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# Study the mineralogy of Al-Faw soil in southern Iraq and determine swelling properties by indirect methods

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**Abstract:**

This study aims to determine the capacity of surface soils, the loading layers of engineered structures with shallow foundations, to swell. For this, five samples were collected using a hand auger at a depth of 1.5–2 meters in the city of Al-Faw in Basra, Iraq. The swelling potential of the soils in the research area was calculated using the clay content, liquid limit, plasticity index, and shrinkage limit values, and the constituent minerals were identified using X-ray diffraction. According to the results of the Atterberg's limit tests, the soil samples taken from the city of Al-Faw fall into one of three categories: clayey silt low plasticity (ML), clay high plasticity (CH), or silty clay low plasticity (CL). The liquid limit in soil samples ranges between 34-55%, and the plasticity index values range between 12 and 28%. Three samples are of medium swelling potential, while the third location has high swelling potential and the second location has low swelling potential, and the X-ray diffraction data demonstrate that Montmorillonite is the main dominant clay mineral, accounting for an average of 31.88%, followed by Kaolinite mineral, which accounts for an average of 28.984%, Illite, which accounts for an average of 19.5702%, Chlorite, which accounts for an average of 12.1864%, and Palegorskite, which accounts for an average of 7.3688%.

**Key words**: clay minerals, swelling soil, x-ray diffraction, plasticity index, clay high plasticity.

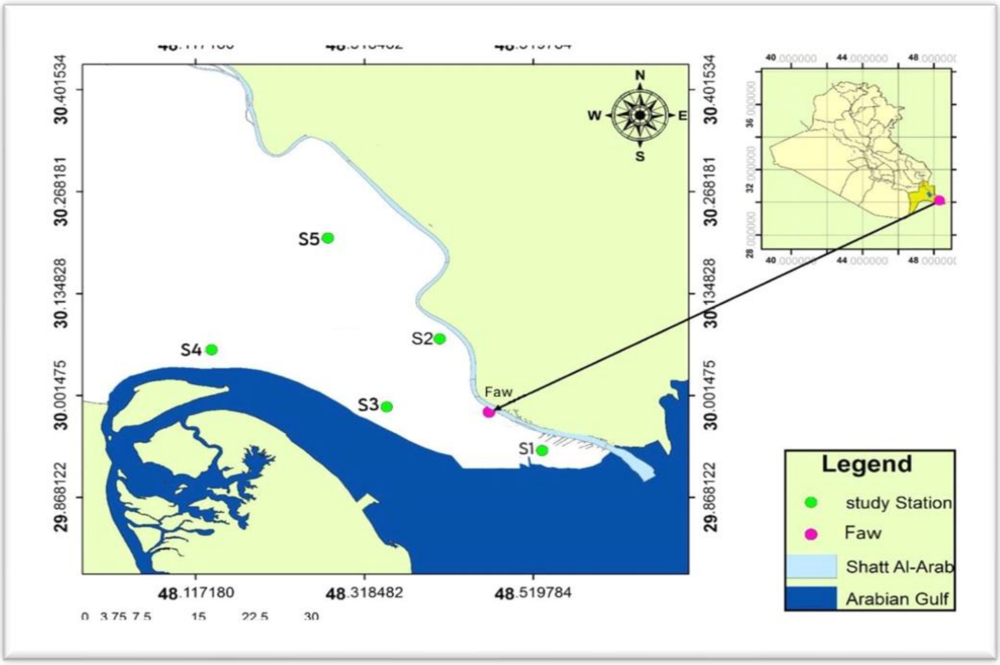
## 1. Introduction:

The swelling in expansive soil is a present significant structural engineering challenge. This is a worldwide problem that presents different facets in different parts of the world. The most widely distributed and costly of geologic hazards may be considered to be one of the foundations and engineering problems still facing because of the potential danger of unpredictable upward movements of different structures founded on such soil. Changes in volume in expansive soils cause foundation instability and damage to loaded structures such as railroads, road pavements, retaining walls, road sidewalks, and liners for reservoirs [1]. When their moisture level is allowed to rise, soils with a high clay concentration have a propensity to swell [2]. Smectite and other expansive clay minerals, which cause soil to inflate and contract, are common in soils. When there is a significant concentration of these clays in the soil, the swelling potential and water absorption rise. As a result, these soils expand when they are wet, increasing in volume, and contract when they are dry. For the most expansive clays, volumetric expansions of 10% are not unusual as they absorb more water [3]. In addition to increasing hydraulic conductivity and decreasing soil shear strength, these wetting processes can also cause buildings to shrink, which can lead to wall cracking and building collapse [4]. In clay soils, Atterberg's limits can be used as a gauge for swell capacity. It alludes to soils having a high swelling potential [5], high swelling ability, and high swelling pressure, which makes them soft soils in the case of wetting. Structures may heave or lift in response to a pressure increase, whereas differential settling may be caused by a pressure decrease [6].Very small quantities of certain clay minerals can have a major effect on the physical properties of clay deposits. Additionally, the degree of crystallinity matters since the different properties are displayed by clay minerals with poorly ordered crystallinity and those with well-ordered crystallinity. The numerous clay mineral families can be represented by the varying degrees of activity of the surface clay particles because expansive materials, such as montmorillonite, have a higher capacity for cation exchange than non-expansive kaolinite minerals, which have a comparatively low capacity [7]. The kind and concentration of clay minerals, the interactions between clay mineral pore water and the soil's surface, and the sedimentary history all affect most of the mechanical properties of soil [8]. The clay minerals that were diagnosed in Basrah governorate are illite, palygorskite, kaolinite, chlorite and montmorillonite[9].

## 2. Location of the study area:

Five sites were selected in the city of Faw, south-east of Basra governorate, between longitudes 48˚ 30′ 45" and 48˚ 28′ 40″ east and latitudes 29˚ 57′ 00″ and 29˚ 58′ 10″ North. It overlooks the Shatt al-Arab banks of the eastern part and is bordered by the city of Umm Qasr to the west, the Sebh District to the north, and the northeast coasts of the Arabian Gulf Fig.1.

Al-Faw is characterized by a dry climate in summer and cold in winter, extreme temperatures, and a high percentage of solar radiation [10]. Winds from the northwest, southeast, and southwest are predominant in the area, in addition to dust storms with high soil content and dust with fine




particles up to 8 metres (1000 years thick), which originate either from local soils or transfer from neighboring countries [11].

**Fig. 1**: Map of studied area

## 3. Stratigraphic and tectonic setting:

The Mesopotamia Plain in Iraq is covered in Quaternary sediments [12], which also include the city of Al-Faw. Climate oscillations and the cyclical change in sea level during the Pleistocene period are very much in the nature of the sediments of this age [13]. The study area is located in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the Zubair secondary zone according to longitudinal tectonic divisions. The secondary Zubair zone encompasses the southern portion of the Mesopotamia plain and is composed of subsurface geological formations, most notably the sandy formations Al-Luhais and Nahr Omar, which continue in a northwest-southeast direction for hundreds of kilometres towards Kuwait and the Arabian Gulf. To the north and north-east, the Takhdad-Qurna fault runs parallel to the secondary Zubair zone [14]. In terms of Iraq's transverse tectonic divisions, the study area lies inside the Basra block, which is defined by the existence of numerous parallel subsurface faults that run northeast to southwest [15]. The study area has a flat terrain consisting mainly of clay and silt deposited by the Tigris, Euphrates and karun rivers[16], the importance of quaternary deposits lies in their being the foundation on which the shallow and deep foundations of engineering structures rest[17], these deposits are dominated by minerals chlorite, illite, kaolinite and an amount of silica[18]. Fig.(2).

