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SOLAR-FORCED 2600 BP AND LITTLE ICE AGE HIGHSTANDS OF THE CASPIAN SEA

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The researches combining a social, economic and ecological content, find out a generality of appendix area and global purpose. This purpose image is hidden behind the term "sustainable development". These restrictions are presented as the multiplicative index of the development. This index is reflecting an information balance of a territory.The level of the Caspian Sea, the largest inland sea in the world, has fluctuated capriciously in history, with amplitudes up to 3 m in the last century, to 25m in the last millennium, and to over 150m since the Last Glacial. The results suggest that the last major highstands occurred around 2600 BP and in the Little Ice Age and coincide with global cooling events associated with minima in solar activity. This suggests that millennial precipitation changes in the Volga River drainage basin are also forced by solar activity.

Исследования, включающие в себя социальное, экономическое и экологическое содержание, выявляют общность сопутствующих областей и глобальной цели. Эта цель скрыта за понятием "устойчивое развитие". Эти ограничения представлены как мультипликативный индекс развития. Этот индекс отражает информационный баланс определенной территории. Уровень Каспийского моря, наибольшего внутреннего моря в мире, сильно колебался в течение своей истории, с амплитудами до 3 м в прошлом столетии, до 25 м в последнем тысячелетии, и до более150 м начиная с Последнего Ледникового периода. Результаты показывают, что последние главные наслоения произошли приблизительно в 2600 г. до н.э. и в Малом Ледниковом периоде и совпадает с глобальным охлаждением, связанным с минимумами в солнечной активности. Это позволяет предположить, что тысячелетние изменения осадков в волжском речном бассейне также вызваны солнечной активностью.

Ключевые слова: солнечная активность, наслоения, Малый Ледниковый период, Каспийское море

1. Introduction

The Caspian Sea, a closed basin since 5.5 Ma ago, has experienced much more rapid sea-level changes than the world's oceans. Three times in the last century, Caspian shore dwellers were caught by surprise. In 1929, Caspian Sea level, until then rather stable at —26 m below oceanic level, unexpectedly started to drop strongly, over 2 m in less than 15 years. Harbours silted up, rivers extended their courses downstream, wetlands desiccated, and sturgeons hardly could reach their spawning grounds anymore, recalling disasters like that of the Aral Sea in the more recent past. Plans were made to divert northwards flowing rivers in northern Russia and Siberia towards the Caspian, and a dam was built to isolate Kara Bogaz Bay from the Caspian. Scientists predicted that sea-level fall would continue.

But in 1977, when sea-level had dropped already 3 m, the Caspian suddenly started to rise, at a rate of 13 cm/year, a hundred times the present eustatic sea-level rise in the oceans. Relief soon turned into concern. Villages were inundated, people had to evacuate, infrastructure built on recently emerged terrain was destroyed, soils suffered salinization, wildlife habitats drowned, and Kara Bogaz Bay was hastily reopened. Plans were made to divert sea water to the drying Aral lake. Scientists predicted that sea level would continue to rise. But in 1995 sea level, now back at —26 m as in the 1920s, suddenly started to drop again, stabilizing around —27 m in the last 10 years (Rodionov, 1994; Cazenave et al., 1997).

In longer time scales, Caspian sea-level oscillations are even more dramatic. During the last 8000 years, sea level fluctuated repeatedly with amplitudes up to at least 25 m, and it dropped even from a Last Glacial highstand at + 50m down to possibly -113 m in the early Holocene (Rychagov, 1977, 1997; Varushchenko et al., 1987; Rodionov, 1994; Kroonenberg et al., 1997; Hoogendoorn et al., 2005).

The causes of Caspian Sea-level change are as yet poorly understood. Influx from the Volga river accounts for 80% of the input side of the water balance, and evaporation at sea level is the main process on the output side (Klige and Myagkov, 1992). But in spite of the great advances in understanding of our climate system, in spite of the predictive power of our Global Circulation Models, in spite of the accurate monitoring by satellite systems such as Topex-Poseidon/Jason, opinions about future Caspian sea-level trends diverge.

