PRELIMINARY OBSERVATIONS ON THE HYDROGRAPHY AND INSHORE PLANKTON IN THE BAY OF BENGAL OFF VISAKHAPATNAM COAST

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Plankton investigation in Indian waters is in its infancy and most of the observations so far made are confined to a narrow coastal belt of water not exceeding two to five miles width, the samples being collected by towing a net from country crafts like the catamaran. Sewell (1913) gave the earliest account of the plankton from the south-east zone of the Bay of Bengal, based on a large number of samples collected from R.I.M.S.S. "Investigator" during the survey season 1910–12. He found that while in the northerly region of the zone under survey the plankton exhibited a regular banded arrangement, there was uniform distribution of the plankton in the southerly region. Other studies have so far been largely confined to the inshore waters. Menon (1931), Aiyar *et al.* (1936), and Rama Murthy (1953) studied the qualitative and quantitative aspects of the plankton off the coast of Madras City. Chacko (1950), Prasad *et al.* (1952) and Prasad (1954) have made preliminary investigations on the seasonal variations and distribution of the plankton in the Gulf of Mannar. Ganapati and Murthy (1953) made a preliminary survey of the quantitative variations of the phytoplankton at various depths and distances in the neritic waters off Visakhapatnam. In addition to these general investigations accounts of special groups of planktonic organisms from the Bay of Bengal are also available.

Our present knowledge of the hydrographical conditions in the Bay of Bengal is largely due to the work of Sewell (1929) who, after carrying out a series of investigations on the surface waters of the Bay from the southern extremity of Ceylon to Duncan passage, prepared a series of four charts showing the isohalines in the Bay corresponding to the seasons, September to November, December to February, March to May and June to August. He showed how the isohalines were influenced by the prevailing currents during the various seasons. Jayaraman (1951) made observations on the chemistry of surface waters of the Bay of Bengal off Madras City during the period 1948–49. Prasad (1952) during a cruise on I.N.S. "Delhi" from Trincomalee in the south to Calcutta in the north and back, made observations on the temperature gradient and light penetration at 22 stations in the

upper 200 feet layer of water. From water samples collected at the above stations as well as from five others during the cruise the author has also given data on the salinity at the different stations. La Fond (1954) investigated the environmental factors affecting the vertical temperature distribution of the upper layers of the sea and also the phenomena of upwelling and sinking of the waters in the central part of the east coast of India. Ganapati and Murthy (1954) made observations on the distribution and seasonal variations of the surface salinity and temperature off the Visakhapatnam coast.

From a hydrographical point of view the coast near Visakhapatnam is of particular interest on account of the influx of large quantities of fresh water into the Bay from the great rivers, Krishna and Godavari, to the south and Mahanadi and Ganges to the North. The surface currents skirting the coast move in a northerly direction during part of the year, and in the opposite direction during the rest of the year. These opposite currents also influence the hydrological conditions in the inshore waters to a marked extent.

In the present investigation a preliminary qualitative and quantitative survey has been made of the micro-plankton with special reference to the diatoms and dinoflagellates. However, it need hardly be emphasized that the conclusions arrived at in the present investigation have to be substantiated by observations and data for the next few years.

Material and Methods

The observations made in the paper are based on samples collected during the period August 1951 to July 1952. To avoid the uncertainty as to the volume of sea water filtered by towing the net from a catamaran, a known volume of approximately 300 litres of water was filtered through a fine bolting silk net suspended from a tripod stand. The collections were made between 7 A.M. and 8 A.M. from the same area in the intertidal zone. The plankton collected was immediately transferred to a clean bottle and examined in the laboratory in a fresh condition. The temperature readings of the surface water were made on the dates of collection and a separate sample of water from the same area used for salinity estimations. After a rapid examination in the fresh condition the organisms were fixed and preserved by the addition of a sufficient quantity of formalin to the sample. The preserved samples were poured into long measuring cylinders and left undisturbed for about 24 hours or longer to allow the organisms to settle down. The supernatant water was centrifuged to collect organisms that may not have settled. This concentrate together with that settled at the bottom of the cylinders was transferred to specimen tubes and sealed for quantitative estimations. The quantitative estimations were made by diluting the preserved samples to a constant volume by the addition of 5% sea-water formalin and 1 c.c. of the aliquot sample

(after separating the larger organisms) analysed by using a Sedgwick-Rafter cell under the binocular microscope. Different symbols had to be used to denote the comparative abundance of the different organisms, such as the diatoms, the dinoflagellates and the copepods. The limitations of such a method are evident, but the difficulties involved in having a common standard of abundance for all the organisms are obvious. In estimating the salinity the method suggested by Harvey (1945) was adopted. 10 c.c. of the sea water sample was titrated against standard silver nitrate solution, using potassium chromate as indicator. The necessary correction, as given by Harvey, was made.

