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RESEARCH PAPER

# Mineralogical reconstruction of Late Pleistocene – Holocene climate and environmental changes in southern wetlands of Lake Urmia

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**Abstract**
To determine the effect of climate changes on current critical conditions of Lake Urmia, paleoclimate of southern wetlands of Lake Urmia was investigated based on clay mineralogy. Kani Barazan and Solduz wetlands on the southern margin of Lake Urmia and also the southern part of the lake have been briefly studied in this research. A total of 24 sedimentary cores were taken for sedimentology and mineralogy study from south to north of Lake Urmia. The clay mineralogy analysis were done by XRD method. The main minerals in the sediments include quartz (over 40%), calcite, feldspars, mica, dolomite and clay minerals. Chlorite and kaolinite were the main clay minerals in the southern coastal plains of Lake Urmia. Distribution of surface samples represents reduction of clay minerals in the sediments from the margin to the center of the basin. This indicate that the percentage of detrital sediments decreases and chemical sediments increase from the margin to the center. Increasing the distance from the edge of the wetland causes it to move away from the source of the sediments. The concentration of water salts in the central part of the basin increases. In the central part of the lake, due to greater depth and high salinity of water, chemical sediments have been predominant and in the margins of the lake, according to low salinity and the volume of clastic materials, this kind of sediments have been predominant. This is consistent with the changes in other clastic minerals (quartz) in the lake. The level of clay minerals increased from the surface to the depth of boreholes indicating a high water level and a more warm–wet paleoclimate. According to the changes in the type of clay minerals in the sediment sequence of the southern part of Lake Urmia, it seems that in the Late Pleistocene (20 cal ka BP) the weather was more humid than the current conditions and the volume of clastic material to the lake was higher.

**Keywords:** Mineralogy, Clay Minerals, Paleoclimate, Sedimentary Cores.

## Introduction

Sedimentology, mineralogy and geochemical characteristics of core sediments are very helpful in identifying evolution of Late Quaternary sedimentary environments (Valero-Garces et al., 2000). Confined basins are most appropriate systems for limnology and paleoclimatology studies due to high sensitivity to evaporation-precipitation balance (Piovano et al., 2002; Sharifi et al., 2018). Paleoclimatology paves the way for discovering the trend and factors affecting climate changes and facilitates prediction of future climate for planning purposes. Lake

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sediments are studied for discovering paleoenvironment and paleoclimate changes (Azizi, 2004, Kwak et al., 2016). Clay minerals can be used to understand soil formation (Graham & O̍Green, 2010), proper management of arid and wet lands (O'Geen et al., 2008) and interpretation of paleoenvironments (Manafi, 2010, Khormali & Abtahi, 2003). The origin and relative frequency of clay minerals provide useful information on paleoclimate, the change in water base level, burial diagenesis and re-transport (Khormali et al., 2005). Climate change causes changes in the clay minerals as genetic signals representing soil formation events. Composition of clay minerals and their changes over during sedimentation reflect rate of weathering of dry masses in surrounding areas (Bockheim & Gennadiyev, 2000). In the meantime, Lake Urmia as the largest hypersaline permanent lake in Iran and one of the supersaturated saline lakes in the world is comparable with Great Salt Lake (Kelt & Shahrabi, 1986). Lake Urmia is located in zerbaijan between eastern longitudes 44˚14’ and 47˚53’ and northern latitudes 35˚40’ and 38˚30’ (Mohammadi et al., 2010, Darvishi Khatoni et al., 2010). Before drought, the length of Lake Urmia varied from 120 to 150 km, its width from 20 to 50 km (Esmaeili Dahesht et al., 2010) and its depth varied from 6 to 16 m with a mean depth of 6 m before critical conditions (Ghaheri & Baghal-Vayjooee, 1999). Lake Urmia has been formed where Iran and Turkey microplates collide (Shahrabi, 1993) in a tectonic zone between Arabian and Eurasian plates (MacKenzie, 1972). The activity of Tabriz fault (Figure 1) in this region caused uplift of the northern piece of the fault which in turn caused formation of Lake Urmia by creating a barrier against water flow (Pourkermani & Sediq, 2003). The most important highlands in north of the lake are the Misho and Moro mountains that follow the Alborz mountains and their continuation in northwestern Iran is connected to the mountains of Ararat in Turkey. The southern mountain of Urmia Lake has a similar trend, in fact it`s the sequence of the Zagros mountains.