Short-term cycles such as the 1929-1995 cycle may be forced by internal atmospheric processes such as the North Atlantic Oscillation or El Nino-Southern Oscillation (ENSO) (Kislov and Surkova, 1998; Arpe et al., 2000), or variations in solar activity (Meshcherskaya, 2001). However, whether these controls apply also for longer time scales cannot be properly validated because the instrumental record of sea-level change reaches back only to 1837. Some authors do not believe in climatic forcing altogether, invoking instead tectonics (Lilienberg, 1994), geochemical causes (Clauer et al., 2000), or chaotic behaviour (Naydenov et al., 1994).

In the past, many age data on pre-1837 highstands have been collected from historical and archaeological archives (Varushchenko et al., 1987), and from outcrops in marine terraces and incised valley fills (Rychagov, 1977, 1997; Svitoch, 1991). However, these data are very fragmentary and often contradictory, partly due to questionable sampling strategies and obsolete dating methods. Most of the radiometric ages published so far are over 30 years old, and were obtained by bulk 14C analysis on large samples of molluscs. As a result, that there is no consensus so far whether highstands record global warming (Velichko et al., 1988), global cooling (Zubakov and Borzenkova, 1990), or only regional effects (Rodionov, 1994; Meshcherskaya, 2001).

Lowstands are even more difficult to date. A lot of modern palaeoecological data have been obtained from cores from the Caspian Sea bottom (Jelinowska et al., 1998; Leroy et al., 2000; Boomer et al., 2005; Marret et al., 2004), but dating is difficult and they cannot be easily interpreted in terms of palaeobathymetry and sea-level.

2. Dating highstands in barrier complexes

One of the most reliable curves of Holocene sea-level change, based on age data alone and not on modelling was obtained by Rychagov (1977, 1997), mainly from outcrops along the Turali-Sulfat canal dug through the Novocaspian

(Holocene) barrier complex at the Turali-7 research station along the western Caspian coast in Dagestan, Russia (Fig. 1).

The Turali barrier complex consists of an 8 km long, 1.5 km wide complex of subparallel shellbearing sand and gravel barriers that have grown from the south into an open bay. At least five eastwards progradational phases have been recognised in the aerial photographs and in the field (Fig. 2), all with a SSE-NNW orientation slightly oblique to the present coast, and with a spit turning southwestwards at their northern extremity. Their top is situated at —21.5 m. A sixth phase, reaching to the —23.5 datum level, is strictly parallel to the present coast, cuts off the southern ends of the previous five phases and closed the bay off from the sea, thus creating the present-day Lake Bol'shoy Turali. The northern part of the barrier complex is covered by dunes. The present-day coast is formed by a narrow barrier-lagoon complex that formed after sea level started to rise in 1977 (Fig. 2).

Barrier complexes are particularly suitable to date highstands because of the nature of their dynamics, as has been observed during the last 1929-1995 Caspian sea-level cycle at this site (Kroonenberg et al, 2000; Storms et al., 2002). During sea-level fall, a widening strandflat and beach are exposed, surf produces low-angle seawards-dipping sand and gravel beds, and no lagoons are formed. As soon as sea level starts to rise, barriers are formed and a lagoon develops behind the barrier.

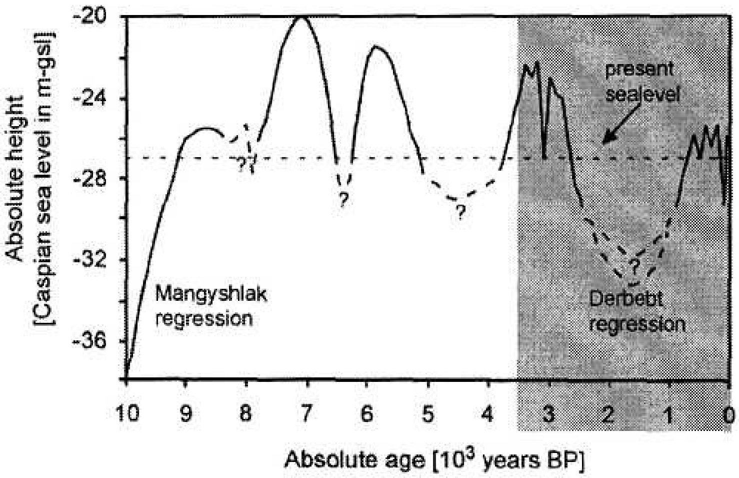

Fig. 1. Holocene sea-level curve of the Caspian Sea according to Rychagov (1977, 1997).

