Vulnerability of the Indian coastal region to damage from sea level rise

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The vulnerability of the Indian coastal region to the consequences of the estimated sea level rise due to the green-house effect is examined. The main observations are: a) The region most vulnerable to inundation from an accelerated sea level rise is the Lakshadweep archipelago. b) The east coast of India, with its lower coastal slopes and higher cyclone frequency, will suffer from increased storm surge damage. c) The belt between approximately 12°N and 18°N on the west coast appears to be the least vulnerable. However, the region to the south of this belt is likely to experience increased coastal erosion.

It is now well established that the concentration of greenhouse gases in the atmosphere has been increasing[1]. CO_2 concentration, for example, has increased from approximately 280 ppm in 1860 to around 350 ppm at present[1]. Though it has been predicted that the build-up of these gases will increase global surface atmospheric temperature, there are considerable uncertainties in the predictions; for example, doubling of CO_2 could increase the temperature[2] by anything between 1.5°C and 4.5°C. Increased surface atmospheric temperature will lead to thermal expansion of the oceans and to melting of snow and ice from high altitudes and latitudes. Consequently, the mean sea level will increase[3].

It has been estimated that during the last century the global sea level rose by 10–15 cm[4,5]. Over the same period, the global warming has been estimated[6] to be about 0.4°C. A rise of about 5 cm in sea level can be linked to thermal expansion because of the global warming; the remaining 5–10 cm rise has been attributed to deglaciation[7]. Because little is known about the rates of deglaciation due to global warming, it has generally been assumed that the ratio of the sea level rise due to thermal expansion to the rise due to deglaciation will vary between 0.5 and 1.0; with such approximations, the estimates of global sea level rise[8] for the year 2050 vary from 23.8 cm to 116.7 cm; for the year 2100 from 56.2 cm to 345.9 cm.

What effects will such a rise have on the coastal region of India, and which areas are vulnerable to an adverse impact? This question is addressed here by a synthesis of available data. The dominant effects of the sea level rise on the coastal region will be: (a) submergence of low-lying coastal areas and increased damage due to erosion; (b) increase in damage due to storm surges; (c) possible salt water intrusion into coastal freshwater aquifers. The total length of the Indian coastline (inclusive of major indentations and shores of islands) is approximately 9000 km. Of these about 55% has beaches and 25% has prograding shore, including deltas[9].

Continental coastline

One indicator of the vulnerability of a coastal region to inundation is the topographic slope (increase in altitude for a given distance perpendicular to the coast). One can get feel for the variation in the topographic slope by examining the 200 m contour shown in Figure 1. The slope is generally the greatest in central west coast. The east coast slopes are usually smaller than those on the west coast.

The sea level rise that we are concerned with will be of a few metres. We should then be examining the

