

3.3 Palynology

Samples were taken every 5 cm in the four cores. Initial processing of samples (1 to 2 ml) involved the addition of sodium pyrophosphate to deflocculate the sediment. Samples were then treated with cold hydrochloric acid (10 % and then pure) and cold hydrofluoric acid (60 %), followed by a further treatment with hydrochloric acid. The residual organic fraction was then screened through 125 µm and 10 µm mesh sieves and mounted on slides in glycerol. *Lycopodium* tablets were added at the beginning of the process for concentration estimates.

The dinocysts were counted at the same time as pollen and other microfossils. The sum for percentages is made of all dinocysts except *Brigantedinium* spp. (including all “round-brown” specimens which are cysts not identified to the species level), because of its ubiquitous character and frequent dominance of the spectra. *Brigantedinium* and *varia* are expressed as a percentage of the same sum as the other dinocysts. The percentages of the foraminifera inner organic linings found in the palynological slides were displayed in the same way. A ratio pollen concentration on dinocyst concentration (P : D) has been determined according to McCarthy and Mudie (1998) in order to estimate the degree of continentality of the assemblage.

A statistical analysis available in Psimpoll (Bennett, 2007), the zonation by cluster analysis (CONISS) after square root transformation of the percentages, was applied. The zonation was calculated for the percentage diagrams.

The taxonomy of many Caspian dinocyst species has been established by Marret et al. (2004). Illustrations of Caspian dinocysts are also available in Leroy (2010) and Mudie et al. (2011). Three forms of *Lm* have been counted separately: ss, A and B. In a worldwide study, Mertens et al. (2009) indicate that *Lm* can be found in surface sediment in a salinity range from at least 12.5 to 42, and for temperature from 9 to 31 °C. The same study established that longer processes are clearly developed at higher summer salinity (Mertens et al., 2009) For the CS, the length of the processes decreases from form ss to form B.

16673

4 Results

4.1 The surface samples

The samples are organised by increasing percentage values of *Lm* B from the top to the bottom of Fig. 5, except the bottom two samples which have high values of forms ss and A.

At the top of the diagram, the assemblages of the two lake samples (Almagol and Alagol) are composed only of *Brigantedinium*. At the bottom of the diagram, the dinocysts are dominated by *Lm* B with increasing values of *Lm* ss and often the presence of *S. belerius* (saline lagoons of BTork 1 and 2, and TR1). The bottom-most two samples are derived from hypersaline settings: the Aral Sea (AS17-5) and the Karabogaz Gol (KBG8-01) explaining respectively the abundance of *Lm* ss and the high peak of *Lm* A.

In the middle sample group, the spectra are dominated by *I. caspiense* and *Caspidinium rugosum rugosum*, with occasionally at the top end of the diagram the development of *Pentapharsodinium dalei* and *S. cruciformis*, respectively in north of the middle Caspian basin (cores US24 and US26) or more freshwater lagoons (Anzali).

4.2 Core sediment and dating

The sediment of core US01, off the coast of Turkmenistan, is silty with up to 20 % clays. It has the highest amount of sand of the four cores, reaching 10–20 % (Fig. 4). The core bottom has 4 % organic matter, but this rapidly decreases upwards to 1 %. The carbonate content is stable around 20 %. The magnetic susceptibility is very low and increases upwards. Foraminifera tests are abundant (Appendix B).

The sediment of core US02, from the middle of the south basin, is clayey and silty with some sand from 8.5 % at the base to 2 % at the top. The organic matter progressively increases from 2 to 4 %. This sequence has the highest content in carbonates of the four cores, reaching 30–40 %. It is likely that some of the carbonate is derived

16674

from benthic ostracod valves as they are known in the top cm of this core (Boomer et al., 2005). The magnetic susceptibility is low. The Curie temperature for sample at 6 cm depth was 580 °C; the mineral carrying the magnetic susceptibility is magnetite (Fe_3O_4).

5 The sediment of core CS03, offshore from Anzali, is comprised of gray silts and clays with darker layers. The sediment is occasionally bioturbated by a network of animal tubes. The mean amounts of organic matter and carbonates are stable with respectively values of 3 and 17 %. The magnetic susceptibility is low.

10 The sediment of core CS10, taken offshore from Babolsar, consists of clayey silts, sometimes with very fine sand, poorly sorted, getting darker with depth, ranging from dark grey to black with a reduced-sediment odour. Sediments are laminated through much of the sequence. Some part of the sequence appears burrowed (particularly the lower portion). The sequence has 3 % of organic matter and 20 % of carbonates as well as the highest magnetic susceptibility of the four cores.

