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Application of sediment cores in reconstruction of long-term temperature and metal contents at the northern region of the Persian Gulf

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Abstract

Long marine sedimentary cores can be effective in paleo-climate reconstruction. The present research aims at analyzing the temporal variation of temperature as an important climate parameter and also variations in metal concentrations (As, Ba, Cd, Li, Mo, Mg, Mn, Na, Pb, Sr, Zn, Fe, Ca, Al) of two long sedimentary cores at the Persian Gulf back to the Holocene. The obtained results revealed that the average elemental concentrations, apart from Ni, Sr, Ca and Na, are less than the shale value in both sedimentary cores. Moreover, the amount of $\delta^{13}c$ varies from -1.31 versus 1.02 in Bushehr, to -1.69 versus 1.56 in Bandar Abbas sedimentary cores, respectively. In addition, $\delta^{18}O$ change from -3.63 Vs -2.02 in Bushehr to -3.79 Vs -1.36 in Bandar Abbas sedimentary cores, respectively. Abrupt change in $\delta^{13}c$ and $\delta^{18}O$ can be seen in both sedimentary cores at two different periods (3000 to 5000 and 8000 to 9000 years ago). The maximum increase in temperature in sedimentary cores was at 0.4°C per 100 years in Bushehr and 0.01°C per 100 years in Bandar Abbas. The minimum temperature reached to -0.8°C per 100 years in Bushehr to -0.02°C per 100 years in Bandar Abbas sedimentary cores. Compared to the previously obtained temperatures in this research, there has been temperature changes in the last 40 years in the Persian Gulf, which indicates that the recent rate change in sea water temperature has been unprecedented.

Keywords: Persian Gulf; Sediment core; Paleo temperature; long-term metals concentration

1. Introduction

Temperature is known as an important indicator in the state of the climate system. Ocean temperatures are also vital, as they are an important single component of the global climate system and hydrosphere evolution (Kushnir, 1994; Bernard *et al.*, 2017; Cui *et al.*, 2018; Henkes *et al.*; 2018). An Increase in oceanic water surface temperatures can increase humidity and decrease barometric pressure. In addition, this important climatic index can be effective on the biological indices or the mineral concentrations in marine environments (Walker *et al.*, 1981; Loubere and Fariduddin, 1999; Schouten *et al.*, 2002; Behrenfeld *et al.*, 2006;). Although some evidence of ocean temperature reductions have been reported in some parts of the world, recent studies clearly demonstrate a trend increase in in ocean temperatures located in arid or semi-arid climate regions (Nasrallah and Balling, 1995; Meehl *et al.*, 2011; Desbruyères *et al.*, 2017; Comiso *et al.*, 2017; Abbasi *et al.*, 2017; Nasrallah and Balling, 1995). Long-term temperature data is needed in order to investigate if the spatiotermal incremental or decremental trends are part of a long-term climatic trend, or if there will be a continuation or change in the trend's intensity or direction in the future (Tabari and Talaee, 2011). Having data on long-term temperature can be used to decrease uncertainty in climate model projections and helps in the understanding of past living organisms, such as shrimp or coral reef, in the ocean (Hansen *et al.*,

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1984; Coles and Fadlallah, 1991; Kastner, 1999; Pourang and Amini, 2001; Pourang and Dennis, 2005; Cane *et al.*, 2006; Dalton *et al.*, 2018,). Many researchers have studied paleo temperatures using marine terrestrial climate archive (sedimentary cores, fossils, or insects), but paleo temperatures in the oceans of the Middle East, such as the Persian Gulf and Oman Sea, have not been properly taken into consideration (Jensen and Andersen, 1992; Waelbroeck *et al.*, 1998; Savin, 1977; Mix *et al.*, 1999; Cui *et al.*, 2018). Persian Gulf temperatures play a crucial role in the precipitation of the Sudanese low-pressure climatological system in the Persian Gulf state. (Walters Sr and Sjoberg, 1990; Bitan and Sa'Aroni, 1992; Barth and Steinkohl, 2004; Mofidi and Zarrin, 2005; Mofidi and Zarrin, 2006; Raziei *et al.*, 2013; Akbary, 2015). The climate of the Persian Gulf is dominated by localized North to Northwest winds (known as shamal), which is a property of temperature in the Persian Gulf (Kehl, 2009; Thoppil and Hogan, 2010). In previous studies on the Persian Gulf, a rise in temperature by 0.8°C has been shown in the past 40 years (Coles and Fadlallah, 1991;Nasrallah and Balling, 1995). However, there are not great amounts of research to indicate temperature changes over a long period of time. Most studies on the sediments of the Persian Gulf have been carried out on surficial sediment to determine the concentrations of heavy metal (Karbassi *et al.*, 2005b; Dobaradaran *et al.*, 2010; Afkhami *et al.*, 2013; Naser, 2013,). Also, none of them have been subjected to oxygen or carbon isotope analysis (Karbassi *et al.*, 2005a; Madiseh *et al.*, 2009; Monikh *et al.*, 2013; Abdollahi *et al.*, 2013; Pejman *et al.*, 2015; Bastami *et al.*, 2015; Raissy, 2016,). This paper will examine paleo temperature and metal bulk concentrations at the northern region of the Persian Gulf. For this purpose, two sedimentary cores, 14 meters on the coast of Bushehr and 10 meters on the coast of Bandar Abbas, were used on the Iranian territory of the Persian Gulf. The present investigation is carried based on isotope and geochemistry approaches and aims to shine light on the following questions:

1) What is the temporal character of temperature at the northern region of the Persian Gulf back to Holocene?

2) What is the relationship between temperature changes and the metal contents of sedimentary cores?

2. Materials and Methods

2.1. Study Area

The Persian Gulf is located in a dry and semi-arid climate and is characterized by high salinities (37 to 39-psu) and evaporation rate ($1.4\, myr^{-1}$) (Privett, 1959; Naser, 2013; Al Senafi and Anis, 2015). Persian Gulf is deeper on its northern part and its maximum depth (approximately 40 meters) can be found at the Hormuz Strait, where Persian Gulf connects to the Oman sea (Kämpf and Sadrinasab, 2006). Persian Gulf has an environmental and ecological significance due to its coral reefs , mangrove forests, and wide range of fish (Coles and Tarr, 1990; Vaezi *et al.*, 2015,). In this research, two sedimentary cores from Bushehr (Lat $36^{\circ}\ 37^{\prime}$, Long $28^{\circ}\ 93^{\prime}$) and Bandar Abbas (Lat $56^{\circ}\ 18^{\prime}$, Long $27^{\circ}\ 19^{\prime}$) at the marginal shore of the north region of the Persian Gulf is studied. The average depth of the sea on the coasts of Bandar Abbas is approximately 30 meters and is approximately 20 meters on the coast of Bushehr (Kämpf and Sadrinasab, 2006). In addition, annual rainfall in Bandar Abbas and Bushehr synoptic stations are 174 and 27mm per year. The precipitation change in this region ranges from 30 to $110 mm\, yr^{-1}$ (Almazroui *et al.*, 2012). Temperature indices (average, minimum and maximum) a decrease from east to west. The average temperature of the Bandar Abbas synoptic station is 27.2°C (maximum= 42.2°C in August and minimum = 8.2°C in December) and Bushehr station is 24.7°C (maximum= 42.1°C in August and minimum= 6.6°C in December).

2.2. Sampling and Experimental Method

A research barge equipped with a rotary drilling machine was used for field operations and sampling. In order to maintain and ensure the texture and structure of the sediments, the hydraulic pressure method and core bar equipped with inside polythene cover have been used. Determinations of bulk elemental concentrations were carried out using the ICP-OES (Perkin Elmer elan 9000) device at the Iranian Geological Survey and Mineral Exploration (for 32 sub samples from Bushehr and 37sub sample from Bandar Abbas cores). Grain size test, up to 63 microns were performed by a sieve shaker and less than 63 microns were carried out by a laser grain size test at the Iranian Geological Survey and Mineral Exploration. C^{14} AMS experiment was done exclusively at Poznań Radiocarbon Laboratory (for 9 sub samples from Bushehr and 13 sub samples from Bandar Abbas sedimentary cores (Figure 1)). In addition, oxygen and carbon isotopes are done at Hatch Stable Isotope Laboratory, Ottawa (24 sub samples from Bushehr and 21 sub samples from Bandar Abbas cores) with an analytical precision of ±0.1 per mil with Delta XP and a Gas Bench II instrument. The extraction of temperature from oxygen isotopes are carried out by the Epstein relationship (Epstein *et al*., 1953).

