Changes in particle sizes and geochemistry of Siyah Keshim lagoon sediment of Gilan province to determine origin and tectonic position of sediment

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Abstract. Useful information was obtained about the environmental condition of this region such as energy, sediment location, origin, sediment carrying path, pond evolutionary process, and tectonic conditions and origins of sediments by studying physical and geochemical sediment changes processes in place and time, distribution of sediments and elements in lagoon bed, and also identification the effective factors on sediment distribution model. In this regard, 59 sediment samples were taken from Siyah Keshim lagoon and were analyzed chemically and aggregation by XRF and ICP-MS technic. Adaptation of data by Folk diagrams showed that this region is placed in a range of sand, muddy sand, sand with a little gravel, muddy sand with a little gravel, and silty sand. Weak to medium sorting and negative tilting shows sediment in a coastal area. Geochemical evidence shows that SiO2/Al2O3 ratio in these sediments is 2.6-3.7. In addition, Na 2 O value shows relatively low sediment investigation for sediments of this lagoon. Moreover, determination of the weathering effect in origin place by the chemical index of alteration (CIA) and chemical weathering index (CWI) shows intensive chemical alteration on sediments. Index of combined variety was averagely 1.54 in the studied sediments and show that sediments resulted from the first cycle sediment. Using tectonic separating diagrams based on the primary and secondary oxidants percentage show the sediment in the active continent margin (ACM), continent-island arc (CIA), and oceanic island arc (OIA) and shows that the studied sediments are related to subduction margin.

Key words: Siyah Keshim, lagoon, sorting, sediment, geochemistry
Introduction. Lagoons have many advantages for having hydrological characteristics. Lagoons not only supply a part of underground waters, but also provide an environment as the best ecosystem to supply many birds and aquatics foods (Nuri, 2009). In addition, lagoon prevents penetration of salty waters and floods prevalence by setting water flow and has a significant role in preventing erosion of coastal lines, stabilization of the mentioned cases, lagoons have a significant role in preventing dessert (Nuri, 2009). In addition to prevalence by setting water flow and has a significant goon prevents penetration of salty waters and floods birds and aquatics foods (Nuri, 2009). In addition, lagoon has the average depth of 1m and us mostly having hydrological characteristics. Lagoons not only shown by Φ is the changed form of Wentworth scale twice bigger than the next smaller grade. Phi scale is a logarithmic scale in which each grade is by Adon and Wentworth for the first time. Wentworth scale is a logarithmic scale in which each grade is bounderies must change to Φ values.

$$\Phi = - \log_2 d$$

where $d$ – particle diameter (mm)

Sediment was geochemically studied in the next step to fill and confirm the obtained information from granulation. Using the geochemical element to determine the old environment conditions is significantly important, and distribution of the main and secondary elements in sediment depends on mineralogical composition, temperature, fluid composition, oxidation, and reduction conditions (Adabi, 2004). Studies show that elements amounts and compositions are sensitive to environmental conditions, sai. Analysis of the main (Mg, Ca) and secondary (Sr, Mn, Na, Fe) elements of sediments open a way of understanding sedimentary environmental time by indicating their dispersion and distribution. The element geochemistry for the present elements in each sample is a good guidance for climate changes because some elements in the soil are sensitive to environmental conditions in a way that some elements report the certain conditions; for example, high amounts of Fe, Mn shows reduction environment, (Nekukhu, 2003). The elements geochemistry can show temperature and raining conditions well. Elements of Mn, Sr, Mn replace with elements such as Ca under the specific climate conditions in crystal network. Changes in Mg/Ca, Sr/Ca, Mg/Ca ratios along cores show changes in lake conditions chronically (Taghavi et al., 2013).

Methods and materials. Geographical conditions and geometry of the studied region. Siyah Keshim lagoon of Gilan province (Fig. 1) is limited to Anzali city from north to Sowme’eh Sara city from south, to Rasht city from east, and to Kapurchal and Anzali waterfront from the west.

Based on the geographical map studies of Bandar-e Anzali in 1: 100000 from publications of Geological Survey & Mineral Explorations of Iran (GSI) Tehran (Khabaznia et al., 2005) of Anzali lagoon region contains rocks of Paleozoic and Caucasian periods and has specific characteristics, but Siyah Keshim lagoon is very new geologically and its creation can be known for about 7 centuries ago.

