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Reconstruction of Caspian Sea level changes using magnetic susceptibility during the last millennium

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Magnetic susceptibility is one of the most important methods for monitoring sediment composition during environmental studies. In this research, to reconstruct the Caspian Sea level changes, magnetic susceptibility variations were used during studies of five sedimentary cores (K1,K3,K5,K7,N1), collected from bottom sediments of Gorgan Bay. Samples were analyzed for grain size, total organic matter, carbonate content and magnetic susceptibility (MS). The results showed a close relationship between particle size distribution and MS magnitude due to variation in terrestrial influx, which is caused by sea-level fluctuations in different times. This process increases with particle size and magnitude of MS simultaneously with sea level fall and decreases during sea level rise. Moreover, no relationship between magnitude of MS and carbonate content was observed. Using magnetic susceptibility curves with other data, such as geological and historical, it can be concluded that these data are suitable for the reconstruction of marine environments, especially in the near shore coastal area.

[Keywords: Magnetic susceptibility; Sea-level fluctuations; Gorgan Bay]

Introduction

Magnetic susceptibility (MS) is one of the most important methods for monitoring during studies of environmental variations and also can be useful index in recognition of unconformities in sedimentary sequences with no outcrops (assessment of location sequences boundaries) and determination of the exact position of the time boundaries in sedimentary sequences without fossils[1,2]. Environmental variations due to climatic changes are associated with different erosion and weathering processes and also various conditions of transportation and deposition of particles. Variations in sediment composition, such as changes in the amount of magnetic minerals, can change the magnetic susceptibility of the sediments [illegible] deposition of shallow marine sediments. Indeed, MS is a standard method extensively used in the study of stratigraphic sections and core sediments from the marine and lacustrine environments. MS is also successfully used for correlation between sediments in different cores[3,4,5]. The advantage of this method is simple and rapid, because small amounts of sample with no orientation can be used for measurement with available tools like the balanced induction coil system (Bridge susceptibility)[6]. Marine sediments are usually composed of siliciclastic and biogenic components, where biogenic components do not show magnetic susceptibility and have low or negative MS, while siliciclastic particles are considered as the major controlling components of magnetization in sediments[7]. Therefore, the processes that control the influx of particles into the marine environment are considered to be responsible for MS in sediments[6,7]. Coastal deposits are mainly used to study sea level fluctuations[8,9,10,11,12,13,14]. During the Late Holocene, Caspian Sea experienced fluctuations with varying magnitudes (Fig. 1). These fluctuations have been subject of many studies[15,16,17,18,19,20,21,22] especially in geosciences but MS has been less considered in these studies.' In this study, we used MS curves of sedimentary cores (collected from Gorgan Bay in the south eastern parts of the Caspian Sea) and also used [illegible]orrelation. Finally, we tried to reconstruct Caspian Sea level changes during the last millennium.

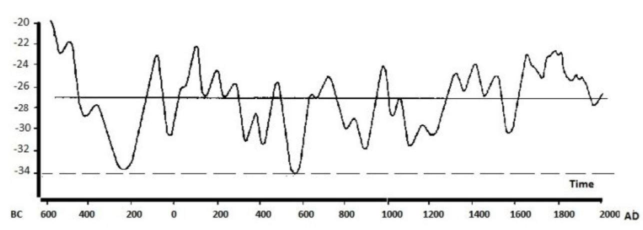

Fig. 1 — Variations in Caspian Sea level of the (sixth century B.C. to the present) (After Klige, 1992)[39]

Materials and Methods

Study area

South Caspian Sea brackish water along the shores is unique and the semi-restricted Gorgan shallow wetland Bay with high ecological status is mainly affected by hydromorphological elements such as depth variation, freshwater flow and wave exposure. The Gorgan Bay (36°48'N, 53°35'E and 36°55'N, 54°03'E, 400 km^2, 60 km ×12 km, maximum depth of 5 m and average depth 1.5 m) is a semi-restricted triangular-shaped bay, located in the south-easternmost parts of the Caspian Sea along the Iranian coastline in the Golestan province (Fig. 2). Gorgan Bay formed during the Holocene period by a sandy spit named Miankaleh coastal barrier system[8]. The bay basin is surrounded on the west, south and north by the main land of the Mazandaran and Golestan provinces as well as Miankaleh Spite, respectively. There are no tides in the Gorgan Bay. It is connected to the Caspian Sea through the inlet of Ashoradeh-Bandar Torkaman (Chapaghli) which is located in the north-eastern part of the Bay (Approximately width of 400 m, 3 km long). There are strong currents in the Ashoradeh-Bandartorkaman inlet affected by storm surge and inter water annually into Gorgan Bay due to fluctuations of water level in the Caspian Sea. This bay is mainly influenced by processes that are operating within the basin. As stated above, water balance in the Gorgan Bay is influenced by water entrance through inlet from the Caspian Sea, precipitation, evaporation and to a lesser extent by fresh river water. It receives freshwater inflow from a number of small rivers and streams, among them two most important including Gorgan-roud from the north of the inlet and Qareh Su from the east. These two rivers drain runoffs from residential and agricultural areas into the Bay[8,9]. Generally, there is a counter-clockwise flow pattern in the Gorgan Bay in four seasons and current pattern is driven primarily by prominent wind stress and then is affected by bottom topography and domain geometry[9]. In the northern and southern shores, currents are along the coastal areas and move from west to east by effecting dominant winds[9]. The Bay is surrounded by urban areas and agricultural lands.

