Internationales Asienforum, Vol. 38 (2007), No. 3–4, pp. 353–374

Sea Level Changes and Tsunamis, Environmental Stress and Migration Overseas

The Case of the Maldives and Sri Lanka

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Introduction

Human migration in the past plays a key role for the spread of cultures across the Indian Ocean. The Maldives occupy an interesting position at the cross-route of ocean trading and exploratory expeditions. Natural phenomena like rapid changes in sea level and tsunami events may pose an extra stress on coastal habitation providing the ultimate push for a migration overseas. Records from Sri Lanka and the Maldives are analyzed in this paper. Recently, a new threat and stress factor for low-lying coastal areas has emerged in the global warming scenario predicting a general flooding due to a rapidly rising sea level. In this scenario, the Maldives would have become flooded in 50 to 100 years.

Before entering into the actual paper, it seems appropriate to explain a few concepts and technical terms used:

- *the geoid* is the equipotential surface of gravity set by the attraction and rotational forces with respect to the density of water thereby controlling the shape of the ocean surface.
- *the dynamic sea surface* is the actual mean sea level as given by a number of dynamic factors, such as ocean circulation, evaporation/precipitation, coastal run-off, air pressure.
- *steric changes* in sea level refer to expansion and contraction of the water column due to changes in temperature and salinity.
- *ocean surface circulation* is a strong factor for the distribution of water masses and energy (water-stored heat) over the globe. Variations in ocean circulation affect sea level.
- *air pressure* changes affect sea level with 1 cm per 1 mbar.

- *the monsoon* is not a constant regime over time, on the contrary it has changed significantly thereby affecting both climate and sea level.
- *tsunami* is a water wave set up by a submarine earthquake or a submarine slide. It travels with a speed of several hundred km per hour, and, when reaching shallower waters, it may rise into a breaking wave of several tens of meters.

The Indian Ocean is like an immense laboratory of different sea level variables (Mörner, 2000); the geoid topography has a sharp relief with a 104 m low over the Maldives, the dynamic sea surface topography undulates with a low due to an extreme rate of evaporation, the ocean currents switch and change with time, oceanic water masses are flushed back and forth in an E–W direction, the annual differences in the mean air pressure rise steeply towards the Himalayas generating significant coastal sea level changes, even the prevailing monsoonal regime varies with time and disastrous tsunamis and earthquakes have often struck the region. Some of these variables are shown in Fig. 1.

The Maldives consist of some 1200 low-lying islands. In the Intergovernmental Panel on Climate Change (IPCC) scenario (e.g. 2001) they have been condemned to become flooded in the near future.

In 2000 we launched an international sea level research project in the Maldives (INQUA, 2000) to shed new light on these manifold sea level problems. We soon understood that this region was by no means undergoing a present sea level rise, and we are now able to give the all-clear for the near future (Mörner, Tooley, Possnert, 2004; Mörner, 2004; 2005; 2006).

1. Changing natural variables

Environmental stress is exercised not only on the annual to inter-annual but also on the decadal to centennial basis (besides even longer units not covered in this paper). The forcing functions for the short-term and long-term factors are not the same; on the contrary they differ considerably thereby putting serious doubts on interpretations based on short-term records and then transferred on long-term records; for the past as well as for the future.

In this paper I will examine a number of natural variables with emphasis on sea level changes and tsunami events.

1.1. Sea level

Sea level changes are the outcome of several interacting factors (Mörner, 1996, 2000). I will here present the new sea level curve established for the Maldives. It is based on six visits to the Maldives, three of which were extensive team expeditions, including the recording and sampling both on islands and below sea level, and the C14-dating of 55 samples. Only a short report has previously been presented (Mörner, Tooley, Possnert, 2004; cf. Mörner, 2005).

To begin with, I explored existing diving guides of the Maldives and observed that they all included the existence of multiple submarine shorelines (terraces, notches, under-cutting, etc.). Also, the nautical charts were examined for prominent terrace/scarp levels. At our two one-month expeditions in 2000 and 2001 we undertook extensive diving programs (lead by Jacques Laborel). All together, we now have a –150 m lowermost terrace (interpreted as the regression maximum of the last glaciation maximum, LGM), a large cave at –80 m, an extensive terrace at –70 m with an undercutting at –64 m (interpreted as a possible Younger Dryas level), caves and shore notches at –27 to –38 m, shore features in the order of –20 m, and a number of higher levels. Though we took numerous samples, our dating has not yet given any firm dating control of these submarine levels. A –2 m *in situ* coral was dated at 5310 ±90 before present (BP; before 1950), and marks the beginning of our sea level curve here presented.

The existence of shore marks and caves implies that the main part of the islands is, in fact, of pre-LGM age. This was confirmed by a >40,000 radiocarbon date of a coral from the roof of a submarine cave. Anderson (1998) was the first to point out the existence of a LGM submarine shoreline. The caves we investigated are both of the shore-cave and karstic type. Even hollows and depressions on land seem to represent old karst weathering.

This means that the Maldives during the LGM low level at about 20,000 BP were restricted to a few large islands. Those islands had flat inland surfaces and a coastal edge of high coral pinnacles. The inland floors were crossed by rivers and, most likely, overgrown by a dense tropical rain forest. Indeed, a remarkable biotope, promoting high biodiversity. We do not know if animals (including Man) could have got there across the sea.