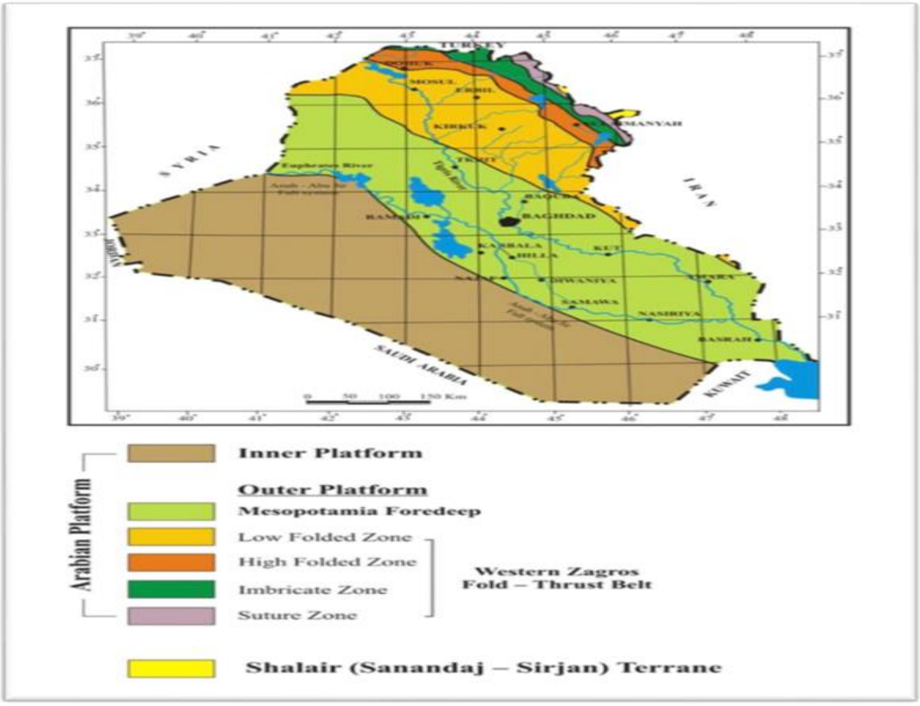

**Fig.2** : Geological map of Iraq after [19]

## 4. Materials and Methods:

### 4.1. Field Work:

The fieldwork was carried out in Al- Faw city to study soil behavior and to select the appropriate locations for this study. Field work was conducted in October 2022 in accordance with British specifications. Drilling was conducted using a hand auger. Undisturbed samples were taken from a depth of 1.5–2 meters. The samples were stored in tightly sealed nylon bags to preserve their moisture content.

### 4.2. Sampling:

Soil samples used in this study were taken from five sites at a depth of a bout (1.5-2) m below the top surface from Al-Faw city, to recognize their classification properties and determination of type of soil.

### 4.3. Laboratory test

#### 4.3.1 : Grain size analysis :

This test is conducted to determine the percentages of the various grain sizes in the study region using sieve analysis of the soil sand and hydrometer analysis of the silt and clay. The examination was conducted in the laboratories of the Department of Geology in the College of Science at the University of Basrah. The method used for the particle size analysis was described in [20].


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**4.3.2 : Moisture Content test:**

It is determined using the drying method in accordance with the American standard [21]. It is the ratio of the weight of water in the soil voids to the weight of its solid particles. In the event that a specific amount of soil is dried for 24 hours at 110 °C, The examination was conducted in the laboratories of the University of Basrah's College of Science, Department of Geology, and Department of Geology.

**4-3.3 : Atterberg limits :**

These tests involved measuring the plastic limit and liquid limit test has been conducted using the Cassagrande apparatus according to ASTM [22].The plasticity index was estimated for all dosages based on the findings from liquid limit and plastic limit tests. The Atterberg limits tests Conducted at Geological Laboratory- college of Science, Basra University.

**4.3.4 : Swelling behavior of soil :**

**A. Direct methods:**

Several direct laboratory tests can measure the soil's ability to swell:

- **Swelling potential:**

Is a sample's swelling ratio surrounded on all sides when, after being compressed to their maximum density and appropriate moisture content in accordance with AASHO, they are submerged in water under pressure (9.6 $KN/m^2$).

**B. Indirect methods:**

Based on other geotechnical parameters previously estimated, there are used to determine swelling in clay soils as follows:

1. **Liquid limit (LL):** Is us the quantitative differences between the liquidity and plasticity limits. The liquidity limit is used in estimating free swell as in Table (1) through the following equation [23].

$$S = 3.75 * 10^{-4} L.L^{2.658}$$

Where :

S = free swelling , LL = liquid limit

**Table 1 : Classification of soils according to their ability to swell in relation to some classification properties**

| Swelling Potential | Specifications | | | |
|---|---|---|---|---|
| | Seed et al. (1962) LL% | Seed et al. (1962) PI% | Terzaghi & Peck (1967) PI% | Chen (1988) LL% |
| Very high | >25 | >35 | >50 | 60-70 |
| High | 25-5 | 20-35 | 25-50 | 40-60 |
| Moderate | 1.5-5 | 20-10 | 14-25 | 30-40 |
| Low | 0-1-5 | <10 | 0-14 | 20-30 |

2. **plasticity index (Pl):** It is the numerical variations between the terms of liquidity and plasticity limits as the following equation:

$$Pl = LL - PL$$

The values of the plasticity index were used before [20] to estimate the swelling potential in clay soils, as shown in Table(2).

