Rapid Holocene sea-level changes along the Iranian Caspian coast

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Abstract

The Caspian Sea is well-known for its rapid sea-level change. During 1929–1995, a full sea-level cycle was observed. First, the sea level dropped ~3 m with a lowstand in 1977, followed by a 3 m rise to 1995, after which the sea level has been relatively stable. These oscillations are a specific feature of the Caspian Sea and its sedimentary record. The main purpose of this study is to reconstruct the sea-level curve in the Holocene by using sedimentological and biostratigraphic analysis and radiocarbon dating along the Iranian part of the Caspian shore. Remote sensing images and historical maps show that two lagoons totally emerged, and the Gorgan delta prograded rapidly at a rate of around 160 m y−1 until the 1975 lowstand. Gorgan Bay was reduced in size considerably and the connection to the sea was blocked due to growth of a spit and change in base level. When sea level started to rise again, the coastal morphology rapidly changed and the Gorgan delta retrograded at the rate of around 140 m y−1. These sedimentary dynamics can be recognized in the preserved deposits. In addition to the recent dynamics, core data from the southeastern lowlands show four earlier highstands. Using characteristic barrier-lagoon deposits, early Holocene sea level rose until a highstand was reached of ca. ~34 m. This phase was followed by fluvial deposition in the Gorgan delta associated with a base level fall. There is also an evidence of sea-level rise between 5000 and 2300 BP at ca. ~27.7 m. On top of these deposits there is evidence of a highstand between 2700 and 2300 BP at ca. ~23.5 m. The fourth highstand from the core data is dated to the Little Ice Age at ca. ~24 m. Data from these last two highstands correspond well with other observations from the Caspian region.

1. Introduction

In recent years, many researchers have studied the rapid Caspian Sea-level changes in modern and Holocene times (Kaplin and Selivanov, 1995; Kroonenberg et al., 1997, 2000, 2007; Mamedov, 1997; Rychagov, 1997; Dumont, 1998; Overeen et al., 2003; Hoogendoorn et al., 2005). However, there is little published literature about the dynamics of the Caspian Sea along the Iranian coast (Kazanci et al., 2004). This paper aims to add information towards closing this gap. The study area is located along the southeast Caspian Sea (Fig. 1).

The South Caspian Basin, with a maximum depth of 1025 m, is the deepest section of the Caspian Sea. Present sea level of this inland water body is about 27 m below global sea level. The sea has virtually no tides and salinity of its water is around 13 mg l−1. The southeastern shores of the Caspian Sea have a semi-arid climate. The mean annual precipitation is 350 mm, ranging from 250 to 550 mm. The relative humidity in the coastal zone ranges from 63% to 90% with an average of 76%. The average maximum temperature is 22.3°C, ranging between 12.4°C and 31.8°C in January and August respectively. The average of minimum temperature is 13°C with a range between 3.2°C and 24.3°C in January and August respectively.

In the Quaternary, sea-level cycles of five orders of magnitude have been identified, with a range between at least ~50 m asl during the last Glacial and ~113 m during the early Holocene (Varushchenko et al., 1987; Kroonenberg et al., 1997, 2000). Holocene sea-level history as reconstructed by Rychagov (1977, 1997) from marine terraces along the Daghestan coast, showed five transgressive phases dated around 8000, 7000, 6000, 3000 and 200 BP. The causes of the Caspian Sea-level changes are not well-known. Changes in water input from major drainage basins as
a result of climate changes and tectonic fluctuations are among the favoured causes suggested by many researchers (Arpe et al., 2000).