From 5300 BP (BC 3350) we have a quite good control of the main sea level changes (Fig. 2) thanks to morphological, stratigraphical and biological analyses coupled with extensive C14-dating. We often recorded flat (pancake-like) *Porites* indicating that sea level had remained stable for some time forcing the *Porites* specimens to grow laterally instead of vertically. The center and edge of a 180 cm circular disk at –0.8 m was dated at

4110 and 4080 BP, respectively. Another disk at –0.25 cm was dated at 4025 BP. Then sea level reached well above the present indicated by corals in a +1.2 m flat, cemented beach (maybe rock-cut platform) dated at 3970 BP and 3235 BP, and a coral in a cemented coral rubble at 0.6 m above the corresponding present deposits dated at 3820 BP. After this high level sea level was low and the older beach material was strongly weathered suggesting a period of warm and wet climate (within the time window of 3200–2200 BP).

A new high level, above +0.5 m and probably in the order of +1.0 m, was recorded and dated (2195 BP and 1965 BP). After that, there was a low level during which the old Buddhist settlement (the Redin people) occurred with the erection of remarkable temples and "hawittas" on several of the Maldive islands (Bell, 1940; Heyerdahl, 1986). Both on the islands of Isdhoo and Gan (in the Laamoo Atoll), the construction extending into pathways towards the sea was recorded at our 2005 expedition. Charcoal between the pathway "stones" was dated at 1610 ±40 BP. Pottery was found on several islands. At the Institute of Archaeology in Uppsala, Sweden, a collection from our 2000 expedition was analyzed and found to have a likely age in the order of AD 500; i.e. right at the Buddhist settlement period. This fits well with our subsequent studies like archaeological investigations by Skjölsvold (1991) and Mikkelsen (2000), especially when our "sea correction" is applied to their dates.

Following the temple period, the sea rose again. On the islands of Isdhoo and Gan in the Laamoo Atoll, the pathway "stones" are, at both sites, covered by a coral beach gravel (cf. Fig. 4). A gastropod from this upper beach was dated at 1420 BP at Gan. At Isdhoo, however, two samples indicated 1725 BP and 1760 BP which is in contradiction to the charcoal date just below (redeposition or a larger "sea correction" may be the explanation). An extreme storm or a tsunami might well have been responsible for the beach material at those sites.

On the island of Viligili (just west of Male), we have a more conclusive sequence, however. A lower level of corals *in situ* peaks at +0.6 m and is dated at 1500 BP. The corals identified (by Jacques Laborel) in this bed need a minimum depth of about 0.6 m, implying that sea level must have been at +1.2 m. This bed is covered by an erosional colluvial material from a period of sea level lowering with the formation of an extensive beach rock at about ±0 m. At the surface, there are traces of a weak soil formation. Subsequently, sea level rose again and there is a second generation of corals *in situ* reaching +0.5–0.6 m and of a biological habitat (determination by Jacques Laborel) corresponding to a sea level of about +1.2 m. A good coral in growing position was dated at 1285 (central bottom part) and 1235 (upper edge). Therefore, we must have had a high sea level 1500–1400 BP, a low sea level 1400–1300 BP, and a new high sea level 1300–1200 BP (as shown in Fig. 2). The high level seems to have lasted, at least, up to 1100 BP judging from a date from the crest of a +2 m beach ridge on Hithadhoo in the Addu Atoll.

By 1050 the sea must have fallen to a level at or just below the present as indicated by a date of 1055 BP of an operculum cemented in a beach rock on Hithadhoo (Addu) and a date of 1045 of a gastropod in a deep soil on a small island in the south of the Baa Atoll. A shore deposit (in a core) at –0.3 m was dated at 890 BP (AD 1060). Finally, at Lhosfushi in the South Male Atoll, we have an excellent site of the so-called "Reef Woman", a female skeleton resting on a sandy shore deposit and covered by coral debris of a rising sea level with a fossil shore at +0.4–0.7 m (Mörner, 2001a). The "Reef Woman" was dated at 875 BP (AD 1075). This low sea level seems to have lasted for about 200 years (~1050–850 BP).

The sea seems to have risen rapidly to a level in the order of +0.4–0.7 m judging from the quite clear stratigraphic sequence at the site of the "Reef Woman". On Viligili Island a beach ridge 0.8 cm above the present one was dated at 835 BP (AD 1115) and 795 BP (AD 1155), providing a second record of a high sea level in the order of +0.7 m. Corals in a sand layer at the extremity of a –38.5 m submarine cave was dated at 735 BP (AD 1215). This sand accumulation far below sea level may represent an old tsunami event. If so, also the beaches both at Lhosfushi and Viligili might represent a tsunami wash-over event.

A new low sea level period is indicated by the onset of gyttja deposition at 660 BP (AD 1290) in Lake Eigigali Kili on Hithadhoo (Addu), a human male skull in a deep soil on Kudadhoo (Baa) dated at 640 BP (AD 1310) and a thick beach rock (beneath an old three) on Isdhoo dated at 450 BP (AD 1500).

At Gan, there is a fossil beach ridge of a sea level some 0.5–0.6 m above the present one. Shells in the sediments just preceding the formation of the beach ridge itself were dated at 415 and 340 BP (AD 1545 and 1610). Corals in a sand layer in a submarine cave at –20 m was dated at 400 BP (AD 1550) and might perhaps represent a tsunami event.