Physical Features and Climate

Visakhapatnam is situated at 17° 44′ N and 83° 23′ E on the east coast of India. The hill ranges of the Eastern Ghats surround the place on the land side and at two points they butt into the sea. The coast is rocky interspersed with sandy patches. The bulk of the rainfall is brought by the south-west monsoon which commences late in June and lasts till early October. The north-east monsoon closely follows the south-west monsoon and extends till December. While the average annual rainfall of the place is about 38″ the period under review had a rainfall of 37·22″. Owing to the sandy nature of the soil the drainage of rain water into the sea is negligible except during periods of heavy rains. There are also no perennial streams or rivers emptying into the sea in the near vicinity.

Salinity

The salinity variations on this coast bear a close resemblance to the conditions observed at Madras (Jayaraman, 1951) with the peak in April and May and the minimum in November (Fig. 1). The local rainfall during the low salinity period was not heavy enough to have brought about this steep decline and it can only be attributed to the strong southerly surface current which brings in large quantities of fresh-water from the mouths of the Brahmaputra, the Ganges and the Mahanadi. From December on there is a steep rise in salinity and it remains practically steady from March till July. The surface current during the period December to July is in a north-easterly direction but our observations show that this current does not bring in any appreciable quantity of fresh-water from the rivers Godavari and Krishna to lower the salinity, though one would normally expect a decline in salinity during this period. It is presumed that the influx of fresh-water from the above rivers is more than countered by a tongue of highly saline equatorial waters entering the bay from December to February and carried in a north-westerly direction by the prevailing currents (Ganapati and Murthy, 1954). The steady high salinity conditions from March to June