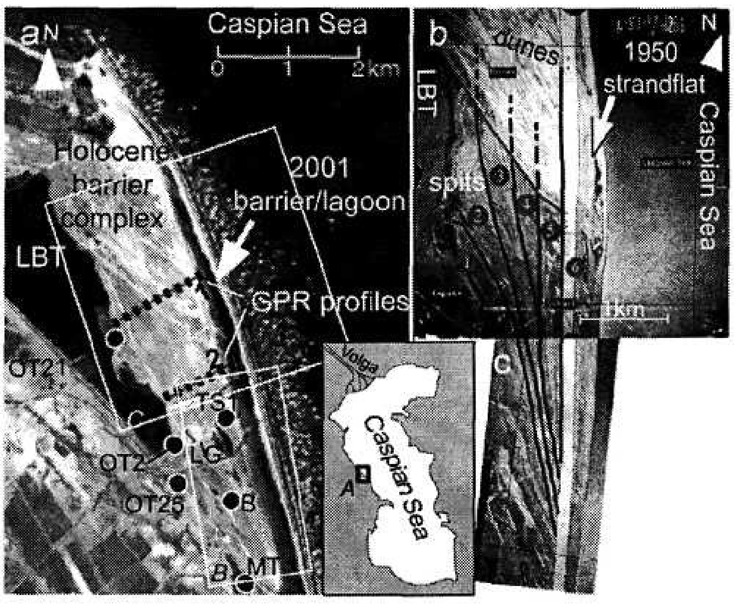

Fig. 2. (a) Location of Holocene barrier complex, 2001 barrier lagoon, GPR profiles (dated lines), outcrops (solid dots with OT and TS symbols) in ASTER image. LBT: Lake Bolshoy Turali. **(b), (c)** Detail same area in 1950 aerial photographs (for location see boxes), six

accretionary stages in the barrier complex, no lagoon along 1950 coast.

As long as sea level keeps rising, the barriers will move landwards due to washover processes during storms, and the lagoonal deposits are overridden by landwards-dipping washover deposits. Eventually, as sea level keeps rising and landwards encroachment of the barrier system continues, the erstwhile lagoonal deposits emerge at the shore face, and are eroded in the surf zone. Only when a highstand is reached, as in 1995, the lagoonal deposits become fossilised below the washover deposits. Top heights of the barriers themselves indicate the maximum storm wave height above the highstand. As sea level drops again, the lagoon dries out, a new strandflat proceeds seawards while the buried lagoonal deposits remain perched above the sea (Fig. 3, Kroonenberg et al., 2000). These overridden lagoonal deposits are the most suitable for obtaining highstand ages.

As long as salinity in the lagoons is not substantially lowered by run-off or groundwater input, they form a suitable habitat for brackish-water molluscs such as Cerastoderma glaucum, Didacna spp. and the mudsnail Ventrosia ventrosa (Yanina et al., 2005). In situ bivalves, recognisable by their vertical position and preservation of both valves, can be sampled from overridden highstand lagoonal deposits, dated, and their elevation and age approximately indicate the maximum sea level reached.