Gastropods and fine corals in a sand layer from a –27 m submarine cave in Addu were dated at 230 and 205 BP, respectively (AD 1720 and 1745). The spreading of sand at such depths below actual sea level might always be taken as a possible trace of a paleo-tsunami. In this case it is backed up by observations of a major destructive flooding in 1733 (Bell, 1940).

A low sea level is indicated from about 200 to 160 BP (AD 1750–1790) by buried peat layers in two fens on opposite sides of the Island of Goidhoo

(Fig. 3). An intra-peat sand layer dated at 190 BP (AD 1760) is likely to represent a true tsunami event (further below). At 160 BP or AD 1790, the peat is covered by lacustrine gyttja, which signifies a rise in ground water level linked to a marine rise in sea level. Both lakes seem to have dried up relatively recently, most probably due to the sea level fall in the 1970s (Mörner, Tooley, Possnert, 2004).

All over the Maldives there is evidence of a sub-recent sea level some 20 cm higher than the present one (Mörner, Tooley, Possnert, 2004). In the 1970s, sea level fell to its present position. We have previously given multiple evidence of this regression as seen in island morphology, storm level displacement, high tide level displacement in open coasts as well as in lagoons, ground-water displacement in the Goidhoo fens, mean sea level as recorded by sailing routs, fishermen observations (Mörner, Tooley, Possnert, 2004). On the island of Gan we got a good record of a sub-recent rock-cut platform with fossil shore marked as sea level in a drawing by Bell in 1922 (Bell, 1940). Today the rock-cut surface is dry land with a present high-tide level 20 cm below (and mean sea level 43 cm below). This is illustrated in Fig. 4.

The data summarized above allow us to construct the sea level curve shown in Fig. 2. The curve is characterized by a number of oscillations in the order of 0.5 to 1.5 m indicating several levels well above the present one. These oscillations do not represent true ocean volume changes but must represent regional dynamic changes of "Super-El Niño-Southern Oscillation (ENSO)" type as defined elsewhere (e.g. Mörner, 1995).

The new sea level curve of the Maldives (Fig. 2) expresses the sea level changes in this region (Lat. 7°N–1°S; Long. ~73°E) as a combined effect of all forces involved. Therefore, it is quite reasonable that it bears little similarity to the sea level curve of Sri Lanka (e.g. Katupotha, 1995) and Bangladesh (Islam, 2001). The "last positive sea level" in Bangladesh (level GP-V) dated 2200–1800 BP (only recorded in the Khulna area) fits very well with the new Maldivian sea level curve, however. In Sri Lanka, we noted a recent sea level lowering (Mörner, 2001b) just as the one recorded in the Maldives in the 1970s (Mörner, Tooley, Possnert, 2004).

1.2. Geoid topography

The Maldives lie in the deepest geoid hole of the world (Fig. 1; Mörner, 2000, Fig. 3). Between New Guinea at +76 m and the Maldives at –104 m, the geoid relief is about 180 m. This geoid topography is not constant with time but constantly deforming in accordance with all factors affecting gravity and global mass distribution and rotation. During the last glaciation maximum, with a strongly increased rate of rotation, the geoid seems to have been lowered over the Maldives by about 30 m, giving a sea level now at about –150 m. For the early Holocene our analyses are not yet completed.

1.3. Local dynamic sea surface

In the Indian Ocean, the dynamic sea level is significantly lowered with respect to the geoid by the very strong regional evaporation (Fig. 1). This lowering is in the order of 3-4 dm (Mörner, 2000, Fig. 4). Hence, changes in the evaporation/precipitation not only affect the hydrological conditions, but also the sea level (e.g. Mörner, 2000; Mörner, Tooley, Possnert, 2004).

1.4. Ocean circulation

The monsoon generates significant regional ocean circulation changes during a year (Fig. 1). Differential rotation with interchange of angular momentum between the solid Earth and the hydrosphere is a strong factor affecting ocean surface circulation on a decadal to centennial basis (e.g. Mörner, 1995). Large-scale E–W displacements of ocean masses are recorded between the coasts of East Africa and South America (Mörner, 1992; 2000, Fig. 5). The so-called "Indian Ocean Oscillation" seems to be directly linked to those changes. This redistribution of water masses is capable of inducing significant changes in local and regional sea levels.

Most of the sharp spikes in the Maldivian sea level curve must originate from dynamic changes, where ocean circulation changes seem to play an important role in combination with associated changes in evaporation/precipitation, air pressure, and steric temperature effects.

1.5. Air pressure

The annual monsoonal cycle gives rise to considerable annual changes in main air pressure gradients from the Himalayas to the Indian Ocean (Fig. 1; Mörner, 2000, Fig. 6). At the coast of Bangladesh, the annual mean difference in air pressure is in the order of 15 mbar which corresponds to a deformation of the mean sea level by ~15 cm (low in January and high in July). Any change in the main monsoonal regime would alter these gradients.

1.6. Monsoonal regime

Almost certainly, the monsoon experiences decadal to centennial variations. Such changes are likely to be linked to the changes in the earth's rate of rotation with interchange of angular momentum between the solid earth, the hydrosphere and the atmosphere as proposed by Mörner (e.g. 1987, 1988, 1995) and briefly discussed under Sections 1.4 and 1.5, above. This would link the observed oceanic effects also with land-based climatic changes in the region (temperature, precipitation, intra-annual coastal flooding).