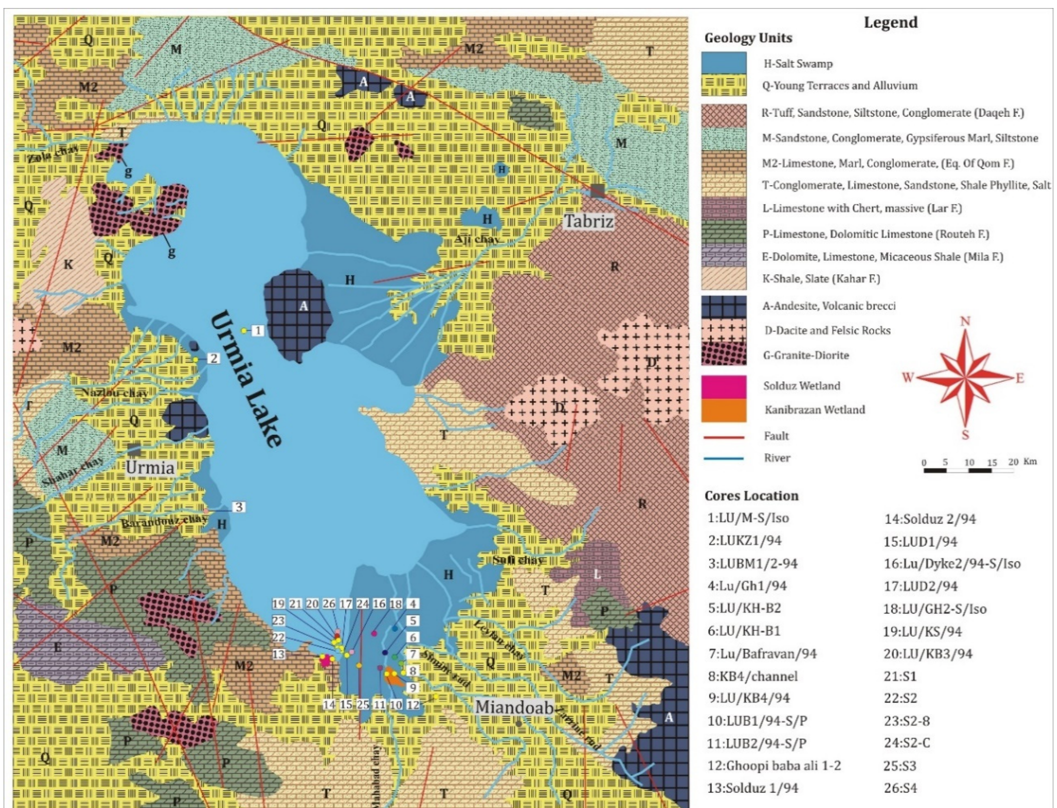


**Figure 1.** Geological map of the study area, location of Kani Barazan and Solduz wetlands, the taken cores and the rivers (derived from Shah Hosseini, 2003)

On the eastern side of the lake, mountains with a north-south trend leads to alluvial plains and eastern coastal lakes with gentle slopes. Soft lake deposits are located on the hardened bottom of lower Cretaceous or marly limestones of Miocene (Qom Formation). The Urmia Lake basin is often composed of Miocene carbonate and clastic formations. In contrast to the Islamic island of Pliocene volcanic rocks, the other islands are the Filish of the Cretaceous or limestone of Miocene (Qom Formation) (Fig. 1).

In terms of origin, Lake Urmia is a young lake which has been formed after Pleistocene (Kelts & Shahrabi, 1986).

Numerous studies have been conducted on the sediments and sedimentary rocks, especially in playas and saline lakes to identify clay minerals and determine their origin, diagenesis variations, paleoclimate and changes in water base level (Droste, 1961; Hillock, 1965; Blair & Aland, 1983; Ingles et al., 1998; Nolan et al., 1999; Pardo et al., 1999; Horiuchi et al., 2000; Ruffel & Worden, 2000; Khormali & Abtahi, 2003; Khormali et al., 2005). Saline lakes and playas have been recently studied in different theses (Lak, 2007) and articles (Pakzad & Ajalloeian, 2004; Rezaei-Moghaddam & Saghafi, 2006; e.g., Khalili & Safaei, 2002; Khalili & Torabi, 2003; Alipour, 2006; Pakzad & Kulke, 2007; Fayazi et al., 2007; Pakzad & Fayazi, 2007) from different points of view. However, few studies have been conducted on clay mineralogy in these regions, especially in Lake Urmia. Kani Barazan and Solduz wetlands are located in the south of Lake Urmia and northern part of Mahabad River basin (Figure 1) which are limited from south to mountains and geological formation outcrop and from north to vast basin areas.

The surface area of Kani Barazan and Solduz wetlands are 9.27 and 2 $km^2$, respectively. According to Water Research Institute (2006), around 50% of water demand of these two wetlands is supplied by surface water. The water sources for these wetlands include direct precipitation on the water body and very few runoffs from southern surrounding hills. According to Quaternary sediments extension in Iran and particularly Urmia also small-size crystals and the presence of improper bonds in clay minerals in terms of ion exchange, it is necessary to study this type of sediments and their various aspects for optimal managing and utilizing of these sediments and predicting their future behavior due to changes in their uses. Study of clay minerals in these sediments help us in better understanding of their past history to determine the intensity of weathering processes and probable climate changes. Considering that climate changes have been associated with changes in the size of the Lake and surrounding wetlands, clay minerals in these wetlands were considered. On the other hand, lake and wetland sediments are completely different in terms of mineralogical composition. So wetlands are a better choice for investigating climate and environmental changes. Accordingly, this study aims at identifying clay minerals in Quaternary sediments in southern wetlands of Lake Urmia (Kani Barazan and Solduz) to investigate formation mechanism and probable climate changes in the region.

Due to this fact that the entrance of the rivers is the best place to study the water table of the lake, so we focused on the two main rivers in south of the lake, where the cores were taken. In addition, the wetlands themselves are suitable environment for preservation and archiving the climate change situation.

Therefore, we focused on these wetlands and the surrounding lands. It should be notified that these wetlands have been separated today, but during previous periods, this area had been a part of the lake due to the results of sedimentary cores, so this study to all above cases has been generalized to the lake.

