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Clay mineralogy and sediment grain-size variations as climatic signals in southern part of Urmia Lake cores, North West of Iran

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ABSTRACT:

Generally, the reconstitution of palaeo-geography and related environments is based on the study of sediment markers such as grain size and clay mineralogy. In this research, 90 surface and subsurface sediment samples from eight cores were analyzed for grain size and clay mineralogy in southern part of Urmia lake coast and adjacent areas. Abundant minerals are quartz, feldspars, calcite and dolomite. Heavy minerals identified were epidote, hornblende and zircon. Clay minerals are Kaolinite and Smectite mainly. Clay mineralogy and mean grain size of sediments in eight cores of Urmia Lake; reflect climatic conditions in this region. Relatively coarse sediments usually deposited during Urmia Lake low stands and relatively fine sediments deposited during high stands. The mineralogy of the clay-size fraction was determined by X-ray diffraction (XRD). Mineral assemblages display two climate conditions: Those having large Kaolinite, quartz, and feldspar peaks but a small smectite peak (interpreted to be cold times), and those with small Kaolinite, quartz and feldspar peaks and a large smectite peak-(warm sediments). In addition, smectite content correlate well with high mean grain size in Urmia Lake sediments, whereas sediments rich in Kaolinite, quartz, and feldspar correlate well with finer mean grain size. Chemical elements of the total sample are mainly of terrigenous origin, supplied by “Discharge Rivers”, which discharges in Urmia Lake. Variations in clay mineralogy and grain size didn’t indicate that the lake-level variations and nature of sediments delivered to the lake vary in concert with global climate changes, recently. Human activities such as Dams’ constructions and agriculture have probably induced variations in the mobilization of chemical elements.

Keywords:
Sediment, Grain size, Clay mineral, Climate, Urmia lake.

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INTRODUCTION

Climate variability is one of the focuses of paleo -climate research, specifically the heterogeneity of regional responses to global-warming. Lake sediments are commonly used to infer climate variation through clay mineral assemblages and preservation, grain-size, geochemistry, and sediment structures (Chamley 1989; Menking, 1997; Asikainen *et al*., 2006; Nelson, 2006; Fathian *et al*., 2016). It has been shown that shifts in the relative abundances of these minerals may correlate with climate changes such as glacial/interglacial transitions (Chamley, 1989; Velde, 1995; Moore and Reynolds, 1989, Sondag *et al*., 1993; Nelson, 2006). In some lacustrine environments with large drainage basin, as in Urmia Lake, depositional patterns are controlled by a number of transport mechanisms including fluvial inflows, and debris. These depositional mechanisms can be revealed by particle-size distribution (Ghaheri and Baghal-Vayjooee, 1999; Menking, 1997). Also, the analysis of sedimentary units sheds light on depositional environments and can be extended to climatic interpretations (Asikainen *et al*., 2006). Many workers have noted a relation between climate condition, grain size and mineralogy of materials deposited in lakes (Sima *et al*., 2013; Sinha and Raymahashay, 2004). Climatic conditions (e.g. rainfall, evapotranspiration, temperature, length of dry season, drought) are dominant factors controlling the leaching of numerous elements (Si, Al, Na, K, Ca, Mg, etc.) from soil cover toward the catchment area. So, probably changes in chemical movement of elements toward downstream in rivers have related with climatic and vegetation amount fluctuations during Quaternary. Thus, we can consider mineralogical and geochemical variations as signals for

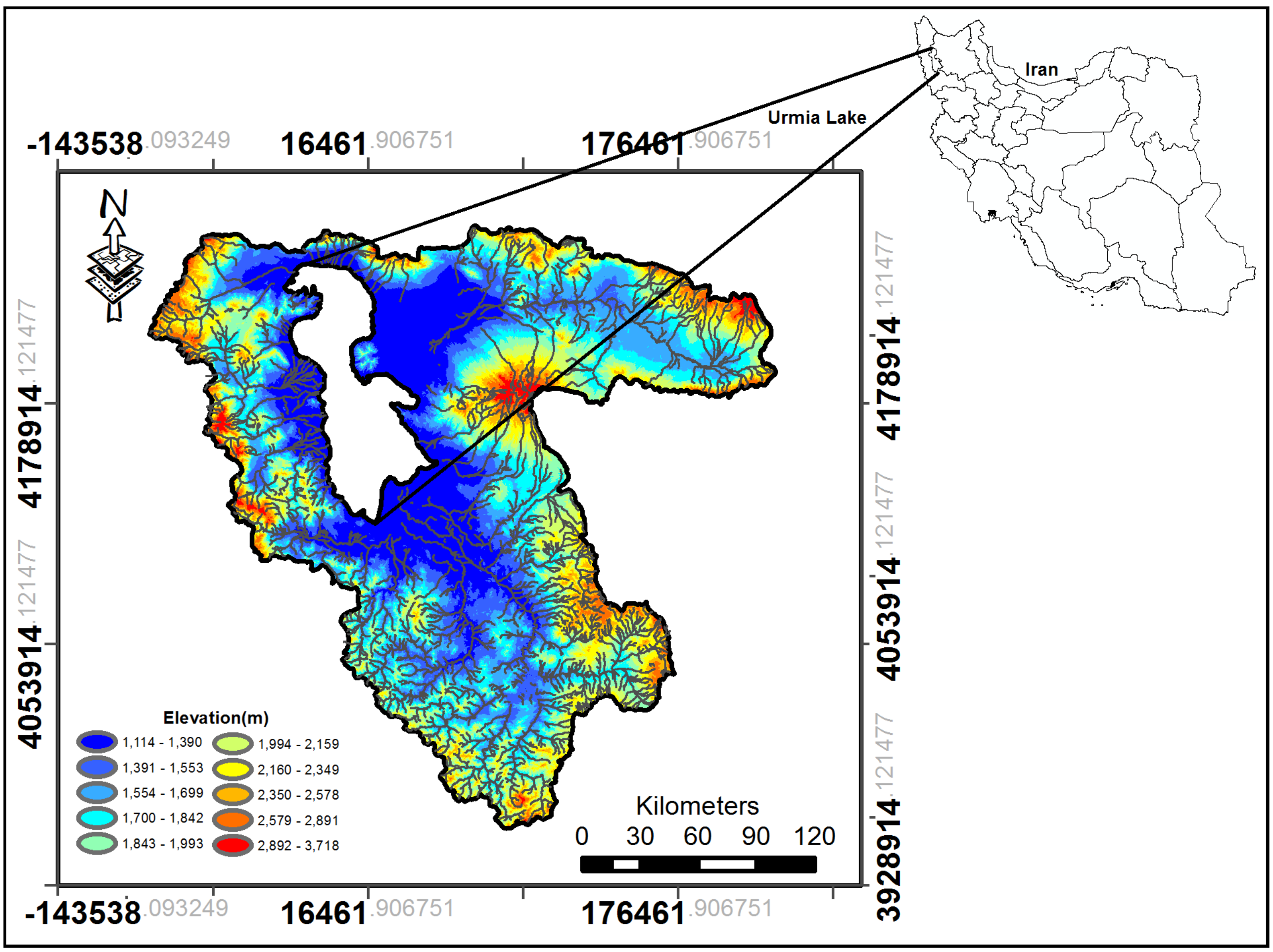

Figure 1. Geographical setting and topographic map of Urmia Lake drainage basin (prepared by author)

climatic changes (Sondag *et al*., 1993). The aim of this work was to seek and identify such signals in southern part of Urmia lake coastal sediments.