For the mega-delta of Ganges-Brahmaputra this would imply that it has passed periods of more and less severe flooding problems, which would have had a direct impact on the way of living and coastal settlement.

1.7. Tsunami events

On 26 December 2004 the world suddenly woke up by the terrible tsunami event cursing the coastal areas of the Indian Ocean. The origin was an exceptionally large earthquake off Sumatra with a magnitude of 9.3. It was physically felt in the Maldives 2400 km away. Tsunami events have occurred in the past and will re-occur in the future.

There are not so many records of past tsunamis in the Indian Ocean. We have some interesting examples from Sri Lanka and from the Maldives, however.

1.7.1. Sri Lanka

At Kalametiya in southern Sri Lanka, a number of 2–3 m deep pits have been dug by the local people for "mining" a buried shell-bank (cf. Katupotha, 1995). In 2001 we examined the site and found quite clear evidence of liquefaction caused by an earthquake (Mörner, 2001b, Figs. 10–13). The stratigraphy is as follows from base to top; (1) a habitation surface with artefacts, bones and charcoal, (2) a 25 cm shell-bank in sand, (3) 25 cm of littoral sand, (4) 15 cm of humic sand (an old land surface) and (5) 115 cm of estuarine silt. The layer 3 sand was strongly liquefied with venting structures penetrating the layer 4 land surface and injecting into the covering layer 5 silt. The light shells (of layer 2) and humus (of layer (4) were "floating" on top of the liquefied sand (layer 3). Fig. 5 shows the venting of shells from layer 2 up into the layer 5 silt. Consequently, the venting and liquefaction must have occurred during the deposition of the estuarine silt, which implies an age in the order of 1–2 thousands of years.

At Gadawaya a Buddha temple said to date from about AD 200 had collapsed, the roof falling in, the entrance stepping stones being displaced in various directions, and erected "stupa" stones besides being tilted in different directions (Mörner, 2001b, Figs. 15–16). The tilted stones are shown in Fig. 6. It is tempting to interpret the collapse and the deformation in terms of a paleoseismic event. In this case, we know that it must post-date AD ~200.

In the Great Chronicle of Ceylon, the Mahavamsa (CGID, 1950), there is a story about King Tissa (who ruled in the late 3rd century BC) which tells that the King heard a sound, that men were thrown into the sea, that the sea overflowed the land, and that the princess was rescued on a golden ship. It sounds like an earthquake with an associated tsunami. In this case, however, it seems to be about 500 years too old to be associated with the earthquake effects recorded at Kalametiya and Gadawaya.

Sri Lanka (Ceylon) is usually considered to have little or no seismic activity. Besides the event discussed above, however, there is a historical record of a "terrible earthquake" in 1615.

1.7.2. The Maldives

At our first main expedition to the Maldives in 2000, our team stayed on the Goidhoo Atoll for a week and worked quite intensively both in the sea (coring, diving) and on land. Two swamps or rather fens were found and cored. A very interesting sea level story was recorded including clear evidence of sea level oscillations. The two fens are located on opposite sides of the island. Still, the recorded stratigraphy was almost identical (Fig. 3). Within a telmatic peat there was a layer of sand in both fens. This layer may denote a sea level oscillation, an accidental storm or even a tsunami event. The base of the peat above the sand layer was C14-dated at AD 1770 ±40 and the top of the peat below the sand layer dated at AD 1760 ±40 (gyttja) and 1700 ±50 (roots); i.e. overlapping at 1735 ±15.

This means that the sand layer represents a very short period of time; i.e. an instantaneous event. This seems to exclude a sea level oscillation. Because the sand layer occurs in two fens on opposed sides of the island, an extreme storm seems less likely. A tsunami, on the other hand, is both instantaneous and capable of affecting the entire island. A guess was not good enough, however. We needed to live up to the sentence: *quod erat demonstrandum.*

In February 2005 we returned to the island and investigated and sampled the signals left on both fens from the terrible December 26 tsunami. On the surface of both fens there now was a sand layer covering the lake gyttja.

These sand layers looked just as the sand layers in the peat in the subsurface. This meant that the tsunami "signature" from 2004 looked just like the proposed tsunami layers in the subsurface. This is a strong argument for an interpretation of the intra-peat sand layers in terms of a paleo-tsunami.

I then started to look for a historical documentation of this event in the book of Bell (1940). Male suffered an earthquake in 1759; i.e. just when the tsunami-like sand layer was deposited in the two fens on Goidhoo. However, an even more tsunami-like event is recorded in 1733 when a disastrous flooding affected many islands, especially the northern ones, with a great loss of lives and properties.

I am quite happy with this. We suspected a tsunami origin of the intra-peat sand layers in our cores of 2000. We got a precise date of 1760–1720. The tsunami of 2004 left an almost identical signal on both fens. Finally, an earthquake was recorded in Male in the year 1759 and a disastrous, tsunami-like flooding in 1733; both events fit well with the age of the intra-peat sand layers on Goidhoo. Submarine spreading of sand is recorded in a –27 m cave in Addu and dated at AD 1720 (garstropods) and 1745 (corals) agreeing very well with a 1733 paleo-tsunami event.