## Methods and Materials

A total of 24 undisturbed sedimentary cores with a maximum depth of 12 m were taken from sediments in the south of Lake Urmia for sedimentology studies (Fig. 2).

In this study, it was tried to take the cores in such a way that it is possible to take the maximum thickness from the sediments of the lake bed and coverage the maximum sedimentary environments of wetlands, so at least one sample in each homogeneous unit were collected. Due to the lack of suitable conditions for taking cores in the center of the lake, the location of the cores was considered along the shore with appropriate distances and dispersion, which climatic changes can be observed and the taken cores can interpret various sedimentary environments in order to reconstruct the climate. Two cores were also taken in the central part of the lake to compare sedimentary facies.

The coordinates coring sites are listed in Table 1. The cores were taken by a handy auger (eg. Piovano et al., 2002). Core description was carefully written and sampling was carried out according to changes in facies and type of sediments (Fig. 3). According to the type and changes of sedimentary facies, different environments were correlated in the sequence of cores. The pattern of environmental model was drawn for facies data and then sampling was performed for xrd analysis based on facies changes. Sample preparation and experiments were performed based on the procedure presented by Lewis & McConchie (1994). Half of the samples were used in experiments and remaining were archived. Clay mineralogy was analyzed by Siemens XRD diffractometer D5000 in Geological Survey and Mineral Exploration of Iran (GIS). For clay mineralogy study by XRD, three intact samples saturated with ethylene glycol were heated up to 500℃ and then tested (Brindley & Brown, 1984).

In this study, radiocarbon dating ($^{14}$CAMS) was performed by using organic materials and bulk samples (Table 3). The age of samples was calibrated by Ox Cal software (17) with 2 Sigma error range and reliability coefficient. of over 95%. These samples included organic materials mainly in silt and clay. Dating analysis was performed at the GEOPS laboratory of Paris university in france.