The amplitude of the sea-level changes in the late Holocene has been estimated up to 25 m (Varushchenko et al., 1987; Rychagov, 1993a, 1993b, 1997; Kroonenberg et al., 1997; Hoogendoorn et al., 2005), and the Pleistocene amplitude was much higher. The latest sea-level cycle occurred between 1929 and 1977 when sea level dropped by \(-3\) m, and from 1977 to 1995 (Fig. 2), it rose at a rate of 15 cm y\(^{-1}\) (Kaplin and Selivanov, 1995). The latest two high-stands occurred at ca. 2600 BP and during the Little Ice Age (Kroonenberg et al., 2007). The Derbent regression, around 1500 BP, reached a minimum of at least \(-32\) m. The highest level reached by the Caspian Sea during the Holocene is around \(-22\) m (Hoogendoorn et al., 2005). Along the Iranian coast, three high-stands during the Late Holocene were identified with ages of 2500, 900 and 500 BP. These highstands correspond to sea levels of \(-22\), \(-24\) and \(-25\) m, respectively (Lahijani et al., 2009). However there is no consensus due to questionable sampling strategies and lack of numerical dating methods (Svitoch et al., 2006; Kroonenberg et al., 2007).

In this paper, the evolution of the Caspian Sea level is examined through the sedimentary record. The investigated samples have a time range from the early to the late Holocene. Using the interpretations from the cores and the dates, this paper presents an improved Holocene sea-level curve based on sedimentological, biostratigraphic analysis and radiocarbon dating from outcrops and core samples. This work was done within the framework of UNESCO-IGCP 481 project Dating Caspian Sea-level change. The paper also aims to show the coastal response during the last cycle of the Caspian Sea-level change.

![Fig. 1. Maps show the location of the study area near Gomishan. Image a shows the regional setting while image b shows the general morphology of the Southern Iranian coast. Fig. 3 shows details of the inset in Fig. 1b.](image)

![Fig. 2. Caspian Sea curve since 1850. Source: National Iranian Oil Company compiled by A. Jafari.](image)
2. Geological setting

The study area comprises the southeastern Iranian part of the coastal plain of the Caspian Sea. The area is contained between two major mountain ranges, the Alborz in the south and Kopeh Dagh in the east and northeast (Fig. 1). Both Alborz and Kopeh Dagh ranges were uplifted since mid-Cenozoic times as a result of shortening between the Eurasian and Arabian plates. Tectonically the coastal plain forms part of the South Caspian Basin, which is underlain by oceanic crust. In this respect it resembles the Black Sea and the eastern Mediterranean, both of which are also thought to be oceanic remnants now caught up in continental collision zones (Jackson et al., 2002). The South Caspian Basin is rapidly subsiding since 5.5 Ma at a rate of 0.44 mm y$^{-1}$ (Allen et al., 2002), or even 2.5 mm y$^{-1}$ (Inan et al., 1997). A major component of the eastern part of the basin fill is the up to 2500 m thick Pliocene sedimentary sequence ("Coloured Series", in Turkmenistan) which consists of deltaic deposits of the Paleo-Amu-Darya river that discharged during a deep regression in the Pliocene (Torres, 2007). These are the main reservoir rocks for oil and gas in western Turkmenistan. These deposits were folded in Late Pliocene times, bounded by an unconformity and overlain by Plio–Pleistocene marine deposits of the Akchagyl transgression (Torres, 2007). Mud volcanoes of the Southern Caspian basin are closely related with the high sedimentation rates and subsidence of the orogenic systems of the Greater and Lesser Caucasus (Huseynov and Guliyev, 2004).

While the southwestern and southern Caspian shelves in Iran have steep offshore slopes and corresponding steep coasts, the offshore gradient in the southeastern Caspian is gentle, which correlates well with the gentle gradient onshore. As tides are negligible in the Caspian Sea, waves, marine currents, coastal nearshore morphology and rapid sea-level change are the most important factors that control coastal morphology. Low-angle coast and especially major coastal plains such as the present study area are the most suitable areas to reconstruct former transgressional coastlines, using remote sensing images and field data. Former delta outlines, former barrier-lagoon complexes and marine terraces are typical features indicating former highstands of the Caspian Sea (Fig. 3).

The southeastern Caspian coastal plain is dissected by the Atrak, Gorgan, and Qareh Su rivers. The Gorgan River system originates from the arid mountains in Golestan, Semnan and Khorasan Provinces. The catchment is approximately 12,600 km$^2$ and the main Gorgan River is approx. 350 km long. Its annual water discharge is around 448 million m$^3$, and the annual sediment load is 1.336 million t (Mister, 2001). The Gorgan River deposited a wave-dominated delta in the southeastern Caspian Sea during sea-level fall. It first discharged further south into Gorgan Bay, a freshwater lagoon situated in the southeastern corner of the Caspian Sea, connected to the sea via a narrow strait. During the last 500 years, the Gorgan river mouth migrated northwards to its present position (Fig. 3).