**Table (2) : Relationship between swelling potential and plasticity index [24]**

| Swelling potential | plasticity index |
|---|---|
| Low | 0 - 14 |
| Medium | 14 - 25 |
| High | 25 - 50 |
| Very high | > 50 |


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3. **Shrinkage limit:** Is defined as the water content at which the soil changes from a semi-solid to a solid state. Shrinkage limit values have been used to estimate the swelling potential of clay soils by [25] in [26].

4. **Method (Van Der Merwe, 1964) :**

This method depends on the percentage of clay and the plasticity index to classify swelling in the soil, as it is classified into low, medium, high and very high as in Fig.(5).

5. **Method ( Dakshanmanthy and Raman, 1973) :**

This method uses plasticity chart ( which based on liquid limit and plasticity index) to classify swelling in the soil as it is classified into low, medium, high and very high Fig.(3)

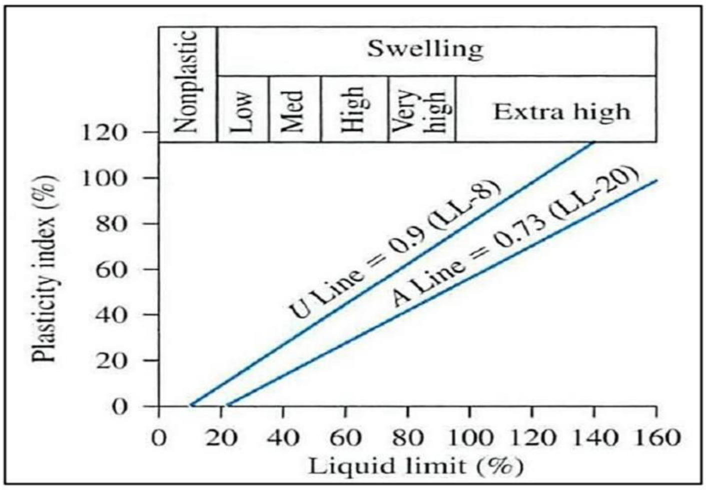


**Fig.3:** Relationship between liquid limit and plastic index to find out the amount of swelling [27].

### 4.3.5 : X-Ray Diffraction (XRD) :

Probably the most common X-ray analytical technique for describing materials is X-ray diffraction analysis (XRD). Using X-ray analysis, the different mineral kinds found in soil samples are determined.

We can use Bragg's Law to determine the separations between the planes of the atoms in a sample when an X-ray beam interacts with it and diffracts: Integer n represents the order of the diffracted beam, number is the wavelength of the incident X-ray beam, number represents the distance between consecutive atomic planes (the d-spacings), and angle of incidence is the X-ray wavelength.

## 5. Results and Discussion:

### 5.1 Classification tests :

Table (3) and figure (4) indicate the results of the grain size distribution of soil in the study area and the proportions of clay, silt and sand components in the different regions. The percentage of clay ranging from 53 to 66% , the percentage of silt ranged from 31 to 44% , the percentage of sand ranged from 2 to 4% , the liquid limit ranged from 34 to 55% and the plasticity index ranged from 12 to 28%, and the soil was classification by Unified Standard Classification System (USCS) to three types of soil: silty clay low plasticity (CL), silty clay high plasticity (CH), and clayey silt low plasticity (ML).

Table (3) show that the moisture content in the soil of the study area ranged from 19-32% at an average of 24.2% which is a rather high percentage. The reason is due to the proximity of the area to the Shatt al-Arab and the high level of groundwater, which affects the bearing capacity of the shallow layers of the soil.


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The moisture content has a significant effect on soil resistance, as the increase in moisture content leads to a decrease in cohesion, internal friction, load capacity of the layers, and stability of the foundations [28].

It also sometimes leads to an increase in the dispersion distance between clay particles, a decrease in gravity and electromagnetism (Van der waals forces), and an increase in adsorption Water content was observed in the study area Table 3, which greatly affects soil swelling as water enters the crystalline structure of some clay minerals (Group smectite), which leads to a widening of the spaces between these layers. Minerals then swell; if these clays are found under foundations, they exert pressure from the bottom towards the top, which leads to... Raising the foundations of buildings, sidewalks, and streets is offset by shrinkage [29].

