Islamic Azad University
Mashhad Branch

M. Taghizade et al. / Iranian Journal of Earth Sciences 4 (2012) / 110-119

Geochemistry, Paleoclimatology and paleogeography of the Northeast Region of the Persian Gulf
(Case Study from Southern Hormuzgan, Iran)

Mojtaba Taghizade*[1], Khosro Khosrotehrani[2], Razieh Lak[3], Seyed Ali Aghanabati[4] and Hamidreza Peyrowan[5]

[1]Ph.D student of Geology, sedimentology, Science and Research Branch of Islamic Azad University.Tehran, Iran
[2]Professor of Geology at Tehran University
[3]Professor Assistant of Geo Science Researching Center, Geological Survey of Iran
[4]Associate Professor, Geo Science Researching Center, Geological Survey of Iran
[5]Professor Assistant, Research Center for Maintenance of Soil and Watershed of Iran

Received 5 December 2011; accepted 9 February 2012

Abstract

The Wisconsin glaciation was started a approximately 125,000 years ago and reached its lowest extend between 20,000 to 21,000 years ago during which the sea level fell 120 to 130 meter. At the end of the ice age, about 18,000 years ago, the sea level increased and reached its present level about 5,000 years ago. The Persian Gulf was exposed in the last glacial moment (LGM). After this moment, the sea level prograted toward the Persian Gulf Basin and reached 1 to 3 meters higher than present levels 4,000 to 6,000 years ago. This study was focused on paleoecology, sedimentation and sea level changes in the northeastern portion of the Persian Gulf and shallow marine area in southern Hormuzgan, Iran near the ports of Bandar Abbas and Shahid Rajaee. Hormuzgan Province is located to the north of Strait of Hormuz. In this study, a core with a length of 10 meters was taken from late Holocene sediments in the northeast marine region of the Persian Gulf using a rotary drilling system. Then different sedimentary types were studied and separated and samples were sent for ICP and XRD elementary analysis and dating. As is already known, increasing and decrease of sea levels are related to moist weather and arid conditions respectively. Additionally, it is proved that variation of elements such as Al, Cr, Fe, K, Mg, Mn, Ti, and Zn have a direct relation to sea level changes. It is shown that the variations of Sr and Ca having a reverse relation to sea level changes. Geochemical study and dating on sediments shows that although the sea level rose 10,000 years ago in the studied region, 3,700 to 6,800 and 7,900 to 9,300 years ago, the sea level and rate of precipitation in this area was higher than the mean. This illustrates an increase in rain and humidity during these two periods.

Keywords: *Persian Gulf, Paleoclimatology, Paleolimnology, Sedimentary Geochemistry.*

Introduction

About 22,800 years ago when the weather was humid, the extreme north western part of the Persian Gulf filled with Siliciclastic sediments that mainly derived from Iran land. Later these sediments were covered by marine shallow white aragonites and Marls due to sea transgression to present level of the Persian Gulf. About 20,000 to 21,000 years ago (during the glacial age) due to the regression of the Wisconsin, seas level decreased 120-130 meters on a global scale and the weather was dry. The Persian Gulf was in a state of water crisis and wind (Eolian) and shore sedimentation were dominant in the region. From 9,00to 12,000 years ago, the weather in the Persian Gulf was dry. The shallower regions of the Persian Gulf were a place for aragonite crystalization and wind sedimentation on the top of Holocene sediment collumn in the south western portion of the Persian Gulf.

When the sea level began to rise, the aragonite sediments reworked by the transgressive waters and again were disolved into the Persian Gulf water. Nine thousand years ago when the weather in south western Iran became humid, the connected rivers formed a series of depositional lobes with a south eastern trend along the north eastern part of the Persian Gulf. Today the warm waters of the Persian Gulf are forming bioclastic grains and in shallower regions show an increase in Ooides deposition. It should be noted that their environment has been described by many researches [1-4]. Terrigenous sediments form a significant part of the top and bottom layers of sediment on the floor of the Gulf. They are the result of the tectonic activities of the Zagross Mountains by which the delta system of the Tigris and Euphrates Rivers transgresed and regressed [4-6].

Research history

The Wisconsin-Holocene sedimentation occurred in the Persian Gulf was during glacial periods that caused variations in the weather and sea water level. The

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*Corresponding author.
E-mail address (es): taghizade_m@pgfkco.com

Wisconsin regression, due to an icy phenomenon, began about 125,000 years ago [7] and about 20000-21000 years ago reached its lowest level to about 120 to130 meters. At the end of the this period and about 18,000 years ago, the sea level rose gradually and about 5,000 years ago reached its current depth. Consequently the Persian Gulf had got the present shape during the last glacial period [5, 8].

Thus during LGM (maximum of last glacial period)between 18,00 and 20,000 years ago, when the water level was 120m below the present level, the bottom of Persian Gulf exposed totally (figure 1). After LGM, the sea water level advanced to the basin and about 4,000 to 6,000 years ago reached a maximum level that was 1-3 meters above the today level (figure 2) [9-12].