The altitudes of the catchment area of this wetland are related to Cretaceous to Jurassic courses and also the third period in the context of limestone, conglomerate, and sandstone. Based on the structural geology of the studied region, a resulted face of the earth performance shear-stress structure is made by the rock of diatomaceous deposits from the Paleozoic era and other sedimentary deposits and Azar Caves
related to the Mesozoic era. Strain-slip faults are one of the most vivid structural element seen in this region. Anticlines and syntaxes in the north-east axis of the Southwest were seen in the southwest of the studied region that changes in center and northwest to west-east and northwest-southeast line. Most of these buildings were unidirectional and classified in conical faults, Aghanabati, (2006).

**Sampling methods and data analysis.** Sampling was conducted in August 2016. Therefore, two stations were selected in various lagoons parts (Fig. 3). And the sedimentary cores were conducted in the Egher machine in the sediment of the lagoon. Thus, the first core section had 675cm depth with 34 samples and the second core section had 486cm depth with 25 samples (Fig. 2).

Samples were transferred to the laboratory to prepare for granulation, studying sedimentary characteristics, mineralogy nature, determination of the major and trace elements. After hydrometric tests, the related calculations to correct data were conducted by calculating laboratory temperature and silt and clay weight percentages were obtained (Feyznia, 2008).

To calculate these parameters, first, the accumulative frequency diagrams of each sample were drawn after performing granulometric tests by Gradistat and Excel software. Then, total skewness index (SKI) and total standard deviation index (SDI), mean (Mz), kurtosis (KU) was calculated as following using relations Folk (1980) and Ward (1957) using values of Ø84, Ø75, Ø50, Ø25, Ø16, Ø5. Since these diameters are based on mm and the obtained formula for statistical parameters are based on ɸ, the related percentage diameters changed from mm to ɸ and then were inserted in formulas (Table 1).

These samples were sent to calculate the major elements (Mg, Ca) and secondary (Sr, Mn, Na, Fe) to Geochemical Laboratory of Geological Survey of...
Iran. The range of the major element (Mg, Ca) and secondary ones (Sr, Mn, Na, Fe) was calculated mg/g by OES, XRF ICP-MS, ICP- methods. Plots of major oxides and sub-elements on different diagrams (Basu et al., 1975; Bhatia., 1983; Dickinson et al., 1983; Roser and Korsch., 1986; Bhatia and Crook., 1986; Suttner and Duta., 1986) helped to obtain the related results to the origin, tectonic position, and climatic conditions of these sediments.

**Discussion and conclusion.** Folk diagrams (1954) were used to determine the name of sediments of this region based on their constitutional particles that showed the sediments of this region were placed around sand, mud sands, gravel sand with slightly muddy sandstone, and silty sand (Fig. 3).

Based on the obtained information from the statistical calculation, and the related tables and diagrams using Excel and Gradistat indicated that sediment sorting of this area is 0.7-1.9, sediment kurtosis is 0.1-0.3, and kurtosis is in 0.6-0.9 (Folk, 1980).

The sediments of this area are widespread based on kurtosis, negative skewness (toward big particles), and medium to bad sorting (Feyznia, 2008). The previous studies on this lagoon confirmed this fact that the sediments of this area are medium to tiny particles (Sabzivala et al., 2011).

Determination of tectonic position of sediments based on geochemistry of the major elements. The tectonic position has two characteristics of studying the origin places including continental blocks, volcanic arc system, and collision belts and examining the boundary type among sheets including rift or inactive continental margins, active or orogeny continental margins, or striped fault margins (Dickinson and Suczek ,1979; Dickinson et al, 1983; Garzanti et al, 2003; Garzanti et al, 2007).

The similar results were obtained in the determination of sediments tectonic position by drawing Rusar and Kurosh tectonic separating diagrams (Roser and Korsch., 1986) and 2d and Bhatia functional separating diagrams (Bhatia, 1983) (Fig. 4&5).

These diagrams based on the logarithmic ratio of $K_2O/Na_2O$ versus $SiO_2$ percent (Fig. 4) and $TiO_2$ and $Al_2O_3/ SiO_2$ values versus $Fe_2O_3 + MgO$ were drawn. Their formation in Arctic islands is confirmed for sedimentary samples. As it is observed in these diagrams, it can be claimed that $TiO_2$ and total values of $Al_2O_3 + Fe_2O_3 + MgO$ in arctic islands reduced to inactive margins (Fig. 6).