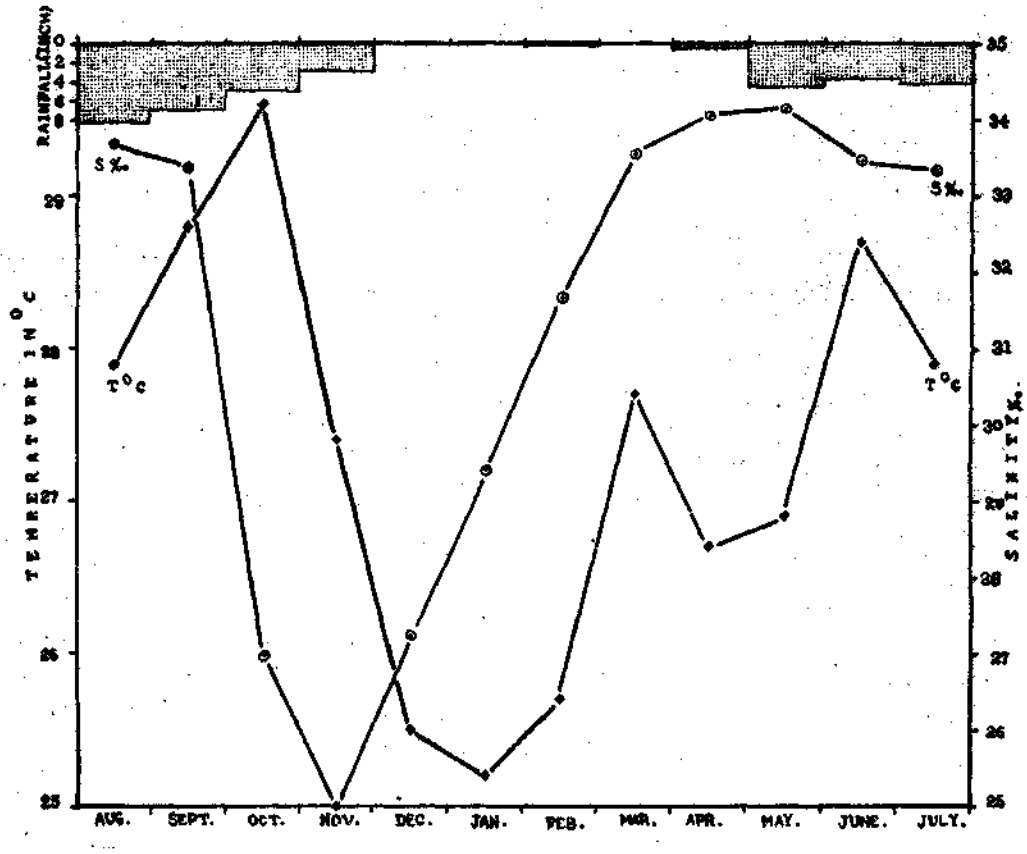

FIG. 1.

could be attributed to the upwelling of the subsurface layers of water (La Fond, 1954).

TEMPERATURE

The surface temperature of the coastal waters showed three peaks and three depressions corresponding to the months October, March, June and January, April, August respectively (Fig. 1). The annual range in the monthly mean temperature on this coast is 4·4° C. The temperature is lowest in the month of January. The increase in temperature from January to March is attributed largely to the reversal in the direction of the current which brings warm highly saline waters from the equatorial region. During April and May upwelling of the cold subsurface layers of water takes place and this might explain the unusual lowering of the surface temperature during these months. From May onwards the increase in temperature is due to the summer heating of the surface water, which is again followed by a decline in July and August. Prasad (1952) observed a shallow thermocline on the

western side of the Bay in August and La Fond (1954) suggests the possibility of a near shore upwelling and deflection of the surface current in an offshore direction during these months. The lowering of temperature in July and August may be attributed to this upwelling of waters from the subsurface layers. From September onwards there is a steep rise in temperature with the peak in October and this period is also marked by a sinking of surface waters characterised by an increase of temperature and lowering of salinity (La Fond, 1954). After October there is a decline in temperature due to the onset of the cold weather and the commencement of the north-east winds.

Seasonal Distribution of Phytoplankton

The phytoplankton of Waltair coast is rich in bulk and variety, exhibiting regular seasonal variations during the year. The maximum numbers of diatoms occurred in April. As on the other coasts of India, the diatom flora is mainly represented here by the genera *Coscinodiscus*, *Biddulphia* and *Thallassiothrix*. These occur throughout the year. The other genera like *Chætoceros*, *Pleurosigma*, *Rhabdonema*, *Asterionella*, *Streptotheca*, *Triceratium*, and *Bacillaria* are restricted to the primary and secondary blooms.

The protozoans that were retained by the silk net represent the groups *Dinoflagellata*, *Tintinnoidea*, *Radiolaria*, *Foraminifera* and others. Among the groups that occurred here dinoflagellates are more common than the other protozoans and they are mainly represented by the genera *Ceratium*, *Peridinium* and *Ornithocercus*. Less common genera are *Ceratocorys*, *Goniodoma* and *Amphisolenia*. Unarmoured forms of dinoflagellates were not observed, as they are so delicate and minute that they escape through the meshes of even the finest net. Lebour's method of taking samples of sea water direct from the sea, centrifuging in tubes with pointed ends and examining the residue was tried with no success. Only the larger armoured forms have been identified. Dinoflagellates in the waters of this coast attain their maximum numbers in May as in Madras. Both *Peridinium* and *Ceratium* occur all through the year with their individual maxima coinciding with the general dinoflagellate maximum. The seasonal variations in the abundance of some of the genera of diatoms, dinoflagellates and the more common groups of planktonic forms are given in the tabulated statement (Table I).

The biological year on this coast may be said to start from September. After the barren months of September and October the diatoms increase suddenly in numbers and reach the autumn maximum during November.