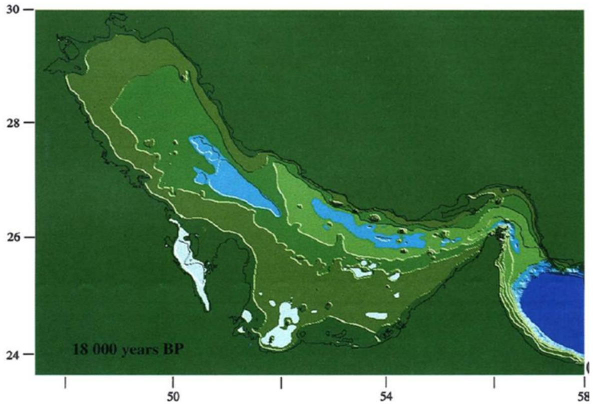

Fig. 1. The Persian Gulf status 18,000 years ago (Please Indicate the location of the cores here).

When the sea level decreased to 70m during the mentioned glaciation an outcrop could be seen throughout most of the basin. During the previously mentioned regression phase along the Emirate coasts, some shallow shells, Ooids and Oolites and terrigenous sediments along with intra basinal chemical sediments (such as gypsum and dolomite) are deposited [cf. 2, 13, 14, 15]. Also Sarnthein [5] argued the region sedimentation throughout where bioclastics and sands with Ooids exist in shallow depth of 40m.

The main sedimentary sequences are deposited in a glacial interval [11]. Globally, the sea water levels increased continuously until 6,000 years ago [Fairbanks et al., 1989], [12]. About 14,000 years ago, the ocean water started to enter the Persian Gulf through the Strait of Hormuz. Then about 12,000 years ago a narrow and shallow channel developed to the westwith several hundreds of kilometer in length (figure 3). Rapid increase of water levels occurred after a glacial period between 8,000 to 12,000 years ago [17, 12]. About 7,000 years ago (between 6,000 and 13,000 years ago) the sea's surface developed for 1,000 km along with Persian Gulf from the Strait of Hormuz to the Tigris and Euphrates Deltas. Then its mean increased by 140m per year.

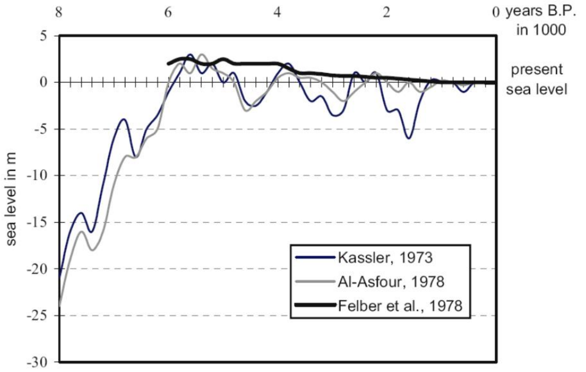

Fig. 2. Curve of global variation of seas water level.

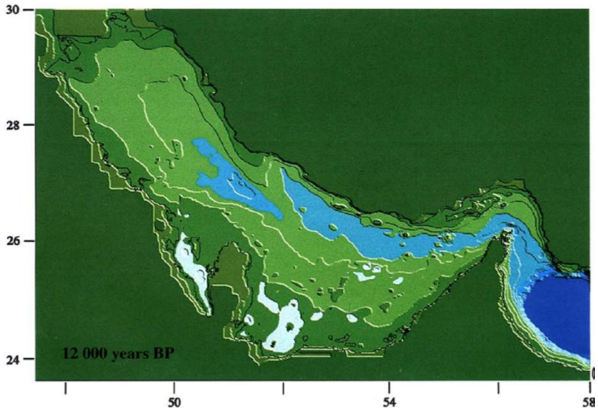

Fig. 3. The canal advancement from the Strait of Hormuz into the Persian Gulf about 13,000 years ago (Please Indicate the location of the cores here).

Based on evidence established in Barbados corals, Fairbanks (1984) concluded that the global rising of sea levels was marked and distinguished by two rapidly increasing stages and by an incoming water stream due to melting ice. The first increase from 70 to 100m occurred about 11,500 to 12,000 years ago while the second increase from 28 to 50m occurred approximately 8,500 to 9,500 years ago (figure 4). While the sea basin completely developed to the west during a 10,000 year time period, some large regions of the south and west remained dry (figure 5) [12]. According to Fairbank [16], the sea level rose from 70 to 100m approximately 11,500-12,000 years ago. This risecaused the waters of the Persian Gulf to move to the west through the Strait of Hormuz Axis (52 to 57 degrees east) a distance equal to 500 kilometers or 1km per year. The rapid uprising of the sea level, about 13.5m during a 12,000 year period was determined by Blanchon and Shaw [18]. Advancement through the east axis of the basin during this period may be higher than 1 km per year during a 300 year time period.