In this research, the results of grain-size analyses and X-ray diffraction (XRD) analyses of clay minerals in eight cores report and compare the relation of variations in grain size and clay mineralogy to other climate proxy records in order to construct a record of climatic variations in the area. Also, on the other hand, since over the past 10-20 years this region has seen the expansion of agriculture and wrong water resources management, especially for the inhabitants of the neighboring Urmia and Tabriz big cities (Ahmadzadeh *et al*., 2016). So, detailed mineralogical studies are important for apprehend of the sedimentary physical processes which control chemical element scattering, together with the exploration of possible pollution problems.

Study area

Lake Urmia, is a closed or terminal basin with no outflow, and hyper-saline (A landlocked body of water with significant concentration of salts more than 35 g/l) basin is located in 37-38 latitudes and 45-46 longitudes, between western and eastern Azerbaijan territories in the uppermost northwestern part of Iran (Figure 1). This lake is extending as long as 140 kilometers from north to south and as wide as 85 kilometers from east to west and occupying 5700 km2 of a depression, with altitude of 1250 m. Thirteen main rivers flow into the lake and bring many geological material with themselves (Alipour, 2006).

The surface area and water level of the lake

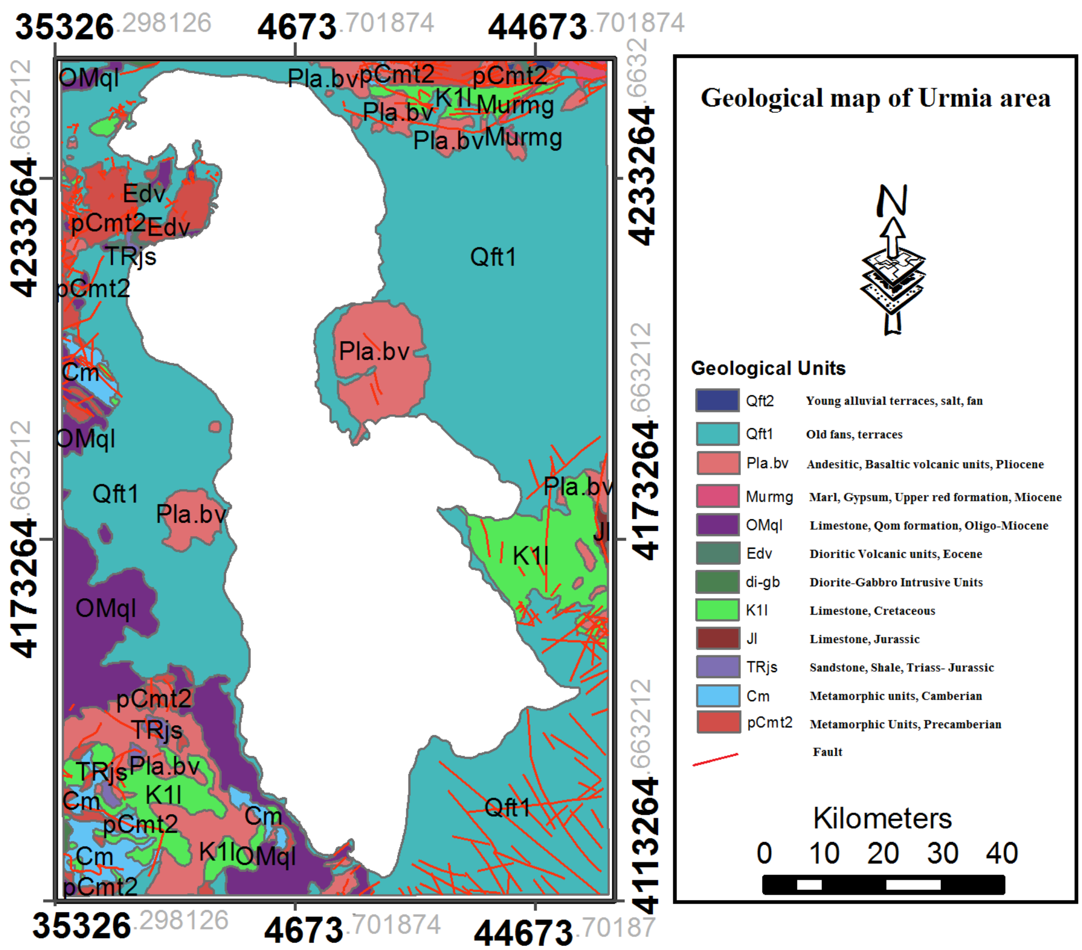

Figure 2. Geological map of Urmia Lake and surrounded area (after from 1:250,000 map GSI, modified by author)

have decreased significantly during the last four decades, with its depletion rate rapidly accelerating in recent years. According to Alipour (2006), Because of ten years of dynamic dry climate in the area, the water level is seven meters short of what it was at 20 years prior (Alipour, 2006). Precipitation between 1950-1998 showed two cyclic periods of around 10-year interims with high peaks at 1957, 1969 and 1994; and a low in1963. According to Hassanzadeh *et al*. (2012), Jalili *et al*. (2016), and Fathian *et al*. (2016), the estimated water level of the lake has decreased 7 meters from its highest level of 1,278 in 1995. Based on Torabian (2014) studies, Despite the decrease in water level does not appear to be noteworthy at first look, it has significantly affected the surface region of the lake because of its unique shallowness (Torabian , 2014). That is, in 1995 the surface zone of the lake was assessed at right around 6,100 km^2 staying stable from 1969, which declined to very nearly 33%, 2,366 km^2 in 2011 (Alipour, 2006; Torabian , 2014).