15 The radionuclide results of core US02 have been published in Leroy et al. (2007). In brief the sedimentation rate obtained is 2.0 mm yr^{-1} for the top 22 cm of sediment. The base of the core is therefore estimated to be at AD 1709.

For core CS03, the record of artificial fallout radionuclides ^{241}Am and ^{137}Cs (Fig. 5) detected in the upper 104 cm. of sediment display a maximum at 83 cm depth that is assigned to the period of maximum weapons fallout (Appleby, 2000) The corresponding averaged sedimentation rate is thus of 19 mm yr^{-1} . The radiometric ^{210}Pb profile (Fig. 5) does not display the regular exponential decrease with depth in the core as expected for a constant sedimentation rate. For the upper 63 cm, the profile exhibits a roughly linear decreasing activity corresponding to a sedimentation rate of 20 mm yr^{-1} in good agreement with the artificial radionuclide results. Deeper in the core, the data are more scattered and would correspond to a higher sedimentation rate. Assuming that the sedimentation rate of the deeper part of the core is higher than 20 mm yr^{-1} , the age of the base of the core is estimated between AD1963 and AD1930. The use of other models (CIC, CRS, Appleby 2000, and SIT, Carroll and Lerche 2003) was not

16675

attempted because of the large discontinuities in the sampling depths. The sedimentation rate that was obtained, 20 mm yr^{-1} is therefore exceptionally high and 10 times higher than that of core US02.

5 No dating is available for cores US01 and CS10. It is however likely that the sedimentation in front of the Babolsar River, for core CS10, will be similar or slightly lower than that of core CS03 because the Babolsar river (in front of the CS10 coring location) sediment discharge is minute when compared to that of the Sefidrud (a powerful river, but east of core CS03): $0.411 \text{ Mton yr}^{-1}$ versus $26\,000 \text{ Mton yr}^{-1}$ (Lahijani et al., 2008).

4.3 Dinocysts in the four cores

10 In general the same range of taxa is found in the four cores (Fig. 6), with the usual dominance of *I. caspienense* and the abundance of *Lm* under two forms: B and ss (Marret et al., 2004). *P. psilata* has only rare occurrences.

4.3.1 Core US1, the shallow core off Turkmenistan

15 This sequence is largely dominated by only two taxa: *I. caspienense* whose percentages decrease slightly from 60 to 40 %, and *Lm* B whose percentages increase. *Lm* ss and *S. beherius* have continuous curves. The P:D ratio is very low (if compared to modern samples, Fig. 3) indicating that more dinocysts than pollen are preserved in the sediment and therefore that the continental influence is low despite the proximity of the continent and that the dinocysts have found optimal conditions to grow. Foraminifera linings have been found in significant numbers throughout the core and form a continuous curve.

4.3.2 Core US2, the last 300 yr in the middle of the south basin

25 Zone US02-d1 has relatively high *S. cruciformis* values and a significant percentage of *C. rugosum*, not met in the surface samples. Zone US02-d2 has slightly less *S. cruciformis*, much less *C. rugosum* and slightly more *Lm* B.

16676

The concentration is the lowest of the four cores due to the distance to the shores. The relatively low P : D displays an increasing overall trend. This diagram shows a mild trend to have opposite fluctuations of *P. dalei* cysts (highest values of the 4 cores) and *Lm B*. This core overall shows assemblages that indicate the lowest salinities of the four cores. This is due to its location in a more open sea. No foraminifera linings have been found in this sequence as the water depth is too great for the survival of these benthic organisms in the CS (Boomer et al., 2005).

4.3.3 Core CS03, the 20th century off Anzali

In zone CS03-d1 *I. caspienense* has maximal values, *P. dalei* cysts are well represented and the percentages of *Brigantedinium* are relatively high. The concentration increases slowly and the P : D decreases upwards. In zone CS03-d2, *Lm B* values are nearly twice as high as before. *P. dalei* cysts become rare. The concentration is clearly higher than in zone 1, while P : D is stable. This core shows a compelling opposition between *P. dalei* cysts and *Lm B*.

The coring location 15 km offshore, does not seem to be influenced by the freshwater outflow from the Anzali lagoon.

4.3.4 Core CS10, with massive algal biomass increase off Babolsar

In zone CS10-d1, the values of *I. caspienense* are the highest of the four cores. The P : D is extremely high: showing a clear terrestrial influence similar to that in surface samples, e.g. in lakes (such as Alagol) and lagoons (Anzali and Bandar-e-Torkman).