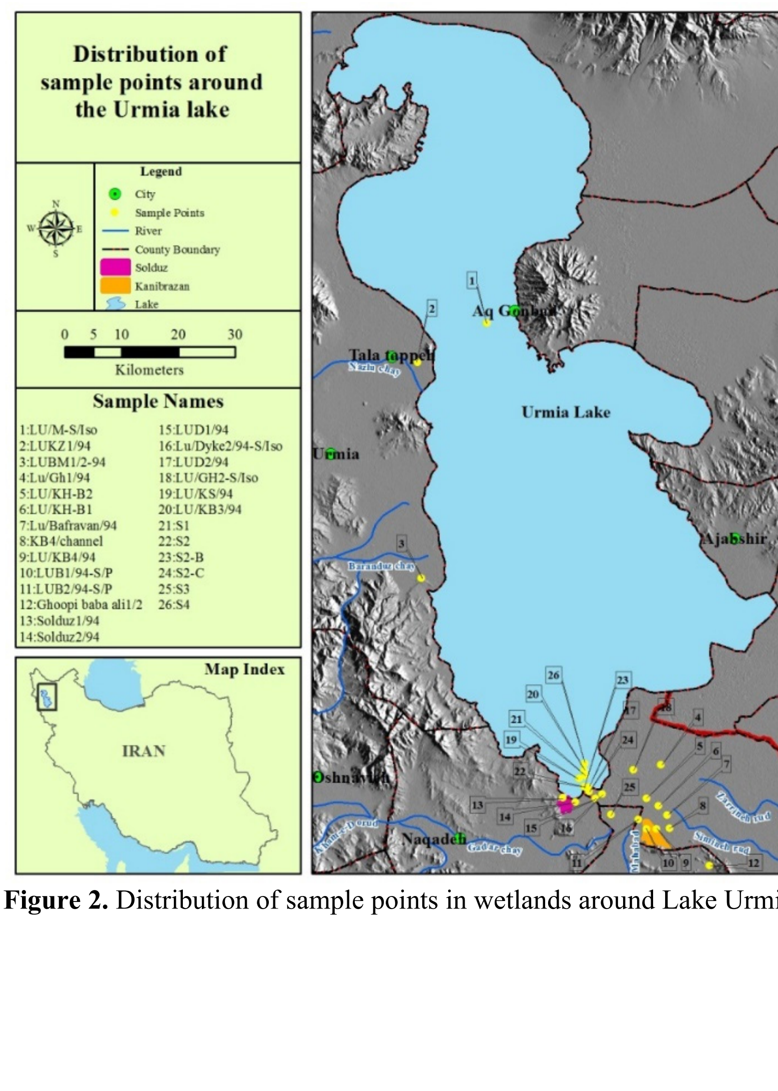


**Figure 2.** Distribution of sample points in wetlands around Lake Urmia

**Table 1.** Coordinates and depth of cores taken by handy auger

| No. | Samples No. | Y (D.D) | X(D.D) | Depth(m) |
|---|---|---|---|---|
| **1** | LU/M-S/Iso | 37.79033333 | 45.36033333 | 11 |
| **2** | LU/KH-B1 | 37.04533333 | 45.77791667 | 7.85 |
| **3** | LU/KS/94 | 37.07936111 | 45.61697222 | 6.6 |
| **4** | LU/KB3/94 | 37.09127778 | 45.62780556 | 8.28 |
| **5** | Solduz2/94 | 37.04116667 | 45.61341667 | 1070 |
| **6** | Lu/Gh1/94 | 57.53472222 | 41.13822222 | 8.65 |
| **7** | Lu/Bafravan/94 | 37.03211111 | 45.79658333 | 10.5 |
| **8** | Lu/Dyke2/94-S/Iso | 37.05777778 | 45.666 | 8.76 |
| **9** | LU/KH-B2 | 37.0565 | 45.75330556 | 9.22 |
| **10** | KB4/channel | 37.01155556 | 45.80338889 | 10.3 |
| **11** | LU/KB4/94 | 37.00925 | 45.77822222 | 8.51 |
| **12** | Solduz1/94 | 37.04619444 | 45.58797222 | 7.4 |
| **13** | LU/GH2-S/Iso | 37.1 | 45.72302778 | 10.58 |
| **14** | Ghoopi baba ali1/2 | 36.95769444 | 45.889 | 2 |
| **15** | LUB1/94-S/P | 37.00797222 | 45.75780556 | 7.28 |
| **16** | LUB2/94-S/P | 37.02111111 | 45.74086111 | 11.88 |
| **17** | LUKZ1/94 | 37.71891667 | 45.22913889 | 9.41 |
| **18** | LUD2/94 | 37.06636111 | 45.63383333 | 7.71 |
| **19** | LUD1/94 | 37.04927778 | 45.65283333 | 6.31 |
| **20** | LUB3/94-Iso | 37.00775 | 45.75763889 | 11.9 |
| **21** | LUBM1/94 | 37.37644444 | 45.27313889 | 2.93 |
| **22** | LUBM2/P-S | 37.3765 | 45.27288889 | 4.27 |
| **23** | S3 (station3) | 37 01 34 | 45 41 11 | 9.7 |
| **24** | S4 (station1) | 37 06 06 | 45 37 37 | 10 |

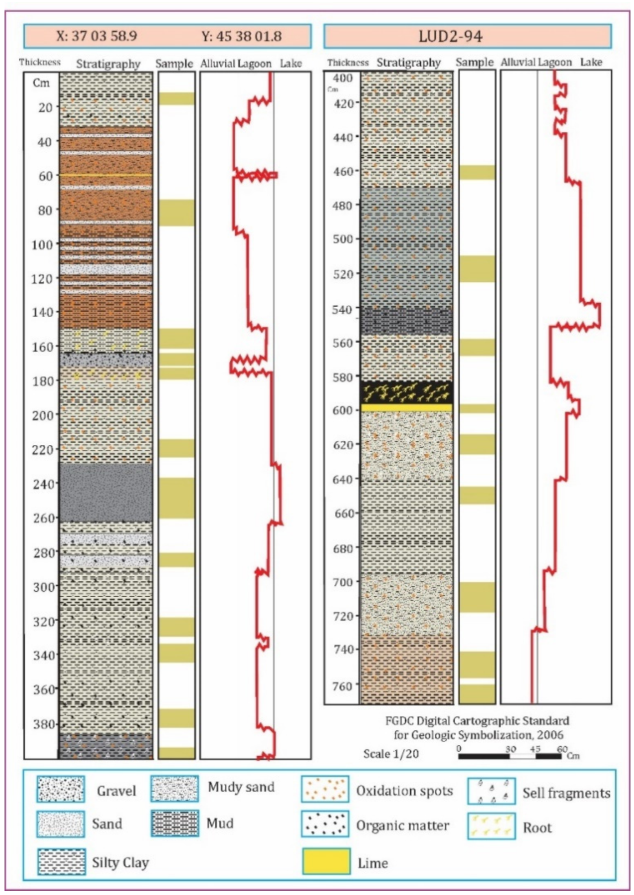


**Figure 3.** Stratigraphic column, relative changes of water level in Lake Urmia, sedimentary sub environments in the south of Lake Urmia

## Discussion

Sedimentary units were described and separated and stratigraphic column of the cores was plotted to show core features. The sub environment was also determined for each unit (e.g. Benison & Goldstein, 2001; Li et al., 1996; Valero-Garces et al., 1998) (Fig. 3). According to XRD patterns, sediments in Lake Urmia contain major minerals, kaolinite, chlorite and other evaporate minerals (Table 2).

In most cases, clay minerals in lakes are of destructive type. Smectite and illite are the most common clay minerals in lakes, but kaolinite and chlorite are also found in such regions (Shoffner, 2000). Major and general minerals including quartz and feldspar and some sedimentary minerals such as dolomite and calcite are also seen in the graphs (Fig. 4).