Geologically, Urmia Lake is supposed to be a tectonic origin of Graben situated among the Turkey and Iran platforms (Mahmoei *et al*., 2012; UNEP, 2012; Vaheddoost *et al*., 2015; Stappen *et al*., 2001). Very high elevated mountains of igneous and sedimentary formations encompass the Urmia Lake (Figure 2). The topography of the territory comprises of rocks from Pre-Cambrian to Quaternary and extremely recent lake sediments (Alipour, 2006). Meta-volcanic series, diorite, tuff, amphibolites, gneiss, Lucite tephrites, phenolite and basanite form oldest units of the Pre-Cambrian in this area. Deltaic sediments of Zarineh and Simineh Rivers cover south shore, widely. Dolomite, shale and partly lateritezed sandstone from continental environments represent Paleozoic unites. Mesozoic rocks in this area include dolomite and fossiliferous limestone, base conglomerate, sandstone, schist and basic and ultra basic rocks (Ophiolite unit) (Jahanbakhsh *et al*., 2011; Mahmoei *et al*., 2012; Alipour, 2006). Limestone, combination, sandstone and shale changing over to tufaceous material with vertebrate fossils from Miocene to quaternary dated 6.9 M.Y. form tertiary rocks around lake (Rasouly, 2008). Traces of rivers, travertine, lake residues, and deltaic salty alluvium show quaternary in the banks of the lake (Alipour, 2006). Tectonically, Alborz and Zagros ranges cross together in Urmia Lake area (Mahmoei *et al*., 2012). Cretaceous limestone, Miocene marls, and gently to unfolded limestone (Qom formations) form the base of the lake and its islands and covered by lake sediments dated back to 30,000–40,000 years old. The lake was created 400,000 – 800,000 years ago (Kelts and Shahrabi, 1986; Touloie, 1998; Ghaheri and Baghal-Vayjooee, 1999; Vaheddoost *et al*., 2016), but it has important changes from 8000 up to 40,000 years and converted to modern form (Takami, 1987; Zoljoodi and Didevarasl, 2014). Although, there is no any lake sediment at elevations more than 5 meters higher than the present level and this fact indicate that the lake has never been much larger, and this lake have been extended only after a active tectonism that a fault rise up in the north of the lake, and pushed the water back towards the south in the low level basin, thus forming the new morphology of the lake. Previously, the focus of geological studies on Urmia lake were on areas surrounding the lake (Stappen *et al*., 2001), or on the geochemistry of the lake in internal parts (Kelts and Shahrabi, 1986; Ghaheri and Baghal-Vayjooee, 1999; Alipour, 2006).

MATERIALS AND METHODS

Two types of samples were taken from eight cores for grain size analysis and clay mineralogy. Point samples represent about 30cm of each core length, 1-1.5 m spacing and collected at drill site. These samples were taken to coincide with visually obvious changes in lithology and each comprised about 100-300g of sediment. Because of the time required for analyses a selection of these samples (one sample about every 1m) was chosen for analyses of grain size and selected solid elements. The second part of the samples were collected in the laboratory, each representing integrated ribbons of sediment weighing about 50g and spanning 1m of each core. The spacing between point samples were chosen to ensure probable good resolution of climatic fluctuations operating on time scales and Nearly 80 samples were analyzed, finally.

According to Menking (1997), samples were treated with weak acetic acid and peroxide to remove carbonate and organic material. In order to separate the gravel, sand, and mud (silt-plus-clay) fractions, the remaining sediment was sieved. The mud fraction of each sample was collected in a 1,000-ml graduated cylinder. Sands and gravels were poured into evaporating dishes, dried, and weighed. Dried gravels were sieved and sands were introduced into settling tubes and their grain sizes determined. To prevent flocculation, sodium hexametaphosphate ("Calgon") dispersant solution was added to each clay and silt solution, and finally, the weight of silt and clay in each sample was determined with an average precision of about 0.25. Sand, silt, and clay contents were in samples were separated by wet and dry sieving. The grains equal and coarser than sands were collected together in several dishes for evaporate, drying and then weighed. Concentrations of mud (silt and clay) in each sample were determined by a scaled-down pipette analysis. Part of the clay-size fraction of each sample was separated for X-ray diffraction (XRD) analysis and clay mineralogy (Moore and Reynolds, 1989; Menking, 1997). All minerals were identified by reflection peak locations (Table 3) and some were further identified by various thermal and chemical treatments (Moore and Reynolds, 1989; Menking, 1997) for separate smectite from Kaolinite, Illite, and chlorite.

RESULTS AND DISCUSSION

In this research, the results of granulometry analyses and clay mineralogy in eight cores were reported and compared the relation of variations in them to other climate proxy records in order to construct a record of probably climatic variations in Urmia lake area. In some boreholes at surface and shallow levels, sediment was removed and not been analyzed, because of a lot of destruction, bioturbation and lack of confidence (Figure 3).

Grain size

In general, sediments vary from an evaporate package at the top of the cores to lacustrine clay, silt, sand and very slightly granule size clastic materials. Clastic sediments at the top of the cores are predominantly clay to silt size, and become interbedded sands. Grain-size analyses of the cores indicated that the mean sizes of sediments vary from 31-4000 µm

Name	X	Y	Z
BH1	521263	4174910	1272
BH2	536639	4182070	1278
BH3	523456	4158386	1274
BH4	568708	4179346	1277
BH5	527887	4136350	1272
BH6	572465	4149048	1279
BH7	538967	4110761	1286
BH8	586182	4130465	1275

Figure 3. Boreholes location of the lake (from Google earth).