In zone CS10-d2, after a sudden change, high percentages of *Lm B* (80%) occur. These are also the highest values ever recorded in the CS. This occurs in parallel to a huge increase in the dinoflagellate cyst biomass.

The limit between zones CS03-d1 and d2 corresponds well to that between zones CS10-d1 and d2, with the same increase in *Lm B* and ss percentages and in total biomass and the same decrease in *Brigantedinium* and in the P/D ratio. This change at

16677

75 cm is well dated in core CS03 as it is just a few cm above the ²³⁷Cs peak of AD1963 at 83 cm, bringing the age of the limit at AD1967.

5 Discussion

5.1 Dinocyst distributions

The spectra from the surface sediment and the four cores are largely dominated by *I. caspienense* and *Lm*. The near absence of *P. psilata* and the low values of *S. cruciformis* (for the latter except the central core and some surface samples in the Lagoon of Anzali) are a characteristic of these four recent records and of the surface samples. *P. psilata* is mostly found in Khvalynian sediment (Leroy, personal communication, 2012) and in lagoons and river deltas such as the Demchik area of the Lower Volga River (K. Richards, personal communication, 2012). This is easily explained both in terms of the higher salinity of the Neocaspian Sea and in terms of survival in lagoons where the salinity is variable and where the lagoons maintain at most times at least small areas of lower salinity if fed by rivers. The higher values of *S. cruciformis* in zone US02-d1 may reflect the much higher water levels of the LIA, which also have less saline waters as also seen in the lagoon of Anzali (Leroy et al., 2011).

The two southern cores have the highest percentages of *Brigantedinium*. This is explained by the proximity of a densely inhabited coastal area producing a lot of nutrients discharged into the sea.

The cosmopolitan species *P. dalei* cyst is clearly more abundant in the northern surface samples (samples US24 and 26), which are characterised by larger amplitudes of sea surface temperatures and the proximity of sea ice in winter (Marret et al., 2004).

On the one hand, based on the locations of the cores and the surface samples, it is possible to show that the three *Lm* forms show an increasing salinity gradient from B, to ss and finally to A. On the other hand, *Lm* percentages (all forms included) display an increase across the CS to the southeast, i.e. towards regions that are warmer and

16678

more saline. So the morphology of the cysts responds to the salinity but its biomass to temperature.

5.2 Exceptional sedimentation rate

The sedimentation rate of core US02, in the centre of the south basin, obtained by the radionuclide method is 2 mm yr^{-1} . This is 10 times higher than that obtained by radiocarbon on core CP14 taken close by (Leroy et al., 2007). This difference could be caused not only by an expected lack of compaction of the top tens of cm of sediment in core US02 but also by a very recent (the last few centuries) increase of the sedimentation influx (Leroy et al., 2007). This radiocarbon-based value falls within the sedimentation rates of other cores from the deep basins i.e. between 0.02 and 0.54 mm yr^{-1} (Amini et al., 2012).

The sedimentation rate in a short core (HCGA05, 170 cm long) from the Anzali Lagoon, is of 5 mm yr^{-1} , that of core HCGL02 (95 cm long) in the lagoon of Amirkola is 2.5 mm yr^{-1} (Leroy et al., 2011), and that in cores from the Gorgan Bay is between 1.4 and 2.45 mm yr^{-1} (Karbassi and Amirnezhad, 2004). These values are higher than those from the core from the centre of the south basin. These lagoonal settings are expected to have higher sedimentation rates than those of the open sea.

On the whole the values of the short cores are in the order of the sedimentation for the Cainozoic (Nadirov et al., 1997; Tagiyev et al., 1997).

However 20 mm yr^{-1} obtained on the coastal core CS03 is truly exceptional (Amini et al., 2012). This value is even higher than that of the Pliocene Productive Series (Kroonenberg et al., 2005). This is explained by the core location on the slope of the continental shelf. The time resolution of the palynological samples therefore reaches one sample every 2.5 yr.

16679

5.3 Shifts in the *L. machaerophorum* percentages

This section focuses on what causes the increase in *Lm* visible in the four cores, more so for the two southern ones (Figs. 6, 7). Moreover these increases of *Lm* are often to the detriment of *P. dalei* cysts when present in the cores. The recent changes are then set in the context of the changes in the last few millennia.