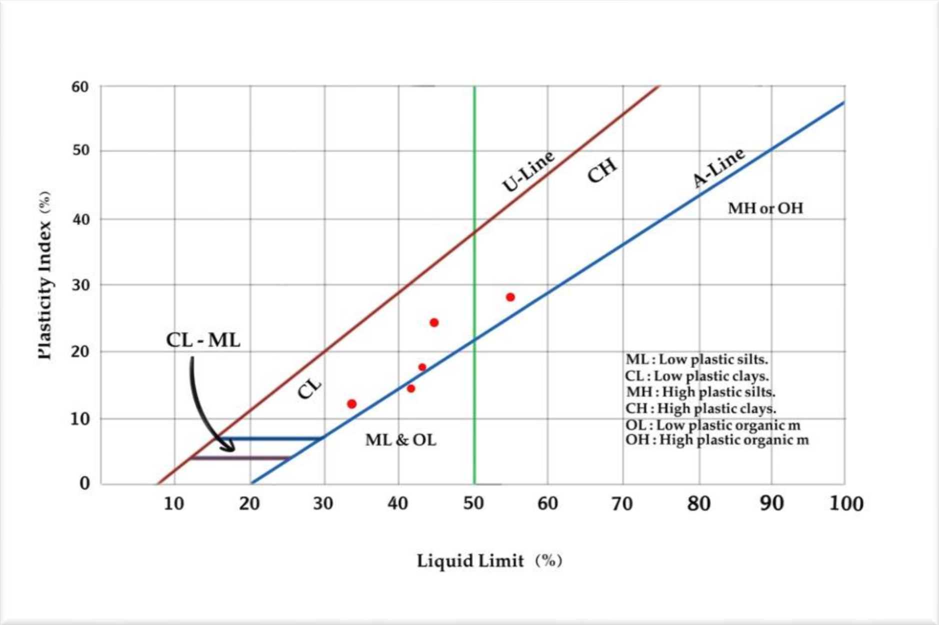


**Fig.4 :** Classification of study area samples according to plasticity chart [30].

**Table (3) :** Results of Classification Test of Study Area

| BoreholeNo. | Depth (m) | Clay% | Silt% | Sand% | Moisture content% | Liquid limit (LL) % | Plasticity Index (PI)% | Shrinkage limit (SL)% | Unified Classification (USCS) |
|---|---|---|---|---|---|---|---|---|---|
| S1 | 1 | 54 | 44 | 2 | 19 | 42 | 15 | 8.25 | ML |
| S2 | 1.3 | 66 | 31 | 3 | 27 | 34 | 12 | 6.5 | CL |
| S3 | 1.7 | 53 | 43 | 4 | 32 | 55 | 28 | 21.25 | CH |
| S4 | 1.5 | 61 | 35 | 4 | 20 | 44 | 18 | 11.5 | CL |
| S5 | 1.5 | 59 | 39 | 2 | 23 | 45 | 24 | 18.27 | CL |

## 5.2 Determination of soil swelling:

The results of swell estimation from Van dar Merwe (1964) chart Fig. (5), which depended on the relationship between clay content and plasticity index in soil samples, showed that three samples (S1,S2,S4,) have low swelling potential and the remaining two samples (S3,S5) have a very high swelling potential.

The classification of Terzaghi & Peck (1967) in Table (1), which depends on the values of plasticity index in determining swelling, shows that three samples (S1,S4,S5) have a medium swelling potential, while one sample (S2) have a low swelling potential and the remaining one sample (S3) have a high swelling potential Table (4). The classification of Seed et al. (1962) , which depends on the values of plasticity index in determining swelling, shows that three samples (S1,S2,S4) have a medium swelling potential and the remaining two samples (S3,S5) have a high swelling potential. The classification of Chen (1988) in Table (1), which depends on the values of


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liquid limit in determining swelling, shows that four samples (S1,S3,S4,S5) have a high swelling potential and the remaining one sample (S2) have a very medium swelling potential.Therefore, the sites contain medium swelling potential, which require treating them first before building constructions on them. Because the expansive soils which clay soils that have a high ability to swell and shrink when the moisture content changes. Thus, provide paths for infiltration and spread moisture under the buildings, which leads to swelling and shrinkage when wetting and drying, and then the spread of cracks, fractures, and collapse, and thus the failure of the buildings.

Thus, when these soils contain clay minerals with high swelling properties, they cause many problems and damages to constructions that build on it. Because of the absorption of water between the sheets of minerals and the causing swelling of the soil.