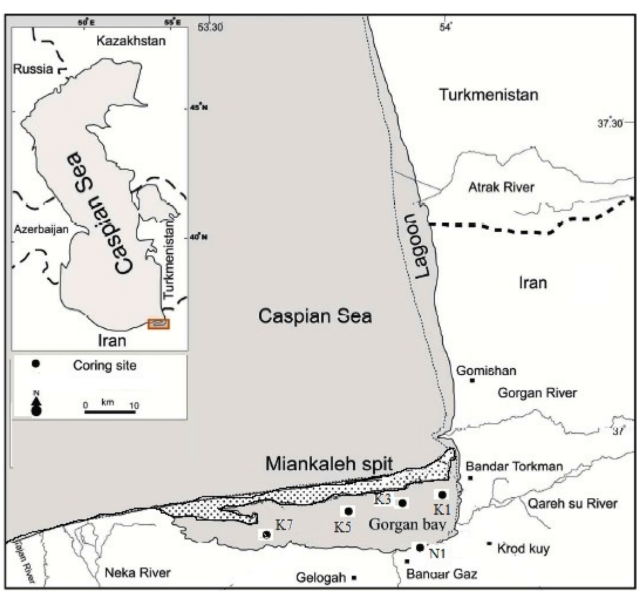

Fig. 2 — Location of study area and sampling sites

Sampling methods

Five cores were collected using a gravity corer in July 2016. The core lengths were 1.78, 1.67, 1.34, 1.30 and 0.98 cm, respectively with the diameter of 6 cm (Table 1). All the samples were sealed by nylon and transferred to the laboratory of Iranian National Institute for Oceanography (INIOAS), Tehran, Iran, for MS analysis.

Magnetic susceptibility measurements

Magnetic susceptibility (MS) is a measurement of the magnetize sediments (particles) when subjected to a magnetic field. The facilities of magnetization are ultimately related to the concentration and composition (size, shape and mineralogy) of magnetizable material within the sample. Any core prossessing done in relation to variation per unit volume in the concentration and composition of magnetizable minerals that will yield a MS curve reflecting these changes[23]. MS measurements are a nondestructive and effective method of determining the presence of iron-bearing minerals in the sediments[24]. The whole cores, or individual sediment samples, are exposed to an external magnetic field which causes the sediments to become magnetized according to the amount of Fe-bearing minerals present in the samples. In our study, we used a Bartington MS system that is moved incrementally

Table 1— Geographic position, length and depth of each core in Gorgan Bay

Sample Name	Depth (m)	Core length(m)	longitude	latitude
K1	2.6	1.78	54° 0' 42.34	36° 51' 49.9
K3	3.24	1.67	53° 54' 38.86	36° 50' 33.5
K5	2.8	1.34	53° 28' 43.5	36° 50' 21.35
K7	0.4	1.3	53° 36' 18.87	36° 48' 26.31
N1	0.1	0.98	53° 54' 62.5	36° 47 6.19

(generally in 2 cm) by a track motor through a susceptibility loop (varying size) where a magnetic field is generated and magnetizes the sample susceptible substances (minerals) in the sediment. Samples rich with magnetizable substances will yield high readings. Samples that are poor of magnetizable substances, or contain diamagnetic minerals, will yield lower or negative values. The MS used here is based on the ratio of the induction torque (Mi or Ji), which is defined as a very low magnetic field (Hj):

$$1 - Ji = Xij\ Hj(density - specific)$$
$$2 - Mi = Kij\ Hj(volum - specific)$$

In the above equations, j and i are parameters of a magnetic field vector, while Xij and Kij represent MS degree. In these equations (in unit SI), when the magnitude of the MS is equal to K, this indicates that the measurement is carried out relative to the volume of one cubic meter (m^3); therefore, the MS has no unit (equation 2). When the magnitude of the MS is X, it shows that the measurement is taken on a mass of one kg and the unit is $m^3/\ kg$[2,23]. In this study, equation 1 was used; therefore, the MS obtained has no unit. MS is a completely different factor from the remnant magnetism and, in general, it is an index for iron concentration, ferro-magnesian and clay minerals in sediments[25]. It should be noted that to facilitate the investigation of the variations, the MS curves were normalized (each of the dependent variable data of magnetic susceptibility is divided into the maximum amount of MS along the core[26,27], thus the data obtained is in the range of -1 to 1.

After slicing the cores and subsampling with certain distances, laser particle size analyzer is used (Horbia LA-950) for grain size analysis (Table 2). Also, to specify total organic matter content (TOM),

Table 2 — Results of grain size, organic matter and carbonate content in five cores