5.3.1 In the last decades

L. polyedra, the motile form of *Lm* usually occurs in the water column during late summer, which suggests that a minimum temperature is needed for its development. *L. polyedra* can bloom in nutrient rich and nutrient depleted waters: thus its distribution does not have to be restricted to areas with high nutrient concentrations in surface waters (Lewis and Hallett, 1997). Dinoflagellate biomass that shows a steep increase as part of anomalous algal blooms that occurred in the last few years in the CS are probably seen in the strong algal biomass increase across core CS10, especially since 1967. The causes for this are multiple, and are often attributed to nutrient washed into the sea by the rivers; however they are also often linked to higher temperature and low wind conditions and therefore stratified waters (Soloviev, 2005; Nasrollahzadeh et al., 2011). A remote sensing analysis for the 2005 large-scale bloom indicated that an increase of 4°C was observed in the bloom itself in comparison to surrounding waters. Low wind conditions and water stratification were also observed. In brief this would tend to indicate that *L. polyedra* responds primarily to high temperatures, with salinity, and nutrients as secondary factors.

In the 20th century, the water level has fluctuated by $\pm 3 \text{ m}$ a couple of times (Fig. 2a), but this seems to have been hardly registered in the fossil record (Fig. 6). More decisively, the sharp sea level rise between 1977 and 1995 has led to a salinity decrease. However *Lm* percentages have strongly increased, more in line with the gradual increase of sea surface and air temperatures throughout this period (Fig. 2b–d)

16680

Acknowledgements. Our gratitude goes to F. Gasse, the leader of the project “Understanding the Caspian Sea erratic fluctuations”, European Contract INCO-Copernicus no. IC15-CT96-0112, to F. Guichard and P. Tucholka for collection of Ussel box cores, to P. J. Giannesini and E. Moreno, past and present curators of cores from the Caspian Sea (Laboratoire de Géologie, 5 Museum d’Histoire Naturelle de Paris, France). We are grateful to M. Naderi (INIO) who helped in the field. The Golestan samples were kindly provided by A. A. Kakroodi. All the palynological samples were treated at Brunel University by C. Miller, who also made the magnetic susceptibility measurements of the two Kajak cores. This article is a contribution to the European project Marie Curie, CLIMSEAS-PIRSES-GA-2009-247512: “Climate Change and Inland 10 Seas: Phenomena, Feedback and Uncertainties. The Physical Science Basis”. S. Kershaw and L. López-Merino (Brunel University) have provided critical feedback on earlier versions of the manuscript.

References

- Adrian, R., O’Reilly, C. M., Zagarese, H., Baines, S. B., Hessen, D. O., Keller, W., Livingstone, D. M., Sommaruga, R., Straile, D., Van Donk, E., Weyhenmeyer G. A., and Winder, M.: 15 Lakes as sentinels of climate change, *Limnol. Oceanogr.*, 54, 2283–2297, 2009.
- Amini A., Mousavi Harami, R., Lahijani, H., and Mahboubi, A.: Holocene sedimentation rate in Gorgan Bay and adjacent coasts in southeast of Caspian Sea, *J. Basic Appl. Sci. Res.*, 2, 289–297, 2012.
- 20 Appleby, P. G.: Radiometric dating of sediment records in European mountain lakes, *J. Limnol.*, 59, 1–14, 2000.
- Arpe, K. and Leroy, SAG: The Caspian Sea Level forced by the atmospheric circulation as observed and modeled, *Quatern. Int.*, 173–174, 144–152, 2007.
- Arpe, K., Bengtsson, L., Golitsyn, G. S., Mokhov, I. I., Semenov, V. A., and Sporyshev, P. V.: 25 Connection between Caspian Sea level variability and ENSO, *Geophys. Res. Lett.*, 27, 2693–2696, 2000.
- Arpe, K., Leroy, S. A. G., Lahijani, H., and Khan, V.: Impact of the European Russia drought in 2010 on the Caspian Sea level, *Hydrol. Earth Syst. Sci.*, 16, 19–27, doi:10.5194/hess-16-19-2012, 2012.