**Table (4): Swelling classification in the study site soils.**

| Site No. | Swell by classification Seed et al. (1962) LL% | Swell by classification Seed et al. (1962) PI% | Swell by classification Terzaghi & Peck (1967) PI% | Swell by classification Chen (1988) LL% | Swell by classification Chart Van Der Merwe (1964) Clay % | Swelling potential PI% | Rate of swell |
|---|---|---|---|---|---|---|---|
| **S1** | Very high | Medium | Medium | High | Low | Medium | Medium |
| **S2** | Very high | Medium | Low | Medium | Low | Low | Low |
| **S3** | Very high | High | High | High | High | High | High |
| **S4** | Very high | Medium | Medium | High | Low | Medium | Medium |
| **S5** | Very high | High | Medium | High | High | Medium | High |

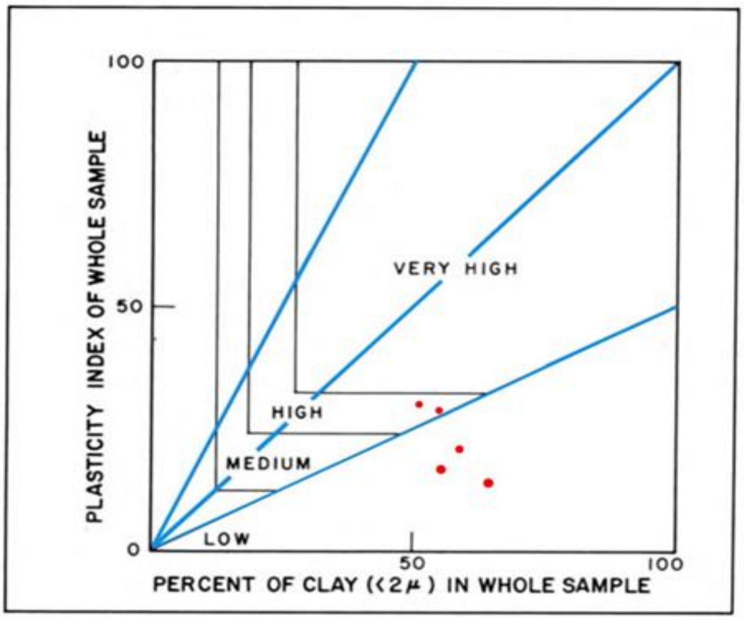


**Fig. 5 : Classification of sites according to swelling potential [31].**

### 5.1.6 X-Ray Diffraction:

The relative presence of clay minerals was estimated on the basis of measuring the area under the main reflection curve for each mineral as showed in Figure (6and 7) It was found that montmorillonite is the main mineral in most of the studied sites, with a highest value of 36.8% in the fourth site and a lowest value of 17.02% in the fifth site with an average of 31.888%. Then comes the mineral kaolinite with a percentage ranging from 45.45% in the third site to 12.95% in the fourth site, at an average of 28.984%. Illite mineral followed by 48.94% in the fifth site to 9.091% in the third site, at an average of 19.5702%, Chlorite mineral followed by 16.58% in the fourth site to 6.061% in the third site at an average of 11.586% . As well as diagnosing the mineral


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playgorskite, with ranging between 18.13% in the third site and 3.03% in the third site, at an average of 7.3688% Table(5). The results show in Table (3) the predominance of mineral montmorillonite, followed by Illite , kaolinite and palygorskite. Explained [32] the dominance of this mineral in most areas of the sedimentary plain, as he found, when studying the proportions of clay minerals in river sediments, that the mineral montmorlinite comes in the first place, followed chlorite, kaolinite, and Illite, also found that small percentages of palygorskite came as a result of the transition or transformation of montmorillonite in the presence of an additional amount of Mg. The presence of these minerals is evidence of the diversity of rocks in the areas of the Karun Basin, which are acidic igneous rocks and metamorphic rocks, which is evidenced by the presence of kaolinite and IIlite.