	K1			K3			K5			K7				N1		
Depth	Sand%	TOM%	Caco3%	Sand%	TOM%	Caco3%	Sand%	TOM%	Caco3%	Pebble	Sand%	TOM%	Caco3%	Sand%	TOM%	Caco3%
-5	16.47	10.29	24.67	0	11.25	19.56	4.44	7.67	47.74	0	53.03	6.51	62.11	30.3	3.01	6.65
-10	36.89	6.59	24.42	0.26	9.65	21.70	15.54	6.8	47.86	12.7	15.53	6.51	62.11	62.25	12.71	28.76
-15	18.94	6.24	28.62	4.84	12.44	27.02	15.27	7.04	34.69	0	63.51	3.66	68.38	75.13	15.59	35.23
-20	25.17	6.87	27.13	14.24	13.08	29.26	16.05	7.19	52.85	0	42.94	5.57	61.00	33.39	8.6	19.46
-25	4.03	7.63	25.47	10.08	10.48	25.03	34.08	13.33	41.41	0.34	59.96	4.78	52.40	76.34	13.33	30.19
-30	29.41	6.43	26.84	0	10.05	25.43	18.71	9.17	29.41	0	12.33	7.18	27.61	57.56	7.49	17
-35	54.79	10.69	30.42	0	12.35	21.71	20.39	9.96	40.95	0	4.04	7.16	27.87	41.18	9.95	22.4
-40	48.55	5.78	33.79	20.63	9.04	34.38	21.66	9.48	35.62	0	22.11	6.30	25.06	49.09	13.87	31.43
-45	53.09	7.03	30.97	6.39	8.03	36.40	34.41	8.55	31.46	0	36.49	6.36	31.60	59.81	10.14	23.01
-50	41.58	5.32	31.54	27.75	10.46	30.05	16.03	7.61	43.48	0	12.76	9.88	24.12	64.87	11.26	25.46
-55	24.1	5.75	31.05	19.86	9.78	61.44	31.86	4.85	15.53	0	15.29	9.29	26.16	23.02	12.49	28.24
-60	44.28	6.01	33.49	24.54	9.66	35.23	4.52	8.76	43.52	0	74.23	10.96	14.44	44.44	11.75	26.52
-65	18.14	5.71	29.68	60.32	11.28	31.68	10.17	10.52	31.57	0	13.78	10.94	11.41	14.03	10.33	23.24
-70	0	6.27	33.35	6.28	11.32	35.51	7.69	10.14	63.68	0	3.58	9.69	7.53	9.59	12.18	27.6
-75	9.91	6.72	40.14	41.22	11.08	41.31	7.45	10.08	43.82	0	0	7.75	11.74	5.81	14.69	33.14
-80	10.8	7.15	35.46	16.19	7.86	40.30	5.74	9.73	43.65	0	8.89	5.87	26.07	14.6	12.2	27.51
-85	20.28	6.97	32.94	8.11	7.93	41.50	11.51	10.84	24.25	0	14.38	5.95	25.25	4.57	21.56	48.8
-90	5.9	8.64	34.61	4.62	10.78	41.52	6.95	9.4	34.64	0	12.81	5.89	27.59	0.11	15.22	34.35
-95	43.73	6.12	33.27	13.9	8.28	45.17	10.41	11.46	32.66	0	10.81	5.23	33.22	50.4	15.49	35.21
-100	19.26	8.53	28.65	16.45	7.41	43.16	0.34	8.85	33.39	0	17.72	5.17	26.14			
-105	6.13	7.66	31.01	5.24	11.98	34.37	7.41	8.91	36.99	0	14.5	5.17	26.48			
-110	9.62	9.20	28.62	4.36	8.83	41.54	0	10.3	34.28	0	14.45	5.48	23.17			
-115	3.61	10.87	26.72	5.97	12.54	28.67	6.91	8.91	37.12	0	17.01	4.77	2.30			
-120	34.09	16.25	21.61	31.99	13.19	27.97	5.21	8.73	37.64	0	22.56	4.77	29.50			
-125	4.14	9.02	23.14	13.34	11.58	31.42	0	10.82	33.05	0	3.75	7.61	25.45			
-130	10.71	9.59	24.20	1.93	10.94	33.04	10.52	11.61	37.74	0	0	7.64	23.85			
-135	5.23	7.81	31.23	6.3	9.26	32.01										
-140	11.01	8.64	31.57	14.96	9.52	30.62										
-145	0	7.79	35.53	11.56	8.09	29.83										
-150	1.47	7.18	36.08	16.66	1.38	36.58										
-155	6.1	7.45	34.05	23.59	6.33	33.04										
-160	46.15	8.50	35.71	17.44	4.29	31.06										
-165	0	7.59	37.34													
-170	3.18	7.81	39.27													
-175	64.69	6.58	38.63													

loss of ignition method (L.O.I) was used. For this purposes, a portion of each sample (about 3 gr) was placed inside a crucible and heated at 550 °C for 5 hours and after that the weighting, percentage of the organic material were reported[28]. For measurement of carbonate content ($CaCO_3$%), coarser grain particles were manually removed and remaining sediments were placed in a muffle furnace (Excitation, EX.1200-12L) for 1 hour at 950 °C[29]. Since there has not been any ^{14}C dating available, last radiometric data from 10 sites in the surrounding area and inside of study area (minimum distances to our sampling sites) were used[17,30,31,32] (Table 3).

Results

The results of grain size, organic matter and carbonate content as well as the MS changes in the samples are shown in Table 2 and Figure 3. The highest amount of sand (the largest volume of coarser-grain in the basin), and consequently the highest MS is related to 30-70 cm depth in the K1 and K3 cores, 20 to 55 cm in K5, 55-60 cm in the K7 and 15-45 cm in the core N1. Also, the amount of organic matter showed a roughly constant trend while calcium carbonate varied and the maximum value of TOM and $CaCO_3$ observed at depth of 55 cm (61.44%) and 68% in K3 and K7, respectively (Table 2). Also, positive significant relation between TOM and MS and negative significant relationship between calcium carbonate and MS obtained in core K1 (Fig. 3).

In five cores, MS curves showed different variations (Fig. 4). K1 core with sharper curve and best correlation with sand trend selected for reconstruction of Caspian Sea level changes (Fig. 4). Since location of this core is very close to recent Gauge measurement (in Bandar Torkaman), Chapaghli mouth and Qareh Su River; therefore magnetic minerals have been intermittently entering into the basin.