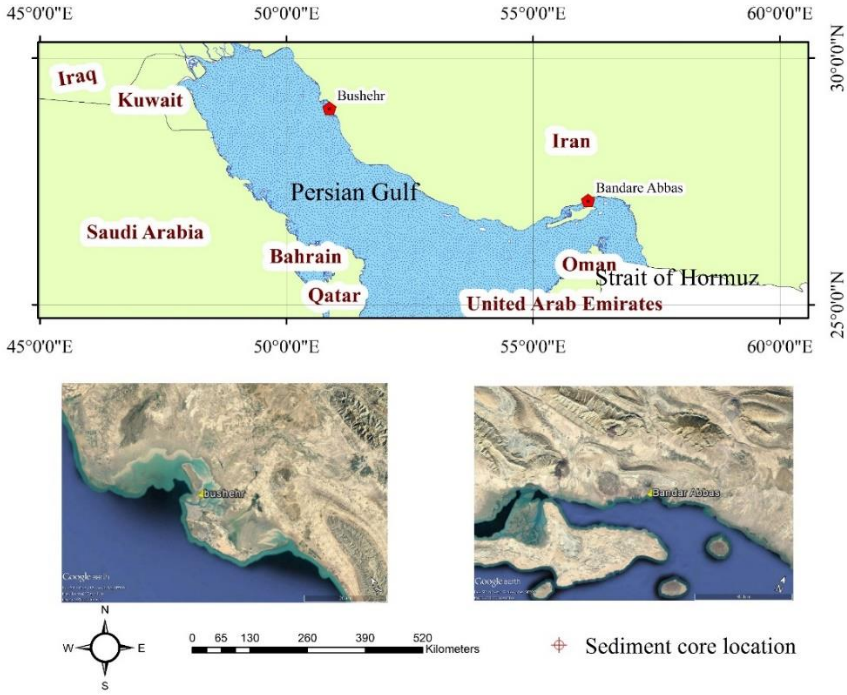

Fig. 1. Map of study area

3. Results and Discussion

Grain size analysis showed that both sedimentary cores were mostly constituted of a fine material (Figure 2). On average, 54.6% of the Bushehr sediment core and 42.4% of the Bandar Abbas sediment core were silt (0.05-0.002mm). In addition, 30.5% of the Bandar Abbas sediment core and 34.4% of the Bushehr sediment core consisted of clay. Moreover, the maximum portion of sand and gravel content were seen at the upper part of the cores, while the maximum portion of the clay content (<0.002mm) was seen at the bottom of the core.

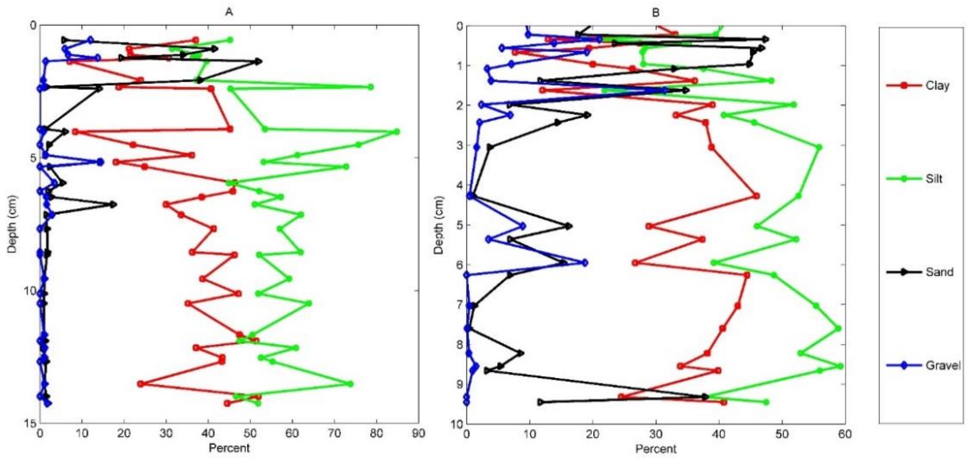

Fig. 2. Sediment grain size A) Bushehr sediment core B) Bandar Abbas sediment core

Based on the carbon-14 AMS results, the age of both sedimentary cores goes back to the Holocene (Figure 3.A). The average sedimentation rate in Bushehr and Bandar Abbas sedimentary cores change as 1.04 and 0.66mm per year with maximum (1.64mm/year in 7105 years ago, 1.24mm/year in 6885 years ago) and minimum (0.2mm/year in 2840, 0.03mm/year in 3700 years ago), respectively (Figure 3.B). In both sedimentary cores, the maximum dynamic sedimentation rate occurred at approximately 4000-5000 years ago, with a value of 2mm per year in Bandar Abbas sedimentary core (Figure 3.C) and 3.05mm per year in Bushehr sedimentary cores (Figure 3.D). In both sedimentary cores, the displacements of sediments were observed in the duration of 6,500 to 8,000 years ago. These displacements were more intense in the Bandar Abbas sediment core. Earthquakes or severe storms in the area might have caused such displacements. During this period, other researchers have reported earthquake and severe storm, which is consistent with the results of this research (Kelsey *et al*., 2002; Soter, 1999; Atwater, 1987).