Gorgan Bay is largely separated from the main Caspian water body by an elongated barrier system, the Miankaleh Peninsula. Another lagoon, Hassan Gholi Bay, was a dominant feature in the study area until 1890, before the start of the latest major drop in the sea level (Fig. 6).

3. Materials and methods

Remote sensing data (ASTER and LANDSAT), image processing techniques, old maps (1890) and field observations were used to show delta progradation and recent coastal evolution, as well as the impact of the last sea-level cycle between 1929 and 1995. All remote sensing data were georeferenced using the UTM Projection. Coordinates of the studied sites were determined using a DGPS device which is based on the Persian Gulf mean water level. To establish the Holocene sea-level curve, outcrop data were collected along the river cuts and suitable old marine cliffs. Coring sites were selected based on experience and fieldwork in this area. Using a mobile drilling machine, four cores up to 19.7 m were obtained during 2006 and 2007 fieldwork. Samples were taken at 60 cm intervals with plastic tubes (diameter 5.5 cm). The cores were split and subsampled for grain size, X-ray diffraction (XRD) and qualitative microfossil analysis.

The lithological descriptions of the cores were used to interpret the depositional environments. Lagoonal deposits are mainly dark reddish sand and abundant shell fragments. Marine deposits are generally characterized by bivalves, mostly *Theodoxus pallasi*. Barrier deposits are characterised by well-sorted, brown to reddish sand and abundant shell fragments. Marine deposits are generally characterized by bivalves, mostly *Cerastoderma*, shell fragments, gastropoda, and marine microorganisms. High mica contents in fluvial and coastal sediments may point to a provenance...
from aeolian deposits, notably from loess deposits in the northeastern Iranian coast. Fluvials deposit are mostly brown sand, silt and clay with plant fragments and roots, and terrestrial gastropoda with weathering traces, and peat.

4. Coastal plain development since 1850

The last cycle of the Caspian Sea totally changed the coastal morphology (Fig. 3). The impact of the recent sea-level cycle will be discussed for the four coastal types in the area: Miankaleh spit; Gorgan Bay; Gorgan River Delta; and Hassan Gholi Bay.

The most prominent morphological feature in the southeastern Caspian Sea is the Miankaleh spit which is around 60 km long. Both the length and width of this spit varied during the last sea-level cycle. During sea-level fall between 1929 and 1975, the spit grew eastwards and increased in size, and almost connected with the mainland (Fig. 4). During sea-level rise after 1975, the spit was broken into several islands and also decreased in width.

The major freshwater input into Gorgan Bay is through the Qareh Su River in the east. During sea-level fall the mouths of the Qareh Su and smaller rivers that discharge into Gorgan Bay prograded into the bay at the rate of ~60 m y⁻¹, large muddy areas emerged, and the bay surface area decreased to 323 km² in 1975 (Table 1). The southern coast of Gorgan Bay has a much steeper slope than its eastern coast. During sea-level rise, Gorgan Bay grew and covered 531 km² in March 2004 (Table 1).

The Gorgan delta prograded since 1890 at a rate of around 160 m y⁻¹ until the 1977 lowstand. The Gorgan delta retrograded landward during rapid sea-level rise between 1977 and 1995 (Fig. 5). On the basis of field observations and SRTM imagery, the Gorgan River seems to have first discharged directly in Gorgan Bay and shifted later to the north. However, tectonic subsidence and sediment compaction leading to delta lobe switching may also have played a role furthermore; rapid sea-level change can accelerate shifting of the delta.