**Table 2.** Cores and minerals in each core (in terms of wt%)

| Cores | Minerals |
|---|---|
| **KB4-Channel** | Quartz -Calcite-Albite -Chlorite -Orthoclase -Dolomite -(Kaolinite) -Na (Al si3o8) -Halite -(Labradorite) |
| **LU-M** | Halite -Quartz -Dolomite -Calcite -Gypsum -Orthoclase -Albite -Chlorite -(Hematite) |
| **S3** | Quartz -Calcite-Dolomite -Halite -Orthoclase –Albite -(Hematite) |
| **S4** | Quartz –Calcite- Dolomite- Halite- Chlorite- Orthoclase- Albite |
| **LU-B1-94** | Quartz- Calcite- Albite- Dolomite- Orthoclase- Sanidine- Chlorite- Gypsum- Kaolinite -Halite - (Hematite) |
| **LU-GH2** | Quartz- Calcite- Albite- Orthoclase- Dolomite- Chlorite- Sanidine- Halite |
| **LUD1** | Quartz- Albite- Calcite- Dolomite- Orthoclase- (Anorthite)- Chlorite- Halite |
| **LUD2** | Quartz- Albite- Calcite- Halite- Kaolinite- Chlorite- Orthoclase- Dolomite- Hematite |
| **LUKH-B1** | Quartz- Albite- Calcite- Orthoclase- Kaolinite- Dolomite- Sanidine- Chlorite, Chromian-Halite |
| **LUKH-B2** | Quartz- Albite- Calcite- Orthoclase- Halite- Chlorite- Kaolinite- (Pyrolusite)- Dolomite-Sanidine |
| **LUKS-94** | Quartz- Albite- Orthoclase- Halite- Chlorite- (Calcite, magnesian)- Kaolinite- Dolomite-Calcite |

**Table 3.** $^{14}$C dating of samples taken from southern wetlands of Lake Urmia

| sample comment | Depth(cm) | $F^{14}C$ | Uncalibrated age | Calibrated Age (cal. Yr BP) | | |
|---|---|---|---|---|---|---|
| | | | | Min age | Mean age | Max age |
| AT S1 2 181CM | 181 | 0,6446 | 3528+/-22 | 3720 | 3798 | 3877 |
| AT S1 B2 207 | 207 | 0,6330 | 3672+/-28 | 3913 | 4000 | 4087 |

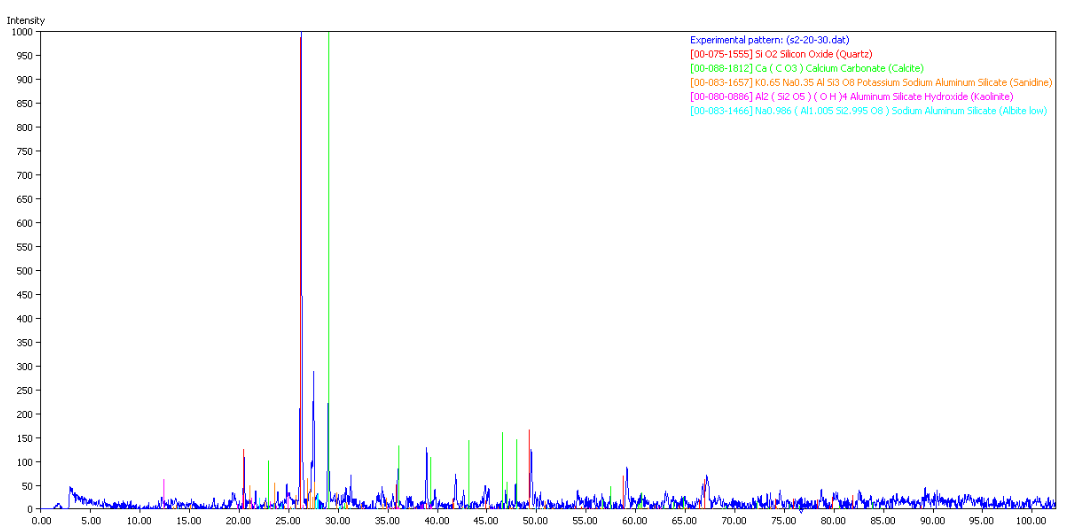


**Figure 4.** Mineralogical graph of the core S1 taken from a depth of 20-30 cm

In general, the lack of clay minerals of diagenesis environments such as sepiolite, paligorskite and kunzite indicates the lake of formation of autogene clay minerals in Lake Urmia and basic sedimentary environments (Mohammadi, 2005, Chamley, 1989). The similarity of clay minerals in three rivers near the coring site (AjiChai, ShahrChai and NazlooChai) with those in the cores studied by Shahhosseini in 2003 indicates the destructive origin of clay minerals in Lake Urmia.

Kaolinite is a 1:1 dioctahedral clay mineral (Chamley, 1989) which is resistant to weathering and transport. This clay mineral is formed by weathering in hot and humid weather, diagenesis or hydrothermal changes of other aluminosilicates (Moore & Reynolds, 1989; Pardo et al., 1999). Granite and grarnodiorite rocks are rich in feldspars and thus considered a good origin for kaolinite (Deer et al., 1966). Under tropical climate, this clay mineral is formed by basalt weathering (Bergaya et al., 2006). It appears that kaolinites in studied sediments have an inherited origin.

Chlorite is a 2:1 layered clay with positively and negatively charged hydroxide interlayers (Moore & Reynolds, 1989; Chamley, 1989). Chlorites with a clastic origin are not resistant to transportation and weathering (Martinez-Ruiz et al., 1999). Chlorite is the main constituent of low-grade metamorphic rocks which is distinguished by physical weathering and mechanical erosion (Deer et al., 1966). Chlorite is formed at high altitudes and undergoes chemical weathering in hot and humid weather (Oliveira et al., 2002). Chlorite can also be formed in soil, high diagenetic shales, porous sandstones, carbonate rocks or by diagenesis processes from illite. Chlorites in the studied sediments seem to have an inherited origin.