TABLE I

Plankton Calendar for the Year 1951–52

	Name	A	S	O	N	D	J	F	M	A	M	J	J
1.	*Coscinodiscus*	C	C	C	C	C	C	S	C	P	S	S	P
2.	*Rhizosolenia* ..	F	C	F	C	F	F	C	F	C	S	S	S
3.	*Chætoceros* ..	..	R	R	S	R	R	R	..	..	..	R	..
4.	*Biddulphia* ..	F	C	F	C	F	F	C	C	C	C	C	C
5.	*Rhabdonema* ..	..	R	..	R	R	F	C	R	F	R	..	..
6.	*Thallassiothrix*	C	F	F	S	C	R	C	C	P	S	P	F
7.	*Bacillaria* ..	R	..	R	R	..	..	R	F	F	R	F	R
8.	*Asterionella* ..	S	R	R	..	..	R	F	F	S	R	P	P
9.	*Streptotheca* ..	F	..	..	..	..	..	F	F	C	R	F	R
10.	*Triceratium* ..	R	R	R	R	R	R	R	R	F	R	F	R
11.	*Pleurosigma* ..	R	R	R	F	F	R	F	F	F	C	C	F
12.	Other diatoms	S	C	C	C	C	F	C	C	S	S	S	C
13.	Total diatoms	S	P	P	S	P	C	S	S	S	S	S	S
14.	*Peridinium* ..	F	F	F	F	F	F	F	F	F	S	F	F
15.	*Ceratium* ..	F	R	F	F	F	R	F	F	F	C	F	F
16.	*Dinophysis* ..	F	F	R	R	R	..	R	..	..	R	R	..
17.	*Ornithocercus*	..	..	..	..	R	R	..	..	..	..	..	..	..
18.	*Noctiluca* ..	..	..	R	R	R	R	..	R	R	F	F	..	F
19.	Other dinoflagellates	F	F	F	F	F	F	C	C	C	C	F	F
20.	Total dinoflagellates	C	C	C	C	C	C	C	C	C	S	C	C
21.	Protozoans ..	F	F	F	F	F	F	C	F	C	C	C	F
22.	Cœlenterates	R	R	R	R	R	R	F	R	R	R	..	R
23.	Polychæte larvæ	R	R	R	R	F	R	R	F	R	F	F	F
24.	Chætognatha	..	..	R	R	R	R	..	R	R	R	R	R	..
25.	Crustaceans ..	C	F	C	C	C	C	C	C	F	C	C	C
26.	Cyphonautes larvæ	..	..	..	R	..	R	R	R	..	R	..	R	R
27.	Mollusca ..	..	..	R	R	..	R	R	R	R	R	..	..	..
28.	Echinoderm larvæ	R	R	R	R	R	R	..	..	..	..	..	..	..
29.	Pro-chordates	R	..	R	R	R	R	R	R	R	F	..	R
30.	Fish eggs and larvæ	R	R	R	R	R	R	R	R	R	F	R	R

R .. Rare .. 1 to 5 individuals per 1 c.c. of Aliquot sample.
F .. Few .. 6 to 20 do
C .. Common .. 21 to 100 do
P .. Plenty .. 101 to 200 do
S .. Swarms .. 201 and above do

This is followed by a steep decline during the next two months, December and January. From February onwards there is a sudden rise with the spring peak in April. A distinct fall in numbers was observed in March. After the peak period there is a steep decline in May and they become sparse till November. A noticeable rise in numbers of diatoms was observed in August 1951, and this is perhaps due to the unusually heavy rains of 11·87″ and 4·81″ during the months of July and August respectively.

Broadly speaking the seasonal variations of phytoplankton production on this coast resemble the conditions obtained at Madras (Menon, 1931). This similarity appears to be in a large measure due to the similarity of hydrographical and climatic conditions at both the places. Two maxima, a primary maximum in spring and a secondary maximum in autumn, are noticed. While the spring maximum on this coast extends from February to April, in Madras it is from March to May. The autumn maximum in November is of very short duration on this coast whereas in Madras it extends from November to January, with the peak in December. In Krusadai, in the Gulf of Mannar, there appears to be only one maximum of phytoplankton which extends from June to November, a secondary maximum being absent (Chacko, 1950). On the west coast, at Trivandrum, the phytoplankton production begins immediately after the monsoon and the peak period is in May. A secondary maximum, if at all present, is said to merge with the general maximum (Menon, 1945). In the waters off Calicut the primary maximum is from May to September and a secondary maximum is reported from January to February (Hornell and Nayudu, 1923; George, 1953). In the Bombay harbour the period of phytoplankton production is from September to February (Gonzalves, 1947).