North of the Gorgan delta in the Gomishan area, a large inland lagoon, the Hassan Gholi Bay, existed at least until 1890 (Fig. 6). The narrow southernmost part of the lagoon was separated from the sea by a spit formed by a northward longshore current, similar to the Miankaleh spit. Further north the lagoon penetrated deeply into the coastal plain, and contained a small delta of the intermittent Atrak River. During sea-level fall between 1929 and 1977, the whole lagoon dried out, the coastline shifted kilometers seaward and narrow parallel sand barriers accreted to the coast. Around 642 km² of the sea bottom emerged.

During rapid sea-level rise after 1977, the sand barriers were breached and a new lagoon was formed behind the sand barriers. The plume of Gorgan River sediment travels northwards by longshore current and penetrates into the lagoon through breaches in the barriers (Fig. 7), feeding the area with fine grained sand.

5. Stratigraphy and paleogeography of the Holocene coastal plain

On remote sensing imagery, but also in the field, elements of paleo coastlines can be observed, including a series of NE-trending barriers between the villages of Bagho and Niaz; a lobate shape associated with a paleo Gorgan delta near the village of Chopaghli (Fig. 8), 4 km inland from the present coast; and a north to northeast trending barrier east of the town of Gomishan, 8–16 km land inward from the present coast (Fig. 3).

The paleo shoreline in the north of Gomishan indicates a former sea-level highstand. A large area emerged during sea-level fall similar to the last sea-level cycle, probably showing the maximum extension of the old Hassan Gholi Bay (Fig. 3). Based on the topographic map, the elevation of these shore lines is around ~24 m. Even 15 km east of the present coastline, marine deposits can be found in cores (discussed below). These data suggest that the southeastern corner of the Caspian Sea extended much farther eastwards than at present. This area was selected for a detailed outcrop study and acquisition of core data, because it was expected to show an alternation of marine and fluvial deposits related to Caspian Sea-level changes in the past. Furthermore, outcrop data were obtained from the delta of the Nokandeh River at the southern shore of Gorgan Bay, which shows a similar development as the Gorgan delta. The marine deposits recorded in the Bagho outcrop.

<table>
<thead>
<tr>
<th>Year</th>
<th>Area (km²)</th>
<th>Sea level (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>323</td>
<td>29</td>
</tr>
<tr>
<td>1987</td>
<td>439</td>
<td>-27.5</td>
</tr>
<tr>
<td>2004</td>
<td>531</td>
<td>-26.5</td>
</tr>
</tbody>
</table>

Fig. 4. Gorgan Bay reaction against the last cycle of the Caspian Sea extracted from Landsat MSS image. Note the growth of the spit during sea-level fall and increasing of Gorgan Bay in size during rapid sea-level rise. The dotted line shows decrease of Gorgan Bay depth during sea-level fall in 1975. Arrows indicate predominant longshore current.
probably stretched from the southern Gorgan Bay area (Nok outcrop) to the paleo shoreline northeast of Gomishan (Fig. 3) showing a major highstand. The ridge indicative for the paleo shoreline as seen at the Bagho outcrop has been buried to the east by sediments from the Qareh Su and paleo Gorgan rivers (Fig. 3).

5.1. Outcrops and boreholes

(1) The "Has" outcrop is a roadcut ca. 60 cm deep at the lower part of the paleo Gorgan delta, about 5 km from its apex, at an elevation of around 23.16 m. It shows a lower layer of 25 cm of structureless brownish silty clay with rootlets, overlain by 20 cm of laminated olive clayey silt with abundant shells, and at the top structureless brownish silty clay with rootlets (Fig. 9).

(2) The "Niaz" outcrop at an elevation of 23.25 m is a small 60 cm deep terrace cliff in the floodplain of the Gorgan River, showing an upper sandy layer with bivalves and gastropods, and a lower layer with non-fossiliferous brown mud.

(3) The "Bagho" outcrop at 22.06 m is a 150 cm deep sandpit situated at the southwestern end of the old NE–SW trending barriers, east of Gorgan Bay. It consists of crossbedded coarse sand with abundant bivalves and gastropods. The lowermost 20 cm consists of dark grey clayey silt with bivalves and gastropods.