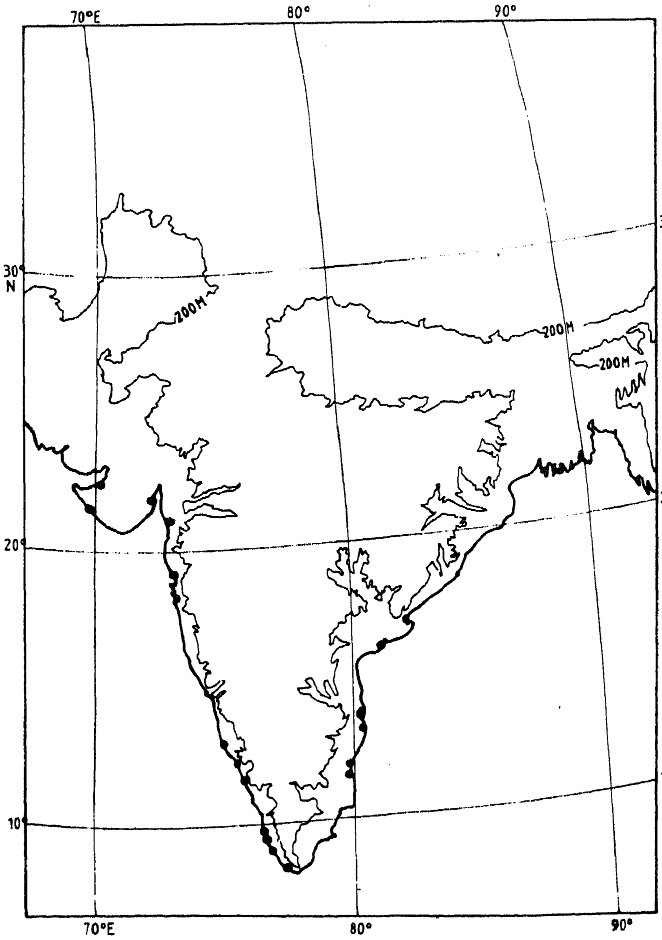

Figure 1. Geometry of the 200 m contour. Dots mark locations of coastal cities with population more than 100,000.

coastal slopes using maps which resolve the topography every one metre or so. There are, however, two difficulties with this approach. First, such charts (with scales 1:5000) are generally not available. Secondly, the intention here is to get a broad national scale picture of the variability of topographic slopes. In view of these, we have determined the slopes using the more easily available survey of India maps on the scale of 1:50,000 with topographic contour interval of 20 m. At every 0.5° latitude interval, the distance between 20 m contour from the coastline was computed. From this, by linear interpolation, we computed the distance by which the coastline would retreat if the sea level rose by one metre. The results are plotted in Figure 2. From the point of view of shoreline retreat, the stretch of the west coast between approximately 12° and 18° is the safest. Topographic slopes decrease both to the north and the south of this region. The slopes are generally smaller on the east coast, making it more vulnerable to inundation. The slopes are particularly small in the region around estuaries. Such areas are likely to suffer the most during storm surges.

Tropical cyclones cause surges along the coasts of India. The magnitude of a surge is the largest in the vicinity of the point where the storm lands on the coast. The India Meteorological Department has documented the tracks of known tropical cyclones in the Indian Ocean[10]. To show the variation in the frequency of their landing on the coasts of India we used these data to determine the number of cyclones that intersected the Indian coasts in a 1° latitude bin. The results summarized in Figure 3 bring out striking dissimilarities between the frequency of cyclones on the east coast versus the west coast, and hence the vulnerability of the former to storm surge damage. Some earlier studies suggest that as the greenhouse effect sets in, the cyclones will get both more frequent and more destructive. Emanuel[11] estimated that in August in an atmosphere with twice the present CO_2 concentration, the destructive potential of hurricanes will be 40–50% larger.

An area of concern from the point of view of coastal erosion is the coast of Kerala. On the basis of a comparison of maps of 1850 and 1966, Earattupuzha and George[12] concluded that the major part of the coast has receded over the period. Since 1966 granite walls have been built to reduce erosion. The tendency of the coast to erode is likely to increase as the sea level rises. It is, however, not possible at present to make a quantitative estimate of this increase.

With the greenhouse effect, it is expected that changes will occur in the global precipitation pattern[1].