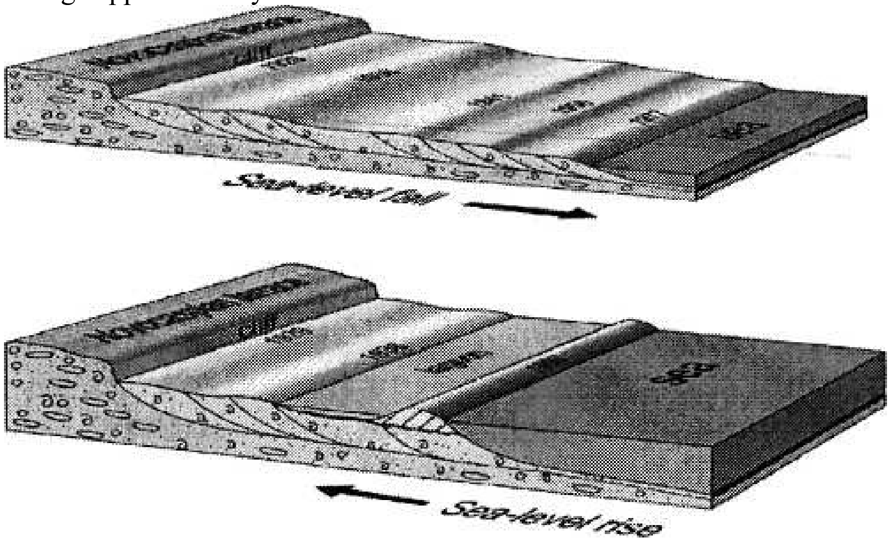

Fig. 3. Barrier dynamics during the full 3 m sea-lcvcl cycle of 1929-1995 AD, according to observations along the Turali coast, Dagestan. Note seaward dipping progradational strata in the strand flat and landwards dipping washover deposits in the barrier. Lagoonal deposits suitable for dating are those overridden by the last highstand barrier, in this case 1997. Modified after Kroonenberg et al. (2000).

Previous mollusc samples from the Turali barrier complex showed an inverted 14C age profile from 5600 BP on top, through 3300 and 1600 BP at the bottom (Rychagov, 1977, 1997). Those samples had not been obtained from lagoonal deposits but were large samples of at least 10 single valves each taken from coarse-grained barrier deposits which contained reworked material, as has been ascertained in the field together with the authors. Moreover, they were dated with conventional 14C techniques for which at least 50 g of shells had to be collected, thus increasing the risk of contamination. Even seemingly fresh mollusc samples from the modern beach gave conventional 14C ages up to 1700 BP. This suggests that also many other ages published in literature should be viewed with caution, the more so as often adequate descriptions of sample occurrences are lacking and possible errors are rarely discussed.

3. Field data

We returned to Turali barrier complex to obtain new data with adequate sampling and dating techniques. In 2001, the outcrops along the Turali-Sulfat canal were no longer visible, and therefore, we made two ground penetrating radar (GPR) profiles, 1465 m and 1080 m long across the complex, perpendicular to the coastline (Fig. 2), using Zond 12c equipment from Radar Systems, Inc., Latvia. The data were acquired with a screened 300 MHz antenna. The profiles consisted of sections of 45 m length, subdivided in sections of 15 m in order to correct for irregularities of observations in horizontal direction. The observations were made in continuous operation mode; the record length was equal to 200 ns. The interval between sounding stations was 3 cm on average. The acquired GPR data were processed in the following steps: (1) X-interpolation; (2) static correction to reveal the start of the record; (3) band-pass filtering to eliminate low-frequency and high-frequency noise; (4) conversion of time section into depth sections; (5) topographic correction. The maximum penetration depth is about 6 m.

In the GPR profiles, the same six growth phases could be established as in the aerial photographs. Highstands in each phase are characterised by the transition of landwards dipping washover lobes and seawards dipping progradational units, both overlying horizontal lagoonal strata (Fig. 4).

On the basis of the previous data and the GPR profiles, we sampled eight sites (outcrops, gravel pits, and borings). The most complete profiles are OT2 from the earliest, westernmost progradational phase 1, OT21 from phase 2 (Fig. 5), and TS 1 in which phase 5 deposits with a palaeosol are overlain by phase 6 deposits. Single bi-valved mollusc specimens were collected in situ from fine-grained lagoonal deposits for accelerator mass spectrometry (AMS) I4C dating and C, O, and Sr isotope analysis. Biogeochemical data are reported by Vonhof et al. (2004).