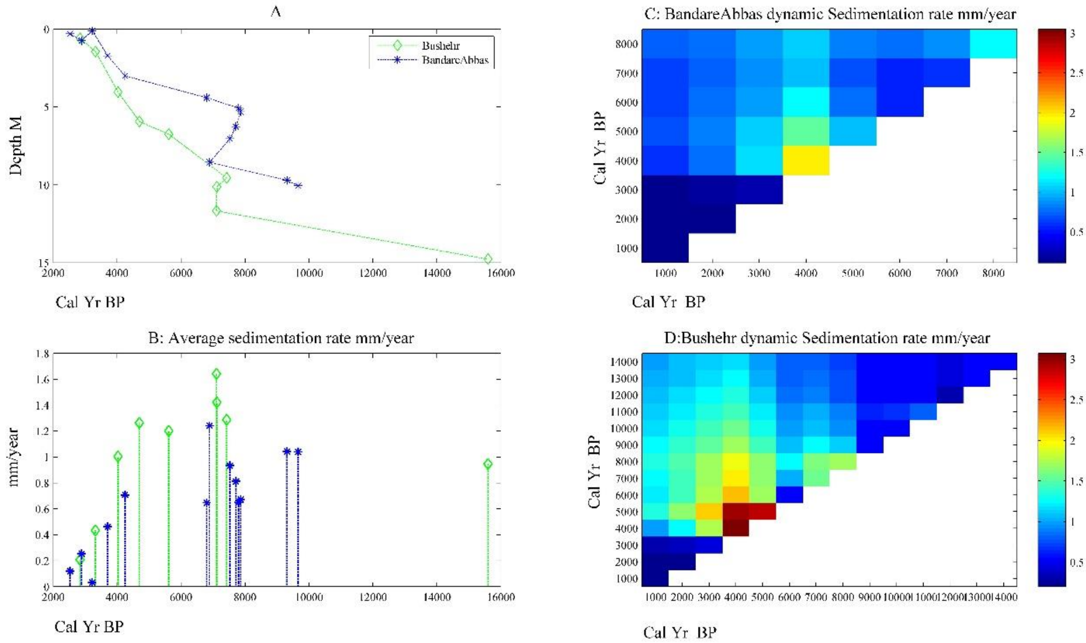

Fig. 3. A) age of sediment (Karbassi *et al*., 2018) and B) average sedimentation rate in Bushehr and Bandar Abbas sedimentary cores C and D) dynamic sedimentation rate , X and Y axis represent the beginning and the end of the sedimentation trend analysis. Legend represents the linear regression slope (mm/year)

In the Bushehr sedimentary cores, the maximum Ca-Sr and the minimum Al, Zn, Na, Mn were found 3688 years ago, while the maximum concentration of Al, Fe, Zn, Sr, Ni, Na, Mn, Mg-Mo, Li, Cd and Ba in Bandar Abbas sedimentary core were found 2579 years ago (Figure 4) . Temporal characteristics of Fe, Al, and Mn were similar to one another, which could be due to the shared origin of the elements. The study investigates a time that lacks human habitations, therefore, the change in metal contents are mostly natural and are due to the changes in climate indicators, the entry of sediments from upstream basins, or caused by biological activities in the Persian Gulf (Gawad *et al*., 2008, Kendall and Patrick, 1969, Sugden, 1963).

Average concentrations of As, Ba, Mo, Mg, Na and Ca in the Bushehr sedimentary core is higher than the Bandar Abbas sedimentary core. In addition, all elemental concentrations, except for Ni, Sr, Ca and Na, were less than shale value. This could be due to the intense biologic activity and high evaporation rate of the Persian Gulf. Apart for As and Mg, the maximum concentration of the other investigated elements in the Bandar Abbas sedimentary core were higher than that of the Bushehr core. In addition, a minimum-recorded concentration of all the elements in the Bandar Abbas core is less than the Bushehr core. The standard deviation of all investigated elements in the Bandar Abbas sedimentary core is higher than the Bushehr sedimentary core, except for Na. This is due to the vicinity of the Bandar Abbas sedimentary cores to the Strait of Hormuz, its direct route to the Oman Sea, and its hydrodynamic direction of water into the Persian Gulf.