This is one paleo-tsunami event recorded in the Maldives. We have traces of others, too. There are also some legends suggesting sudden events in the past.

The Maldives were inhabited by Buddhists from Sri Lanka who built remarkable temples at various atoll islands. Several of them were recorded and even measured in detail by Bell (1940). We have investigated, sampled and dated some of them. The first to become attracted by those forgotten temples was Heyerdahl (1986). On the island of Fula Mulaku he visited an old mound ("hawitta") and recorded the legends of "the redin" people who built them. At that time, it was said, the sea was connected with the present inland lake. A huge storm threw up a beach ridge separating the lake from the sea. We may ask: could this great storm have been a tsunami? In 2005 we investigated and sampled two "hawittas" on the islands of Isdhoo and Gan in the Laamu Atoll. Fresh shore erosion from the 2004 tsunami had exposed a good section of the "hawitta" construction on the island of Isdhoo. The "hawitta" (or "dagaba") was connected to a pathway of cut, flat coral "stones". In the new section (Fig. 7) these pathway "stones" were seen resting upon 80 of older beach material covered by 40 cm of a younger beach generation.

The temple and "hawitta" on the island of Gan is truly impressive (Bell, 1940). It must have been an important religious centre with lots of people around. It flourished AD 300–400. It seems to have been abandoned with the younger beach event at about AD 500 that might represent an extreme storm or a tsunami event although a higher sea level is also recorded at this time (Section 1.1).

We sampled the sand in several submarine caves with the intention of dating the sea level position at the time of the sea cave erosion. The biological content in the sand was carefully examined and classified (by Jacques Laborel) and divided up in ecological groups. Shallow water gastropods and corals were picked out for C14-dating. None of our dates refer to the sea level position in question. In this view, our efforts failed. Instead, we seem to have found a new technique of recording possible paleo-tsunami events. The deposition of sand far below the maximum depth of normal wave actions implies that we were dating special events like extreme storms or tsunami events. At the 2004 tsunami, submarine "sand storms" were reported by divers. The following events of submarine sand shedding were dated by us: (1) –26 m at 6300 BP in the Baa Atoll, (2) –38.5 m at 735 BP or AD 1215 in the Addu Atoll in close agreement with the formation of a major beach ridge on Viligili and the coral rubble bed covering the "Reef Woman" at Lhusfushi, (3) –20 m at 400 BP or AD 1550 in the Baa Atoll, (4) –27 m at 230 and 205 BP or AD 1720 and 1745 in the Addu Atoll agreeing very closely with the AD 1733 disastrous flooding and the intra-peat sand on Goidhoo, and (5) modern age from a –21 m cave in the Baa Atoll.

Some of the beach ridge deposits might, in fact, represent large storms and tsunami events. For example: (1) the lower beach on Gan and Isdhoo reaching some 80 cm above the present equivalent and dating at about AD 150-250 (ending the high level ca. 2000 BP), which precedes the Buddhist settlement and perhaps might be linked to the tsunami event on Sri Lanka though this seems to be a little younger, (2) the upper beach ridge on Gan and Isdhoo, some 130 cm above the present equivalent and dating at about AD 530, (3) the beach ridges surrounding Queens Bath in Addu reaching about 2 m above the present equivalent and dating at AD 850 and seemingly correlative with the legendary beach ridge on Fua Mulaku, (4) the lower beach ridge on Viligili reaching 60 cm above the present equivalent and dating at AD 1115, in correlation to the deposition of the beach rubble covering the "Reef Woman", and (5) the upper beach material on Viligili reaching some 90 cm above the present equivalent and dating at the last 50 years (or so) because it covers a soil horizon with bear cans and wine bottles of 20th century origin.

2. Implications and conclusions

2.1. Migrational stress

When a biological population has reached a critical size, migration may occur, sometimes taking the form of a direct migration pressure. Migration takes place by walking or creeping over land, by swimming or rafting over the sea, or by flying in the air. Certain factors may act as stimulus or push to migrate. Sea level changes and climatic changes are factors that may induce migration of people and animals. The same applies for catastrophic events like earthquakes and tsunamis. These natural factors will also be the main forcing functions in the future.

2.1.1. Sea level oscillations

The new sea level curve of the Maldives here presented (Fig. 2) includes a number of rapid transgressive spikes, caused not by global water-volume changes but by regional dynamic forces (Mörner, 2000). Those spikes may have acted as important forcing factors for the migration over the seas by ancient people, and for the opening and closing of trading routs.

2.1.2. Tsunami events

Tsunami events are terrible experiences for all people connected to the affected coasts. We have a case open for speculations. The Sri Lanka paleoseismic event at AD 200–400 is not yet precise enough to determine its relation to overseas migration by the Buddhist monks who settled on the Maldives and erected “hawittas” and remarkable temples. Could the earthquake and tsunami event have been the impulse of the maritime migration to the Maldives? And, what ended this settlement (or at least took the force out of it)? Could it be a second tsunami event ca. AD 850; responsible for the beach ridge on Fua Mulaku and the younger beaches on the islands of Isdhoo and Gan? At present, I leave it as a hypothesis.