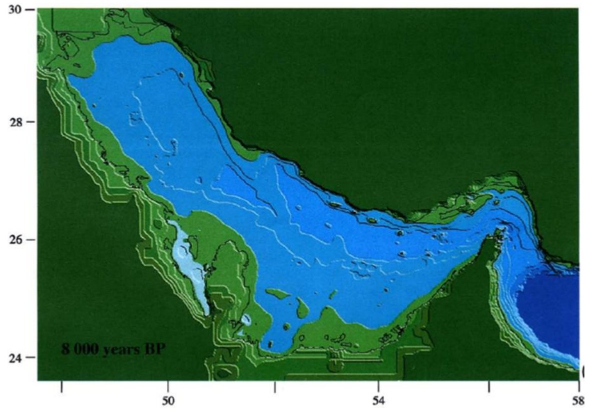

Fig. 4. Relative rapid advancing that occurred 9500-8500 years ago.

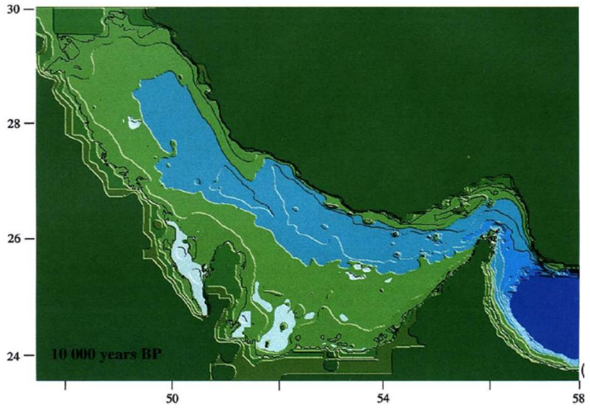

Fig. 5. The Persian Gulf status in 10000 years ago.

During the next rapid uprising, 8,500 to 9,500 years ago, the sea level rose an additional 20m [16]. Blanchon and Shaw [18] recognized a very rapid uprising of about 7.5m (from 49 to 55m) for a short period only 10,000 years ago. Based on their theory the Persian Gulf expanding may be t 1km per year during this period. Between 11,000 and 10,500 years ago during the Younger Dryas, the sea level rose from only 60 to 70m. Given this, in many times r during the Ice Age, humans lived on the bottom of the Persian Gulf and practiced continent variations, rapid overflow and advancing sea water over several decades.

The present research is based on geochemical analyses of core samples using ICP and XRD methods. The sudied area is located to the south of Bandar Abbas, Hormuzgan Governorate. measuring The age of the samples are determined with C14 isotope. Also discussed, is the Persian Gulf depth level variation in addition to continental variations during this period. Rising sea water has a direct and inverse relations to tropical weather and drying of continents respectively. Additionally, based on discussions that will be established later, variations of many elements such as aluminum, chromium, iron, potassium, magnesium, manganese, titanium and zinc are interdependent and the variation trend is directly related to sea level variations, along with variations in some elements such as calcium and strontium having an inverse relation with sea level height.

Continent

According to geogpraphical location of the Persian Gulf, it is placed in a dry region with respect to the climate. Its evaporation is much more than the incoming fresh water to the basin [19]. The rate of vaporization in this basin is estimated by Privett [20] and Meshal & Hassan [21] to be about 144-500 cm/ year; and about 200cm/year respectively. Six rivers, namely the Mand, Hileh, Hendijan, Karoon, Tigris and Euphrates have a mean yearly flow of about 203 m3/s (Hendijan) while 1,387 m3/s (Mand) come into the Persian Gulf. The incoming water from these rivers, deviates after flowing to the basin from source [22-24]. The Persian Gulf is mainly affect by a tropical weather system from the North West. The common and specific atmospheric phenomenon which exist in the Persian Gulf is wind called Shamals which are northwest winds [25-27]. The north winds start in May and last through June andpeaking in July. These winds have a large effect on the increase of the disturbance of the region’s surface waters which cause resuspension of deposits and in addition to their effect on wave making and surface streams, these winds carry a large amount of terrigenous sediments to the marine environment. The winds from the higher topography of Saudi Arabia, in its west with winds (Shammal winds) from the Zagros Mountains in the north blow over the Gulf [28] with speeds reaching 15-20m/s from the ground to a height of 300m [29]. Before reaching the sea, Shammal winds deviate from their direct path to the south and then merge with the south westerly winds of the Arabian coast. These south west winds come from the Red Sea [30]. The continental data was obtained from the nearby meteorology station’s website in Bandar Abbas. Data processing shows that the yearly rainfall average for 1982-2009 was about 152mm and the average temperature for this period varied between 22 and 27° C.

Oceanography

Tide is one of the most important water movement in the Persian Gulf which has quite large variations throughout the basin. These variations at the head (its northwestern part) of the Persian Gulf are larger than 3m and in other its regions are relatively smaller, which is reported at about 1m [31]. As an example, the tide limit is 0.4-0.7m in the country of Qatar [1].