**Table 1.** Sedimentary parameters and the related relations were tested for geochemical studies

<table>
<thead>
<tr>
<th>index</th>
<th>mean diameter</th>
<th>sorting</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>formula</td>
<td>$M = \frac{\phi_{16} + \phi_{26} + \phi_{44}}{3}$</td>
<td>$\alpha = \frac{\phi_{16} - \phi_{16}}{4} + \frac{\phi_{26} - \phi_{26}}{6.6}$</td>
<td>$Sk = \frac{\phi_{16} - \phi_{26} - 2\phi_{44} + \phi_{44}}{2(\phi_{16} - \phi_{16})}$</td>
<td>$K = \frac{\phi_{44} - \phi_{44}}{2.44(\phi_{44} - \phi_{44})}$</td>
</tr>
</tbody>
</table>

**Fig. 3** Sediment based on its constitutional particles (folk, 1954)
Therefore, the secondary elements are significantly mentioned in the determination of tectonic origin and place (Bhatia and Crook, 1986; McLennan, 2001; Eriksson et al., 1994) which cause many studies on the present secondary elements in the sedimentary rocks to determine the tectonic position and their origin (Bahlburg, 1998; Burnett and Quirk, 2001; McLennan et al., 1993; Zimmermann and Bahlbarg., 2003).

Therefore, 3d diagrams for the secondary elements were drawn to determine the tectonic position and the obtained results of them in confirmation the resulted diagrams for the major elements showed that the tectonic position of Quaternary sediments of Siyah Keshim lagoon is an arctic continental island (Fig. 7). The related area to the firmed sediments in active and inactive continental margins was overlapped in the La-Th-Sc 3d drawing, while these two environments are completely separated in Th-Se-Zr/10 3d drawing (Fig. 7) (Adabi, 2004).
Based on drawing the paired Ti/Zr elements versus La/Sc that is shown in Fig. 8, sediments tectonic position in Suyah Keshim area of Gilan province shows arctic continental margin (ACM) and arctic continental island (CIA). Moreover, the mentioned rocks tectonic environments by diagram (Schandl & Gorton, 2002) are shown in Fig. 9 and 10 based on the secondary elements. All the studied samples are around ACM based on this diagram.

The determined areas include A: oceanic arctic islands, B: arctic continental island, C: active continental margin, D: inactive margins

Based on the obtained results from drawing the high geochemical diagrams based on the oxidants percentage of the major and secondary elements that show the tectonic position of this region sediments of continental and oceanic arctic island, continental active margin, and inactive continental margin. It can be concluded based on citing studies (Asiabanha & Foden, 2012) that the related studied sediments are related to subduction margin. **Interpretation of origin area weathering.** The mobility of the major elements during weathering, transportation, and processes after sediment can be used to determine the chemical maturity of sediments, (McLennan et al., 1993).

The very low concentration of Na₂O in sediments shows high sedimentary maturity (Fig. 11). Moreover, SiO₂ /Al₂O₃ ratio is the usable index to determine sediment maturity (Potter, 1978). SiO₂ /Al₂O₃ ratio higher than 5-6 in sedimentary rocks show their high sedimentary maturity (Roser et al., 1996). SiO₂ /Al₂O₃.

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**Fig. 6** Tectonic separating diagrams of sediments based on TiO₂ percent versus Fe₂O₃+MgO logarithmic ratio.

**Fig. 7** Tectonic separating diagram of sediments based on the secondary elements frequency (Bhatia & Crook, 1986)
ratio in samples is varied in 2.6-3.7. These numbers show relatively low maturity in the studied region sediments.

ICV combined variety can be used to determine the first cycle sediment or the obtained sediments from the second cycle (Cox et al., 1995) that is obtained from the following formula:

$$ICV = \frac{(Fe_2O_3 + K_2O + Na_2O + CaO + MgO + MnO + TiO_2)}{Al_2O_3}$$

Samples with higher ICV than 1 are probably for the first cycle sediments, and which with smaller...
ICV than 1 may be from the second cycle sediments or the severely weathered sediments from the first cycle sediments (Cullers & Podkolyvroy, 2002). The calculated values from ICV in quaternary sediments of this region are 0.9-5.35 with an average of 1.54. Thus, it can be stated that the most sediments of the studied lagoon are related to the first cycle sediments.