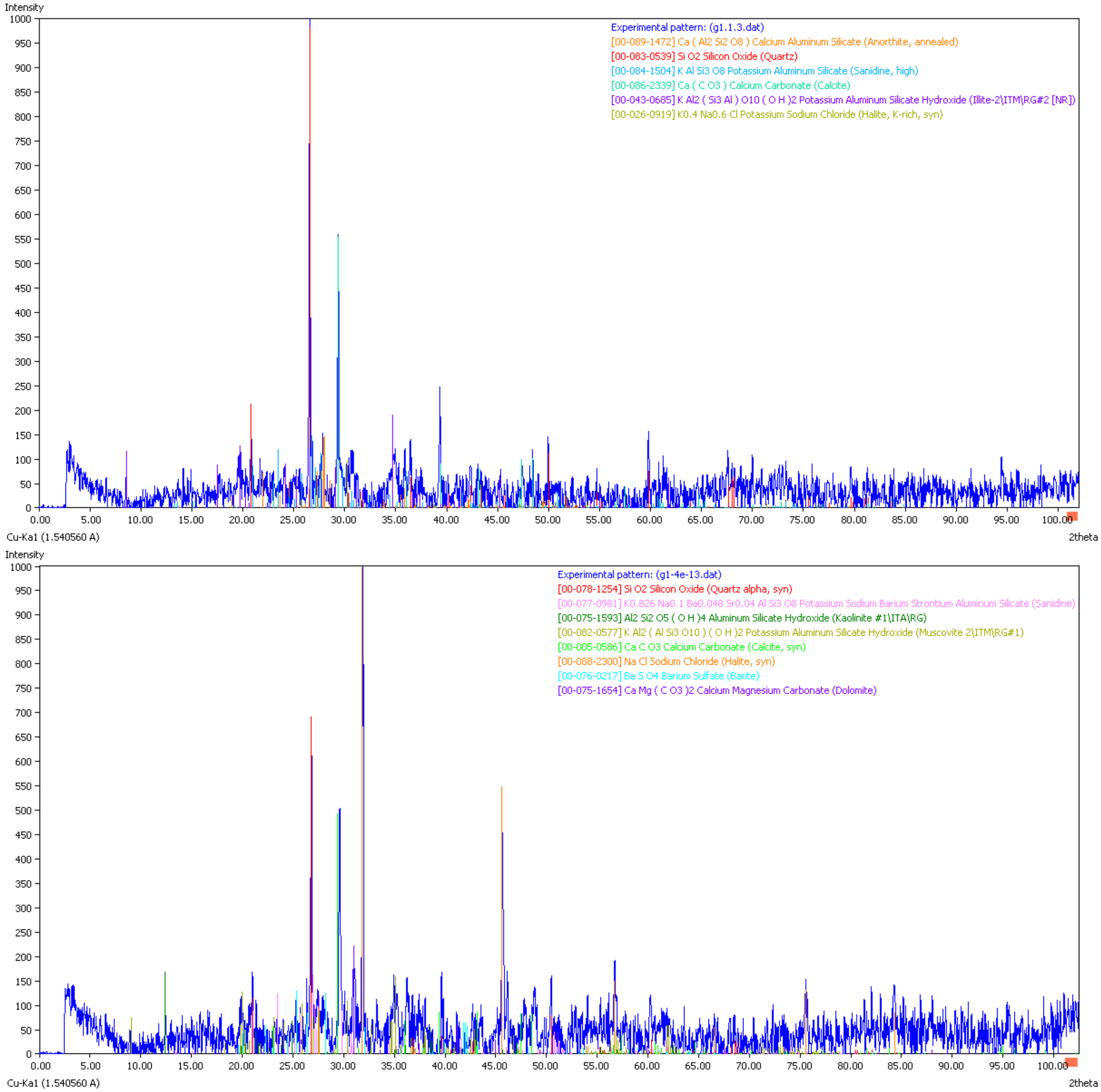

Figure 4. X-ray diffractograms from representative 2 samples, for example

deposited during probably glacial and interglacial periods (Figure, 4). Interglacial or warm periods are marked by both coarser deposition and more size variations. Below 200cm, in southern cores, no correlation between grain size and climatic regime is apparent. As suggested by Sondag *et al.* (1993), lacustrine grain size is a function of fluvial inflow rates that allow some plumes of fine sediment to penetrate far into a lake. The difference in grain size variability in the Urmia Lake cores, as well as the predominance of finer deposition during probably glacial or cold periods and of coarser deposition during interglacial or warm periods can be explained by these processes and by consideration of the hypsometry of the Urmia Lake basin.

Also, eastern and western shores of Urmia Lake don't show complete sedimentary correlation and probably factors such as topography and lithology differences and probably faulting in this area have been affected. There is little change in altitude for several