The salinity of the Persian Gulfis high due to its high evaporation and its location in a zone of high pressure and tropical weather. [32] The average vaporization reaches 2m in a year [20, 33, 21, 27]. The salinity for the Persian Gulf is 39-40g/L while in the lagoons and Sabkha it reaches 100g/L [34]. Its surface water temperature is variable between 20°C in February and 34°C in August [1]. Due to the fact that the Persian Gulf is surrounded by land, the ocean effect on the Persian Gulf is very little. Thus the speed of the horizontal and under streams in are very slow measuring at speeds of about 10cm/s. The higher salinity of the Persian Gulf compared to the ocean is caused by its restriction which which manily supplied by a stream from the India Ocean which flows into the Persian Gulf Through Hurmz Strarit. This stream is parallel to the Iranian coast and turns in a anticlockwise direction.

The Persian Gulf is known as a super saline zone because it is subjected to dry weather, is surrounded by a desert region. The evaporation is much higher than the amount of fresh water coming in [19]. The regional winds at the head of the Persian Gulf blow in a westerly and a north to north easterly direction in the southeastern portion of the Gulf. Gales, as opposed to hurricanes, were observed in the Persian Gulf region. Very little development in hurricane sediments was found. In the northern portion of the Persian Gulf, the native weather is affected by its mountains. The Persian Gulf is affected mainly by super torrid weather from the North West. Also a large volume of detrital sediment is carried to this region by air. The hurricane’s winds carry a large amount of terrigenous materials from the north and north western desert to the Persian Gulf [26].

Sugden [35] estimated that about one third of the total sediments of the Persian Gulf is carried to this region by wind. Also Al Ghadban and et al. [36] argued that the wind effect is more important than the Arvand River for providing depositions. Also Pilkey and Nobel [37] believed that wind blown sediments and biological carbonates are the most important sources of sediment in the Persian Gulf.

The stability of native winds and the direction of the waves are the depositing long and continuous sand structures in the south eastern part of the islands and shoals in many parts of the Persian Gulf [3]. The barrier lagoons direction and depositional views on the southern coast of the Persian Gulf is dependent on wave direction [3]. The sand bar direction, the sands origin and direction of the sand’s movement, are all controlled by pervailing winds. The temperature degree, wind intensity and humidity degree relative to evaporation from the sea’s surface play the highest role.The vapor pressure in the atmosphere, the water properties, and the depth and salinity degree of the water all have an effect on evaporation [32]. These factors ressult an evaporation of more than 2 meters per year in the Persian Gulf [20, 21, 33]. In more recent studies this rate has been reported at 1.8m/year [27].

Typically it can be said that the high rate of evaporation of Persian Gulf is the result of its dry weather .which was higher than river water coming into the Gulf. The estimated rate for evaporation is reported as 144-500 cm/year [32].

The total process of the water circulation in the Persian Gulf is cyclonic. The water flow to the western part of the Gulf is supplied from the India Ocean northern thruogh the Hormuz Strait which flows north along the Iranian shores [1, 22, 23]. Since the northern portion of the Persian Gulf has a lower salinity due to the presence of the Arvandrood Delta as well as other Iranian rivers and also with respect to un impressible from the ocean, the water circulation in this region is caused mainly by wind [38, 39].

With respect to the differing rates of salinity during different months of the year, the flow rates in different seasons differ, with the rate of rain reaching its maximum value from October to December and its minimum rate in the months of March to May [27]. It should be mentioned that tidal circulations, due to their limited time, cannot account for promoter currents. The currents that come in from the ocean to the Persian Gulf will be denser due to evaporation during their movement to the North West and the returning current from the southern Persian Gulf. Therefore the total process of circulation in the Persian Gulf is counter clockwise (figure 6).

The largest contributing factors with regard to the circulation in the Persian Gulf is incoming water from the eastern part of the Oman Gulf in addition to lower salinity (36-37 Psu) along with Iranian shores. Here the water is being replaced with concentrated waters that form in the shallow and wide regions on the Arabian side of the Persian Gulf which is more saline (about 40-41 Psu). The beginning of a reduction in salinity and density of the water occurs in the north western portion of the Persian Gulf. The dense, saline water moves to shallow regions and semi closed lagoons along the southern coast of the Persian Gulf. This water outflows below incoming water from the Oman Gulf into the Persian Gulf through the Hormuz Strait. This kind of water exchange is known as Mediterranean. But unlike the Mediterranean and Red Sea, there is no compacting of the water by undersea hills to limit water exchange with neighboring seas so the water exchange between the Persian and Oman Gulf is not limited.

The current circulation due to density difference is dominant mainly in the central and southern parts of the Persian Gulf while current circulation due to wind forces is dominant in the north western parts because of surface currents toward the south and along the shores of both sides of the Persian Gulf. Along the Iranian shores these currents are supported by Baroclinic forces made from low density and incoming river currents.