(4) The "Nokandeh" outcrops are steep river banks in the delta of the small Nokandeh River. Nokandeh 1 at around 23 m is 2 m thick and has coarse crossbedded sand with abundant bivalves at its base, followed by an alternation of fine sand and brown silty clays with rootlets, and fine fossiliferous sand at the top. Nokandeh 2 at around 25 m, close to Gorgan Bay coastline, consists of alternation of fine pebbly sands with bivalves and gastropods.

![Fig. 5. Gorgan delta progradation from 1890 to 1975 and the regression from 1975 until 2004 during rapid sea-level rise. There was no image available for 1995.](image1)

![Fig. 6. The old Hassan Gholi Bay during high (a) and lowstand (b). Note that two lagoons emerged during rapid sea-level fall.](image2)
Fig. 10 presents the boring logs and the dated Bagho outcrop.

(1) Gm1 at elevation of -20.61 m, situated farthest onshore in the floodplain of the Gorgan River, consists of fine laminated gray mud and partly mottled mica-rich silt at the base (between 19.7 and 14.2 m) with abundant ostracods and foraminifera, structureless brown clayey silts in the middle, rich in root and plant fragments, and at the top alternating fine sands, silts and silty clays. It contains an evaporite layer with gypsum, dolomite and calcite at 15.6 m and a peat layer at 2.5 m depth.

(2) Gm2 core, taken at 200 m of Gm1 at a similar elevation, consists of alternating fine sand and gray fine silty clay layers with shell fragments at the base, in the middle dominated by brown silts with some gray shell laminae and plant fragments. Between 6 and 2.5 m depth is gray fine sand with two organic-rich layers, the lower layer containing gastropods. The top layer consists of brown mud and laminated fine sand with rootlets and plant fragments.

(3) Agh core is located at -23.02 m in the Gorgan river floodplain, close to the present shoreline. It consists of at least three beds of reddish coarse sand with abundant shell and gastropoda fragments, alternating with olive to brown clay and laminated dark clay with organic matter. The top horizon consists of gypsiferous brown clay.

(4) Cho core at -24.16 m shows structureless fine to medium sand and laminated dark clay with bivalve and shell fragments in the base and the middle of the core. At the top it shows mainly brown clay interbedded by olive silty deposits. Brown clay contains roots and plant fragments and has a high gypsum content.

5.2. Sedimentary environments

The sedimentary environments have been interpreted from different logs as follows:

(1) Gm1: The dominantly laminated silty deposits at the bottom until 15 m below surface (bs) depth contain abundant brackish water ostracods (mainly Cyprideis) and brackish water foraminifera, mostly Elphidium and few Ammonia beccarii. Mottling and evaporates, e.g. at 15.4 m, indicate temporary emergence and subaerial exposure. The abundance of mica probably
indicates that these marine silts are at least partly reworked aeolian deposits. The dark organic-rich clay with abundant gastropoda (*Theodoxus*) and shell fragments at 14.1 m depth probably represents the first lagoonal deposits. This lagoonal deposit is overlain by a thin olive clayey silt layer with abundant shell fragments. At the top, at 13.8 m depth, it is overlain by brown mud with plant fragment, roots and gypsum crystals, but without any marine organisms, probably deposited in a fluviodeltaic environment. Between 12.4 m and 8.40 m, dark clayey silt with shell fragments and bivalves occur and probably represent reworked fluvial deposits. Dark gray silty clays between 6 m and 2.5 m are rich in organic matter, Gastropoda, bivalve and shell fragments, indicating lagoonal deposits. X-ray diffraction analyses of four samples show quartz, calcite, feldspar, dolomite, mica and gypsum as main detrital and diagenetic minerals. Among the clay minerals illite and chlorite dominate. Montmorillonite only occurs in the top meters of the core but is absent from the bottom part.

(2) Gm2 shows much similarity to Gm1, with dark silty clay rich in Gastropoda (mostly *Theodoxus*) and bivalves (*Cerastoderma*) at 5.0 m and 2.5 m depth as observed in Gm1. However, this core shows more fine sandy layers, located between 12 and 14 m and between 3 and 5 m depth. Because of the absence of marine fauna, these deposits are interpreted as fluvial sediments deposited by the Gorgan River.