The source of clay minerals in the study area is a detrital source, that is, it moved from the areas of its formation to the study area. The importance of knowing clay minerals stems from their role in knowing the source rocks from which they are derived, the physical and chemical changes that led to their formation, the nature of the climate, and then reaching the nature of the sedimentation environment. These minerals have a significant effect on soil swelling, as they absorb water in large quantities, leading to significant damage to engineering facilities. To determine the types of clay minerals, present in soil and evaluate their activity for swelling potential, X-ray diffraction was used. Most experts tend to agree that clay mineral type and quantity affect soil expansion. Also, they tend to agree that the main factor causing changes in soil volume is clay minerals[33]. Kaolinites and Illite are the least active clays, whereas the active clays have the most potential for swelling. The most active type of montmorillonite can swell by allowing water molecules to enter its space lattice directly[34]. On the other side, expansive soils are characterized by the presence of highly active montmorillonite minerals, which are in responsible of the soils pronounced capacity for volume change [35].

Four types of clay minerals have been found in the study sites, montmorillonite, Illite, kaolinite and, palegorskite . The clay should typically be extensible due to the presence of clay minerals and the dominance of montmorillonite.

**Table** (5): Semi quantitative determination of Clay minerals by using the area under the curve method.

| Sample | Montmorillonite | Chlorite | Illite | palygorskite | Kaolinite |
|---|---|---|---|---|---|
| S1 | 33.33 | 14.81 | 11.11 | 3.704 | 37.04 |
| S2 | 35.93 | 14.97 | 13.17 | 11.98 | 23.95 |
| S3 | 36.36 | 6.061 | 9.091 | 3.03 | 45.45 |
| S4 | 36.8 | 16.58 | 15.54 | 18.13 | 12.95 |
| S5 | 17.02 | 8.511 | 48.94 | 0 | 25.53 |

**Fig.6 :** X-ray diffraction patterns of clay minerals of S1

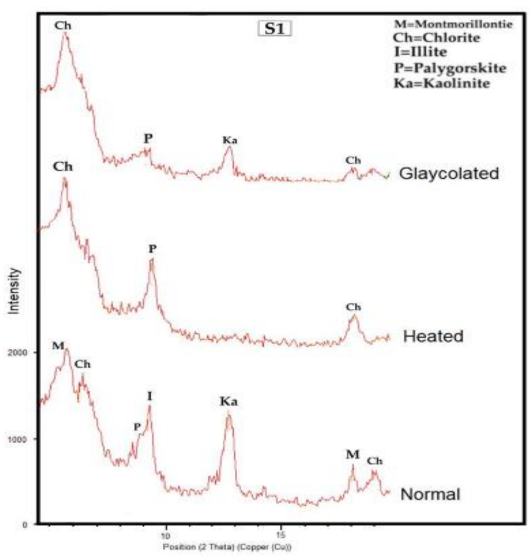
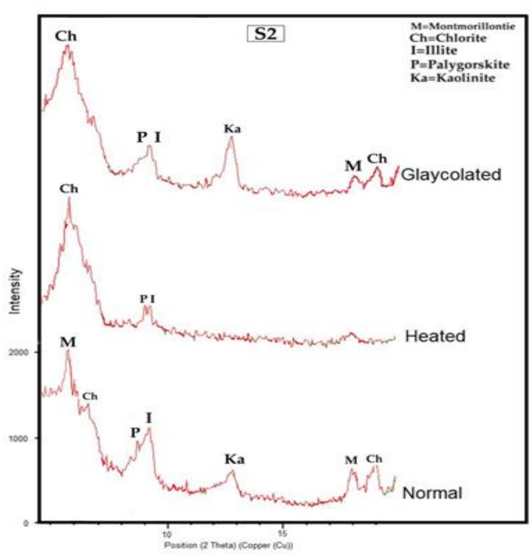



**Fig.7:** X-ray diffraction patterns of clay minerals of S2





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## 6. Conclusions:

1. The results showed that Al- Faw soil consists of three types : silt of low plasticity (CL), silt of high plasticity (CH), and silt of low plasticity (ML).
2. The soils of the Al-Faw city have a medium to high swelling potential, which requires treatment first before construction. The reason for this swelling in study sites is due to the high percent of the mineral montmorillonite, which in turn absorbs water in a large amount, causing swelling.
3. The soils in the study sites are classified as highly compressive soils because they have a high liquid limit and as a result have a low bearing capacity and need to treatment.
4. The difference in the proportions and type of clay leads to a variation in the swelling potential in the soils of the study area.
5. Montmorillonite is the main dominant clay mineral in most of the study sites, followed by Kaolinite and Illite and chlorite and Palygorskite. Accordingly, the high levels of montmorillonite are main cause of the swelling of soil in the sites of study.

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