Discussion and Conclusion

Over the past 1800 years, four major rises in the Caspian Sea levels occurred in the fifth, ninth, fifteenth and nineteenth centuries[11]. Many historical and geological reports about Caspian Sea level are commonly used by researchers, and in many cases they are not similar. This difference is especially noticeable in the first century of the last millennium; and as it gets closer to the recent times, the differences decrease. Some periods, such as the water rises at the beginning of the 16th century and the sudden fall in the early 18th century, these results are closer and more consensual. However, at some periods, such as the mid-fifteenth century, there is a relative agreement on the absolute sea level; however, Brückner (1890)[33] reported the Caspian Sea level was

Table 3 — Radiocarbon dating and sedimentation rates in Gorgan bay and neighboring regions during Holocene (Amini et al. 2012)[31]

Sampling Site (References)	Period	Depth (Cm)	Age (Year)	Sedimentation Rate(mm)
Amini et al., 2012	Upper Newcaspian	1917	2225	8.6
Amini et al., 2012	Upper Newcaspian	52	880	0.59
Karbbassi and Amirnezhad.,2004	Upper Newcaspian	70	500	1.4
Lahijani et al., 2009	Upper Newcaspian	520	2400	2.1
Kakrudidi., 2012	Upper Newcaspian	200	2280	0.84
Kakrudidi., 2012	Upper Newcaspian	340 800 1400	650 5990 8990	4.6 1.3 1.5
Kakrudidi., 2012	Upper Newcaspian	180 450	2203 3369	0.78 1.2
Kakrudidi., 2012	Upper Newcaspian	250	956	2.9

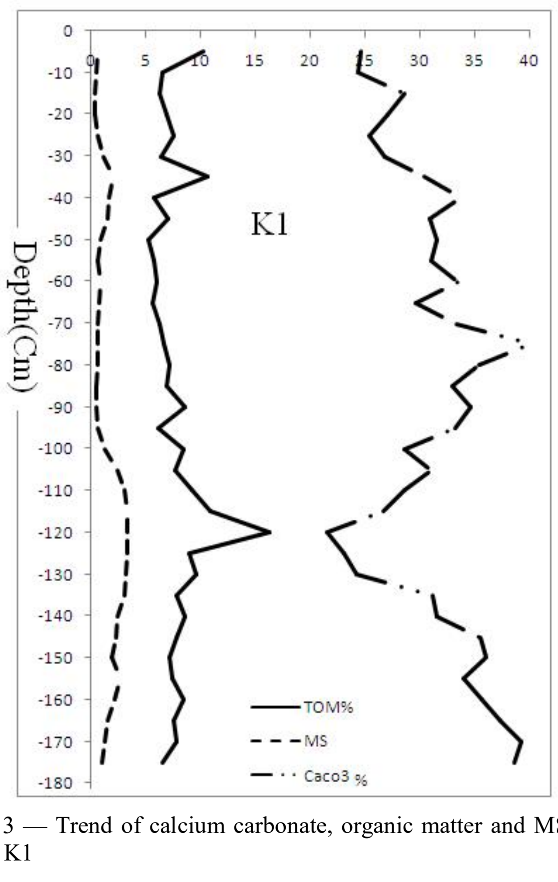

Fig. 3 — Trend of calcium carbonate, organic matter and MS in core K1

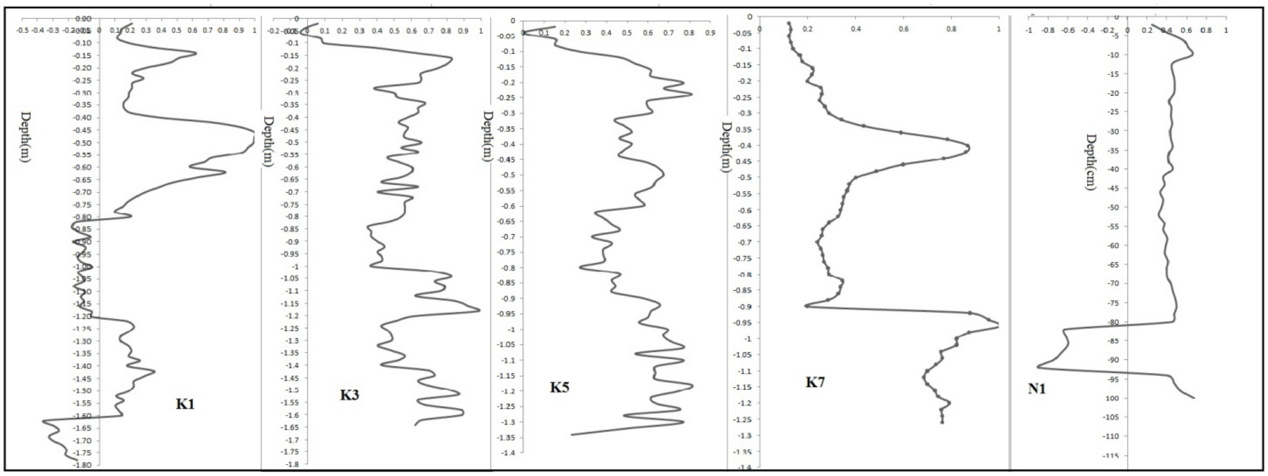

Fig. 4 — Variations of MS in different cores (MS charts are normalized)