(3) Agh: At the base of the core slightly mottled olive clayey silts rich in bivalves and shell fragments occur, with intercalations of well-sorted, coarse and medium reddish brown shell-bearing sand layers (Fig. 11). The sands were probably deposited in a beach or barrier environment. The uppermost part shows brown silt and mud with plant remains, indicating a fluvial origin. The content of gypsum strongly increases towards the top of the core.

(4) Cho: The Cho core consists at the base, between 7.0 and 3.0 m depth, structureless gray fine sand, containing bivalves, mostly *Cerastoderma*, with intercalations of shell-bearing laminated organic-rich dark clay with plant remains. Between 3.0 m and the surface, sediments are mottled silt and mud, interbedded with coarse sand with bivalves, shell and gastropoda fragments. The whole core probably represents a nearshore barrier—lagoonal complex.
5.3. Radiometric dating

Seven samples from the cores and the Bagho outcrop were selected for radiocarbon dating. The results of these analyses, location of the cores, and the type of samples are shown in Table 2. Samples were selected carefully and only double-valved molluscs were considered for analysis, in order to avoid sampling reworked specimens that yield an overestimation of the actual age of the deposits (Svitoch et al., 2006; Kroonenberg et al., 2007). The shell samples were also checked for possible recrystallization.

The sample radiocarbon dating process was carried out by Oxford (UK) and Poznan (Poland) laboratories. Same reservoir age correction was applied as used by Hoogendoorn et al. (2005) and Kuzmin et al. (2007). Calendar ages were obtained using intcal 09.14C and marine.09.14C software through Calib Rev 6.0.1 (Reimer et al., 2009). The ages obtained consistently increase with depth in the cores.

6. Discussion

6.1. Interpretation in terms of sea-level change

The oldest age obtained is from organic-rich lagoonal deposits in Gm1 at −34 m, 9737–10200 cal BP. This is plotted in the sea-level curve of Fig. 12. The fact that marine deposits occur below the organic horizon and contain an evaporite layer means that older, undated sea-level fluctuations are recorded here as well.

Apart from a short marine or lagoonal interval, fluvial deposits were deposited on top of the dated organic horizon showing that sea level had fallen after 9737–10,200 cal BP. Fluvial deposition continued at least until 6286–6524 cal BP, when a shell-bearing layer formed at ca. −28 m.

A third, undated, lagoonal deposit occurs in Gm1 at −26.61 m and at −23.5 m in Gm2. Accepting the 9737–10,200 cal BP and 556–670 cal BP (see below) ages from this core, the sedimentation rate of the core between −34 m and −23 m amounts to about 1.2 mm y−1. At this sedimentation rate the undated horizon would give an age of approximately 2710 cal BP. At about the same elevation, the lagoonal deposit from the Bagho outcrop has been dated at 2303 BP.

The Agh core is not easily correlated with data from the other cores and outcrops. Two radiocarbon dates obtained from the bottom and top of core ranged between 3145–3334 and 1821–1999 cal BP, indicating sea-level datum at −27.7 m and −25.1 m respectively, and a sedimentation rate of almost 2 mm y−1. Several cycles have been found between two radiocarbon dated shells and probably indicate more frequent base level changes of the Caspian Sea towards the present sea-level datum.

The uppermost lagoonal deposit in Gm1 at −23 m has been dated at 556–670 cal BP, and probably corresponds with a similar horizon in Gm2 at the same depth, and possibly as well as with the 504–615 cal BP age from a barrier deposit in the Cho core, although the elevation of the latter is much lower (−27.5 m).