2.2. Future perspectives

Future perspectives and predictions have to be formulated on the basis of past experiences and observational facts. Modelling has a high risk of producing out-put data far from the real world (e.g. IPCC, 2001). Our sea level investigations of the Maldives (detailed, well-dated and conducted by a team of specialists) have shown that the sea in not at all in a rapidly rising mode, probably not rising at all, and with a significant fall in the 1970s (Mörner, Tooley, Possnert, 2004; Mörner, 2004; 2005). We are, therefore, not able to subscribe to the view that certain areas of the world are liable to extensive flooding in the near future. This is a novel finding with far-reaching implications for future planning.

At the same time, however, our sea level records have documented the occurrence of a number of rapid sea level "spikes" in the order of 60–100 cm that are of a regional to local dimension and often directly compensational nature; i.e. the redistribution of water masses, in full agreement with the concept of the occurrence of global "Super-ENSO" events.

These ocean dynamic changes seem often to be closely linked to changes in the monsoon regime. Therefore, the effects may be both multi-dimensional and spatially far-reaching. The coasts of the Indian Ocean will always continue to be severely threatened by tsunami events and extreme storms.

Acknowlegements

The Maldives Sea Level research project was initiated as a part of the INQUA Commission on Sea Level Changes and Coastal Evolution. The project includes six visits to the Maldives; (1) in 2000; setting up the project, (2) in 2000; main expedition 1, (3) in 2001; the "Reef Woman" investigation, (4) in 2001; main expedition 2, (5) in 2003; recording a TV-documentary, (6) in 2005; main expedition 3. Our research group included: N.-A. Mörner (main project leader), J. Laborel (diving leader, biozonation), M.J. Tooley, S. Dawson (tsunami research), W. Allison, J. Collina, F. Laborel, C. Rufin, S. Islam, B. Lembke, D. Dominey-Howes, A. Dupuch, M. Banfield and our local friends from the National Centre for Linguistic and Historical Research (N. Mohamed et al.), from Ecocare (M. Zhair, M. Manik, H. Maniku), from Sea Explorer and Whale Submarine. Paul Sinclair arranged our travel to Sri Lanka. This article is based on a paper presented at the 18th European Conference of Modern South Asian Studies in Lund, July 6-9, 2004.

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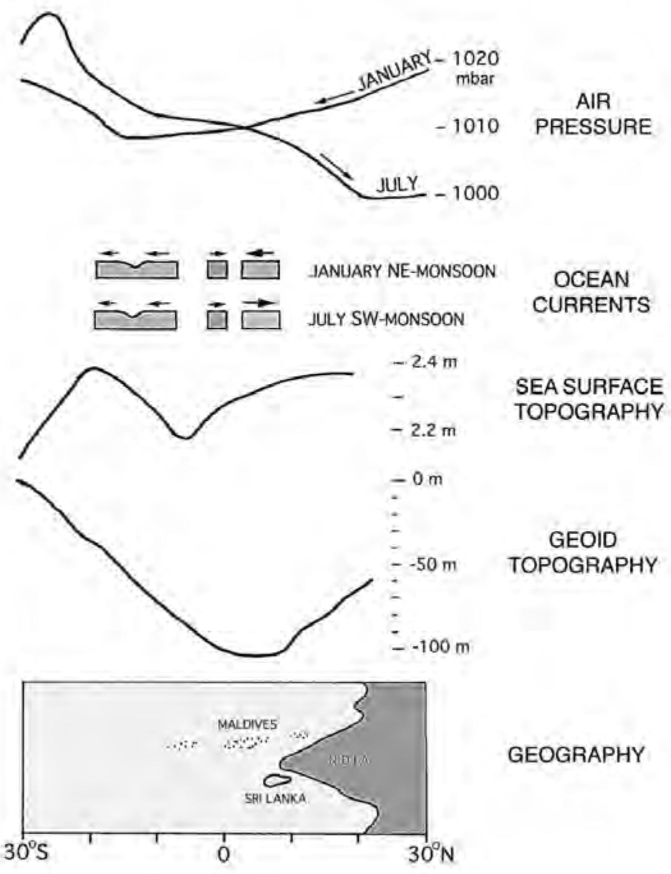

Figure 1

Indian Ocean variables in a N–S profile from 30°N to 30°S Latitude. Air pressure, ocean currents and dynamic sea surface topography are all subject to short-term changes. Even the geoid topography is subject to time-variations. The Maldives have a key role for the recording of these changes. It has directs implications for the understanding of migration and trading through time.

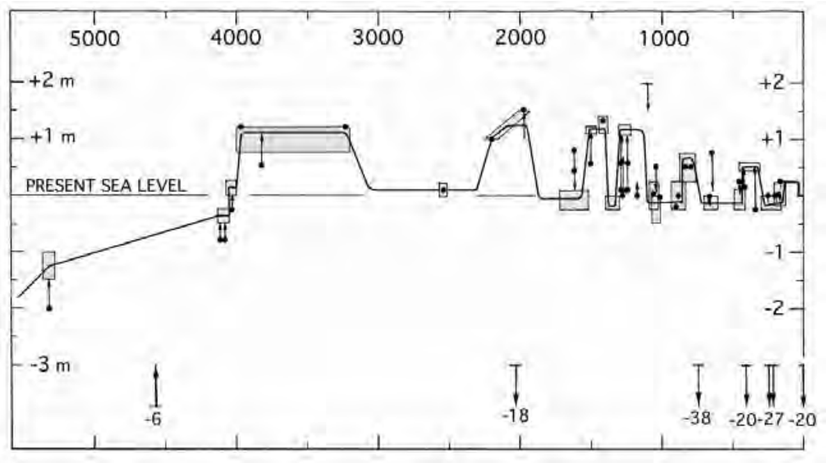

Figure 2

The new sea level curve of the Maldives. Age in C14-years BP with a "sea correction" of –350 years as defined by shell vs peat ages in the core on Goidhoo (Fig. 3). At the base: arrows down refer to sand spreading down into submarine caves at depths given by the numbers below, and arrow up refer to a coral in situ at –6 m.