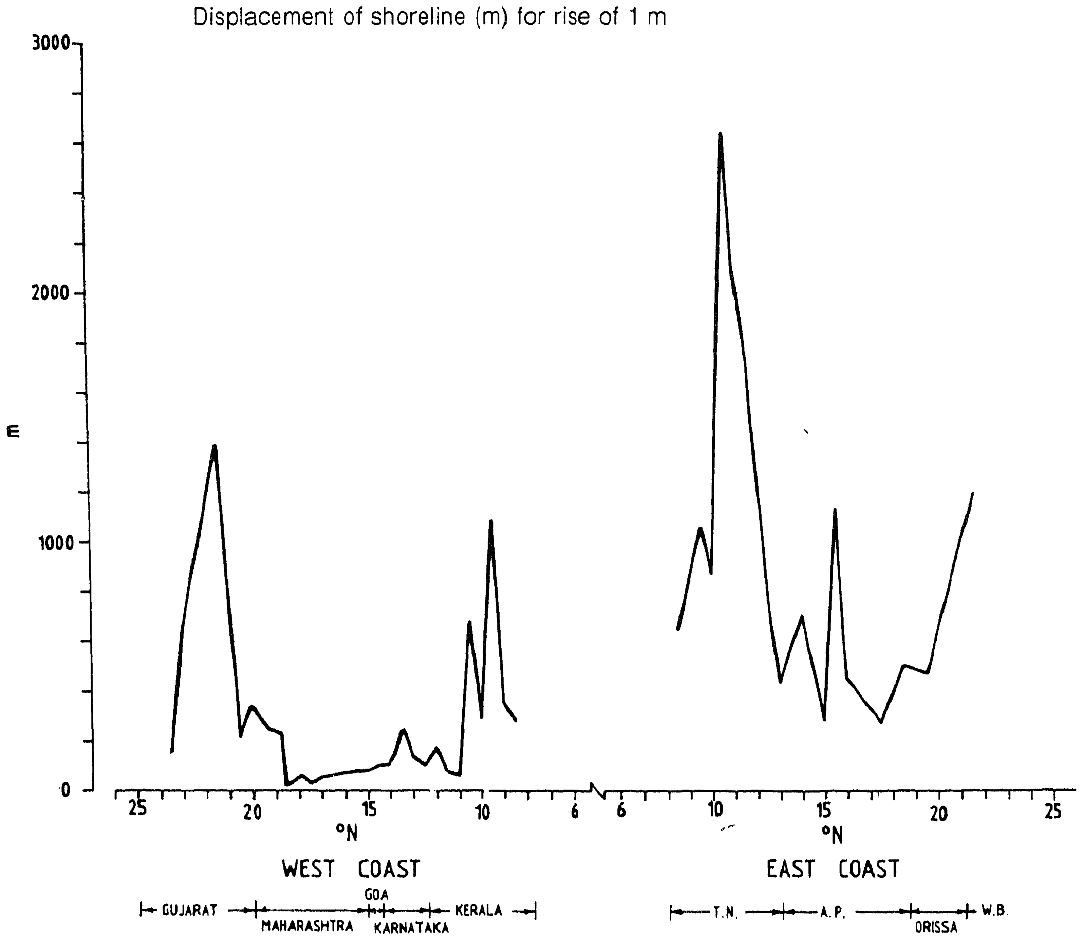

Figure 2. Estimate of distance by which coastline will recede if sea level rises by 1 m, shown as a function of latitude of the east and the west coastlines.

