 0.33 | 0.10 | 0.04 | 0.62 | 7.74 | 98.470 |

Table 3: Semi-quantitative mineral composition of the bulk rock samples

| Sample No. | Kaolinite (%) | Quartz (%) | Muscovite/Illite (%) | Alunite (%) | Hematite (%) |
|---|---|---|---|---|---|
| 0 | 35.92 | 36.51 | 10.40 | 1.82 | 8.82 |
| 1 | 41.17 | 33.90 | 10.33 | 1.42 | 7.36 |
| 8 | 59.59 | 18.41 | 8.81 | 1.64 | 4.90 |
| 9 | 47.66 | 31.39 | 7.93 | 1.12 | 7.56 |
| 11 | 48.48 | 29.27 | 9.05 | 0.99 | 5.38 |
| 14 | 44.12 | 31.73 | 7.08 | 1.35 | 8.67 |
| 15 | 59.31 | 20.55 | 8.02 | 1.66 | 2.65 |
| 18 | 63.72 | 17.45 | 7.53 | 1.75 | 2.43 |
| 19 | 60.25 | 23.73 | 6.88 | 1.28 | 2.67 |
| 20 | 34.80 | 48.38 | 4.16 | 0.94 | 7.61 |
| 24 | 40.85 | 28.26 | 12.41 | 0.97 | 8.51 |
| 25 | 36.84 | 30.68 | 13.75 | 1.19 | 8.63 |
| 36 | 44.99 | 29.73 | 8.14 | 1.03 | 7.20 |
| 42 | 43.47 | 39.88 | 1.62 | 2.52 | 9.58 |
| 43 | 62.25 | 19.73 | 6.65 | 1.46 | 4.43 |
| 44 | 64.07 | 16.92 | 6.81 | 2.56 | 1.38 |
| 45 | 60.21 | 17.80 | 7.22 | 1.01 | 6.01 |
| 43 | 42.75 | 42.96 | 3.69 | 0.79 | 5.44 |
| 49 | 52.67 | 28.27 | 7.49 | 1.71 | 5.31 |
| 53 | 53.43 | 24.22 | 4.88 | 2.65 | 7.63 |
| 54 | 59.93 | 20.49 | 5.71 | 2.07 | 5.42 |
| 55 | 66.13 | 13.54 | 5.02 | 2.54 | 5.52 |
| 56 | 63.06 | 20.28 | 4.34 | 1.26 | 5.43 |
| 57 | 67.78 | 18.63 | 3.80 | 1.30 | 4.88 |
| 58 | 44.99 | 39.12 | 2.93 | 1.39 | 7.49 |

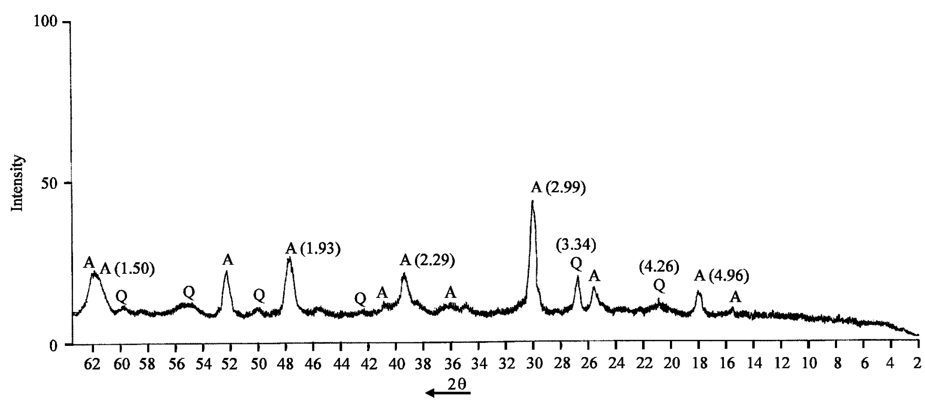


Fig. 8: Random XRD trace of the alunite patches and spots along the bedding planes from the study area. Numbers between brackets indicate d-spacing. (A: Alunite; Q: Quartz)

A semi-quantitative mineral composition of Hiswa clay deposits is represented in Table 3. The calculations are based on the chemical results (Olphen and Fripiat, 1979; Worrall, 1982; Chapman, 1983; Weaver, 1989; Chen *et al*., 1997).

The content of kaolinite, quartz, muscovite/illite, alunite and hematite ranges from 34.80 to 67.78%, 13.54 to 48.38%, 1.62 to 13.75%, 0.79 to 2.65% and 1.38 to 9.58%, respectively.

The results indicated that kaolinite is the most abundant clay mineral with quartz, hematite, mica and alunite constitute the chief non-clay minerals.

## DISCUSSION

The Hiswa clay deposit contains well-preserved graptolites, *Didymograptus bifidus* (Fig. 3) of Middle Ordovician age. The occurrence of well preserved graptolite molds in Hiswa clays (Fig. 3) indicate that the clays were deposited in a quite marine environment (deep marine depositional environment).

Graptolites are marine organisms usually form simple and chitinous colonies, belong to the order Graptoloidea. They are considered as index fossils and are used for stratigraphic correlation and for age determination. They have particularly played an important role as stratigraphical markers for Silurian and Ordovician periods being worldwide in distribution. Graptolites have short vertical range in time, abundance and show rapid evolution in their species. In most cases, *Didymograptus* consists of two symmetrical branches diverging from at any angle between 0° to 180°, commonly occurs in Hiswa shales and are characteristic to a pelagic (epiplanktonic) marine environment. It is important to note that broken

*Didymograptus* can be confused with uniserial straight *Monograptus* (Bates and Jackson, 1982; Prokop, 1981; Omari and Abawi, 1982; McKinney, 1991; Aiyengar and Prasad, 1996; Moore *et al*., 1997).