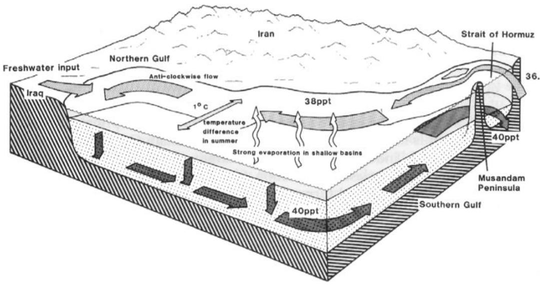

Fig. 6. Schematic diagram of water exchange of Mediterranean kind and main current movement in the Persian Gulf. The counter clockwise circulation pattern in the Persian Gulf is distinct. Bold arrows show the high concentration of water [Sheppard et al., 1992]. (Please Indicate the location of the cores here).

Samples and Methods

A core sample with a length of 1,070cm and with coordinates 2999700 and 412100 (UTM) provided by the marine-geology department of the geological survey of Iran, in southern Shahid Rajaee Seaport was taken by turning core sampling with a revolving drill device that can provide samples from deep depths (figure 7). This device was mounted on a barge (figure 8). In order to preserve the sediments texture and keep the core healthy, hydraulic pressure using a special core barer (Ufer) was applied; the Polyca pipe was placed in this barer and exposed to hydraulic pressure. A healthy core with an unaffected texture can be provided with a length of between 1m and10m.

Next the physical and superficial properties of the sediment such as color, percentage, structure, and contact nature were described (figure 9).

Fig. 7. The geographical position of studied core

The depositional facies were separated from each other and samples based on facies type were sent for lab studies and required analyses such as sediment sorting, determining the physical properties of the grains, geochemical analyses and mineralogy tests. These samples were maintained in a refrigerator at a temperature between 0-4° C.

Fig. 8. The revolving drill device and core obtained from the sea bed sediments.

Fig. 9. Description of core sediments

Age measuring was conducted using the 14C AMS method at Poznan Radiocarbon Laboratory in Poland on 10 samples after preparatory steps including placement of samples in an ultrasonic bath, washing with distilled water and removing mud grains, and picking up appropriate samples using gloves were done. The constituents used for age measurement include, health and Pelagic Foraminifers inside the depositions. The sediment samples were separated from their cores at a thickness of about 1cm using plastic spoons [e.g. 40]. Preparation of samples and all testing was conducted based on instructions by Lewis & McConchie [41]. Next, the available samples were powdered and analyzed with XRD for mineralogy and ICP in order to determine the content of the elements in the samples [e.g. 42]. For sorting grains bigger than 63 micron, a shaker sieve was used. For grains smaller than 63 micron a Laser Analysett22 as a particle sizer was used followed by the physical diffraction principle of electromagnetic waves for determining the particle size distribution [43]. Finally, a stratigraphic chart of the core was drawn (Figure 10).

Discussion

The investigations conducted on Holocene sediments and the core obtained from shallow depths of the sea show that more than 50% of the sediment content is comprised of carbonates and mainly contains calcite with a high concentration of magnesium (>1%), aragonite and a small quantity of dolomite. Among the carbonate minerals calcite averaging 52% (varying between 21-77% in total sediments) had the highest content, aragonite with between 0-40percent showed an average of 18%.Argonite was placed in a secondary ranking because its content, at a depth of 235cm reached 0 due to the effect of digenetic actions and the conversion of aragonite into calcite. The XRD results showed that despite the sedimentology compound throughout the core the sequence consists of carbonate siliciclastic mixture. In all the samples the level of calcium carbonate as calcite, dolomite and aragonite was more than 50% of the total sediments. The kinds of carbonates vary by temperature. In water with a temperature of 30° C or higher only aragonite can be deposited on the bottom [48], while in temperatures of between 15-17° C a mixture of calcite with a high concentration of magnesium and aragonite can be formed [34]. The geographical position of the Persian Gulf implies that it is placed in a tropical to semi tropical region and it is clear that its carbonate compound in the lower latitudes often is aragonite. Toward higher latitudes and along the Iranian coast the aragonite decreases while calcite increases. Based on the previously mentioned information it can be inferred that the mineralogical compound of the carbonate core studied at a latitude of about 27 degrees north(semi tropical region) will be a mixture of aragonite and calcite with a high concentration of calcium. In figure 11 varying levels of calcite and aragonite in the analyzed samples of the studied core using an XRD device are shown in figure 12in which the aragonite content, strontium and their variations and the relationship between these variations are shown. As you can see, a variation of the strontium element has a direct relation to the aragonite mineralogy.