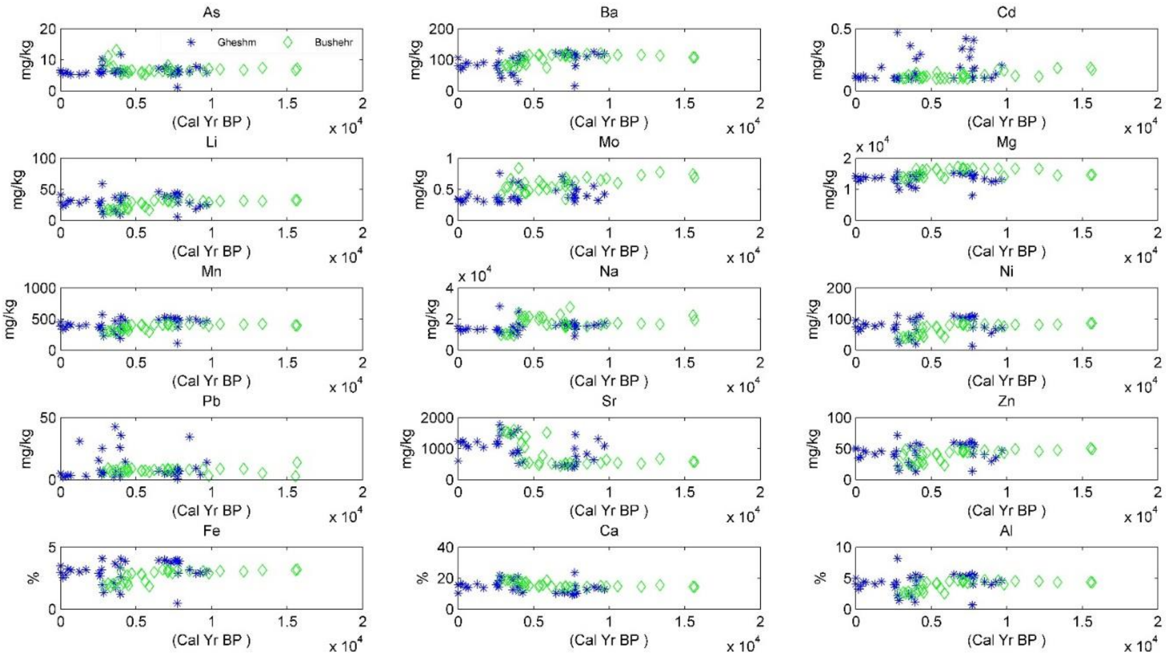

Fig. 4. Temporal profile of elemental contents in Bushehr and Bandar Abbas sediment core

Table 1. Statistical parameter of observed bulk metal contents (BA=Bandar Abbas sedimentary core, BU= Bushehr sedimentary core)

Element	Average		Maximum		Minimum		Standard deviation(±)		Shale value
	BA	BU	BA	BU	BA	BU	BA	BU	(Turekian and Wedepohl, 1961)
As (mg/kg)	6.4	6.9	11.8	13.1	1.1	5.3	2.0	1.80	13.0
Ba (mg/kg)	92.5	104.3	129.5	120.5	15.0	74.0	31.8	14.60	580.0
Cd (mg/kg)	0.2	0.1	0.5	0.2	0.1	0.1	0.1	0.01	0.3
Li (mg/kg)	30.6	26.8	58.6	33.5	5.7	15.3	13.0	6.30	66.0
Mo (mg/kg)	0.4	0.6	0.8	0.8	0.3	0.3	0.1	0.10	2.6
Mg (mg/kg)	13397.4	15501.5	15503.9	17227.9	7928.6	13102.9	1936.3	1283.50	15000.0
Mn (mg/kg)	410.1	375.5	566.5	429.1	110.6	285.0	116.0	45.50	850.0
Na (mg/kg)	15066.4	17931.7	27993.3	27541.4	8905.5	9357.7	4246.5	4258.60	9600.0
Ni (mg/kg)	77	69.0	110.0	88.0	13.0	37.0	30.0	17.00	68.0
Pb (mg/kg)	11.1	7.5	42.5	13.7	0.5	2.6	11.9	2.40	20.0
Sr (mg/kg)	964.5	789.6	1773.2	1597.0	407.6	440.3	429.0	392.60	300.0
Zn (mg/kg)	43.7	40.0	71.3	50.5	13.1	22.4	16.0	9.50	95.0
Fe (%)	3.0	2.7	4.1	3.2	0.5	1.8	1.0	0.50	4.7
Ca (%)	14.4	15.5	23.4	19.2	9.3	13.8	4.1	1.70	2.2
Al (%)	4.3	3.9	8.2	4.7	0.6	2.5	1.7	0.80	8.0

The amount of $\delta^{13}c$ varies from (-1.31 to 1.02) in Bushehr to (-1.69 to 1.56) in Bandar Abbas sedimentary cores, respectively) (Figure 5 A and Figure 5B).

In addition, $\delta^{18}O$ change from (-3.63 to -2.02) in Bushehr to (-3.79 to -1.36) in Bandar Abbas sedimentary cores, respectively. Abrupt change in $\delta^{13}c$ and $\delta^{18}O$ can be seen in both sedimentary cores at two different periods (3000 - 5000 and 8000 - 9000 years ago) (Figure 5 C and Figure 5D).