16687

- Bagheri, S., Mansor, M., Makaremi, M., Sabkara, J., Wan Maznah, W. O., Mirzajani, A., Khodaparast, S. H., Negarestan, H., Ghandi, A., and Khalilpour, A.: Fluctuations of phytoplankton community in the coastal waters of Caspian Sea in 2006, *Am. J. Appl. Sci.*, 8, 1328–1336, 2011.
- 5 Bennett, K.: Psimpoll and pscomb programs for plotting and analysis, Version psimpoll 4.27, available at: <http://chrono.qub.ac.uk/psimpoll/psimpoll.html> (last access: 26 July 2012), 2007.
- Birshtein, Y. A., Vinogradov, L. G., Kondakov, N. N., Astakhova, M. S., and Romanova, N. N. (Eds.): Atlas of Invertebrates of the Caspian Sea, Pishchevaya Promyshlennost, Moscow, 10 1968 (in Russian).
- Boomer, I., Hoorne, D., and Slipper, I. J.: The use of ostracods in palaeoenvironmental studies, or what can you do with an ostracod shell?, *Paleontol. Soc. Papers*, 9, 153–179, 2003.
- Boomer, I., von Grafenstein, U., Guichard, F., and Bieda, S.: Modern and Holocene sublittoral ostracod assemblages (*Crustacea*) from the Caspian Sea: a unique brackish, deep-water 15 environment, *Palaeogeogr. Palaeoclimatol.*, 225, 173–186, 2005.
- Bradley, L., Marret, F., Mudie, P., Aksu, A., and Hiscott, R.: Constraining Holocene sea-surface conditions in the southwestern Black Sea using dinoflagellate cysts, *J. Quaternary Sci.*, 27, 835–843, doi:10.1002/jqs.2580, 2012.
- Brückner, E.: Klima-Schwankungen seit 1700 nebst Bemerkungen über die Klimaschwankungen der Diluvialzeit. Geographische Abhandlungen herausgegeben von Prof. Dr Albrecht Penck, E. Hölzel, Vienna and Olmütz IV (2), 153–484, 1890.
- Carroll, J. and Lerche, I.: Sedimentary Processes: Quantification Using Radionuclides, Elsevier, Oxford, 2003.
- Cazenave, A., Bonnefond, K., Dominh, K., and Schaeffer, P.: Caspian Sea Level from Topex-Poseidon altimetry: level now falling, *Geophys. Res. Lett.*, 24, 881–884, 1997.
- 25 Climatic Research Unit: University of East Anglia, available at: <http://www.cru.uea.ac.uk/cru/data/temperature/crutm4/station-data.htm>, last access: 30 August 2012.
- Crétau, J.-F. and Birkett, C.: Lake studies from satellite radar altimetry, *C. R. Lake studies from satellite radar altimetry C. R. Geosci.*, 338, 1098–1112, 2006.
- 30 Crutzen, P. J.: Geology of mankind, *Nature* 415, 23, doi:10.1038/415023a, 2002.
- Dean Jr., W. E.: Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods, *J. Sed. Petrol.*, 44, 242–248, 1974.

16688

- Dee, D. P., Uppala, S. M., Simmons, A. J. et al.: The ERA-Interim reanalysis: configuration and performance of the data assimilation system, *Q. J. Roy. Meteor. Soc.*, 137, 553–597, doi:10.1002/qj.828, 2011.
- Deflandre, G. and Cookson, I. C.: Fossil microplankton from Australia late Mesozoic and Tertiary sediments, *Aust. J. Mar. Fresh. Res.*, 6, 242–313, 1955.
- Dumont, H. J.: The Caspian Lake: history, biota, structure, and function, *Limnol. Oceanogr.*, 43, 44–52, 1998.
- Einsele, G. and Hinderer, M.: Terrestrial yield and the lifetimes of reservoirs, lakes and larger basins, *Geol. Rundsch.*, 86, 288–310, 1997.
- Firoozfar, A., Bromhead, E. N., Dykes, A. P., and Neshaei, M. A. L.: Southern Caspian Sea coasts, morphology, sediment characteristics, and sea level change, in: *Proceedings of the Annual International Conference on Soils, Sediments, Water and Energy*, 17, 123–150, 2012.
- Ghaffari, P., Lahijani, H. A., and Azizpour, J.: Snapshot observation of the physical structure and stratification in deep-water of the South Caspian Sea (western part), *Ocean Sci.*, 6, 877–885, doi:10.5194/os-6-877-2010, 2010.
- Ginzburg, A. I., Kostianoy, A. G., and Sheremet, N. A.: Sea surface temperature variability, in: *The Caspian Sea Environment*, edited by: Kostianoy, A. and Kosarev, A., Springer, Berlin, Heidelberg, 59–81, 2005.
- Golitsyn, G. S. and Panin, G. N.: The water balance and modern variations of the level of the Caspian Sea, *Soviet Meteorol. Hydrol. (English Translation)* 1, 46–52, 1989.
- Howard, M. D. A., Smith, G. J., and Kudela, R. M.: Phylogenetic relationships of Yessotoxin-producing dinoflagellates, based on the large subunit and internal transcribed spacer ribosomal DNA domains, *Appl. Environ. Microbiol.*, 75, 54–63, 2009.
- Jamshidi, S. and BinAbuBakar, N.: Oceanographic study in coastal waters in Babolsar, *Asian J. Earth Sci.*, 4, 1–8, 2011.
- Kakroodi, A. A., Kroonenberg, S. B., Hoogendoorn, R. M., Mohammadkhani, H., Yamani, M., Ghassemi, M. R., and Lahijani, H. A. K.: Rapid Holocene sea-level changes along the Iranian Caspian coast, *Quatern. Int.*, 263, 93–103, 2012.
- Kakroodi, A. A., Leroy, S. A. G., Kroonenberg, S. B., Lahijani, H. A. K., Alimohammadian, H., Yamani, M., and Nohegar, A.: Late Pleistocene and Holocene sea level-change and coastal palaeoenvironment along the Iranian Caspian shore, *Earth Planet. Sci. Lett.*, submitted, 2012.