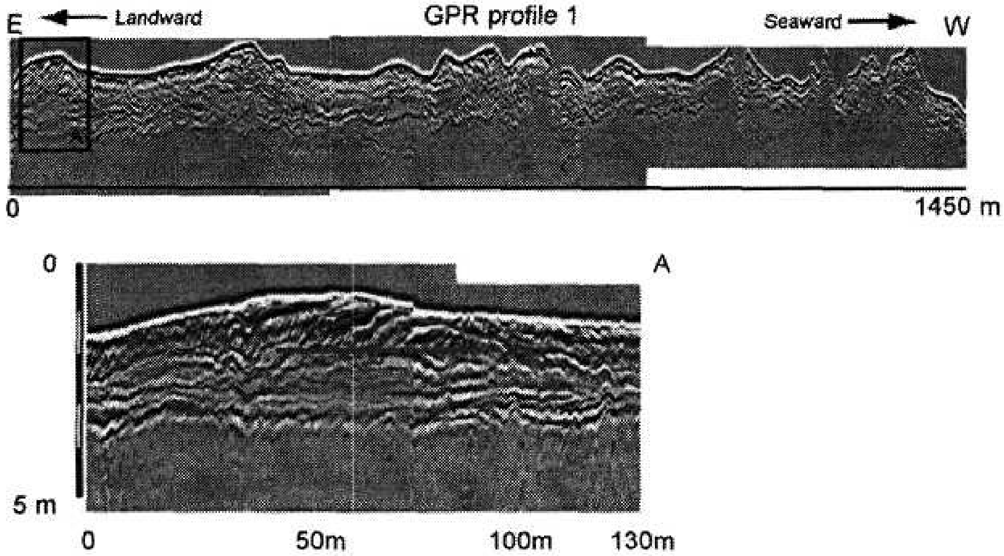

Fig. 4. Compressed GPR profile perpendicular to outcrop OT21 (Fig. 5) and detail (box A), showing landward (left) dipping washovcr lobes and seaward (right) dipping progradational stratification overlying horizontal lagoonal deposits. Signal disappears at depth due to saline groundwater. The velocity of the wave propagation at 300 MHz frequency and a permittivity of 6.25 relative to free space is about 0.12 m/ns. The wavelength for this configuration is 0.40m. Resolution is about one third of the wavelength, i.e., ~15cm.

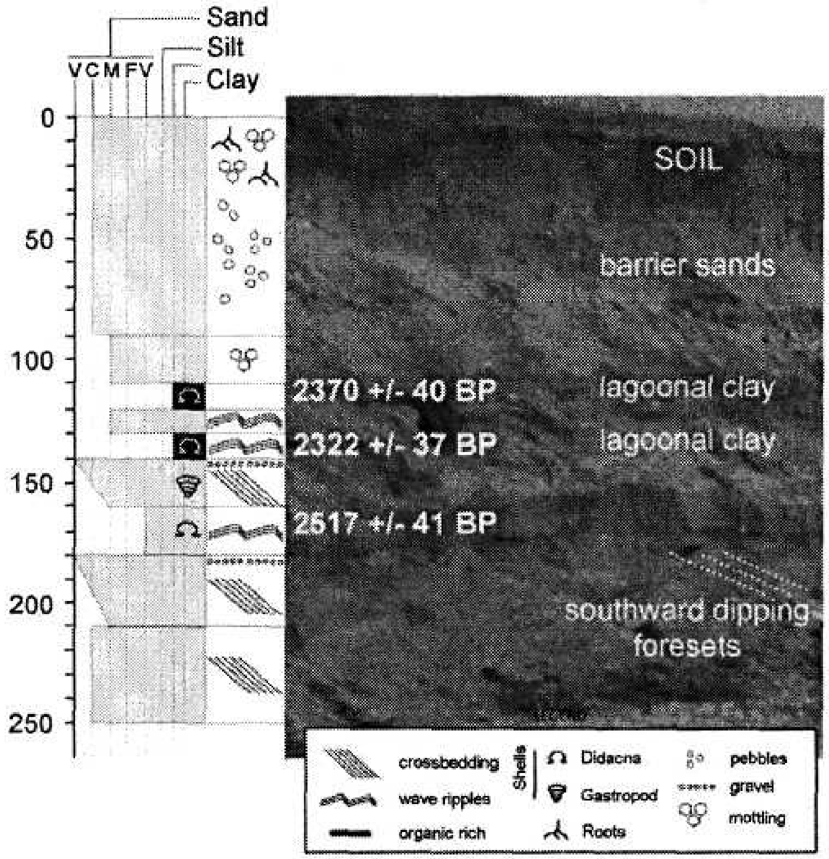

Fig. 5. Alongstrike outcrop OT21 through 2nd phase barrier, with dated lagoonal deposits. For location see Fig. 2.

4. Radiocarbon data

Two groups of I4C ages are found: one group within 280-40 BP, and another group within 2320-2750 BP (Table 1). Calendar ages (lc-probability) were obtained using the computer code Calib version 5 (Stuiver et al, 2005) with the marine calibration curve Marine 04 (Hughen et al., 2004) taking into account a 290 + 30 reservoir age calculated from the recent samples UtC-11477 and -11479. The data suggest that the highstand was reached around 2600 cal BP and continued, possibly with some fluctuations, to around 2200 cal BP. According to stable isotope data (iSO) on Didacna cf trigonoides palaeotemperature and palaeosalinity conditions were similar to the present ones (Vonhof et al., 2004).