Distribution of accessory elements is dependent upon their distribution coefficient. Generally, cations larger than Ca (such as U, B, Na, Sr) and preferentially take a position in the open building network of the orthorhombic aragonite. Inversely, those cations that are smaller than Ca (such as Cu, Zn, Mn, Fe, Mg, Cd) take a position in the closed building network of rhombohedra calcite [44, 45]. In figure 12 despite high relative strontium concentration, at some points with more depth the existence of aragonite was not appeared in the XRD results. The reason for this is the conversion of the unstable aragonite to calcite creates a high concentration of magnesium. There are two reasons for the calcite showing a low magnesium content (LMC) rather than a high magnesium content (HMC). First, as mentioned before, LMC often forms in cold water at temperatures below 3°C [46]. Secondly, based on ICP analysis results, the Mg content in the sediment is higher than 1% while LMC is considered to be lower than 1% Mg. Additionally, the Sr and Mg contents of most of the samples have an inverse relation to each other (figure 13). This is due to the increasing HMC. [46], Aragonite mineralogy as a LMC shows a low content of Mg with respect to the HMC. As mentioned before and as shown in figures 11 and 12, the 0-40% content of aragonite in the samples may be related to temperature and depth variations in the carbonate formation environment at different times. In other word there is a positive relationship between the aragonite and strontium content and the depth of converting aragonite to calcite. As mentioned earlier, the Sr content increases because of the aragonite [47]. In figure 12 the content variation curves for aragonite and strontium are introduced and compared. It can be seen that their variation trends follow a similar pattern. Most of the aragonites were formed in biochemical reactions. After conducting the XRD test and determining the mineralogy of the sediments, the elemental analysis conducted by ICP method and the variation trend of the elements relative to depth were compared (figure 14). In figure 14 it can be seen that the variation trends in most of the elements such as Al, Cr, Fe, P, Mg, Mn, Ti and Zn are directly dependent on each other. Also by comparing the variation of these elements (Fe and Mn as examples of this group) with the calcite variations in figure 15 a direct relation between these elements and calcite percentage and its reverse relation with Ca is clear. On the other hand, a direct relation between Ca and aragonite mineralogy and strontium variations (refer to figure 12) and a reverse relation of other element variations with respect to the aragonite mineralogy is clear in figure 16.

Thus in the studied core at depths that show an increase of calcium and strontium content, the rainfall was relatively low with respect to vaporization and the water level . In periods that reduction of these two elements with an increase of elements such as aluminum, chromium, iron, potassium, magnesium, manganese, titanium and zinc was reported, we see an increase in rainfall and more humid conditions along with a relative uprising of the water level.

Some parts of the carbonate sediments of the core are related to sediments with a collapsing origin, whichmainly they are Marl s of the top. but the main part of these sediments is related to the chemical and biochemical depositions of the basin. Therefore, it is indisputable that limitation of Aragonite inside the basin is due to its unstable mineralogy and its relationship to the basin depth and temperature of crystalization.

For converting the depth to time age measurements were conducted on some of the core samples. The age measurement results whicg are shown in the figure 17. It imply that in some time intervals the sedimentation rate had a significant increase. In particular, 7,900-9,300 years ago the sedimentation rate was higher than average (1mm/year). As most sediments of the Persian Gulf are carbonates in the basin, the sedimentation rate increased with the rising sea level.