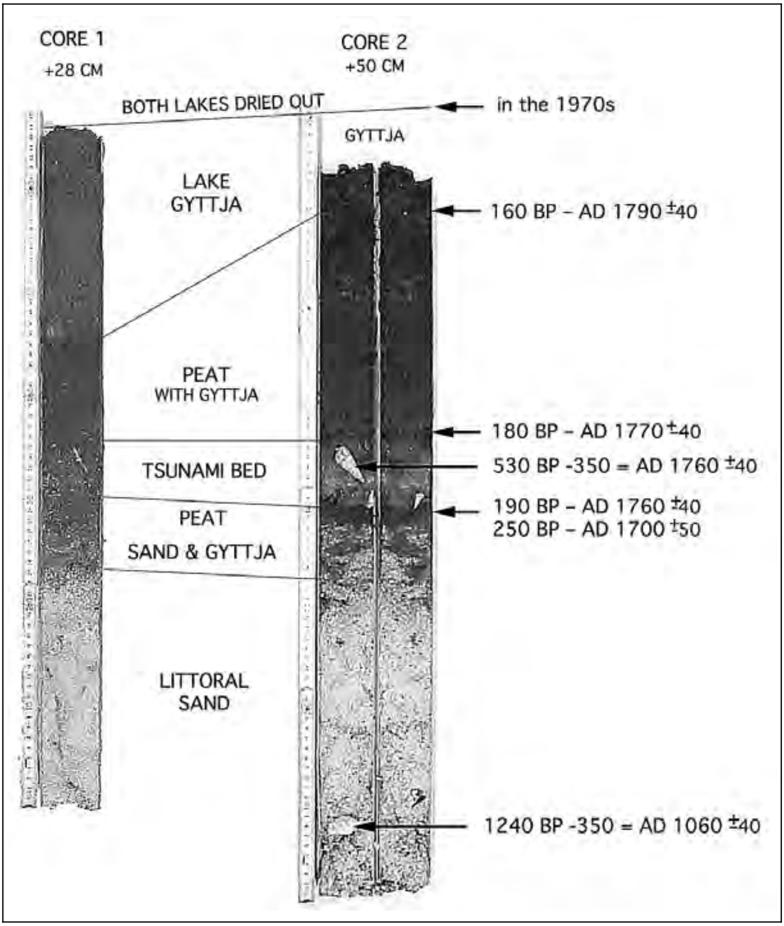

Figure 3

Stratigraphic records from the two fens on Goidhoo; Core 1 from the "Shaidul Fen" on the south side of the island, and Core 2 from the "Bjarne Fen" of the northern side. The 2004 tsunami signal recorded at the top of the two fens is almost identical to the intra-peat sand-layers, here denoted "tsunami bed", in the two cores (note that the *Turritella* shells are not lying horizontally bedded). The difference between the shell-age and the peat-ages gives a good record of the local "sea correction" of –350 years.

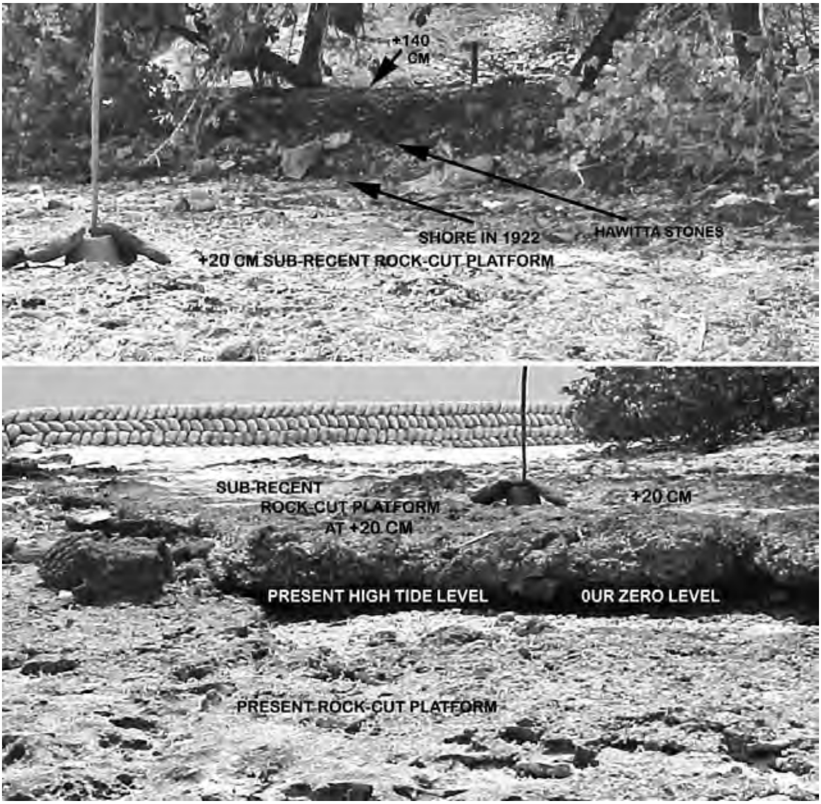

Figure 4

The shore morphology just north of the big “hawitta” on the Island of Gan. Above: A fossil, sub-recent shore and rock-cut platform at +20 cm. This shore was active in 1922 when Bell visited the site and made a drawing (Bell, 1940). Below: The present shore with high-tide level (zero at levelling), rock-cut platform in formation and mean sea level at 23 cm below local zero. This give firm evidence of the fall in sea level recorded in the 1970s by multiple criteria (Mörner, Tooley, Possnert, 2004).