The group of young ages refers to lagoonal deposits below and behind the phase 6 barrier, related to extensive ponding when this barrier cut off the bay from the sea at a highstand at about —24 m. Two of these ages are modern and two others correspond to 240-360 and 510-600 cal BP, respectively, close to the Little Ice Age.

Similar barrier complexes at similar levels are found also elsewhere in the Caspian, such as the extensive Agrakhan spit further north in Dagestan, and the barrier complex near Anzali lagoon and the Miankaleh spit along Gorgan Bay along the southern Caspian coast in the Islamic Republic of Iran. Lahijani et al. (personal communication) found 14C AMS ages of 2400 and 2480 BP in similar deposits along the southern Iranian coast. This might indicate that the 2600 BP highstand caused a major pulse of barrier deposition along the whole western and southern Caspian shore.

We found evidence for an intervening lowstand between 2600 and 300 BP in a geophysical and drilling campaign in the offshore Kura delta, Azerbaijan (Fig. 6) (Hoogendoorn et al., 2005). Sparker profiles show an erosional unconformity at about 21m below the present water surface (—48 m below oceanic level) and is underlain by deltaic deposits with shelly intervals at 16-17 m depth dated around 1400 BP. At a sedimentation rate of 1.2 cm/year calculated from the core, the erosional unconformity represents an age around 900 BP. Mollusc fauna indicates depositional depths between 10 and 20 m below sea level (i.e. 34 and 44 m below oceanic level). Although a few of these molluscs might not be not in situ, the 14C data are consistent enough to position this lowstand between the 2600 BP and the ~300 BP highstand (Hoogendoorn et al., 2005). From historical and archaeological data, prominent lowstands are reported for the 6th and 12th century AD (Varushchenko et al., 1987).

Table 1

Accelerator mass spcctrometry ages on mollusc specimens

Site	Sample	Elevation (m)	613C (%)	14C age (BP)	Calender age (cal BP)	UtC No.
DagTSl	HV#06a	-24.10	-2.9	525 ±33	240-360	11478
DagTSl	HV#07a	-24.50	-2.2	299 + 41	Reservoir age'1	11479
DagTSl	HV#08b	-24.70	-6.7	2603 ±33	2340-2470	11424
DagTSl	HVDag14a	-27.30	1.7	2747 ±35	2560-2710	11620
DagLG	HV#04c	-24.00	1.4	2350±43	2020-2190	11476
DagOT2	HV#03a	-24.60	-0.7	837 + 33	510-600	11502
DagOT2	HV#01a	-26.50	1.3	2373 ±38	2080-2240	11475
DagOT2	HV#02c	-26.50	1.6	2366 ±30	2050-2210	11423
DagOT2 5	HVDag8a	-28.00	-0.4	2504 ±34	2210-2230	11616
DagOT2 1	HVDag9B°	-25.15	0.3	2370 ±40	2060-2240	11617
DagOT2 1	HVDaglT	-25.25	0.6	2322 ±37	2000-2140	11619
DagOT2 1	HVDaglOAc	-25.55	-0.6	2517±41	2240-2390	11618
DagMT	HVDagK"	-26.00	-0.4	2507 ±35	2210-2230	11621
DagB	HV#05a	-24.00	-3.2	283 ±35	Reservoir agcd	11477

14C ages from Turali barrier complex, Dagestan (sites at Fig. 2). Dated mollusc species:
a Cerastoderma glaucum.
b Gastropod (terrestrial).
c Didacna cf. trigonoides. Elevation with respect to Kronshtadt Baltic sea level = elevation top outcrop minus profile depth. Calendar age [cal BP] assuming 290±30 year reservoir age estimated from ages obtained for UtC-11477 and -11479, indicated as
d Rcservoir age.