16689

- Karbassi, A. R. and Amirnezhad R.: Geochemistry of heavy metals and sedimentation rate in a bay adjacent to the Caspian Sea, *Int. J. Environ. Sci. Te.*, 1, 191–198, 2004.
- Kazancı, N., Gulbabazadeh, T., Leroy, S. A. G., and Ileri, O.: Sedimentary and environmental characteristics of the Gilan-Mazenderan plain, Northern Iran: influence of long- and short-term Caspian water level fluctuations on geomorphology, *J. Mar. Syst.*, 46, 145–168, 2004.
- Khrustalyov, Y. P. and Artiukhin, Y. V.: Sedimentation in the southern inland seas of the arid zone of the USSR, *Mar. Geol.*, 103, 503–512, 1992.
- Kideys, A. E., Roohi, A., Eker-Develi, E., Mélin, F., and Beare, D.: Increased chlorophyll levels in the Southern Caspian Sea following an invasion of jellyfish, *Res. Lett. Ecol.*, 2008, 185642, doi:10.1155/2008/185642, 2008.
- Kosarev, A. N.: Physico-geographical conditions of the Caspian Sea, in: *The Handbook of Environmental Chemistry*, edited by: Hutzinger, O., vol. 5 water pollution, Pt. P, Springer, Berlin, 5–31, 2005.
- Kosarev, A. N. and Yablonskaya, E. A.: The Caspian Sea, SPB Academic Publishing, The Hague, 259 pp., 1994.
- Kouraev, A. V., Papa, F., Mognard, N. M., Buharizin, P. I., Cazenave, A., Cretaux, J.-F., Dozortseva, J., Remy, F.: Sea ice cover in the Caspian and Aral Seas from historical and satellite data, *J. Mar. Syst.*, 47, 89–100, 2004.
- Kroonenberg, S. B., Simmons, M. D., Alekseevski, N. I., Aliyeva, E., Allen, M. B., Aybulatov, D. N., Baba-Zadeh, A., Badyukova, E. N., Davies, C. E., Hinds, D. J., Hoogendoorn, R. M., Huseynov, D., Ibrahimov, B., Mamedov, P., Overeem, I., Rusakov, G. V., Suleymanova, S., Svitoch, A. A., and Vincent, S. J.: Two deltas, two basins, one river, one sea: the modern Volga delta as an analogue of the neogene productive series, South Caspian Basin, river deltas – concepts, models, and examples (SEPM Special Publication No. 83, SEPM Society For Sedimentary Geology), 231–256, 2005.
- Kroonenberg, S. B., Abdurakhmanov, G. M., Badyukova, E. N., van der Borg, K., Kalashnikov, A., Kasimov, N. S., Rychagov, G. I., Svitoch, A. A., Vonhof, H. B., and Wesselingh, F. P.: Solar-forced 2600 BP and Little Ice Age highstands of the Caspian Sea, *Quatern. Int.*, 173–174, 137–143, 2007.
- Lahijani, H. and Tavakoli, V.: Identifying provenance of South Caspian coastal sediments using mineral distribution pattern, *Quatern. Int.*, 261, 128–137, 2012.
- Lahijani, H. A. K., Tavakoli, V., and Amini, A. H.: South Caspian river mouth configuration under human impact and sea level fluctuations, *Environ. Sci.*, 5, 65–86, 2008.