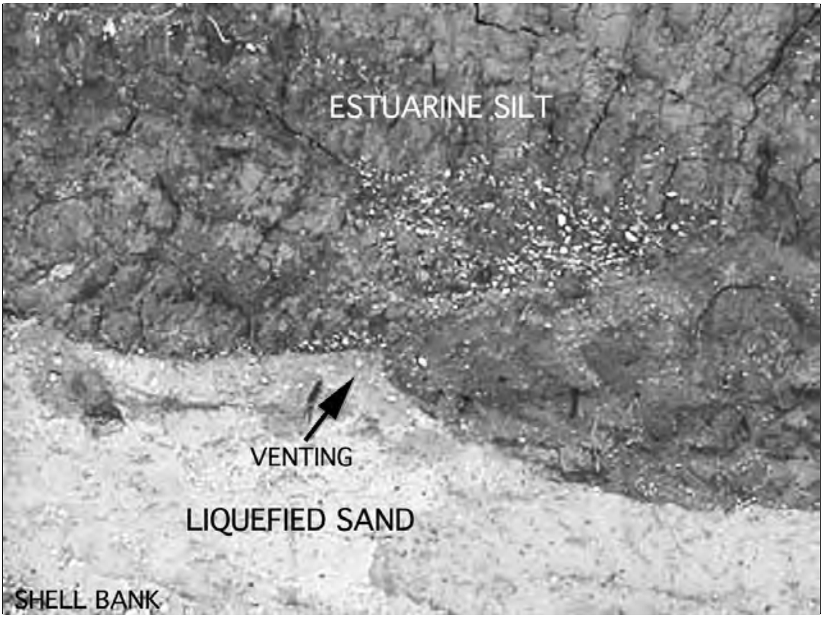

Figure 5

Liquefaction structure at Kalametiya. The liquefied sand behaves like a heavy fluid; lighter shells and organic matter flute up to the surface, the boundary to the estuarine silt above becomes wavy, and shells are being vented high up into the estuarine silt. This seems to call for an origin in seismic ground shaking of a paleoseismic event of a magnitude of >6 on the Richter scale.

Figure 6

Erected “stupa” stones outside a collapsed Buddha temple at Gadawaya. The stones are tilted in different directions as if violently shaken by an earthquake. The temple beside has collapsed in a manner common at ground shaking. A paleoseismic event is assumed. This may be supported by an old legend in the Mahavamsa chronicle.

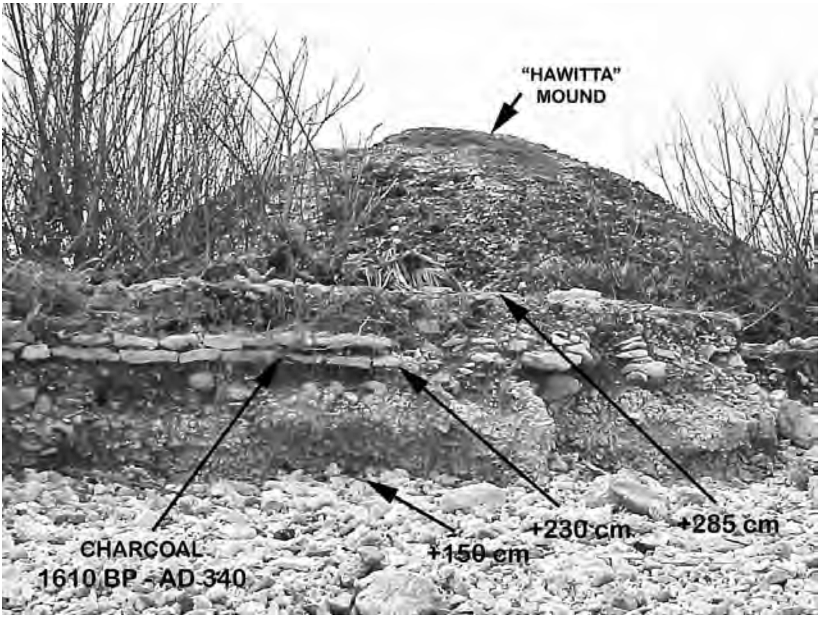

Figure 7

Stratigraphic section just off the main "hawitta" ("dagaba") on the island of Isdhoo (a similar record was obtained on Gan). Charcoal between the flat "stones" of the pathway from the "hawitta" was C14-dated at 1610 BP or AD 340. It rests upon a lower beach material deposited 80 cm above the present limit of beach gravel (at +150 cm) and is covered by an upper beach deposit reaching 135 cm above the present beach gravel.