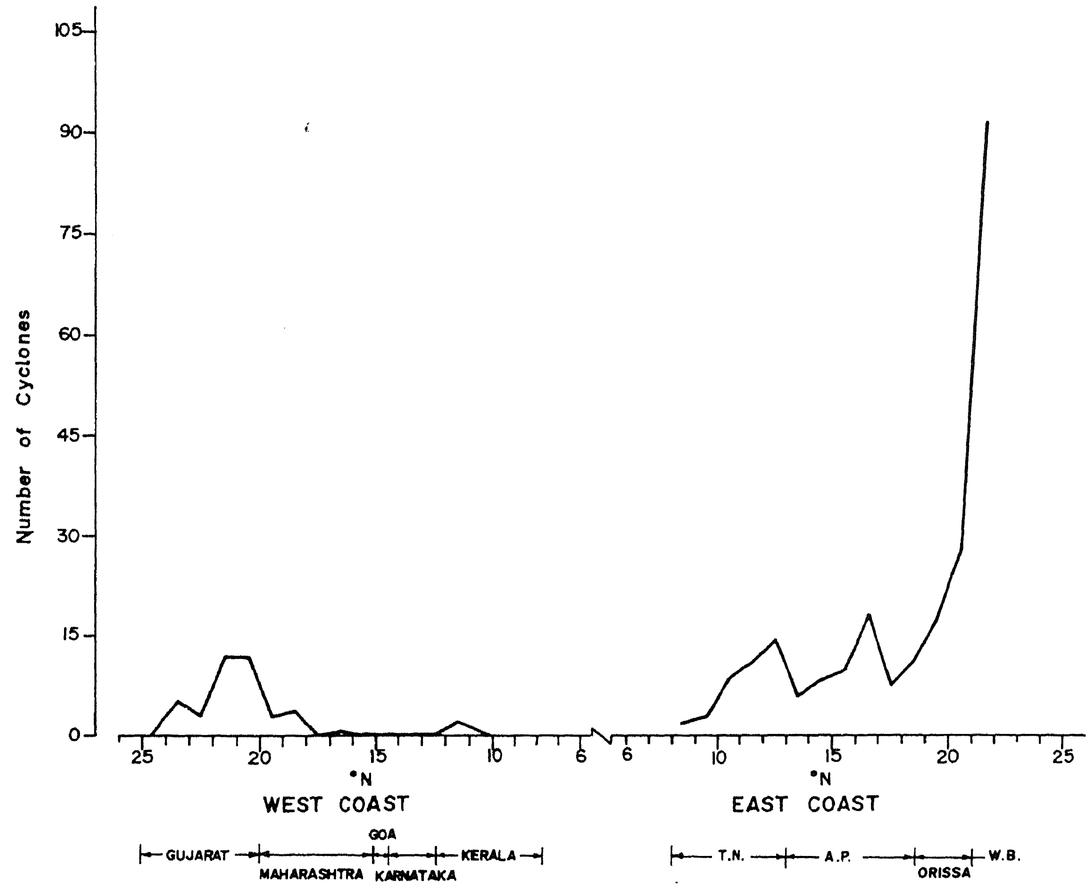

Figure 3. Number of cyclone landings along the coast of India shown as a function of latitude of the east and the west coastlines.

This in turn will alter the rate of recharge of groundwater aquifers. But, if this rate does not change for the better, then with the increased sea level salt water will penetrate the freshwater aquifer thus bringing coastal water supply under pressure. At present the coastal drought-prone areas include Kutch and parts of Saurashtra, southern Tamil Nadu, central coastal Andhra Pradesh and southwestern West Bengal[13]. Moreover groundwater availability in Kerala and Goa is low, less than one million hectare metres/year[13].

The ability of a region to adapt to the changes from

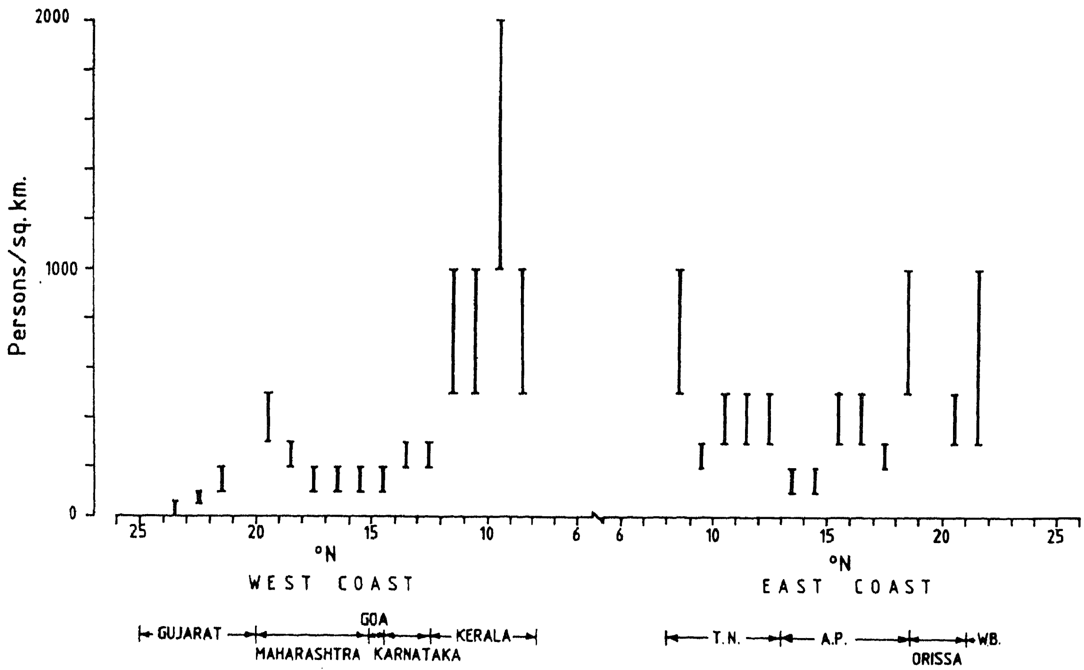

Figure 4. Variation of population densities in coastal districts as a function of latitude of the east and west coastlines.

the sea level rise depends on the investment of resources that has been made in the region. An indicator of this, but not a complete one, is the population density of the region. Figure 1 shows the locations of all coastal cities with population more than one lakh. Figure 4 shows the variation of population densities in coastal districts using the data given in Muthiah[13]. A feature that stands out in the figure is the high population density in the coastal region of Kerala. Other than this region, the population densities on the west coast are generally lower than on the east coast.