The temperature of the Bandar Abbas sedimentary core is higher than the Bushehr sedimentary core except between 2500 to 4000 years ago (Figure 6). Additionally, the average, maximum, and minimum temperatures were (33.8°C, 37.3°C, and 28.7°C) in Bushehr and (33.2°C, 38.3°C, 25.2°C) in the Bandar Abbas sedimentary core. A temperature variation in the Bandar Abbas sedimentary core was greater than Bushehr. Moreover, in both sedimentary cores, a decrease in temperature was found as compared to the past.

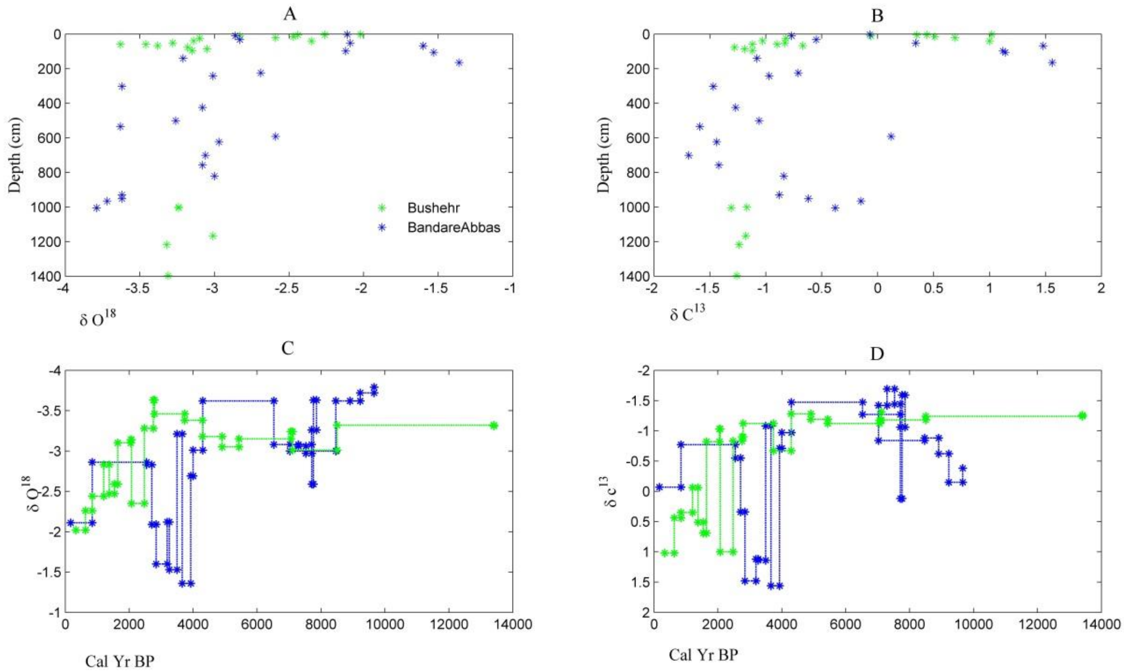

Fig. 5. Temporal and profile characteristics of $\delta^{13}c$ and $\delta^{18}O$, A and B shows $\delta^{13}c$ and $\delta^{18}O$ distribution across Bushehr and Bandar Abbas sedimentary cores, C and D shows temporal characteristics of $\delta^{13}c$ and $\delta^{18}O$ across Bushehr and Bandar Abbas sedimentary cores