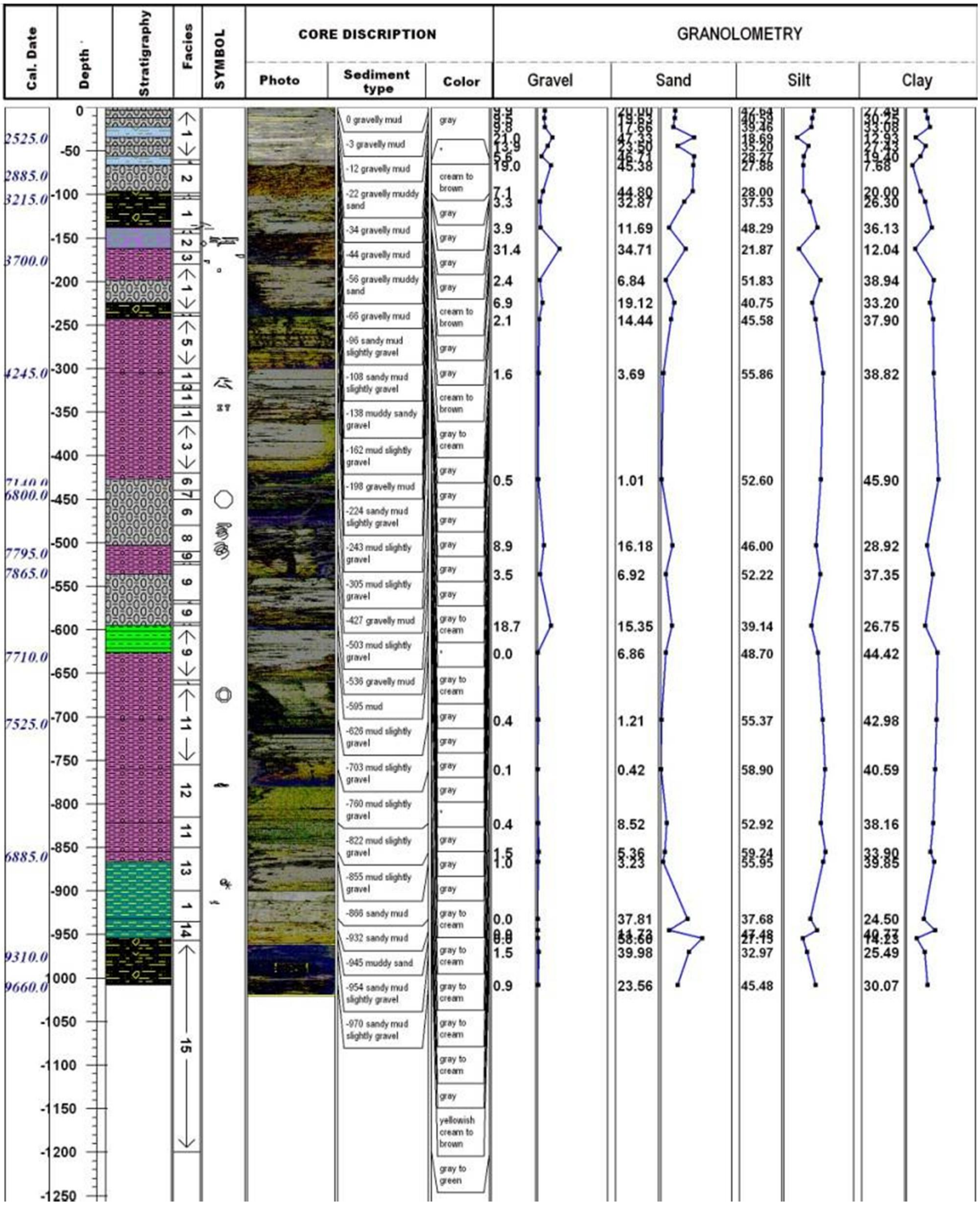

Fig. 10. Sedimentary facieses of studied core

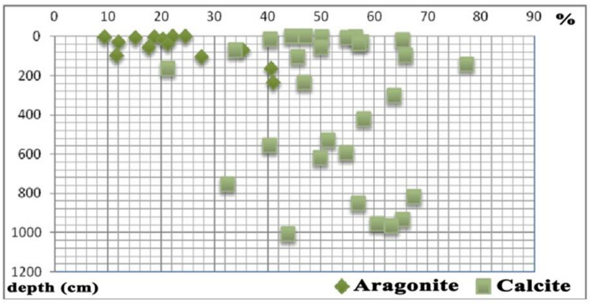

Fig. 11. The comparison curve between calcite and aragonite showing amounts from surface to depth of core.

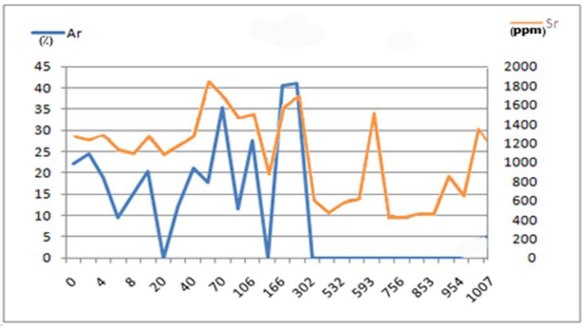

Fig. 12. Comparison curve between aragonite percentage and strontium content.

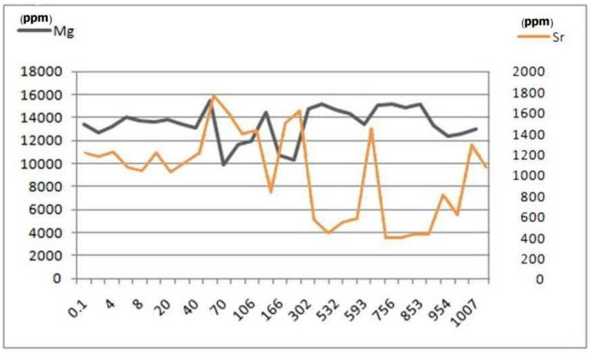

Fig. 13. Curve showing inverse relation between Mg and Sr contents

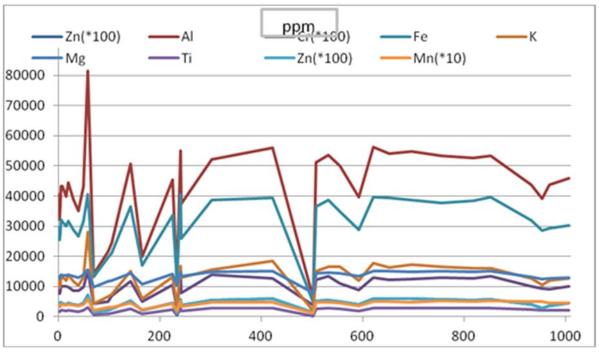

Fig. 14. Elemental variation trend relative to depth in studied core.