Islands

The Lakshadweep archipelago off the southwest coast of India consists of 27 separate coral reefs and islands with a total area[14,15] of 32 km^2. Ten of the islands are inhabited. The population of Lakshadweep is about 32,000, thus making the inhabited islands one of the most densely populated regions of the country. The Lakshadweep islands are low lying with the highest point on the islands generally not higher than a few metres above the sea level. The Andaman and Nicobar islands represent the unsunken remnants of the Tertiary folded mountains. The Andamans include 204 islands and islets[16]. The Nicobars have 12 inhabited and 7 uninhabited islands[16]. The total population[15] of the Andamans and Nicobars is about 115,000 and their combined area is 8,293 km^2.

The vulnerability of the low-lying Lakshádweep islands to sea level rise can be appreciated from the cross-sections given in Figure 5. These sections of the Minicoy island are based on the data given in Gardiner[17]. The difference between the mean low level (average of mean lower low and mean higher low tidal level) and mean higher high spring tide at Minicoy[18] is 0.86 m. Most human activity is restricted to regions above the mean higher high spring tide. From the figure it is clear that a rise of 1 m in the mean sea level will severely restrict human activity on the island and a rise of 2 m will virtually make it impossible.

The Andamans and Nicobars have steeper slopes, the maximum altitude on the islands often exceeding 100 m. Hence the danger from inundation due to sea level rise in this archipelago is small in comparison to that in the Lakshadweep. The higher population densities in the latter also make it more vulnerable than the Andamans and Nicobars. The frequency of storms, that generally originate in the Bay of Bengal, is however higher in these islands than in the Lakshadweep.

Little data exist at present on the groundwater table in the Indian islands. In islands the freshwater aquifer forms a lens surrounded by heavier saline water. If the sea level rises and if the recharging of the aquifers remains unchanged, the freshwater aquifer will be polluted by saline water intrusion.