Earlier workers have maintained that the increase in the nutrient salts in the sea water, either due to the upwelling of the nutrient, laden deeper waters, or due to the influx of great bodies of river water, causes the various diatom maxima (Allen and Nelson, 1910; Atkins, 1928; Marshall and Orr, 1930; Gran and Barraud, 1935; Riley, 1938). This explanation holds good for the phytoplankton production on this coast also. There is a strong southerly current in the Bay during the months, September to November, which brings large bodies of fresh-water from the rivers, Mahanadi and Ganges. A steep fall in salinity during this period shows that the current affects the coastal waters. The autumn bloom corresponds to this period. As for the spring bloom, taking the steady and evenly increasing salinity conditions during the period February to April, it can be said that the northerly current does not seem to affect the coastal waters to any marked

extent. The total rainfall during these months is also not sufficient to alter the salinity values or add appreciable quantities of nutrients. It has, however, been observed that there is an upwelling of the subsurface layers of water which commences in March, and continues throughout April and part of May (La Fond, 1954). This upwelling of the nutrient-laden, more saline deeper waters is responsible to a large extent for the spring bloom.

As was observed at Trivandrum (Menon, 1945) and Calicut (Hornell and Nayudu, 1923) the diatom maximum on this coast also is followed by dinoflagellate maximum. The April maximum of diatoms is found to be closely followed by the dinoflagellate maximum. Sverdrup *et al.* (1942) attributed the dinoflagellate maximum to the " depletion of plant nutrients by the diatoms to a point suboptimal for their abundant proliferation, but still sufficient for the dinoflagellates which are able to reduce the nutrients further...." Though they are far less in numbers than the diatoms, they occur in swarms during their maximum period, along with the diatoms. At Madras the dinoflagellate maximum is said to coincide with the general diatom maximum (Menon, 1931). We have observed a summer maximum of dinoflagellates as in Plymouth (Lebour, 1917), but a winter maximum can also be recognised though it is not so pronounced.

Various workers have observed that there is a regular succession of organisms in the plankton of any sea area, so that the composition of the plankton of that area is not constant throughout the year. It varies with seasons, but groups of organisms abundant in one season are succeeded by other groups of organisms during another season. Many explanations have been put forward to explain this phenomenon (Johnstone, 1908; Herdman and Scott, 1910; Atkins, 1925, 1926, 1928, and 1930; Marshall and Orr, 1927; Dakin and Colefax, 1933; Cupp, 1937). Johnstone (1908) maintains that " the hinge round which most seasonal variations in the abundance of the animals in the sea turn, is the annual reproductory phase some time or other during the first six months of the year." Dakin and Colefax (1933) maintain that the periodicity of the plankton is controlled no less by the internal factors than by the directly potent factors of the environment in the fullest sense. On this coast we have observed a regular succession of the three major groups of planktonic organisms, *i.e.*, diatoms, dinoflagellates and copepods, similar to what has been reported from the European waters (Fig. 2). The seasonal distributions of these groups of organisms are also in general agreement with those at Plymouth (Lebour, 1917). There is a spring and early summer maxima for diatoms, a summer maximum for the dinoflagellates and an autumn and early winter maxima for copepods.

Ganapati and Rao (1953) observed that there is a regular sequence in a north-to-south direction in the commencement of the primary maximum of the phytoplankton on the east coast of India. At Waltair it commences