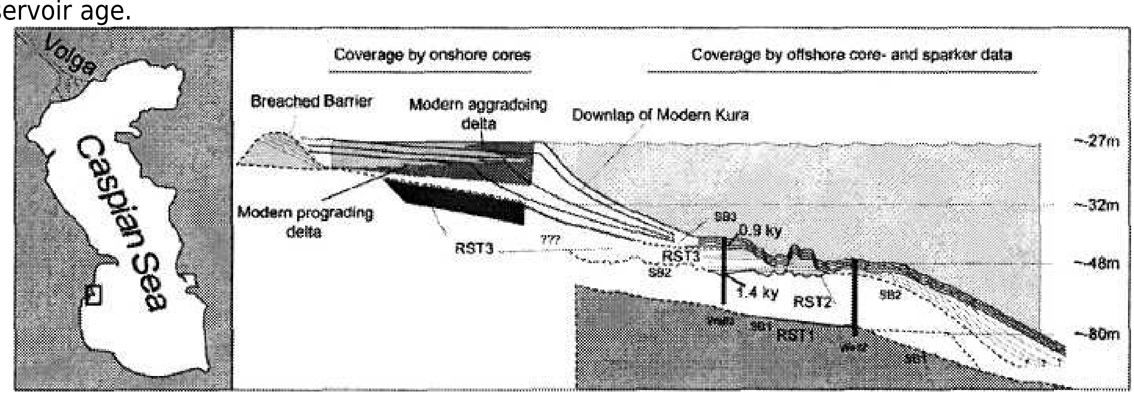

Fig. 6. Offshore cross-section through Kura delta, Azerbaijan. Dotted line in subsurface

marked ~900 BP indicates erosional discontinuity interpreted from sparker data. —1400BP age refers to dated mollusc horizons. For details, see Hoogcndoorn et al. (2005).

5. Discussion

The two Caspian highstands recognised at the Turali site coincide both with periods of global cooling and wetter climates. The ~2600 BP event has been recognised in the dendrochronological record (Damon and Sonett, 1992; Vasiliev and Dergachev, 2002), in the GISP2 ice core (O'Brien et al., 1995), as a rise in groundwater levels in peats all over Europe from Ireland to Poland (Van Geel and Renssen, 1998), increasing ice-rafting in the North Atlantic (Bond et al., 2001), as glacier advances in west-central Europe (Holzhauser et al., 2005) and marks the beginning of the Subatlantic period (Van Geel and Renssen, 1998). At the Minino archaeological site north of Moscow, extensive flooding by the upper Volga River around 2590 BP ended a long period of habitation (Gracheva et al., 2002).

The second group of ages probably corresponds to the Little Ice Age, while the intermediate lowstand at —48 m around 900 BP may correspond to the Mediaeval Warm Period, both equally represented in the dendrochronological and GISP2 ice record.

Both highstands correspond with prominent minima in solar activity and hence higher impact of cosmic rays, as shown by the 14C and 10Be maxima in various archives (Stuiver and Braziunas, 1988; Stuiver et al., 1997; Van Geel et al., 1999). Eygenson (1957) showed already that Caspian Sea level since 1837 is negatively correlated with sun spot activity, and Braun et al. (2005) demonstrate the existence of a solar-forced 1470-year glacial climate cycle. Also modelling Total Solar Irradiance with the coupled global atmosphere-ocean-vegetation model ECBilt-CLIO-VE-CODE shows minima in this period (Renssen et al., 2006). The new palaeodata strengthen the case for solar-forced sea-level cycles also on much longer time scales, and therefore, may help in better forecasting the Caspian Sea level.

Caspian Sea level depends largely on the balance between the influx of Volga River water and evaporation over the sea surface (Klige and Miagkov, 1992; Cazenave et al., 1997; Arpe et al., 2000). The correlation of Volga discharge with sea level is highly significant in the period of instrumental observation (Rodionov, 1994; Cazenave et al., 1997), and the 2590 BP Upper Volga flooding event (Gracheva et al., 2002) suggests this holds also for the 2600 BP Caspian highstand. But the correlation of Caspian Sea level with global and regional circulation patterns which cause precipitation in the Volga basin is often surprisingly poor, or only significant for specific intervals with relatively stable sea level (Meshcherskaya, 2001; Cazenave et al., 1997). By elucidating the way in which solar activity influences global and regional atmospheric circulation patterns, forecasts may be improved.

6. Caspian sea and Dark Nature

Both Caspian sea-level rise and sea-level fall have caused catastrophes and near-catastrophes in the recent past (Fig. 7). Coastal management along vulnerable Caspian shores requires a much greater awareness and reactivity than along most of the other coasts in the world. Better forecasts of its future behaviour are urgently needed, but require crucial improvements in the record of past changes in the first place: that is the jest of the UNESCO-IGCP project 481 Dating Caspian Sea Level Change (www.caspiansealevelchange.org).