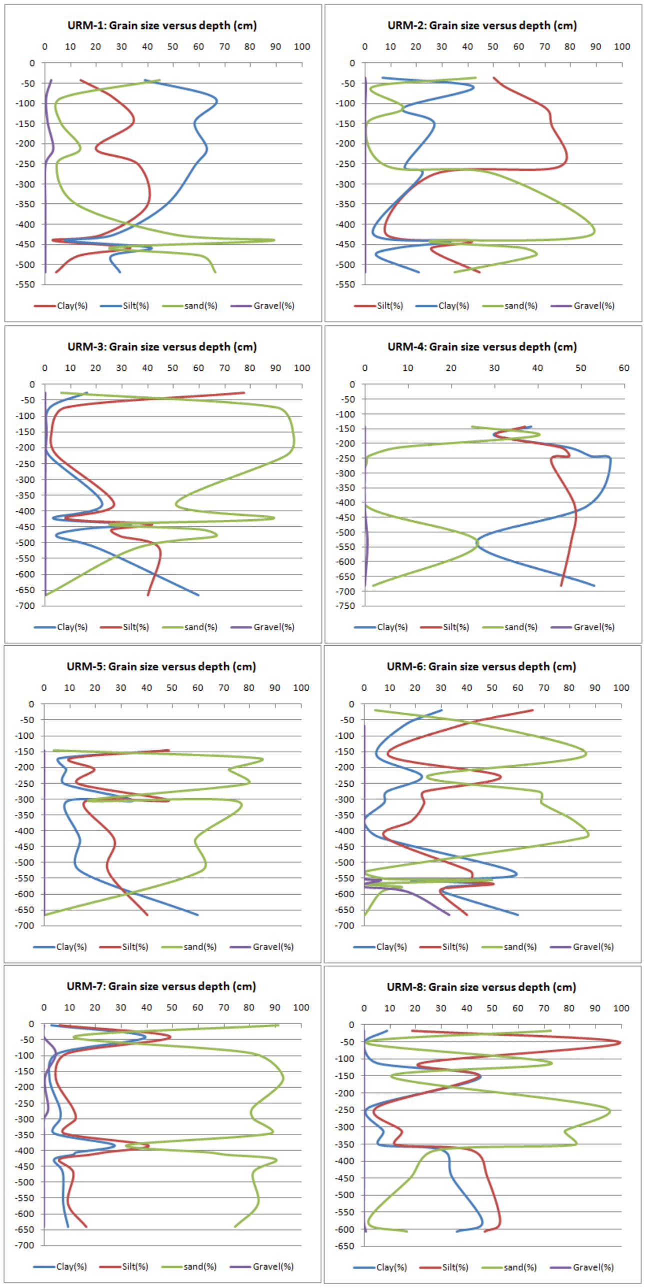

Figure 5. Grain size changes versus depth in 1-8 boreholes

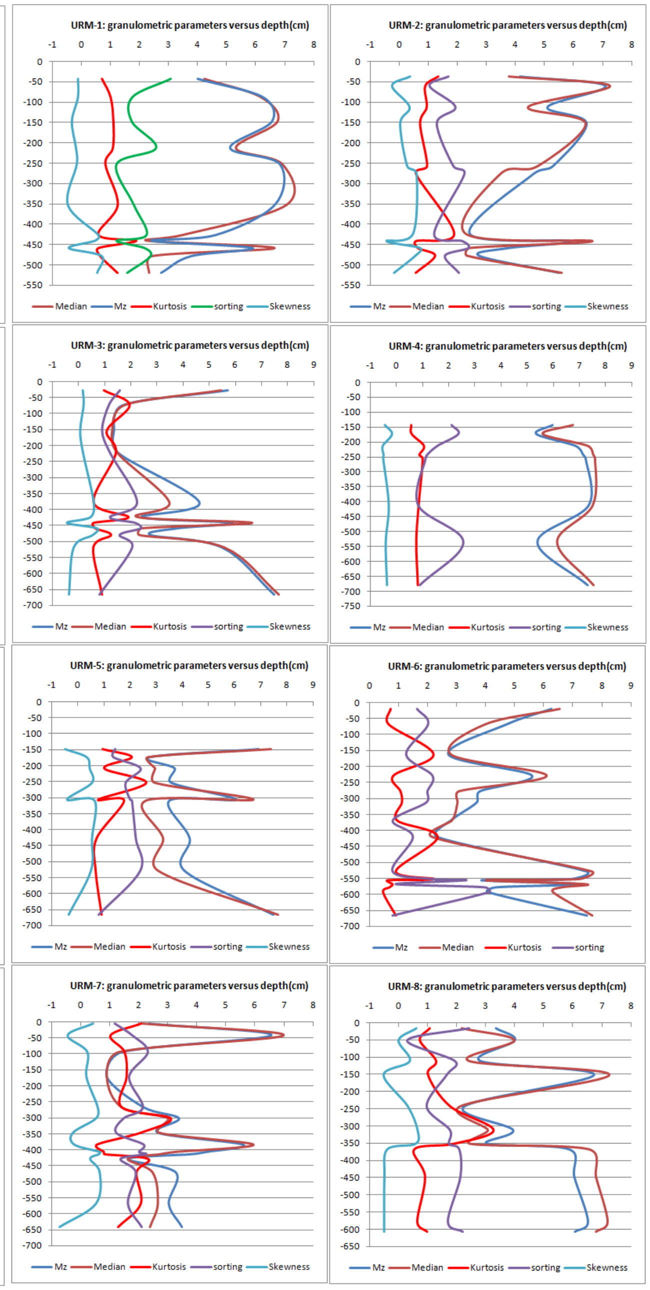

Figure 6. Plots of granulometry parameters versus depth in 1-8 borehole logs

kilometers in west and southwest direction from the lake center and a rapid increase in altitude over a small distance in other directions.

High lake levels are thought to have characterized cold and glacial periods, should have resulted in deposition of fine sediments at the core sites. During interglacial periods, if lake levels were lower, mean grain size would have increased. If the lake fell to the point where the basin floor was nearly flat, further lowering would have caused a large contraction of the lake, and the shorelines would have rapidly approached the core sites. The morphology of area could also explain why the mean grain size in the glacial sediments varies less than that in the interglacial sediments. During cold periods, when the lake was high, small changes in lake level would lead to little change in shoreline distance, and sediments having nearly uniform grain sizes would be deposited at the core site. During

Table 1. Sedimentary statistic parameters for sediment samples in cores 1-4

Core	Depth (cm)	Sediments type	Skewness	Kurtosis	Sorting
URM1	-42	Slightly gravelly sandy mud	Coarse	Platy	Very bad
	-87	Slightly gravelly mud	Coarse	Meso	Bad
	-147	Slightly gravelly mud	Strongly coarse	Meso	Bad
	-212	Slightly gravelly sandy mud	Coarse	Meso	Very bad
	-252	Slightly gravelly mud	Coarse	Platy	Bad
	-352	Sandy mud	Strongly coarse	Lepto	Bad
	-426	Muddy sand	Strongly fine	Very platy	Very bad
	-440	Muddy sand	Strongly fine	Very lepto	Bad
	-458	Sandy mud	Strongly coarse	Very platy	Very bad
	-478	Muddy sand	Strongly fine	Very platy	Very bad
	-519	Muddy sand	Strongly fine	Lepto	Bad
URM2	-37	Sandy mud	Strongly fine	Lepto	Bad
	-60	Slightly gravelly mud	Coarse	Meso	Bad
	-112	Sandy mud	Strongly fine	Meso	Bad
	-152	Mud	Near symmetrical	Platy	Bad
	-257	Mud	Fine	Meso	Bad
	-276	Muddy sand	Strongly fine	Very platy	Very bad
	-423	Muddy sand	Strongly fine	Very lepto	Bad
	-458	Muddy sand	Strongly fine	Very platy	Very bad
	-477	Muddy sand	Strongly fine	Lepto	Bad
	-519	Sandy mud	Coarse	Very platy	Very bad
URM3	-27	Mud	Fine	Mesokurtic	Bad
	-73	Sand	Fine	Very leptokurtic	Bad
	-153	Slightly gravelly sand	Near symmetrical	Mesokurtic	Medium
	-223	Slightly gravelly sand	Fine	Lepto	Bad
	-377	Muddy sand	Strongly fine	Very platy	Very bad
	-423	Muddy sand	Strongly fine	Very lepto	Bad
	-479	Muddy sand	Strongly fine	Leptokurtic	Bad
	-518	Sandy mud	Coarse	Very platy	Very bad
	-665	Mud	Strongly coarse	Meso	Medium
URM4	-142	Sandy mud	Strongly coarse	Very platy	Very bad
	-172	Sandy mud	Coarse	Very platy	Very bad
	-212	Mud	Strongly coarse	Meso	Bad
	-242	Mud	Strongly coarse	Platy	Bad
	-257	Mud	Strongly coarse	Meso	Bad
	-412	Mud	Coarse	Platy	Medium
	-535	Slightly gravelly sandy mud	Strongly coarse	Platy	Very bad
	-680	Mud	Strongly coarse	Platy	Medium

warm and interglacial, if lake levels were lower, fluctuations could have produced large variations in shoreline distance relative to the core site, and mean grain sizes of particles deposited at the core site might have varied more. However, determination of absolute lake level from granulometry results may be not correct, because other processes such as aeolian and river inputs might also have influenced grain sizes. But in many case studies, mean grain size could be a useful and fast way for determination of lake level.