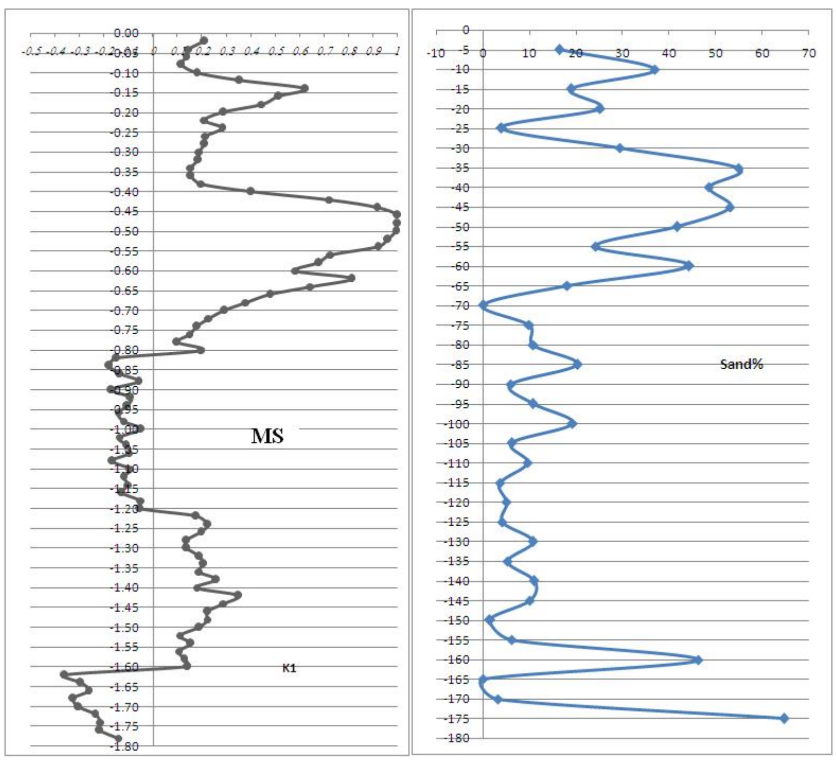

Fig. 5 — Correlation of MS and % sand values in the K1 core

at its highest level, while Varushchenko et al (1987)[10] considered it has been at its lowest level. By comparing the curve of the Caspian Sea level changes over the last 50 years (Gauge measurement) and MS curves, it is possible to reconstruct sea level fluctuations[26,27] (an increase in the amount of MS is associated with falling water level, when the coarser grain material, such as sand enter the basin and its decrease due to rising sea level which is related to low sediment influx in the basin); therefore, its highest value indicates the highest sea level fall and the lowest amount indicates the highest rising of sea level[27,34,35].

The last fluctuation of the Caspian Sea level occurred in the 20th century during a period of less than 100 years when the Caspian Sea experienced a complete transgression and regression cycle with a height of three meters[28,36,37,38]. Based on the results obtained in this study and comparison with available data, three significant increases in the MS curve can be observed (Fig. 6), which indicates that during these periods sea level fallen and erosion of the continental

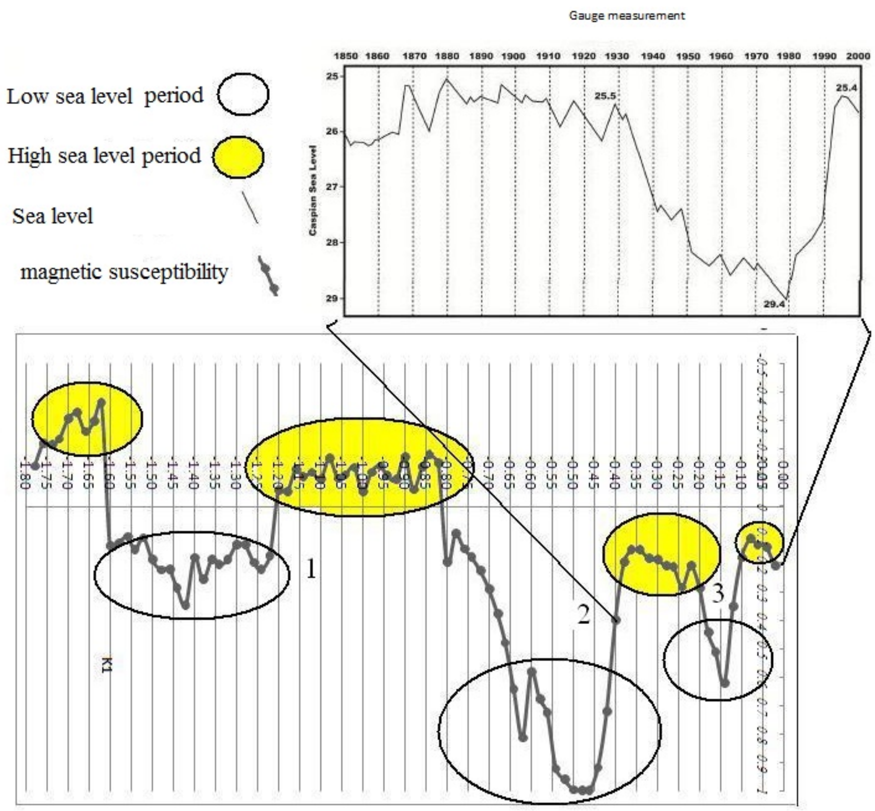

Fig. 6 — Adaptation of sea level changes using recent gauge measurement curve and MS data (core K1)

sediments increased. Also, there are four sharp drops in magnetic susceptibility present which indicates the sea level rise and shorter times as compared to regression periods. In other words, three important cycles can be identified based on MS changes. These cycles can be seen very clearly in core K1, where the first cycle starts from a depth of 160 to 85 cm, second cycle from 85 to 20 cm, and third cycle from 20 to 5 cm, respectively (Fig. 6). Also based on various studies, sedimentation rate in this area (especially the eastern and central parts of bay) is about 0.5-8 mm per year[17,28,29,39]. Since there has not been any age measurement in this study, therefore sedimentation rate is calculated based on changes in the transgression and regression curves in recent decades[30] (gauge measurement) and the changes on MS curve, which is about 3.3 to 3.5 *mm/y* in the core K1 and this core represent about 600 cal. years are comparable with historical Caspian sea level variation curves[10,27,31,32] (Fig. 7).