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6.2. Correlation with data from other Caspian coasts

The first Caspian curve for the Holocene was presented by Rychagov (1977, 1997), based on dating of marine terraces along the western shore of the Caspian Sea in Dagestan. It was revised and supplemented with new data by Varushchenko et al. (1987), Karpychev (2001), Hoogendoorn et al. (2005, 2010) and Kroonenberg et al. (2008) (Fig. 12). These curves show a deep regression at the start of the Holocene, possibly as deep as −50 m. Varushchenko et al. (1987) mention −113 m asl on the basis of interpretation of bathymetric data, but Rychagov does not present...
age data for this period because lowstand deposits are not recorded in the marine terraces. Some dates on the Mangyshlak lowstand have been obtained by Bezrodnykh et al. (2004) from cores in the offshore Volga delta, around 7000–9000 BP. From an offshore borehole near the Kura delta, it appears that the Mangyshlak lowstand may have been as low as ~92 m (Kroonenberg et al., 2010). Furthermore, aeolian deposits in the Baer hills which were thought to have been deposited near the present-day Volga delta during the Mangyshlak regression give ages around 10000 BP (Svitoch et al., 1987, 1993). Core data obtained during the French INCO cruise in 1994 from the deepest parts of the Middle and southern Caspian Sea show a sharp transition between the Pleistocene and Holocene deposits at a model age of 10000 years (Chalié et al., in preparation). In the offshore Kura delta, a similar transition was dated at around 12000 BP (Kroonenberg et al., 2010). The available data concur in a deep regression around 10000 BP. Preliminary data from another dated core from the Iranian part of the SE Caspian Sea also give ages around 10,700 to 10,470 cal BP (Kakroodi et al., in preparation).

The marine deposit at the base of core Gm1, therefore, probably resulted from the initial sea-level rise in early Holocene after the deep Mangyshlak regression. The lagoonal deposit at 14 m depth in Gm1 probably represents a highstand deposit (Maximum Flooding Surface) at 9737–10,200 cal BP at ~34.61 m.

After maximum flooding, fluvial sedimentation started to predominate, probably from the Gorgan River delta, at least until 6286–6524 cal BP. This could indicate delta progradation as a result of sea-level fall. In another Iranian core close to the shore, there is evidence of subaerial exposure during this period down to at least ~43 m (Kakroodi et al., in preparation). Rychagov (1977, 1997) postulates highstands at about 6000 and 8000 BP. However, the data on which these highstands are of questionable reliability, as possibly reworked shell samples were used for dating. A 6400 BP mollusc sample in a marine terrace at ~20 m in the Talginka valley in Dagestan appears to have been sampled from a coarse gravelly deposit, which might be a reworked specimen (Rychagov, 1977). A mollusc with an age of 6445–6200 cal BP and an U–Th age of 6400 ± 300 from the Dzhorat settlement at ~28.0 m (?) in the Apsheron Peninsula, Azerbaijan (Rychagov, 1977; Varushchenko et al., 1987; Arslanov et al., 2002) are of uncertain stratigraphic and geomorphic position, and therefore cannot be taken as sea-level indicators. So at present there is insufficient evidence to postulate highstands between 8000 and 6000 BP.

In core Gm1 there is a shell-bearing layer at 8.40 m depth dated at 6236–6524 cal BP, intercalated between largely fluvial deposits. From the available data it cannot be concluded whether this represents a short-lived highstand as suggested by Rychagov (1977, 1997; Fig. 12) or a fluvial lag deposit consisting of reworked shells. From data obtained from an extensive coring programme in the Volga delta, numerous data points indicate a general sea-level rise between 5000 BP until a highstand at ~2300 BP (Kroonenberg et al., 2008; Hoogendoorn et al., 2010; Richards and Bolikhovskaya, 2010; Richards et al., 2011; Fig. 12). The data from barrier deposits at the bottom of the Agh core, 3145–3334 cal BP, indicate an age for another highstand which occurred during rapid sea-level rise between 5000 and 2300 BP (Fig. 12).

There is ample evidence for a highstand around 2600–2300 BP from various sources. In an outcrop at the western part of Gorgan Bay along the Iranian coast, Lahijani et al. (2009), present evidence of a highstand based on radiocarbon dating on in situ molluscs at 2480 and 2400 uncal BP. The new study of the Turali area that was investigated by Rychagov before (see above) shows a highstand at 2600 to 2300 BP with an absolute elevation ranging between ~24 and ~26 m (Kroonenberg et al., 2007). The data obtained from Baho, 2380 uncal BP and the top of the Agh core, 2303 uncal BP, independently confirm this highstand, although the calibrated date at the top of Agh core is younger. Mamedov (1997) and Karpychev (2001) conclude that a highstand occurred during this time interval. This highstand coincides with the humid period at the start of the Subatlantic, and is widely recognized in various archives (Van Geel et al., 1999).