Grain-size analysis of core samples defines at least four distinct depositional regimes, especially in north area (Figure 5 and 6). Although, sediments in the northern boreholes (URM1-4) showed greater correlation compared to borehole in southern region (URM5-8). It can be seen several abrupt changes in sediments as mud increasing and sand decreasing in the northern part. In cores URM1-6, subtle variations in grain size between depths at 4 to 5 m , although mostly in the clay- and silt-size ranges, show a definite climatic

Table 2. Sedimentary statistic parameters for sediment samples in cores 5-8

Core	Depth (cm)	Sediments Type	Skewness	Kurtosis	Sorting
URM5	-147	Mud	Strongly coarse	Meso	Bad
	-172	Muddy sand	Strongly fine	Very lepto	Bad
	-252	Muddy sand	Strongly fine	Very lepto	Bad
	-305	Sandy mud	Strongly coarse	Platy	Bad
	-427	Muddy sand	Strongly fine	Platy	Very bad
	-527	Muddy sand	Strongly fine	Platy	Very bad
	-665	Mud	Strongly coarse	Meso	Medium
URM6	-20	Mud	Coarse	Platy	Bad
	-68	Sandy mud	Strongly fine	Very platy	Very bad
	-162	Muddy sand	Fine	Very lepto	Bad
	-228	Sandy mud	Strongly coarse	Platy	Very bad
	-312	Muddy sand	Strongly fine	Lepto	Bad
	-368	Muddy sand	Near symmetrical	Meso	Medium
	-420	Muddy sand	Strongly fine	Very lepto	Bad
	-527	Mud	Strongly coarse	Meso	Medium
	-577	Gravelly sandy mud	Strongly coarse	Platy	Very bad
	-665	Mud	Strongly coarse	Meso	Medium
URM7	-5	Sand	Strongly fine	Very lepto	Bad
	-42	Sandy mud	Strongly coarse	Meso	Bad
	-94	Slightly gravelly muddy sand	Fine	Very lepto	Very bad
	-172	Slightly gravelly sand	Fine	Very lepto	Bad
	-267	Slightly gravelly muddy sand	Strongly fine	Lepto	Very bad
	-347	Muddy sand	Fine	Lery lepto	Bad
	-407	Muddy sand	Strongly fine	Platy	Very bad
	-471	Muddy sand	Strongly fine	Very lepto	Bad
	-569	Muddy sand	Strongly fine	Very lepto	Bad
	-642	Muddy sand	Strongly fine	Lepto	Very bad
URM8	-17	Muddy sand	Strongly fine	Meso	Very bad
	-52	Mud	Near symmetrical	Platy	Very good
	-112	Muddy sand	Strongly fine	Lepto	Bad
	-152	Sandy mud	Strongly coarse	Meso	Bad
	-243	Sand	Strongly fine	Very lepto	Medium
	-312	Muddy sand	Strongly fine	Extremely lepto	Bad
	-352	Muddy sand	Strongly fine	Very lepto	Bad
	-368	Sandy mud	Strongly coarse	Very platy	Very bad
	-448	Sandy mud	Strongly coarse	Meso	Very bad
	-578	Mud	Strongly coarse	Very platy	Bad
	-607	Slightly gravelly sandy mud	Strongly coarse	Meso	Very bad

signal; deposits were finer grained during glacial periods and coarser during interglacial periods. However, the abrupt transition from fine sediments above 3 m in southern part, to silt- and sand-rich sediments remains unexplained. The transition may be the result of climatic or tectonic factors. However, from the grain size point of view, there is a difference between the top and bottom sections of the cores, and also, all sections appear to represent poorly sorting like all lacustrine materials (Figure 6), and as mentioned earlier, the poor sorting may be affected by sampling technique Like Newton (1991).

Mineralogy

Menking (1997) interpreted the presence in the clay-size fraction of non-clay minerals (quartz, plagioclase, and K-feldspar) to be the result of glacial abrasion that produced large volumes of glacial sediments. Indeed, it is rare to find quartz and feldspars in the clay-size fraction of any sediment unless that sediment had a glacial origin (Moore and Reynolds,

Table 3. Clay minerals in URM1-8 core samples

Borehole name	Depth (m)	Clay minerals	Non-clay minerals
URM1	0-1.5	Kaolinite	Halite, Gypsum, Quartz, Muscovite, Albite, Calcite, Sanidine, Anortite
	1.5-3	Kaolinite	Quartz, Muscovite, Albite, Calcite, Dolomite
	3-4.5	Chamosite, Kaolinite	Quartz, Muscovite, Albite, Calcite, Halite
	4.5-6	Chamosite, Kaolinite, montmorionite	Quartz, Muscovite, Albite, Calcite, Halite
URM2	0-1.5	Kaolinite	Quartz, Muscovite, Albite, Calcite, Dolomite
	1.5-3	Kaolinite	Quartz, Muscovite, Albite, Calcite, Dolomite
	3-4.5	Kaolinite, Chamosite	Quartz, Muscovite, Albite, Calcite, Dolomite
	4.5-6	Kaolinite, Illite	Quartz, Muscovite, Albite, Calcite, Dolomite
URM3	0-1.5	Kaolinite	Quartz, Muscovite, Albite, Calcite, Anortite
	1.5-3	Kaolinite, Chamosite	Quartz, Muscovite, Albite, Calcite, Anortite
	3-4.5	Kaolinite	Quartz, Muscovite, Albite, Calcite, Anortite
	4.5-6	Montmorionite, Chlorite	Quartz, Muscovite, Albite, Calcite, Anortite
URM4	0-1.5	Kaolinite	Quartz, Muscovite, Calcite, Dolomite, Halite
	1.5-3	Kaolinite	Quartz, Muscovite, Albite, Calcite, Anortite
	3-4.5	Kaolinite, Illite	Quartz, Muscovite, Albite, Calcite, Anortite
	4.5-6	Kaolinite, Illite	Quartz, Muscovite, Albite, Calcite, Anortite
URM5	0-1.5	Kaolinite	Quartz, Albite, Calcite, Dolomite, Halite
	1.5-3	Kaolinite	Quartz, Muscovite, Albite, Calcite, Anortite
	3-4.5	Kaolinite, Montmorionite	Quartz, Muscovite, Albite, Calcite, Anortite
	4.5-6	Kaolinite, Chlorite, Montmorionite	Quartz, Muscovite, Albite, Calcite, Anortite
URM6	0-1.5	Kaolinite	Quartz, Muscovite, Albite, Calcite, Halite
	1.5-3	Kaolinite, Illite	Quartz, Muscovite, Albite, Calcite, Anortite
	3-4.5	Kaolinite, Chamosite	Quartz, Muscovite, Albite, Calcite, Anortite
	4.5-6	Kaolinite, Chlorite	Quartz, Muscovite, Albite, Calcite, Anortite
URM7	0-1.5	Kaolinite	Quartz, Muscovite, Albite, Calcite, Halite
	1.5-3	Kaolinite, Illite	Quartz, Muscovite, Albite, Calcite, Anortite
	3-4.5	Kaolinite, Chlorite, Montmorionite	Quartz, Muscovite, Albite, Calcite, Anortite
	4.5-6	Kaolinite	Quartz, Muscovite, Albite, Calcite, Anortite
URM8	0-1.5	Kaolinite, Chlorite	Quartz, Muscovite, Albite, Calcite, Halite
	1.5-3	Kaolinite	Quartz, Muscovite, Albite, Calcite, Anortite
	3-4.5	Kaolinite, Illite	Quartz, Muscovite, Albite, Calcite, Anortite
	4.5-6	Kaolinite, Chlorite, Montmorionite	Quartz, Muscovite, Albite, Calcite, Anortite