As a result, from 1400-1500 (AD), the sea level was the same as the present day (~ -26.7) and dropped noticeably from 1500 to 1580 (~ -29), then reached to its highest level from 1580 to 1790 (~-22). After that,

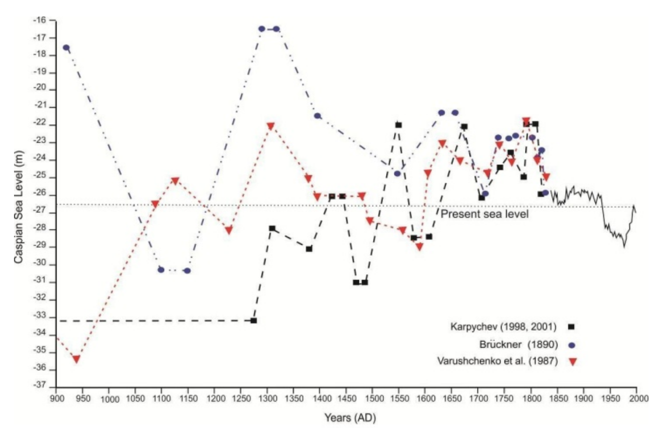

Fig. 7 — The Caspian Sea level curve based on Bruckner (1890), Varushchenko et al. (1987) and Karpychev (1998, 2001). The dashed lines connecting the filled symbols are interpolations. The continuous line from 1850 to 2000 shows the gauge observations.

it began to regret and suffered a great regression during a period of 100 years (from 1790 to 1890 AD 5 m dropped). From 1929 to 1995, there was another regression and transgression cycle (Fig. 8). The sea level has fallen about ~3 m from 1929 to 1978, followed by a rise of ~2.7 m from 1978 to 1995

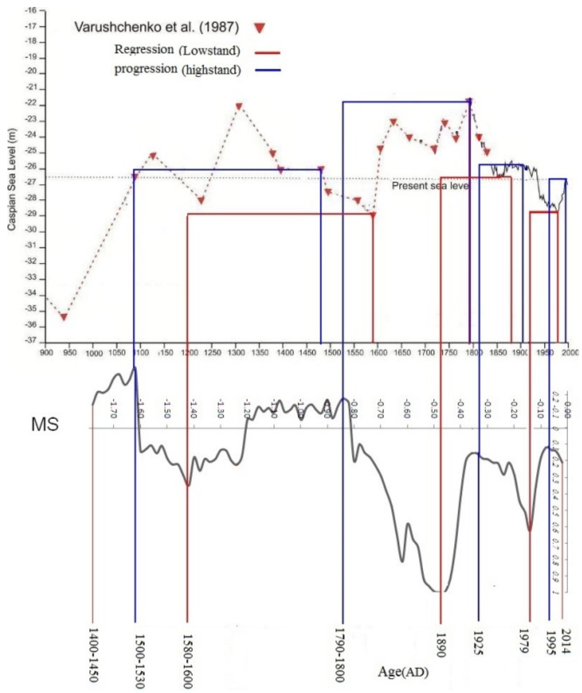

Fig. 8 — Adaptation of Caspian Sea level curve based on Varushchenko et al. (1987) and MS in the core K1

Table 4 — The Caspian Sea level (CSL) during the last millennium based on comparison between historical observations and geological events (After Naderi Beni et al., 2013)[18]

No	Age (AD)	CSL (m)	Historical Observation	Reference	Geological event	Reference
1	907	−23	Sea level position in Ahlam, Chālus and Rāmsar	Hudud al-'Alam (1973), Ibn Hawqal (1988), Jayhāni (1989)	Progradation of the old Kura Delta	Hoogendoorn et al. (2005)
2	977	−24	Sea level fall in Dahestan	Hudud al-'Alam (1973), Ibn Hawqal (1988)	Sea-level fall	Hoogendoorn et al. (2005)
3	982	≫ −23.8	Bāb Island is in the map	Hudud al-'Alam (1973), Ibn Hawqal (1988),	–	–
4	1208	−24	Ābeskun was on the shoreline	Al-Bakri (1999)	–	–
5	1260	> −24	Ābeskun was flooded	Jovayni (1911)	High-stand	Naderi Beni et al. (2013)
6	1304	−19	Rapid sea-level rise	Banāketi (1969), Mostowfi (1999), Marin Sanudo (1320 in Gümilev, 1980), Al-'Umari (2010)	High-stand	Kakroodi et al. (2012), Naderi Beni et al. (2013), Rekavandi et al. (2007)
7	1587	−28	Construction of Safavid castle in Derbent	Gümilev (1980)	–	–
8	1628	−23	Establishment of ports and structures along the Caspian Sea coast	Parodi (1987), Gümilev (1980)	Sea-level rise and barrier formation	Kroonenberg et al. (2007)
9	1771	−23	Sea-level rise	Abbott (1858), Brückner (1890), Rabino (1980),	Widespread evidence	Leroy et al. (2011), Naderi Beni et al. (2013)
10	1815	−23.5	Sea-level position in Galugāh and Gomishān	Rabino (1980)	Anzali Spit broken into barriers	Leroy et al. (2011)
11	1875	−25	Sea-level rise at Anzali royal tower	Farhād Mirzā (1987)	Karā Bogāz Gol	Leroy et al. (2006)

(at a rate of 100 times faster than the present global sea-level rise)[13]. Also, many other historical and geological data that have been used by various researchers to reconstruct the Caspian Sea level[11, 17, 18, 33] have also supported our interpretation (Table 4). Although it is difficult to convert historical descriptive data into numerical data (such as sea levels), but historical data are very valuable for calibrating geological results as they provide a detailed history of major events occurred in the Caspian Sea (The problem arises from the type of these observations, the type of interpretation, and the extent to which these observations are assured). However, using MS curves with other data, including geological and historical data, can be a suitable idea for the reconstruction of marine environments, especially near the coastal area where reconstruction of the sea level is facing challenges.