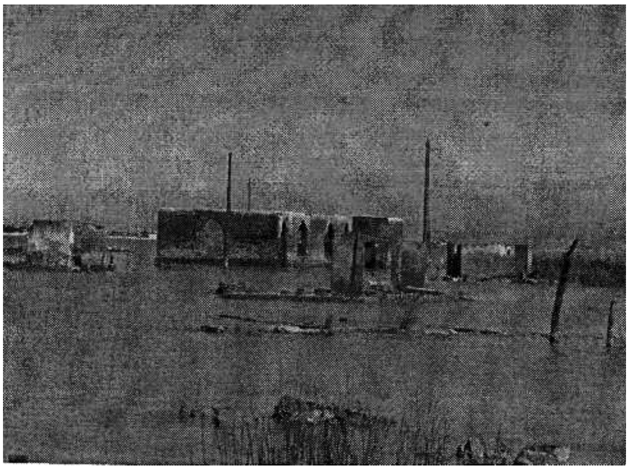

Fig. 7. Drowned mosque along the southeastern Caspian shore, Miankaleh spit, Gorgan Bay, Iran.

However, the Caspian also serves as a natural laboratory for global change and coastal dynamics. Each year of Caspian sea-level change offers an accelerated picture of coastal response to a century of sea-level change along oceanic coasts. This can be used to validate numerical models of coastal response (Storms et al., 2002). Furthermore, Caspian sea fluctuations are a record of global precipitation changes, which are much less easily reconstructed than past temperature changes.

Caspian shore dwellers have experienced what we tend to forget: that climate and sea-level changes are cyclic processes, some of them at human time scales like the Caspian, but often at greater-than-human scales: on Nature's time scales. If we are prepared to see the present period of global warming as part of time's cycle, or even as a short spike in Nature's time, if we try to look beyond the future global sea-level highstand, Nature might look less dark to us.

7. Conclusions

The coincidence of the last two major Holocene high-stands with periods of global cooling and decreased solar activity around 2600 BP and in the Little Ice Age, strengthens the case for solar forcing of Caspian sea level] as already postulated by Eygenson (1957) on the basis of the shorter sea-level fluctuations. This means there is hope to finally understand the so far elusive connection between Caspian Sea level and global processes. It might remind us that Nature is maybe less capricious than we always seem to fear.

Acknowledgements

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ГЕОИНФОРМАЦИОННЫЕ АСПЕКТЫ ГЛОБАЛИЗАЦИИ УСТОЙЧИВОГО РАЗВИТИЯ ОБЩЕСТВА

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Исследования, сочетающие социальный, экономический и экологический контент, обнаруживают общность области приложения и цели, образ которой скрыт за термином «устойчивое развитие». Применение «информационного подхода» позволяет раскрыть этот образ наиболее полным образом. Полученные результаты представлены в виде мультипликативного индекса развития, отражающего геоинформационный баланс территориальной единицы.

The researches combining a social, economic and ecological content, find out a generality of appendix area and global purpose. This purpose image is hidden behind the term "sustainable development". These restrictions are presented as the multiplicative index of the development. This index is reflecting an information balance of a territory.

Ключевые слова: геоинформатика, устойчивое развитие, глобализация

Введение. Термин «устойчивое развитие» по изначальному определению, данному Комиссией Брундланд [28], звучащему в оригинале как «development that meets the needs of the present without compromising the ability of the future generations to meet their own needs», имеет явный социально ориентированный смысл. Однако если вспомнить, что природные «ресурсы – это нечто, извлекаемое нами из природной среды, для удовлетворения своих потребностей и желаний» [11. С. 26], то его экологичность становится явной.

Такой вывод совпадает с мнением определенной части ученых о том, «что не существует внутренней методологической разницы между научным познанием человеческих явлений и научным познанием физических явлений» [3. С. 128].

Практическое признание внутреннего единства социума и природной среды в нашей стране обрело законодательную основу, например, в «Концепции перехода Российской Федерации к устойчивому развитию», где утверждается, что «улучшение качества жизни людей должно обеспечиваться в <…> пределах хозяйственной емкости биосферы <…> выполнение этих условий гарантирует сохранение нормальной окружающей среды и возможность существования будущих поколений людей» [18].