1989; Sondag *et al*., 1993; Sinha and Raymahashay, 2004). Clay mineralogical variations do not indicate changes in lake level but reflect changes in the weathering environment in this area or changes in the composition and salinity of Urmia Lake. Of the true clay minerals, Illite and Chlorite are typically found as products of intense physical weathering of micas by glaciers in the absence of strong chemical weathering (Chamley, 1989; Nelson, 2006). On the other hand, during soil formation, Smectite and Kaolinite, are produced from the weathering of silicate minerals and therefore, be more indicative of climates conducive to chemical weathering (Chamley, 1989). In addition, Smectite is a common weathering product of volcanic ash, and care must be taken to distinguish between true climatic variations and volcanic events (Chamley, 1989). In Urmia area there are both probable sources for Smectite and so, other evidence must be important. The correlation of feldspars with Illite and chlorite (not Kaolinite) may indicate a mechanical origin because they feldspars may indicate immature, mechanically produced sediments. Also, in the Urmia Lake samples, there are several correlations between Illite/quartz and Chlorite-Kaolinite/quartz peak ratios correlate with the K-feldspar/quartz and plagioclase/quartz ratios, like other researches (Menking, 1997). Usually, samples with high feldspar peaks always exhibit large Illite peaks, while samples displaying weaker and fewer feldspar peaks show large smectite peaks. This peak pattern suggests that the Illite is a low-grade alteration product of igneous Muscovite or Biotite and that the Illite-plus-feldspar amounts represents cold and probably glacial period. Smectite formed by a different process because of the poor correlation of smectite/ quartz to Illite/quartz, K-feldspar/quartz, and plagioclase/quartz ratios. On the other hand, the plagioclase/K-feldspar ratio correlates negatively with the smectite/quartz ratio. Because generally, plagioclase is less resistant to chemical weathering than K-feldspar and in Bowen series set upper than Orthoclase (Loughnan, 1969). So, in chemically weathered sediments, Plagioclase/ K-feldspar ratios should be lower than those sediments unaltered by chemical processes. Smectite is a chemical-weathering product, and naturally, ratios of smectite/quartz should be high in those sediments that were chemically altered and low in those sediments that were unaltered (Menking, 1997). Therefore, smectite/quartz and plagioclase/K-feldspar ratios behave inversely. (Table 1 and 2).

During periods of high salinity during low lake levels in Urmia Lake and the abundance of calcite (interglacial periods), smectite may have formed authigenically and this fact could be an alternative explanation for the variation in sedimentation especially for smectite or Illite (Bischoff *et al*., 1993). Sometimes, authigenically K-feldspar and Zeolites are formed in saline lakes such as Searles Lake and Albert Lake, beside to authigenically clay minerals (Hay *et al.*, 1991; Banfield *et al*., 1991). Presently, we cannot determine origin for clay minerals and K-feldspars in the cores that are detrital or authigenic. But, evidence for the high salinities necessary for authigenically K-feldspar precipitation is scant. While, the only evidence for high salinities is the evaporate minerals found between surface and -1.5m depth. Despite some small and fine evaporites minerals, no other large evaporate minerals exist in high depth of the cores, and evidence of dissolution of evaporites is lacking. Also, no Zeolites were found in the clay-size fraction. Generally, these minerals are found in saline lakes and altered tephra layers. The absence of Zeolites in the clay-size fraction of the Urmia Lake core may show that authigenically mineral formation is not a significant process in the lake. As clay size particles (<4µm) have various proportions of bedrock, pedogenic or authigenic sources; the mineralogy of them would reflect climate and initial hypothesis that appears confirmed. The smectite and Illite components form frequent mineralogy in sediments.

Bulk grain size and clay mineralogy correlate and reflect other paleo-climatic proxies in the Urmia Lake cores. During cold periods in Urmia Lake area, a dominance of Kaolinite, feldspar, and quartz over smectite in the clay-size fraction; fine mean grain size (3 µm); low carbonate and organic carbon contents; very low CEC values that probably indicate bedrock can be identified and show a very fresh and low-productivity lake like the other researches (Bischoff *et a1.,* I993). In contrast, warm and interglacial periods show less vigorously overflowing or non overflowing lake and have coarser mean grain sizes (100µm), high carbonate and organic carbon contents, high CEC values and of course, smectite clay minerals. During the Holocene interglacial period, the dark muds deposited with high carbonate content and show a shallowing period and temporary saturation in lake. Mean grain size also appears to reflect variations in lake level; coarse grained materials were deposited during times of' lake low stands, when the shores of Urmia Lake were closer to our core site, and fine-grained sediments were deposited during high stands, when the shoreline was farther from the core sites.

One chemical parameter (SiO_2) was of particular interest as geochemical indicator of vegetation modifications and climatic changes. During the most recent forest period (9500-5500 a B.P.), there is an excellent correlation between the SiO_2, content and the percentage of arboreal pollen: SiO_2 increases as the forest dominates. Because no correlation was found between SiO_2 and Al_2O_3, this increase is not related to the inflow of Kaolinite.

Based on grain-size analysis, the 220 μm fraction of the sediment was always high and usually includes detrital quartz, While mineralogical analysis revealed abundant amorphous SiO_2 (opal) in the silt fraction. This point can assume that the SiO_2 peaks are mainly related to soluble inputs rather than to clastic ones. Also, this agrees with the lowering of the erosion rate under vegetation cover and with weathering conditions affect on soluble SiO_2 exportation. The high Si % levels are generally found in ground waters in warm and rainy condition with higher acid content and well known hydrolytic action in soils (Grimaldi, 1988; Newton, 1991; Robert *et al*., 1987; Last, 2002).