The last group of younger highstand ages was obtained from the Daghestan coast, ranging between 299 and 837 BP uncal years with an absolute elevation of around ~24 m (Kroonenberg et al., 2007). These younger ages were also reported by Karpychev (1999), who obtained these ages from different sources. Along the Iranian Caspian coast, part of Anzali and Amircola lagoons, younger highstands

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### Table 2

<table>
<thead>
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<th>Sample ID</th>
<th>Elevation (m)</th>
<th>Depth (m)</th>
<th>Dated material</th>
<th>δ¹³C (‰)</th>
<th>¹³C age (BP)</th>
<th>Calendar age (cal BP)</th>
<th>Lab. No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co11</td>
<td>-22.06</td>
<td>-23.66</td>
<td>Organic matter</td>
<td>n/a</td>
<td>2380 ± 35</td>
<td>2339–2491</td>
<td>Poz-19943</td>
</tr>
<tr>
<td>Gm1</td>
<td>-20.61</td>
<td>-28.71</td>
<td>Shell</td>
<td>n/a</td>
<td>5990 ± 50</td>
<td>6286–6524</td>
<td>Poz-19944</td>
</tr>
<tr>
<td>Gm25.2</td>
<td>-20.61</td>
<td>-34.62</td>
<td>Organic matter</td>
<td>n/a</td>
<td>8890 ± 69</td>
<td>9737–10,200</td>
<td>Poz-19945</td>
</tr>
<tr>
<td>Gm6</td>
<td>-20.61</td>
<td>-23.23</td>
<td>Organic matter</td>
<td>n/a</td>
<td>650 ± 30</td>
<td>556–670</td>
<td>Poz-19885</td>
</tr>
<tr>
<td>Agh4</td>
<td>-23.02</td>
<td>-25.12</td>
<td>Shell</td>
<td>-8.01</td>
<td>2303 ± 30</td>
<td>1821–1999</td>
<td>OxA-17879</td>
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<tr>
<td>Agh7</td>
<td>-23.02</td>
<td>-27.72</td>
<td>Shell</td>
<td>-1.56</td>
<td>3369 ± 29</td>
<td>3145–3334</td>
<td>OxA-17880</td>
</tr>
<tr>
<td>Cho7</td>
<td>-24.16</td>
<td>-27.5</td>
<td>Shell</td>
<td>-0.69</td>
<td>956 ± 24</td>
<td>504–615</td>
<td>OxA-17882</td>
</tr>
</tbody>
</table>

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Fig. 12. New Caspian Sea curve of the Holocene, after Kroonenberg et al. (2008) and, Hoogendoorn et al. (2010), completed with data from this study.
occurred between 150 and 359 uncal years BP and also 290 and 440 y (Leroy et al., 1997). This highstand coincides with the Little Ice Age humid and cool period.

7. Conclusions

The southeastern part of the Caspian Sea in Iran shows rapid coastal evolution in comparison with other Iranian Caspian coasts. The gently sloping coast is characterized by barrier, spit and lagoon complexes and is very sensitive to sea-level fluctuations. Lagoons such as Hassan Gholi form during sea-level rise but are dry during sea-level fall. Moreover, local deltas experience major shifts in their position due to sea-level change. The Caspian Sea experienced a deep lowstand at the boundary between the late Pleistocene and the early Holocene, to at least –50 m. After this lowstand, sea level rose at least until 9737–10200 cal BP to a highstand at ~34.61 m. After this period, fluvial deposition in the Gorgan delta took over, until 6286–6524 cal BP. A layer of shell debris with that age at –28.71 m might represent a short-lived highstand but was not well represented in this data. The latest highstand occurred during the Little Ice Age, which according to the data reached ~24 m, dated at 504–615 and 556–670 cal BP. At that time the SE Iranian coast was situated considerably further east than at present.

Acknowledgments

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References


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