The results of the field, chemical and mineralogical (XRD and SEM) studies indicated that the alunite is present as minor and trace constituents (1.79-2.65%) in kaolinite bed of the Hiswa clay deposits, South Jordan. The alunite occurs within the lower part of the Shale Member, which belongs to the lowest part of Hiswa Sandstone Formation.

The Hiswa Sandstone Formation contains well preserved graptolite of middle Ordovician (Sunna *et al*., 1988; Khalil, 1989; Powell, 1989; Teimeh *et al*., 1990).

The sulfur trioxide ($SO_3$) content (1.42-1.44%) is related to the presence of gypsum and alunite. Iron sulfides (source of sulfur) could be originally produced by mineral replacement of chitinous tests of graptolites in oxygen deficient marine environment.

Alunite is a very fine sulfate mineral ($KAl_3(SO_4)_2(OH)_6$), secondary precipitation of alunite is present in voids and along the bedding planes. The formation of alunite within the kaolinite beds indicates the presence of a sulfur source, which is a possibly sulfide.

Occurrences of the alunite in the Kaolinite beds of the Hiswa Clay Deposits, South Jordan and to explain its possible mode of origin were the target of this work. Iron sulfides (pyrite; $FeS_2$) could be originally produced by the mineral replacement of the chitinous tests of graptolites in oxygen-deficient marine environment and pyrite could be the source for sulfur. The oxidation of pyrite and the formation of sulfuric acid could explain the possible source for the $(SO_4)^-$ group, which is presented in the alunite and/or gypsum.


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## REFERENCES


Aiyengar, N.K.N. and K.N. Parasad, 1996. An Introduction to Invertebrate Palaeontology. Vikas Publishing House PVT Ltd., India.

Bates, R.L. and J.A. Jackson, 1982. Glossary of Geology. 2nd Edn. American Geological Institute, Virginia, USA.

Chapman, G.P., 1983. Mica. In: Industrial Minerals and Rocks. Lefond, S.J. (Ed.). AIME, Society of Mining Engineers, USA.

Chen, P.Y., M.L. Lin and Z. Zheng, 1997. On the origin of the name kaolin and the kaolin deposit of the kauling and dazhou areas. Kiangsi, China. Applied Clay Sci., 12: 1-25.

Frost, R.L., Rachael-Anne Wills, Matt L. Weier, Wayde Martens and J. Theo Kloprogge, 2005. A raman spectroscopic study of alunites. J. Mol. Struc., 785: 123-132.

Khalil, B., 1989. Geological Map of Ad-Disa Area (Qannassiya), Map Sheet No 3149 III. NRA/Geology Directorate, Geological Mapping Division, Amman.

Khoury, H.N., 1987. Alunite from Jordan. N. Jb. Mineral Mh. H., Stuttgart, 9: 426-432.

Long, D.T., N.E. Fegan, J.D. McKee, W.B. Lyons, M.E. Hines and P.G. Macumber, 1992. Formation of alunite, jarosite and hydrous iron oxides in a hypersaline system: Lake Tyrrell, Victoria, Australia. Chem. Geol., 96: 183-202.

McKinney, F.K., 1991. Exercises in Invertebrate Paleontology. Blackwell Scientific Publications, UK.

Moore, R.C., C.G. Lalicker and A.G. Fischer, 1997. Invertebrate Fossils. CBS Publisher and Distributer, India.

Mutlu,H., K. Sariiz and S. Kadir, 2004. Geochemistry and origin of the Şphane alunite deposit, western Anatolia, Turkey. Ore Geol. 1Rev., 26: 39-50.

Olphen, H.V. and J.J. Fripiat, 1979. Data Handbook for Clay Materials and other Non-metallic Minerals. Pergamon Press, UK.

Omari, F. and T. Abawi, 1982. Paleontology. Al-Mousel University, Iraq (In Arabic).

Powel, J.H., 1989. Stratigraphy and Sedimentation of the Phanerozoic Rocks in Central and South Jordan, Part A. Ram and Khreim Group. Bulletin 11A. NRA/Geology Directorate, Geological Mapping Division, Amman.

Prokop, R., 1981. Fossils. Hamlyn Publishing Group Limited, Czechoslovakia.

Sunna, B., M. El-Hiayri, M. Teimeh, M. Abdelhadi, H. Rabi and T. Al-Harthi, 1988. Nomenclature Unification Committee of the Jordanian Stratigraphical Column. Part 1: Palaeozoic Sequences. Natural Resources Authority, Amman.

Teimeh, M., O. Abu Lihie, Y. Taani and L. Abu Saad, 1990. A Study of the Palaeozoic Formation of Jordan at Outcrop and in the Subsurface (Including Measured Sections and Regional Isopach Maps). Subsurface Geology Bulletin 1, Geology Directorate, NRA, Amman.

Weaver, C.E., 1989. Clays, Muds and Shales. Elsevier, Amsterdam.

Worrall, W.E., 1982. Ceramic Raw Materials, 2nd Edn. Pergamon Press, UK.