According to dating results (Table 3) of Lake Urmia sediments, the annual sedimentation rate varies from 0.1 to 1 mm (Kelts & Shahrabi, 1986). An average rate of 0.5 mm per year has been reported in some references (Lak et al., 2011). According to $_{14}$C dating of two plant remnant of samples in cores taken from Lake Urmia wetlands, the calibrated age is 0.5 mm per year which confirms the results of Lak et al. (Table 3).

Distribution of clastic particles in sub sediments of south wetlands in Lake Urmia provides invaluable information on the origin and factors affecting sedimentation. Due to a difference between the density of water inflow and lake water and wind currents with a south-north trend, these particles have been transported a relatively long distance. According to mineralogical composition of sediments, the temporal variation of the frequency of clastic components is a function of multiple factors such as change in the river stream regime, direction and intensity of wind currents on the lake surface, density difference of water inflow and lake water and fluctuation of Lake water level.

The significant diversity of clastic particles (in terms of composition) indicates contribution of multiple processes and a variety of origins in supplying clastic sediments to this part of sedimentary basin (Amini et al., 2009). This type of distribution can be attributed to the role of origin in supplying clastic sediments. Quartz, feldspar, mica, calcite and dolomite particles are the largest and most abundant clastic particles in sediments have been transported from the south of Lake Urmia (Zarrinehrud and Siminehrud basins) to the study area. Obviously, the high water level of the lake is another factor affecting their frequency so that these particles have been mainly deposited on the margins and are less transported to the mouth when water level rises. The rivers in the south of Lake Urmia are the origin of clastic particles such as fine sand and silt (Erfan, 2018). Dense currents in the lake play a key role in the transport of these particles from the south of the lake to northern and central regions as confirmed by similar clastic particles in the sediments of southern rivers. The shape of clastic particles and the effect of transport mechanism on particle shape indicate that these particles have been mainly transported as suspended load to the basin. Accordingly, they can be identified only by evaluating their composition using X-ray diffraction. Carbonate calcium as calcite and dolomite as clastic pieces are observed with angular and irregular transport signs in the samples. The irregular shape of these particles (given their instability against erosion) along with a thin carbonate layer in sediments indicate that some particles have an intra-basin Some more rounded and spherical carbonate calcium particles with the same size of find sand and silt in the sediments have been transported out of the basin along with other clastic particles. During wet condition, clastic sediments dominated but in dry condition chemical minerals such as calcite and dolomite precipitated because of increasing water concentration. The presence of calcite in the suspended load of southern rivers represents transport of some carbonate particles to the sedimentation site from out of the sedimentary basin. Sings of weathering (iron oxides) on the margin of these particles confirm their transport out of the basin (Amin et al., 2009). Expansion of Qom formation on southwest of the lake has a key role in the transport of these particles to the basin. In general, evaporate minerals increase in the south-north trend of cores such that the frequency of evaporate minerals in the core S4 clearly increases from the depth to the vicinity of the surface. Comparing the cores KB4-Channel and LU-KS-94, one can conclude that the level of evaporate minerals increases toward the north from the center of the lake in LU-KS-94 sediments. With return to the past (increasing depth), the frequency of evaporate minerals such as halite in some inshore cores like KB4-Channel increases relative to the current wetland environment (Fig. 5). This is the case in southeastern cores like LUD1-94 in an approximate depth of 6 m indicating at that time this area was playa Lake environment. Quartz, calcite, feldspars, mica and chlorite in a depth of 1 to 3 m of southern cores and evaporate horizons in a depth of 2-3 m and 4-8 m are added to these minerals. There is a good relevance between the profiles of some clay minerals on the same position in both sides of the lake (Fig. 5).

According to the literature Ghazban et al., (1998) on the key role of AjiChai River on the entry of different minerals, evaporative sediments are expected to found in northeastern regions at different times. The clay minerals in cores taken from Lake Urmia and Solduz and Kani Barazan wetlands indicate that clay minerals constitute 20 to 60% of sediments of the lake bed in different horizons. In fact, clay minerals are found at all depths and constitute the highest frequency of sedimentary components in certain horizons (Fig. 5). The frequency of clay minerals varies along the core length and does not show a certain trend with depth. The clay minerals, chlorite and kaolinite, are observed almost in all cores at all depths. These minerals can represent wet and dry environments (Zhou & Keeling, 2013). Given the mineralogy of clays in different regions and to ensure the lack of effect of diagenesis on mineralogy and considering the type and similarity of clay minerals in the lake and rivers flowing into the lake (Lak & Mohammadi, 2005), one can conclude the inherited origin of clay minerals in these horizons. The clay sediments increase in the column of cores taken from south to north (Fig. 5). Zarrinehrud, Siminehrud, LilanChai, SufiChai and MahabadChai (Fig. 1) are the main rivers supplying destructive clay minerals to the Lake Urmia (Amini et al., 2007). Given different facies in the cores, the reason for reduction of clay minerals from north to south can be explained as follows. Chlorite is the main clay mineral in Kani Barazan (such as LUB1-LUKB4 sedimentary cores) and Solduz (such as Solduz 1-2) (Figure. 2) cores which is presumably originated from changes in volcanic rocks and weathering of metamorphic rocks (Urmia-Dokktar metamorphic zone) (Chamley, 1989). Chlorite is formed at high altitudes and undergoes chemical weathering in hot and humid weather (Oliveira et al., 2002). Chlorite can also be formed in soil, high diagenetic shales, porous sandstones, carbonate rocks or by diagenesis processes from illite.