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References

1 Crick, R.E., Ellwood, B.B., Feist, R., El Hassani, A., Schindler, E., Dreesen, R., Over, D.J. and Girard, C., Magnetostratigraphy susceptibility of the Frasnian/ Famennian boundary. *palaeogeography, Palaeoclimatology ,Palaeoecology, 181(2002)* 67-90.

2 Ellwood, B.B., Tomkin J.H, Ratcliffe K.T., Wright, M., Kafafy, A.M., High-resolution MSand geochemistry for the Cenomanian/Turonian boundary GSSP with correlation to time equivalent core. *Palaeogeography, Palaeoclimatology, Palaeoecology, 261 (2008)* 105-126.

3 Mead. G.A., Lisa, T., LaBrecque J. L., Oligocene paleoceanography of the South Atlantic: Paleoclimatic implications of sediment accumulation rates and MS measurements. *Paleoceanography, 1(3) (1986)* 273-284

4 Williams, B.C., Gatti, M., Goldberg, M.L. Bipolar spindle attachments affect redistributions of ZW10, a Drosophila centromere kinetochore component required for accurate chromosome segregation. *Journal of. Cell Biology, 134(5) (1996)* 1127-1140.

5 Sun, F.L., Cuaycong, M., Craig, C.A., Wallrath, L.L., Elgin, S.C.R. Toward an analysis of the fourth chromosome: interspersed euchromatic and heterochromatic domains *A. Dros. Res. Conf, 39 (1998)* 775p.

6 Ellwood, B.B., Garcia-Alcalde, J.L., EL Hassani, A., Hladil, J., Soto, F.M., Truyols-Massoni, M., Weddige, K., & Koptikova, L., Stratigraphy of the Middle Devonian boundary: formal definition of the susceptibility magnetostratotype in Germany with comparisons to sections in the Czech Republic, Morocco and Spain. *Tectonophysics, 418 (2006b)* 31-49.

7 Febo, L.A., Ellwood, B.B. and Watkins, D.K., Detrital controls on magne to susceptibility and cyclostrati graphyrecords. In: Ellwood, B.B., Tomkin, J.H. Ratcliffe K.T., Wright M. and Kafafy A.M. (Eds.). High-resolution MS and geochemistry for the enomanian/Turonian boundary GSSP with correlation to time equivalent core. *Palaeogeography, Palaeoclimatology, Palaeoecology, 261 (2007)105-126.*

8 Kakroodi, A.A., Rapid Caspian Sea-level change and its impact on Iranian coasts, PhD thesis, *Delft University, Netherland. (2012)* 121 pp.

9 Sharbati, S., Hosseni, S., Taghizadeh, V., Imanpour, M. and G orgin, S.,Two dimentional modeling in Gorgan Bay Currents influence by sea level changes and wind pattern changes, proceeding of first conference of Caspian sea ecology. *NRCES (2010)*.

10 Varushchenko, S.I., Varushchenko, A.N., & Klige, R.K., Changes in the regime of the Caspian Sea and closed basins in time. *Moscow*, *Nauka, (1987)* 240 p.

11 Mamedov, A.V., The late Pleistocene-Holocene history of the Caspian Sea. *Quaternary International, 41/42 (197)* 161-166.

12 Rychagov, G.I., Holocene Oscillations of the Caspian Sea and forecasts based on paleogeographical reconstructions. *Quaternary International*, *41/42 (197)* 167-172.

13 Kroonenberg, S.B., Badyukova, E.N., Storms, J.E.A., Ignatov, E.I., & Kasimov N.S., A full sea-level cycle in 65 years: barrier dynamics along Caspian shores. *Sedimentary Geology, 134 (2000)* 257-274.

14 Leroy, S.A.G., Marret, F., Gibert, E., Chalie, F., Reyss, J.L., &Arpe, K., River inflow and salinity change in the Caspian Sea during the last 5500 years. *Quaternary Science Reviews, 26 (2007)* 3359-3383.

15 Lahijani, H., Rahimpour-Bonab, H., Tavakoli, V., & Hosseindoost, M., 2007. Evidence for late Holocene highstand in Central Gilan - East Mazanderan, South Caspian coast, Iran. *Quaternary International, 197 (2009)* 55-81.

16 Leroy, S. A. G., Lahijani, H. A. K., Djamali, M., Naqinezhad, A., Moghadam, M. V., Arpe, K., Shah-Hosseini, M., Hosseindoust, M., Miller, C. S., Tavakoli, V., Habibi, P., and Naderi, M., Late Little Ice Age palaeoenvironmental records from the Anzali and Amirkola lagoons (south CS): vegetation and sea level changes: *Palaeogeography, Palaeoclimatology, Palaeoecology,*302 *(2011)* 415-434.

17 Kakroodi, A. A., Kroonenberg, S. B., Hoogendoorn, R. M., Mohammd Khani, H., Yamani, M., Ghassemi, M. R., and Lahijani, H. A. K., Rapid Holocene sea level changes along the Iranian Caspian coast, *Quaternary International, 263 (2012)* 93-103.

18 Naderi Beni, A., Lahijani, H., Moussavi Harami, R., Leroy, S. A. G., Shah-hosseini, M., Kabiri, K., and Tavakoli, V., Development of spit-lagoon complexes in response to Little Ice Age rapid sea level changes in the central Gilan coast, South CS, Iran, *Geomorphology, 187 (2013)* 11-26.