Climate change

Several direct and indirect human-induced factors are recognized as causes of the lake's rapid drying in the last three decades. Among the indirect causes, climate change impacts such as drought and low precipitation levels are considered as the two major contributing factors to the lake's desiccation. About precipitation, by comparing the mean value of the recent 20-year spell (1996 to 2016) to the previous one, we found precipitation declines on the basin around 56 mm. The annual rainfall over the Lake has decreased by 40 percent from its average 235 mm from 1967 to 2006 (Hassanzadeh *et al*., 2012; Pengra, 2012), leading also to a decline in the level of groundwater in the area (Zarghami, 2011). The impacts of such indirect environmental factors on Urmia Lake have been quite significant. In comparison with the Sevan Lake in Armenia and the Van Lake in Turkey, from surface level point of view, despite similarities in their geographical situations, both of which are located less than 200 km away from Urmia Lake, we can observe that none of them have declined as has Urmia Lake (UNEP, 2012). Although, Urmia Lake has been more effectible to climate change and low precipitation rates. Temperature also shows a significant increasing trend on the basin, as in total we have found around 1.89˚C grow in temperatures mean by comparing the recent 40-year period. The two degrees rise of temperature in the lake's region also bears a negative impact on the Lake's sustainability.

As indicated by Zoljoodi and Didevarasl (2014), the standard deviations and standard mean errors of precipitation and temperature data series amid the two specified spells are declining step by step alongside the varieties of mean values, and illustrating the persistency and furthest point of the dryness on the basis particularly over the last 20-year spell, by low positive and negative fluctuations parallel to a falling habit of precipitation and an expanding habit of temperature. Precipitation commonly through its created runoff on the basis, fills the lake, whiles the runoff amazingly has been held and controlled by dams and irrigation channels particularly through last 15 years on the Urmia basin bowl (Zoljoodi and Didevarasl, 2014).

In light of investigation of Zoljoodi and Didevarasl, (2014) temperature raise could specifically and indirectly influences the water-level of the lake by raising evaporation and water-use rate in agricultural and urban issues, and so for. Presence of the man-made factors on the basin that increase the water crisis of Urmia lake could bring about a poor consistency between water-level variations of the lake and the progressions of meteorological factors. Because of the precipitation and temperature of the basin, the low linear relationship evaluated ranks don't suggest application probability of prediction situations for the lake's water-level behaviour (Zoljoodi and Didevarasl, 2014).

However, direct human-induced impacts have played a greater role in the rapid desiccation of the Lake. Common causes of the Lake's decline are recognized to be: a) construction of dams; b) poor water management policies; and c) construction of a primitive -type causeway (An elevated road/railway over a wetland) dividing the lake into two north and south lakes with almost no connectivity. In addition, rapid increase in population size and aggressive use of the lake's water and nearby underground water reserves for irrigation purposes and diversion of in-flow rivers have worsened the situation. The increase in water consumption for irrigation and the rise in population have not only resulted in the rapid decrease of Lake's surface water but also an aggressive use of underground waters. Only a decade ago, Local farmers could reach underground water digging wells of 30 to 40 meters while currently they have difficulty accessing water even with 70 meters deep wells. The decreases in water and surface levels have two immediate impacts in Urmia Lake; salinity increase in the water and changes in saline brines and finally changes in the lake's food cycle. The first one is the unprecedented, i.e., 300 g/L- more than 8 times salt in any typical saline basin, which has proved fatal for the lake's brine shrimp (Torabian, 2014). These dried surfaces of the lakebed have turned into a wide salty desert of more than 400 square kilometers. They not only threaten agriculture and natural vegetation growth around the lake but also endanger cities and villages within close approximation to the lake due to high probability of future salt and sand storms (Hassanzadeh *et al*., 2012). Urmia Lake is the third largest hyper-saline basin in the world and the first largest in the Middle East, and previously registered as a UNESCO biosphere reserve and an internationally significant wetland in the 1971 Ramsar convention (Nazaridoust, 2011). This lake ecosystem involve more than 210 species of birds, reptiles, amphibians and mammals, a unique salt-water shrimp species called *Artemia urmiana* and a obviously variety of salt tolerant plants (UNEP, 2012; Torabian, 2014). The Urmia basin surround villages and cities are home to 6.4 million people and an estimated 76 million people live within a radius of 500 kilometers (Food and Agriculture Organization of the United Nations, FAO 2010; Torabian, 2014).

During the recent years, water crisis of Urmia Lake is intensified, as from 16-years ago to the present the water-level of the lake has been slumped persistently below its long term average (1275.35 m). These conditions extremely damaged its valuable ecosystems as well as socio-economic activities of the surrounding areas. We have found that the meteorological variables on the Urmia Lake basin during this period show a different behavior, as precipitation's mean value is decreased around 76 mm, on the other hand the temperatures mean value increased 1.8˚C compared to the previous periods. However, reduction of the water-level of the lake, in monthly or yearly scales was more harsh and different than the changes of precipitation and temperature.

Temperature with a more regular seasonal cycle could significantly affect the water-level of Lake by evaporation and raising the water-use rate on the basin and on the other hand, Runoff produced by precipitation on the basin extremely is reserved beyond the dams, and disorderly feeds the lake, contrarily (Zoljoodi and Didevarasl, 2014).

CONCLUSION

In this research, the results of grain-size analyses and clay mineralogy in eight cores report and comparison of the relation of variations in them to other climate proxy records in order to construct a record of climatic variations in the area. Variations in grain size of the sediments between 3-4 m in cores reflect variations in the depth of Urmia Lake. Fine sediments (average grain size 5 μm) were deposited at the core site during the periods of high lake level, when the shores and wave base of Urmia Lake were far from the site, coarse sediments (average grain size 70μm) were deposited during lower lake stands, when the shores of Urmia Lake may have approached the core site. Also, variations in grain size show only relative variations in lake level and not absolute lake depths. Alternations in clay mineralogy reflect cyclic climate changes in this lake. The assemblage dominated by smectite may create by chemical weathering processes on active tectonism during warm periods or authigenic phyllosilicate formation within a shallow, saline Urmia Lake, while those assemblages dominated by illite, K-feldspar, and plagioclase most likely indicates bed rock produced during cold and glacial periods. The comparison of geochemical with mineralogical data in the sediments of Urmia Lake allowed the recognition of one geochemical signal (SiO_2) possibly related to changes of vegetation and climate.

Finally, the unusual drying of Urmia Lake especially through the recent decade could imply existence of some anthropogenic factors such as: hyper exploitation of groundwater via deep wells, construction of dams on the rivers of the basin and extraordinarily reserving the runoff, construction of a causeway through Urmia Lake that disturbed the normal water cycles of the Lake, over-developing of agriculture and industries on the upstream areas, population growth followed by increase of water use on the basin, which could be considered the supplementary causes in recent water crisis of the Lake.

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