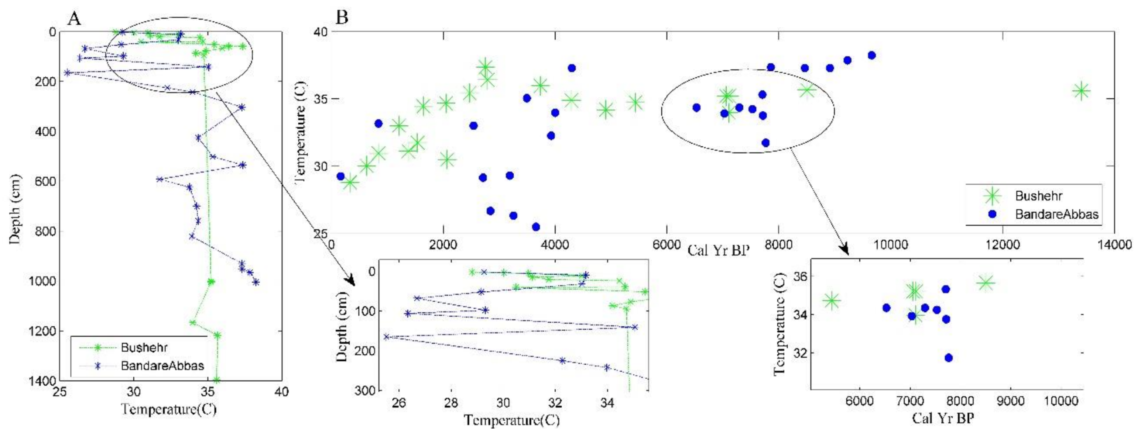

Fig. 6. Temporal and temperature characteristics in both sedimentary cores A) temperature variation across the sedimentary core B) temperature distribution across past time

Temperature variations in the Bushehr sedimentary core are mild and moderate but are high and severe in the Bandar Abbas core. The increase and decrease in temperatures of both sedimentary cores can be seen at different time intervals. The maximum increasing rate in Bushehr was at 0.4°C per 100 years, and 0.01°C per 100 years in the Bandar Abbas sedimentary core. The minimum rate was at -0.8°C per 100 years in Bushehr, and -0.02°C per 100 years in the Bandar Abbas core. Comparing these values to the 0.6°C per 100 years (ocean temperatures change over a period of 100 years), fewer changes in historical temperature than overall recent ocean temperature changes are indicated (Bale *et al*., 2002, Walther *et al*., 2002). Both sedimentary cores have experienced a long-term trend of temperature rise for a period of many thousand years. (3500 to 7000 years ago in Bushehr sedimentary core and 4500 to 6000 years ago in Bandare Abbas sedimentary core). Also, both cores experienced a constant increasing trend of temperature in the past.

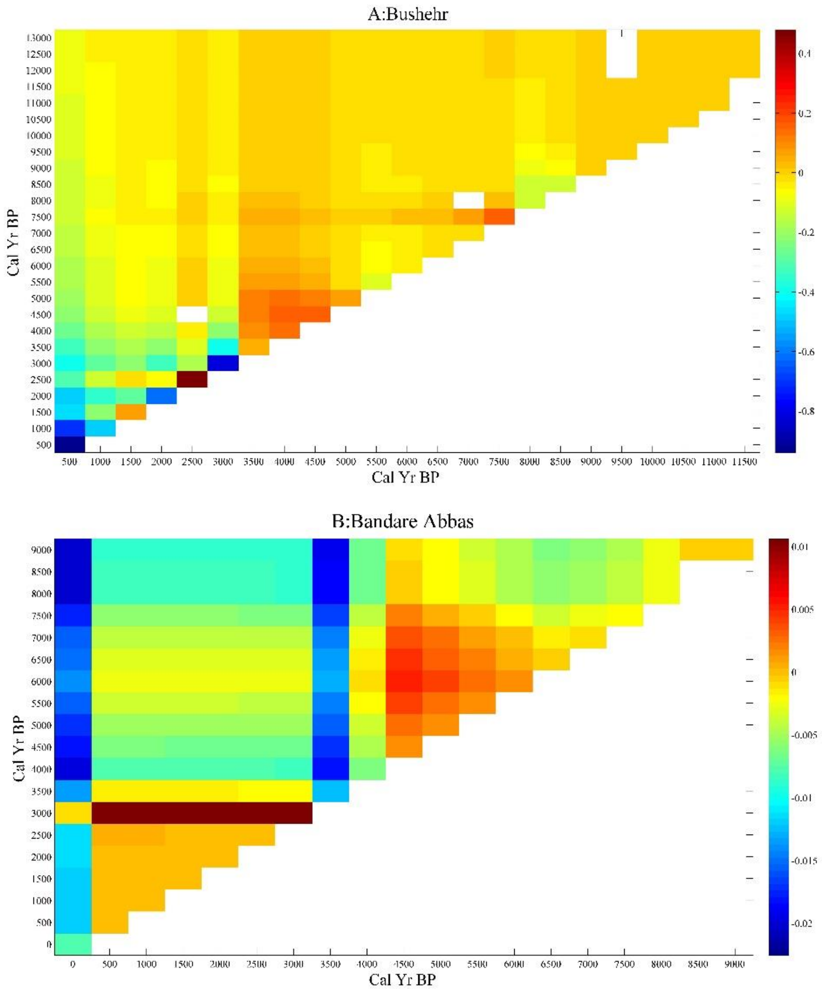

Fig. 7. Trend analysis of temperature. X and Y-axis represent the beginning and the end of the trend analysis. Legend represents the linear regression slope (° C/100Year). Temperature trend in A) Bushehr sediment core B) Bandar Abbas sediment core

An investigation of Pearson correlation coefficient with the concentration of elements over time, shows temperature has a positive correlation with the concentration of all elements except Ca, Sr and As. Ba shows the highest positive correlation with temperature in both sedimentary cores. Sr shows the highest negative correlation. While Mg readily substitutes for Ca in the calcite structures, an increase in temperature can reduce calcium and increase magnesium concentrations (Finch and Allison, 2007; Folk and Land; 1975).