This mineral is observed at all depths of cores taken from the margin of the lake due to the same origin of particles. If it is indicative of climate change, the type of clay minerals would change at different depths. The clay minerals reach a minimum in the northern cores. Since Zarrinehrud, Siminehrud, ShahrChai (Bardesur), NazlouChai and BarandouzChai are the main rivers supplying destructive clay minerals to the Lake Urmia, the reason for reduction of clay minerals from north to south can be explained as follows. Kaolinite is formed in the vicinity of the lake margin where fresh water enters the lake (more acidic environment).

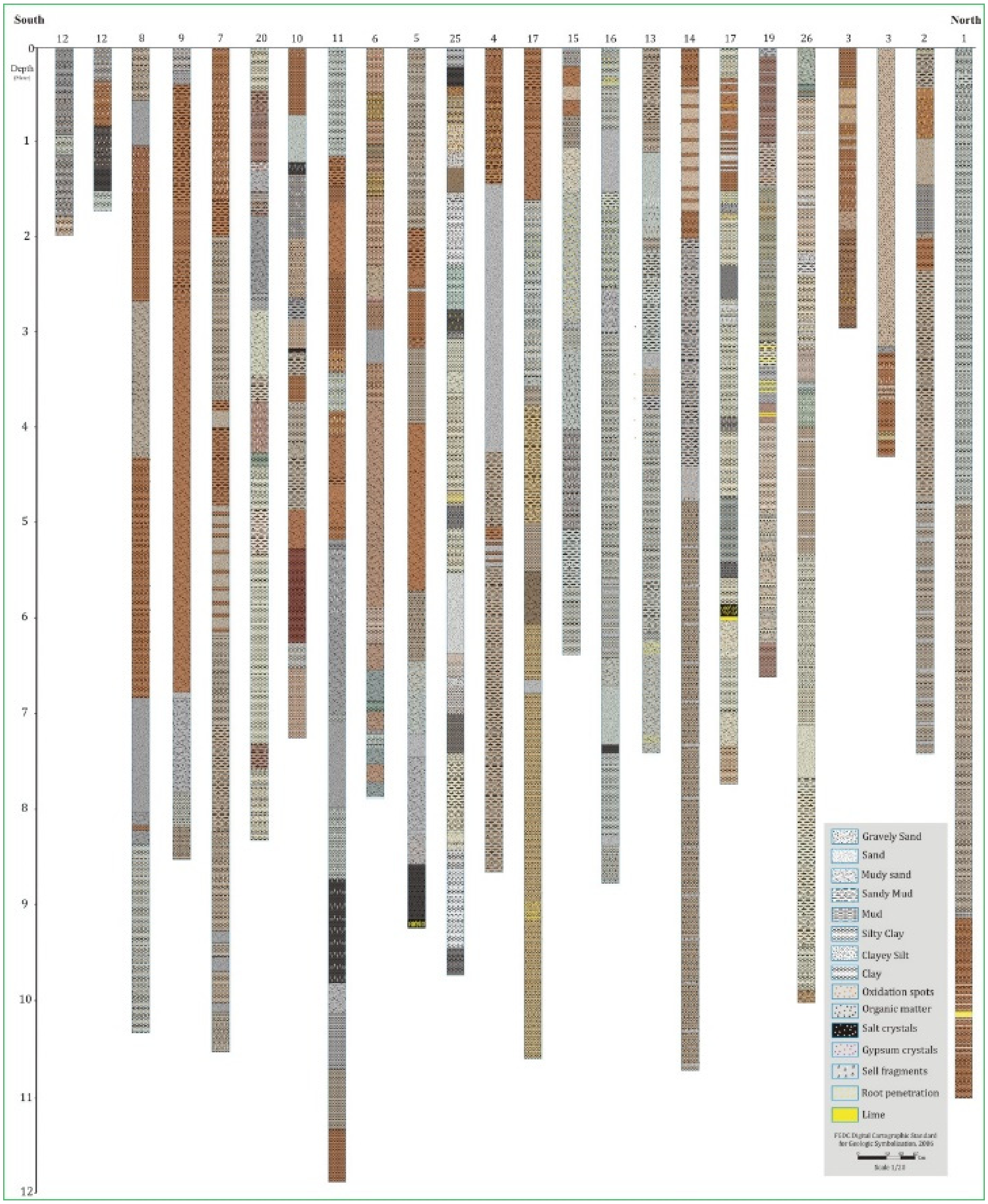


**Figure 5.** The stratigraphic column of cores taken from the south to north

The level of kaolinite decreases and chlorite increases towards the center of the lake (more basic environment) due to reactions in clay minerals by scouring and environmental conditions (Eh, pH) (Abdi, 2010). The same situation is observed in Lake Urmia and level of kaolinite increases at different depths with increasing distance from the center of the lake. Level of kaolinite decreases approaching the center of the lake and chlorite increases in a more basic environment.

To determine the origin of clay minerals in the sediments of the basin, it is necessary to identify clay minerals in the surrounding rock outcrops. Clay minerals are originated from formations around the lake. These formations have been eroded under humid weather conditions and entered the lake through rivers. The similarity of clay minerals in cores taken from Lake Urmia and rivers flowing into the lake, a very weak diagenesis process in the sediments and lack of diagenetic clay minerals in the cores indicate the destructive and inherited origins of clay minerals (Lak & Mohammadi, 2005).