16690

- Leroy, S. A. G.: Palaeoenvironmental and palaeoclimatic changes in the Caspian Sea region since the Lateglacial from palynological analyses of marine sediment cores, *Geography, Environment, Sustainability*, 2, 32–41, 2010.
- 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., Naderi, M.: Late Little Ice Age palaeoenvironmental records from the Anzali and Amirkola lagoons (South Caspian Sea): vegetation and sea level changes, *Palaeogeogr. Palaeoclimatol., 302*, 415–434, 2011.
- Leroy, S. A. G., Marret, F., Giralt, S., and Bulatov, S. A.: Natural and anthropogenic rapid changes in the Kara-Bogaz Gol over the last two centuries by palynological analyses, *Quatern. Int.*, 150, 52–70, 2006.
- Leroy, S. A. G., Marret, F., Gibert, E., Chalié, F., Reyss, J.-L., and Arpe, K.: River inflow and salinity changes in the Caspian Sea during the last 5500 years, *Quatern. Sci. Rev.*, 26, 3359–3383, 2007.
- Lewis J. and Hallett R: *Lingulodinium polyedrum (Gonyaulax polyedra)* a blooming dinoflagellate, *Oceanogr. Mar. Biol. Annu. Rev.*, 35, 97–161, 1997.
- Loeblich, A. R. and Tappan, H.: *Foraminiferal Genera and their Classification*, Van Nostrand Reinhold, New York, 1182 pp., 1987.
- Londeix, L., Herreyre, Y., Turon, J.-L., and Fletcher, W.: Last Glacial to Holocene hydrology of the Marmara Sea inferred from a dinoflagellate cyst record, *Rev. Palaeobot. Palynol.*, 158, 52–71, 2009.
- Makhlough, A., Nasrollahzadeh, H. S., Pourgholam, R., and Rahmati, R.: The Introduction of toxic and harmful new species of phytoplankton in the Iranian coastal water of the Southern Caspian Sea, *J. Biol. Sci. Lahijan*, 5, 77–93, 2011 (in Persian).
- Marret, F. and Zonneveld, K. A. F.: Atlas of modern organic-walled dinoflagellate cyst distribution, *Rev. Palaeobot. Palynol.*, 125, 1–200, 2003.
- Marret, F., Leroy, S., Chalié, F., and Gasse, F.: New organic-walled dinoflagellate cysts from recent sediments of Central Asian seas, *Rev. Palaeobot. Palynol.*, 129, 1–20, 2004.
- Marret, F., Mudie, P., Aksu, A., and Hiscott, R. N.: A Holocene dinocyst record of a two-step transformation of the Neoeuxinian brackish water lake into the Black Sea, *Quatern. Int.*, 197, 72–86, 2009.

16691

- McCarthy, F. M. G. and Mudie, P. J.: Oceanic pollen transport and pollen : dinocyst ratios as markers of late Cenozoic sea level change and sediment transport, *Palaeogeogr., Palaeoclimatol.*, 138, 187–206, 1998.
- Mertens, K., Ribeiro, S., Bouimetarhan, I. et al.: Process length variation in cysts of a dinoflagellate, *Lingulodinium machaerophorum*, in surface sediments: investigating its potential as salinity proxy, *Mar. Micropaleontol.*, 70, 54–69, 2009.
- Mudie, P. J., Leroy, S. A. G., Marret, F., Gerasimenko, N., Kholeif, S. E. A., Sapelko, T., and Filipova-Marinova, M.: Non-Pollen Palynomorphs: Indicators of Salinity and Environmental Change in the Caspian-Black Sea-Mediterranean Corridor. in *Geology and Geoarchaeology of the Black Sea Region: Beyond the Flood Hypothesis*, edited by: Buynevich, I., Yankov-Hombach, V., Gilbert, A. S., and Martin, R. E., Geological Society of America Special Paper, 473, 89–115, 2011.
- Nadirov, R. S., Bagirov, E., Tagiyev, M., and Lerche, I.: Flexural plate subsidence, sedimentation rates, and structural development of the super-deep South Caspian Basin, *Mar. Petrol. Geol.*, 14, 383–400, 1997.
- NASA: available at: <http://data.giss.nasa.gov/gistemp/>, last access: 30 August 2012.
- Nasrollahzadeh, H. S., Din, Z. B., Foong, S. Y., and Makhlough, A.: Trophic status of the Iranian Caspian Sea based on water quality parameters and phytoplankton diversity, *Cont. Shelf Res.*, 28, 1153–1165, 2008a.
- Nasrollahzadeh, H. S., Din, Z. B., Foong, S. Y., and Makhlough, A.: Spatial and temporal distribution of macronutrients and phytoplankton before and after the invasion of the ctenophore, *Mnemiopsis leidyi*, in the Southern Caspian Sea, *Chem. Ecol.*, 24, 233–246, 2008b.
- Nasrollahzadeh, H. S., Maklough, A., Pourgholam, R., Vahedi, F., Qanqermeh, A., and Foong, S. Y.: The study of *Nodularia spumigena* bloom event in the Southern Caspian Sea, *Appl. Ecol. Environ. Res.*, 9, 141–155, 2011.
- Omrani Rekavandi, H., Sauer, E. W., Wilkinson, T., Safari Tamak, E., Ainslie, R., Mahmoudi, M., Griffiths, S., Ershadi, M., Jansen Van Rensburg, J., Fattah, M., Ratcliffe, J., Nokandeh, J., Nazifi, A., Thomas, R., Gale, R., and Hoffmann, B.: An Imperial frontier of the Sasanian Empire: further fieldwork at the great wall of Gorgan, Iran, 45, 95–136, 2007.
- Patimar, R.: Fish species diversity in the lakes of Alma-Gol, Adji-Gol, and Ala-Gol, Golestan province, Northern Iran, *J. Ichthyol.*, 48, 911–917, 2008.