19 Hoogendoorn, R.M., Boels, J.F., Kroonenberg, S.B., Simmond, M.D., Aliyeva, E., Babazadeh, A.D., & Huseynov, D., Develop of Kura delta, Azarbaijan; a record of Holocene Caspian sea-levelchanges. *Marine Geology, 222-223 (2005)* 359-380.

20 Kazanci, N., Gulbabazadeh T. and Ileri O.,. Sedimentology and Environmental characteristics at theGuilan-Mazenderan plain, northern Iran; influence of long- and short-term Caspian level fluctuations on geomorphology.*Marine Systems, 46 (2004)*154-168.

21 Zenkovich, V.P., Structure of the South-East Coast of the Caspian Sea. USSR Academy of Sciences,*Oceanographic Commission Works, 2 (1957)* 1-4.

22 Voropaev, G.V., Krasnozhon, G.E., & Lahijani, H., Riverine sediments and stability of the Iranian coast of the Caspian Sea. *Water Resources, 2 (1998)*2747-758.

23 Ellwood, B.B., Balsam, W.L. and Roberts, H.H., Gulf of Mexico sediment sources and sediment transport trend from MS measurements of surface samples, *Marine Geology 230 (2006a*) 237-248.

24 Ellwood, B.B., Petruso K.M. and Harrold F.B., The utility of MS for detecting palaeoclimate trends and as a stratigraphic correlation tool. *Journal Field Archaeol, 23 (1997)* 263-272.

25 John, A. Dearing., Environmental magnetic susceptibility using the Bartington MS 2 system, *British Library Cataloguing in Publication Data. (1999)* 54p.

26 Haghani, S., Amini, A.H., Alizadeh, H., Leroy, S., Application of MSof Holocene deposits in survey on Caspian sea-level fluctuation, *EGU General Assembly conference, (2010)* .Vienna, Austria

27 Haghani, S., Amini,A., Lahijani, H., Leroy, S.,. Application of MS of Holocene deposits in survey on Caspian Sea-level fluctuation, *Journal of Iranian Geology, 5(19)(2010)* 81-92.

28 Abrantes, A., Pinto, F. & Moreira, M., Ecology of Polychaete Nereis diversicolor, in the Canal de Mira (Ria de averio, Portugal). Population dynamics, production and oogenic cycle. *Acta Oceanology, 20 (4) (1999)* 267–283.

29 Heiri, O., Lotter, A. & Lemcke, G., Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of Paleolimnology, 25 (2001)* 101-110.

30 Leroy, S. A. G., Kakroodi, A. A., Kroonenberg, S. B., Lahijani, H.A. K., Alimohammadian, H., and Nigarov, A.: Holocene vegetation history and sea level changes in the SE corner of the Caspian Sea: relevance to SW Asia climate, *Quaternary Sci. Rev, 70 (2013)*28-47.

31 Karbassi, A.R and Amirnezhad, R. Geochemistry of heavy metals and sedimentation rate in a bayadjacent to the Caspian Sea, *International Journal of Environmental Science &Technology,1(4) (2004)* 191-198.

32 Amini, A., Harami, R.M., Lahijani, H.K., Mahboubi, A., Holocene Sedimentation Rate in Gorgan Bay and Adjacent Coasts in Southeast of Caspian Sea. *J. Basic. Appl. Sci. Res, 2(1) (2012)* 289-297.

33 Bruckner, E., Klima-Schwankungenseit 1700: nebst Bemerkungen ¨uber die Klimaschwankungen der Diluvialzeit, E. Holzel, 1890.Dearing, J. A.: *Environmental magnetic susceptibility using the Bartington MS system, (1999).*

34 Jiménez, C.; Benavides, J.; Ospina-Salazar, D.I.; Zúñiga, O.; Ochoa, O.; Mosquera, C. Relationship between physical properties and the MS in two soils of Valle del Cauca. Rev. *Cienc. Agri,34(1) (2017)* 33-45.

35 Xin Zhou, Liguang Sun, Wen Huang, Yi Liu, NanJia, Wenhan Cheng., Relationship between MSand Grain Size of Sediments in the China Seas and its Implications. *Continental Shelf Research*,72 *(2014)*131-137.

36 Frolov, A.V.,. Modeling of the Long-Term Fluctuations of the Caspian Sea Level; Theory and Applications. *MoscowGOES, (2003)* 172 p.

37 Karpychev, Y. A.: Dating of Regressive Stages in the Caspian Sea Using 14C, *Vodn. Resur, 25 (1998)* 274-278.

38 Kroonenberg, S.B., Abdurakhmanov, G. M., Aliyeva, E. G., Badyukova, E. N., van der Borg, K., Hoogendoorn, R. M., Huseynov, D., Kalashnikov, A., Kasimov, N. S., Rychagov, G. I., Svitoch, A. A., Vonhof, H. B., and Wesselingh, F. P.: Solarforced 2600 BP and Little Ice Age high-stands of the CS, *Quaternary International, 173/174 (2007)* 137-143.

39 Naderi Beni, A., Lahijani, H., Moussavi Harami, R., Leroy, S. A. G., Shah-hosseini, M., Kabiri, K., and Tavakoli, V., Development of spit-lagoon complexes in response to Little Ice Age rapid sea level changes in the central Gilan coast, South CS, Iran, *Geomorphology, 187 (2013)* 11-26.

40 Klige, R. K., Myagkov, M. S.,1997. Changes in the water regime of the Caspian Sea. *Geo Journal 27 (1997)* 299.