Weathering history of the clastic rocks is mostly estimated by calculating the mobile oxides ratio of K$_2$O, Na$_2$O, and CaO than non-mobile oxide Al$_2$O$_3$ (Nesbitt & Young, 1982). The most used index in this formula is alternation chemical index (Nesbitt & Young, 1982). This index is obtained by the following relation and oxides in it was stated in mole.

$$\text{CIA}=\left[\frac{\text{Al}_2\text{O}_3}{\text{Al}_2\text{O}_3+\text{CaO}+\text{Na}_2\text{O}+\text{K}_2\text{O}}\right] \times 100$$

CaO is the present calcium in rock silicate components, and this value must be modified in samples that high CaO is related to diagenesis cement. CIA range may be low, medium, and high varied from 50 to 100. Increasing CIA from down to up is related to alternation chemical degree. Low CIA shows no alternation or very low alternation and is a reflection of cold and dry climate conditions, while medium and high CIA with mobile cations transmission such as (K$^+$, Na$^+$, Ca$^{2+}$) and remaining the constituters (Ti$^{4+}$ and Al$^{3+}$) is related to less mobility (Nesbitt & Young, 1982). Samples were considered with higher CaO than 5% to determine CIA precisely and CaO removal from carbonate cement (Batumike et al., 2006, Nesbitt, 2003, Garcia et al., 2004).

The calculated CIA for the studied samples was 0.78-63 and is 72 averagely in samples which show severe chemical alternation in sediments. Chemical index of weathering (CIW) is extensively used to determined rock weathering degree and is obtained by the following formul (Harnois, 1988).

$$\text{CIW}=\left[\frac{\text{Al}_2\text{O}_3}{\text{Al}_2\text{O}_3+\text{CaO}+\text{Na}_2\text{O}}\right] \times 100$$

The mean of this index for the sediments of Siyah Keshim area is 80.73. Using CIA and CIW indexes in samples with high CaO changes doesn’t show interesting results (Cullers, 2000). In this regard (Cullers, 2000), another weathering index can be offered for samples with high CaO. This index is stated as follows:

$$\text{CWI}’=\left[\frac{(\text{Al}_2\text{O}_3+\text{Na}_2\text{O})}{\text{Al}_2\text{O}_3}\right] \times 100$$

In which, oxides are considered in molecular ratio. The mean of this index in the studied samples is 95.47 that show the severe weathering of these samples.

This result was obtained finally based on the calculated indexes in which the sediments of Siyah Keshim area is for the first sedimentary cycle with relatively low sedimentary maturity, and has severe chemical weathering on then and alternate them. **Conclusions.** Sediments are considered as data in environmental studies and its conditions are the most important evidence particularly in the previous environmental conditions. Many other pieces of

![Fig. 11 Drawing Na$_2$O versus K$_2$O](image)

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evidence such as paleontology, botanical, and biological effects generally and even hum civilization effects are evaluated by sedimentary data.

In other words, the real history of the earth and its conditions are hidden in the body of the earth sediments. Sediments can be examined through various views such as particles size and diameter, ration of the formed particles of a sediment, sorting, particles kurtosis, skewness, rounding, and some other statistical parameters such as mean, mode, standard deviation, etc. each of these cases shows genre, origin, and environmental conditions that formed sediments.

Studying quaternary sediments for two studied sections of Siyah Keshim lagoon in Gilan province showed that this area has a sandy texture, mud sands, sand with slightly gravel, sandy mud with slightly gravel, and silty sand through sedimentology view. Sediments sorting are medium to weak, negative skewness, and many big particles and plate kurtic through kurtosis view which show sediment in the coastal area. Regarding the obtained results from drawing the geochemical diagrams based on the major and secondary elements oxides, it can be concluded that the studied sediments are related to a subduction margin. Moreover, geochemical evidence shows that SiO₂/Al₂O₃ ratio in these sediments is 2.6-3.7 and also Na₂O has the relatively low sedimentary maturity for the sediments of this lagoon. The mean coefficient weathering indexes such as ICV, CIW, CWI, and CIA also show that the mentioned sediments are mainly related to the first sediment cycle and tolerate high chemical weathering.

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