16692

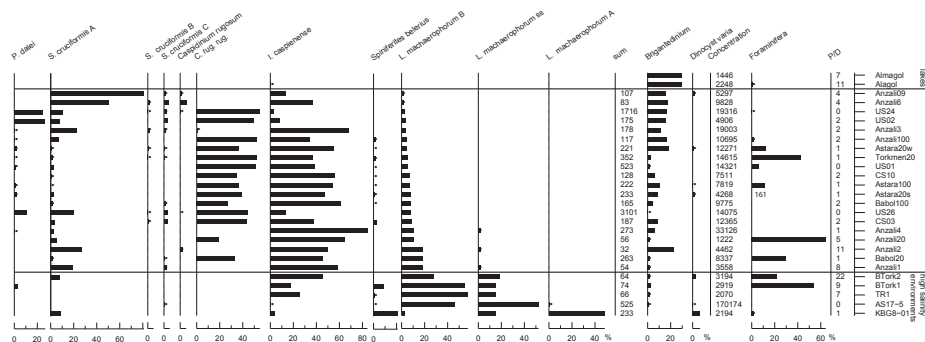


Fig. 3. Dinocyst assemblages from marine and lagoonal surface samples, mostly from the south basin of the Caspian Sea, topmost samples from two lakes and bottommost samples from high salinity environments. Percentages on sum of all dinocysts, except *Brigantedinium*. For the latter and for the foraminifera linings the sum also includes respectively *Brigantedinium* or foraminifera. Concentration in numbers of dinocysts ml^{-1} of wet sediment.

16699

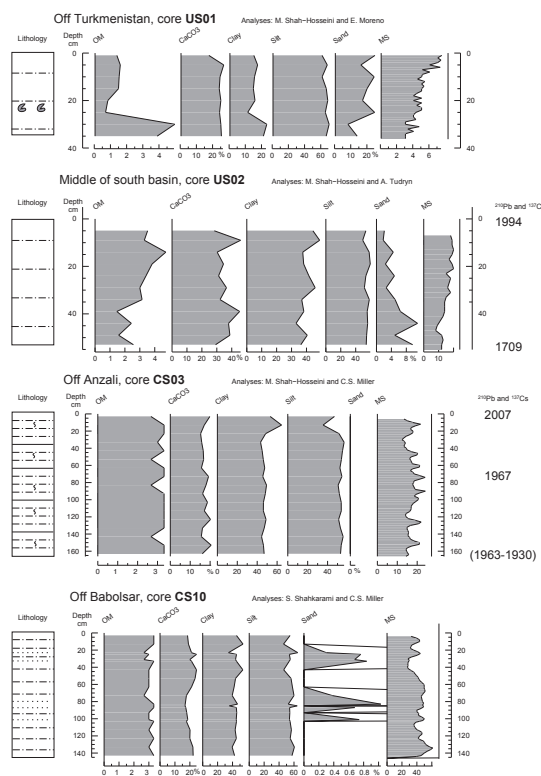


Fig. 4. Sedimentology of the four short cores: visual description of the lithology, organic matter (OM) and calcium carbonate (CaCO_3) contents in percentages after Loss-On-Ignition, clay, silt and sand percentages by particle size analysis, as well as magnetic susceptibility (MS).

16700