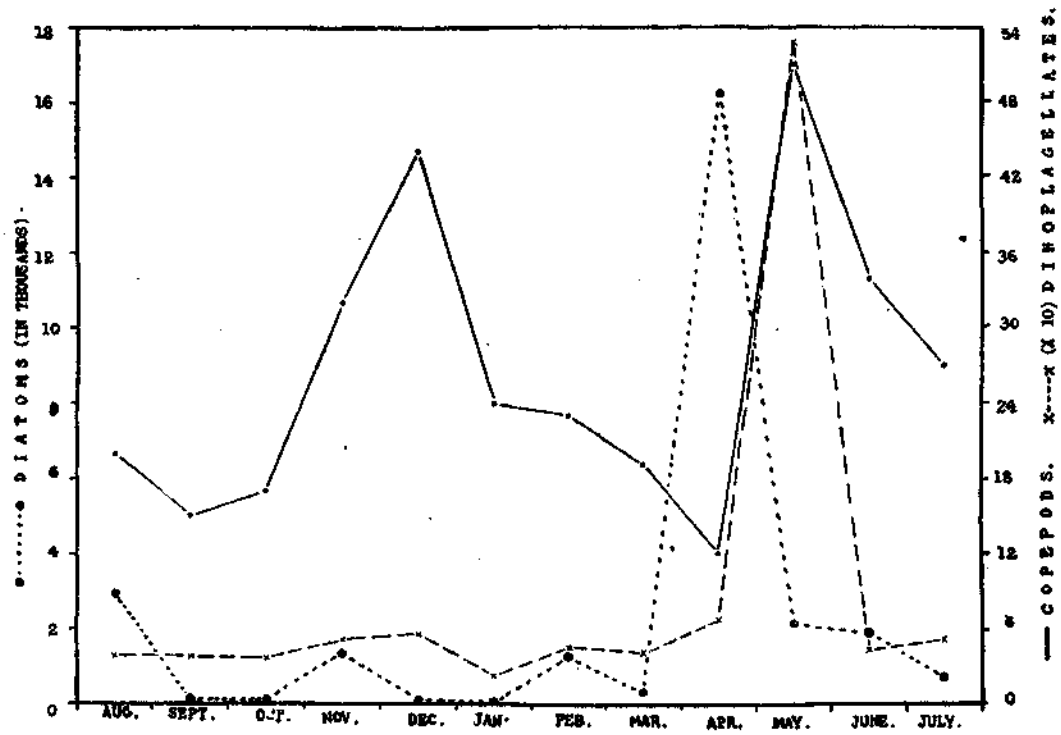

FIG. 2.

in February, at Madras (Menon, 1931) in March and at Krusadai (Chacko, 1950) it is from June. The same sequence in the phytoplankton production is noticed on the west coast also which, however, moves in a south-to-north direction. At Trivandrum the bloom is from January to May (Menon, 1945), at Calicut it is from May to September (Hornell and Nayudu, 1923) and at Bombay it is from September to February (Gonzalves, 1947). More recent investigations by Ramamurthy (1953) in the waters off the Madras City during the years 1951–52 have shown that the distribution of diatoms was quite irregular with periods of high productivity in the months of February, April, May, August, September, November and December, and low production in January, March, June, July and October. Similarly, Prasad (1954) working at Mandapam in the Gulf of Mannar, during 1950–51 observed more than one maximum of diatom production, a summer peak in May with others in February to March and August to November.

It is clear from the observations of the various workers cited above that while the phytoplankton production on the east coast is fairly continuous throughout the year, there are periods of intense production which are subject to variation, from year to year, perhaps depending on the

optimal hydrographical conditions in the years concerned during the periods of intense production. Before we can arrive at any definite conclusion as to the possible causes for these variations on our coast it is necessary to study the periodical abundance of the various organisms in the plankton for a few years. In addition to this it is essential to have a sound knowledge of the hydrographical conditions, particularly the distribution and variation of the nutrient salts, during the different seasons of the year and in different years.

Zooplankton

The bulk of the zooplankton consists of copepods and to a lesser extent of crustacean and polychæte larvæ. Copepods have their maximum density during May. This group of organisms succeeds immediately the diatom and dinoflagellate maxima. The other components of zooplankton like crustacean larvæ, polychæte larvæ, *Sagitta*, cladocerans, ostrocods, appendicularians and fish eggs and larvæ are common during periods of phytoplankton intensity.

Summary

A quantitative and qualitative investigation of the microplankton from the local inshore waters with special reference to the diatoms and dinoflagellates has been made by filtering a known volume of sea water through a bolting silk net and estimating the organisms collected.

The salinity and temperature variations of the surface waters during the period August 1951 to July 1952 have been examined in relation to the prevailing currents and other water movements and an attempt made to correlate the plankton production with the hydrographical conditions.

Two maxima have been observed in plankton production, a primary maximum in "spring" and a secondary maximum in "autumn," the dinoflagellate maximum following the diatom maximum, and the latter closely followed by the copepod maximum. The primary maximum is attributed to the upwelling of the nutrient laden deeper waters and the secondary maximum to the influx of river water. Reference is made to the interesting succession in a north to south direction observed in the commencement of the spring bloom of the phytoplankton on the east coast of India and the same sequence, but in the reverse direction, observed on the west coast.

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