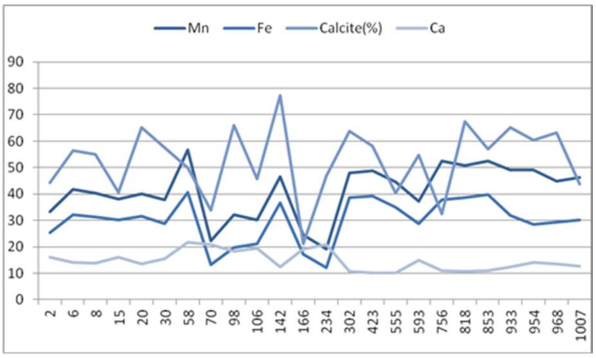

Fig. 15. Relation between content variation of calcium, iron, manganese and calcite percentage.

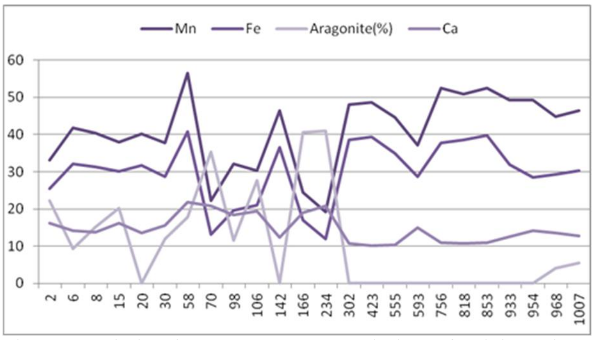

Fig. 16. Relation between content variation of calcium, iron, manganese and aragonite percentage.

In figure 17 it can be seen that 3,700 years ago about 1,800mm (on average 0.48mm/year) was deposited. From 3,700 to 6,800years ago about 2700mm (in average 0.87mm/year), 6,800 to 7,900 years ago about 700mm (on average 0.63mm/year), 7,900 to 9,300 years ago about 4,600mm (on average 3.2mm/year), and from 9,300 to 9,650 years ago about 200mm (on average 0.5mm/year) was deposited. The time interval of 7,900-9,300 years ago, based on age measurement data, had the highest sedimentation rate, with high contents of iron and manganese and calcie. These two parameters show that during that time the sea level was high. Using age measurement could significantly help us in determining the sedimentation rate and ancient geographical status, but limited due to its high cost. Therefore, geochemical analysis was used to ascertain the weather pconditions during the sediment's formation time. In addition to an interval of 7,900-9,300 years ago which is related to a depth of 550-980cm of the core, depths of 8, 60, 150 and 400 cm also show rising sea levels in the related times. Also, based on figure 15, the calcite at a depth of 150cm reached its highest content. This implies that during a time period 10,000 years ago the sea's height was at its highest level. This maximum level of rising is related to a time period beginning 3,800-4,000 years ago. This conclusion validates the results obtained by [9-12] that state the maximum water level of the Persian Gulf was related to a time period between

4,000 to 6,000 years ago and was 1-3m higher than present day levels. Based on this we can say that the most humid weather in the Persian Gulf occurred during this time.

Fig. 17. Age measurement results in studied core

Conclusions

1. Geochemical analysis of the core showed that variations of most elements such as Al, Cr, Fe, K, Mg, Mn, Ti and Zn are directly dependent on each other and their variation trends have a direct relationship to sea height variation.
2. Geochemical investigations of the studied core showed that variation trends of calcium and strontium have a reverse relation with the above mentioned elements as well as sea level variations.
3. The increase in Fe and Mn and other teammate elements at different depths of the core is relevant to calcite increase and aragonite decrease.
4. Comparisons between aragonite and strontium variations showed that an increase of strontium at different depths of the core is relevant to aragonite increase. Of course from 300cm and lower, despite an increase in strontium, the aragonite was not observed. This could be due to the effect of diagenetic processes on unstable aragonite and its conversion to calcite.
5. Additionally, with regard to the previously mentioned points, it can be deducted that decreasing sea levels are related to aragonite while increasing sea levels are related to calcite.
6. In the most samples the Sr content reduces with an increase in Mg content due to the increase of HMC.
7. In the studied core, at depths that show an increased strontium and calcium, the rainfall rate was low with respect to vaporization and the sea level was relatively low. During time intervals that showed a decrease in these two elements and an increase in other elements such as aluminum, chromium, iron, potassium, magnesium, manganese, titanium and zinc, there was an increase in rainfall rates along with more humid conditions and rising sea levels.
8. Based on age measurement data the time period 7,900 to 9,300 years ago and related to a depth of 550-980cm in the core, showed the highest rate of sedimentation and manganese, iron and calcite. During this time period, these two parameters imply that there was a high level of sea water.
9. Also based on geochemical data at depths of approximately 8, 60, 150 and 400 cm it can be observed that in those related times, the sea water level was high. Additionally the calcity mineralogy at a depth of 150 cm was related to a time period beginning 3,800-4,000 years ago and reached its highest limit approximately 10,000 years ago.

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