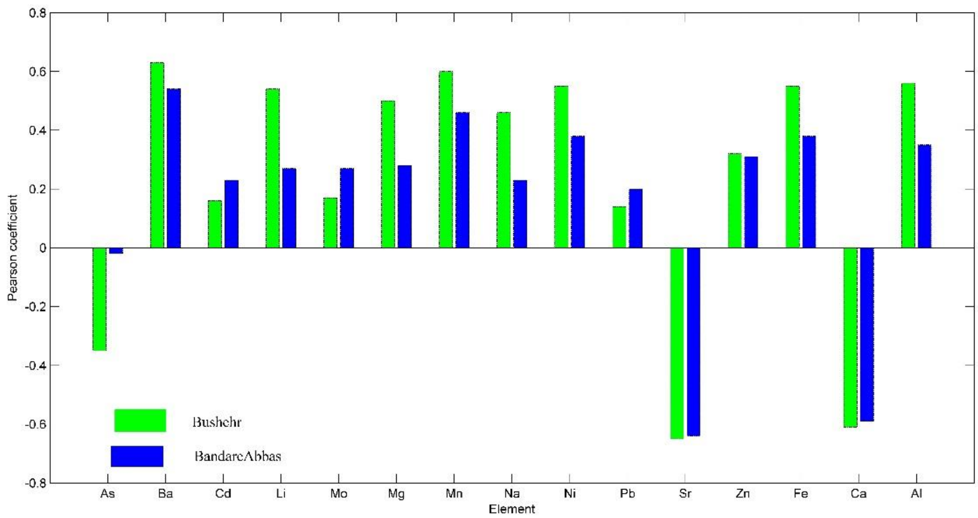

Fig. 8. Pearson coefficient, elemental content and temperature in Bushehr and Bandar Abbas Sedimentary cores

4. Conclusion

Two marginal long sedimentary cores from the northern region of the Persian Gulf at the coasts of Bushehr and Bandar Abbas along the lands of the Iranian territory were studied by their geochemistry and isotopic characteristics. The grain size test result showed that both sedimentary cores constituted of mostly fine materials. Carbon-14 AMS results showed that, the age of both sedimentary cores date back to the Holocene. The average sedimentation rate in Bushehr and Bandar Abbas sedimentary cores varied as 1.04 and 0.66mm per year, respectively. The maximum (1.64mm/year in 7105 years ago, 1.24mm/year in 6885 years ago) and minimum (0.2mm/year in 2840, 0.03mm/year in 3700 years ago). ICP– OES results clearly showed, except for As and Mg, that the maximum concentration for other investigated metal elements in the Bandar Abbas sedimentary core were higher than that of the Bushehr sedimentary core. Also, the minimum recorded concentration in all elements in the Bandar Abbas core was less than Bushehr core. The standard deviation of all the investigated elements in Bandar Abbas sedimentary core was higher than the Bushehr sedimentary core, except for Na. This is attributed to the vicinity of the Bandar Abbas sedimentary core to the Strait of Hormuz, its direct route with the Oman Sea, and its hydrodynamic direction of water into the Persian Gulf. In addition, the oxygen and carbon isotopic test results showed that the amount of $\delta^{13}c$ varies in the ranges of (-1.31 to 1.02) in Bushehr, and (-1.69 to 1.56) in Bandar Abbas sedimentary cores. Moreover, temperature reconstruction showed that temperature variations in the Bushehr sedimentary core are mild and moderate but are high and severe in the Bandar Abbas core. The temperature increase and decrease in both sedimentary cores were seen at different time intervals. The maximum increase in temperature was 0.4°C per 100 years in Bushehr, and 0.01°C per 100 years in Bandar Abbas sedimentary cores. The minimum temperature reached to -0.8°C per 100 years in Bushehr, and -0.02°C per 100 years in Bandar Abbas sedimentary cores. Compared to the temperatures of the past, and with the recent temperatures changes of the past 40 years in the Persian Gulf, an unprecedented rate in sea water temperature changes is indicated. The correlation matrix showed that temperature has a positive correlation with the concentration of all elements except Ca, Sr and As. Ba showed the highest positive correlation with temperature in both sedimentary cores. Sr showed the highest negative correlation.

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