Most of the clay minerals in the Late Pleistocene - Holocene sediments of the lake also the Solduz and Kani Barazan wetlands are inherited except the chlorite in the center of the lake, which is formed by the conversion of kaolinite to chlorite.

Due to the entry of clay minerals to the lake at the time of high lake water level, there is doubt on the possibility of entry of clay minerals in periods of low lake water level (in the event of river flooding, clay minerals entered the lake by erosion of flooding plains). It should be noted that despite the entrance of some clay minerals to the lake by this mechanism, most clay minerals have entered the lake in periods of humid climate with high precipitation rate when the lake water level was high (Mohammadi et al., 2005). Typically, iron oxide and kaolinite are dominant minerals under tropical humid and hot weather conditions with maximum weathering. The frequency of clay minerals such as kaolinite in the suspended load of rivers has a significant role in the supply of clay minerals in the study area. Obviously, some clastic particles have been transported to the sedimentation site by wind currents from the lands surrounding the lake. It is not currently possible to determine the level and mechanism of transport to the sedimentation site.

**Paleoclimate reconstruction**

As previously mentioned, non-clastic clay minerals are representative of special environmental and climate conditions, while inherited clays provide information on the origin of sediments and regional climate. Chlorites are the most important clay mineral in the sediments of Kani Barazan and Solduz wetlands and can be used as paleoclimate indices. Quartz and calcite are most abundant minerals and chlorite and kaolinite are the main clay minerals. Kaolinite is associated with an increase in the level of clastic minerals (especially quartz) in hot and humid periods and relatively low water periods with an increase in the level of chemical sediments, especially evaporate minerals. The studied cores with a depth of 10 m belong to the current period about 20 cal ka BP. Considering the presence and repetition of evaporate facies in the cores taken from the margin of Lake Urmia, the marginal areas have experienced many fluctuations. The intensity of changes is higher in distant regions which are currently cultivated as alluvial plains. The diversity of minerals is greater in southern regions than northern parts, but evaporate minerals are more concentrated in northern region probably due to more river inflows in southern and western regions. The frequency of kaolinite as an index of high-water periods is larger in southern parts than northern regions. Given the depth of sampling, more humid climate dominated the region about 20 cal ka BP (Late Pleistocene). This is consistent with paleoclimate studies in Iranian Plateau. As mentioned by Crinsly in 1970, the atmospheric conditions of Pleistocene in Iranian Plateau have been colder and more humid than current period because of more runoffs and a lower evaporation rate in Iranian Plateau. The origin of minerals in Lake Urmia is mainly destructive and inherited and to less extent transformative. Relatively low-water periods are identifiable with an increase in the level of chemical sediments, especially evaporate minerals while high-water periods are identified with an increase in the level of clastic sands (Darvishi Khatooni, 2011). However, destructive sediments are found with evaporate minerals in some regions (especially in southern and eastern areas). This indicates the entry of minerals from northeast to Lake Urmia when water concentration was high and rivers on southern shores were able to travel longer distances in the lake. Under such circumstances, fine-grained destructive sediments are observed along with evaporate minerals and pieces. With increasing the depth of samples, the level of evaporate minerals is relatively reduced indicating an increase in the salinity of Lake Urmia with time.

The results obtained in this study with studies conducted in Miqan Playa (Abdi et al., 2014), Urmia Lake (Lak et al., 2011), Jazmourian Playa (Vaezi et al., 2018), Hamoon (Hamzeh et al., 2016), Lake Maharloo (Lak, 2007: Sabok khiz, 2019), Gahar Lake (Akbari et al., 2015) show a good relevance. It seems that during the Late Pleistocene, the Central Iran and Zagros plateaus have passed suitable humidity conditions with some delay and according to the low evaporation, the weather would be probably colder.

The present study is innovative in that nothing has been done on these wetlands before and also it`s sedimentary environments and climatic conditions have not been studied and reconstructed. The studies have been done up now covered the inner part of the basin and the water level changes are much less than the river entrance and the estuary input delta. While in the deltas, due to the low slope, these changes are obvious and the transgression and regression can be studied more precisely.

Also, the diversity of sedimentary environment is more in the marginal parts and have a larger scale. On the other hand, the slope of the lake is less in the southern part therefore the studies has more accuracy.

## Conclusion

According to the results of the sediments, the clay minerals decrease from the margin of the basin to the center. This is indicative of clastic nature of these sediments. Sedimentology and mineralogy study of sediments taken from boreholes in the wetlands shows an increase in the clastic sediments and minerals (especially clay minerals) with increasing depth. Despite formation of kaolinite at some depths due to wet climate of the region, chlorite is the main clay mineral. Thus, physical weathering and mechanical erosion are dominant processes in the region. Therefore, clay minerals are of clastic type and have entered the basin through transportation. Over 20000 years (Late Pleistocene), while weather and climate fluctuations as revealed by mineralogical and sedimentological variations in the lake, regional weather has been more humid. Under the influence of such paleoclimate which is indicative of lower evaporation rate and more runoffs in the region, more clastic sediments (especially clay minerals) have entered the region with increasing the water level.

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