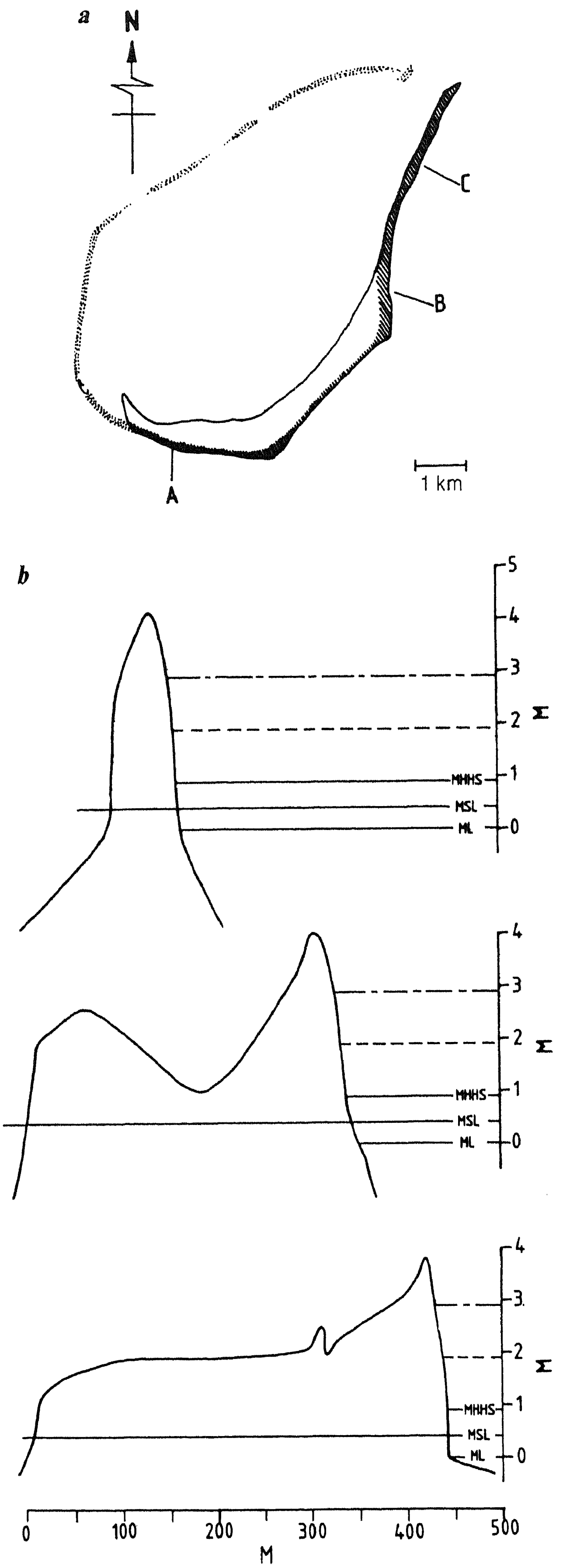

Figure 5. ***a***, The Minicoy Island. Boulder zone is dotted. Rocky region on the island is shaded. ***b***, Topography along lines A, B and C is shown in Figure 5***a***. Present levels are shown by ML (mean low), MSL (mean sea level) and MHHS (mean high high spring). ---, the future MHHS if the mean MSL rises by 1 m; —·—, MHHS if the sea level rises by 2 m.

Concluding comments

Ahmed[9] has documented the evidence of land subsidence along the coasts of India. This includes the presence of peat bed, 6–13 m below the surface, at several locations near Calcutta and submerged forests in Valimukkam Bay near Tirunelveli, and off Bombay. Local depressions occurred during the earthquake of 1819 in Kutch leading to submergence of 500 km^2. Most of these studies, however, are much too local to determine the nature of the large-scale crustal deformation, and the geological factors controlling it.

Tide gauge data are useful to determine the trend of submergence or emergence along the coast. In one such analysis Emery and Aubrey[19] concluded that Mangalore during 1953–1976 showed a drop of 1.33 mm/year in the sea level. Four other ports, Bombay (1878–1963), Cochin (1939–1978), Madras (1916–1977) and Visakhapatnam (1937–1978) showed a rise (indicating relative sinking of land) of 1.28, 2.27, 0.36 and 0.76 mm/year respectively. Data from these five stations give an average rise of 0.67 mm/year and a median of 0.76 mm/year. As pointed out earlier, similar studies[4,5] on a global scale suggest a rise of 1.0 to 1.5 mm/year. Note that this trend is almost an order of magnitude smaller than the predicted rate of sea level rise due to the greenhouse effect.

In summary, our conclusions regarding the vulnerability of the Indian coastline to the sea level rise are as follows:
(a) The region most vulnerable to accelerated sea level rise is the low-lying coral atolls of the Lakshadweep archipelago. (b) The east coast of India, with a larger frequency of storms and lower continental slopes, is more vulnerable than the west coast to damage from storm surges. (c) The stretch between approximately 12° and 18° N on the west coast appears to be the least vulnerable. The coastline to the south of this belt, however, has shown a tendency to get eroded and this tendency is likely to increase when the sea level rises.

It should be noted that the conclusions derived here are based on large scale features. Considerable smaller scale variations are expected to be superimposed on them. These will need to be examined before planning one's response to sea level rise. A major difficulty in deciding about the response is the uncertainty associated with the predictions of sea level rise. At this stage it would be prudent to restrict the response to those problems which already exist (and need to be addressed anyway) and which will get worse as the sea level rises. On the basis of the discussion here we identify three such areas. First, the stability of the Lakshadweep islands from the point of view of sediment transport, geomorphology, etc. needs to be better understood. Secondly, the capability to face the storm surges on the east coast needs strengthening. Third, efforts to prevent erosion along the southwest coast need to be enhanced.

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